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High- and Low-Altitude AVIRIS Observations of Nocturnal Lighting

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1. Introduction

Since the electric light was first commercialized in 1879 by Thomas Edison, utilization of exterior lighting of streets and buildings has expanded to become the normal practice in virtually every part of the world. Today the typical commercial center is bathed in continuous lighting, and pockets of nocturnal illumination (e.g., street and house lights) extend to the very edges of human settlements. Elvidge et al. (1997) developed methods to locate and define the spatial extent of nocturnal lighting across large land areas using low-light imaging data from the Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS). This sensor has a unique capability to detect low levels of visible - near infrared radiance at night (Figure 1). The primary function of the DMSP-OLS is to provide global imagery of cloud cover. At night the observed visible - near infrared (VNIR) radiance is intensified, for the purpose of cloud detection using moonlight. In addition to moonlit clouds, the light intensification makes it possible to detect VNIR emissions emanating from the earth's surface, from cities, towns, industrial sites, gas flares, and ephemeral events such as fires. In the latter part of this decade NOAA, NASA and DoD plan to fly a new sensor (Visible Infrared Imaging Radiometer Suite – VIIRS) which will continue the record of low-light imaging earth observations, with improved spatial and radiometric properties over the OLS.

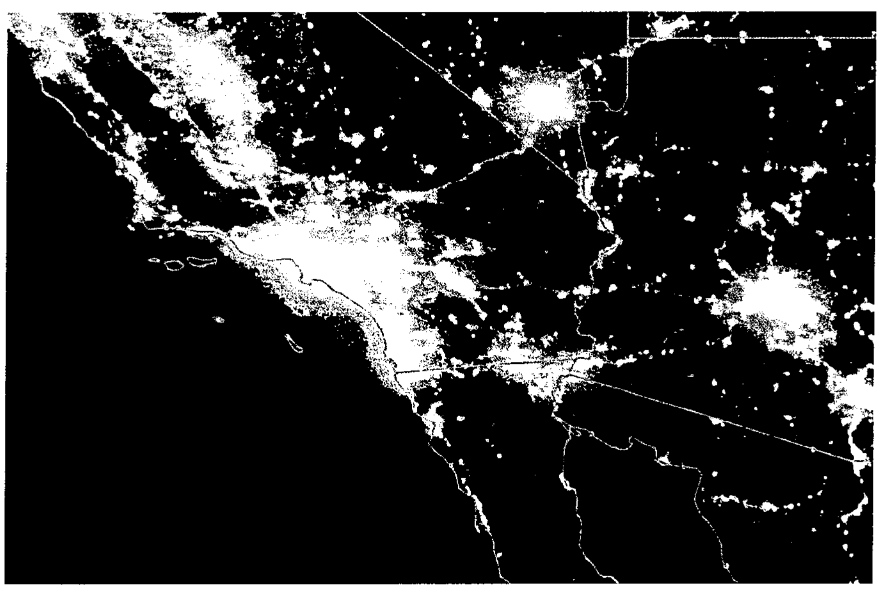

Figure 1. Cloud-free annual composite of DMSP nighttime lights of the Southern California region from 2003. Contrast enhanced to show all detected lighting.

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The spatial linkage between nocturnal lighting and the locations of concentrated human activity has lead to a series of applications for the DMSP nighttime lights data, including (1) spatially explicit estimates population numbers (Sutton *et al.*, 2003), (2) heat island effects on meteorological records (Owen *et al.*, 1998), (3) urban sprawl impacts on agriculture (Imhoff *et al.*, 1997), (4) greenhouse gas emissions (Saxon *et al.*, 1997), (5) terrestrial carbon dynamics (Milesi *et al.,* 2003), spatial distribution and density of man made impervious surfaces (Elvidge *et al.*, 2004) and mapping spatial and temporal variations in squid fishing effort (Maxwell *et al.*, 2004).

