Using Multi-Sensor Aerosol Optical Depth Retrievals to Improve Infrared Radiance Assimilation

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Motivation

- Space-borne satellite sensors measure varying aerosol mass concentrations and particle sizes throughout the globe
- Coarse dust particles are capable of scattering and absorbing infrared radiation, which have been shown to lead to heating rates > 1 K d^{-1} within dust layers and cooling rates > 1.5 K d^{-1} near top when composed of particles > 2 µm in radius

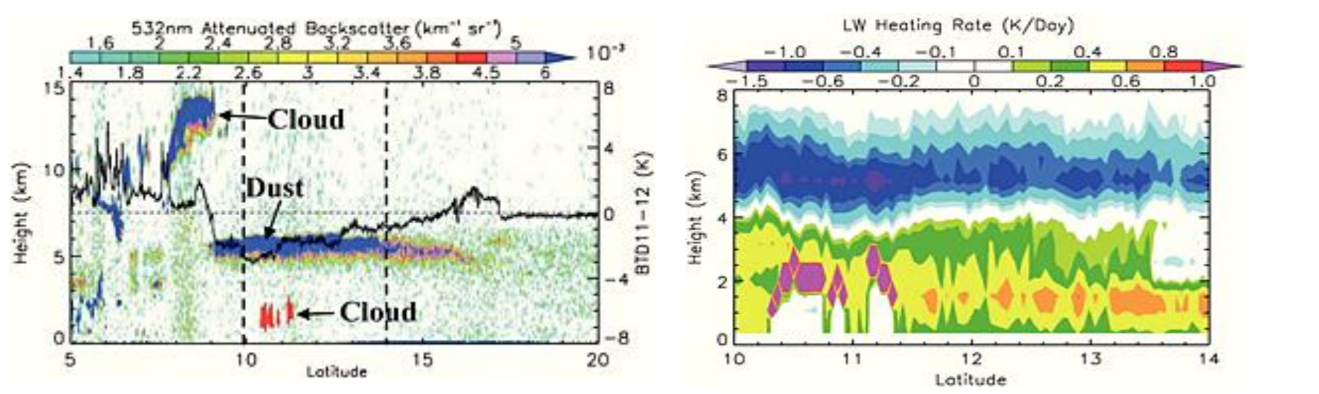

Figure 1. (left) CALIOP transect over a Saharan dust layer on 21 June 2007 showing L1 attenuated backscatter measurements, (right) RTM LW heating/cooling rates within the Saharan dust layer over the Eastern Atlantic Ocean.

- Dust can impact clear-sky satellite radiances, which can introduce significant biases in temperature, moisture, and wind fields of model analysis, and consequently, reduce the forecast skill
- Modules accounting for aerosol impacts on radiation have been implemented into CRTM framework (Liu and Boukabara, 2014), but operational centers continue to assume aerosol-free conditions when assimilating infrared radiances into NWP models.

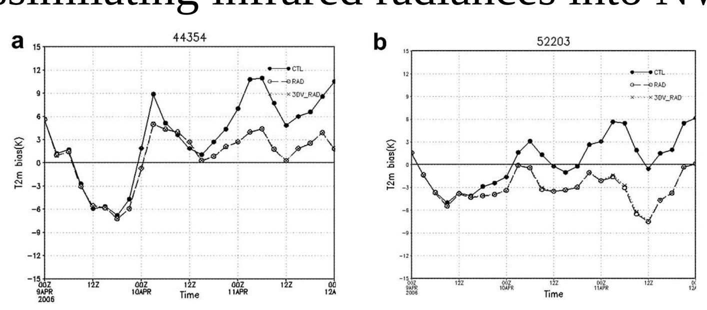

Figure 2. 2-m temperature from control and experimental runs over (left) Mongolia and (right) Taklimakan deserts.

- **Motivational Questions in this study**:
1. How well can current aerosol modules in the CRTM simulate the satellite infrared radiances of coarse dust aerosols?
2. What is the overall impact of dust on satellite infrared radiances from the CRTM?
3. Does the assimilation of aerosol-affected radiances lead to a reduction in error in the model analysis fields? What is the overall impact on the forecast?

