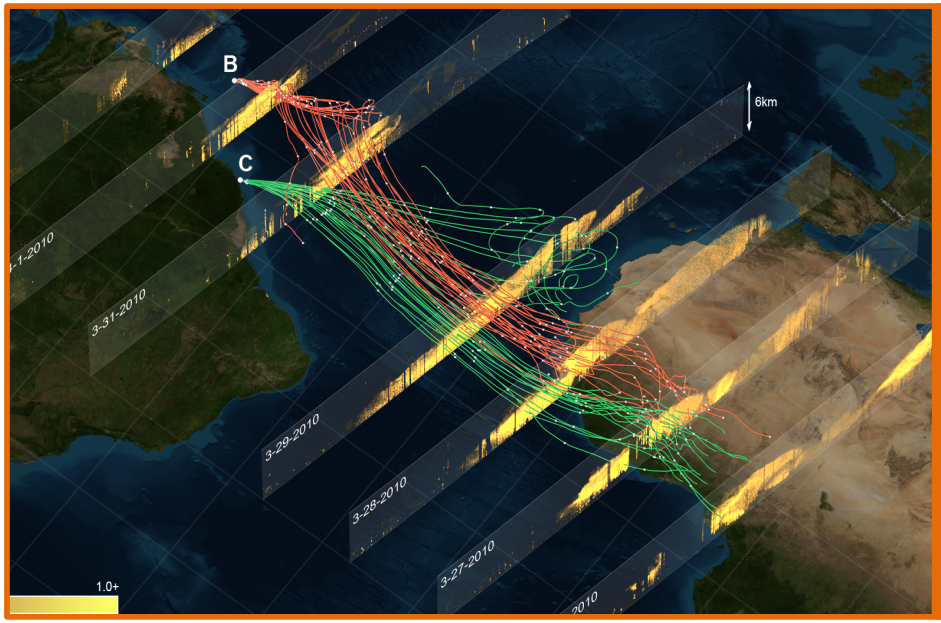


Satellite-based Estimates of Dust Deposition into Tropical Atlantic Ocean

Hongbin Yu [a], Mian Chin [a], Qian Tan [b], Zhibo Zhang [c],
Qianqian Song [c], Dongchul Kim [a, d], Huisheng Bian [a, c], Tianle Yuan [a, c]

[a] NASA Goddard Space Flight Center, [b] Bay Area Environmental Research Institute, [c] University of Maryland Baltimore County, [d] Universities Space Research Association

Acknowledgements:

CALIOP – David Winker, Ali Omar

MODIS – Robert Levy, Lorraine Remer

MISR – Ralph Kahn, Olga Kalashnikova

IASI – Laurent Crepeau, Virginie Capelle, Alain Chedin

MERRA2 – Cynthia Randles, Arlindo da Silva

FENNEC – Claire Ryder

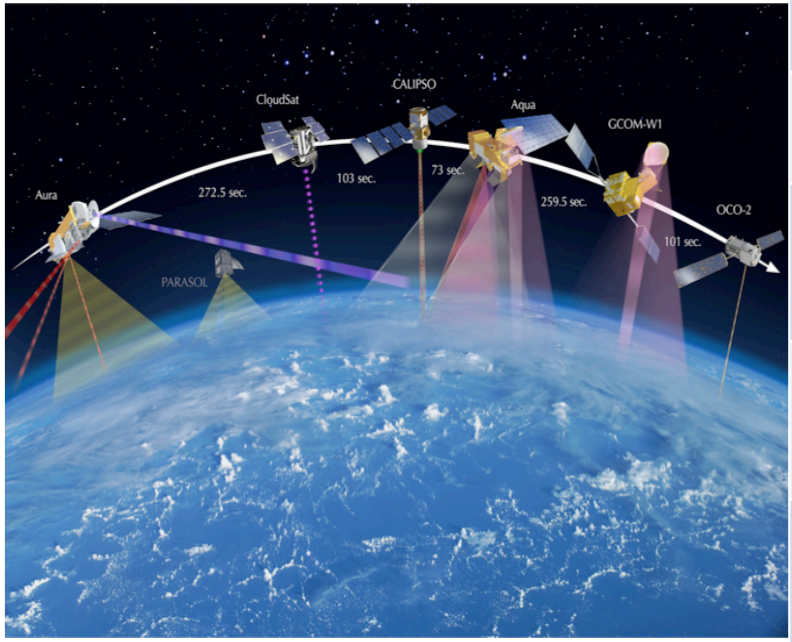
NASA support under the CALIPSO/CloudSat Science Team

Motivation & Objectives

- Dust deposition is believed to play important roles in ocean biogeochemical cycles, carbon sequestrations, and climate change.
  - **direct fertilizing effect**—providing essential nutrients Fe, P etc.
  - **indirect fertilizing effect**—promoting nitrogen fixation
  - **ballasting effect**—aggregating & sinking particulate organic carbon (POC)
- Observations of dust deposition are rare and model simulations are highly uncertain.
- **Objectives: (1)** to estimate the dust deposition into Atlantic Ocean from satellite measurements of aerosol 3-D distributions; **(2)** to evaluate model simulations.

A-Train (+other) provides several capabilities of observing global dust from space

- Dust, generally large and non-spherical particles, can be separated from other types based on A-Train(+other) measurements.
- A synergy of these measurements can characterize the dust transport in 3-D *(passive + active)*



Sensor	Technique	Observables
CALIOP CATS	polarization lidar	Vert. profiles & particle shape
MODIS	multiple wavelengths	AOD & particle size
MISR	multi-angle, multiple wavelengths	AOD & particle shape
IASI AIRS	thermal IR	AOD at 10um & height info
POLDER	multi-angle, multiple wavelengths, polarization	AOD & particle shape

** POLDER GRASP data will be analyzed in near future*

Step-by-step Estimation of Dust Transport & Deposition

1. Aerosol extinction/backscatter profile from CALIOP

Dust particles are large in size and non-spherical in shape, so large depolarization ratio.

DOD derived from MODIS, MISR, IASI is distributed using the CALIOP dust extinction profile

2. Dust extinction profile

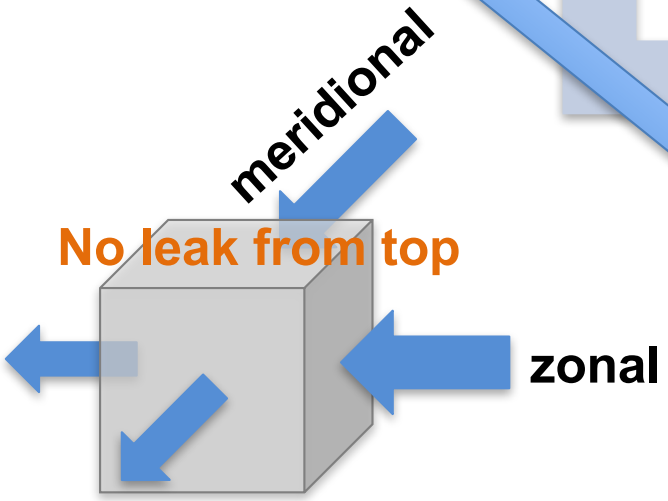
Extinction = Mass Conc. * MEE

3. Profile of Dust Mass Concentration

MERRA Reanalysis wind

4. Dust Mass Flux

$$F = \int m(z)u(z)\,dz$$



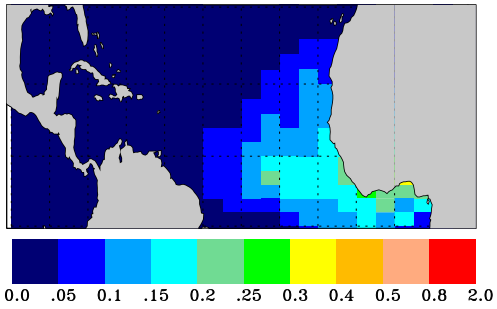
5. "Mass Balance" ➡ Dust deposition

Yu et al., Remote Sens. Environ., 2015 & Yu et al., Geophys. Res. Lett., 2015

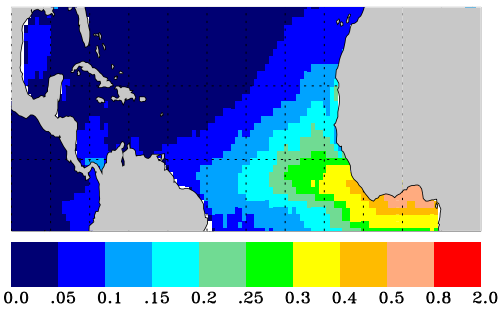
Dust Optical Depth Derived from Satellites

