Investigate the infrared radiative signatures of dust aerosols based on CALIOP, IIR, and other A-Train Observations

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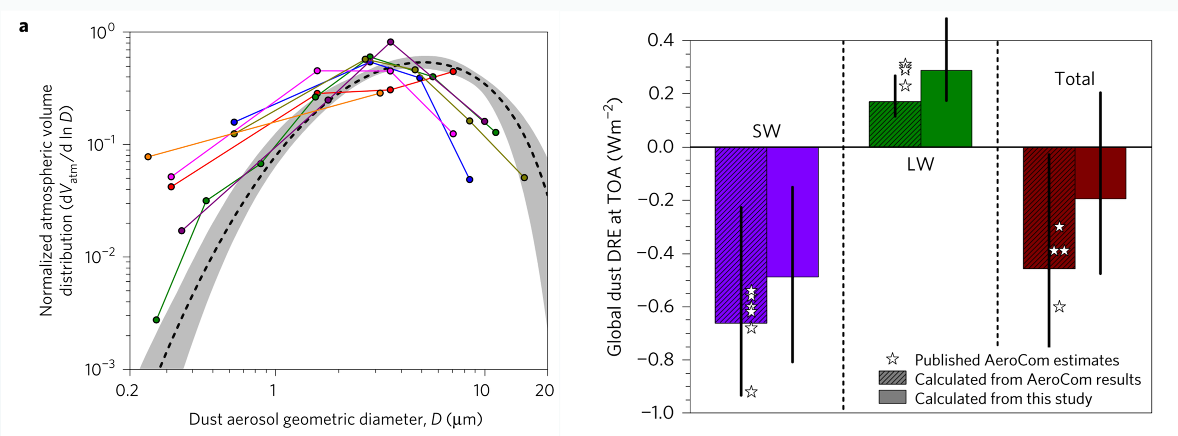
Introduction

The direct radiative effects (DRE) of mineral dust aerosols at both shortwave solar (SW) and longwave thermal infrared (LW) radiation region are significant but remain uncertain. The left panel from Kok et al shows that dust particle sizes are underestimated in current climate models (Kok et al. 2017). Because dust LW DRE is more sensitive to the coarse mode of the dust (Peyridieu et al. 2010; Capelle et al. 2014), the underestimated dust particle size leads to an overestimated SW cooling DRE and an underestimated LW warming DRE (as shown in the right panel from Kok et al).



The uncertain dust optical depth (DOD) in thermal infrared (TIR) region is one of the main sources for the uncertain dust LW DRE. DOD_{TIR} in climate models is simply extrapolated by the retrieved DODVIS, which leads to a large uncertainty in dust LW DRE simulations (Capelleet al. 2014). DOD_{TIR} retrieval is difficult because it highly depends on the altitude and the temperature of dust layers, which is difficult to be obtained by passive satellite sensors.

The remain uncertainties is urging a better understanding of the radiative properties of dust, in particular, the optical depth, in TIR region. The Imaging Infrared Radiometer (IIR) and the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) onboard CALIPSO can be used to develop a new way to retrieve TIR dust optical depth (DOD). In addition, using the spectral difference between multiple TIR bands on MODerate resolution Imaging Spectroradiometer (MODIS) onboard Aqua can distinguish the dust radiative signature.

Data & Model

Data:

1. Imaging Infrared Radiometer (IIR) onboard CALIPSO (CAL_IIR_L2_Track-V4):
   Three infrared bands centered at: 8.65 μm, 10.60 μm and 12.05 μm
   Provide the brightness temperature (BT) at the top of atmosphere (TOA).

2. Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) onboard CALIPSO (CAL_LID_L2_05kmAPro):
   Dust extinction coefficient profiles at the visible band (532 nm).
   The accurate vertical position of dust layers and the retrieved DOD at 532nm.