As part of our effort to further explore the remote sensing of nocturnal lighting, requests were made for a nighttime AVIRIS data acquisition over urban centers. There were five primary reasons for exploring the hyperspectral remote sensing of nocturnal lighting:

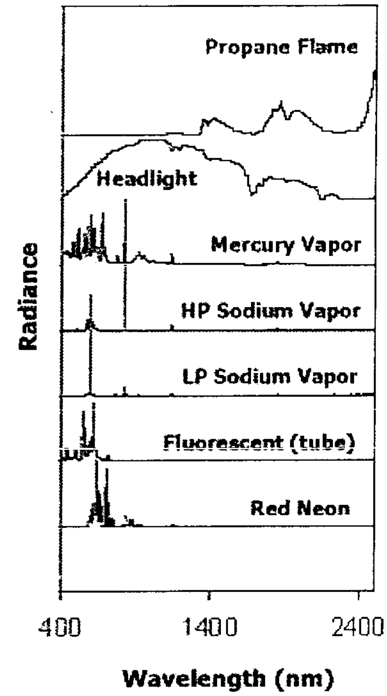
1. Primary types of outdoor lighting emit distinctive sets of narrow line emissions, which may be amenable to hyperspectral remote sensing (Elvidge and Jansen, 1999).
2. Distingishing lighting types may be useful for a variety of applications, such as analyzing the biological impacts of lighting (reference) or modeling the spatial distribution of economic activity.
3. Detection of specific emission lines could be used in the validating wavelength calibration of hyperspectral remote sensing data (Chrien, 1999).
4. It may be possible to calibrate or validate DMSP nighttime lights data using hyperspectral data.
5. It may be possible to simulate future planned or hypothetical sensor data of nocturnal lighting using AVIRIS data.

The requests for nighttime data resulted in the collection of low-altitude nighttime AVIRIS data over Las Vegas, Nevada, in 1998 and a high-altitude flight over Los Angeles in 2003. This paper describes our initial findings from an examination of these unique AVIRIS data sets.

2. Spectral Character of Nocturnal Lighting

Mercury and sodium vapor lamps are the primary type of lighting for streets, roads, parking lots and commercial / industrial facilities in many parts of the world. Mercury vapor lamps have a white or blue-white appearance produced via a large number of narrow line emissions (see Figure 2). High pressure sodium lamps produce an amber light, and have fewer emission lines than the mercury lamps. In areas near optical telescope facilities, low-pressure sodium lamps can be found, with even fewer emission lines. Many private homes and motorized vehicles have incandescent lamps, which have a strong blackbody emission character, with the bulk of the radiant emission in the infrared. Gas flares may exhibit emissions patterns that are indicative of the combination of gases being combusted.

Figure 2. Ground-based spectra of several types of outdoor lighting and a propane flame.



3. AVIRIS Data Acquisitions

Las Vegas, Nevada is internationally recognized as the most colorfully and brightly lit of cities (Figure 3). The Las Vegas lighting, along with its proximity to the primary AVIRIS staging area, dry air, and low cloud cover make it ideal for studying the hyperspectral remote sensing of nocturnal lighting. Low-altitude AVIRIS data were acquired over the central area of Las Vegas, Nevada at approximately 6:35 pm the night of October 4, 1998. AVIRIS was flown on a NOAA Twin Otter aircraft, acquiring data at an altitude of 12,500 ft above sea level (ASL), resulting in data with approximately 3-meter spatial resolution. The AVIRIS data that we analyzed had been radiometrically corrected, but had not been geometrically corrected. Two