CALIOP | **MODIS** | **MISR** | **IASI (x2)**

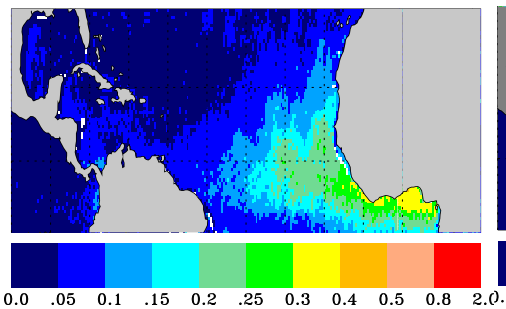
Dust AOD CALIOP DJF



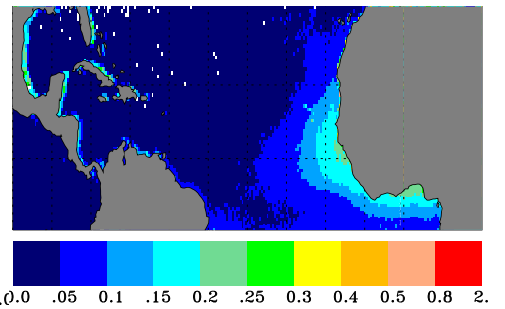
Dust AOD Aqua DJF



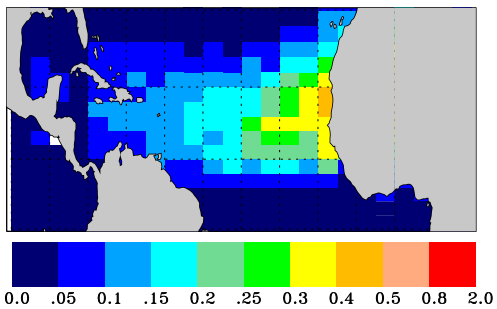
Dust AOD MISR DJF



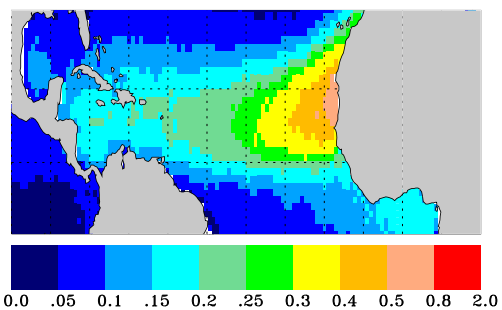
Dust AOD (x2) IASI DJF



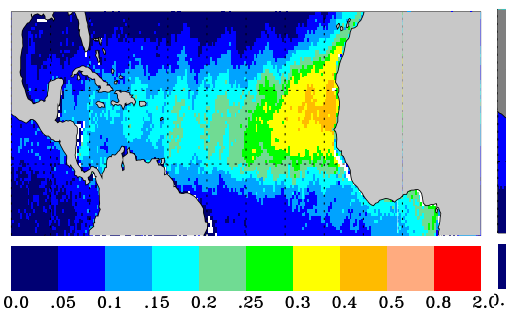
Dust AOD CALIOP JJA



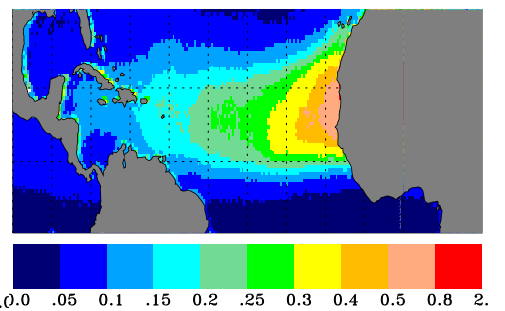
Dust AOD Aqua JJA



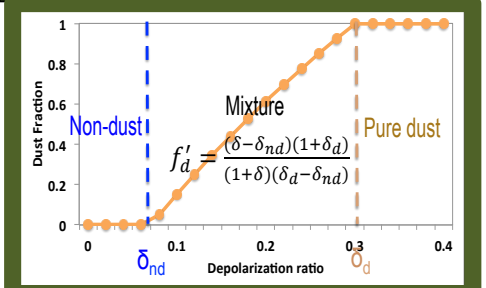
Dust AOD MISR JJA



Dust AOD (x2) IASI JJA



DOD = AOD*f_d



DOD = $[AOD(f_c-f)-AOD_m(f_c-f_m)]/(f_c-f_d)$

f – fine-mode fraction

d – dust; m – marine;

c – combustion

DOD = AOD*$f_{non\text{-}sph}$

$f_{non\text{-}sph}$: non-spherical fraction from multi-angle observations

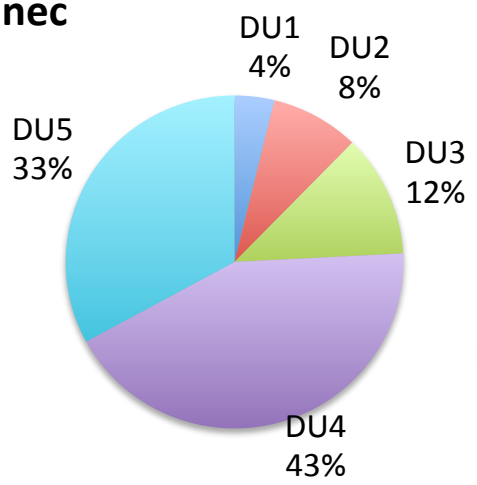
DOD = AOD $_{10um}$

thermal infrared channels only sensitive to elevated coarse particles.

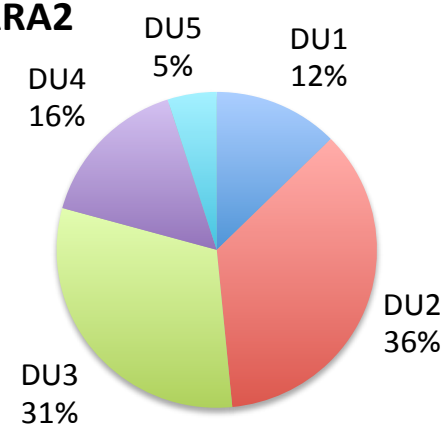
Dust Mass Extinction Efficiency (MEE)