Methodology

1. Use CALIOP and AERONET aerosol retrievals within dust storms along with meteorology from reanalysis data for providing accurate aerosol and meteorology profiles into the Community Radiative Transfer Model (CRTM)
2. Validate simulated dust aerosol-affected infrared radiances against multiple satellite sensor measurements from channels with central wavelengths ranging from 8.5 to 12.5 µm
3. Quantify dust impact on satellite infrared radiances by comparing CRTM simulated brightness temperatures to observations
4. Use GSI to assimilate aerosol-affected infrared radiances into the GEOS-5 model and evaluate impact on dust impact on forecast fields.

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Evaluation of Dust Impact on Infrared Radiances from CRTM

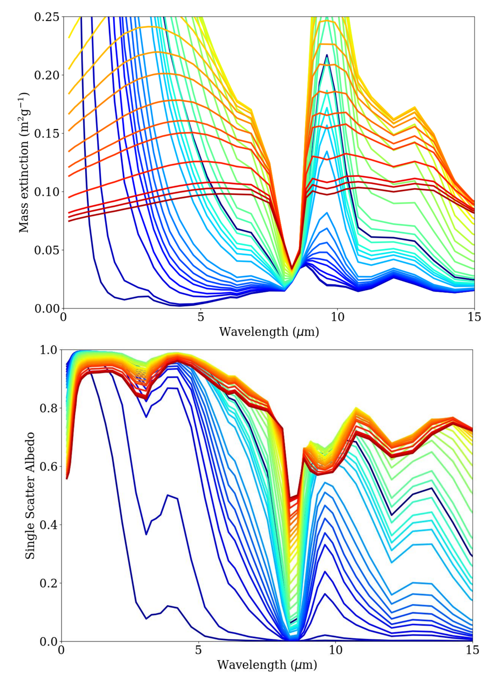


Figure 3. Mass extinction (top) and single scatter albedo (bottom) prescribed within CRTM GOCART aerosol module for dust aerosols. Colors indicate effective radius bins with values ranging from 0.01 (bluish) to 8 µm (reddish).

30 March 2018 Dust Event

- CALIOP measurements show moderately high backscatter and high depolarization ratio within aerosol plume over Yellow Sea.
- Coarse aerosols with moderately high AOD measured by AERONET.
- CALIOP and AERONET retrievals as input into CRTM lead to improved simulation of VIIRS and AHI infrared brightness temperatures.

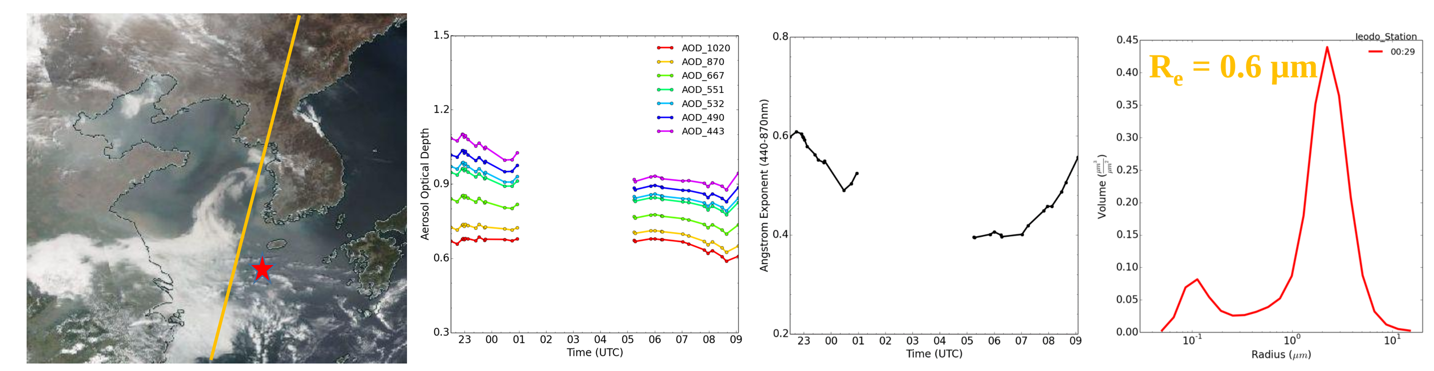


Figure 4. (far left) Suomi-NPP VIIRS true-color red-green-blue (RGB) image at ~0400 UTC 30 March 2018 with AERONET Ieodo Station site (red star) and CALIOP transect (orange line) also shown. AERONET Version 3 Level 1.5 retrievals of AOD (center left), 440-870 nm Angstrom exponent (center right), and size distribution (far right) around time period of dust event.

