

ONE SATELLITE FOR THE WORLD: THE AMERICAN LANDSAT EARTH
OBSERVATION SATELLITE IN USE, 1953-2008

A Dissertation Presented to The Academic Faculty

By

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LIST OF ABBREVIATIONS

ARS	Agricultural Research Service	1953
CCCT	Cabinet Council for Commerce and Trade	1981
CCRS	Canadian Centre for Remote Sensing	1970
CIA	Central Intelligence Agency	1947
COMSAT	Communications Satellite Corporation	1963
DOC	Department of Commerce	1903
DoD	Department of Defense	1947
DOI	Department of the Interior	1849
EOSAT	Earth Observation Satellite Company	1985
ERIM	Environmental Research Institute of Michigan	1972
EROS	Earth Resources Observation and Science Data Center	1973
ERTS	Earth Resources Technology Satellite	
GAO	Government Accountability Office	1921
LACIE	Large Area Crop Inventory Experiment	
LARS	Purdue University Laboratory for Agricultural Remote Sensing	1966
LDCM	Landsat Data Continuity Mission	2001
MSS	Multispectral Scanner	
NAS	National Academy of Sciences	1863
NASA	National Aeronautics and Space Administration	1958
NOAA	National Oceanic and Atmospheric Administration	1970
NRC	National Research Council	1916
OMB	Office of Management and Budget	1970
OTA	Office of Technology Assessment	1972
SPOT	Système Probatoire d'Observation de la Terre	
TDRSS	Tracking and Data Relay Satellite System	
TIROS	Television Infrared Observation Satellite	
TM	Thematic Mapper	
USAID	United States Agency for International Development	1961
USDA	United States Department of Agriculture	1862
UN	United Nations	1945
USGCRP	United States Global Change Research Program	1990

SUMMARY

In July 1972, the National Aeronautics and Space Administration (NASA) launched the Earth Resources Technology Satellite-A, later renamed Landsat, which was the first of its kind. NASA launched seven more Landsats with one failure. The satellites orbited north to south covering the entire Earth while its instruments gathered imagery across several spectral bands at medium resolution of the Earth's terrestrial and coastal surface. Using archival materials, government documents, and informal interviews, my dissertation argues in an introduction, four chapters, and a conclusion that the use of Landsat imagery changed over time and that international law and domestic policy deeply affected its availability despite a commitment by the US government to non-discriminatory access. My first chapter argued that agricultural applications became the first major application of Landsat data and later adopted by the intelligence community to conduct economic espionage on the Soviet Union. Using documents from the United Nations and American National Archives, one chapter demonstrated how these institutions deliberated over and configured international law and domestic policy such that Landsat data would be available to developing countries for use. My last two chapters describe how Landsat became a commercial entity which ultimately failed and the government recovered the program and committed to its continuity. Since Landsat's development in the late 1960s, the satellite program began as a publicly run experimental project, commercialized into a private operation, and later became a public-private partnership.

This study has the following major contributions and findings. My dissertation covers the history of the Landsat program from its origins in the 1950s to open data access in 2008 building upon previous studies of Landsat. I also argued that there are four major periods of Landsat's history. These periods reflect the differing use and availability of Landsat throughout its history.

My thesis found that the commercialization of space technology, a fast growing trend, was a highly political process that pushed Landsat from the public to private sector and led to cost-prohibitive data that drove away the user community. Similarly, the US government attempted to foster a strong foreign user base through ground stations and development programs and experienced success as well as difficulty given trade and export policies to certain countries. Lastly, Landsat, despite being a civilian program, was used heavily by the intelligence community in studies of natural resources in America's Cold War adversaries. Overall, the various applications of Landsat data and the various laws and regulations put into place by the US federal government deeply affected Landsat data availability and ultimately made it more difficult to access throughout much of its history until the 2000s.

Introductory Chapter: “The Time is Now Right and Urgent:” Reconnaissance to Remote Sensing, 1957-1972

In January 1975, National Aeronautics and Space Administration (NASA) Administrator James C. Fletcher claimed that “if I had to pick one spacecraft, one Space Age development to save the world, I would pick ERTS.”¹ Administrator Fletcher, speaking amidst oil embargoes, acute crop shortages around the world, the passage of several pieces of major American environmental legislation, and the famed ‘Blue Marble’ image taken from the Apollo-17 flight in December 1972, to name a few, predicted that the Earth Resources Technology Satellite (ERTS, later renamed Landsat) and follow-on satellites offered a modern, space-age solution to human-induced environmental degradation as well as a mechanism for more efficient use of Earth’s limited natural resources. Since Fletcher’s prediction in 1975, seven Landsat satellites have produced millions of images of the Earth continuously and routinely for over forty years and contributed to myriad scientific investigations in a wide range of fields such as agriculture, biology, geology, urban-planning, among many others. In addition to the scientific community, the military also had a stake in Earth observation having used satellites to gather strategic intelligence. Industry also explored the use of Landsat data for mineral extraction, agricultural production, land development, and software development among many. Over time, as other countries became capable of using imagery from Landsat, scientific investigations expanded globally. The community of people who used Landsat data and imagery² for scientific, military, or industrial purposes undoubtedly increased and expanded over four decades. However, this

¹ ERTS-B Press Kit, 14 January 1975, NASA History Office, Washington, D.C.
<https://mira.hq.nasa.gov/history/ws/hdmshrc/all/main/Blob/42690.pdf?w=NATIVE%28%27KEYWORDS+ph+is+%27%27%22landsat%22%27%27%27%29&rpp=20&order=native%28%27SERIES%27%29&r=1&m=2> date accessed: 25 November 2013

² Throughout this dissertation I use the terms Landsat data and Landsat imagery. Landsat data refers to unprocessed imagery which users calibrate for their purposes while Landsat imagery refers to processed imagery that is ready to be interpreted.

process proved incredibly complex politically and economically and experienced resistance from several forces in both the domestic and international domains.

My thesis addresses political history and history of science and technology of the U.S. federal government's ERTS/Landsat Earth observation satellite program. The Landsat program is currently in its forty-fourth year of existence and has seen the launch of seven satellites, each with increasingly powerful scanners capable of mapping global environmental change. The satellite program, launched at the height of the Cold War, was a civilian effort of the U.S. federal government that evolved from an experimental program into a commercial venture, and then transforming yet again into a public-private partnership over the forty years of the program's lifespan. In the midst of these governmental changes, the satellite's community of users, I contend, grew from a few specialists in the Departments of the Interior (DOI) and Agriculture (USDA) into an international user base of data consumers. For the purposes of this thesis, a 'user' is an individual or a community of individuals who derive and create new knowledge of the Earth from Landsat imagery. The problem I will address directly is Landsat's changing structures of governance and how these changes affected the use of the satellite domestically and internationally. By shedding light on this problem, I will assess how the U.S. federal government, with particular attention to its Executive Branch and federal agencies, develops, governs, fosters, and eventually commercializes science and technology during the late Cold War and beyond. In essence, this thesis will demonstrate how the United States governed and transformed scientific and technological programs from the 1960s to the present.

My intellectual goal is to contribute a new study of Landsat which assesses how the U.S. federal government, particularly the Executive Branch, developed, governed, fostered, and eventually commercialized remote sensing technology from the 1960s to present for use both

domestically and internationally. I study both how laws and policies affected the availability, whether more broad or restricted, of Landsat data and how that data came to be used such as how and by whom. Fundamentally I am guided by three questions: What is the relationship between technology and the state and how does it change over time? How does the use of a technology change over time? How do state policies change the nature of technology-in-use over time?

From Pigeons to Processors: A Century of Earth Observation

Humans have longed for a better view of the world in which they live. Earth observation, which I broadly define as the viewing and mapping of Earth through aviation or space-based technological means, began to quickly evolve in the late 19th century. The Union Army used hot-air balloons to photograph battlefields during the American Civil War. In 1889, Arthur Batut attached a camera to a kite and photographed Labruguiere, France. In Germany, Julius Neubronner fitted pigeons with cameras leading to the Bavarian Pigeon Corps in 1903. However, it was around World War I and the beginnings of aviation that humans began to see the Earth more routinely from above. Aerial photography served as a dominant method for gathering such image based data, most commonly for military purposes. Military officials used cameras onboard aircraft to gain strategic advantage through reconnaissance.

Reconnaissance became the term for cartographic intelligence gathering via aircraft for military use. The development of the airplane significantly contributed to military reconnaissance for strategic planning with its ability to photograph terrain. Italians first used fixed-wing aircraft for aerial photography, that is, reconnaissance, during the Italo-Turkish War in 1911, and most powers practiced reconnaissance during the World Wars. Amron Katz, a RAND Corporation photogrammetric specialist “estimated that about 80 percent of the

information secured on the Axis powers and their activities during World War II resulted from aerial reconnaissance.”³ Such heavy emphasis on reconnaissance during the war preceded improvements in remote data gathering afterward. Reconnaissance involved the use of airplanes, and later satellites for strategic intelligence, surveillance, and target acquisition. By the 1940s, both aircraft and rocketry served as platforms for reconnaissance.

The end of the Second World War led to the acquisition of many scientific and technological resources for the United States which later contributed to its Earth observation efforts. American interest in satellite reconnaissance began as early as 1941 “when the concept of a surprise attack on U.S. territory became a vivid reality,” after the Japanese attack on Pearl Harbor.⁴ Germany’s defeat in 1945 secured a great many scientific resources for the U.S. (and the Soviets), particularly the knowledge gained from the Peenemünde engineers.⁵ Shortly after obtaining scientists, rockets and materials at war’s end through Operation Paperclip in 1945, military, scientific, and institutional interests brought together a civilian panel “composed of an informal group of activists and scientist-entrepreneurs who designed experiments for the missiles.”⁶ Both the Naval Research Laboratory (NRL) and the Applied Physics Laboratory at Johns Hopkins University (APL) were powerful participants that attempted aerial photography with V-2 rockets. Initially, scientists at APL were interested in rocket behavior but a photograph

³ John Cloud “American Cartographic Transformations during the Cold War” *Cartography and Geographic Information Science* (2002) Vol. 29, No. 3, pp. 263

⁴ Dwayne Day et al. *Eye in the Sky: the story of the Corona spy satellites*, (Washington, DC: Smithsonian Institution Press, 1998), pg. 29

⁵ There is an expansive field of work on German rocketry science and technology, particularly during the Third Reich. See: *The Rocket and the Reich* by Michael Neufeld. Rocketry, as well as an exhaustive history of applications satellites and their origins, is beyond the scope of this thesis. See also: *Science with a Vengeance* by David H. DeVorkin concerning American adoption of V-2/A-4 into upper atmospheric research and military use.

⁶ David H. DeVorkin, “Organizing for Space Research: The V-2 Rocket Panel” *Historical Studies in the Physical and Biological Sciences* Vol. 18, No. 1 (1987), pg. 1-24

of Earth from 104 kilometers caught the attention of the American newspapers.⁷ The detection of a tropical storm in 1947⁸ alluded to practical application for the Weather Bureau, who also sat on the V-2 Panel. Despite their participation on the panel and the efforts of the NRL and APL, little interest followed since the V-2 launches did not promise consistent data. Meteorological studies, as much as military reconnaissance, required data *continuity*, a capability requiring access to space through Earth-orbiting satellites via rocketry.

German rocket engineers informed Clark Millikan and Hsue-Shen Tsien, both of the California Institute of Technology, of “the possibilities opened by their rocketry: artificial earth satellites.”⁹ Shortly after, the Navy, later collaborating with the Army Air Force (AAF) and the RAND Corporation, formed the Earth Satellite Vehicle Program (ESVP) in 1946. RAND produced a report suggesting delivery vehicle specifications, military value, but placed great emphasis on the scientific applications.¹⁰ These included both scientific such as meteorology, earth physics, and astronomy, and technical, such as communications and remote sensing applications. The AAF attempted to gain control of the ESVP, however disagreements with the Navy and military unification forced the project off the table. Congress passed the National Security Act of 1947, which reorganized the AAF into separated branches including the U.S. Army and the newly formed U.S. Air Force (USAF). This also led to the establishment of the Research and Development Board (RDB, built from the Joint Research and Development Board of the AAF and Navy). A year later in 1948, the Navy canceled the ESVP project all together

⁷ David H. DeVorkin, *Science with a Vengeance: How the Military Created the U.S. Space Sciences after World War II*, (New York: Springer-Verlag, 1992), pg. 145

⁸ David H. DeVorkin, *Science with a Vengeance: How the Military Created the U.S. Space Sciences after World War II*, (New York: Springer-Verlag, 1992), pg. 145

⁹ Walter A. McDougall, *...the Heavens and the Earth: A Political History of the Space Age*, (New York: Basic Books, Inc., Publishers, 1985), pg. 101

¹⁰ Walter A. McDougall, *...the Heavens and the Earth: A Political History of the Space Age*, (New York: Basic Books, Inc., Publishers, 1985), pg. 102

due to President Truman's funding cuts and high costs of the program.¹¹ The Navy's "attempts to go beyond preliminary investigations with satellite proposals continued to be frustrated."¹² The cancellation of the ESVP and the recommendation from the RDB favored the USAF which "eventually became 'the only service authorized to expend defense department funds on studies of satellite vehicles'."¹³

Cold War from Above

The Cold War brought about an ideological bifurcation of world politics, culture, and economics inspiring rivalry among superpowers that only enhanced the imperatives of national security in the wake of World War II. The capitalistic democracies of the West began to clash with the communist authoritarian regimes of the East in contests to best each other in scientific and technological feats. These competitions produced in a highly militarized standoff between the United States and Soviet Union. President Dwight Eisenhower felt compelled to assess the Soviet Union's strategic capabilities. Thus, the U.S. defense and intelligence community began the development of a reconnaissance satellite program. The origins of reconnaissance from space lie in defense mapping interests with the particular involvement of the USAF and the CIA. The military strictly controlled remote sensing for its use in reconnaissance.

The USAF contracted with RAND Corporation, a California based think tank, as well as others to study how to implement a satellite reconnaissance platform. Project Feedback employed a team consisting of "Westinghouse, RCA, and Lawrence R. Hafstad, recently of the Department of Defense (DoD) R & D Board [Department of Defense Research and Development

¹¹ Walter A. McDougall, *...the Heavens and the Earth: A Political History of the Space Age*, (New York: Basic Books, Inc., Publishers, 1985), pg103

¹² Paul B. Stares, *The Militarization of Space: U.S. Policy, 1945-1984*, (Ithaca: Cornell University Press) pg. 28

¹³ Paul B. Stares, *The Militarization of Space: U.S. Policy, 1945-1984*, (Ithaca: Cornell University Press) pg. 28

Board]” to study necessary hardware.¹⁴ By 1954, Feedback “received high-level support within the Air Force,” and its goal to assess the enemy capabilities through targeting “airfield runways and future intercontinental missile launch sites.”¹⁵ The USAF and the CIA developed these capabilities and corresponding technologies between 1956 and 1959 eventually launching the Corona program, which is discussed in greater detail in the next section. Meanwhile, the USAF and CIA moved ahead with another reconnaissance program utilizing high-altitude aircraft.

The CIA and the USAF contracted with Lockheed Martin to design an aircraft capable of high-altitude reconnaissance. The U-2 spy plane entered service in 1955 because the US “needed to spy on the Soviet Union” in order to “attend to the technological problem of preventing another Pearl Harbor.”¹⁶ This spy plane program, authorized by President Eisenhower became an important intelligence gathering system over Soviet airspace for the CIA. The U-2 had necessary range and altitude providing for all-weather imagery. The U-2 assisted to accumulate imagery of Soviet military installations, airfields, ammunition sites, transportation routes and atomic production facilities. However, for the military to effectively maintain Soviet surveillance, it needed to be continuous as well as be able to target particular Soviet installations.¹⁷ Also, the U-2 was not invincible, even with its great altitude; the USAF pilots flying them were at great risk to anti-aircraft defenses. The Soviet Union shot down U-2 pilot Francis Powers over Sverdlovsk after which he endured almost 2 years of imprisonment. Soviet officials used Powers to stage a “widely publicized public trial that was designed to embarrass the United States.”¹⁸ Thus, most

¹⁴ Walter A. McDougall, ...*the Heavens and the Earth: A Political History of the Space Age*, (New York: Basic Books, Inc., Publishers, 1985), pg110

¹⁵ Paul B. Stares, *The Militarization of Space: U.S. Policy, 1945-1984*, (Ithaca: Cornell University Press) pg. 30

¹⁶ Walter A. McDougall, ...*the Heavens and the Earth: A Political History of the Space Age*, (New York: Basic Books, Inc., Publishers, 1985), pp. 115

¹⁷ Walter A. McDougall, ...*the Heavens and the Earth: A Political History of the Space Age*, (New York: Basic Books, Inc., Publishers, 1985), pg. 117

¹⁸ Francis Powers Jr. “From U-2 to CORONA: 50 Years Later” *Quest: The History of Spaceflight Quarterly* (2010) 17:3 pg. 6

concerning to the US government was the violation of Soviet airspace. The U-2 proved politically dangerous since “Soviet leaders viewed aircraft overflights as hostile incursions.”¹⁹ The U-2 successfully returned data instrumental to intelligence, however, the U.S. government and military demanded greater Earth-viewing power. The U-2 program did not provide *continuous* data feedback; it provided little spatial and temporal coverage. The data only represented the time and flight path of the U-2 airplane. Such limited data sets came at a high risk due to anti-aircraft weaponry and international law. The U-2 program continued service, but compared to what satellite reconnaissance promised it was reduced to a “stopgap” while the US developed reconnaissance capabilities from outer space.²⁰ These risks and data concerns effectively encouraged the development of new remote sensing apparatuses to counteract these concerns. For remote sensing, data continuity and spatial coverage were of highest concern, just such capabilities satellites promised to improve.

Communist expansion into Eastern Europe, instability in Greece and Turkey, the Berlin blockade, and Soviet nuclear weapon acquisition led to an “American inclination to assume the worst about Soviet intentions.”²¹ Further, the outbreak of the Korean War solidified American policy manifesting in NSC-68. This highly classified report led to increased military spending, coordination of Western militaries, and advocated containment of Soviet influence.²² Despite the shift away from satellites as a priority, the USAF and RAND sustained the view that satellites could provide a means of intelligence gathering through earth observation. RAND’s continued

¹⁹ Howard E. McCurdy, *Space and the American Imagination*, (Washington, D.C.: Smithsonian Institution Press, 1997) page 59

²⁰ Walter A. McDougall, *...the Heavens and the Earth: A Political History of the Space Age*, (New York: Basic Books, Inc., Publishers, 1985), pg. 113

²¹ Walter A. McDougall, *...the Heavens and the Earth: A Political History of the Space Age*, (New York: Basic Books, Inc., Publishers, 1985), pg. 91

²² There is great debate in American historiography among schools of thought addressing the role of the US during the formative state of the Cold War: the liberal view, revisionist view, and more recently, the post-revisionism. This vibrant debate is outside the scope of this thesis and well documented elsewhere.

study of reconnaissance satellites revealed a glaring error. The US (and the Soviets) had the capability to place satellites in space, yet no legal precedent existed for orbital flight over foreign soil.

Freedom of space became an issue at the outset of the space age. The Americans, especially when Eisenhower took office in 1953, insisted on legal mandate protecting the freedom of space. The Soviets, however, recognized American intentions, effectively filibustering United Nations (UN) legislation on freedom of space for 10 years. International law disallowed overflight by aircraft unless previous agreements among heads of state were in place. However, orbiting satellites around the earth “raised the question of the international law of territorial waters and airspace, in which individual nations controlled those territories as if they were their own soil.”²³ The Eisenhower administration pushed for space “to be recognized as free territory not subject to the normal confines of territorial limits.”²⁴ Opposition, led by the Soviets, suggested that state territorial borders extended into space. In July 1955, the US and Soviet Union held a summit in Geneva, Switzerland concerning the freedom of space access issue. Eisenhower presented his “Open Skies” policy, which Soviet Premier Nikita Khrushchev outright rejected. US Ambassador to the UN Henry Lodge presented a

“plan of controls whereby ‘future development in outer space would be directed exclusively to peaceful purposes and scientific purposes’ by bringing ‘the testing of [satellites and missiles] under international inspection and participation.’”²⁵

This situation presented three courses of action for Eisenhower. First, continue to pursue legality either through the UN or precedence via a peaceful, scientific satellite (hoping no other state

²³ Roger D. Launius, *NASA: A History of the U.S. Civil Space Program*, (Malabar, FL: Krieger Publishing Company, 1994) pg. 19

²⁴ Roger D. Launius, *NASA: A History of the U.S. Civil Space Program*, (Malabar, FL: Krieger Publishing Company, 1994) pg. 20

²⁵ Walter A. McDougall, *...the Heavens and the Earth: A Political History of the Space Age*, (New York: Basic Books, Inc., Publishers, 1985), pg. 127

objects). Second, the Eisenhower administration used the Soviet launch to argue that *Sputnik* set freedom of space precedence. Third, the US pursues a covert reconnaissance program without regard to international law. Eisenhower found he could have all three.

The implications of space legislation and satellites signaled the beginning of the space age. The US, as well as the USSR, had institutions in place to address the new technological era hopefully without implying deepening Cold War tensions. The US government hoped a commitment to science and peaceful uses of space may not signal belligerence. In 1950, a group of scientists suggested a worldwide, yearlong research initiative mirroring the International Polar Years of 1882 and 1932. Five years later after funding discussions with the National Science Foundation and the U.S. National Academy of Sciences (NAS), the US government saw the benefits of earth satellites and global science. However, “unbeknownst to the IGY people... establishing legality for overflight as well as being first into space,” were the administration’s real motivations.²⁶ Nonetheless, the US emphasized peace and science in space. That same year, 1955, the National Security Council (NSC) approved the IGY and ensured its lack of involvement with military programs during the year from July 1957 until December 1958. The US and the Soviets committed to launching satellites during that time. The NRL proposed Project Vanguard as the American contribution to the IGY. The Vanguard project however faced both technical and managerial problems, all the while remaining a second priority to the Polaris missile, among other IRBM projects. Vanguard’s upper stage boosters proved inert and the system ultimately failed. American hopes to reach space did not materialize with Vanguard, nor did the US achieve orbit first. Before Vanguard’s eventual failure, the Soviets successfully placed *Sputnik* into orbit on 4 October 1957.

²⁶ Walter A. McDougall, ...*the Heavens and the Earth: A Political History of the Space Age*, (New York: Basic Books, Inc., Publishers, 1985), pg. 119-120

The American public and press reacted with great panic to the Soviet launch. For the US, Sputnik supposedly expressed Soviet superiority.²⁷ The Soviet accomplishment gained worldwide congratulations shortly after launch, which the Soviets, indeed Khrushchev, used as part of his political agenda. The *Pravda* pushed the propaganda campaign domestically, despite its initial lack of interest. After 9 October, the *Pravda* had published world responses of praise and launch details.²⁸ The satellite, as Launius argued, was the result of Sergei Korolev's efforts and reaction to American space efforts.²⁹ Korolev was one of the Soviet Union's top rocket engineers and led the project to build Sputnik. The American reaction to Sputnik "demanded that the United States reassert the superiority of American technology by surpassing the Soviet Union in space exploration."³⁰ While prestige played a key role in defining the Cold War space race, for Eisenhower it was merely a superficial phenomenon. Further, prestige only provided a bi-state analytical lens of a widely more complex and internationalized spaceflight narrative. American interest in the international legal precedence of overflight remained a critical issue on the Eisenhower administration's agenda.

The Soviet launch of Sputnik alarmed the American public while the President and Deputy Secretary of Defense Donald Quarles kept a calm demeanor as Eisenhower's second course for freedom of space materialized. The Soviet launch lent President Eisenhower the leverage he needed for subsequent satellite-based cartography. For Eisenhower and achievement of freedom of space access, it was an absolution. The Soviets and Sputnik *prima facie* resolved the issue of freedom of space. Soviet satellites crossed international boundaries without

²⁷ Walter A. McDougall, *...the Heavens and the Earth: A Political History of the Space Age*, (New York: Basic Books, Inc., Publishers, 1985), pg. 148

²⁸ Roger Launius, John M. Logsdon, Robert W. Smith, *Reconsidering Sputnik: Forty Years Since the Soviet Satellite*, eds., (Harwood Academic Publishers, 2000), pg. 66

²⁹ Roger Launius, John M. Logsdon, Robert W. Smith, *Reconsidering Sputnik: Forty Years Since the Soviet Satellite*, eds., (Harwood Academic Publishers, 2000), pg. 66

³⁰ Roger Launius, John M. Logsdon, Robert W. Smith, *Reconsidering Sputnik: Forty Years Since the Soviet Satellite*, eds., (Harwood Academic Publishers, 2000), pg. 197

diplomatic protest, thus the Soviets unintentionally provided the means for Eisenhower to press ahead with the launching of reconnaissance satellites.³¹ Sputnik provided the US the precedence it needed to pursue applications satellites for observance while the US continued to seek formal legality through the UN Committee on the Peaceful Uses of Outer Space. Quarles summed up the positive suggesting the “Russians have in fact done us a good turn,” establishing freedom of space.³²

Observing Earth from Space

The U.S. continued to pursue stronger national security in 1959 as they had in 1941. Eisenhower realized that Soviet military might prove more powerful and unpredictable than anticipated; he therefore mobilized American resources to prevent another first strike disaster like Pearl Harbor.³³ His administration along with the CIA and DoD expanded the reconnaissance program beyond that of the precarious U-2 program. Thus, the US government began to invest in a system capable of capturing photographic intelligence from space over the next thirteen years. The highly classified satellite reconnaissance program, run by the CIA and operated by the USAF, became known as CORONA.

In 1959, earth scientists and CIA officials converged on a top secret military mapping project. Corona addressed the “emerging importance of strategic intelligence to national security policy” while making “contributions to advancing space technology.”³⁴ The Corona project, a

³¹ Roger D. Launius, *NASA: A History of the U.S. Civil Space Program*, (Malabar, FL: Krieger Publishing Company, 1994), pg. 27

³² Walter A. McDougall, *...the Heavens and the Earth: A Political History of the Space Age*, (New York: Basic Books, Inc., Publishers, 1985), pg. 134

³³ Several works address both Truman’s and Eisenhower’s obsession with preventing a surprise, first strike from another state, as Japan had done in December 1941. The Cold War led many to believe the Soviet Union could and would be capable of such an attack. See McDougall, Day et al., Launius (1994)

³⁴ Dwayne Day et al. *Eye in the Sky: the story of the Corona spy satellites*, (Washington, DC: Smithsonian Institute Press, 1998), pg. 19

classified program, was devised to monitor Soviet and Chinese military movement via strategic reconnaissance satellites with CIA and DoD funding. The USAF launched and recovered satellites while the National Reconnaissance Office, established in 1961 as a top secret covert agency, managed reconnaissance and interpreted data. Essentially, the USAF carried out operations, while the DoD, CIA, and NRO formed the user community. The project came under a similar management regime as the U-2, under the CIA and USAF. Eisenhower placed Corona directly under Richard Bissell at the CIA who “formed a close, high-level, informal working partnership”³⁵ with Undersecretary of the Air Force Joseph Charyk. Project Corona however, provided more continuous data without risk to American pilots as U-2 had. Corona utilized low Earth orbit satellites with 60cm focal length cameras which produced high resolution (about 2 meters) grayscale imagery. This project grew out of cartographic specialty and CIA-industry linkages. The CIA signed contracts with Lockheed, Eastman Kodak and Itek Corporation (formerly part of Boston University) to research and develop cameras and sensors. One such employee of Eastman Kodak, Donald L. Light, who also had experience with the US Army Map Service and the United States Geological Survey (USGS), assisted with “topographic information systems based on co-registered geodetically-rectified image pixels derived from photography.”³⁶ Essentially Light’s work improved the interpretation of imagery without revealing the source of the photography. If CORONA photographs fell into the hands of America’s Cold War rivals, they would reveal little detail about the capabilities of Corona’s cameras without sacrificing Americans’ ability to conduct photointerpretation. Thus, while Light assisted the military with cartographic literacy, he masked the devices that captured the data.

³⁵ Dwayne Day et al. *Eye in the Sky: the story of the Corona spy satellites*, (Washington, DC: Smithsonian Institute Press, 1998), pg. 148

³⁶ John Cloud “Imaging the World in a Barrel: CORONA and the Clandestine Convergence of the Earth Sciences” *Social Studies of Science*, Vol. 31, No. 2, Science in the Cold War (Apr. 2001), pp. 231- 251, pg. 241.

John Cloud described the Corona program as one in which earth scientists and others converged to not only provide an alternative to aerial photography gathered from U-2 flights but also to address the prospect of nuclear war defense, and one that “eroded the nominal separations between the ‘civilian’ and ‘classified realms of American government and science.”³⁷ Cloud essentially argued that civilians played a crucial role in a highly classified, military funded program.

Further many participants in the Corona program had military experience. I suggest that the erosion of nominal separations suggested by Cloud is a moot point given the nature of the Corona program. The military and military officials not only maintained the program but segregated its governance from other federal outfits. Corona’s *user community*, however, included civilian sector individuals but their functions benefitted the military, even when the NRO began absorbing CIA duties. The military handled many of Corona’s operations as well.

The military handled delivery via Thor-Delta rockets and recovery of capsules containing photographic data via USAF cargo planes or Navy vessels in the Pacific. The data returned to Earth in a capsule which detached from the platform in Earth orbit, deployed a parachute, and was recovered by the military, then shipped to the civilian mapping interpretation centers on the East Coast. The interpreters were well-trained geodesists (mapping based on ground surveys) and photogrammetrists (mapping based on aerial photographs). These interpreters, many having formal training in geography and mathematics, cognitively processed the data. The CIA trained interpreters to visually read Corona photographs and identify locations of interest. For example, interpreters learned to distinguish Soviet and Chinese missile sites or tank depots from the surrounding environment. Day et al.’s work recounted the work of four

³⁷ John Cloud “Imaging the World in a Barrel: CORONA and the Clandestine Convergence of the Earth Sciences” *Social Studies of Science*, Vol. 31, No. 2, Science in the Cold War (Apr. 2001), pp. 231- 251, pg. 241

such interpreters whose job was essentially to “put the cross hairs on the target.”³⁸ Their work led to the identification of Soviet military installations which would potentially be strike points for American ICBMs and aircraft. These interpreters developed innovative cartographic-interpretive techniques that contributed to geodesy and photogrammetry laying the foundation for global mapping datums. Corona data tied together continental-scaled datums across ocean basins while resolving sea-level undulation, that is, the mathematical process using a form of least squares regression to determine the mean elevation of the Earth’s surface.³⁹ These cartographic developments improved missile guidance and strategic targeting through the creation of coordinate systems layered over the Earth’s surface. Further, the Corona imagery provided to the Eisenhower administration and intelligence community allowed him to deny a ‘missile gap’ and better gauge Soviet military capability.

Succeeding presidents Kennedy, Johnson, and Nixon likewise used Corona data to “assess and defuse a variety of dangerous situations” such as the Chinese nuclear detonation at Lop Nur and enforce arms limitations treaties.⁴⁰ Dwayne Day et. al hailed Corona as the program that “helped keep peace in the nuclear age” and “a triumph of American technology.”⁴¹ The U.S. government strictly controlled the clandestine Corona program and its technological capability as a military reconnaissance program with clear operators (military) and users (military/intelligence) in the political context of Cold War national security. The Corona program successfully flew throughout the 1960s and came to a formal end in 1972. At that time, merely by coincidence, space-based Earth observation became a civilian enterprise after the

³⁸ Dwayne Day et al. *Eye in the Sky: the story of the Corona spy satellites*, (Washington, DC: Smithsonian Institution Press, 1998), pg. 215

³⁹ John Cloud “Imaging the World in a Barrel: CORONA and the Clandestine Convergence of the Earth Sciences” *Social Studies of Science*, Vol. 31, No. 2, Science in the Cold War (Apr. 2001), pp. 231- 251, pg. 240

⁴⁰ Dwayne Day et al. *Eye in the Sky: the story of the Corona spy satellites*, (Washington, DC: Smithsonian Institution Press, 1998), pg. 28 and pp. 178-180

⁴¹ Dwayne Day et al. *Eye in the Sky: the story of the Corona spy satellites*, (Washington, DC: Smithsonian Institution Press, 1998), pg. 28 and pp. 18

launch of Earth Resources Technology Satellite-A (ERTS). We see then that a varied set of actors is critical to understanding the history of Landsat.

Chapter 1: Launching Landsat

Situating Landsat

This thesis contributes to the fields of history of science and technology and to space history and federal history in particular. Also, I situate Landsat within America's Cold War struggle for global supremacy which positioned science and technology as state instruments. This thesis contributes to history of technology as I consider how governance structures and policies affect how technologies are used. My study of Landsat contributes to space history, particularly studies of NASA and its applications satellites in the international domain, by contributing a new analysis of Landsat that extends from its prelaunch years into the understudied 1990s and 2000s. In addition to the Cold War, I characterize Landsat's historical moment as one of political transformation given the federal government's efforts to cut federal spending and invigorate the economy during the 1980s. By the 1990s, NASA entered an era in which it focused on cheaper, more focused missions. Throughout the dissertation, I trace how the use of Landsat changes over time, drawing from literature in history of technology.

The history of technology has concerned itself strongly with studies of innovations and inventions. Yet Ruth Schwartz Cowan moved the field towards users of technology. Cowan's work, using a largely feminist lens, demonstrates how the interaction of users and technologies produced unintended consequences.⁴² Cowan argues that focusing on the user and ensuing unintended consequences produced by use highlights the successes and failures of a particular technology.⁴³ She also introduced the 'consumption junction' in which users choose among technologies in a market. For Cowan, this notion is "the place and time at which the consumer

⁴² Ruth Schwartz Cowan, *More Work for Mother: The Ironies of Household Technology From the Open Hearth to the Microwave*, (BasicBooks, 1983)

⁴³ Nelly Oudshoorn and Trevor Pinch, eds., *How Users Matter: The Co-Construction of Users and Technology*, (Cambridge: MIT Press, 2005), pg. 2-3

makes choices between competing technologies,” suggesting the user is also a consumer.⁴⁴ Both of these notions are useful in that this thesis seeks to argue how many uses of Landsat emerged and a number of unintended consequences did as well such as national security concerns over data misuse, international backlash over economic espionage, and a skeptical user base. By the mid-1980’s, Landsat commercialization and foreign competitors created a market in which users chose among remote sensing products forming a consumption junction in which Landsat was no longer the sole civilian Earth observation apparatus.

David Edgerton critiqued the innovation/invention trend first by considering how innovative technologies such as bicycles, automobiles, and aviation were used, rather than invented. Secondly he proposed ten theses to draw the field’s attention towards how technologies are used.⁴⁵ His ten theses argue that technology-in-use generates a better understanding of the relations between technology and society and that “we should not conflate the history of invention and innovation with the history of technology.”⁴⁶ Edgerton argues that innovation has a narrower geography and chronology than does a use-based approach. Innovation and invention is spatially confined to where the research and development takes shape, namely within the nation-state. He demonstrates how use has international components since technology transfers, indeed flows, across borders. A technology-in-use framework “can be genuinely global. It includes all places that use technology, not just the small number of places where invention and innovation is concentrated.”⁴⁷ In *Shock of the Old*, Edgerton considers how technology transfer facilitated the use of various technologies, namely the rickshaw, the sewing machine, the bicycle,

⁴⁴ Ruth Schwartz Cowan, “The consumption junction: A proposal for research strategies in the sociology of technology,” in *The Social Construction of Technological Systems*, eds., Wiebe Bijker et. al, (MIT Press, 1983)

⁴⁵ David Edgerton, “From Innovation to Use: Ten Eclectic Theses on the Historiography of Technology,” *History and Technology*, Vol. 16 (1999), pp. 111-136

⁴⁶ David Edgerton, “From Innovation to Use: Ten Eclectic Theses on the Historiography of Technology,” *History and Technology*, Vol. 16 (1999), pp. 111-136, pg. 129

⁴⁷ David Edgerton, *The Shock of the Old: Technology and Global History since 1900*, (Oxford University Press, 2007) pg. xiii

among several others. In essence, innovation-based history is far more limited than is use-based history. Sociologists of technology also addressed technology in use. Nellie Oudshoorn and Trevor Pinch gave definition to the user-technology relationship as one that is subject to co-construction since “users of technologies do not arrive de novo.”⁴⁸ Thus, it is vital to resolve and define the contours of the user-technology interface. For the purposes of my research, users are social and political actors who employ Landsat data during scientific projects to produce new truths about the Earth’s terrestrial environment.

As self-conscious user groups, users are generally associated with a U.S. government agency, university or research institution, foreign government, or a private industry. Individually, users commonly have a university education ranging across many disciplines, typically in agriculture, engineering, physics, or the earth sciences⁴⁹. Also, there are two other classes of actors who facilitate co-construction: designers and policymakers. Designers are those actors who recommend specifications, design and build the Landsat satellites, and place them into orbit. A majority of the actors in this class are associated with NASA and its contractors but also the USDA and the USGS. Policymakers are those that enable or impede the transfer of Landsat data from NASA and USGS -governed data reception centers to users. This class is generally actors working for the United States Agency for International Development (USAID), the State Department, NASA administration, Congress, the White House, and to a lesser extent, the DoD and CIA. Some actors cross these boundaries given the various bureaus within the executive departments and the expertise of certain individuals enables them to design, use, and/or dictate policy. Furthermore, Oudshoorn and her collaborators recall that “there is no one correct use for a technology,” but rather that a single scientific or technological practice can have myriad users

⁴⁸ Nelly Oudshoorn and Trevor Pinch, eds., *How Users Matter*, pg. 2-3

⁴⁹ I define the earth sciences broadly: geology, physical geography, soil science (especially pedology), geophysics, and, for more specialized remote sensing inquiries, glaciology and the atmospheric sciences.

interested in it.⁵⁰ Landsat and the imagery it produces is no exception. NASA policy as well as political rhetoric toward Landsat framed the satellite and its data as a scientific instrument for the benefit of humanity. Thus, this thesis takes an interest in the changing relationship between Landsat designers, civil remote sensing policymakers, and Landsat data users, both domestic and international. It is also interested in the changing nature of Landsat use and it argues that use broadened from agricultural purposes to a wide range of environmental applications in which many user communities employ Landsat imagery in their investigations.

For this thesis, communities are groupings of users within a state while users are individuals or singular agencies which employ the terrestrial cartographic data produced by Landsat to carry out scientific investigations which produce new knowledge of the Earth. A singular individual or agency such as the U.S. Department of Agriculture denotes a user while a community of users denotes a consortium of users which employ Landsat for a number of scientific investigations. The Department of Agriculture as well as the Laboratory for Agricultural Remote Sensing at Purdue University (LARS) and NASA's Johnson Spaceflight Center is a user community, all of which took part in agricultural experimentation with Landsat technology. Similarly, a community extends internationally, as this thesis will demonstrate the participation of foreign Landsat users in a community of investigators. Subsequent examples include the Canadian Centre for Remote Sensing's participation in Landsat data collection, the process by which China acquired a Landsat ground receiving station, and African participation in remote sensing.

My study of Landsat contributes to space history as well, which is a subdiscipline that draws strongly from themes in history of science and technology and is characterized by the

⁵⁰ Oudshoorn and Pinch, *How Users Matter*, pg. 1. Also see: Nelly Oudshoorn, Els Rommes, and Marcelle Stienstra, "Configuring the User as Everybody: Gender and Design Cultures in Information and Communication Technologies," *Science, Technology, & Human Values*, Vol. 29, No. 1, (Winter, 2004) pp. 30-63

Cold War. Akin to history of technology, space history has focused strongly on the innovative aspects of spaceflight, rocketry, and instrumentation. From an institutional perspective, space history strongly focuses on studies of NASA.⁵¹ Moreover, NASA projects such as the Apollo program and the Space Transportation System (more commonly known as the Space Shuttle) have received considerable attention.⁵² The space sciences and astronomy have also been explored in space history.⁵³ In addition to human spaceflight and the space sciences, space history also includes a growing literature that focuses on applications satellites, which refers to uncrewed spacecraft that gather, downlink, and relay information to Earth. These systems include communications satellites, navigation, global positioning, and Earth observation.⁵⁴ Earth

⁵¹ For studies of NASA, see: Roger Launius, *NASA: A History of the U.S. Civil Space Program*, (Malabar, FL: Krieger Publishing, 1994) and Howard McCurdy, *Faster, Better, Cheaper: Low-Cost Innovation in the U.S. Space Program*, (Baltimore: Johns Hopkins University Press, 2001) and *Inside NASA: High Technology and Organizational Change in the U.S. Space Program*, (Baltimore: Johns Hopkins University Press, 1994). For a study of NASA in the international domain see: John Krige, Angelina Long Callahan, and Ashok Maharaj, *NASA In the World: Fifty Years of Collaboration in Space*, (Palgrave MacMillan, 2013).

⁵² For analyses of the Apollo program and its predecessors, consult John Logsdon, *The Decision to Go to the Moon*, (MIT Press, 1970), *John F. Kennedy and the Race to the Moon*, (Palgrave MacMillan, 2010), Stephen Johnson, *The Secret of Apollo: Systems Management in American and European Space Programs*, (Johns Hopkins Press, 2002). For more on the Shuttle program, see: Diane Vaughn, *The Challenger Launch Decision*, (University of Chicago Press, 1996) and John Logsdon, *After Apollo?: Richard Nixon and the American Space Program*, (Palgrave MacMillan, 2015).

⁵³ David DeVorkin, *Science with a Vengeance: How the Military Created the US Space Sciences after WWII*, (Springer Verlag, 1992), Patrick McCray, *Giant Telescopes: Astronomical Ambition and the Promise of Technology*, (Harvard University Press, 2006), and Robert Smith, *The Space Telescope: A Study of NASA, Science, Technology, and Politics*, (Cambridge University Press, 1993).

⁵⁴ There is a growing literature of applications satellite studies: David Whalen, *The Origins of Satellite Communications 1945-1965*, (Washington, D.C.: Smithsonian Institution Press, 2002; Andrew Butrica, ed., *Beyond the Ionosphere: Fifty Years of Satellite Communication*, (Washington, D.C., NASA-SP 4217, 1997), among others. For analyses of military applications satellites, see Dwayne Day, John Logsdon, and Brian Latell, eds., *Eye in the Sky: The Story of the CORONA Spy Satellites*, (Washington, D.C.: Smithsonian Institution Press, 1999); John Cloud, "Imaging the World in a Barrel: CORONA and the Clandestine Convergence of the Earth Sciences," *Social Studies of Science*, Vol. 31, No. 2 (2001) and "American Cartographic Transformations during the Cold War," *Cartography and Geographic Information Systems* Vol. 29, No. 3 (2002) and Paul Stares, *The Militarization of Space: U.S. Policy, 1945-1984*, (Ithaca: Cornell University Press, 1985). For a recent analysis of weather satellites, see: Angel Long Callahan, "Satellite Meteorology in the Cold War Era: Scientific Coalitions and International Leadership," (Ph.D dissertation, Georgia Institute of Technology, 2013) and Margaret Courain, "Technology Reconciliation in the Remote Sensing Area of United States Civilian Weather Forecasting, 1957-1987," (Ph.D dissertation, Rutgers University Department of History, 1991). John Krige addresses European weather satellites in "The European Meteorological Satellite Programme," in John Krige, Arturo Russo, and Lorenza Sebesta, *A History of the European Space Agency, 1958-1987: Volume II The Story of ESA, 1973-1987* (ESA: Noordwijk, ESA SP-1235, 2000). Pamela Mack addressed Landsat into the late 1980s in *Viewing the Earth: The Social Construction of the Landsat System*, (Cambridge: MIT Press, 1990).

observation satellites include both military and civilian satellites that collect imagery of the terrestrial surface, oceans, and weather through remote sensing or photography. Remote sensing, a term which carries a civilian scientific connotation, refers to the gathering and processing of scientific data using a device that is not in physical contact with the object or objects under investigation.⁵⁵ Earth observation for military and intelligence purposes is usually represented by the term reconnaissance which is addressed in the following sections in greater detail as it forms the backdrop of Landsat's origins.

This dissertation focuses on the civilian Earth remote sensing satellite Landsat, which primarily gathers imagery of the Earth's terrestrial surface. I situate Landsat's history within the wider literature on the history of Earth observation beset within the context of the Cold War. My thesis on Landsat compliments and contributes to space history in several ways. First, it adds a new analysis of applications satellites both in a domestic and international domain and considers their legality and uses by an international user community. This dissertation is a contribution to studies of NASA that analyzes its role in Earth science missions and adds to space history by considering the participation of federal agencies such as USDA, USGS, and NOAA, who are not traditionally associated with spaceflight. Also, this thesis analyzes how data gathered by a spacecraft is used by a user community and how that use is guided by policy. Moreover, I present here the four different eras of Landsat history that consider both the domestic and international domains by contributing a new analysis of Landsat that extends from its prelaunch years into the understudied 1990s and 2000s.

A Brief Historiography of Landsat

⁵⁵ This definition is derived in part from the one used by the American Society for Photogrammetry and Remote Sensing, see: <https://www.asprs.org/organization/what-is-asprs.html>, date accessed: 5 September 2016

On 23 July 1972, NASA launched ERTS-A (the satellite series was renamed Landsat later in 1975 and henceforth referred to as Landsat) into a sun-synchronous orbit and became the first of its kind; a satellite used for mapping that produced data available to the public.⁵⁶ The first three Landsat satellites (Landsat-1, 2, and 3) carried an operational Return Beam Vidicon (RBV) and an experimental Multispectral Scanner (MSS) which scanned the Earth's terrestrial surface and returned the data to ground based signals receiving stations, or simply ground stations. However, the construction and operation of the satellites became deeply politically contentious. Pamela Mack's work on Landsat addressed the experimental stage of the program and how Landsat became a product of bureaucratic politics because NASA failed to effectively market Landsat's capabilities to an already suspicious market. NASA was neither motivated to develop a commercially viable system nor was it fully vested in training users to utilize Landsat data. Mack draws upon the social construction of technology perspective to demonstrate how "a community of interested individuals and organizations negotiates a definition of the character and goals of the new technology."⁵⁷ The various agencies involved with Landsat, including NASA, the USDA, Defense (DoD), and the DOI and the Office of Management and Budget (OMB) often disagreed over the technical specifications to be implemented on Landsat. NASA failed to effectively convince potential users in universities, industry, state and local governance, as well as abroad. In essence, Mack depicts a program predicated upon development and experimentation hoping to achieve routine use but ultimately falls short of expectations due to bureaucratic contention, confusion, and an uncommitted user base. Pamela Mack's work is

⁵⁶ NASA launched ERTS-A and ERTS-B, which will be referred to as Landsat-1 and Landsat-2 respectively. When a satellite number is not specified, I am referring to Landsat as a program.

⁵⁷ Pamela Mack, *Viewing the Earth: The Social Construction of the Landsat System*, (Cambridge: MIT Press, 1990), pg. 4

definitive and convincing in this light yet focuses too strongly upon NASA's efforts to build a user community and difficulties building the scanning devices.

I depart from and build off of Mack in several key ways. I depart from Mack's social constructivist framework and instead analyze Landsat through recent scholarship on technology-in-use, to be discussed below. Also, I demonstrate how policy changes over time expanded and constricted Landsat data use over time. I also depart from Mack's argument that NASA failed to convince potential users of Landsat's value. Rather, NASA built partnerships with federal agencies and other countries to foster a domestic and international user community. Lastly, whereas Mack focused on the construction of the Landsat satellites and scanning devices, I emphasize the effect of policy change on Landsat data use. My work complements Mack's work by building off her work on the history of Landsat's agricultural applications and its use abroad. Also, I address the period of commercialization and post-commercialization with newly available sources since Mack published *Viewing the Earth*. Since Mack's book, several dissertations and master's theses also addressed Landsat's history.

Donald T. Lauer completed his dissertation, "An Evaluation of National Policies Governing the United States Civilian Satellite Land Remote Sensing Program," at University of California, Santa Barbara's Department of Geography in 1990. His work identified several critical policy gaps in the American space remote sensing program and offered four options intended to improve the program such as commercialization, public/private partnership, amalgamating military and civilian programs, and accelerated international cooperation. He concludes that for America to sustain its technical remote sensing leadership, a single agency should manage the Landsat program, that it should cooperate internationally, and eventually commercialize the remote sensing system in order to build and sustain a successful civil remote

sensing program. Gerald B. Thomas's dissertation from 1998, "Analyzing Environmental Policy Change: U.S. Landsat Policy, 1964-1998," at Colorado State University's Department of Political Science uses the Advocacy Coalition Framework to analyze policy changes in the Landsat program. Thomas emphasizes the influence of policy conflicts, policy learning, and political events on policy changes through ACF. More recently, Kenneth Thompson's dissertation completed at Virginia Tech's Department of Science and Technology Studies in 2007 is a political history of commercial remote sensing. He addresses knowledge voids in the policy making process from 1984 to 2007. James Allen and Shanaka De Silva published a brief overview of Landsat's history in a 2005 edition of *Quest* which outlines and highlights significant moments in the program. Catherine Rayner provides an international perspective having completed an M.Phil. thesis at Australian National University on a history of remote sensing in Australia from 1971 to 1989. She focuses on the role of Landsat in developing Australian capabilities in remote sensing. In *NASA in the World*, Ashok Maharaj recounts Indian efforts to utilize and eventually launch the Indian Remote Sensing (IRS) satellite as both a modernizing and internationally cooperative effort. Rayner and Maharaj's contributions offer non-American analyses of Landsat's use abroad. Also of relevance, Rebecca Johnson's *What It Took: A History of the USGS EROS Data Center* demonstrates the history of the United States Geological Survey Earth Resources Observation and Science Center (EROS) in Sioux Falls, South Dakota where Landsat data is processed and made available to users. My dissertation draws from and contributes to this growing body of literature. Moreover, I situate Landsat within a wider historical literature that addresses the uses of air and space borne cartographic imagery as well as the legal issues and policies related to Earth observation, especially during the Cold War.

Major Actors in Landsat History

There are many individual actors throughout Landsat's 40-plus year history across the federal government, private sector, and among the elected officials who played a part in legislation and those who use Landsat imagery. While there are many significant individual officials from the Landsat program highlighted here, this dissertation largely focuses on the institutions that shaped Landsat's complex political and policy history. Within the federal government, the primary actors are NASA, the U.S. Department of Agriculture (USDA), the USGS and its parent agency, the DOI. These agencies played a central role in the experimentation, management, and operations of the Landsat satellites.

NASA is a very large independent agency of the U.S. federal government with laboratories, flight centers, and management outfits spread across the United States and satellite communication centers around the world. Its mission is to conduct research and development in the areas of space science, aeronautics, astronautics, Earth science, and human spaceflight, among others. Among NASA's many offices and flight centers, the principal actors include NASA's Headquarters in Washington, D.C., Goddard Spaceflight Center in Greenbelt, Maryland (GSFC), and the Johnson Space Center in Houston, Texas (JSC). NASA Headquarters is largely a managerial and decision making outfit which coordinated policies and policy making with other federal agencies. GSFC conducted research and development, built, and operated the Landsat satellites. JSC's role was experimental and is documented in Chapter 2. When I refer to 'NASA,' I am referring specifically to NASA Headquarters. NASA as an institution is a crucial actor throughout this dissertation.

USDA is also a very large executive agency of the U.S. federal government that played a critical role in Landsat's history as a user and initially as a player in research and development.

Within USDA, there are several key offices and bureaus that conducted formative studies using Landsat imagery which is detailed in Chapter 2.

The USGS and DOI both played a crucial role in Landsat's operational history. The idea of an earth resources satellite did not originate at NASA. Rather, the DOI took the space agency by surprise on 21 September 1966, when Secretary Stewart Udall announced the Earth Resources Observation Satellites program. The program, "aimed at gathering facts about the natural resources of the earth from earth-orbiting satellites carrying sophisticated remote sensing instruments," would "provide data useful to civilian agencies of the Government such as the USDA who are concerned with many facets of our natural resources."⁵⁸ Even though NASA carried out a number of feasibility studies with USGS to explore the possibility of such a satellite, DOI "became impatient with NASA's lack of progress toward defining a satellite system."⁵⁹ Despite the DOI's lack of budgeting for a satellite program, or even experience with satellites, the political gambit captured NASA's attention and the agencies began to work towards developing the first instruments flown on Landsat which is detailed in later chapters.

The National Oceanic and Atmospheric Administration (NOAA) and its parent agency the Department of Commerce (DOC) played a critical role in Landsat management. NOAA assumed managerial responsibility for Landsat in the late 1970s and DOC facilitated the transfer of Landsat from a publicly run experimental project to an operational program and later commercialized its operations. This process is closely detailed in Chapter 3. Each of these actors, NASA, USGS/Interior, NOAA/Commerce, and USDA played critical roles in the formation and trajectory of Landsat's history. Several more federal government actors played more specialized roles in the shaping of the satellite program.

⁵⁸ Department of the Interior Office of the Secretary news release, "Earth's Resources to be Studied From Space," 21 September 1966, courtesy of Raymond Byrnes, US Geological Survey, Reston, Va., 14 January 2015

⁵⁹ Pamela Mack, *Viewing the Earth*, (MIT Press, 1990), pg. 58

Other agencies enter Landsat's history and play more specialized roles which are detailed later in this dissertation. In particular, the Department of State and the DoD play regulatory roles with regards to the development of Landsat's use aboard and its capabilities. DoD also became one of the largest users of Landsat imagery for defense mapping. Similar to DoD, the intelligence community, in particular the Central Intelligence Agency (CIA), National Reconnaissance Office, and National Geospatial Intelligence Agency, become significant users of Landsat imagery for intelligence gathering and often played an advisory role with regards to Landsat's instrument capabilities. As I will detail in Chapter 2, USAID partnered with NASA to assist with the expansion of Landsat data use in the developing world. Lastly, the Office of Management and Budget (OMB) also plays a budgetary role in Chapter 3 during the process of Landsat commercialization. Each of these agencies impacted Landsat's history in different ways, but so too did a number of private sector firms and universities, in several cases via government contracting, who are also profiled in this dissertation at various points in the program's history. As such, I argue there are different episodes of Landsat history, which I broadly define into four periods, described below.

Eras of Landsat History

The genesis of Landsat began in the mid-1960s when NASA and the USDA began experimenting with multispectral scanning technology to be placed aboard an orbiting satellite, however, the various techniques and methods for gathering and interpreting land imagery were developed in the 1950s. Landsat's history spans nearly five decades and during that time, several government agencies and private companies conducted Landsat's various technical and managerial operations. Also, there have been eight launches in the Landsat series including one

failure; Figure 1 below details each satellite's sensor array and operational years. Many of the satellites' operational years overlap and therefore it is less useful to divide Landsat's history alongside the satellites themselves, but rather upon the regimes that operated them as dictated by policy. Thus I employ turning points, defined by Roger Launius as "an event or set of events that, had it not happened as it did, would have prompted a different course in history...and are representative of the dominant culture in which they are situated," to distinguish Landsat's eras apart from each other.⁶⁰

While the satellites produced more data at higher quality over time, several key turning points characterized by policy changes in the form of Presidential decision making and Congressional legislation in Landsat history significantly altered the ways in which the federal government and its commercial contractor distributed data. Thus, these turning points serve as organizing moments for this dissertation but also, I propose, more broadly for understanding the trajectory of Landsat's history.

The first era, the Pre-Launch Years ranged from 21 September 1966 to 29 July 1972. During this time, NASA and its partners developed and built the first scanners to be placed aboard the experimental satellites. After months of discussion between Secretary of the Interior Stewart Udall and his USGS Director Dr. William Pecora and his colleagues, Udall's Office published a news release announcing the Earth Resources Observation Satellites, "a program aimed at gathering facts about the natural resources of the earth from earth-orbiting satellites carrying sophisticated remote sensing observation instruments."⁶¹ It was a bold political gambit by DOI since the agency had no experience with operating satellites nor did it have funding to do

⁶⁰ Roger Launius, "What Are Turning Points in History, And What Were They for the Space Age?" in Steven J. Dick and Roger Launius, eds., *Societal Impact of Spaceflight*, (NASA History Office, 2007)

⁶¹ News Release, Department of the Interior Office of the Secretary, "Earth's Resources to be Studied from Space," 21 September 1966, courtesy Raymond Byrnes, U.S. Geological Survey, Reston, VA

so but the seemingly untimely news release reflected very strong support from DOI for a civilian Earth observation satellite program. The announcement amounted to no more than a “total bluff” to twist NASA’s arm into cooperating in the project.⁶² NASA, DOI, and USDA, began a series of experiments to develop and test the scanners placed aboard the first three Landsat satellites. NASA launched Landsat-1 on 29 July 1972 from Vandenberg Air Force Base in California. The following chapter addresses this era.