Size distribution

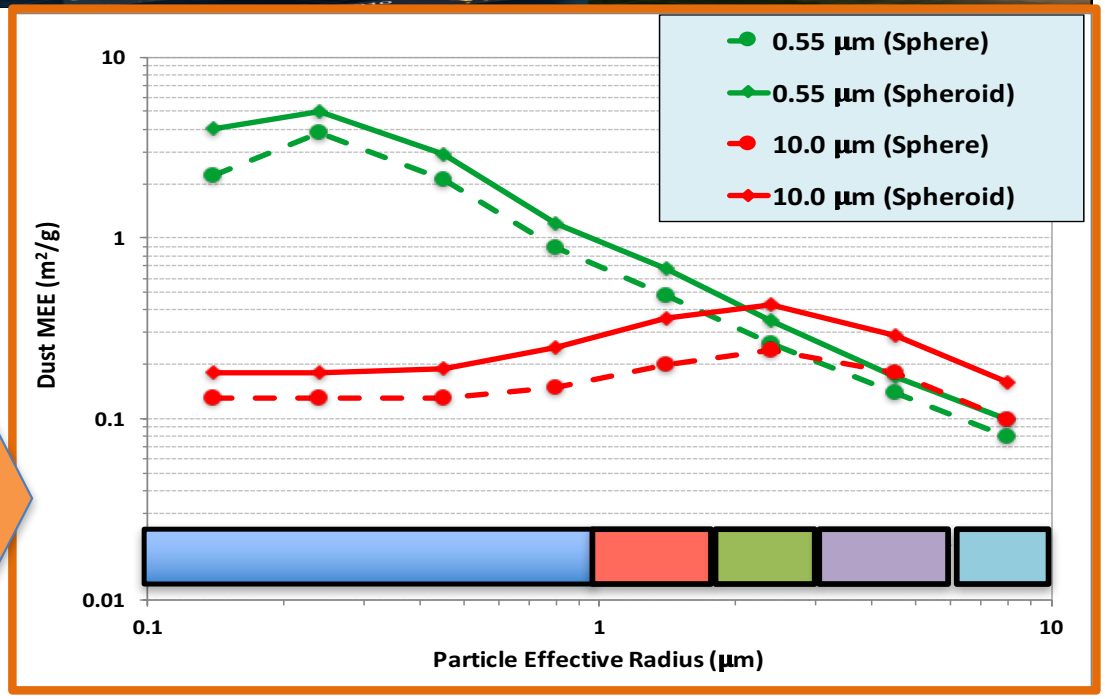
Fennec

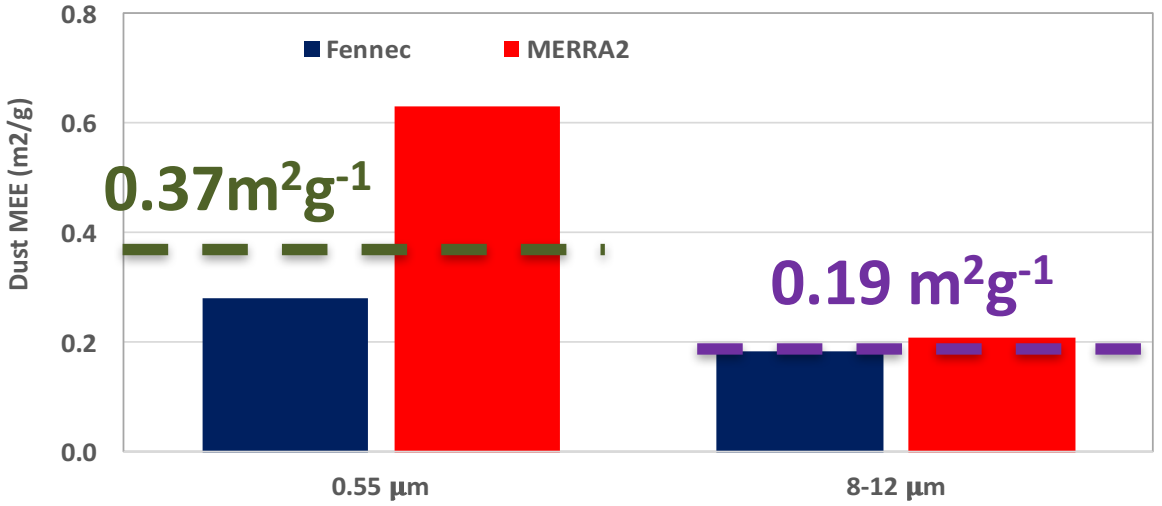


MERRA2



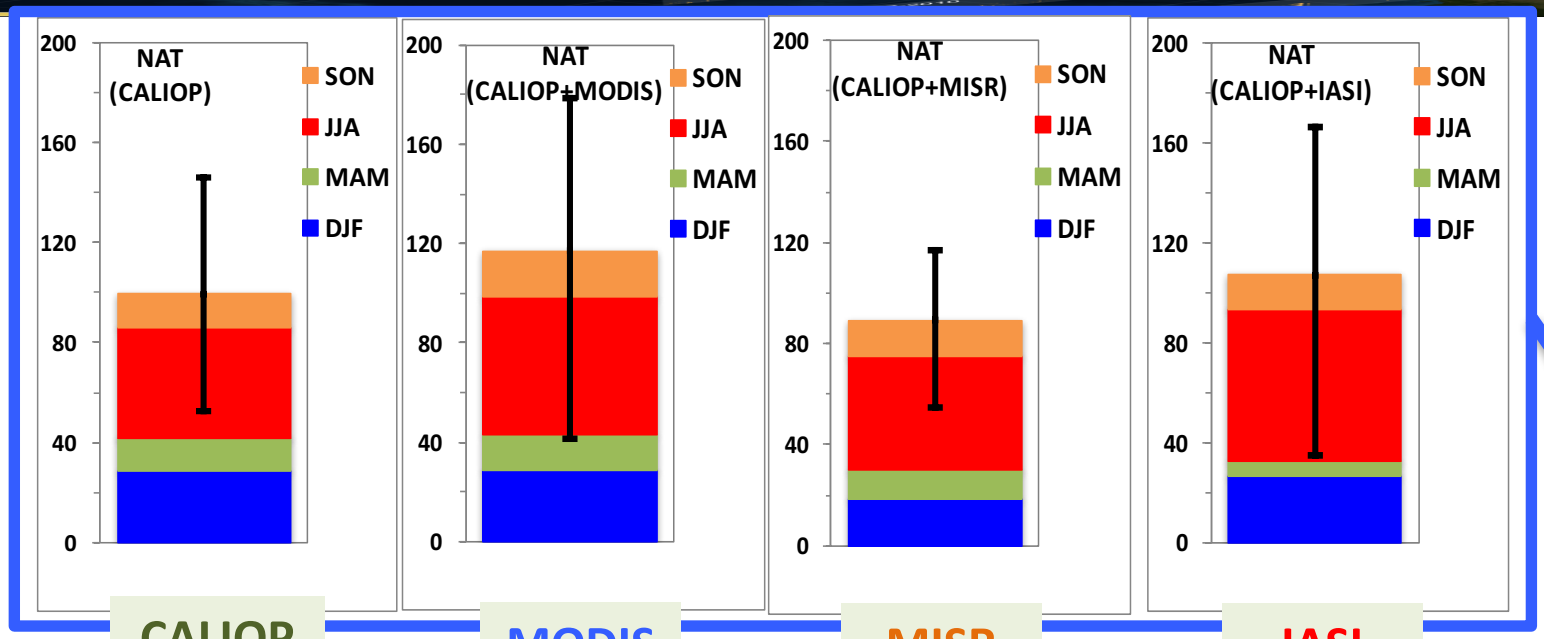
MERRA2 biases to fine particles (R_e < 3 µm, DU1-DU2- DU3)

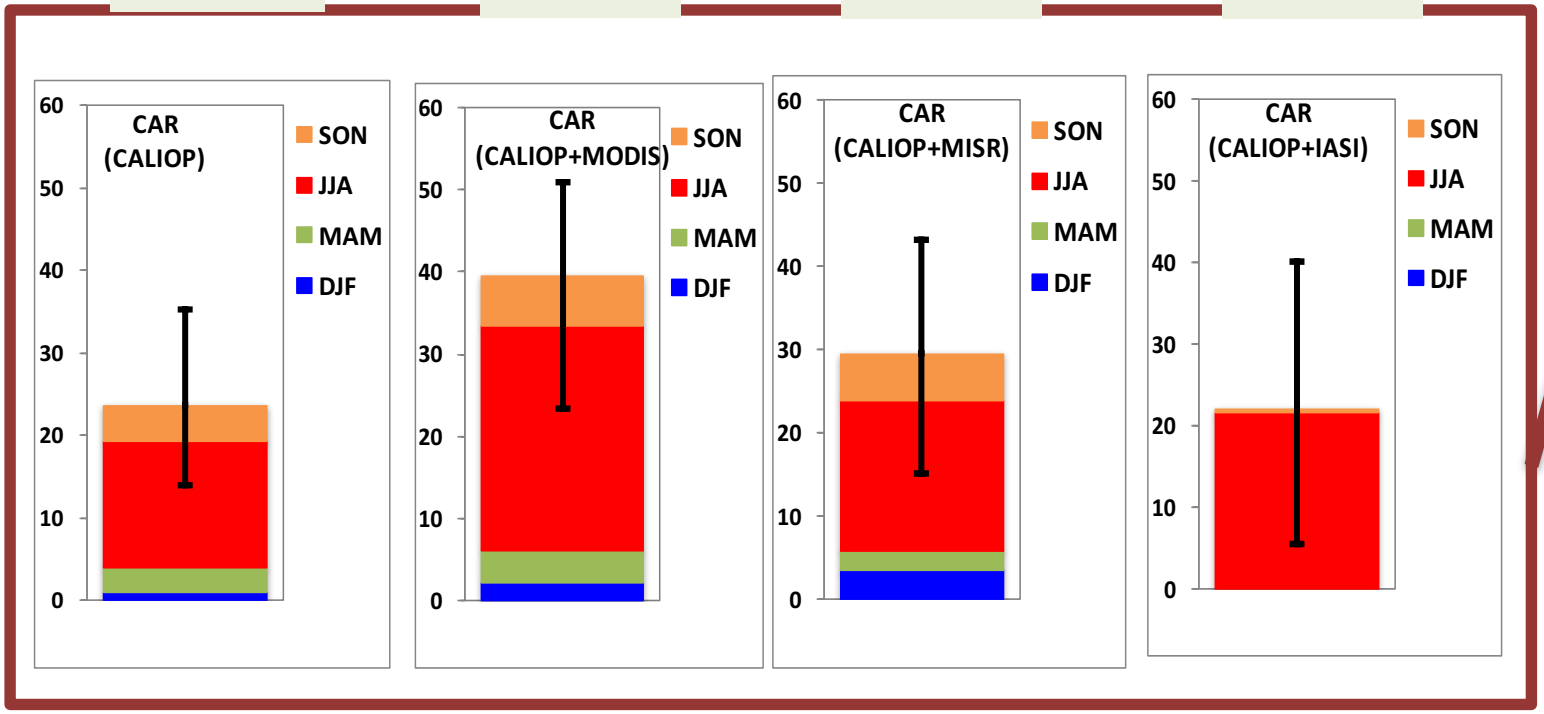




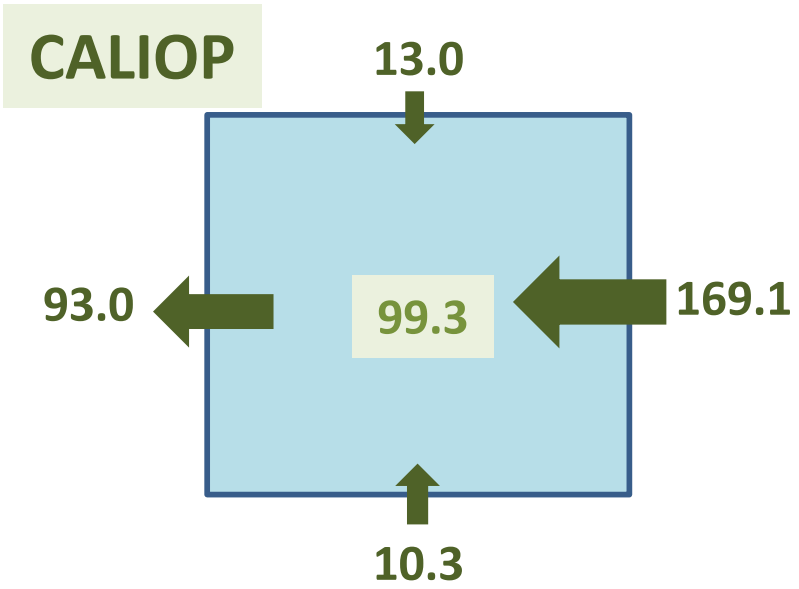
Satellite-Based Estimates of Dust Deposition (Tg)

