Impact of Dust Aerosols on Simulated Infrared Radiances within the Community Radiative Transfer Model (CRTM)

Naeger et al. (to be submitted, JGR)

Aaron Naeger[1], Clay Blankenship[2], Jayanthi Srikishen[2], Emily Berndt[3]

[1]University of Alabama at Huntsville / Earth Science System Center

[2]USRA Space Technology Institute (STI), Huntsville, AL, USA

[3]NASA Marshall Space Flight Center (MSFC), Huntsville, AL, USA

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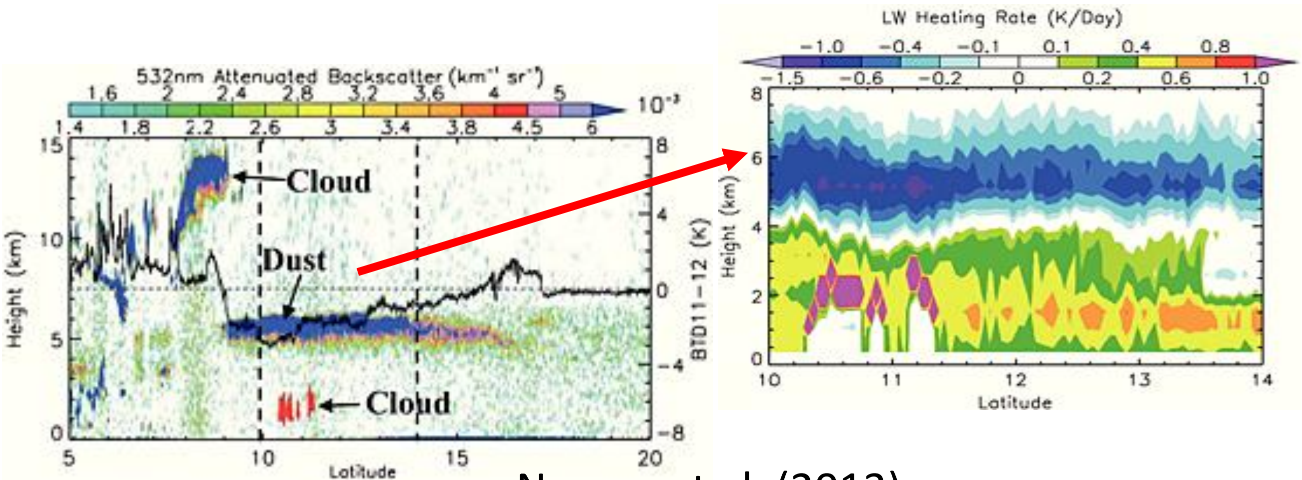
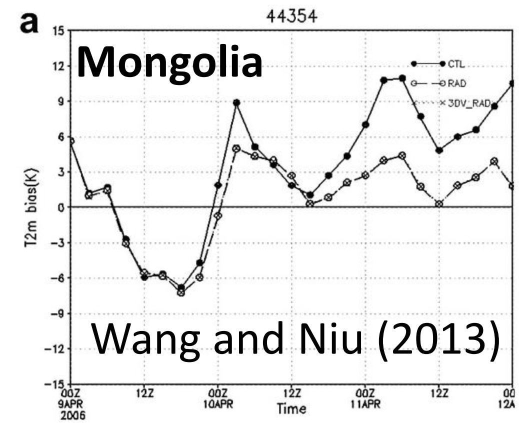
Motivation



Naeger et al. (2013)



Wang and Niu (2013)

- Coarse aerosols (dust) scatter and absorb terrestrial radiation, impact on satellite infrared radiances
- Aerosol-free conditions typically assumed when assimilating radiances into NWP models, which introduce biases in analysis fields and reduce forecast skill
- Modules accounting for aerosol impacts on radiation have been implemented into CRTM framework

Motivational Questions

1. **How well can current aerosol modules in the CRTM simulate the satellite infrared radiances of coarse mode 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

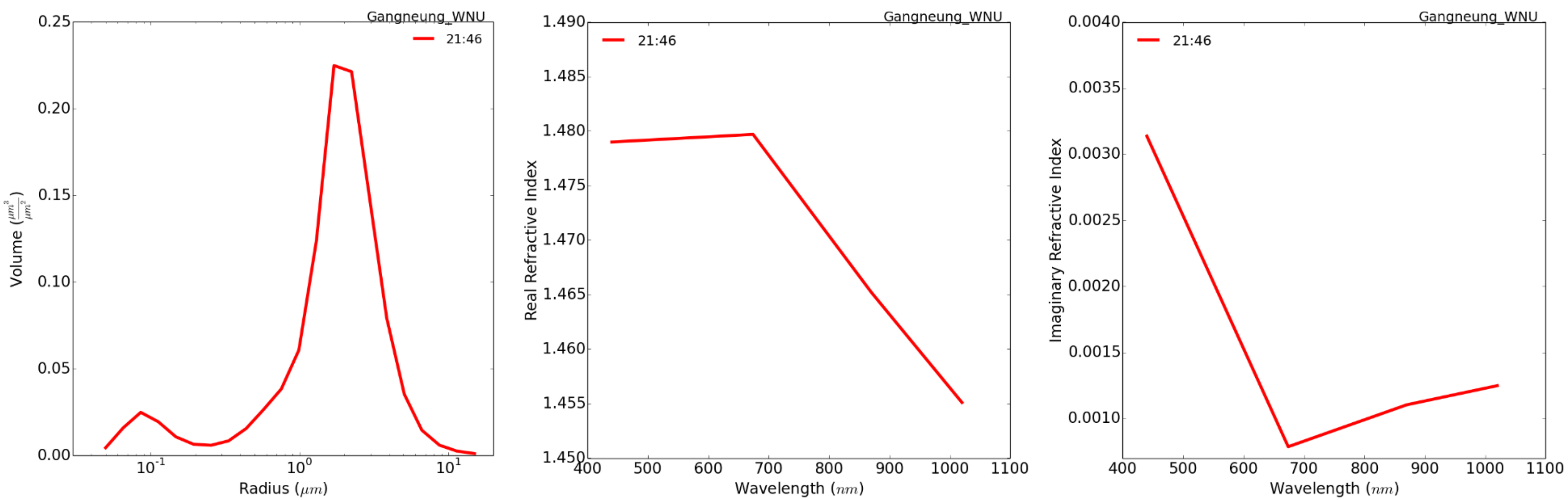
1. **Use quality-assured CALIOP and AERONET aerosol retrievals of dust storms along with meteorological reanalysis data for providing accurate vertical profiles into the Community Radiative Transfer Model (CRTM)**
2. **Validate simulated dust aerosol-affected infrared radiances against multiple satellite 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.

Dust Profiles for CRTM

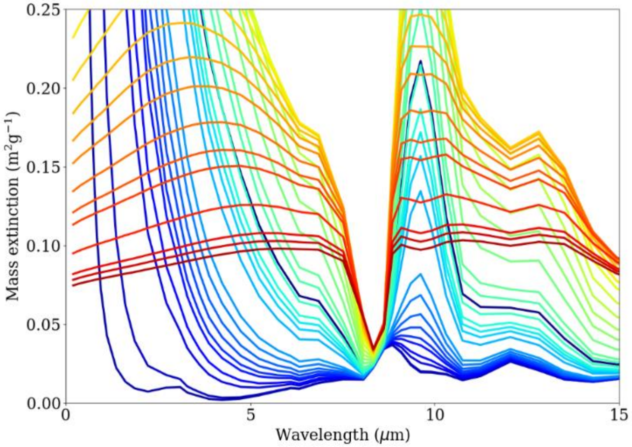
- CALIOP 532 nm AOD (τ) profiles are converted to mass concentration
- Use nearby AERONET retrievals and Mie code to calculate extinction efficiency (Q_E)
- Calculate mass concentration (M_d) profiles for input into CRTM

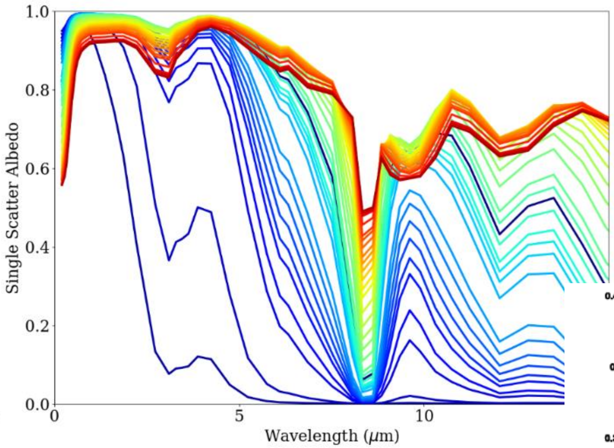
$$M_d = \frac{1.33 * \rho_d * \tau * r_e}{Q_E}$$

- AERONET provides columnar measurements; therefore, assume constant size distribution and effective radius (r_e) throughout the column

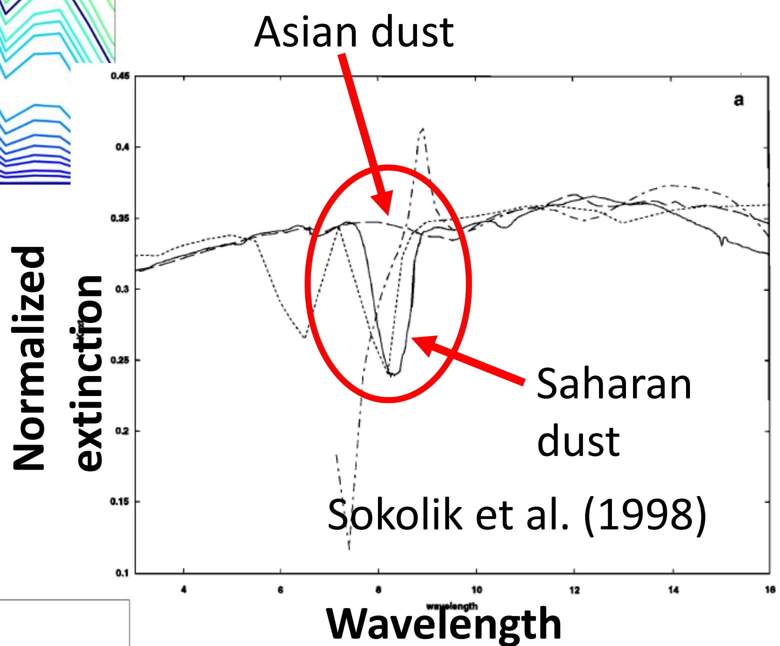


GOCART dust properties

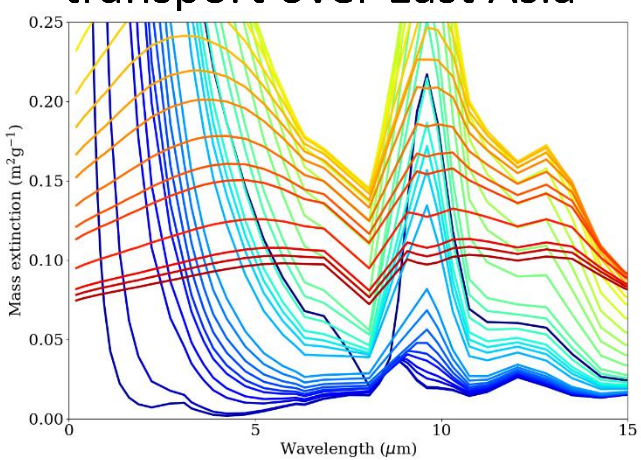


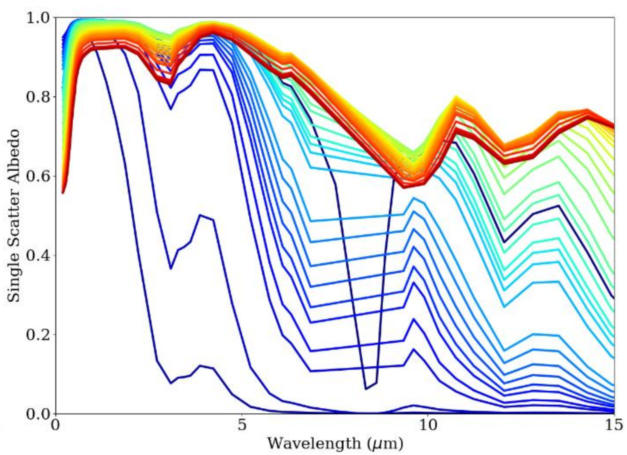


- **Prescribed dust properties within GOCART aerosol module**



- Previous work shows notable difference in extinction between Asian and Saharan dust near 8 µm
- Asian dust particles become coated with pollution aerosols (sulfate, nitrate) during transport over East Asia

