A Phase I Final Report

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Principle Investigator: Robert Stockwell, PhD.

Project Title: Dissemination of climate model output to the public and commercial sector.

Topic number: 47: Scientific Visualization and Data Understanding
Subtopic: a: Collaborative Data Analysis and Visualization.

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1 Introduction - The Motivation for Climate Data Visualization

Climate is defined by the Glossary of Meteorology as the mean of atmospheric variables over a period of time ranging from as short as a few months to multiple years and longer. Although the term climate is often used to refer to long-term weather statistics, the broader definition of climate is the time evolution of a system consisting of the atmosphere, hydrosphere, lithosphere, and biosphere. Physical, chemical, and biological processes are involved in interactions among the components of the climate system. Vegetation, soil moisture, and glaciers are part of the climate system in addition to the usually considered temperature and precipitation (Pielke, 2008).

Climate *change* refers to any systematic change in the long-term statistics of climate elements (such as temperature, pressure, or winds) sustained over several decades or longer. Climate change can be initiated by external forces, such as cyclical variations in the Earth's solar orbit that are thought to have caused glacial and interglacial periods within the last 2 million years (Milankovitch, 1941). However, a linear response to astronomical forcing does not explain many other observed glacial and interglacial cycles (Petit et al., 1999). It is now understood that climate is influenced by the interaction of solar radiation with atmospheric greenhouse gasses (e.g., carbon dioxide, chlorofluorocarbons, methane, nitrous oxide, etc.), aerosols (airborne particles), and Earth's surface. A significant aspect of climate are the interannual cycles, such as the El Nino La Nina cycle which profoundly affects the weather in North America but is outside the scope of weather forecasts. Some of the most significant advances in understanding climate change have evolved from the recognition of the influence of ocean circulations upon the atmosphere (IPCC, 2007).

Human activity can affect the climate system through increasing concentrations of atmospheric greenhouse gases, air pollution, increasing concentrations of aerosol, and land alteration. A particular concern is that atmospheric levels of CO_2 may be rising faster than at any time in Earth's history, except possibly following rare events like impacts from large extraterrestrial objects (AMS, 2007). Atmospheric CO_2 concentrations have increased since the mid-1700s through fossil fuel burning and changes in land use, with more than 80% of this increase occurring since 1900. The increased levels of CO_2 will remain in the atmosphere for hundreds to thousands of years. The complexity of the climate system makes it difficult to predict specific aspects of human-induced climate change, such as exactly how and where changes will occur, and their magnitude.

The Intergovernmental Panel for Climate Change (IPCC) was established by World Meteorological Organization (WMO) and the United Nations in 1988. The IPCC was tasked with assessing the scientific, technical and socioeconomic information needed to understand the risk of human-induced climate change, its observed and projected impacts, and options for adaptation and mitigation. The IPCC concluded in its Fourth Assessment Report (AR4) that warming of the climate system is unequivocal, and that most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increased in anthropogenic greenhouse gas concentrations (IPCC, 2007). (A more complete listing of climate change detection is found in Table 9.4 of the AR4.)

Figure 1 is from the Goddard Institute for Space Studies Web Site (`http://data.giss.nasa.gov/gistemp/2007/`). It is colloquially referred to as the "hockey stick," and shows the rapid increase in surface temperature over the past decade. This figure is probably one of the most politi-

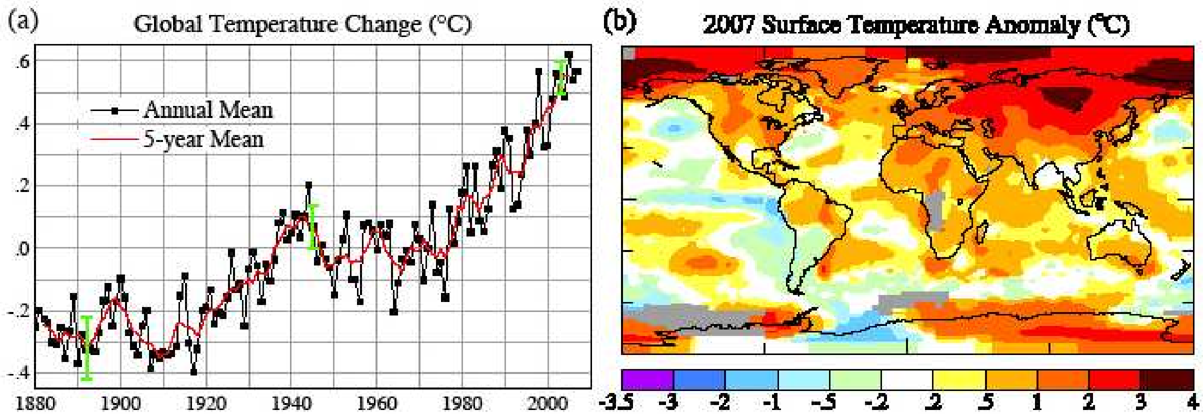

Figure 1: (a) Annual surface temperature anomaly relative to 1951-1980 mean, based on surface air measurements at meteorological stations and ship and satellite measurements of sea surface temperature. (b) Global map of surface temperature anomalies for 2007.

cized in science, and attempts have been made to discredit the science. However, the US National Academy of Science has released a report that basically affirms the findings (Nature (2006), vol. 441, p. 1032)

Shown are 2007 temperature anomalies relative to the 1951-1980 base period mean. The global mean temperature anomaly, 0.57C (about 1F) warmer than the 1951-1980 mean, continues the strong warming trend of the past thirty years that has been confidently attributed to the effect of increasing human-made greenhouse gases (GHGs) (Hansen et al. 2007). The eight warmest years in the GISS record have all occurred since 1998, and the 14 warmest years in the record have all occurred since 1990.