I entitled the second era the Experimental Years which range from July 1972 until November 1979. The Landsat satellites were flown and operated by the U.S. federal government exclusively as an experiment of NASA with the USGS archiving the data. In particular, the multispectral scanning sensors aboard the Landsat 1, 2, and 3 satellites were experimental in nature, hence the name of the era. This era is characterized by NASA sponsorship of and participation in numerous experiments utilizing Landsat data to monitor natural resources, understand hydrological and geological processes, and improve cartographic capabilities. NASA partnered with U.S. government agencies to facilitate international usage of Landsat data through grant programs. In addition, NASA negotiated with the UN to legitimize Landsat as a beneficent program as well as foreign space agencies to build ground stations abroad to directly receive Landsat data from the satellites. During this era, the U.S. government, prompted by President Nixon, adopted a policy requiring non-discriminatory data access to all potential users, foreign and domestic. Accordingly, NASA and its partners attempted to make Landsat data widely available but experienced many difficulties which is covered in Chapter 3. In November 1979, the Landsat program underwent significant changes. President Carter released NSC-54 which

⁶² Rebecca L. Johnson, *What It Took: A History of the USGS EROS Data Center*, (The Center for Western Studies, Augustana College, 1998), pg. 7

called for NOAA to assume Landsat operations and to eventually commercialize the program. I cover this era in Chapter 2.

NOAA operation and later commercialization by contracting with EOSAT characterizes the Commercial Years, the third era of Landsat's history which spans from November 1979 until October 1992. This era, covered in detail in Chapter 4, begins with three PD/NSC documents in which President Carter identified Landsat as an operational, rather than experimental, program. Thus, in November 1979, NOAA assumed a managerial role of Landsat. When President Reagan assumed office, he charged NOAA with finding a suitable commercial operator for not only land remote sensing, but the weather and ocean sensing satellites in orbit as well. In 1984, Congress passed the Land Remote Sensing Commercialization Act and the DOC awarded a commercial contract a year later in September 1985. The process proved long and fundamentally altered Landsat data availability since the Reagan Administration reneged on its commitment to subsidies for Landsat and EOSAT began to suffer from falling data sales. During the late 1980s and early 1990s, funding for Landsat ran out each fiscal year and it became apparent that Landsat commercialization had failed to foster an enterprise. Congress once again passed sweeping legislation in 1992 that withdrew the Landsat program from the private sector, though EOSAT continued to operate Landsat 5.

The final era, the Partnership Years, is distinguishable by the partnership that NASA and the USGS formed to manage the Landsat program in October 1992 and ensure data continuity which eventually came to fruition in 2008. Commercialization precipitated major budgetary and managerial issues that prompted the federal government to reassume control of Landsat. In 1992, Congress passed the Land Remote Sensing Policy Act and a joint USGS/NASA effort began to ensure data continuity. However, this did not necessarily mean new satellites in the Landsat

series. Landsat 6 was the last proposed satellite which EOSAT built and launched in late 1993. However, due to a hydrazine manifold rupture, the doomed satellite crashed into the Indian Ocean. By 2008, DOI announced its decision to make Landsat data free of charge and open to all potential users. I argue this monumental policy change was both originally conceived in a speech by President Nixon to the UN General Assembly and represented the scientific value of Landsat data due to its wide range of uses developed over its forty-year history.

My dissertation addresses each of these eras with particular attention to how federal government policy changes affected data continuity and accessibility. These four eras of Landsat history informed how I chose to organize this dissertation, described further below. Given the broad coverage of Landsat's history and its various agencies, I utilize a mixed methodology.

Methodology

My dissertation draws from each of these scholarly perspectives on the Landsat program while also drawing heavily from several archival sources, government documentation, a few interviews, periodicals, the Congressional record, and web-based sources.

This dissertation is primarily built upon federal government agencies, whose records I gathered from several archives, government repositories, and agency headquarters. NASA Headquarters in Washington, DC houses the NASA Historical Reference Collection (NASA HRC) which is an archive of NASA technical reports, press releases, memoranda, Congressional documents, and policy documents, among other forms of records. I consulted their numerous record groups related to Landsat.

I also consulted the National Archives and Record Administration (NARA) facilities in College Park, Maryland and Fort Worth, Texas for federal government agency records. Also

under the NARA umbrella are the presidential libraries of Lyndon Johnson, Gerald Ford, Jimmy Carter, and Ronald Reagan each of which provided perspectives from the White House on Landsat through memoranda, press releases, and meeting minutes. I visited the Jimmy Carter Presidential Library in Atlanta and requested records via mail from the other aforementioned libraries. These records informed the White House perspective on Landsat and the broader issues affecting the program.

A major interest of Chapter 3 is to understand the international dimensions of Landsat imagery use. I utilized resources from the UN Archives in New York City to understand the adoption of laws and policies that reflected the international community's interest and opposition to Landsat and the imagery it produced. The documents there also provided me with a sense of how other interested countries made use of Landsat imagery.

In order to better understand the scientific community and the applications of Landsat, I consulted the archives of the National Academies and National Research Council in Washington, D.C. The records located there strongly informed my understanding of the development of Earth remote sensing both scientifically and technically. Moreover, they were highly valuable in Chapter 2 discussing the applications of Landsat imagery to agriculture.

In addition to NASA, I went to the USGS Headquarters in Reston, Virginia to obtain both public records and hold informal interviews with Landsat officials there. Raymond Byrnes, who worked at EROS, the Earth Observation Satellite Company (discussed later), and USGS Headquarters shared his wealth of institutional and technical knowledge with me. Byrnes also linked me with EROS where I later visited and gathered more public records and conducted informal interviews with Landsat officials.

I also used a few web-based repositories to draw Landsat-related records from. WikiLeaks, the George Washington University National Security Archive, and the National Technical Information Service each has records that related to various aspects of Landsat's history that populate different sections of this dissertation.

As a secondary method, I conducted informal interviews and discussions with several individuals who worked on different aspects of the Landsat program, either managerially or technically. Since Landsat remains an ongoing effort of NASA and USGS, many of these individuals were still active either with the federal government or private sector. During my aforementioned visit to USGS EROS, I spoke with several individuals there including John Faundeen, Thomas Holm, Eugene Fosnight, Kristi Kline, Steve Labahn, and Tom Loveland. Each of these people gave me exceptional insight into the managerial and technical history of the Landsat program from the USGS perspective. I also informally interviewed D. James Baker, former administrator of NOAA, for a higher level perspective on Landsat management from DOC and NOAA perspective. Similarly, I spoke with Jim Irons of GSFC and Darrel Williams, formerly of NASA as well for the NASA perspective. I am also indebted to James Zimmerman formerly of NASA, Raymond Byrnes of USGS Headquarters, and James David of the Smithsonian National Air and Space Museum who shared their personal collection of public Landsat documents with me. John Faundeen and Thomas Holm of USGS EROS also shared many USGS public records and statistics with me. I appreciate the time and effort each of these individuals contributed to the completion of my research, the errors of course are my own. I used informal interviews, rather than formal interviews given the time constraints on many of these people. All of the aforementioned individuals are active in their careers. The combination of

primary, archival records with informal interviews, allowed me to gather the broad narrative of Landsat's history while also understanding the technical and managerial nuances of the program.

Landsat in Use: Technical Details

When describing Landsat as a satellite program, I am referring to all actors involved with the research and development of instruments and applications, data reception, processing and dissemination, as well as program management. While actors come and go, the term Landsat program, refers to all those actors involved in those activities as well as in programmatic decision making. Generally, NASA, USGS, NOAA, and their private industry contractors comprised the Landsat program. Some of these activities were muted at times, such as research and development or building a new satellite, but since 1972, there was consistent data gathering, reception, and dissemination. Prior to 1972, there was a significant amount of experimentation and research and development on Landsat instrumentation that became vital to the satellite later.

As mentioned, this dissertation is focused on the politics and policies of Landsat and its use, however, the various technical details of Landsat shape the types of data available to users and require at least brief discussion here. A distinctly technical history of Landsat is outside the scope of this dissertation.⁶³ However, there are a number of technical details worth presenting to the reader for context and clarity such as Landsat's various instruments and their capabilities, satellite operations, and data applications.

⁶³ Pamela Mack's *Viewing the Earth: The Social Construction of the Landsat Satellite System*, (MIT Press, 1990) provides great detail regarding the construction of the Landsat sensors and processing systems. Also, a group of NASA civil servants are compiling a forthcoming technical history of Landsat entitled *The Landsat Legacy Project*. Other technical details of Landsat can be found at www.landsat.usgs.gov, www.landsat.gsfc.nasa.gov, and through the American Society for Photogrammetry and Remote Sensing's journal *Photogrammetric Engineering & Remote Sensing*.

The Landsat satellites orbit the Earth in a sun-synchronous pattern, returning to the same point on the planet's surface roughly every sixteen days achieving global coverage. Several types of sensors have flown since Landsat 1, including the multispectral scanner (MSS), return beam vidicon (RBV), thematic mapper (TM) and its more advanced iterations (TM, Enhanced TM, Enhanced TM Plus), the operational land imager (OLI), and the thermal infrared sensor (TIRS). These instruments capture light reflected from Earth across several bandwidths which enables users to analyze land cover characteristics and change otherwise undistinguishable to the human eye. As the Landsat satellites orbit and the instruments scan the Earth, data collects aboard the satellite's recorder and gets downlinked to ground stations around the world or via the Tracking Data and Relay Satellite System (TDRSS). Ground stations collect data through antennae and TDRSS is a constellation of communications satellites capable of relaying data to Earth. Ground stations and TDRSS will be discussed in greater detail later. Once Landsat data reaches the ground, it is archived by the USGS's Earth Resources Observation Science Data Center (EROS) located near Sioux Falls, South Dakota as well as ground stations around the world operated by USGS international cooperators such as the European Space Agency, the Brazilian National Institute for Space Research, the Canadian Centre for Mapping and Earth Observation, among many others. At centers such as these, raw Landsat data is digitally processed by computers and converted into digital imagery that can be acquired by users in digital or printed form. A value-added industry emerged after Landsat's launch offering data analysis services and tools that enhance Landsat data for specific applications. The following chart lists the evolving instrument payloads and their manufacturers, Landsat 1 to present.

Table 1: Landsat Satellites

Satellite	Sensors	Sensor Manufacturer	Operations
Landsat 1	MSS, RBV	GE Space Division	1972-1978
Landsat 2	MSS, RBV	GE Space Division	1975-1983
Landsat 3	MSS, RBV	GE Astrospace	1978-1983
Landsat 4/D	MSS, TM	Fairchild	1982-1993
Landsat 5	MSS, TM	GE Astrospace, Hughes	1984-2013
Landsat 6	ETM	Hughes	1993* Failed
Landsat 7	ETM+	Hughes	1999-Present
Landsat 8	OLI, TIRS	Ball Aero, NASA	2013-Present

Each of the Landsat satellites fly in a sun-synchronous orbit at an inclination of roughly 98 degrees and an apogee/perigee median of just over 700 kilometers. The spacecraft fly north to south and circle the Earth in about 98 minutes. Within this orbital trajectory, a single Landsat spacecraft returns to a specific point on Earth every 16 days, since the Earth rotates below the satellite's orbit. Thus, a single Landsat satellite gathers multispectral, infrared, and (on later platforms) hyperspectral data across the entirety of the Earth's surface. This data is then downlinked to ground stations for processing, archiving and distribution.

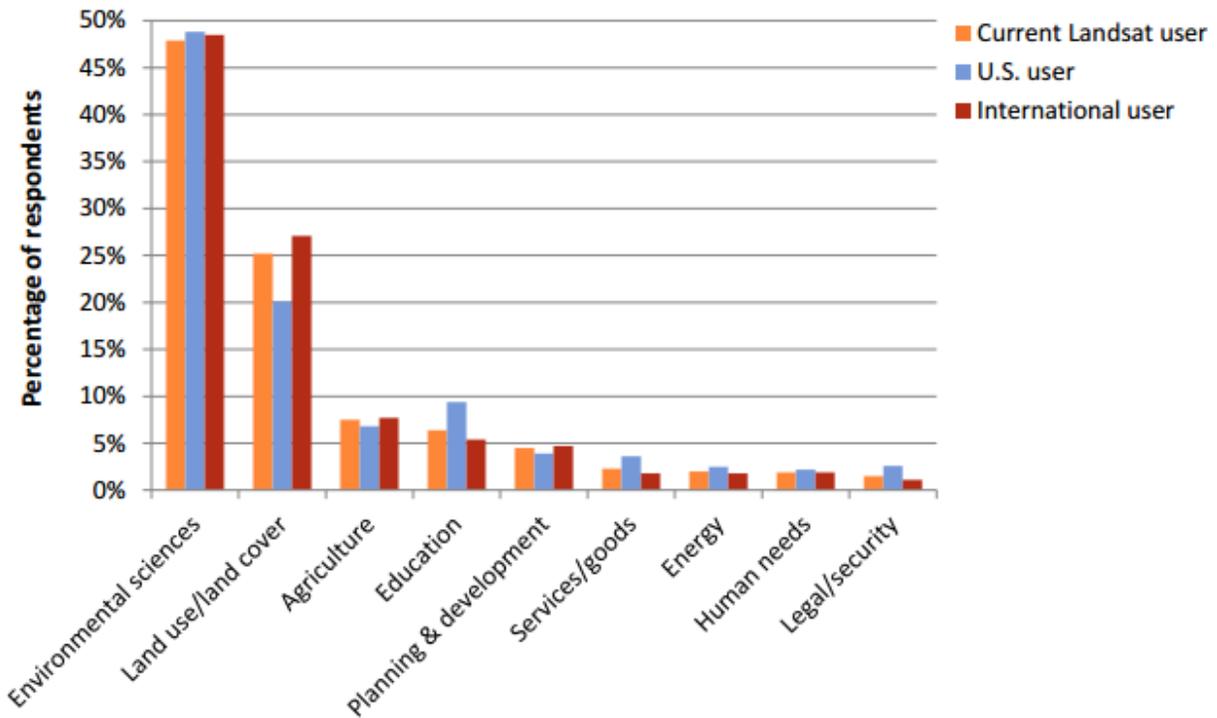
Defining Landsat data

I define Landsat data as any imagery collected by any of the seven Landsat satellites. The various instruments collected data across several spectra at resolutions of roughly 30 meters with a land cover of 185 square kilometers per image. Not all data is particularly useful due to atmospheric disruption, cloud cover, and technical difficulties but nonetheless millions of Landsat images became available. Given the spectral coverage, large land area, and resolution of Landsat, its data became very widely used by government, industry, and academia alike due to

its vast array of applications. The chart below depicts several broad categories of applications that Landsat data supports as defined by USGS.

Table 2: Primary Applications of Landsat Imagery

Table is drawn from “Users, Uses, and Value of Landsat Satellite Imagery- Results from the 2012 Survey of Users,” 2013, U.S. Geological Survey, Reston, VA, <https://pubs.usgs.gov/of/2013/1269/pdf/of2013-1269.pdf>



In 2013, USGS surveyed 11,190 Landsat data users to understand how the imagery was used.⁶⁴

They utilized these nine categories, selected for the purpose of USGS’s analysis, incorporated numerous individual applications. For example, the environmental sciences category included applications such as climate science, ecosystem management, wildlife science, and geology, among others. Other categories were more specific such as education, which includes applications such as using Landsat imagery for instructional purposes, and agriculture, for purposes such as crop forecasting which I dedicate a chapter to in this dissertation. Human needs

⁶⁴ Holly Miller, Leslie Richardson, Stephen R. Koontz, John Loomis, and Lynne Koontz, “Users, Uses, and Value of Landsat Satellite Imagery- Results from the 2012 Survey of Users,” 2013, U.S. Geological Survey, Reston, VA, <https://pubs.usgs.gov/of/2013/1269/pdf/of2013-1269.pdf>, date accessed: 6 September 2016

included emergency and disaster relief and legal/security refers to purposes of defense and national security as well as environmental law and regulation enforcement. Energy refers to users who prospect for oil, natural gas, and minerals. Services and goods include culture resource management, real estate, and Landsat imagery use in software development. The bar graph above shows that among the 11,190 Landsat user respondents, nearly 50% of them stated environmental sciences was the primary application of Landsat imagery in their particular investigations.

How Users Acquire Data

Users had to acquire their data first from NASA through Goddard Spaceflight Center in Greenbelt, Maryland (GSFC). For NASA, “users are defined to be either individual investigators or agencies which have been approved by the NASA/ERTS Project Office for receipt of ERTS data.”⁶⁵ GSFC housed a User Services Section at the Data Processing Facility (NDPF). For Landsats 1, 2, and 3, users could acquire data in one of two ways from the facility. A user requested data by mail or telephone from the NDPF and placed a standing order and/or a data request. NDPF designed the standing order as a way for users to request data that did not yet exist. The facility would notify a user when a particular requested scene had been scanned by Landsat and would ship it. NDPF shipped orders immediately for data requests of imagery already processed. Users had to specify particular longitudes and latitudes, a maximum percentage of cloud cover, quantity of images, which spectral bands as well as resolution, tone, and granularity specifications. These specifications were imperative since each image was, drawn from the archive, uniquely processed, and prepared for the user. Once NDPF received these specifications for a scene, they could process the order and then the requested data and

⁶⁵ “NASA Earth Resources Technology Satellite Data User Handbook,” 17 November 1972, courtesy of Mr. Raymond Byrnes, USGS, Reston, VA., pg. 4-1

finally provide the user with Landsat data. NASA and later USGS provided a catalog as well as the “Landsat Data User Notes” series for users to specify which data would be best for their particular investigation. In addition, these periodicals kept users apprised of new data products as Landsat 1, 2, and 3 data amassed in the data archive at GSFC. NDPF’s role processing and distributing data was short-lived however, as the USGS readied a more capable and robust facility in South Dakota.

Data processing and distribution moved to southeastern South Dakota where the DOI assumed the operation. The USGS established the Center for EROS, based in Sioux Falls to receive, process, and distribute Landsat imagery in 1971 and construction completed in 1973. In addition, EROS began to maintain a data archive on its campus where it collected all Landsat data. The facility also became a repository for aerial photography, cartographic resources, scientific data from other Earth observation satellites, declassified DoD and CIA reconnaissance imagery and the like. There were two types of products initially available to users. NDPF and EROS processed data into printouts of maps, also called scenes. Users could also acquire computer compatible tapes which contained the digitally corrected data requested by users and could be analyzed using computer software. The types of products and how they were priced is covered in detail in the following chapter. NDPF and EROS were the central nodes of Landsat data distribution throughout the 1970s. Even as ground stations emerged around the world, none rivaled the data output of EROS in particular. These various applications and processes discussed above emerge throughout the history of Landsat, which is laid out in this dissertation in four chapters and a conclusion.

Dissertation Layout

As mentioned, I describe four eras of Landsat history which are broadly captured in four chapters in this dissertation. As I argue, Landsat imagery and data use changed over time to include more applications and users, yet the laws and policies that governed the Landsat program did not necessarily facilitate this vision. The four eras reflect both this argument and the layout of the following four chapters of this dissertation.

Chapter 1 traces the pre-launch years of Landsat into the experimental years describing how agricultural purposes, such as mapping and predicting crop yields, became the first major application of Landsat imagery. Many of the early instruments that eventually flew aboard the first three Landsats

Chapter 2 demonstrates how Landsat data use expanded both in the number of applications and to users abroad. However, Landsat and the data it produced was a contentious issue among the international community. Records from the UN Archive demonstrate that several key countries took issue with Landsat since it potentially compromised that particular country's sovereignty. Many more states supported the use of Landsat data for its environmental applications and ordered data sets from NASA and USGS. As this legal contest played out in New York, NASA and USGS grew Landsat's international presence through ground stations, technical seminars, and aid packages. NASA and USGS expanded Landsat data use through agreements with several countries that downlinked imagery directly to foreign ground stations. However, exporting such technology was deeply contentious among several agencies in the U.S. federal government. I demonstrate these difficulties through the case of the Chinese ground station that took years to build, as opposed to months in the case of Canada. With the help of

USAID and several contractors, NASA and USGS also sponsored training seminars via aid packages in several developing countries that facilitated broader use of Landsat data, specifically in Africa. This chapter demonstrates the constraints and difficulties of broadening Landsat data use in an international context.

Chapter 3 explains the domestic complexities of expanding Landsat data usage and narrates the third era of Landsat history when the program became a commercial entity. In 1978, President Carter brought the experimental years to a close and set the program on a trajectory towards commercialization. This chapter details this process and the consequences that befall the government, the contractors, and the satellite program itself. In this chapter, access to Landsat data effectively constricts due to the cost prohibitive pricing of Landsat imagery and sales precipitously drop.

Chapter 4 describes the process by which Landsat decommercializes and becomes a government operation once more. USGS assumed a larger role in Landsat operations and alongside NASA adopted a mission committed to ensuring data continuity. These agencies explored and adopted various means to expand Landsat imagery use. This chapter analyzes this effort which became known as the Landsat Data Continuity Mission manifest in several initiatives such as data acquisition agreements, Department of Defense participation, data repatriation, and the eventual launch of Landsat 7. As mentioned, the 2008 decision to remove prices on Landsat imagery greatly expanded Landsat data use.

The concluding chapter reviews these chapters, evaluates the argument posed in this introduction, and offers an epilogue that covers the launch of Landsat 8, which occurred as I conducted research on this dissertation. I will also address the international aspects of Landsat data availability as well as their first significant applications to agriculture. This combination of

case studies provides broad coverage of Landsat's history and addresses how use of the satellite program changed over time.

Chapter 2: Farming in the Space Age: Landsat and Agricultural Applications, 1953-1987

Introduction

As early as the 1930s, the United States' government began to explore ways in which it could increase agricultural output and predict those outcomes successfully through aerial photography, the forerunner to remote sensing. Pam Mack demonstrated that "Agricultural Adjustment Administration engineers and technicians made and updated maps of agricultural land use so that the federal government could regulate production and locate abandoned farmland in need of erosion control." The Tennessee Valley Authority made use of aerial photographs to control flooding.⁶⁶ By 1934, the practice of producing and analyzing aerial photographs became professionalized with the establishment of the academic journal *Photogrammetric Engineering* and the American Society of Photogrammetry was formed.⁶⁷ After the onset of the Cold War and the subsequent "space race," the U.S. Government sought more advanced technology and methods for monitoring agriculture, both domestically and internationally. The NAS and National Research Council (NRC) sponsored studies of methods for improving what was then referred to as photo-interpretation through multispectral technology, the first experimental remote sensing of agriculture. Photointerpretation involved training an individual to identify land cover variables (such as water, vegetation types, urban structures, etc.) and distinguish them from each other, a process called classification. The Navy and University of California carried out these experiments in California, Oklahoma, North Dakota and a few others. NASA, Purdue University, and University of Michigan later developed

⁶⁶ Pamela Mack, *Viewing the Earth*, (MIT Press, 1990), pg. 32

⁶⁷ Pamela Mack, *Viewing the Earth*, (MIT Press, 1990), pg. 32. See also: <http://www.asprs.org/About-Us/What-is-ASPRS.html>. The society has since added "and remote sensing" to its title and adopted remote sensing and Geographic Information Systems to its mission of advancing knowledge of both cartographic practices and improving their applications.

computers that could classify images automatically, in particular that could classify forms of vegetation from remotely sensed images of the American Midwest. NAS encouraged NASA and USDA to conduct research and development towards new technology capable of inventorying crops from the air using multispectral imaging technology by the 1960s as global food supplies hung in the balance. Agriculture became a critical arena of the Cold War as massive crop failures in the Soviet Union, India, the African Sahel, among others, characterized the decade. To policymakers in Washington, it became imperative not only to survey crop yields, but to *predict* them. NASA and USDA, and later the CIA, conducted a series of experiments to that end worldwide. From the 1950s through the 1970s, widespread agricultural failures resulted in famine and destabilized global markets.

In this chapter, I trace the origins of remote sensing applications to agricultural experiments in the 1950s sponsored by the NAS, the Navy, and the University of California on instrumentation and development of interpretation techniques. In late 1966, DOI, USDA, and NASA began developing instruments for the Landsat platform and chose to test them in the Midwest over wheat and corn fields. Along with the University of Michigan they conducted a series of experiments designed to test these instruments and to monitor and eventually predict crop growth. In the 1970s, into the 1980s, NASA and USDA carried out two ambitious transnational crop yield prediction experiments. Simultaneously, the CIA used these experiments as a model for gathering economic intelligence in the 1970s and 1980s. Accordingly, remote sensing of agriculture evolved from a formative scientific experiment into a component of American national security. I argue that Landsat in particular became an instrument of America's Cold War surveillance imperative to monitor global crop yields and bring greater legibility to the volatile global wheat market. Moreover, the Landsat program emerged from a perceived need to

understand, monitor, and manage Earth resources. Among the myriad applications of Landsat and the data it produced, agriculture became one of the most significant. This chapter further discusses how the U.S. government fostered use of Landsat, in this case through agricultural applications. In particular, continuous, routine multispectral scanning of crop fields enabled users to monitor crop growth and health over the course of a growing season and ultimately predict and forecast crop yields.

Cold War Agriculture and the ‘Surveillance Imperative’

Cold War scholarship has focused increasingly on the nexus of agriculture and technology by historians of technology and American foreign relations historians alike. Nick Cullather’s work demonstrates how food and technology became a critical front of Cold War diplomacy between the U.S. and developing states in the 20th century.⁶⁸ He followed the Rockefeller Foundation’s efforts in Mexico and, more closely, India to innovate agricultural science for the development of high-yield varieties of wheat and rice which would ultimately halt the spread of famine. For American development policy makers in the 1950s and 1960s, this Malthusian-informed modernization theory contained communism by defeating hunger and poverty. The U.S. feared India’s largely peasant population would submit to communism as China did under similar conditions and sought to stifle communist revolution with a “Green Revolution.” Ron Doel and Kristine Harper address U.S.-India foreign policy similarly. They show how the U.S. secretly undertook Project Gromet, a military weather modification initiative meant to end the Bihar drought in 1966 and 1967. The military experiment required the seeding

⁶⁸ Nick Cullather, *The Hungry World: America’s Cold War Battle Against Poverty in Asia* (Harvard University Press, 2010)

of clouds with silver iodide to artificially stimulate rainfall.⁶⁹ Biologist John Perkins argued that “wheat breeding was linked to national security planning and to the need for countries to manage their foreign exchange.”⁷⁰ Among those countries were the U.S., Mexico, India, and Great Britain which he included as case studies. For the United States, wheat breeding became part of its Cold War effort to contain the Soviet Union through managing exports and foreign exchange whereas for the British wheat breeding was part of the transition to a post-imperial economy. India and Mexico sought greater autonomy from potential threats to its population. The literature demonstrates how agriculture became a significant theater of the American Cold War effort to contain communism, with particular attention to the Green Revolution in India.

This chapter moves beyond the Green Revolution to show how space technology became an instrument of American Cold War agricultural efforts. The launch of *Sputnik* led “chiefs of governments and their scientific advisers to envisage modern forms of global surveillance and helped to establish the geosciences in Cold War strategic planning.”⁷¹ Turchetti and Roberts et. al. demonstrated how Cold War sensibilities convinced the Cold War West to establish Earth observation detection systems after the IGY which “simultaneously demonstrated the power of the geosciences to understand the whole earth (and its environs) and showcased competition as well as cooperation between the superpowers.”⁷²

Landsat, the data produced, and the ground stations that emerged around the world became a global scientific surveillance program during the Cold War akin to those mentioned by

⁶⁹ Ron Doel and Kristine Harper, “Prometheus Unleashed: Science as Diplomatic Weapon in the Lyndon B. Johnson Administration,” in John Krige and Kai Henrik-Barth, eds., *Global Power Knowledge: Science and Technology in International Affairs*, Osiris 2006, 21

⁷⁰ John H. Perkins, *Geopolitics and the Green Revolution: Wheat, Genes, and the Cold War*, (Oxford University Press, 1997) pg. vi

⁷¹ Simone Turchetti and Peder Roberts, eds., *The Surveillance Imperative: Geosciences during the Cold War and Beyond*, (Palgrave MacMillan, 2014)

⁷² Simone Turchetti and Peder Roberts, eds., *The Surveillance Imperative: Geosciences during the Cold War and Beyond*, (Palgrave MacMillan, 2014), pg. 2

Turchetti and Roberts that came to benefit the United States. However, I depart from their work in a few ways. Foremost, I contend that agriculture, certainly as much as the geosciences, was an arena of Cold War surveillance by both the civilian scientific communities as well as the defense and intelligence community. In addition, where Turchetti and Roberts focus strongly on the sciences themselves, I sustain focus on agriculture as a science *as well as* the technology and techniques of surveillance. Further, I demonstrate how it was civilian scientists at universities, NASA, and USDA, rather than the military or intelligence community, which first conducted agricultural surveillance. The Army and Navy played a crucial role in funding and overseeing several early experiments, but it was NASA, USDA, and university scientists that led several key experiments. This chapter argues that it was remote sensing scientists whose experiments showcased the capabilities of multispectral scanning and of Landsat itself. Meanwhile, the intelligence community later came to value crop inventorying.

In the early 1950s, the National Academy of Sciences encouraged the USDA and several universities to gain a greater understanding of crop inventorying capabilities. The outgrowth of interest in what became photo-interpretation of agriculture led to several major investigations that empowered America's ability to monitor natural resources. This chapter describes how several federal government agencies and their contractors experimented with Landsat data to monitor and attempt to predict crop yields around the world. NASA, USDA, and their partners carried out a series of agricultural monitoring experiments to demonstrate Landsat's capabilities from the late 1960s into the 1980s. During this period, the world food market became volatile as a result of numerous crop failures precipitating famines in Asia and Africa. I argue that in 1971, a major shift in the agricultural market precipitated by Soviet grain failures prompted the U.S. government to enroll Landsat data in its surveillance imperative. Shortly after Landsat's launch,

NASA and USDA as well as CIA embarked on large scale agricultural monitoring programs using the satellite data. As Landsat came to fruition, agricultural surveying evolved from a scientific experiment into a surveillance imperative. This chapter broadens Turchetti and Roberts et. al.'s work on geosciences surveillance during the Cold War to also include agriculture in addition to extending Cold War agriculture scholarship into the 1970 and 1980s.

National Academy Promotes Agricultural Applications, 1952-1961

In the early 1950s, the NAS began to investigate crop monitoring capabilities and photo-interpretation from aircraft. Several committees and subcommittees assumed this task including the NAS-NRC Agricultural Board Committee on Plant & Crop Ecology, which over saw the Subcommittee on Geography & Vegetation Analysis (Colwell Subcommittee) and the Subcommittee on Plant Diseases and Pests in 1952 through 1953. These committees became active sponsors of scientific research in photo-interpretation of crops.

Dr. Robert N. Colwell, who chaired the Colwell Subcommittee, became a leading researcher in multispectral remote sensing research and its agricultural applications. A graduate of University of California Berkeley in Forestry, he went on to earn a Ph.D in plant physiology from University of California at Davis. Thereafter, he became a professor of forestry at UC Davis, and served as a silviculturalist with the USDA Forest Service at the UC Davis Agricultural Experiment Station. During World War II, Colwell served as an air combat intelligence officer, using aerial photography to map and help plan the Okinawa and Guadalcanal military campaigns.⁷³ He returned to Berkeley to teach and research new applications for aerial photography and, later, remotely sensed satellite data. In mid-1952, the NAS's Committee on

⁷³ "Robert N. Colwell, 87; Developed Satellite Analysis of Forests," 12 May 2005, *Los Angeles Times*, www.articles.latimes.com/2005/may/12/local/me-colwell12, date accessed: 5 October 2015

Plant & Crop Ecology sponsored a joint University of California-USDA-Department of the Navy study to “develop techniques for differentiating between diseased and healthy cereal crops on aerial photography.”⁷⁴ Colwell played a major role conducting this research which took place in the Central Valley of California from April to September, 1953. The Navy allowed Colwell use of the Naval Air Station at Oakland which conducted twelve flights between April and June. In September, Colwell focused his investigation on cereal crop health near Davis. He and his associates at UC Davis inoculated crops with black stem rust and photographed the diseased crops from aircraft on September 1, 12, and 22 and again later in October. These flights flew up to 10,000 feet in altitude and carried an infrared filter camera and a black and white camera. While the black and white camera did not return useful data, the infrared camera successfully detected the diseased crops.⁷⁵ Colwell also indicated that similar experiments in North Dakota and Oklahoma yielded similar results. In particular, the North Dakota experiment used a helicopter to photograph crops at high quality from altitudes of 50 to 100 feet, even at oblique angles.

Colwell’s experiments pleased both the NRC and the Navy. He had been funded by the Navy, Bureau of Standards, USDA, and to a small extent, by the National Research Council (NRC). Throughout 1953, Colwell reported to Everett Davis, the Executive Secretary of the Committee on Plant and Crop Ecology who relayed Colwell’s progress on to the Office of Naval Research and the newly formed USAF. Davis reported that Colwell’s work “will have far reaching applications from the standpoint of national defense as well as in establishing new tools

⁷⁴ Memo, “Aerial photography of Selected Grain Fields in California,” Executive Secretary of the Committee on Plant & Crop Ecology to Commanding Officer, U.S. Naval Air Station, Oakland, California, Folder: B&A Agricultural Board, Committee on Plant & Crop Ecology: Subcommittee on Geography & Vegetation Analysis, 1953-1954, NAS Archive, Washington, D.C.

⁷⁵ Robert Colwell, University of California to Everett Davis, National Research Council, 25 September 1953, Folder: B&A Agricultural Board Committee on Plant & Crop Ecology: Subcommittee on Geography & Vegetation Analysis, 1953-1954, NAS Archive, Washington, D.C.

for the use of agronomists and plant pathologists.”⁷⁶ The military had a significant presence throughout Colwell’s experiments beyond use of the Oakland Naval Station. At a 13 November 1953 meeting in Maryland, Davis shared Colwell’s data for evaluation by the Army Navy, and Air Force, as well as USDA, the Weather Bureau, and the Smithsonian. One of the topics of the meeting was to discuss and evaluate “the classified nature of the photographic interpretation project”⁷⁷ The Navy conducted the aforementioned North Dakota and Oklahoma experiments in order to “develop techniques for differentiating between diseased and healthy cereal crops on aerial photography...[which] would have very important military applications.”⁷⁸ These experiments contributed to national defense and civilian science but also simultaneously inspired international collaboration.

In December 1952, the USDA’s Division of Forest Economics requested “information on the possibilities of an exchange of information between Canadian and USA sources in the field of photo-interpretation of vegetation.”⁷⁹ Everett Davis of the NRC proposed coordination of the USDA Forest Survey and the Canadian Department of Mines and Technical Surveys, the Joint Intelligence Bureau, and Department of Defence. Davis and the Forest Survey sought to assess Canadian efforts of unclassified photo-interpretation of crops from aerial photography including

⁷⁶ Everett Davis, National Research Council, to the Office of Naval Research, United States Air Force, and Assistant Secretary of Defense for Research and Development, “Enclose ‘confidential’ copy of progress report by Dr. Robert N. Colwell, Chairman, Subcommittee on Crop Geography and Vegetation Analysis,” 30 September 1953, Folder: B&A Agricultural Board, Committee on Plant & Crop Ecology: Subcommittee on Geography & Vegetation Analysis, 1953-1954, NAS Archive, Washington, D.C.

⁷⁷ Committee on Plant and Crop Ecology to Dr. Frank Campbell, “Preliminary planning session with respect to attendance, agenda, etc., for November 13 meeting,” 26 October 1953, Folder: B&A Agricultural Board, Committee on Plant & Crop Ecology: Subcommittee on Geography & Vegetation Analysis, 1953-1954, NAS Archive, Washington, D.C.

⁷⁸ Everett Davis to Commanding Officer, U.S. Naval Air Station, Oakland, California, “Aerial Photography of Selected Grain Fields in California,” 6 February 1953, Folder: : B&A Agricultural Board, Committee on Plant & Crop Ecology: Subcommittee on Geography & Vegetation Analysis, 1953-1954, NAS Archive, Washington, D.C.

⁷⁹ Memo, “Implementation of a request to explore and effect Canadian-U.S.A. exchange of research information in the field of photo-interpretation of vegetation,” Dr. Paul Weiss, Chairman Division of Biology and Agriculture to Everett F. Davis, Executive Secretary, NRC, 16 January 1953, Folder: B&A Agricultural Board, Committee on Plant & Crop Ecology: Subcommittee on Geography & Vegetation Analysis, 1953-1954, NAS Archive, Washington, D.C.

geographic locations, resulting publications, and potential for research channels.⁸⁰ The USDA among several other agencies put forth this request for exchange to the NAS Committee on Plant and Crop Ecology. They recognized the lack of knowledge of Canadian activities in crop photo-interpretation which had been under way by several research outfits in Canada. Also, there was no international committee or singular governmental agency in either the U.S. or Canada that received communications or publications. There was no coordination of civil and defense interests either, with the lone exception of the Interservice Committee on Photo-Interpretation Research Keys and Techniques, headed by Colwell. This Interservice Committee gave “its attention chiefly to methodology and to the standardization of techniques, rather than to the kind of helpful coordination and survey requested of this Committee.”⁸¹ Thus, Davis reached out to the Canadians.

In January 1953, Davis contacted a promising young British meteorologist, Dr. Kenneth Hare of McGill University’s Department of Geography. After earning his B.S. from King’s College London and serving with the British Air Ministry, Hare received a PhD from Université de Montréal and a professorship at McGill. While Hare was not actively involved with remote sensing, he was an ardent environmentalist that expressed enthusiasm for the technique as a method for understanding the planet’s surface. Hare and Davis both worked towards a scientific relationship between the U.S. and Canada in crop photo-interpretation. Davis hoped to “establish channels for the exchange of unpublished information in the field of photographic interpretation

⁸⁰ Everett Davis to Paul Weiss, “Request for Information on the Possibilities of an Exchange of Information Between Canadian and USA Source in the Field of Photo-Interpretation of Vegetation,” 15 January 1953, Folder: B&A Agricultural Board, Committee on Plant & Crop Ecology: Subcommittee on Geography & Vegetation Analysis, 1953-1954, NAS Archive, Washington, D.C.

⁸¹ Everett Davis to Paul Weiss, “Request for Information on the Possibilities of an Exchange of Information Between Canadian and USA Source in the Field of Photo-Interpretation of Vegetation,” 15 January 1953, Folder: B&A Agricultural Board, Committee on Plant & Crop Ecology: Subcommittee on Geography & Vegetation Analysis, 1953-1954, NAS Archive, Washington, D.C.

of vegetation with several Canadian groups.”⁸² However, little came of the correspondence and while the relationship between the U.S. and Canada remained in its infancy, it would play a significant role in the advancement of agricultural remote sensing in the 1970s. The National Academies continued to play a role encouraging new agricultural remote sensing applications.

Mitigating Losses from Above, 1959-1974

In 1959, the National Academies-NRC Agricultural Board Committee on Agricultural Pests recommended that the Board form a subcommittee that would foster research in using aerial photographic surveying to mitigate damage to crops caused by diseases, insects, and other flora. The NRC and Navy sponsored a 1956 study conducted by Colwell that successfully detected cereal rust. Cereal rust is a form of fungus that killed crops in the American Midwest, which is an issue I return to in this chapter. Colwell’s successful experiment encouraged the NRC to continue supporting and funding such research. The NRC sought to reduce crop losses using aerial surveys and set up a subcommittee headed by J.R. Shay, a plant pathologist at Purdue University. The Aerial Surveys Subcommittee included members from academia such as Colwell, industry, and the defense community. One of the members, Dr. Marvin Holter, Head of the Sensory Device section at University of Michigan’s Willow Run Laboratories would play an important role developing multispectral scanning devices later used on Landsat. His research in the late 1950s and early 1960s focused on the “use of the longer wavelength infrared rays in non-military applications of aerial detection.”⁸³ With members able to speak to advances in industry, defense, and academia, the Executive Committee of the Agricultural Board (Ag Board) formed

⁸² Everett Davis to Kenneth Hare, 9 February 1953, Folder: B&A Agricultural Board, Committee on Plant & Crop Ecology: Subcommittee on Geography & Vegetation Analysis, 1953-1954, NAS Archive, Washington, D.C.

⁸³ R.E. Krauss to Executive Committee of the Agricultural Board, “Personnel of the aerial survey subcommittee,” 23 November 1960, Folder: B&A Agricultural Board Committee on Agricultural Pests: Subcom on Aerial Surveys, 1959-1961, NAS Archive, Washington, D.C.

the subcommittee in December 1960 with Colwell, Shay, and Holter as members to “develop plans for strictly exploratory studies to determine the possible usefulness, as well as limitations, of aerial survey for identifying and evaluating damage to crops caused by diseases, insects, nemas, weeds, and nutritional and topic conditions.”⁸⁴

Quickly, it became apparent to the Ag Board that the newly formed subcommittee’s mandate was very broad. In February 1961, the NAS established under the Ag Board in its Division of Biology and Agriculture the “Committee on the Use of Aerial Photographic Surveys in Agriculture” known informally as the Shay Committee, given its chair, J.R. Shay mentioned above. Within two months of the former subcommittee’s formation, it increased its status and became a committee. The Shay Committee planned its first meeting in Washington for September 1961 in which it discussed a research proposal involving the Army Engineers Research and Development Laboratories in Virginia, Purdue University’s Research Foundation, USDA’s research facilities in Beltsville, Maryland, and the National Science Foundation. The proposed research involved using a portable reflectance spectrophotometer for detection of crops such as grain, soybeans, and corn. Army Engineers noted that the main issue with crop detection was that “choice of film and filter has hampered these efforts and has interfered with the securing of quantitative data on the validity of the technique.”⁸⁵ Effectively, when researchers flew the spectrophotometer over a crop field, different spectral filters provided different, and often inconsistent, data sets. Thus, the Shay Committee scientists had a difficult time training its instruments to identify different crops whether they were grains, soybeans, or corn. Army Engineers Lab Basic Science division chief Charles Johnson continued to carry out experiments

⁸⁴ R.E. Krauss to F.L. Campbell, “Appointment of Subcommittee on Aerial Surveys, 16 December 1960, Folder: B&A Agricultural Board Committee on Agricultural Pests: Subcom on Aerial Surveys, 1959-1961, NAS Archive, Washington, D.C.

⁸⁵ B.T. Shaw to E. Claussen, 8 November 1961, Folder: B&A Agricultural Board Committee on Use of Aerial Photographic Surveys in Agriculture: General, 1961-1963, NAS Archive, Washington, D.C.

and gather data with the spectrophotometer at the USDA Agricultural Research Service (ARS) Plant Industry Station in Beltsville, Maryland the following April and May 1962.

By August 1962, the ARS and Army Engineering Research and Development Laboratory (Army ERDL) jointly conducted spectrophotometer flights in Beltsville that began to reveal differences in grasses and broad-leaf plants, specifically to understand how wheat and soybean signatures reflected differently. The ARS and Army studied several plant species to compare reflectances of different field plots.⁸⁶ This work was critical to classifying land cover variables and distinguishing crops from each other. Johnson worked closely with fellow Shay Committee member H.A. Rodenhiser of ARS on these experiments through 1963.

The Shay Committee also sought funding and assistance among government agencies and from industry. The committee submitted a proposal for \$7,000 from a then four year old NASA to support the committee and develop a further proposal for a laboratory. Shay's 1963 proposal requested permission from the Governing Board of the Academy to seek \$20,000 in funds and assistance from USDA, DoD, the Universities of California and Michigan and Purdue University, which the NRC and NAS approved in December 1963.

In the proposal, Shay laid out benefits of remote sensing applications to agriculture, current research in the area, and potential improvements to the existing techniques. Shay argued that agricultural remote sensing "may improve the accuracy and reduce the cost of enumerative and mailed surveys for collection of agricultural information," specifically regarding cattle in rangelands, fruit and vegetable acreage measurements, and better predict losses from crop damage.⁸⁷ Shay also described how using infrared and ultra violet spectral regions yielded

⁸⁶ J.R. Shay to Frank Campbell, 5 August 1962, Folder: B&A Agricultural Board Committee on Use of Aerial Photographic Surveys in Agriculture: General, 1961-1963, NAS Archive, Washington, D.C.

⁸⁷ J.R. Shay on behalf of the Committee on Aerial Surveys in Agriculture of the National Academy of Sciences to the Governing Board of the Academy, "Suggestion to National Aeronautics and Space Administration on Remote

“important types of agricultural information not previously obtainable.”⁸⁸ This current research conducted by Shay and his colleagues at USDA, Michigan, California, Purdue, and DoD revealed several research needs going into 1964. Shay sought to explore variations in other spectral regions using existing spectrophotometers, map soil moisture distribution, and better detect ground temperatures. The proposal also stated a strong need “for basic research on the spectral reflectance and emissivity of plants in health and disease and soils under various conditions.”⁸⁹ He urged that remote sensing research needed to be done in all major spectral regions so scientists could better classify land cover variables. The major components of the proposal included the collection of aerial spectrophotometer data using a DC-6 aircraft, fly a similar instrument on a Gemini crewed mission, and then generate standards and procedures with the ground and flown data. Shay recognized and advised strong coordination between the participating institutions which included ARS, several DoD offices, as well as the aforementioned universities. Shay’s proposal to sustain funding for the Committee on Research on Remote Sensing for Agricultural Purposes (I shall now use ‘Shay Committee’ to refer to this body) under the Agricultural Board at NAS was accepted and would continue its review and advisory role in the field.

Alongside the acceptance of funding, the Committee changed its name to include ‘Remote Sensing’ rather than ‘Aerial Photographic Surveys’ suggesting a recognition of the field of remote sensing. Shay secured funding for remote sensing activities for three years beyond

Sensing,” 12 November 1963, Folder: Folder: B&A Agricultural Board Committee on Use of Aerial Photographic Surveys in Agriculture: General, 1961-1963, NAS Archive, Washington, D.C.

⁸⁸ J.R. Shay on behalf of the Committee on Aerial Surveys in Agriculture of the National Academy of Sciences to the Governing Board of the Academy, “Suggestion to National Aeronautics and Space Administration on Remote Sensing,” 12 November 1963, Folder: Folder: B&A Agricultural Board Committee on Use of Aerial Photographic Surveys in Agriculture: General, 1961-1963, NAS Archive, Washington, D.C.

⁸⁹ J.R. Shay on behalf of the Committee on Aerial Surveys in Agriculture of the National Academy of Sciences to the Governing Board of the Academy, “Suggestion to National Aeronautics and Space Administration on Remote Sensing,” 12 November 1963, Folder: B&A Agricultural Board Committee on Use of Aerial Photographic Surveys in Agriculture: General, 1961-1963, NAS Archive, Washington, D.C.

February 1964. The goal of this newly rechristened committee was to “take the lead in designing experiments and in obtaining the funds, personnel, land, equipment, and instrumentation needed to do the work with the help of interested agencies.”⁹⁰ In early 1964, NASA provided \$7,000 in support of the committee but not for experiments. The committee began to plan further remote sensing experimentation as tests continued on multispectral instruments at the University of Michigan overseen by Holter, who also held a position on the Shay Committee. Holter and Shay addressed the primary concern of the committee: which government agencies should lead in remote sensing research? While the committee had strong support and a committed membership, it had no formal government agency to carry out its recommendations and proposed experiments after it reorganized.

Organizing for a Satellite Program

However, the Committee, which changed its name to the Committee on Research on Remote Sensing for Agricultural Purposes, could not locate a funding agency until late 1963 when NASA began contracting grants with NAS. The committee took on a larger role than initially planned, it was “prepared to act as an advisory committee to whoever might want its advice” since no Government agency “nor any combination of agencies, has established a broad research program on remote sensing for agricultural purposes.” Therefore, the Committee recognized “that if progress is to be made it must take the lead in designing experiments and in obtaining the funds, personnel, land, equipment, and instrumentation needed to do the work with

⁹⁰ Beryl Evans to Dr. T.C. Byerly, 13 December 1963, Folder: B&A Agricultural Board Committee on Research on Remote Sensing for Agricultural Purposes: Funding General, 1963-1968, NAS Archive, Washington, D.C.

the help of interested agencies.”⁹¹ The goal of the Committee was to promote “research in the use of remote sensing, in the broadest context of that term,” due to the value of natural resources.⁹² In a series of meetings that took place in 1964 into 1965, the Shay Committee fostered a dialogue between NASA and USDA to explore experimentation in remote sensing techniques such as multispectral sensing, spectrophotometric studies, thermal sensing, among others to better understand crop density and health, soil, and water composition.⁹³ These discussions began to lead to action in 1965 which I return to in the section below. As these meetings occurred however, DOI took NASA and USDA by surprise in September 1966.

“But it worked!”: Interior’s Political Gambit, 1966

The idea of an earth resources satellite did not necessarily begin at NASA, USDA, or NAS. Rather, DOI took the space agency by surprise on 21 September 1966 when Secretary Stewart Udall announced the Earth Resources Observation Satellites program. The program, “aimed at gathering facts about the natural resources of the earth from earth-orbiting satellites carrying sophisticated remote sensing instruments,” would “provide data useful to civilian agencies of the Government such as the USDA who are concerned with many facets of our natural resources.”⁹⁴ Even though NASA carried out a number of feasibility studies with USGS to explore the possibility of such a satellite, DOI “became impatient with NASA’s lack of

⁹¹ Memo, Beryl Evans, Admin. Asst. to Executive Office, NAS to T.C. Byerly, Division of Biology and Agriculture, NRC, 19 December 1963, Folder: B&A Agricultural Board, Committee on Research on Remote Sensing for Agricultural Purposes: Funding General, 1963-1968, National Academy of Sciences archive, Washington, D.C.

⁹² B.L. Kropp and Howard Sprague, “Proposal for Continuation of Support of Committee on Remote Sensing for Agricultural Purposes (Contract NsG-492,” 25 May 1966, Folder: B&A Agricultural Board Com on Research on Remote Sensing for Agricultural Purposes: Funding Natl Aeronautics & Space Adm Support, 1964-1970, National Academy of Sciences archive, Washington, D.C.

⁹³ Minutes of the Meeting of the Committee on Research on Remote Sensing for Agricultural Purposes, 10-11 November 1964, Folder: B&A Agricultural Board Committee on Research on Remote Sensing for Agricultural Purposes: Meetings, 1963-1968, NAS Archive, Washington, D.C.

⁹⁴ Department of the Interior Office of the Secretary news release, “Earth’s Resources to be Studied From Space,” 21 September 1966, courtesy of Raymond Byrnes, US Geological Survey, Reston, Va., 14 January 2015

progress toward defining a satellite system.”⁹⁵ Dr. William Pecora, a geologist by training, received his Ph.D from Harvard University and eventually became Director of USGS in 1964. Immediately, he began advocating for a remote sensing program capable of gathering information about Earth resources. Pecora and two of his USGS scientist colleagues, Charles Robinove and William Fischer urged Secretary Udall to act boldly on the earth resources satellite issue. Glenn Landis, former Chief of the Earth Resources Observation Systems Data Center (EROS), said “they [Robinove, Fischer, and Pecora] convinced Udall to basically twist NASA’s arm...it was a total bluff. But it worked!”⁹⁶

The gambit by USGS prompted a long partnership with NASA which precipitated serious research and development that resulted in Earth Resources Technology Satellite A (ERTS-A, later renamed Landsat 1). In a 1969 letter from Pecora to NASA, he expressed the Survey’s support of Landsat as “a means of acquiring on a national or worldwide scale data specifically designed to be useful for the widest variety of resource-related activities.”⁹⁷ Alongside USGS, USDA also partnered with NASA to encourage a civil remote sensing program. NASA, USGS and the USDA, with advice from the National Academy of Sciences “initiated research to investigate the feasibility of assessing agricultural conditions with automated remote sensing techniques.”⁹⁸ Pecora alongside Dr. Archibald Park of the USDA committed their institutions to Landsat as users. Dr. Archibald Park served as head of remote sensing research. Park made recommendations to NASA for Landsat specifications, in particular on resolutions necessary to view vegetation, on behalf of USDA. NASA responded by offering grants for

⁹⁵ Pamela Mack, *Viewing the Earth*, (MIT Press, 1990), pg. 58

⁹⁶ Rebecca Johnson, *What It Took: A History of the USGS EROS Data Center*, (Center for Western Studies, Augustana College, 1998), pg. 7

⁹⁷ William T. Pecora, 5 May 1969, “Statement of support by USGS for NASA’s ERTS Program,” <ftp://landsat-legacy.gsfc.nasa.gov/outgoing/documents/LL-37877001909409>, date accessed: 14 January 2015

⁹⁸ R.B. MacDonald, “The Large Area Crop Inventory Experiment,” 2nd Annual William T. Pecora Memorial Symposium, Sioux Falls, SD. 25-29 October 1976. Presentation

further study of agricultural applications. NASA and USDA began collaborative experiments to study agriculture from space. In addition, NASA awarded a grant to Purdue University to establish LARS, in 1966. NASA also awarded a contract to the University of Michigan's Willow Run Laboratories in Ann Arbor.

Viewing Vegetation: NASA-USDA Experimental Collaboration, 1965-1971

In the mid 1960s, NASA began working with the USDA to develop scanners and techniques which could map vegetative land cover and be able to distinguish between various species of flora. In order to do so, these agencies and their university partners, mentioned below, had to produce imagery from multispectral scanner data and build algorithms that could identify types of terrain, such as forest, grassland, or rocky surfaces, among others. This process became known to the remote sensing community as classification, as mentioned earlier, whereby scientific investigators distinguish different land cover variables from each other. With the NAS advising and coordinating efforts, NASA, USDA, and a few universities developed technologies and experiments to classify crops and track their maturation over a growing season using multispectral scanners. The agencies attempted to perfect an algorithm that could help scientists watch from afar as crops matured and also identify which crops became diseased or infested with parasites. NASA and USDA conducted several experiments in the late 1960s and 1970s to this end that also became the first major application of Landsat imagery and led to its first expansion of use in the mid 1970s by government users.

On 19 February 1965, the first major interagency agricultural remote sensing partnerships and experiments materialized. The ARS required new ways to identify crops from high altitude aircraft and satellites. NASA and USDA formally agreed to a partnership in remote sensing of

agriculture and forestry. Secretary of Agriculture Orville Freeman and NASA Administrator James Webb signed the “Interagency Task Statement of Agreement between the USDA and NASA For Joint Research and Development Activities to Define Manned Earth-Orbital Experiments in Agriculture and Forestry.” The ARS oversaw the program, which sought to “characterize the reflectance and emission signatures of different land covers (crops and range) that would permit their identification using sensors on aircraft and satellite platforms.”⁹⁹ Throughout 1965 into 1966, ARS used ground observations and aircraft to identify crops near Weslaco, Texas; a site chosen for its year-long growing season. The ARS experiment sought to test different spectral bands and instruments to determine which best identified crops. It was critical to NASA and USDA scientists to resolve which spectral signatures particular crops reflected. However, the difficulty was that as crops matured, they gave off different spectral signatures. NASA also had to build an instrument which had spectral bands that covered a significant portion of the green portion of the spectrum. The ARS Weslaco experiments made a significant contribution towards configuring the specifications of Landsat-1’s sensor array.¹⁰⁰ NASA also carried out similar research collaboratively with universities.

Through this committee, the NAS began working with USDA and NASA. As mentioned, the University of California had played a role in aerial remote sensing research and manual interpretation technique development under the direction of Colwell, but two more universities

⁹⁹ Paul Pinter, Jerry Ritchie, Jerry Hatfield, and Galen Hart, “The Agricultural Research Service’s Remote Sensing Program: An Example of Interagency Collaboration,” *PE&RS* Vol.69, No.6, June 2003, pp. 615-618, pg. 615

¹⁰⁰ Paul Pinter, Jerry Ritchie, Jerry Hatfield, and Galen Hart, “The Agricultural Research Service’s Remote Sensing Program: An Example of Interagency Collaboration,” *PE&RS* Vol.69, No.6, June 2003, pp. 615-618, pg. 615. See also: R.H. Miller, *Remote Sensing in the Agricultural Research Service*, U.S. Department of Agriculture, Beltsville, M.D., 1975

began to make contributions towards a high altitude and space-based apparatus. NASA and ARS offered grants to University of Michigan and Purdue University to establish laboratories for research in agricultural remote sensing.

Willow Run and LARS

As mentioned, the University of California played a crucial role beginning investigations into agricultural remote sensing, yet with the help of grants from NASA and USDA, Michigan and Purdue became major players in the development of what became the scanners aboard Landsat. NASA and several university scientists used the multispectral scanner data to distinguish crops from other land cover variable. Essentially as the satellite flew over terrain, the scanning device translated geographic features such as lakes, forests, and cropland into color schemes to produce a map. For example, bodies of water appear dark blue, forest as dark red, and corn as bright pink. In the 1960s, NASA and ARS awarded grants to Purdue University and University of Michigan to build a multispectral scanning device capable of distinguishing vegetation from other land cover variables. In addition, the two laboratories in Ann Arbor and West Lafayette also developed methods for processing the Earth imagery and conducting detailed studies of crop maturation and disease.

In 1966, grants from NASA and ARS allowed Purdue University to establish the LARS. LARS drew several professors from Purdue's School of Electrical Engineering and Department of Botany and Plant Pathology as well as from IBM Corporation. Three individuals in particular played a crucial role at LARS, Ralph Shay mentioned above moved from Oregon State University to Purdue University, Purdue Electrical Engineering professor David Landgrebe, and LARS Technical Director R.B. MacDonald who had come to Indiana on leave from IBM.

