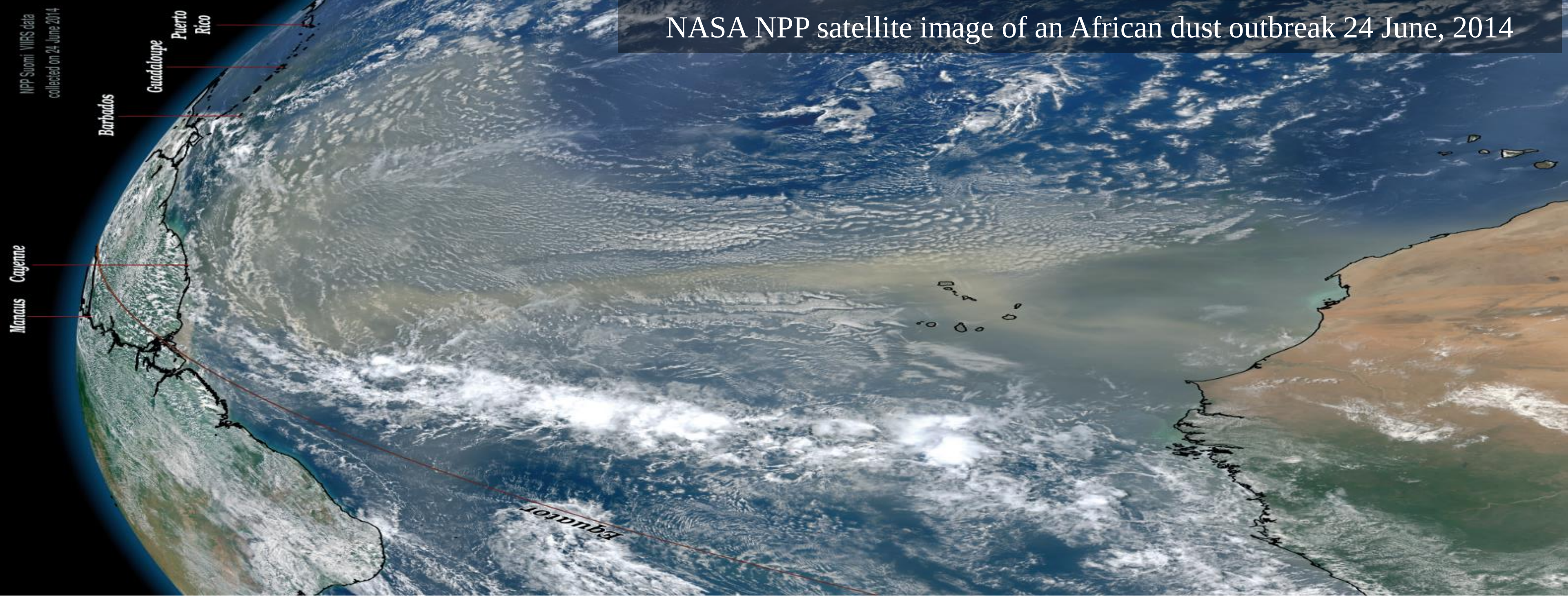


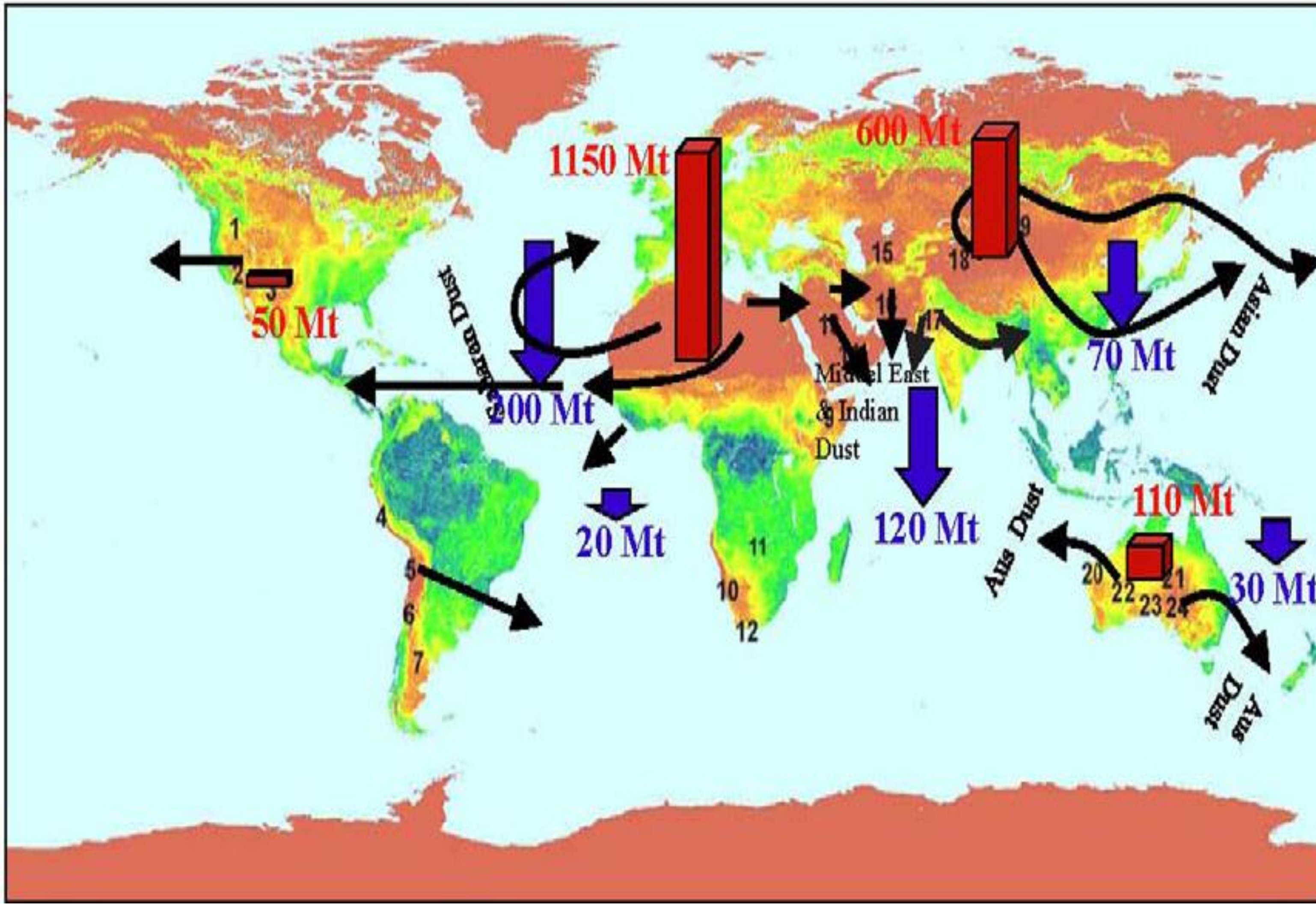
NASA NPP satellite image of an African dust outbreak 24 June, 2014

A multi-model analysis and comparison with remote-sensing data of North African dust
- What do we know and what we don't?