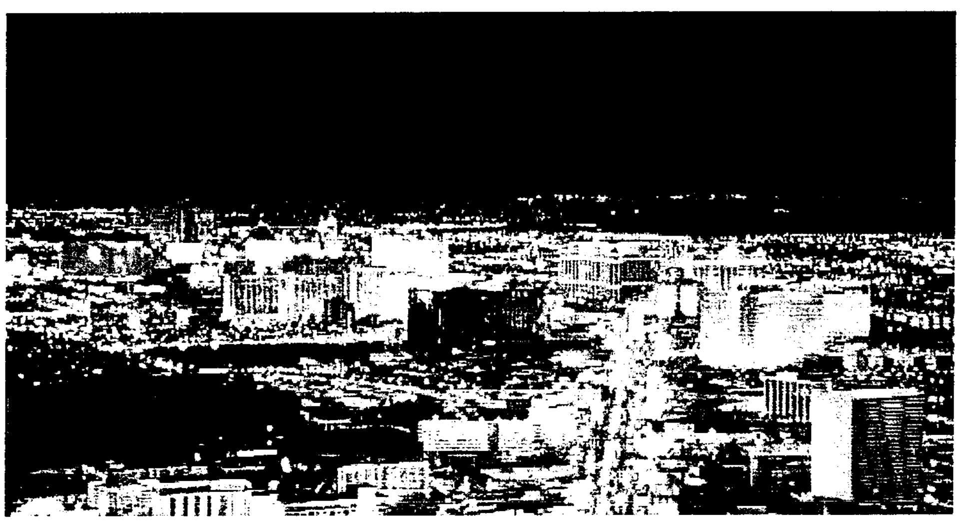


Figure 3. Oblique aerial photograph of the Las Vegas Strip at night.

papers in the 1999 AVIRIS proceedings (Chrien, 1999 and Elvidge and Jansen, 1999) were based on the 1998 nighttime AVIRIS collect over Las Vegas.

Los Angeles is one of the largest cities in the world and has lighting that is typical of most cities in the developed world (Figure 4). High-altitude AVIRIS data were acquired over Los Angeles, California, at approximately 8:10 pm the night of September 22, 2003. AVIRIS was flown on NASA's ER-2, acquiring data at an altitude of 65,000 (+/-) feet ASL, yielding data with 20-meter spatial resolution. Two flight lines were acquired, a north–south line over central Los Angeles and an east–west line over San Gorgonio Pass, east of Los Angeles. DMSP visible and thermal band imagery acquired about 30 minutes later indicate that both areas were largely clear of cloud cover (Figure 5) and that lights were present in Los Angeles. As with the Las Vegas

Figure 4. Oblique aerial photograph of nocturnal lighting in Los Angeles, California.

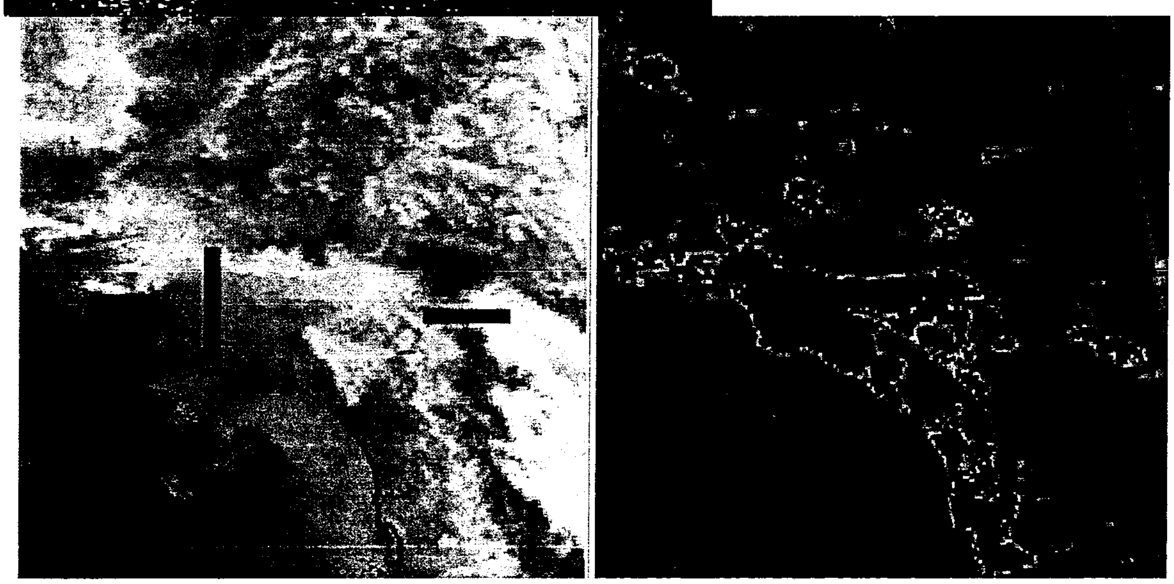


Figure 5. Thermal (left) and visible (right) band DMSP-OLS imagery from Satellite F-14 acquired at 03:43 GMT on September 22, 2003. The AVIRIS flight lines are shown in red. The areas where bright light saturated the OLS sensor are shown in blue.

data, the Los Angeles data were radiometrically corrected, but had not been geometrically corrected.

