J11.7 Applications of the NPOESS Visible/Infrared and Microwave Imagers

Thomas F. Lee, Jeffrey D. Hawkins, F. Joseph Turk, P. Gaiser, M. Bettenhausen
Naval Research Laboratory
Monterey CA and Washington DC

Steve Miller
Cooperative Institute for Research in the Atmosphere
Fort Collins CO

1. Introduction

The National Polar-orbiting Operational Environmental Satellite System (NPOESS) will be the next-generation U.S. operational polar satellite constellation. Designed to monitor the global environment, including the atmosphere, oceans, land surfaces and sea ice, the NPOESS program is overseen by the Integrated Program Office (IPO), a multi-agency group comprising the Department of Defense, Department of Commerce and the National Aeronautics and Space Administration (NASA). NPOESS consolidates civilian and military environmental sensing programs and expertise under a single national system.

Satellites from the NPOESS will contain two key imagers responsible for a large number of operational products. These are the Visible Infrared Imaging Radiometer Suite (VIIRS), and the Microwave Imager Sounder (MIS). VIIRS will fly on all NPOESS satellites, initial launch expected in 2013, and the NPOESS Preparatory Project (NPP) satellite to be launched in 2010. Three of the four planned NPOESS satellites will carry MIS, starting in 2016. This presentation will discuss each sensor and show prototype products from heritage sensors.

The VIIRS instrument will contain 22 channels, ranging from the visible to infrared. It will have a swath of 3000 km. Data from all of the VIIRS channels will be produced using scan geometry which allows only slow pixel expansion toward the edge of scan. This feature enables imagery which is as sharp at the edge of scan as near nadir, enabling many more high-resolution zooms per overpass. The Day/Night Band (DNB) is a channel for low-light imaging at night. The DNB will be considerably improved compared to the nighttime visible channel available from the Defense Meteorological Satellite Program (DMSP) satellites with many more display levels, decreased noise and artifacts, higher spatial resolution, and full integration into the VIIRS radiometer suite (Lee et al. 2006a).

The MIS design is still being completed. However, with a larger number of channels than predecessor sensors, it will have the capability to improve upon the products from the DMSP Special Sensor Microwave Imager (SSM/I) and the Special Sensor Microwave Imager Sounder (SSMIS). It will also create products previewed by WindSat, the first spaceborne polarimetric microwave imager built by the Naval Research Laboratory and flown aboard the DoD Space Test Program's Coriolis satellite. Products include sea surface temperature, soil moisture, sea surface wind vectors, total precipitable water, snow/ice properties, cloud characterizations, and imagery, including depictions of tropical cyclone structure.

2. VIIRS

VIIRS draws from the best capabilities of contemporary operational and research observing systems to support tomorrow's operational constellation. The twenty-two channels featured on VIIRS are derived primarily from three legacy instruments: the National Oceanic and Atmospheric Administration (NOAA) Advanced Very High

Thomas F. Lee, Naval Research Laboratory
Monterey CA Thomas.lee@nrlmry.navy.mil

Resolution Radiometer (AVHRR), the NASA Moderate Resolution Imaging Spectroradiometer (MODIS), and DMSP Operational Linescan System (OLS). The two operational predecessor instruments are reviewed in Johnson et al. (1994). With a low-light nighttime visible sensing capability, the OLS provides the sole heritage to the VIIRS DNB. Table 1 summarizes the VIIRS Imaging (I) resolution channels, Moderate (M) resolution channels, and the DNB. Table 1 represents pixel dimensions in the down- and cross-track directions. Some of the Moderate Channels have dual gains, capable of measurement within two discrete ranges of radiance. The nadir spatial resolution of the dual gain channels will be converted to the resolution of the other Moderate channels (0.742 x 0.776 km) by ground processing.