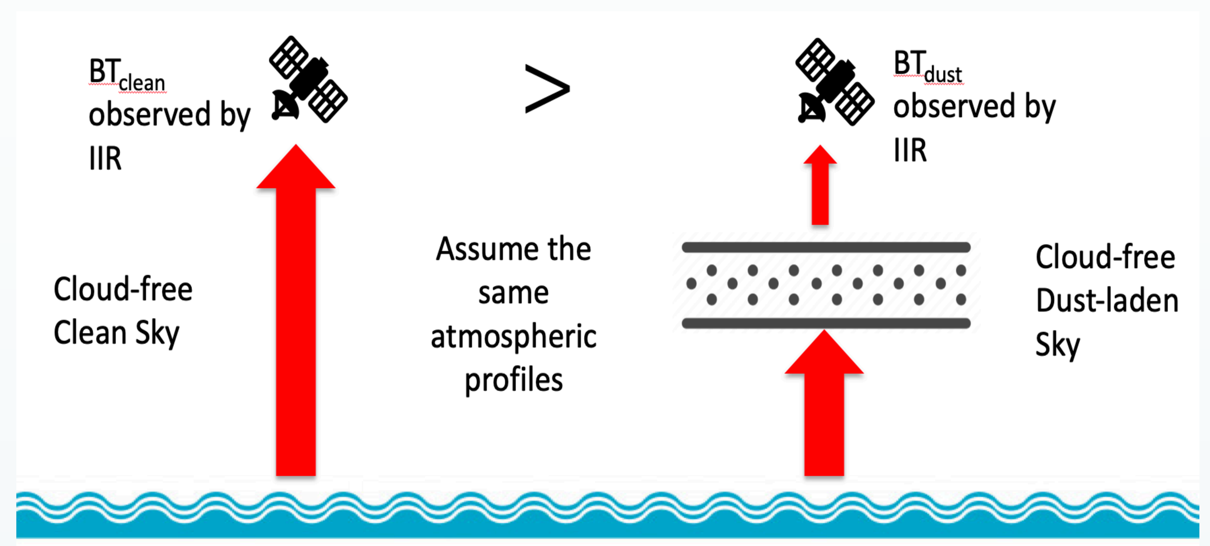
3. MERRA-2 assimilated data (Inst_3d_asm_Nv):
   The atmospheric vertical profiles include water vapor, temperature and ozone.

Radiative Transfer Model:

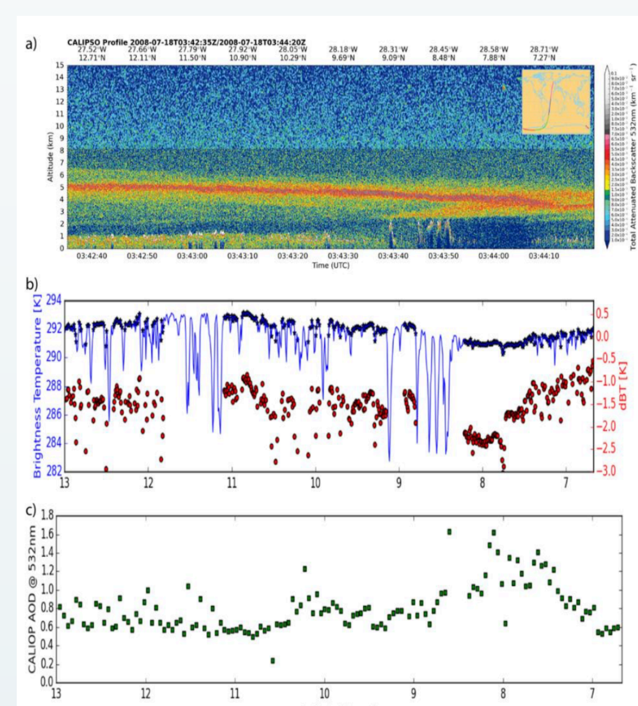
1. Fast radiative transfer code with the discrete ordinate method (FASDOM):
   Provide the simulation of the outgoing radiance (and corresponding BT) to be measured by IIR.
   Need the input of atmospheric profiles, vertical position of dust layer and dust optical depth