4. Results from Las Vegas AVIRIS data

Nocturnal lighting was detected in AVIRIS data collected over the Las Vegas Strip. Figure 6 shows the total radiance obtained by summing all the AVIRIS channels in the flight line. Note that most of the flight line lighting levels were below the detection limits of AVIRIS (in 1998). The aggregate spectrum of the flight line (Figure 7) shows a set of emission lines consistent with features found in mercury and sodium vapor lamp spectra.

Figure 8 shows a sampling of the spectra found in the Las Vegas data. Note that most of the spectra contain narrow emission lines, characteristic of vapor lamps, which emit light based on the excitation of electrons in specific elements. The lights observed at Las Vegas exhibit mercury and sodium emission features, plus a number of other more exotic elements associated with specialty lighting. The spectrum in the lower right hand corner shows a blackbody curve and is probably an incandescent light source.

Color composite images of the 1998 Las Vegas data revealed a series of landmark casinos and associated parking lots (Figure 9). It is possible to discern different types of lighting based on brightness differences in three spectral channels.

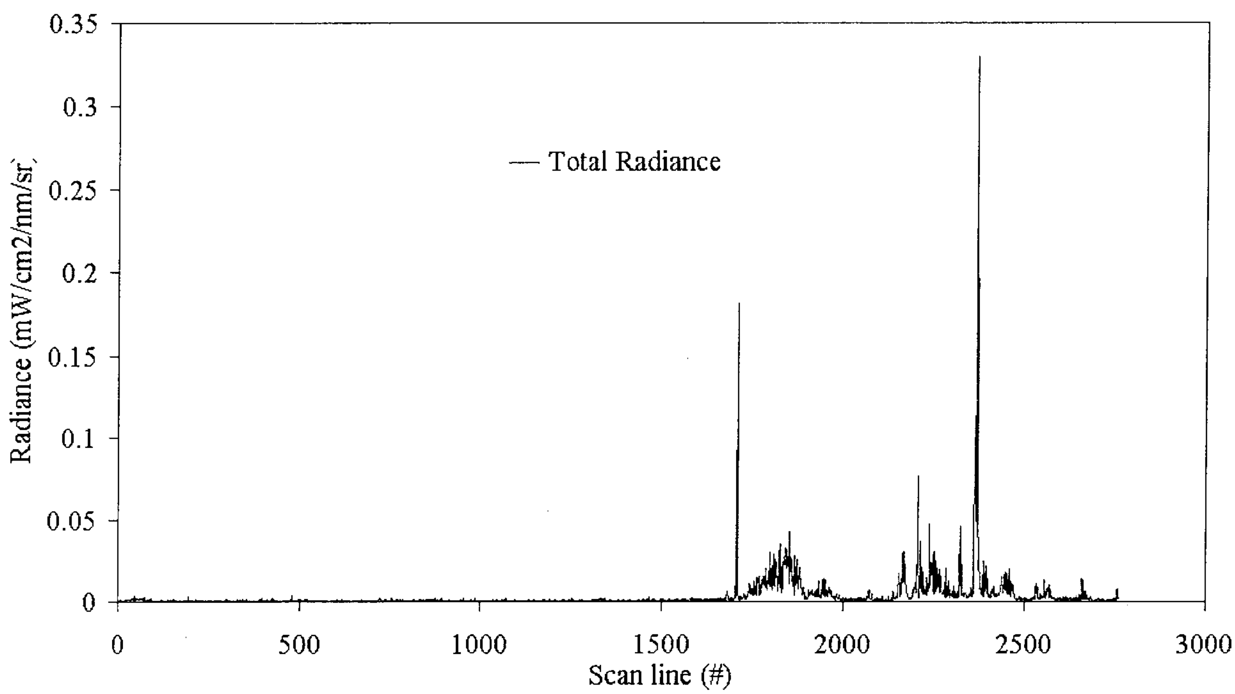


Figure 6. Total radiance observed by AVIRIS versus scanline from the 1998 low-altitude collection over Las Vegas, Nevada.

