Poster 335

Ninth Annual Symposium on Future Operational Environmental Satellite Systems
American Meteorological Society
93rd Annual Meeting
6-10 January, Austin, TX

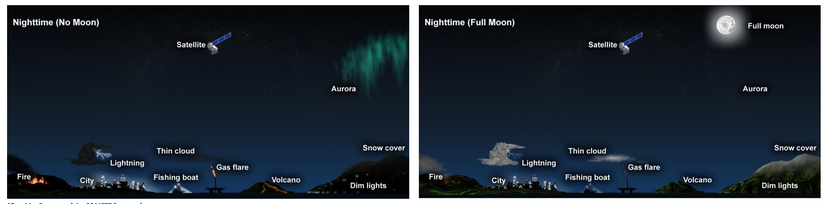
A New Frontier of Nighttime Environmental Sensing Brought to Light by the Suomi NPP VIIRS Day/Night Band

Steven D. Miller[1,*], Stephen P. Mills[2], Christopher D. Elvidge[3], Daniel T. Lindsey[4], Thomas F. Lee[5], and Jeffrey D. Hawkins[5]

Cooperative Institute for Research in the Atmosphere

1. Background: Suomi NPP Satellite

- The Suomi National Polar-orbiting Partnership (Suomi-NPP) satellite was launched into polar orbit on 28 October 2012.
- Sun-synchronous orbit, 1330 Local Time Ascending Node, 834 km altitude.
- Provides risk reduction to the next-generation Joint Polar-orbiting Satellite System (JPSS) operational satellites (managed by NOAA) and continuity to the NASA Aqua mission in global change science.
- The Day/Night Band, carried on the Visible/Infrared Imager/Radiometer Suite (VIIRS) of Suomi-NPP, offers the unique ability to detect extremely low-levels of visible and near-infrared light:



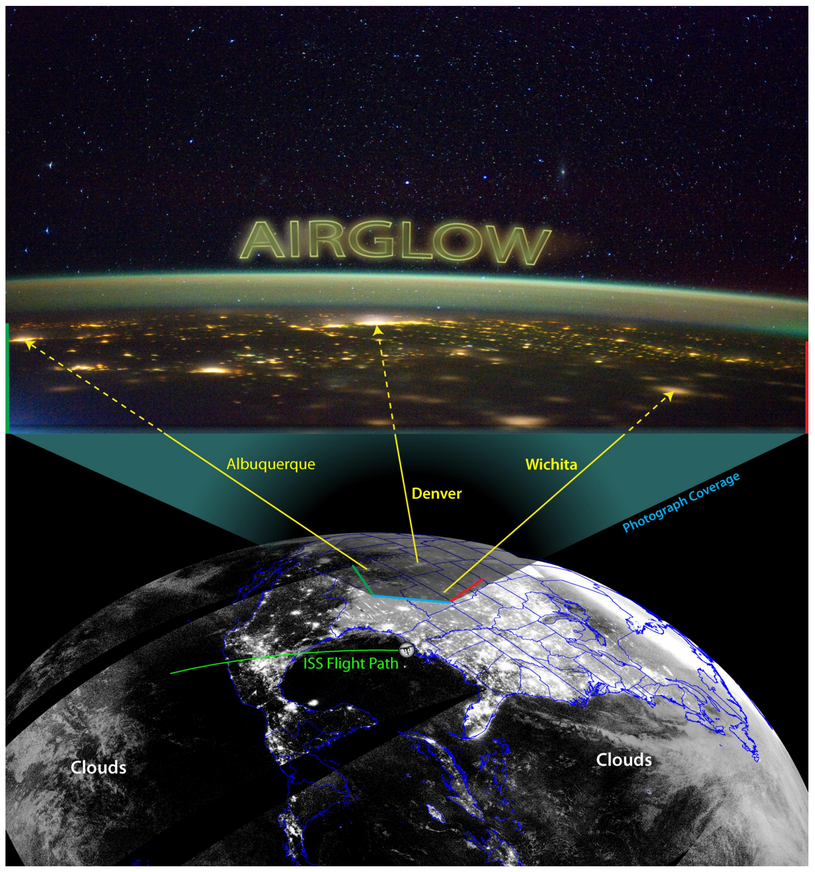
(Graphics Courtesy of the COMET® Program)

