"Dust Sinking"

African Dust and Its Deposition into Tropical Atlantic Ocean: Satellites vs. GEOS Model

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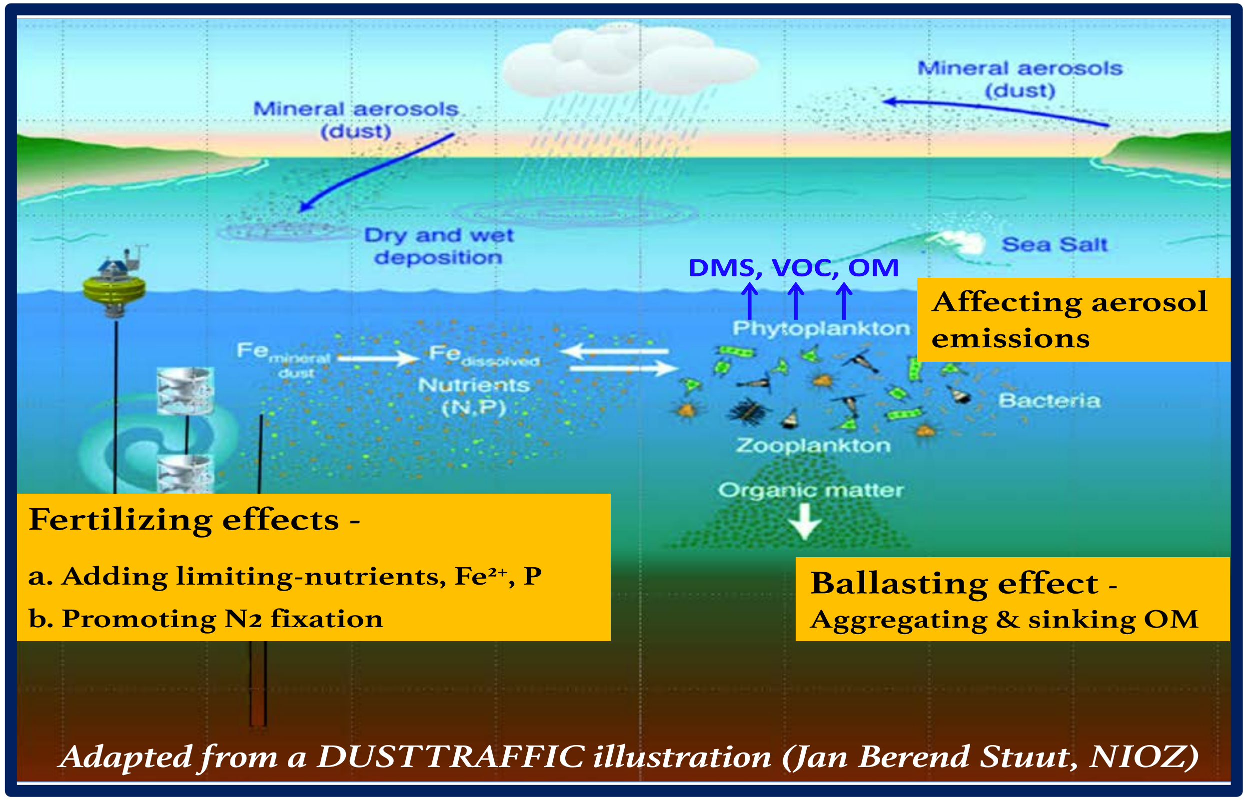
Motivation

- Dust deposition is crucial for understanding the dust impacts on ocean biogeochemical cycle and climate change.



Current Status

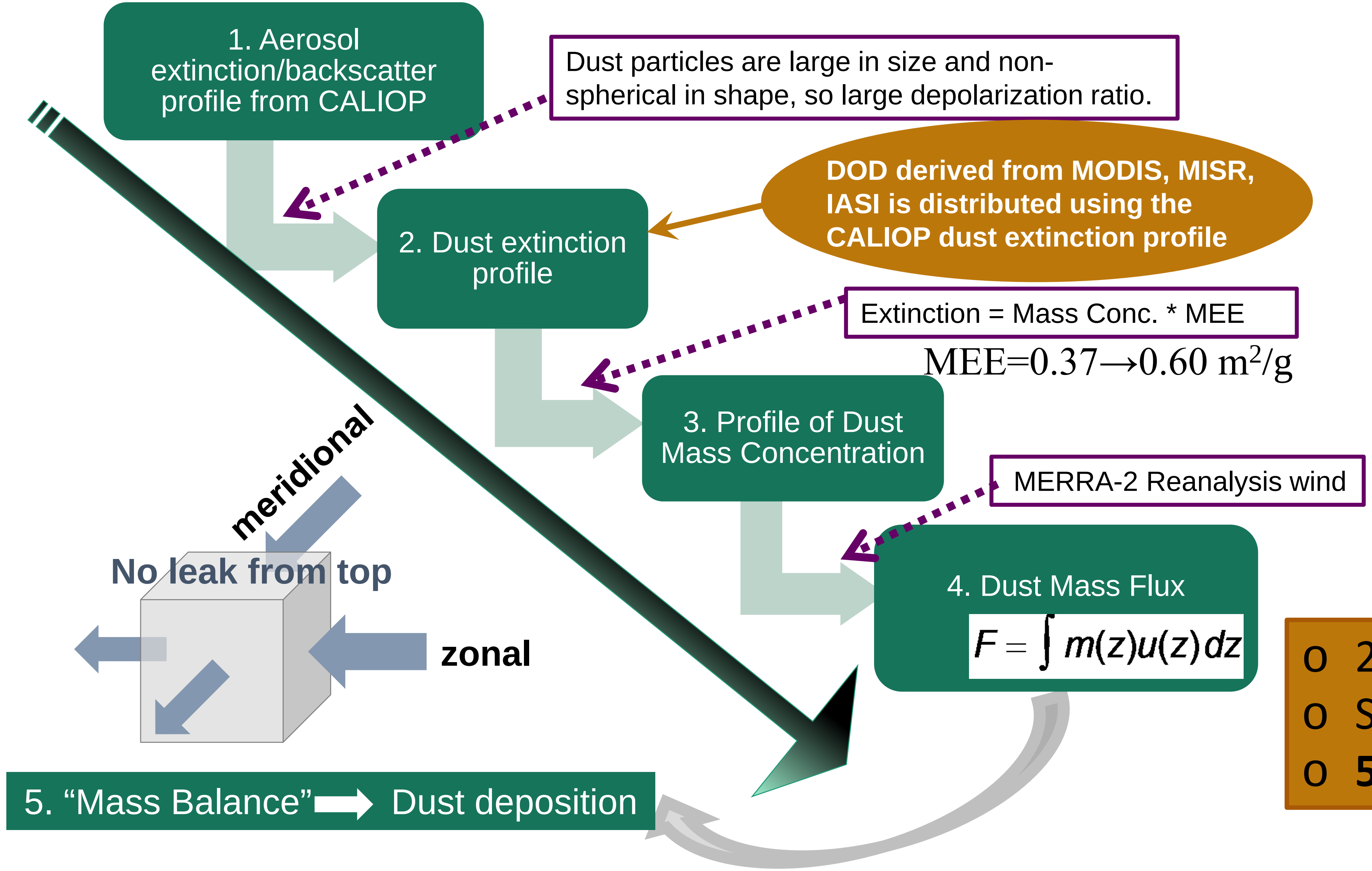
- <u>Observations</u> are scarce & over short periods, esp. in remote oceans.
- <u>Model simulations</u> are very uncertain:
  - Most of dust processes are highly parameterized without adequate obs. constraints, e.g., scavenging, emissions.
  - Data assimilation, being widely used to constrain aerosol loading in the atmosphere (AOD), does not constrain the dust deposition.

Objectives

- **Explore the use of satellite routine measurements to estimate:**
  - dust deposition (DD) into tropical Atlantic Ocean
  - loss frequency (LF) of dust *(i.e., how efficient dust is removed)*

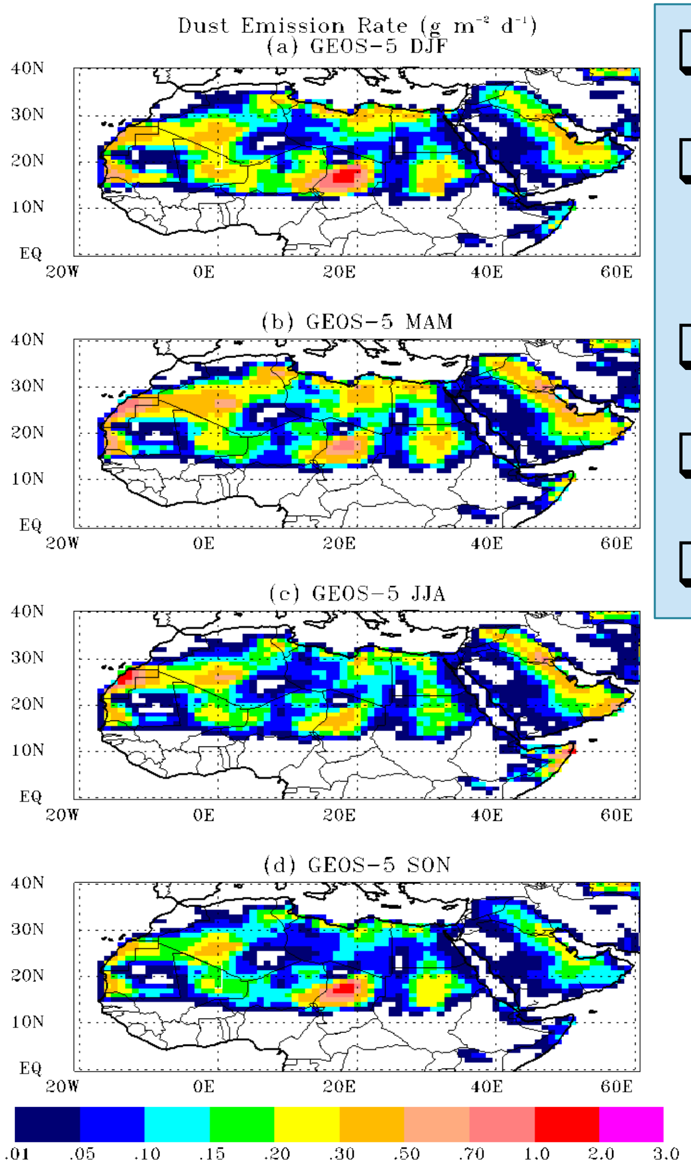
- **Compare satellite-based estimates with GEOS simulations to understand:**
  - *How large is the difference in dust deposition?*
  - *How do processes, e.g., transport/removal vs. dust emissions, contribute to the observation-model agreement or discrepancy in the dust deposition?*