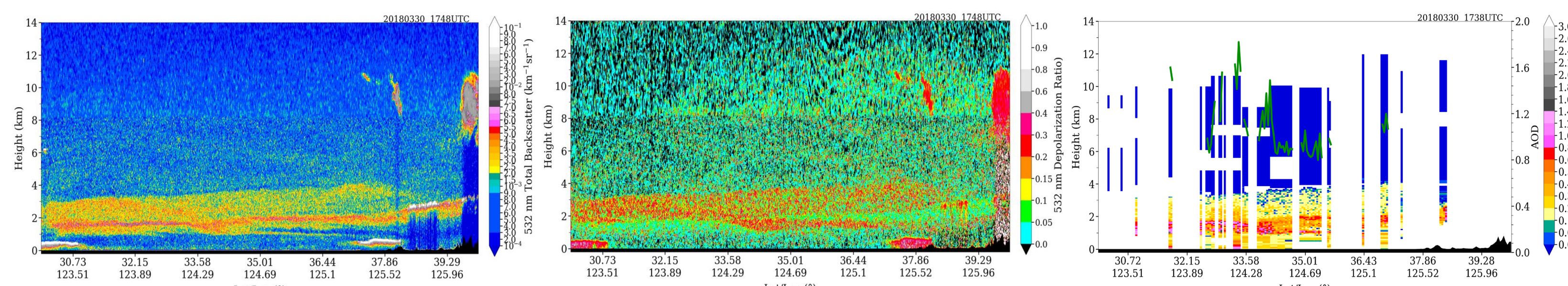


Figure 5. Nighttime CALIOP L1 attenuated backscatter at ~1750 UTC (left), depolarization ratio (center), and L2 extinction coefficient retrievals (right) along transect in Fig. 4.