Fig. 1 illustrates how the VIIRS (right panel; Lee et al. 2006b) pixel expansion (in the cross track direction) differs from AVHRR (left panel) and OLS (middle panel). Within a sample pass over southern Europe we can see that the pixel size for AVHRR is about 1 km in the middle of pass (violet color, approximately over Italy). However, at the edges of scan (over Spain toward the western edge of the pass and over Turkey toward the eastern edge) the pixel size expands to over 5 km (red). Imagery that falls into these regions will be constructed using very large pixel sizes and will therefore be degraded. In fact, nearly half of the area of the AVHRR image (reds and greens) has pixel sizes of 3 km or greater. Thus, although AVHRR has the name “advanced very high resolution” in its title, the description is apt only near subpoint. DMSP OLS has a different strategy. The pixel size is .55 km at nadir, begins to increase to the edges, but onboard engineering causes it to decrease again at a discontinuity, then to increase somewhat toward the edge. This explains the superior appearance of OLS imagery compared to AVHRR at the edge of scan. OLS retains sharpness and usability for most applications in these regions, whereas AVHRR is of limited usefulness. The OLS strategy was adopted to comply with the original requirement of the US Department of Defense for uniform imagery across the scan. However, the data are completely uncalibrated. The advantage of the AVHRR, the civilian counterpart, is that it was built as a fully calibrated radiometer, capable of scientific measurements.

VIIRS is a radiometer like AVHRR but has an engineering strategy similar to DMSP OLS in that pixel size is constrained in the cross track direction. The pixel size of the Moderate resolution channels is 750 m at nadir, expands toward the edge, falls at a discontinuity, rises again, falls again at another discontinuity, then rises toward the edge of scan to about 1600 m. In this way imagery is always imaged using data no more than about twice the resolution at nadir, a great improvement over AVHRR. For the VIIRS DNB (Lee et al. 2006a) channel (not shown in Fig. 1) pixel size is constant across the scan, starting at 750 m at nadir and staying at that exact value to the edge of scan. The pixel size of VIIRS Imager channels (Table 1) behaves in a similar way as the VIIRS moderate channels but the pixel size at every stage is half, increasing from 371 m at nadir to about 790 m at the edge of scan.

There are a large variety of VIIRS products that can be demonstrated from MODIS data, for example a dust enhancement (Miller 2003). Fig. 2 is a MODIS dust enhancement that enables interpreters to detect dust plumes which often are invisible on other satellite images. The left side shows the Red Sea dividing Africa from Asia. The right side is a zoom showing a dust plume (bright pink) emanating from a dry lake bed and curving anticyclonically across the water. Superimposed are vectors from the COAMPS™ mesoscale model, tracing the gap wind flow in which the dust embedded.

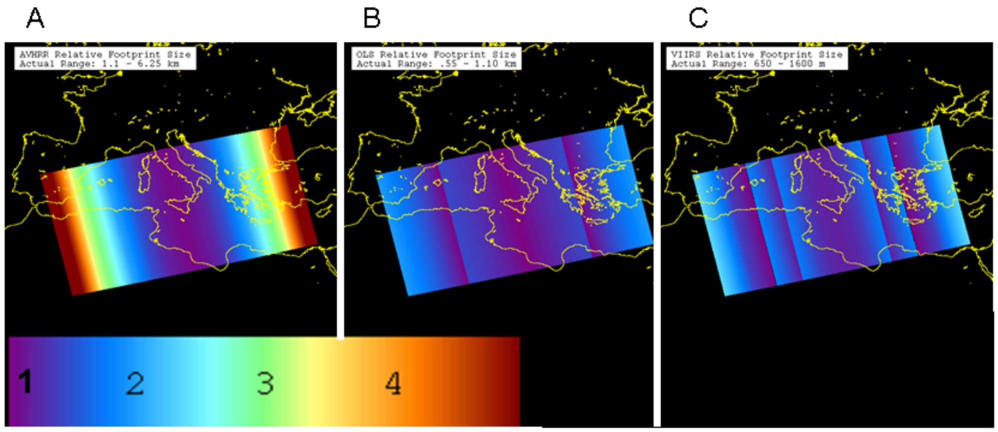

Figure 1 Expansion of pixel size over a sample swath: A) AVHRR; B) OLS Fine; C) VIIRS Moderate Resolution. Pixel sizes in km.