Examples of nighttime low-light visible signals, with and without moonlight

2. Day/Night Band Specs

- Among 22 VIIRS bands spanning the optical spectrum(0.4-13 µm)
- 505-890 nm panchromatic band (full-width/half-maximum response)
- 0.742 km pixel resolution, constant across 3000 km swath
- 14-bit radiometric resolution (16,384 levels of radiance quantization)
- 3 stages [Low (day), Mid (Low x 475), High (Mid x 200)] of gain avoids saturation over wide radiance range (4E-9 to 3E-2 W cm^2 sr^{-1} in-band)
- Radiometric calibration ~11% for High Gain Mode
- Low-end Signal-to-Noise Ratio (SNR; at nadir):
  - 30 @ 4.0 x 10^{-9} W cm^2 sr^{-1} (ref: Full Moon ~10^{-8} W cm^2 sr^{-1})
  - 3 @ 3.2 x 10^{-10} W cm^2 sr^{-1}
  - **Noise floor @ ~7.0 x 10^{-11} W cm^2 sr^{-1}**

Open Access Article: www.pnas.org/content/early/2012/09/05/1207034109.full.pdf

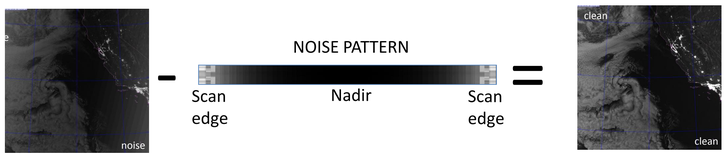


International Space Station (ISS) photography (upper) captures a horizon of nightglow and the stars above the central U.S. on a moonless night. Space/time matched imagery from the VIIRS Day/Night Band sensor on the Suomi NPP satellite (lower) shows the sensor's ability to detect reflection from these faint light sources; far offshore and well removed from city lights, clouds patterns emerge from the darkness.

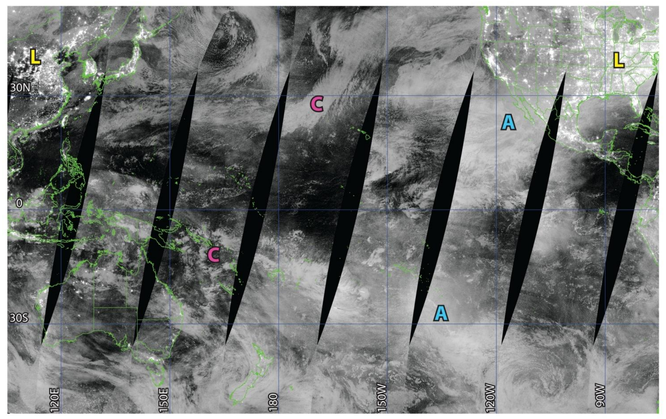
(ISS photograph ISS030-E-84309, collected 25 January 2012 at 07:48:13 UTC, courtesy of the Image Science and Analysis Laboratory, NASA Johnson Space Center)

3. 'Anomalous' Signals Detected

- Scan-angle dependent gain/offset corrections are required to remove low-signal detector noise from the Day/Night Band imagery:



- To characterize the noise pattern, we examined New Moon nights over the central Pacific Ocean (astronomical darkness conditions)
- Instead of seeing just the noise pattern, reflecting clouds (and other coherent structures) were also present!

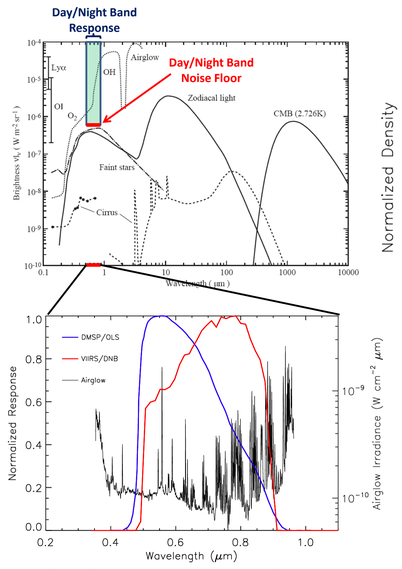


Low-light imagery from a series of adjacent Suomi NPP VIIRS/DNB nighttime passes over the Pacific Ocean near New Moon on 22 February, 2012 (no sunlight or moonlight present). In addition to city light emissions (e.g., L), the observations capture clouds (e.g., C) illuminated by reflected airglow and starlight. Also apparent are broad, diffuse regions of primary airglow emission (e.g., A).