Shay helped to organize the laboratory and recruited talent to Purdue in addition to his aforementioned responsibilities at the National Academies. Landgrebe, a Purdue educated electrical engineer who had experience with Bell Labs and Douglas Aircraft Company and had served on NRC and NASA advisory committees became one of the key researchers and director of LARS. MacDonald, another Purdue graduate went onto a career with IBM's Advanced Systems Research group in New York but returned to West Lafayette and later would go onto NASA as a leading expert in land remote sensing research.¹⁰¹ Under the direction of Shay, Landgrebe, and MacDonald, LARS realized several major breakthroughs in agricultural remote sensing. In 1966, LARS demonstrated multispectral pattern recognition methods permitting the identification of individual crop species.¹⁰² Over the next three years, LARS realized methods for classifying land cover variables, constructing multitemporal data sets, calibrating data processing and data compression, and built algorithms that could identify the best spectral bands for investigations of certain crops.¹⁰³ The sum of LARS's research from 1966 to 1971 produced the knowledge necessary not only to map crops from high altitudes and space, but to track their maturation over a growing season.

Under Shay and Landgrebe's direction, LARS identified and resolved several key issues in agricultural remote sensing within its first five years. The laboratory demonstrated the first algorithms capable of multispectral pattern recognition that classified individual crop species, developed a digital image registration system, and developed methods for identifying soil types,

¹⁰¹ "Remembering Robert B. MacDonald," 22 May 2014, <http://landsat.gsfc.nasa.gov/?p=8288>, date accessed: 21 September 2016

¹⁰² David Landgrebe, "A Brief History of The Laboratory for Applications of Remote Sensing," December 1986, <https://www.lars.purdue.edu/home/LARSHistory.html>, date accessed: 17 September 2016

¹⁰³ David Landgrebe, "A Brief History of The Laboratory for Applications of Remote Sensing," December 1986, <https://www.lars.purdue.edu/home/LARSHistory.html>, date accessed: 17 September 2016. Many of these techniques are still in use.

water quality, and forests.¹⁰⁴ These accomplishments provided the scientific and processing capabilities to study agriculture from space. Meanwhile, Willow Run conducted the technological research and development producing the first multispectral scanner for land remote sensing.

In addition to LARS, Willow Run Laboratories at University of Michigan also worked to develop agricultural remote sensing capabilities. The university acquired the laboratory after World War II and carried out contract work for the American military but moved towards civilian applications developing a reputation for its work in radar, infrared, acoustic, and optical remote sensing.¹⁰⁵ Dr. Marvin Holter, a University of Michigan professor who became a Willow Run Deputy Director, served as head of the Infrared and Optical Sensing Laboratory. Holter collaborated with Shay at the National Academies on Ag Board subcommittees as well. The lab began experimenting with the use of electromagnetic scanning devices aboard aircraft. It developed the forerunner to Landsat's multispectral scanner, the M-7 instrument. Its spectral coverage ranged from ultraviolet to near infrared and thus was capable of distinguishing vegetation, but the scanner itself was not enough. The development of the M-7 and later multispectral scanners enabled scientists to differentiate vegetation from other land cover variables since "green vegetation foliage produces a stepped reflectance, with low visible and high near infrared reflectance, a result of pigment absorption in the visible region and strong light scatter from cell walls in the near infrared."¹⁰⁶ Effectively, chlorophyll reflected distinct signatures that multispectral sensors and data processors could help data users distinguish. A

¹⁰⁴ David Landgrebe, "A Brief History of The Laboratory for Applications of Remote Sensing," December 1986, <https://www.lars.purdue.edu/home/LARSHistory.html>, date accessed: 17 September 2016

¹⁰⁵ John Walsh, "Willow Run Laboratories: Separating from the University of Michigan," *Science*, Vol. 177, No. 4049, 18 August 1972, pp. 553-639

¹⁰⁶ Samuel N. Goward and Darrel L. Williams, "Landsat and Earth Systems Science: Development of Terrestrial Monitoring," *Photogrammetric Engineering & Remote Sensing*, Vol. 63, No. 7, July 1997, pp. 887-900, pg. 890

Landsat data user could then index areas of vegetation within an image. This concept became known as the Spectral Vegetation Index (SVI) which recorded “high values for land surfaces covered with green foliage and low values for non-foliar land surfaces”¹⁰⁷ Between 1966 and 1971, scientists and engineers at several universities and at NASA improved both the SVI technique and the multispectral scanner, discussed later in this chapter. Despite its success developing the M-7, Vietnam War protests enveloped Ann Arbor creating friction between the university and its laboratory.

Willow Run and the University of Michigan itself found themselves engulfed in turmoil due to protests against American aerial bombing campaigns and resistance to weapons development. In addition to its research in civil remote sensing, Willow Run conducted research and development on ballistic missile guidance systems which drew protest from the community. The criticism reached its boiling point in the first two years of the 1970s and forced the Michigan Board of Regents to reevaluate its relationship with Willow Run.

Campus-wide criticism focused on research and development that “translated directly into such things as remote sensor technology for locating and targeting vehicles and troops on the ground and laser guidance for so-called ‘smart’ bombs.”¹⁰⁸ Pressure from the student body, the university’s board of regents, and state legislature forced three major moves. First, University of Michigan separated itself from Willow Run. Second, the laboratory became an incorporated non-profit and renamed itself Environmental Research Institute of Michigan (ERIM) since the organization looked to move into civilian projects despite its strong DoD patronage. Lastly, the

¹⁰⁷ Samuel N. Goward and Darrel L. Williams, “Landsat and Earth Systems Science: Development of Terrestrial Monitoring,” *Photogrammetric Engineering & Remote Sensing*, Vol. 63, No. 7, July 1997, pp. 887-900, pg. 890. Goward and Williams also provided several references to early studies from the 1960s and 1970s that contributed to the first SVI as well as later SVIs that emerged later. These studies were published in different journals from several disciplines including the geosciences, electrical engineering, optics, plant biology, ecology, and remote sensing.

¹⁰⁸ John Walsh, “Willow Run Laboratories: Separating from the University of Michigan,” *Science*, Vol. 177, No. 4049, 18 August 1972, pp. 553-639, pg. 594

state legislature still wanted the laboratory to maintain its stature as a leading remote sensing R&D outfit as well as support industry jobs and bring in revenue. Thus, the Michigan state legislature appropriated \$2 million in loans in June 1972 for ERIM's transition period. In addition to state funds, the Board of Regents allowed all Willow Run contracts and equipment titles (technically owned by University of Michigan) to transfer to ERIM. In essence, University of Michigan quelled campus protests by severing ties and ERIM became an independent non-profit research institution and a major player in remote sensing research and development. I discuss ERIM further in later chapters.

Michigan and Purdue continued to research agricultural applications of remote sensing meanwhile cultivating a relationship with NASA and USDA. By 1968, NASA and USDA decided to include a multispectral scanner on the ERTS platform to be launched in 1971 and used the Apollo IX mission to simulate this proposed payload and study the data it gathered. Having established methods for identifying crops from high altitude aircraft using reliable multispectral scanners, those at Michigan, Purdue, NASA, and USDA hypothesized that it was possible to monitor and even inventory certain crops from above. In 1971, these institutions tested that hypothesis over the American Midwest.

Cultivating Inventory: Corn Blight Experiment, 1971

In 1971, disease ravaged corn crops in parts of the Midwest where agriculture was the chief economic driver, especially in Indiana where LARS had conducted many of its remote sensing experiment. Thus, crop inventorying became the next application of agricultural remote sensing. The multispectral scanning technology was still undergoing testing yet the problem of crop disease provided a salient case study. NASA and the USDA first applied the technology to

crop inventorying during the 1971 Corn Blight Experiment (CBE) using multispectral scanners aboard aircraft to manage diseased crops in the Midwest Corn Belt which included Indiana, Illinois, Ohio, Missouri, Nebraska, and Minnesota. For NASA, this project was a critical test of the multispectral scanner designed for Landsat and for USDA it was an opportunity to address a major crop yield problem. As for Michigan and Purdue, the CBE was a chance to continue their research and development.

The American Midwest witnessed prolific shortfalls in corn production in the 1970 and 1971 growing years. Indiana experienced the most acute losses. Agricultural specialists at the USDA predicted a 4.82 billion bushel yield in 1970. The fungus which afflicted the corn, known as southern corn leaf blight (SCLB), destroyed 15 % of the 1970 crop, western Indiana alone losing 95 million bushels.¹⁰⁹ Much of the fungus survived the winter of 1970 and again affected crops the subsequent year. The USDA and NASA realized this possibility and designed an experiment alongside the University of Michigan and Purdue University implementing multispectral scanners to observe SCLB and using computers at the aforementioned universities. The CBE used the multispectral scanners to classify stages of SCLB fungus infestation.

Plant pathologists discovered SCLB proliferating through windborne spores that lived best in warm, humid conditions generally attacking the lower portions of corn stalks first. SCLB also flourished due to the widespread, large-scale monocropping of corn in the American Midwest. The pathologists sought to understand how the disease infected the plant in order to build a system by which to classify light to severe infection. Disease-ridden corn stalks progressively changed from green to tan as chlorophyll died out. This allowed remote sensing investigators to design their experiment according to six levels of disease infection. The USDA

¹⁰⁹ Earth Resources Program, Johnson Space Center. *Corn Blight Watch Experiment*, Scientific and Technical Information Office, NASA HQ, Washington, D.C., (NASA: SP-353, 1974) pg. 2

now could classify corn blight from imagery and then select test areas for sampling in the Corn Belt, where it was worst.

Initial visits by scientists on the ground provided the basis by which to not only implement the aforementioned classification levels but also select sample segments. The Statistical Reporting Service of the USDA sent ground observers to 10 corn fields for ground truthing in conjunction with sensor overflight.¹¹⁰ Segments were divided in to 1 mile by 8 mile samples. Indiana received particular attention from both multispectral and photographic technology flown in planes. The USAF provided a RB-57F aircraft for high altitude (60,000 feet) flight, while University of Michigan provided a C-47 aircraft for low flight. Color infrared film was used to detect SCLB¹¹¹, which NASA reviewed before agricultural experts classified the imagery against the six levels with red being vigorous vegetation while light pink or gray indicated diseased crops. Throughout 1971, flights over the test areas took place in three phases.

These three phases provided greater temporal resolution, providing imagery in April (Phase I), May (Phase II) and June through September (Phase III). Each phase also contributed to the objectives of the experiment. During Phase I, the USDA collected black and white data while scientific personnel performed corn field visits for baseline information on crop-use mapping. Phase II implemented the high altitude flights for infrared imaging to evaluate soil conditions. Phase III used low and high altitude flights with false color infrared film for vegetation detection and Michigan's scanner with 12 multiband data channels for terrain. The field visits undertaken by agricultural experts corroborated what the interpreters saw in imagery regarding the spatial distribution of blight. The interpreters played the next significant role in identifying blight.

¹¹⁰ Earth Resources Program, Johnson Space Center. *Corn Blight Watch Experiment*, Scientific and Technical Information Office, NASA HQ, Washington, D.C., (NASA: SP-353, 1974) , pg. 4

¹¹¹ Earth Resources Program, Johnson Space Center. *Corn Blight Watch Experiment*, Scientific and Technical Information Office, NASA HQ, Washington, D.C., (NASA: SP-353, 1974) , pg. 5

NASA, USDA, and University research scientists classified sections of maps according to land cover, namely healthy crops against partially and fully diseased crops. These techniques allowed LARS to assess the spatial distribution and severity of SCLB in the Corn Belt. By the start of Phase III in July 1971, the summer had been unusually cool and dry which inhibited the disease severity significantly as the CBE was carried out.¹¹² Photointerpretation against field observations produced a regression of 0.77 at low blight severity while high blight severity had a correlation of 0.67. Each had a sample population of 30 fields using stratified random sampling for field observations. Correlations of MSS against field observations had significantly higher correlations of 0.94 for low blight severity and 0.92 for high blight severity, suggesting that MSS data provided considerably better detection. LARS concluded that while the blight was very widespread, manifesting most strongly in Indiana and parts of Illinois and Missouri, many of the infections were not severe. While the CBE successfully detected infestations in corn, it could not forecast yields of corn. NASA and the USDA began just such an experiment three years later that built upon the corn blight experiment utilizing the same technologies.

The Corn Blight Experiment in the early 1970s was a critical, formative episode which suggested that the U.S. government possessed the resources to pursue agricultural inventorying on a larger scale. The CBE was a yearlong experiment that successfully tested multispectral scanning technology, to be launched on ERTS in 1972 (the launch was delayed from 1971). The experiment also suggested that crop growth could not only be inventoried, but also predicted. Thus, USDA would become one of the largest users of ERTS data after its launch in 1972. The CBE and preceding experiments produced knowledge and technology in a precarious moment characterized by Cold War rivalry and a volatile global agricultural market. In mid-1972 as

¹¹²Earth Resources Program, Johnson Space Center. *Corn Blight Watch Experiment*, Scientific and Technical Information Office, NASA HQ, Washington, D.C., (NASA: SP-353, 1974) pg. 9

NASA readied the Delta rocket to place ERTS into orbit, the Soviet Union would clandestinely secure the largest wheat purchase in history throwing destabilizing the U.S. food supply.

“The Great Grain Robbery,” 1971-1972

Soviet farmers across the Ukraine and Volga River valley planted wheat as usual in late 1971 hoping to reap a large winter wheat crop in 1972. However, the fields and weather of the Eastern Bloc had other plans for the Soviets. A long, cold winter destroyed much of the crop and forced the Kremlin to dispatch two individuals to New York City to negotiate the purchase of one quarter of the 1972 American wheat crop in addition to barley, corn, oats, rye, and soybeans.¹¹³ The ensuing deal struck between the U.S. government, Soviet purchasers, and several grain companies became known as the Soviet Wheat Deal, or more notoriously described by Martha Hamilton and James Trager as the ‘Great Grain Robbery,’ a reference to the 1903 film *The Great Train Robbery* about outlaws who stole loot from a train in the American West.¹¹⁴ The deal involved several major grain companies including Cargill and Continental, the USDA, Soviet brokers. The implications of the Soviet Wheat Deal were far-reaching as the wheat deal suggested to the American public that the USDA was more concerned that the “grain trade was served by the sale rather than American farmers or taxpayers.” As a result, USDA came under fire from the American public and from Congress. As the Soviet wheat deal came to light in July 1972, NASA successfully launched Landsat-1 into orbit that same month.

The stakes were incredibly high when it came to the shrouded agricultural markets and crop yield prediction. Dan Morgan, an investigative journalist in the 1970s wrote of the deep secrecy in which grain firms operated describing the sheer difficulty of obtaining interviews with

¹¹³ James Trager, *The Great Grain Robbery*, (Ballantine Books, 1975), pg. 6

¹¹⁴ Martha Hamilton, *The Great American Grain Robbery & Other Stories*, (Agribusiness Accountability Project, 1972) and James Trager, *The Great Grain Robbery* (Ballantine Books, 1975)

executives and, at that point, the lack of information available.¹¹⁵ With information so difficult to obtain from both the American and Soviet side, crop yield prediction required immense detail and time. One American agricultural attaché to Moscow stated “it’s a task that takes everything you can find, from weather reports to a line out of a newspaper, and it takes 18 hours a day. And then you go to bed, wondering if you’re right.”¹¹⁶

The USDA looked to utilize Landsat as a control mechanism exerted upon the world agricultural market. As NASA prepared Landsat 1 for launch, drought and unusual global temperatures prompted worldwide wheat crop failures during the 1971 growing year. Notwithstanding the emergence of détente between the U.S. and Soviet Union, the Soviets aggravated the American wheat market through what the USDA called a “grain grab” that year. Failed wheat crops in the Ukrainian Soviet Socialist Republic led to a shift in Soviet agricultural policy from export to import, placing a heavy demand on the market. Unaware, American agricultural officials did not realize Soviet intentions because initially the Soviets expressed “a great interest in US corn and soybeans when it was wheat that was really critical.”¹¹⁷ Furthermore, several American grain companies, namely Cargill Incorporated based in Minneapolis, Minnesota and Continental Grain headquartered in New York City, controlled a large share of the world trade in grain through their secretive demeanor and production of grain seed and fertilizer.¹¹⁸ In mid-1972 shortly before the grain deal, these companies pressed the USDA to obscure the proposed deal in order to maintain higher prices. Nonetheless, the Soviets effectively secured vast amounts of wheat under this guise at low prices, on the order of 440

¹¹⁵ Dan Morgan, *Merchants of Grain*, (New York, NY: The Viking Press, 1979)

¹¹⁶ Angelia Herrin, “U.S. Spy in sky keeps watch on Soviet Union wheat fields,” 2 July 1985, *Miami Herald*, pg. 2-A, CREST RAC Number: CIA-RDP90-00965R000402650026-0, College Park, MD

¹¹⁷ “We Can’t Take Food for Granted Anymore,” Lawrence A. Mayer, *Fortune* February 1974 reprinted in Herbert Marx, ed., *The World Food Crisis* Vol. 47 No. 6 (New York: H.W. Wilson Company, 1975) pp. 25

¹¹⁸ Dan Morgan, *Merchants of Grain*, (New York: The Viking Press, 1979)

million bushels for \$750 million. Congress claimed negligence in the deal “but the real negligence of 1972 had as much to do with long-standing policies as with the conduct of officials in power,” namely policies assumed during the Kennedy administration such as reducing surplus, humanitarian aid, and economic self-interest.¹¹⁹ For the Soviets however, the government sought to avoid famine and improve Soviet diets through a transition to import.

The Soviet Union’s altered import policy precipitated further shifts in the world food market as it cut its exports to Eastern Europe. The policy also affected importers such as China, Japan, and Western Europe. These global shifts caused by the “massive Soviet grain purchases in 1972-1973 were the principal factor in the decline of carryover stocks in the major exporting countries,”¹²⁰ which caused a sharp increase in grain prices on the world market and acute shortages in the Soviet Bloc. With little to no accurate information from the Soviet Union on the wheat yield collapse in Russia and Ukraine, the USDA did not anticipate Moscow procuring such a massive grain crop. Thus, it turned to NASA for assistance in developing the ability to inventory and predict crop yields around the world.

The aforementioned testing of scanners over agricultural fields and the potential of a space-based platform led many at NASA and USDA to believe that it was possible to inventory crops worldwide. Both domestic pressure from the American public and Congress as well as Cold War sensibilities came into play in 1971 as the U.S., especially USDA, urgently sought to achieve the surveillance imperative and bring greater legibility to the volatile global food supply.

Legitimizing LACIE

¹¹⁹ Dan Morgan, *Merchants of Grain*, (New York: The Viking Press, 1979), pg. 121

¹²⁰ Fred H. Sanderson, “The Great Food Fumble,” *Science* Vol. 188, No. 4188, 9 May 1975 pp. 504

From 1972 to 1974, NASA tested Landsat data reception and quality and collected a global environmental database. Multispectral scanner experiments over agricultural fields alongside the successful launch of Landsat encouraged the development of the Large Area Crop Inventory Experiment or LACIE. The USDA, NASA, and some contributions from the NOAA for long term weather patterns developed LACIE as a predictive algorithm for crop production over vast tracts of land. Also, NASA launched a second Landsat satellite in early 1975. While NASA did not launch Landsat-2 solely for the LACIE project, the experiment held significant weight deciding launch date. Data collection and continuity deeply concerned NASA since it expected Landsat-1 to only operate for one year.¹²¹ NASA Administrator James Fletcher pressed the White House to move Landsat-2's launch earlier. Fletcher wrote to Assistant to the President for Economic Policy George Schultz to "reschedule the ERTS-B satellite [later renamed Landsat-2] from 1976 to 1974, within available resources" citing the generally positive reception the satellite received from the global community. Fletcher stated that the "international community has responded enthusiastically to the new technology and...a national program of continuous global data acquisition, whether described as experimental or operation, provides a meaningful new instrument of foreign policy."¹²² That stated, Fletcher insisted that Landsat-2's launch be moved earlier in order to also provide data for grain forecasts of the 1975 growing year. Fletcher nearly succeeded as NASA placed Landsat-2 in orbit on 22 January 1975, one year ahead of schedule. With one satellite in orbit, another scheduled, and cooperation with NOAA,

¹²¹ Landsat-1 actually continued to successfully operate until 1978, yet NASA officials were reluctant to give these satellites long design lives due to uncertainty. Mirroring such longer-than-expected warranties, Landsat-2 operated from 1975 until 1982.

¹²² *Foreign Relations of the United States, 1969-1976, Vol. E-3, Documents on Global Issues, 1973-1976, Document 83, Letter From the Administrator of NASA to the Assistant to the President for Economic Policy, Washington, 5 September 1973, National Archives, RG 59, Central Files 1970-73, SCI 20. Secret.*

NASA and the USDA carried out the project in three phases which also involved predictions of Soviet production.

The aforementioned market shift caused by the perceived ‘grain grab’ likewise distressed the U.S. government as it moved closer to crop inventorying capability. The LACIE prompted considerable interest as a technological mechanism in the U.S. government. The experiment originated from “a major problem faced by the United States in foreign trade decisions [namely] the lack of timely, accurate information on the potential resupply from new harvests overseas,” according to two chief scientists working on LACIE.¹²³ The USDA derived its experiment data from NOAA meteorological information as well as “crop reports, which are made public as a routine service to the domestic and international agricultural community.”¹²⁴ In much the same way that President Nixon promoted agricultural initiatives that became LACIE at the UN in 1969, the U.S. government continued to promulgate the LACIE at a 1974 UN World Food Conference. U.S. Secretary of State Henry Kissinger hailed the experiment as “a promising and potentially vital contribution to rational planning of global production.”¹²⁵ Effectively Kissinger set the stage for LACIE’s international implications as Landsat users at the USDA projected power via agriculture.

International Agreements

Furthermore, the U.S. government assuaged international concerns of ‘economic espionage’ resulting from American knowledge of foreign resource bases. NASA and the USDA positioned themselves and LACIE to reflect “the notion that because NASA’s programs are in

¹²³ R.B. MacDonald and F.G. Hall, “Global Crop Forecasting,” *Science* Vol. 208, 16 May 1980

¹²⁴ *Earth Resources Technology Satellite-B Press Kit*, 14 January 1975, Box 6093 “Landsat Documentation II,” NASA History Program Office, NASA Headquarters, Washington, DC, pg. 3

¹²⁵ *Earth Resources Technology Satellite-B Press Kit*, 14 January 1975, Box 6093 “Landsat Documentation II,” NASA History Program Office, NASA Headquarters, Washington, DC, pg. 3

the experimental phase organizations responsible for that type of operation [crop forecasting] are not doing anything specific about predicting Soviet wheat production.”¹²⁶ Rather, the U.S. entered negotiations for agreements in agriculture. Both the Soviet Ministry of Agriculture and the USDA sought to coordinate “research in the fields of farm crops and farm animals and the mechanization of agricultural production.”¹²⁷ Over several months from 1972 to 1973, the U.S. and Soviet Union negotiated and eventually signed the U.S.-U.S.S.R. Agriculture Research Agreement. Similarly, these negotiations resulted in the “Agreement on Cooperation in Agriculture,” signed 19 June 1973 by Soviet Foreign Minister Andrei Gromyko and U.S. Secretary of Agriculture Earl Butz. Article II of the agreement obligated both countries to “regular exchanges of relevant information,’ including ‘forward estimation on production, consumption, demand and trade of major agricultural commodities,’” however the Soviets often complicated the agreement’s terms.¹²⁸ For example, the Soviets refused to provide their reports and denied American inspectors from carrying out their trip itineraries. In 1974, American surveyors were denied access to Kazakhstan and the southern Urals while attachés were denied entry to the Volga River Valley. Moscow based attachés’ travel was also restricted. The US-USSR Joint Committee on Agricultural Cooperation, meant to govern the exchange of information, failed to foster cooperation. Landsat became a viable option for inspecting crops from space. These international negotiations legitimized LACIE’s agricultural goals for the USDA but overflight and sovereignty remained an issue to be resolved at the UN.

The Soviet Union challenged American efforts to legalize satellite overflight. The Eisenhower administration pushed for space “to be recognized as free territory not subject to the

¹²⁶ Christopher Kraft to NASA Headquarters, Washington, D.C., 1 August 1973, 25/1a FLO; ER 1 January 1973, Earth Resources 1975 FIT OPS, RG 255, National Archives Southwest Region, Fort Worth, Texas

¹²⁷Edward C. Keefer, General Editor., *Foreign Relations of the United States, 1969-1976 Vol. XV Soviet Union, June 1972-August 1 1974*, (USGPO: Washington, D.C.) pg. 246-7

¹²⁸ Dan Morgan, *Merchants of Grain*, (New York, NY: The Viking Press, 1979), pg. 14

normal confines of territorial limits.”¹²⁹ Opposition, led by the Soviets, suggested that state territorial borders extended into space. In July 1955, the US and Soviet Union held a summit in Geneva, Switzerland concerning the freedom of space access issue. The eventual launch of *Sputnik* in 1957 prima facie resolved the overflight issue, though it was later legally achieved in the Outer Space Treaty of 1967. Despite this, U.S. government continued to pursue agreements legitimizing the use of earth-observing satellites to assuage international concerns of military reconnaissance. The U.S. worked with the UN to attain international legitimacy for land remote sensing and assuage concerns of economic espionage, which I address in greater detail in the following chapter.

Concurrently, NASA also entered negotiations with the Soviet Academy of Sciences to cooperate in remote sensing. The U.S. did not express a willingness to transfer hardware but in order to respect the “Agreement Concerning Cooperation in the Exploration and Use of Outer Space for Peaceful Purposes,” signed 24 May 1972, the U.S. must maintain “the open availability and basically scientific nature of the information that NASA has exchanged and proposes to exchange.”¹³⁰ The State Department confirmed that “there is no basis for concern with the implications of the cooperative program from the standpoint of our economic and commercial interests or with respect to its security and arms control implications.”¹³¹ The U.S. and Soviet Union also established a collaborative effort via the U.S.-U.S.S.R. Cooperation in the Natural Environment working group which addressed not only remote sensing of agriculture but also geology and hydrology as part of the wider collaboration in science and technology. The

¹²⁹ Roger D. Launius, *NASA : A History of the U.S. Civil Space Program*, (Malabar, FL: Krieger Publishing Company, 1994) pp. 20

¹³⁰ National Security Council Under Secretaries Decision Memorandum 113, Washington, D.C., 14 September 1973, Nixon Presidential Materials, White House Central Files, Subject Files, Box 1, EX, OS Outer Space, 1-1-1973 <http://history.state.gov/historicaldocuments/frus1969-76ve03/d85#fnref1> accessed: 14 January 2013

¹³¹ National Security Council Under Secretaries Decision Memorandum 113, Washington, D.C., 14 September 1973, Nixon Presidential Materials, White House Central Files, Subject Files, Box 1, EX, OS Outer Space, 1-1-1973 <http://history.state.gov/historicaldocuments/frus1969-76ve03/d85#fnref1> accessed: 14 January 2013

State Department, NASA, and the USDA allayed international concerns of American espionage and instead framed Landsat agricultural mapping as a beneficent international responsibility, which enabled the U.S. to undertake the LACIE by 1973.

World Food Conference, 1974

As NASA began the LACIE, the UN addressed food security as a global issue in the wake of a brutal famine afflicting Bangladesh. The UN Food and Agriculture Organization (FAO) hosted the first World Food Conference in Rome, Italy in November 1974 which brought together heads of state, ministers of agriculture, and diplomats to address world food security. Among the three broad security questions discussed was “global information and early warning system on food and agriculture.”¹³² The Conference recommended that such a system be put into place as a mechanism to warn against famine and crop loss. However, the delegations from the Soviet Union and China opposed the global warning system since it “could call in question the sovereignty of States, include the communication of information of a strategic nature and could also contribute to the speculative operations of the multinational companies.”¹³³ These concerns reflected those the Soviets voiced in the aforementioned discussions with the U.S. regarding satellite overflight and reconnaissance, yet the Soviets found few allies in their resistance. The U.S. had effectively convinced the world community of the value of civilian Earth observation satellites and the data they produce.

¹³² Commission of the European Communities, “Communication from the Commission to the Council World Food Conference,” 9 December 1974, pg. 1, [www.aei.pitt.edu/15701/1/SEC_\(74\)_4955_final.pdf](http://www.aei.pitt.edu/15701/1/SEC_(74)_4955_final.pdf), date accessed: 19 November 2015

¹³³ Commission of the European Communities, “Communication from the Commission to the Council World Food Conference,” 9 December 1974, pg. 3, [www.aei.pitt.edu/15701/1/SEC_\(74\)_4955_final.pdf](http://www.aei.pitt.edu/15701/1/SEC_(74)_4955_final.pdf), date accessed: 19 November 2015

In much the same way President Nixon promoted agricultural initiatives that became LACIE at the UN in 1969, the U.S. government continued to promulgate the experiment at the Conference. U.S. Secretary of State Henry Kissinger hailed the experiment as “a promising and potentially vital contribution to rational planning of global production.”¹³⁴ Effectively Kissinger set the stage for LACIE to be part of his wider diplomatic vision to eradicate hunger within ten years of the Conference.¹³⁵ Despite Kissinger’s vision for hunger eradication through technological potential, LACIE scientists at NASA and USDA experienced serious difficulties that made the idea of a global food warning system seem far less possible.

USDA and NASA Select Wheat

The USDA identified wheat as its crop of interest due to its significant presence in the global agricultural market. The U.S. pushed for cost effective wheat production in order to prevent a second Soviet grain grab. NASA’s Johnson Spaceflight Center in Houston, Texas (JSC) carried out the project through various USDA and NOAA data collecting field stations in the U.S. that contributed significant information regarding domestic crop statistics and meteorological patterns. Operationally, the satellite collected Earth surface data which receiving stations in the U.S. and Canada registered and sent to JSC and Goddard Spaceflight Center (GSFC) for processing and quality inspection. GSFC also governed the Landsat satellite itself, thus its role also included scheduling satellite operations and data acquisition (GSFC was a receiving station itself). From these two locations, NASA disseminated processed maps to the USDA and collaborating states. Domestically, the JSC team selected large tracks of wheat in Kansas, Montana, and North Dakota to classify wheat according to its maturation from greening,

¹³⁴ *Earth Resources Technology Satellite-B Press Kit*, 14 January 1975, Box 6093 “Landsat Documentation II,” NASA History Program Office, NASA Headquarters, Washington, DC, pg. 3

¹³⁵

to heading, to maturity as well as for two of wheat's biological phases, emergence and jointing.¹³⁶ At the time, Montana in particular had the largest monolithic wheat fields in the US. The USDA Agricultural Stabilization and Conservation Service recommended Montana for its diverse wheat fields to collect a comprehensive range of wheat signatures such as spring, winter, dryland, and irrigated wheat as well as assessing the signatures of competing cereal crops.¹³⁷

LACIE experimenters drew estimates of the spatial proportion of classified wheat pixels and compared it to all of the pixels in the sample.¹³⁸ LACIE used a stratified random sampling scheme according to climate and political boundaries allocating 637 sample segments, each measuring 5 x 6 nautical miles. One Landsat frame measured 100 square nautical miles. LACIE premised its classification upon 4 acquisitions of wheat: crop establishment, greening, heading, and mature. Likewise, LACIE used a crop calendar composed of meteorological measurements provided by NOAA, namely of daily temperature, as well as USDA estimates of planting start dates. LACIE required international collaboration since the USDA and NASA needed wheat area reports and production reports from cooperating states in order to construct a crop calendar. These indicated stages of wheat growth during the year. The crop calendar correlated with Landsat data and the trained classification system provided a basis for gauging crop maturation to predict wheat yields. The approach to LACIE involved significant care in classification over very large land areas.

¹³⁶ R.B. MacDonald, F.G. Hall, and R.B. Hall, "The Use of Landsat Data in a Large Area Crop Inventory Experiment (LACIE)," Symposium on Machine Processing of Remotely Sensed Data, Laboratory for Applications of Remote Sensing, Purdue University, 3-5 June 1975, pg. 4

¹³⁷ William L. Ruble, Deputy Administrator, Agricultural Stabilization and Conservation Service, USDA to William Stoney, Director, Earth Observation Programs, NASA "Proposed Site for Collection of Wheat Spectral Signatures," 10 July 1974, ER 25/1a MIS, Box 18E, RG 255 National Archives Southwest Region, Fort Worth, Texas

¹³⁸ R.B. MacDonald, F.G. Hall, and R.B. Hall, "The Use of Landsat Data in a Large Area Crop Inventory Experiment (LACIE)," Symposium on Machine Processing of Remotely Sensed Data, Laboratory for Applications of Remote Sensing, Purdue University, 3-5 June 1975, pg. 4

The Landsat MSS, which was 30-meter resolution data across 4 spectral bands) was the major source of remote sensing data for the LACIE. Each MSS viewed an area of the Earth of about 1.1 acres or 0.45 hectares, across a 185 km line. Along this line, measurements were recorded at 57 m increments forming pixels. Each MSS pixel represented light intensity captured across four spectral bands. Over three years from 1975 to 1978, the USDA, NASA, and NOAA implemented the LACIE in the American Midwest, the Canadian provinces of Saskatchewan, Alberta, and Manitoba, as well as several Soviet oblasts to varying degrees of success. However, extreme weather patterns, especially wide variation of precipitation and temperature, skewed historical yield data and meteorological models over the four years of the LACIE. Similarly, LACIE scientists experienced greater difficulty distinguishing wheat from other grains than expected. Thus, ecological factors limited the effectiveness of Landsat technology.

Constraining LACIE

LACIE scientists experienced both ecological and technological factors which constrained the experiment. Three major constraints inhibited the project. One factor manifested technologically as scientists experienced difficulty distinguishing wheat from its surroundings and the other two ecologically as the environment hindered satellite data collection.

Technologically, LACIE had difficulties in classification, image feedback, and operation.

Despite LACIE's organized classification for wheat, not all imagery was homogenous. The appearance of non-croplands, such as forests and urban areas obscured classification. Landsat's resolution further inhibited the process as certain areas appeared highly heterogeneous making wheat identification, much less individual stages, difficult. Thirty-meter resolution as well as environmental variability affected the data feedback. A wheat field bordering a heavy forest

obscured that pixel's accuracy. A LACIE scientist was unable to accurately classify that pixel, equivalent to a 30 square meter plot, as a forest or wheat. Since Landsat data indicated the presence of chlorophyll, vegetation with like chlorophyll signatures appeared the same or similar in Landsat imagery. As LACIE scientists discovered, sometimes Landsat data misrepresented wheat for soybeans or other cereals. The Landsat imagery was not nuanced enough to distinguish among vegetated land cover variables.

Ecologically, the very imagery itself also constrained data as cloud cover impeded the MSS's ability to scan the Earth, producing 'holes' in the imagery. Likewise, 'noise', or unwanted distortion in imagery which reduced useable information, also increased classification difficulty. Refraction and reflection affected Landsat imagery since moisture scattered and absorbed light as it penetrated the atmosphere and reached the Earth's surface. As such, meteorology posed a major constraint on the LACIE project. Cloud cover rendered data opaque and therefore useless for crop identification. This concern heavily constrained the project throughout in all sample areas. Early in the project, scientists understood that "cloud cover over site in relation to ERTS passes we will not collect enough useable data in all areas to meet the four pass requirement."¹³⁹ By the fall of 1974, LACIE scientists looked to implement ERTS-B data with full-frame registration, that is, fully implementing the satellite's data with specified locations as opposed to raw data. This method presented an advantage for "reducing sampling errors introduced by the cloud cover problem" since "selection of the sample segments could be made in cloud-free locations."¹⁴⁰

¹³⁹ John Overton, Acting Project Manager, LACIP to LACIP Distribution, "Results of Project Technical Review on April 3, 1974," 9 April 1974, ER25/1a MIS, Box 18E, RG 255 National Archives Southwest Region, Ft. Worth, Texas

¹⁴⁰ Clifford Charlesworth, Manager, Earth Resources Program to William Stoney, Director, Earth Observations Program "LACIP Justification of Full-Frame Registration of ERTS-B Data," 6 August 1974, ER 25/1a MIS, Box 18E, RG 255, National Archives Southwest Region, Fort Worth, Texas

Also, weather patterns likewise constrained LACIE through the meteorological models applied by NOAA. As NASA and NOAA initiated LACIE, Director of Earth Observation Programs William Stoney suggested a problem emerged at the interface of crop yield prediction from Landsat data and meteorological conditions modeled by NOAA. It became Director Stoney's concern that neither agency addressed this "agro-meteorological problem" in great detail prior to 1974 because it presented a challenge to precisely modeling temperature, precipitation, and soil moisture over several countries.¹⁴¹ This precision was necessary since NOAA used "ground-based data to establish weather trends in various world regions and relate these conditions through statistical models to the yield of the crops in those regions."¹⁴² Furthermore, these statistical models served as a function within the crop predictive algorithms utilized by the USDA. The agro-meteorological problem rested on the practical issue of deviating weather conditions over four years and their effects upon wheat yields during those growing years. In a 1974 report, Director Stoney argued this problem required year to year measurements since crop production varied so widely that linear trends were too simple for understanding meteorological effects on yield. Also, production variability depends upon acreage and yield, the amount planted in the first place, since these factors changed each growing year. Director Stoney averaged yield, acreage, and production between 1948 and 1973 in the U.S., India, and Australia and revealed that U.S. production departed from its average trend 10% or more in 10 of the last 25 years, India departed 10% or more in last five years, and Australia 18 of

¹⁴¹ William Stoney, Director of Earth Observations Programs to Goddard Space Flight Center, Greenbelt, M.D., 8 May 1974 ER 1 April 1974 "Large Area Crop Inventory Project," Box 18E, RG 255 National Archives Southwest Region, Fort Worth, Texas

¹⁴² William Stoney, Director of Earth Observations Programs to Goddard Space Flight Center, Greenbelt, M.D., 8 May 1974 ER 1 April 1974 "Large Area Crop Inventory Project," Box 18E, RG 255 National Archives Southwest Region, Fort Worth, Texas

last 25 years.¹⁴³ This high variation strained the correlations made between crop yield and meteorology.

The U.S. government intended LACIE to be a global crop prediction experiment yet these constraints severely scaled the project back. NASA and JSC approached the LACIE as an eight country analysis applicable to several crops. However NASA ultimately retreated from such a broad project.¹⁴⁴ Ecological and technological limitations rendered Landsat data intermittent due to atmospheric interruption, cloud cover, the inability to accurately distinguish wheat from other crops and vegetation, and insufficient meteorological models. These factors confined the American effort to predict global wheat yield available for human consumption. Thus, NASA continued its efforts with a LACIE follow-on and the intelligence community also began to monitor crops.

AGRISTARS

In 1979, several federal agencies formed the Joint Program for Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS).¹⁴⁵ The joint agencies intended for AgRISTARS to be the follow-on program to LACIE as a means of “extraction of agronomic information at a large, if not global scale, of a type and quality relevant to decision makers, and in an efficient and cost-effective manner.”¹⁴⁶ NASA’s objective was “to provide a capability for the USDA to respond in a timely manner to factors which affect the quality and

¹⁴³ William Stoney, Director of Earth Observations Programs, Office of Applications to Goddard Space Flight Center, Greenbelt, M.D., 8 May 1974 ER 1 April 1974 “Large Area Crop Inventory Project,” Box 18E, RG 255 National Archives Southwest Region, Fort Worth, Texas, figures 1, 2, and 3

¹⁴⁴ Originally, the U.S., Canada, Australia, Argentina, Brazil, the Soviet Union, India, and China were considered for the project.

¹⁴⁵ USDA, NASA, DOC, DOI, and USAID participated in AgRISTARS and ERIM served as lead contractor.

¹⁴⁶ Technical Report, Q.A. Holmes, R. Horvath, R.C. Cicone, R.J. Kauth, W.A. Malila, “Development of Landsat-Based Technology for Crop Inventories,” December 1979, <http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19800010232.pdf>, date accessed: 10 July 2015

production of economically important crops.”¹⁴⁷ AgRISTARS had a specific division of labor among the agencies. NASA conducted research and development on new techniques and scanners for subsequent Landsats. NOAA also performed research and development on meteorological satellites and uses of weather data for agricultural purposes. USDA provided and applied agricultural data (such as soil and crop conditions), performed statistical tests based upon their data and that which was gathered by NASA and NOAA, and communicated with users. EROS facility continued to store, retrieve, and disseminate data for AgRISTARS. USAID evaluated developing countries for potential applications of AgRISTARS. ERIM served again as a contractor for NASA and it conducted research, development, testing, and system design. The above technical report listed three broad goals for the program: to design a system as a basis for technological development, address estimation issues and self-evaluation, and improve technology to be able to distinguish crops and estimate crop proportions.

AgRISTARS built on LACIE in two particular ways to produce a more comprehensive natural resource inventory. First, it broadened the scope of LACIE to include crop yield predictions for several cereal commodities beyond wheat including barley, rice, soybeans, and corn in several countries. Also, AgRISTARS second main objective was to produce an ‘early warning system’ to “improve the objectivity, reliability, timeliness, and adequacy of information available to help USDA establish national agriculture and trade policies.”¹⁴⁸ NASA and USDA proposed to monitor twelve crops across six countries to achieve improved forecasts operationally in the US and abroad. The crops included corn, soybeans, wheat, barley, sorghum,

¹⁴⁷ Technical Presentation, “AgRISTARS Familiarization Briefing,” 5 March 1980, Johnson Space Center, document courtesy of James Irons, Goddard Spaceflight Center, Greenbelt, M.D.

¹⁴⁸ NASA, “NASA 5-Year Planning Fiscal Years 1980 through 1984,” 31 January 1979, NTRS: <http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19790079404.pdf>, date accessed: 21 September 2016, pg. 83

rice, cotton, and sunflowers. Despite the marginal success of LACIE, AgRISTARS proved far more difficult to accomplish.

Given the large scope of AgRISTARS, the project encountered several key issue areas centered on the difficulty of extracting “agronomic information at a large, if not global scale, of a type and quality that is relevant to decision makers, and in an efficient and cost-effective manner.”¹⁴⁹ In a December 1979 technical report from ERIM, the contractor laid out the problem in three parts: conceptualization and area estimation, technological issues from processing to performance, and the technology itself.¹⁵⁰ One of the main challenges was developing software advanced enough to distinguish and extract information from Landsat imagery that identifies different land cover variables. This required an adaptive system that could allow for labeling of such variables and allow for analysis over a very large area estimation. Again, AgRISTARS was ambitious in its goal to provide a mechanism for crop predictions worldwide. ERIM also proposed technology capable of “assigning crop labels to samples (called objective labeling) and that technology related to the efficiency of crop proportion estimation (called machine processing).”¹⁵¹ NASA, ERIM, and USDA worked towards resolving these issues as the project progressed.

The Johnson Space Center (JSC) in Houston, Texas carried out AgRISTARS and received roughly \$16 million in FY1980 with another \$33 million planned for FY1981.¹⁵² In

¹⁴⁹ Q.A. Holmes, R. Horvath, R.C. Cicone, R.J. Kauth, and W.A. Malila, “Development of Landsat-Based Technology for Crop Inventories,” ERIM Technical Report, December 1979, <http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19800010232.pdf>, date accessed: 21 September 2016, pg. v

¹⁵⁰ Q.A. Holmes, R. Horvath, R.C. Cicone, R.J. Kauth, and W.A. Malila, “Development of Landsat-Based Technology for Crop Inventories,” ERIM Technical Report, December 1979, <http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19800010232.pdf>, date accessed: 21 September 2016

¹⁵¹ Q.A. Holmes, R. Horvath, R.C. Cicone, R.J. Kauth, and W.A. Malila, “Development of Landsat-Based Technology for Crop Inventories,” ERIM Technical Report, December 1979, <http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19800010232.pdf>, date accessed: 21 September 2016, pg. v

¹⁵² “NASA FY 1981 Budget Meeting,” 28 January 1980, NASA NTRS: <http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19800071930.pdf>, date accessed: 21 September 2016, pg. 5

1980 into 1981, JSC conducted several different image analyses using Landsat data from 18 different states across the US. Project scientists sought to build and train software to process Landsat data and identify and label the aforementioned crops within the imagery. In addition to crop estimates, AgRISTARS emphasized soil as well, as it was a key determinant of crop health. In the American West, snowpack provided a means of irrigation and water supply forecasting became another application of Landsat imagery. Thus, AgRISTARS scientists evaluated “remote methods for predicting both the areal extent and depth of snow pack.”¹⁵³ By late 1982, AgRISTARS began to end operations as it was planned for four years. During several informal interviews with NASA and USGS officials, they stated that increased Landsat data pricing in 1982 made the project more expensive and more difficult to budget for. Since the project drew heavily upon vast amounts of Landsat data, costs ballooned for federal agencies whose budgets for AgRISTARS remained static or even decreased. I discuss this change in pricing and the consequences in Chapter 3.

Other Experiments: Mitigating Pests from Space

NASA continued to explore ways to mitigate agricultural losses by detecting pests from space. In March 1974, scientists from both JSC and the Mexican Comision Nacional del Espacio Exterior (CNEE) finalized a plan to assist the Mexican American Commission for the Eradication of the Screwworm, a joint agreement of the Mexican and American Secretaries of Agriculture, in its mission to defeat a particular species of fly that had been destroying cattle and poultry. The small fly proliferated throughout much of northern Mexico and from California to Florida. USDA predicted annual American losses of livestock up to \$200 million due to the large

¹⁵³ Paul Pinter, Jerry Ritchie, Jerry Hatfield, and Galen Hart, “The Agricultural Research Service’s Remote Sensing Program: An Example of Interagency Collaboration,” *PE&RS* Vol.69, No.6, June 2003, pp. 615-618, pg. 615

number of screwworm infestations.¹⁵⁴ With Mexico experiencing similar losses, both governments sought to eradicate the fly from central and northern Mexico also buffering the U.S. from infestation since the flies often migrated northward from Central America. The Life Science Directorate of JSC carried out the project using Landsat data to identify “soil temperature, moisture, and vegetative cover – all of which affect the breeding patterns of the screwwormfly.”¹⁵⁵ Through Landsat data, Mexican aircraft pinpointed heavily saturated areas for distribution of sterile flies that would in turn reduce the screwworm fly population. NASA and CNEE selected a site near Cordoba, Mexico to experiment with Landsat data. A few years later, a similar experiment took place in Pennsylvania.

In 1980, the Pennsylvania Department of Environmental Resources sought the capability to monitor damage caused by gypsy moths. The gypsy moth caterpillar fed upon the hardwood forests, composed largely of oak and maple trees, heavily defoliating 178,062 hectares in 1980 capping off nearly \$32 million in losses over 10 years to the state’s forest industry. Pennsylvania foresters used Landsat “multispectral scanner data from NASA’s Landsat satellites to examine hardwood forests conditions before and after defoliation occurs” which allowed “forested areas exhibiting gypsy moth damage to be identified and located on the satellite image” and track forest damage over time.¹⁵⁶

CIA Crop Inventorying

¹⁵⁴ JSC Press Release, “NASA Remote Sensing to Assist in Eradicating Screwworm,” 12 March 1974, Untitled Folder 6091, NASA Historical Reference Collection, NASA HQ, Washington, D.C.

¹⁵⁵ JSC Press Release, “NASA Remote Sensing to Assist in Eradicating Screwworm,” 12 March 1974, Untitled Folder 6091, NASA Historical Reference Collection, NASA HQ, Washington, D.C.

¹⁵⁶ NASA News, “NASA Satellite to Monitor Pennsylvania’s Gypsy Moth Damage,” 15 October 1980, Untitled Folder 6083, NASA Historical Reference Collection, NASA HQ, Washington, D.C.

As demonstrated, the military played a role in crop inventorying through remote sensing since the Navy funded Colwell's work in the 1950s. But by the late 1970s, the CIA began to monitor crops abroad using methods similar to those developed during LACIE and AgRISTARS. The methods used by NASA and USDA were adopted by the CIA which began to closely track crop growth in the Soviet bloc and various parts of the developing world. After the "Soviet Grain Grab" mentioned above, the CIA Bureau of Economic Research assumed a larger role in crop estimation. The Bureau neither trusted the Soviets who overstated its figures nor the USDA and began to revise its modeling "to reflect more complete data on the previous winter's rainfall and soil moisture, and to utilize information in the first LACIE satellite pictures."¹⁵⁷ The CIA began to realize that Soviet crop yields were far lower than both their own reports and USDA's estimates. Accordingly, crop inventorying by remote sensing became an imperative of the intelligence community to protect American farmers.

In the late 1970s into the 1980s, the Environment and Resource Analysis Center and in the Office of Geographic and Cartographic Research, in conjunction with the Office of Economic Research and Office of Soviet Analysis, both of CIA, produced reports on Soviet grain production using a algorithm similar to LACIE. The CIA coordinated this effort with the USAF's Environmental Technical Applications Center and the Foreign Agricultural Service of USDA. Much like LACIE, CIA crop inventorying drew data from satellite imagery, meteorological data, historical and current crop estimates, fertilizer production, and crop models in addition to human intelligence and open, scientific literature. At times the Soviet Union's Central Statistical Administration shared crop yield information with the U.S. federal government. CIA derived its production estimates "from crop models which are used to aggregate and compare both current and historical data. All intelligence data sources, including

¹⁵⁷ Dan Morgan, *Merchants of Grain*, (New York, NY: The Viking Press, 1979), pg. 22

satellite imagery systems” were used and analyzed by teams of “imagery analysts, agronomists, geographers, meteorologists, economists, and computer specialists.”¹⁵⁸ Much of the growth tracked was in the Ukraine near the Black Sea, Kazakhstan, North Caucasus, Moldavia, northern Belorussia, and sections of the Volga River Valley. As LACIE drew to a close, the CIA began to closely monitor Soviet crop yields in the 1980s.

The Americans used Landsat imagery to better predict Soviet crop yields tracking several variables. Throughout the 1970s, the USDA tracked Soviet crop production and had general figures for average production which it shared with the CIA. As mentioned, CIA was skeptical. In the late 1970s, the Soviets experienced sporadic wheat production. In 1976, the Soviet Union produced a record 224 million tons of grain, considerably higher than their average of roughly 210 million, tracked by USDA. While the 1976-1977 yield was successful, several years of below average yields plagued the Soviets. Moscow took action to try to resolve its growing pains. After three below average yields, the Soviets devoted more land to fallow. In 1982, Soviet premier Leonid Brezhnev introduced his Food Programme. The CIA interpreted Brezhnev’s goals for the programme as one that “reorganizes the management of food production, redirects investment resources between the farm sector and supporting industries, revises incentives for farm workers, and lists new targets for output of key agricultural commodities.”¹⁵⁹ Among its principles, the Soviet government sought to cut back on hard currency expenditures on Western agricultural imports. CIA’s report on the programme viewed it as a continuation of past policies but the agency took a keen interest in it as it began using Landsat imagery to more closely monitor Soviet crop yields in the early 1980s.

¹⁵⁸ Central Intelligence Agency, “USSR: Early August Prospects for Grain Production,” 10 August 1977, CIA CREST RAC Number: CIA-RDP79-01056A000100200001-6, College Park, MD, pg. 1

¹⁵⁹ CIA Directorate of Intelligence, “The Brezhnev Food Program,” September 1982, https://www.cia.gov/library/readingroom/docs/DOC_0000496809.pdf, date accessed: 21 September 2016, pg. iii

In 1983, the Soviets harvested its best crop in years. The USSR produced roughly 210 million metric tons. CIA models of “weather, straw dumps, grain procurements, [redacted],” alongside “excellent crop vigor observed on Landsat imagery” suggested another successful crop for the Soviets.¹⁶⁰ The CIA report for 1984, based on this model that used Landsat imagery, warned that American grain sales to the Soviets might drop off, yet an August 1983 agreement between the two countries committed to Soviets to buying American crops. The US-USSR Long Term Agreement required the Soviets to purchase 9 million tons of US grain in FY 1983, with an option for an additional 3 million. The CIA estimated that a large Soviet grain yield would deter it from purchasing an amount higher than the Long Term Agreement minimum and ultimately reduce the market for American farmers. With a higher grain yield, the Soviets fed more people as well as more livestock adding to the meat supply. CIA’s evaluation of a large crop year for 1984 would allow the Soviets to cut back imports and save “nearly \$2 billion in hard currency.”¹⁶¹ Through crop estimates, the Americans could better anticipate fluctuations in trade and pricing, despite the difficulty of producing crop yield predictions.

However, the CIA report for 1984, expressed several uncertainties. A prolonged wet season threatened crops in several part of the Soviet Union. The report was also concerned the Soviets may harvest more of the corn acreage than they anticipated. The CIA tracked a larger than average use of fertilizer due to its availability by Soviet farmers in the northern oblasts which also received a high amount of rainfall. The Soviet Union also made several international moves to suggest they also anticipated a very large yield. The US Embassy reported to the CIA that the Soviets rejected a 2 million ton grain offer by Australians, refused to increase grain sale

¹⁶⁰ CIA Directorate of Intelligence, “USSR: Fourth-Largest Grain Crop in History: An Intelligence Assessment,” November 1983, RAC: CIA-RDP85T00283R000200100005-0, CREST, College Park, MD, pg. 1

¹⁶¹ CIA Directorate of Intelligence, “USSR: Fourth-Largest Grain Crop in History: An Intelligence Assessment,” November 1983, RAC: CIA-RDP85T00283R000200100005-0, CREST, College Park, MD, pg. 7

contracts with Canada and Argentina, and lowered their purchases from France.¹⁶² The USDA also held in place a minimum 22 million ton sale which the Soviet Union had as an option to sustain and grow its grain reserves. These uncertainties and brokered deals held strong implications for both the U.S. and Soviet Union.

In 1984, the CIA tracked poor weather in April that it argued “eliminated Moscow’s chances this year for even an average grain harvest.”¹⁶³ The report in 1984 stated that the Soviets would produce 185 million tons, well below its average and the previous year’s yield. Moscow purchased roughly 22 million tons in August 1984, which the CIA interpreted as either preparing for a low yield mixed with a need to supply its military given its ongoing combat operations in Afghanistan, discussed in more detail later. By the end of 1984, that 22 million more than doubled to 53 million tons of grain imports.¹⁶⁴ The CIA predicted that the US would be in a strong position to export grain to the Soviet Union, despite this going against Brezhnev’s Food Programme. Yet, the 1985 crop for the Soviets vastly improved cutting the need for imports. Moscow produced nearly 200 million tons and would only import roughly 25 million tons which was less than half of the previous year’s imports. Within just a few years of crop monitoring, Soviet grain yields fluctuated from high import needs to very little at all. In each of these cases, the CIA used Landsat imagery, in much the same way NASA conducted LACIE, in addition to a number of other variables to predict Soviet crop yields and guard the American farmer from market volatility.

¹⁶² CIA Directorate of Intelligence “USSR: Fourth-Largest Grain Crop in History: An Intelligence Assessment,” November 1983, RAC: CIA-RDP85T00283R000200100005-0, CREST, College Park, MD

¹⁶³ CIA Directorate of Intelligence, “USSR: 1984 Grain Crop Shortfall Necessitates Massive Imports,” September 1984, CREST RAC Number: CIA-RDP85S00315R000200070003-1, CREST College Park, MD

¹⁶⁴ CIA Directorate of Intelligence, “USSR: Good Grain Crop Cuts Import Needs,” October 1985, CREST RAC Number: CIA-RDP86T00586R000500530008-0, CREST, College Park, MD, pg. iii

The Soviets never confirmed that either USDA or CIA estimates were correct. Bobby Spires, who oversaw crop estimates for USDA's Foreign Agriculture Service Analysis Branch, confirmed both the difficulties and investment of using Landsat for crop estimates: "I [Spires] spent \$7 million a year to get data, but that works out to less than 10 cents for every ton of wheat exported," yet he was "confident we're real close. I just wish I could get my hands on those numbers from the Soviet Union and prove it."¹⁶⁵

Despite the sheer difficulty in generating accurate crop yields, the CIA came close using Landsat imagery in part to predict and report Soviet grain yields in the 1980s and inform American decision making with regards to grain exports. Much akin to LACIE however, CIA crop yield predictions also fell short. Landsat imagery alongside other meteorological and soil data and crop models could not fully apprise the intelligence community of Soviet agricultural decision making. The Soviet Union held numerous agreements with other countries, sought to use grains for livestock production, and did not readily report all potential variables necessary for crop prediction. These gaps complicated CIA's ability to predict Soviet yields. The CIA also experimented with using Landsat imagery to inventory and predict illicit crop growth including narcotics in South American and Afghanistan.