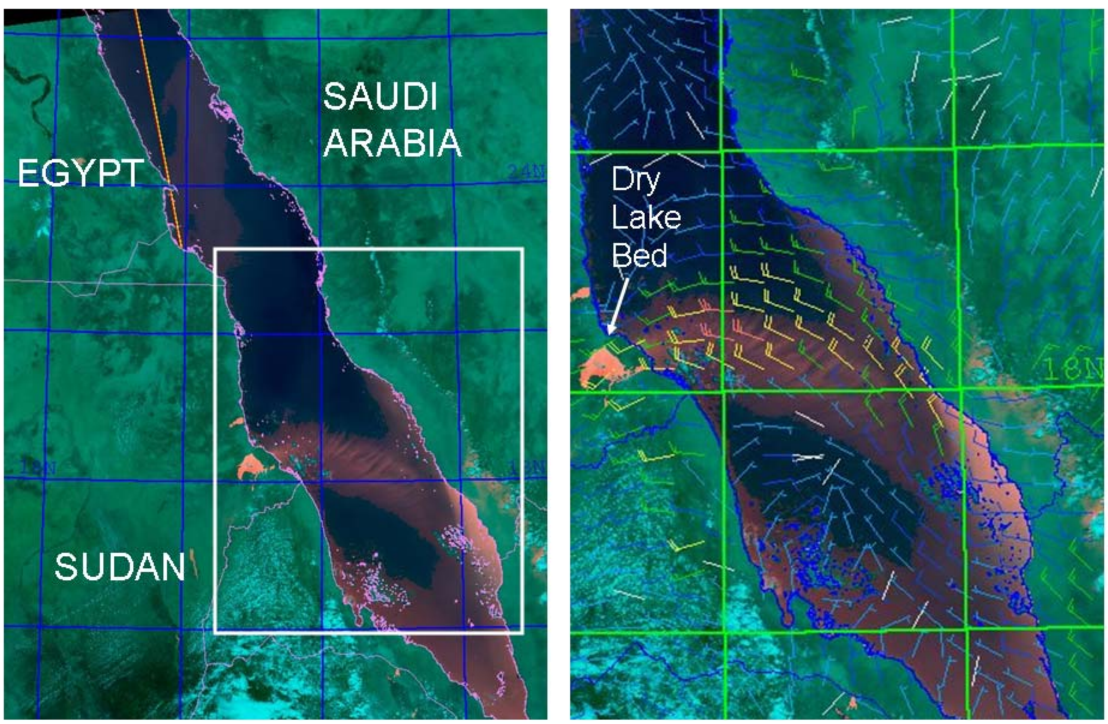

Figure 2 MODIS dust enhancement over the Red Sea. Left side: Overview. Right side: Zoom (from white box on left) overlaid with COAMPS ™ wind vectors.

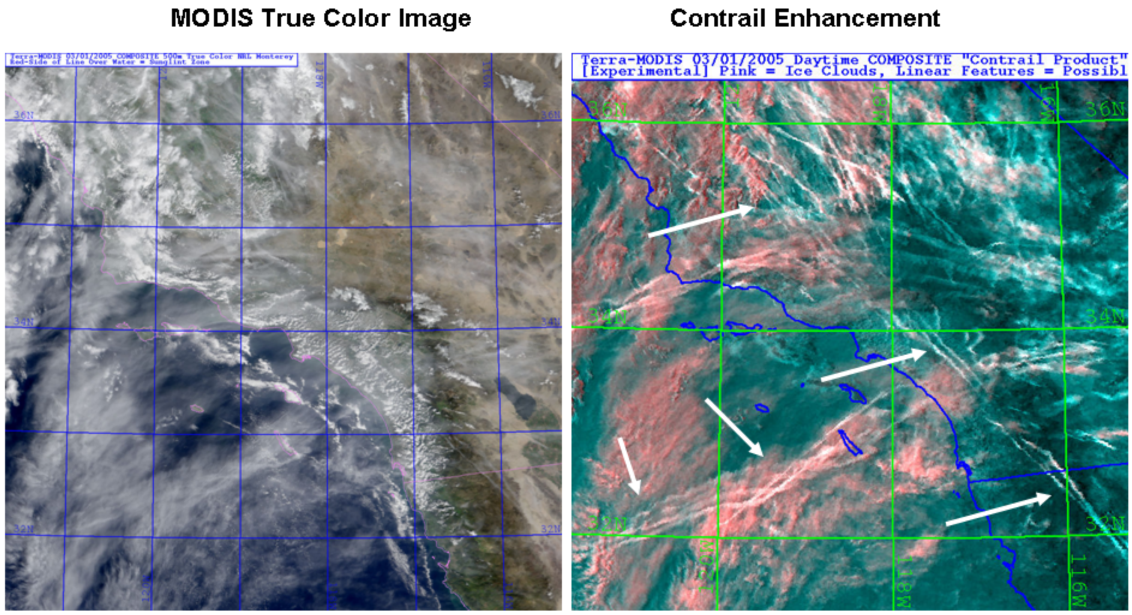

Figure 3 Left side: True Color image of Southern California; Right Side: Same scene but contrail enhancement. Long, narrow features are contrails. MODIS imagery, 1 March 2005.