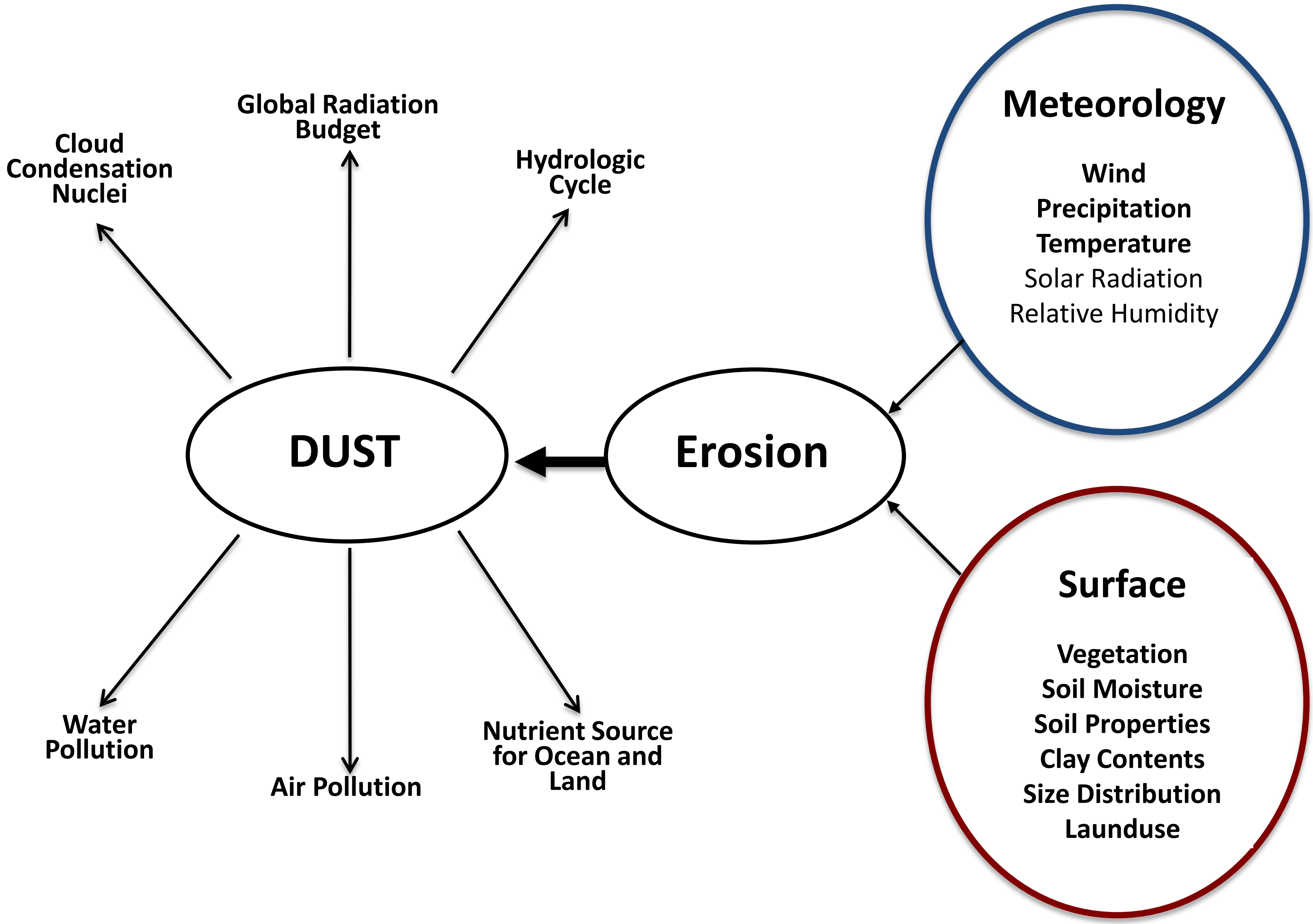
AeroCom Meeting
September 30, 2014
Dongchul Kim (GESTAR, NASA/GSFC)

Acknowledgement:
- GOCART Group: Mian Chin, Thomas Diehl, Hongbin Yu, Huisheng Bian, Qian Tan
- AeroCom Models: Susanne Bauer, Toshihiko Takemura, Luca Pozzoli, and Nicolas Bellouin
- NASA MODIS, Sea-WiFS, MISR, CALIOP, and AERONET teams, AIRS data team

Global Dust Cycle



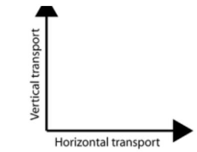
Effect and Process of Dust

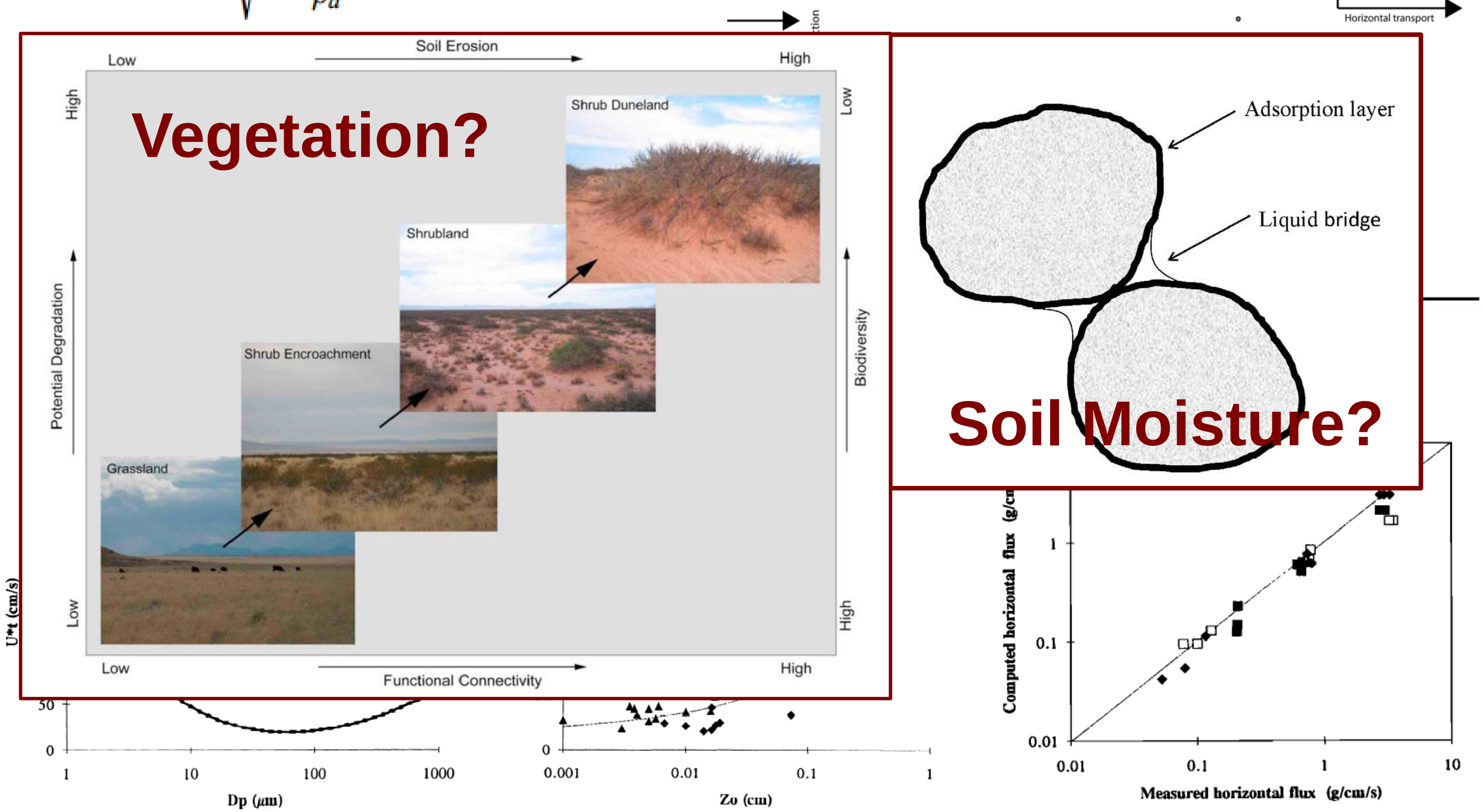


Physical Mechanism of Dust Uplifting

Bagnold (1941)

$$u_t^* = \mathrm{A}\sqrt{\frac{(\rho_s - \rho_a)}{\rho_a} gd},$$





Bagnold (1941), Iversen and White (1982), Marticorena and Bergametti (1995), Ginoux et al. (2001,2004)