War on Drugs from Space

In 1971, President Richard Nixon announced an effort, which informally came to be called the 'War on Drugs,' to curb illicit drug use in the United States as it became a public health concern. However, the effort did not gain widespread traction as drug production and trafficking into America rose in the 1970s. The U.S. sought to stifle these activities at their

¹⁶⁵ Angelia Herrin, "U.S. Spy in sky keeps watch on Soviet Union wheat fields," 2 July 1985, *Miami Herald*, pg. 2-A, CREST RAC Number: CIA-RDP90-00965R000402650026-0, College Park, MD

origin. In 1984, Congress passed the Hawkins-Gilman Amendment to the Foreign Assistance Act of 1961 (the bill that created the USAID and administered economic and technical aid to developing countries) which had the goal of curtailing foreign narcotics production. The Hawkins-Gilman Amendment allowed Congress to block economic and military assistance “if a country does not make satisfactory progress in curtailing its drug business.”¹⁶⁶ In order to make such an assessment, the U.S. narcotics control establishment at CIA, the Drug Enforcement Administration (DEA), and the State Department had to assess and reduce the amount of acreage committed to coca cultivation abroad through crop eradication. This section also demonstrates how the 1979 Soviet invasion of Afghanistan fostered expanded opium production and trafficking, which CIA tracked with Landsat imagery. The Afghanistan opium estimate experiment informed the larger program of estimating coca production in South America: CIA “chose to apply the same imagery-based estimating technique that we have used successfully to estimate opium production in Asia.”¹⁶⁷ The lessons of LACIE and related experiments addressed above proved crucial to CIA’s techniques. CIA coca estimates drew “heavily on methodology developed to estimate licit crop production in countries like the USSR.”¹⁶⁸ In both cases, CIA implemented crop yield prediction techniques to address the burgeoning illicit drug trade in Afghanistan and South America; all of which were countries subject to the Hawkins-Gilman Amendment.

When the Soviet Union invaded Afghanistan in 1979, it sparked a war between the Red Army and guerilla Mujahedeen fighters. The Soviet military appropriated the Afghan

¹⁶⁶ CIA Directorate of Intelligence, “Coca Cultivation in South America: Assessing the Magnitude of the Problem,” 15 August 1986,” RAC: CIA-RDP86T01017R000201340001-0, CREST, College Park, MD, pg. 3

¹⁶⁷ CIA Directorate of Intelligence, “Coca Cultivation in South America: Assessing the Magnitude of the Problem,” 15 August 1986,” RAC: CIA-RDP86T01017R000201340001-0, CREST, College Park, MD, pg. 3

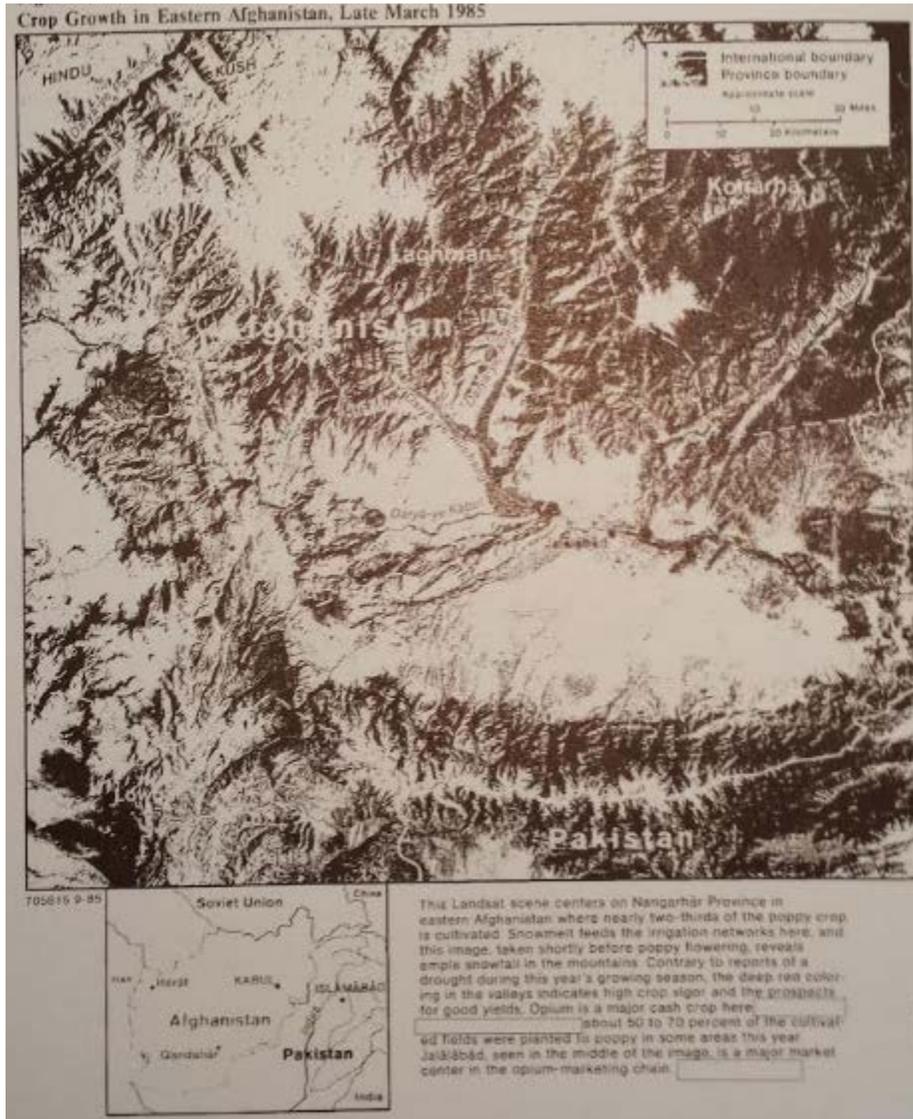
¹⁶⁸ CIA Directorate of Intelligence, “Coca Cultivation in South America: Assessing the Magnitude of the Problem,” 15 August 1986,” RAC: CIA-RDP86T01017R000201340001-0, CREST, College Park, MD, pg. 3

government and installed a sympathetic regime under Babrak Karmal. With no state suppression of illicit drug trade or containment from neighboring Iran or Pakistan, opiate production and trafficking grew as the conflict persisted. The CIA, in conjunction with the Department of State and DEA, closely monitored the conflict and reported in 1985 that a major byproduct of the war was an expanded opium trade.

The CIA used a similar crop yield method to map and track the illicit opium trade in 1985. The below picture, taken from a September 1985 CIA report, depicts crops and snowfall in the Nangarhar Province of Afghanistan.¹⁶⁹

¹⁶⁹ CIA Directorate of Intelligence, "Afghanistan's Expanded Opium Trade: Byproduct of War [Redacted]," September 1985, RAC: CIA-RDP97R00694R000500240001-9, CREST, College Park, MD, pg. 3

Figure 1: Landsat Imagery of Afghanistan



Landsat Image of Afghanistan, March 1985, NARA, College Park, MD

While depicted here in black and white, the Landsat image would have been in false color showing opium crops in red, snow in white, and exposed rock as a grey. The snowmelt was a key variable as it provided irrigation for crops and Jalalabad was the urban node of the opium trade in the region. CIA, DEA and Department of State used Landsat imagery to study and track illicit drug trade in Afghanistan and postulated that it would continue to expand. While the report

expressed little concern for Soviet or Afghan drug abuse and public health, CIA's main concern was the Afghan opium market playing a larger role in the international narcotics market.

CIA use of Landsat imagery revealed an increase in acreage committed to poppy crops, in Nangarhar Province "approximately 50 to 70 percent of the cultivated fields are planted to poppy."¹⁷⁰ The crops were spread throughout rural mountain valleys in areas controlled by the insurgency, rather than Soviet or Afghan government controlled territory. Despite the conflict disrupting the irrigation infrastructure, CIA estimated that there was little crop loss since "destruction of crops and farms caused by military operations affects only a small portion of cultivated land, less than 1 percent of total farm crop areas observed on satellite imagery."¹⁷¹ The CIA report argued that the Soviets and Afghan regime would not address the growth in narcotics production given its attention to the armed conflict. Rather, the report focused on containment of opium trade.

The satellite imagery revealed the origins of poppy seed cultivation as well as major trade routes and the locations of major conflict. From these variables, CIA and DEA deduced the movements of drug smuggling into Pakistan and Iran. Within Afghanistan, opium provided a means of revenue for insurgents, who often also had farms. The CIA and DEA, concerned with drug containment, argued that the only potential motivation to curb the narcotics production and trade would be if the Soviets "perceive that drug abuse threatens the performance of Soviet troops in Afghanistan or that drug sales finance the insurgent movement."¹⁷² While CIA and DEA would not be able to contain drug trafficking, Landsat imagery played a crucial role in

¹⁷⁰ CIA Directorate of Intelligence, "Afghanistan's Expanded Opium Trade: Byproduct of War [Redacted]," September 1985, RAC: CIA-RDP97R00694R000500240001-9, CREST, College Park, MD, pg. 2

¹⁷¹ CIA Directorate of Intelligence, "Afghanistan's Expanded Opium Trade: Byproduct of War [Redacted]," September 1985, RAC: CIA-RDP97R00694R000500240001-9, CREST, College Park, MD, pg. 5

¹⁷² CIA Directorate of Intelligence, "Afghanistan's Expanded Opium Trade: Byproduct of War [Redacted]," September 1985, RAC: CIA-RDP97R00694R000500240001-9, CREST, College Park, MD, pg. 14

revealing the increased opium trade in Afghanistan. As mentioned, the Afghanistan project informed the methods CIA used in South America.

In 1984, CIA and State began to use Landsat imagery to uncover the widespread cultivation of coca as well as marijuana and opium. The Agency sought to “use imagery-based estimative techniques to give policymakers and drug enforcement specialists a more precise understanding of the extent of coca production in South America,” namely targeting Bolivia, Peru, Colombia, Brazil, Ecuador, and Venezuela.¹⁷³ By 1985, each of these countries began counternarcotics eradication programs. Meanwhile, the DEA worked to stem the flow of cocaine into the United States and sought to do so at its origin in South America.

Coca cultivation was easily identifiable on Landsat imagery as it is a perennial crop planted in legible rows over several thousand hectares in each of the aforementioned countries. CIA and DEA “relied on Landsat data to delineate agricultural from non-agricultural areas – the first phase in sorting out likely coca growing areas from forests, mountains, and other uncultivated areas.”¹⁷⁴ CIA also flew several U-2 flights over Bolivia and Colombia. From this space and aerial imagery, CIA estimated that a minimum of 140,000 hectares was under coca cultivation in South America in 1984 with the largest commitments of land in Bolivia and Peru. In July 1984, the Bolivian government sought the assistance of the U.S. military and began Operation Blast Furnace which was a coca eradication program predicated on locating illicit coca cultivation. The operation disrupted the infrastructure of processing laboratories and trafficking routes as well.

¹⁷³ CIA Directorate of Intelligence, “Coca Cultivation in South America: Assessing the Magnitude of the Problem,” 15 August 1986,” RAC: CIA-RDP86T01017R000201340001-0, CREST, College Park, MD

¹⁷⁴ CIA Directorate of Intelligence, “Coca Cultivation in South America: Assessing the Magnitude of the Problem,” 15 August 1986,” RAC: CIA-RDP86T01017R000201340001-0, CREST, College Park, MD, pg. 4

Peru presented an even bigger challenge to illicit drug control. In July 1985, the Peruvian government agreed to eradicate 6,000 hectares of coca a year through 1989.¹⁷⁵ President Alan Garcia charged the Guardia Civil and regional departments with ground truthing in areas more difficult to conduct surveillance and carry out crop eradication. From the Americans, the CIA analyzed Landsat imagery covering most all of Peru. In 1986, the CIA mapped “suspected coca-growing areas with Landsat imagery to help evaluate Peruvian coca cultivation” in Peru’s upper Huallaga River Valley, Cuzco, and the Apurimac and Marañon River Valleys.¹⁷⁶ However, one of the main technical complications in 1985 was cloud cover which blocked certain drug enforcement efforts.¹⁷⁷ Another complication was labor, which Peruvian drug enforcements severely lacked to carry out eradication once the coca was revealed on Landsat imagery.

Colombia, Brazil, Ecuador, and Venezuela also carried out drug eradication programs that attempted to use Landsat imagery as well as U-2 aerial photographs. However, regions of these countries proved more difficult to obtain imagery from in 1985 and 1986 given the highly frequent cloud cover and dense vegetation and rainforests where much of the coca cultivation was taking place. While Landsat imagery played a crucial role identifying coca cultivation in portions of South America it was not ubiquitously successful given the environmental conditions. Moreover, the efforts of the South American governments fell short of their coca eradication and interdiction goals and instead, coca cultivation increased over the two year study period aggregated over the six countries.

Conclusion

¹⁷⁵ CIA Directorate of Intelligence, “Coca Cultivation in South America: Assessing the Magnitude of the Problem,” 15 August 1986,” RAC: CIA-RDP86T01017R000201340001-0, CREST, College Park, MD, pg. 9

¹⁷⁶ CIA Directorate of Intelligence, “Coca Cultivation in South America: Assessing the Magnitude of the Problem,” 15 August 1986,” RAC: CIA-RDP86T01017R000201340001-0, CREST, College Park, MD, pg. 8

¹⁷⁷ A portion of this section of the “Coca Cultivation in South America” report cited above was redacted.

The backdrop of the Cold War and national security imperatives loomed large as scientists found new ways to look at Earth from above. One such critical imperative was surveillance, specifically of the planet's geographic features. The fusion of the American scientific and intelligence communities buttressed and deployed the environmental sciences to gain strategic leverage over its Cold War adversaries. In this chapter, agriculture increasingly came under surveillance as the United States demonstrated greater abilities in remote sensing. Where Turchetti and Roberts focus on the sciences themselves, they pay little attention to the technology and techniques of surveillance. I demonstrated how the techniques of surveillance were developed and how the data obtained came to be used by the scientific and intelligence communities.

Since the 1950s, the NAS, several universities, USDA, and finally NASA contributed to numerous experiments that applied remote sensing to agriculture. NASA, the Army, and the Navy supplied funding and oversaw several early experiments. In the 1960s and 1970s, the federal government and their academic partners developed both the technology and scientific techniques to begin crop yield estimates domestically. By the 1980s, NASA had conducted international crop yield prediction which captured the attention of the intelligence community. CIA in particular adopted similar techniques to predict the crop yields of several countries and to understand and stifle the flow of narcotics. While there were tremendous technological difficulties, some of which were not resolved, the Landsat program essentially proved itself a useful scientific instrument to the U.S. federal government, which later sought to expand its use abroad. This chapter demonstrated how several federal agencies developed and expanded the use of remote sensing through agriculture. Cold War and national security, especially after the Soviet wheat deal in 1972, provided the not only the crucial backdrop for the first major use of Landsat

imagery but also the imperative for its use by multiple federal agencies. In the next chapter, I demonstrate how NASA and USGS made Landsat data available for the world to use, though the process was difficult.

Chapter 3: “Demonstrating the Value of Remote Sensing from Space”: Fostering Use in the Experimental Years (1957-1984)

Introduction

By the 1950s, scientific data began to globalize as several international initiatives encouraged the collection of scientific data from around the world. The International Geophysical Year in 1957-1958 inspired geologists, physicists, oceanographers, among others to gather data about Earth’s various phenomena. This worldwide scientific effort, the “IGY was distinguished by its emphasis on and the visibility of Big Data – a synoptic collection of observational data on a global geographic scale,” which precipitated the establishment of World Data Centers and the proliferation of scientific data.¹⁷⁸ The IGY inspired later data collection programs including the International Biological Program and the Long-Term Ecological Research program. As Aronova et. al. demonstrated further, these programs “ultimately succeeded in providing a renewed legitimacy for synoptic data collection in biology.”¹⁷⁹ As early as 1946, the U.S. military placed various instruments aboard V-2 rockets which it used to gather data from the upper atmosphere.¹⁸⁰ The Soviet contribution to the IGY included the launch of *Sputnik*, which inspired data collection from space-based instruments. Throughout the 1960s, American meteorological satellites such as the Television and Infrared Observation Satellites (TIROS) and Improved TIROS Operational System (ITOS) collected low resolution imagery of the planet’s surface to study Earth’s weather patterns. Yet despite these growing collections of

¹⁷⁸ Elena Aronova, Karen S. Baker, and Naomi Oreskes, “Big Science and Big Data in Biology: From the International Geophysical Year through the International Biological Program to the Long Term Ecological Research (LTER) Network, 1957-Present,” *Historical Studies in the Natural Sciences*, Vol. 40, No. 2 pps. 183-224, pg. 185

¹⁷⁹ Elena Aronova, Karen S. Baker, and Naomi Oreskes, “Big Science and Big Data in Biology: From the International Geophysical Year through the International Biological Program to the Long Term Ecological Research (LTER) Network, 1957-Present,” *Historical Studies in the Natural Sciences*, Vol. 40, No. 2 pps. 183-224, pg. 187

¹⁸⁰ David DeVorkin, *Science With a Vengeance: How the Military Created the US Space Sciences After World War II*, (Springer-Verlag, 1992)

biological and meteorological data, no synoptic, global scale program existed to gather scientific data of the Earth's land masses.

The USAF and CIA clandestinely gathered imagery of Earth's terrestrial surface for intelligence purposes relying upon the academic geography community.¹⁸¹ Cloud also showed the contributions of Corona to cartographic science in the context of the Cold War.¹⁸² Dwayne Day et al. considered how Corona both played a role in the dire national security concerns of the Cold War while also advancing the burgeoning space capabilities of the U.S.¹⁸³ However, the classified nature of Corona data made it impossible for the broader scientific community to use. The Department of the Interior and NASA saw the value of terrestrial satellite data, leading to the launch of Landsat in 1972 and the subsequent effort to build an archive of data for use by a global scientific community.

In this chapter, I demonstrate how the U.S. government, NASA and USGS in particular, fostered Landsat data abroad in three ways simultaneously. First, it leveraged the UN into favoring such a program by assuaging concerns of espionage and building a global consensus. Second, NASA and USGS collaborated with foreign space programs to allow direct receipt of Landsat data through a network of international ground stations and through two working groups that maintained these relations. Third, the aforementioned agencies worked with AID to offer remote sensing data use training seminars and grants to developing countries. However, in each case the U.S. government experienced both domestic and international barriers to expanding Landsat data use. I argue that the U.S. government, beginning with President Nixon, envisioned

¹⁸¹ John Cloud "Imaging the World in a Barrel: CORONA and the Clandestine Convergence of the Earth Sciences" *Social Studies of Science*, Vol. 31, No. 2, Science in the Cold War (Apr. 2001), pp. 231- 251

¹⁸² John Cloud "American Cartographic Transformations during the Cold War" *Cartography and Geographic Information Science* Vol. 29, No. 3, 2002

¹⁸³ Dwayne Day, John Logsdon, and Brian Latell, eds., *Eye in the Sky: The Story of the Corona Spy Satellites*, (Smithsonian History of Aviation and Spaceflight, 1999)

a non-discriminatory, open access Earth remote sensing data policy during Landsat's experimental years (1972-1978) but it proved very difficult to implement due to international legal concerns voiced through the UN, domestic national security restrictions, and financial concerns.

This argument proceeds in two parts: the first analyzes the slow proliferation of Landsat data ground receiving stations abroad and the policies that govern them as well as the applications explored through training seminars and seed grants provided by the U.S. government to expand the user community. In particular, NASA, USAID, and USGS played a central role in this regard. These agencies not only had to adopt domestic policies to allow international cooperators to receive Landsat data, they also had to build a legal framework at the UN. The UN had been the site of debate in the 1960s between not only the superpowers but the rest of the world with regards to international law in space. In the early 1970s, the UN General Assembly in New York, New York again dealt with the challenge space-based Earth observation satellites posed to national sovereignty. In addition, many countries needed to acquire the technology and expertise to use Landsat imagery for various environmental investigations. There were numerous countries, many in the developing world, who reacted to Landsat's potential with enthusiasm, though others viewed it skeptically. In effect, Landsat data use does not simply appear uniquely of its own kind nor does it proliferate transnationally without a conducive political environment laden with technical expertise and legal mandates.

Initial International Reaction to Land Remote Sensing

In September 1969, President Richard Nixon gave a speech before the UN General Assembly. The speech covered several aspects of world affairs such as America's role in the

world, peace in Vietnam, strategic arms limitations, and peace-building. Among those divisive issues, Nixon introduced five areas which he argued should be unanimously supported including safe air travel, voluntary service, economic development, environmental protection, and space exploration. He spoke of great potential for space technology to benefit humanity, in particular, “we [the United States] now are developing earth resource survey satellites...capable of yielding data which could assist in as widely varied tasks as these: the location of schools of fish in the oceans, the location of mineral deposits on land, the health of agricultural crops.”¹⁸⁴ Nixon further stated that “this program [Earth resource satellites] will be dedicated to produce information not only for the United States, but also for the world community.”¹⁸⁵ The speech cannot be taken as hard policy, but this statement relates to NASA’s mandate that it should “provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof.”¹⁸⁶ In addition, Nixon’s speech echoed the language of the Outer Space Treaty of 1967 which stated that the “use of outer space should be carried on for the benefit of all peoples irrespective of the degree of their economic or scientific development” and to “broad international co-operation in scientific” uses of space.¹⁸⁷ Effectively both national and international law mandated that Landsat data was meant to be available to all potential users.

Following Landsat’s launch, the UN conducted a survey of Member States which assessed the legality of remote sensing in countries around the world. The UN’s Request for Information solicited responses within three areas: laws that either allowed remote sensing or

¹⁸⁴ Richard Nixon address to United Nations General Assembly, 2 September 1969, <http://www.state.gov/p/io/potusunga/207305.htm>, date accessed: 22 May 2015

¹⁸⁵ Richard Nixon address to United Nations General Assembly, 2 September 1969, <http://www.state.gov/p/io/potusunga/207305.htm>, date accessed: 22 May 2015

¹⁸⁶ National Aeronautics and Space Act of 1958 (Unamended), 29 July 1958, <http://history.nasa.gov/spaceact.html>, NASA Historical Reference Collection, date accessed: 21 April 2016

¹⁸⁷ United Nations, “Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies,” Resolution 2222 (XXI) UNOOSA, <http://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/outerspacetreaty.html>, date accessed: 21 April 2016

disallowed foreign land remote sensing of domestic land, and, thirdly, countries that did not have any related laws. The results of the survey indicated an overwhelmingly positive response to the satellite's capabilities, discussed later in this chapter, but a select few detractors raised a concern central to the very mission of the United Nations: that of sovereignty.

Remote Sensing Resistance: Domestic and International Concerns, 1973-1975

Despite Nixon's pitch to the UNGA and a generally positive international reception for Landsat and its applications, several UN Member States and U.S. government officials expressed concern regarding international use of Landsat data. For several countries around the world, State sovereignty, especially regarding domestic control of natural resource exploitation, became the chief concern. The UN Working Group on Remote Sensing of the Earth by Satellites of the Committee on the Peaceful Uses of Outer Space (COPUOS) held a session from 29 January to 10 February 1973 to address international concerns regarding land remote sensing. The Working Group

“requested the Secretariat to compile ‘information drawn from international law and national legislation as well as practices that States consider relevant to environmental and natural resources surveying’ as well as ‘relevant existing legislation and practices in the use and dissemination of environmental and earth resources information.’”¹⁸⁸

The Secretary-General's office distributed the Request for Information to 94 Member States and 7 Non-Members in December 1972 and began receiving responses in early 1973. The Scientific and Technical Sub-Committee, under COPUOS, assessed the responses in May 1973 to understand Member states' legal objections to a system such as Landsat. Many countries stated they had no established domestic legislation or regulatory machinery relevant to land remote

¹⁸⁸ 20 February 1973, “Background paper by the Secretary-General assessing United Nations documents and other pertinent data related to remote sensing of the Earth by satellites,” Political and Security Matters 1955-1983, PO 312(4) Part 2 1973-1978, Central Registry 1954-1983, S-0442-0377-01, UN Archives, New York, NY

sensing for resource surveying.¹⁸⁹ Others used this Request for Information to express their support of land remote sensing systems for earth resource surveying. Jamaica, the Philippines, and the Netherlands each announced the formation of government outfits to use Landsat data for environmental analyses. Norway was in the process of establishing a remote sensing laboratory under its Ministry for Environmental Affairs. Jamaica in particular established a Remote Sensing Laboratory under its Ministry of Mining and Natural Resources. Jamaica's Mission to the UN argued that Member States should be able to maintain sovereignty over their natural resources and should have the right to access the findings of earth resource surveys. In their view, "the study of earth resources through the techniques of remote sensing satellites shall be based on international co-operation for the benefit of all mankind."¹⁹⁰ Throughout the Request for Information process in 1973, several Member States expressed concern over sovereignty of natural resources.

Satellite overflight became generally accepted after the launch of Sputnik in 1957 and formalized in the Outer Space Treaty of 1967 after a protracted legal battle between the United States and the Soviet Union. However, Landsat and the promise of open access to its data raised a serious sovereignty question for UN Member States. For example: if an American used Landsat data to discover mineral resources in Oman, Great Britain, or Jamaica, does the American have the right to exploit those resources? Several countries including Sweden and Australia strongly defended national sovereignty against foreign exploitation of domestic natural resources.

¹⁸⁹ I found responses from Cyprus, Denmark, Barbados, Norway, Kenya, Kuwait, Sierra Leone, and Dahomey to this effect in the file.

¹⁹⁰ Memo, Mission of Jamaica to the UN to the UN Secretary-General, 29 June 1973, Political and Security Matters 1955-1983, PO 312(4) Part 2 1973-1978, Central Registry 1954-1983, S-0442-0377-01, UN Archives, New York, NY

Sweden also framed sovereignty as a concern for Landsat coverage. Swedish Ambassador to the UN Olof Rydbeck expressed concern that international law in 1973 did not adequately address land remote sensing since “States will not be able to see with equanimity that such information is being gathered about their territories if they have not ascertained that they have complete access to it and, perhaps, the right to deny its use to anybody else unless prior consent has been given.”¹⁹¹ First, Rydbeck addressed ‘international areas’ covered in Landsat imagery, such as oceans which lie outside national jurisdictions. As an example, Sweden argued that nations capable of mapping the seabed gained an economic advantage in fisheries. For Sweden and fishing, “it is easy to see that those states which would have at their disposal up-to-date information might gain important advantages.”¹⁹² The Swedish Ambassador stated how the Outer Space Treaty legitimized weather satellites, but contended that land remote sensing satellites presented more direct economic issues. Rydbeck called for ‘new concepts’ in international law such as legal mechanisms that protect observed states from observing states through distribution and use regulations. While the ambassador did not provide specifics, he urgently advocated for legislation and coordination from the UN and COPUOS in particular. The Australians voiced a similar concern.

Australian Representative to the Working Group on Remote Sensing of the Earth by Satellites Dr. L.M. Gillin responded to the RFI with a statement he made to the Working Group in January 1973. Gillin expressed concern over the economic benefits that Landsat promised to

¹⁹¹ Attachment to Memo, Ambassador Olof Rydbeck of the Permanent Mission of Sweden to the United Nations to Secretary-General of the UN, 4 December 1973, Political and Security Matters 1955-1983, PO 312(4) Part 2 1973-1978, Central Registry 1954-1983, S-0442-0377-01, UN Archives, New York, NY, pg. 18

¹⁹² Attachment to Memo, Ambassador Olof Rydbeck of the Permanent Mission of Sweden to the United Nations to Secretary-General of the UN, 4 December 1973, Political and Security Matters 1955-1983, PO 312(4) Part 2 1973-1978, Central Registry 1954-1983, S-0442-0377-01, UN Archives, New York, NY, pg. 12

countries that received data regarding minerals extraction. Gillin posed the question regarding Australian legislation to the Working Group:

“exploration rights in an area are exclusive to the holders of a permit in respect to that area. What are we to do, then, about a situation in which any company can obtain, from an agency outside Australia [EROS], information about a part of Australia to which, in Australia, it would have no legal right and no means of gaining access?”¹⁹³

For the Australian delegation, remote sensing technology posed a serious concern to national legislation. Under Australian law, any form of prospecting for mineral resources required a permit from the government. However, Landsat data provided users the means of prospecting, defined by the Australians, to any Landsat data user from anywhere in the world since EROS provided data openly. In essence, Landsat data privileged mineral prospectors outside Australia even though they would not have the legal right to potential discoveries. For the Australians, Landsat data compromised Australian sovereignty over natural resources and indeed their national laws. Accordingly, the Australians also interpreted the Outer Space Treaty differently. The Australian delegation did not interpret Outer Space Treaty Article I¹⁹⁴ to permit land remote sensing. As discussed, the United States viewed land remote sensing as permissible under the Treaty as a civilian activity. Gillin expressed optimism however.

Despite these concerns, Gillin stated his enthusiasm for Landsat by noting the “excellent cooperation between NASA and the Australian Committee for ERTS [ACERTS].” Established in 1971 by the Australian government, ACERTS became the national coordinating committee for Australian use of Landsat for scientific investigations. Australia’s Bureau of Mineral Resources first gained experience with earth imagery taken of Amadeus Basin from NASA’s Gemini V

¹⁹³ Attachment to Memo, First Secretary R.H. Wyndham, Australian Mission to the United Nations to Secretary General of the UN, 12 March 1973, Political and Security Matters 1955-1983, PO 312(4) Part 2 1973-1978, Central Registry 1954-1983, S-0442-0377-01, UN Archives, New York, NY

¹⁹⁴ <http://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/outerspacetreaty.html>, 19 December 1966, date accessed: 12 June 2015

spacecraft and conducted later investigations with USGS which “set the stage for Australia to take full advantage of data from satellite-based systems.”¹⁹⁵ Gillin understood the benefits of remote sensing and sought to resolve land remote sensing legal and political issues he brought forth in response to the UN RFI.

The American response to the RFI was brief. It stated that data is widely available from EROS and encouraged developing countries to review its Landsat data. The U.S. held “the view that the principles embodied in the Outer Space Treaty clearly apply to the activities of states in remote sensing of the earth by satellites,” but that the U.S. sought to “facilitate the maximum international availability and effective utilization of data.”¹⁹⁶ The United States reiterated Nixon’s promise from his 1969 speech to the UNGA that data will be made available to all potential users which helped to assuage concerns about national sovereignty and disproportionate economic advantages.

Several Member States raised salient concerns regarding national sovereignty yet none expressed outright disapproval of the Landsat satellites. Nearly all respondents to the UN RFI mentioned above sought to use Landsat data in some experimental fashion. Sweden and Australia raised key legal concerns that the United States addressed through policies that made Landsat data internationally available through ground stations abroad and non-discriminatory sales at EROS. Due to these concerns, Sweden and Australia become two of the first countries to establish Landsat data receiving ground stations so as to have access to, and thus control over, data collected of their countries. Canada became the first country to build a ground station which set the precedent for others to follow.

¹⁹⁵ Catherine Rayner, “A History of Satellite-Based Remote Sensing in Australia, 1971-1989,” (M.Phil thesis, Australian National University, 2002), pgs. 38-39

¹⁹⁶ Attachment to Memo, United States Mission to the United Nations to the Secretary-General of the UN, 7 February 1973, Political and Security Matters 1955-1983, PO 312(4) Part 2 1973-1978, Central Registry 1954-1983, S-0442-0377-01, UN Archives, New York, NY, pg. 3

Building a Ground Station

In order to operate a satellite and acquire data from its instruments, NASA needed ground-based facilities to communicate with objects in orbit. These installations, commonly referred to as ground stations, had numerous on site antennae to uplink and downlink with Landsat satellites. Only one station can uplink to the satellites, the Goddard Spaceflight Center (GSFC) in Greenbelt, Maryland. The satellites also transmit data to ground stations through downlinks. After GSFC, EROS, and their International Cooperators (ICs)¹⁹⁷ received raw Landsat data, these sites used processing equipment, such as large IBM or Sperry Univac computer systems, to convert the data into imagery. These ground stations stored and archived the satellite data on large mainframes with huge memory space for the time. From the 1970s through the 1980s, Landsat imagery came in two forms: a film-based map or in digital form on a Computer Compatible Tape (CCT). A film-based image was either a paper map or a transparency whereas a CCT was a large disk with embedded imagery. Prior to Landsat's launch, NASA designated Goddard Space Flight Center (GSFC) in Maryland, the Jet Propulsion Laboratory-Goldstone NASA facility in California, and the Poker Flat Research Ranger near Fairbanks, Alaska as Landsat ground stations to receive data. GSFC had two special responsibilities, commanding the Landsat satellites and disseminating data. GSFC became (and remains) the only station capable of controlling Landsats in orbit which includes maintaining stability by commanding the satellites to fire its hydrazine-powered boosters to change its pitch, yaw, roll, or altitude. Also, GSFC served as a data dissemination facility for all gathered data; Goldstone and Fairbanks gathered data, loaded it onto tape recorders, and sent it to Maryland for

¹⁹⁷ International Cooperator was the term used by USGS for a foreign entity operating a ground receiving station. ICs were always government agencies, such as the Canadian Centre for Remote Sensing or contractors, such as Telespazio on behalf of the Italian Space Agency and ESA. ESA became the only supra-national governmental organization to operate Landsat ground stations.

dissemination. In 1973, USGS established a receiving and dissemination ground station near Sioux Falls, South Dakota named EROS which coordinated with NASA.¹⁹⁸ In order to gather more data and more readily disseminate Landsat imagery around the world, NASA, and later with USGS, negotiated for ground stations around the world. Ground stations are not unique to Landsat; NASA maintained agreements around the world to sustain several satellite initiatives.

The notion of the ground station, or more broadly research stations in general, served many scientific disciplines. The purpose of such facilities was to gather scientific data about distinct geographic locations. USDA and Rockefeller Foundation established remote agricultural research stations throughout the U.S. and Mexico to observe crop growth¹⁹⁹ The National Science Foundation and United States Navy built and sustained stations in Antarctica to gather biological, geological, and meteorological data for polar research.²⁰⁰ Andrew Butrica et. al. argued that ground stations form a ‘global village’ through the government and commercial establishment of a communications satellite constellation.²⁰¹ This literature suggests that ground stations played a central role not only in gathering scientific data but also disseminating it. I situate Landsat within this literature arguing that they established an American presence abroad that facilitated and fostered Landsat data usage.

Shortly after the Landsat-1’s launch, NASA began coordinating with other countries to establish data receiving ground stations abroad. Three broad technologies comprised a ground station: receiving antenna(e), an archiving computer which stored data, and a data processing

¹⁹⁸ For more on EROS’s history, see Rebecca Johnson, *What It Took: A History of the USGS EROS Data Center*, (Augustana Center for Western History, 1999). EROS maintains a collection of all Landsat data, aerial photography, Corona reconnaissance imagery, among other forms of cartography.

¹⁹⁹ Nick Cullather, *The Hungry World: America’s Cold War Battle Against Poverty in Asia*, (Harvard University Press, 2010)

²⁰⁰ Roger Launius, “Historical Analogs For the Stimulation of Space Commerce,” *Monographs in Aerospace History*, no. 54, (NASA SP-2014-4554). See also: Dian Belanger, *Deep Freeze: The United States, the International Geophysical Year, and the Origins of Antarctica’s Age of Science*, (University Press of Colorado, 2006)

²⁰¹ Andrew Butrica, ed., *Beyond the Ionosphere: Fifty Years of Satellite Communication*, (NASA SP-4217, 1997)

unit. With these three components, an International Cooperator (IC) could receive data in the form of X-band downlinks from the Landsat satellites. The data archiving computers stored the received data and processing units made the data useful. For example, when data downlinked, it was initially subject to atmospheric disruptions and data was often skewed since the scanning device swept back and forth. The processing units received data in the form of long strips of Earth imagery and converted them to 185 x 185 kilometer images. The storage computers pieced strips of imagery together to form an image, a method termed geometric correction. Several images placed together formed a county or state as desired by the user, a process called mosaicking. These three broad technologies were required to receive and effectively use Landsat data.

The U.S. government, including NASA, did not provide any of this equipment to potential ICs. Rather, ICs approached NASA with a proposal for a Landsat ground station and ICs had to acquire antennae, processors, and archiving computers on their own generally through domestic hardware suppliers or through American companies such as GE, IBM, or Sperry. None of these items fell under International Traffic in Arms Regulations (ITAR) in the 1970s, a point explored later in this chapter. The Canadians, through the newly formed Canadian Centre for Remote Sensing, developed their own equipment to their own specifications and had superior turnaround time to the GSFC systems.²⁰² I will discuss the Canadian efforts in greater detail below. Other stations such as Iran ordered their equipment from America through Sperry. In addition to technical requirements, NASA also abided by a specific set of guidelines established by its Deputy Director of International Affairs, Arnold Frutkin. Once the IC had the requisite equipment in place and recognized NASA's terms of cooperation, the IC negotiated a

²⁰² Pamela Mack, *Viewing the Earth: The Social Construction of the Landsat Satellite System*, (MIT Press, 1990), pg. 191

Memorandum of Understanding with NASA and after 1973 with EROS. ICs worked completely independent of NASA, though remained in dialogue with the agency and USGS through international annual symposia mentioned below. I detail this process below using several different cases.

Ground Control: Building Ground Stations Abroad

Negotiations for ground stations began between an international cooperating agency, such as a foreign space agency or public-private firm, and NASA's Office of International Affairs (NASA/OIA). Frutkin helped formulate guidelines for international space programs during his NASA tenure.²⁰³ Accordingly, his policies played an important role in establishing Landsat stations abroad. John Krige summarized Frutkin's policies into five basic guidelines which each applied to Landsat ground station negotiations.²⁰⁴ In order for an IC to receive a station, they applied to NASA through a government agency or a contracted private entity. Domestically, each individual country selected a government agency, a public-private firm, or contractor which would correspond directly with NASA. Each of these agencies negotiated with NASA, who consulted the Departments of State, Commerce, and Defense, for their respective ground stations. In addition, the potential IC must agree to conduct projects of scientific value,

²⁰³ Rebecca Wright interview with Arnold W. Frutkin, *NASA Johnson Space Center Oral History Project*, (Houston: Johnson Space Center, 2002, Interview in Washington, D.C.). Frutkin elaborated on his policies in a 1965 publication, *International Cooperation in Space* (Prentice Hall) which became guiding principles for the NASA Office for International Programs and its collaborative projects. Krige, Callahan, and Maharaj further discuss these policies in *NASA in the World: Fifty Years of International Collaboration in Space* (Palgrave Macmillan, 2013).

²⁰⁴ John Krige, Angel Callahan, and Ashok Maharaj, *NASA in the World: Fifty Years of International Collaboration in Space*, (Palgrave Macmillan, 2013), pg. 11

acknowledge mutual interest, accept financial responsibility, and provide for the “widest and most practicable dissemination of results.”²⁰⁵ These details are discussed in greater detail below.

In mid-1971 a year before ERTS-1’s launch, Canada became the first country to approach NASA about receiving Landsat data directly. Canada became interested in space technology, in particular communications and land remote sensing capabilities, given the vastness of the Canadian landmass.²⁰⁶ In particular, “geographically large countries such as Canada have a need for regional topographic maps...which may serve either as preliminary maps of regions not yet mapped by conventional methods, or as complimentary information to existing maps.”²⁰⁷ Dr. Lawrence Morley, a University of Toronto trained geophysicist, played a key role in developing Canada’s Landsat receiving capabilities. After receiving his Ph.D, he joined the Geological Survey of Canada and eventually became the Director of its Geophysics Branch. Through his influence at the Geological Survey of Canada, he convinced Natural Resources Canada administrators “to support a proposal to found a Canadian Centre for Remote Sensing (CCRS) that would receive data directly from Landsat and distribute it within Canada.”²⁰⁸ Upon the founding of CCRS in 1970, Morley became its first Director and built it into a premier data receiving and processing facility. The Ottawa-based Canadian Centre for Remote Sensing (CCRS), then under Natural Resources Canada, eventually established a station on site and two more ground stations later on in Prince Albert, Saskatchewan and Gatineau, Quebec.

CCRS developed processing technology differently from those found at GSFC. By 1971, the Canadians completed development, spending less on machines that could process data faster

²⁰⁵ John Krige, Angel Callahan, and Ashok Maharaj, *NASA in the World: Fifty Years of International Collaboration in Space*, (Palgrave Macmillan, 2013), pg. 11. This language Krige draws from Frutkin appears nearly verbatim in several Memoranda of Understanding I found between NASA and Landsat ICs.

²⁰⁶ Jocelyn Mallett, “Canada’s space programme,” *Space Policy*, Vol. 6, Issue 1, pp. 53-59

²⁰⁷ Attachment to Memo, Permanent Mission of Canada to the United Nations to Secretary-General of the UN, 6 November 1973, Political and Security Matters 1955-1983, PO 312(4) Part 2 1973-1978, Central Registry 1954-1983, S-0442-0377-01, UN Archives, New York, NY, pg. 4

²⁰⁸ Pamela Mack, *Viewing the Earth: The Social Construction of the Landsat System*, (MIT Press, 1990), pg. 191

than NASA. The Americans and Canadians both experienced technical problems with technology in the pre-launch testing phase using aerial surveys, “Canada had distributed 50,000 copies of Landsat images, a respectable figure next to NASA’s 218,000,” by the end of January 1973.²⁰⁹ The Canadians established a station at Prince Albert, Saskatchewan which had a vast coverage area from the Arctic Archipelago south to Mexico and Alaska to central Québec. Canada followed its own precedent by establishing a second station at Shoe Cove, Newfoundland on the island of Labrador which began processing data in 1977. This station provided nearly full coverage of Canada as the Shoe Cove station²¹⁰ covered the whole of Atlantic Canada. Only parts of the Queen Elizabeth Islands and northern Baffin Island were not covered. Thus, CCRS provided nearly national coverage within 5 years of Landsat 1’s launch. Canada became the first country to establish a foreign ground station and began to use data from the Landsat program routinely. Following Canada’s Prince Albert station and CCRS’s impressive data output, considerable interest from international users convinced NASA to increase Landsat’s footprint globally.

The Canadians set the precedent for international cooperation regarding Landsat ground stations between NASA (later USGS) and foreign space agencies. Several states followed Canada furnishing ground stations as well. Shortly after CCRS opened its doors, Brazil’s national space agency, Instituto Nacional de Pesquisas Espaciais (INPE), also requested a ground station based in Cuiaba. Also, two stations emerged in Europe as a result of American ties. NASA relations with the European Space Research Organization (ESRO) and the European Launch Development Organization (ELDO) began to move towards greater cooperation in space,

²⁰⁹ Pamela Mack, *Viewing the Earth: The Social Construction of the Landsat System*, (Cambridge: MIT Press, 1990) pg 192

²¹⁰ The Shoe Cove station has since relocated to Gatineau, QB, yet provides essentially the same coverage area. The Gatineau station operated until 2011 when it no longer received data from Landsat 5.

yet simultaneously their reliance on NASA launch functions in the late 1960s undermined their independence from NASA.²¹¹ Both ESRO and ELDO experienced crises from lacking technical knowledge and financial instability. These crises combined with the desire for autonomy led to the reorganization of the European space programs into one European Space Agency (ESA). Much of Western Europe joined ESA (or had already been members of ESRO) with each making certain commitments and taking on responsibilities to Europe including “the provision of general facilities: platforms, satellites, launchers, and operations in orbit,”²¹² yet also was actively involved with international cooperation. Cooperation “evolved from an essentially exclusive relation with NASA,”²¹³ which eventually broadened. Much of this exclusivity in relations came in the 1970s as NASA extended Landsat’s global reach. Fucino, Italy became the site of the first European Landsat station contracted in 1974, and then received data in 1975. Unlike the Canadians who built an in-house agency directly under the federal government, the Europeans used a different model. The Italians contracted Telespazio, a public-private telecommunications firm who operated the stations on behalf of ESA and the Italian government. In a similar contractual model, ESA added a second ground station through the Swedish Space Corporation’s Esrange Space Center near Kiruna in 1978. The Swedish and Italian stations covered a significant portion of the European landmass as well as a significant portion of the Arctic polar region. These relationships hinged on the negotiation of a mutually-beneficial Memorandum of Understanding.

²¹¹ John Krige, Angel Callahan, and Ashok Maharaj, *NASA in the World: Fifty Years of International Collaboration in Space*, (Palgrave Macmillan, 2013). For more on the history of the European space program more broadly see John Krige, *Fifty Years of European Cooperation in Space*, (Paris: Beauchesne, 2014) and Krige, Russo, and Sebesta, *A History of the European Space Agency, Vol. II: The History of ESA from 1973 to 1987*, (Noodwijk, ESA SP1235, 2000)

²¹² Roger M. Bonnet and Vittorio Manno, *International Cooperation in Space: The Example of the European Space Agency*, (Cambridge, MA: Harvard University Press, 1994), pg. 73

²¹³ Roger M. Bonnet and Vittorio Manno, *International Cooperation in Space: The Example of the European Space Agency*, (Cambridge, MA: Harvard University Press, 1994), pg. 73

Memoranda of Understanding and Misunderstanding

As mentioned, an IC MOU was signed between either NASA or EROS, often with State Department consultation, and a government affiliated institution abroad. In December 1978, NASA signed a MOU with the Australian Department of Science for a ground station located at Alice Springs in the Northern Territory of Australia. The four and a half page MOU addressed the responsibilities assumed by both parties as well as joint priorities.²¹⁴ The agreement stated that the United States and Australia would have access to each other's data sets, designated technical representatives to coordinate functions, attend annual meetings of the Landsat Ground Station Operations Working Group, and stated that the MOU was void if Australia did not have a functioning facility within 15 months or if either side fell short of necessary funding. ICs had to acknowledge Landsat's experimental nature and that it was subject to technical and programmatic modifications. Australia's obligations included building and maintaining a receiving station in Alice Springs and an imagery dissemination center in Canberra. The agreement obliged Australia to conform to NASA's non-discriminatory data access policy at reasonable data prices, ensure users their investigations are within range of the Alice Springs station, send NASA catalogs of data listings, and make data available to NASA free of charge. NASA's roles included insuring Australia received data from Landsats 1, 2, and 3 as well as Landsat 4 planned for launch in 1982 as well as other technical requirements for downlinks. NASA held the responsibility for ensuring Australia received timely and useful data. For example, NASA saw to it that Australia's antennae were properly calibrated and that its data was comparable in quality to American data. After the signing of the agreement, Australia began

²¹⁴ "Memorandum of Understanding (MOU) for Australian Establishment of Landsat Ground Station," 14 December 1978, Folder 6093, NASA Historical Reference Collection, Washington, D.C.

construction on the station which was completed and began receiving Landsat downlinks in September 1979. The station remains in operation today. At this point, Landsat ground stations received data in Sweden, Italy, Brazil, Canada, Japan, and Australia. At that time, NASA was also engaged in discussions with South Africa, Iran, Zaire, and China to build new stations.

As these stations materialized, several key similarities applied to all the above ground stations. NASA also discouraged potential ICs from proposing stations close to each other such that they had substantial overlap in coverage to avoid duplication of efforts. Also, an international cooperator could distribute data openly, as was the policy in the U.S., and charge comparable prices. There was no obligation to repatriate data to the U.S., however many stations did so on an irregular basis.²¹⁵ Furthermore, NASA did not generally staff the stations, it simply ‘flipped the switch’ once the Memorandum of Understanding (MoU) became valid which meant the satellite began a downlink to the foreign ground station for data reception when it was in range. A station would only receive data within its antenna’s range. Furthermore, an international cooperator only received data specified in the MoU. For example, some ground stations only received MSS data from Landsats 1, 2, and 3. A new agreement was required if Italy or Canada wished to receive TM data from Landsat 4. Since NASA (or other agencies) did not have a permanent presence at any international ground stations, the international cooperator provided their own staff. For example, CCRS staffed its station with Canadian civil servants and Telespazio staffed the Fucino station with Telespazio employees. Eventually, ESA requested a second station based in Kiruna, Sweden, Geoscience Australia established a station in Alice Springs and the South African National Space Agency built a station in Hartebeesthoek. In each

²¹⁵ In recent years since the Open data policy in December 2008, the USGS has begun data repatriation efforts in earnest. This effort, entitled the Landsat Global Archive Consolidation (LGAC), is explored further in Chapter 4. LGAC involves international cooperators sending worldwide data to EROS for archiving. USGS estimates that roughly 70-80% of data has been repatriated and many international cooperators have cooperated amiably with the USGS repatriation request.

case, stations cost \$4-7 million to establish and build, \$1-2 million per year to operate, and NASA levied an annual fee to ICs of \$200,000 to receive data in July 1976.²¹⁶ However, ICs could distribute data directly without U.S. government intervention. NASA, USGS, and their Landsat ICs set up an annual meeting series to discuss these particulars. On 13 June 1975, JSC hosted the first Landsat Ground Station Operations Working Group meeting (LGSOWG).

The meeting dovetailed with NASA's Earth Resources Survey Symposium, also held in Houston to display various projects Landsat data had been used in. Leonard Jaffe, Deputy Associate Administrator for Space Applications, chaired LGSOWG on behalf of NASA. LGSOWG's purpose was to provide a "forum for the exchange of information on remote sensing problems and opportunities among nations operating LANDSAT data acquisition and processing facilities" as well as give ground station operators from each of the nations represented an opportunity to present a report summarizing their experiences in acquiring, processing, and disseminating LANDSAT data."²¹⁷ The key concern of the first meeting and of their cooperation was to respond to user community concerns. The meetings rotated around different ICs and also held meetings at either Johnson Space Center or at EROS in South Dakota. The first meeting set the precedent that NASA and USGS would share the ongoing activities of NASA and EROS operations of Landsat and proposed changes. Afterwards, each of the ICs presented their activities, shared user concerns, and discussed data availability and quality. For example, the Canadians discussed the progress of the Prince Albert station construction and discussed the heavy use of Landsat data by the Canadian Forest Research Agency. Zaire and Iran also attended the first LGSOWG as they hoped to build a Landsat ground station. Both countries announced plans for stations in Kinshasa and Tehran respectively but faced shortages of technical expertise

²¹⁶ Press Kit, "Landsat C," 22 February 1978, pg. 6, courtesy James David, Curator, NASM

²¹⁷ "Minutes of the Landsat Ground Station Operations Working Group Meeting," Johnson Space Center, Houston, TX, 13 June 1975, documents courtesy of James Zimmerman, formerly of NASA

and funding. Zaire's representative. Dr. Sendwe Ilung of the Office of the President expressed his hopes that a remote sensing training center and data reception would benefit all African nations.

In 1976, Italy and Canada hosted the next two LGSOWG meetings in March and October respectively. At the Telespazio Headquarters in Rome, Jaffe again convened Canada, Brazil, Iran, Zaire, Italy, and new potential IC, Chile. The University of Chile began soliciting for proposals to build a ground station outside Santiago from suppliers to procure processing and receiving equipment. Frutkin and Jaffe updated the group on Landsat 1 and 2 as well as NASA's progress towards launching Landsat 3 as well as making its data available. By the end of 1976, several countries approached NASA about ground stations. As mentioned, NASA sought to reduce the overlap of coverage of nearby ground stations. For example, Norway, Argentina, Brazil, and France each approached NASA about stations. At the third LGSOWG meeting in Ottawa in October 1976, Frutkin and his deputy James Zimmerman, Senior Applications Programs Officer of NASA HQ, encouraged ESA to coordinate remote sensing data sharing efforts among Sweden and Italy (with stations in place) with France and Norway (who sought to receive data). As a result, CNES and Telespazio agreed to a data sharing memorandum. In South America, Chile and Argentina built stations that would reduce overlap with Brazil's station in Cuiaba, which began to receive data in May 1973. Just prior to the Ottawa LGSOWG, Zimmerman met with 18 African governments to coordinate ground station planning. The plan, further discussed at the Ottawa LGSOWG, proposed ground stations in Kinshasa, Zaire and Ouagadougou, Upper Volta as well as training centers in Kinshasa, Ouagadougou, Nairobi, Cairo, and Ile-Ife.²¹⁸ The ambitious plan also proposed a remote sensing council to govern and

²¹⁸ "Minutes of the Landsat Ground Station Operations Working Group Meeting," Canadian Centre for Remote Sensing, Ottawa, Ontario, 27-29 October 1976, documents courtesy of James Zimmerman, formerly of NASA

coordinate the network. While the U.S. kept ICs apprised of developments with new Landsats and technical information, the Ottawa LGSOWG began the discussions necessary to create continental remote sensing programs which continued at the next several LGSOWG meetings.

Over the next several years, ESA and Telespazio built a European capacity for remote sensing data dissemination. ESA planned the Earthnet program with Landsat data as a crucial component. Earthnet became a data service that made Earth Observation data available to European scientific investigators. Between October 1976 and November 1978, Telespazio and the Swedish Space Corporation coordinated Europe's remote sensing data gathering and dissemination efforts on behalf of ESA. During this time period the Kiruna and Fucino stations received data from all three Landsats in orbit and Telespazio distributed Landsat images in both paper and CCT form from its headquarters in Rome. The coordinated effort of SSC, Telespazio, and ESA resulted in "European-wide operations and the subsequent demand for data by ESA member countries" grew as a result.²¹⁹ Elsewhere, data availability became more difficult to achieve.

Two countries experienced major setbacks with regards to their Landsat ground station proposals: Chile and Zaire. In Santiago, the University of Chile completed a feasibility study meant to satisfy the government. The university proposed a ground station that would collect and disseminate Landsat data as well as information from NOAA meteorological satellites. Throughout 1977, the university failed to convince the Chilean government "of the importance of proceeding with funding for a Landsat station" yet continued to experiment "with the use of

²¹⁹ "Minutes of the Seventh Landsat Ground Station Operations Working Group Meeting," Canadian Centre for Remote Sensing, Ottawa, Ontario, 8-10 November 1978, documents courtesy of James Zimmerman, formerly of NASA

Landsat for relay of data collection information.”²²⁰ The university continued these experiments, as well as others on crop inventorying and urban land use patterns without significant government funding in the following years. However, Chile never established a Landsat ground station. Zaire experienced similar struggles despite broader, more ambitious plans that had the support of the UN.

As mentioned, Kinshasa led the way with bringing remote sensing capabilities to the African continent. The Zairian government proceeded with a data reception facility and training center located near Kinshasa. The government prepared technical plans but failed to procure funds to see the construction through. From 1977 into 1978, West Germany supported a feasibility study for Zaire and eventually financially support ground station construction.²²¹ In addition, the UN Economic Commission for Africa (ECA) provided managerial support to help build the African remote sensing network mentioned above which could include ground stations and training centers. However, economic and political turmoil engulfed the young state complexifying the export of a Landsat ground station. Zaire gained its independence from Belgium in 1960. The First Republic of the Congo quickly fell into political turmoil and remained so until Mobutu Sese Seko rose to power in the 1960s, when the republic was renamed Zaire. The United States heavily courted the Mobutu regime as part of its anti-communist agenda for Africa since the Kennedy administration. The US provided development funds to the Mobutu government while Mobutu suppressed communism. Zaire became one of “Washington’s favored Third World allies,” as American banks enabled it to mortgage their “futures in order to secure

²²⁰ “Minutes of the Fifth Landsat Ground Station Operations Working Group Meeting,” Sioux Falls, SD, 27-29 October, documents courtesy of James Zimmerman, formerly of NASA

²²¹ “Minutes of the Sixth Landsat Ground Station Operations Working Group Meeting, Stockholm, Sweden, 9-11 May 1978, documents courtesy of James Zimmerman, formerly of NASA

the short-term survival,” of Zaire’s Mobutu regime.²²² Stable relations between the American and Zairian governments set the stage to negotiate a ground station.

NASA’s agreement with Zaire made it the first state in Africa proposing a station. Zaire formed a government body of prospective users called ERTS-Zaire through which NASA negotiated. The station’s proposed coverage area extended north-south from Chad to South Africa and east-west from Côte d’Ivoire to Kenya. The station proposed to “produce both computer tapes and photographic imagery using data transmitted by the satellite.”²²³ The Zaire station hoped to gain knowledge of natural resource deposits and conduct agricultural research while providing a vast coverage of Africa. Yet these goals fell short of accomplishment. The contracting organization ERTS-Zaire signed the agreement in 1975 yet from the outset, witnessed acute funding problems. Landsat’s operating costs and data reception fees put the ground station out of reach for the African nation whose gross domestic product was far lower than other states proposing stations. In 1978, ground stations cost roughly \$1.7 million in construction and \$750,000 in yearly operation, which included a \$250,000 annual fee paid to NASA for Landsat downlinks.²²⁴ Against these figures and realities, Zaire’s economy could not support a ground station, which never materialized.

NASA and its ICs in Canada, Europe, and South America experienced little difficulty establishing stations while potential partners in Africa fell short of funding. The United States abandoned diplomatic relations with Iran, resulting in suspension of the negotiations for a station in Tehran after the storming of the American Embassy. By 1980, both Canada and ESA operated two stations and Australia, Brazil, and Japan operated a station each. India and South Africa

²²² Odd Arne Westad, *The Global Cold War*, (Cambridge University Press, 2007), pg 157

²²³ *NASA News*, “Zaire to Build Landsat’s First African Ground Station,” 27 February 1975, Untitled Folder 6084, NASA History Program Office, NASA Headquarters, Washington, DC

²²⁴ Pamela Mack, *Viewing the Earth: The Social Construction of the Landsat System*, (Cambridge: MIT Press, 1990) pg 192

moved towards operations while Chile eventually dropped its plans for a ground station. NASA's biggest challenge remained ahead as a new potential IC came to the table, the People's Republic of China which had not been present at the first eight LGSOWG meetings.