There are a large number of MODIS prototype products that VIIRS will produce with much greater detail. Among them are the fog product (Ellrod 1996), contrails product, and true color composite. Fig. 3 (left side) shows a true color image over southern California. The VIIRS sensor will be the first operational weather sensor to produce true color imagery. The value of true color as a weather forecasting tool has been previewed by MODIS, but delays in product receipt inherent in MODIS processing has lessened its value. In the VIIRS era enhanced timeliness will create high demand for true color imagery. However, true color, despite its value, can not depict a large number of environmental parameters that must be imaged using a different combination of channels. No contrails, for example, appear in the true color image. On the other hand, the contrails product in the right side shows contrails distinctly as long narrow lines. Contrails are thin cirrus which has a differential response in two of the longwave infrared channels of MODIS. In the VIIRS era the two requisite longwave channels will have finer resolutions for more detailed views. The 11.4 micron channel will be set at .37 km at nadir (compared to 1 km for MODIS), and the 12 micron channel will be set at .74 km at nadir (compared to 1 km MODIS). Thus, more contrails will be detectable.

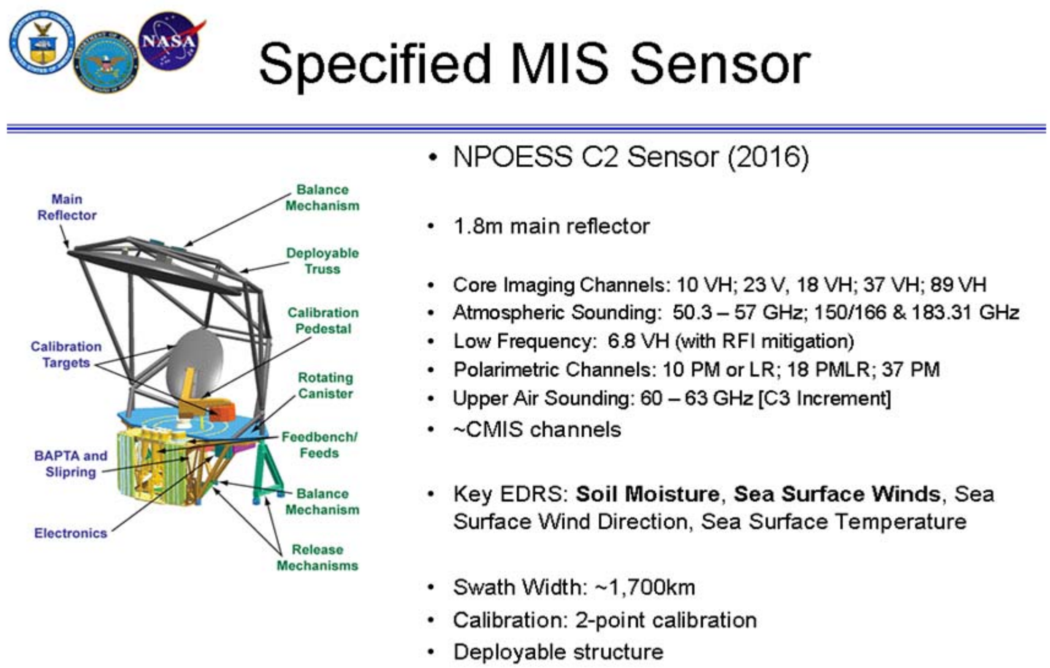

Figure 4 Microwave Imager Sounder

3. Microwave Imager Sounder

The new Microwave Imager Sounder (MIS) sensor replaces the Conical Microwave Imager Sounder (CMIS) that was previously planned for NPOESS. MIS will fly first aboard C2 with likely launch of 2016 (Fig. 4, Kunkee et al. 2008). Of key importance is its ability to create surface wind vectors over the surface of the ocean, a capability previewed by WindSat. WindSat is a completely passive microwave radiometer designed to receive microwave radiation at various frequencies from the atmosphere and the surface. Of key importance for its wind vector derivation capability are the polarimetric channels at 10, 18, and 37 GHz.