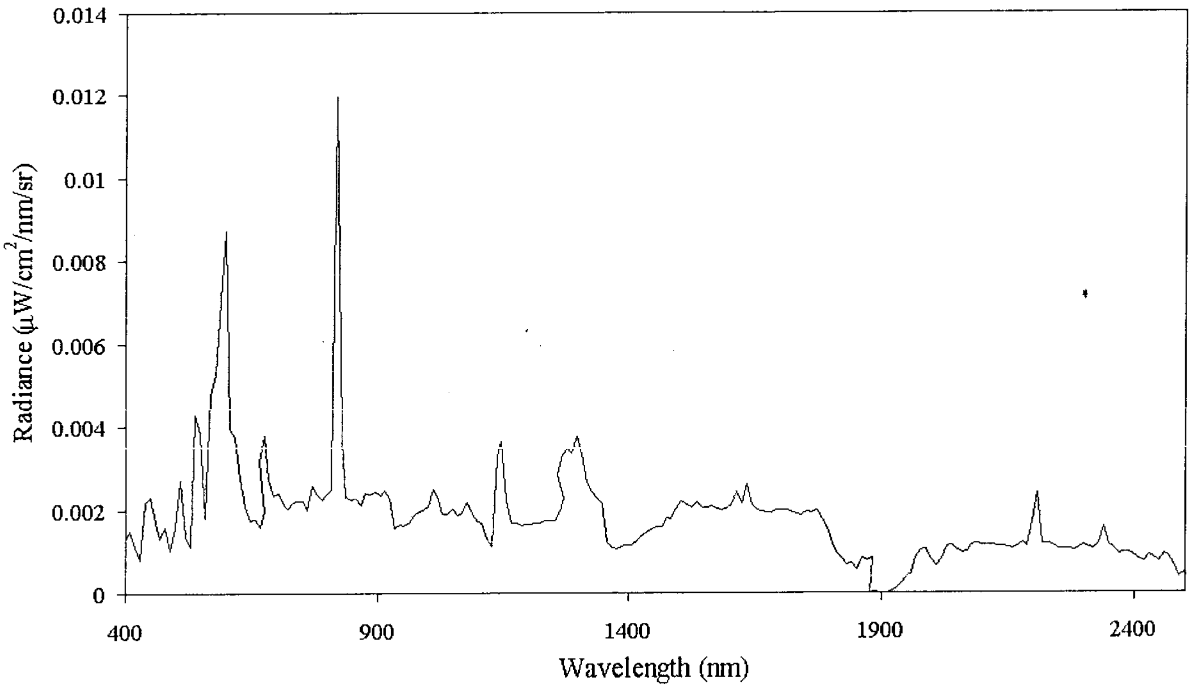


Figure 7. Aggregate spectral radiance observed by AVIRIS from the 1998 low-altitude collection over Las Vegas, Nevada.

