A look at the latest satellite technology used to track and measure major dust storms.
Dust storms in the Southwest United States lead to deteriorated air quality and impair visibility. Levels of particulate matter smaller than 2.5 μm and 10 μm in median diameter (PM<sub>2.5</sub> and PM<sub>10</sub>, respectively) exceed the National Ambient Air Quality Standards (NAAQS) set by the U.S. Environmental Protection Agency (EPA).<sup>1</sup> The dust storms form rapidly, aided by unstable convective systems that bring strong downdrafts with gusty winds, and dissipate within a few hours of forming.<sup>2</sup> The remnants of airborne dust, however, linger with widespread impacts on air quality, visibility, and human health in the region for days. Dust storms have been on the rise in the last two decades as a result of changing weather patterns, combined with land use/land cover changes.<sup>3</sup> The dust storms in North America typically form in the late evening and last into the night, which makes observing the events from satellites difficult.<sup>2</sup>

Polar-orbiting satellites such as NASA’s Aqua and Terra MODIS (MODerate resolution Imaging Spectrometer) and NASA-NOAA Suomi National Polar-orbiting Partnership Visible Infrared Imaging Spectrometer Suite (SNPP VIIRS) that can detect dust and aerosols have a mid-afternoon ascending overpass time and cannot observe the storms that last into the night. The current operational geostationary satellites are weather satellites that have a very limited capability to observe dust despite 30-minute sampling of the Continental United States (CONUS). The recently launched NOAA’s GOES-16 Advanced Baseline Imager (ABI), however, is a 16-channel instrument with a wavelength range from visible to infrared.<sup>4</sup> ABI spectral capabilities enable the creation of RGB (Red–Green–Blue) imagery obtained from band differencing techniques that provide for qualitative aerosol detection (i.e., dust, smoke, volcanic ash) and enable the quantitative retrieval of aerosol optical depth (AOD) to assess the amount of aerosols in the atmosphere.

**GOES-16 ABI**

The GOES-16 ABI was launched on November 19, 2016, to monitor environmental hazards such as fires, dust storms, severe weather, and hurricanes over the Western Hemisphere. In its default mode, the ABI observes the western hemispheric full disk every 15 minutes, the CONUS every five minutes, and a dynamically selectable mesoscale region every 30 seconds. Two techniques applied to detect dust are a band differencing method applied to generate the RGB imagery and an objectively derived aerosol detection product (ADP) that classifies the aerosol in the scene as dust or smoke. While the ADP is a daytime only product, the dust RGB product is for both day and night and allows night-time tracking of dust storms.

**Dust RGB**

The dust RGB is generated using brightness temperature (BT) measurements at three different channels to identify dust. The BT difference between 12.3 μm and 11.2 μm (BT<sub>12-11</sub>), BT difference between 11.2 μm and 8.4 μm (BT<sub>11-8.4</sub>), and BT at 11.2 μm (BT<sub>11</sub>) are displayed using shades of colors Red, Green, and Blue, respectively, so the airborne dust looks pink/magenta color in the image. The optical properties of dust are such that it absorbs more at shorter wavelengths (11 μm and 8 μm vs. 12 μm), while surface emissivity increases with wavelength.

For example, in presence of dust over a bright surface during the day, BT<sub>12-11</sub> is positive because dust absorbs more at 11 μm than 12 μm. Similarly, BT<sub>11-8.4</sub> is positive though less positive than BT<sub>12-11</sub> because the emissivity difference is not very high. Thus, the BT<sub>11-8.4</sub> is close to zero and the values for BT<sub>12-11</sub> and BT<sub>11</sub> plugged into red and blue colors dominate giving the dust a magenta/pink color.<sup>5</sup> The colors for desert surface during the day are cyan blue/white and during the night are lighter shades of pink, making it difficult at times to confidently identify airborne dust in the night, especially if only a single image from polar-orbiting satellites such as VIIRS is used. However, the 5-minute refresh rate of GOES-16 ABI provides one dust RGB image for every five minutes to aid with the interpretation of a moving dust plume versus a stationary surface feature. Different types of clouds will have different colors (black, bright red, green, etc.) in the dust RGB image owing to different absorption features of water and ice.

**Dual Dust Storms in March 2017**

On March 30, 2017, high winds with gusts as high as 90 mph near Palm Springs, CA, gave rise to a sand storm starting around 4:00 p.m. local time, according to news reports.<sup>6</sup> Figure 1 shows time series of the dust storm as observed by ABI dust RGB *(note: time is in UTC, hence, the date is shown as 31 March 2017)*. This storm, as observed by ABI, lasted several hours with transported dust (pink color) mixing in with clouds (brown–red) over Arizona and eventually dissipating by midnight. The dust plume location is highlighted by a circle and is shown only for the top of the hour starting 0001 UTC (4:01 p.m. local time), though images are available every five minutes.