Evaluation using Surface Measurements and AEROENT AOD

AERONET AOD
- Column

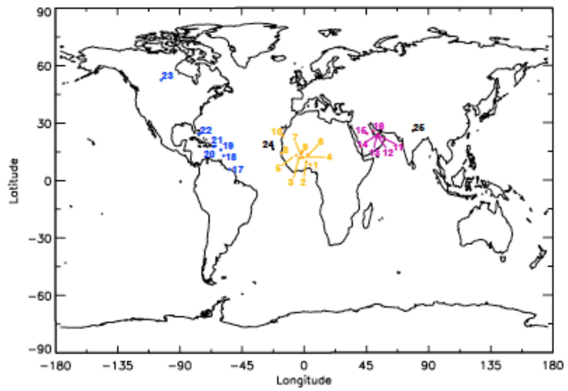
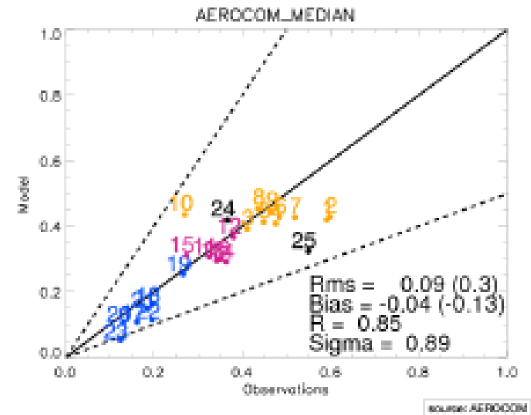
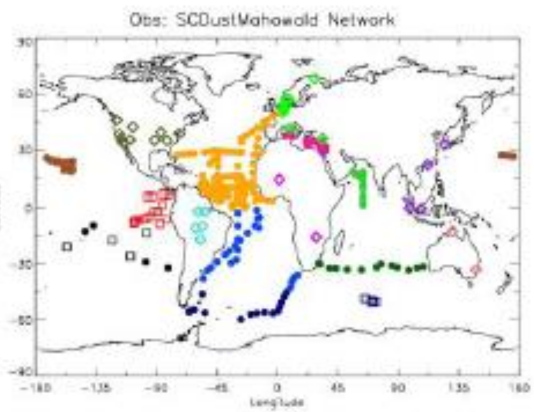
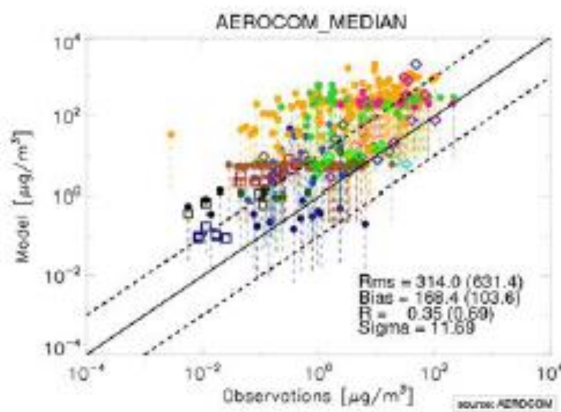


Fig. 8. Location of selected AERONET dusty sites based on the climatology built from the multi-annual database 1996–2006.



Surface Dust Concentration





Huneeous et al. (2011)

Vertical Distribution of Extinction Coefficient from 12 models with CALISOP

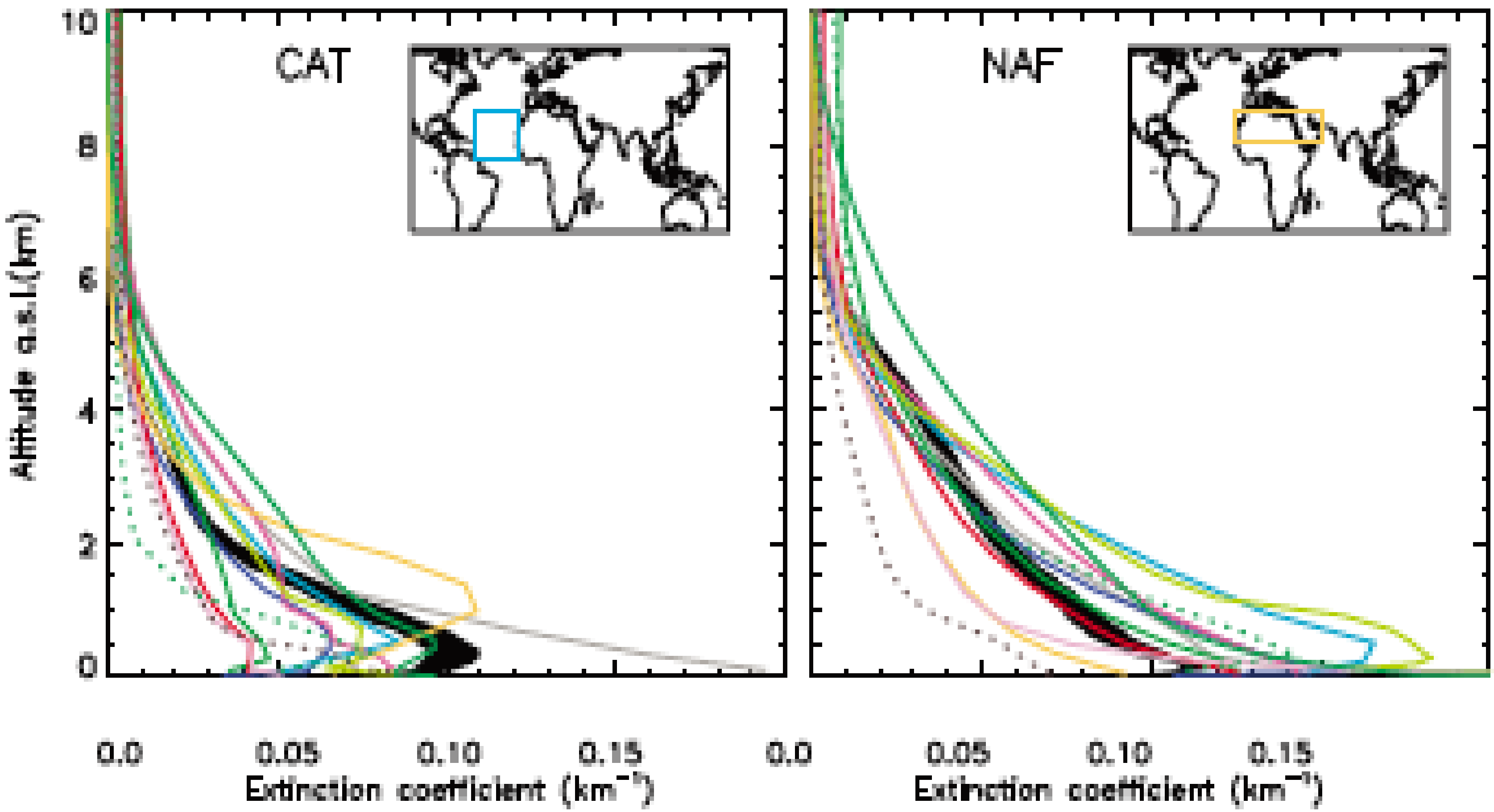


Figure 4. AeroCom I (12 models) and CALIOP mean annual extinction coefficient (km^{-1}) profiles profiles (at 550 and 532 nm, respectively). The 2007 to 2009 range (mean ± std) is shown for CALIOP (black). The 2000 and climatic (9999) modeled profiles are shown in continuous and dashed lines, respectively. See Figure 1 for the definition of the regions and Table 1 for the definition of the models and experiments. Results for the SEA region are given in auxiliary material (Figure S3).