The Naval Research Laboratory has developed retrieval algorithms to derive vectors from the WindSat polarimetric measurements. A low spatial resolution retrieval package has major limitations since it can not produce retrievals near coastlines. This effect is seen in the left side of Fig. 5 showing retrievals (colors) in the Atlantic (upper right) and Pacific (lower left). However, the central part of the area is all gray. This absence of data is because retrievals are not possible over or near islands (microwave side lobe effects from land), and because retrievals are not possible in precipitation (for example, over Hurricane Dean). The more recently developed high resolution retrieval package (right side) produces winds much nearer to coastlines, for example in the vicinity of Cuba and Hispanola. The gale force (red) winds near the islands mark flow that is forced topographically through the islands in a counter-clockwise direction around the northern periphery of Dean.

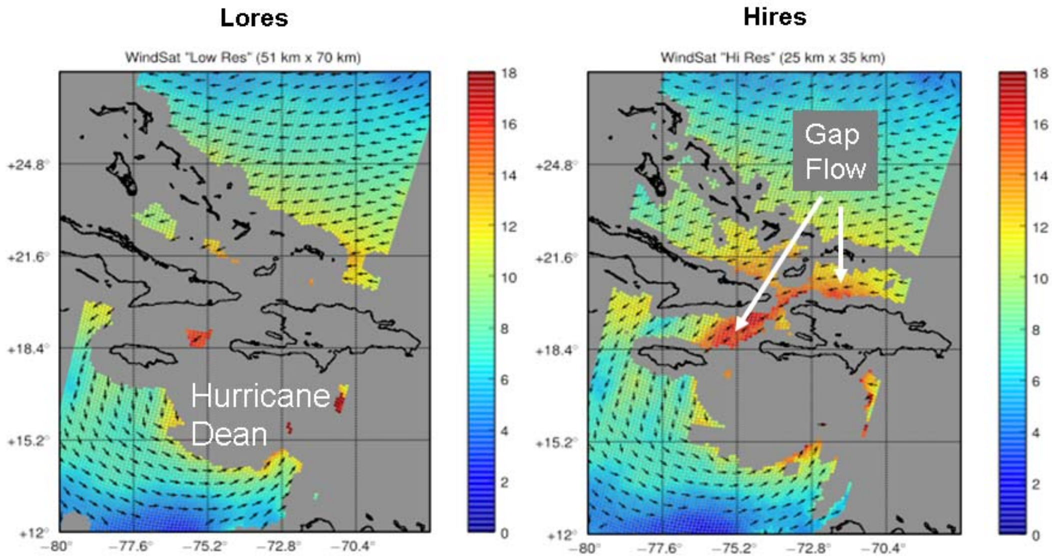

Figure 5 Left: Low Resolution WindSat Wind Vector Retrievals; Right: High Resolution Retrievals.

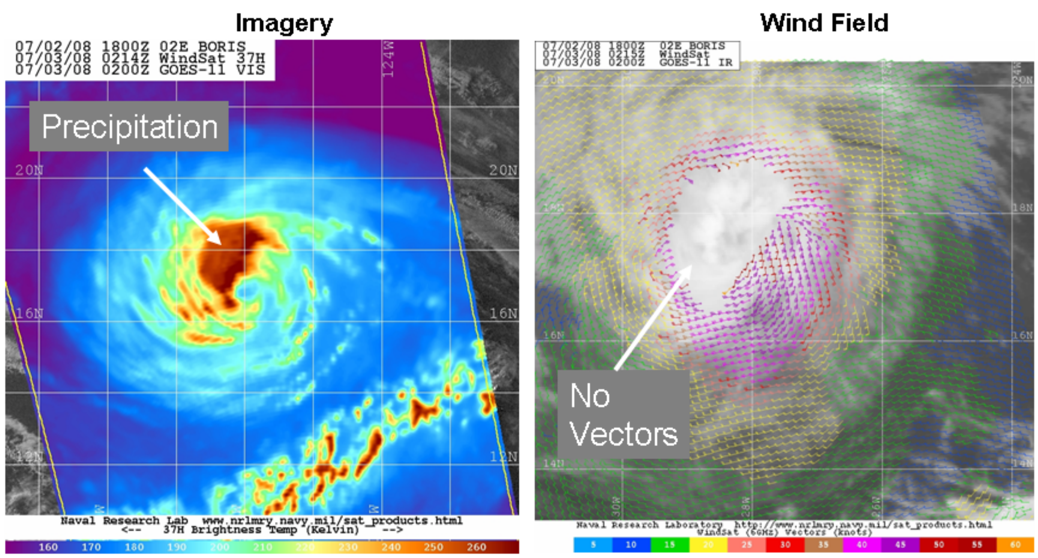

Figure 6 WindSat Imagery over Tropical Storm Boris. Left: 37 GHz Imagery; Right Side: WindSat Wind Barbs using same WindSat overpass.