Regional temperature increases are affecting natural systems such as hydrologic systems (exhibiting increased run-off in glacier- and snow-fed rivers), Arctic and Antarctic ecosystems, and terrestrial biological systems (i.e. earlier leaf-unfolding, bird migration, and egg-laying). The IPCC AR4 also notes that climate change can be surprisingly rapid. The findings of the IPCC are based upon observational evidence of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level. The AR4 also relied upon evaluations and intercomparisons of state of the art, coupled atmosphere-ocean climate models.

While the global effects of climate change are indeed alarming, they exceed the horizon of a typical business's financial outlook. However, the regional and short term effects, in addition to changes in the well known climate variability, can have a profound effect on a business in a number of ways. It can effect future project planning, land development projects, and risk mitigation strategies.

Climate change has implications for the world's water and food supplies, energy, civil infrastructure in flood-prone regions, settlement patterns, business, and health. Several institutions have developed excellent websites for distribution of climate model products. Among these are the Program for Climate Model Diagnosis and Intercomparison (PCMDI) at the Lawrence Livermore National Laboratory (LLNL) (`http://www-pcmdi.llnl.gov`), the Community Climate System Model

(CCSM) at National Center for Atmospheric Research (NCAR, http://www.ccsm.ucar.edu/), the Hadley Center of the UK Met Office (http://www.metoffice.gov.uk/climatechange/science/hadleycentre/), and the Geophysical Fluid Dynamics Laboratory (GFDL) Data Portal (http://data1.gfdl.noaa.gov/). In particular, PCMDI maintains a large catalog of experimental runs of the world's leading AGCMs, as part of its mission to improve methods and tools for AGCM intercomparison. Most of these websites are served by the Earth System Grid (ESG), that integrates supercomputer data and analysis servers located at numerous national labs.

2 Identification and Significance of the Problem and Technical Approach:

Existing data portals generally serve climate model output files in network Common Data Form (netCDF). NetCDF is a set of software libraries and machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data. These tools are appropriate for the scientific community, but are beyond the scope of non-researchers. Also, expert advice is required in finding needed data, understanding the implications of what the data means, and judging the validity of the data to the non-researcher's business at hand.

Instructions for interfacing netCDF files with many hardware platforms, along with ubiquitous software applications (e.g., MS-Windows, Fortran and C compilers) can be found (among other places) at the Unidata project, operated by the University Corporation for Atmospheric Research (UCAR) Office of Programs (UOP) (http://www.unidata.ucar.edu/). Unidata develops, maintains, and supports a variety of software packages, geared primarily for use in geoscience education and research. Geographic Information Systems (GIS) is a more widely-used tool that manages and displays all forms of geographically referenced information. The emerging GIS Strategic Initiative at NCAR (http://www.gis.ucar.edu) is charged with making atmospheric data sets compatible with GIS tools. These efforts are expected to result in stronger ties between environmental and social scientists. GIS is slowly emerging as a tool in the business sector, primarily in marketing.

Google Earth (GE) is a well-known "virtual globe" application or Geobrowser, currently available for Windows, Linux and Mac OSX. The primary method for visualizing data is to create Keyhole Markup Language (KML) files. GE is aimed at the general public primarily as a search and browse tool. This makes GE very easy to use, and as a result it has attracted a large community of people: state and federal agencies involved with the environment, space research, land management projects, homeland security, and defense intelligence.

The goal of this project was to develop a web-based portal that explicates distributed AGCM output, serves their data in a user friendly manner and produces GE imagery according to user specifications. Future goals (Phase II) will be to include expert analysis on climate forecasts, and high resolution regional climate forecasting. The target users are primarily from the commercial (i.e. nonscience) sector. The site aims to circumvent the opacity of science-oriented data portals by creating interfaces between these sites and near-universal utilities such as GE and Windows. Ultimately, the proposed project will culminate in wider understanding and usage of climate model predictions within the global economy and infrastructure.

3 Overview of Climate Modeling

Computer investigations of climate are important because the atmosphere cannot be recreated and experimented upon in a test tube. Close to a dozen fully coupled atmosphere-ocean models are now being used around the world to study climate change. The output from the models that participated in the IPCC AR4 Working Group I are available at `https://esg.llnl.gov:8443/index.jsp`. In this project we concentrated on the NCAR Community Climate System Model (CCSM), and build our proof-of-concept website around CCSM products. Inclusion of products from other well-known models, including regional climate models, will be a feature of a Phase II system.