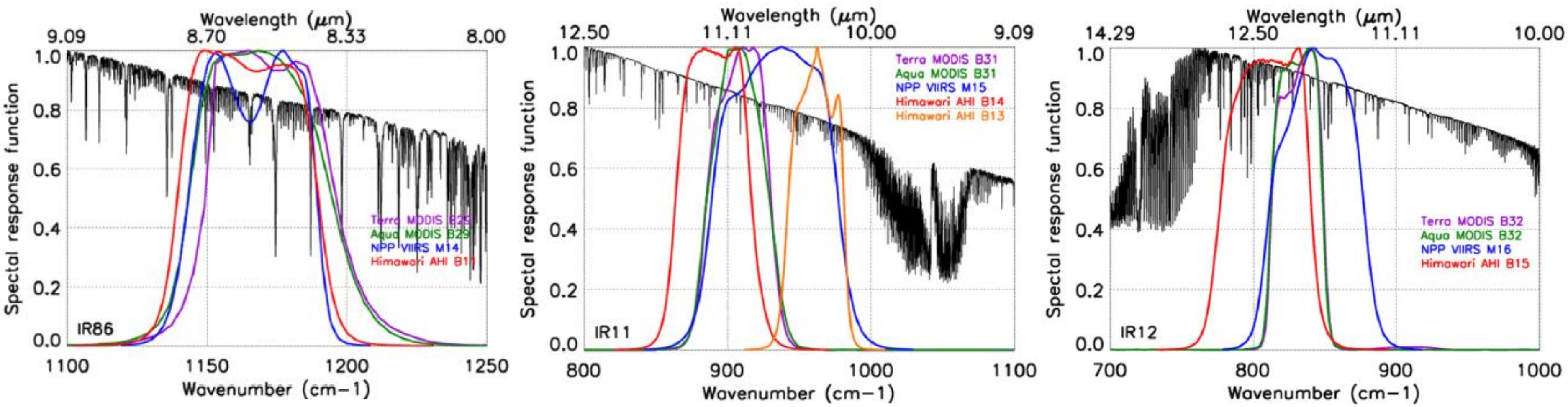




- **Modified dust properties within GOCART aerosol module**

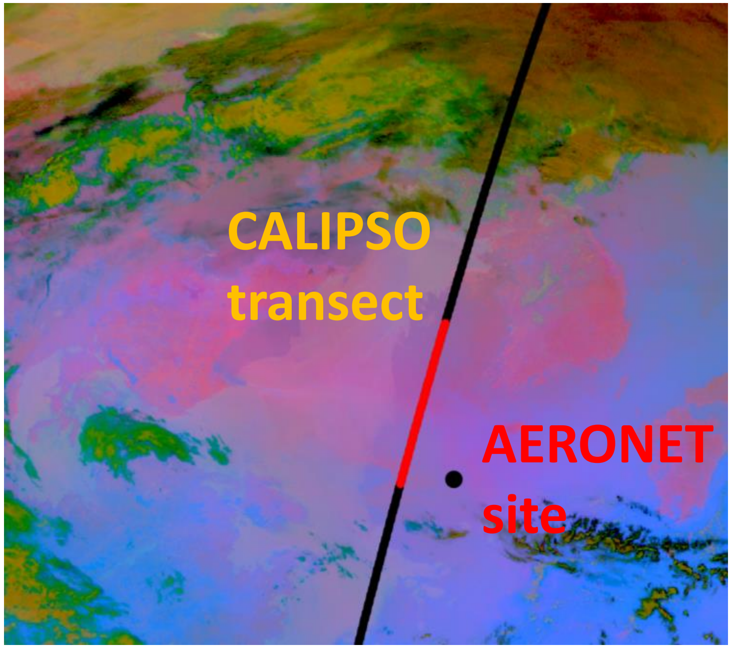
Infrared bands

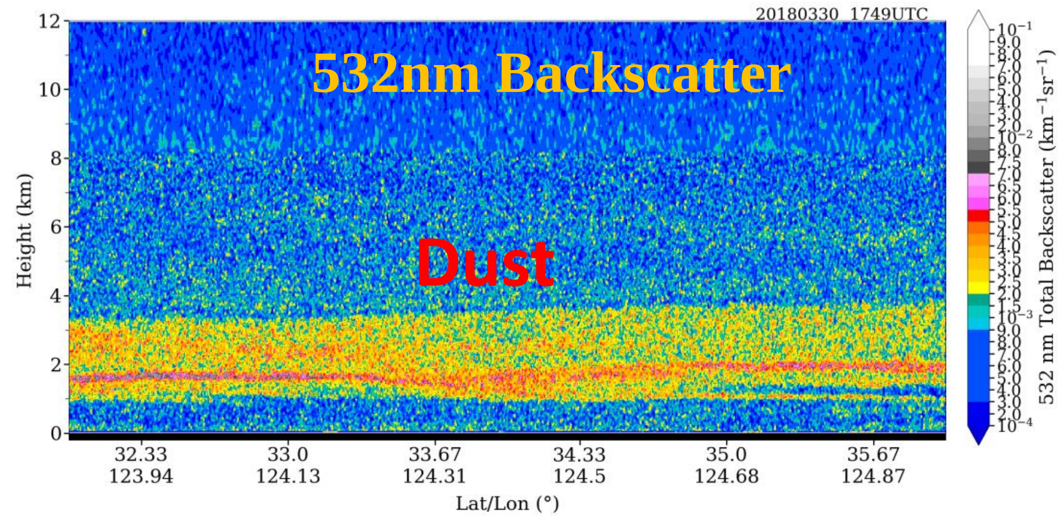
Band Name	AHI			VIIRS			MODIS		
	B	CW (μm)	SR (μm)	B	CW (μm)	SR (μm)	B	CW (μm)	SR (μm)
IR37	7	3.85	3.59–4.11	M12	3.70	3.66–3.84	20	3.75	3.66–3.84
IR86	11	8.60	8.12–9.07	M14	8.58	8.40–8.70	29	8.55	8.40–8.70
IR10	13	10.45	9.90–10.96						
IR11	14	11.20	10.31–12.18	M15	10.73	10.26–11.26	31	11.03	10.78–11.28
IR12	15	12.35	11.17–13.66	M16	11.85	11.54–12.49	32	12.02	11.77–12.27

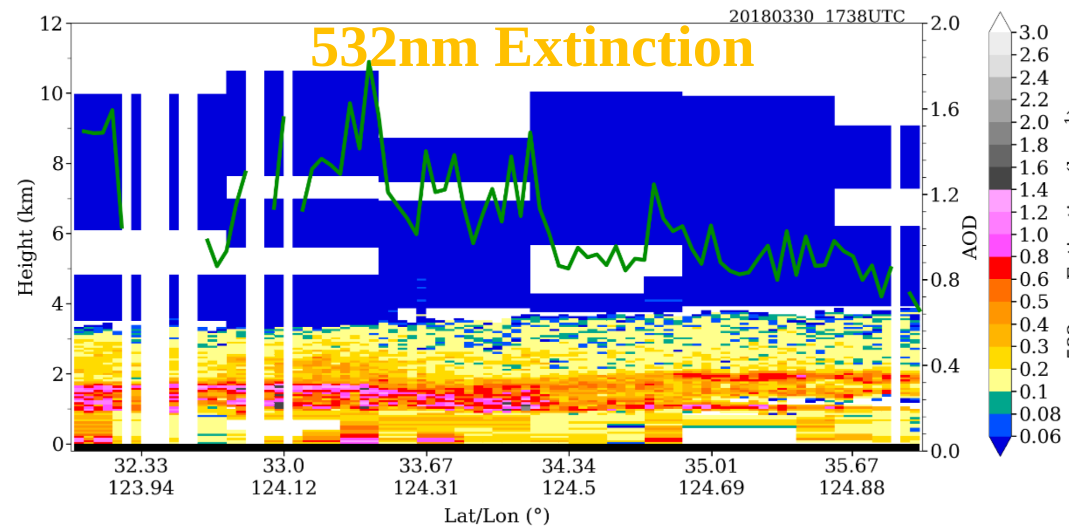


- We focus on infrared bands between 8 and 12.5 µm onboard AHI, VIIRS, and MODIS, which can be impacted by coarse mode dust particles
- JMA AHI gridded L1B data at 5 km spatial resolution is used here, along with VIIRS and MODIS at 0.75 and 1 km resolution, respectively