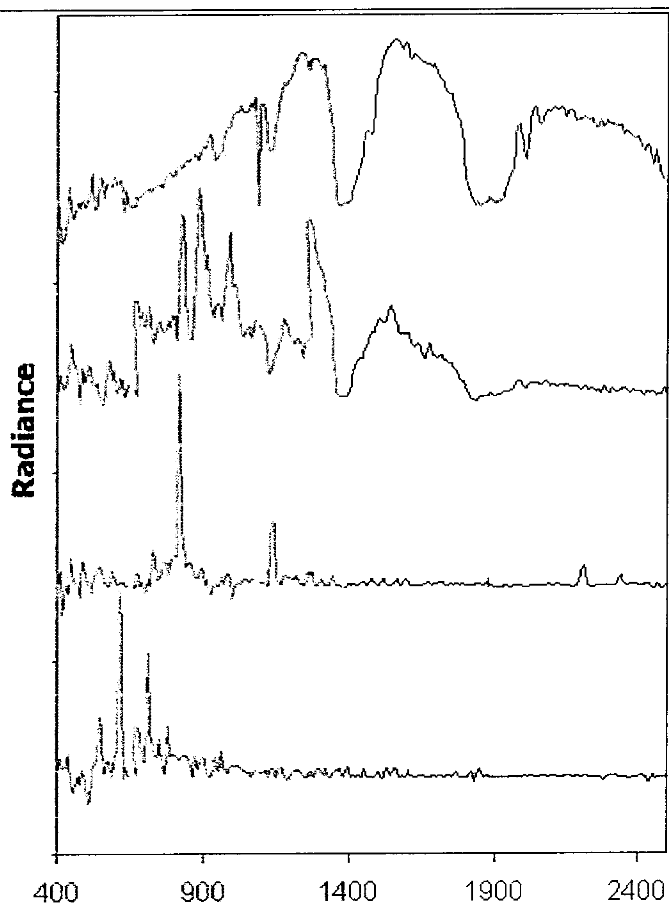


Figure 8. Radiance spectra for a sampling of pixels exhibiting nocturnal lighting from the 1998 low-altitude AVIRIS collection over Las Vegas, Nevada.

