Social Science Applications for Nocturnal Imagery of the Earth

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By Paul C. Sutton and Benjamin Tuttle, Department of Geography, Denver University,
USA (email: paul.sutton@ du.edu), and Christopher D. Elvidge,
NOAA-NESDIS National Geophysical Data Center, USA

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Images of the 'Earth at night' derived from mosaics of hundreds of orbits of the Defense Meteorological Satellite Program's Operational Linescan System (DMSP OLS) have captured the public imagination and been incorporated into posters, news media weather presentations, and Google Earth (Sullivan, 1989; Elvidge *et al*., 1997a). These images of the Earth at night also contribute to many studies that measure and map human impacts on the Earth. Since the turn of the twenty-first century, many studies have used nighttime satellite imagery to explore various facets of human environment interaction (Doll, 2008).

Not surprisingly, there have been many studies examining the significant relationship between nighttime lights data products and population parameters such as urban extent, urban sprawl, and exurban development (Imhoff *et al*., 1997; Elvidge *et al*., 1997b; Sutton, 2003; Small *et al*., 2005; Sutton *et al*., 2006). Urban areas are the most densely populated parts of the world and city lights data products have been used to map and estimate urban populations and intra-urban population density (Sutton *et al*., 2001; 2003; Potere Et al., 2009). Chris Doll has explored how the nighttime imagery serves as proxy measure for non-population related socio-economic phenomena such as CO2 emissions and economic activity (Doll *et al*., 2000; Doll, 2003). Numerous studies have used the nighttime imagery to map, estimate, and/or measure various facets of economic activity at a range of spatial scales (Sutton and Costanza, 2002; Ebener *et al*., 2005; Sutton *et al*., 2007; Ghosh et al., 2009). Data sets derived from nighttime satellite imagery have been used to produce maps of impervious surface area (ISA; Elvidge *et al*., 2004). Impervious surface area has also been identified as an important environmental indicator variable (Arnold and Gibbons, 1996) for such things as its impact on water quality (Carlson, 2008).

Applications of nighttime lights data are far reaching and also include monitoring of natural gas flaring, monitoring coral reef health, estimating poverty, and observing electrification rates. Natural gas flaring is a serious environmental hazard and also wastes larges amounts of energy each year. As part of an effort by the World Bank Global Gas Flaring Reduction Initiative there is ongoing research on estimating volumes of natural gas flaring around the globe (Elvidge et a., 2009). Nighttime lights have also been used to estimate and monitor coral reef stressors to better understand this complex process (Aubrecht et al., 2008). Elvidge et al. (2009) used nighttime lights data and population data to make the first globally consistent map of poverty estimates. Additionally, nighttime lights can be used to observe global electrification rates (Elvidge et al., 2010). There are also applications currently being explored including observations of power outages after natural disasters and the impacts of lights at night on sea turtles, which use the moon to determine the correct direction to travel to the sea after hatching.

Nighttime imagery of the Earth's demonstrated capabilities for serving as a proxy measure of human impacts on the environment and other socio-economic phenomena have stimulated a lot of interest in the development of a NightSat mission (Elvidge *et al*., 2007a). A NightSat mission would be a satellite program designed specifically to observe the Earth from space at night using sensors with higher spatial and spectral resolution. Recall that the DMSP OLS was designed in the late 1960s as a meteorological satellite to see sunlight and moonlight reflected off clouds.

The threats of climate change as driven by increases in the concentration of greenhouse gases such as CO2 seem to be increasingly recognized as significant and real. Al Gore's highly publicized narration of the movie 'An inconvenient truth' and the Stern report of 2007 (Stern, 2007) are seen by many as a 'tipping point' in overall public conviction as to the reality and seriousness of the problems associated with climate change. It is interesting, and perhaps surprising, to note that simple measurements of an extremely basic component of the atmosphere (CO2) (Keeling *et al*., 1995) have most likely triggered more public awareness and acceptance of deleterious human impact on the Earth than the combined lamentations of prominent neo-Malthusian scholars such as Garret Hardin, Paul Ehrlich, and Jared Diamond (Hardin, 1968; Ehrlich and Ehrlich, 1990; Diamond, 2005). The now famous 'Keeling Curve' charting atmospheric CO2 concentrations over Mauna Loa in Hawaii through time (Keeling *et al*., 2004) is an interesting and poignant globally aggregate measure of anthropogenic impact on the planet. In many respects Keeling's curve is like a planetary 'idiot light' on the dashboard of a car telling humanity that something might be wrong. And, like the 'idiot light' on the dashboard of a car, the 'Keeling Curve' only provides a limited amount of information as to what the exact nature of the problem is and how it can be addressed.

Nonetheless, 'idiot lights' are invaluable devices if they trigger the following three responses: (1) stop the behavior that has serious potential negative consequences (ie, continuing to drive a car with an overheating engine or allowing atmospheric CO2 concentrations to double); (2) diagnose what caused the 'idiot light' to turn on; and (3) treat the cause (eg, putting oil in the engine, coolant in the radiator, shifting to renewable energy supplies, etc). The seemingly endless debates about the reality of global warming seem to be waning at this point which suggests that these three steps might be taken more vigorously in the near future. However, new and more difficult questions arise when it is necessary to decide which and whose behavior must change and how we hope to bring about those changes. The analogy between the 'Keeling Curve' and an 'idiot light' may hold some validity; however, the subsequent information needed to make diagnoses and change behavior is more complicated than simply 'looking under the hood'. Fortunately, there is an abundant amount of information in the form of remotely sensed satellite imagery that can inform our understanding of the human-environment-sustainability problematic. In contrast to the globally aggregate measure that the CO2 data at Mauna Loa provides, remotely sensed nocturnal images of the Earth provide spatially explicit data that can be used as inputs for a suite of methods and analyses that enable more accurate measurement, mapping, and monitoring of human impacts on the Earth.

The 2007 National Research Council report *Earth science and applications from space: national imperatives for the next decade and beyond* (NRC, 2007) specifically identifies the requirement for measuring the ‘human footprint’ on ecological systems. Human impacts on ecosystems are myriad in nature and magnitude. Nighttime images of the earth can provide a diverse array of empirical measurements of human impacts on ecosystems in a spatially explicit manner that is uniformly measured across the globe. These images can serve as proxy measures of a myriad number of important social, economic, and political variables that inform our understanding of the human-environment interaction dynamic.

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