Fig. 6 shows two products from WindSat over Tropical Storm Boris in the Eastern Pacific in 2004. Fig. 6 (left side) images Boris with the 37 GHz channel, a very useful application described in Hawkins et al. (2001). At this frequency ice clouds are transparent, revealing underlying signatures from precipitation in brownish red. Notice the small blue spot near the center of circulation. This is the storm eye which is often obscured on most images produced by visible and infrared data. On the right side the GOES infrared image corresponds to the same scene. Overlaid are vectors produced from WindSat. Color coding on the vectors reveals that speeds increase from about 10 knots at the periphery to about 40 knots near the center. Notice that the center of the storm is not overlaid with vectors because precipitation (reddish brown on the left side) obscures the signal. The ability of precipitation to block retrieval of wind vectors marks an important limitation to passive microwave wind retrieval. On the other hand, there are many important wind systems, including high winds influenced by nearby land terrain, which are usually precipitation-free, and where accurate retrievals are possible.

4. Conclusions

Both imagers, VIIRS and MIS, continue important heritage capabilities and both contain new capabilities. Thus, training and education of forecasters are an important aspect of NPOESS preparation and readiness. Lee et al. (2007) summarize training materials compiled by the Cooperative Program for Operational Meteorology, Education and Training (COMET). Miller et al. (2006) review the NexSat education resource that trains new users at the same time it provides near-realtime examples from a variety of satellites, including NOAA, DMSP, MODIS, and GOES.

5. Acknowledgements

The authors are grateful for the support of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Integrated Program Office (IPO).

6. References

Ellrod, G.P., 1995: Advances in the Detection and Analysis of Fog at Night Using GOES Multispectral Infrared Imagery. Wea. Forecasting, 10, 606-619.

Hawkins, J.D., T.F. Lee, , J. Turk, C. Sampson, J. Kent, and K. Richardson, 2001: Real-time Internet distribution of satellite products for tropical cyclone reconnaissance. Bull. Amer. Met. Soc., 82, 567-578.

Johnson, D. B., P. Flament, and R. L. Bernstein, 1994: High resolution satellite imagery for mesoscale meteorological studies. Bull. Amer. Meteor. Soc., 75, 5–33.

Kunkee, D., NPOESS Microwave Imager/Sounder (MIS), 2008: The Next Generation Operational Microwave Imaging and Sounding Radiometer. Proceedings International Geoscience and Remote Sensing Symposium 2008.

Lee, T. F., Miller, S. D., Turk, F. J., Schueler, C., Julian, R., Deyo, S., Dills, P., and Wang, S., 2006a: The NPOESS VIIRS Day/Night Visible Sensor. Bulletin American Meteorological Society, 87, 191-199.

Lee, T.F., S.D. Miller, C. Schueler, and S. Miller, 2006b: NASA MODIS Previews NPOESS VIIRS Capabilities. Wea. Forecasting, 21, 649–655.

Lee, T. F., Miller, S. D., Turk, F .J., Hawkins, J. D., Wang, S., Dills, P., Hoffman, C., McWilliams, G., Mineart, G., and Jelenak, Z., 2007: NPOESS Online Satellite Training for Users. Bulletin American Meteorological Society, 88, 13-16.

Miller, S. D.,Hawkins, J. D., Kent, J., Turk, F. J., Lee, T. F., Kuciauskas, A. P., Richardson, K., Wade, R., and Hoffman, C., 2006: NexSat: Previewing NPOESS/VIIRS Imagery Capabilities. Bulletin American Meteorological Society, 87, 433-446.

Miller, S. D., 2003: A consolidated technique for enhancing desert dust storms with MODIS. Geophys. Res. Lett., 30, 2071—2074.