Overview of DMSP Nightime Lights and Future Possibilities

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Abstract— **The Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) has a unique capability to collect low-light imaging data of the earth at night. The OLS and its predecessors have collected this style of data on a nightly global basis since 1972. The digital archive of OLS data extends back to 1992. Over the years several global nighttime lights products have been generated. NGDC has now produced a set of global cloud-free nighttime lights products, specifically processed for the detection of changes in lighting emitted by human settlements, spanning 1992-93 to 2008. While the OLS is far from ideal for observing nighttime lights, the DMSP nighttime lights products have been successfully used in modeling the spatial distribution of population density, carbon emissions, and economic activity.**

I. Introduction

Nocturnal lighting is a unique indicator of human activity that can be measured from space. Interest in satellite remote sensing of nocturnal lighting stems, in part, from the difficulty in global mapping of human settlements in a repeatable, timely manner from traditional sources. Although development features can be extracted from high spatial resolution (~1-m) satellite imagery, the production of global annual maps of development from these data sources is not feasible (at this time) from either a collection or analysis perspective. Moderate resolution Landsat-style systems offer the potential of global collections on an annual basis and such data have been used effectively for mapping urban areas and tracking growth in local settings. Detailed analyses of Landsat data from diverse urban areas worldwide indicate that the spectral heterogeneity of building materials worldwide precludes the existence of any unique spectral characteristic of urban areas as a thematic class [1]. In addition, Landsat-style data are poorly suited for the detection of sparse development.

In contrast, the remote sensing of nocturnal lighting provides an accurate, economical, and straightforward way to map the global distribution and density of developed areas. The widespread use of outdoor lighting is a relatively recent phenomenon, tracing its roots back to the electric light bulb commercialized by Thomas Edison in the early 1880s. Since that time nocturnal lighting has emerged as one of the hallmarks of modern development and provides a unique attribute for identifying the presence of development or human activity that can be sensed remotely. Although there are some cultural variations in the quantity and quality of lighting in various countries, there is a remarkable level of similarity in lighting technology and lighting levels around the world. The primary factor affecting the quantity of lighting is wealth. Regions with high per capita income have much more lighting than regions with low per capita income. Even within affluent regions, however, lighting technology (lamps and lighting fixtures) is gradually changing as pressure is applied to reduce nighttime sky brightness and conserve energy. Nighttime lights have been used as a proxy for variables that are difficult to measure in a globally consistent manner, including many socioeconomic variables such as population density, gross domestic product, and poverty [2,3,4]. A growing body of research indicates that exposure to nighttime lights interferes with the human circadian cycle leading to sleep disorders and in some cases disease [5].

The only satellite sensor currently collecting global nighttime lights data is the U.S. Air Force Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS). The NOAA National Geophysical Data Center (NGDC) has been producing DMSP nighttime lights products since 1994 and has worked extensively with the scientific community to develop applications for this data source This paper reviews the current state of product development, a discussion of how the products are being used

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and some future possibilities for low light imaging from space at night.

II. THE DMSP OLS

The U.S. Air Force Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) has a unique capability for global mapping of artificial lighting present at the earth's surface. DMSP operates satellites in sun-synchronous orbits with nighttime overpasses in the 7 pm to 9 pm range local time. With a swath width of 3000 km and fourteen orbits per day, each OLS instrument is capable of generating a complete coverage of nighttime data in a twenty-four hour period. The operational data collections have a spatial resolution of 2.7 km (ground sample distance). The OLS is an oscillating scan radiometer with two spectral bands. The visible band pass straddles the visible and near-infrared portion of the spectrum (0.5 to 0.9 µm) and the thermal band pass covers the 10.5 to 12.5 µm region. DMSP-OLS is basically designed for global observation of cloud cover. At night, the visible band is intensified with a photo-multiplier tube (PMT) to permit detection of clouds illuminated by moonlight. The light intensification enables observation of faint sources of visible- near infrared emissions present at night on the earth's surface including cities, towns, villages, gas flares, heavily lit fishing boats and fires. The low light sensing capabilities of the OLS at night permit the measurement of radiances down to 10^{-9} watts/cm^2/sr.

III. GLOBAL NIGHTTIME LIGHTS PRODUCTS

NGDC has developed a series of procedures to generate global cloud-free composites of DMSP nighttime lights [6] With a full year of data from a single satellite there are generally sufficient cloud-free coverages to identify an remove fires based on their ephemeral nature. When the fires and background noise are removed the products are termed "stable lights".