Asian Case – 30 March 2018



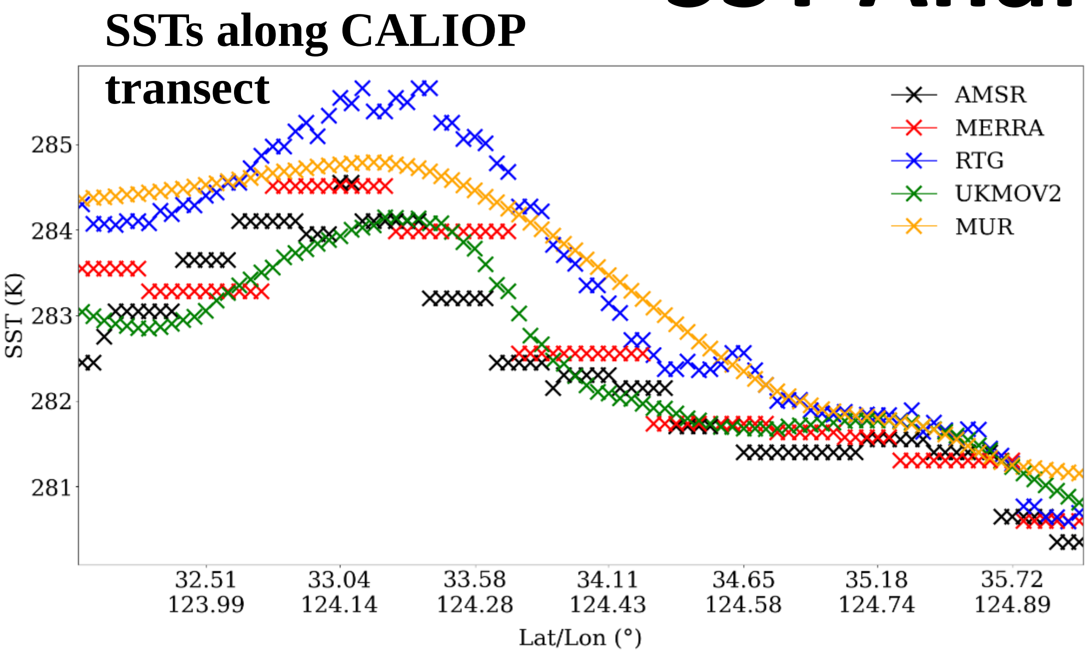




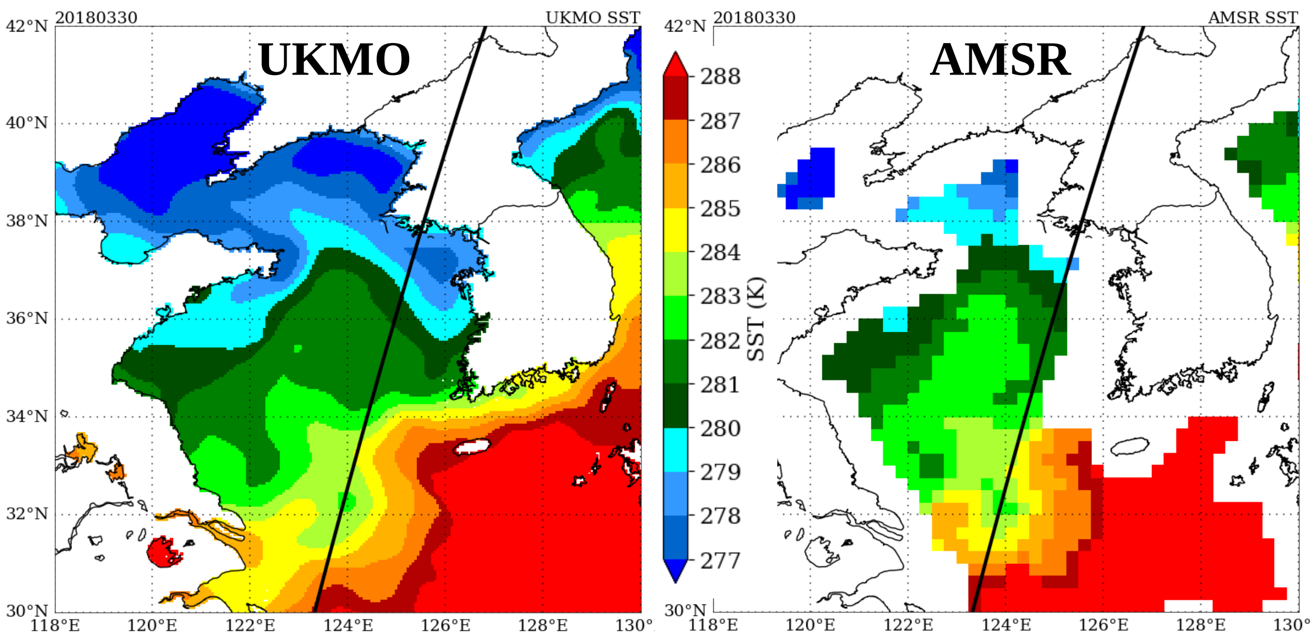
- Nighttime CALIOP measures a lofted dust plume over the Yellow Sea
- Nearby AERONET sites provide high-quality aerosol retrievals
- CALIOP L2 profile retrievals for aerosol input and MERRA2 reanalysis for meteorology

- Update SSTs after careful analysis of SST retrievals/products

SST Analysis

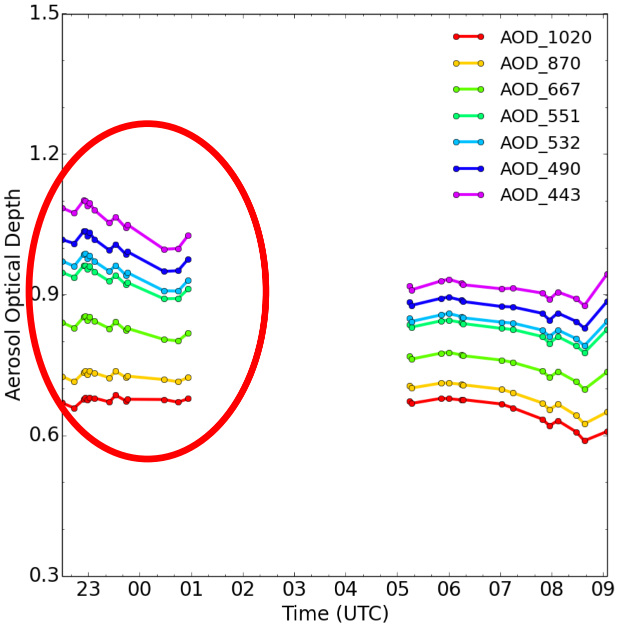


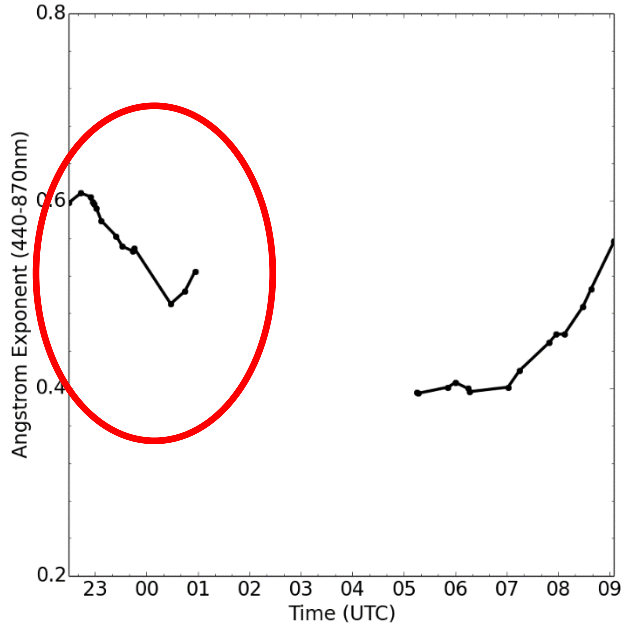
- SSTs are critical input, especially over Yellow Sea and Sea of Japan where known SSTs biases of up to 3°C have been found (Kwak et al. 2015)

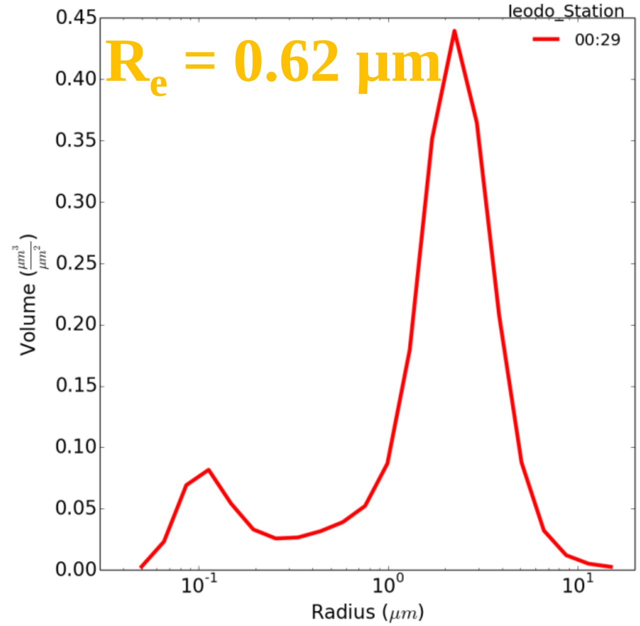


- SST retrievals from microwave sensors are more reliable in dusty regions, longer wavelengths are unaffected by dust (Nalli and Reynolds, 2016)
- AMSR SST retrievals are used as our benchmark

