Improving the Usability of Nighttime Imagery from Low Light Sensors

Thomas F. Lee
F. Joseph Turk
Jeffrey D. Hawkins
Cristian Mitrescu

Naval Research Laboratory, Monterey California (USA)

Steven D. Miller
Cooperative Institute for Research in the Atmosphere
Fort Collins Colorado (USA)

Mike Haas
Aerospace Corporation
Silver Spring Maryland (USA)

1. Abstract

This article presents the nighttime visible sensor on the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument to be flown aboard the upcoming NPOESS and NPP polar-orbiting satellites. First, we will introduce the sensor and explain how it improves on a similar sensor, the Operational Linescan System (OLS) flown on the Defense Meteorological Satellite Program (DMSP) series. A brief summary of the new instrument will be given, followed by a few example products from the OLS. The paper will close with a discussion of how the crossing time of the satellite affects the number of scenes that will have lunar illumination.

2. Introduction

Low light imagery from the Operational Linescan System (OLS) aboard the Defense Meteorological Satellite Program (DMSP) satellites (Johnson et al. 1994) has prompted a number of important applications never foreseen by the United States Air Force which originally designed and launched the sensor in the early 1970's. The unforeseen applications include composites of worldwide city lights at night; detection of fires; imaging of the aurora; monitoring of fishing boats; imaging of snow fields; detection of bioluminescence (Miller et al. 2005); and the detection of power outages. However, the sensor is still underutilized for the application for which it was originally designed, the imaging of clouds using moonlight. Nighttime visible imagery is especially valuable in higher latitudes in winter when daytime visible images are scarce, but lunar illumination is often excellent.

This underutilization occurs because the lunar illumination cycle is poorly taken into account by most users compared to the solar cycle. Daytime visible images are always anticipated after the sun rises over a specific region every morning. However, the nighttime moon appears and disappears according to a rhythm that is much less fixed to the 24-h cycle. In addition, lunar illumination varies strongly with the lunar phase. If the phase is insufficient, the resulting imagery is degraded beyond usefulness. For both reasons, unaware forecasters may miss adequate lunar conditions and therefore neglect information-rich imagery.

The same prospect lies ahead for forecasters using imagery from the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Visible Infrared Imaging Radiometer Suite (VIIRS), first scheduled for launch in late 2009. The low light sensor, called the Day/Night Band (DNB), is vastly improved compared to the DMSP OLS but the challenges to forecasters will remain, similar to those described above. This paper will discuss strategies for assessing optimal lunar conditions and anticipate systems for using this information to alert forecasters when useful imagery is available. It will also show examples of how color composites can increase the information content of the DMSP OLS data stream by combining infrared, visible, and terrain information into a single product.

3. Background

VIIRS (Table 1) draws from the best capabilities of contemporary operational and research observing systems to support tomorrow's operational constellation (Lee et al. 2006). The twenty-two VIIRS channels are based on several instruments: the National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR), the NASA Moderate Resolution Imaging Spectroradiometer (MODIS), and the DMSP OLS mentioned earlier. The OLS, with a low-light imaging capability, is the only satellite precursor to the VIIRS DNB. Table 1 summarizes the VIIRS Imaging (I) resolution channels, Moderate (M) resolution channels, and the DNB.

The DNB will measure visible energy from the earth and atmosphere during both day and night portions of the orbit, including solar/lunar reflection and both natural and anthropogenic nighttime light emissions. Some of the DNB improvements compared to OLS are: less frequent pixel saturation; smaller Instantaneous field of view, leading to reduced spatial blurring; superior calibration and radiometric resolution; co-location with multispectral measurements on VIIRS and other NPOESS sensors; and increased spatial resolution and elimination of cross-track pixel size variation.