Methodology

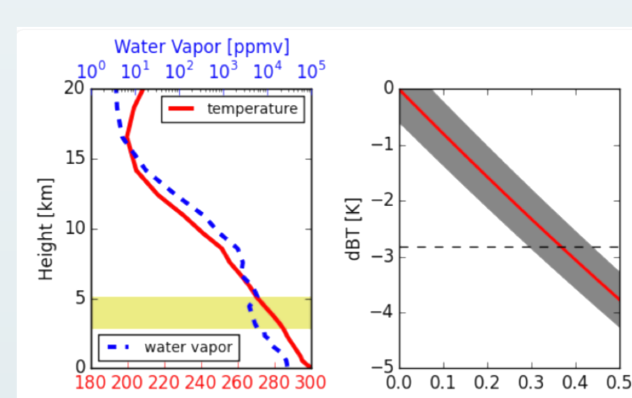
Firstly, the IIR provides brightness temperature (BT) observations in three TIR bands centered at 8.5,10.8 and 12 μm, respectively. The difference between dust-laden BT and dust-free BT (dBT) is the signal for DOD_{TIR} retrieval (Fig. 3).



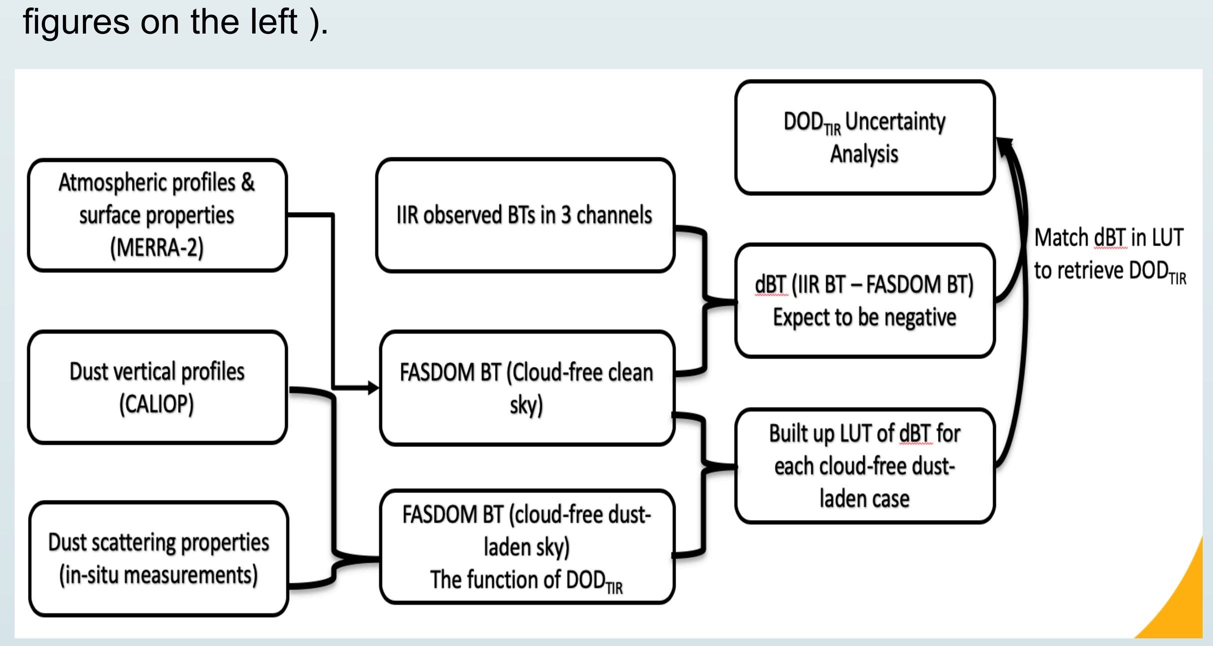
By using the fast radiative transfer model using discrete ordinated method (FASDOM), we can simulate the BT in cloud-free clean sky with the same atmospheric profiles obtain from MERRA-2 assimilated data in cloud-free dust-laden sky. Then we can obtain dBT_{obs} by substracting the simulated BT_{clean} from the observed BT_{dust}.