Estimation of Dust Deposition from Satellites

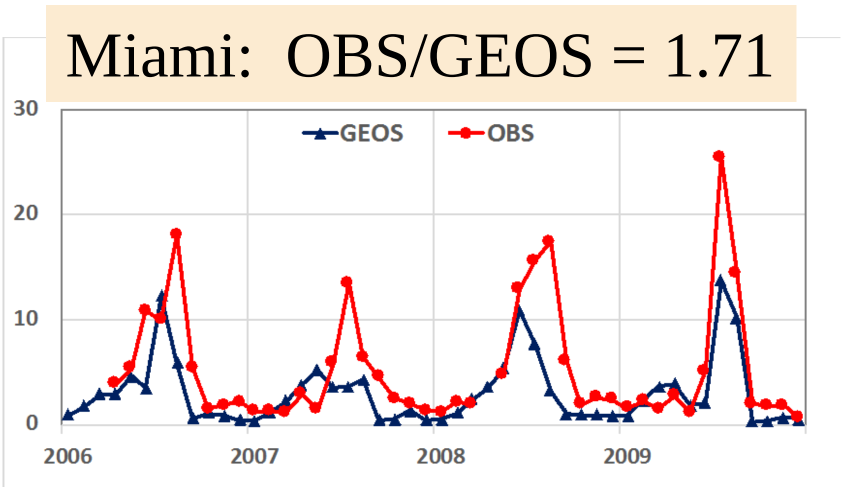


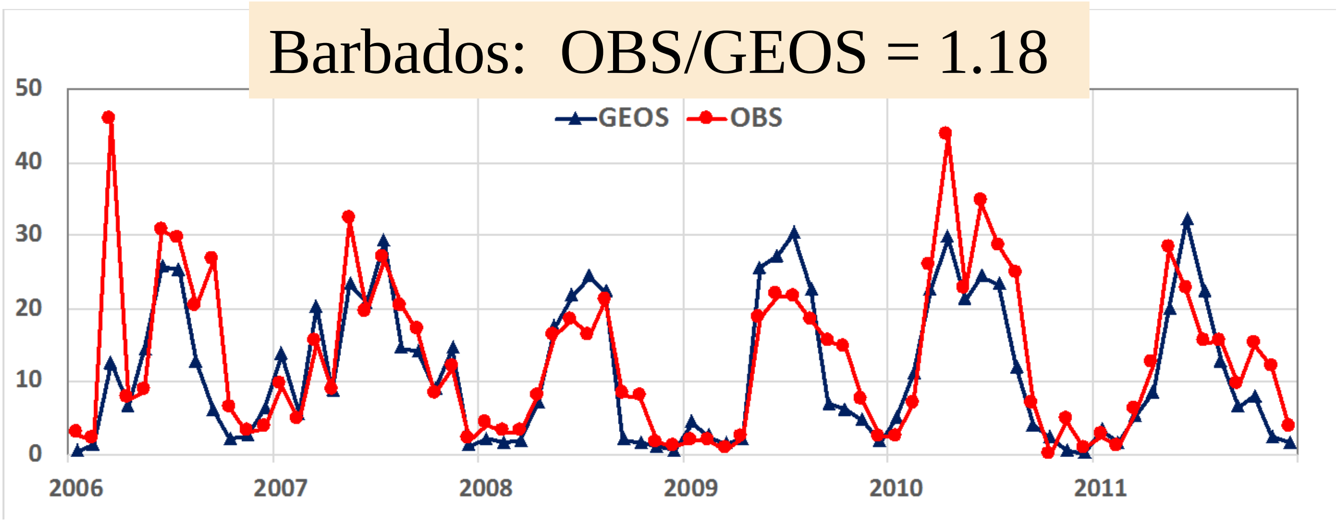
- 2007-2016 data
- Seasonal basis
- **5ºx2º resolution**

GEOS Dust Simulations

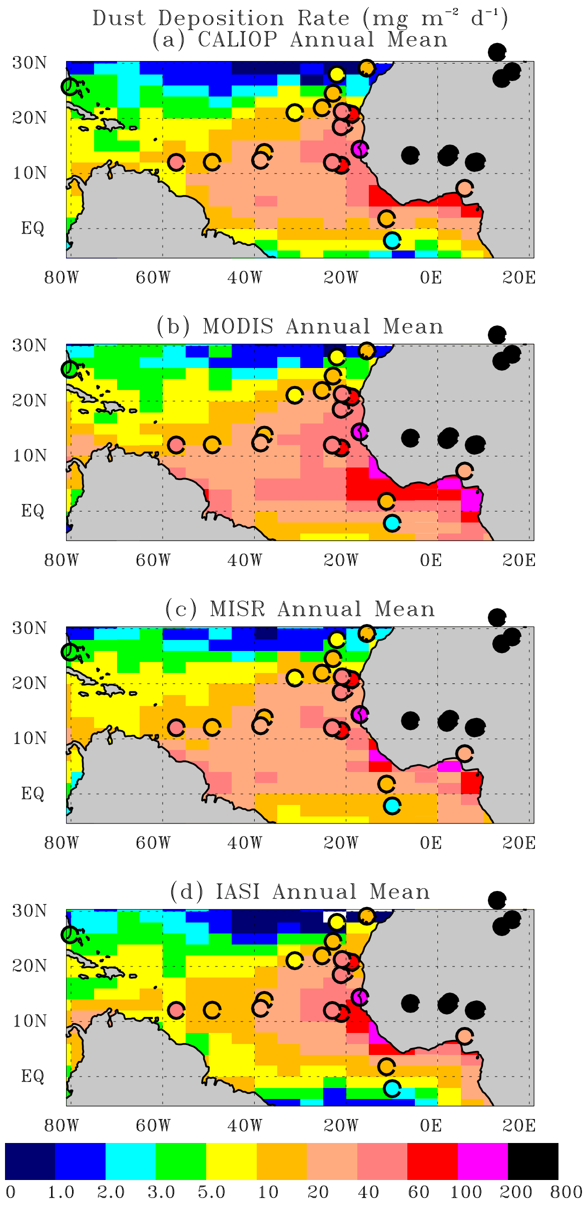


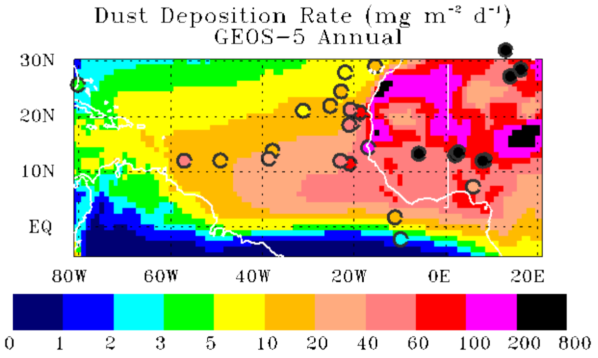
- Huisheng Bian
- GOCART dust module *(0.2 ~ 20 μm)*
- MERRA-2 meteorology
- 1°x1° horizontal resolution
- 72 vertical layers





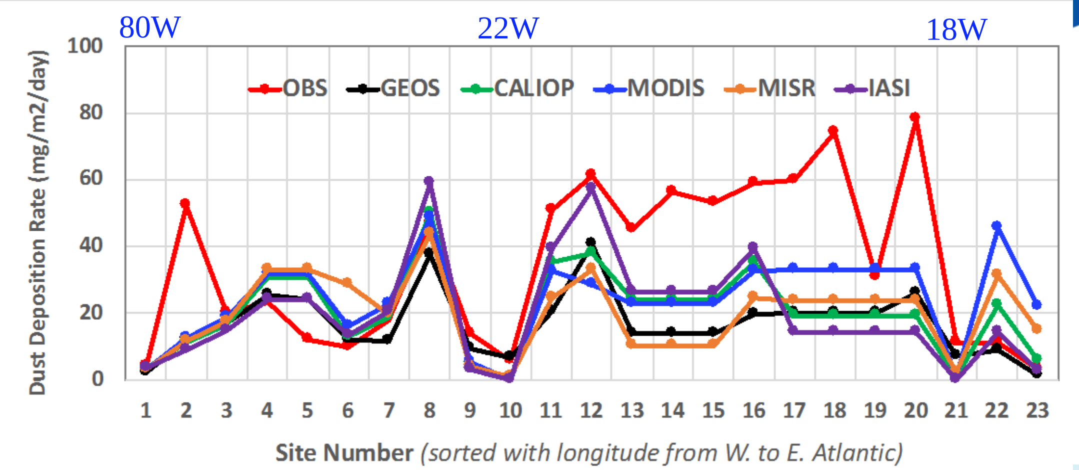
Dust Deposition: Satellites vs GEOS [1]





