Identifying and Mapping Night Lights using Imaging Spectrometry

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Abstract—Remote mapping of night lights using the Defense Meteorological Satellite Program (DMSP) has been used for decades to inventory the global distribution of human activity. [©±] The coarse spatial and spectral resolution of DMSP, however, has precluded discrimination of lighting types or spectral characteristics. Recent demonstrations using photography from the International Space Station and airborne multispectral simulations demonstrate significant potential, but high-spectral-resolution field and laboratory measurements indicate that these methods do not take full advantage of the spectral information available. This research demonstrates the use of imaging spectrometer data to identify, characterize, and map urban lighting based on comparison to a lights spectral library. The library provides information about spectral emission lines unique to specific lighting types. ProSpecTIR-VS imaging spectrometer data of Las Vegas, Nevada were analyzed to extract spectral features and these were compared to the spectral library measurements on a pixel-by-pixel basis, resulting in a detailed spatial map showing different lighting types. The nature and distribution of lights can be used as a surrogate for characterization of urban settings, and measurement of urban development.

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1. Introduction

Nocturnal lighting is nearly ubiquitous in many urban areas (e.g. Figure 1). Historically, nighttime lighting has been associated with technological development and urbanization, and changes over time. The global distribution of nighttime lights has been mapped using remote sensing data from the Defense Meteorological Satellite Program (DMSP) which has operated since the early 1970s [1, 2]. DMSP, however, has coarse spatial resolution and only one spectral band, so it has not been possible to discriminate lighting types or spectral characteristics. Astronauts have photographed cities at night from the International Space Station, confirming that remote sensing can be used to make detailed maps of a variety of light sources. Recent multispectral simulations demonstrate that it is possible to identify selected lighting types with a few properly placed broad spectral bands [3]. Ideally, however, high-spectral-resolution measurements are required for direct identification of light sources based on spectral signatures [4].

Figure 1 - Paris Hotel and Casino, Las Vegas, Nevada, USA at night. Photo courtesy of http://www.freedigitalphotos.net

There has been some previous research directed at remote sensing of night lights using imaging spectrometers (hyperspectral or "HSI" sensors) [5, 6], however, most sensors are not optimized for low-light operation. This research uses state-of-the-art-imaging spectrometer data of the central part of the city of Las Vegas, Nevada to further develop hyperspectral analysis approaches for identifying nocturnal lighting, and to validate spectral mapping capabilities.

2. NIGHT LIGHTS SPECTRAL LIBRARY

NOAA has measured emission spectra of a variety of lighting types using an Analytical Spectral Devices (ASD) field spectrometer. These include measurements from 0.4 – 2.5 micrometers for forty-three different lamps, encompassing nine of the major types (liquid fuel lamps, pressurized fuel lamps, incandescent (including quartz halogen), mercury vapor, fluorescent, metal halide, high pressure sodium, low pressure sodium, and light emitting diodes (LED) [3]. Measured spectra of selected neon lights were also recently added. All these have been compiled into a binary spectral library for comparison to imaging spectrometer data. Figure 2 shows selected spectra.

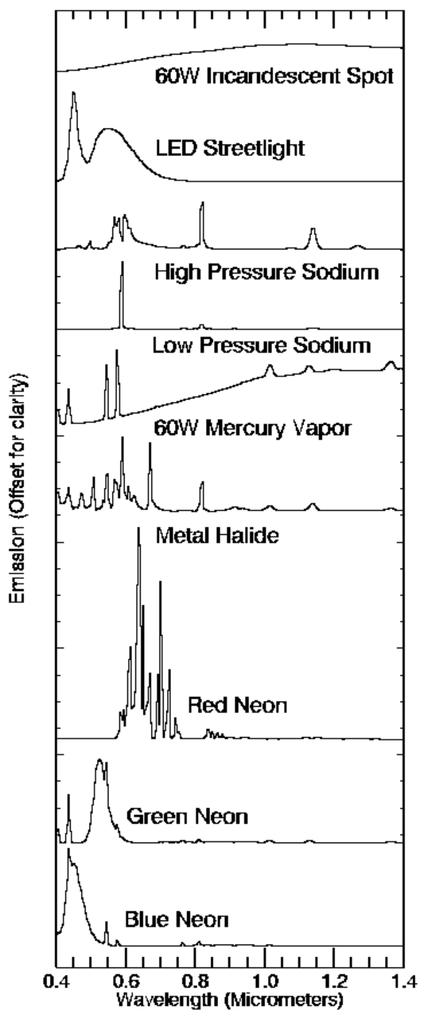

Figure 2 - Comparison of VNIR/SWIR radiance spectra for selcted night light types showing emission features. Spectra from the NOAA night-lights spectral library, measured with an Analytical Spectral Devices Spectroradiometer [3].