Atmosphere general circulation models (AGCMs) consist of a three-dimensional representation of the atmosphere coupled to the land surface and cryosphere. Systems of differential equations derived from the basic laws of physics, fluid motion, and chemistry are evaluated on a 3-dimensional grid. The computations are stepped forward in time. In this sense, an AGCM is similar to a model used for numerical weather prediction (weather forecasting), but because it has to produce projections for decades or centuries, rather than days it uses a coarser level of detail. Since ocean currents and temperatures are a major component of the overall climate system, an AGCM must be provided with data for sea-surface temperatures and sea-ice coverage. However, an AGCM cannot indicate how conditions over the ocean will *change*, and is therefore not useful for climate *prediction* on their own. The ocean must be included.

Ocean general circulation models (OGCMs) are the oceanic counterparts of an AGCM: three-dimensional representations of the ocean and sea ice. These models, however, must be supplied with surface air temperature and other atmospheric data. Climatologists began “coupling” ocean and atmosphere models in the 1980s (Manabe and Stouffer, 1988). Coupled atmosphere-ocean general circulation models, or AOGCMs, are the most complex models in use, consisting of an AGCM coupled to an OGCM. These models are suitable for studies of the prediction and rate of change of future climate on a global scale. But to understand how global warming will affect drinking water, storage or crop yields, regional simulations and impact studies are needed.

Local climate change is influenced greatly by features such as mountains, which are not well represented in global models because of their coarse resolution. Regional climate models (RCMs) depict the climate of a smaller area in more detail. This is challenging because scientists are still studying the influence of small-scale phenomena such as clouds and local storms, and how best to portray them in regional models. With the inclusion of highly transient processes such as thunderstorms, the models must reflect changes in the atmosphere, land, oceans, and other parts of the environment over shorter time scales. The required higher resolution usually demands more computing power and “run” time than is practical for global simulation over long periods of time. Therefore, climate modeling teams generally use a “nested” approach to RCMs. This means that RCMs take input at their boundaries and for sea-surface conditions from the global AOGCMs, and are then run at higher resolution (typically 50 km) over limited areas, and for shorter periods.

The Met Office Hadley Centre has run RCMs for three regions: Europe, the Indian subcontinent and southern Africa. An RCM has been developed to run on PCs for any region as part of a regional climate modeling system named PRECIS. Output from this model is not currently distributed. However, PRECIS has been ported to run on a PC (under Linux) with a simple user interface, so that experiments can easily be set up over any region. Thus, for a user to obtain a desired regional-scale forecast, the model has to be purchased from the PRECIS web site (http://precis.metoffice.com), then set up and "run".

CCSM3, which is the latest version of CCSM, is a coupled climate model composed of four separate components that simultaneously simulate the earth's atmosphere, ocean, land surface and sea-ice. These four models are linked by a coupling module that transmits boundary conditions and state information among the four components. CCSM3 is the third generation of NCAR Community Climate models, and was released in 2004 following upgrades in virtually every aspect: cloud physics, radiation, chemistry, atmosphere-ocean dynamics, and model functionality and interoperability. (Specific details can be found at http://www.ccsm.ucar.edu/models/ccsm3.0/notableimprovements.html.) Consequently, CCSM3 has been shown to perform significantly better than its predecessors in several key aspects of polar and tropical climate, although some biases remain (Collins et al., 2006).

4 Interpreting Distributed Model Output

A large collection of CCSM3 model output files is described at http://www.ccsm.ucar.edu/models/ccsm3.0/, and available from http://www.earthsystemgrid.org. (Registration is required for new users.) It is important that the prospective user have some understanding of the science underpinning the different model climates, or "runs". One of the key features of the proposed website will be explanations of how to parse the titles of the run files, which are often tantamount to understanding some of the basic scientific details behind the experiments. Links to related scientific literature will also be provided. For example the CCM3 files to be explained below were the basis of a CCM3 assessment paper by Collins et al. (2006).

The standard version of CCSM3 is designed to run at 3 different spatial resolutions, and output files on data servers are segregated by the wave resolution parameters. These are referenced by the maximum number of spherical wave modes that can be sustained on the 2-dimensional Earth's surface. For "triangular" wave truncation, files are indicated and coded by T31, T42, and T85, representing 31, 42, and 85 spherical harmonics, respectively. A collection of files corresponding to a particular resolution generally contains at least one or more *control* runs. These establish the basic climate of the model. Control runs are are long integrations in which the model input forcings (solar irradiance and sulfates, ozone, and greenhouse gas concentrations) are held constant at either present day values (e.g., 1990) or pre-industrial values (e.g., 1870). The CCSM is then run for an extended period of model time (hundreds of years) until the system is close to equilibrium.

Climate change *scenarios* are examples of what can happen under particular assumptions on use of fossil fuel and other human activities. A scenario should not be thought of as a specific prediction of future climate, but rather a plausible alternative future. The CCSM archives include integrations in which the atmospheric CO_2 concentration increases by 1% yr^{-1} (from a reference level of 335 ppm) starting from the present-day (1990) run. Two additional integrations have been branched from the "1%" experiment. One of these is started when the CO_2 level is twice the present-day level, the other at 4 times the present-day value.