Over land: *OBS = 5 x GEOS*

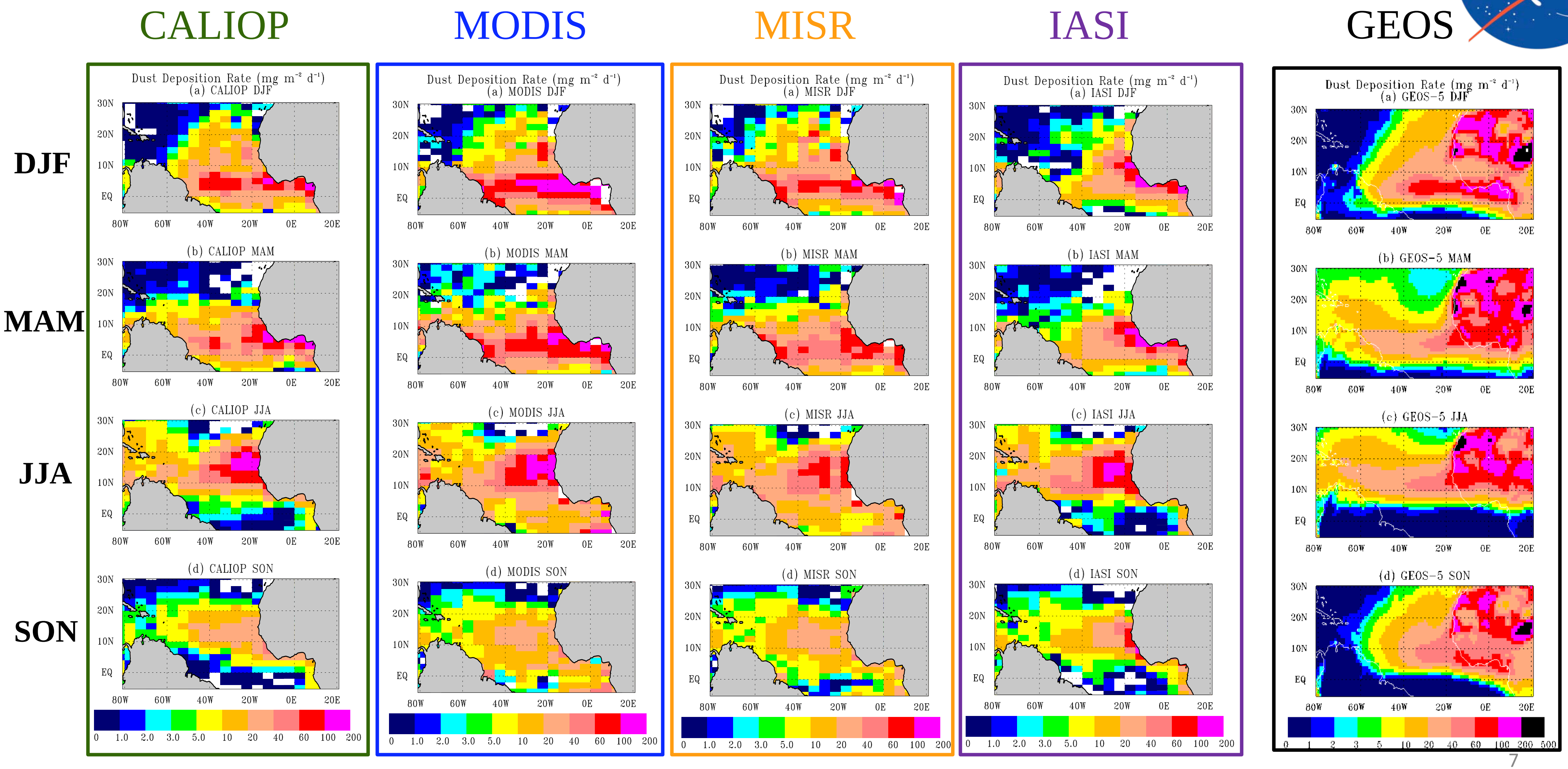
North Atlantic Ocean



● **representing surface-based climatology (34 = *23 ocean* + *11 land*)**

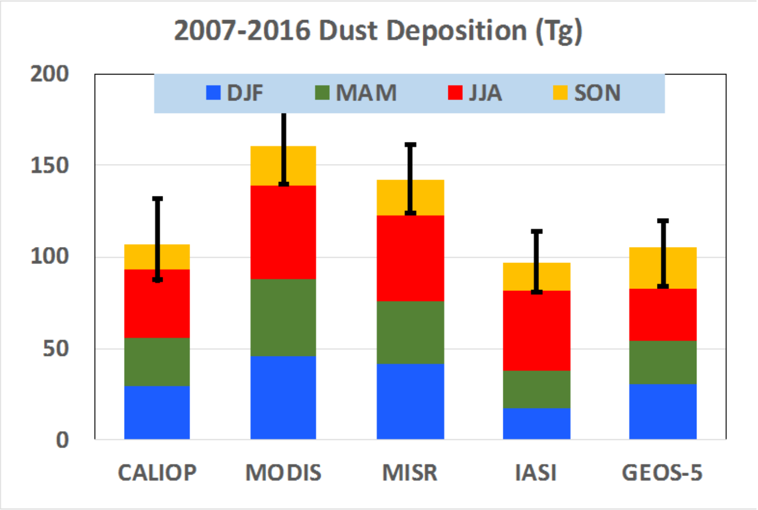
- historic data at 23 sites (16 ocean + 7 land) (*widely used in model evaluation, e.g., Albani et al., 2014*)
- 5 DUSTTRAFFIC ocean moorings along ~12N (*Korte et al., 2017; dust = total - biogenic*)
- 2 sediment traps around 20N (*Fries et al., 2017*)
- 3 Sahelian Dust Transit (AMMA) sites (LAND ONLY) (*Marticorena et al., 2016*)
- 1 site in Mbour (W. Africa margin) (*Skonieczny et al., 2013*)

Dust Deposition: Satellites vs GEOS [2]

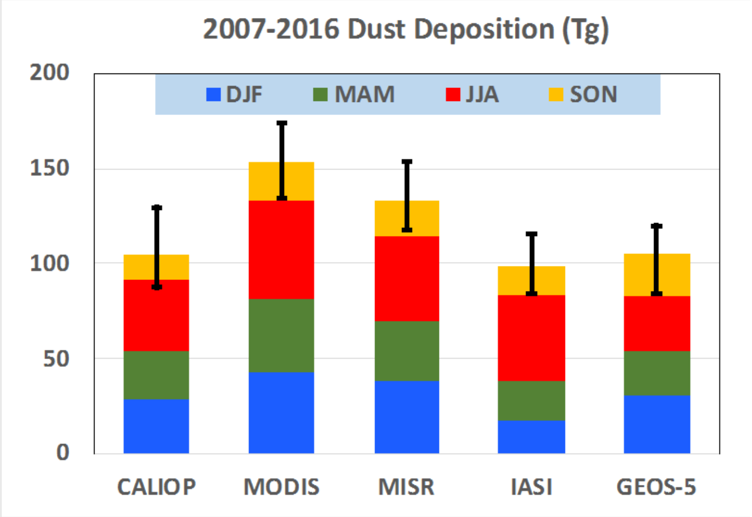


Dust Deposition: Satellites vs GEOS [3]

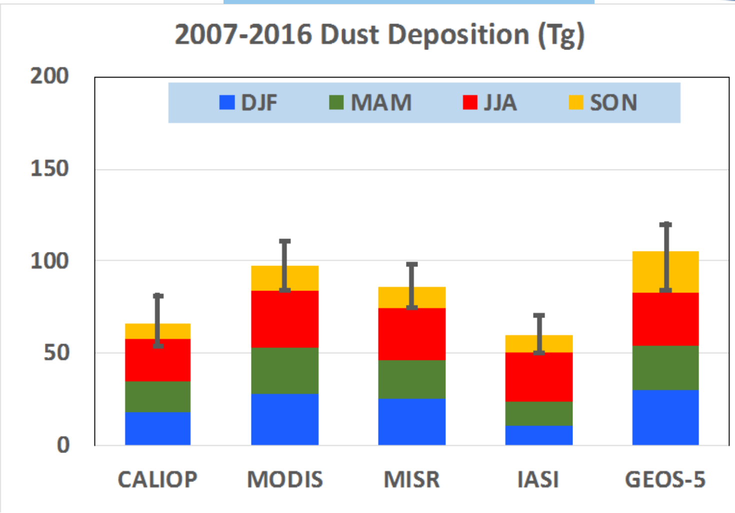
MEE = 0.37 m^2/g

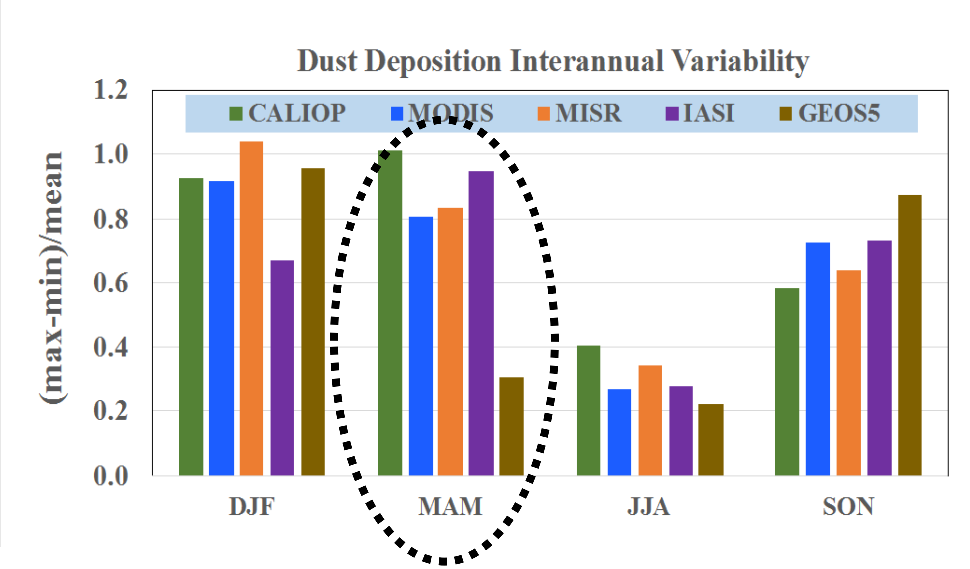


MEE = 0.37 → 0.60 m^2/g



MEE = 0.60 m^2/g





In MAM, model's interannual variability is much smaller than satellites.

What We Have Learned:

The GEOS model simulations of **dust deposition** into tropical Atlantic Ocean fall within the range of those derived from CALIOP, MODIS, MISR, and IASI observations.

Next Steps:

We examine how two dust processes, i.e., **(1) transport/removal**, and **(2) emissions**, contribute to the dust deposition estimates.

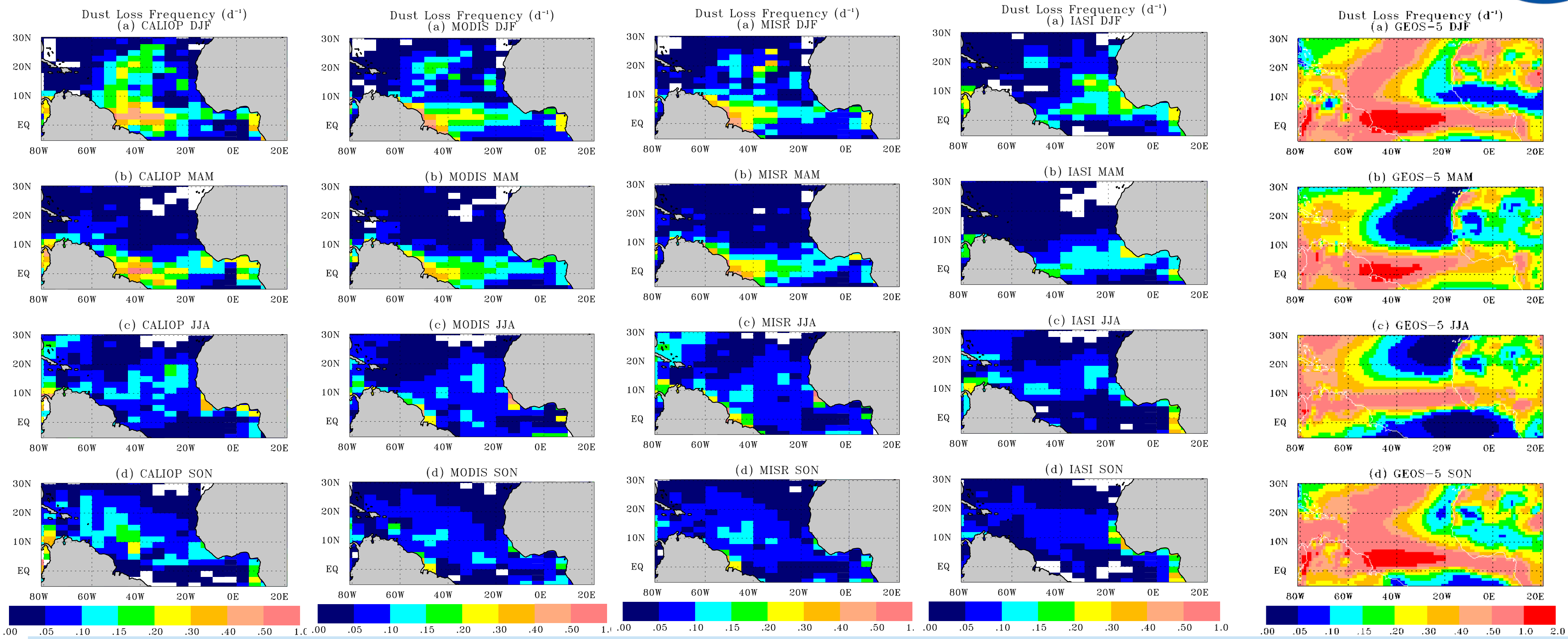
To isolate the uncertainty associated with the transport/removal processes from that of dust emissions:

Loss Frequency (LF) *[1/day]* = [Dust Deposition Rate] *[g/m²/day]* ÷ [Dust Mass Loading=DOD/MEE] *[g/m²]*

- ➢ less sensitive to assumed dust MEE (more accurate than dust deposition)