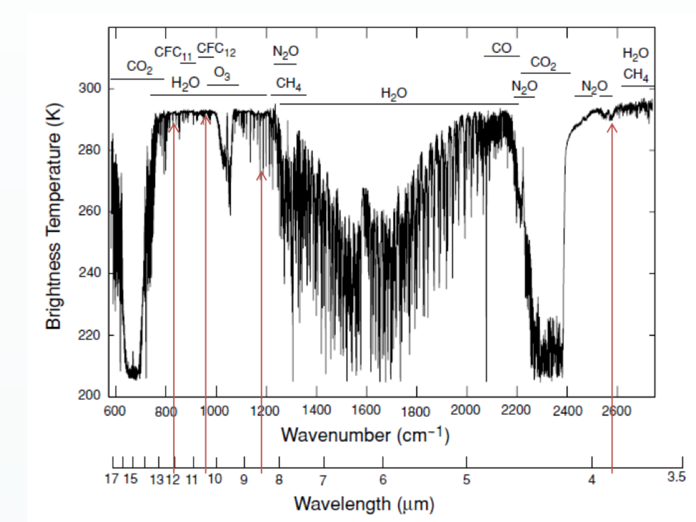
In addition, FASDOM can simulate the BT in cloud-free dust-laden sky by using the given AOD at 3 IIR bands, the vertical position of dust layers from CALIOP, the dust scattering properties from in-situ measurements (e.g. Feinnec Campaign) and the atmospheric profiles from MERRA-2 assimilated data.

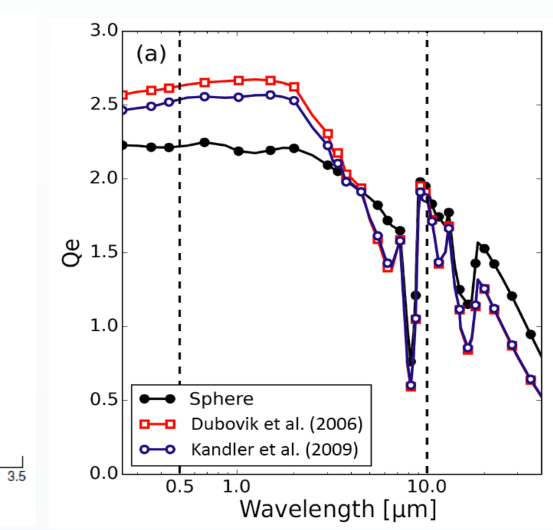


Then we can build up a look-up table (LUT) of dBT by scaling AOD at 3 IIR bands. Once we match dBT_{obs} with the LUT, we can retrieve the AOD as our DOD_{TIR} (Example shown in figures on the left).



MODIS Spectral Difference





MODIS has 10 IR bands to use the difference of BT at each band to discover the dust infrared radiative signature.