The first step in producing a global nighttime lights composite is to extract the data from the archive and geolocated into 30 arc second grids. To improve the sharpness of the lighting features and geolocation accuracy only the data from the center half of each swath are processed. The data are automatically screened to remove data that are contaminated by sunlight, moonlight, and solar glare. Clouds are identified by comparing the OLS thermal band brightness temperature against surface temperature grids from the NOAA National Center for Environmental Prediction (NCEP). The cloud-free nighttime visible band data that are free of solar and lunar illumination and glare are then analyzed to identify outliers (primarily fires). The remaining observations are averaged. A manually drawn mask is used to define background areas that are devoid of lighting. Statistics from grid cells under the background mask are used to set local thresholds for the stable lights. An example of a global nighttime lights composite is shown in Figure 1.

IV. GLOBAL POVERTY MAP

In this section we review an application developed for nighttime lights developed in conjunction with the U.S. Department of Energy Landscan gridded population data [7, 8]. There are several population grids available. We chose Landscan because the current versions of this product do not use DMSP nighttime lights and are produced on the same 30 arc second grid as are the nighttime lights.

If nighttime lights and the Landscan population data are overlain it is possible to discern disparities in the quantity of lighting per person in different locations around the world. If the developed countries are used as a reference, one can see that in many of the impoverished regions of the world the OLS instrument detects much less lighting relative to the population numbers. Based on this observation we developed the notion of using the quantity of lighting per person as an indicator of poverty levels. The concept is that in prosperous regions of the world there is no shortage in lighting. The quantity of lighting per person declines as poverty rates increase.

Poverty has emerged as one of the chronic dilemmas facing civilization during the 21st century. Based on data from the World Development Indicators [9] approximately 42% or 2.6 billion people live in poverty. Poverty is the general term describing living conditions that are detrimental to health, comfort, and economic development. There are different forms of poverty, such as inadequate supply or quality of food, water, sanitation, housing, clothing, schools, and medical services. In locations where poverty levels are high there is typically a convergence of inadequacies across several of these areas. Widely noted consequences of poverty include higher infant mortality, shorter life spans and lower literacy rates. Poverty is also closely associated with environmental degradation (Snel, 2004). The United Nations Millenium Development Goals includes a 50% reduction in extreme poverty by the end of 2015.

The primary source for statistics on global poverty is the World Bank, which has collected and distributed national level data on poverty levels since 1990. Their methods are based on the analysis of household surveys conducted in almost 100 countries. Survey questions cover sources of income, consumption, expenditures, and numbers of individuals making up the household. Most surveys are conducted by government employees. Two styles of poverty data are produced - national poverty line data and international poverty line data. Individual countries establish their own poverty line for the national data. Differing standards in defining poverty make pooling the national poverty line data problematic. More recently, purchasing power parity has been introduced into the formulation of international poverty line data, which is specified in terms of the number of individuals living on either $1 or $2 per day (Figure 2).

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There are a number of problems recognized with the World Bank poverty line data. Not all countries conduct the surveys, the currently available data were derived from surveys spanning 1988 through 2004 and the survey repeat cycle is uncertain. The inter-comparability of the estimates is uncertain due to difficulties in reconciling consumption and income data, plus discrepancies in the purchasing power parity estimates for individual countries. It is also possible for governments to influence the outcome of the surveys since they design the questions, select the areas for survey and conduct the interviews. The use of the $1 and $2

We developed a poverty index by dividing the population count by the brightness of the DMSP lights (Figure 3). A calibration for estimating poverty levels based on the World Bank values shown in Figure 2. Two spatially disaggregated data sources have been combined to form a global poverty index: LandScan population counts and DMSP nighttime lights. A calibration was developed using the national level poverty data shown in Figure 2. It was then possible to estimate poverty levels across the full 30 arc second grid and aggregate these results to administrative units. Figure 4 shows the subnational poverty estimates.

