Developing an Atmospheric Correction of Tropospheric Dust in the Infrared SST Retrieval for the NOAA ACSPO System

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Motivation

- Among the sources of uncertainty in sea surface temperature (SST) retrievals from infrared (IR) radiometers, tropospheric/stratospheric aerosols can alter the atmospheric absorption property and cause a negative SST bias up to –2 K. This bias should be corrected based on physical understanding of atmospheric radiative transfer at IR wavelengths.
- Assuming sea surface emissivity=1, the deviation of top-of-the-atmosphere brightness temperature (BT, *T*) from SST depends on (1) the absorber optical depth (β) and (2) temperature difference between the sea surface (T_s) and absorber (T_a), which in turn depends on the absorber vertical profile.

$$T = T_s - \beta(T_s - T_a) \quad \text{where} \quad \beta = (\tau_{gas} + \tau_{wv} + \tau_{aer})\sec^n\theta$$

- Regional SST biases are caused by seasonal dust outflows over the North Atlantic, North Pacific, and Arabian Sea. The dust optical property varies with the mineralogy of source soils. During transport, the dust size distribution, composition, and vertical profile display strong dynamics in space and time. These factors need to be accounted for in designing the correction method.

Model and Data

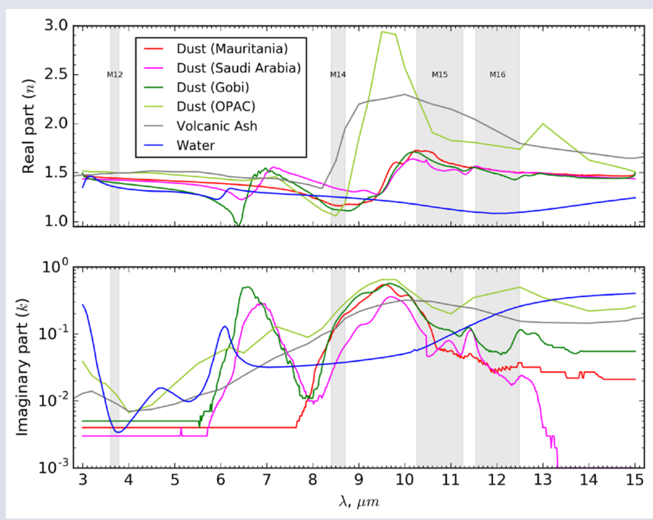
- Dust spectral optical properties are calculated based on Mie theory using recent data on region-specific refractive index and in situ measurement of particle size distribution of regional dust outflow over oceans.
- RTTOV v12.1 simulates nighttime BT in four VIIRS channels centered at 3.7, 8.6, 10.8 and 12 µm, at seven view angles (0°, 12°, 24°, 36°, 48°, 60°, 72°) under aerosol-free and dust-affected conditions.
- The Modern-Era Retrospective analysis for Research and Applications Version 2 (MERRA, 0.5°x0.625°, 72 vertical layers) provides the atmospheric profiles of pressure, temperature, and humidity, as well as the mixing ratios of dust aerosols.

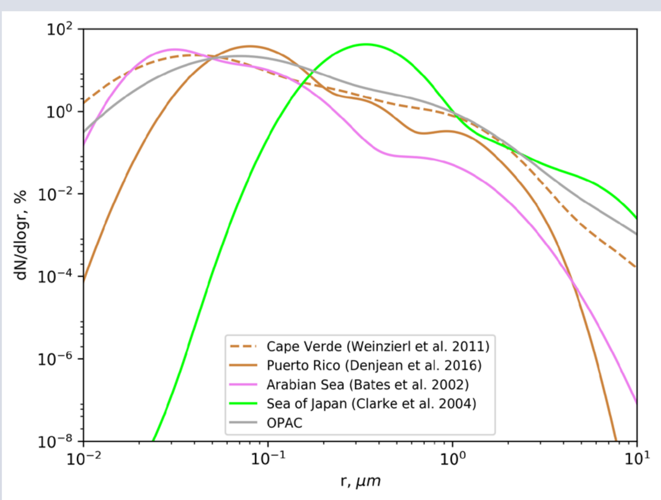
Dataset Name	Variable(s)	Temporal	Purpose
Const_2d_asm_Nx	Fraction of ocean	constant	Land/ocean mask
Inst3_3d_asm_Nv	P, T, Q, Ps	3-hourly	Profile input
Inst1_2d_asm_Nx	2m T, 2m Q, Ts	1-hourly	Profile input
Tavg1_2d_rad_Nx	Total cloud fraction	1-hourly	Cloud screening
Inst3_3d_aer_Nv	Dust mixing ratios	3-hourly	Aerosol input
Tavg1_2d_aer_Nx	Dust AOD (550 nm)	1-hourly	Aerosol input