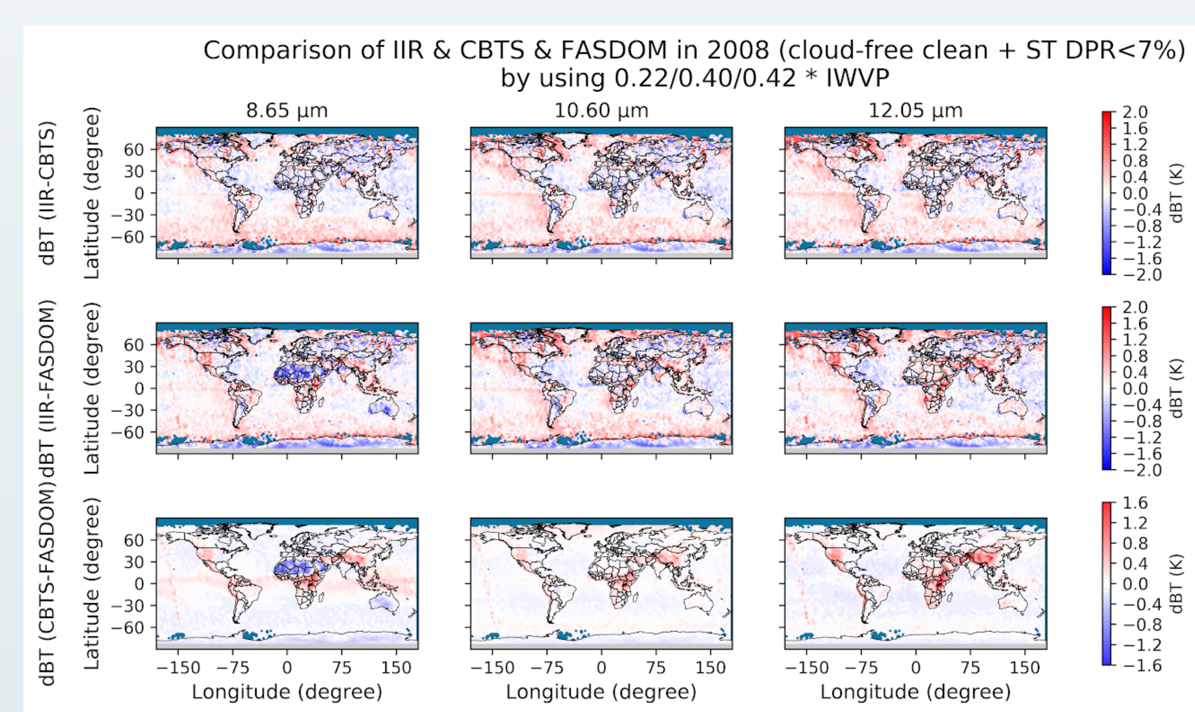
The left panel shows the observed infrared spectrum displaying all the absorption gases and their spectral locations in cloud-free clean sky. The "clean window": 11 μm (Band 31) and 3.75 μm (Band 20). The "dirty window": 12 μm (Band 32).

A dust layer can have different extinction coefficient (Qe) at different wavelength. Dust at 11 μm has the highest Qe (the right panel).

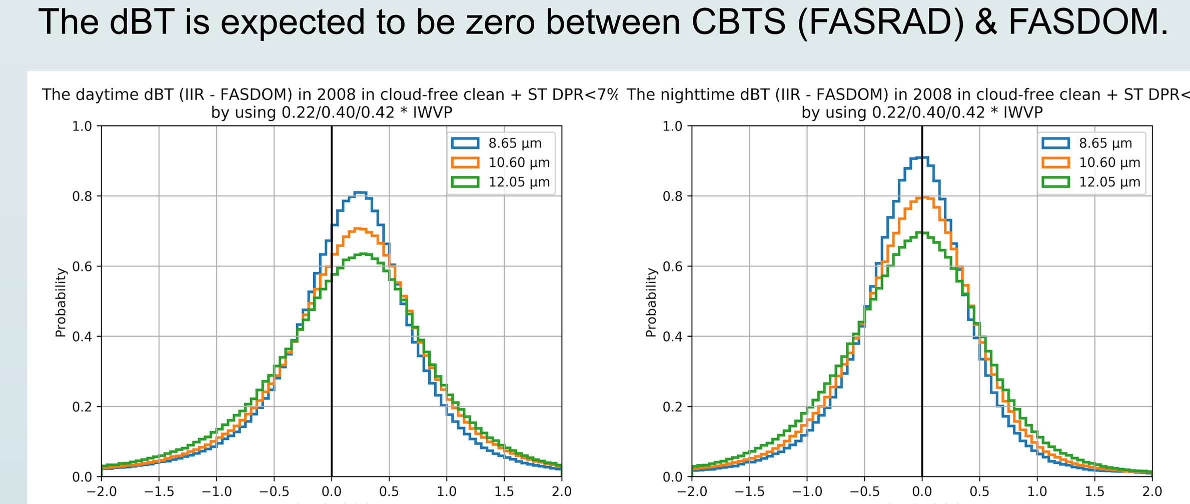
In cloud-free clean sky:
dBT of 8um – 10um < 0 (larger magnitude)
dBT of 10um – 12um > 0 (smaller magnitude)