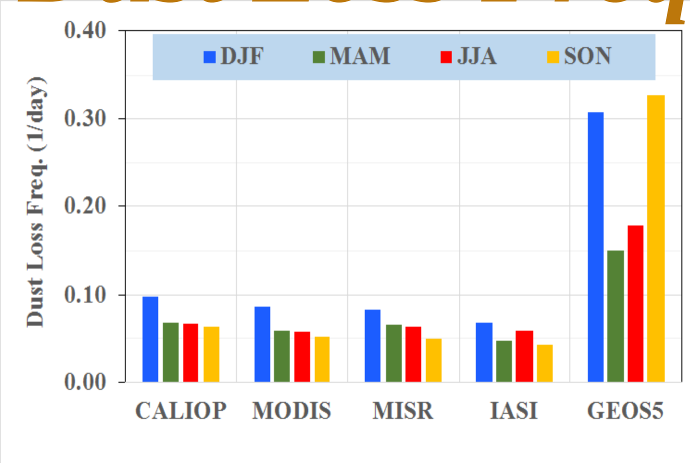
Dust Loss Frequency: Satellites vs Model [1]

CALIOP **MODIS** **MISR** **IASI** **GEOS**



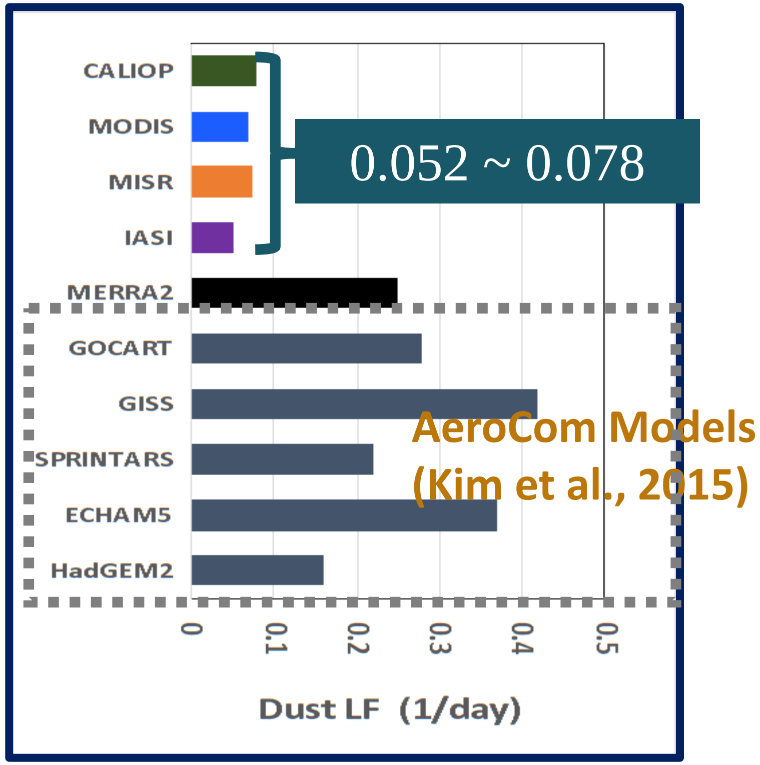
Compared to dust deposition, the loss frequency shows much larger satellite-model difference, with the model substantially overestimating the removal efficiency of the dust.

Dust Loss Frequency: Satellites vs Model [2]



Pronounced differences between the satellites and GEOS model:

- ➢ GEOS model > Satellites
- ➢ much larger in winter & fall than in spring & summer

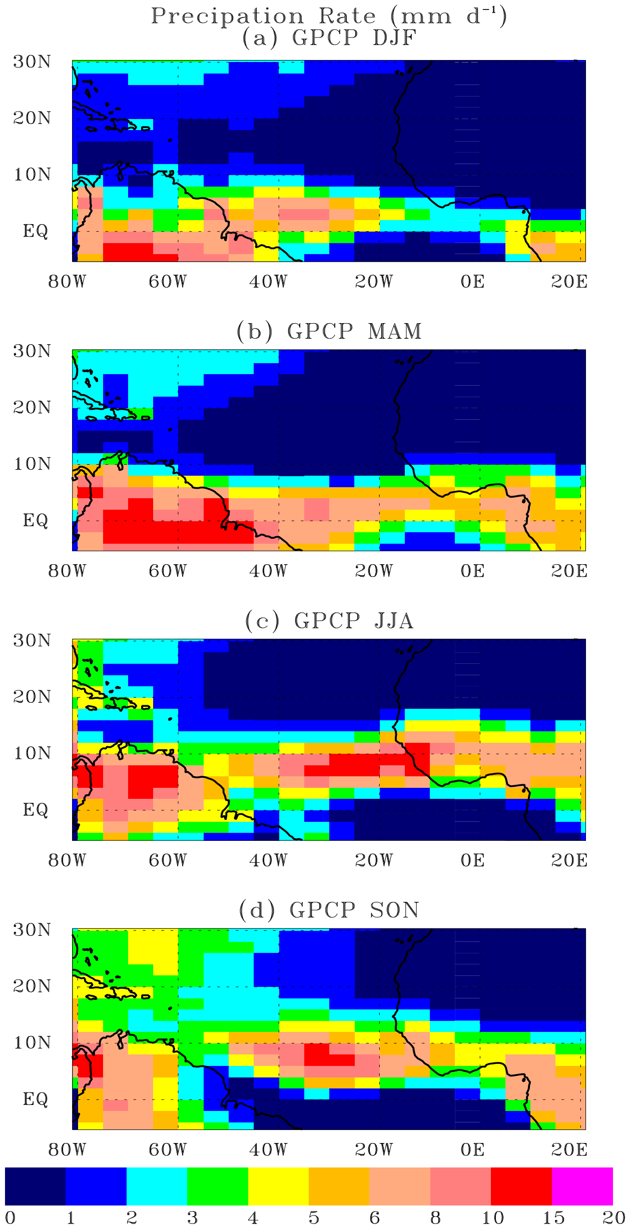


<u>*Possible model deficiencies*</u>

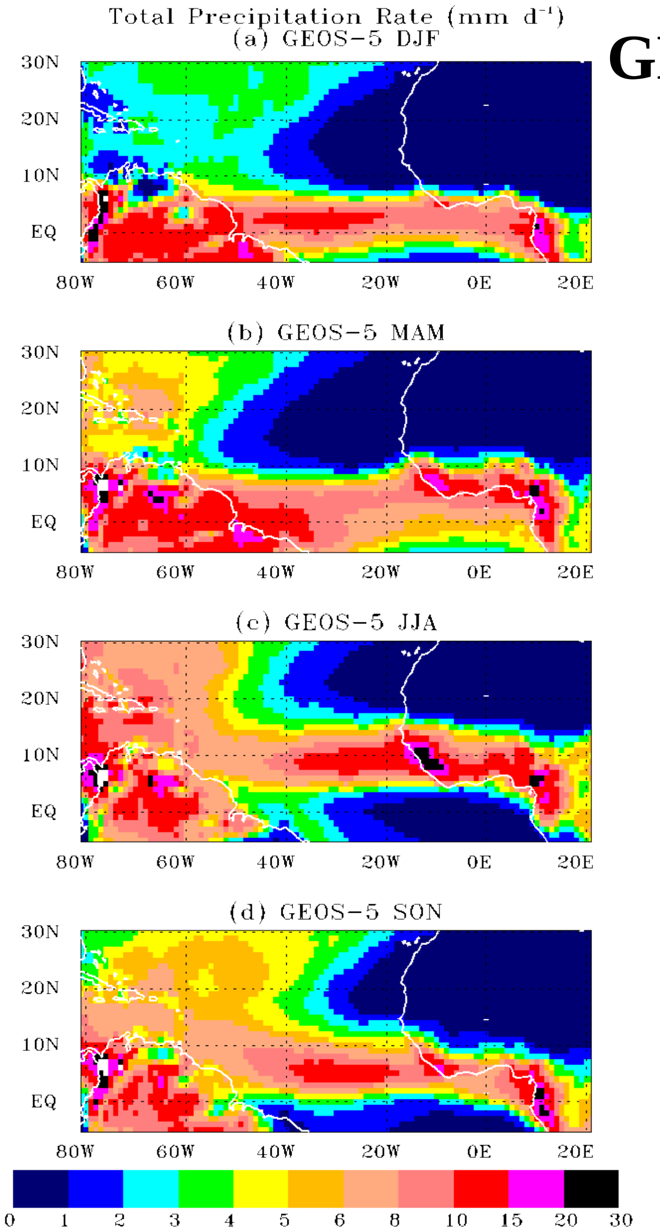
- ➢ ***Rainfall may be too intense***
- ➢ ***Altitude of dust layer may be too low***
- ➢ Scavenging coefficient may be too high
- ➢ Settling and dry deposition may be too fast

Model's rainfall is much more intense than GPCP

GPCP



GEOS5



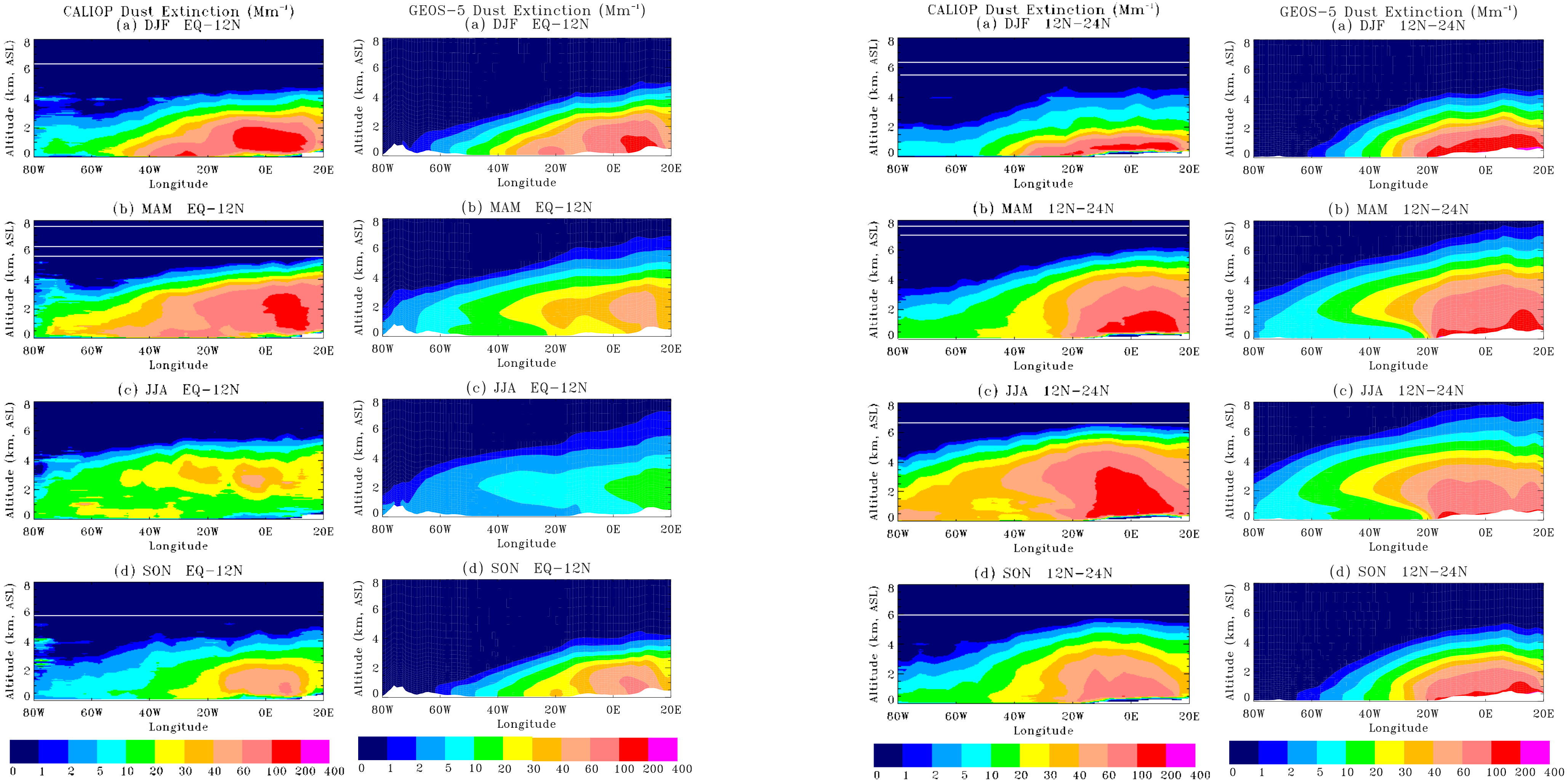
Model's dust extinction profiles show reasonably good agreement with CALIOP observations