AERONET retrievals



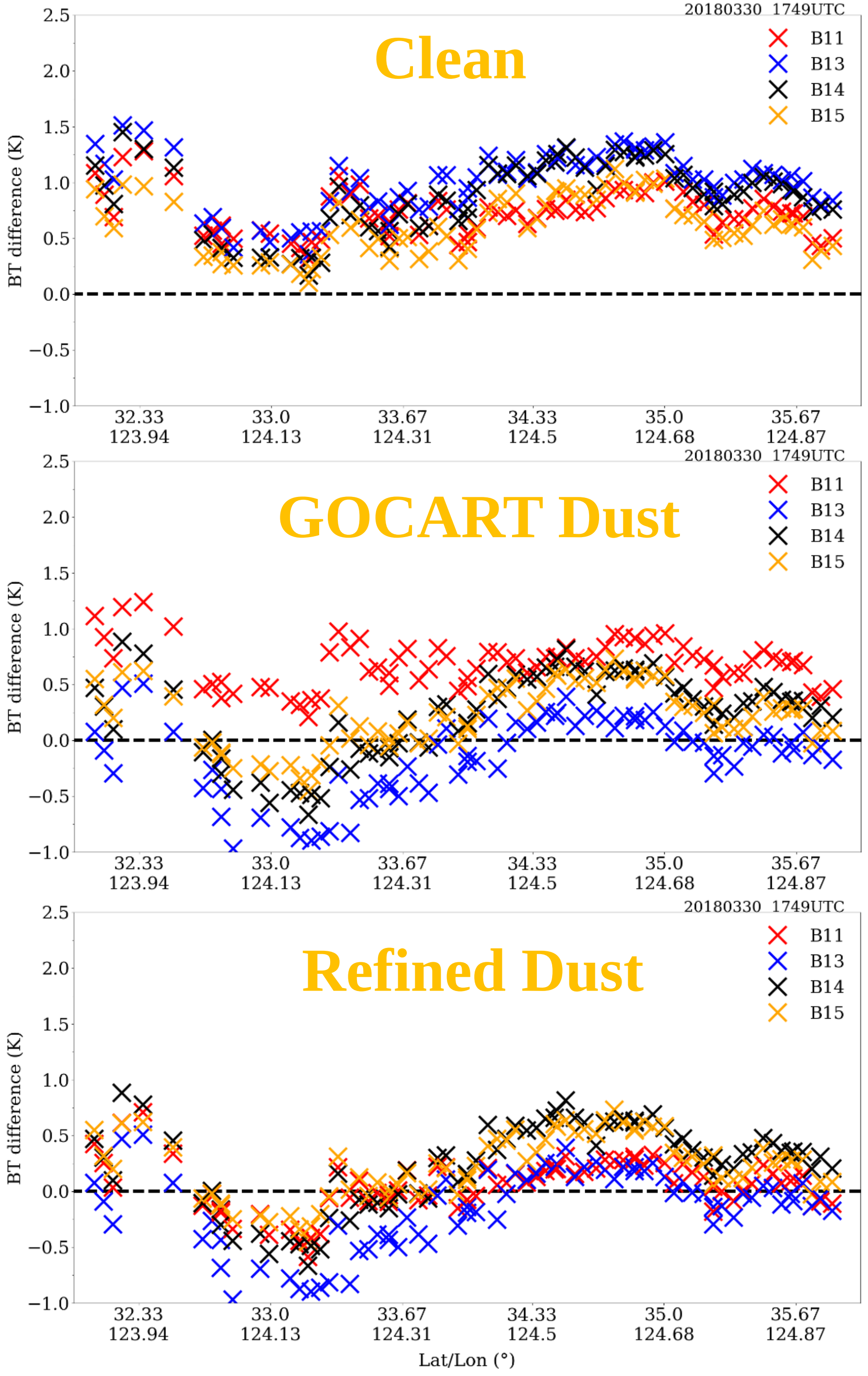




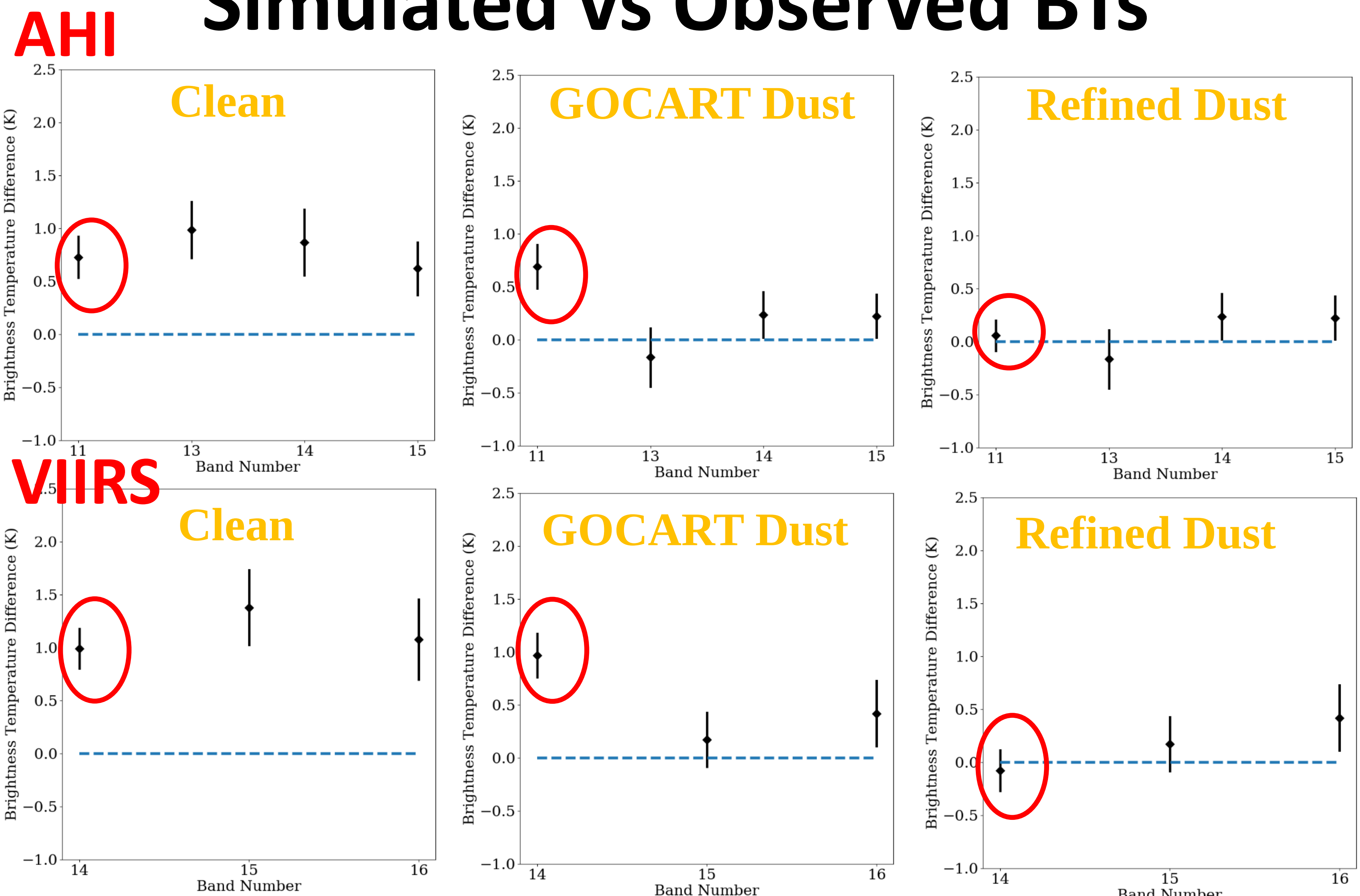
- AOD at 532 nm from AERONET site is about 0.9, which is well within range of CALIOP AOD along transect.
- Angstrom exponent decreasing to 0.5 indicates dominance of coarse mode particles (dust)
- Volume size distribution shows strong coarse mode presence, along with much weaker accumulation mode
- Clear signal of dust aerosols over AERONET site

Simulated AHI vs Observed BTs

- Run CRTM with clean and dusty profiles, along with same meteorology from MERRA
- Use high-resolution UK Met SST product (L4 OSTIA) due to close comparison to AMSR SSTs
- Simulated AHI BTs are overestimated when not accounting for dust
- Improved comparison to observed BTs when using GOCART dust properties, except at 8.6 µm
- Refined dust properties significantly improve comparison at 8.6 µm

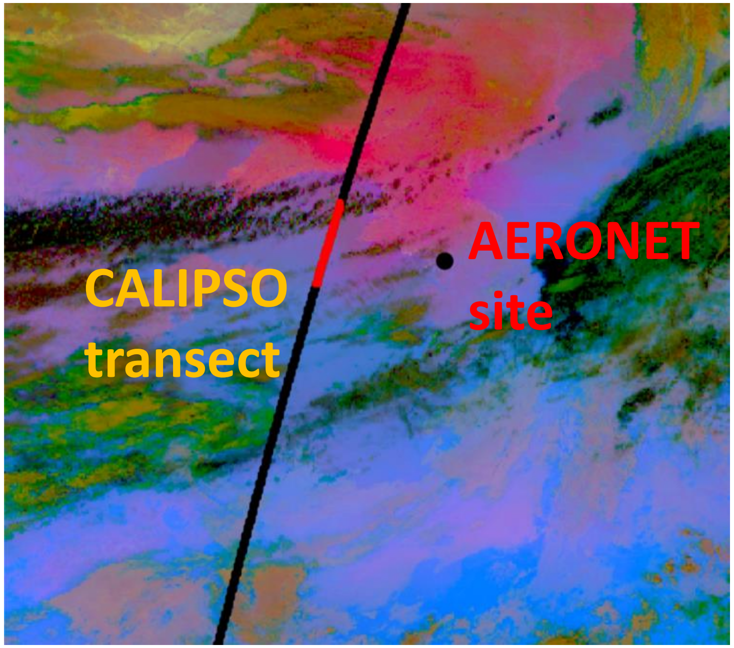


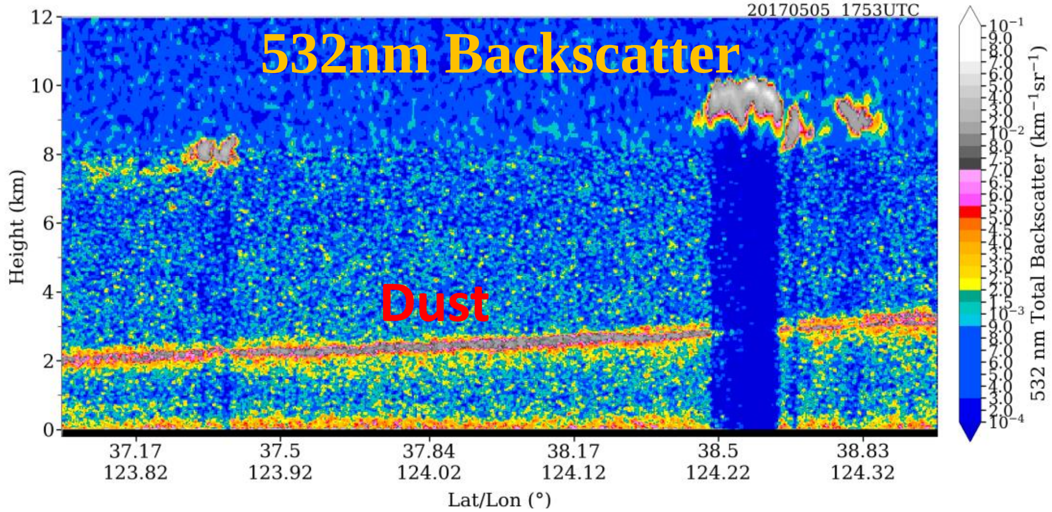
Simulated vs Observed BTs

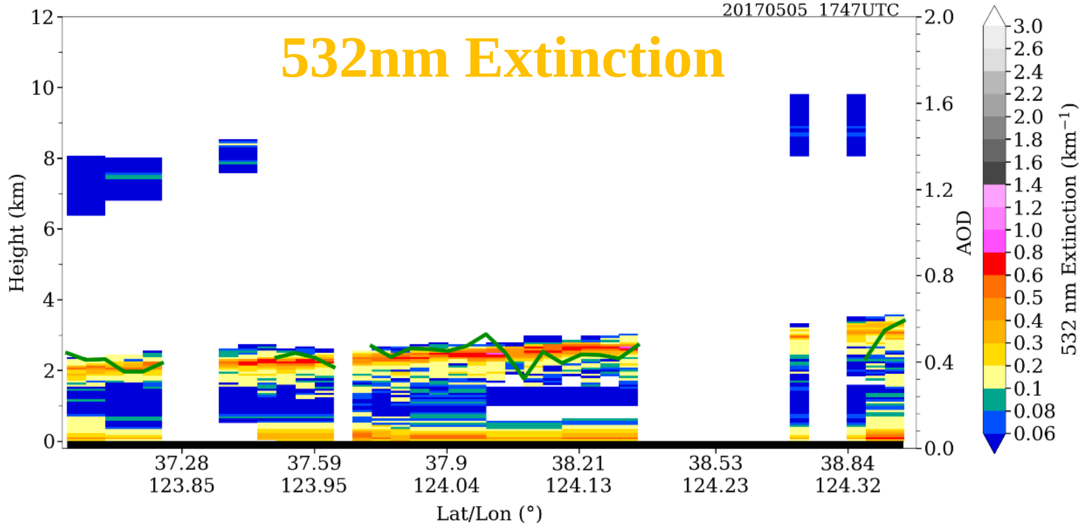


- AHI VZA ~44°, VIIRS VZA ~58° … VIIRS high VZA likely contributing to larger BT differences

Asian Case – 05 May 2017



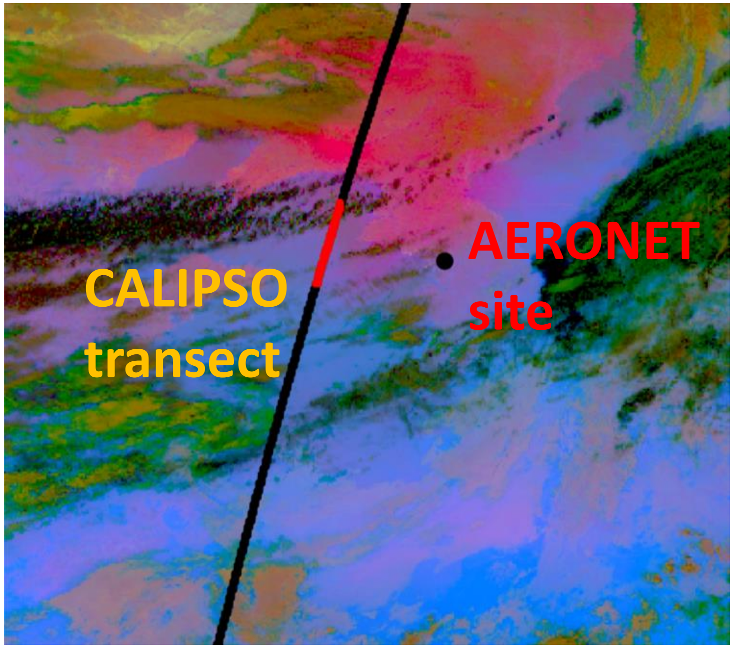


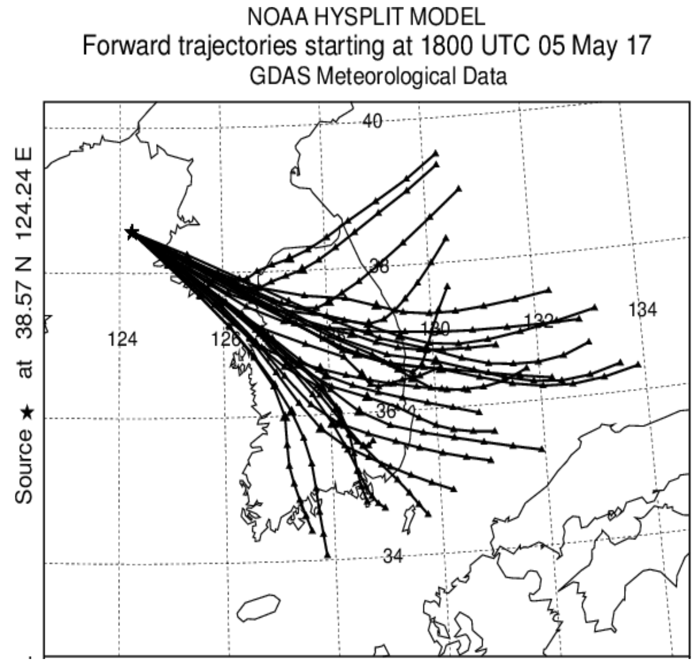


- Nighttime CALIOP measures a lofted dust plume over the Yellow Sea
- AERONET site is downwind of CALIOP transect
- CALIOP aerosol profiles, UKMO SSTs, and MERRA meteorology for CRTM input

- Can cases with more space/time discrepancies be applied within this validation framework?