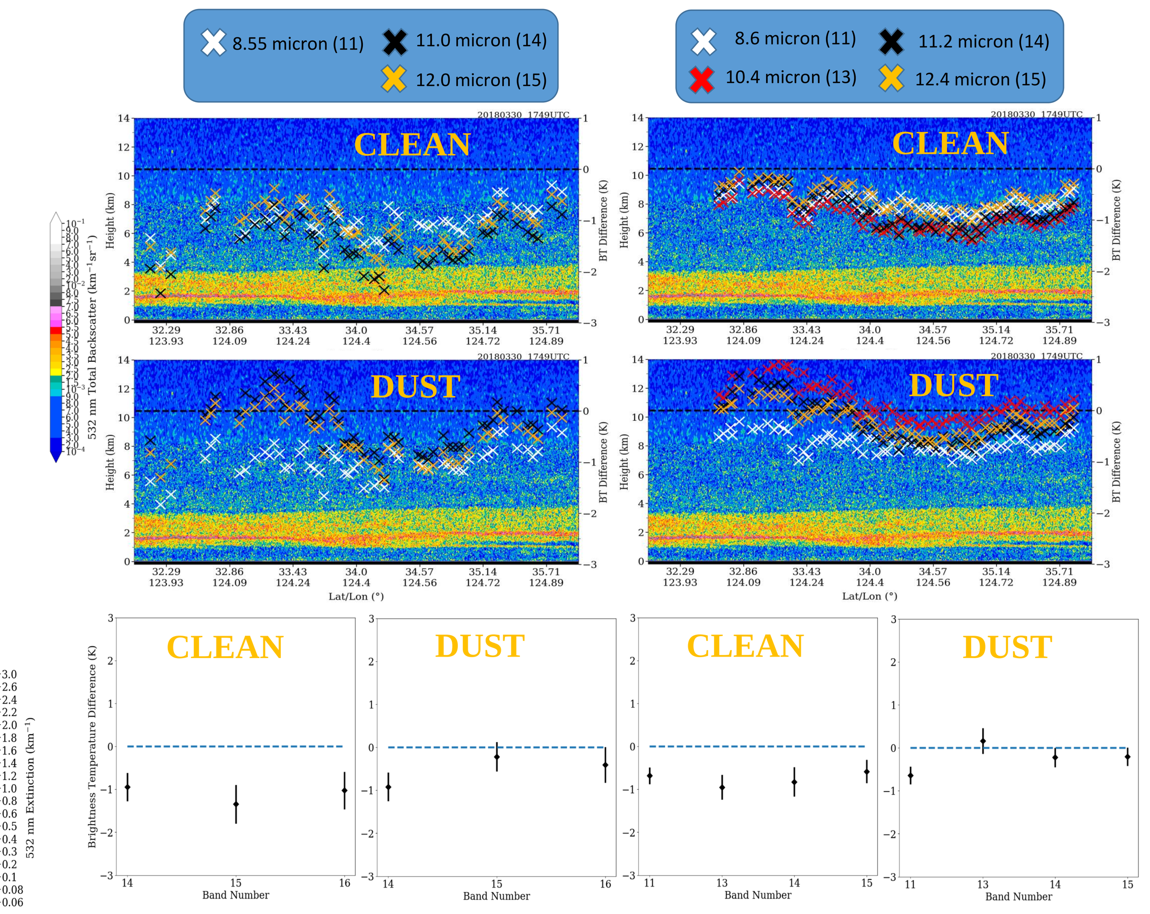


Figure 6. Difference between observed and simulated satellite brightness temperatures along CALIOP transect. (top left) VIIRS no aerosol and dust aerosol simulations, (top right) AHI no aerosol and dust aerosol simulations. (bottom left to right) Mean and standard deviation of VIIRS no aerosol, VIIRS dust, AHI no aerosol, and AHI dust simulations.

5 May 2017 Dust Event

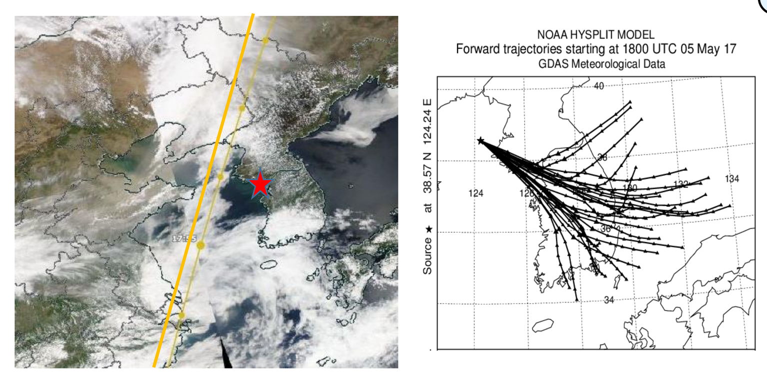


Figure 7. (left) Suomi-NPP VIIRS true-color RGB image at ~0440 UTC 5 May 2017 with AERONET Yonsei University site (red star) and CALIOP transect (orange line) shown. (right) HYSPLIT forward trajectory ensemble for 12-h forecast beginning at 1800 UTC.

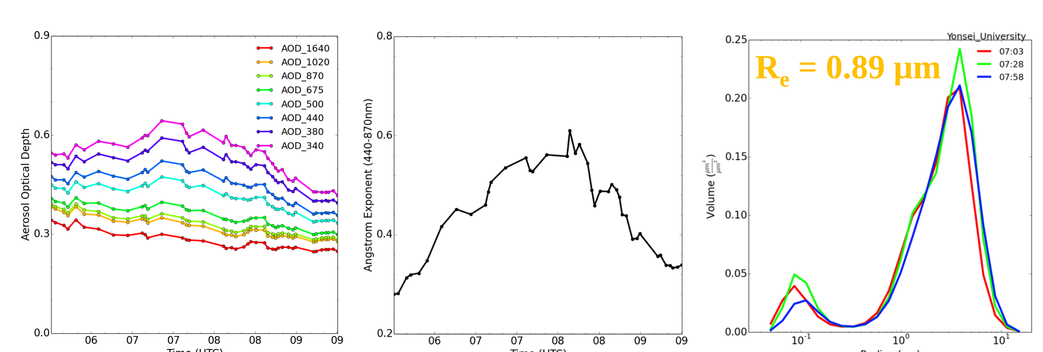


Figure 8. AERONET Version 3 Level 2 retrievals of AOD (left), 440-870 nm Angstrom exponent (center), and size distribution (right) around time period of dust event at Yonsei University site in Fig. 7.

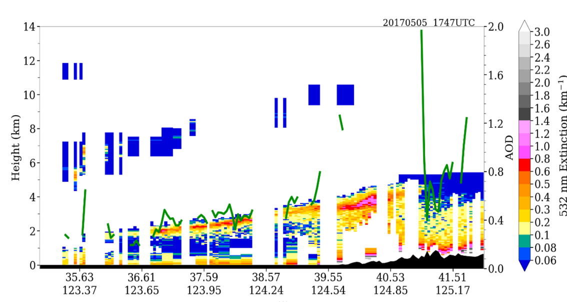


Figure 9. Nighttime CALIOP L2 extinction coefficient retrievals at ~1750 UTC 5 May along transect in Fig. 7.

