Quantification of the Global Dust Direct Radiative Effects using MODIS, CALIPSO and other satellite observations

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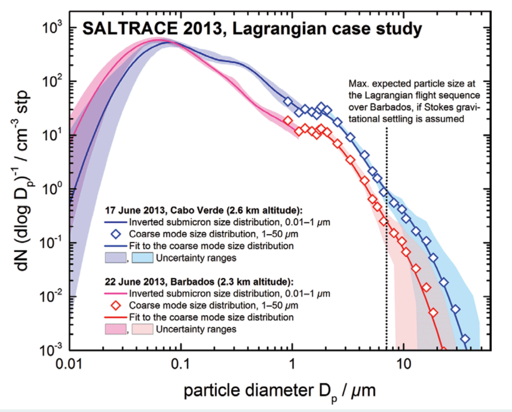
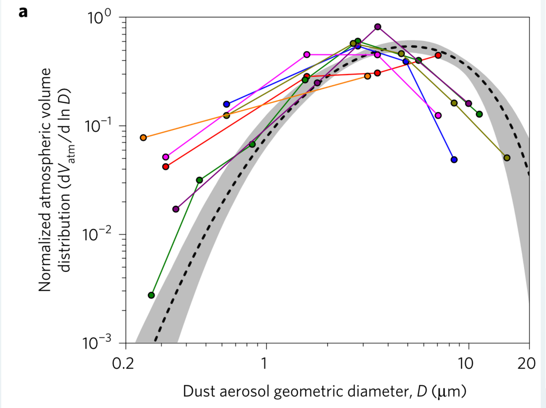
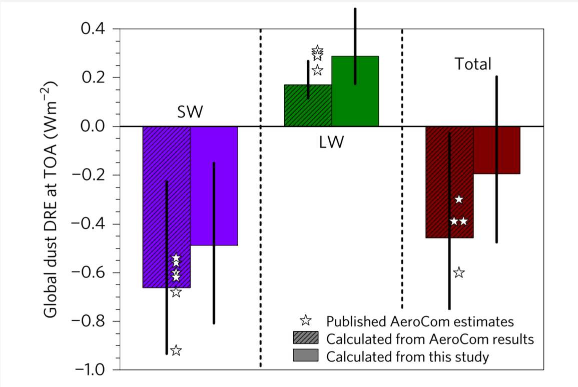
Introduction

- Mineral dust aerosol is the most abundant aerosol component in terms of dry mass. These particles can interact with solar and terrestrial infrared radiation, thereby influencing Earth's energy budget. This effect is called Direct Radiative Effect (DRE).
- There exists large uncertainty in estimating shortwave (SW) and LW DRE of dust due to its dependence on many factors (size, refractive index, shape, surface and atmospheric properties).
- Dust DRE is strongly sensitive to dust size. Finer dust particles tend to cool the planet, whereas, coarser dust particles tend to warm the planet.
- Stokes gravitational settling overestimate the loss of large dust particles during transport over North Atlantic. According to Stokes gravitational settling, no particle larger than $7\mu m$ should be present at an altitude of 1.3km after 5 days transport. Whereas, a large portion of dust particles with size larger than $7\mu m$ was measured after transport over Atlantic as shown in the left figure. [Maring et al, 2003. Weinzierl et al, 2017]
- Recent study indicate that dust size is underestimated in models (see the figure in the middle), as a result, the SW cooling effect of dust aerosols is overestimated and LW warming effect is underestimated. There is even a possibility that dust aerosol is warming our planet (see the figure in the right). [Kok. et al, 2017]