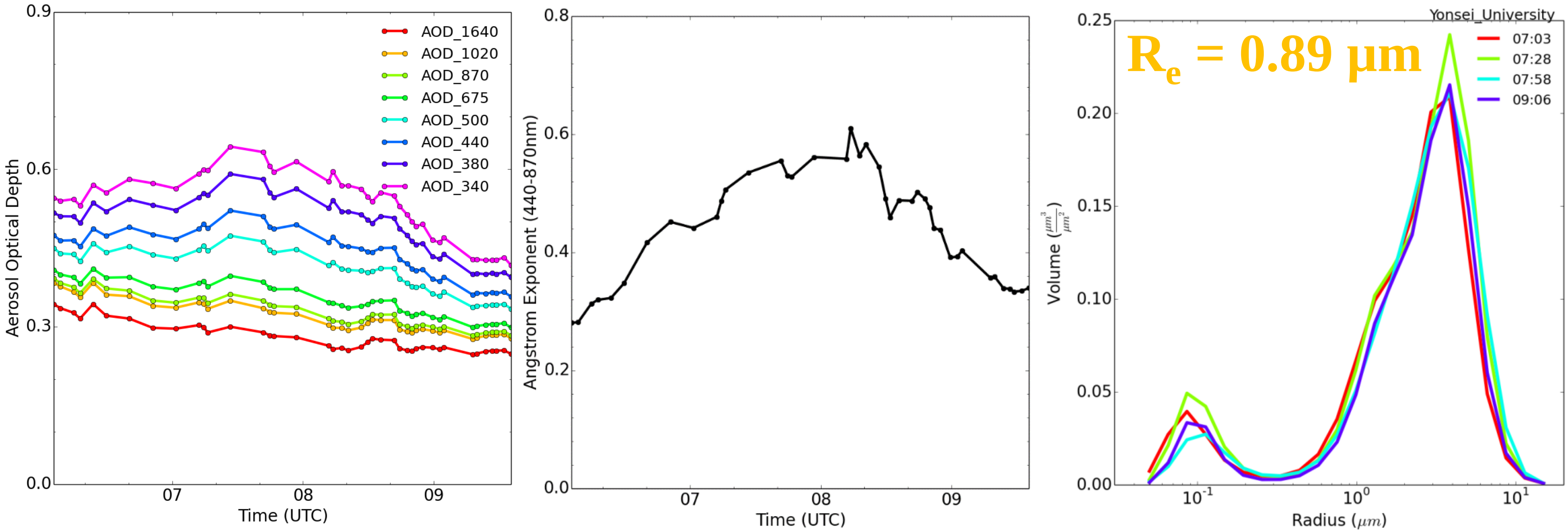
Asian Case – 05 May 2017





- NOAA HYSPLIT trajectories initiated at dust location along CALIOP transect show the dust plume being transported over the Korean Peninsula
- Available AERONET site is within ensemble of trajectory paths from HYSPLIT

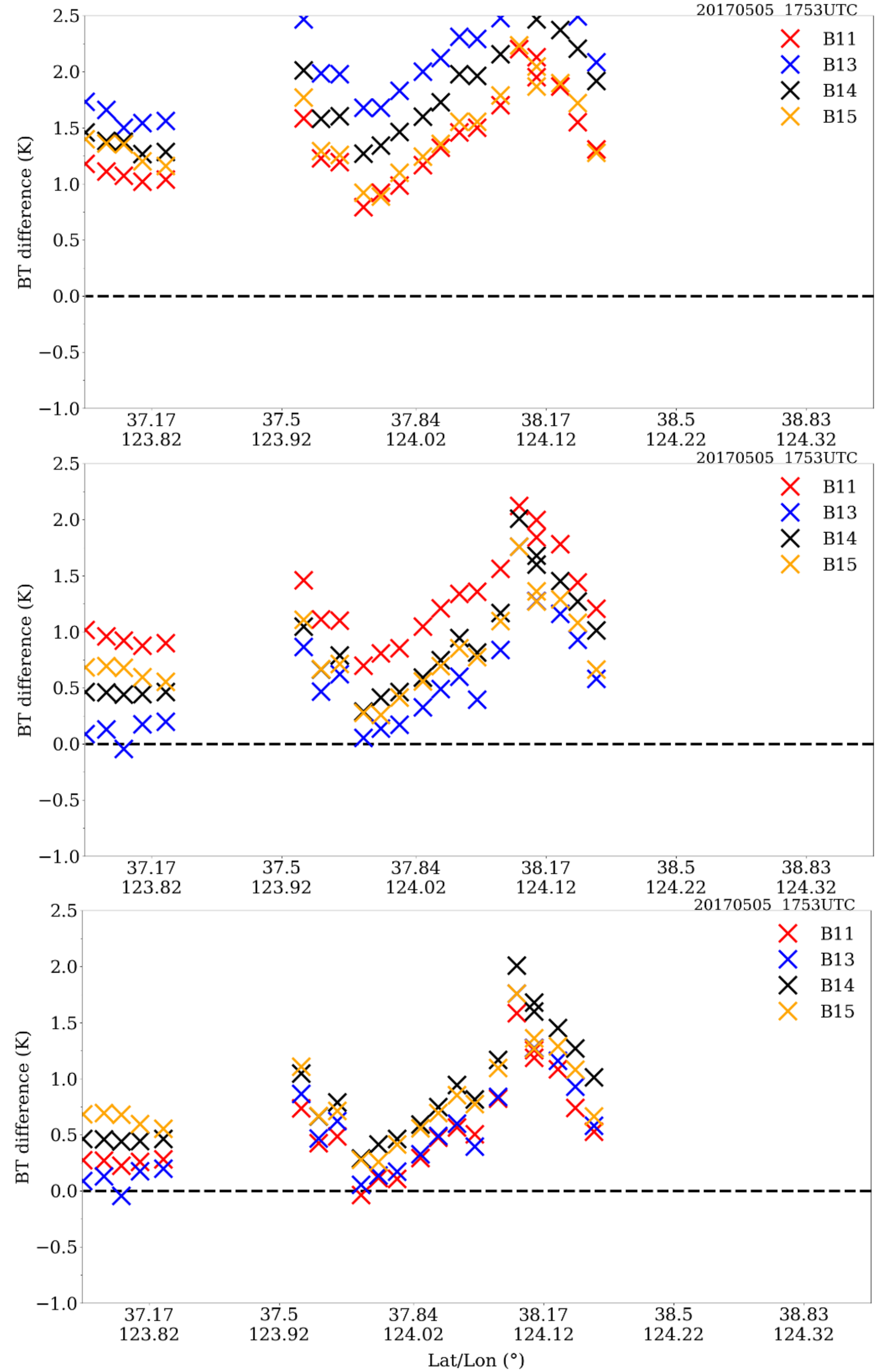
AERONET retrievals



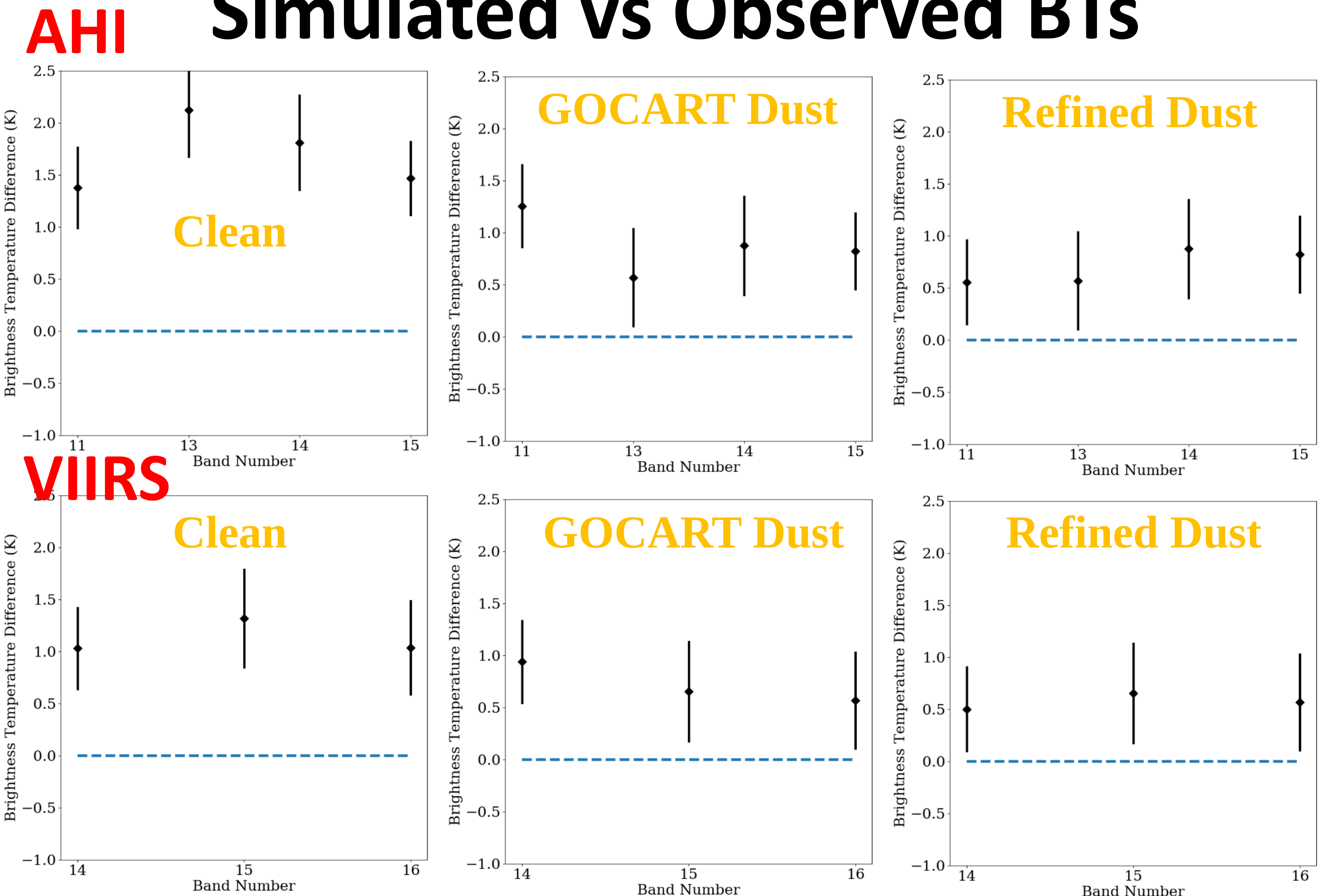
- AOD at 532 nm from AERONET site is about 0.45, which is on the lower end of the CALIOP AOD retrievals along the transect
- Similar Angstrom exponent and volume size distribution as 30 March 2018 case, except that AE is slightly lower and coarse mode peak shifted to larger radius values
- AERONET volume size data likely represents lower bound of the dust environment observed by CALIOP
- Lower AOD but larger dust particles compared to 30 March 2018 case, and strongest dust signal at higher altitude than 30 March

Simulated AHI vs Observed BTs

- Stronger overprediction in BTs than previous case
- Larger particle size playing critical role in reducing observed BTs
- Closer comparison between simulated and observed BTs when accounting for dust, especially refined dust module
- Possible too small R_e from AERONET site due to space/time discrepancies