V. SHORTCOMINGS OF DMSP NIGHTTIME LIGHTS DATA

While the OLS is remarkable for its detection of dim lighting it is clear that the quality of global urban mapping products could be improved through the detection of even dimmer lighting with improvements in spatial resolution. The full suite of shortcomings of the OLS data for urban mapping include: 1) coarse spatial resolution (2.7 km ground sample distance), 2) lack of on-board calibration, 3) lack of systematic recording of in-flight gain changes, 4) limited dynamic range, 5) six-bit quantitization, 6) signal saturation in urban centers resulting from standard operation at the high gain setting, 7) lack of a thermal band suitable for fire detection, 8) limited data recording and download capabilities (most OLS data are averaged on-board to enable download of global coverage), 9) lack of a well characterized Point Spread Function (PSF), 10) lack of a well characterized Field-of-View (FOV), and 11) lack of multiple spectral bands for discriminating lighting types. \

VI. FUTURE POSSIBILITIES

Several of the observational shortcomings of the OLS will be addressed by the low light imaging data that will be acquired with the VIIRS (Visible Infrared Imaging Radiometer Suite) which will fly on the NPOESS (National Polar Orbiting Environmental Satellite System) during the next decade. The VIIRS low light imaging sensor will continue to acquire nightly global data, but will have onboard calibration and at higher spatial resolution (0.8 km) than the OLS. Thus it can be expected that poverty assessments made with VIIRS data will be of higher quality than those that can be achieved with the OLS. However, there are no plans to fly VIIRS instruments in early evening orbits, which are the best for observing nighttime lights.

Neither the OLS nor the VIIRS low light imaging capabilities were designed with the specific objective of imaging nighttime lights. Technically it is feasible to develop a sensing system that is optimized for the global mapping and characterization of nighttime lights. There is a "Nightsat" mission concept [10] for a sensor and orbit similar to Landsat – but with low light imaging capabilities.

VII. CONCLUSION

Even with their shortcomings DMSP nighttime lights have been successfully used for a wide variety of scientific applications. They have emerged as one of the most widely used and recognized images of the earth. It can be anticipated that in the future a sensor system optimized for the remote sensing of lighting will be flown and that this will be one of the most widely used global data sources for urban and environmental studies.

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Figure 1. Example of a global cloud-free composite of DMSP OLS nighttime lights. This image was derived from observation made from DMSP satellite F-15 during 2003.

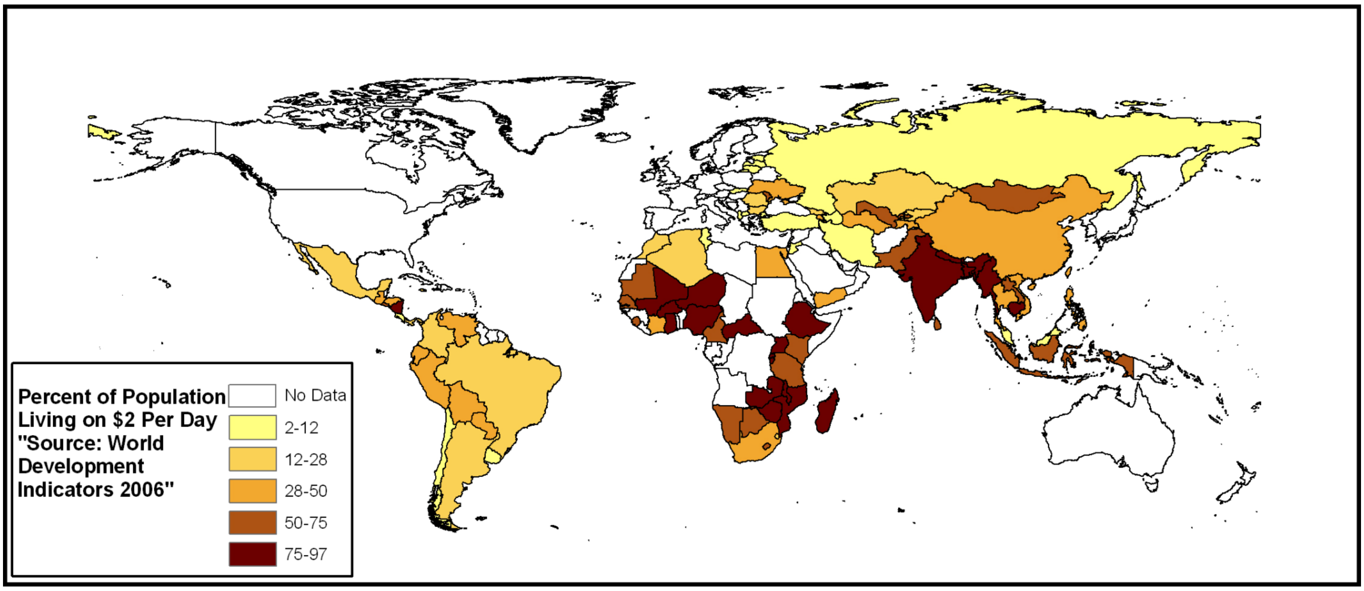

Figure 2. Global poverty maps from the World Development Indicators 2006 database.