Because climate models are an imperfect representation of the Earth's climate system, modelers employ a technique called *ensembling* to capture the range of possible climate states. A climate model ensemble run consists of two or more climate model runs made with the exact same climate model that differ only in the initial conditions. Averaging over a multi-member ensemble of model climate runs gives a measure of the average model response to the forcings imposed on the model.

These concepts are illustrated by the collection of CCSM simulations used in the IPCC AR4. The experiments are described at `http://www.cgd.ucar.edu/ccr/strandwg/CCSM3AR4Experiments.html` and their files can be downloaded from Earth System Grid (`http://www.earthsystemgrid.org/`). They consist of 26 different runs with the CCSM3, as described below:

1. One 500-year control run, defining the long-term climate of the simulated system. The model boundary forcings are held constant at values for the year 1870.

2. One 5-member ensemble simulating the 1870-2000 historical period. Each ensemble member run was initialized from a different year in the 1870 control run, and integrated forward in time to the year 2000, thereby representing a possible climate state during this period. In each case, the simulated climate response to the increasing greenhouse gasses in the atmosphere during this period is reflected in an increase of the surface temperatures.

3. Four 5-member ensembles corresponding to the IPCC A2, A1B, B1 and constant 20th century-forcing future scenarios. Each ensemble member was run from the year 2000 to 2100, starting from the end of the 1870-2000 historical simulations (discussed in item 2). The constant 20th century forcing shows the least increase in future surface temperature. The A1B and B1 storylines describe a future global, highly technological economy reliant upon both fossil and non-fossil energy sources, with greater emphasis in B1 upon sustainability; both scenarios display moderate increases. The A2 scenario is marked by a very heterogeneous world with slower technological change and rapidly increasing population (Nakicenovic and Stewart, 2000; IPCC, 2007). This scenario exhibits the largest surface temperature response.

5 Visualization - "The presentation is the data"

"The presentation is the data" is a quote from one of the Google Engineers at the U of M conference. The meaning is, that for the majority of users, they lack the expertise to process, analyze, and fully understand the data, and all they can understand of the data is what you present to them. It underscores the importance of presentation in a situation such as this, of providing state of the art global climate model results for non-researchers.

Google earth has truly amazing capabilities. It is unprecedented to be able to interact so easily and intuitively with a global data set in the context of the geographical earth. One can examine the ocean surface winds around Antarctica, and zoom into a closeup view of their house in Colorado, and back again. The key to this zoom feature, to go from a very large global picture, down to very high resolution picture (i.e. the user's house) is based on a technology called regionation. Large low resolutions graphics are created for the global view. Then Google employs a network linked quadrature tree of higher resolution data when the user zooms in. Each large top level low resolution image is broken into 4 quadrants, each containing higher resolution images. This can be nested any number of times, in that each of these 4 quadrants it itself broken into 4 quadrants. This continues for several levels, until one has an image of very high resolution (on the order of meters or less for the high resolution data available in google earth). It may be that geobrowsing is the next stage of internet interaction and could very well be a revolution analogous to the jump from programs like gopher and ftp, to the world wide web of the early 1990s.

5.1 Data Mashup

One of the great synergetic aspects of Google earth is called Data Mashup. It means that the user can view one particular data set, but then incorporate any other data set available on the whole internet, and simultaneously examine both of them. This is an extremely powerful feature, and can greatly enhance understanding.

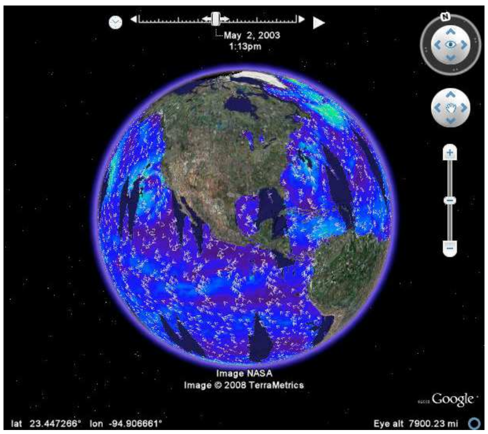

Figure 2: Ocean surface vector winds presented in Google Earth. This example has a time animation available.

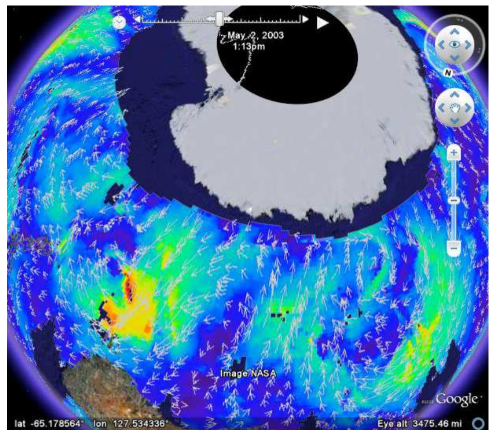

Figure 3: Ocean surface vector winds presented in Google Earth, zooming in on the Antarctic region.