3. IMAGING SPECTROMETRY

Imaging Spectrometry (Hyperspectral Imagery or HSI)

Imaging spectrometry, simultaneous measurement of continuous spectra and images in up to hundreds of spectral channels or bands, is a proven technology for identifying and mapping materials based on their spectral signatures [7, 8]. It has also become known as "Hyperspectral Imaging" or 'HSI". Spectral mapping using imaging spectrometer data is well established and routinely used for numerous applications [9-15].

Instrumentation Used for this Research:
ProSpecTIR-VS Imaging Spectrometer System

The ProSpecTIR-VS hyperspectral system operated by SpecTIR, LLC (www.spectir.com) is a custom integrated system that incorporates Specim (www.specim.fi) AISA Eagle (VNIR) and Hawk (SWIR) imaging spectrometers. The combination of these two high performance sensors provides for the simultaneous acquisition of full hyperspectral data covering the 0.4 – 2.45 micrometer spectral range. The two imaging spectrometers are co-aligned and generate a single, full-spectrum data cube covering 320 pixels cross-track. In airborne operation, as a pushbroom instrument and utilizing a 24 degree scan and 0.075 degree (approximately 1.3 milliradian) instantaneous field of view (IFOV), the system achieves spatial resolutions varying from 0.5 – 5m depending upon altitude and platform speed. The data collected for this experiment constitute data with 360 spectral bands total covering the 0.4 – 2.45 micrometer spectral range at approximately 5nm spectral resolution. Only the 0.4 – 1.4 micrometer range was used in this research.

4. APPROACH, METHODS, AND RESULTS

Las Vegas, Nevada, USA represents a "target-rich" environment for night lights, with a wide variety of types and intensities (Figure 1). While not representative of a typical urban area (more highly illuminated and many more unique light types), it does present an ideal case for testing of HSI identification and mapping capabilities.

ProSpecTIR-VS data were acquired at 10:55 PM on July 28, 2009 at an altitude of approximately 1800m over the city, yielding 1.2m pixels. On-board GPS and inertial navigation provided excellent positioning information allowing geocorrection, and geocoding despite the lack of readily apparent ground features at night. Data were corrected to radiance by SpecTIR LLC using dark current correction, array normalization ("flat fielding"), and radiometric calibration using a Labsphere USS-2000-V uniform source (NIST-traceable integrating sphere). The resultant calibration typically produces VNIR/SWIR radiance data within +/- 5% of absolute radiance (Personal communication 2010, SpecTIR, LLC). Wavelength calibration was performed using an Oriel Cornerstone 130

1/8m monochromator. The central wavelength locations are known and certified within 0.5nm accuracy. The radiance data were further normalized to remove anomalous response near 1.0 micrometers by dividing out a “background” radiance taken from a dark area in the scene.

A wide variety of lighting types were easily observed in the normalized SpecTIR radiance data utilizing color images based on known lighting spectral responses (Figs 3 and 4).

