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Advances in Remote Sensing: Imaging the Earth by Moonlight

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Earth's nighttime environment is being revealed in unprecedented detail by the new satellite-mounted Visible/Infrared Imaging Radiometer Suite (VIIRS). VIIRS' Day/Night Band (DNB) is a highly sensitive broadband visible channel capable of detecting light from cities and other terrestrial emission sources.

Of potential greater import to the Earth science community, though, is the DNB's ability to image the atmosphere, land, ocean, and cryosphere using moonlight. The instrument can even capture images on moonless nights for scenes that are illuminated by nightglow, the light emitted by recombination of mesospheric molecules ionized by sunlight during the daytime.

DNB in Detail

Nighttime remote sensing techniques have traditionally relied on infrared and microwave channels. However, infrared observation of low-altitude atmospheric and surface features often fails due to obscuration by upper level clouds and a lack of thermal contrast, while microwave techniques provide either limited spatial and/or temporal coverage, such as with synthetic aperture radar, or significantly lower resolution as seen in passive microwave imaging.

These limitations are mitigated with the VIIRS DNB. Riding on board the Suomi National Polar Orbiting Partnership (S-NPP) satellite, VIIRS uses knowledge and technology gained from the Advanced Very High Resolution Radiometer (AVHRR), the Operational Linescan System (OLS), and the Moderate Resolution Imaging Spectroradiometer (MODIS) [*Hillger et al.,* 2013]. It provides data in 21 traditional spectral bands (ranging from visible to 12 micrometer infrared wavelengths) along with the DNB.

In fact, the DNB—a technology borrowed and improved upon from OLS—is a huge step forward compared to its predecessor, which also viewed the night sky. Improvements over the OLS's 1970s technology include significantly higher radiometric resolution and radiometric range, spatial resolution improved from 2.8 kilometers (OLS) to 0.750 kilometers (DNB), and more accurate geolocation (~120-meter pointing accuracy). Similar to the OLS, the DNB has nearly constant resolution across its 3000-kilometer swath, providing highly detailed imagery regardless of the look angle.

Additionally, the DNB provides calibrated radiances, allowing for quantitative applications that the OLS could not accommodate. With seven orders of magnitude of radiance sensitivity, the DNB's imaging capabilities span from full daylight to the dead of night. This high sensitivity allows the DNB to discern reflective atmospheric (e.g., clouds, dust, and pollution), land (e.g., snow, desert, and rivers), and ocean (e.g., sea ice) features under illumination from moon phases as low as one quarter.

Even on moonless nights, the DNB is sometimes capable of producing imagery. The response of the channel to extremely low

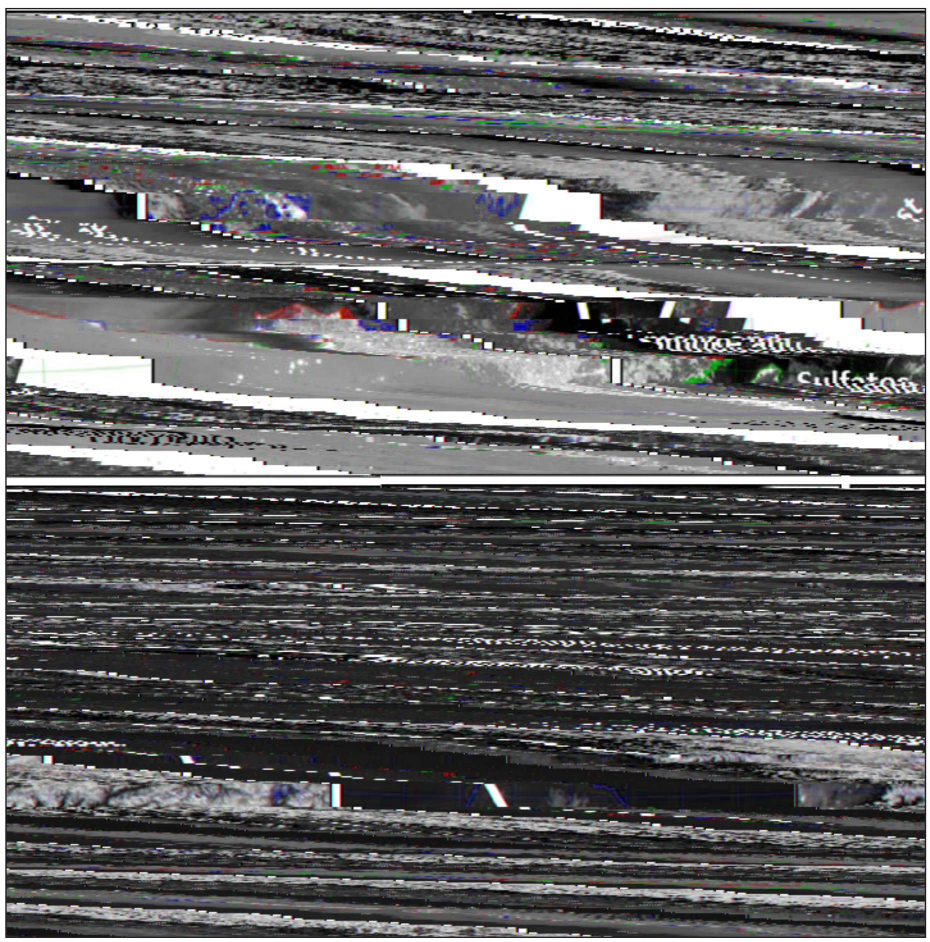

Fig. 1. Day/Night Band images depicting (a) a dust plume over the southern Mediterranean Sea (north of the Nile delta) on 7 April 2012, (b) pollution over the western Pacific Ocean (east of China) on 8 April 2012, (c) snow-capped Tian Shan Mountains in Uzbekistan on 6 April 2012, and (d) low cloud over the Korean Peninsula on 8 April 2012.