- CALIOP and nearby AERONET observe coarse dust aerosols over Yellow Sea.
- Dust layer observed by CALIOP advected over AERONET site according to short-term HYSPLIT forecast.
- Aerosol retrievals as input into CRTM lead to improved brightness temperatures, but too warm compared to observations, particularly at 8.6 µm.

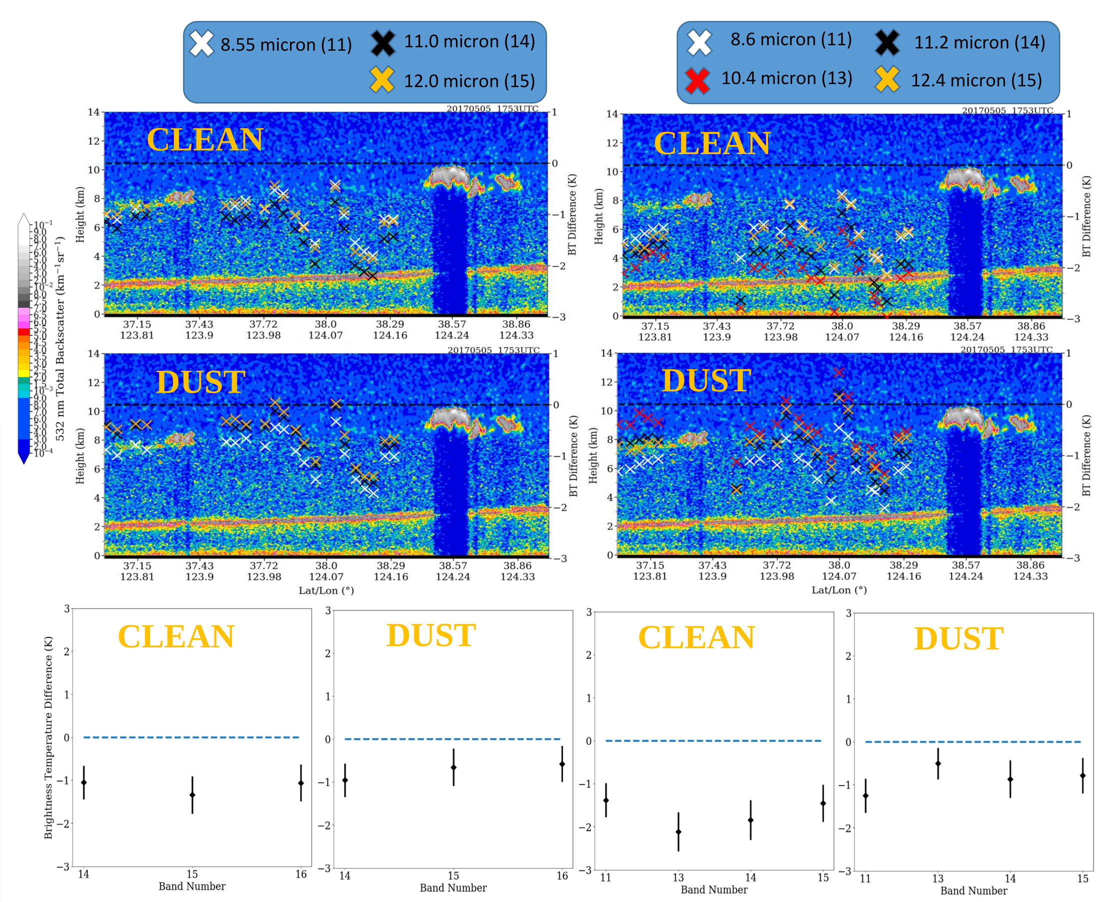


Figure 10. Same as Fig. 6, except valid for 5 May 2017 at ~18 UTC.

