Global Night-Time Lights for Observing Human Activity

S. Hipskind[a], C. Elvidge[b], K. Gurney[c], M. Imhoff[d], L. Bounoua[d], E. Sheffner[a], R. Nemani[a], D. Pettit[e], M. Fischer[f]

[a]NASA Ames Research Center, Moffett Field, CA (steve.hipskind, rama.nemani, edwin.j.sheffner)@nasa.gov, [b]NOAA Earth Science Research Lab, Boulder, CO chris.elvidge@noaa.gov, [c]Arizona State University, Tempe, AZ (gurney@asu.edu), [d]NASA Goddard Space Flight Center, Greenbelt, MD (marc.imhoff, lahouari.bounoua-1)@nasa.gov, [e]NASA Johnson Spaceflight Center, Houston, TX Donald.r.pettit@nasa.gov, [f] University of California, Berkeley, Berkeley, CA Marc.Fischer@ucb.edu

ABSTRACT – We present a concept for a small satellite mission to make systematic, global observations of night-time lights with spatial resolution suitable for discerning the extent, type and density of human settlements. The observations will also allow better understanding of fine scale fossil fuel CO_2 emission distribution. The NASA Earth Science Decadal Survey recommends more focus on direct observations of human influence on the Earth system. The most dramatic and compelling observations of human presence on the Earth are the night light observations taken by the Defence Meteorological System Program (DMSP) Operational Linescan System (OLS). Beyond delineating the footprint of human presence, night light data, when assembled and evaluated with complementary data sets, can determine the fine scale spatial distribution of global fossil fuel CO_2 emissions. Understanding fossil fuel carbon emissions is critical to understanding the entire carbon cycle, and especially the carbon exchange between terrestrial and oceanic systems.

Keywords: urban, human settlement, smallsat, CO_2 emissions

1. INTRODUCTION

The most dramatic and compelling observations of the human presence on the Earth from space are the night light observations taken by the DMSP Operational Linescan System. Even more striking are higher resolution, color images taken by Don Pettit and other astronauts from the International Space Station. Pettit has compiled a sequence of the night-time images into a movie entitled "Cities at Night, an Orbital Tour Around the World" (www.youtube.com/watch?v=eEiy4zepuVE), in which Pettit describes the images of city lights as "…one of the most beautiful unintentional consequences of humanity."

This paper presents a concept for a small satellite mission to obtain systematic, global observations from space of night-time lights on the surface of the Earth. The observations should be at a resolution capable of delineating the primary features of human settlement.

The cornerstone of NASA's program in space and Earth science is the community guidance in setting scientific priorities and recommended observations. NASA obtains this guidance through the National Academy of Science, which provides the community consensus in scientific priorities in "Decadal Surveys". The first NASA Decadal Survey for Earth Science was released in February, 2007 (NRC, 2007). In that report one of the recurring themes was the importance of obtaining direct observations of the impact of human activity on the Earth system. There have been no more direct observation from space of the imprint of human presence than that obtained from the DMSP night lights data. Almost everyone has seen the deep purple poster showing the global night-time lights compiled from OLS, Figure 1 (Elvidge, et al, 2001, http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Night_Lights_Poster.html). Elvidge and collaborators have demonstrated, through many studies, the variety of information that can be gleaned from the night lights data beyond mapping of cities: from identifying fires, oil field flares, to fishing fleets to understanding human energy consumption (Elvidge 1997, 2001, 2009, 2010).