Table 1 VIIRS Channels

Band Number/Gain	VIIRS Wavelength (µm)	VIIRS Nadir Pixel Size Downtrack x Crosstrack (km)	Primary Application
M1 Dual	0.412	0.742 x 0.259	Ocean Color, Aerosols
M2 Dual	0.445	0.742 x 0.259	Ocean Color, Aerosols
M3 Dual	0.488	0.742 x 0.259	Ocean Color, Aerosols
M4 Dual	0.555	0.742 x 0.259	Ocean Color, Aerosols
I1 Single	0.640	0.371 x 0.387	Imagery, Vegetation
M5 Dual	0.672	0.742 x 0.259	Ocean Color, Aerosols
M6 Single	0.746	0.742 x 0.776	Atmospheric Correction
I2 Single	0.865	0.371 x 0.387	Vegetation
M7 Dual	0.865	0.742 x 0.259	Ocean Color, Aerosols
DNB Single	0.7	0.742 x 0.742	Imagery
M8 Single	1.24	0.742 x 0.776	Cloud Particle Size
M9 Single	1.38	0.742 x 0.776	Cirrus Cloud Cover
M10 Single	1.61	0.742 x 0.776	Snow Fraction
I3 Single	1.61	0.371 x 0.387	Binary Snow Map
M11 Single	2.25	0.742 x 0.776	Clouds
M12 Single	3.70	0.742 x 0.776	Sea Surface Temperature (SST)
I4 Single	3.74	0.371 x 0.387	Imagery, Clouds
M13 Dual	4.05	0.742 x 0.259	SST, Fires
M14 Single	8.55	0.742 x 0.776	Cloud Top Properties
M15 Single	10.76	0.742 x 0.776	SST
I5 Single	11.45	0.371 x 0.387	Cloud Imagery
M16 Single	12.01	0.742 x 0.776	SST

4. Examples

Fig. 1A shows how clouds, fog, land surfaces, snow cover, and smoke/ash clouds will be readily detectable through moonlight reflection. Self-contained light sources (e.g., fires, lightning, city lights, gas flares, brightly-lit fishing boats, and lava flows) will also be seen but will appear relatively faint compared to moon-free conditions. For little or no moon, some features will disappear altogether (Fig 1B).

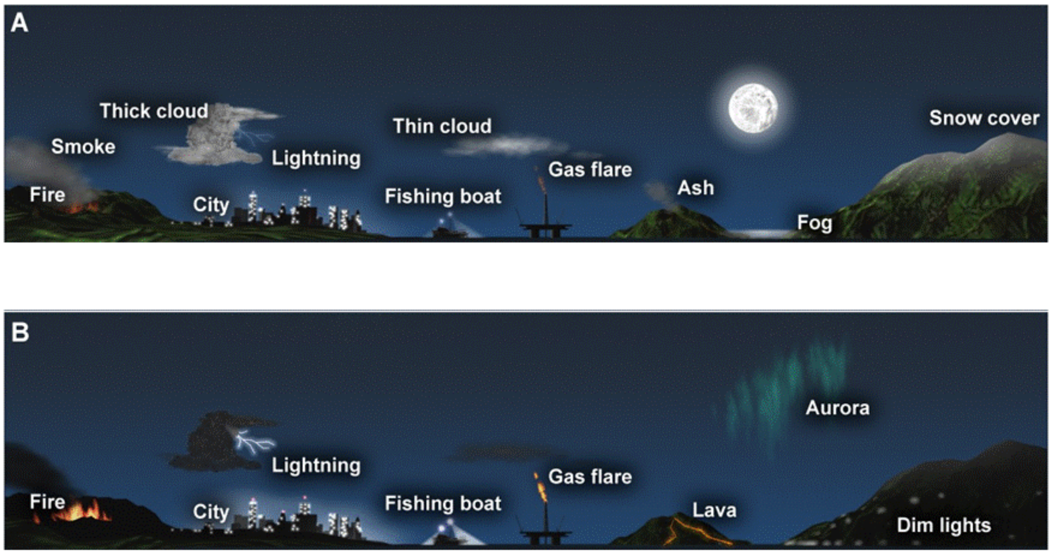

Figure 1 Top Diagram: full moonlight. Reflective features such as clouds, snow cover, and smoke are revealed. Bottom Diagram: no moonlight. Self-contained light sources are enhanced such as fires, city lights, lightning, fishing boats, gas flares, lava floes, and the aurora.