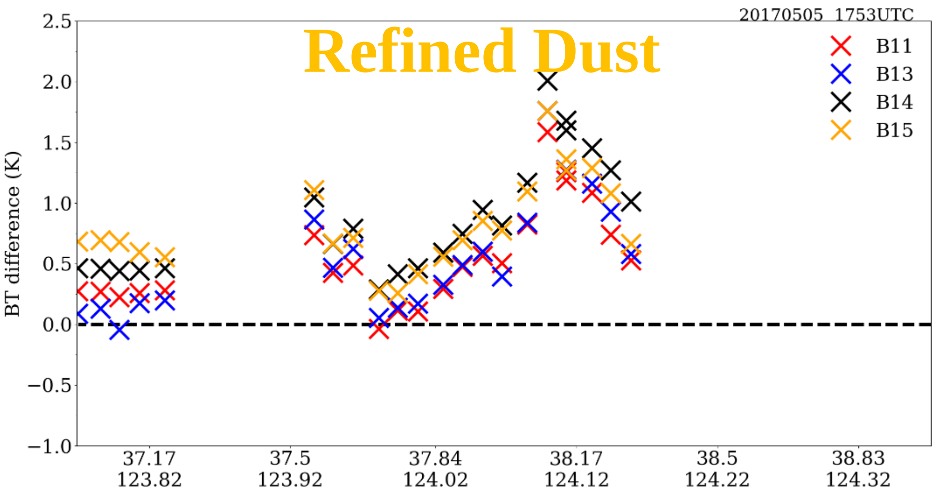


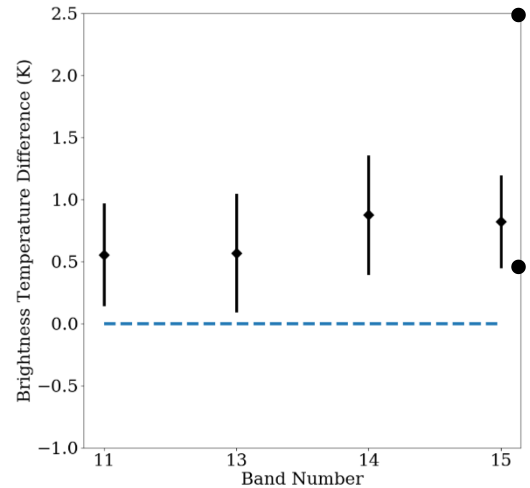
Simulated vs Observed BTs

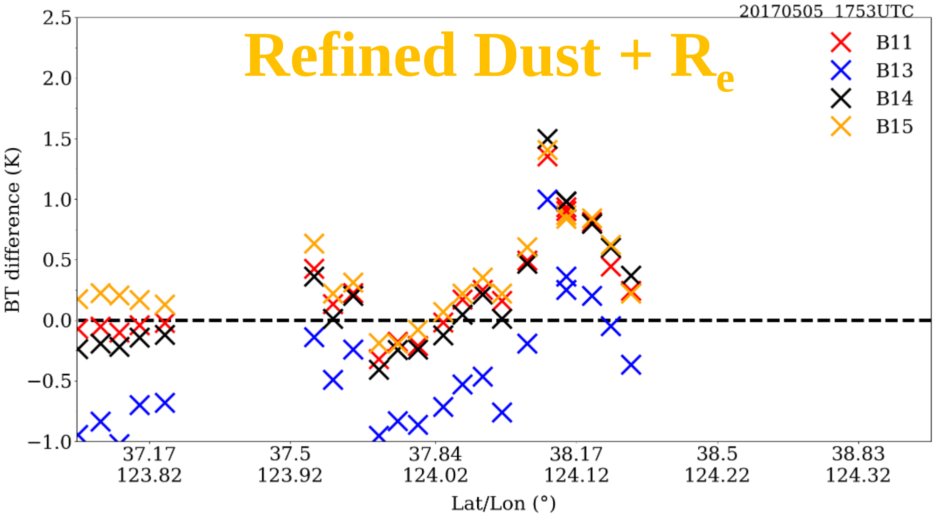


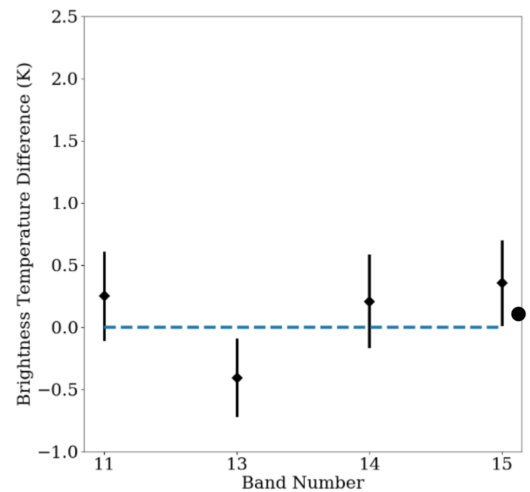
- AHI VZA ~46°, VIIRS VZA ~15°

Sensitivity Analysis



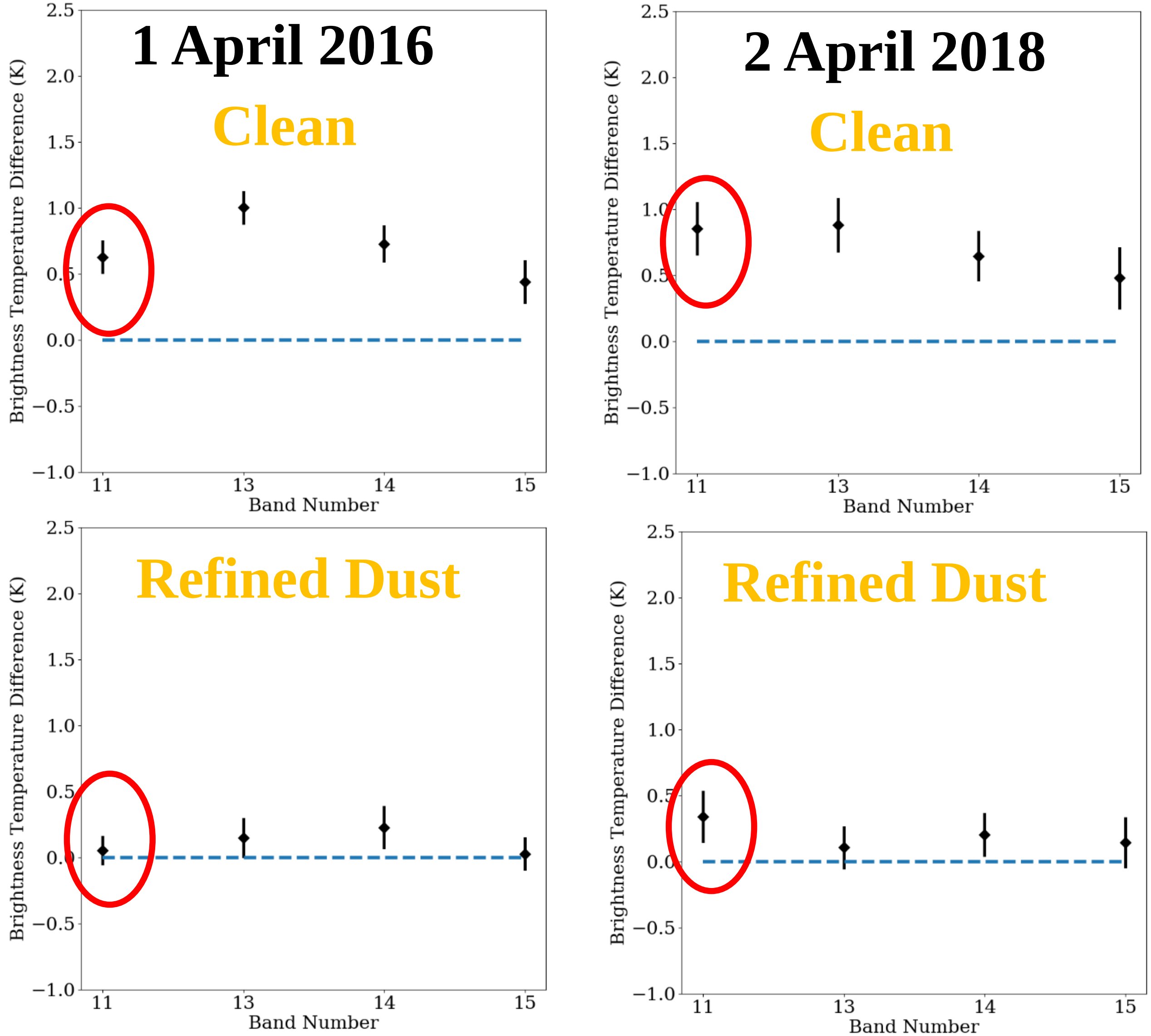






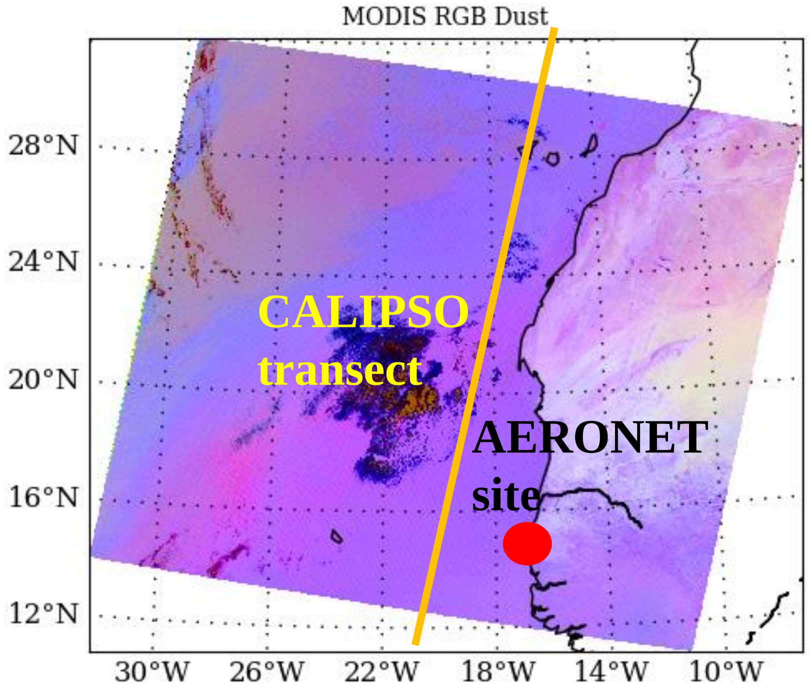
- Sensitivity run applying 30% increase in R_e (1.16 μm)
- Based on AERONET site being downwind of CALIOP transect and 30% uncertainty in AERONET retrievals
- Simulated BTs mostly within ±0.5 K of observations for larger R_e
- Strong sensitivity to R_e so realistic values are critical for validation analysis

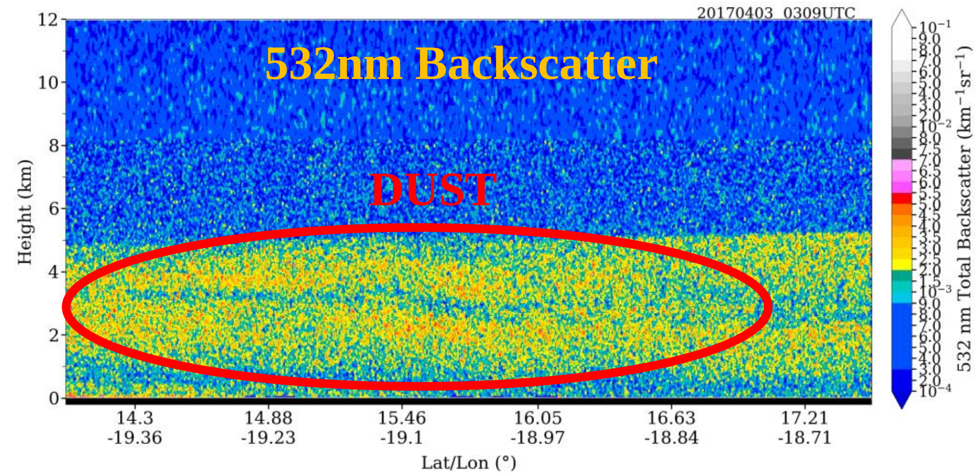
Additional Asian Dust Cases

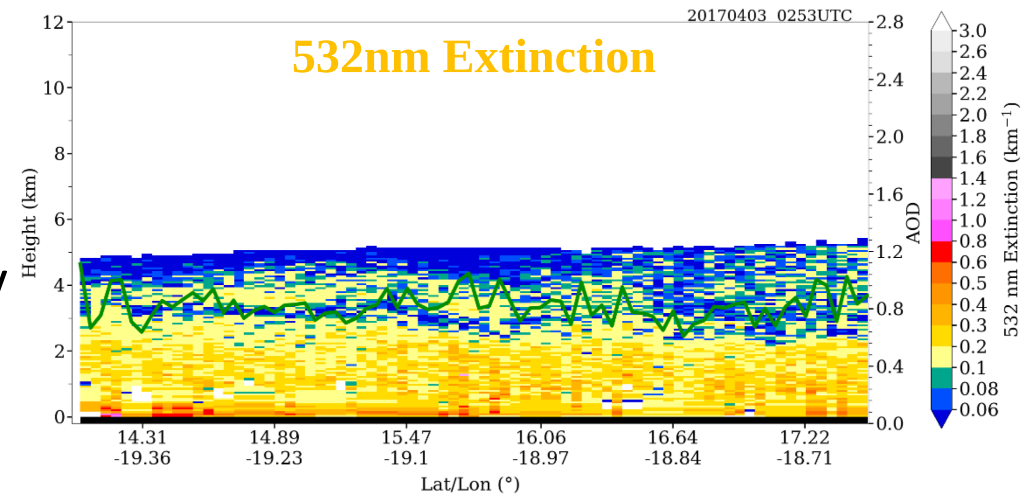


- Cases further highlight the improvement at 8.6 μm using the refined GOCART dust module