Koffi et al. (2012)

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

10.1002/2013JD021099

Key Points:

- North African dust is studied using observations and models
- Observations agree in the magnitude, distribution, and seasonality of dust
- Models show large differences

Sources, sinks, and transatlantic transport of North African dust aerosol: A multimodel analysis and comparison with remote sensing data

Dongchul Kim[1,2], Mian Chin[2], Hongbin Yu[2,3], Thomas Diehl[1,2], Qian Tan[1,2], Ralph A. Kahn[2], Kostas Tsigaridis[4,5], Susanne E. Bauer[4,5], Toshihiko Takemura[6], Luca Pozzoli[7], Nicolas Bellouin[8], Michael Schulz[9], Sophie Peyridieu[10], Alain Chédin[10], and Brigitte Koffi[11]

Scientific Questions:

1. What are the characteristics of dust from the observations?
2. What are the differences between models?
3. What are the differences between models and observations?
4. What are the causes of the differences in models?

Methods (Observation)

- Aerosol Optical Depth (AOD), (2000-2005):
  - MODIS, MISR, SeaWiFS, and AERONET

- Dust Optical Depth (DOD), (2000-2005):
    - MODIS: Aerosol type and size (Kaufman et al., 2005)
    - MISR: Non-spherical AOD (Kahn et al., 2009)
    - AERONET: Coarse mode Fraction (Eck et al., 2010)
    - CALIOP: Depolarization ratio (>0.06)
    - AIRS: Centroid Height of Dust

- Fraction of DOD (fDOD)

Name **Emission**

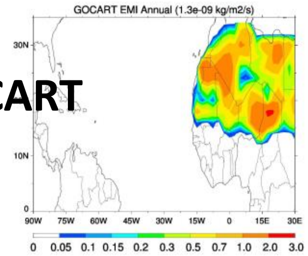
Model description

Table 1. Description of the Participating Models and Their Dust Physical Characteristics

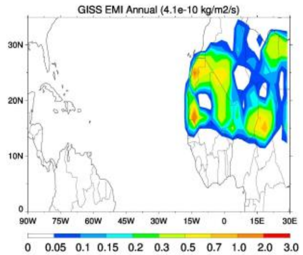
	GOCART	GISS-ModelE	SPRINTARS	ECHAM5-HAMMOZ[a]	HadGEM2
Resolution	2.5° × 2°	2.5° × 2°	1.125° × 1.125°	2.8° × 2.8°	1.875° × 1.25°
Vertical layers	30	40	56	31	38
Meteorology	GEOS4 DAS	Horizontal winds nudged to NCEP Reanalysis	NCEP Reanalysis	ECMWF Reanalysis	ECMWF Reanalysis
Winds for emissions	U_{10m}^3	U_{10m}^3	U_{10m}^3	U_*^3	U_*^3
Size distribution (μm)	Five bins 0.1-1.0-1.8-3.0-6.0-10.0	Five bins 0.1-1-2-4-8-16	Six bins 0.1-0.22-0.46-1.0-2.15-4.64-10.0	Two modes (acc. and coarse) $0.05 < r_m < 0.5$ $0.5 < r_m$	Six bins 0.0316-0.1-0.316-1.0-3.16-10-31.6
Density (g m^3)	2.5	2.5 for clay 2.65 for silt	2.6	2.5–2.6	2.65
Major references	*Chin et al.* [2002, 2009] and *Ginoux et al.* [2001]	*Miller et al.* [2006] and *Bauer and Koch* [2005]	*Takemura et al.* [2000, 2005]	*Pozzoli et al.* [2008, 2011]	*Bellouin et al.* [2011, Appendix A]

[a]Dust particles are emitted in the insoluble accumulation and coarse modes with mass median radii of 0.37 μm and 1.75 μm, respectively. Once emitted, dust particles can be mixed with other aerosols, and dust is distributed in two additional modes: internally mixed soluble accumulation and coarse modes.