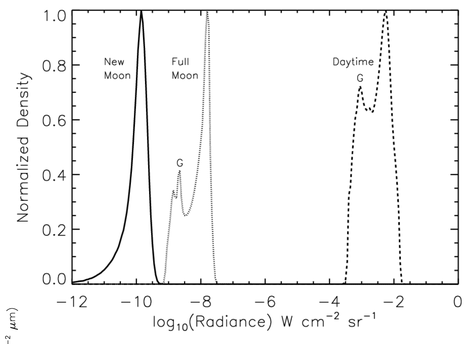
4. Principal Light Source: Nightglow

- In order of significance, the principal sources of non solar/lunar light at high elongation angles from the Sun (characteristic of the 0130 Suomi-NPP pass):
  - Nighttime Airglow (Nightglow) ~ 0.1-10 x 10^{-9} W cm^2 sr^{-1} µm^{-1} (*primary*)
  - Starlight ~ 2-4 x 10^{-10} W cm^2 sr^{-1} µm^{-1} (*secondary, strongest in ~June*)
  - Zodiacal Light ~ 4-10 x 10^{-11} W cm^2 sr^{-1} µm^{-1} (*negligible*)
  - Galactic/Cosmic Light ~ 3-8 x 10^{-12} W cm^2 sr^{-1} µm^{-1} (*negligible*)

- Nightglow = chemiluminescence reactions between atmospheric gases
  - Vibrationally excited Hydroxyl (OH*; reactions between O_3 and atomic Hydrogen), atomic Oxygen, Sodium and Nitrogen dissociated by UV sunlight
  - Brightest emissions in ~10 km thick layer near the mesopause (85-95 km)
  - Strong correlation with temperature and atomic Oxygen mixing ratio
  - Highly variable emissions across space & time
  - *Van Rhijn effect* leads to brightening near horizon (longer optical paths)
  - Roughly 10x starlight brightness



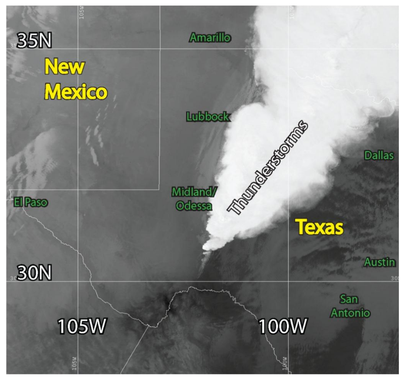
(Upper) Fig. 37 from Leinert et al. (1997), showing relative brightness of nighttime light sources. (Lower) Response functions for VIIRS Day/Night Band (red) and DMSP/OLS (blue), with example nightglow spectrum.



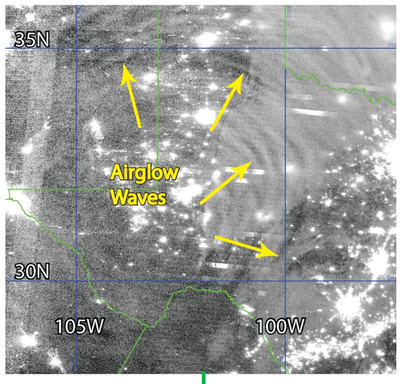
(Above) Distributions of Suomi NPP VIIRS Day/Night Band measured radiances over the north/central Pacific Ocean for nighttime new moon, full moon, and daytime illumination.

The distributions show that nighttime scenes illuminated by a full moon are roughly 1 millions times dimmer than sunlit scenes, and the new moon (nightglow) signals are roughly 100 times fainter than full moon.

The features labeled "G" arise from specular reflectance of the solar and lunar disks on the water surface—a feature that does not occur for the pan-horizon night glow source.



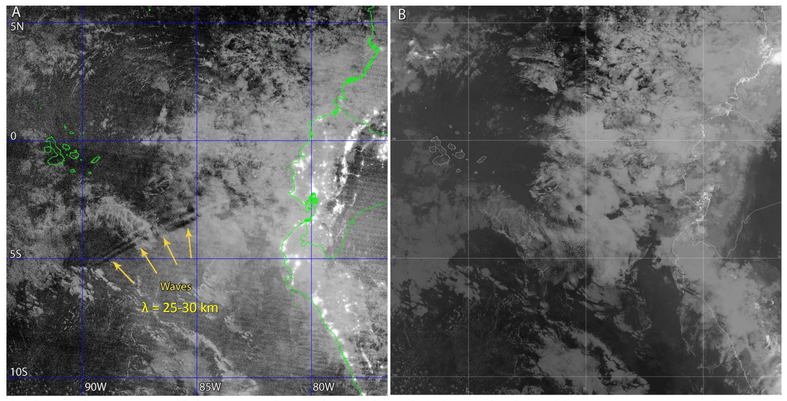
(Upper Left) VIIRS infrared (M15; 10.7 µm) captures a powerful line of T-storms rolling across central Texas on the evening of 15 April 2012 (0746 UTC).