Calculation of Dust Optical Properties in the IR

Refractive Index (Di Biagio et al. 2017)

- Compared to water, dust has opposite spectral behavior in *k*.
- Dust has peak absorption at 9.6 µm (clay), 7 µm (calcite), 9.2 and 12.5 µm (quartz), but with different magnitude for regional sources.
- OPAC overestimates absorption in the window region.



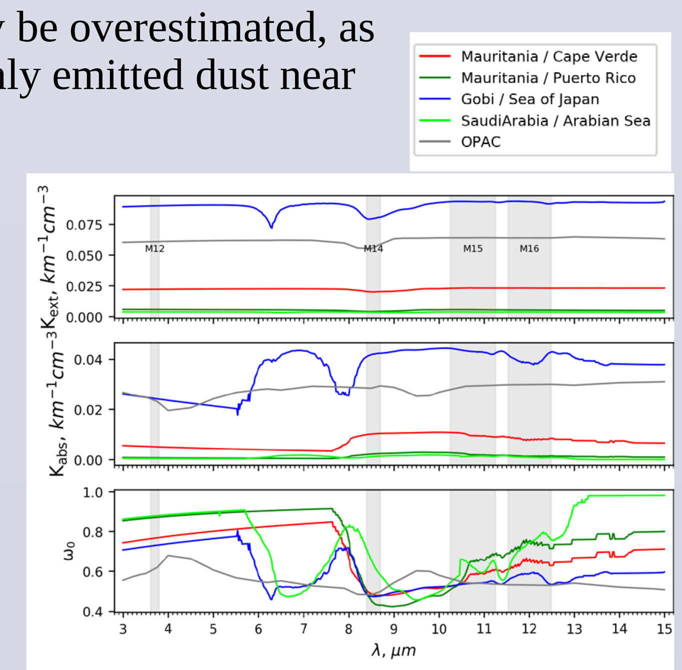


Particle Size Distribution

- Dust size distribution is fairly constant during long-range transport.
- Loss of coarse particles in African dust from Cape Verde island to Puerto Rico
- The coarse mode of Asian dust over Sea of Japan may be overestimated, as it resembles freshly emitted dust near source

Dust IR Optical Properties

- The coarse size mode has prominent effects on the magnitude of K_{ext} and K_{abs}.
- K_{abs} and ω_0 display strong spectral variations (e.g. ω_0 increases from 8.6 to 12 µm).
- OPAC shows weaker spectral dependence but strongest absorption (i.e. lowest ω_0).