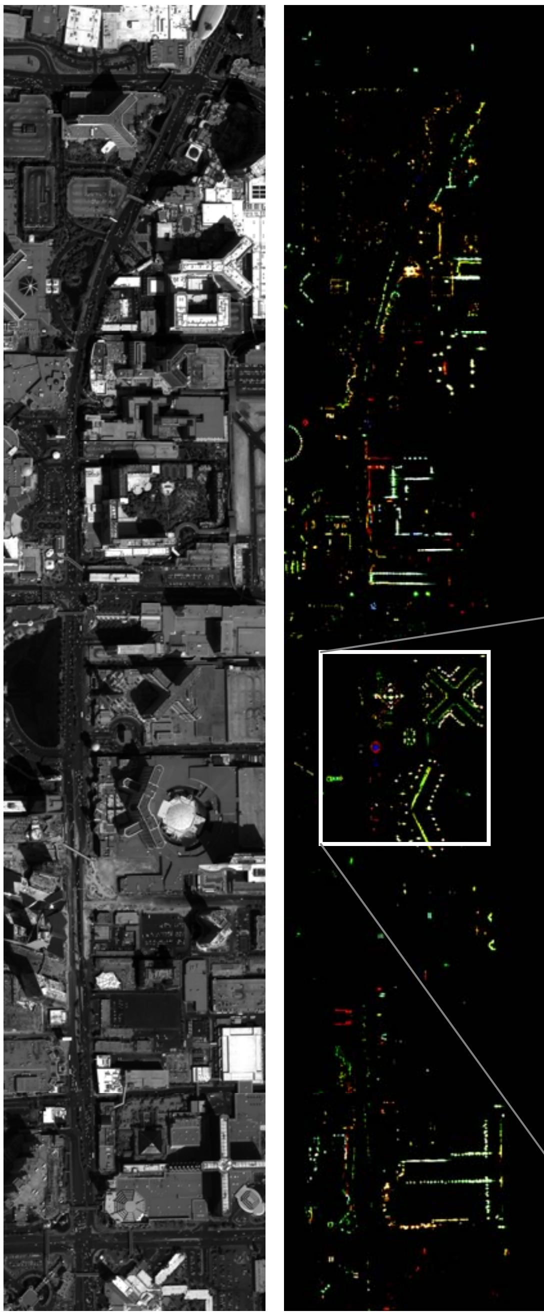

Figure 3 – Left: Quickbird image at approximately 0.6m spatial resolution for a portion of the city of Las Vegas, NV. Right: True-color (0.65, 0.55, 0.45 micrometers as RGB) ProSpecTIR image covering the same area.

Once specific light sources were located, then radiance spectra were interactively extracted from the imaging spectrometer data and visually compared to NOAA’s light sources spectral library (Figures 2 and 5). Because specific light source ground locations were difficult to identify in the nighttime HSI data, a Quickbird (QB) 0.4m spatial resolution panchromatic image acquired 6 September 2009 was used as a base image. The night-time ProSpecTIR data were viewed adjacent to, and overlain on the QB data for location purposes and for comparison to known Las Vegas buildings and other lighting sources (Figures 3 and 6). Despite slight spatial offsets resulting from the fact that neither dataset was orthorectified (and some high buildings), there were clear associations between specific lighting types and known Las Vegas illuminated locations. Specific light sources identified were correlated with known locations in the QB data and their origins determined based on spectral signatures and geographic locations. These included, for example for a subset image, blue and red neon lights at the Montgolfier balloon replica and sign (A) and (B), high pressure sodium lights at the Vegas Tour Eiffel (C) (Figure 1), and metal halide lights at the Paris Hotel and Casino main building (D) as well as other locations (Figure 4). There were some indications of possible spectral mixing or variants of these specific light types, as evidenced by extra spectral lines in some of the extracted spectra (Figure 5).

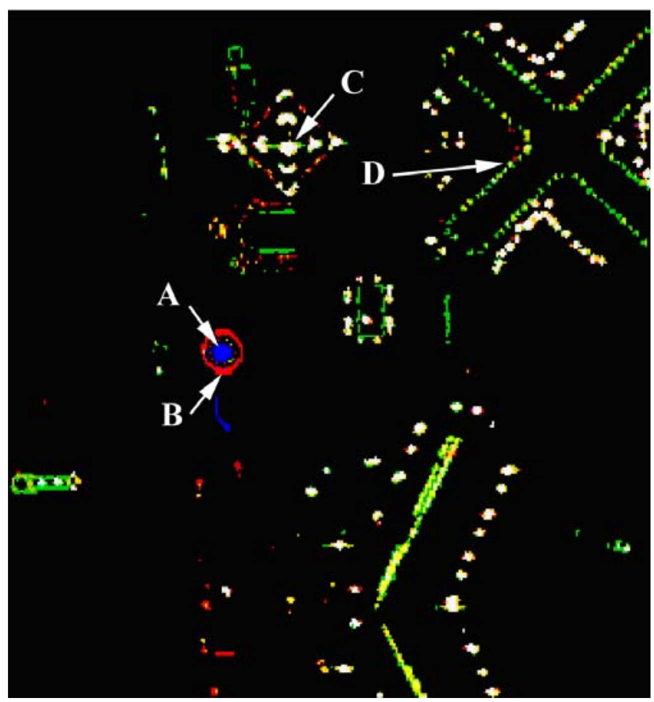

Figure 4 - True color composite image of night lights for a portion of the Las Vegas, Nevada ProSpecTIR Data. Red areas (A) are red neon, blue areas (B) blue neon, white areas (C) are mostly high pressure sodium lights, and green areas (D) are principally metal halide lights (See Figure 5).