[EQ-12N]

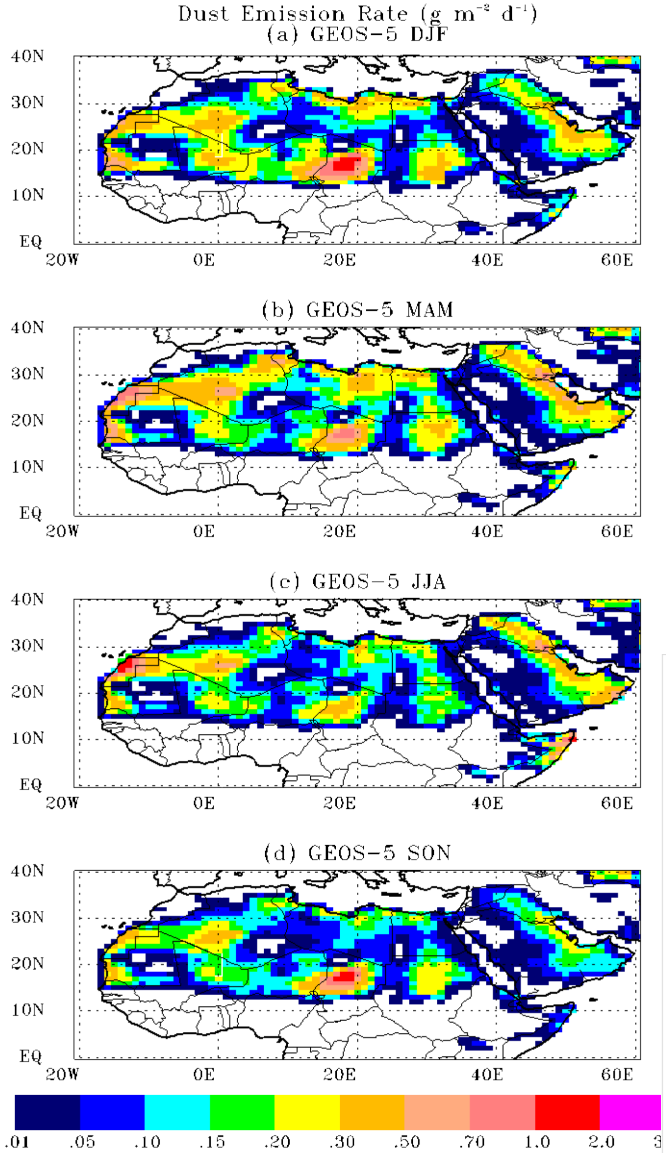
CALIOP **GEOS-5**

[12-24N]

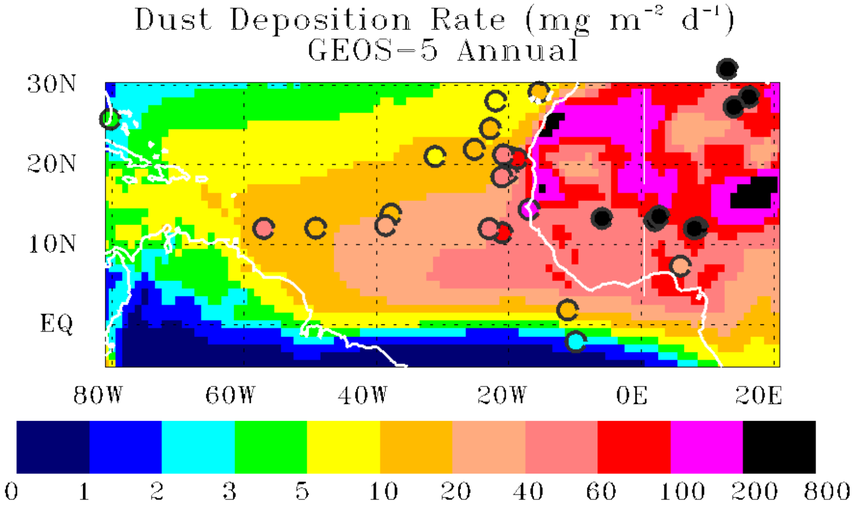
CALIOP **GEOS-5**



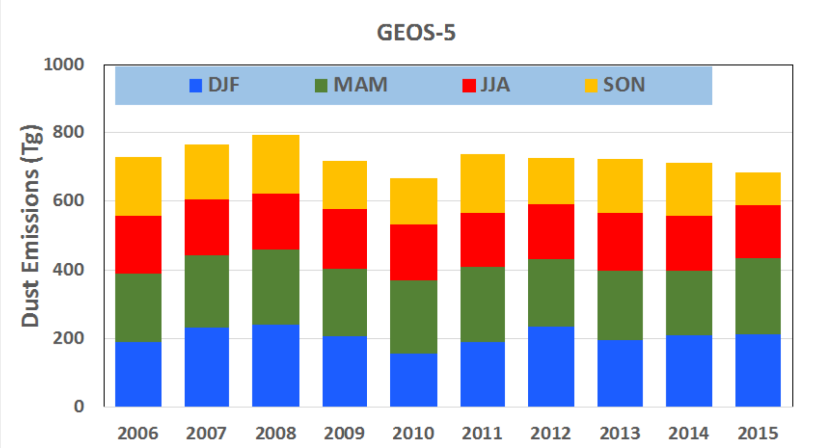
How Well Does GEOS Represent Dust Emissions? [1]



- *Does the model capture major dust sources?*
- *Are magnitudes of dust emissions biased high or low?*



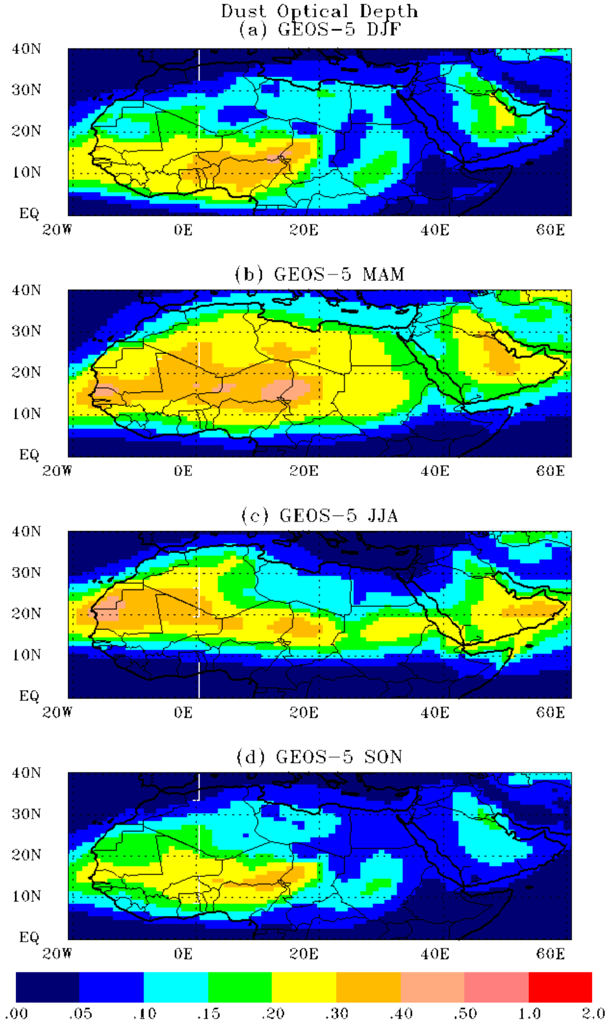
North Africa & Middle East



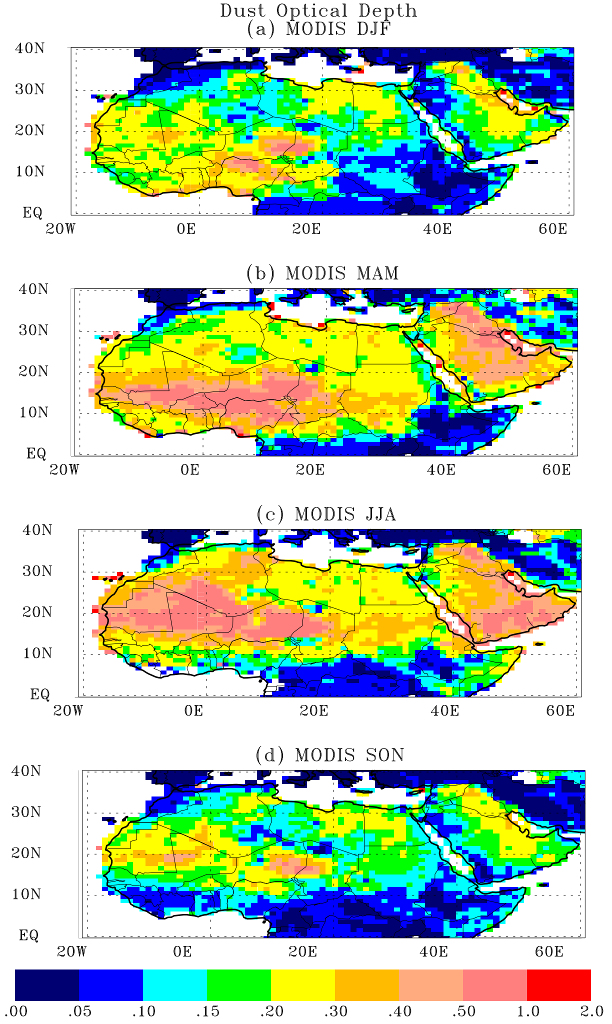
Over land, the comparison against surface dust deposition measurements appears to indicate a substantial underestimate of dust emissions.