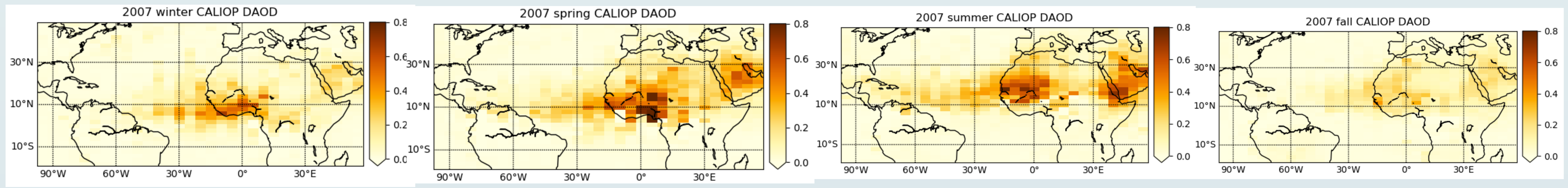


Our objective of this study is to derive observation-based global dust DRE by using satellite, in-situ measurements and radiative transfer models.

Dust Climatology and Ancillary Data

Dust Climatology data derived by using CALIOP observation of depolarization profile. [Yu et al. 2015]

The figure below shows seasonal AOD distribution of trans-Atlantic dust aerosols in 2007.



Using CALIOP observed dust extinction profile to specify dust altitude and dust vertical distribution.

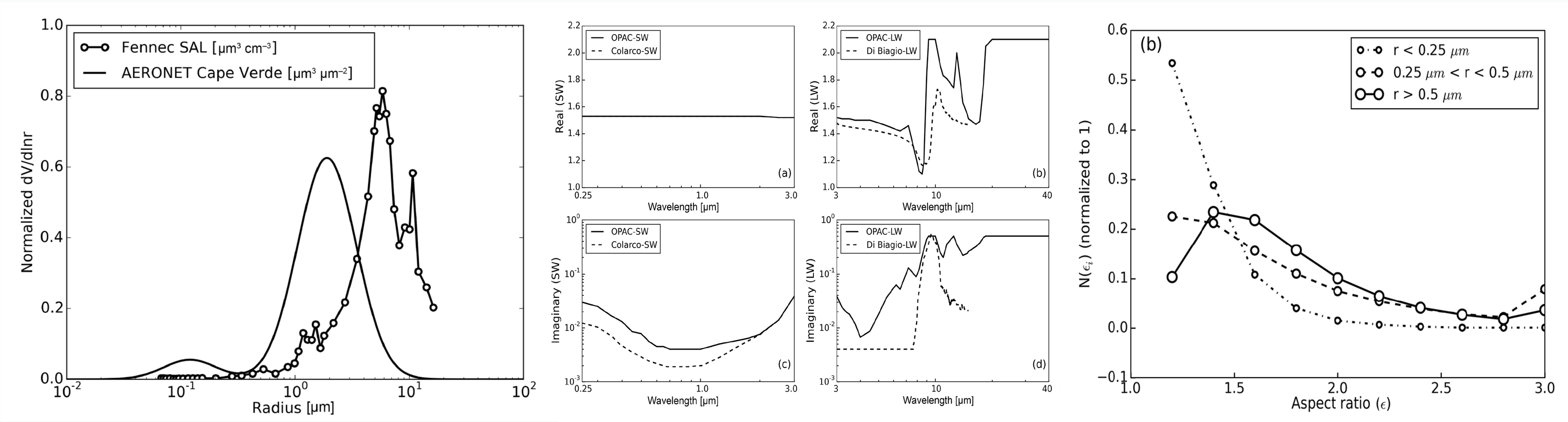
Merra2 atmospheric profile and surface properties

Rapid Radiative Transfer Model (RRTM)