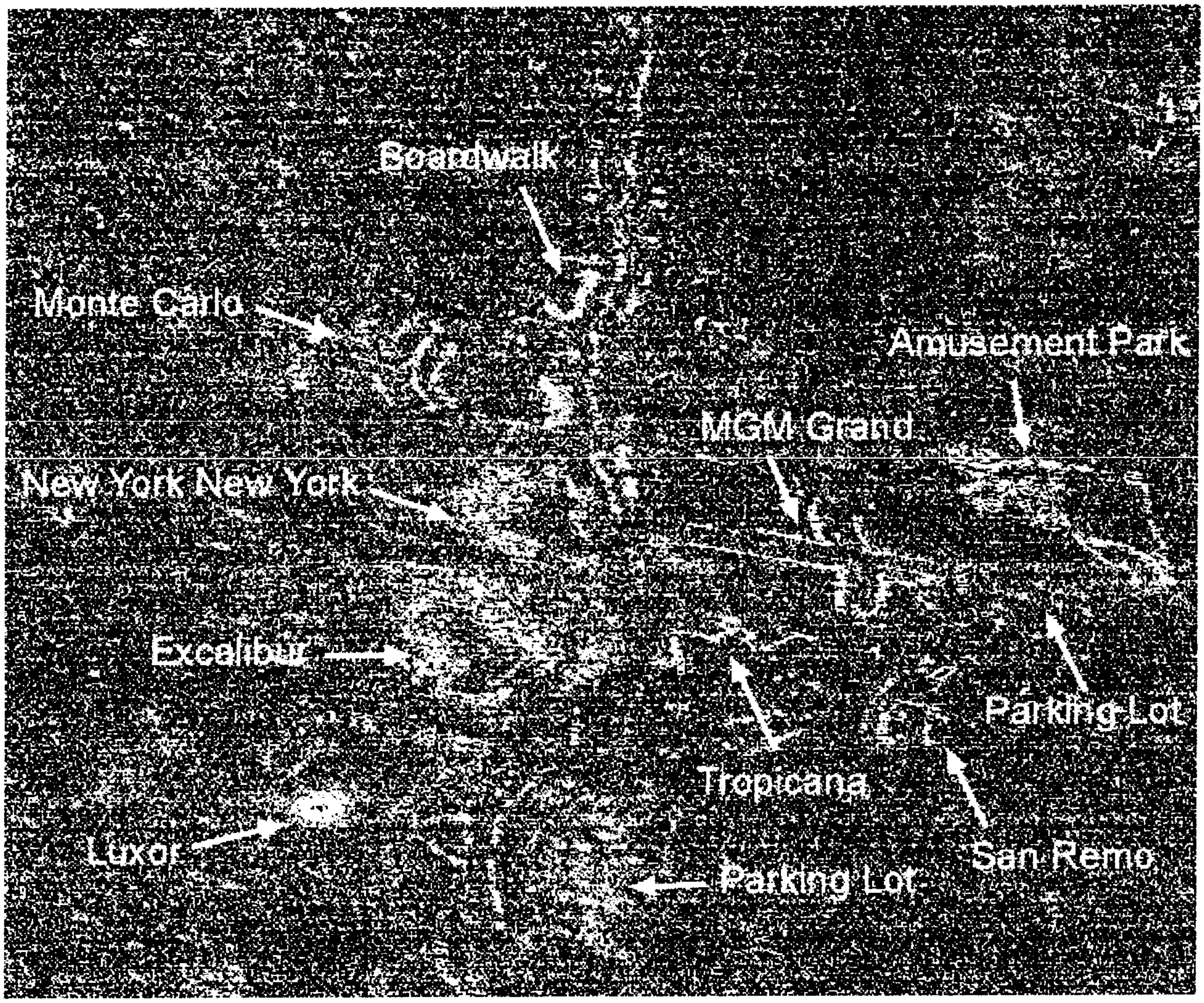


Figure 9. AVIRIS image color composite formed with bands 69, 50, and 83 as red, green, and blue respectively. Major landmarks are labeled in yellow.

5. Results from Los Angeles AVIRIS data

Very few areas in Los Angeles were bright enough to be detected using AVIRIS flown at high altitude in 2003. Unlike the aggregate spectrum of the Las Vegas flight line (see Figure 7), the aggregate spectrum of the Los Angeles flight line (Figure 10) exhibited none of the emission lines that characterize most outdoor lighting. The only feature of note from the aggregate spectrum is the slight downturn in radiance at the longest wavelengths (2300 to 2500 nm). This turns out to be an artifact induced by a previously unknown blackbody emission from the shutter used to block light transmission into the AVIRIS during the dark current measurement. The small number of pixels with detected emissions (Figure 11) appear to be heavily lit automobile dealerships, gravel quarries, and gas flares in oil refineries.

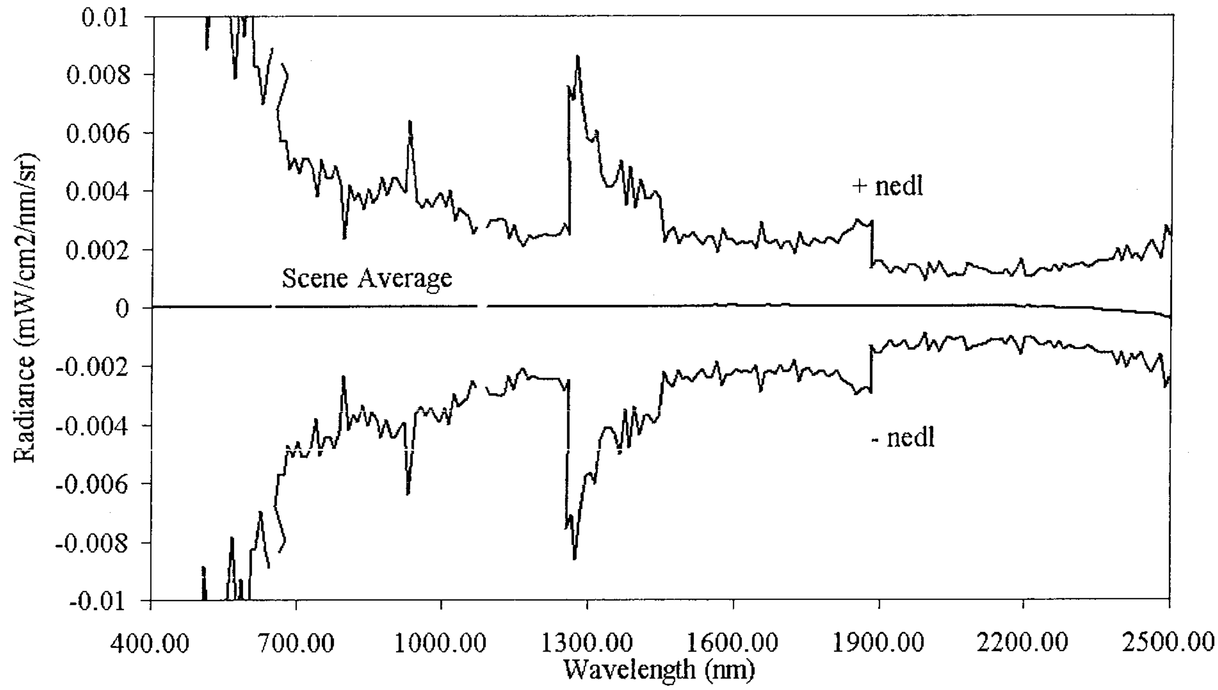


Figure 10. Aggregate spectral radiance observed by AVIRIS from the 2003 high-altitude nighttime collection over Los Angeles, California. (nedl = noise equivalent delta radiance)