Saharan Case – 3 April 2017

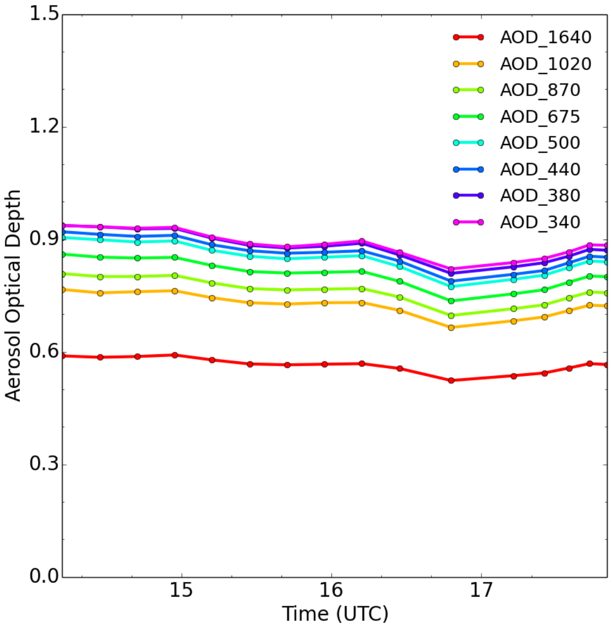


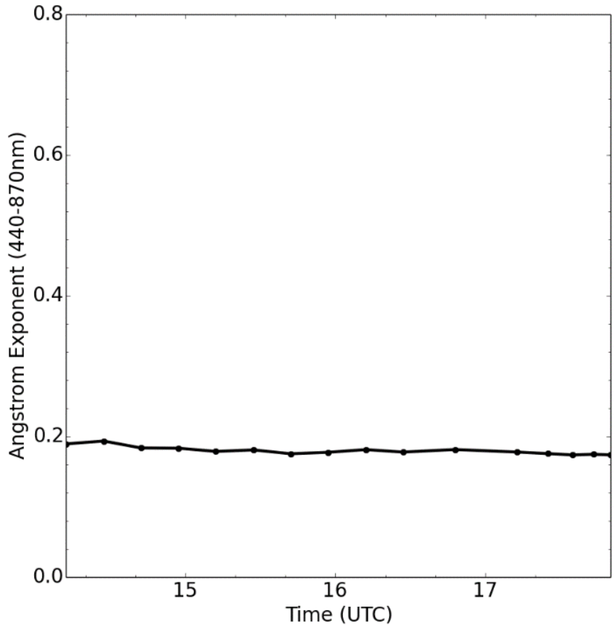


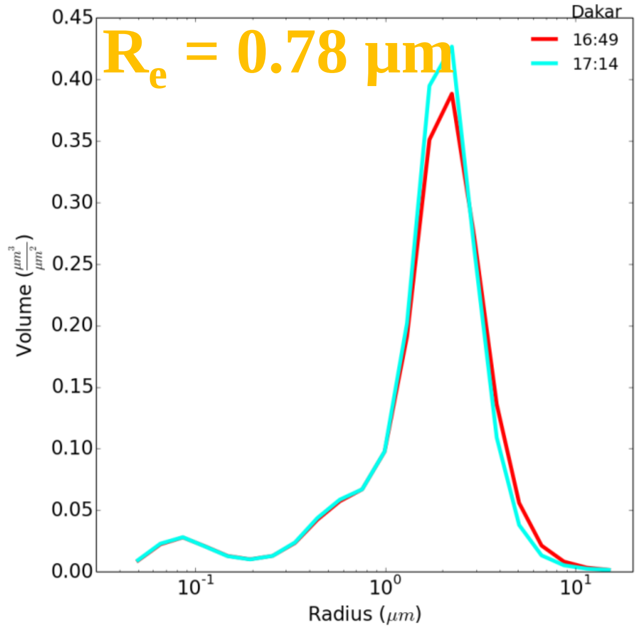


- Optically thick dust plume measured by CALIOP observed by nearby AERONET site
- More elevated, optically thicker dust plume than Asian cases
- Compare simulated and observed BTs from VIIRS and MODIS

AERONET retrievals

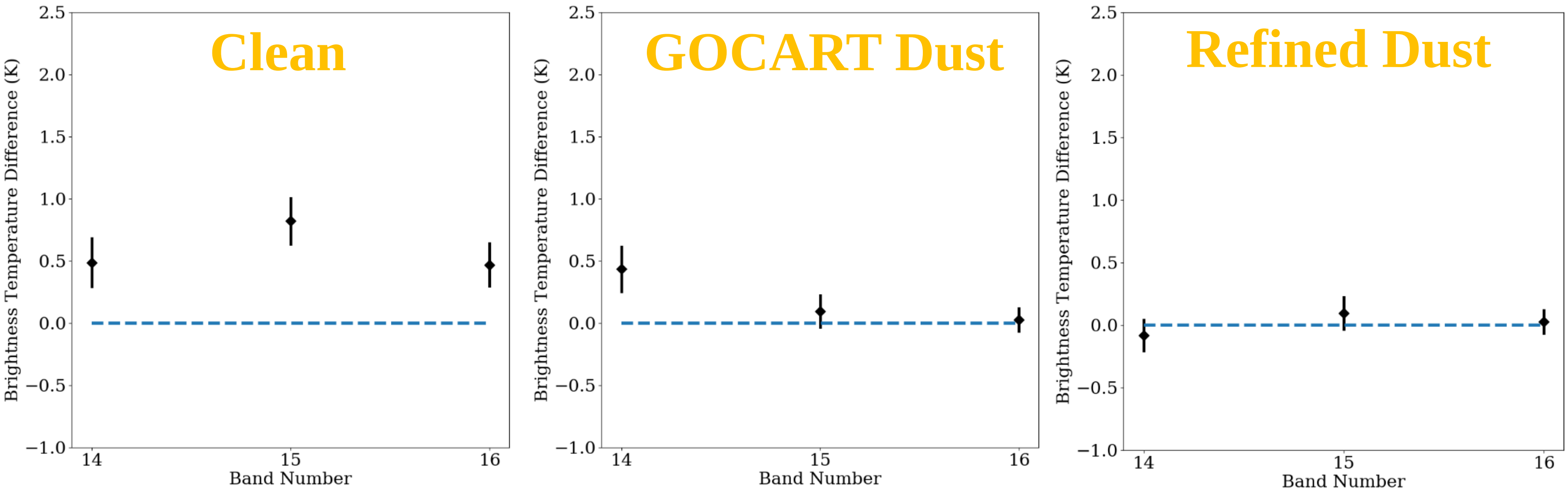






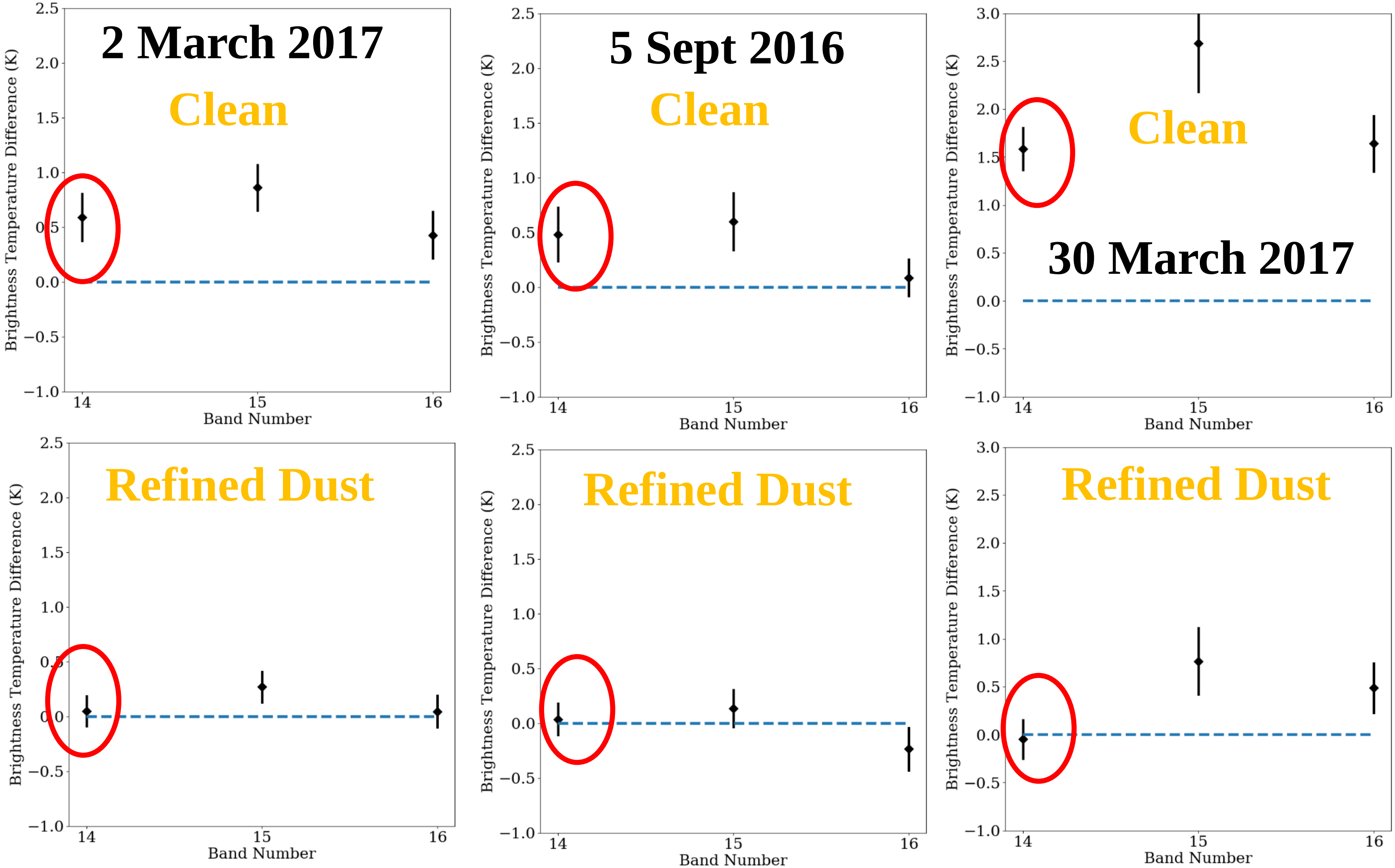
- AOD at 532 nm from AERONET site is about 0.9, which is in good agreement with the CALIOP AOD
- Similar Angstrom exponent and volume size distribution as 30 March 2018 case, except that AE is slightly lower and coarse mode peak shifted to larger radius values

Simulated vs Observed VIIRS BTs



- GOCART dust properties promote more accurate simulated VIIRS BTs at 10.7 and 11.85 µm
- Refined GOCART dust properties also lead to more realistic simulated VIIRS 8.6 µm BTs for Saharan dust

Additional Saharan Dust Cases



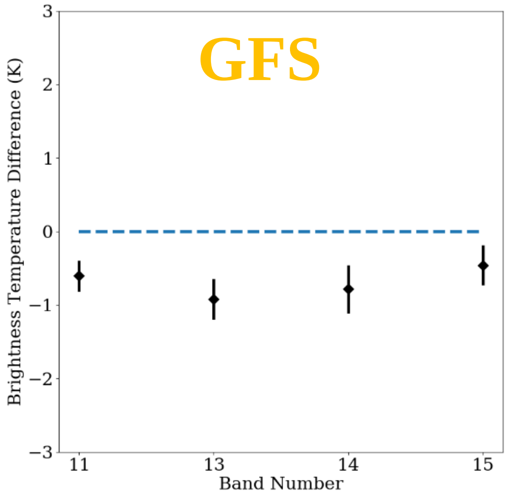
- Cases further highlight the improvement at 8.6 μm using the refined GOCART dust module

