NASA'S BLACK MARBLE PRODUCT SUITE: VALIDATION STRATEGY

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ABSTRACT

NASA's Black Marble nighttime lights product suite (VNP46) is available at 500 m resolution since January 2012 with data from the Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band (DNB) onboard the Suomi National Polar-orbiting Platform (SNPP). The retrieval algorithm, developed and implemented for routine global processing at NASA's Land Science Investigator-led Processing System (SIPS), utilizes all high-quality, cloud-free, atmospheric-, terrain-, vegetation-, snow-, lunar-, and stray light-corrected radiances to estimate daily nighttime lights (NTL) and other intrinsic surface optical properties. Extensive benchmark tests at representative spatial and temporal scales were conducted on the VNP46 time series record to characterize the uncertainties stemming from upstream data sources. Current and planned validation activities under the Group on Earth Observations (GEO) Human Planet Initiative are aimed at evaluating the products at different geographic locations and time periods representing the full range of retrieval conditions.

Index Terms— GEO Human Planet, Suomi-NPP, JPSS, NOAA-20, NASA Black Marble, VIIRS, Night Lights, NTL, Urban, Long-term monitoring, Lunar BRDF, Albedo, Atmospheric Correction

1. INTRODUCTION

With a quickly expanding time series record of high-quality nocturnal imagery, the Day/Night Band (DNB) sensor of the Visible Infrared Imaging Radiometer Suite (VIIRS) on board the Suomi-National Polar-orbiting Partnership (Suomi NPP) is starting to come out of its early exploratory stage to become a reliable source of global nighttime remote sensing data that can expand upon the science and applications enabled by the heritage Defense Meteorological Satellite Program's Operational Line Scanner (DMSP OLS) [1]. These products have been widely used to support urban policy development, disaster response, and decision making. Of particular relevance to urban remote sensing science and applications is the synergistic and quantitative use of satellite-derived nighttime lights across spatial and temporal scales, as called for by the Group on Earth Observations Human Planet Initiative. This multinational group of 40 registered research teams (accounting >120 individual researchers) working in governmental and international organization, NGOs, academic, and private firms, seeks to develop a new generation of measurements and spatial statistics products to support international frameworks on sustainable urban development and resilience.

2. KNOWLEDGE GAPS AND SOLUTIONS

Variations in satellite-derived nighttime lights are the result of natural and environmental changes, as well as human-induced changes. By isolating the noise contributions embedded in the VIIRS DNB temporal signatures, pixel-scale variations in energy and infrastructure use can be extracted to monitor changes over long time periods. This enables the assessment e.g., of: (1) abrupt short-term changes, caused by disturbances in power delivery such as conflict, storms, earthquakes, and brownouts [2]; (2) cyclical changes, driven by reoccurring human activities (e.g., holiday periods), and/or seasonal migrations [3]; and (3) gradual changes, such as urbanization, out-migration, economic changes, and electrification [4]–[7].

Additional gaps remain, most notably, in the implementation of proper quality assurance and uncertainty quantification strategies for nighttime lights products [8], [9]. While it is generally neither desirable nor practical to delay the applied use of satellite-derived products until they are proven to be error-free, or until known sources of error have been removed by product reprocessing, it is important to note CEOS Space Agencies, put a high priority on providing statements concerning product accuracy and performance. This information is needed by decision makers, to consider products in their appropriate context, and by the science community to identify products that are performing poorly so that improvements may be implemented. Accordingly, to enable the quantitative application of global nighttime lights products for the many initiatives and decision-making scenarios mentioned in GEO's Work Programme, NASA along with its international partners, are coordinating calibration and validation activities to quantify global nighttime product accuracy and evaluate its scientific quality with respect to intended performance.

In this context, a new cross-cutting activity under the auspices of GEO's Human Planet Initiative, known as the Nighttime Product Validation Task (NPV), is dedicated to the uncertainty assessment of nighttime lights through validation – the process of comparing satellite-derived products to independent reference data [10].

3. GEO-NPV VALIDATION PROTOCOLS

The enhanced coordination of the validation of global nighttime remote sensing products, through GEO-NPV, is meant to support the urban nighttime remote sensing community in a number of areas, including: (1) increased traceability of product uncertainties, (2) a reduction of costs through sharing of quality-assessed in-situ reference data, (3) structuring of work distribution between expert communities and stakeholders, and (4) uncertainty terminology and methodological development across product developers.
Following established CEOS Land Product Validation (LPV) best-practices for terrestrial essential climate variables (ECVs) [10]–[13], a key deliverable of NPV is the development of benchmark metrics and best practices, which emphasize quantitative validation of satellite-derived nighttime lights products. Key components to be included as part of the NPV task, are: (i) variable definitions and accuracy metrics following traceable units of the Système Internationale; (ii) best practice guidelines for field sampling and scaling techniques; (iii) recommendations for reporting and use of accurate information; (iv) guidelines for product inter-comparison exercises; and (v) recommendations for data and information exchange.

4. SATELLITE AND AIRBORNE DATASETS

The GEO-NPV task also seeks to combine multiple urban remote sensing datasets across scales. Figure 1 illustrates the flow of information products across multiple NPV subtasks.