How Well Does GEOS Represent Dust Emissions? [2]

GEOS DOD

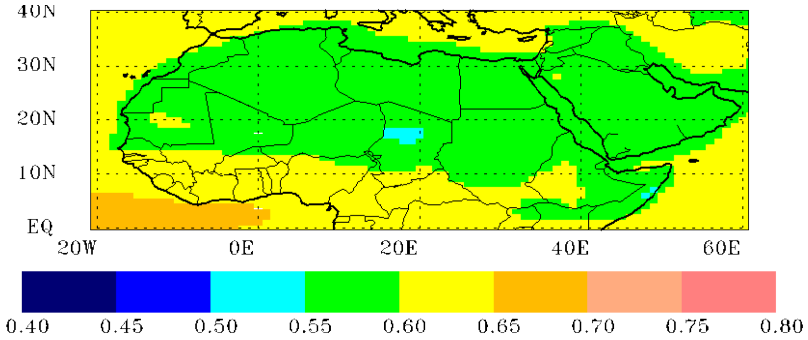


MODIS-derived (Paul Ginoux)



- *The model is mass-based.*
- *DOD = [Mass Loading] * MEE*
- *It is necessary to understand potential bias in MEE.*

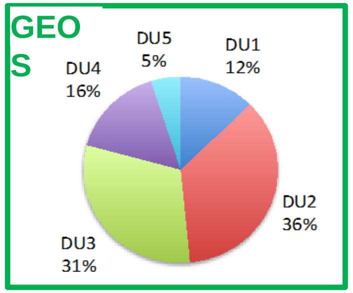
GEOS Dust MEE

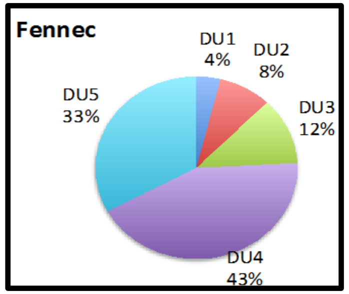


PSD

DU1-DU2-DU3:
$0.2<D_e<6.0\mu m$

DU4-DU5:
$6.0<D_e<20\mu m$

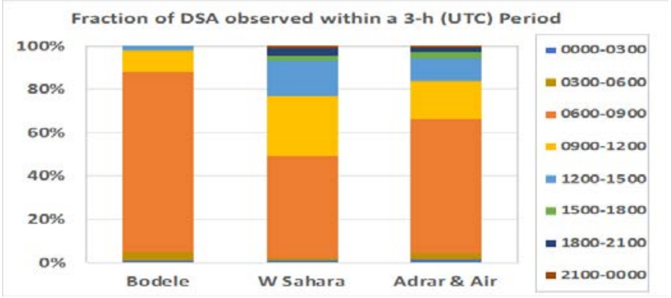




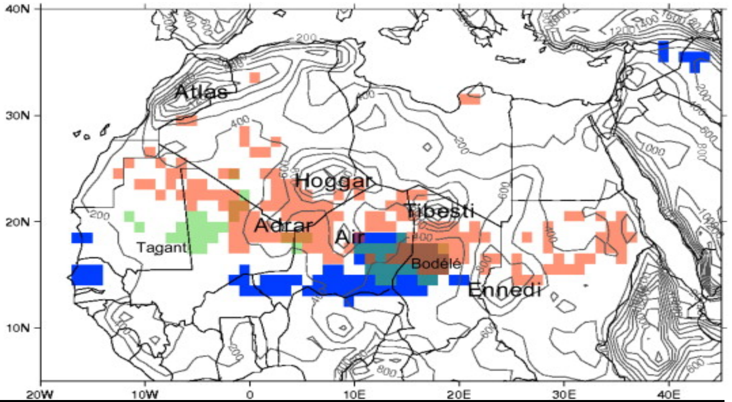
- ✓ The PSD is biased to fine particles
- ✓ Particles >20μm excluded
- ✓ The model MEE would be biased high.

How Well Does GEOS Represent Dust Emissions? [3]

SEVIRI Dust Source Activation (DSA)



Satellite-identified dust source regions

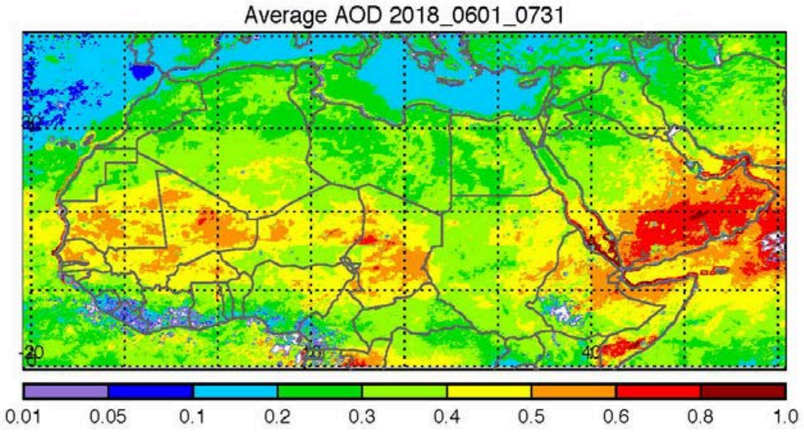


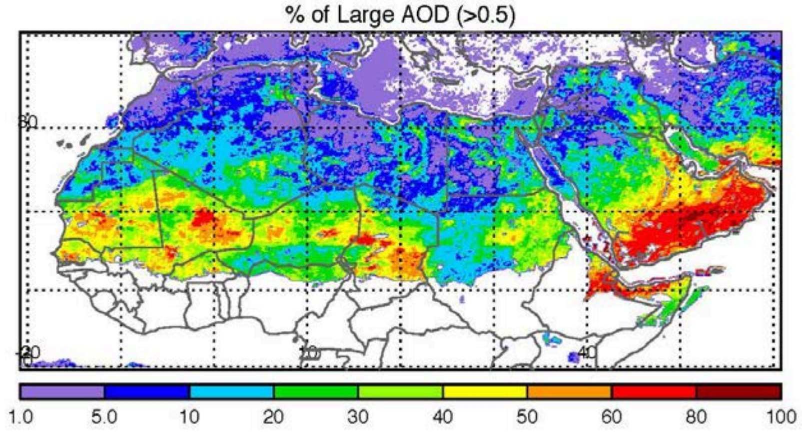
- Red – SEVIRI DSA frequency (> 6%)
- Blue – MODIS OF[AOD>0.5] > 40%
- Green – OMI OF[AI>2]> 40%.

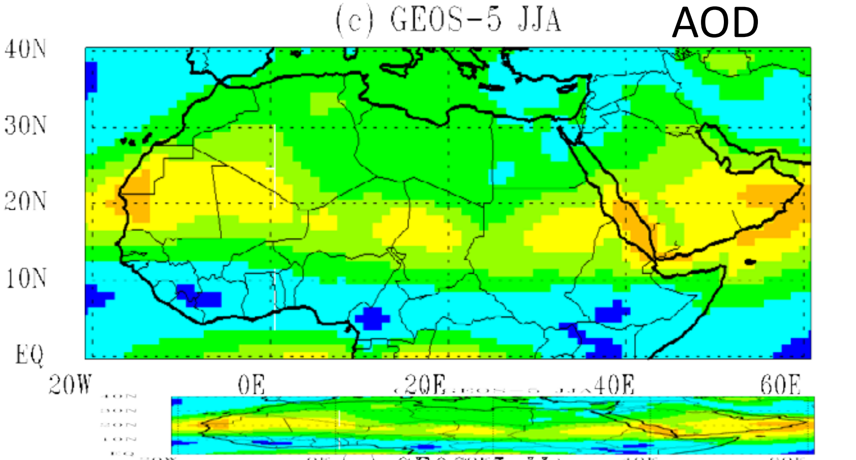
Large discrepancies in dust source areas are believed to be related to the temporal resolution of satellite measurements *(Schepanski et al., 2009, 2012)*

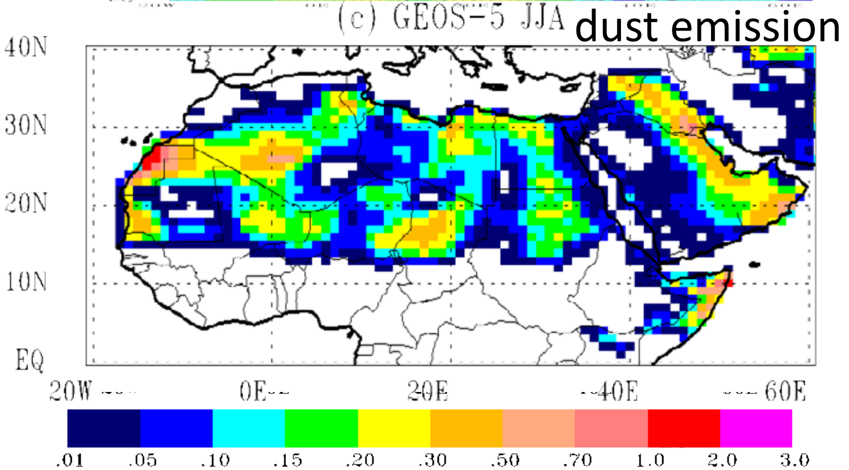
DSCOVR/EPIC MAIAC product (Alexei Lyapustin)

- **D**eep **S**pace **C**limate **O**bser**V**ato**R**y (L1, one million miles away)
- **E**arth **P**olychromatic **I**maging **C**amera
- Sunrise-to-sunset, 1-2 hourly frequency, ~10km pixel resolution
- MAIAC atmos. Corr. Product (including AOD)