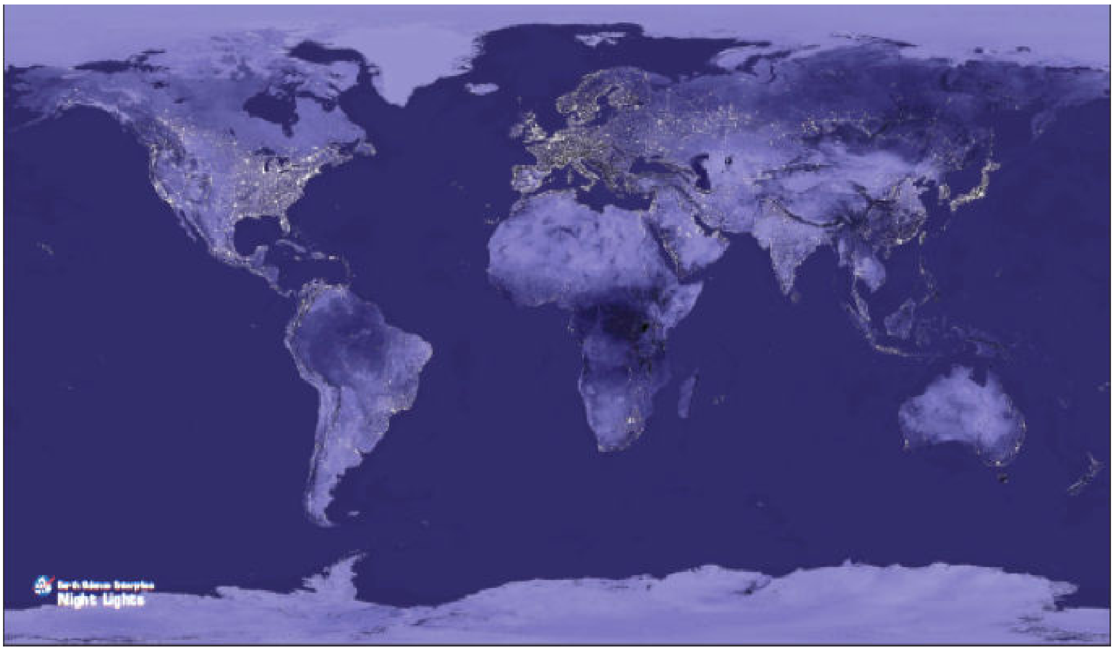


Figure 1. Global Night-time Lights from DMSP/OLS

2. FOSSIL FUEL CO_2 EMISSIONS

Beyond their ability to delineate the location and activities of human settlement, the night light observations can provide the key link to fill gaps in our understanding of the global carbon cycle. Fossil fuel combustion is the largest single source of CO_2 emissions into the Earth's atmosphere. We understand the fossil fuel emissions at national and annual time scales reasonably well. The US Department of Energy's Carbon Dioxide Information Analysis Center (CDIAC) and the International Energy Agency (IEA) provide a global database of CO_2 emissions for countries.

For both a better scientific understanding as well as increasing need for policy and regulatory decision making, it is crucial that we accurately estimate the magnitude and space/time distribution of fossil fuel emissions at scales equivalent to the terrestrial ecosystem processes. Fossil fuel CO_2 estimates are a critical component of all carbon budgeting studies (both inverse/top-down and bottom-up) and are typically utilized with zero uncertainty, This results in widely-acknowledged bias in estimates of the remainder of the carbon budget. As carbon cycle studies move to finer scales (motivated by policy *and* science questions), the uncertainty in fossil fuel estimation will become a central weakness of carbon source/sink estimation. The Vulcan project led by Gurney (Gurney et al, 1997) is the most comprehensive effort to date to quantify fossil fuel carbon emissions in the US at sub-national spatial scale. The Vulcan Project is a NASA/DOE funded project under the North American Carbon Program (NACP). "The purpose is to aid in quantification of the North American carbon budget, to support inverse estimation of carbon sources and sinks, and to support the demands posed by higher resolution CO_2 observations (in situ and remotely sensed). The Vulcan project has achieved the quantification of the 2002 US fossil fuel CO_2 emissions at the scale of individual factories, powerplants, roadways and neighbourhoods on an hourly basis. The entire inventory is on a common 10 km X 10 km grid to facilitate atmospheric modelling. In addition to improvement in space and time resolution, Vulcan is quantified at the level of fuel type, economic sub-sector, and county/state identification. " (https://www.purdue.edu/eas/carbon/vulcan/index.php). Vulcan utilizes the wealth of bottom up information on energy production and consumption uniquely available in the United States.

Downscaling fossil fuel emissions globally is problematic. Much of the land surface of the Earth does not have the detailed information on fossil fuel emissions as in the US and other developed nations. Efforts in the last decade have sought to downscale the spatial distribution of CO_2 emissions through available proxy information, primarily through population databases (Andres et al., 1999; Blasing et al., 2005). More recently researchers have demonstrated the value of the night lights data to inform the fundamental problem of understanding the distribution of fossil fuel CO_2 emissions on a global basis at sub national scales (Rayner, 2010, Oda, 2010, Ghosh, 2010). Rayner has shown that the combination of population and night lights does a better job of reproducing the Vulcan emissions than either population or night lights alone. Rayner has developed a Fossil Fuel Data Assimilation System (FFDAS). The system is based on a modified Kaya identity, which expresses emission as a product of areal population density, per captia economic activity, energy intensity of the economy, and carbon intensity of energy. They use data assimilation to constrain their model with various observations, notably, the statistics of national emissions and data on the distribution of nightlights and population.