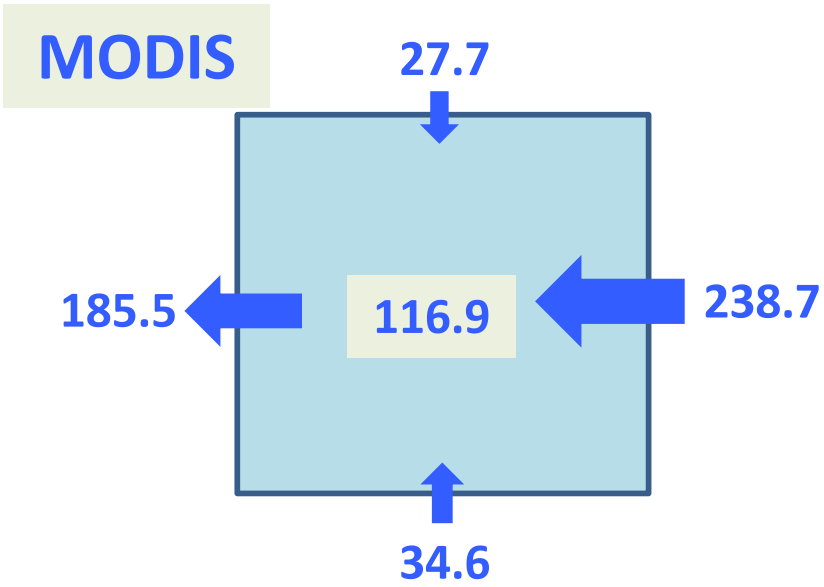
2007-2014

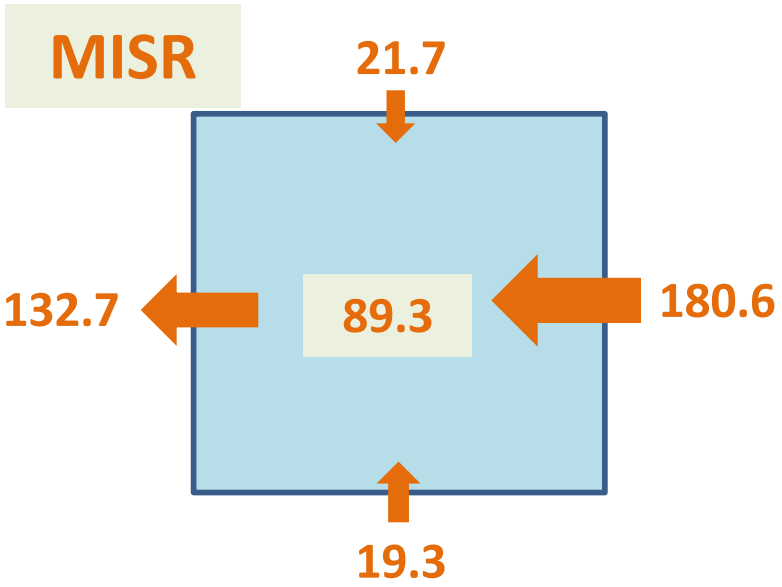


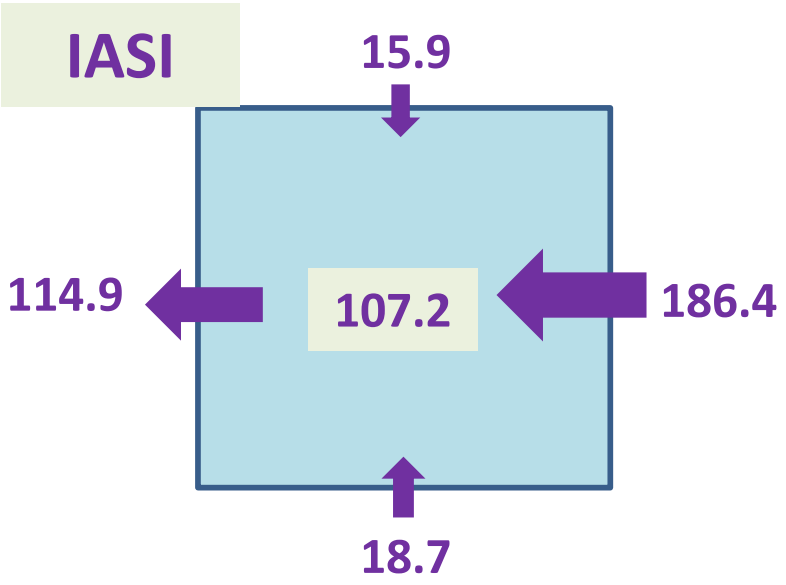


Budget of Dust Transport -NAT

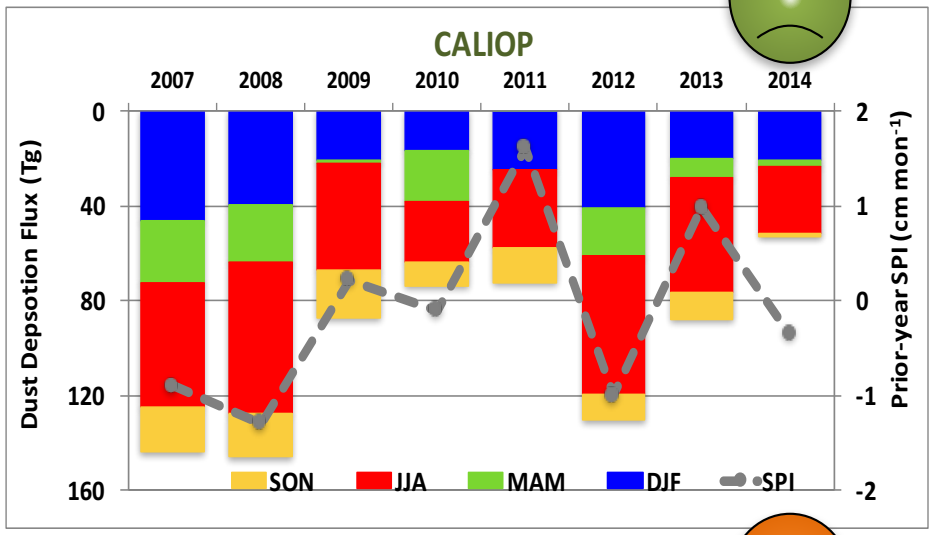


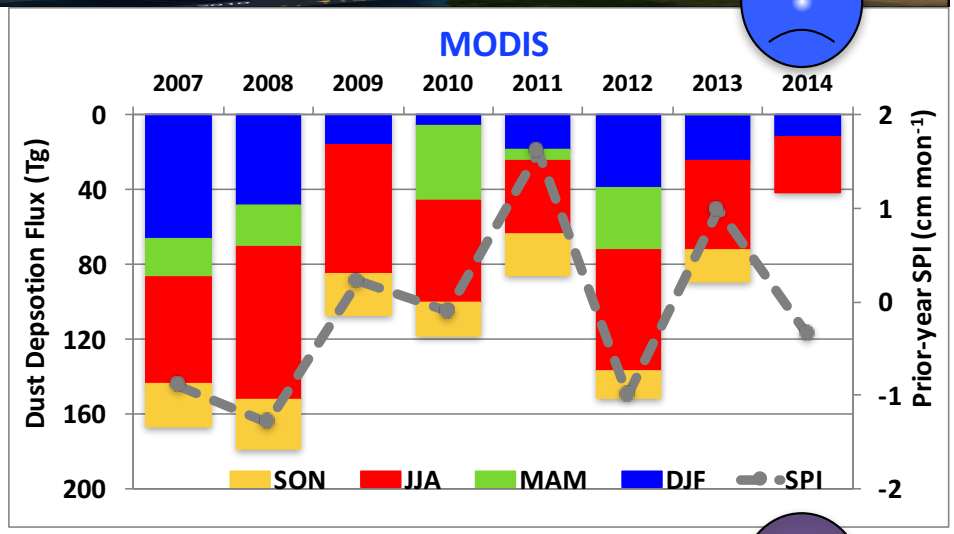


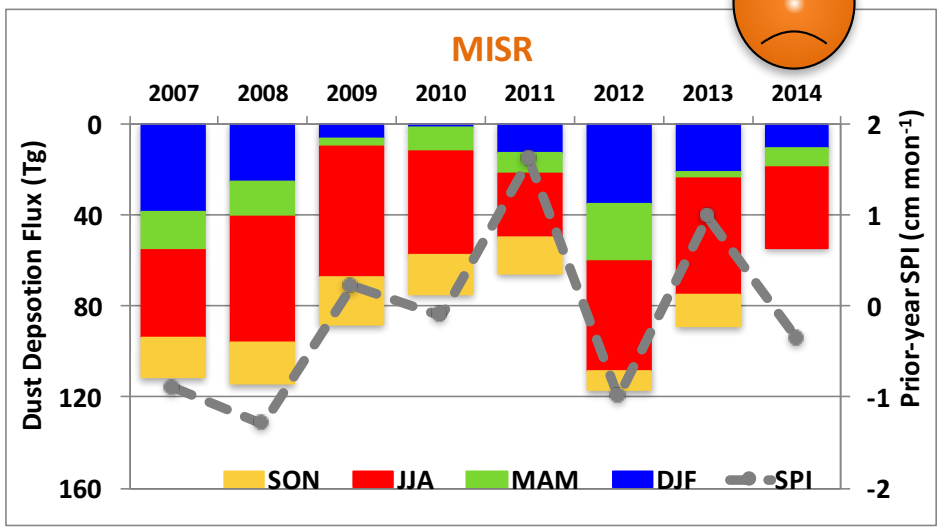




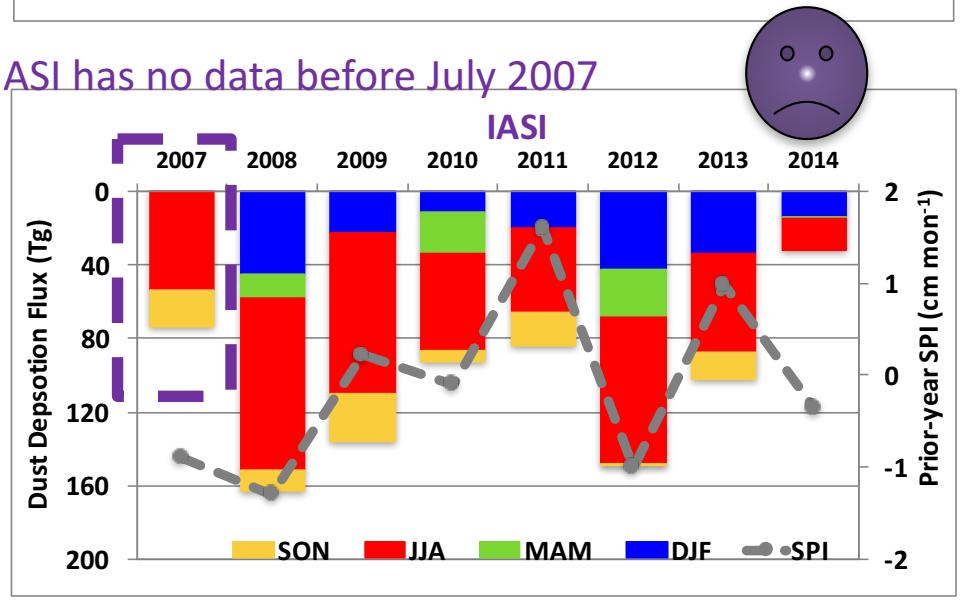
Interannual Variations of Dust Deposition [1]







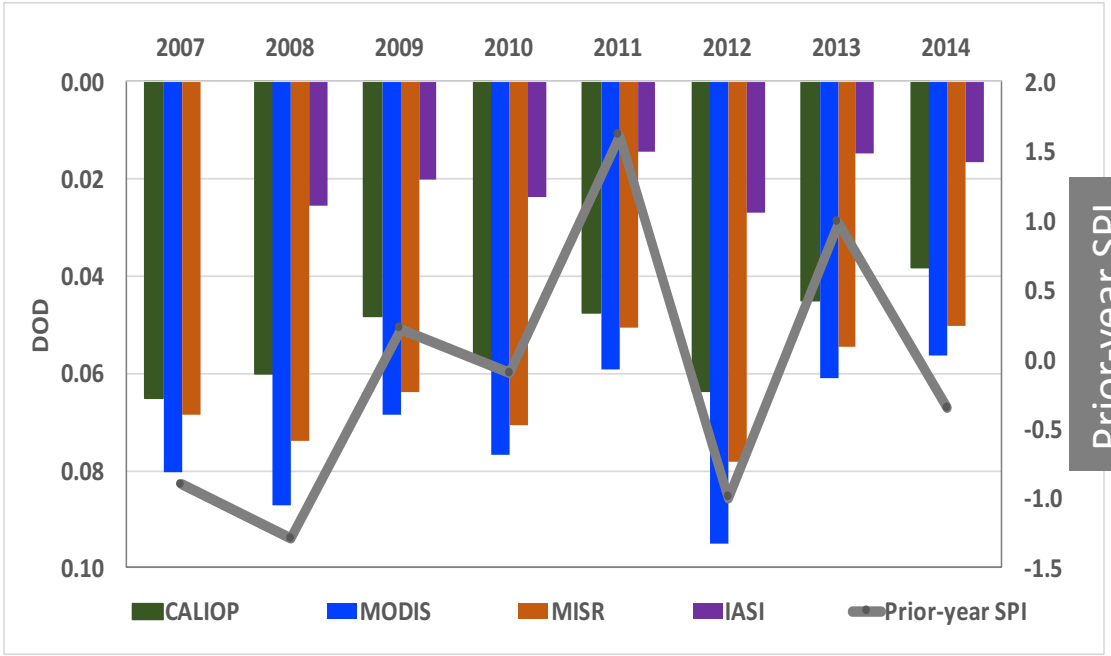
IASI has no data before July 2007