Dust optical properties

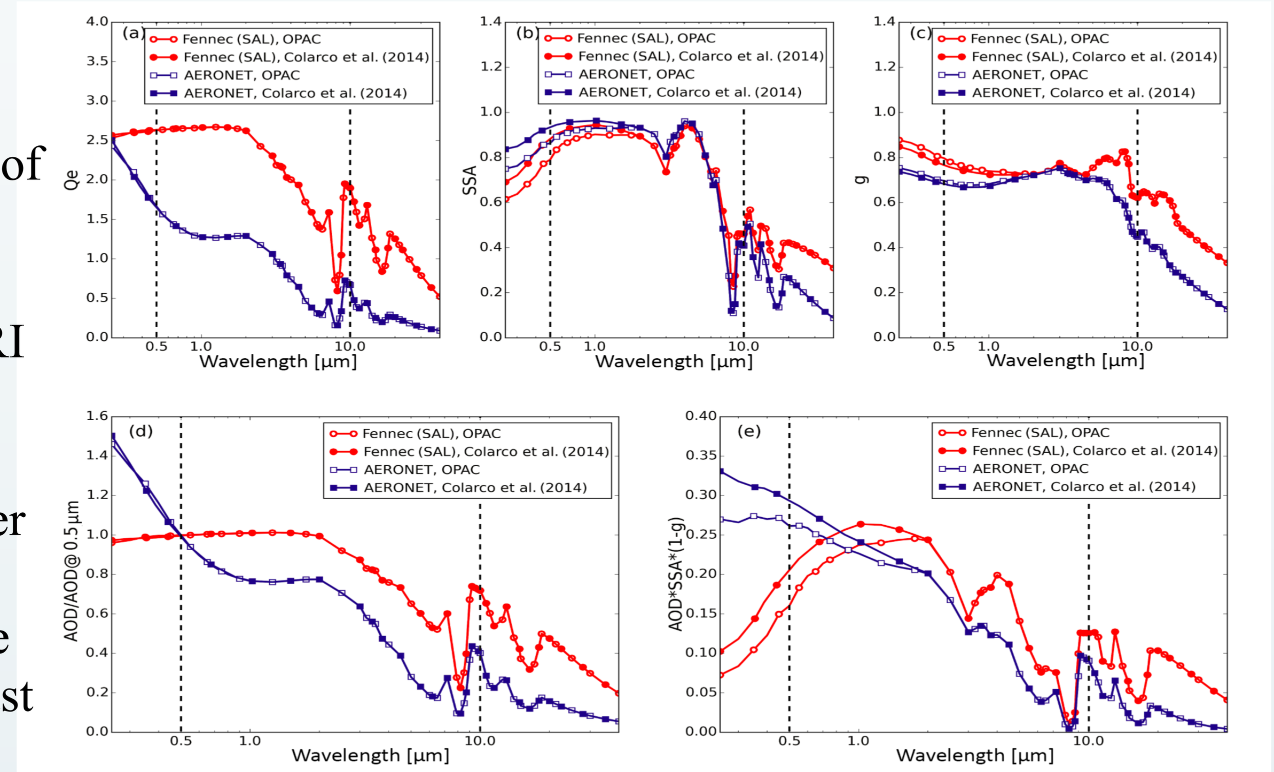
Dust optical properties is derived from the 'optimal' dust model developed in Song et al. 2018.

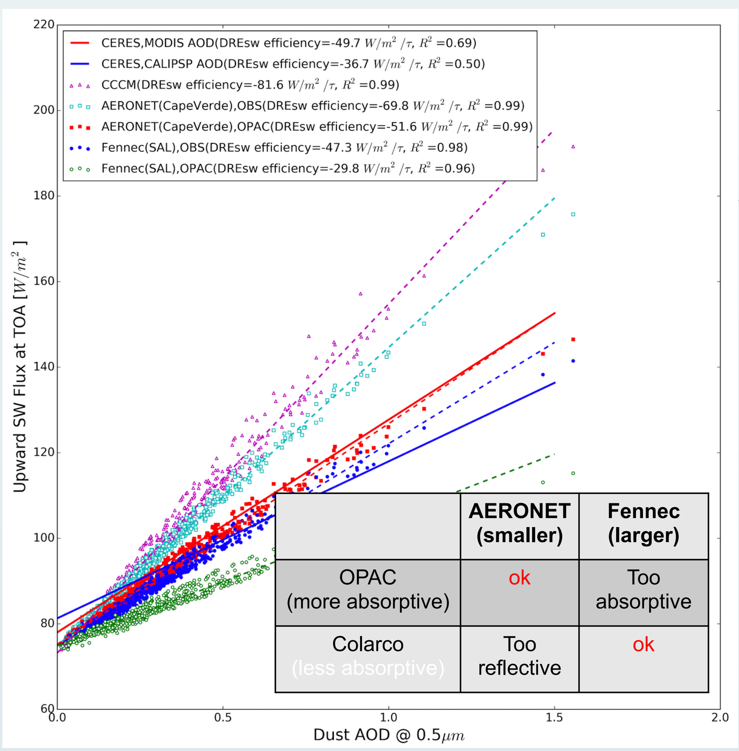
Dust Model: Fennec (SAL) particle size distribution, SW refractive index (RI) from Colarco et al. 2014, LW refractive index from OPAC and dust shape distribution from Kandler et al. 2009. See the figure of dust model below