6. Conclusion

Investigation with both high- and low-altitude AVIRIS data collected at night over urban centers indicates that the sensor is capable of detecting bright lights pointed up towards sky and minor gas flares in SWIR. In Las Vegas, hotel and casino lighting is directed upwards to illuminate the sides of buildings. In the typical American city, very few areas (e.g., automobile dealerships) are bright enough for AVIRIS detection at night. Open flames, such as those present in many oil refineries, have high emission in the short wave infrared and can be readily detected with AVIRIS. The spectral signatures of AVIRIS-detected nocturnal lighting and gas flares appear to have sufficient detail to make the identification of lighting type or the composition of the burning gas(es) feasible. Overall, our assessment is that AVIRIS detection limits (as of 2003) were not low enough to detect the bright emission lines associated with general street and outdoor lighting.

Aggregation of the 2003 Los Angeles nighttime AVIRIS data shows that the dark-current correction works well. We discovered a previously unknown blackbody emission coming from the shutter used to collect dark current data for spectrometer D.

As hyperspectral remote sensing technologies improve, the detection and mapping of nocturnal lighting features can be expected to advance. High-latitude nighttime AVIRIS imagery of Los Angeles was collected in 2004, affording another opportunity to examine these issues following a round of major upgrades to the AVIRIS sensor.

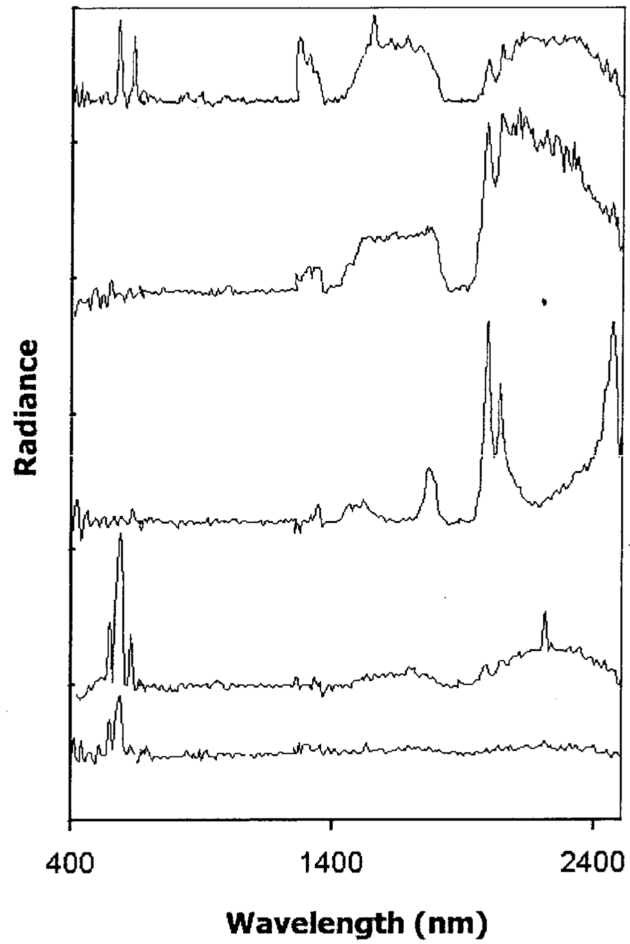


Figure 11. Radiance spectra for a sampling of pixels exhibiting nocturnal lighting from the 2003 high-altitude nighttime collection over Los Angeles, California. The upper three spectra came from gas flares in oil refinery areas.

7. Acknowledgments

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