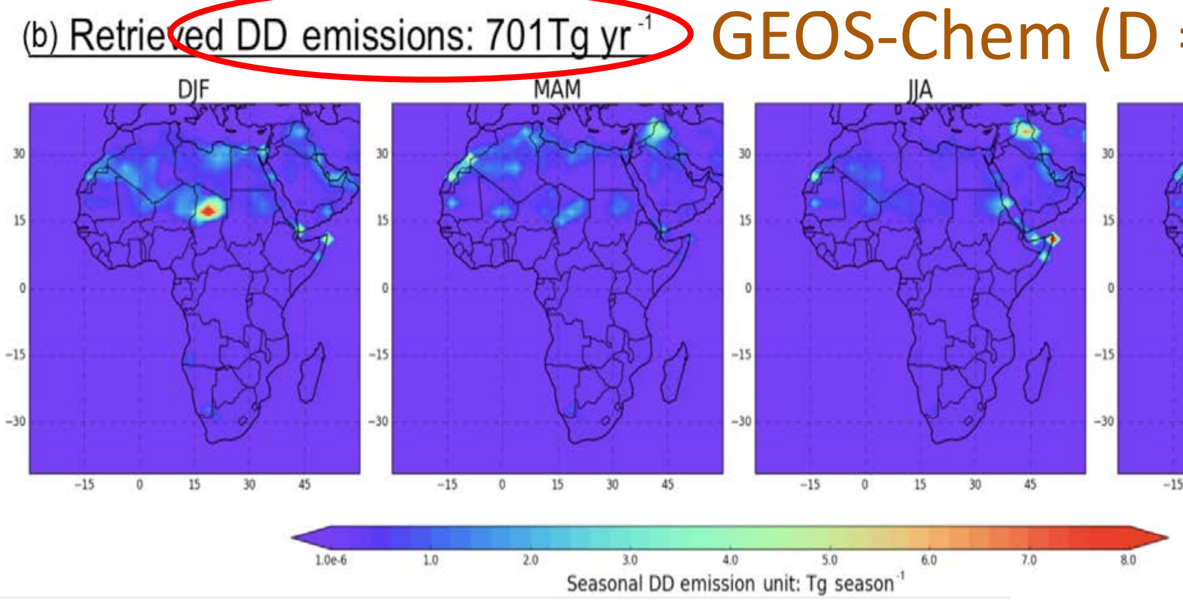


Conclusions

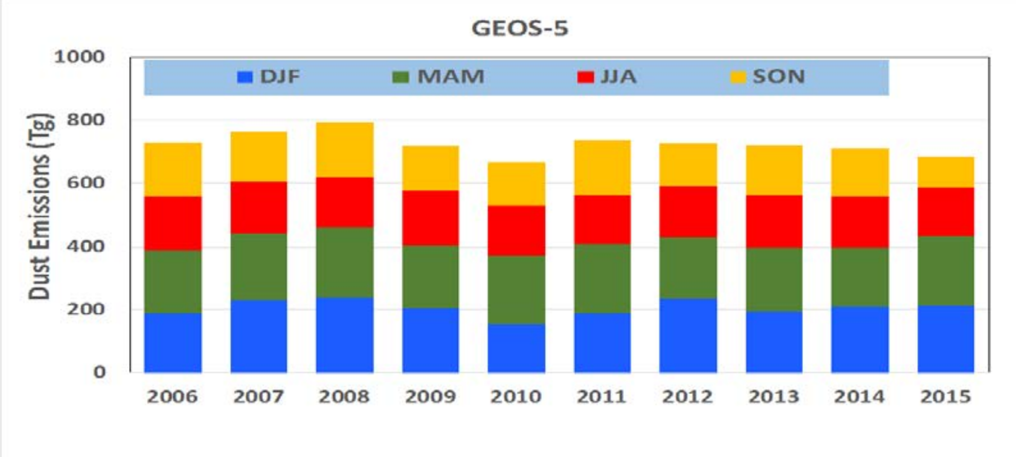
- ***A 10-year climatology of dust deposition*** into tropical Atlantic ocean was developed from CALIOP, MODIS, MISR, and IASI measurements *(seasonal, 5°x2° resolution)*.
- The GEOS modeling of dust deposition *falls within the range* of satellite-based estimates.
- However, the reasonable agreement in the dust deposition is a ***compensation*** of the model's:
  - ***underestimate of dust emissions,*** and
  - ***overestimate of dust removal efficiency*** (i.e., higher dust loss frequency, which is due largely to the model's ***overestimate of rainfall rate***).

How Well Does GEOS Represent Dust Emissions? [2]

Chen, C., *Retrieval of desert dust and carbonaceous aerosol emissions over Africa from POLDER/PARASOL products generated by the GRASP algorithm, ACP, 18, 12551-12580, 2018.*

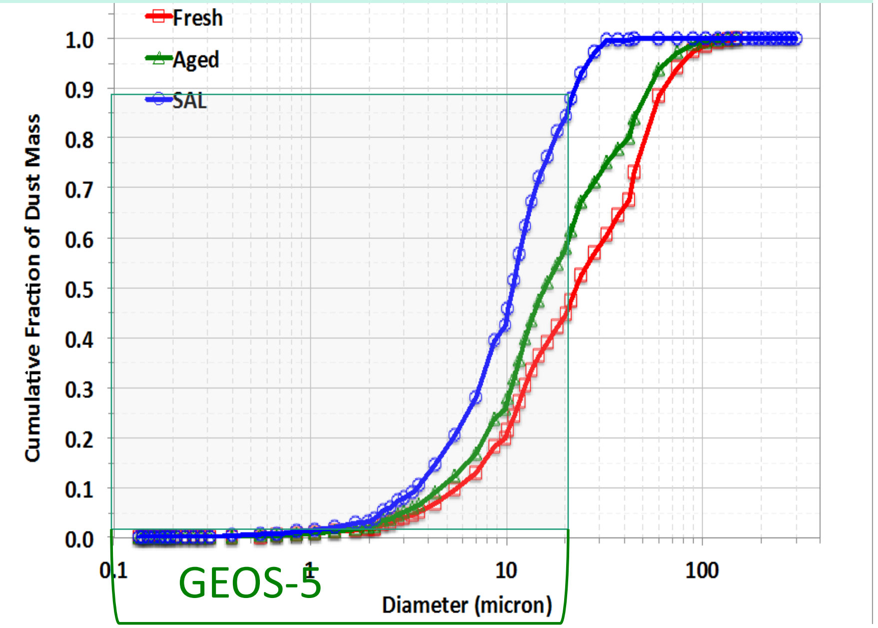


GEOS-Chem (D = 0.2~12 um)

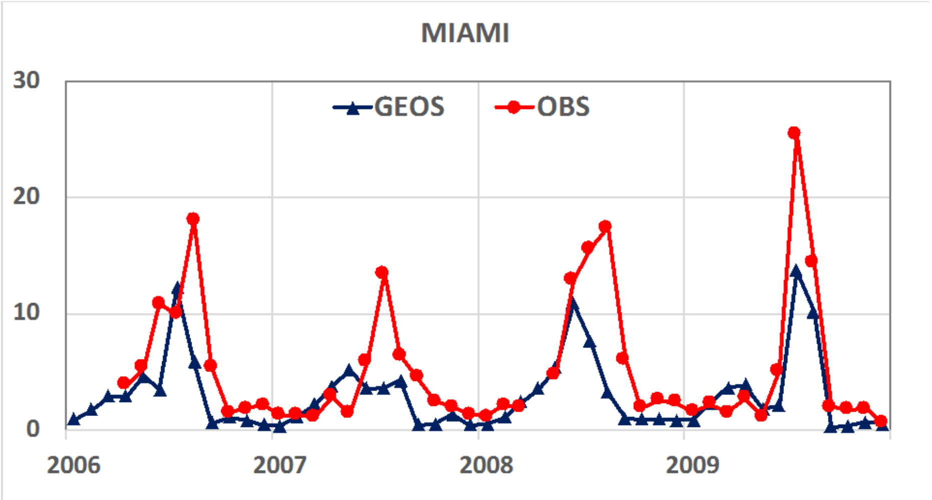


GEOS (D = 0.2~20 um)

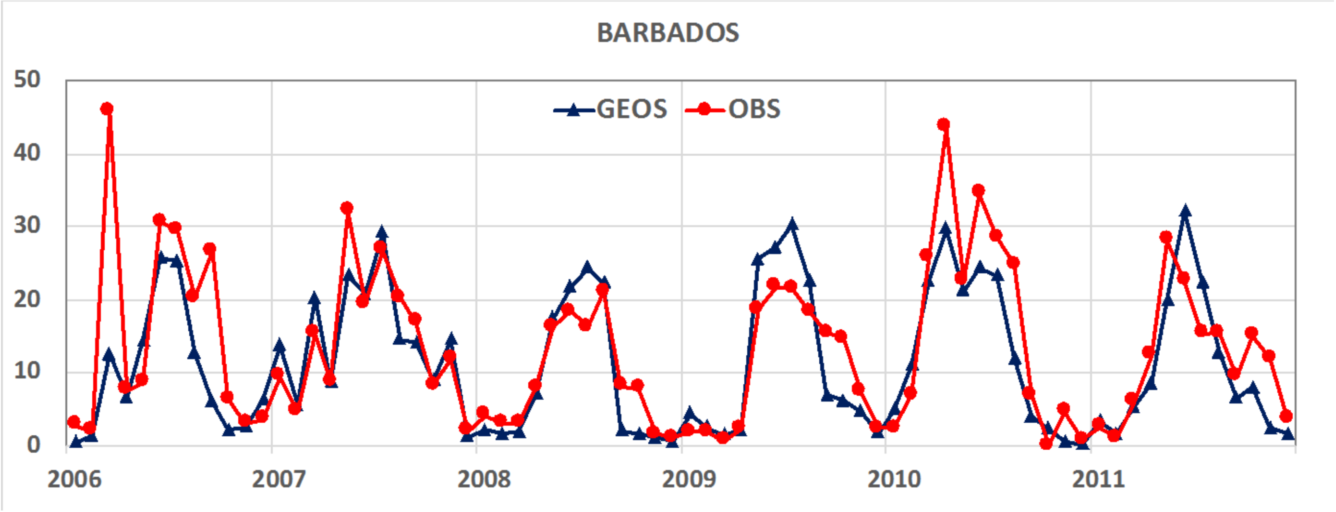
Fennec Cumulative Fraction of Dust Mass as a Function of Particle Size



Does GEOS model underestimate dust concentration?



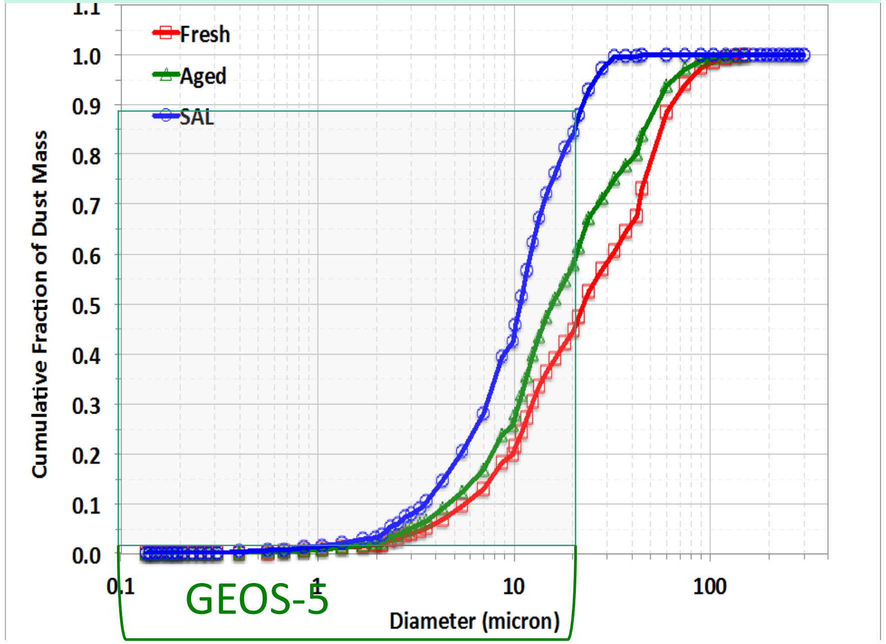
Miami: OBS/GEOS = 1.71



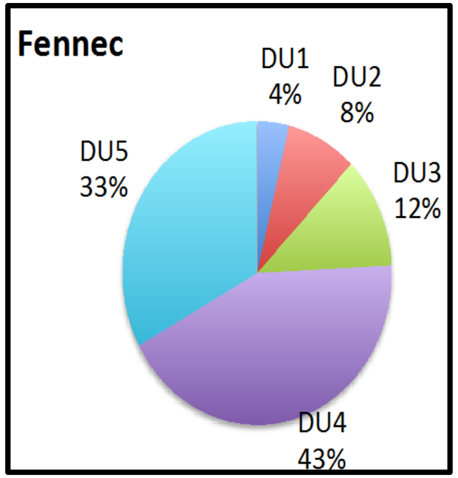
Barbados: OBS/GEOS = 1.18

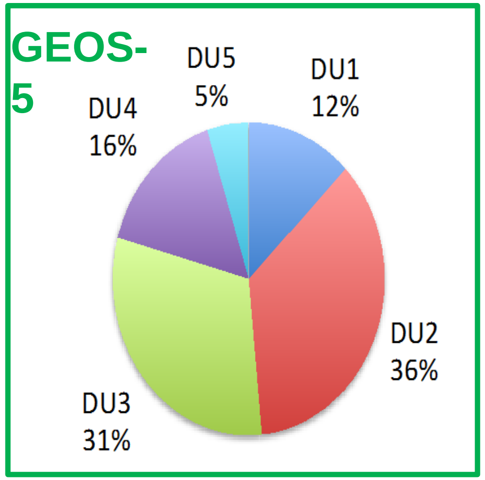
GEOS-5: underestimating coarse particles, but overestimating fine particles

Fennec Cumulative Fraction of Dust Mass as a Function of Particle Size



Size distribution (SAL)





DU1-DU2-DU3: $0.2 < D_e < 6.0$ **μ**m
DU4-DU5: $6.0 < D_e < 20$ **μ**m

- GEOS-5 substantially **overestimates the fraction of dust < 6 μm**, but **underestimates the fraction of very coarse particles (> 6 μm) :**
  - higher dust MEE – affecting model-satellite comparisons/assimilation
  - longer transport of dust, *IF dust removals are accurately done.* But we just showed that the dust loss frequency is much larger than satellites – need to improve dust removal schemes .