- Negative correlation with prior-year Sahel rainfall Index (SPI).
- 2014 is kind of outlier.

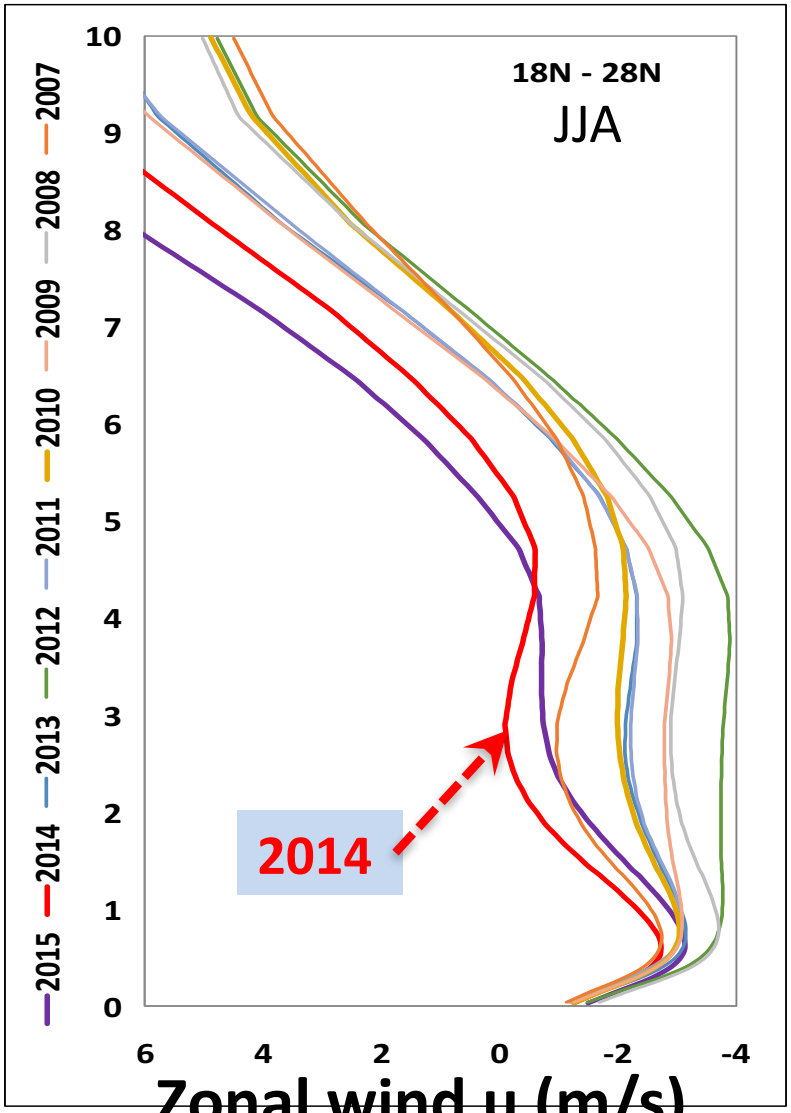
R	CALIOP	MODIS	MISR	IASI
2007-2014	-0.67	-0.65	-0.63	-0.44
2007-2013	-0.86	-0.96	-0.87	-0.85

Interannual Variations of Dust Deposition [2]



R	CALIOP	MODIS	MISR	IASI
2007-2014	-0.63	-0.77	-0.76	-0.84
2007-2013	-0.89	-0.94	-0.94	-0.96

- Tighter negative correlation between DOD and prior-year SPI.



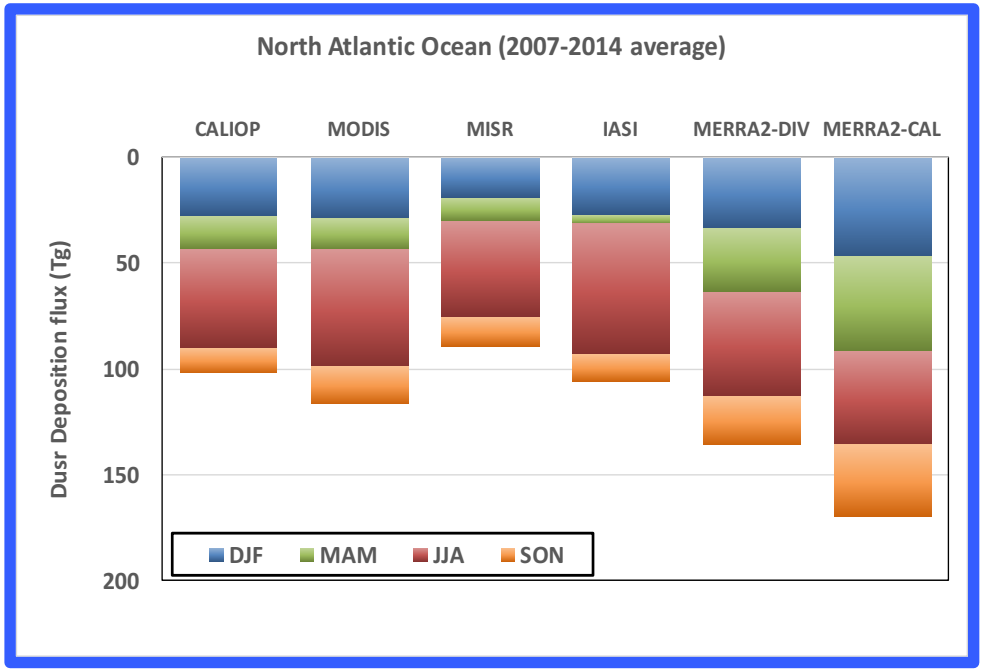
- The easterly was substantially weakened in 2014.