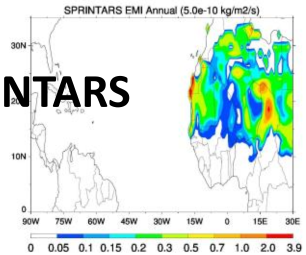
GOCART



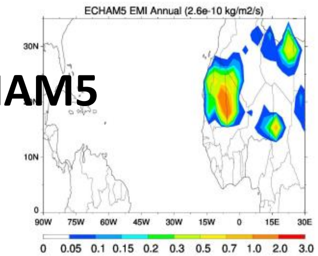
GISS



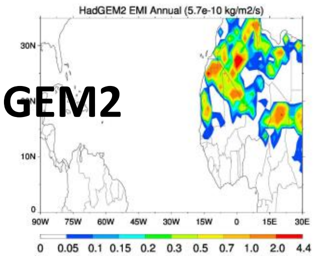
SPRINTARS



ECHAM5



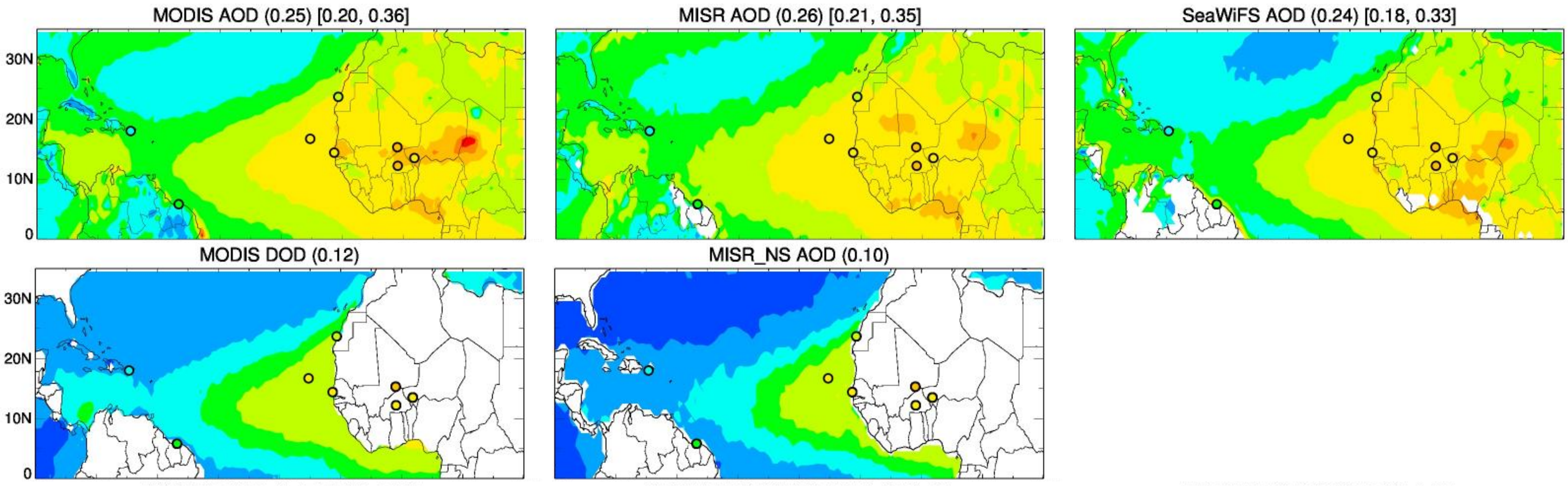
HadGEM2

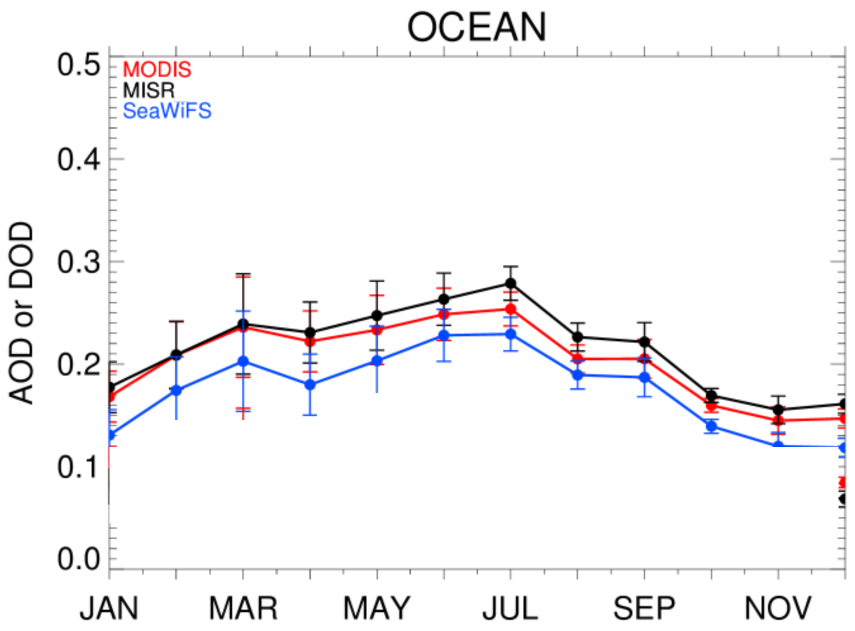


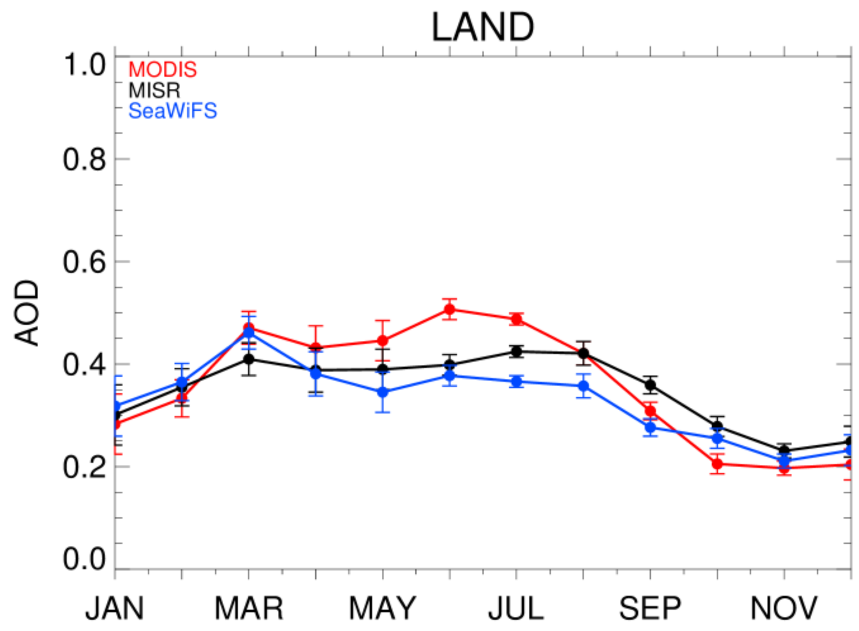
Model Parameters

- Standard model output (2000-2005)
  - AOD, DOD, EMI, DRY, WET, and LOAD
- Normalized parameters
  - Loss frequency
  - Wet deposition fraction
  - Longitudinal gradient of DOD
  - Mass extinction efficient