The geobrowser allows the user to import a limitless variety of data into their visualizations. Unlike a webbrowser, where each site has its own page and the user leaves one site to visit another site, in a geobrowser all geosites are simultaneously available potentially. The particulars become apparent based on the the geographic region, and the level of geographical detail. To illustrate this point, as a user, one initially starts by viewing the entire earth. The user types in his/her street address, and the Geobrowser zooms into a level of detail such that cars and buildings can be recognized. The user can zoom out again, and then again zoom into a building on the other side of the world. Thus there is an incredible amount of data that is simultaneously available in this example of aerial/satellite photography. However, this also applies to scientific and geophysical data. For a concrete example, one of us (Stockwell) has created KML pages, where the user can bring up a global picture of ocean surface vector winds (measured at 0.5 by 0.5 degree bins, every 3 hours). The user can then open up sea ice data around Antarctica for the same time periods, which shows imagery of the extent of the polar ice. Thus, without any collaboration between the two groups, the user can incorporate both data sets simultaneously, which can lead to a much greater and more profound understanding of the entire physical system. Such uses, that go beyond the original intent of the separate data providers, is referred to by the Google engineers as Data Mashup. This powerful ability allows the user make connections one never would have otherwise made.

This example and others, created by the PI and Co-Is, can be found at `http://www.cora.nwra.com/~stockwel/rgspages/osw/`. It is a profound way to intuitively organize georeferenced information, and indicates new paradigm in organization of data, information and ideas.

6 The Phase I Performance Schedule

From the Phase I proposal, the perfomance milestones consisted of the following tasks:

- Downloading and Pre-Processing of Climate Data (10%).
- create webpage hierarchy - CMS (5%).
- create wiki, write tutorial pages (15%).
- create Data analysis and error processing routines (20%).
- create software to convert data into user's preferred format (binary files, csv files etc) (10%).
- create the KML generation software, map projection code, figure creation code (30%).
- unify all components into seamless webpage (5%).
- test system and resolve outstanding issues (5%).

7 Degree to which Phase I has Demonstrated Technical Feasibility

All of the technical objective milestones were achieved. Phase I had the following technical objectives:

1. automated download of climate model data: The first task accomplished wass the GCM data acquisition and download system, whose purpose is to fetch the most recent data from the NCAR data servers, in their native format and to provide the raw data files to our data storage system.

2. creation of data processing and graphic data representation software: The second task accomplished was the data analysis and presentation generation model. A library, primarily written in IDL (Interactive Data Language) was created to perform basic data diagnostics to ensure quality and integrity of the data.

3. automated generation of geobrowser-ready KML files: KML stands for Keyhole Markup Language, which is an XML (eXtensible Markup Language) specification for use in Geobrowsers such as Google Earth, NASA's WorldWind, EarthBrowser, or Microsoft Virtual Earth (`http://scispace.net/geobrowsers/`). It manages the display of three dimensional geospatial data, much in the same way an html file presents text and image/video data to a webbrowser.

A great deal is required to convert the raw model output data into the user friendly Google Earth product. The original data must be read and processed, and then the data must be projected into the appropriate georeferenced mode for inclusion into the Geobrowsers, so that it can be displayed on the virtual earth. Google earth uses the equidistant cylindrical map projection, also called the plate carree projection. Thus, images must be created presenting the data in latitude and longitude coordinates, then these are transformed into the proper projection. Other geobrowsers may require different map projections, and thus the creation of their own specific image files.

The IDL code has been developed to process the GCM model output into the proper georeferenced form, applied the appropriate map projection image warping routines and created the output imagery files. Simultaneously with the creation of these presentation files, the thousands of KML files were automatically created, and distributed to the webserver. There are thousands of these files available from the website.

4. creation of user friendly data files, such as spreadsheet files: IDL output routines were also created to automatically generate generic spreadsheet data output files, in the form of generic CSV files which can be read by any spreadsheet program.

5. creation of public website climate.cora.nwra.com: The final task accomplished was the creation of the website - containing tutorial pages, several documents regarding the current state of the scientific understanding of our climate, news pages with updates of recent articles and presentations that are available. The use and further development of the website is ongoing, and is currently being used as a portal to our current clientele. The website is described in more detail below.

One issue we did not anticipate in the planning stage of Phase I was the availability of the Google Earth plug-in (and its associated API). This advance by Google allowed us to achieve two important goals: 1) keep the data presentation wholly self-contained within the browser itself, which provided a nice experience for users, and 2) it allowed us a very high level of user interaction: the Google Earth API (Application Programming Interface) allowed us to write our own Javascript functions and allow the user to directly interact with the google earth visualizations via normal html constructs such as drop down lists and buttons. We were able to create a compact, clean, simple, user friendly, highly interactive data visualization webpage.

Of special note: at the time of the end of Phase I, the Google Earth plug-in was not available for Linux or for the Safari browser. However, the Google development blog had announced that it was indeed in progress. Thus, in order to efficiently apply our resources, we did not pursue an alternative method for users in the Linux system at the present time. We anticipate that the solution will be worked out and Google will provide the Google Earth plug-in sometime during further development. For the meantime, we have provided the external Google Earth capabilities for linux users on our website.