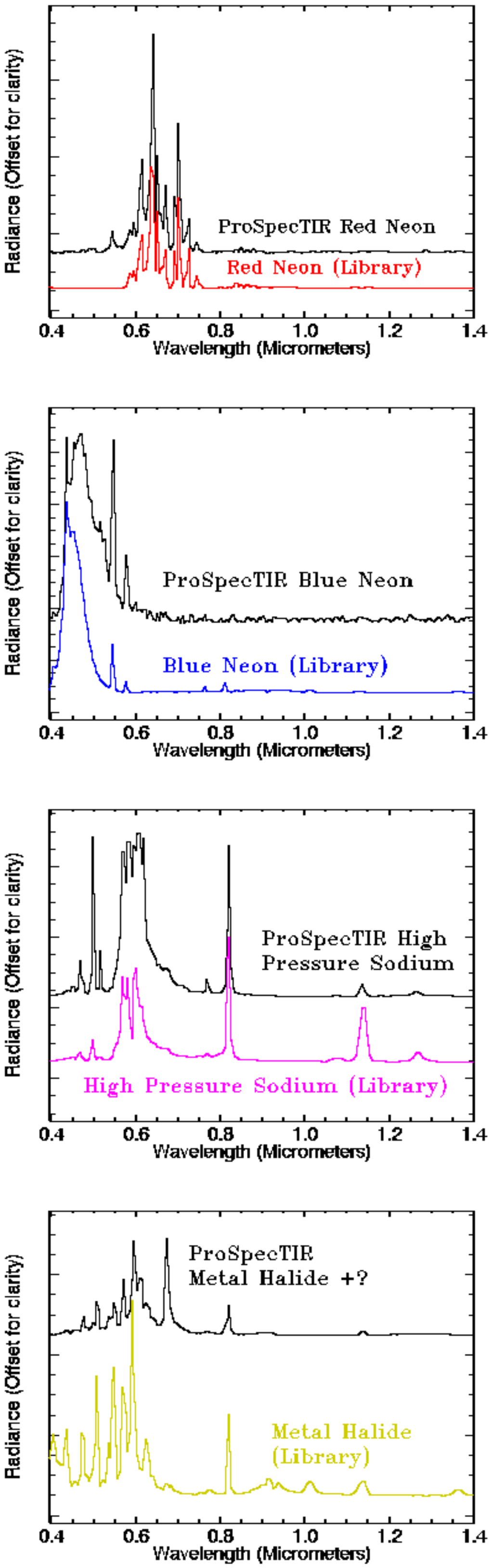

Figure 5 - Comparison of selected NOAA Spectral Library spectra and ProSpecTIR night lights radiance spectra showing correspondence of emission lines for specific lighting types.