Fig. 2 shows the ability of nighttime visible sensors to see detail in tropical cyclones that is not apparent in accompanying infrared images. The low-level circulation of Tropical Cyclone Iselle cannot be seen in the infrared image on the left but stands out in the visible/infrared composite on the right.

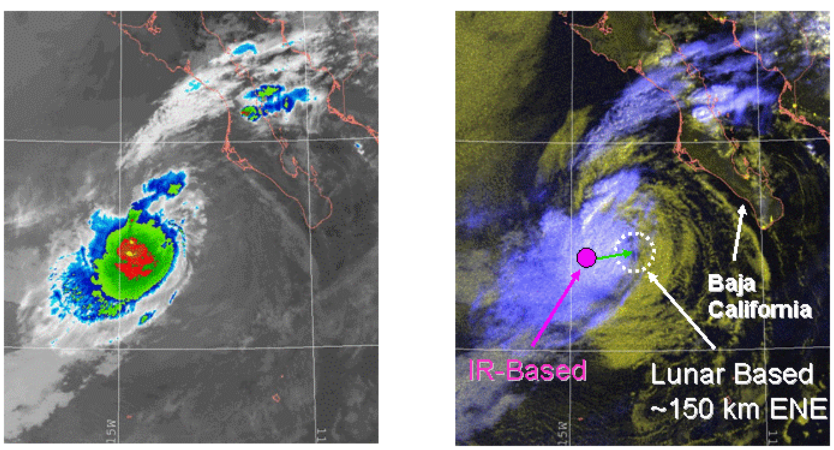

Figure 2 Left: Infrared image of Tropical Storm Iselle near Baja California off the west coast of North America, 2002. High canopy is apparent in blues, greens and reds, but low-level center is hard to identify. Right: DMSP OLS Nighttime visible composite showing low clouds in yellow and high clouds in blue. Low-level center can now be identified.

Near-realtime examples of DMSP OLS nighttime visible products (Miller et al. 2006) can be found at: http://www.nrlmry.navy.mil/NEXSAT.html

Figure 3 illustrates the fraction of nighttime scenes that will be illuminated by moonlight by latitude, allowing the imaging of clouds, snow cover, land, dust clouds, and other features. The 2130 Local orbit, shown as a dashed line, has been eliminated from planned NPOESS orbits. Fig. 3 (for example, 0130 local) indicates that illuminated scenes are more than twice as prevalent near the equator as at the poles. This trend may be due to a shortage of nighttime scenes in the polar samples because of long summer days. But this is not a real disadvantage in these regions because additional daytime visible passes will be available.