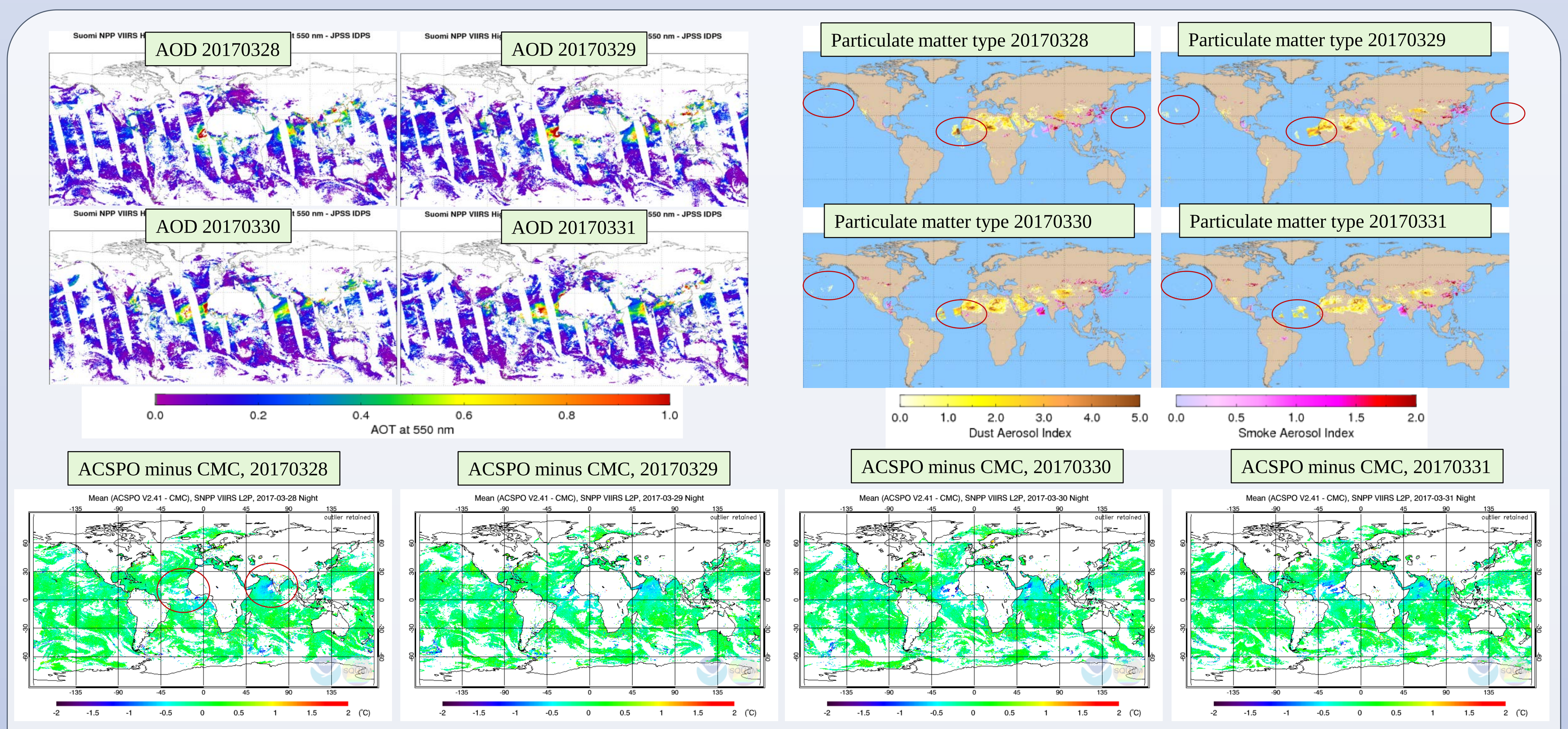
Dust Outflow during March 28-31 2017

VIIRS Aerosol Products (AOD and particulate matter type)

- A strong dust plume travels from West Africa to the Atlantic Ocean
- A moderate plume extends from Middle East/India to the Arabian Sea
- A weak plume travels from East Asia over the Pacific toward North America