In cloud-free dust-laden sky:
BT at 10um decrease more than 8/12um.
dBT of 8um – 10um shift to positive
dBT of 10um – 12um shift to negative

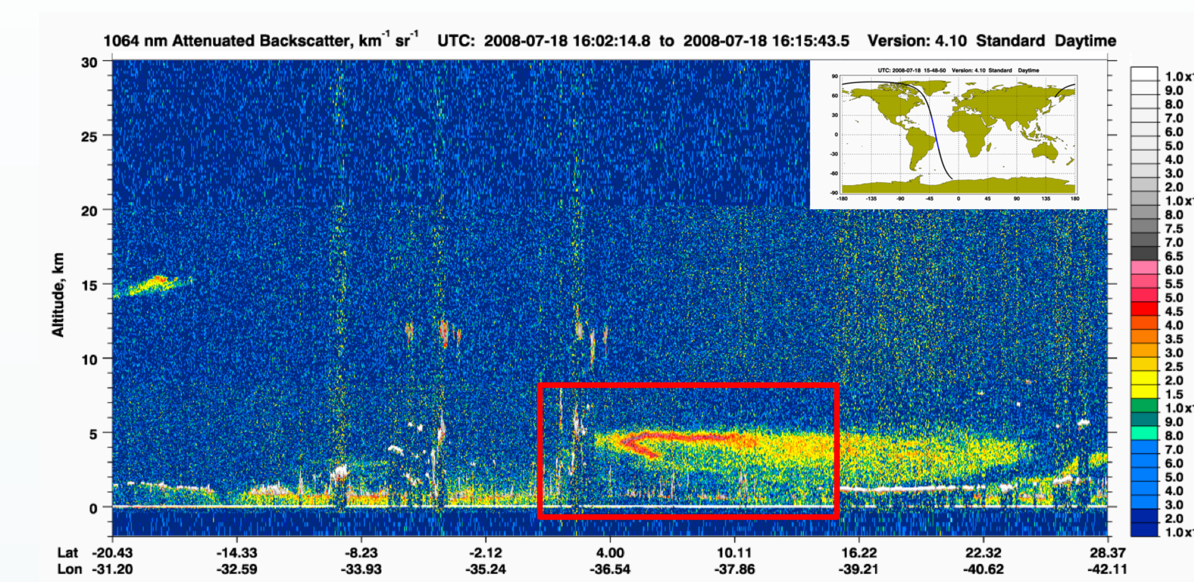
Cloud-free clean sky benchmark of FASDOM