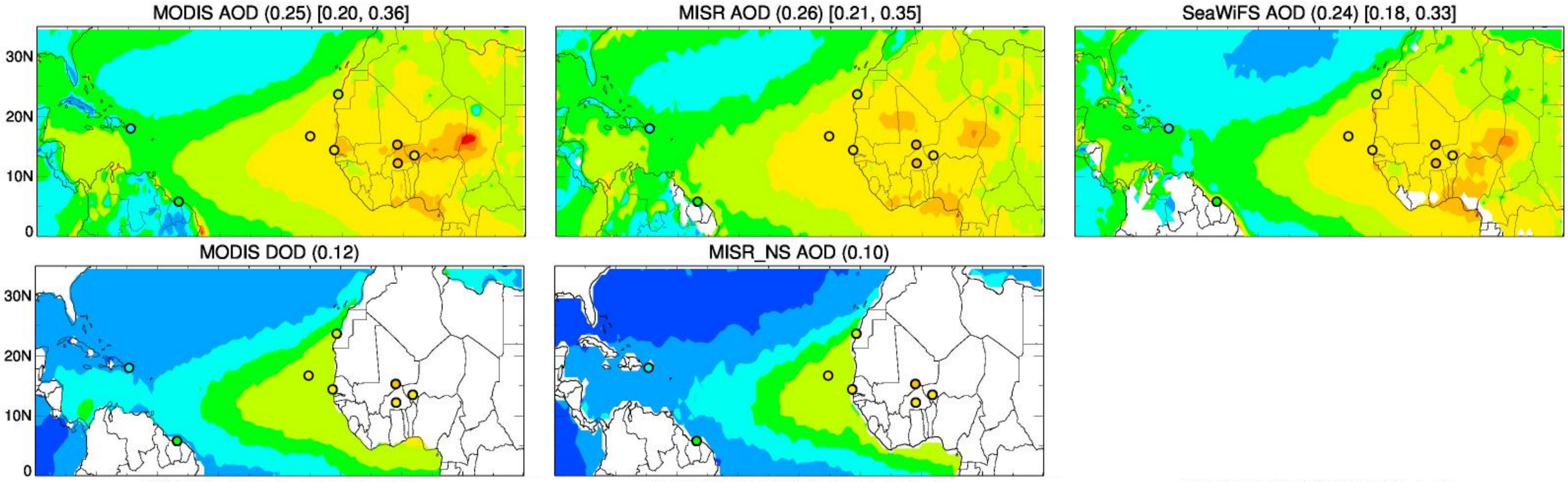
AOD and DOD from Observations

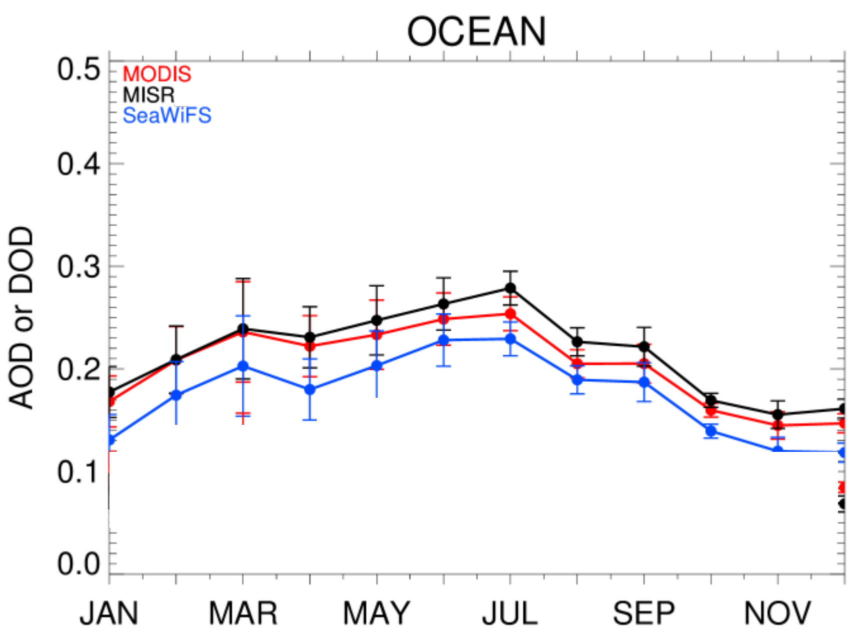


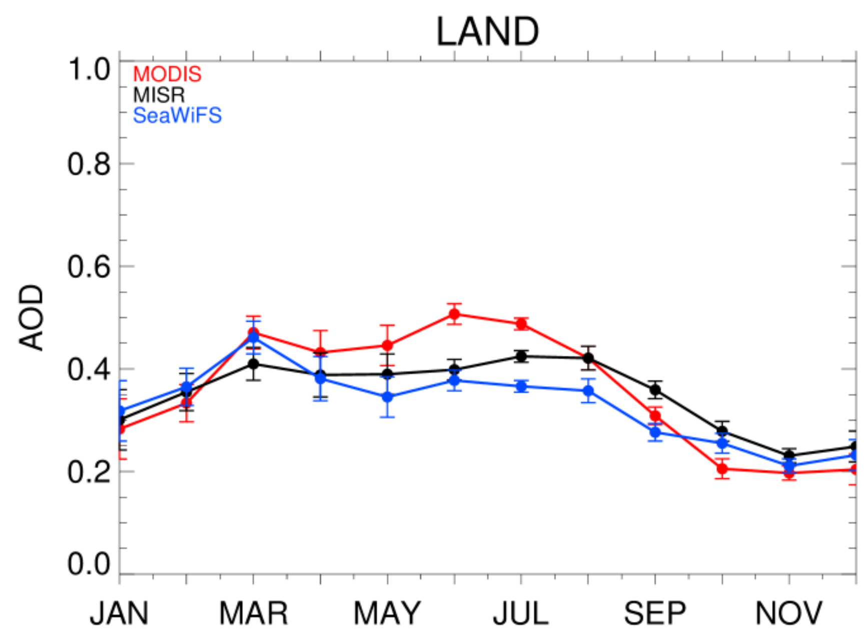




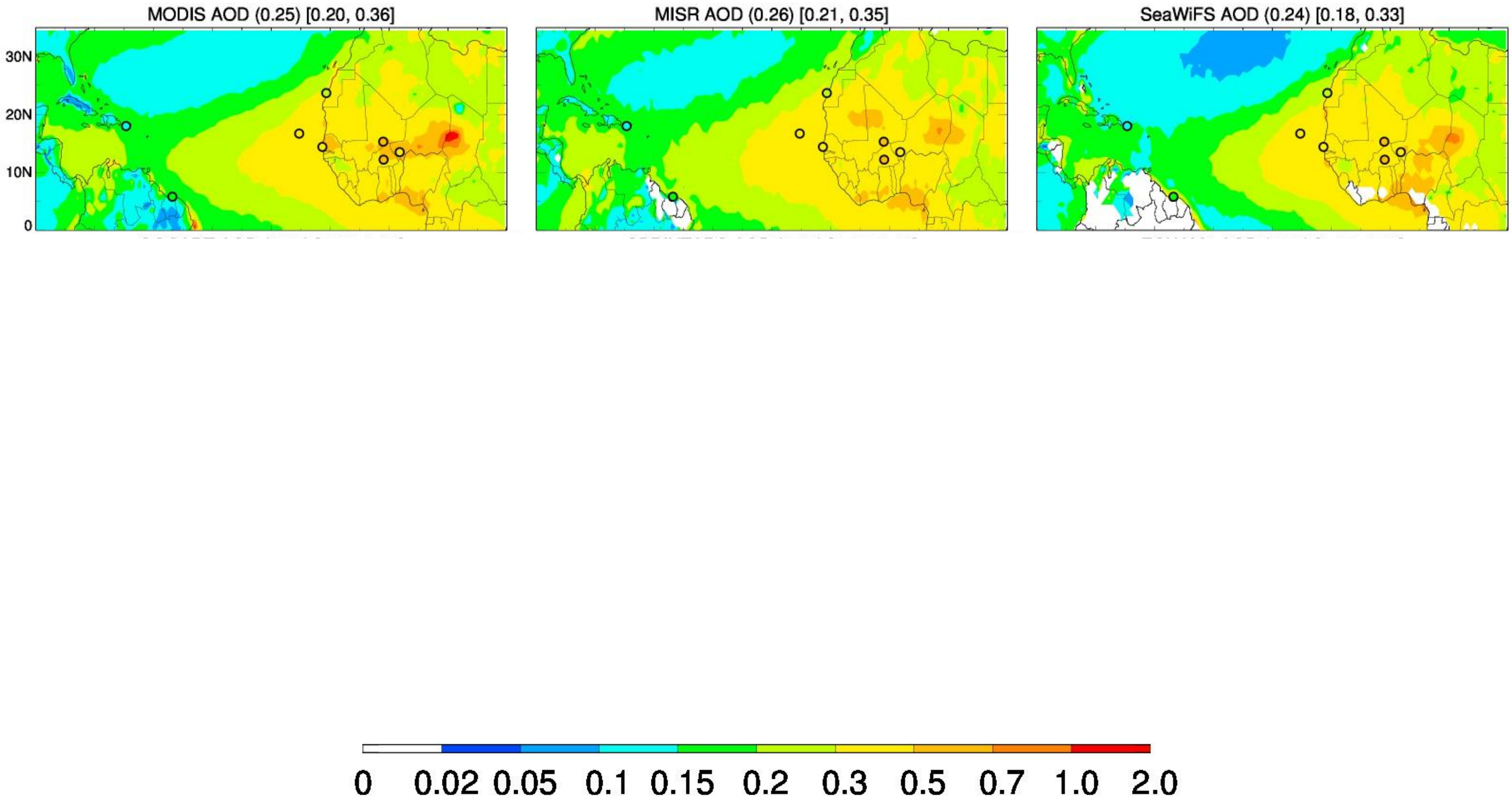
AOD and DOD from Observations





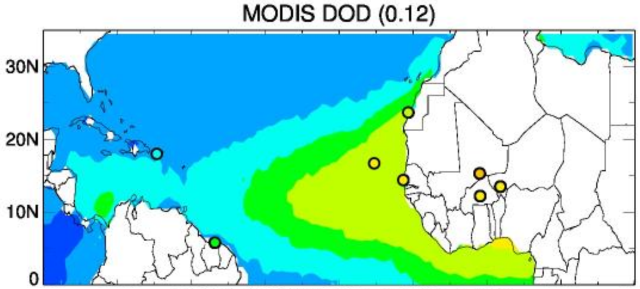


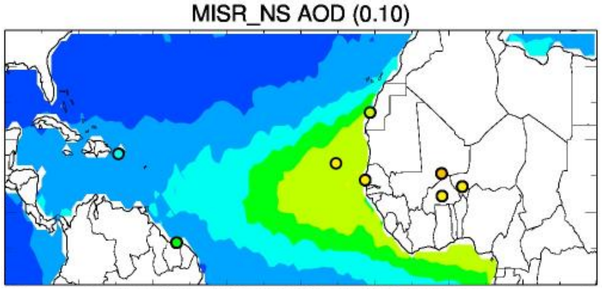
Distribution of AOD: Observation and Models



- About ±50% difference between Satellites and Models.
  - Satellite:0.24~0.26
  - Models:0.13~0.36