Landsat *Mis-Use*: Ground Station Export and National Security

NASA and USGS rode a wave of success in the late 1970s with three successful Landsat satellites in orbit returning data to ICs around the world. Each of the ICs who built stations enjoyed a privileged status under U.S. trade laws. In 1976, the U.S. government developed a constellation of unilateral trade restrictions on advanced technology. The Arms Export Control Act of 1976 and International Trade and Arms Regulation (ITAR) primarily emphasized items related to rocketry, especially ballistic missiles and satellites as well as remote sensing technology, though to a lesser extent. Under ITAR, the State Department issues a 'proscribed countries list' which restricts exports to particular countries such as China. These restrictions, discussed in greater detail below, complicated China's proposal to receive Landsat downlinks to a ground station it sought to build outside Beijing. However, strained diplomatic relations and U.S. intelligence community concerns over Beijing's intentions further complicated ground station negotiations despite Sino-American efforts towards normalized relations.

In 1969, President Nixon and National Security Adviser Henry Kissinger revised American foreign policy to "reestablish international stability and American strength" due to the declining prestige of the United States and the global discontent of the 1960s.²²⁵ Nixon and Kissinger sought to strengthen American influence globally through *détente* which centered on eased tensions with the Soviet Union treating it "as an ordinary state with reasonable national

²²⁵ Jeremi Suri, "Henry Kissinger and American Grand Strategy," in Fredrik Logevall and Andrew Preston, eds., *Nixon in the World: American Foreign Relations, 1969-1977*, (Oxford University Press, 2008), pg. 80. See also: Jeremi Suri, *Power and Protest: Global Revolution and the Rise of Détente*, (Harvard University Press, 2003).

goals and interests,” promoted improved economic relations through trade and investment in the Eastern bloc, and placed greater value in state sovereignty for establishing greater international stability.²²⁶ A major corollary of the Nixon and Kissinger détente ideal was opening relations with the People’s Republic of China. Nixon paid visits to Beijing and Moscow, organized summit meetings, and ultimately oversaw the signing of arms limitation treaties which defined a period of détente between East and West. In what became known as the Shanghai Communique, the U.S. government and China “made clear that normalization of relations was their common goal” in 1972.²²⁷ President Gerald Ford continued Nixon’s normalization efforts, as did President Jimmy Carter who announced on 15 December 1978 his endorsement of the Shanghai Communique. President Carter and the new, far less radical Chinese regime under Deng Xiaoping “moved rapidly to establish full diplomatic relations between their two countries” as relations began to normalize having formally begun diplomatic relations following the Joint Communique, issued by both governments in December 1978.²²⁸ This meant sustained trade, amiable diplomatic relations and visits, and increased cultural exchange, among other diplomatic ties. The Beijing government under Deng Xiaoping sought to “develop its industrial and technical base, maintain an adequate standard of living for a population of over 950 million, and simultaneously build a credible military deterrent force.”²²⁹ The goals of the Chinese leadership

²²⁶ Robert D. Schulzinger, “Détente in the Nixon-Ford years, 1969-1976,” in *The Cambridge History of the Cold War, Volume II Crisis and Détente*, eds. Melvyn Leffler and Odd Arne Westad, (Cambridge University Press, 2010) pp. 373-375

²²⁷ Memorandum, Douglas J. Bennet, Assistant Secretary of State to Congress, “Diplomatic Relations with the People’s Republic of China and Future Relations with Taiwan,” December 1978, Folder 3 “China Briefings [To Business Leaders] 1/3/78-1/18/78,” Box 170, Office of the Chief of Staff Stephen Selig, Jimmy Carter Presidential Library, Atlanta, GA

²²⁸ Margaret MacMillan, “Nixon, Kissinger, and the Opening of China,” in Fredrik Logevall and Andrew Preston, eds., *Nixon in the World: American Foreign Relations, 1969-1977* (Oxford University Press, 2008), pg. 122

²²⁹ Presidential Review Memorandum/NSC 24, “People’s Republic of China,” 5 April 1977, Jimmy Carter Presidential Library, RAC Project Number NLC-17-30-9-3-6

presented the U.S. government with several difficulties regarding the potential Landsat ground station export as negotiations began in the late 1970s.

The Chinese ground station export case demonstrated the difficulties of building an international cooperator network and, moreover, of expanding Landsat use worldwide. The United States enacted legislation which prevented technology transfer to the communist world and established the Coordinating Committee for Multilateral Export Controls (COCOM) to ensure that its Western allies did likewise. Cold War tensions, in particular strained diplomatic relations, the arms race, and the ‘space race’ led Congress to pass legislation restricting trade of sensitive technologies to the communist world. The Export Control Act of 1949 and the Arms Export Control Act of 1976 (AECA) levied restrictions against defense-related exports, effectively embargoing communist Asia and Cuba. The Department of State also regulated trade through International Traffic in Arms Regulations (ITAR) which specified items that cannot be traded on its United States Munitions List. More problematically, under ITAR and AECA, “all space-related items and technology are on the U.S. Munitions List” and therefore “denies the exportation of Munitions List items to all Communist controlled countries.”²³⁰ Yet despite these increased measures against military trading, the United States traded openly with China since restraints had been rolled back under the Export Administration Act of 1969 which relaxed regulations on non-military exports, previously conceived of under the Export Control Act of 1949. COCOM, too, adopted eased regulations on non-military trading. Furthermore, the Secretary of State could sign waivers on particular technologies specified for export, since ITAR was enforced through State’s Directorate of Defense Trade Controls. Essentially this legislation and regulation restricted military exports to the communist world but opened most trade with

²³⁰ Review, “Review: US-USSR Agreement for Cooperation in Space,” 19 September, 1977, Jimmy Carter Presidential Library, RAC Project Number NLC-17-30-6-5-9

China and, potentially, a Landsat ground station could be restricted or waived. China's diplomatic tensions with the Soviet Union raised concerns in the U.S. intelligence community that a ground station might become a liability rather than an internationally cooperative project.

Remote Control: Chinese Data Purchases and National Security

The U.S. government became deeply concerned over Landsat technology transfer for two particular diplomatic reasons, the Sino-Soviet split and the border skirmishes that resulted and, more broadly, supplying a nuclear China with targeting coordinates. The diplomatic relationship between Moscow and Beijing deteriorated in the 1960s and the 2,738-mile-long border between the communist states increasingly militarized. In March 1969, Chinese People's Liberation Army troops attacked a Soviet border station on Zhenbao Island later matched by a Soviet retaliation resulting in an exchange of artillery for several days. The Chinese perception that the Soviet Union controlled Chinese territory in addition to more potential border conflict prompted Beijing to expand its collection of cartographic resources along with its other military capabilities. Accordingly, NASA and CIA became concerned that the dual-use nature of Landsat technology might serve to benefit the communist military.

In February 1971, the CIA Directorate of Science and Technology released a classified issue of *Scientific Intelligence Digest* that demonstrated how the "Chinese have been conducting a partially successful, accelerated collection program for foreign maps and related geodetic information" with particular regional emphasis on the Soviet Union as well as the United States and its Pacific territories since 1969.²³¹ At this time, the Chinese did not have a space-based reconnaissance program capable of gathering accurate geodetic or cartographic information

²³¹ Author's name redacted, "Communist Chinese Attempts to Obtain Maps and Related Information," *Scientific Intelligence Digest*, February 1971, CIA Directorate of Science and Technology, Report courtesy of James David, Curator, Smithsonian National Air and Space Museum

though it did have nuclear capabilities and delivery systems. Many of the maps collected contained topographic, hydrographic, coastal, and gravitational information. While the report does not identify a specific reason for the increased Chinese collection of maps, it speculated that the Chinese sought to improve its ICBM targeting capability with better maps and an understanding of the gravitational field. In particular, this geodetic information assisted with predicting missile trajectories to improve targeting. The Chinese government acquired its collection through its embassies in Sweden, Austria, and West Germany by requesting cartographic catalogs available from the USGS, a Vienna-based map company, the US Coast and Geodetic Survey, as well as the London Geographic Society, Japan Geological Society and Geological Survey Institute, and the Australian Geological Survey. The Chinese representatives used intermediaries, such as map dealers and trading companies in Europe and Asia to acquire these sources. CIA report also speculated that the Chinese would try to acquire USAF Aeronautical Chart and Information Center navigation charts and concluded with a list of each major map acquisition since 1969. With the Landsat launch scheduled for the following year, its data became a potential new avenue for foreign acquisition of maps of the U.S. and other strategic locations which became a national security concern of CIA and NASA.

In August 1973, the CIA produced a brief, classified study, "Probable Chinese Collection of U.S. Satellite Imagery" which evaluated the ways in which Chinese agents acquire U.S. scientific data and how it may be translated into strategic information. Prior to this CIA report, the EROS, where Landsat data was processed, stored, and distributed, was contacted by an Asian-based contact in six letters sent between September 1972 and July 1973. The correspondence noted that " a [redacted] on behalf of an unidentified client, has ordered broad coverage that includes China and neighboring countries to a distance of about 1,000 miles from

the Chinese border.”²³² Specifically, the letters also requested data samples, images across Landsat-1’s four spectral bands of the Sino-Soviet border region, and very low cloud cover image specifications. The CIA’s Directorate of Intelligence investigated and hypothesized that it was a Chinese client based upon a “review of previous activities of the [redacted] who originated the ERTS order.”²³³ The CIA study cited cases back to the 1950s that a redacted actor gathered “US civil defense plans...and a series of US patents for the PRC” in addition to “topographic, gravity, aeromagnetic, and hydrographic, maps and charts,” with offers of \$5,000 for topographic maps of the Sino-Soviet border region, and returned them to an Eastern bloc agent.²³⁴ Chinese agents also requested US-based scientific publications. EROS eventually received a July 1973 letter urgently requesting about 800 images and a check payment totaling \$9,463. The CIA and EROS recognized that, despite potentially data-limiting variables such as cloud cover, poor ground control point identification (using terrestrial features as a reference point for identifying other locations on a map), poor resolution, and lacking orbital track information, the aforementioned 800 images “would be particularly valuable for identification and positioning of specific targets in the USSR, where the PRC has probably had limited success in acquiring adequate maps.”²³⁵ NASA and USGS, under their open access policy, were compelled to fulfill the order despite CIA’s concerns. However, Landsat data could be transferred as print-out images or as magnetic tapes, which could easily be digitally enhanced if the buyer had the appropriate technology and technical expertise. Sioux Falls opted not to supply

²³² Central Intelligence Agency report, “Probable Chinese Collection of U.S. Satellite Imagery,” August 1973, The George Washington University National Security Archive, Washington, D.C.,

<http://www2.gwu.edu/~nsarchiv/NSAEBB/NSAEBB404/docs/01.pdf>, date accessed: 1 October 2014

²³³ CIA report, “Probable Chinese Collection of U.S. Satellite Imagery,” August 1973, GWU-NSA,

<http://www2.gwu.edu/~nsarchiv/NSAEBB/NSAEBB404/docs/01.pdf>, date accessed: 1 October 2014

²³⁴ CIA report, “Probable Chinese Collection of U.S. Satellite Imagery,” August 1973, GWU-NSA,

<http://www2.gwu.edu/~nsarchiv/NSAEBB/NSAEBB404/docs/01.pdf>, date accessed: 1 October 2014

²³⁵ CIA report, “Probable Chinese Collection of U.S. Satellite Imagery,” August 1973, GWU-NSA,

<http://www2.gwu.edu/~nsarchiv/NSAEBB/NSAEBB404/docs/01.pdf>, date accessed: 1 October 2014

image-enhancement techniques but still fulfilled the 800 image order with images alone in late 1973.

The CIA undertook a more robust study of Landsat data's strategic intelligence potential for foreign users in 1975. CIA expressed concern that foreign users could derive strategic intelligence from Landsat data using Soviet ICBM sites as a case study.²³⁶ The CIA Office of Geographic and Cartographic Research assisted by the Office of Research and Development and the National Photographic Interpretation Center prepared the report. They argued that the

“study reveals little evidence that foreign countries are exploiting the military and strategic potential of purchased ERTS data; but the Peoples Republic of China, which has shown interest in ERTS data and has made a considerable effort to obtain geodetic information and maps covering the Soviet Union and other areas, appears to be a possible user of ERTS data for such applications.”²³⁷

CIA analyzed EROS's top quality Landsat data available in 1975 which were 30m resolution Multispectral Scanner data produced in the form of Computer Compatible Tapes (CCTs) which EROS made available to all potential users. As mentioned, CIA knew China began gathering a substantial amount of Landsat data covering the Soviet Union. China needed Landsat data because it “already possess[ed] long-range missiles with nuclear warheads but does not yet have access to reconnaissance satellite photography for missile targeting and other military purposes.”²³⁸ In particular, Landsat data at 30 meter resolution distinguished several land cover features, such as cities, roads, and transport hubs making it potentially useful for military intelligence which deeply concerned the CIA.

²³⁶ CIA report, “Strategic Intelligence from ERTS? An Analysis of Digital Data on Soviet ICBM Sites,” June 1975, GWU-NSA, <http://nsarchive.gwu.edu/NSAEBB/NSAEBB404/docs/02.PDF>, date accessed: 1 October 2014

²³⁷ CIA report, “Strategic Intelligence from ERTS? An Analysis of Digital Data on Soviet ICBM Sites,” June 1975, GWU-NSA, <http://nsarchive.gwu.edu/NSAEBB/NSAEBB404/docs/02.PDF>, date accessed: 1 October 2014

²³⁸ CIA report, “Strategic Intelligence from ERTS? An Analysis of Digital Data on Soviet ICBM Sites,” June 1975, GWU-NSA, <http://nsarchive.gwu.edu/NSAEBB/NSAEBB404/docs/02.PDF>, date accessed: 1 October 2014, pg. 2

In July 1978, EROS received a huge order of Landsat data from an unidentified buyer from Hong Kong. In a memo from National Security Council Staff member Samuel Hoskinson to National Security Adviser Zbigniew Brzezinski, Hoskinson raised concern over the data request.²³⁹ The order, financed by Hong Kong Bank, requested nearly 2,800 images of the Soviet Union at a cost of \$105,000. Hoskinson stated the order was far larger than generally received and that Chinese agents had been requesting meteorological data for many years to that point. For the National Security Council, “the circumstances of acquisition have led US officials to believe that agent is acting on behalf of China.”²⁴⁰ The USGS officials, who remained anonymous in the press, did not publicly release details of the buyer, but stated “it appears that the Chinese, who lack a reconnaissance satellite system of their own, are trying to gain information of potential military value about their bitter communist rival, Russia.”²⁴¹ Yet the case of the mysterious Chinese data sale added fuel to the fiery debate between USGS and the intelligence community over the military significance of Landsat data.

At this juncture, NASA had launched Landsat 3 in March 1978 with a similar platform to the previous two satellites. According to USGS, Landsat’s 30-meter resolution could not provide accurate enough imagery for locating particular strategic targets. Most targets, such as tactical aircraft, tanks, or ballistic missiles did not reflect a strong enough signature in Landsat imagery to be useful. However, terrain mapping and urban infrastructure was well captured by the satellite instruments. On the opposite side of the debate was the intelligence community in particular, CIA. As noted in the previous case, Landsat imagery “would be suitable for

²³⁹ Memorandum, Samuel Hoskinson to Zbigniew Brzezinski, 18 July 1978, Jimmy Carter Presidential Library, RAC Project Number NLC-10-13-5-9-2

²⁴⁰ Memorandum, Samuel Hoskinson to Zbigniew Brzezinski, 18 July 1978, Jimmy Carter Presidential Library, RAC Project Number NLC-10-13-5-9-2, pg. 4

²⁴¹ “China Seeks Soviet Peek With U.S. Satellite Data,” Associated Press, 20 July 1978, Folder 6112, NASA Historical Reference Collection, Washington, D.C.

determining areas and complexes and placing this data into the Chinese geodetic network, which is necessary for accurate ICBM targeting.”²⁴² As a result, Landsat imagery in Chinese hands remained a concern for CIA and moreover, exporting ground receiving and processing equipment remained out of the question in 1978. Yet in 1979, the U.S. changed its approach to diplomatic relations with China opening up the possibility for a Beijing ground station.

On 24 December 1979, Leonid Brezhnev sent the Soviet 40th Army rolling into Afghanistan. Within a few months, the Soviets occupied several major cities such as Kandahar and the Afghan capital of Kabul and appropriated all of its government ministries. The UN passed a resolution 104-18 condemning the Soviet maneuver and, for the United States, effectively the move ended détente.²⁴³ The invasion also stirred Beijing’s national security concerns further given the aforementioned Soviet border skirmishes and now the occupation of China’s western neighbor. The U.S. feared that the export of a Landsat ground station to Beijing would become a liability either for Chinese military strikes against the US itself or if it struck somewhere else (notably the Soviets) since it used American technology. The Soviet invasion of Afghanistan increased Chinese national security concerns and prompted talks between Washington and Beijing. Thus, American fears for misuse of Landsat data increased. In the few months ending 1979 into early 1980, discussions between NASA and DOC identified specific technological concerns over Landsat equipment.

NASA Deputy Anthony Calio identified eight essential characteristics that required export licensing. In a November 1979 memo, OEA identified three of those eight components required “detailed considerations, cause some licensing delay, and perhaps require equipment

²⁴² Memorandum, Samuel Hoskinson to Zbigniew Brzezinski, 18 July 1978, Jimmy Carter Presidential Library, RAC Project Number NLC-10-13-5-9-2, pg. 4

²⁴³ “U.N. General Assembly Votes to Protest Soviet Invasion of Afghanistan,” *Toledo Blade*, 15 January 1980, pg. 1

design modifications,” especially since their performance levels remained in question.²⁴⁴OEA specified that data recorders, data processors, and image enhancement equipment required further review. China planned for its station to receive and process Landsat 4 data which demanded higher processing capability given the Thematic Mapper’s greater spectral coverage. By comparison, the AMPEX 3010 processor used for MSS data processing had a 15 megabyte per second capability. To process TM data, 85 megabytes per second was required. The U.S. government and CoCom discussed data processing and image enhancement parameters which should be commercially available. When the Soviet Union requested comparable equipment for Landsat data earlier in 1979, OEA denied their request yet China received positive news towards their bid for a Landsat ground station a few months later. By January 1980, the DoD cleared the station for export which Defense Secretary Harold Brown announced during his China visit.

From 8 to 15 January 1980, Brown visited Vice Premier Deng Xiaoping. The two officials discussed the strengthening of Sino-American relations. Brown stated “the United States and China should coordinate their policies in the face of the threat from the Soviet Union.”²⁴⁵ The U.S. government no longer felt the need to deal evenhandedly with the Soviets and Chinese, which allowed Brown to more easily justify exporting Landsat technology to China. Though the DoD and CIA maintained that Landsat data processing equipment and data tapes could be used for strategic intelligence, Deng assured Brown and his delegation that China had no intention to utilize Landsat data for military purposes. Deng told Brown “China and the United States should do something in a down-to-earth way so as to defend world peace against Soviet

²⁴⁴ Memorandum, John Boidock to Al Solga, “Response to NASA letter of 21 November 1979 On Landsat-D Ground Station for PRC,” Folder “Export Policy: LANDSAT-D, 9/79-1/80, Collection 12 National Security Affairs Brzezinski Material, Box 24, General Odom File, Jimmy Carter Presidential Library, Atlanta, GA

²⁴⁵ Jay Mathews, “China to Receive Satellite Station,” *Washington Post*, 9 January 1980, NASA Historical Reference Collection, Folder 6083 “Landsat Satellite General I, 1975-1989,” NASA HQ, Washington, D.C.

hegemonism.”²⁴⁶ Furthermore, Deng maintained that China planned to use Landsat data for its stated purposes, environmental applications. A Chinese Academy of Sciences spokesman stated Landsat data will

“help analyze China’s geological structure, locate mineral resources and provide data to the Departments of Water Conservancy, Agriculture, Forestry and Environment for utilization of land, estimation of crop yields, irrigation control, control and prevention of plant diseases and insect pests, environmental monitoring and protection, alterations in river courses and shorelines, and predict natural calamities.”²⁴⁷

In October 1981, DOC approved the export licenses for equipment necessary to build the ground station and in December, the Chinese government awarded a contract to Maryland based Systems and Applied Sciences Corporation yet the export licenses were not issued until 1985.²⁴⁸

By 1982, the Chinese had yet to purchase its Landsat ground station. NASA scheduled the launch of Landsat 4 for July 1982 which featured both a MSS and a new, experimental scanner called the Thematic Mapper offering improved spectral coverage. Shortly after reaching orbit however, two of the satellite’s solar panels and its two downlink transmitters malfunctioned and it could not transmit data until the Tracking and Data Relay Satellite System (TDRSS) became operational.²⁴⁹ The first satellite in the TDRSS, abbreviated TDRS-1, became operational in April 1983 and was a satellite with several large antennae used to retransmit and relay information between the Shuttle primarily, satellites, and ground stations. Amidst Landsat 4’s technical problems, NASA readied Landsat 5, which also featured a Thematic Mapper, for launch by March 1984. Landsat 5 carried both a downlink transmitter to send data to ground

²⁴⁶ Fox Butterfield, “U.S. Plans to Sell a Satellite Ground Station to China,” *New York Times*, 8 January 1980, NASA Historical Reference Collection, Folder 6083 “Landsat Satellite General I, 1975-1989,” NASA HQ, Washington, D.C.

²⁴⁷ “PRC to Import Landsat Ground Station from U.S.,” *Xinhua*, 18 January 1983, NASA Historical Reference Collection, Folder 6083 “Landsat Satellite General I, 1975-1989,” NASA HQ, Washington, D.C.

²⁴⁸ Email message, Terry Arvidson to James Irons, Stephen Garber, James David, Steve Covington, and Steve Labahn, 22 June 2011, “Contact Info for ‘China Hands,’” courtesy James David, Curator, NASM

²⁴⁹ “Landsat 4,” www.landsat.gsfc.nasa.gov/?p=3178, date accessed: 17 November 2015

stations and an extra transmitter to use the TDRSS. NASA and USGS officials speculated that the Chinese government was reluctant to move forward with its proposed ground station given that Landsat 4 experienced the aforementioned issues and sought to gain assurance Landsat 5 would be successfully operational.²⁵⁰ In 1985, the State Department approved the export licensing for the Landsat ground station equipment. The U.S. Systems and Applied Sciences Corporation based in Maryland served as contractor and began to build the station near Beijing. In April 1986, 8 years after discussions first began, the station began to receive data from Landsats 4 and 5.

China's Landsat data receiving capability consisted of an antenna site in a small town outside Beijing called Miyun and a processing facility in Beijing. The entire facility cost \$11 million, built by ST Systems Corporation of Lanham, Maryland (same company mentioned above but it adopted a new name). NASA and USGS's IC that governed the receiving station was the Chinese Academy of Sciences, an arm of the Chinese government, which also developed plans for a station in KaShi, Urumqi, though it did not receive data until 2008. According to executive vice president of ST Systems Corporation Ashok Kaveeshwar, "the Landsat ground station hardware was the first large U.S. aerospace export to China allowed by the State Department following the normalization of relations."²⁵¹ When Landsat became a commercial entity (discussed in the following chapter), China also signed an agreement with Earth Observation Satellite Company (EOSAT) to market data internationally. EOSAT, Dai Zixin, the China ground station deputy director and image processing chief, and sales manager Li Chuan Rong led the effort to develop a user base of local and state ministries, urban planners, and national

²⁵⁰ Email message, Terry Arvidson to James Irons, Steven Labahn, Stephen Garber, and James David, "Goddard Landsat Project," 21 June 2011, courtesy of James David, Curator, NASM

²⁵¹ Craig Covault, "China Evaluates Benefits, Intelligence Value of Landsat," *Aviation Week & Space Technology*, 5 October 1987, Folder 6083, NASA Historical Reference Collection, Washington, D.C.

government users. Li stated “many people are amazed at the imagery from a cosmetic point of view, but to explain the usefulness of the pictures to a customer we must know something about their business.”²⁵² The Chinese government and local ministries in Yunan, Heilongjiang, and the Yellow River basin began numerous investigations into mineral and petroleum geology, pollution monitoring, agriculture, and flooding. EOSAT’s contract with China to sell data internationally began in June 1987 and expected revenue of \$1-3 million.

In addition to growing a user community, the Chinese Landsat station had to cultivate technical expertise. As mentioned, the marketing staff at EOSAT and the Beijing processing facility had to learn what the capabilities of the imagery was to reach out to users as mentioned above. The Landsat processing facility, staffed entirely by an indigenous workforce, was comprised of a Floating Point System AP180 array processor, two Digital Equipment Corporation VAX 11/780 computers a VAX 750 film-generation subsystem, and supporting hardware and software. The staff of 22 Chinese technicians, including station deputy Dai, all trained in the United States “in different Landsat training programs at various locations across the country.”²⁵³ They learned how to properly use the equipment as well as maintenance strategies. In particular, Beijing’s dry climate initially caused the processing equipment to produce faulty imagery due to static electricity present in the laboratory. The array processor’s rollers produced images with blotches resembling lightning. The Chinese staff learned to correct that problem and maintain as dustless of a laboratory environment as possible. Kaveeshvar also visited the site continually for quality assurance for the Chinese Academy of Sciences. The Beijing and KaShi stations continue to operate successfully.

²⁵² Craig Covault, “China Evaluates Benefits, Intelligence Value of Landsat,” *Aviation Week & Space Technology*, 5 October 1987, Folder 6083, NASA Historical Reference Collection, Washington, D.C.

²⁵³ Craig Covault, “China Evaluates Benefits, Intelligence Value of Landsat,” *Aviation Week & Space Technology*, 5 October 1987, Folder 6083, NASA Historical Reference Collection, Washington, D.C.

NASA, USGS, and its government agency partners experienced both success and failure in the creation of an international ground station network. In several cases, funding issues hampered development of several stations while poor diplomatic relations dashed hopes for a station in Iran. The China ground station presented several cases which complicated the ground station development process. Export control, strained diplomatic relations, and funding shortfalls all made the expansion of a Landsat IC network increasingly complicated. Yet despite these difficulties, NASA and USGS broadened Landsat data usage on the world stage in the late 1970s across five continents. Simultaneously, NASA sought to bring Landsat data to countries in the developing world through its government agency partners and contractors.

Expanding Use through Application: Training Seminars and International Workshops

As mentioned above, the response to Landsat through the UN was generally positive as numerous countries sought to build indigenous ground stations to receive Landsat downlinks and either undertook or sought to undertake scientific investigations with Landsat data. UN Members from Jamaica to the Philippines began projects using the imagery to survey natural resources, produce hydrological maps, and oil prospect, among other applications. Several countries established ground stations but for those without the immediate interest or financial means, open access to data allowed other states to utilize the growing archive of Earth remote sensing imagery. In addition to the UN facilitating use of remote sensing data, NASA coordinated bilaterally with interested users in the developing world to provide imagery and, in particular cases, funding and expertise to assist with scientific investigations. Nearly a year after Landsat's launch, NASA formed partnerships which it could foster greater Landsat data use abroad in countries where a Landsat ground station was not feasible. NASA forged a partnership with the

USAID, the U.S. government agency established in 1961 under President John Kennedy tasked with administering civilian foreign aid and assistance often to developing countries. NASA also relied on several contractors to facilitate the use of Landsat data abroad. In Part 2, I concentrate on the third component of my argument that NASA, through its partnerships with federal agencies and contractors, expanded Landsat data use in the 1970s. This third expansion fostered data availability and use largely in the developing world where space remained largely inaccessible. Furthermore, I suggest that land remote sensing provided an entrée into the space community at low cost to interested countries in the developing world.

President Gerald Ford sought to strengthen relations with Africa. In 1976, Secretary of State Henry Kissinger traveled to Lusaka, Zambia to deliver a speech about America's commitment to African development. In particular, Kissinger's speech committed the U.S. government to an "expanded role for remote sensing in Africa."²⁵⁴ NASA, USAID, and their contractors accomplished this vision throughout the 1970s through the establishment of training seminars, grant packages, and technical assistance. Below, I highlight two cases: a major remote sensing training seminar held in Bamako, Mali and a grant package and technical assistance project that supported a major hydrological study based on Landsat imagery in Lesotho.

Making Maps in Mali

NASA, among other US federal agencies, also facilitated the flow of remote sensing expertise to the developing world through both domestic and international seminars, workshops, and symposia. Domestically, NASA, in conjunction with the USGS, held the annual, month-long training course, the International Remote Sensing Workshop and Seminar at the EROS Data

²⁵⁴ Merrill Conitz to A.A. Jackson, 3 May 1976, Project 931-11-995-902 Remote Sensing Applications, WW-Lesotho FY 75-, Remote Sensing for Resources Assessment Box 4, General Records of US Agency for International Development, Record Group 286, NARA II, College Park, MD

Center in Sioux Falls, South Dakota. This seminar instructed representatives and scientists representing roughly 20 states each year “how to use and interpret satellite photographs taken by the two Landsat Earth resources spacecraft.”²⁵⁵ Within five years of Landsat 1’s launch, “a total of 185 representatives from 57 nations attended the seven previous international remote sensing workshops,”²⁵⁶ with at least one country from every continent. The USGS Office of International Geology and USAID’s Technical Assistance Office coordinated with its contractor ERIM to provide domestic, bilateral, and regional training programs to teach promising individuals in Africa how to apply Landsat data to environmental issues in the developing world. USAID and USGS held numerous workshops in the United States and abroad to facilitate remote sensing expertise. However, in order to reach other developing states, USAID provided funding for workshops to be held abroad, such as the Sahelian Zone Remote Sensing Seminar and Workshop.

Within a year of Landsat 1’s launch, the Malian government hosted the USGS and USAID to address “ERTS Experiment Data Acquisition and Processing, the EROS Program, and Applications of ERTS Data in Cartography, Geology, Geography, Hydrology, Agriculture, and Forestry.”²⁵⁷ Specifically, USAID’s Office of Science and Technology provided the funding while USGS’s Office of International Geology presented the conference at the École Normale Supérieure in Bamako. In April 1973, USGS officials Maurice Grolier, Raymond Fary, and Stephen Gawarecki flew from Washington to Bamako, Mali to conduct a training seminar hosted by the Government of Mali. Nine countries and nine commissions represented by a total of 35

²⁵⁵ *Defense/Space Daily*, 1 May 1975, pp. 5, Untitled Folder 5757, NASA History Program Office, NASA Headquarters, Washington, DC

²⁵⁶ *Defense/Space Daily*, 4 May 1977, pp. 23, Untitled Folder 5757, NASA History Program Office, NASA Headquarters, Washington, DC

²⁵⁷ Maurice J. Grolier et. al.. “The Sahelian Zone Remote Sensing Seminar/Workshop,” Washington: NTIS, USAID, March 1974 (1974 PB-236 657), see also <https://pubs.er.usgs.gov/publication/ofr74196>, date accessed: 23 August 2016

scientists and project managers gathered in Bamako to explore land remote sensing applications and learn techniques.

The seminar “provided instruction in principles and techniques of remote sensing; most emphasis was on the application of Earth Resources Technology Satellite (ERTS) data to the evaluation and development of resources in the African Sahel environment.”²⁵⁸ Mali initiated the seminar through its proposal to participate in NASA’s ERTS program. U.S. Ambassador to Mali Robert O. Blake as well as Mali’s Department of Mines and Geology head Cyr Samake requested an initial visit be performed by NASA and USGS officials two years prior to the seminar. Through the embassy in Bamako, John Fry of USAID, Dr. Norman Macleod of NASA’s Goddard Space Flight Center, and John Dorr of the USGS met with Malian government officials. The US representatives discussed “ERTS-1 Experiment, the satellite, expected characteristics of the data to be obtained, uses to which the data might be put, and nature of resources problems in Mali that might be amenable to use of ERTS data.”²⁵⁹ The Malian government cordially approved the US proposal designating Mamadou Konaté of the Department of Mines and Geology in Mali as principal investigator. The US arranged for Mr. Konaté to then visit the corresponding US government agencies while receiving briefings on the multidisciplinary applications of ERTS data. Mr. Konaté’s month long visit in 1972 led to the decision to host a conference in Mali for West Africa the following year.

The US then staffed its team while many participants from across West Africa accepted invitations to the seminar. Dr. Maurice Grolier became project director having both worked

²⁵⁸ Maurice J. Grolier et. al.. “The Sahelian Zone Remote Sensing Seminar/Workshop,” Washington: NTIS, USAID, March 1974 (1974 PB-236 657), see also <https://pubs.er.usgs.gov/publication/ofr74196>, date accessed: 23 August 2016, pg. 1

²⁵⁹ Maurice J. Grolier et. al.. “The Sahelian Zone Remote Sensing Seminar/Workshop,” Washington: NTIS, USAID, March 1974 (1974 PB-236 657), see also <https://pubs.er.usgs.gov/publication/ofr74196>, date accessed: 23 August 2016, pg. 3

extensively with remote sensing as he had worked in ERTS development, his familiarity with geology and hydrology, and his fluency in French. Jack Palgen of Terratek Incorporated, a geomechanics and analysis service company, also joined the seminar leadership for his familiarity with ERTS technology, land use remote sensing, and fluency in French. The contingent presenting the seminar had backgrounds broadly in the earth sciences and cartography. Thirty-one participants attended at least part of the seminar representing a range of backgrounds, from ecology to business administration but heavily favoring the earth sciences²⁶⁰. The educational backgrounds of participants favored science and engineering universities in the US, Europe, the USSR, China, Egypt, and Mali. The attendees “however, with the exception of the Malian and American instructors, only the participant from France had significant exposure to remote-sensing techniques prior to the seminar.”²⁶¹ Three Malian scientists served as instructors alongside the Americans, Mr. Dembélé taught hydrological applications while Mr. Konaté and Mr. Zuboye conducted geology and forestry applications, respectively. The American and Malian scientists addressed two key aspects in their lessons: the technology and the environmental applications.

The scientists provided lectures concerning the basics of remote sensing, the sensor characteristics, and the data acquisition process. The attendees then utilized imagery data to interpret ERTS color prints and transparencies. As mentioned, the spectral bands allowed Landsat to distinguish among aspects of the Earth’s surface. A field trip to Forêt Classes de la Faya near Bamako led by the three Malian scientists served as an example to compare ERTS data to subjects in the field. This provided the basis for the “attendees to recognize the

²⁶⁰ Earth sciences is broadly defined but for the backgrounds of those in Mali, I refer to agricultural sciences, forestry, hydrology, ecology, geology geophysics, and geography.

²⁶¹ USAID. “The Sahelian Zone Remote Sensing Seminar/Workshop,” Maurice J. Grolier et. al., Washington: NTIS, March 1974 (1974 PB-236 657) pg. 6

relationships between tonal variations on the ERTS imagery and actual environmental conditions on the ground,” such as “contrasts among the appearance of the forest, savannah, and degraded savannah, and the influence of leaf litter in the forest on the tones of the forest area.”²⁶² The Sahelian Zone report included a survey of the participants following the seminar addressing critiques. Workshop feedback from participants indicated that the most successful sessions included the agriculture and forestry applications while the problems of land-use classification and drought control should have been further addressed.²⁶³ This seminar effectively addressed “the needs and desires of the officials and scientists of the Sahel countries for training that would be valuable... to the independent application of ERTS data by any of the West African countries.”²⁶⁴ This seminar highlighted the utility of Landsat data in not only addressing environmental issues but also in the developing world.

USAID Grant Program, 1973-1976

In 1974, USAID sponsored ten grants to explore Landsat’s role in foreign assistance. Bolivia, Chile, Pakistan, Peru, and Zaire received the initial round of grants. The success of seven of the ten initial grants inspired program growth to a “three-year 50 million dollar program with activities in 32 developing countries” during which participants undertook “crop inventories and estimates, ground water location, geological mapping and resource inventories.”²⁶⁵ The proposals were evaluated by the AID Grant Program which had representatives from

²⁶² USAID. “The Sahelian Zone Remote Sensing Seminar/Workshop,” Maurice J. Grolier et. al., Washington: NTIS, March 1974 (1974 PB-236 657) pg. 9

²⁶³ USAID. “The Sahelian Zone Remote Sensing Seminar/Workshop,” Maurice J. Grolier et. al., Washington: NTIS, March 1974 (1974 PB-236 657) pg. 9-11

²⁶⁴ USAID. “The Sahelian Zone Remote Sensing Seminar/Workshop,” Maurice J. Grolier et. al., Washington: NTIS, March 1974 (1974 PB-236 657) pg. 7

²⁶⁵ Report, “Civil Land Remote Sensing System,” Subcommittee on Space Science and Applications to Committee on Science and Technology, 97th Congress, First Session, December 1981, Untitled Folder 6097, NASA Historical Reference Collection, NASA HQ, Washington, DC, pg. 13

government, academia, and industry.²⁶⁶ Specifically, USAID's Office of Science and Technology and Africa Bureau, NASA's Office of International Affairs, and EROS represented government while NASA contractors Environmental Research Institute of Michigan (ERIM) and Systems Planning Corporation (SPC) also had members on the AID Grant Program. University of Michigan's Center for Research on Economic Development (UMCRED) also sent a member.

Among all the members, Donald Lowe, Deputy Director of the Infrared and Optics Division at ERIM, played a significant role selecting proposals for the USAID Grant Program and coordinating with principal investigators abroad. Lowe held a Master's degree in Physics from Duke University, was an active member with the Optical Society of America and the American Society of Photogrammetry, and had worked for the Naval Ordnance Laboratory. He then moved to the private sector researching and developing airborne spectroradiometric instruments and remote sensing systems. Many of the members on the USAID Grant Program had similar technical backgrounds.

USAID and its contractors (AID/cm/ta-73-38), ERIM, and SPC, assessed "the economic value of ERTS Data Utilization by Developing Countries" which led the Office of Science and Technology after twelve months of study to initiate a grant program "designed to provide funds and technical assistance to selected countries who desired to develop or expand their capability in ERTS data utilization."²⁶⁷ First, USAID commissioned its contractors to assess the cost and benefit of data use in development. From August 1973 to August 1974, ERIM, SPC, and Mathematica Incorporated qualitatively evaluated four case studies of ERTS data use by Bolivia,

²⁶⁶ Donald Lowe and Fred Thomason represented ERIM; Dr. Robert Summers, William L. Smith, and Bruce W. MacDonald represented SPC; Merrill Conitz represented OST/AID; JD Blumgart represented the USAID Africa Bureau; Charles Robinove represented EROS; James Zimmerman represented NASA OIA; Robert Pogson represented University of Michigan's CRED.

²⁶⁷ "ERIM Proposal," 25 July 1975, [File Unit?], [Series?], [Subgroup?], Record Group 286: Records of the Agency for International Development, 1948-2003, National Archives at College Park, MD

Thailand, Botswana, and Kenya through interviews with UN officials, USAID missions, and ERTS Principal Investigators.²⁶⁸ Each country presented an opportunity to study different applications of ERTS data, such as hydrological, geological and cartographic uses of Landsat data.

ERIM and USAID hoped to develop state-by-state plans which would maximize public welfare through “political and economic feasibility of change via new technology, investment, and social and economic reorganization.”²⁶⁹ In 1974, NASA, USAID, SPC, and ERIM partnered to create a grant program to both foster Landsat data use internationally and to assist developing states. The AID Grant Proposal Panel²⁷⁰, comprised of members of the aforementioned outfits as well as the USGS and UMCRED, met on 22 and 23 January 1975 to evaluate fifteen applications from developing states. Dr. Robert Summers of SPC hosted the evaluation team in Arlington, Virginia which had developed a scoring process to that favored several key criteria. The criteria included technical validity, probability of accomplishment, impact of derived information, national need for economic development based upon USAID’s priority, and evidence of national interest.²⁷¹ The committee also strived for geographic diversity among its awardees. From this pool of applicants, six were selected to receive approximately \$20,000 in funding, some technical expertise, and Landsat data to undertake original scientific investigations that would ultimately demonstrate an innovative application of Landsat. One of the six awardees was Lesotho.

²⁶⁸ D.S. Lowe, R.A. Summers, and E.J. Greenblat, “An Economic Evaluation of the Utility of ERTS Data for Developing Countries,” Vol 1. Final Report, August 1974, with thanks to Hollie Wheeler, University of Michigan Libraries

²⁶⁹ D.S. Lowe, R.A. Summers, and E.J. Greenblat, “An Economic Evaluation of the Utility of ERTS Data for Developing Countries,” Vol 1. Final Report, August 1974, with thanks to Hollie Wheeler, University of Michigan Libraries, pg. 9

²⁷⁰ Members of the Proposal Panel included: Dr. Merrill Conitz, Physical Scientist, Office of Science and Technology; Mr. Donald S. Lowe, Deputy Director, Infrared & Optics Division, ERIM; Robert Summers, VP and Executive Director, Space Systems and Applications, System Planning Corporation;

²⁷¹ CITATION FROM IMG 100_2006

Mapping Lesotho

In November 1974, Dr. J.V. Hepworth of the Lesotho Geological Survey and Mines Department sent a cable to Donald Lowe, then Deputy Director of the Infrared & Optics Division at ERIM expressing interest in submitting a proposal for a USAID grant. As mentioned, the AID Grant Program convened in January 1975 to evaluate proposal from several countries seeking financial assistance to conduct an investigation using Landsat data, after having allowed a period in which potential applicants expressed interests and inquired about the grants. The AID Grant Proposal Panel selected six of the fifteen grant proposals, one of which was awarded to the delegation from Lesotho. A. A. 'Tony' Jackson of the Department of Biology at the University of Botswana, Lesotho, and Swaziland (UBLS) in Maseru submitted an application as principal investigator to study "snowfall patterns in Lesotho in order to obtain previously inaccessible water run-off data of importance to the agricultural development of the country."²⁷² The project emphasized "soil, drainage, and vegetation mapping for conservation purposes" noting that "soil erosion is a major critical problem in Lesotho."²⁷³ Snowmelt, rising rivers, and lose top soil disrupt Lesotho's agriculture and often cause unanticipated flooding in many parts of the country, which the investigation sought to understand better. To address these drainage concerns, the faculty at UBLS produced data analyses that led to a map representing drainage patterns to resolve the central issue of soil erosion across most of the country.

In April 1975, SPC sent Robert Summers, another member of the AID Grant Program, to Maseru to meet with the Lesotho Landsat principal investigator Tony Jackson and his team

²⁷² Donald S. Lowe to A.A. Jackson, 29 January 1975, "Competitive Grants Program to Foster Broader Utilization of ERTS Data for Development Purposes," [File Unit?], [Series?], [Subgroup?], Record Group 286: Records of the Agency for International Development, 1948-2003, National Archives at College Park, MD

²⁷³ Robert Summers to Donald Lowe, 18 April 1975, [File Unit?], [Series?], [Subgroup?], Record Group 286: Records of the Agency for International Development, 1948-2003, National Archives at College Park, MD

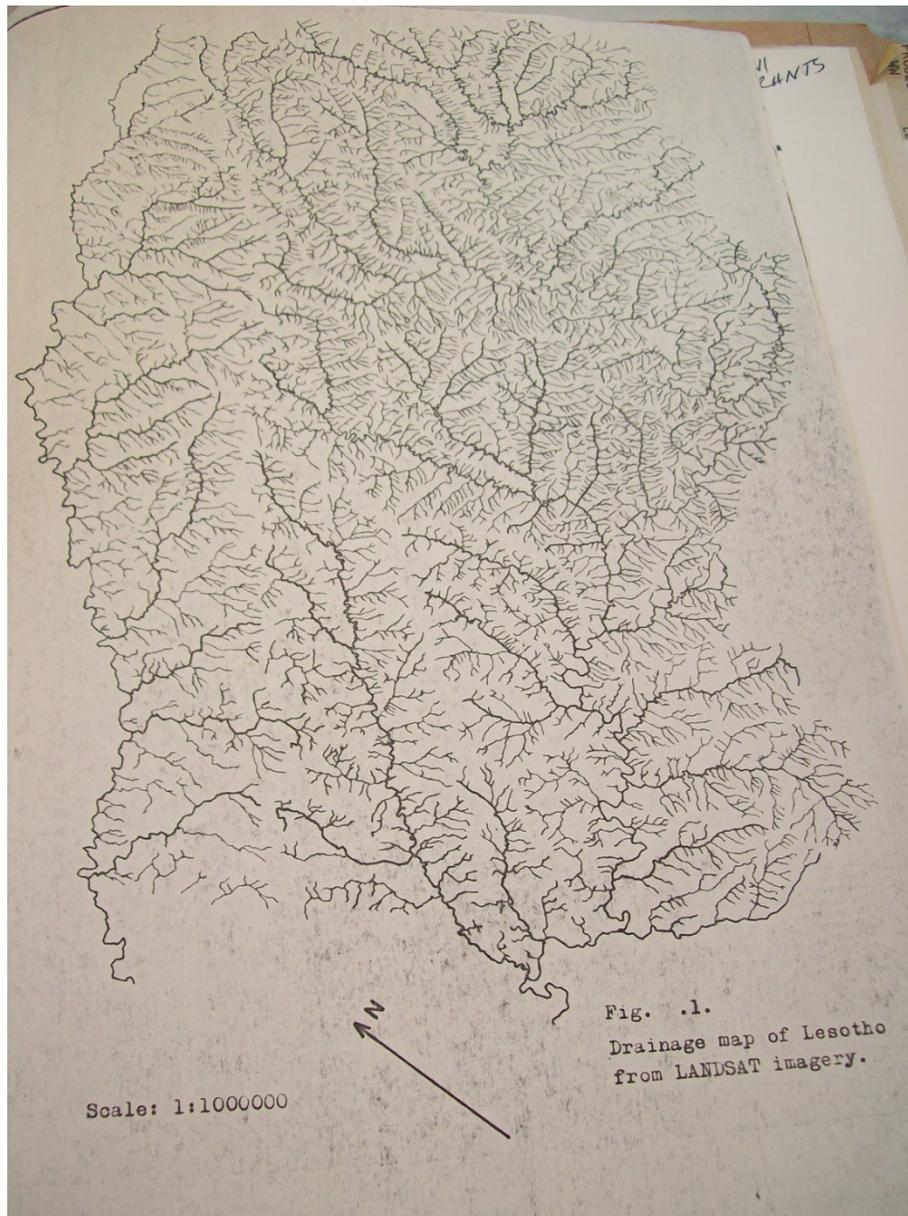
members as well as Government of Lesotho officials as the project was getting started. The team discussed procuring new equipment after having sent one of the Lesotho Landsat team members to EROS for data processing training. A major component of the investigation is snowmelt drainage and the need for more “trees and terracing to limit soil erosion.”²⁷⁴ Furthermore, heavy snow falls and subsequent melts stress the agricultural extension service since livestock need to be moved from major drainage areas.

The Lesotho project team used Landsat data of the entirety of the country in CCT form in addition to aerial photography. The project scientists also conducted ground truthing field trips to ascertain the veracity of their cartographic imagery. UBLS had Hewlett-Packard processing equipment on campus that experienced difficulties at times and processed map scales incorrectly, which also led to problems with digitization. The project team mitigated the issues by reprocessing data at the same scales and fixing apparent hardware problems. For Jackson, discerning topographical relief was critical to producing a useful drainage map of Lesotho. The team revealed that eastern Lesotho has a higher drainage density than western Lesotho and thus has a “higher catchment area in the relatively flat lowlands than a stream of the same order in the mountains.”²⁷⁵ The asymmetric drainage basins demonstrated how rivers and streams are captured by the landscape informing the project’s goal of understanding water-run off. The Lesotho project team concluded its study in early 1976 having successfully created a nationwide drainage map using Landsat data.

²⁷⁴ Memorandum, “Trip Report to Visit by W.L. Smith and R.A. Summers to Lesotho, April 1-5, 1975,” Folder: Contract Reports AID-ta-c-1148 Environmental Research Inst. Of Mich Project 931-11-995-902 FY75-, Box 4, RG 286: Records of the Agency for International Development, Bureau for Science and Technology/Office of Forestry, NARA II, College Park, MD, pg. 2

²⁷⁵ Untitled Draft, pg. 4, Project 931-11-995-902 Remote Sensing Applications, WW-Lesotho FY 75-, Remote Sensing for Resources Assessment Box 4, General Records of US Agency for International Development, Record Group 286, NARA II, College Park, MD

Figure 2: Lesotho Drainage Map



Landsat imagery of Lesotho river drainage basins, 1976. NARA, College Park, MD

The project in Lesotho, among numerous other initiatives in East and West Africa caught the attention of the State Department and USAID. In essence, the AID Grant Program and the use of Landsat imagery qualified the United States for a stronger role in the developing world through remote sensing.

Conclusion

The Landsat program underwent significant transformation in the 1970s as its data quickly became available to users around the world via efforts by NASA and its government and contractor partners. Both the UN and bilateral cooperation facilitated the expansion of Landsat data availability and use through the establishment of a legal regime, a growing network of ground stations, as well as training seminars and funding for states with fewer means to access space technologies. Despite the goal of NASA to distribute data widely, it and its partners experienced a number of difficulties that problematized data availability as well. Initially, Landsat appeared to a few UN Member States, particularly Australia and Sweden, as a technology that could plausibly be used to compromise national sovereignties. In particular, Landsat data potential enabled certain users to conduct natural resource prospecting and economic espionage. This possibility conflicted with domestic law in Australia and Sweden expressed similar concerns. However, the overwhelming interest in Landsat at the UN indicated that its data held high scientific value. As a result, several countries approached NASA about establishing ground stations to receive data directly and many more, many in the developing world in Africa, sought to use Landsat imagery for development. Canada, followed by Brazil and ESA, became the first to receive data outside the U.S. and set precedents for foreign use. The move by NASA and USGS to negotiate and see the establishment of foreign ground stations was a significant expansion of Landsat data use. However, there were limits as demonstrated by the case of the Chinese station. The politics and national security concerns of the U.S. federal government fueled by the Cold War complicated the export of a ground station to Beijing. ITAR regulations, Munitions List items, and potential use of Landsat imagery for military operations

against the Soviets all prompted the defense and intelligence community to block the Chinese from acquiring a Landsat data ground receiving station. Diplomatic tensions with Iran, economic hardship in Zaire, and uncertain political commitment elsewhere all compromised the establishment of stations. Thus, while Landsat data use expanded abroad via ground stations, it was by no means internationally ubiquitous.

NASA and USGS expanded Landsat data use through training seminars and international aid as well, especially in Africa. In 1973, the USGS sent officials to Mali to conduct a training seminar to assist West Africans with the technical uses and applications of Landsat imagery. West Africa, geographically characterized by the Sahel, was an area prone to desertification and low agricultural yields. The training seminar instructed participants how to use Landsat imagery for land-use classification, which they applied to issues of drought and forestry. Training seminars and grant packages helped facilitate the use of Landsat data abroad but they also had their limits. The users in Mali and Lesotho both did not always possess the requisite technologies required for Landsat data processing. Expertise in remote sensing also had to be developed in much of Africa. Both equipment and expertise required investments and foreign aid to enable these investigations, which also were difficult to sustain once foreign aid packages ended, such as the AID Grant Program. Pamela Mack recounts that the “U.S. Embassy in Mali reported that the ‘U.S. government has gained a million dollars worth of Malian political mileage’ from Landsat.”²⁷⁶ Despite its limits, both Lesotho and Mali saw Landsat data use as a success.

Landsat’s user community, produced through state agencies at NASA, USGS, and USAID in particular, was about to see the program change drastically. The low-cost nature of the data sharing, a major incentive for the user community, began to create problems for the

²⁷⁶ Pamela Mack, *Viewing the Earth: The Social Construction of the Landsat Satellite System*, (MIT Press, 1990), pg. 189

longevity and stability of Landsat. Shortfalls in funding threatened the program, especially while President Carter looked to cut government costs. Also, the American monopoly of remote sensing, through Landsat began to dissolve as other states launched satellites of their own. Funding issues and international competition began to transition Landsat in late 1979 into commercialization.

In the next chapter, I demonstrate how the scientific value of Landsat data transforms into commercial value. At this juncture in 1978 into 1979, Landsat as a program began transitioning from an experimental project into a commercial program managed by the DOC and operated by the private sector. This transition profoundly changed the availability and use of Landsat data and imagery into the 1980s.

Chapter 4: Landsat For Sale: Commercializing Civil Remote Sensing Operations, 1978-1989

Introduction: Commercializing Space

In the previous chapters I demonstrated how NASA, USDA, and USAID fostered use of Landsat data domestically and abroad through grant programs, agricultural applications in particular, and the establishment of an international ground station network. Government agencies, industry, and scientific users conducted investigations around the world with affordable, relatively easy access to continuous, repetitive, and timely data produced by three Landsat satellites, EROS, and international cooperators by 1978. However, these operations made it apparent to the White House that Landsat was no longer experimental, a program characterized by research and development only. To the Carter Administration, Landsat was not only an operational system, but one that was ripe for commercialization. The Carter and Reagan administrations and Congress began to bring sweeping changes to the Landsat program as it entered the 1980s. For the executive and legislative branches, the “principal reasons for transferring remote-sensing services to private hands are that the private sector excels both at innovation and at developing markets.”²⁷⁷ In addition, the federal government sought to reduce its expenditures and foster Landsat use through new spacecraft and an expanded market.

This chapter chronicles the process by which Landsat first transitioned from an experimental program under NASA to an operational program under NOAA and became a fully commercial venture owned and operated by EOSAT. However, historians of technology demonstrated the difficulties of transitioning such a space technology from experimentation to

²⁷⁷ *Remote Sensing and the Private Sector: Issues for Discussion – A Technical Memorandum*, (Washington, D.C., U.S. Congress, Office of Technology Assessment, OTA-TM-ISC-20, March 1984), pg. 3, CREST CIA-RDP05T02051R000200260002-9, NARA II, College Park, MD

operations. Pamela Mack argued, with regards to NASA that it “has generally been very successful as a research and development agency, but the agency has shown less skill in working with the ultimate practical users of space technology.”²⁷⁸ John Krige presented a similar European case with regards to ESA’s difficulty transferring the European Meteorological Satellite (Meteosat) “across the interface” from a research and development phase to an operational program run by users.²⁷⁹ Also, the Swedish Space Corporation, a public-private entity, formed Satellite Image to commercialize remotely sensed land and meteorological data obtained via Landsat and SPOT but “struggled as a nonprofitable subsidy...despite the fact that images produced were actually used.”²⁸⁰ These studies depict American and European state space agencies as unable to foster commercial use of remotely sensed data. My chapter demonstrates that indeed commercially viable data sales proved out of reach in the 1980s. However, I show that NASA’s role was minimal in the commercialization process. I diverge from the aforementioned literature regarding Landsat since it was a combination of NOAA, Congress, and EOSAT, rather than NASA that failed to foster commercial use of land remote sensing data.

In the Landsat case, neither the government nor EOSAT offered the funds necessary for the program to operate and distribute data sending the program into turmoil. Ultimately the program required an emergency Congressional bailout in 1989 to sustain operations. In this chapter, I argue that Landsat mismanagement led to increasing data prices, fewer data products available to users, reduced government subsidies, and insufficient private investment drove away

²⁷⁸ Pamela Mack, *Viewing the Earth: The Social Construction of the Landsat Satellite System*, (MIT Press, 1990), pg. 15

²⁷⁹ John Krige, “Crossing the Interface from R&D to Operational Use: The Case of the European Meteorological Satellite,” *Technology and Culture*, Vol. 41, No. 1 (January 2000), pp. 27-50

²⁸⁰ Nina Wormbs, “Eyes on the Ice: Satellite Remote Sensing and the Narratives of Visualized Data,” in Miyase Christensen, Annika E. Nilsson, and Nina Wormbs, eds., *Media and the Politics of Arctic Climate Change: When the Ice Breaks*, (Palgrave MacMillan, 2013), pg. 56. See also: Nina Wormbs and Gustav Källstrand, *A Short History of Swedish Space Activities*, (Nordwijk: ESA, HSR-36, December 2007)

users. Landsat data evolved from a public good into a private commodity which constrained Landsat use. Between 1978 and 1985, the White House and Congress swiftly commercialized Landsat in a way that changed its use significantly in the latter 1980s.

Carter's Call for Commercialization, 1978-1979

President Jimmy Carter brought sweeping space policy changes that redefined Landsat as a commercial entity over several years. The process began on 11 May 1978 when Carter issued PD/NSC-37, "National Space Policy." It emphasized maintaining American leadership in remote sensing, data continuity, and advancing "the interests of the United States through the exploration and use of space," while also reiterating provisions of "Open Skies," the Space Act of 1958, and DoD reconnaissance programs classification.²⁸¹ First among its objectives for civil space programs, "the United States shall encourage domestic commercial exploitation of space capabilities and systems for economic benefit."²⁸² However, PD/NSC-37 also stated that Earth remote sensing satellites are subject to Government regulation.

Later in 1978 on 10 October, Carter released PD/NSC-42 which provided further detail about the commercialization process. It defined Landsat as a developmental and experimental program. However, the Carter Administration viewed data usage as an operational process. The directive also placed Landsat, as well as weather and ocean satellite systems, on a timeline. Carter called for these satellite programs to be "addressed in the FY 1980 budget review," that

²⁸¹ Presidential Directive/NSC-37, 11 May 1978, "National Space Policy," Carter Presidential Library, Atlanta, GA, <http://www.jimmycarterlibrary.gov/documents/pddirectives/pd37.pdf>, date accessed: 11 November 2013. For more on "Open Skies," see Walter McDougall, ... *The Heavens and the Earth: A Political History of the Space Age*, (Basic Books, 1985). For the Space Act of 1958, see <http://history.nasa.gov/spaceact.html>, date accessed: 26 January 2015. For more on space-based reconnaissance, see Dwayne Day et. al., *Eye in the Sky: The Story of the CORONA Spy Satellites*, (Smithsonian Institution Press, 1998) and John Cloud, "Imaging the World in a Barrel: CORONA and the Clandestine Convergence of the Earth Sciences," *Social Studies of Science* 31:2 (April 2001), pp. 231-251.