7.1 Summary of Status of Phase I Performance tasks

The Phase I project consisted of the following tasks:

- downloading and pre-processing of climate data (COMPLETED).
- create webpage hierarchy - CMS (COMPLETED).
- create wiki, write tutorial pages (COMPLETED).
- create data analysis and error processing routines (COMPLETED).
- create software to convert data into user's preferred format (binary files, csv files etc) (COMPLETED).
- create the KML generation software, map projection code, figure creation code (COMPLETED).
- unify all components into seamless webpage (COMPLETED).
- test system and resolve outstanding issues (COMPLETED).

All of these goals were achieved in Phase I of this project, as is demonstrated by the website currently at `https://climate.cora.nwra.com/`.

The objectives of Phase I were completely achieved.

8 Web Site examples

A selection of page examples from the current website is shown here. These pages have been tested in Internet Explorer, FireFox, Chrome, Safari and Opera. The Google Earth plugin is not yet available on all platforms, therefore an page was created for the use of an external geobrowser (which works with any of the geobrowsers the user wishes).

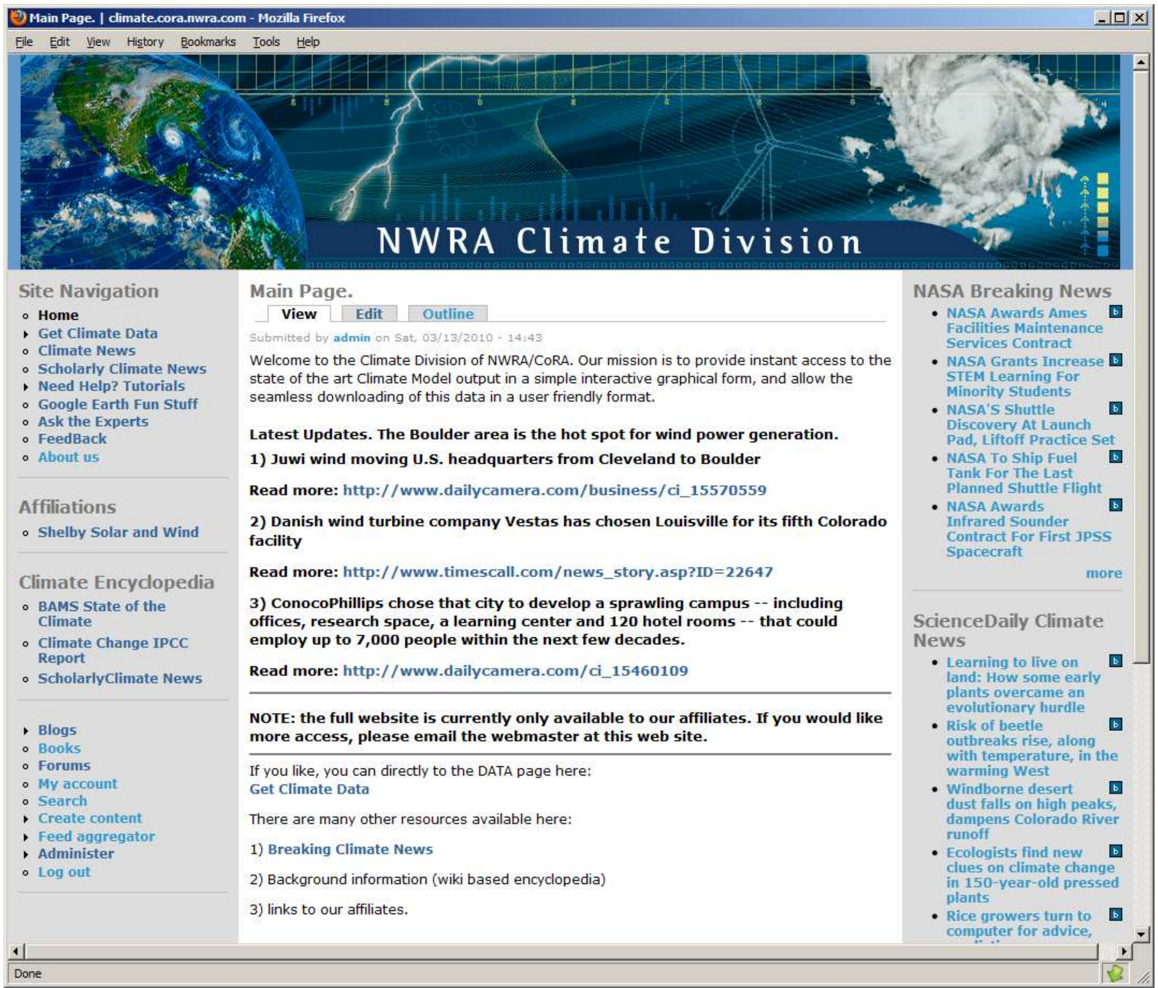

Figure 4: The Phase I climate.cora.nwra.com website (Firefox): The main page which shows the full menu and recent news items and site updates.