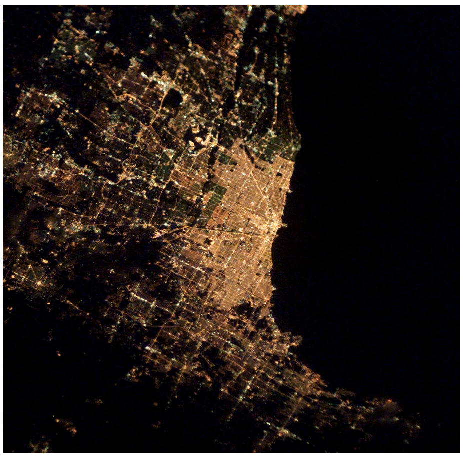
Oda (2010) has also used night-time light observations combined with a world-wide point source database to develop the Open source Data Inventory of Anthropogenic CO_2 emission (ODIAC), a 1 km X 1 km annual fossil fuel inventory for the years 1980-2007. His effort was driven by the goal of providing an a priori dataset on fossil fuel CO_2 emissions for region flux inversions using GOSAT (Greenhouse Gas Observing Satellite) observational data. His approach is to estimate national emissions using global energy consumption statistics. Then emissions from point sources were estimated separately and were spatially allocated to exact locations indicated by the point source database. Emissions from other sources were distributed using a special night light dataset that had fewer saturated pixels compared with regular night light datasets. He, too, was able to better match the Vulcan dataset in the US than previous efforts using population data.

Ghosh, et al (2010) have taken a different, much simpler approach, developing regression models based on the Vulcan data in the US. An initial regression of the carbon emissions of the five sectors (residential, commercial, aircraft, industrial and mobile sector) of the Vulcan data with only the DMSP-OLS data and distributed based on the global night-time data underestimated CO_2 emissions for most countries. A second regression model using both night lights and population data from the DOE LandScan grid improved the emission estimates. This makes sense, since lighting usage and distribution around the globe can be quite different than in the US. Population data, where there is no detectable night light data, acts as the proxy for distributing CO_2 emissions. Their conclusion is that current coarse resolution night light data from DMSP is inadequate for making independent estimates of CO_2 emissions. It cannot be used to articulate the variability between sectors. With higher spatial resolution and multispectral night-time lights it would be possible to distinguish the lighting from residential, commercial/industrial, and transportation sectors (Elvidge, 2007, 2010).

3. NIGHTSAT MISSION

One of the limitations of the current DMSP-OLS night lights dataset is that it was not designed to focus on Earth surface lights and the signal saturates in bright areas. Because of frequent saturation, studies using the DMSP night lights data have to apply statistical corrections which add uncertainty to their analyses. The DMSP data has a relatively coarse spatial resolution of 2.7km. It cannot resolve human infrastructure. This is seen dramatically by comparing scenes from DMSP and the roughly 60m resolution images taken from the International Space Station (figures 2a and 2b).

2a. Chicago – 2.7km DMSP-OLS



2b. Chicago - ~60m Nikon image from ISS

We propose to address the current shortcomings of the available night lights dataset by designing a mission that is focused on the information content available from night light observations with greater low light sensitivity and dynamic range, as well as greater spatial resolution to delineate human infrastructure, such as residential versus industrial development, transportation corridors, etc.

This concept speaks directly to the Decadal Survey concept of the Venture Class missions which is described in the NRC Report (NRC, 2007): Priority would be given to cost-effective, innovative missions rather than those with excessive scientific and technological requirements. The Venture class could include stand-alone missions that use simple, small instruments, spacecraft, and launch vehicles; more complex instruments of opportunity flown on partner spacecraft and launch vehicles; or complex sets of instruments flown on suitable suborbital platforms to address focused sets of scientific questions. These missions could focus on establishing new research avenues or on demonstrating key application-oriented measurements.

Based on detailed airborne studies by Elvidge et al (2006), significant effort has gone into understanding the needs for sensitivity in light detection, as well as the spatial scales that allow optimization between good swath coverage while retaining enough spatial detail to identify major constructs of human activity – industrial versus residential building, major transportation arteries, power plants and oil refineries.

Using those previous studies we have defined the optimal NightSat mission. The target spatial resolution is 50m. The sensitivity required for low light detection is $2.5E^{-8}$ Watts $cm^{-2}sr^{-1}\mu m^{-1}$ (Elvidge, 2006)). Having multiple spectral detection bands would allow further delineation of attributes, such as lighting types (sodium, mercury vapor, etc). Much of the information is attainable from a panchromatic imager with high sensitivity and a wide dynamic range.