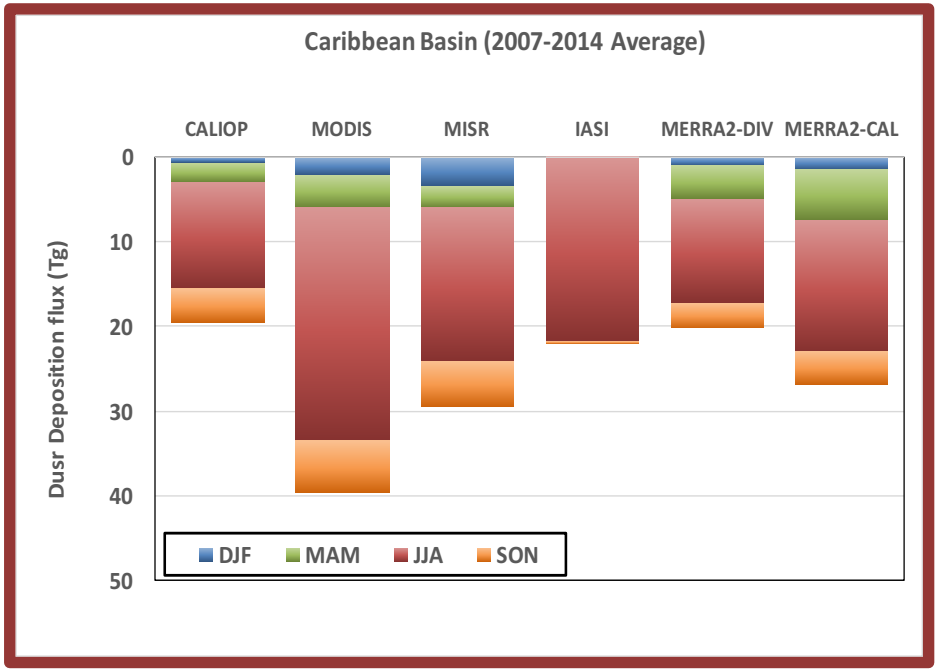
Dust Deposition: Satellites vs MERRA2

Two MERRA2 estimates of dust deposition

- **CAL**– based on para. of dry & wet removals **(*mass imbalance*)**
- **DIV** – the **"mass balance"** method *(similar to satellite estimates)*

Data assimilation *doesn't* constrain the deposition, but could even *exacerbate* the bias of dust deposition (due to imperfect representations of dry and wet removals)





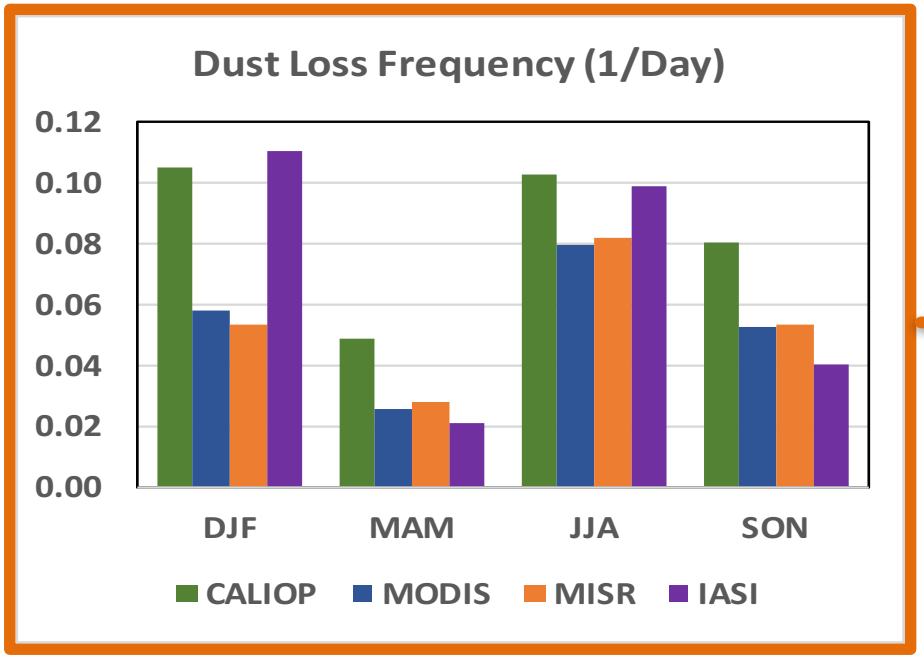
Dust Loss Frequency (LF) from Satellites

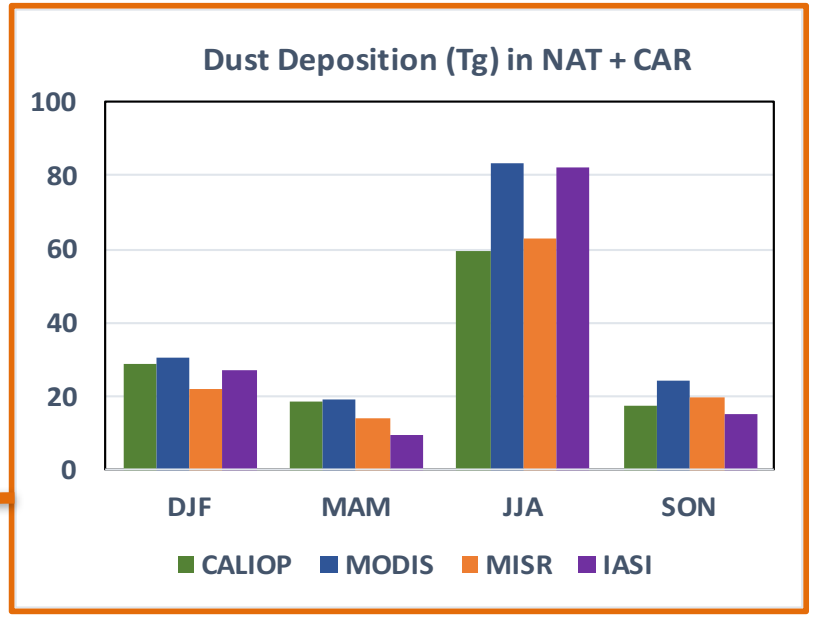
Dust Loss Frequency (LF) (1/day) =

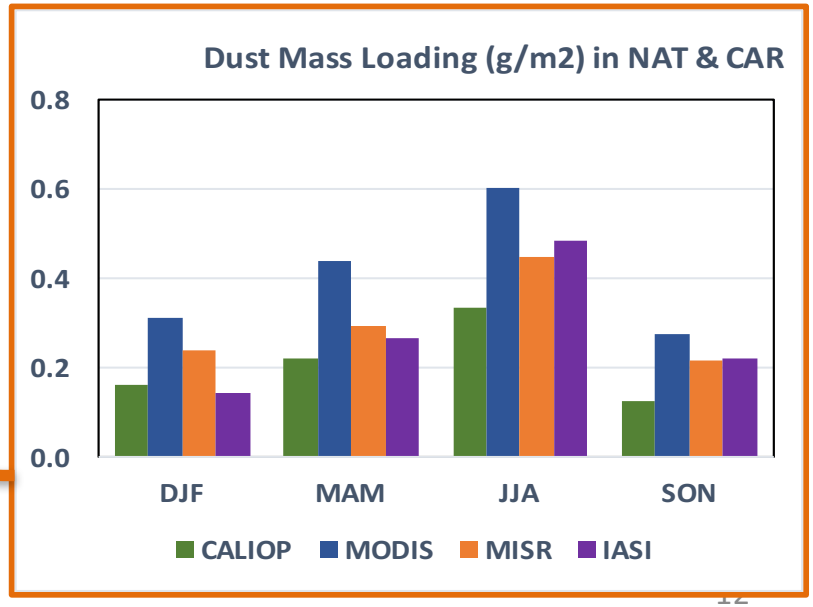
[Dust Deposition Flux Rate] ($g/m^2/day$)

÷ [Dust Mass Loading=DOD/MEE] (g/m^2)