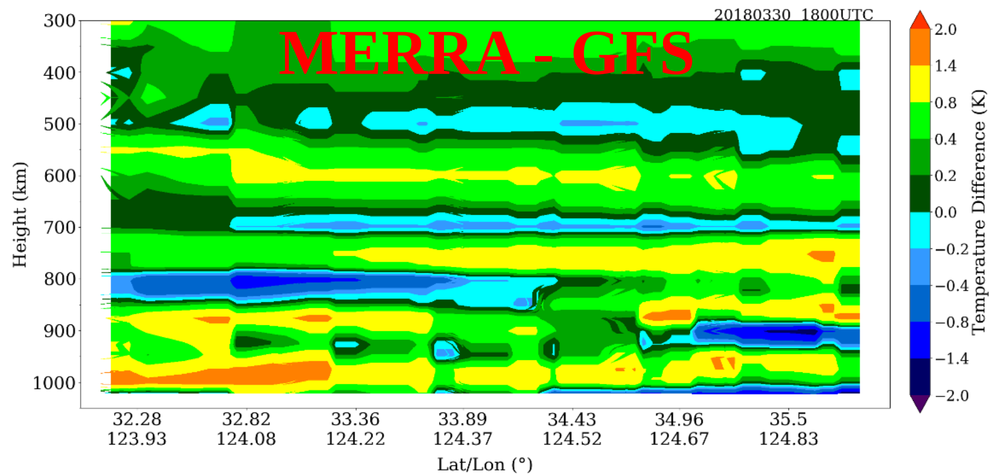
Summary and Future Work

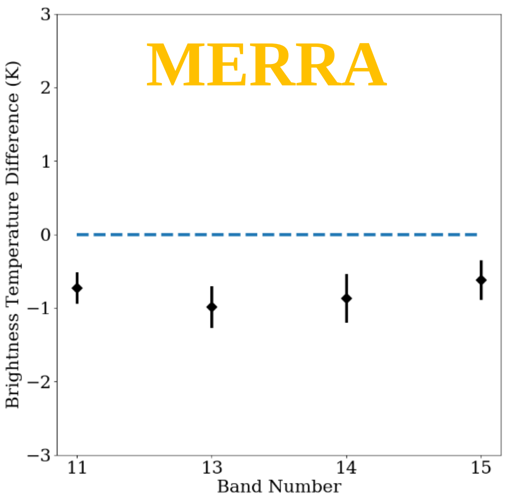
- We provide realistic CALIOP aerosol vertical profiles as input into the CRTM, which leads to an overall better agreement between the simulated and observed VIIRS, MODIS, and AHI infrared BTs when compared to assuming pristine conditions.
- However, the 8.6 µm band shows a notable warm bias in the simulated BTs even when accounting for realistic aerosol information within dust plumes
- Our refined dust properties within the GOCART reduces the warm bias at 8.6 µm for Asian and Saharan dust.
- We plan to extend this work to assess the impact of dust aerosols on hyperspectral measurements from CrIS.
- Upcoming results on impact of aerosol-affected infrared radiance assimilation on model analysis and forecast fields using the GEOS-5 framework.

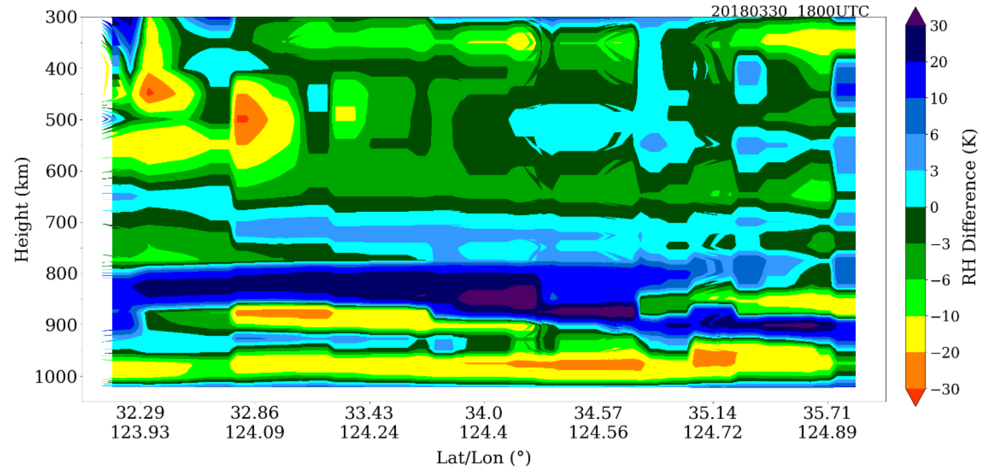
Backup slides

Sensitivity Analysis – Asian Case



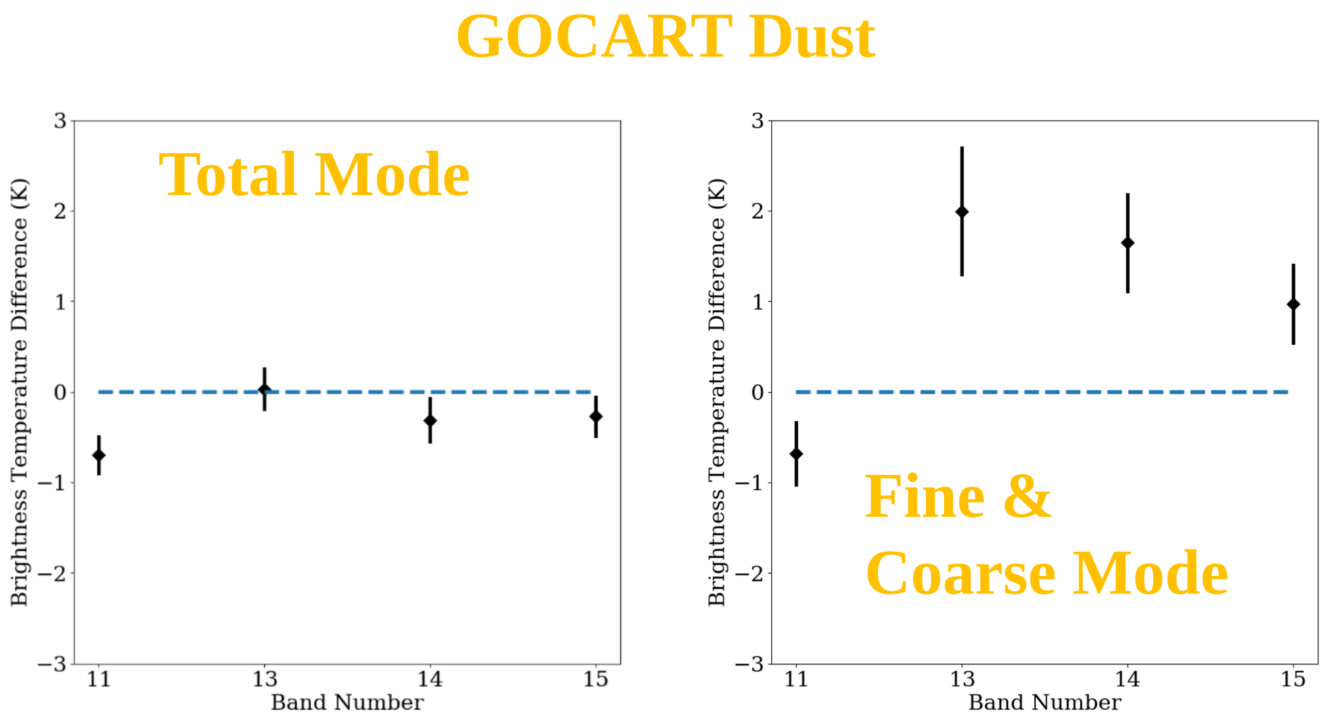






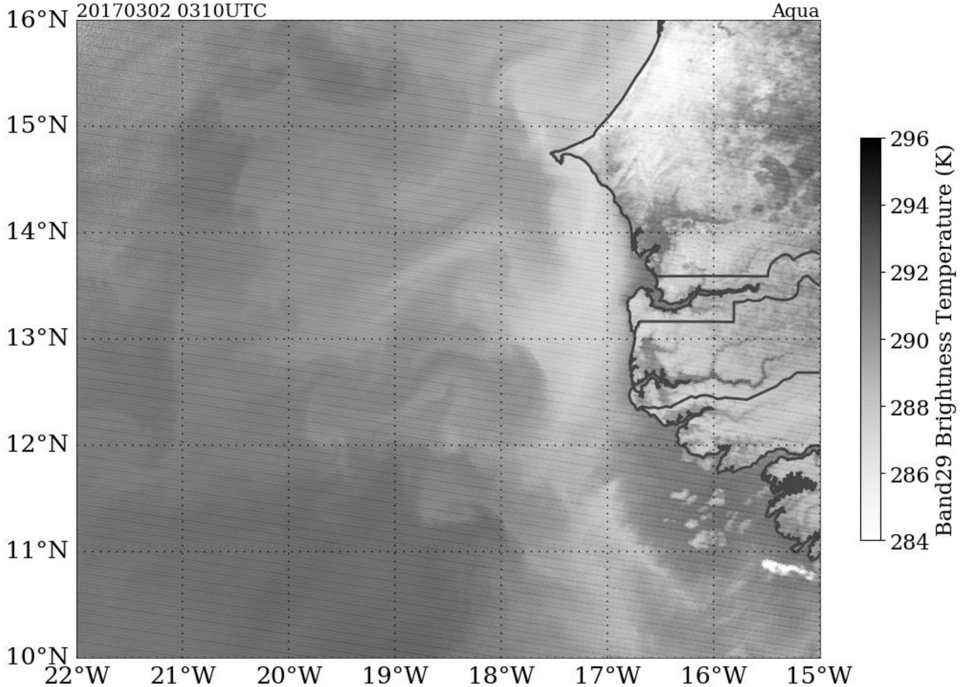
- Non-negligible differences between CRTM results when using GFS and MERRA meteorology, GFS is slightly cooler at low levels which causes lower simulated BTs from CRTM
- However, these differences do not impact overall results and conclusions

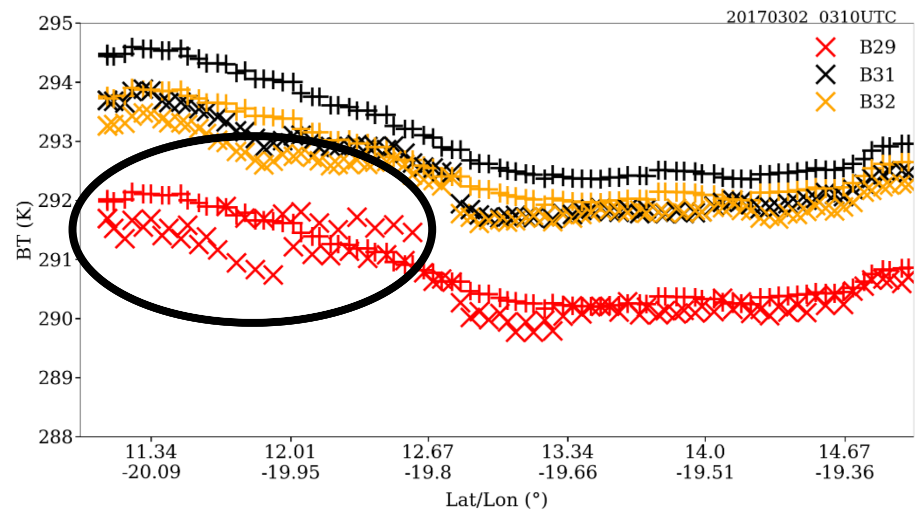
Multiple Modes – Asian Case



- We developed a technique to input fine and coarse mode dust profiles into the CRTM
- However, simulated BTs are much too cool when utilizing this technique, which is likely due to coarse R_e being too large for associated mass concentration
- Difficulty separating total extinction from CALIOP into separate fine and coarse mode mass fractions
- Too warm of BTs at 8.6 µm still apparent in multiple mode run

MODIS Issues





- Calibration issue (striping) in the MODIS 8.6 µm band prevented the use of this band within our validation framework
- This issue is apparent even in the more recent Collection 6.1 product
- The 8.6 micron band has three detectors that are flagged as "noisy" in the L1B product, which likely manifests into these striping artifacts.