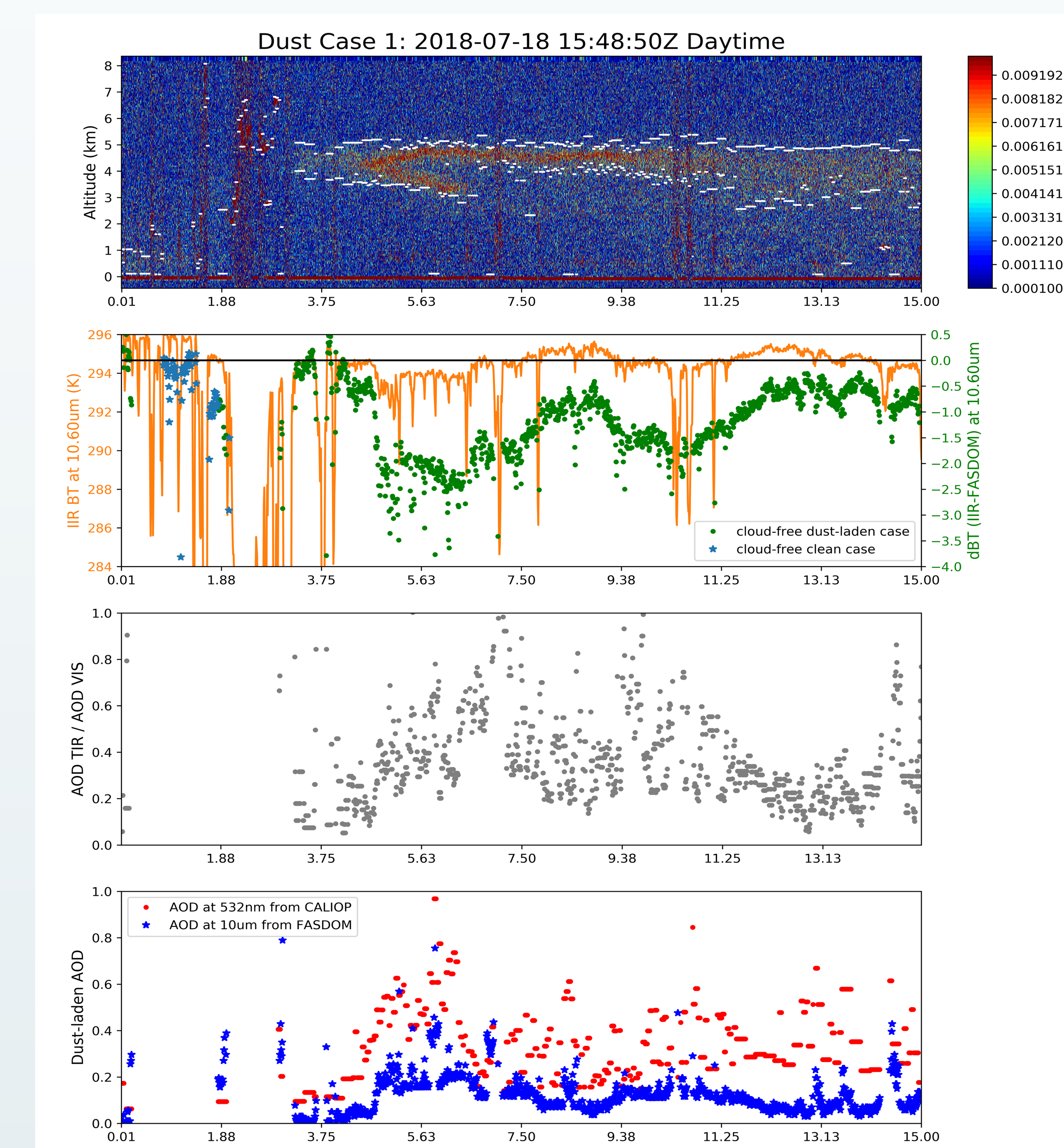


The dBT is expected to be random errors ($\pm 2K$) between IIR & FASDOM. The dBT is expected to be zero between CBTS (FASRAD) & FASDOM.



Cloud-free dust-laden sky case study.





DBT shows strong negative trend along with the change of the thickness of dust layer.

The ratio of DOD_{TIR}/DOD_{VIS} shows corresponding variations to the change of dBT.

The change of some dust properties is more sensitive to DOD_{TIR} than to DOD_{VIS}. (might be the dust particle size)

Reference

Kok, J.F., Ridley, D.A., Zhou, Q., Miller, R.L., Zhao, C., Heald, C.L., Ward, D.S., Albani, S., Haustein, K., 2017. Smaller desert dust cooling effect estimated from analysis of dust size and abundance. arXiv. doi:10.1038/ngeo2912

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