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levels of light (as low as 70 trillionths of a watt per square centimeter per steradian) and spectral response including the near infrared (~500–900 nanometers) allows DNB to use faint nightglow emissions from the Earth's own atmosphere to view cloud fields [*Miller et al.,* 2012]. This phenomenon may provide a new source of illumination for atmospheric monitoring; however, much research is required to fully understand its utility because the nightglow is both highly transient and very weak.

Selected Capabilities

Via moonlight illumination, the DNB detects low-altitude aerosols over ocean areas at night, a capability not performed well by even multispectral infrared sensors. For example, the bright wedge in the southeastern portion of Figure 1a depicts the visible light arising from anthropogenic sources in the Nile River delta within Egypt. The smooth, gray feature running from the southwest to the northeast is a lofted dust plume revealed through reflected moonlight.

Other types of low-altitude aerosol plumes can also be seen due to their visible contrast against the surface background. A plume of pollution can be seen in Figure 1b as a bright, wide, diffuse streak drifting eastward from China.

Snow cover lacks horizontal thermal contrast, making it difficult to detect using infrared imagery alone. Uzbekistan's Tian Shan mountain range can be seen in Figure 1c. Via reflected moonlight, the DNB can readily discriminate between snow-covered and snow-free landscapes. In fact, most observers cannot distinguish this image from daytime visible imagery unless they notice the scattered city lights on the valley floor.

Low clouds and fog are similarly difficult to detect using infrared techniques. However, DNB imagery reveals them easily. Figure 1d, centered over the Korean Peninsula, shows a cloud-free region in the north, while the southern portion is largely hidden under a sheet of low-altitude stratus.

DNB's ability to see by nightglow allows it to image clouds on nights without moonlight. Figure 2 illustrates the capability over the Pacific Ocean on a moonless night. A VIIRS infrared image using the 10.763-micrometer band is shown in Figure 2 (left), and the corresponding DNB nightglow reflectance imagery is shown in Figure 2 (right).

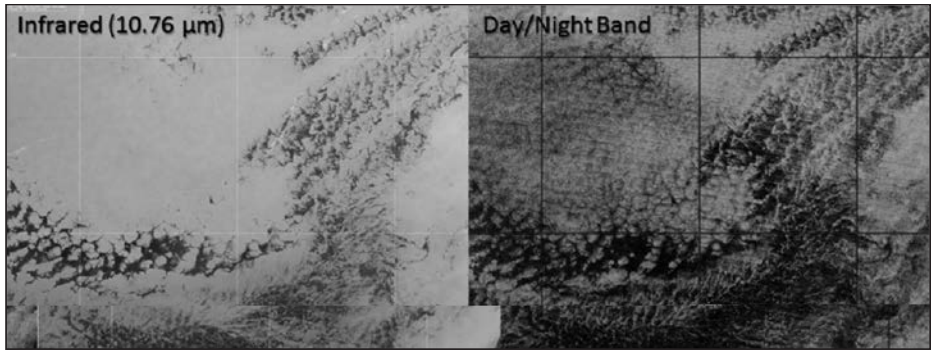

Fig. 2. Cloud scene over the Pacific Ocean from 19 June 2012 under a new moon depicted by (left) infrared and (right) DNB. Figure 2 (right) demonstrates the DNB's ability to utilize reflected nightglow to create detailed imagery.

Viewing Earth at Night

The VIIRS DNB dramatically extends the bounds of nocturnal remote sensing. On its own, the DNB provides a significant amount of information concerning many different atmospheric, terrestrial, and oceanographic phenomena, including nighttime cloud locations, lightning, fires, atmospheric plumes (pollution, ash, and dust), ocean roughness and turbidity (in moon glint regions), etc. The DNB's utility also extends to anthropogenic light sources. By using changes in city lights as a proxy, the DNB could potentially monitor power outages (e.g., after natural disasters) and economic growth. It is also capable of monitoring fishing fleets and gas flares from oil and gas wells [*Small and Elvidge,* 2013].

The DNB may also be useful in conjunction with VIIRS's 21 other channels. For example, infrared channels can be used to detect and characterize fires, but with the addition of the DNB, researchers may someday be able to determine which parts of a fire are smoldering and which have active flames. Research on the multispectral uses of the DNB is ongoing. Much remains to be explored with the DNB, but future advances may provide scientists with everything from previously unattainable atmospheric information at night to algorithms that model fine details of cloud movements through night and day. As the research community pushes forward with nighttime visible research and applications, DNB should become an integral part of the remote sensing toolkit.

Acknowledgments

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