Distribution of DOD: Observation and Models

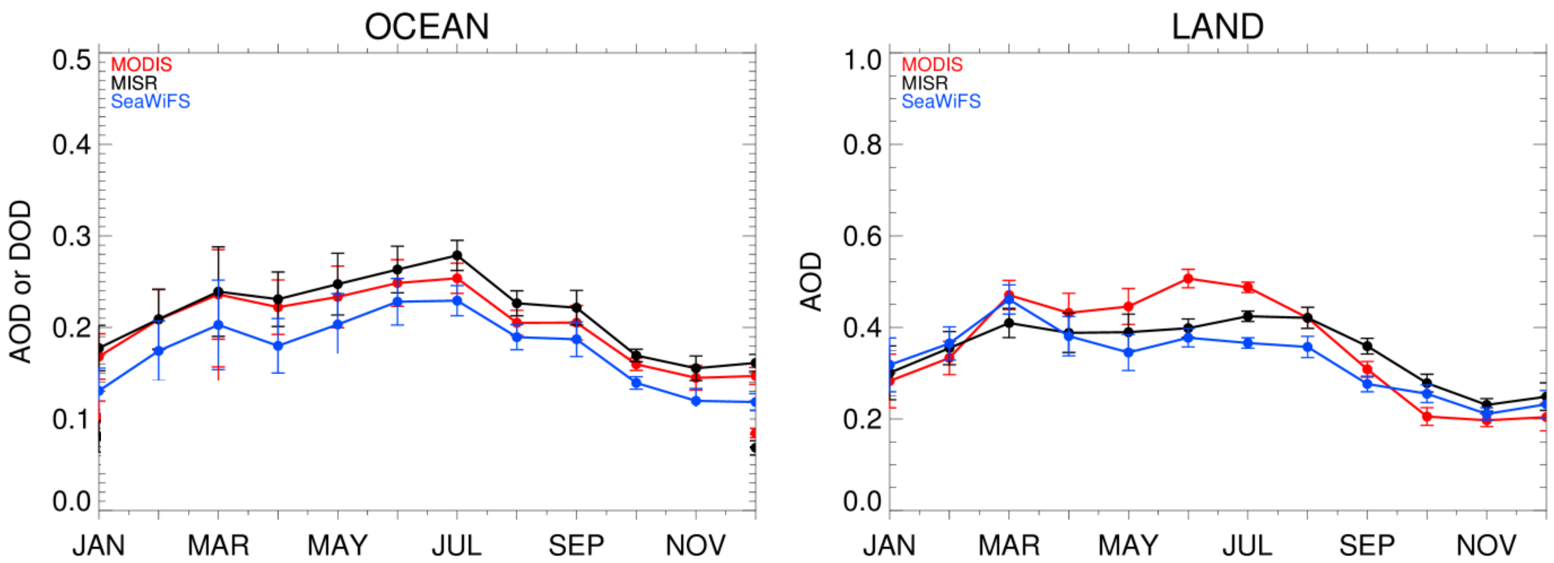




- Larger differences (factor of 4~5) between Satellites and Models than AOD.
  - Satellite:0.10~0.12, Models:0.03~0.15

AOD Seasonal Cycles: Observation and Model

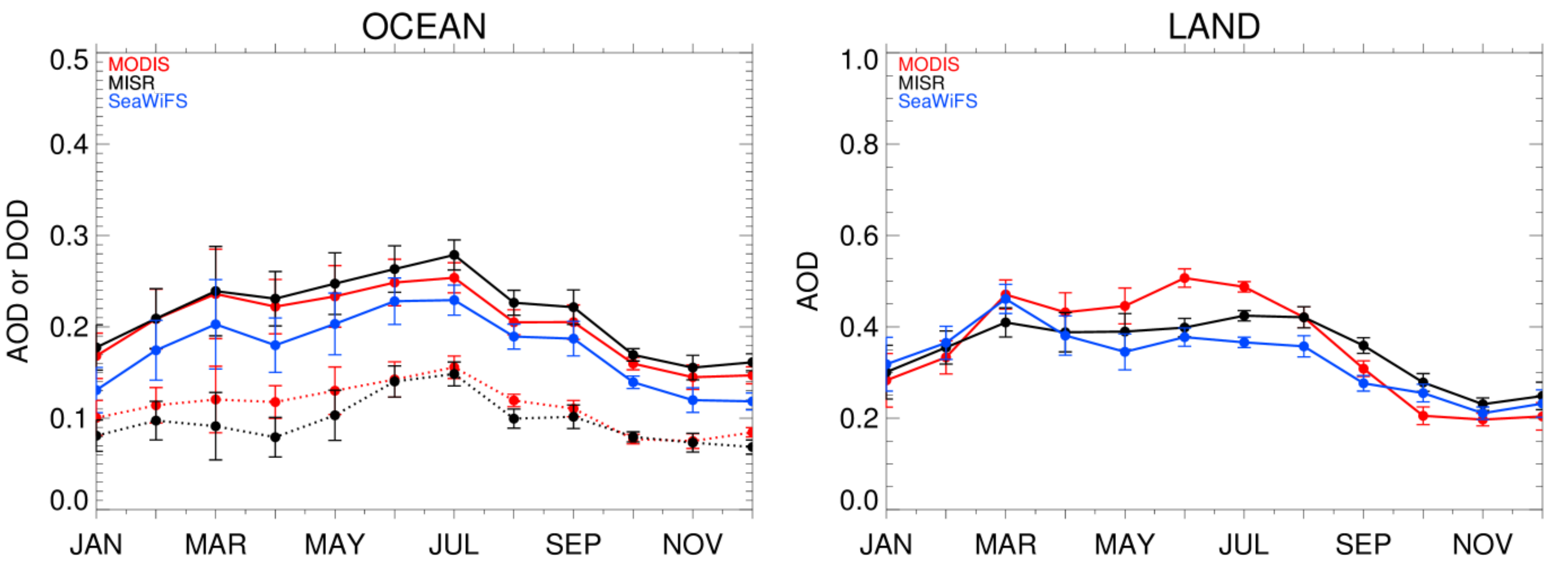
OBS



MOD

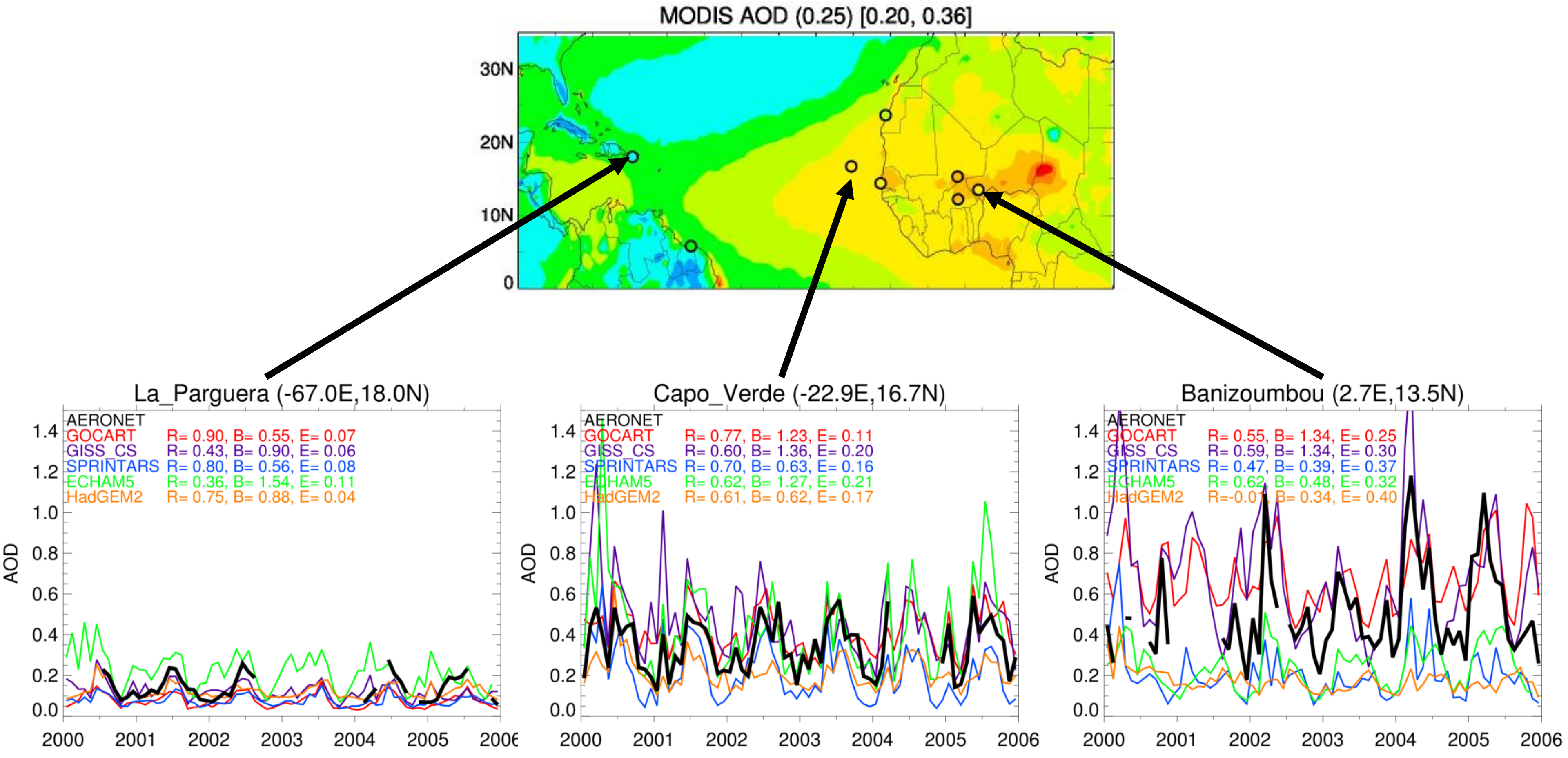
DOD Seasonal Cycles: Observation and Model