²⁸² PD/NSC-37, 11 May 1978, "National Space Policy," Carter Presidential Library, Atlanta, GA, <http://www.jimmycarterlibrary.gov/documents/pddirectives/pd37.pdf>, pg. 6, date accessed: 11 November 2013.

would “examine approaches to permit flexibility to meet the best appropriate technology mix, organizational arrangements, and potential to involve the private sector.”²⁸³ Carter also sought to integrate the various remote sensing programs by building upon the partnerships between NASA, USGS, and USDA commissioning an interagency task force that consulted with OMB to recommend methods to amalgamate US remote sensing programs before FY 1981. These considerations guided the formation of the third of Carter’s Landsat-related Presidential Directives.

On 16 November 1979, Carter released PD/NSC-54 “Civil Operational Remote Sensing,” which was unlike the other two in that it was particular to Landsat. PD/NSC-54 brought two sweeping changes to Landsat. First, the directive moved Landsat management from NASA to NOAA which was already responsible for atmospheric satellites and potential oceanic satellites. This move built off the partnership between NASA and the Environmental Science Services Administration (reorganized as NOAA) which played a key role in the TIROS weather satellites. As mentioned, OMB reviewed U.S. government meteorological programs under DOC and DoD and recommended that they remain as “dual polar orbiting meteorological programs, with joint development and procurement to maximize technology-sharing and minimize cost.”²⁸⁴ The second change in PD/NSC-54 to Landsat was that it set commercialization in motion. The directive stated the White House’s “goal is the eventual operation by the private sector of our civil land remote sensing activities.”²⁸⁵ It directly targeted Landsat and removed weather and

²⁸³ PD/NSC-42, 10 October 1978, “Civil and Further National Space Policy,” Carter Presidential Library, Atlanta, GA, <http://www.jimmycarterlibrary.gov/documents/pddirectives/pd42.pdf>, pg. 3, date accessed: 11 November 2013.

²⁸⁴ “Chronology of Events Related to the Proposed Transfer of the Civil Remote-Sensing Satellite Systems to the Private Sector, May 1978 to December 1983,” courtesy of Raymond Byrnes, USGS Headquarters, Reston, VA.

²⁸⁵ PD/NSC-54, 16 November 1979, “Civil Operational Remote Sensing,” Carter Presidential Library, Atlanta, GA, <http://www.jimmycarterlibrary.gov/documents/pddirectives/pd54.pdf>, pg. 2, date accessed: 11 November 2013

ocean satellites from consideration. Effectively the White House tasked DOC with managing Landsat until it formulated what type of arrangement Landsat became commercially.²⁸⁶

The Carter administration Presidential Directives moved Landsat away from NASA's control. At the time of PD-37, NASA was responsible for nearly all of Landsat's operations including: management, research, development, launches, guidance/tracking, data reception, and processing. USGS handled data distribution at EROS and the international ground stations received their data, but NASA handled everything else. As a result, NASA HQ became keen to start reducing its Landsat budgeting. With the transfer of Landsat to NOAA, it became the managerial outfit for Landsat but NASA still handled technical maintenance of satellites presently in orbit as well as research and development of Landsat 4 and 5. NOAA Administrator Richard Frank testified before the Subcommittee on Science, Technology, and Space in mid 1980 to present two options for private operation of Landsat.²⁸⁷ Frank postulated that both options cost over \$1 billion and occur over a ten year period, concluding in 1989. The first option was to select a "private corporation or consortium to own and operate all or part of the system and to sell data to Federal agency users under a guaranteed purchase contract" and the second was to set up a legislated for-profit entity, similar to the COMSAT arrangement from the 1960s.²⁸⁸ Frank warned that either commercial venture would not "be self-sustaining before the end of this century, even with a fivefold increase in fees and an annual ten percent growth in the market."²⁸⁹ Despite the precedents set by TIROS for environmental satellite operations to transition from NASA to NOAA and the COMSAT episode for communications satellites,

²⁸⁶ PD/NSC-54 recommended several options including a joint government-industry venture, leasing, or a quasi-government corporation.

²⁸⁷ NOAA, 26 June 1980, "NOAA Urges Development of Civil Land Remote Sensing Satellite," *Department of Commerce News*, Folder 6097 "Landsat Corp," NASA Historical Reference Collection, Washington, D.C.

²⁸⁸ NOAA, 26 June 1980, "NOAA Urges Development of Civil Land Remote Sensing Satellite," *Department of Commerce News*, Folder 6097 "Landsat Corp," NASA Historical Reference Collection, Washington, D.C., pg. 2

²⁸⁹ NOAA, 26 June 1980, "NOAA Urges Development of Civil Land Remote Sensing Satellite," *Department of Commerce News*, Folder 6097 "Landsat Corp," NASA Historical Reference Collection, Washington, D.C., pg. 2

neither this transition nor the commercialization effort proceeded smoothly. The White House not only earmarked Landsat for commercialization but also weather satellites already under NOAA operation and potential ocean remote sensing satellites.

The Reagan Administration's Vision for Landsat

President Ronald Reagan took the oath of office 20 January 1981 and within a few months brought rapid changes to the Landsat program. Originally, Carter's FY1982 budget "included \$123.8 million for NOAA's initiation of the program in order to assure program continuity" as well as funds for Landsats 6 and 7 appropriated to NASA. However, Reagan slashed the NOAA budget significantly and eliminated funding for Landsats 6 and 7 entirely.²⁹⁰ For the new White House, the Landsat program was not only operational, but also an enterprise to be developed entirely by the private sector. Reagan tasked OMB and DOC with carrying out this directive. In February 1981, Reagan reorganized the presidency by setting up "a network of six Cabinet councils to serve as the formal bodies for debating and shaping the major policies of his Administration."²⁹¹ Since Landsat formally came under NOAA management, the newly formed Cabinet Council on Commerce and Trade (CCCT), headed by Secretary of Commerce Malcolm Baldrige, assumed the commercialization policy issue. OMB Director David Stockman's request to Secretary Baldrige that the CCCT "determine the best mechanism for transferring Landsat to the private sector as soon as possible, and whether the government's four

²⁹⁰ Report, "Civil Land Remote Sensing System," Subcommittee on Space Science and Applications to Committee on Science and Technology, 97th Congress, First Session, December 1981, Untitled Folder 6097, NASA Historical Reference Collection, NASA HQ, Washington, DC

²⁹¹ Hedrick Smith, "Reagan Setting Up 6 Cabinet Councils to Shape Policies," *New York Times*, 15 February 1981, <http://www.nytimes.com/1981/02/15/us/reagan-setting-up-6-cabinet-councils-to-shape-policies.html?pagewanted=print>, date accessed: 17 March 2015

operational civil weather satellites should be transferred at the same time,”²⁹² encapsulated President Reagan’s vision for the Landsat program. In addition to CCCT, Baldrige formed two more committees to address Landsat commercialization implementation. What followed was six years of heated debate between Congress, the Executive, industry, and users with regards to the reshaping of Landsat and its use entering the 1980s.

Baldrige also played a pivotal role establishing two more groups that formulated Landsat commercialization policy. Within DOC, Baldrige approved the formation of the Program Board for Civil Operational Land Remote Sensing from Space. The Board’s goal was to “provide the continuing Federal coordination and regulation needed by DOC to manage the operational Landsat system to be implemented by NOAA in 1983 and its membership included Assistant Secretary-level federal employees.²⁹³ Baldrige also formed the Land Remote Sensing Satellite Advisory Committee to

“advise the Secretary on matters pertinent to the implementation and management of the operational Landsat program...[and] provide advice and make recommendations in such Landsat areas as those having to do with data requirements, priorities, data and product pricing, and proposals for private sector ownership.”²⁹⁴

This committee included fifteen members from non-Federal user communities, including state and local governments, the value-added service industry such as data analysis companies, university representatives, and potential investors such as those in the aerospace industry.

The CCCT, Program Board, and LRSSA met between 1981 and 1984 to form commercialization policy. These are the groups that pushed commercialization on behalf of

²⁹² Kathleen Eisenbeis, *Privatizing Government Information: The Effects of Policy on Access to Landsat Satellite Data*, (Metuchen, NJ: Scarecrow Press, 1995), pg. 8

²⁹³ NOAA, September 1981, “Information Update for Users of NOAA/NESS Satellite Data,” Folder 6097: “Landsat Corp,” NASA Historical Reference Collection, NASA HQ, Washington, D.C.

²⁹⁴ NOAA, September 1981, “Information Update for Users of NOAA/NESS Satellite Data,” Folder 6097: “Landsat Corp,” NASA Historical Reference Collection, NASA HQ, Washington, D.C., pg. 2

Secretary Baldrige and President Reagan. In 1981, NOAA and USGS operated Landsats 2 and 3 and maintained seven international ground stations. The government terminated Landsat 3 operation in 1983, Landsat 4 launched in 1982 and 5 in 1984. Over the course of several years, CCCT's role was to commercialize Landsat 4 and 5, encourage later Landsats to be paid for by private operators (essentially to enforce Reagan's cutting of Landsat 6 and 7 from FY1982 budget), and also commercialize weather satellites. A proposal from COMSAT in 1981 quickly began to reveal the serious complications of commercialization remote sensing satellites.

Conceptualizing Commercialization: Contacts with COMSAT

The Carter administration's effort to commercialize remote sensing met sharp criticism from the DOC regarding weather and ocean satellites. NOAA operated weather satellites, such as the TIROS and Nimbus series, and distributed their data as a public good. In 1979, no distinct ocean remote sensing satellites flew. As mentioned, the Carter administration dropped weather and ocean satellites from commercialization, however, the issue reemerged as a NOAA Request for Information solicited for proposals from industry. Congress received several proposals, via hearings and testimonies, but deemed Communications Satellite Corporation's (COMSAT) proposal to buy both NOAA weather satellites and Landsat as a commercial package strongest. In 1962, Congress passed the Communications Satellite Act which created the federally subsidized COMSAT to establish an American commercial space communications presence which it grew successfully through mobile communications, television broadcasting, and to a lesser extent, domestic communications.²⁹⁵ Ronald Reagan won the Presidency and renewed

²⁹⁵ David Whalen, *The Rise and Fall of COMSAT: Technology, Business, and Government in Satellite Communications*, (Palgrave MacMillan, 2014). See also: Communications Satellite Act of 1962, P.L. 87-624, August 31, 1962.

efforts to commercialize all remote sensing satellites despite the recommendations made ahead of PD-54.

In August 1979, COMSAT proposed Stereosat, a stereoscopic remote sensing apparatus akin to Landsat to NASA Administrator Robert Frosch. NASA welcomed the proposal but could do little with it once PD-54 moved Landsat to NOAA control. In November 1979, COMSAT CEO John Johnson contacted Carter's NOAA Administrator Richard Frank about Stereosat encouraging funding and agency support of the project in return for adherence to Landsat policies such as non-discriminatory data access and accessible data pricing as well as to help "accomplish the space policy goals established by the President for your Agency."²⁹⁶ Frank responded that NOAA began working on a transition plan in 1980 for an operational Landsat system and he hoped for COMSAT's views as the plan materialized.²⁹⁷ Essentially COMSAT had come to the table too early.

COMSAT returned to the negotiating table in earnest. COMSAT Chairman Joseph Charyk lobbied hard throughout 1981 in support of his corporation's proposal to win Landsat and the meteorological satellites. On 9 April 1981, COMSAT General proposed to OMB to buy Landsat and all NOAA weather satellites in operation and later did so publicly before a joint House-Senate Committee. COMSAT's proposal called 'EarthStar' attempted to accelerate commercialization, develop new sensors, and provide new data products. Charyk's plan would "include near-term product and service-oriented R&D, but that the government would continue long-term high-risk technology development."²⁹⁸ During the congressional hearing, Charyk stated

²⁹⁶ Letter, COMSAT CEO John Johnson to NOAA Administrator Richard Frank, 29 November 1979, Folder 6097: "Landsat Corp," NASA Historical Reference Collection, NASA HQ, Washington, D.C.

²⁹⁷ Letter, NOAA Administrator Richard Frank to COMSAT CEO John Johnson, 8 January 1980, Folder 6097: "Landsat Corp," NASA Historical Reference Collection, NASA HQ, Washington, D.C.

²⁹⁸ Memo, "Joint Hearings by Senate Subcommittee on Science, Technology and Space and House Subcommittee on Space Science and Applications on Civil Land Remote Sensing," 23 July 1981, Folder 6097: "Landsat Corp," NASA Historical Reference Collection, NASA HQ, Washington, DC

“if implemented, we believe our plan could substantially reduce overall federal expenditures and increase the federal tax base as a result of new companies entering the market, as well as from increased earnings from existing companies” and he reminded the Joint Committee of 1962 when the government set up COMSAT as a means of promoting private sector satellite development.²⁹⁹

On 23 July 1981, Charyk testified before a Joint Committee of the Senate Subcommittee on Science, Technology and Space and the House Subcommittee on Space Science and Applications. The hearing welcomed several from industry, including University of California, GE, and Resources Development Associates in addition to COMSAT in order to gather information about commercialization issues. The other industry agents raised concerns about subsidies and market size while David Simonett, Dean of University of California’s Graduate School advocated university access to “lower-than-market price, or for NASA or NSF to budget for university access to use of data.”³⁰⁰ Charyk took a much different approach in the hearing describing COMSAT’s ‘EarthStar’ as “‘uniquely qualified’ to meet the responsibilities entailed in private sector transfers” to answer both Congressional and industry concerns such as developing new applications and overall profitability by combining land meteorological satellites but did not comment on data pricing.³⁰¹

In December 1981, COMSAT’s formal proposal went public during a Subcommittee on Space Science and Applications hearing. Charyk testified that “COMSAT is the logical entity to assume such a responsibility [becoming the private sector operator of Landsat]. If so designated,

²⁹⁹ Merrill Brown, “Comsat Wants U.S. to Give up Land, Weather Watching Business,” *The Washington Post* July 27, 1981, pg. WB3, date accessed: 11 March 2015

³⁰⁰ Memo, “Joint Hearings by Senate Subcommittee on Science, Technology and Space and House Subcommittee on Space Science and Applications on Civil Land Remote Sensing,” 23 July 1981, Folder 6097: “Landsat Corp,” NASA Historical Reference Collection, NASA HQ, Washington, DC

³⁰¹ Memo, “Joint Hearings by Senate Subcommittee on Science, Technology and Space and House Subcommittee on Space Science and Applications on Civil Land Remote Sensing,” 23 July 1981, Folder 6097: “Landsat Corp,” NASA Historical Reference Collection, NASA HQ, Washington, DC

COMSAT is prepared to proceed to dedicate the resources necessary for the successful development of such a system.”³⁰² When asked about combining systems and which types of observations require satellites, Charyk proposed combining instruments on a single COMSAT operated satellite platform that included ocean, weather, and land imaging sensors. With regards to timely, uninterrupted data service, Charyk warned that Landsats 4 and 5 do not guarantee service beyond the 1980s but that “COMSAT has studied ways to continue and improve a Landsat-type service,” and Congress should pass legislation designating an “an appropriate private entity with a proven record of performance both domestically and internationally” to operate Landsat commercially.³⁰³ For Congress and potential operators alike, the development of a market for land remote sensing data was a pressing concern. However, for the Subcommittee and those testifying, there appeared to be an established meteorological data market anchored by NOAA-operated weather satellites. Thus, Charyk proposed that both weather satellites and Landsat commercialize as a package since “an operator could assume ownership and operation of the Landsat system for incremental costs and use the meteorological business to leverage the development of the market for Landsat data.”³⁰⁴ Charyk also strongly supported the non-discriminatory data access policy given a lack of resistance from the international community and it does not constrain potential entrepreneurship.

Throughout 1982, Congress, DOC, and the White House wrestled over weather satellite commercialization, which greatly complicated COMSAT’s plan to take over Landsat, polar-

³⁰² Report, “Civil Land Remote Sensing System,” Subcommittee on Space Science and Applications to Committee on Science and Technology, 97th Congress, First Session, December 1981, Untitled Folder 6097, NASA Historical Reference Collection, NASA HQ, Washington, DC, pg. 21

³⁰³ Report, “Civil Land Remote Sensing System,” Subcommittee on Space Science and Applications to Committee on Science and Technology, 97th Congress, First Session, December 1981, Untitled Folder 6097, NASA Historical Reference Collection, NASA HQ, Washington, DC, pg. 31-32

³⁰⁴ Report, “Civil Land Remote Sensing System,” Subcommittee on Space Science and Applications to Committee on Science and Technology, 97th Congress, First Session, December 1981, Untitled Folder 6097, NASA Historical Reference Collection, NASA HQ, Washington, DC, pg. 36

synchronous weather satellites, and the GOES systems. COMSAT also began to search for a successor to Joseph Charyk in March 1982. Among COMSAT's potential candidates was Guy Fiske, a Department of Energy undersecretary who received a transfer to DOC. Fiske met with COMSAT executives and lobbyists in addition to exchanging letters and phone calls throughout 1982. Fiske "described his role as that of an 'expediter'" despite Baldrige's testimony that he had no policymaking authority.³⁰⁵ As a result, the COMSAT 'EarthStar' bid became more precarious in May 1983 when it came under further scrutiny by the Department of Justice. The investigation revealed that then-Deputy Secretary of Commerce Fiske, who played a key role advocating commercialization, also had been "meeting privately with COMSAT representatives about becoming president of COMSAT."³⁰⁶ Commerce General Counsel Sherman Unger "concluded that Mr. Fiske had violated the agency's stands of conduct" which a Department of Justice investigation confirmed citing Fiske's four meetings with Comsat executives.³⁰⁷ As a result of the conflict of interest investigation, Fiske resigned his DOC post that month as the debate continued. The Fiske hearings revealed "a long pattern in which Comsat gained a pipeline of information into, and private meetings with, DOC officials that no other company or even Congress had during the decision making on the satellite proposals."³⁰⁸

Capitol Hill Comes In: GAO Reports, 1977-1982

³⁰⁵ Philip J. Hilts, "Justice Begins Criminal Investigation In Proposal to Sell Weather Satellites," *The Washington Post*, May 12, 1982, Folder 6097: "Landsat Corp," NASA Historical Reference Collection, NASA HQ, Washington, D.C.

³⁰⁶ Philip J. Hilts, "Reagan Signs Bill to Kill His Plan to Sell Weather Satellites," *The Washington Post*, November 29, 1983, pg. A1, date accessed: 11 March 2015

³⁰⁷ Michael Wright and Caroline Rand Herron, "The Nation," *New York Times (1923-Current File)*, May 15, 1981, pg.181, date accessed: 11 March 2015

³⁰⁸ Philip J. Hilts, "Baldrige Aides Excused From Satellite Sale Talks," *The Washington Post*, April 15, 1983, Folder 6097: "Landsat Corp," NASA Historical Reference Collection, NASA HQ, Washington, D.C.

The Government Accountability Office (GAO) played a role in the commercialization debate since it published numerous reports that informed Congressional policymaking. Kathleen Eisenbeis argued that these reports “established the conceptual framework for Congressional studies on Landsat for the next decade.”³⁰⁹ The GAO studied the political, economic, and national security ramifications of commercializing Landsat data with particular attention to how it impacted federal agencies. Reports published in 1977, 1982, and 1984 steadily demonstrated federal and private resistance to commercialization due to the fear of cost prohibitive data and data discontinuity.

The initial report in 1977 called for cost benefit analyses that ultimately suggested Landsat commercialization policy issues remained inconclusive which was corroborated in a 1978 report on Landsat 4’s budget eclipsing \$650 million and LACIE’s “mixed success in achieving its performance goals.”³¹⁰ In 1982, Ronnie Flippo (D-AL), House Subcommittee on Space Science and Applications chair, directed GAO to report on federal agency use of Landsat, which in FY82 was about 25% of all Landsat products distributed and in a 1984 report revealed “most federal users believed that ‘an increase in the cost of Landsat data would either prevent them from continuing to buy the data or reduce the amount they could buy.’”³¹¹ The states agreed, by December 1981 “fifteen states have routine operational capabilities to use Landsat data; state use of Landsat data has grown 61 percent since 1978.”³¹² The GAO also disclosed

³⁰⁹ Kathleen Eisenbeis, *Privatizing Government Information: The Effects of Policy on Access to Landsat Satellite Data*, (Metuchen, NJ: Scarecrow Press, 1995), pg. 20

³¹⁰ Kathleen Eisenbeis, *Privatizing Government Information: The Effects of Policy on Access to Landsat Satellite Data*, (Metuchen, NJ: Scarecrow Press, 1995), pg. 20. See also: Elmer Staats, Comptroller General, Report to the Congress of the United States, “Landsat Policy Issues Still Unresolved,” (Washington, DC: GAO, 1978), <http://www.gao.gov/assets/130/122525.pdf>, date accessed: 2 November 2012

³¹¹ Kathleen Eisenbeis, *Privatizing Government Information: The Effects of Policy on Access to Landsat Satellite Data*, (Metuchen, NJ: Scarecrow Press, 1995), pg. 20-21

³¹² Report, “Civil Land Remote Sensing System,” Subcommittee on Space Science and Applications to Committee on Science and Technology, 97th Congress, First Session, December 1981, Untitled Folder 6097, NASA Historical Reference Collection, NASA HQ, Washington, DC, pg. 3

private and university opposition to commercialization since “cost-cutting would also ‘affect the availability or continuity of data and investment in research and development.’”³¹³

Despite the opaqueness of the evolving land remote sensing policy towards commercialization, GAO revealed considerable opposition due to potential price hikes and data continuity. Nonetheless, President Reagan’s administration continued to pursue the policy given the billion-dollar cost to the government of Landsat 6 research and development and program costs. Despite the users’ concerns coming forth via GAO, NOAA went forth with its Request for Proposals (RFP).

Calling for Contractors: NOAA’s RFP and Resistance, March - November 1983

In March 1983, NOAA officially released its Request for Proposals (RFP) to solicit for commercial operators of Landsat *and* weather satellites. The RFP signaled that, despite a lack of legislation, considerable opposition, and myriad unresolved policies, Landsat would become a commercial entity. Thus, I argue the NOAA RFP was less a mechanism for soliciting proposals and more a political (rather than policy) instrument meant to accelerate Landsat commercialization. However, it elicited strong opposition from the House of Representatives and international cooperators which led to the removal of weather satellite, and very nearly Landsat itself, from the commercialization process.

In line with Reagan’s vision for Landsat, the White House charged Commerce Secretary Malcolm Baldrige with soliciting for commercial operators. DOC did so by forming a Source Evaluation Board (SEB), headed by William P. Bishop of NOAA in May 1983. Secretary Baldrige tasked this in-house group with both soliciting and evaluating proposals from private

³¹³ Kathleen Eisenbeis, *Privatizing Government Information: The Effects of Policy on Access to Landsat Satellite Data*, (Metuchen, NJ: Scarecrow Press, 1995), pg. 22

sector parties who sought to operate Landsat and weather satellites, after having issued a request for proposals.³¹⁴ The RFP required all potential operators are American, communicate directly with DOC, abide by all relevant laws and regulations (such as the Export Administration Act, Arms Export Control Act, Sherman Anti-Trust Act, etc.), and ensure no employment conflict of interests. Furthermore, the RFP had three basic objectives:

1. “to develop a commercial system based on the present Landsat operational satellite system capabilities;
2. to maintain U.S. leadership in remote sensing data from space; and
3. to foster the economic benefits of such data for the private sector and public good.”³¹⁵

In order to accomplish these objectives, NOAA sought an operator that could distribute data and data services, operate Landsat 4 and 5 throughout their lifetimes, and develop subsequent Landsats. The RFP also presented a number of issues that complicated the commercialization process and it also elicited strong resistance from the House of Representatives.

The first major issue was that the White House insisted on commercializing both Landsat and weather satellites, despite the aforementioned resistance. The COMSAT episode mentioned above demonstrated the issues with weather satellite commercialization, however, the issue continued to manifest since DOC received more industry proposals to operate weather satellites in addition to Landsat. From March to November, the RFP went through more iterations and an 18 November 1983 draft had cut all meteorological and oceanic satellites from its language,

³¹⁴ National Research Council Space Application Board, *Remote Sensing of the Earth from Space: A Program in Crisis*, (National Academy Press, 1st Edition, January 1985), pg. 30

³¹⁵ Department of Commerce, “Request for Proposals for Transfer of United States Civil Operational Remote Sensing Satellites to the Private Sector,” CREST-CIA-RDP05T02051R000200380019-8, NARA-II, College Park, MD

which originally included the Polar Meteorological Satellites and the Geostationary Meteorological Satellites (GOES). Without certainty regarding the weather satellites' status, potential operators did not have a clear notion of what they proposed for. The SEB was unable to jettison weather satellites entirely for several more months. Below, I discuss how Congress intervened with legislation to resolve the weather and ocean satellite issue.

A second issue presented by the RFP to potential operators and the user community was its myriad unresolved details and opacity. The November 1983 iteration of the RFP had yet to identify which type of contract arrangement most suitable for civil remote sensing. The government anticipated a Cost Plus Fixed Fee contract which paid the operator a fixed fee while the government assumed research and development risks. The RFP did not specify a fee or a time-scale. Also, what remained unclear was the “the transition from Government to private ownership and operation [which] will involve some considerable period of time. The terms and conditions of an actual sale are expected to be part of a separate contract.”³¹⁶ A separate chart on page IV-5 of the RFP anticipated that NOAA continue operating Landsat for eighteen more months before the actual transition period initiated in mid-1985 extending into 1986. The government's commercialization plan under Section V of the RFP's Contract Schedule Articles remained reserved and would be “inserted after negotiations.”³¹⁷ The RFP stated that the contracting period last 10 years but dependent upon the performance of Landsats 4 and 5, but given no hard start time, it was unclear when those 10 years began.

³¹⁶ Department of Commerce, “Request for Proposals for Transfer of United States Civil Operational Remote Sensing Satellites to the Private Sector,” CREST-CIA-RDP05T02051R000200380019-8, NARA-II, College Park, MD, pg. III-7

³¹⁷ Department of Commerce, “Request for Proposals for Transfer of United States Civil Operational Remote Sensing Satellites to the Private Sector,” CREST-CIA-RDP05T02051R000200380019-8, NARA-II, College Park, MD, pg. V-3

Another difficulty for potential operators was national security provisions. This section of the November 1983 RFP was classified and not discussed in other sections. Unless the potential operator had staff with security clearances, they did not have a competitive edge to vie for the contract. Lastly, The RFP's 'Commercialization Plan' section left many details to potential operators. In particular, the Landsat data pricing schedule for eleven products left prices to potential operators.³¹⁸ Despite the lack of developed market, NOAA left data pricing to potential operators to decide the cost of Landsat data, a cause for great concern discussed below.

Opposition emerged on the House and voiced its frustration with civil remote sensing commercialization. To be clear, NOAA and the House agreed that weather and oceanic satellites should remain public assets but disagreed on Landsat. By November, the House put the weather satellite commercialization issue to rest. Public Law 98-52, the NASA FY1984 authorization bill prohibited Baldrige from transferring civil land, weather, and ocean satellites to the private sector.³¹⁹ Weeks later, Representative Thomas Daschle (D-SD) announced that "by a vote of 377 to 28, the House went very strongly on record in opposition to any attempts to transfer this country's civil weather satellites and land natural resource satellites."³²⁰ The vote passed House Concurrent Resolution 168 which became an expression of House opposition to commercialization since H.Con. Res. 168 did not have any binding legal authority over ending commercialization. The Senate indefinitely postponed their vote on the resolution. Daschle also claimed on record that numerous committee and subcommittee chairs (controlled by Democrats in the 97th Congress) opposed land and weather satellite commercialization. The House

³¹⁸ Under the RFP, this included paper-based, film positive, and film negative MSS imagery at scales of 1:250,000, 1:500,000, and 1:1,000,000 as well as CCTs, both geometrically corrected and uncorrected data. For TM data, potential operators could price paper-based imagery at scales of 1:375,000, 1:750,000, and 1:875,000 in black and white or color-based composites.

³¹⁹ Public Law 98-52, July 15, 1983, 98th Congress, www.gpo.gov/fdsys/pkg/STATUTE-97/pdf/STATUTE-97-Pg281.pdf, date accessed: April 21, 2015

³²⁰ Hon. Thomas Daschle, House of Representative, "Weather Satellites," *Congressional Record*, November, 15, 1984, Folder 6097: "Landsat Corp," NASA Historical Reference Collection, NASA HQ, Washington, D.C.

Committee on Government Operations also reported evidence of resistance to commercialization from Landsat international cooperators.

On September 28, 1983, J. Dexter Peach, Director of the GAO Resources, Community, and Economic Development Division, testified before the House Subcommittee on Legislation and National Security on international reactions to Landsat commercialization.³²¹ The GAO report surveyed several countries in Europe, Asia, and South America as well as the World Bank, Inter-American Development Bank, the Asian Institute of Technology, and UN agencies. These agencies corroborated the arguments of the aforementioned GAO reports from the late 1970s, arguing that a commercial market has yet to be realized but also they disagreed with defining Landsat as an operational program. These agencies told Peach that Landsat data “is used mostly on a research and development or demonstration basis rather than an operational basis.” Furthermore, Landsat commercialization threatened “investments made by developing countries in acquiring the capability to receive and use Landsat data [which] represent significant commitments of their governments’ resources.”³²² Landsat commercialization also deeply threatened international ground station operators’ investment in Landsat since the MOUs they signed with the U.S. government provided “for termination upon cessation of U.S. Government operation of the Landsat system.”³²³ Essentially foreign operators and users saw commercialization as a termination of the non-discriminatory data access policy. Furthermore, the foreign representatives Peach spoke with argued private operation of Landsat placed them “at

³²¹ Statement, J. Dexter Peach, GAO, to Subcommittee on Legislation and National Security, “International Reaction to the Proposed Commercialization of Landsat,” 28 September 1983, General Accounting Office, <http://www.gao.gov/assets/110/100607.pdf>, date accessed: 23 April 2015

³²² Statement, J. Dexter Peach, GAO, to Subcommittee on Legislation and National Security, “International Reaction to the Proposed Commercialization of Landsat,” 28 September 1983, General Accounting Office, <http://www.gao.gov/assets/110/100607.pdf>, date accessed: 23 April 2015, pg. 3

³²³ Department of Commerce, “Request for Proposals for Transfer of United States Civil Operational Remote Sensing Satellites to the Private Sector,” CREST-CIA-RDP05T02051R000200380019-8, NARA-II, College Park, MD, pg. V-I.8-4

an unfair economic disadvantage” and “the satellites could be used to acquire and distribute military intelligence harmful to their national interests.”³²⁴ Without guaranteed non-discriminatory data access policy, foreign representatives feared for both their countries’ economic development initiatives and their national sovereignty.

Congressional and GAO concerns alongside NOAA’s continued RFP revisions began to shape civil remote sensing policy and the future of Landsat use. At the behest of both the House and NOAA, the SEB eroded the possibility of weather and ocean remote sensing satellite commercialization by striking them from the RFP. NOAA kept Landsat on the table at the White House’s urging despite House disapproval. Effectively the NOAA RFP attempted to set guidelines for a potential operator to foster commercial land imaging data use and define the segments of the satellite system ripe for private operation. However, the RFP continued to evolve into 1984 as Congressional reports and legislation kept Landsat in transition. Similar to GAO’s reports, the Congressional Office of Technology Assessment published a report in 1984 that expressed the similar concerns of data discontinuity and cost prohibition, but expressed further concerns regarding Landsat commercialization.

Congressional Concerns: OTA Report, March 1984

In March 1984, OTA published a technical memorandum addressing remote sensing issues for the House Science and Technology Committee and the House Government Operations Committee. The report was “designed to help Congress determine the appropriate requirements and conditions for private sector ownership of the U.S. land remote-sensing system,” to better

³²⁴ Statement, J. Dexter Peach, GAO, to Subcommittee on Legislation and National Security, “International Reaction to the Proposed Commercialization of Landsat,” 28 September 1983, General Accounting Office, <http://www.gao.gov/assets/110/100607.pdf>, date accessed: 23 April 2015, pg. 6

inform legislation.³²⁵ Having eschewed the meteorological satellite issue, OTA framed the question of Landsat's future as either an operationally appropriate Government program, transition to the private sector or discontinue the program entirely. OTA assessed several key issues pertaining to commercialization that redefined Landsat use.

The memorandum began by critiquing the SEB RFP from 1983. The aforementioned report became the basis for soliciting offers from potential Landsat operators. However, the OTA memo revealed that the RFP left some policy precedent to be set by the private sector. Given the lack of direction regarding satellite operations, "the private offeror runs an awkward and expensive risk of offering to invest and become involved in ways that could later be changed by policymaking legislation."³²⁶ At the time of the report, Congress continued to debate government versus private operation of Landsat. The OTA memo also addressed five broad policy areas that commercialization overlaps with: foreign policy, domestic public goods, federal data regulations, national security, and foreign competition.

As mentioned, several states around the world received Landsat data via ground stations through partnerships with NASA and USGS. In addition, countries without ground stations also used Landsat data through data purchases. Given Landsat's vast international presence, the government could not compromise its international obligations. The OTA postulated that a potential Landsat operator might not be able to assume those obligations and remain profitable. OTA also recommended that a nondiscriminatory data sales policy remain in place, just as it had during Landsat's experimental years given its obligation to open skies and "the powerful

³²⁵ *Remote Sensing and the Private Sector: Issues for Discussion – A Technical Memorandum*, (Washington, D.C., U.S. Congress, Office of Technology Assessment, OTA-TM-ISC-20, March 1984), pg. iii, CREST CIA-RDP05T02051R000200260002-9, NARA II, College Park, MD

³²⁶ *Remote Sensing and the Private Sector: Issues for Discussion – A Technical Memorandum*, (Washington, D.C., U.S. Congress, Office of Technology Assessment, OTA-TM-ISC-20, March 1984), pg. 6, CREST CIA-RDP05T02051R000200260002-9, NARA II, College Park, MD

message to send to all governments, especially those opposed to the open interchanged of...Landsat data [which] are available even to our political and economic adversaries.”³²⁷ The government remained wedded to ‘Open Skies’ which Landsat data fell under its jurisdiction. OTA also recognized the government’s need to maintain strong relations with the developing world, a significant user of Landsat data. Despite the Reagan administration’s desire to see a competitive market emerge, data distribution and value-added services under commercial management potentially could drive up prices prohibiting developing countries from data use. OTA recommended that “it may be appropriate for the United States to restrict the private data distributor from entering into the value-added business, or to regulate it closely to prevent such a company from exerting unfair economic leverage over others.”³²⁸ In the previous chapter I argued USAID became a huge federal user of Landsat data for development projects. OTA recommended that, should commercialization bring about cost prohibitive data for federal users, “it will therefore be important to assure the appropriate Government funding is continued for these projects, and that access to data will also continue.”³²⁹ Similarly, the Government needed to ensure that commercialization did not compromise NASA and USGS ground station agreements. In essence, OTA cautioned against compromising foreign policy and international agreements while maintaining legality under ‘Open Skies’ and the nondiscriminatory data access policy.

³²⁷ *Remote Sensing and the Private Sector: Issues for Discussion – A Technical Memorandum*, (Washington, D.C., U.S. Congress, Office of Technology Assessment, OTA-TM-ISC-20, March 1984), pg. 7, CREST CIA-RDP05T02051R000200260002-9, NARA II, College Park, MD

³²⁸ *Remote Sensing and the Private Sector: Issues for Discussion – A Technical Memorandum*, (Washington, D.C., U.S. Congress, Office of Technology Assessment, OTA-TM-ISC-20, March 1984), pg. 8, CREST CIA-RDP05T02051R000200260002-9, NARA II, College Park, MD

³²⁹ *Remote Sensing and the Private Sector: Issues for Discussion – A Technical Memorandum*, (Washington, D.C., U.S. Congress, Office of Technology Assessment, OTA-TM-ISC-20, March 1984), pg. 8, CREST CIA-RDP05T02051R000200260002-9, NARA II, College Park, MD

OTA also argued that Landsat data served as a domestic good. The memo raised many of the same concerns for developing countries as it did for federal agencies, universities, and state and municipal governments. Cost prohibitive data and computing hardware and software threatened to drive away users domestically as well. OTA also stated the importance of continuing research and development on more advanced instruments. While NASA prepared to launch Landsat 5 in 1985, having just launched Landsat 4 in 1982, neither NASA nor NOAA made any commitment to research and development on subsequent Landsat instrumentation. OTA recommended research and development could become a function of university involvement not only to develop new sensor capabilities but also with broadening the market through researching applications of remote sensing data. Commercialization's potential effects on EROS data distribution also became a domestic issue. Since data continuity and nondiscriminatory access were major concerns, it became crucial to preserve EROS financially and ensure that data copyrights remained within the Government.

Civilian federal requirements also complicated the commercialization plot. The OTA report did not offer solutions but raised three particular issues. First, Landsat 4, and the eventual launch of Landsat 5 added a new form of data provided by the TM. TM data proved to be more difficult to process and, as a result, more expensive. TM data was far more detailed since the sensor detected across seven spectral bands, as opposed to only four on the MSS. OTA vaguely recommended developing Federal applications for TM data, suggesting that the satellites' instruments may be well ahead of the user community's adaptation to the new data. OTA stated "for Federal mission agencies, data equivalent to MSS in format, spectral and spatial

characteristics will satisfy most civilian Federal needs for the rest of the 1980's.”³³⁰ OTA also argued that a single federal agency oversees all US remote sensing activities, but that it should not conflict with private entrepreneurship except to “demand improved service and products.”³³¹ This is in partial reaction the French SPOT system (discussed later in this chapter) which planned to fly higher resolution instruments in 1986 and will compete with American companies for data and services. Lastly, OTA recommended cost cutting in operations but sustain government sponsored research and development efforts.

The fourth broad area the OTA report addressed is national security. Landsat's status as a government entity allowed for easier control over data distribution, yet OTA speculated that a private entity would be more difficult to regulate with regards to data sales and that the defense and intelligence community may launch their own moderate-resolution system. Meanwhile, DoD restrictions on satellite instrumentation and data processing imposed limits on potential operators as well as the value-added data analysis industry. OTA suggested that Congress must strike a balance between establishing national security policies and fostering a remote sensing market.

Lastly, potential foreign competition diminished American leadership in remote sensing. The announcement of SPOT signaled the end of Landsat's monopoly in 1986. SPOT reinforced OTA's argument that data continuity alongside research and development would sustain U.S. leadership in remote sensing technology.

The broad, unresolved Landsat policy areas of international obligations, domestic issues, federal regulations, national security, and foreign competition reported on through NOAA, GAO,

³³⁰ *Remote Sensing and the Private Sector: Issues for Discussion – A Technical Memorandum*, (Washington, D.C., U.S. Congress, Office of Technology Assessment, OTA-TM-ISC-20, March 1984), pg. 12, CREST CIA-RDP05T02051R000200260002-9, NARA II, College Park, MD

³³¹ *Remote Sensing and the Private Sector: Issues for Discussion – A Technical Memorandum*, (Washington, D.C., U.S. Congress, Office of Technology Assessment, OTA-TM-ISC-20, March 1984), pg. 12, CREST CIA-RDP05T02051R000200260002-9, NARA II, College Park, MD

and OTA reports were hotly debated until these issues reached the House chamber floor and took legislative form in 1984.

Congress Votes Commercialization: Land Remote Sensing Commercialization Act of 1984

In 1984, two significant changes promised to expand data use and sustain the Landsat program for the next decade. On 1 March 1984, Landsat 5 left Vandenberg AFB on a Delta 3920 launcher vehicle successfully reaching Sun-synchronous orbit. This satellite became the longest-operating of all Landsats at present, producing nearly 2.5 million images over 29 years, far outstripping its 3 year design life.³³² Landsat 5's longevity proved fortuitous given President Reagan's 1982 decision to cut all Landsat satellites after it, dropping Landsat 6 and 7 from the federal budget.

At that time, Congress continued to debate new legislation that ensured sustained funding, management, and new technology that expanded data use. President Reagan signed into law the Land Remote Sensing Commercialization Act of 1984 a week ahead of Landsat's twelfth anniversary on 17 July 1984. This legislation attempted to change the nature of Landsat use through privatization, however, this new management regime struggled and nearly ended American land remote sensing entirely.

The aforementioned efforts of the Carter and Reagan administrations to commercialize Landsat took legislative form in early 1984. Representative Don Fuqua (D-FL) sponsored H.R. 4836, the "Land Remote Sensing Commercialization Act of 1984." This began a discussion between Congress and the Executive branch regarding best practices for implementing commercialization. When President Reagan entered office in early 1981, he directed OMB

³³² US Geological Survey, 19 June 2013, http://www.usgs.gov/newsroom/article.asp?ID=3626#.U_9hH_ldV8E, date accessed: 28 August 2014

Director David Stockman to cut Landsats 6 and 7 from the budget immediately, originally provided for under Carter's FY1980 budget. Stockman "was philosophically opposed to any kind of 'operational' activity by the government. Once Landsat D [4] dies in 1985 and D' [5] in 1987 says the OMB, that will be the end."³³³ Reagan and OMB wanted the U.S. government out of the remote sensing industry as soon as possible. As mentioned, NASA's role diminished since it only built, launched, and maintained the satellites' orbits at this point. It played no role in data collection, distribution, analysis, or marketing. The DOC now managed Landsat and raised a few key issues in response to H.R. 4836 via the SEB.

The SEB began to study the weather satellite issue further and commercialization still required legislation from Congress. SEB studies led its Chairman William Bishop to argue against the commercialization of weather satellites since "the only customer big enough to support them was the government."³³⁴ In a response to OMB's request for DOC's views on H.R. 4836, Bishop argued that the scope of the bill needed to narrow. Bishop dispensed of ocean remote sensing from commercialization, stating that

"there is no generally recognized operational capability in ocean remote sensing at the present time [1984]. Including ocean sensing within the scope of the bill will have the effect of specifying the government's conditions for commercialization of ocean remote sensing long before the parameters of such a system – or the need for commercialization – have been established. This may have the effect of inhibiting innovation in this area."³³⁵

William Bishop continued to work against commercializing ocean and weather satellites in his response to H.R. 4836 and his work as SEB Chairman. The SEB recognized the problematic nature of commercializing weather satellites. Congress and the SEB both opposed weather

³³³ M. Mitchell Waldrop, "Imaging the Earth (II): The Politics of Landsat," *Science*, New Series, Vol. 216, No. 4541 (April 2, 1982) pg. 41.

³³⁴ William P. Bishop, "Partnerships in remote sensing: A theme with some examples," *Space Policy*, November 1986, pg. 331

³³⁵ William Bishop response to Legislative Referral Memo, James Muir, "Commerce proposed testimony for 3/6/84 on H.R. 4836/ Land Remote-Sensing Commercialization Act of 1984," CREST-CIA-RDP05T02051R000200380019-8, NARA-II, College Park, MD

satellite commercialization since weather data had become so important for public safety, namely in storm forecasting. Several members of Congress speculated that data companies could inflate data prices in a time of domestic emergency, which they argued was outside the national interest. As arguments against packaging Landsat with the weather satellites piled on, members of Congress began legislating against it. By fall 1983, both chambers of Congress passed resolutions opposing the transfer of weather satellite operations to the private sector, a position which was solidified in November 1983.

Congress passed an appropriations bill specifying that no funds will be allocated for NOAA “to transfer the ownership of any meteorological satellite or associated ground system to any private entity.”³³⁶ In addition, Don Fuqua (D-FL) chairman of the House Committee on Science and Technology recognized that commercializing weather satellites further impeded Landsat commercialization. As an added measure, Fuqua sponsored House Concurrent Resolution 168 which defined weather satellite data as a public good and prohibited weather satellite operation from commercialization. The resolution identified “the Federal Government as the principal user of data gathered by civil meteorological satellites” which are implemented in federally provided weather forecasts.³³⁷ Furthermore, in Fuqua’s support of the resolution on the House floor, he reiterated a joint NASA/DoD study’s conclusion that “there is considerable financial, policy, and program risk to the Government in commercializing weather satellites and

³³⁶ “Making appropriations for the Departments of Commerce, Justice, and State, the Judiciary, and related agencies for the fiscal year ending September 30, 1984, and for other purposes,” P. L. 98-166, 98th Congress, November 28, 1983, 15 U.S.C. 1517, <http://www.gpo.gov/fdsys/pkg/STATUTE-97/pdf/STATUTE-97-Pg1071.pdf>, date accessed: 27 October 2014

³³⁷ “Transfer of Civil Meteorological Satellites,” House Concurrent Resolution 168, November 14, 1983, NASA Historical Reference Collection, NASA History Office, NASA HQ, Washington, D.C. in John M. Logsdon, Roger Launius, David Onkst, and Stephen Garber, eds., *Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program, Volume III Using Space*, (NASA SP-4407, 1998), pg. 321

there is no clear policy or financial benefit to be realized.”³³⁸ The resolution overwhelmingly passed 377-28. Subsequent legislation passed in March 1984 by Congress and signed by President Reagan in July 1984 officially prohibited the commercialization of weather satellites, under the Land Remote Sensing Commercialization Act of 1984 (Landsat Act). Congress officially defined weather satellite data as a public good, but had yet to do so with Landsat data.

Accordingly, the SEB promptly revised its request for proposals after Congress released its FY1984 appropriations. It released a new request on 3 January 1984 and received seven proposals over the subsequent three months including COMSAT, Fairchild Industries, Eastman Kodak, and an RCA/Hughes consortium. However, the SEB could do little with the proposals since several proposals included weather satellite operations, a policy yet unresolved. Landsat commercialization also required legislation, the potential operators could not seize control of Landsat despite a DOC offer.

Even though DOC solicited for proposals and began to select a winning bid, Secretary Baldrige needed legal authority to award a commercial contract for Landsat operations. The efforts of both the Carter and Reagan administrations as well as DOC coalesced first on the floor of the House of Representatives. On 9 February 1984, Representative Don Fuqua (D-FL) introduced H.R.4836, the “Land Remote Sensing Commercialization Act of 1984” (Landsat Act). The bill attempted to answer policy questions regarding Landsat data continuity and use.

- Maintain American leadership in remote sensing, preserve national security, and meet foreign obligations
- Promote private sector involvement in remote sensing
- Minimize Government subsidy (duration and amount)

³³⁸ “Transfer of Civil Meteorological Satellites,” House Concurrent Resolution 168, November 14, 1983, NASA Historical Reference Collection, NASA History Office, NASA HQ, Washington, D.C. in John M. Logsdon, Roger Launius, David Onkst, and Stephen Garber, eds., *Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program, Volume III Using Space*, (NASA SP-4407, 1998), pg. 322

- Open access data policy
- Prohibit meteorological satellite commercialization

H.R. 4836 revealed several knowledge gaps between policymakers and lawmakers regarding Landsat use. As mentioned, the White House pressured DOC and Congress to commercialize weather satellites and ocean satellites, but against numerous policy recommends, Congress removed these applications satellites from the bill altogether. Ocean remote sensing referred to satellites that mapped oceanic bathymetry, currents, and other maritime variables. The bill included ocean remote sensing satellites for commercialization. However, the Committee on Science and Technology had overestimated American space capabilities since no such satellite existed nor was Landsat designed for marine observations beyond coastlines. The SEB chairman William Bishop raised this concern on 2 March 1984. Bishop remarked “including ocean sensing within the scope of the bill will have the effect of specifying the Government’s conditions for the commercialization of ocean remote sensing long before the parameters of such a system –or the need for commercialization have been established,” further stating it may stifle innovation.³³⁹

Another gap between DOC’s RFP and H.R.4836 regarded Landsat data marketing. I demonstrated that NASA, USGS, and AID and their contractors undertook initiatives to expand Landsat use through development projects, ground station exports, and transferring remote sensing expertise, but no agency actively marketed Landsat data to users. H.R. 4836 Section 201(A) called for the Commerce Secretary to contract out marketing services which the SEB’s RFP did not require. Thus, Bishop stated “if the successful bidder in the RFP process does not undertake to market the data, an additional procurement action would be required for the

³³⁹ Legislative Referral Memorandum, “Commerce Proposed testimony for 3/6/84 on H.R. 4836/Land Remote-Sensing Commercialization Act of 1984,” CIA-RDP86B00338R000200280012-9, NARA II, College Park, MD

marketing component.”³⁴⁰ This gap between DOC and the House, Bishop stated, further extended and complicated the commercialization process by requiring yet another contractual procurement costing more time and dollars. At this juncture, Bishop encouraged Congress to include data marketing as a formal objective of the potential Landsat operating contractor.

The Commercialization Act addressed concerns raised both by private industry and the scientific community. Fuqua, chairman of the House Committee on Science and Technology, recognized that slow market development meant that private industry and potential research outfits would not be able to plan long-term, multi-year studies without a guarantee of data continuity and a competitive market which could provide numerous data products. Ironically, the bill sought to maintain nondiscriminatory data access to broaden Landsat use, which private industry did not favor. Pam Mack explained this irony stating “customers who would pay a high price for the exclusive use of Landsat data would not be interested if it were available to their competitors as well.”³⁴¹ H.R. 4836 essentially tried to reconcile the open access policy through fostering a remote sensing data market with a competitive industry.

The House revised H.R. 4836 as H.R. 5155 which cleared the House by voice vote, then the Senate also by voice vote as S. 2292, and it made its way to President Reagan’s desk on 17 July 1984 as the Land Remote-Sensing Commercialization Act of 1984. At the bill’s signing, Reagan reiterated his motivations for Landsat commercialization stating the bill is “in the national interest,” that it reduced “burdensome governmental regulation,” and that it encouraged competition.³⁴² Reagan also stated “we will make every effort to minimize the duration and

³⁴⁰ Legislative Referral Memorandum, “Commerce Proposed testimony for 3/6/84 on H.R. 4836/Land Remote-Sensing Commercialization Act of 1984,” CIA-RDP86B00338R000200280012-9, NARA II, College Park, MD

³⁴¹ Pamela Mack, *Viewing the Earth: The Social Construction of the Landsat Satellite System*, (MIT Press, 1990), pg. 180

³⁴² President Ronald Reagan, “Statement on Signing the Land Remote-Sensing Commercialization Act of 1984,” 17 July, 1984, <http://www.reagan.utexas.edu/archives/speeches/1984/71784e.htm>, date accessed: 23 April 2015

amount of any Federal subsidy,” a promise which plagued the very policy he promoted and the Landsat program itself over the next five years.³⁴³

Commercialization to Contract: NOAA takes Landsat to Market, 1984-1985

The Land Remote Sensing Commercialization Act of 1984 provided the legal precedent necessary to officially offer Landsat to private sector operation. Initially, DOC received eighteen inquiries from firms interested in Landsat *and* weather satellite operations and data sales. These firms were diverse in practice, a combination of engineering firms, data systems and analysis companies, and applied sciences. However, the long process, described above, that removed weather satellites from the commercialization equation prompted all but two potential operators to remove themselves from the competition following the Commercialization Act’s signing. COMSAT, in particular, was one of the first to withdraw from the competition. Between July 17, 1984 and September 25, 1985, the DOC essentially conducted a process of elimination to ultimately select the commercial operator for Landsat.

By September 1985, only two proposals remained on the table for the SEB to consider. Eastman Kodak Company, an optics and imaging services firm that had been involved with developing cameras for the classified joint CIA/USAF reconnaissance satellite series named Corona. A consortium named EOSAT which included RCA Astro-Electronics, Hughes Aircraft’s Santa Barbara Research Center, and Computer Sciences Corporation presented the other remaining proposal. However, Eastman Kodak withdrew their proposal in mid-1985.

Thus, EOSAT won the bid for Landsat operations. As a consortium, the EOSAT proposal divided labor among three subcontractors. The Hughes Santa Barbara Research Center took

³⁴³ President Ronald Reagan, “Statement on Signing the Land Remote-Sensing Commercialization Act of 1984,” 17 July, 1984, <http://www.reagan.utexas.edu/archives/speeches/1984/71784e.htm>, date accessed: 23 April 2015

responsibility for developing Landsat 6 and 7 instruments which included a Thematic Mapper and Multispectral Linear Array Sensor, similar to the multispectral scanner. RCA Astro-Electronics operated the “spacecraft bus and satellite operations control center” while Computer Sciences Corporation controlled “ground operations and ground receiving and processing facility design and Earthsat for market development and data enhancement.”³⁴⁴ The U.S. government finally completed the commercialization process on September 27, 1985 with the signing of the contract between Anthony Calio representing the DOC and EOSAT President Charles P. Williams representing EOSAT. In addition to the aforementioned division of labor, the contract obligated the federal government to operate the EROS Data Center, retain rights to the data without any guarantee of data purchases, turn over operation of Landsats 4 and 5 (the only satellites in operation at that time), subsidize EOSAT up to \$250 million paid out over five years, and subsidize Landsat 4 and 5 operation up to \$20 million. The contract divided the \$250 million among ground system development and Landsat 6 and 7 construction, launch, and integration. Lastly, the contract assumed EOSAT grew their revenue from \$19 million in 1986 to \$45 million in 1989.³⁴⁵ In this way, EOSAT required fewer subsidies each successive fiscal year. The government and EOSAT clearly defined the division of labor and developed a collegial working relationship throughout the bidding process, but quickly the arrangement fell into disarray as the DOC withheld portions of the \$250 million promised to EOSAT. President Reagan’s promise to reduce federal expenditures began to complicate the vision his very administration championed.

Commercialization Collapses: EOSAT Contract and Issues: 1986-1989

³⁴⁴ “RCA/Hughes Form Joint Venture for Landsat Commercialization,” 1 June 1984, *Defense Daily*, pg. 175, Folder 6097: “Landsat Corp,” NASA Historical Reference Collection, NASA HQ, Washington, D.C.

³⁴⁵ Donald T. Lauer, “An evaluation of national policies governing the United States civilian satellite land remote sensing program, Ph.D Dissertation, University of California at Santa Barbara, 1990, pg. 157

Under the Commercialization Act, NOAA formally relinquished control of the Landsat program on September 30, 1984 and EOSAT assumed operations a year later as contractor. Once EOSAT controlled the Landsat program and data marketing, it set about commercializing the satellite data. However, its agreement with Congress included a pledge of “up to \$250 million for capital investments and other costs during a 10-year transition to private ownership” provided for under the Land Remote-Sensing Commercialization Act of 1984 and the OMB had “not yet released the \$69.5 million in government funds that EOSAT says it needs” for new ground stations and for the development of additional satellites.³⁴⁶ The dispute began between OMB and the House Science and Technology Committee. Legally, OMB could not release funds until the DOC approved the \$27.5 million authorized by Congress for FY1987, still short of EOSAT’s needs. Furthermore, President Reagan’s proposed budget included no funds for Landsat. Still, Rep. Bill Nelson (D-FL) urged OMB Director James Miller III to authorize Congressional funding stating “it would be a significant detriment to the country if this falls apart. We need remote sensing capability up in space for many reasons, not the least of which is national security” and EOSAT President Charles Williams informed the *Washington Post* how the elimination of Landsat and its data would deleteriously “affect U.S. foreign relations, hand over technological leadership to the French, and destroy the first U.S. attempt to commercialize space.”³⁴⁷ However, both OMB Director Miller and predecessor David Stockman opposed Landsat subsidies arguing the satellite costs ran too high. Both Rep. Nelson and Williams linked Landsat use to broad implications such as U.S. foreign relations, since so many linkages had been put in place even prior to launch, and to technological leadership, a goal of American

³⁴⁶ Nell Henderson, “Landsat Management Firm Says U.S. Withholds Funds,” *Washington Post*, 5 December 1986, pg. G1, date accessed: 26 August 2014

³⁴⁷ Henderson, “Landsat Management Firm Says U.S. Withholds Funds,”

spaceflight endeavors both scientifically and commercially. EOSAT received its subsidy behind schedule for FY 1986 but the funding issues continued.

In January 1987, unpaid FY1987 funds for EOSAT forced the company to terminate its efforts to build Landsats 6 and 7. As mentioned, EOSAT began receiving its \$250 million subsidy but “pressure from the Gramm-Rudman-Hollings deficit exercise led the White House OMB to delete the fiscal year 1987 installment of EOSAT’s subsidy – \$69.5million.”³⁴⁸ In 1985, Congress passed the Gramm-Rudman-Hollings Balanced Budget Act which required cuts in federal spending to reduce the federal budget deficit that had developed under the Reagan Administration. The Balanced Budget Act’s policies filtered down to all federal agencies and their contracts which made fulfilling the EOSAT subsidy far more difficult for NOAA as federal expenditures remained high in the late 1980s. Congress restored only a fraction of what EOSAT was owed, about \$27.5 million. Meanwhile, NOAA and EOSAT continued to negotiate its subsidy rate, despite the contractual obligation of \$250 million and two new satellites, NOAA planned for \$209 million and one new satellite. For EOSAT, the funding issue delayed construction of Landsat 6 and 700 employees faced potential layoffs or reassignments.