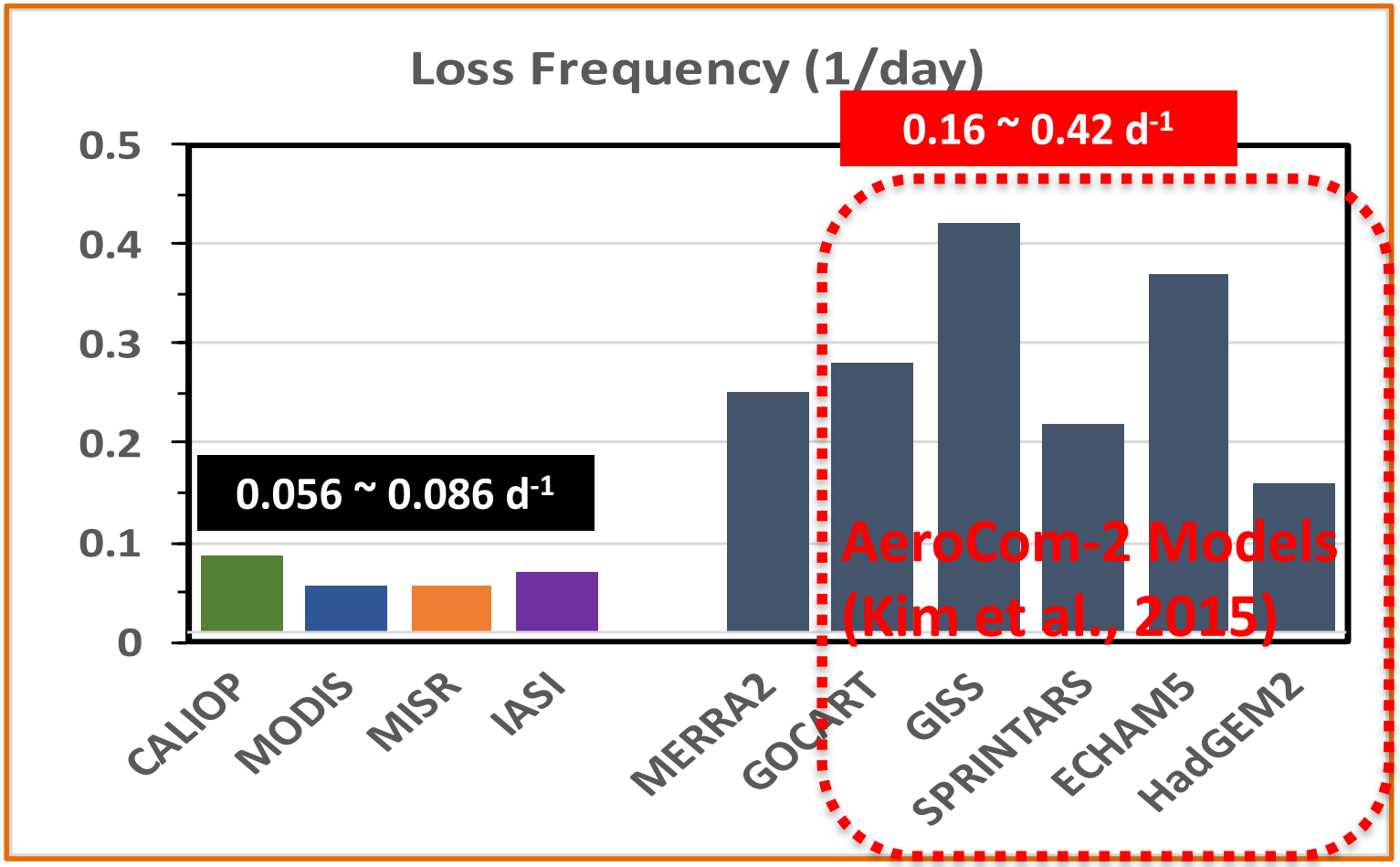
**** LF is not sensitive to dust MEE***







Dust Loss Frequency: Satellites versus Models



Models' loss frequency is more than a factor of 2 greater than that derived from the satellite observations.

Summary

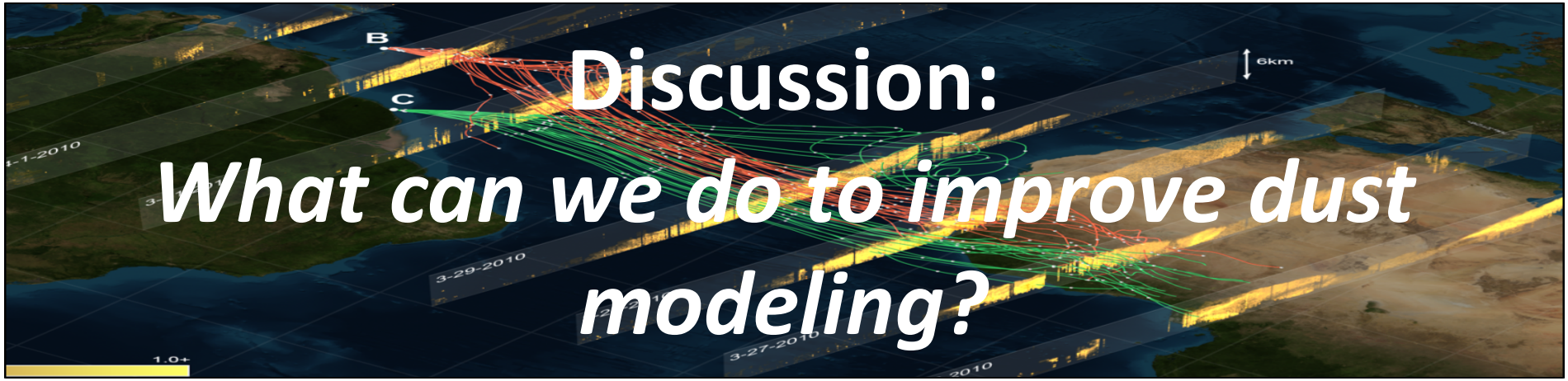
We have used 2007-2014 observations from CALIOP, MODIS, MUSR, and IASI to quantify dust deposition into tropical Atlantic Ocean and Caribbean Basin.

- The 8-year average dust deposition is **90 ~117 Tg** (North Atlantic) and **22 ~ 40 Tg** (Caribbean Basin).
- The dust deposition shows **negative correlation** *(R = -0.85 ~ -0.96)* with prior-year Sahel rainfall anomaly (e.g., SPI) over 2007-2013. But the correlation was substantially degraded by **2014** when the easterly was substantially weakened (further investigation needed).
- We estimated the regional dust loss frequency (LF) of **0.056 ~ 0.086 d^{-1}** from the satellite observations (<u>not sensitive to MEE</u>), which is at least a factor of 2 smaller than model simulations of **0.16 ~ 0.42 d^{-1}**.

Discussion

Michael Schulz offered some guidance on dust discussion:

- What is the recommendation for the dust modelling?
- For evaluating the models ?
- What should global aerosol models be able to simulate dust properly?
- Any recommendation how to parameterize?
- Good examples?



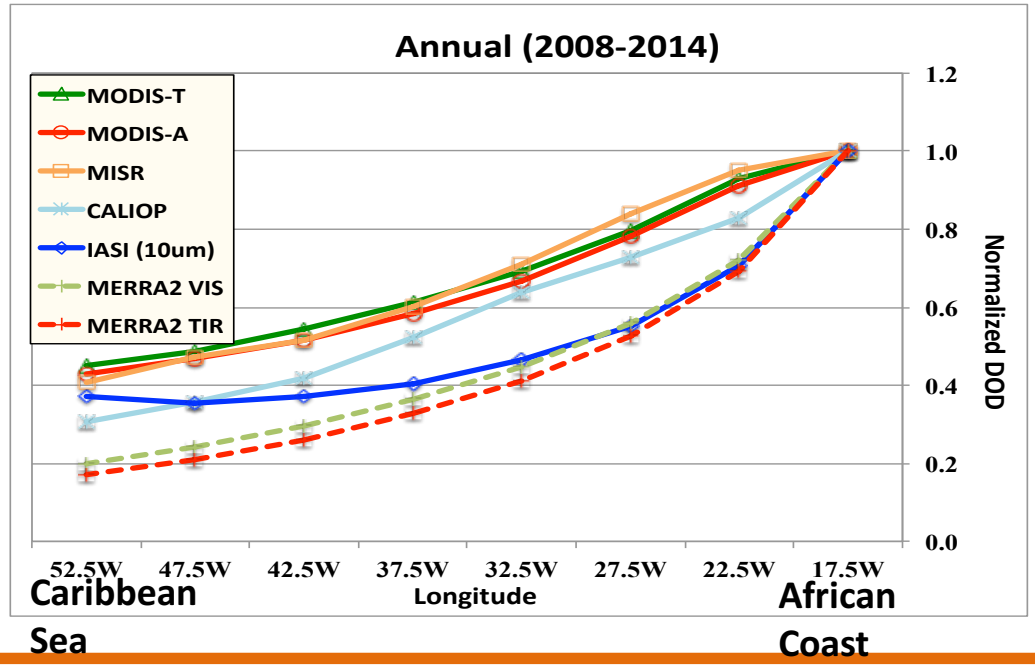
Discussion:
What can we do to improve dust modeling?

- Proposed Activity: Use recently available data sets to comprehensively evaluate model simulations of trans-Atlantic dust transport, deposition, and direct effect on SW and LW radiation.
  - Assimilation of satellite observations is a powerful tool to constrain dust loading in the atmosphere; but it doesn't necessarily improve model representations of dust processes.
  - Previous AeroCom dust activities have largely focused on global perspective.
  - More datasets are emerging over Saharan desert and the trans-Atlantic transit.