Sensitivity / Experimental Simulations

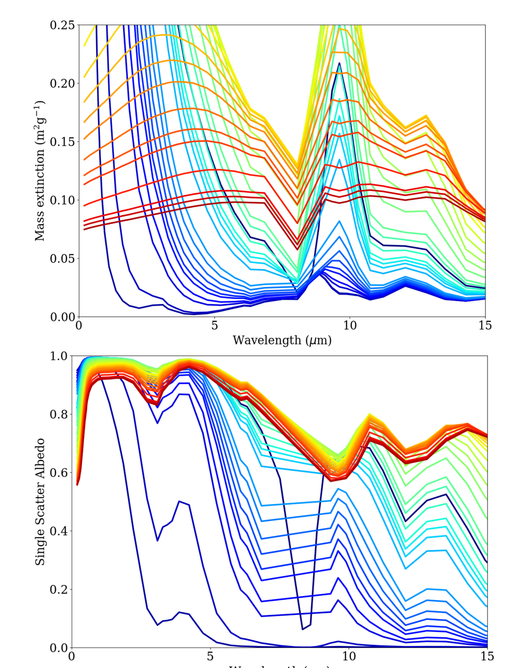


Figure 11. Same as Fig. 3, except modified dust properties within CRTM aerosol module specific for Asian dust.

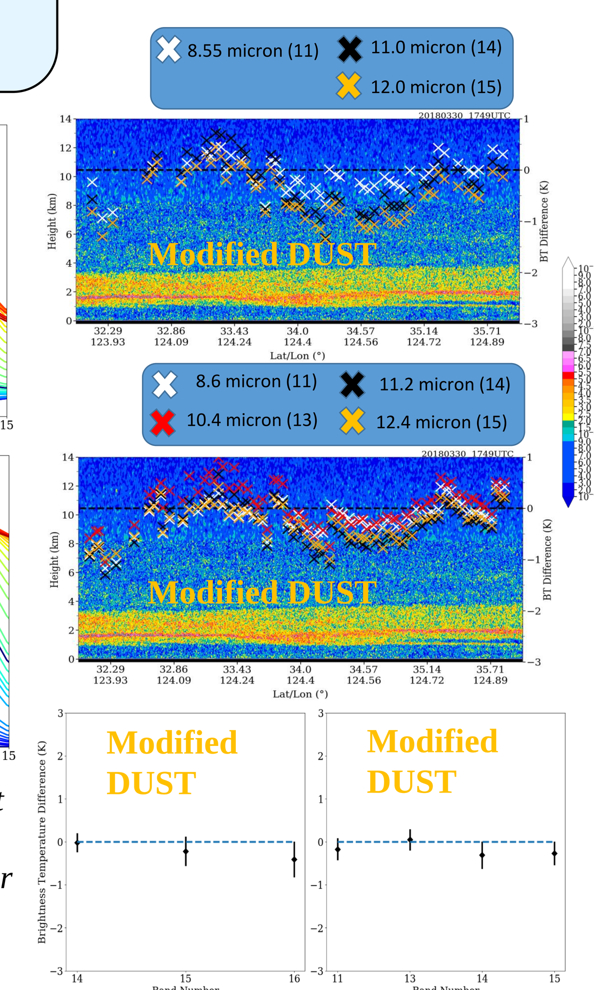


Figure 12. Similar to Fig. 6, except for VIIRS (top) and AHI (center) simulated brightness temperatures for 30 March 2018 using modified dust aerosols within CRTM.

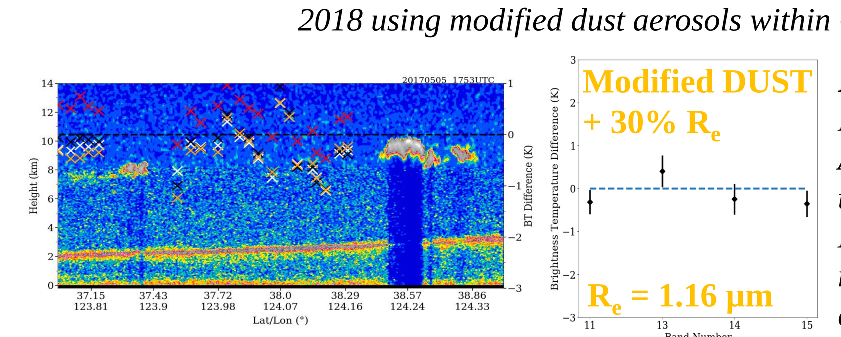
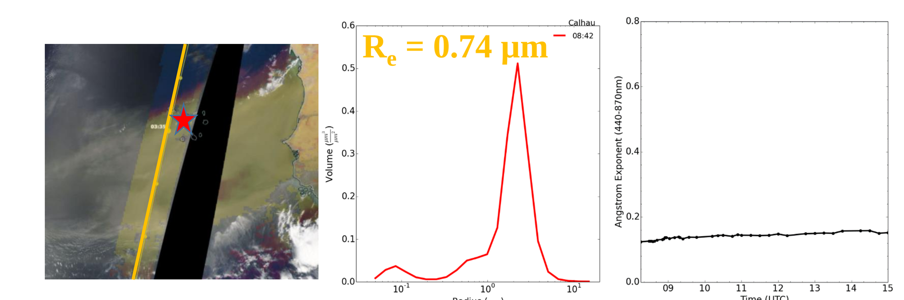