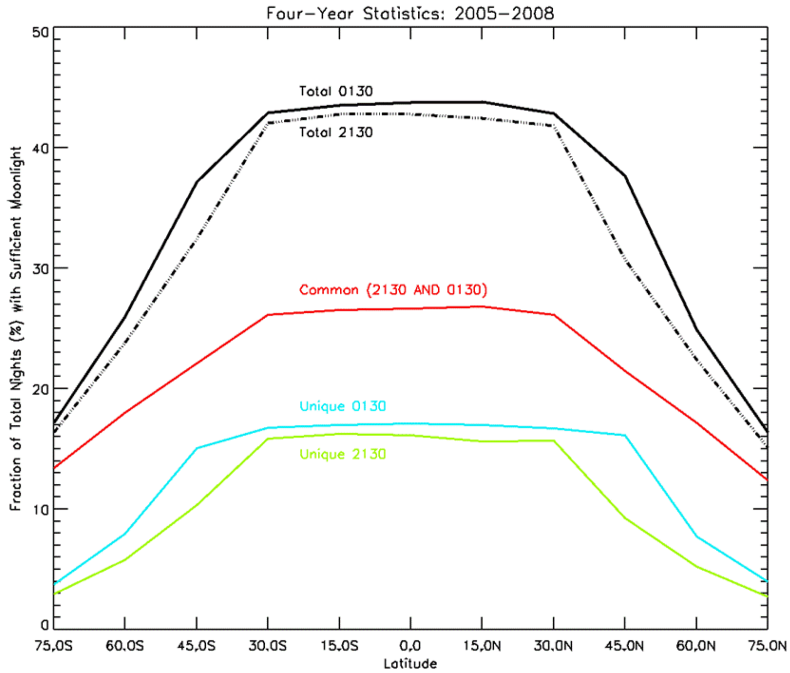

Figure 3 Shows fraction of total nights with sufficient moonlight for adequate illumination. Top two traces: all illuminated orbits of both satellites. Red trace: signifies that both orbits have sufficient illumination on a given night. Cyan and green traces: either but not both orbits have sufficient illumination on a given night. 2130 local orbit will be eliminated as part of NPOESS restructuring.

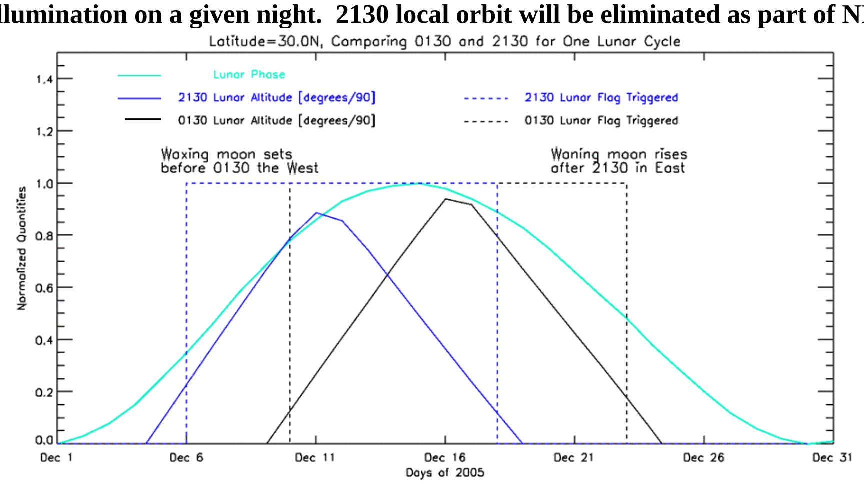

Figure 4 Cyan curve shows lunar phase during the month of December 2005, full on December 15. Solid dark blue and black cures show the altitude of the moon (highest possible = 1.0) during a particular crossing time. Dashed line outlines dates of useful imagery (sufficient lunar illumination for cloud illumination). Blue dashes indicate a useful interval for 2130 local Time of December 6 through December 18; black dashes indicate a useful interval for 0130 local Time of December 10 through December 22.

Fig. 4 shows how we determine how we flag sufficient illumination over a period of a month. The cyan curve shows lunar phase with new moon on December 1, full moon on December 15 and new moon again just before the end of the calendar month. In order for us to flag a pass on a specific date as sufficiently illuminated, it must be associated with sufficient lunar phase and elevation. The phase can be sufficient, but in many instances the moon is low, even under the horizon, precluding illumination.

5. Summary and Conclusions

The NPOESS VIIRS represents a substantial improvement compared to the DMSP OLS. Thus, it will allow for the creation of unprecedented imagery and products. DMSP OLS represents technology borne out of the 1960's and 1970's. NPOESS VIIRS will be dramatically better. We have demonstrated the value of DMSP OLS products by blending nighttime visible and infrared channels in color combination. In the VIIRS era there will be not two, but twenty-two, channels for multispectral combination. So the effectiveness of products will be multiplied, including nighttime snow/cloud depictions, land cover products, aerosols depictions, images of smoke, and fire products.

The loss of the 2130 local orbit from the NPOESS configuration will result in the loss of a large number of illuminated scenes, but the 0130 local orbit will remain intact and will provide large quantities of illumination. The tropics will get more illuminated passes in a given year than the poles. This is because during the polar summers there is seldom enough darkness to support lunar illumination. But this shortfall in the poles is misleading. There will be many passes with partial lunar illumination near the poles. Since passes overlap with such frequency near the poles, these "terminator" orbits, taken together, will provide considerable imagery of lunar illuminated scenes.

6. Acknowledgements

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