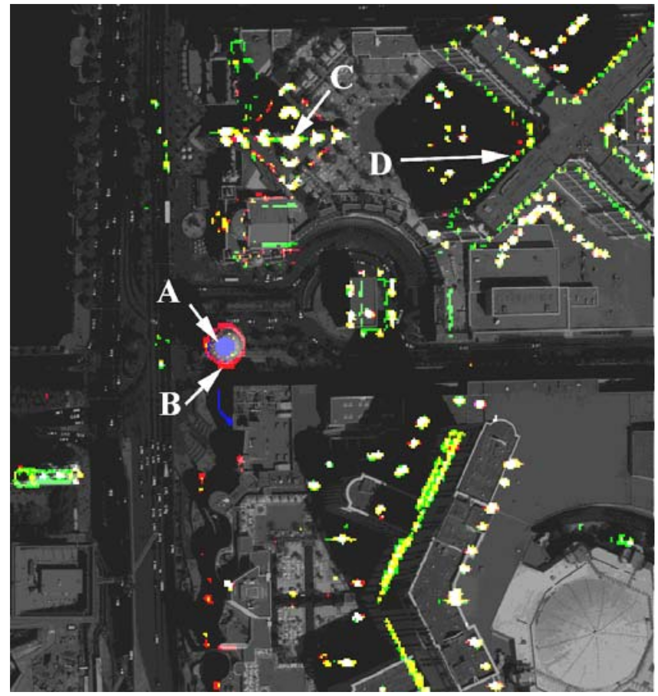

Figure 6 - Night lights true color composite image overlain on Quickbird base. Note slight misregistration caused by non-nadir Quickbird view. These offsets could be corrected by orthorectifying both datasets with a high resolution DEM that included building models.

The radiance data were searched for matches to the emission features in the NOAA night light spectral libraries using a binary encoding approach [8, 16]. Binary encoding is a fast spectral matching algorithm that compares each image spectrum (pixel) in the imaging spectrometer dataset to each spectrum in the spectral library. The data and library spectra are encoded into zeros and ones (binary encoded), based on whether a band falls below or above the spectrum mean, respectively. The results are a binary representation of spectral amplitude [16]. In the case of the Las Vegas ProSpecTIR emission spectra, which typically have sharp spectral lines, binary encoding results in clear delineation of the strongest spectral emission features (Figure 7).

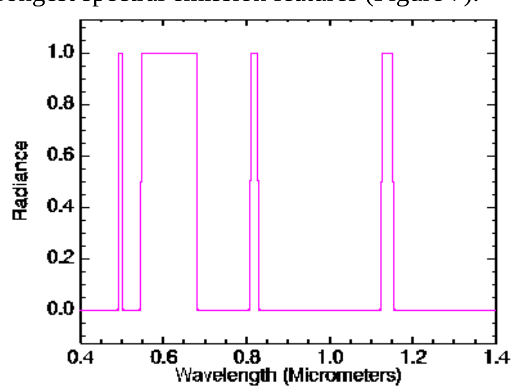

Figure 7 – Binary encoded high pressure sodium library spectrum. Values of 1.0 represent emission features. Compare to Figure 5 High Pressure Sodium spectrum.

When applied to a full imaging spectrometer dataset, full-spectrum matching scores between 0 – 100% are assigned to each image spectrum based on the number of spectral bands that match each binary encoded spectral library spectrum [17]. The spectral library member with the highest score is the best match and is carried forward into a classified image showing the spectrally predominant lighting type. A percent-match threshold (tied to the degree of match – higher scores equal better matches) is used to control which pixels are classified. Pixels that do not meet the threshold criteria are unclassified.

Binary encoding classification maps for specific lighting types were produced using 190 spectral bands (0.4 – 1.4 micrometers) and spectra from the NOAA spectral library (Figure 8). Mapping was verified utilizing spectral-spatial data browsing and visual inspection of specific spectral lines present in the ProSpecTIR data and library data (Figures 2 and 5). Lighting types located and identified based on their high resolution spectral signatures in the imaging spectrometer data included high and low pressure sodium, metal halides, mercury vapor, and a variety of colored neon lights, as well as mixtures. Figure 8 shows the distribution of metal halides, high pressure sodium and two colors (red and blue) of neon lights overlain on Quickbird data.