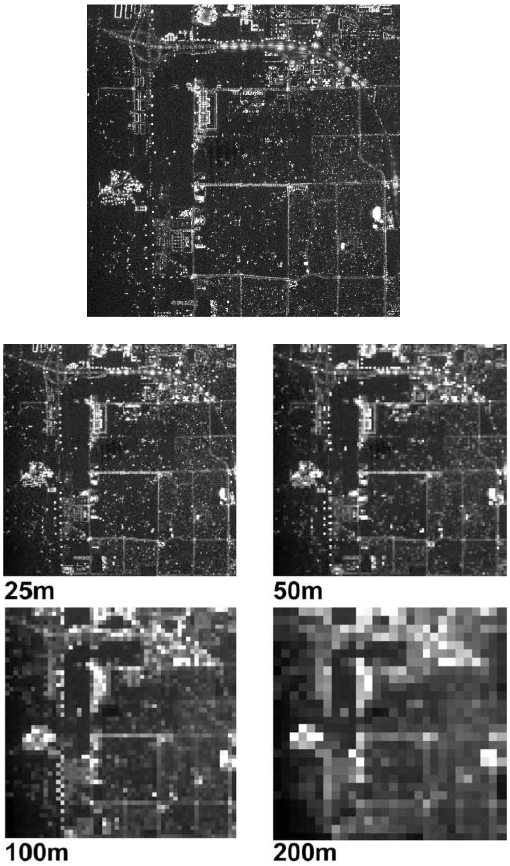


Figure 3. Simulation of night light data at 25, 50, 100 and 200m resolution generated from an ER-2 image taken at 13.7km over Las Vegas, NV with a Cirrus DCS digital camera at 1.5m resolution (top). (Elvidge, 2006)

REFERENCES

Andres, R. J., et al, “Carbon dioxide emissions from fossil-fuel use. 1751-1950, *Tellus*, 51B, 759-765, 1999.

Blasing, T. J., et al, The annual cycle of fossil-fuel carbon dioxide emission in the United States, Tellus, 57B, 107-115, 2005.

Committee on Earth Science and Applications from Space: A Community Assessment and Strategy for the Future, National Research Council (NRC): Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond, ISBN: 0-309-66714-3, 456 pages, 8 1/2 x 11, (2007)

Elvidge, C. D., Baugh, K. E., Kihn, E. A., Kroehl, H. W., and Davis, E. R.:, Mapping city lights with night-time data from the DMSP operational linescan system, Photogramm. Eng. Rem. S., 63, 727-734, 1997.

Elvidge, C. D., Imhoff, M. L., Baugh, K. E., Hobson, V. R., Nelson, Il, Safran, J., Dietz, J. B., and Tuttle, B. T.: Night-time lights of the world: 1994-1995, J. Photogr. Remote Sensl, 56, 81-99, 2001.

Elvidge, et al, The NightSat Mission Concept, International Journal of Remote Sensing, 2006.

Ghosh, T., Elvidge, C., Sutton, P., Baugh, K., Ziskin, D., Tuttle, B., Creating a Global Grid of Distributed Fossil Fuel CO_2 Emissions from Night-time Satellite Imagery, Energies, 3, 1895-1913,; doi:10.3390/en3121895, 2010.

Gurney, K. R., Rachel, L. M., Denning, A. S., Rayner, P. J., Baker, D., Bousquet, P., Bruhwiler, L., Chen, Y.-H., Ciais, P., Fan, S., Fung, I. Y., Gloor, M., Heimann, M., Higuchi, K., John, J., Maki, T., Maksyutov, S., Masarie, K., Peylin, P., Prather, M., Pak, B. C., Randerson, J., Sarmiento, J., Taguchi, S., Takahashi, T., and Yuen, C.-W.: Towards robust regional estimates of CO2 sources and sinks using atmospheric transport models, Nature, 415, 626–630, 2002.

Gurney, K. R., Mendoza, D. L., Zhou, Y., Fischer, M. L., Miller, C. C., Geethakumar, S., and de la Rue du Can, S. Geethakumar, C. Miller (2009) The Vulcan Project: High resolution fossil fuel combustion CO2 emission fuxes for the United States, Environ. Sci. Technol., 5535–5541, doi:10.1021/ es900806c, 2009.

Gurney, K. R., et al, “Research needs for process-driven, finely resolved fossil fuel carbon dioxide emissions.” EOS, December 4, 2007.

Oda, T., S. Makasyutov, A very high-resolution global fossil fuesl CO_2 emission inventory derived using a point source database and satellite observations of night-time lights, Atmos. Chem. Phys., 11, 543-556, 2011.

Prentice, I. C., et al., The carbon cycle and atmospheric carbon dioxide, in Climate Change, 2001, edited by J.T. Houghton et al., pp. 185-225, Cambridge University Press, New York, 2001

Rayner, P. J., Raupach, M. R., Paget, M., Peylin, P., and Koffi, E.: A new global gridded dataset of CO2 emissions from fossil fuel combustion: Methodology and evaluation, J. Geophys. Res., 115, D19306, doi:10.1029/2009JD013439, 2010