In August 1987, the USGS feared EROS Data Center closure due to the federal budget shortfall extending from recent legislation and EOSAT’s woes. USGS “stated that a more likely solution would be for the facility to expand its scope to include collecting and analyzing remote sensing data for other branches of government. Currently, the EROS Data Center has lost about a third of its workload to EOSAT, a private company, as part of the government’s move towards during certain elements of the space program. In the process, EROS will lose about \$7 million of

³⁴⁸ M. Mitchell Waldrop, “Landsat Commercialization Stumbles Again,” 9 January 1987, *Science*, Folder 6097: “Landsat Corp,” NASA Historical Reference Collection, NASA HQ, Washington, D.C.

its annual federal budget by 1989. EROS processes Earth images received from the Landsat program's two-satellite system.”³⁴⁹

Shrinking federal budgeting and inadequate private investment did not simply doom EROS, but the Landsat program itself in 1988 and into 1989. In 1988, the annual operational cost of Landsat totaled \$18.8 million, but NOAA spokesman Bud Littin announced in early 1989, “we’re out of money, that’s all. The situation’s pretty bleak.”³⁵⁰ In late 1988, NOAA ran short \$9.4 million for EOSAT subsidies. The news angered science advocate Representative George Brown (D-CA) who stated “this is a damned outrage, and I’m going to do everything in my power to stop it from happening.”³⁵¹ Brown, along with 103 other Congress members, authored a letter addressed to President Bush and Vice President Dan Quayle to President Bush and Vice President Dan Quayle “urging them to find a way to keep the Landsat remote sensing satellites in operation.”³⁵² Quayle, as head of the National Space Council, explored several options for keeping Landsat aloft through 1989. Quayle, working with Congress, explored a number of options such as moving appropriated funds from NOAA’s other programs to Landsat or amending the Commercialization Act to draw funding from NASA’s budget. Landsat’s situation was precarious, if Quayle and the National Space Council could not find funding for the satellites, NOAA threatened to “turn off Landsat 4 and 5 on March 27 [1989].”³⁵³ In addition to the satellite shutdown, EOSAT speculated the end of its data distribution services, effectively

³⁴⁹ “Satellite Center May be Closed Because of Budget Shortage,” July/August 1987, *Space Age Times*, Folder 6083, “Landsat Satellites General I, 1975-1989,” NASA Headquarters, Historical Reference Collection, Washington, D.C.

³⁵⁰ William J. Broad, “Last Civilian Photography Satellites to Shut Down,” *The New York Times*, March 2, 1989, Untitled Folder 6083, NASA Historical Reference Collection, NASA HQ, Washington, D.C.

³⁵¹ William J. Broad, “Last Civilian Photography Satellites to Shut Down,” *The New York Times*, March 2, 1989, Untitled Folder 6083, NASA Historical Reference Collection, NASA HQ, Washington, D.C.

³⁵² “Rep. Brown, 103 Lawmakers Push President Bush to Fund Landsat,” *Aerospace Daily*, March 13, 1989, Untitled Folder 6083, NASA Historical Reference Collection, NASA HQ, Washington, D.C.

³⁵³ “Washington Roundup,” *Aviation Week & Space Technology*, March 6, 1989, Untitled Folder 6083, NASA Historical Reference Collection, NASA HQ, Washington, D.C.

closing access to over 2 million Landsat images collected to date. EOSAT continued Landsat 6 development since Congress appropriated \$36 million for construction, but not yet for launch.

The funding issue was the result of friction between DOC's order to limit funds for Landsat and the satellite's advocates at NOAA, the Hill, and Dan Quayle of National Space Council. The House Subcommittee on Space, Science and Technology held a hearing on March 7, 1989 but little came of the meeting except for numerous Representatives coming to Landsat's defense. NOAA's frustration grew with DOC's obdurate funding attitude as well, one unnamed official lamented "they [Commerce] don't give a damn about Landsat" and that "it is a very awkward situation – the user community should raise hell," which the DoD responded to.³⁵⁴ Dan Quayle met with OMB Director Richard Darman and proposed that DoD provide emergency funds to NOAA and EOSAT to resume Landsat operations for FY1989 and eventually adopt Landsat 7 construction (this issue will be addressed in the next chapter). Through Quayle's discussions with DoD, NASA, and Congress, he secured funding for Landsat until the end of FY1989 in September. Beyond 1989, Landsat's fate rested on the Hill.

On 6 September 1989, the House began negotiations to provide emergency funds to EOSAT for Landsat under a bill designated for NOAA appropriations. The bill for Landsat funds, H.R. 2427, originated in the House Subcommittee on Natural Resources, Agricultural Research and Environment and received bipartisan support. Rep. Bob Roe (D-NJ), House Committee on Science, Space, and Technology chairman, put forth H. Res. 230 and Rep. Jimmy Quillen (R-TN) spoke on its behalf. He acknowledged the funding crisis Landsat had been facing and the imminent threat to use. Quillen stated

“the loss of these Landsat satellites would interrupt the availability of remote sensing data for key government, scientific and foreign users; abandon the substantial Federal

³⁵⁴ “Landsat Satellites Scheduled to be Deactivated April 1,” *Defense Daily*, January 18, 1989, Untitled Folder 6083, NASA Historical Reference Collection, NASA HQ, Washington, D.C.

investment (\$1.5 billion) in a highly valuable data acquisition system; and severely damage, if not destroy, the Landsat commercialization initiative.”³⁵⁵

Robert Walker (R-PA), Chairman of the House Science Committee, continued to support Landsat by elucidating more of its recent uses. Walker stated that Landsat “is absolutely critical to oil, gas, and mineral exploration, agricultural planning, global environmental monitoring.”³⁵⁶ More representatives rose in support of Landsat mentioning uses in several states. In all, Quillen and Walker urged their fellow Representatives to continue funding Landsat and secured a 380 to 1 vote in favor.

President Reagan and the DOC’s commitment to Landsat commercialization plunged the program into severe financial problems. Despite the introduction of new data forms from Landsat 4 and 5’s Thematic Mapper and EOSAT’s Landsat data archive, its profits struggled. Landsat advocates at NOAA, on the Hill, and the Vice President secured just enough funds for Landsat to live another fiscal year into 1990, which will be discussed in the next chapter. As the Landsat program seemingly unraveled domestically throughout the 1980s, EOSAT also lost its competitive edge internationally.

Remote Sensing Becomes a Market: SPOT and SPOT Image

About six months after NASA, NOAA, and EOSAT signed their contract to commercialize Landsat, France became the second country to launch a land remote sensing satellite. Pierre-Marie Adrien, a member of NASA’s Space Applications Advisory Committee, argued that American investment in Landsat “stimulated heavy remote sensing investments

³⁵⁵ H.Res. 230, “National Oceanic and Atmospheric Administration Atmospheric and Satellite Program Authorization,” 6 September 1989, 101st Congress, 1989-1990, pg. H5365

³⁵⁶ H.Res. 230, “National Oceanic and Atmospheric Administration Atmospheric and Satellite Program Authorization,” 6 September 1989, 101st Congress, 1989-1990, pg. H5365

exceeding US\$90 million in Japan, US\$500 million in France's SPOT programme and a projected US\$280 million from Brazil by 1990.”³⁵⁷ India also began funding remote sensing research and development in the 1980s. Thus, he concluded that in order to maintain American leadership in remote sensing, a goal from the beginning of the Landsat program, the US government must remain involved with land remote sensing, at least financially. Adrien directed his plea for government support of remote sensing to OMB, in reaction to the emerging global competition in land remote sensing which threatened to further discourage use of Landsat data.

The capabilities and applications of Landsat led other states to develop satellites of their own. France presented the first challenge to the virtual monopoly held by the Americans. Over the early years of the 1980s, the French government declassified its high-resolution reconnaissance satellite imagery which was far superior in detail to that of Landsat. The U.S. remained reluctant to release its deeply classified reconnaissance data produced by Corona, Gambit, and Hexagon. Likewise, the French also launched the *Système Probatoire d'Observation de la Terre* (SPOT) which produced highly detailed imagery with resolutions superior to Landsat. The French began planning the satellite for commercialization in 1978 and used a Toulouse-based company, SPOT-Image to market its data. Based in France, SPOT-Image developed interest in Europe, but competed with Landsat through its Washington, D.C. based subsidiary for the U.S. market. By 1983, SPOT-Image sold its experimental data to the U.S. government, establishing itself as legitimate competitor. This data came from “a successful series of tests from high-altitude aircraft over the United States designed to simulate the data from the SPOT system.”³⁵⁸ These tests returned data at resolutions of 30 meters or better, more detailed than

³⁵⁷ Pierre-Marie Adrien, “A US Dilemma – satellite remote sensing privatization,” *Space Policy*, Vol. 2, No. 2, May 1986, pg. 93

³⁵⁸ *Defense/Space Daily*, 30 September 1983, pp. 143, Untitled Folder 6083, NASA History Program Office, NASA Headquarters, Washington, D.C.

Landsat. The French government committed US\$ 400 million while SPOT- Image “mounted an aggressive world –wide marketing campaign to promote success of their venture.”³⁵⁹ France launched a series of SPOT satellites beginning in 1986. SPOT was received well, particularly by the time of its launch with the aforementioned troubles facing EOSAT and the life span of Landsats 4 and 5 supposedly beginning to expire (Landsat 4 was retired, Landsat 5 actually remains in operation presently). In these ways, SPOT became not only viable competition but also penetrated the American remote sensing market.

Interest in remote sensing also expanded to Asia where two programs emerged. India began using Landsat data early in the 1970s at the behest of scientists such as P.D. Bhavsar, Vikram Sarabhai, and P.R. Phisaroty.³⁶⁰ These scientists worked received American training, developed remote sensing applications, and worked in remote sensing laboratories to build India’s remote sensing capacity in the 1970s. Following the launch of India’s first satellite, Aryabhata, the Indian Space Research Organization began working on a satellite for Earth resources called the Satellite for Earth Observation (SEO). India meant for it to serve two purposes: “‘management of natural resources through remote sensing technology’; and it should also satisfy national pride in that it uses 85% indigenous technology.”³⁶¹ The satellite, launched in 1988, reflected much of Landsat’s objectives for agriculture, forestry, and hydrology but as the satellite series continued, it expanded its applications. India launched a series of satellites after IRS-1 and maintains the program to present. The Indians launched Oceansat for studying biomass in the oceans and currents. Likewise, Cartosat produces three-dimensional mapping at

³⁵⁹ *Defense/Space Daily*, 30 September 1983, pp. 143, Untitled Folder 6083, NASA History Program Office, NASA Headquarters, Washington, DC

³⁶⁰ Ashok Maharaj, “An Overview of NASA-India Relations,” in John Krige, Angelina Long Callahan, and Ashok Maharaj, *NASA in the World: Fifty Years of International Collaboration in Space*, (Palgrave MacMillan, 2013)

³⁶¹ Dilip M. Salwi, *Nature* Vol. 274, 10 August 1978, pp. 526, Untitled Folder 6083, NASA History Program Office, NASA Headquarters, Washington, D.C.

resolutions superior to Landsat. The Indian remote sensing series has expanded beyond the applications of Landsat yet was not the only Asian state to develop remote sensing.

Japan also began competing in remote sensing through its space agency. In January 1979, the Earth Observation Center of the National Development Agency of Japan (NASDA) began work on its Marine Observation Satellite -1 (MOS-1). Landsat was largely incapable of observing marine phenomena since its purpose was to scan land cover, thus Japan looked to address an emerging market. Japan's MOS satellite was capable of both land remote sensing as well as ocean sensing at slightly better resolutions than the first three Landsats at about 50 meters. The Japanese government launched the satellite in 1987 and added another satellite in 1990. India's involvement has been more robust than Japan's, yet both challenged Landsat's monopoly, especially in ocean mapping and in resolution.

The aforementioned domestic funding issues in addition to the emergence of international competition seriously threatened the future of Landsat data usage. The effects of commercialization policy had a profound impact upon the satellite program's use throughout the 1980s. In order to meet the cost recovery requirement, EOSAT raised the prices of Landsat data which, in turn greatly decreased data sales. I argue the sunken data sales reflected constrained use of Landsat data which stood in contrast to the non-discriminatory data access policy set forth early in Landsat's history.

Commercial Consequences: Data Sales and the Problem of Use

In the previous chapter, NASA fostered use abroad but could not achieve non-discriminatory data access for all potential users given the constraining nature of American foreign policy and obligations. In this chapter, domestic politics and international competition

constrained Landsat data use, which is best represented by falling sales of data due in large part to increased prices. As mentioned, the Landsat program underwent sweeping changes towards a commercial program which altered the availability of data to users in two ways. Full cost recovery mandated by OMB in conjunction with legislation and NOAA policies required EOSAT to raise its prices on Landsat data. Just as USGS did so previously, EOSAT generally offered two types of products: CCTs and printed imagery. Printed imagery was the preferred product for a majority of users since it was cheaper and did not require expensive, cumbersome processing computers. However, EOSAT discontinued offering printed imagery and raised CCT prices. Furthermore, the introduction of the Thematic Mapper (first launched aboard Landsat 4) produced even higher quality data with its added spectral bands. With new data products and higher quality data to sell, EOSAT in accordance with government raised prices. As a result of price hikes and less product availability, Landsat data became cost prohibitive for many users and the satellite program ultimately suffered.

Two academic studies in particular connect Landsat data pricing to data usage. Donald Lauer, formerly Chief of EROS, and several colleagues published a 1997 article in *PE&RS* demonstrated that U.S. Government policies played a significant role shaping Landsat data pricing and availability.³⁶² Kathleen Eisenbeis's book argued that cost prohibitive data pricing resulted in a reduction of academic users.³⁶³ In this section, I present several data sets and argue that Landsat data pricing ultimately constrained the use of satellite data and went against the non-discriminatory data access policy.

³⁶² William C. Draeger, Thomas Holm, Donald Lauer and R.J. Thompson, "The Availability of Landsat Data: Past, Present, and Future," *PE & RS*, Vol. 63, No. 7 July 1997, pp. 869-875

³⁶³ Kathleen Eisenbeis, *Privatizing Government Information: The Effects of Policy on Access to Landsat Satellite Data*, (Metuchen, NJ: Scarecrow Press, 1995)

In the following chart, Lauer et. al. demonstrated how average Landsat data prices increased tenfold for film products and CCTs quintupled. While CCT sales increased steadily over 10 years before and after commercialization, film items dramatically decreased. EOSAT focused on selling more CCTs than film, but the sheer volume of film items sold constituted broader Landsat data use.

Table 3: Domestic Landsat Data Sales

Landsat Data, from Lauer et. al., 1997

TABLE 2. U.S. LANDSAT DATA SALES AND PRICE HISTORY

Year	Film Items Sold	Average Film Price (\$)	CCT Items Sold	Average CCT Price (\$)
1979	134,482	15	2,982	200
1980	128,403	15	4,139	200
1981	128,755	15	4,351	200
1982	115,025	20	4,974	250
1983	76,621	30	5,599	500
1984	34,964	60	5,042	500
1985	39,079	60	6,704	500
1986	19,061	125	7,808	1,000
1987	12,388	150	8,341	1,000
1988	9,088	150	8,530	1,000
1989	3,623	150	9,103	1,000

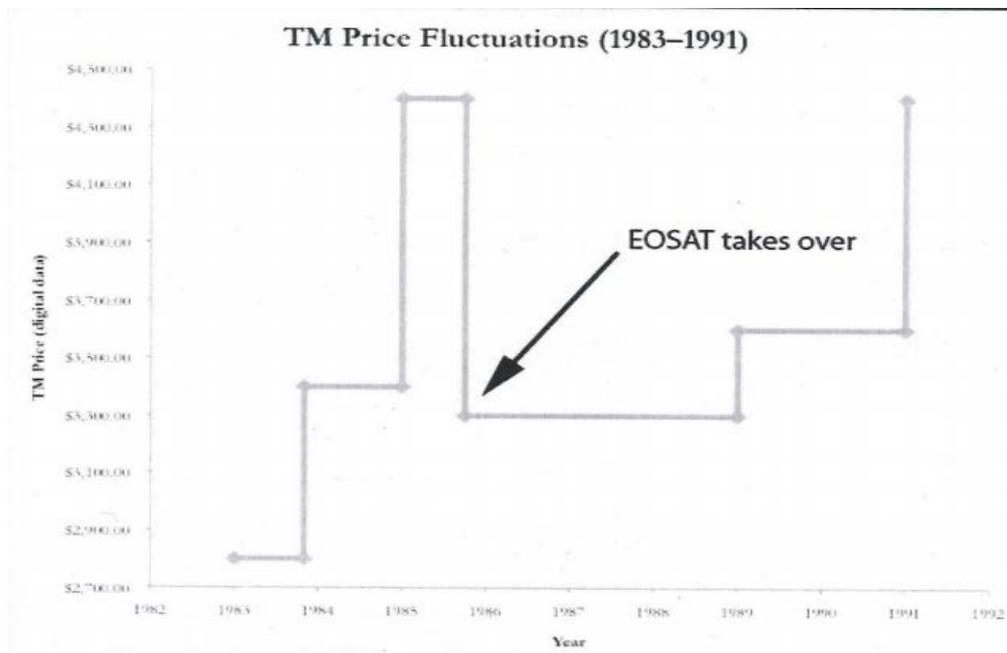
Source: U.S. Geological Survey, EROS Data Center, Sioux Falls, South Dakota

As mentioned, NOAA released its Landsat commercialization RFP in 1983, the same year film prices jumped \$10 and CCTs doubled in price. EOSAT fully assumed control of Landsat in 1986 when film item prices jumped from \$60 to \$125 (and accordingly sold 20,000 fewer scenes) and CCTs doubled from \$500 to \$1000. Film prices hiked one more time in 1987 as its user base diminished further. Thematic Mapper data in particular, introduced with Landsat 4, was especially problematic as its prices fluctuated wildly and it was less desirable from the user

community since it required higher processing power. The next chart depicts the price fluctuation of TM data between \$2800 and \$4500 from 1983 to 1991. The final chart demonstrates the aggregate number of Landsat scenes sold between 1979 and 1989, the scope of this chapter. The downward slope occurs ahead of the EOSAT contract in 1985 as the aforementioned policy uncertainties and price hikes drove away users.

Table 4: Thematic Mapper Imagery Price Fluctuations

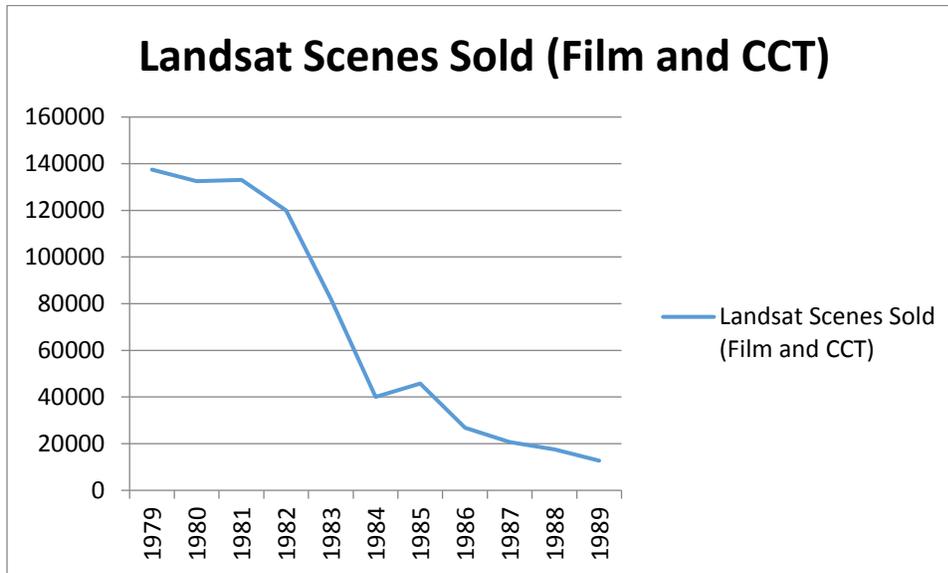
Thematic Mapper Scene Prices, courtesy, Raymond Byrnes, USGS, Reston, VA



In the following chart, I aggregated the total scenes of Landsat film and CCT products sold out of EROS and EOSAT, according to data from Lauer and USGS. Data sales held steady into 1981 but began to drop off in 1982 when both film and CCT prices went up. From 1982 to 1984, the most serious plunge in data sales occurred when film prices tripled and CCT prices doubled. Sales recovered very modestly after the launch of Landsat 4 in 1984 but continued to decline after DOC and EOSAT signed their contract in 1985.

Table 5: Landsat Scenes Sold, 1979-1989

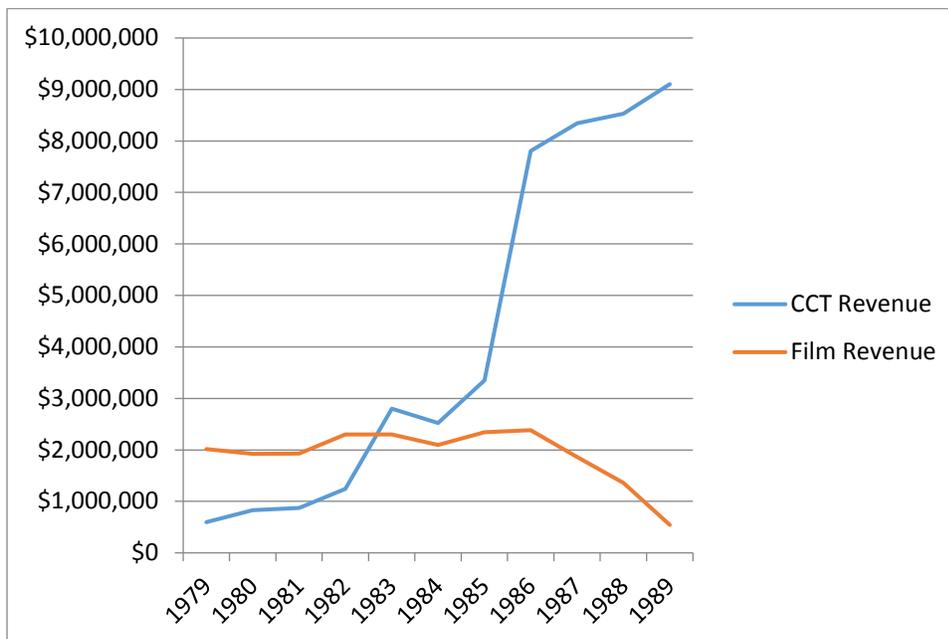
Landsat Scenes Sold 1979-1989, Brian Jirout



This huge drop off in products sold did not necessarily mean lowered revenues.

Table 6: Film and CCT Product Sales, 1979-1989

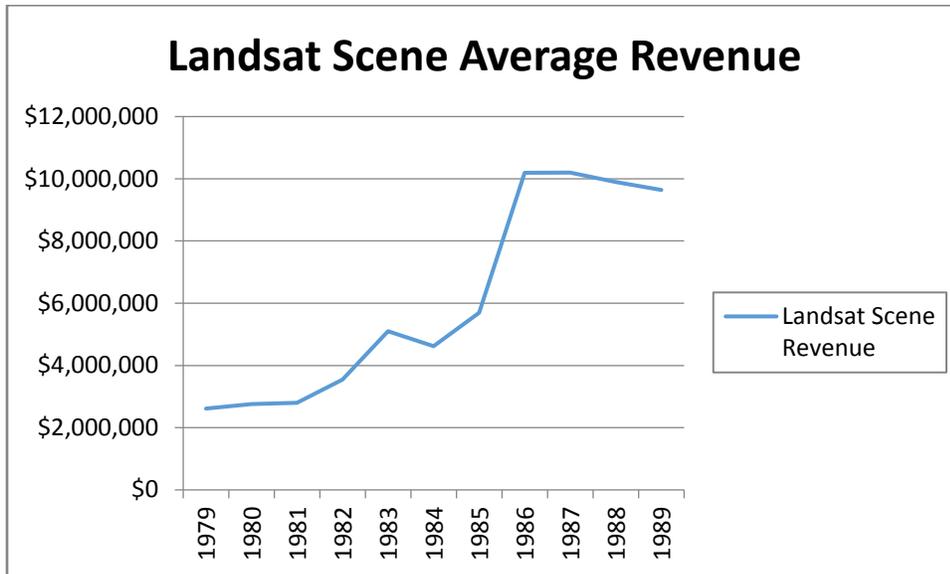
Film and CCT Revenues, USGS data , courtesy Raymond Byrnes, USGS, Reston, VA



Between 1979 and 1989, film revenue hovered around \$2 million before dropping below \$1 million in 1989. CCT revenue soared after commercialization to just over \$9 million. Film revenue averaged \$1,914,890 and CCTs averaged \$4,181,127.

Table 7: Landsat Scene Average Revenue, 1979-1989

Landsat Scene Average Revenue, USGS data, courtesy, Raymond Byrnes, USGS, Reston, VA



Revenues grew throughout the 1980s since EOSAT had to maintain cost recovery. Even at its peak revenue in 1986, at just above \$10 million, EOSAT did not recover the nearly \$18 million, mentioned above, that Landsat operations cost annually. EOSAT also generated very modest revenue from international ground stations.

Table 8: Global Landsat Data Revenues

Worldwide Revenues, from Lauer et. al., 1997

TABLE 4. WORLDWIDE LANDSAT SALES REPORTED REVENUE*

Country	CY 1979	CY 1980	CY 1981	CY 1982	CY 1983	CY 1984	CY 1985	CY 1986	CY 1987
Argentina	\$ —	\$ —	\$ 150,983	\$ 76,851	\$ 69,747	\$ 54,982	\$ 28,864	\$ 67,794	\$ 77,648
Australia	—	24,496	347,312	382,770	339,400	479,100	463,400	425,508	353,941
Brazil	272,220	377,901	353,513	585,823	340,953	233,486	453,578	693,280	931,516
Canada	316,875	389,654	358,715	290,637	274,758	364,890	362,485	578,000	504,289
China	—	—	—	—	—	—	—	—	—
Ecuador	—	—	—	—	—	—	—	—	—
ESA (Earthnet)	155,359	335,192	676,143	742,152	760,800	1,040,271	1,629,028	1,561,389	1,727,848
India	—	18,529	38,523	103,839	103,959	86,507	235,675	347,619	828,161
Indonesia	—	—	—	—	—	—	—	—	—
Japan	27,838	114,451	128,021	145,552	135,529	221,543	675,766	973,975	1,518,213
Pakistan	—	—	—	—	—	—	—	—	—
South Africa	—	22,800	98,000	107,937	128,634	67,752	60,495	103,892	54,006
Thailand	23,059	24,353	26,330	66,662	43,090	124,391	135,749	204,646	271,471
Taiwan	—	—	—	—	—	—	—	—	—
USA	2,242,473	2,493,639	2,663,326	3,422,753	3,850,557	3,964,186	5,776,092	8,395,224	7,834,976
Total	\$3,037,824	\$3,801,015	\$4,840,866	\$5,924,976	\$6,047,427	\$6,637,108	\$9,821,132	\$13,351,327	\$14,102,069

Country	CY 1988	CY 1989	CY 1990	CY 1991	CY 1992	CY 1993	CY 1994	CY 1995
Argentina	\$ 17,975	\$ 7,360	\$ —	\$ —	\$ —	\$ —	\$ —	\$ —
Australia	750,060	829,245	991,918	1,051,900	817,451	886,754	1,425,547	3,779,482
Brazil	716,307	864,092	355,194	888,716	1,065,106	691,450	1,064,858	—
Canada	550,419	636,583	923,862	1,339,082	1,173,881	942,189	1,140,686	1,248,469
China	243,936	354,236	196,766	179,629	112,462	155,855	267,082	369,840
Ecuador	—	—	—	17,580	78,702	42,492	124,700	—
ESA (Earthnet)	2,174,485	2,851,146	2,760,242	3,243,889	2,990,478	4,348,040	3,846,051	2,864,227
India	669,819	203,928	567,619	331,563	258,999	268,800	216,878	124,037
Indonesia	—	29,771	—	—	—	—	6,425	6,425
Japan	1,321,438	1,139,807	841,757	873,836	1,488,867	1,287,070	1,786,871	2,004,209
Pakistan	—	—	21,600	148,325	83,861	151,284	262,073	159,150
South Africa	41,216	59,480	232,152	340,887	579,836	571,542	776,077	747,598
Thailand	171,485	423,069	764,879	1,017,275	847,030	1,092,744	1,471,730	1,648,109
Taiwan	—	—	—	—	—	—	5,441	—
USA	8,621,655	10,018,267	13,205,019	14,601,910	13,498,849	13,405,789	10,746,077	6,678,925
Total	\$15,278,795	\$17,416,984	\$20,861,008	\$24,034,593	\$22,995,522	\$23,844,009	\$23,140,496	\$19,630,471

*As reported by International Ground Station Management in \$US.

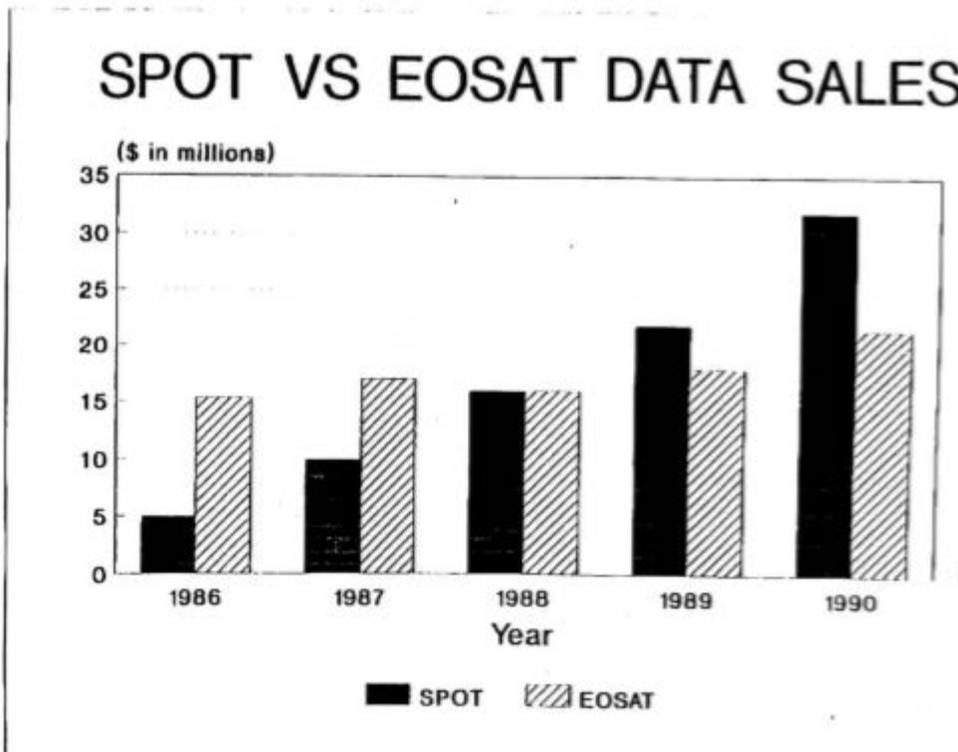
—Indicates station not operating or data not reported.

USGS, and later EOSAT, generated modest revenues from abroad by charging a \$200,000 operating fee to all international cooperators. In Brazil, INPE paid that sum to USGS to receive data to its station in Cuiaba, whereas the CCRS paid three installments of the sum for its three ground stations across Canada. EOSAT received anywhere from five to fourteen payments of \$200,000 between 1979 and 1989. All revenues generated by a ground station in Brazil kept its own revenues, however. EOSAT simply collected the operating fee. Thus, over 10 years from 1979 to 1989, total revenues from Landsat data and ground station fees did not exceed the cost recovery policy set forth by OMB. Without NOAA appropriations in FY1989, Landsat nearly ceased to operate.

Lastly, international competition from the aforementioned SPOT program began to outperform EOSAT.

Table 9: SPOT and EOSAT Sales Comparisons, 1986-1990

SPOT vs EOSAT Data Sales, 1986-1990, courtesy: John Faundeen, USGS EROS Data Center, Sioux Falls, SD



The above chart demonstrates not only the static data sales of EOSAT against the increasing revenues of France's SPOT system. In 1988, their revenues were nearly identical, but within two more years, SPOT's revenues outpaced EOSAT by over \$10 million. By 1989, EOSAT's troubles extended beyond Washington.

Concluding Commercialization

The commercialization policy introduced by President Carter and championed by President Reagan nearly ended Landsat data use altogether. PD-54 moved Landsat operations from NASA responsibility to NOAA, under DOC. Furthermore, NASA received no funds to

continue research and development on Landsat satellites beyond Landsat 5. Thus, NOAA assumed two tasks: operate the Landsat program until it found a private-sector operator. Part of its broad platform for the United States and its federal government, the Reagan Administration pursued Landsat commercialization in the national interest in order to reduce government regulation, promote competition in an emerging market, and reduce federal subsidy. The White House pushed hard for commercialization, Congress passed major legislation to authorize commercialization, and after a bidding process, DOC signed a contract with EOSAT. However, the arrangement quickly unraveled when OMB clamped down on Landsat subsidies and NOAA's funds dried up. OMB required cost recovery with regards to Landsat data revenues. However, EOSAT failed to achieve the revenue benchmarks in its contract. Essentially, Landsat commercialization drove data prices to cost prohibitive levels for users and EOSAT did not receive its subsidies in a timely manner. This combination led NOAA to announce a program shutdown and only the actions of Congress and the Vice President in 1989 saved Landsat from elimination. The transformation of Landsat data from a public good to a private commodity went against the non-discriminatory data access policy set forth during Landsat program formation and deeply constrained satellite data use.

Chapter 5: “Commitment to Continuity: The Formation of a National Land Imaging Program, 1990-2008”

Introduction: Landsat

The previous three chapters demonstrated how the federal government, Congress, and the private sector attempted to foster use domestically and abroad through accessible data and applications, only to have its momentum stifled by commercialization. The policy set into place by President Carter and overseen by President Reagan promised to foster use through a growing market in remote sensing data and imagery with Landsat at the forefront. OMB’s cost recovery policy alongside the price hikes instituted by NOAA and EOSAT pushed many users away, despite the growing number of applications in agriculture, forestry, geology and others. In the late 1980s, the Landsat program faced elimination as data use waned. The commercial arrangement had failed to foster, and rather, restrict Landsat data usage. The White House and Capitol Hill took action to reverse this trend and revise its legislation and policies to achieve a truly non-discriminatory data access policy. The government began to roll back commercialization after the budget and revenue shortfalls of 1989. The early 1990s became a period of transition for the Landsat program as much as it was for NASA, the federal government, and the world.

On 25 December 1991, the Soviet Union collapsed with the resignation of Mikhail Gorbachev and the lowering of the hammer and sickle over the Kremlin. The global landscape changed quickly with the Soviet dissolution as the United States assumed its role as the sole superpower. Accordingly, many of its policies began to change. The end of the Cold War prompted an overhaul of America’s space policy, which had played a crucial role in America’s efforts to be the global leader in science and technology. Presidents George H.W. Bush and

William Clinton alongside Congress made significant changes to space policy through executive orders, presidential decisions, and legislation. In particular, Congress passed two key bills and Presidents Bush and Clinton used presidential directives to make data more available. When President George H.W. Bush entered the White House, he adopted a robust space policy regime that sought to sustain American leadership into the post-Cold War era by promoting cooperation between the public and commercial sectors to cut costs.

Policymakers sought to find ways to conduct spaceflight more cheaply without sacrificing reliability or safety using advanced technology and efficient management methods. In 1992, NASA executives had designed and implemented an agency reform that emphasized inexpensive and reliable spacecraft development called the “Faster, Better, Cheaper” initiative. NASA’s objectives were to “cut costs, take greater risks, and dispatch spacecraft that actually flew...through changes in technology and project management.”³⁶⁴ The agency sought to diminish cost overruns often experienced during research and development, especially during its planetary exploration missions to Mars as well as in launches. NASA, the spaceflight advocacy community, and the aerospace industry believed that launch costs would drop with reliable vehicles such as the Titan IVB, the reusable Shuttle orbiter, or, later on, commercial vehicles. While Faster, Better, Cheaper emphasized launch costs and planetary exploration, I argue here that the initiative also affected the Landsat program. NASA’s drive to lower costs caused the agency to nearly abandon the satellite series altogether. However, the agency remained committed to land remote sensing data and attempted to make Landsat data more accessible on a more non-discriminatory basis.

³⁶⁴ Howard McCurdy, *Faster, Better, Cheaper: Low Cost Innovation in the U.S. Space Program*, (Johns Hopkins University Press, 2001), pgs. 1-2

During the 1990s, federal government agencies and Congress sought to adopt a policy regime and legislation that would make Landsat data more accessible again. These decisions amounted to greater emphasis on commercializing certain activities in space, declassifying reconnaissance programs and their associated photography, and preserving the collection of remote sensing data. The highest levels of government displayed a commitment to Landsat continuity, yet the commitment came in many forms due to the changing managerial structures of Landsat, such as the inclusion of the DoD, removing NOAA from Landsat management, and the movement away from commercialization.

In the early 1990s, the defense community began using Landsat data for tactical purposes during the First Gulf War and the DoD briefly raised its involvement with the satellite program. The combination of civilian and defense agencies as well as Congressional support led to new commitments to the Landsat program and the planning of the Landsat 7 satellite. Despite this initiative, several key challenges plagued the Landsat program and threatened its longevity. The program experienced technical setbacks, commitment issues from federal agencies, funding concerns, and an emerging domestic and international market for remote sensing data that threatened to make Landsat obsolete.

After the DoD's involvement, USGS and NASA collaboratively explored ways to pursue new satellites and access to continuous Landsat data. The agencies experimented with several managerial structures and even attempted to commercialize the program a second time. With the failure of Landsat 6 and an unsettled management and funding profile, the program seemed to be at its end. But in 2001, out of the tumult of the commercialization years and nearly a decade of policy changes, these agencies organized the Landsat Data Continuity Mission (LDCM). LDCM

led to the launch of Landsat 7 and an amalgamated data archive that sought to sustain Landsat and its data into the 21st century.

In this chapter, I argue that USGS and NASA worked towards and eventually achieved the non-discriminatory data access policy originally proposed by Nixon in 1969.

Commercialization, gaffes in management, and funding shortfalls generated a storm that pushed Landsat to the brink throughout the 1990s. I show how the federal government passed legislation that brought Landsat back under its control but had difficulty implementing and sustaining a funding and management profile for Landsat until 2001. Also, the federal government tried to foster a remote sensing industry which slowly began to materialize. However, a major distinction emerged: Landsat data was considered *moderate* resolution data (30 meters) which was useful only for civilian government purposes and academic institutions whereas the defense, intelligence, and industry groups valued *high* resolution (finer than 10 meters) imagery. Thus, remotely sensed imagery markets became more nuanced and the market for moderate resolution Landsat data was unable to prosper commercially without government involvement. NASA and USGS recognized this reality in 2001 when it initiated LDCM. I demonstrate how the adoption of new federal imperatives and a second failure of commercialization in 1998 stimulated the formation of LDCM which made Landsat data widely available and accessible. The move back to federal operation began with the White House.

Presidential Directives for Remote Sensing, 1990-1992

Following the example of President Carter, President Bush established in November 1989 his National Space Policy through a directive. National Security Presidential Directive-1 (NSPD-1) articulated Bush's vision for space which included the goal to sustain American leadership in

space, strengthen national security, obtain economic, scientific, and technological benefits, encourage private sector involvement, and international cooperation.³⁶⁵ President Bush reaffirmed these central tenets from the NASA Act for the post-Cold War era. It also increased the emphasis on establishing a commercial space sector. Bush's NSPD-2, the Commercial Space Launch Policy of 1990, specifically sought to foster a market for space launches and launch vehicles. NSPD-3 and 4 both released in 1991 provided the guidelines for commercial space policy and launches.

“U.S. Commercial Space Policy Guidelines,” or NSPD-3 released on 11 February 1991 stated that in order for the United States to remain the leader in space and stay competitive in an international environment, it must promote “commercial use and exploitation of space technologies and systems for national economic benefit.”³⁶⁶ Among several space technologies including satellite communications, launch vehicles, and materials processing, NSPD-3 also identified remote sensing. The directive promoted “private development, manufacture, and operation of remote sensing satellites and the processing and marketing of remote sensing data” as imperatives of commercial space policy.³⁶⁷ Bush proposed cost effective use of commercially available products by government agencies, government transfer of technology, avoid regulations that stifle commercialization, and cooperation between the private and public sectors in research, development, and operations. While promoting a private sector, President Bush also addressed public space operations.

³⁶⁵ President George H.W. Bush, National Security Presidential Directive-1, 2 November 1989, <http://www.au.af.mil/au/awc/awcgate/nspd1.htm>, date accessed: 30 September 2016

³⁶⁶ President George H.W. Bush, National Security Presidential Directive-3, 11 February 1991, <http://www.au.af.mil/au/awc/awcgate/nspd3.htm>, date accessed: 2 October 2016

³⁶⁷ President George H.W. Bush, National Security Presidential Directive-3, 11 February 1991, <http://www.au.af.mil/au/awc/awcgate/nspd3.htm>, date accessed: 2 October 2016

The president specifically sought to revise the federal government's commitment to Landsat itself and data continuity. The Landsat Remote Sensing Strategy (NSPD-5), released on 13 February 1992, acknowledged the capabilities of Landsats 4 and 5 and how they "benefit the civil and national security interests of the United States and makes contributions to the private sector which are in the public interest" and thus will "seek to maintain continuity of Landsat type data."³⁶⁸ The White House's vision for Landsat was that it would provide sufficiently consistent data for its various applications, make data available to address concerns of national security and environmental research and those of federal users, and promote commercial opportunities.³⁶⁹ The directive also called for continuity of data archiving, minimizing regulations on private sector remote sensing, and most importantly, called for a Landsat 7 satellite.

President Bush called for several agencies to implement the directives guidelines. In 1992, EOSAT had developed Landsat 6 for a 1993 launch date under its contract with DOC as well as sustain Landsat 4 and 5 operations via EOSAT. The directive also suggested a move away from the private sector as it charged NASA and DoD, not EOSAT, with developing the Landsat 7 satellite, discussed in more detail later in this chapter. However, NSPD-5 stated that funding, management, operations, and data archiving and dissemination would be a coordinated effort among various agencies. While the White House sought to revise policies and laws to sustain Landsat, so too did Capitol Hill through two major pieces of legislation in 1990 and 1992.

The Global Change Research Act, 1990

³⁶⁸ President George H.W. Bush, National Security Presidential Directive-5, 13 February 1992, <http://www.au.af.mil/au/awc/awcgate/nspd5.htm>, date accessed: 30 September 2016

³⁶⁹ President George H.W. Bush, National Security Presidential Directive-5, 13 February 1992, <http://www.au.af.mil/au/awc/awcgate/nspd5.htm>, date accessed: 30 September 2016

When President Bush entered the White House, he initiated a government program for tracking and understanding the global environmental change. In 1990, Congress followed suit and passed the Global Change Research Act of 1990 creating “a comprehensive and integrated United States research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change.”³⁷⁰ The act quickly passed the House by voice vote and a full 100-0 vote in the Senate and President Bush signed it into law on 16 November 1990. Under Title I, the Global Change Research Act formed the United States Global Change Research Program (USGCRP) overseen by the Subcommittee on Global Change Research and the Executive Office of the President. The act called for participation from twelve government agencies, including NASA and USGS. Congress tasked USGCRP with “understanding and responding to global change, including the cumulative effects of human activities and natural processes on the environment.”³⁷¹ In particular, the act itself called for “new developments in interdisciplinary Earth sciences, global observing systems, and computing technology make possible significant advances in the scientific understanding and prediction of these global changes and their effects.”³⁷² Further, the act required USGCRP to consult the National Space Council with regard to larger projects.

One of USGCRP’s main functions was to produce scientific assessments and research reports and plans. For some of its projects, it relied on satellite data from various environmental, meteorological, and land remote sensing satellites. Accordingly, Landsat data was a critical component of USGCRP’s efforts to carry out its objectives. The program recognized that

³⁷⁰ U.S. Global Change Research Program, “Our Changing Planet: The U.S. Global Change Research Program for Fiscal Year 2011,” January 2011, <https://www.whitehouse.gov/sites/default/files/microsites/ostp/ocp2011.pdf>, date accessed: 2 October 2016, pg. 1

³⁷¹ “Global Change Research Act of 1990,” P.L. 101-606, 101st Congress, 16 November 1990, www.gpo.gov/fdsys/pkg/STATUTE-104/pdf/STATUTE-104-Pg3096.pdf, date accessed: 3 August 2015

³⁷² Title I, Section 101, “Global Change Research Act of 1990,” P.L. 101-606, 101st Congress, 16 November 1990, www.gpo.gov/fdsys/pkg/STATUTE-104/pdf/STATUTE-104-Pg3096.pdf, date accessed: 3 August 2015

Landsat was crucial and advocated on its behalf to fund it and ensure data continuity. Shortly after the Global Change Research Act, Congress addressed USGCRP's recommendations to sustain Landsat.

USGCRP's concerns played a significant role in the writing of the Landsat Policy Act. The Landsat Policy Act addressed the cost prohibitive data issue raised by USGCRP. In Chapter 3, I demonstrated how Landsat prices rose under the Commercialization Act and made data unavailable to potential users. Under Section 5601 of the Landsat Policy Act, Congress declared "the cost of Landsat data has impeded the use of such data for scientific purposes, such as for global environmental change research, as well as for other public sector applications."³⁷³ Since Landsat became critical for government operations mandated by law, the USGCRP recommended that the Policy Act made data more available to government and scientific users. Moreover, members of Congress recognized that the bill should transfer the satellite program from a commercially contracted entity under the DOC to an managerially integrated program of DoD and NASA and "unenhanced Landsat 4 through 6 data be made available, at a minimum, to United States Government agencies, to global environmental change researchers, and to other researchers who are financially supported by the United States Government" according to user demands.³⁷⁴ The bill also included unenhanced Landsat 7 data. In 1992, the Hill passed even more sweeping legislation that sought to sustain Landsat continuity into the 21st century.

Passing the Policy Act: The Land Remote Sensing Policy Act of 1992

As EOSAT struggled to recover its costs and Landsat faced shut down, Congress began to enact legislation that would profoundly change the nature of Landsat and the data it produced.

³⁷³ www.geo.arc.nasa.gov/sge/landsat/15USCch82.html, date accessed: 3 August 2015

³⁷⁴ www.geo.arc.nasa.gov/sge/landsat/15USCch82.html, date accessed: 3 August 2015

The cleavages of the Landsat Act of 1984, addressed earlier in Chapter 3, became apparent on Capitol Hill. Representative George Brown (D-CA), who played an important role sustaining the Landsat program in the previous chapter, came to Landsat's assistance again in October 1992. Brown introduced H.R. 6133 as the 102nd Congress was closing its session. The main purpose of the bill was to repeal the Land Remote Sensing Commercialization Act of 1984 given its inability to foster a commercial remote sensing market and to sustain Landsat operations. In so doing, it significantly altered the managerial structure of Landsat. Joanne Gabrynowicz, a Professor Emerita and Director of the National Center for Remote Sensing, Air, and Space Law at the University of Mississippi School of Law, identified several main changes H.R. 6133 brought to Landsat including:

“Landsat 7 procurement, Landsat 4 to 7 data policy, transfer of Landsat 6 program responsibilities, regulatory authority and administration of public and private remote sensing systems, federal research and development, advanced technology demonstration, Landsat 7 successor systems, data availability and archiving, and the continued prohibition of weather satellite commercialization.”³⁷⁵

At the time of H.R.6133's introduction, NOAA managed Landsat, which had been contracted out to EOSAT. The proposed Policy Act also sought more coordination among agencies and integration of managerial responsibilities. The bill transferred Landsat management from DOC to NASA and DoD and called for a the “establishment of an integrated program management structure,” which became known as Landsat Program Management.³⁷⁶

The NASA Administrator and the Secretary of Defense jointly headed Landsat Program Management in addition to other program heads where the President saw appropriate. Their main goal was to establish a management plan that included agency roles and responsibilities as well

³⁷⁵ Joanne Gabrynowicz, “The promise and problems of the Land Remote Sensing Policy Act of 1992,” *Space Policy* (1993) Vol. 9, Issue 4, pp. 319-328

³⁷⁶ Congressional Research Service Summary, “H.R. 6133 (102nd): Land Remote Sensing Policy Act of 1992,” <https://www.govtrack.us/congress/bills/102/hr6133/summary>, date accessed: 28 September 2016

as develop a funding profile. Its main goal was to secure “the continuity of unenhanced Landsat data through the acquisition and operation of a Landsat 7 satellite as quickly as practicable” and funding was the responsibility of NASA and DoD for the research and development as well as the operations phase.³⁷⁷ The federal government procured the first five Landsats directly through NASA and its contractors and the sixth through NOAA’s contract with EOSAT. However, H.R.6133 questioned “whether such a spacecraft should be funded by the United States Government, by the private sector, or by an international consortium.”³⁷⁸ This essentially left the future of Landsat undecided as far as a follow-on satellite system and did not construct any strategy for Landsat 7 procurement and beyond. It specified that although commercialization was not feasible in the short term, it was a long-term goal to promote a commercial remote sensing market. The bill only allowed for private industry involvement with satellite operations and data preprocessing. H.R. 6133 carried over the ban on a commercially run weather satellites from the Commercialization Act of 1984.

At the time of the bill in late 1992, EOSAT built Landsat 6 with roughly \$250 million in subsidies from DOC and NASA providing launch services for a 1993 launch. Landsat 6 featured an Enhanced Thematic Mapper (ETM), built by Hughes Santa Barbara Research Center (part of the EOSAT consortium), which was integrated to a Lockheed Martin spacecraft bus. Thus, Landsat 6 was the first Landsat whose scanners and payload were developed primarily by the private sector. However, H.R. 6133 transferred Landsat 6 from EOSAT’s management to NASA and DoD. This section was crucial as it effectively brought the Landsat program back into the federal government. USGS carried out data archiving and dissemination, but research,

³⁷⁷ Land Remote Sensing Policy Act of 1992, 28 October 1992, Title I Landsat, Sec. 101 Landsat Program Management, <https://www.govtrack.us/congress/bills/102/hr6133/text>, date accessed: 3 October 2016

³⁷⁸ Land Remote Sensing Policy Act of 1992, Subchapter 1: Landsat, Section 5601, <https://www.nasa.gov/offices/ogc/commercial/15uscchap82.html>, date accessed: 29 September 2016

development, technical operations, and procurement had been run by EOSAT. In practice, the bill acquired Landsat 6 from EOSAT for NASA but the EOSAT continued to operate Landsats 4 and 5 under its previous contract. However, the bill was unclear as to how the Landsat program would proceed beyond its sixth satellite.

H.R. 6133 generally received bipartisan support but had fiscally conservative opponents. Ernest Hollings (D-SC), one of the architects of the aforementioned Gramm-Rudman-Hollings Act which restricted government spending, opposed the bill arguing that the failure of privatization was not fully understood. On the other hand, Al Gore (D-TN) “said for years that that [commercialization of Landsat] was a nonsensical idea.”³⁷⁹ After little debate, the bill passed the House and Senate, both by voice vote, within two days and President Bush signed the Land Remote Sensing Policy Act into law on 28 October 1992. Among the significant revisions to Landsat data policy and program architecture was the increased role the White House and Congress attributed to the DoD. As these measures passed and were implemented, the DoD put Landsat data to the test on the battlefield.

Landsat at War: Defense Mapping Agency, 1990-1991

In 1990, Iraqi tanks rolled across the Kuwaiti border in what became the first post-Cold War armed conflict in the Middle East. Iraqi dictator Saddam Hussein sought to invade and appropriate the vast oil supply central to Kuwait’s economy. In response, Coalition forces spearheaded by the United States sought to repulse the Iraqi Republican Guard Army in what became codenamed Operation Desert Shield. Naval and aerial bombardment expelled the Iraqi occupying force but not before Saddam Hussein ordered the destruction of petroleum extracting

³⁷⁹ Kenneth P. Thompson, “A Political History of U.S. Commercial Remote Sensing, 1984:2007: Conflict, Collaboration, and the Role of Knowledge in the High-Tech World of Earth Observation Satellites,” (Ph.D dissertation, Virginia Polytechnic and State University, 2007), pg. 21

infrastructure through the torching of oil wells. The Iraqi army set fire to roughly 650 oil wells and damaged nearly 75 more causing widespread leaks across the Kuwaiti desert and Persian Gulf.³⁸⁰ Over the next 10 months, Kuwaiti emergency responders, firefighters, and scientists attempted to quell the environmental disaster. Landsat 5's Thematic Mapper captured infrared signatures of the 1300 degree Fahrenheit fires raging across the Kuwaiti landscape. The worst environmental damage occurred in the Alburoan and Umm Gudair oil fields south of Kuwait City. Subsequent studies of the Kuwait oil fire disaster have estimated that "25 to 40 million barrels ended up spread across the desert and 11 million barrels in the Persian Gulf."³⁸¹ The military began using Landsat data extensively in June 1991 to mitigate the ensuing oil fire crisis.

On 26 June 1991, the Director of the Defense Mapping Agency Major General William James of the USAF testified before a joint hearing of the House Permanent Select Committee on Intelligence and the House Science, Space, and Technology Committee. General James was an experienced pilot who logged over 6,500 hours of flying time and held an undergraduate degree in geology.³⁸² Despite his lack of experience with remote sensing, his leadership made transformed DMA from a producer of maps into a critical organization that made geographic information readily available to military commanders across the Unified and Specified Commands. DMA produced imagery products as both compact disks and paper maps (akin to USGS production of Landsat imagery). DMA products "are all characterized by cartographic representations of natural and cultural features found on the earth's surface or beneath the

³⁸⁰ "Landsat Top Ten – Kuwait Oil Fires," 23 July 2012, http://www.nasa.gov/mission_pages/landsat/news/40th-top10-kuwait.html, date accessed: 13 March 2016

³⁸¹ "Landsat Top Ten – Kuwait Oil Fires," 23 July 2012, http://www.nasa.gov/mission_pages/landsat/news/40th-top10-kuwait.html, date accessed: 13 March 2016

³⁸² U.S. Air Force Biography, "Major General William K. James," www.af.mil/AboutUs/Biographies/Display/tabid/225/Article/106646/major-general-william-k-james.aspx, date accessed: 17 March 2016

ocean's surface.”³⁸³ The DMA discussed its uses of Landsat and recommended “modifications to the system that would make it more suitable for mapping, charting and geodetic (MC&G) production.”³⁸⁴ General James described DMA's need for both broad area image coverage as well as high resolution (finer than 10 meters) imagery. In addition, DMA required continuous, routine imagery collection in order to identify and track natural and cultural change over time. High resolution imagery taken from classified reconnaissance satellites primarily supported weapon systems guidance, particularly Tomahawk cruise missile guidance. General James claimed the Tomahawk cannot fly without high resolution imagery since they provide coordinates for strategic and tactical targeting as well as elevation information. Imagery for guidance purposes needed to be 10 meters resolution or finer, which Landsat could not provide but General James made the case that Landsat complemented and supplemented DMA's products.

As mentioned, Landsat provided the broad image coverage DMA needed for hydrographic, bathymetric, and terrain categorization using Landsat's multispectral capabilities. DMA began using Landsat to map coastal hazards and water depths. NASA had not designed Landsat's scanners for bathymetric applications, but DMA found that Landsat imagery detected hazards, such as rocks, in coastal waters. This allowed DMA to alert the Navy, Coast Guard, and others to navigational risks. General James cited two large DMA mapping projects in which it was using Landsat data in the two years leading up to the hearing. In 1982, Vice President George H.W. Bush enrolled the military and CIA in America's counternarcotics “war on drugs” campaign to interdict illicit drugs entering the United States, discussed in Chapter 1. DMA

³⁸³ Major General William K. James, “Statement on the Defense Mapping Agency Uses of Landsat,” 26 June 1991, GWU NSA, <http://nsarchive.gwu.edu/NSAEBB/NSAEBB404/docs/06.pdf>, date accessed: 17 March 2016

³⁸⁴ Major General William K. James, “Statement on the Defense Mapping Agency Uses of Landsat,” 26 June 1991, GWU NSA, <http://nsarchive.gwu.edu/NSAEBB/NSAEBB404/docs/06.pdf>, date accessed: 17 March 2016

sought to map the source of the drugs by gathering 192 Landsat images of Bolivia, Colombia, Panama, and Peru.³⁸⁵ The other project is mentioned in part above in which 122 Landsat images provided topographic information of Saudi Arabia, Iraq, and Kuwait for Operation Shield/Storm. DMA also used Landsat routinely for terrain analysis, soil studies, and vegetation classification, much the same way NASA, USDA, and CIA did in their crop forecasting experiments discussed in previous chapters. Accordingly, DMA used Landsat as an additional source of terrain analysis data for understanding soil composition and moisture to classify vegetation. These applications assisted the military with its operations since Landsat imagery covered such broad geographic areas, but General James also expressed Landsat's limits.