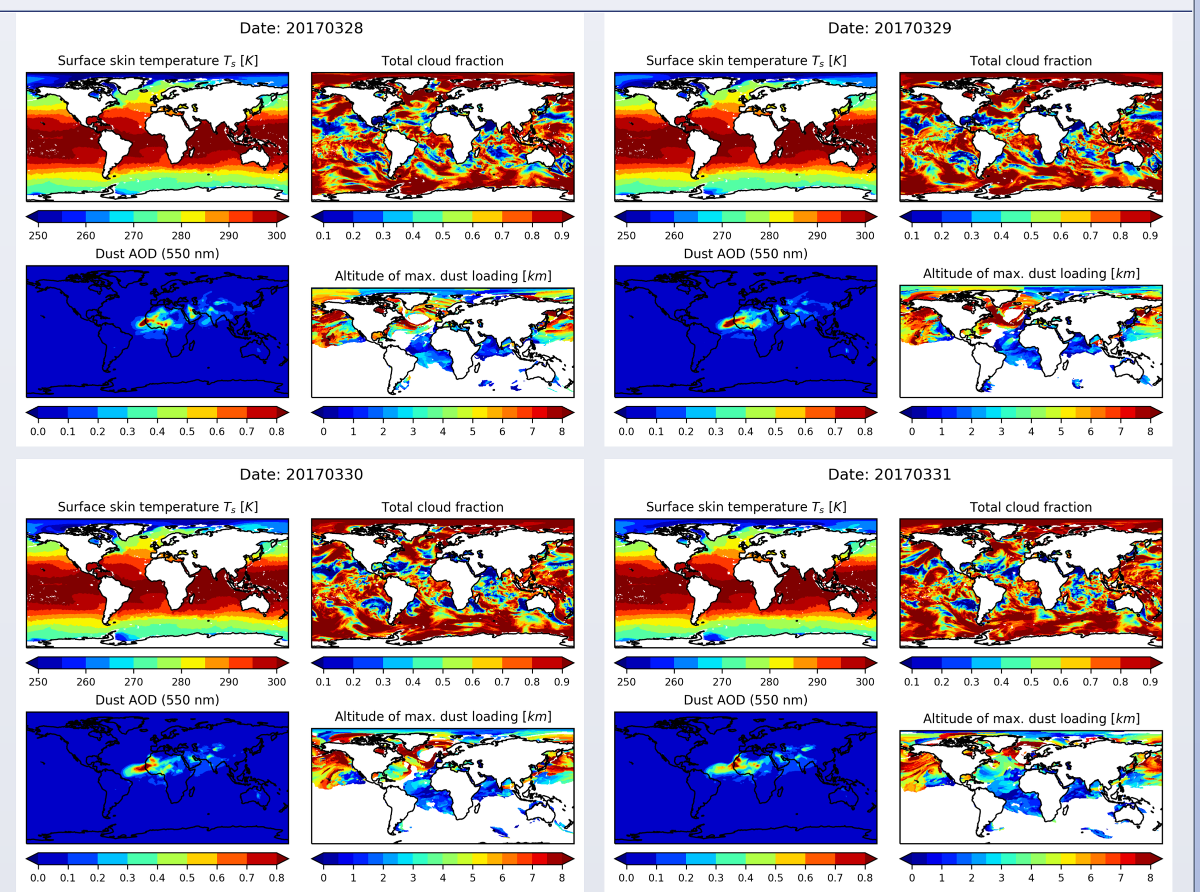
VIIRS ACSPO L2 SST Products (www.star.nesdis.noaa.gov/sod/sst/squam/) show

- Negative SST bias (up to -1.5 K) at dust outflow regions
- Strong plumes may be removed by cloud screening resulting in retrieval gaps