The advantage of the 'optimal' dust model:

The figure on the right shows dust optical properties of 4 dust models. The larger size + more absorptive RI is the most absorptive dust model. The smaller size + more reflective RI is the most reflective dust model.





The **differences** between **computed OLR** and **CERES OLR:**

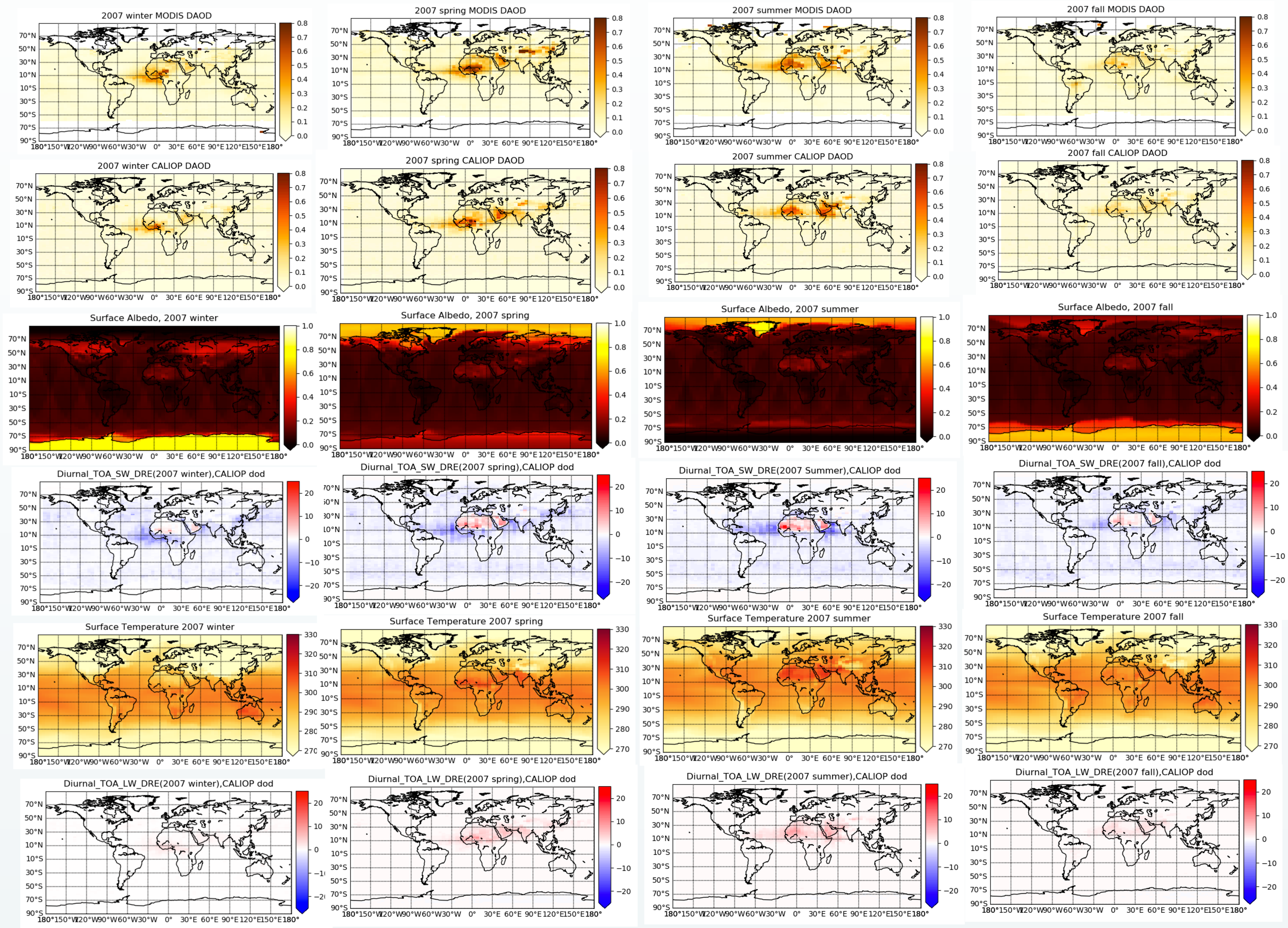
PSD	Refractive index	shape	Mean Difference	Standard Deviation	t-score	p-value
Fennec -SAL	OPAC-LW	Dubovik	0.5 (-0.2)	3.8	1.2 (-0.62)	0.23 (0.55)
Fennec-SAL	Di-Biagio-LW	Dubovik	1.0 (0.3)	3.7	2.67 (0.83)	0.008 (0.41)
AERONET	OPAC-LW	Dubovik	1.6 (0.9)	3.7	4.21 (2.36)	2.7e-5 (0.02)
AERONET	Di-Biagio-LW	Dubovik	2.2 (1.5)	3.7	5.82 (3.94)	7.7e-9 (8.5e-5)