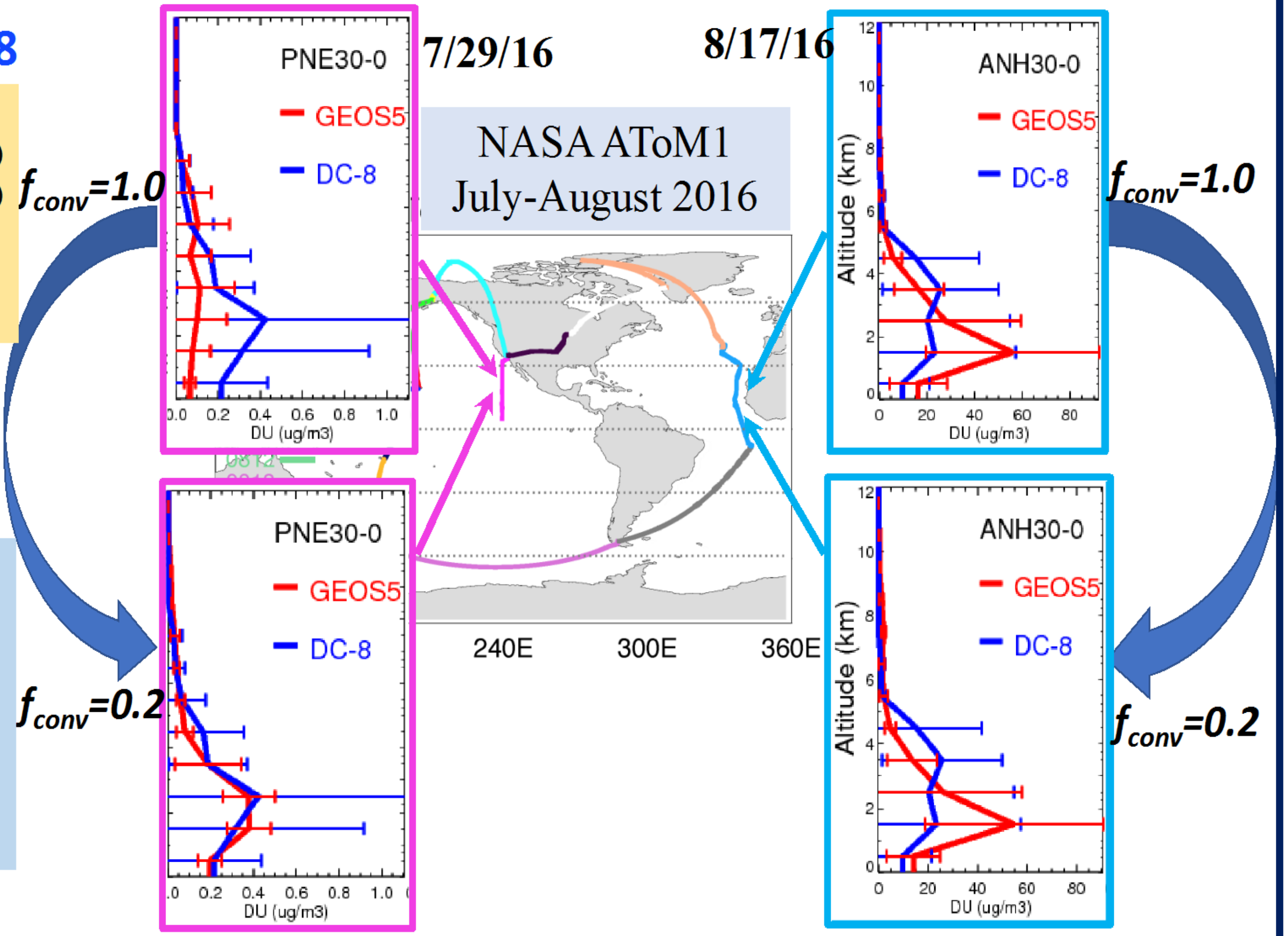
Reducing Convective Scavenging Efficiency Improves GEOS & AToM Agreement

GEOS5 vs. DC-8

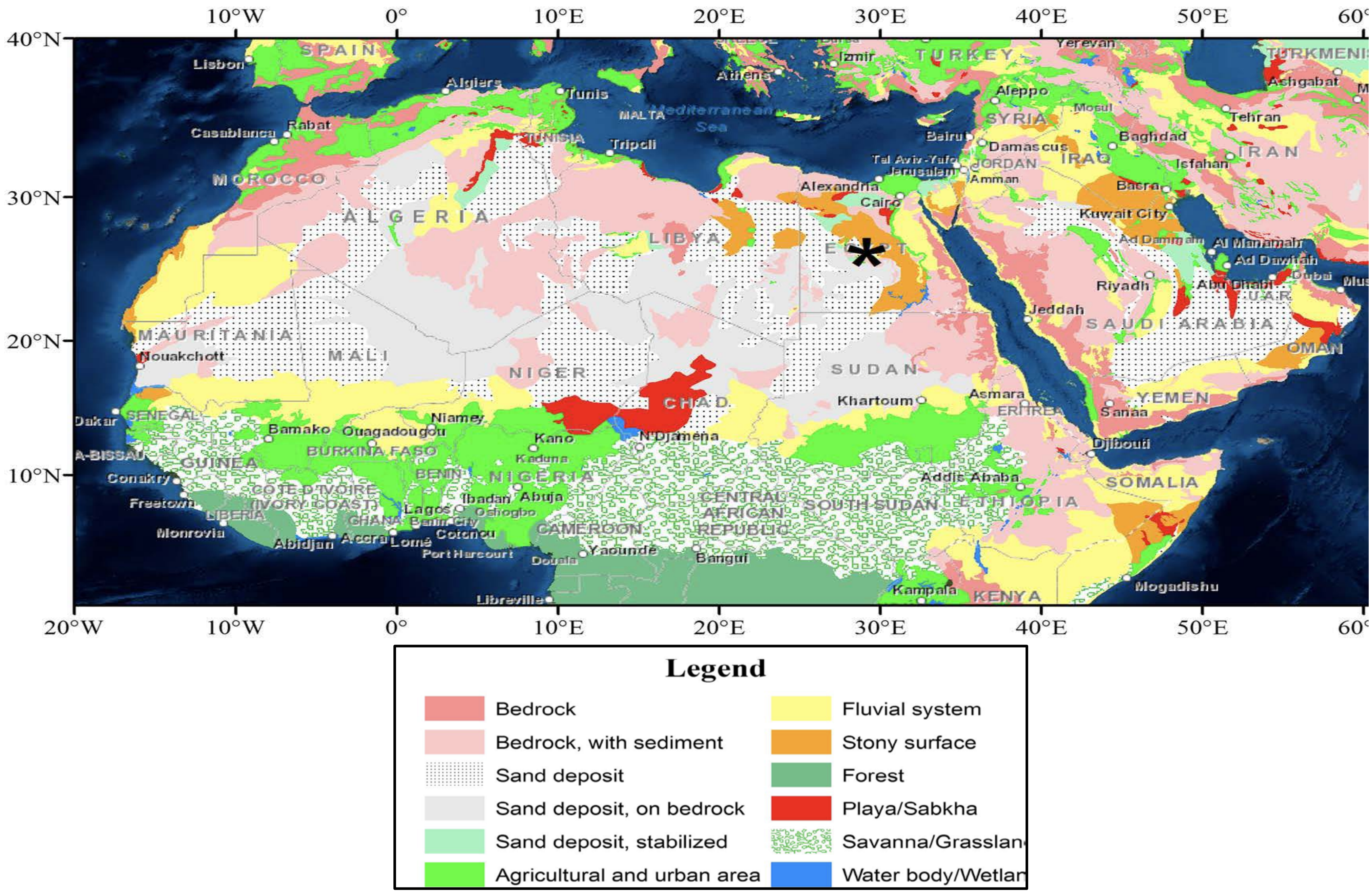
<u>African Coast:</u>
GEOS5 >DC-8 (<3km)
GEOS5 <DC-8 (>3km)

<u>Tropical E. Pacific:</u>
GEOS5 <DC-8

Reducing convective scavenging efficiency (f_{conv}) from 1.0 to 0.2 leads to much better agreement with observations in tropical E. Pacific.



Figures from Huisheng Bian


10°W
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30°E
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50°E
40°N
30°N
20°N
10°N
20°W
SPAIN
Lisbon
Algiers
Tunis
Rabat
Casablanca
MOROCCO
ALGERIA
TUNISIA
Tripoli
MALTA
Mediterranean Sea
Athens
Izmir
TURKEY
Yerevan
Aleppo
Mosul
SYRIA
Beirut
Damascus
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JORDAN
Amman
IRAQ
Baghdad
Tehran
IRAN
Isfahan
Ashgabat
Basra
Kuwait City
Alexandria
Cairo
LIBYA
EGYPT
Riyadh
Jeddah
SAUDI ARABIA
OMAN
U.A.R.
Dubai
Abu Dhabi
Ad Dawhah
Al Manamah
Ad Dammam
MAURITANIA
Nouakchott
MALI
NIGER
CHAD
SUDAN
Khartoum
Asmara
ERITREA
YEMEN
Sanaa
Djibouti
SOMALIA
Dakar
SENEGAL
Bamako
Ouagadougou
Niamey
BURKINA FASO
Kano
N'Djamena
Kaduna
GUINEA
Conakry
Freetown
Monrovia
LIBERIA
COTE D'IVOIRE (IVORY COAST)
GHANA
BENIN
NIGERIA
Abuja
Ibadan
Oshogbo
Lagos
Abidjan
Accra
Lomé
Cotonou
Port Harcourt
CAMEROON
Douala
Yaoundé
CENTRAL AFRICAN REPUBLIC
Bangui
SOUTH SUDAN
ETHIOPIA
Addis Ababa
Kampala
KENYA
Mogadishu
Libreville
Legend
Bedrock
Bedrock, with sediment
Sand deposit
Sand deposit, on bedrock
Sand deposit, stabilized
Agricultural and urban area
Fluvial system
Stony surface
Forest
Playa/Sabkha
Savanna/Grasslan
Water body/Wetlar

Satellites Capabilities of Observing Global Dust

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

- Dust, generally large & non-spherical particles, can be separated from other types based on measurements of particle size & shape.
- A synergy of passive & active measurements can characterize dust in 3-D.