Outside of the dust plume near the Southeast California and Nevada border, the soil/desert dominated regions are in whitish–cyan color when it is still daylight, but at night fall most of the surface turns pink making dust detection difficult. However, given that the ABI observes the earth every five minutes, dust plume detection is easy as it can be seen moving whereas the surface changes color but is static. The transported dust blended in with the clouds around 500 UTC (10:00 p.m. local time) but re-emerged a few hours later. This can be seen in Figure 2 (right) for 830 UTC where a streak of intense pink color is wedged in between clouds shown by dark brown color. The same dust plume can be
Figure 1. Hourly GOES-16 ABI dust RGB imagery for March 31, 2017, starting 0001 UTC (this corresponds to 4:01 p.m. in California).

Note: The series of images show dust storm (highlighted by a circle) forming in California, moving over Arizona, and dissipating after mixing in with clouds indicated in the images by dark red color. Surface changes color from white-cyan color in the day time to pink color in the night time. The contrast between dust plume and surface is stark in the day time compared to night time.
seen clearly in the SNPP VIIRS dust RGB image at night time (Figure 2, left). Dust plumes observed around 0830 UTC by ABI and VIIRS are nearly identical. The location of dust plume, clouds, and surface features are very similar except the intensity of dust (pink color) in the VIIRS is stronger than the one for ABI. That is likely due to minor differences in band passes of the wavelengths on the two instruments. The nearly identical visualizations demonstrate the high degree of confidence in the dust plume identification technique.

While the dust event of Palm Springs, CA, completely dissipated by 11 UTC (indistinguishable from surface features), another dust storm brewed in the northern Mexico farm lands. Figure 3 shows a series of hourly dust RGBs that point to dust emanating from northern Mexico farm lands and moving into Texas/New Mexico area and blowing over the White Sands source region. This storm grew in size as the day progressed and lasted all day. The ground monitor in El Paso, TX, recorded high concentrations of PM$_{10}$ on March 31, as this dust storm passed by, with recorded values reaching as high as 800 µg/m$^3$. EPA’s 24-hr average PM$_{10}$ standard is 150 µg/m$^3$, observed values ranged between 100 and 800 µg/m$^3$ during the course of the day.

To warn the public of potentially harmful exposure to particles, the U.S. National Weather Service (NWS) provides dust forecast guidance. On March 31, 2017, the operational forecast using the Community Multiscale Air Quality Model (CMAQ) missed the second dust storm. It correctly predicted the first storm originating in California, but not the one in northern Mexico because the model wind fields were not in the right direction and magnitude. Figure 4 shows surface PM$_{2.5}$ and wind vectors forecast for 1900 UTC. Observed PM$_{2.5}$ values at different ground stations are overlaid as circles with the color code the same as forecast PM$_{2.5}$. The map shows three notable features: (1) the first dust storm that originated in Palm Springs, CA, is still present over Arizona at 1900 UTC; (2) there is no dust storm over northern Mexico and Texas; and (3) the ground monitor in El Paso, TX, has elevated PM$_{2.5}$ values.

According to ABI dust RGB imagery, the first storm dissipated around 1100 UTC, yet the model shows a distinct dust plume still present over Arizona and Utah. The second dust storm lasted all day according to ABI dust RGB imagery, but it is not forecast by the model because wind fields in the model are southerly and not of right magnitude. This is a case where the near-real-time observations of dust and smoke from GOES-16 imagery could have been used by forecasters to provide dust forecast guidance versus the NWS model guidance.

**Conclusion**

Scientists who study the Southwest U.S. dust storms and their impact on human health and the economy have concluded that the noncontinuous sparse air quality and meteorological monitoring is insufficient to aid with monitoring and forecasting of dust storms. The accuracy of air quality forecasting depends very much on wind speed and direction, especially for dust predictions. The timing and the amount of dust emitted from the surface depends on winds and surface characteristics such as vegetation cover, soil texture, and moisture. Additionally, very few records of dust storm history exists and only recently have scientists began to study closely impacts of dust storms on human health and economy.

The new capabilities for dust detection using the rapid refresh GOES-16 ABI dust imagery can become the viable tool that scientists and operational forecasters are looking for.
Tracking Dust Storms Using the Latest Satellite Technology by Shobha Kondragunta et al.

Figure 3. Hourly GOES-16 ABI dust RGB imagery for March 31, 2017, starting at 1457 UTC.

Note: The series of images show dust storm (highlighted by a circle) that formed in Mexico and moved into southwestern Texas. The dust plume is easily discernible with a good contrast of light pink to cyan-white colors of surface.
to understand the morphology of dust storms and improve the models to accurately predict the storms. Analysis of the two dust storms reported here sheds light on how the dust RGB imagery at 5-minute interval for both day and night can help build needed information.

**More Information**

The derived RGB data presented here is available in real-time online (https://www.star.nesdis.noaa.gov/smcd/spb/aq/AerosolWatch/).

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**Figure 4.** CMAQ model predicted PM$_{2.5}$ concentrations for March 31, 2017, at 1900 UTC.

*Note: Color contours are for PM$_{2.5}$, color circles are ground observations of PM$_{2.5}$, and arrows are wind vectors in units of m/s. PM$_{2.5}$ concentrations are in units of µg/m$^3$. Note the very high observed PM$_{2.5}$ value (purple color) for El Paso, TX.*

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**References**