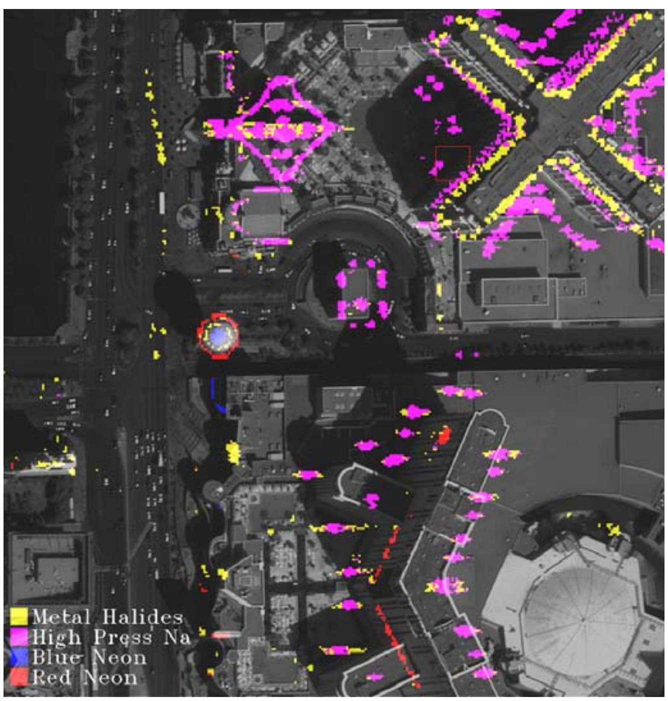

Figure 8 - Night lighting type classification image map produced using binary encoding overlain on Quickbird data. Colors match Figure 5.

The origin of specific spectral signatures was determined based on spectral signatures and geographic locations utilizing the Quickbird data and a Google Earth city model with 3D building profiles (Figure 9). Use of the 3-D model with the QB data and the spectral mapping results allowed assignment of specific lighting types to specific buildings, structures, and surface features (street lights, etc), thus enabling virtual validation based on descriptions of known Las Vegas illuminated landmarks (e.g. the Montgolfier balloon replica and sign (A) and (B) on Figure 4 and 6 – commonly described as “a red and blue neon sign…”).

Figure 9 - Perspective view of the Las Vegas 3-D building model corresponding approximately to coverage in Figures 4, 6, and 8 . Labels A-D match those on the image figures.

5. Summary and Conclusions

Night-time ProSpecTIR-VS imaging spectrometer data acquired of Las Vegas Nevada demonstrate that high-spectral-resolution emission spectra can be measured that allow detection and identification, and mapping of the character and location of nocturnal lighting. Comparison of image spectra to a NOAA spectral library of known lighting types shows that image-extracted spectra have the same emission features present in the library data. Extension of automated spectral matching methods (binary encoding) to the imaging spectrometer data using the spectral library results in a night lights image map that can be overlain on high-spatial-resolution day time imagery (e.g. Quickbird) for location purposes. Using the ProSpecTIR-VS imaging spectrometer data, we identified and mapped metal halide lights, high pressure sodium lights, and two colors (red and blue) of neon lights. We expect that nocturnal lights mapping using imaging spectrometer data can be used as a surrogate for characterization of urban settings, and measurement of urban development.

6. Acknowledgments

The ProSpecTIR-VS night lights imaging spectrometer data were provided by SpecTIR, LLC, Reno, Nevada, USA (http://www.spectir.com). This paper builds on extensive previous research by Chris Elvidge and other researchers. Readers are encouraged to view the cited literature.

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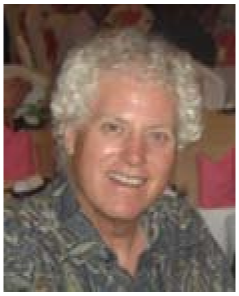
BIOGRAPHIES

Fred A. Kruse *received the Ph. D. Degree in geology from the Colorado School of Mines in 1987. He is currently a Research Professor of Physics at the Naval Postgraduate School, Monterey, California. He teaches courses in spectral remote sensing and synthetic aperture Radar and is developing internet and computer-media-based remote sensing courses. Dr Kruse's research focuses on physics-based exploration of diverse visible/near infrared (VNIR), short-wave infrared (SWIR), and long-wave infrared (LWIR) imaging spectrometer data and multifrequency, polarimetric, and interferometric SAR remote sensing datasets. Interests include extraction of information for geologic mapping, exploration for ore deposits, geothermal/hydrothermal systems, geologic hazards, and environmental monitoring, and for military purposes. Dr. Kruse is also one of the scientists that originally developed the image analysis software, "ENVI".*



Christopher E. Elvidge *is a physical scientist at the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), National Geophysical Data Center (NGDC) in Boulder, Colorado. Elvidge leads the Earth Observation Group (EOG) in the Solar and Terrestrial Physics Division. Current EOG projects include satellite monitoring of gas flaring in oil and gas fields in sixty countries, construction of a global GDP map, and the analysis of electrification rates in more than 200 countries. Elvidge graduated with a Ph.D. in Applied Earth Sciences from Stanford University in 1985 and has been at NGDC since 1994. He has an extensive set of publications (http://www.ngdc.noaa.gov/dmsp/pubs.php).*