Figure 13. Similar to Fig. 12, except only AHI brightness temperatures for 5 May 2017 using modified dust aerosols and 30% larger r_e.

Saharan Dust



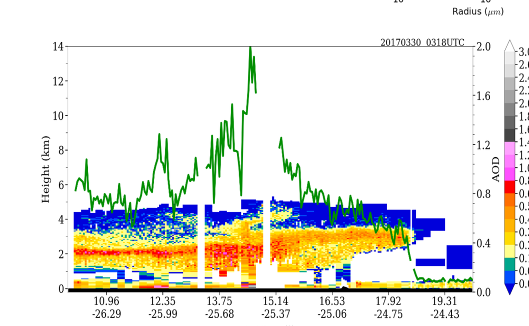


Figure 14. (top left to right) MODIS RGB image at ~1600 UTC 30 March 2017, AERONET size distribution and 440-870 nm Angstrom exponent. (bottom) CALIOP L2 extinction coefficient.

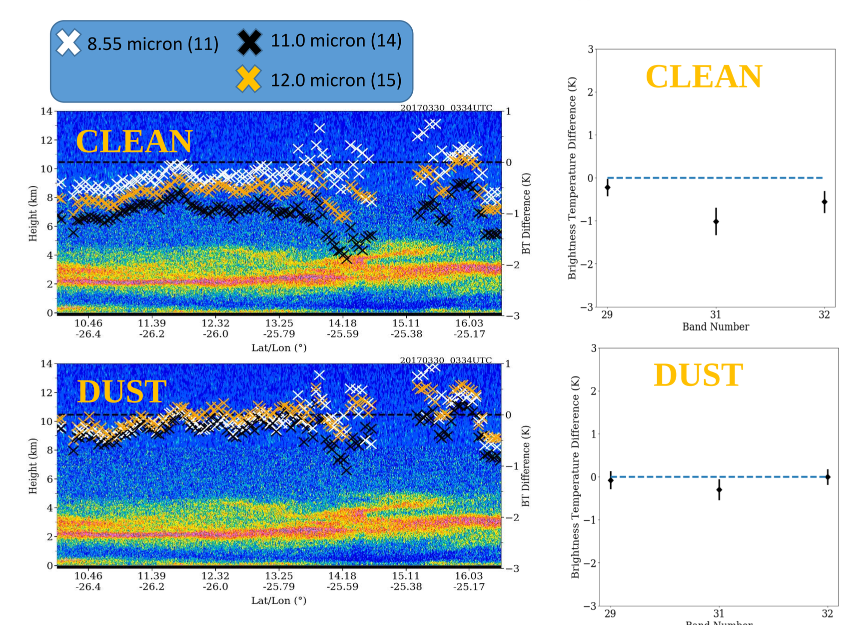


Figure 15. Similar to Fig. 10, except valid for Saharan dust on 30 March 2017.

Summary and Future Work

We provide accurate dust optical and physical properties into the CRTM via CALIOP vertical profiles and AERONET ground-based retrievals, which led to an overall better agreement between the observed and simulated VIIRS, MODIS, and AHI infrared brightness temperatures. However, the 8.6 µm channel of VIIRS and AHI shows a notable warm bias in the simulated brightness temperatures even when accounting for the accurate aerosol information within Asian dust plumes. We modify the prescribed CRTM dust properties according those specifically for Asian dust shown in Sokolik et al. (1998), which significantly reduces the warm bias at this channel. This bias is not observed for Saharan dust plumes. We are currently investigating the impact of aerosol-affected infrared radiance assimilation using the GEOS-5 framework. We plan to extend this work to assess the impact of dust aerosols on hyperspectral measurements from CrIS.