Despite these examples, three key components limited Landsat's ability to be useful to DMA. Landsat imagery was too low of resolution and it lacked stereoscopic coverage and precise metric positioning data. Without these variables, DMA would be unable to precisely locate targets and calculate elevation. General James expressed a need for broad area imaging but with higher resolutions, broader spectral coverage, and stereoscopic coverage in order to improve the imagery products provided by DMA. Essentially DMA's use of Landsat was limited to interim special purpose and crisis support products in the case of the Gulf War and counternarcotics, but the agency found little use elsewhere. General James found that Landsat data met too few of DMA's requirements for its purposes. DoD's interest in Landsat began to wane until the dissolution of the Soviet Union created a new imperative.

When the Soviet Union dissolved, fifteen new states emerged and the defense community sought to gather imagery of those regions. This initiative was written into law as the DoD Appropriations Act for Fiscal Year 1994 required the DMA "to evaluate and procure available

³⁸⁵ Major General William K. James, "Statement on the Defense Mapping Agency Uses of Landsat," 26 June 1991, GWU NSA, <http://nsarchive.gwu.edu/NSAEBB/NSAEBB404/docs/06.pdf>, date accessed: 17 March 2016. The NASA Historical Reference Collection has a Landsat image of Peru identifying coca plantations.

imagery photographs and materials from successor states of the former Soviet Union.”³⁸⁶ Under the Appropriations bill, Congress required DMA to acquire imagery of the newly independent states from Landsat, the French SPOT remote sensing system, commercial, and Russian sources. The DMA report expressed doubt that Russian imagery would be difficult to acquire as it was a not a free market economy and declassification rules were unclear. The Russian government made some military imagery, civilian cartographic resources, and remote sensing data available through an agency called Priroda (which was also the name of a Russian Earth resources experiment module that flew on the Mir Space Station in 1996). Priroda screened projects and served in a contractor role to sustain control over the imagery used by DMA and its contractors. DMA obtained Landsat imagery as a baseline for comparison with Russian-based imagery as part of the broader Russian imagery acquisition project. DMA’s comparative study of Landsat with publicly available Russian remote sensing data revealed that Landsat had coarser resolution and comparable pricing and areal coverage. However, the advantage of Landsat was that it covered a broader spectral range and its data was available digitally whereas only two of Russia’s nine publicly available sensor systems were digital. DMA also conducted the project to secure Russian scientific data for USGS, NOAA, and the Bureau of Land Management. Moreover, the Russian comparative project also proved useful since “it may be useful as a stopgap if Landsat fails,”³⁸⁷ suggesting the DoD’s concern the program might continue to languish.

³⁸⁶ Response to PL 103-139, HR 3116, “Defense Mapping Agency Report on the Evaluation and Procurement of Former Soviet Union Imagery and Materials,” 10 March 1994, document courtesy of Raymond Bynres, USGS, Reston, VA

³⁸⁷ Response to PL 103-139, HR 3116, “Defense Mapping Agency Report on the Evaluation and Procurement of Former Soviet Union Imagery and Materials,” 10 March 1994, document courtesy of Raymond Bynres, USGS, Reston, VA

Expanding the U.S. Data Archive through Industry and Intelligence, 1992-1995

Following the passage of the Land Remote Sensing Policy Act in 1992, the Clinton Administration sought to expand American remote sensing data access to foreign users. President Clinton, in consultation with National Security adviser Sandy Berger and many other Cabinet members, handed down Presidential Decision Directive-23/NSC-23 (PDD23) in March 1994 with the goal to remove barriers to foreign use. President Clinton also made significant changes to commercial remote sensing policy. PDD23 acknowledged classified military reconnaissance programs that, like Landsat, provided imagery to the defense and intelligence communities which are “among the most valuable US national security assets because of their high quality data collection, timeliness, and coverage and the capability they provide to monitor events around the world on a near real-time basis.”³⁸⁸ As mentioned previously, Landsat had become a critical national security asset after the crop forecasting experiments and Gulf War. Moreover, other countries were beginning to develop indigenous reconnaissance programs and satellites of their own or sought imagery from the United States, Soviet Union, and France primarily. As a result of this growing international demand and continued emphasis on national security in remote sensing, the PDD23 reconciled those interests. President Clinton sought to both “enhance US industrial competitiveness in the field of remote sensing space capabilities while at the same time protecting US national security and foreign policy interests.”³⁸⁹ The directive did so by effectively changing the licensing procedure for American firms who sought to operate land remote sensing satellite systems.

³⁸⁸ Presidential Decision Directive/NSC-23, 9 March 1994, “US Policy on Foreign Access to Remote Sensing Space Capabilities,” GWU National Security Archive, <http://nsarchive.gwu.edu/NSAEBB/NSAEBB404/docs/10.pdf>, date accessed: 13 March 2016, pg. 2

³⁸⁹ Presidential Decision Directive/NSC-23, 9 March 1994, “US Policy on Foreign Access to Remote Sensing Space Capabilities,” GWU National Security Archive, <http://nsarchive.gwu.edu/NSAEBB/NSAEBB404/docs/10.pdf>, date accessed: 13 March 2016, pg. 2

The 1994 directive, in accordance with the LRS Policy Act of 1992, relinquished the government's monopolistic control of remote sensing and allowed an industry to open up. Despite the failure of EOSAT to turn a profit, the government saw a potentially lucrative, robust industry primed to grow. Part of the issue was licensing and operation; the technology worked well. PDD23 maintained that certain technologies, such as scanners, lenses, or image processing equipment, would remain under control on the US Munitions List and the Commerce Control List. The United States government sought to control the industry though through licensing which the directive defined. A potential company applied for a license from DOC and would be favorably considered if it was willing to sell imagery on a global marketplace and abided by eight principles in the directive. Among them, a licensee would still need export licenses on top of its commercial license, allow US government inspection, and limit distribution or data collection if deemed a national security contingency. Licenses also had expiration dates. Technology transfer was a main concern as well. Foreign recipients of American technologies were beholden to U.S. government rules and regulations in areas such as data sharing and technological restraints such as resolution, spectral coverage, coverage, and data processing. The U.S. government reserved the right to reject licenses if they did not ensure oversight or enabled a competitor to surpass the United States in remote sensing capability. The LRS Policy Act and PDD23 sought to open an industry of which Landsat was the centerpiece, yet they created numerous issues as well.

Kenneth Thompson's dissertation and Gabrynowicz highlighted a major cleavage between space policy and foreign policy apparent in the two aforementioned policies.³⁹⁰ The Policy Act of 1992 did not provide clear language for industry to begin investments in

³⁹⁰ Kenneth P. Thompson, "A Political History of U.S. Commercial Remote Sensing, 1984:2007: Conflict, Collaboration, and the Role of Knowledge in the High-Tech World of Earth Observation Satellites," (Ph.D dissertation, Virginia Polytechnic and State University, 2007)

commercial remote sensing. Thompson stated the Policy Act “simply provided an opportunity for CRS [commercial remote sensing] satellite companies to seek licenses, but it did not encourage the US government to purchase CRS imagery to help the CRS industry in its early stages.”³⁹¹ For example, in 1992 WorldView Imaging Corporation applied for and received a license from the DOC. The license offered no subsidies and rather than unenhanced data being released to all potential users, instead the Policy Act required companies to make “unenhanced data available to the governments of sensed states.”³⁹² Thus, if a company gathered imagery of another country, the US government had no way to directly acquire that data. In effect, this went against the non-discriminatory data access policy subject to Landsat and became a significant difference between Landsat and commercial remote sensing systems, such as WorldView’s EarlyBird-1.

The non-discriminatory data access policy fit well into foreign policy as it provided a mechanism for international cooperation in science and technology, but commercialization stifled its use abroad. As demonstrated, Landsat data became expensive during commercialization and cost prohibitive for foreign users, especially in the developing world. During the Policy Act debates, Congress attempted to “strike a balance between international treaty obligations to maintain non-discriminatory data access [and the] interests of private sector firms.”³⁹³ The concern was that private sector remote sensing data would be too expensive to serve as an instrument of cooperation for foreign policy and that Landsat data would have to be available on a non-discriminatory basis. With Congress committed to Landsat data continuity,

³⁹¹ Kenneth P. Thompson, “A Political History of U.S. Commercial Remote Sensing, 1984:2007: Conflict, Collaboration, and the Role of Knowledge in the High-Tech World of Earth Observation Satellites,” (Ph.D dissertation, Virginia Polytechnic and State University, 2007), pg. 22

³⁹² Joanne Gabrynowicz, “The promise and problems of the Land Remote Sensing Policy Act of 1992,” *Space Policy* (1993) Vol. 9, Issue 4, pp. 319-328

³⁹³ Joanne Gabrynowicz, “The promise and problems of the Land Remote Sensing Policy Act of 1992,” *Space Policy* (1993) Vol. 9, Issue 4, pp. 319-328, pg. 322

the US government could also foster a competitive remote sensing industry by not subjecting it to non-discriminatory data access.

Within a few months of the Policy Act's passage, DOC received several applications from private satellite operators for a license to fly remote sensing satellites. As mentioned above, WorldView Imaging Corporation was the first to successfully apply for a license and eventually launch a remote sensing satellite. It also won the first high resolution (finer than 30 meters) remote sensing satellite license. WorldView merged with Ball Aerospace and Technologies Corporation in March 1995 and changed its name to DigitalGlobe, to conduct research and development on what became the Earlybird-1 spacecraft launched in 1997 and the first high resolution remote sensing satellite, DigitalGlobe's IKONOS in 1999. Lockheed Martin and Orbital Sciences also submitted applications to DOC for licenses as well. In addition to industry sources of remote sensing data becoming more available, the intelligence community also released nearly 30 years' worth of imagery to public use.

As mentioned in Chapter 1, the intelligence community made use of Landsat data and was a large purchaser of imagery. In 1995, President Clinton made signed an Executive Order that directed CIA and the National Reconnaissance Office (NRO) to declassify imagery collected from the CORONA, ARGON, and LANYARD missions.³⁹⁴ In fact, the NRO itself had only recently been declassified itself. The agency remained secret until its existence was declassified in September 1992 at the behest of the Director of Central Intelligence.³⁹⁵ Much of this imagery

³⁹⁴ National Reconnaissance Office Press Release, "President Orders Declassification of Historic Satellite Imagery Citing Value of Photography to Environmental Science, 24 February 1995, <http://www.nro.gov/news/press/1995/1995-01.pdf>, date accessed: 10 October 2016

³⁹⁵ For extra reading on NRO's history and declassification, see Jeffrey Richelson, "Out of the Black: The Declassification of the NRO," *National Security Archive Electronic Briefing Book*, No. 257, <http://nsarchive.gwu.edu/NSAEBB/NSAEBB257/index.htm>, George Washington University National Security Archive, Washington, DC, date accessed: 28 March 2016. NRO Center for the Study of National Reconnaissance produces program histories which can be found at www.nro.gov/history. See also: Bruce Berkowitz, "The National

was high resolution, black and white photographs initially collected by the CIA and USAF and used by DMA, CIA, the National Imagery and Mapping Agency, among others. The sensor system was very different from Landsat, however. The cameras returned black and white imagery since that scheme offered the highest resolution possible. Color and infrared were only used three times as they had lower resolution. CIA and Air Force placed a premium on resolution. Eastman Kodak manufactured a unique 70 millimeter film and each satellite carried roughly 8,000 feet of film. In the mid-1990s, much of the declassified imagery collected by the intelligence community went into storage at EROS and the National Archives and Records Administration and became readily accessible in the same way as Landsat imagery.³⁹⁶

The combination of formerly classified imagery and commercial high resolution imagery helped expand the market for land remote sensing data especially given the potential data gap should Landsat 5 fail and Landsat 7 delays continue. While remote sensing data ostensibly became more available through intelligence community declassification and private industry began building a market for commercial satellite data with the passage of the Policy Act and PDD23, Landsat's future had yet to be resolved by the federal agencies and private industry slowly developed.

Landsat in Limbo: Technical Failures and Managerial Turnover, 1992-1996

During the early 1990s, the Landsat program suffered a series of setbacks. In 1992, EOSAT withdrew from data processing operations. However, EOSAT's struggles did not end in 1992. After years of investment in Landsat 6 and its upgraded MSS and ETM, the satellite failed

Reconnaissance Office at 50 Years: A Brief History," (NRO, 2011), www.nro.gov/history//csnr.programs/NRO_Brief_History.pdf, date accessed: 28 March 2016.

³⁹⁶ Since 1995, EROS has made over 990,000 formerly classified images available to the public. For more information: see USGS, "Declassified Intelligence Satellite Photographs," July 2008, <http://pubs.usgs.gov/fs/2008/3054/pdf/fs2008-3054.pdf>, date accessed: 11 October 2016

to reach orbit, plunging the satellite into the Indian Ocean. A Titan II launcher vehicle took off from Vandenberg AFB, California on 5 October 1993, but a ruptured hydrazine manifold which “rendered the satellite’s reaction engine assemblies useless because fuel could not reach the engines. As a consequence, there was a failure to maintain attitude control during the apogee kick motor (AKM) burn.”³⁹⁷ Therefore, the launcher did not sufficiently place the satellite in orbit since the engine did not burn enough. Both a NOAA review board chaired by Director of NOAA’s Systems Acquisition Office Thomas McGunigal and a Martin Marietta Corporation review board, the company who had designed Landsat 6, reached similar conclusions. The launch failure left both EOSAT and Landsat operations in a precarious position with no additional satellite planned for and funds running bare.

Two months after the Landsat 6 crash, Landsat 4, already plagued with technical problems, ceased to function properly. Landsat 4 experienced several technical problems since its launch in 1984. Landsat 4 featured a new scanner, the Thematic Mapper (TM), with a broader spectral coverage than its predecessors. Despite the TM’s success, much of the rest of the payload did not. Within a year of reaching orbit, two of its four solar panels malfunctioned and both of its downlink transmitters. Thus the satellite did not downlink any imagery until the Tracking and Data Relay Satellite System (TDRSS) became operational in April 1983. Thus, NASA and USGS did not received any Landsat 4 for a couple months. For 10 years, Landsat 4 did not operate optimally yet NASA had built Landsat 4 with a transmitter, the Ku-band transmitter, that made it capable of communicating with TDRSS. However, since TDRSS handled data relays from multiple satellite systems, as well as the Shuttle orbiter, Landsat data sometimes had to ‘compete’ for downlinks. In December 1993, the Ku transmitter gave out

³⁹⁷ “Landsat 6 Failure Attributed to Ruptured Manifold,” 10 March 1995, http://landsat.gsfc.nasa.gov/pdf_archive/NOAA_landsat6.pdf, date accessed: 26 August 2014

entirely on Landsat which brought its data downlinks to an end. With the failure of Landsat 6's launch and Landsat 4's inability to transmit data, data continuity became precarious.

The several malfunctions on Landsat 4 prompted the early launch of Landsat 5 in 1984, which was an identical payload. The Landsat 4 and 5 platforms also made data continuity perilous as neither included a data recorder. The first three satellites carried an onboard recorder which allowed them to store data until it came within range of a ground station. Once in range, the recorder downlinked its collected data. Without an onboard recorder, Landsats 4 and 5 had no way to store data except to downlink or relay data. Rather than have onboard recorders, NASA designed Landsats 4 and 5 to be able to dock with the Shuttle, which would allow the agency to perform repairs to the spacecraft. However, this required the Shuttle to launch out of Vandenberg Air Force Base so as to achieve the same orbit as the Landsats. After a \$4 billion investment in Vandenberg to add a Shuttle launch facility, the USAF cancelled the project.³⁹⁸ By 1993, Landsat 6 failed to achieve orbit, Landsat 4 had malfunctioned, and the lack of data recorders and ability to repair the satellites endangered the program. In addition to technical problems, Landsat management also began to malfunction.

In the mid-1990s, a series of White House decisions provided new guidance to the Landsat program in the wake of the Landsat 6 accident and subsequent managerial confusion. The Landsat management structure began to shift in 1993 with severe budget cuts applied to NASA and DoD, the two agencies charged with running the satellite program. The end of the Cold War signaled a significant draw down in defense spending in the mid-1990s. Without another major superpower to contest America's supremacy, there was little rationale to fund the DoD as profoundly as when the Soviet Union loomed large. As mentioned above, DoD was not

³⁹⁸ Justin Ray, "From Shuttles to Rockets: Long History for California Launch Pad," 19 January 2011, <http://www.space.com/10644-california-launch-pad-history-shuttles-rockets.html>, date accessed: 27 September 2016

especially interested in broad usage of Landsat data and budget cuts caused the agency to withdraw its support for the Landsat 7 project to be undertaken with NASA. In May 1994, the White House relieved the DoD of its duties with Landsat and transferred its responsibilities to NASA per Presidential Decision Directive-3: the Landsat Remote Sensing Strategy.

In late 1993, the National Science and Technology Council reevaluated Landsat program management and its technical aspects. By May 1994, the White House established a strategy for Landsat. The aging Landsats 4 and 5 and the DoD withdrawal prompted the White House to promote new policy goals for the satellite program. The Landsat Remote Sensing Strategy committed the federal government to continue acquiring Landsat data, make data available at a cost of no more than required to meet user requests, and “promote and not preclude private sector commercial opportunities in Landsat-type remote sensing.”³⁹⁹ The directive charged four agencies with implementing the strategy, first with DoD transferring its duties to NASA and DOI with continuing its archiving activities at EROS. The White House also maintained NOAA, via DOC, as the managerial outfit for all current Landsats⁴⁰⁰ and future Landsats and charged it with coordinating with NASA to develop Landsat 7 and with USGS to operate it. The White House also directed NOAA to seek agreements with foreign ground stations to receive data. NASA’s role grew considerably after DoD’s withdrawal. Originally, NASA and DoD would conduct research and development on Landsat 7 jointly, but the space agency was left with this responsibility and to develop a strategy beyond Landsat 7. The White House provided greater clarity with the release of the National Space Policy (NSP).

³⁹⁹ Office of the Press Secretary, Presidential Decision Directive 3: Landsat Remote Sensing Strategy, 10 May 1994, <http://clinton3.nara.gov/WH/EOP/OSTP/NSTC/html/pdd3.html>, date accessed: 11 October 2016

⁴⁰⁰ At this juncture, NOAA’s contract with EOSAT was still in place which was operating Landsats 4 and 5. NOAA was the managerial outfit for Landsat, which was essentially contract oversight.

President Clinton unveiled his vision for space in September 1996. The NSP confirmed the White House's interest in revisiting commercialization as an option for Landsat operations while defining certain functions for the government. The NSP maintained the federal government's central space policy objectives which included a commitment to leadership in space science and technology and a space program that supports national security, economic growth, foreign policy, and, as Clinton's administration added, environmental stewardship. Thus, the NSP placed a greater emphasis on Earth observation "to better understand global change and the effect of natural and human influences on the environment."⁴⁰¹ The White House directed DOC, via NOAA, to coordinate remote sensing activities across the federal government and to acquire data from remote sensing satellites while USGS continued to operate EROS and support its functions as the land remote sensing data archive. Thus, in part, NSP supported the aforementioned USGCRP's mission to support and collect environmental data for scientific purposes. The NSP also discussed government use of the private sector for remote sensing data.

While the Policy Act of 1992 explicitly returned Landsat operations to federal government responsibility, the NSP advocated leveraging the private sector as an additional source of remote sensing data. As mentioned, the DOC began awarding licenses to potential commercial remote sensing satellite operators after the passage of the Policy Act of 1992, though no satellites were launched as of 1996. The NSP also committed the federal government to pursuing "technology development programs, including partnerships with industry" and "providing U.S. Government civil data to commercial firms on a nondiscriminatory basis to foster the growth of the 'value-added' data enhancement industry."⁴⁰² The value-added data

⁴⁰¹ White House National Science and Technology Council, "Fact Sheet: National Space Policy," 19 September 1996, <http://history.nasa.gov/appf2.pdf>, date accessed: 25 October 2016

⁴⁰² White House National Science and Technology Council, "Fact Sheet: National Space Policy," 19 September 1996, <http://history.nasa.gov/appf2.pdf>, date accessed: 25 October 2016

enhancement industry began to emerge to offer refined remote sensing data and data analysis products. Given its various obligations to both environmental concerns, technological leadership, and fostering a private sector, Congress responded to the White House's NSP and passed another major bill to address those issues. By late 1997, Congress took action again to bring stability to the Landsat program while also fostering not only a remote sensing industry, but more commercial space activity.

Passing the Commercial Space Act of 1998

In May 1997, several key senators presented H.R. 1702 to the House floor which went to the House Science Committee. The bill, referred to as the 'Commercial Space Act of 1997' identified several key aspects of American spaceflight activities primed for commercial opportunities. With H.R. 1702, Congress sought to promote commercial activities aboard the International Space Station, commercial space launches, Global Positioning Systems, and in remote sensing. In particular, the bill overhauled policy by encouraging acquisition of Earth science data from commercial providers. The bill specified NASA as the agency which would "acquire, where cost-effective, space-based and airborne Earth remote sensing, data, services, distribution, and applications."⁴⁰³ The passage of this section of law allowed the federal government to procure remote sensing data from the private sector, which had not previously been addressed in space policy or law. The bill also provided for a seventh Landsat, also previously left unaddressed.

The bill also put into law that the Landsat program and data be protected by law. H.R. 1702 rewrote a key section of the Policy Act of 1992 that addressed the design of Landsat 7.

⁴⁰³ Commercial Space Act of 1998, Title II, - P.L. 105-303, 28 October 1998, <https://www.nasa.gov/offices/ogc/commercial/CommercialSpaceActof1998.html>, date accessed: 25 October 2016

Originally, the Policy Act ambiguously legislated that Landsat 7 will be pursued by either the government, private sector or an international consortium.⁴⁰⁴ This language suggested no commitment to Landsat or data continuity beyond Landsat 7. However, the 105th Congress took action to commit the federal government Landsat. The Commercial Space Act of 1998 stated that Congress will ensure “the continuity of Landsat quality data.”⁴⁰⁵ For the first time, Landsat’s future was etched into legislation, albeit ambiguously. The Act prompted NASA and USGS to pursue a new goal for data continuity: data purchase rather than collection. In November 1997, the House passed the bill by voice vote and it went onto the Senate which did not address the bill for nearly a year. By October 1998, the Senate passed the bill by Unanimous Consent and President Clinton signed it into law on 28 October. Shortly after its passage, NASA sent the next Landsat into space.

Continuity through Cooperation: SPOT and USGS Agreement 1999-2001

In April 1999, NASA successfully launched Landsat 7 into orbit, again from Vandenberg Air Force Base. The satellite was jointly managed by NASA and USGS and featured new scanners offering data across several spectral bands. Landsat 5 remained a commercial operation though the satellite had aged considerably. Early on, Landsat 7 experienced trouble of its own as the scan line corrector, a critical component of the Enhanced Thematic Mapper, broke and returned skewed data. While ETM data was still serviceable through more robust processing methods, the component failure made many NASA officials and the user community question the longevity of Landsat 7 as fears of a gap in data grew steadily. NASA and USGS sought to find ways to make Landsat data more widely available without massive investments in large,

⁴⁰⁴ Land Remote Sensing Policy Act of 1992, 15 U.S.C. Chapter 82, <https://www.nasa.gov/offices/ogc/commercial/15uscchap82.html>, date accessed: 28 September 2016

⁴⁰⁵ Commercial Space Act of 1998, Title II, Section 201, Amendment C, 22 May 1997

singular spacecraft. The two agencies pursued this agenda in two broad ways: they sought to procure data and imagery from commercial and international sources and it reexamined commercializing Landsat.

While NASA readied Landsat 7 for launch in early 1999, it and USGS sought an alternative to launching large, singular satellite systems to sustain Landsat. Neither NASA nor Congress wanted to commit to more than one Landsat satellite at a time even though this threatened data continuity. Thus, NASA and USGS sought a solution predicated on *Landsat-like* data acquisitions from multiple sources even if the source was not a Landsat satellite. They recognized that there was a growing market of commercial and foreign land remote sensing satellite systems and data from which it could procure imagery. As mentioned, USGS began acquiring data from the intelligence community but also sought to leverage the domestic and international market of remotely sensed data.

In 1986, the French launched the first SPOT satellite with several follow-on SPOTs orbited in 1990, 1993, and 1998 and a fifth SPOT planned for 2002. The SPOT satellites offered multispectral image products at six meter resolution across similar bands to Landsat, though with less spatial coverage at sixty square kilometers. Essentially its resolution was generally five times better than Landsat but with a viewpoint three times less than Landsat. SPOT was a public-private partnership between the Centre National d'Etudes Spatiales (CNES, the French space agency) and SPOT Image, a Toulouse-based data and information firm. SPOT Image also established a US presence with an office in Reston, Virginia near the USGS Headquarters. In the previous chapter, I demonstrated how SPOT image sales outstripped Landsat sales into the 1990s. USGS recognized SPOT's success and sought to set up a data acquisition agreement. In October 1998, USGS and SPOT Image Corporation signed a cooperative Memorandum of

Agreement to acquire, preserve, and distribute SPOT data via EROS. Theodore Nanz, President of SPOT Image wrote to Donald Lauer, EROS Chief stating “all of us at SPOT look forward to forging a strong mutually beneficial relationship between our two entities.”⁴⁰⁶

The agreement served both institutions’ interests: EROS’s mission to collect and archive Earth imagery and SPOT’s mission to make imagery available. In particular, the agreement ensured “the long-term management and preservation of SPOT satellite data and assist the broadest spectrum of users in obtaining timely access to SPOT data for monitoring global, regional, and local changes in natural resources and the environment.”⁴⁰⁷ SPOT made all of its acquired data from 1986 to 1998 available to EROS for archiving and preservation, joint use of EROS equipment, and open consultation between EROS and SPOT on technical and managerial matters. The agreement also stated that both parties will compensate each other for services rendered and both will make best efforts to minimize costs. Richard Witmer, Chief of USGS’s National Mapping Division and Theodore Nanz signed the agreement on 4 August 1998 which took effect in October and lasted for three years. The United States sought to leverage the success of the French SPOT series while also encouraging a private sector of its own, despite its struggles with EOSAT and Landsat data continuity more broadly.

Commitment to Continuity: Formation of the Landsat Data Continuity Mission, 2001-2003

Congress and the White House left the particulars of Landsat data continuity to federal agencies, but struggled to find a working model throughout the 1990s. But in late 2001, NASA

⁴⁰⁶ Memo, Theodore Nanz to Donald Lauer, 2 October 1998, document courtesy of John Faundeen, EROS, Sioux Falls, SD

⁴⁰⁷ Memorandum of Agreement between the U.S. Geological Survey and SPOT Image Corporation for Cooperation in the Management, Preservation, and Distribution of SPOT Satellite Data, signed 4 August 1998, document courtesy of John Faundeen, EROS, Sioux Falls, SD

and USGS struck an agreement to jointly manage the Landsat program and ensure data continuity and availability, primarily through commercial means.

The USGS and NASA's Office of Earth Science entered a partnership to procure Landsat-quality data "which meets both NASA and DOI/USGS scientific and operational requirements for observing land use and land change, which include supporting the U.S. Global Change Research Program" and will be "provided to the Government by the private sector via a to-be-determined means, presumably using one or more satellites."⁴⁰⁸ The objective of the agreement was to sustain continuity and availability of Landsat data while striking a balance between the necessity of Landsat data to government and academia with the lack of an independent moderate-resolution commercial imagery business. Essentially what NASA and USGS proposed as an alternative to a government run satellite series was to purchase and collect Landsat-like data from one or multiple commercial providers and make the data available to government agencies and academic investigators via USGS. This joint NASA/USGS initiative assumed the title of Landsat Data Continuity Mission (LDCM).

In order to implement LDCM, NASA and USGS agreed to a list of responsibilities and work within appropriated funds from Congress. For its part, NASA agreed to calibrate and validate data reception and lead data procurement. USGS assumed responsibility for data archiving, accessing, processing, and distributing data via EROS. Jointly, the agencies established a science team to analyze data and a formulation team for acquisitions, provided financial support to for their agency's personnel, and acquired data through a vendor mutually agreed upon. On 25 October 2001, NASA Associate Administrator for the Office of Earth Science Ghassem Asrar and USGS Director Charles Groat signed the Initial Implementation

⁴⁰⁸ Initial Implementation Agreement Between the National Aeronautics and Space Administration Office of Earth Science and the U.S. Department of the Interior United States Geological Survey for a Landsat Data Continuity Mission, signed 1 November 2001, document courtesy of Raymond Byrnes, USGS Headquarters, Reston, VA

Agreement authorizing their participation in the Landsat Data Continuity Mission. First, the agencies needed assess private sector interest in land remote sensing.

EOSAT, nearing the end of its contract with DOC as Landsat 5 aged and expressed no interest building Landsat 7. WorldView's Earlybird had taken flight while other private firms readied systems for launch. Moreover, a large industry emerged alongside the satellite systems business, the data processing industry. NASA and USGS began to explore methods to acquire remotely sensed Earth imagery without major investments in singular satellite systems. In mid-1999, the two agencies issued a Request for Information and reviewed it in the summer of 1999.

NASA's Landsat Program Executive Dr. Charles Wende and USGS Earth scientist Bruce Quirk surveyed industry and academia requesting its interest in a commercial data purchase for the government.⁴⁰⁹ The ROI revealed that none of the respondents believed that Landsat data itself had an economically viable commercial market and a data purchase was preferable from contractor owned space and ground systems, and only one contractor planning to launch a satellite met Landsat continuity standards which included 30 meter resolution imagery collected continuously and within NASA and USGS specified spectral bands.⁴¹⁰ The standards also required certain numbers of images collected per day of specific scene sizes. Since industry did not view Landsat itself as a commercially viable program, NASA and USGS began to draw up a Request for Proposals and organize industry workshops for a commercial data buy, rather than pursue government procurement of satellites beyond Landsat 7.

At the NASA/USGS industry workshops, attended by over 200 individuals and run by Charles Wende and USGS Landsat program official Raymond Byrnes, the agencies revealed

⁴⁰⁹ Industry included Space Imaging, Orbital Imaging Corporation, TRW Space and Electronics Group, Lockheed Martin Management, Lockheed Missiles, Raytheon, Resource21, and SPOT Image Corporation. Academia included University of Virginia, University of Maryland, College Park, and Michigan State University.

⁴¹⁰ Presentation, "Assessment of Landsat Continuity Mission Request for Information Responses," 15 October 1999, document courtesy of Raymond Byrnes, USGS Headquarters, Reston, VA

their findings from the previously mentioned industry survey conducted by Wende and Quirk. NASA and USGS found that non-discriminatory data access policy was favorable, that longer term deals are preferable such as ten-year data purchases and long-term strategies for satellite procurement, and industry favored international collaboration. The survey also revealed to NASA and USGS that “there was consensus among data providers that there is no viable commercial market for 30m data.”⁴¹¹ Industry players also concurred that longer term plans, such as ten year data purchasing plans (rather than five years or less) are preferable in addition to a long term land remote sensing program plan beyond Landsat 7. The survey also demanded technical improvements to Landsat such as the addition of a thermal imaging band, decrease revisit time (Landsat 7 had a revisit time of 16 days), and sustain Landsat’s calibration.

As these meetings took place, DOC already began awarding licenses for flying remote sensing satellites to industry. Among the twenty-four licenses awarded by NOAA for commercial remote sensing systems, one went to Boeing for a joint company called Resource21. Boeing, alongside BAE Systems, Farmland Industries, and the Mississippi-based Institute for Technology Development formed Resource21 as a remote sensing satellite development project. Boeing envisioned Resources21 as a remote sensing information project planned to prime the market and provide remote sensing data for use in natural resources, national security, and by the scientific community. Resource21’s business model primarily targeted agricultural users who relied on aerial photography. The consortium also sought to launch a satellite closely based on Landsat specifications, and move into data distribution. Ball Aerospace and Technologies Corporation agreed to build the proposed spacecraft which would be similar to Landsat with the capability of acquiring 30-meter resolution imagery continuously.

⁴¹¹ Meeting minutes, Second Landsat Data Continuity Mission (LDCM) Workshop, St. Louis, MO, 23-24 April 2001, document courtesy of Raymond Byrnes, USGS Headquarters, Reston, VA

Colorado-based DigitalGlobe also announced it would compete for the LDCM bid. As mentioned, it flew the first commercial remote sensing satellite called Earlybird. In early 2002, DigitalGlobe already had QuickBird, a high-resolution remote sensing satellite flying and it sold imagery to the U.S. military, especially with combat operations being conducted in Iraq. Given their interest in the LDCM bid, NASA awarded both Resource21 and DigitalGlobe a \$5 million study grant to draw up a business model and technical specifications. NASA ran the LDCM bid competition on behalf of USGS and set a deadline of 25 February 2002.

In February 2002, as Resource21 submitted its bid for Landsat operations, DigitalGlobe shocked the industry and pulled its application. The company's chief executive officer Herb Satterlee stated that the "the concern was the structure of the contract [which] put all the risk on the contractor, much more so than if NASA had just gone out and procured a satellite."⁴¹² Satterlee believed the contract drawn up by NASA placed too much risk on the company and ultimately put them out of business. Satterlee was skeptical that operating Landsat commercially alongside QuickBird would turn a profit. Neither NASA nor USGS commented on the withdrawal but EROS Director R.J. Thompson feared "what message this might send to Congress or [OMB]...the perception that it is not a commercially viable activity could certainly have an impact on how a mission or program like this is viewed."⁴¹³ This left NASA with only the Resource21 bid to consider.

By September 2002, NASA notified Resource21 that it had rejected its bid to commercialize the Landsat program. The Colorado-based remote sensing firm submitted a \$595 million bid to NASA to fly a Landsat-like satellite and provide 30 meter resolution to the federal

⁴¹² Jason Bates, "DigitalGlobe Abandons Landsat: No-Bid Decision Casts Doubt on Commercialization Effort," 31 March 2003, *Space News International*, periodical courtesy of Raymond Byrnes, USGS Headquarters, Reston, VA

⁴¹³ Jason Bates, "DigitalGlobe Abandons Landsat: No-Bid Decision Casts Doubt on Commercialization Effort," 31 March 2003, *Space News International*, periodical courtesy of Raymond Byrnes, USGS Headquarters, Reston, VA

government for five years.⁴¹⁴ The bid also included a clause stating that Resource21 would replace a faulty satellite within two years. By comparison, Landsat 7 cost \$700 million plus \$20 million a year for operations. The move by NASA shocked the industry as it left Landsat with little clarity as to its future as a program. NASA Associate Administrator for the Office of Earth Science Ghassem Asrar and his team of evaluators at NASA “explored every avenue for making this partnership arrangement a success and in the end we could not reach that stage.”⁴¹⁵ While the rejection came despite a lack of competition, Asrar further stated that a commercial data buy remained an option that a “government owned and operated satellite remains his ‘least desired option’” and that an international consortium was also under consideration.⁴¹⁶ Samuel Goward, former Landsat science team leader and University of Maryland Professor of Geography expressed concerns similar to that of Thompson mentioned above. Goward believed that the rejection may send the message to policymakers that Landsat was not desirable as a program and added that the rejection was a potentially longer delay on the next satellite in the series that may lead to a gap in the data record.⁴¹⁷ By the end of 2002, Landsat 5 had aged well beyond its expected lifetime and Landsat 7 already experienced difficulties from a broken scan line corrector that obscured much of the data it downlinked. Resource21 fought the rejection.

Resource21 President and CEO Vic Leonard immediately lobbied the space agency to reconsider its decision. Leonard, backed by Boeing Company argued that his offer of \$595 million to provide five years of Landsat data was fair, yet NASA claimed the deal “amounted to the government shouldering the entire cost of building and operating a private owned

⁴¹⁴ Brian Berger and Jason Bates, “Resource21 Lobbies For NASA To Reconsider Landsat Bid,” 28 October 2003, *Space News International*

⁴¹⁵ Brian Berger, “NASA Rejects Only Bid For Landsat Data Buy Contract,” 29 September 2003, *Space News International*, periodical courtesy of Raymond Byrnes, USGS Headquarters, Reston, VA

⁴¹⁶ Brian Berger, “NASA Rejects Only Bid For Landsat Data Buy Contract,” 29 September 2003, *Space News International*, periodical courtesy of Raymond Byrnes, USGS Headquarters, Reston, VA

⁴¹⁷ Brian Berger, “NASA Rejects Only Bid For Landsat Data Buy Contract,” 29 September 2003, *Space News International*, periodical courtesy of Raymond Byrnes, USGS Headquarters, Reston, VA

satellite.”⁴¹⁸ Resource21 claimed it spent \$89 million on research and development, planned another \$183 million in investments and debt, assumed operational costs, and it offered government access to 10 meter resolution data from a separate instrument aboard the proposed satellite system.⁴¹⁹ Leonard stated that Resource21 offered a \$145 million discount to NASA and a higher performance system than Landsat 7. However, NASA’s Asrar did not view the discount as significant enough and expressed no interest in the 10 meter resolution imagery, without further comment. Resource21 led by Leonard disputed the rejection unsuccessfully. By the end of 2003, Resource21 ceased operations having failed to secure government funding or contracts for data purchases.

After the LDCM bid period and Resource21 rejection, the federal government again revised its remote sensing policy. The Bush White House authorized the U.S. Commercial Remote Sensing Policy in April 2003 (CRS Policy) which superseded Clinton’s PDD-23 from 1994. While the new policy reinforced many of the United States’ goals for Landsat and commercial remote sensing broadly such as American leadership, preserving national security, and enhancing industry, it rewrote several key aspects of remote sensing policy. The goal of the CRS Policy was to “foster economic growth, contribute to environmental stewardship, and enable scientific and technological excellence.”⁴²⁰ The policy required the government to both foster and utilize where possible the commercial sector for remote sensing systems and data. But the policy still did not make a commitment to a follow-on Landsat satellite. Still, NASA and

⁴¹⁸ Brian Berger and Jason Bates, “Resource21 Lobbies For NASA To Reconsider Landsat Bid,” 28 October 2003, *Space News International*

⁴¹⁹ Brian Berger and Jason Bates, “Resource21 Lobbies For NASA To Reconsider Landsat Bid,” 28 October 2003, *Space News International*

⁴²⁰ NOAA, “Commercial Remote Sensing Policy,” 25 April 2003, <http://www.nesdis.noaa.gov/CRSRA/files/Commercial%20Remote%20Sensing%20Policy%202003.pdf>, date accessed: 18 October 2016

USGS as well as the Landsat data user community remained concerned about data continuity and availability given an aged Landsat 5 and broken Landsat 7.

Concluding the Commitment

In the 1990s and early 2000s, the federal government considered many options for Landsat operation and management that would meet both user requirements and government objectives cost-effectively. After the LDCM bid period in 2003 that yielded no successful bids, the DoD returned to the table after having established a relationship with DOC and NASA under Clinton PDD-23. In 2003, the White House Office of Science and Technology Policy (OSTP) recommended that Landsat sensors be placed aboard a large multi-instrument environmental satellite combined with weather satellite sensors. The agencies developed a plan to converge the civilian and defense satellites onto one platform called the National Polar Orbiting Environmental Satellite System (NPOESS). Not long after the plan materialized, the DoD withdrew from the project to continue operating its own weather satellite constellation. Following a technical evaluation, OSTP formally directed NASA to pursue and build an eighth Landsat satellite, solidifying the White House's commitment to LDCM and the Landsat program itself.

Between 1992 and 2003, the federal government remained committed to Landsat, but disagreed over what form it should take whether as a public or private entity or even as a satellite program in general. Immediately after the Policy Act of 1992, Landsats 4, 5, and 6 were commercial but any future Landsats 7 would be government entities operated by NASA and USGS. EROS's role remained to archive land remote sensing data throughout this time period though it began to procure not only Landsat imagery, but also imagery from other environmental

satellites and SPOT. Throughout the 1990s and 2000s, the federal government also fostered a commercial sector that came to separate itself from Landsat in terms of products. EarlyBird and IKONOS were some of the first commercial remote sensing satellites, but produced high resolution imagery effectively creating a new niche in the remote sensing data market. Meanwhile, Landsat filled a market niche of its own with its moderate resolution data with the value added component of its multi-decade long archive of imagery held at EROS. Despite NASA and USGS collaboration and strong user community interest in Landsat, Congress never sought to commit to more than one Landsat satellite at a time. Moreover, constrained federal agency budgets complicated commitments to Landsat. Twice between 1992 and 2003, DoD participated in planning future Landsats, but ultimately pulled away. NASA's constrained budget broadly partially due to budget cuts and partially due to the 'Faster, Better, Cheaper' initiative prompted the agency to approach Landsat with reticence. The federal government sought to reorganize Landsat as a public-private partnership between NASA, USGS, and a private sector it fostered. Throughout this time period, the federal government remained committed to data continuity and availability, but sought to cut costs through different management structures that leveraged privately obtainable assets. Despite the numerous forms Landsat took in the 1990s and early 2000s, NASA and USGS have sustained Landsat 7 and successfully launched Landsat 8 in 2013.

Conclusion: Preserving Continuity Through Change

Lessons of Landsat, 1953-2003

Historians of technology are producing a growing literature that explores how technologies are used in society. The use and availability of a particular technology however is shaped by the political forces in which it was developed. I analyzed how politics and policies, mostly in the United States but to some extent internationally, shaped the use of environmental data gathered by Landsat's multispectral scanning instruments. In 1969, President Nixon gave a speech to the United Nations General Assembly speaking of Earth observation satellites that will better humanity and will be available to all. While his speech to the UN was hardly a policy initiative, it prescribed a non-discriminatory data access policy for Landsat imagery; a policy which would make data available to anyone. Throughout the history of Landsat, NASA and USGS sought to provide Landsat data to users as openly as possible. As I argue in this thesis, a non-discriminatory data access policy proved immensely difficult to achieve due to many political and policy factors. "Farming in the Space Age" demonstrated the limits of the technology itself in agricultural experimentation through use by the scientific community and the intelligence agencies. "Demonstrating the Value of Remote Sensing from Space" detailed the difficulties of fostering use abroad in developing countries and the challenges of ground station export. "Landsat For Sale" showed how Landsat failed as a commercial entity and drove away use through cost prohibitive data pricing. "Commitment to Continuity" demonstrated how funding crises and managerial turnover caused the satellite program to nearly end altogether. Furthermore, technical failures corrupted Landsat collection from Landsat 7. Each of these challenges limited the extent to which users had access to Landsat data. I contextualized these

technical and managerial difficulties within broader political environments that characterized the four eras of Landsat history I outlined in this dissertation.

The first era of Landsat history is its prelaunch years, largely captured in the first chapter. In the first era, the scientific community and Navy became interested in multispectral technology since it provided agricultural information detailing the health of crops. From this user base of agricultural scientists, multispectral imagery increasingly was used by scientists, the military, and the intelligence community across many applications in the environmental sciences. Thus the first era, the Pre-Launch Years, is characterized by research and development and finding a user community. In the second era I call the Experimental Years, a growing user community in the US and abroad experimented with satellite imagery in many applications following the launch of Landsat 1 in 1972. NASA, USAID, and private contractors orchestrated foreign assistance programs to facilitate use abroad in addition to establishing memoranda of understanding for ground stations abroad. “Demonstrating the Value of Remote Sensing” showed how NASA and its many partners adopted policies that expanded Landsat data use in the 1970s. Once it became apparent that the data was useful, the White House saw a satellite program ripe for commercialization. During the third era, the Commercialization Years, Landsat transforms into a private entity that ultimately fails due to a market still in its infancy, a viciously frugal federal government, and poor management and contract oversight. This era is covered in “Landsat For Sale” which revealed that Landsat imagery was cost prohibitive to its users. With Landsat on the ropes, Congress returned Landsat to federal government operations and began to experiment with several program management schemes. The fourth era is the Partnership Years in which Landsat endured funding crises, numerous policy and management changes, and more commercialization initiatives due to the federal government’s attempts to build a partnership

with a growing private sector. Throughout this narrative, NASA and USGS continually made Landsat data available and yielded several lessons for historians and policy alike.

History of technology often considers the political and economic context of a particular technology, but it should also show how it is used. This dissertation considered how politics and policies shape the use of a particular technology. Several key governmental outfits including the White House, Congress, and federal government, and UN each played important roles deciding how Landsat's data would be used and by whom which informs both history of science given the regulation of scientific data and political history given the impact of the presidency and Congress on federal government operations. This dissertation also demonstrated how space technologies are used in society and made available to the taxpayers that initially funded them. The story of Landsat also informs Cold War history and agricultural history, as in Chapter 1, the two become intertwined as the intelligence community used Landsat to predict Soviet crop yields to stay competitive in the global agricultural market. The policy story also provides four particular lessons for policy.

The first lesson of Landsat is that it is difficult to transition a scientific public good to a privately sold commodity. Initially, NASA and USGS made Landsat available publicly through various means but as the cost burden of the satellite moved to the private sector, data and imagery prices increased to cost prohibitive levels. Thus, Landsat, just as the weather satellite constellation has always been, remains a publicly run government operation. A second, closely related lesson is that the designations of experimental and operational require careful consideration when transitioning a government project from one to the other. In 1978, the Carter administration declared Landsat operational, a designation outside the lawful scope of NASA but within that of USGS and NOAA. The story of Landsat demonstrates that transition plans require

careful coordination of appropriate government agencies, leadership, and managerial and budgetary commitment. Landsat's third lesson is that it demonstrates how commercialization is a highly politicized, non-linear process, as opposed to a product. Commercialization became a long political process began by President Carter and took the form of legislation and a contract between NOAA and EOSAT. When the government reconsidered commercialization in the 1990s and early 2000s, after a series of presidential directives and a bidding period, industry did not meet the requirements of government and was ultimately rejected. Lastly, despite Landsat's broad range of applications, the market for moderate resolution satellite data and imagery never fully materialized. While Chapter 4 demonstrates how *high* resolution satellite imagery steadily grew, *moderate* resolution imagery never became a profitable industry. Moreover, Chapter 3 demonstrated how the Reagan Administration stifled development in moderate resolution imagery since it refused to fund Landsat or provide timely subsidies to EOSAT. The story of Landsat provides many lessons as well as future research areas.

Epilogue

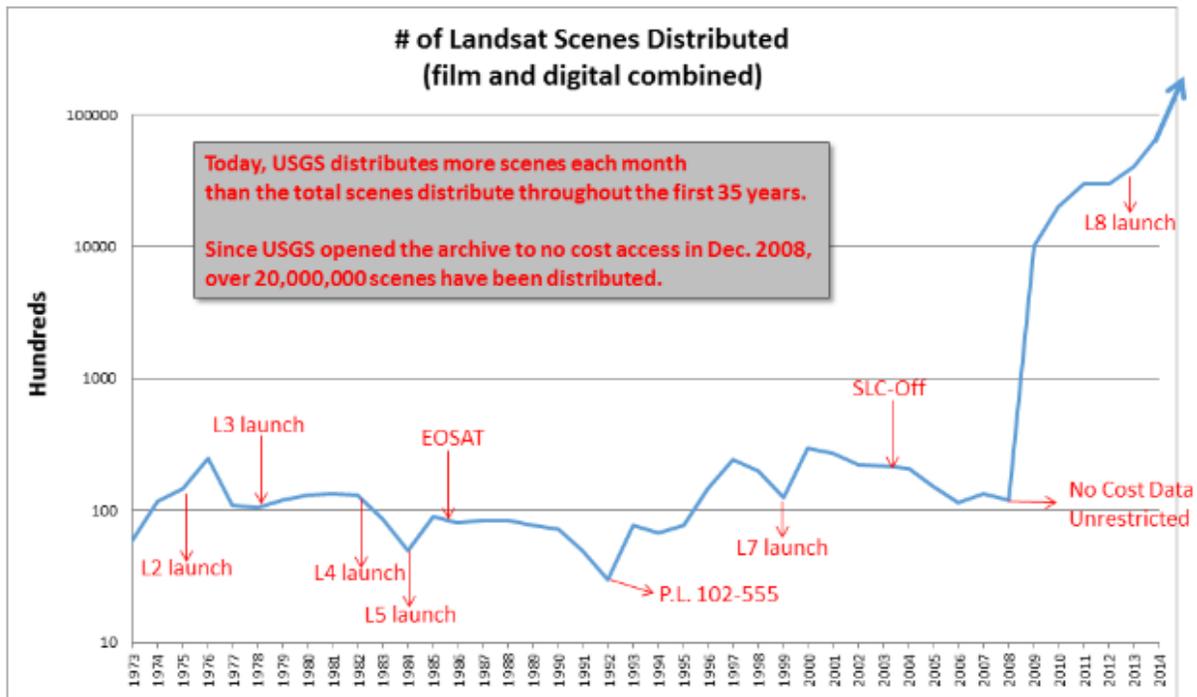
As mentioned in Chapter 4, the White House revived the Landsat Data Continuity Mission and committed the federal government to an eight Landsat satellite. NASA and USGS collaboratively managed and operated Landsat 8 and contracted out construction of the satellite to Orbital Sciences Corporation and instrument research and development to Ball Aerospace, mentioned in Chapter 4. Both Landsat 7 and 8 operate today, downlinking Landsat data to a global ground station network every eight days. While the two satellites demonstrate the continuity of data, it was DOI that made Landsat data more available than ever in December 2008.

USGS took its most significant step towards fully non-discriminatory data access.

Secretary of the Interior Dirk Kempthorne officially announced that all Landsat data would be available via the internet and *free of charge*. Even though the decision implied a roughly \$10 million loss in annual income, the user community quickly reacted and requested Landsat data more than it ever had.

Table 10: Landsat Scenes Distributed, 1972-2014

Landsat Scenes Distributed by EROS as of 2014, chart courtesy of John Faundeen, USGS EROS



The above chart, provided by EROS, shows the total number of scenes distributed by EROS since its opening in 1973. The chart depicts many major points in Landsat's history that led to either increases or decreases in data usage. Commercialization in the 1980s and the funding crises of the early 1990s coincided with decreases in data acquisition. The launches of Landsats 2, 5, and 7 and the Policy Act of 1992 prompted increased Landsat data acquisition. However, in December 2008 with the no-charge free access to Landsat imagery, USGS distributed more

Landsat data than ever within a month. Kempthorne's policy to make Landsat data readily available for free via internet download allowed the Landsat data archive to reach all potential users, as President Nixon suggested it should in his 1969 speech to the UN.

Four years after the DOI opened the Landsat archive to the world free of charge, NASA launched the eighth Landsat satellite. It was the conclusion of the LDCM that featured an entirely new array of scanners that featured an Operational Land Imager (OLI) and a Thermal Infrared Scanner (TIRS) built in partnership with Ball Aerospace and Goddard Spaceflight Center. Meanwhile, USGS continues its many Landsat-related data collection, archiving, and dissemination practices. In 2010, USGS formalized its data repatriation efforts into a project entitled the Landsat Global Archive Consolidation (LGAC). EROS began a project to make all Landsat data from USGS International Cooperators available. As a critical component of LDCM, USGS and NASA began to repatriate Landsat data from ICs. The project, spearheaded by EROS, became known as the Landsat Global Archive Consolidation (LGAC). As previously described, EROS housed nearly three decades of Landsat data, in addition to collections of aerial photography dating back to 1930 and declassified reconnaissance imagery from the Corona satellites. A vast majority of this imagery collection was of the United States and EROS held very little international cartography. In Chapter 2, I discussed several details of the Memoranda of Understanding NASA and USGS signed with International Cooperators to establish ground stations abroad. Even though ground stations received data from American satellites, neither NASA nor USGS required the ICs to repatriate data to the United States. A few ground stations did so sparingly while EROS collected data through second hand sources, such as scientific publications or through collaborative projects. While Canada and ESA repatriated data early on in the 1970s, USGS formally set up LGAC in 2010 to build its archive further with a more global

data set. As mentioned in the previous chapter, ICs were not obligated to repatriate Landsat imagery, but during my visit to EROS, its staff praised the project as a success as many countries have returned millions of images. As of January 2015, USGS held 5,532,454 Landsat images and approximately 3.2 million of them came as a result of LGAC.⁴²¹ Just ahead of my visit in May 2015, EROS received shipments from International Cooperators in China, Indonesia, and Pakistan.

Landsat uses and users have expanded well beyond its original starting point with agricultural users in the 1960s. Landsat captured imagery of the receding rainforest in the Amazonian basin, the Chernobyl accident in the Soviet Union, human rights abuses in Africa and North Korea, and melting glaciers in the Polar regions. While the 2008 decision to open the Landsat data archive proved to be a boon for scientific research and the Presidency declared a commitment to data continuity, some issues remain and new ones emerge. As a publicly funded government project and operation, Landsat has long been subject to budget cuts as demonstrated in this dissertation, but other political issues as well. Political forces from the political ‘right’ deemphasize Earth sciences missions given their association with understanding climate change. Some elected officials ‘do not believe’ in climate change and thus are reluctant to fund projects that contribute towards a better understanding of the blatantly obvious transformations the planet’s environment is undergoing. In addition, there is renewed interest in human spaceflight at NASA and on Capitol Hill in the wake of the Shuttle program shutdown and increased use of Russian and commercial launch vehicles. In this case, Landsat’s priority dropped below that of

⁴²¹ Michael Wulder, Joanne White, Thomas Loveland, Curtis Woodcock, Alan Belward, Warren Cohen, Eugene Fosnight, Jerad Shaw, Jeffrey Masek, and David Roy, “The global Landsat archive: Status: consolidation, and direction,” *Remote Sensing of Environment*, 2 December 2015, <http://landsat.usgs.gov/documents/1-s2.0-S0034425715302194-main.pdf>, date accessed: 27 October 2016

other, higher cost and higher public visibility programs. Another potential issue is competition and obsolescence from both the private sector and international operators.

While Landsat has provided moderate-resolution satellite data and imagery, other countries began to launch Earth remote sensing satellites of their own. The price hike and managerial issues mentioned in Chapter 3 offered an opportunity for the French SPOT satellites to break into the remote sensing data market. On 22 February 1986, an Ariane 1 carried SPOT-1 into sun-synchronous orbit and returned 10 meter resolution Earth imagery to Earth and the French have since launched several more satellites mentioned previously in this dissertation. As the federal government commercialized Landsat and the French readied SPOT for launch in Kourou, Brazil and China collaboratively entered the remote sensing race as well.

In May 1984, the China Academy of Space Technology signed an agreement with the Brazilian INPE to collaborate in the area of remote sensing technology. The cooperative venture came to greater fruition in July 1988 when the two governments agreed to establish the joint research and development China-Brazil Earth Resources Satellites (CBERS) program. The agreement, the Complementary Protocol on Cooperation on Space Technology has been renewed twice in 1994 and 2004. Initially, the China Academy of Space Technology and INPE launched two satellites, Zi Yuan 1 launched 14 October 1999 and functioned until August 2003 while Zi Yuan-2 was launched 21 October 2003 and retired in January 2009. These satellites, also called CBERS-1 and CBERS-2 respectively, were the first two CBERS satellites and they carried infrared cameras as well as a global positioning system and an onboard recorder. Both CBERS satellites followed the same orbit as Landsat, a sun-synchronous orbit at 98.5 degrees. However, with an altitude of roughly 778 kilometers, its repeat time was slower at 26 days. The Chinese and Brazilians went on to launch two more satellites under its agreements.

For the Brazilians, it was their first land remote sensing satellite. Brazil's particular interest in CBERS originated from the necessity to monitor the Amazon rainforest. Since 1973, the Brazilians relied on Landsat imagery gathered from its indigenous ground station in Cuiaba. The Brazilian Science Ministry began using Landsat data to monitor the forest, with particular attention to illicit logging, mining, and narcotics trafficking. Governmental changes in 1988 prompted an expansion in national security imperatives which included the health of the rainforest which comprised a third of the Brazilian landscape. CBERS-1 allowed the ministry to use domestic high-resolution satellite imagery to combat these activities.⁴²² CBERS was the first internationally cooperative remote sensing satellite system followed years later by ESA's European Remote Sensing Satellite in 1991. The mutually beneficial agreement between Brazil and China remains in place today. Since the launches of SPOT and CBERS, many other countries, such as India, Russia, Japan, among others, began to develop and launch remote sensing satellites in the 1990s.

Since the launch of ERTS-A, or Landsat 1 in July 1972, seven more satellites (nearly) flew and five different institutions managed its operations. Over the past 44 years, the US federal government and several private sector firms invested billions of dollars to collect, process, archive, enhance, and disseminate imagery of the Earth's surface across multiple spectral bands from vendors in the US government and private industry. An ISI Web of Science search with 'Landsat' as a key word returned over 18,000 publications in 930 journals. The journals focused in areas such as engineering, physics, geography, information science, and the environmental sciences such as hydrology, geology, forestry, and glaciology, among many others. Many were international journals and foreign journals from China, France, Brazil, Germany, Saudi Arabia,

⁴²² Robert C. Harding, *Space Policy in Developing Countries: The search for security and development on the final frontier*, (Routledge 2013) pgs. 117-119

and Canada, among others. The use of the satellite series and its data has had a strong impact on the environmental sciences as well as on fostering new markets in the aerospace industry through use. At the time of writing, NASA and USGS are preparing for a Landsat 9 launch within the next five years to carry on the Landsat lineage of Earth observation.

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