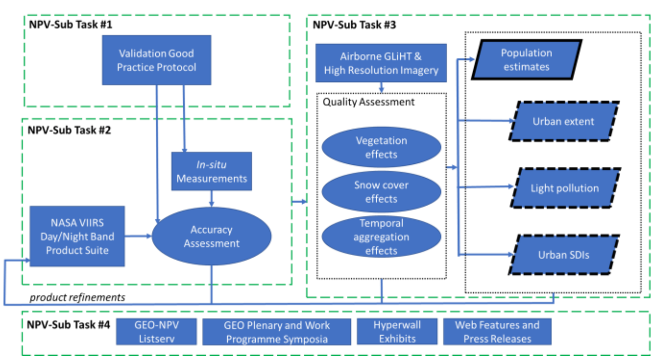

Figure 1. Flowchart of GEO's Nighttime Product Validation (NPV) Sub-Tasks and associated NASA Earth Science datasets.

The primary satellite measurement suite of initial interest to NPV is NASA's Black Marble product suite (VNP46) (Figure 2), which will be transitioned to daily routine operations at NASA's Land Science Investigator-led Processing Systems (Land SIPS) in 2018. The VNP46 product is available at 500 m resolution since 19 January, 2012 with data from the Suomi-NPP and NOAA-20 VIIRS DNB sensors. The retrieval algorithm, utilizes all high-quality, cloud-free, atmospheric-, terrain-, vegetation-, snow-, lunar-, and stray light-corrected radiances to estimate daily nighttime lights (NTL) and other intrinsic surface optical properties.

Figure 2. NASA Black Marble composite images for year 2016 provide full-hemisphere views of Earth at night. Natural surfaces, clouds, and sun glint — added here for aesthetic effect — are derived from the MODIS Blue Marble Next Generation Imagery products.

Key VNP46 algorithm enhancements include: (1) lunar irradiance modeling to resolve non-linear changes in phase and libration; (2) vector radiative transfer and lunar bidirectional surface anisotropic reflectance modeling to correct for atmospheric and BRDF effects; (3) geometric-optical and canopy radiative transfer modeling to account for seasonal variations in NTL; and (4) temporal gap-filling techniques to reduce persistent data gaps.

As part of the NPV protocol development effort, extensive benchmark tests at representative spatial and temporal scales were conducted on the VNP46 time series record to characterize the uncertainties stemming from upstream data sources. Initial validation results are presented in Román et al., [2018] [15] together with example case studies illustrating the scientific utility of the products. This includes an evaluation of temporal patterns of NTL dynamics associated with rapid urbanization, socioeconomic factors, cultural characteristics, and the living conditions of displaced populations affected by natural hazards and conflict.
Additional airborne remote sensing datasets include NASA's Goddard Space Flight Center's (NASA/GSFC) LiDAR, Hyperspectral and Thermal (G-LiHT) [16]. The G-LiHT platforms is being used as reference to assess the performance of the VNP46 product across areas that experience seasonal effects in nighttime lights [17]–[19]. In particular, canopy heights derived from G-LiHT's LiDAR, combined with hyperspectral products, enables us to identify tall trees (higher than street lights and other light sources) and grass patches to estimate the spatial distribution of vegetation cover

at 1 m spatial resolution. Multi-spectral 2 m spatial resolution images, are also being collected during leaf-off (fall-winter) periods over select field sites in North America. The scenes serve as additional reference data to further assess vegetation impacts. High spatial resolution fractional snow cover maps area also being generated from these source datasets (as well as Landsat and VIIRS 375m fractional snow cover products) [20], [21] to assess the performance of the nighttime products over snow-covered surfaces.

Key to achieving the goals as set out by the Group on Earth Observations (GEO) Global Human Settlement Working Group's Nighttime Product Validation (NPV) task is the enhanced assessment of nighttime aerosol estimates. To support these evaluations, our future validation plan calls for the synergistic use nighttime aerosol measurements (e.g., from AERONET, Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP), and Cloud-Aerosol Transport System (CATS) retrievals) [22]–[24] to support ongoing product validation efforts.

5. IN-SITU MEASUREMENT STRATEGY

Under technical guidance from GEO Human Planet's NPV task, Puerto Rico's Working Group on Light Pollution (PRWGLP) seeks to develop measurement standards and protocols for in-situ data collection. The primary driver for this activity is the development of a sustainable development indicator, based on NTL time series data, to better meet the multiple regulatory and scientific aspects of PR's light pollution laws and ordinances. To that end, a number of scoping exercises are being conducted across multiple light pollution abatement zones in the US and Puerto Rico.

The validation approach follows the assessment method first described in Cao and Bai [2014] [25], which relies on quantitative analysis and stability monitoring of stable light point sources (Figure 3).

Initial assessment activities are aimed at evaluating NASA's Black Marble product suite at several locations and time periods, representing different retrieval conditions and assessing the uncertainty of seasonal effects due to vegetation seasonality and snow cover, temporal aggregation, and the impacts of these effects on datasets and products that are directly called for by GEO's Work Programme. This also includes end-to-end analyses of downstream product impacts, due to sources of measurement error in the nighttime lights data, to help expose discrepancies that affect GPW4 (Gridded Population of the World version 4) estimates [26], as well as other datasets produced from additional demographic and mobility layers, e.g., the American Community Survey (ACS), and the Puerto Rico Community Survey (PRCS). These datasets, which are currently provisioned by team members at NASA's Socioeconomic Data and Applications Center (SEDAC), also as part of GEO's Work Programme, must be thoroughly assessed to generate accurate estimates of populations at high frequency time intervals [27].

Figure 3. Initial deployment of Ground-based Accurate Active Light Source (AALS) for radiometric calibration of the VIIRS DNB's High Gain Stage (Image Credit: Robert Ryan NOAA-SBIR/IIR, Inc.).

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