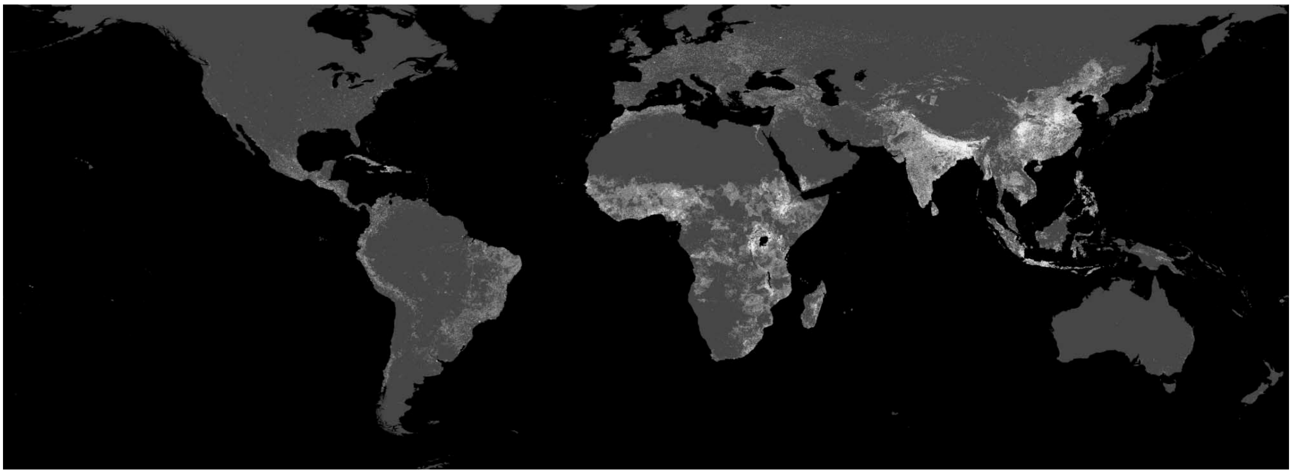

Figure 3. The poverty index is defined as the polution count divided by the brightness of the DMSP lights.

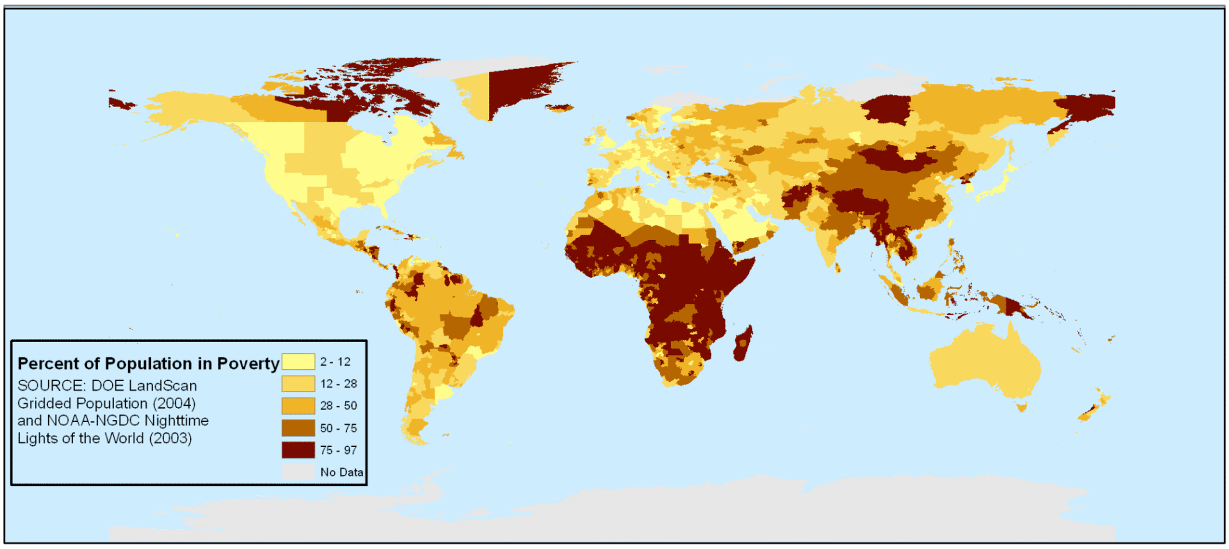

Figure 4. Based on the poverty index values it was possible to estimate poverty levels at a 30 arc second resolution and then aggregate to the subnational level.

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