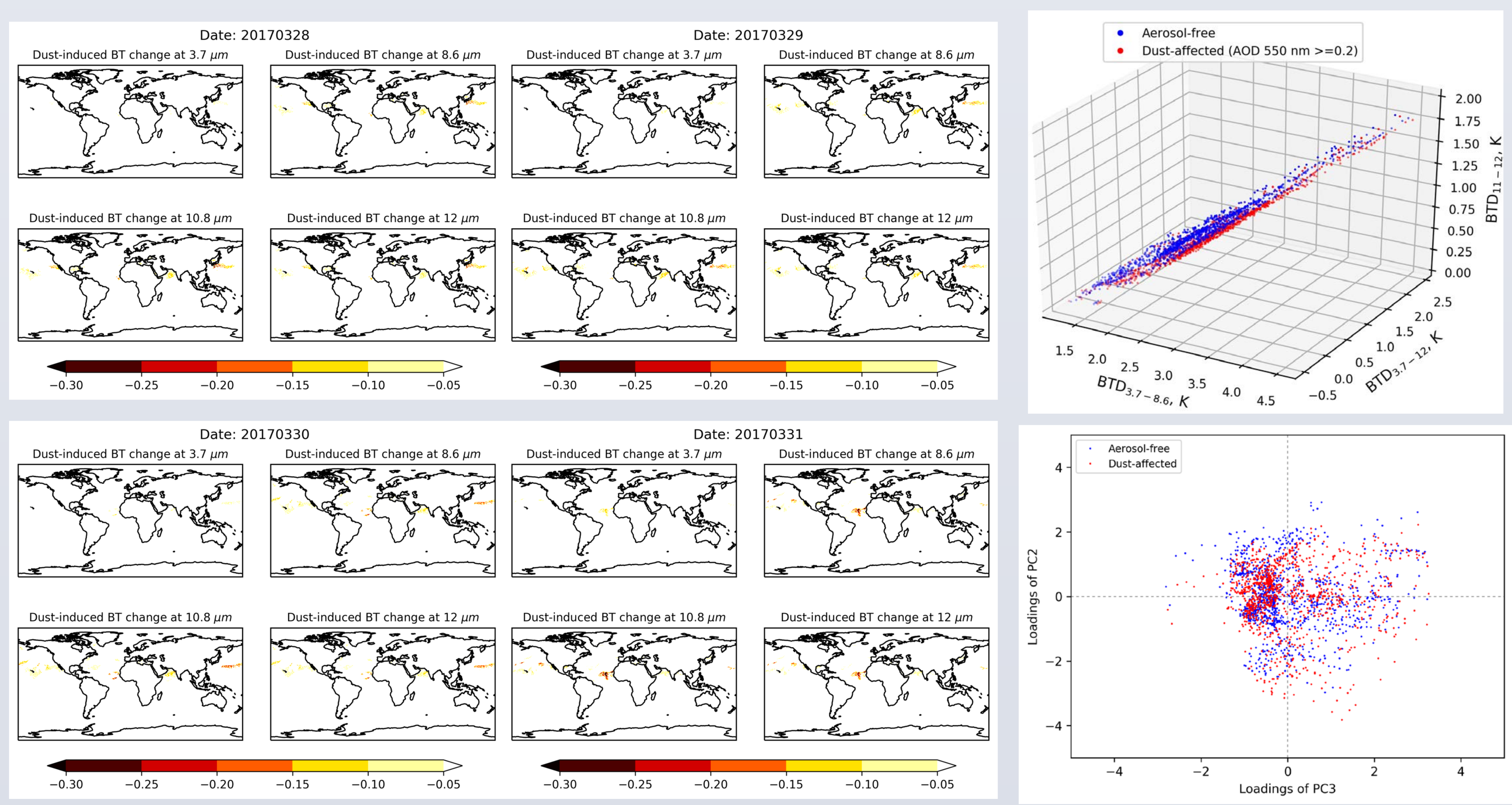


MERRA Daily Fields

- Simulated dust AOD captures the African and Asian dust plumes
- A total of **213,948** cloud-free (cloud fraction<0.2) profiles were selected
- SST bias depends on dust optical depth and vertical profile, which show contrasting conditions over the Atlantic and Pacific



Simulation of Dust Impact on the BT and SST



- Dust optical model is Mauritania/Cape Verde.
- BT suppressions for African and Asian dust outflows are comparable, even though the Asian AOD is much smaller. This is because Asian dust is located at higher altitudes.
- Aerosol-free simulations are distributed along a main axis of variability (99% variance) in the BTD space [BTD3.7-8.6, BTD3.7-12, and BTD11-12].
- Dust-affected simulations are displaced from the aerosol-free simulations.
- However, the preliminary principle component analysis (PCA) did not discriminate the dust signal, as suggested by prior studies by Merchant et al. [2006].

Future Work

- To develop physical correction for aerosols in the NOAA ACSPO system, the global atmospheric and aerosol reanalysis from MERRA2 are being incorporated to simulate brightness temperature deficits at major dust source downwind regions.
- Next step is to compare the BT simulations with the observed and CRTM-simulated aerosol-free BTs in the ACSPO VIIRS L2P product, in order to determine the extent to which the observed BT deficits are captured by RTM simulations.
- Developing physical correction to the aerosol biases in BT (as opposed to SST) simplifies the SST algorithm formulation, and potentially increase the number of valid pixels, which otherwise may be mistreated as clouds.
- Physical correction must work along with empirical correction (i.e. NOAA Single-Scanner Error Statistics, SSES) to achieve optimal results of SST accuracy against in situ data, as well as SST image quality.

References:

Di Biagio, C., et al. (2017), Global scale variability of the mineral dust long-wave refractive index: a new dataset of in situ measurements for climate modeling and remote sensing, Atmos. Chem. Phys., 17, 1901-1929, doi:10.5194/acp-17-1901-2017.

Merchant, C.J., Embury, O., Leborgne, P., & Bellec, B. (2006). Saharan dust in nighttime thermal imagery: Detection and reduction of related biases in retrieved sea surface temperature. Remote Sensing of Environment, 104(1), 15–30.

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