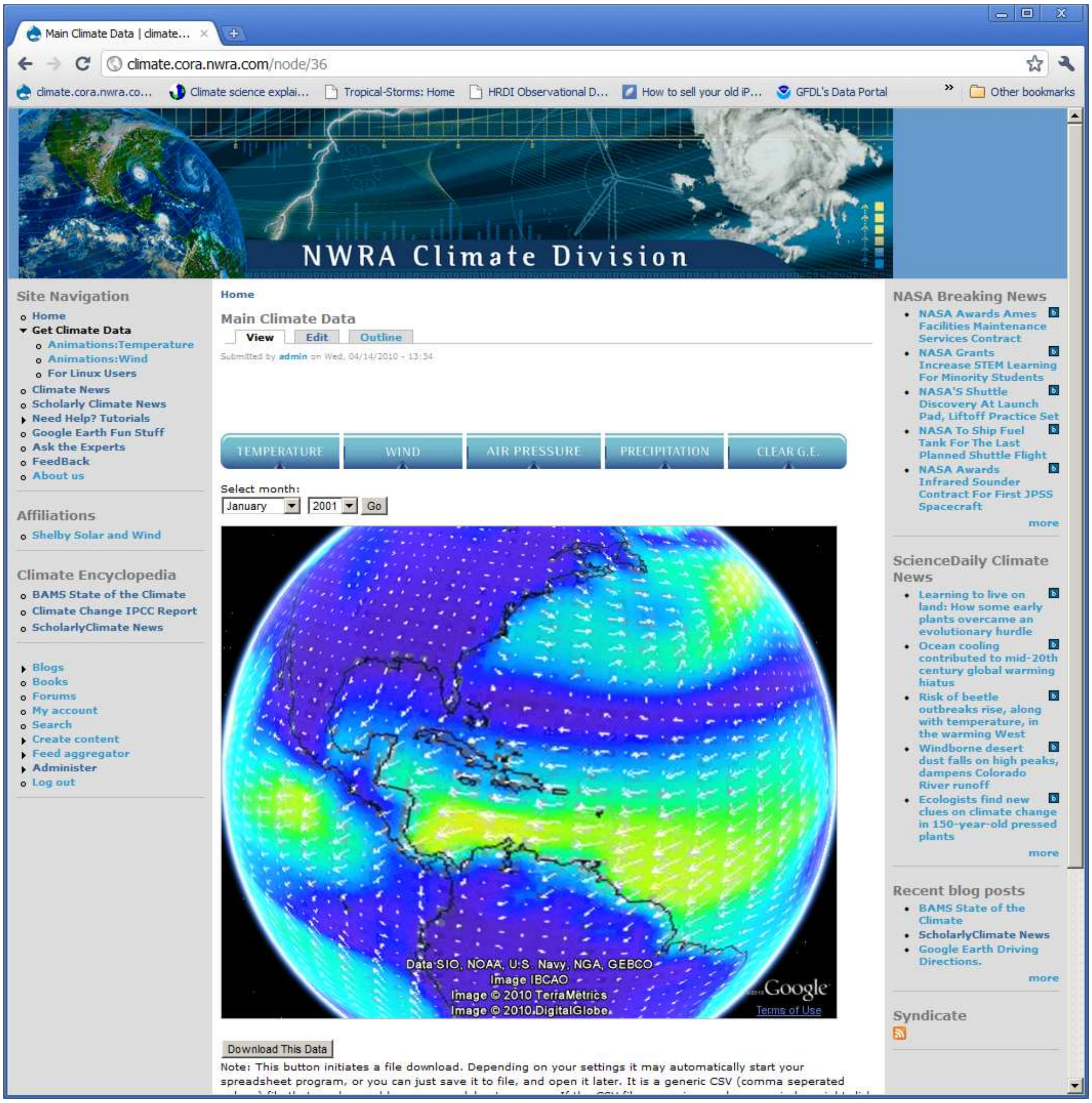

Figure 5: The Phase I climate.cora.nwra.com website (Chrome): One of the data exploration pages showing an example of the wind output from a global climate model.

Figure 6: The Phase I climate.cora.nwra.com website: A page showing automated results of a scholar search of relevant articles.

Figure 7: The Phase I climate.cora.nwra.com website: Recent news items in the climate field, these are updated every 5 minutes.

9 Current Status and Future Work

The over-arching goal of this project was to create a website to deliver climate model visualizations and products to a variety of users in an informed, yet transparent manner. The most obvious technical benefit of the site is its accessibility and user-friendliness to clients outside the world of climate modeling. With this system, a user with no background in climate science and no literacy in Earth System Grid navigation will be no further from climate model data than a browser, and other ubiquitous desktop utilities (such as Microsoft Excel).