(Upper Right) The VIIRS Day/Night Band imagery reveals airglow waves, ~90 km above in the mesosphere, emanating radially away from the tropospheric storms that forced them. City lights appear as bright patches.

(Right) Surface-based photograph from Lamy,NM (35.49 N, 105.86 W), Azimuth 82° (~east-viewing) on 15 April 2012 ~0500 UTC captured the concentric gravity waves from the Texas storms.

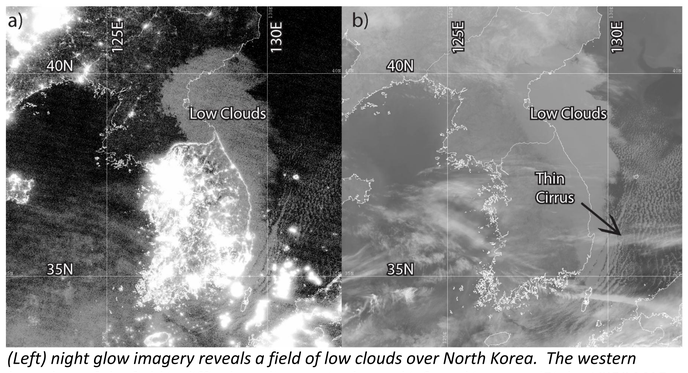
Canon 1000D with IR blocking removed to extend sensitivity up to 900 nm. Courtesy, Walt Lyons



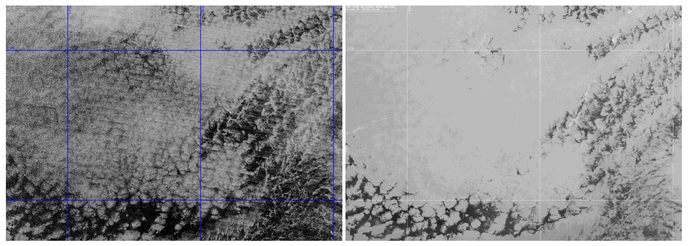
(Left) Airglow waves off the coast of Ecuador, and (Right) thermal infrared (M15; 10.763 µm, where waves are absent) band imagery on 24 January 2012 at 653 UTC. Unlike the T-storm example, the forcing for these waves does not appear to be directly associated with strong tropospheric convection.

5. Selected Examples

- This new kind of low-light visible measurement contains both reflection and emission components
  - Direct emissions from nightglow layer (diffuse regions & waves)
  - Cloud/surface reflection of the pan-horizon nightglow source



(Left) night glow imagery reveals a field of low clouds over North Korea. The western boundary of the field is difficult to discern via thermal infrared imagery (Right; VIIRS M15, 10.763 µm) due to similar temperatures between the clouds and the surface.



(Left) night glow imagery of open and closed-cell marine stratocumulus clouds in the Eastern Pacific ocean reveals more detailed structure information than thermal infrared (Right) due to better sensitivity to variations in cloud water content at visible wavelengths.

6. Conclusions

- The VIIRS Day/Night Band's unanticipated ability to detect extremely low levels of airglow and starlight opens exciting new possibilities.
- Extends benefits of visible imaging capability to nights without moonlight, potentially valuable at high latitudes in winter.
- Direct airglow emissions show troposphere/mesosphere coupling.
- Much work is needed to understand the extent of information content, limitations, and quantitative potential of the measurements.

AFFILIATIONS: 1=Cooperative Institute for Research in the Atmosphere, Colorado State University, Fort Collins, CO. 2= Northrop Grumman Aerospace Systems, Redondo Beach, CA. 3=National Geophysical Data Center, National Oceanic and Atmospheric Administration (NOAA), Boulder, CO. National Environmental Satellite, Data, and Information Service, NOAA. 5=Satellite Meteorological Applications Section, Marine Meteorology Division, Naval Research Laboratory, Monterey.

ACKNOWLEDGMENTS: Research sponsored by the Naval Research Laboratory through contract NOO173-10-C-2003, the Oceanographer of the Navy through the Program Executive Office PMW-120 under program element PE-0603207N, and the National Oceanic and Atmospheric Administration Joint Polar Satellite System Cal/Val and Algorithm program. The views, opinions, and findings in this presentation are those of the authors, and should not be construed as an official NOAA and/or US Government position, policy, or decision.