Emerging Datasets [1]: Satellites and Ground-based Networks

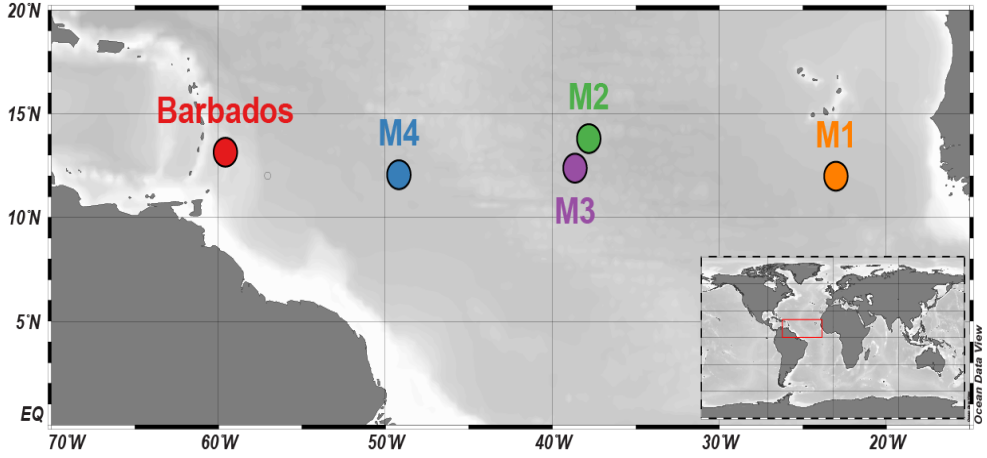
- **Ground-based networks**
- **Satellites**
  - Emissions inferred from PARASOL
  - Dust optical depth (0.55um & 10 um)
  - Dust vertical profiles
  - Dust transport & deposition (including loss frequency)

Decrease of DOD along the trans-Atlantic transit (normalized with that of African coast)

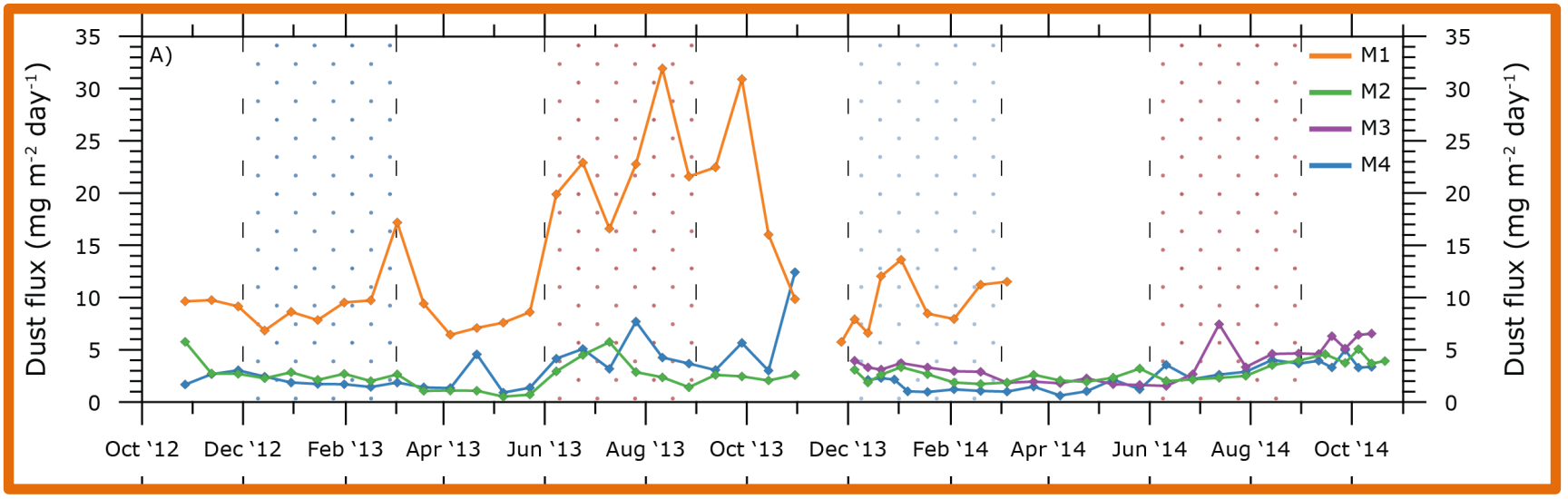


Emerging Datasets [2]: Field Campaigns
Dust Deposition from DUSTTRAFFIC

- PI: Jan-Berend Stuut
- Multi-year project *(since late 2012)*
- Sediment-trap sampling stations M1-4 , ~1200m deep, every 8-16 days
- Biogenic constituents are chemically removed

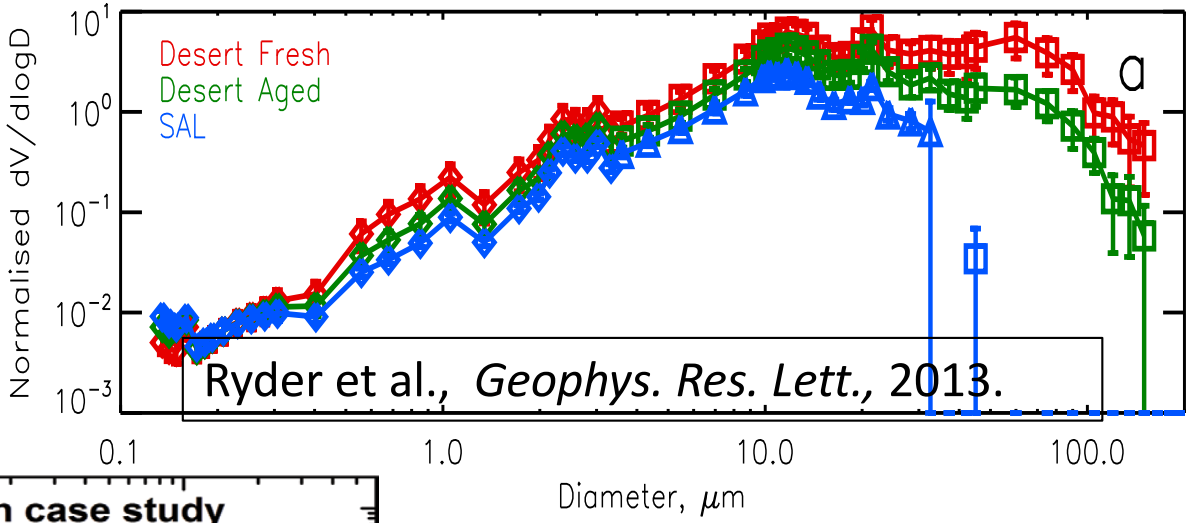


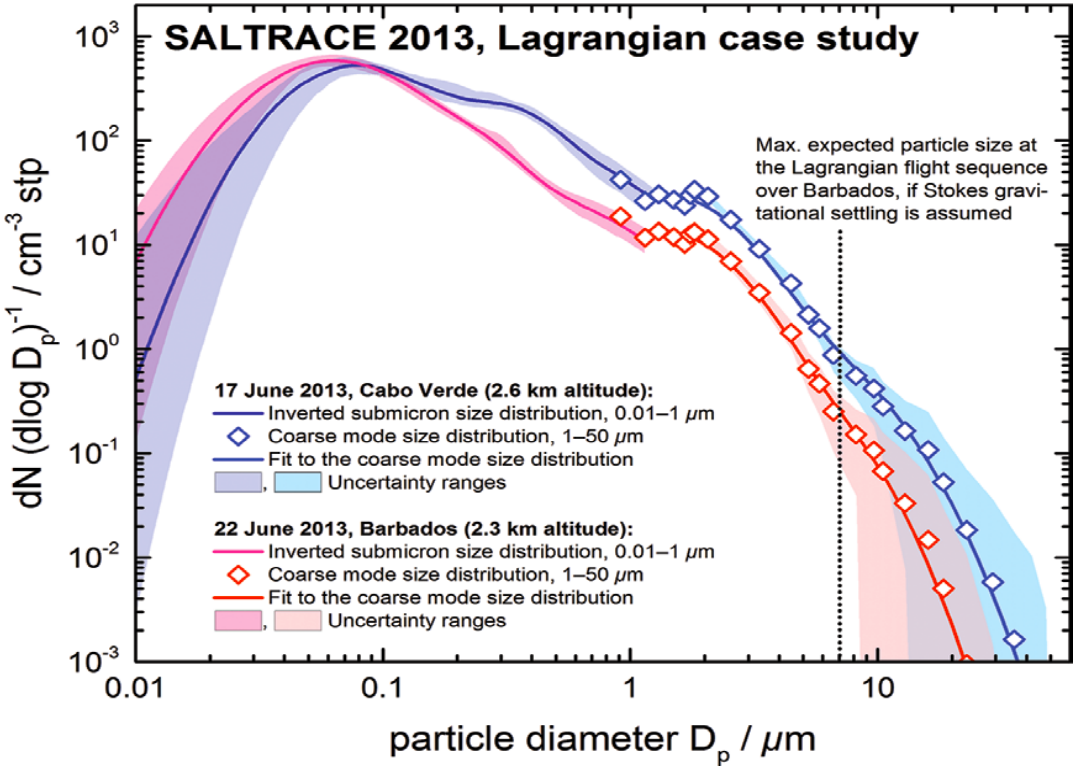
Courtesy of Michelle van der Does



Emerging Datasets [3]: Field Campaigns
FENNEC & SALTRACE

FENNEC Campaign (2010)





SALTRACE: The Saharan Aerosol Long-Range Transport and Aerosol–Cloud-interaction Experiment (2013-2014)

Weinzierl et al., *BAMS*, 2017