9.1 Ongoing interactions with potential clients

Our interactions with potential clients during Phase I of this project were greatly encouraging. We found that there is a great deal of interest in climate forecasting, the high resolution regional climate modeling, and the data visualization. Also, there have been a number of recent news stories about our city of Boulder, Colorado becoming the new hot place for a business to start up. For example (from our website):

> "A long list of communities around the country have tried to become "the next Silicon Valley." But very few have the mix of money, universities, a high-tech talent pool and appealing lifestyle needed to hatch tech start-ups. Boulder, however, has been luring tech industry veterans and young entrepreneurs from Silicon Valley and Manhattan with promises of a tech community that allows for lunch-break hikes in the foothills of the Rocky Mountains." - NY Times `http://www.nytimes.com/2010/05/14/business/14boulder.html`

Latest Updates: The Boulder area is the hot spot for commercial ventures in wind power generation.

1. Juwi wind moving U.S. headquarters from Cleveland to Boulder Read more: `http://www.dailycamera.com/business/ci_15570559`
2. Danish wind turbine company Vestas has chosen Louisville for its fifth Colorado facility Read more: `http://www.timescall.com/news_story.asp?ID=22647`
3. ConocoPhillips chose that city to develop a sprawling campus – including offices, research space, a learning center and 120 hotel rooms – that could employ up to 7,000 people within the next few decades. Read more: `http://www.dailycamera.com/ci_15460109`

The following is a list of clients and collaborators we have developed during this project:

9.2 Wind Energy Farming

The most critical aspect of producing sustainable energy from wind turbine based devices is the speed of the wind. Predicting geographic regions that will be expected to experience high winds in the future can distinguish between an economically viable wind farm, and one that cannot compete with grid based electricity. Because of the large costs involved in constructing a wind power system, it is necessary to determine a priori whether a particular site has the potential wind field to produce the expected power, and what seasonal, annual, and longer term variations in the wind field are expected. Customer feedback and satisfaction will depend greatly on how successful the company's prediction of power generation will be (Renfrow, 2008).

Shelby Solar and Wind, LLC is an alternate energy business located in Michigan that provides solar and wind powered power generation systems for residential and commercial purposes. The U.S. Department of Energy (USDOE) estimates that Michigan has the potential to be one of the top eight states for wind energy generation in the country, making Michigan an attractive customer market for wind turbine manufacturers. One of us (Stockwell) has been in discussions with Shelby Solar and Wind, and they are a motivated potential client for these services. Additionally, this client has introduced us to Ventera Energy, WindSpire, SkyStream, as well as the Great Lakes Renewable Energy Association.

9.3 Conservation and Sustainable Development

Another company we have had discussions with is **Redstone Strategy Group, LLC** (`http://www.redstonestrategy.com`), a consulting firm in Boulder, CO. The company provides strategy development, and institutional and program planning services to non-profit organizations that address societal problems such as conservation and sustainable economic development. Redstone Strategy recently advised the Packard Foundation on the protection of coastal wetland sites between Alaska and Chile showing a marked decline in Pacific shorebird populations (`http://www.redstonestrategy.com/nonprofit/publications`). In a 2003 assessment, Redstone Strategy evaluated the feasibility of sustainable economic development on the northern coast of British Columbia. Their report explicitly singled out weather variations and climate change as important variables to consider at remote northern latitudes.

9.4 USDA-ARS Agricultural Systems Research Unit

The Agricultural Systems Research Unit performs systems research for developing sustainable and adaptive integrated agricultural systems. Their plan includes modeling of climate change effects on soil water availability, crop water demand, and production of current cropping and rangeland systems in the Great Plains, as well creating the decision tools for adaptations to this change. Dr. Ahuja is very interested in high resolution climate forecasts of daily weather variables such as max-min temperatures, precipitation, and wind speed, and we are currently working with him to provide this vital information.

9.5 USDA-ARS Rangeland Resources Research Unit

The Rangeland Resources Research Unit performs research that includes: vegetation and soil changes in plant communities; managing for multiple uses; range monitoring; invasive species; plant-animal interactions; and climate change impacts on rangelands; and evaluating rangeland management practices in regards to their effects on green house gas emissions and carbon sequestration. They plan on using climate/weather projections to help develop adaptive management practices for ranchers and public land managers.

9.6 New Sky Energy

New Sky Energy, LLC is a carbon negative chemical manufacturing company. Their proprietary capture process technology utilizes water electrolysis to scrub CO2 from the air, and converts it into safe, stable chemicals. Their business model calls for the technology to be co-located at the plants of large buyers, who in turn can produce carbon-negative goods that cost the same or potentially less than the carbon-positive competition. They plan to use climate forecasts for day/night temperature differences, which have a strong effect on their chemical processes.

9.7 Brookefield Renewable Power, Inc

Brookefield Renewable Power, Inc is a company working with hydroelectric stations located in mid-Ontario and Western Quebec. These stations suffered from a major drought this recent spring/summer and is ongoing. These potential clients have just recently contacted me for information to explain the different factors that caused this drought; and to perform a study aimed at quantifying the probability of re-occurrence.

It is our hope that our group can continue to work on 4D visualizations of global and regional climate data, and address specific data visualization problems, such as the "zoom problem", as well as continue to provide valuable climate model output information. This project has been very successful and will provide a strong base for further development.

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