In shortwave (SW), we compare the simulated dust DRE efficiency of 4 dust models (dashed lines) with DRE efficiency based on CERES observation (solid lines), we found the dust model with larger particle size + less absorptive refractive index is equivalent to the one with smaller particle + more absorptive refractive in terms of agreement with CERES observation . They are both within the range of CERES observation (see the figure on the left).

In longwave (LW), only the dust model with larger particle size + less absorptive refractive index agrees with CERES observation.

Overall, the 'optimal' dust model could achieve both SW and LW closure.

Global Dust Direct Radiative Effect at TOA in 2007



	Winter	Spring	Summer	Fall	Annual
DAOD	0.024 (0.033)	0.032 (0.045)	0.029 (0.041)	0.024 (0.031)	0.027 (0.38)
DRE_SW(Wm^{-2})	-0.70 (-1.2)	-0.85 (-1.2)	-0.70 (-0.85)	-0.79 (-0.99)	-0.76 (-1.1)
DRE_LW(Wm^{-2})	0.14 (0.19)	0.29 (0.41)	0.28 (0.38)	0.19 (0.24)	0.23 (0.3)
Net_DRE(Wm^{-2})	-0.56 (-0.84)	-0.56 (-0.76)	-0.42 (-0.47)	-0.6 (-0.75)	-0.53 (-0.8)

The table above shows global dust DRE based on CALIOP dust AOD and MODIS dust AOD (values in the parentheses).

Generally, in SW, dust aerosols have a cooling effect over dark ocean and warming effect over bright surface (see the negative DREsw over ocean and positive DREsw over Sahara), whereas, in LW, dust aerosols warm our planet due to its absorption of thermal radiation.

The mean DRE-SW over North-Atlantic ocean is about $-7W/m^2$, the mean LW-DRE is about $2W/m^2$. LW warming effect cancels about 28% of SW cooling effect, which is consistent with our results in Song et al, 2018.

References

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