OBS



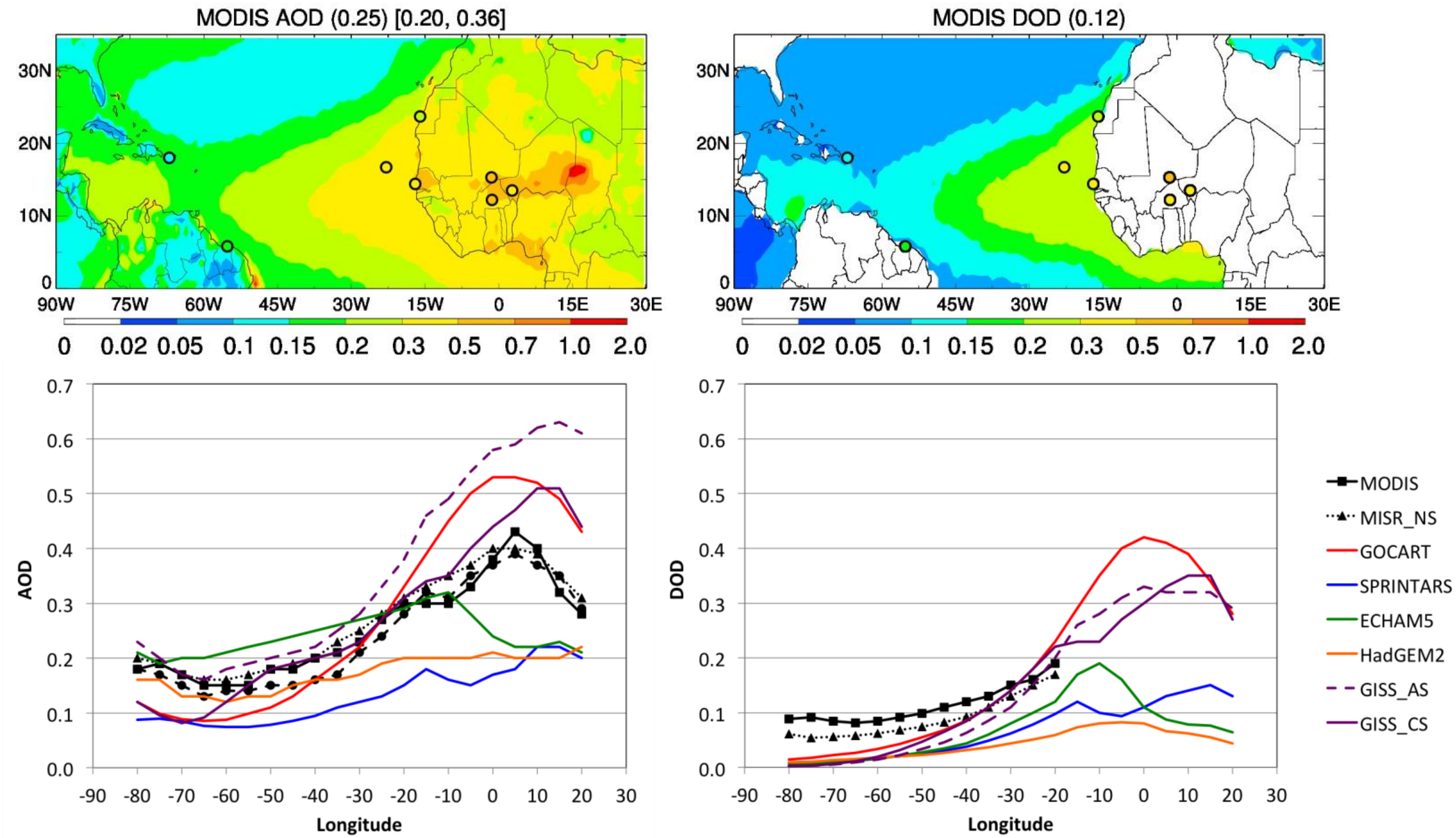
MOD

AOD Seasonal Cycles : Observation and Model



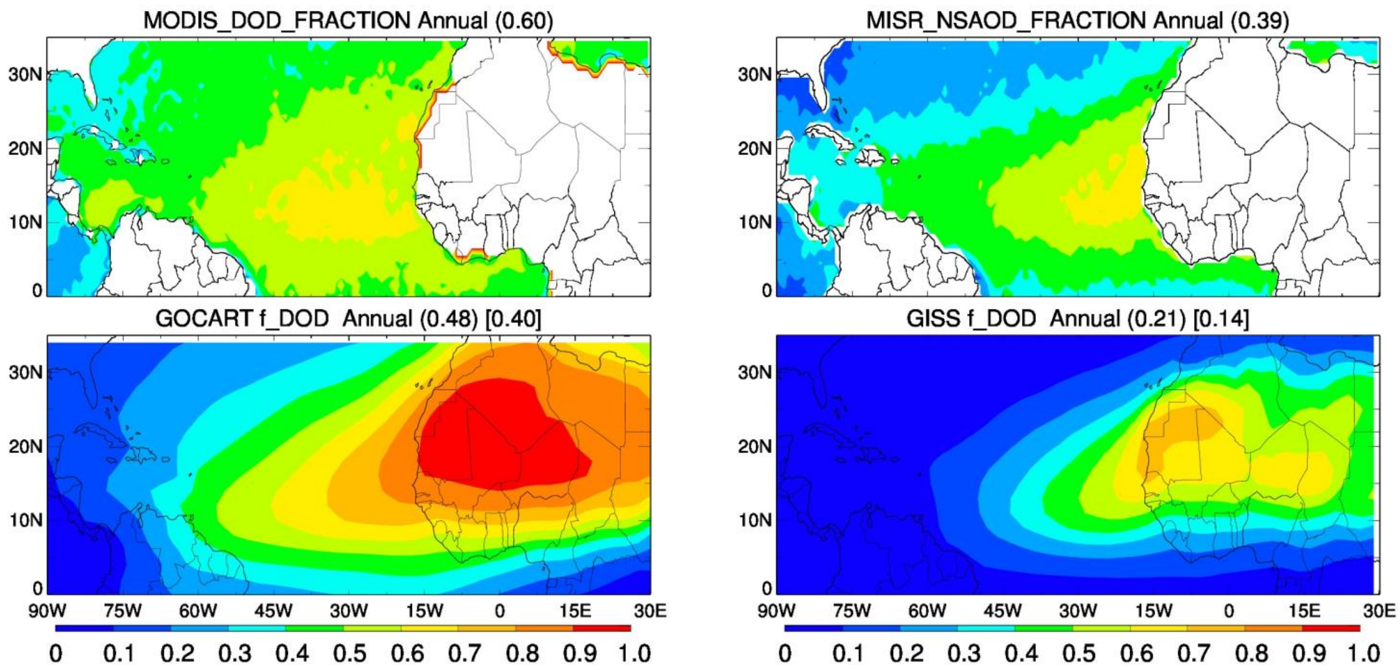
- AERONET AOD is considered as the most reliable data.
- AERONET AOD shows strong inter-annual and spatial variation.
- Models show large discrepancy with AERONET and between models

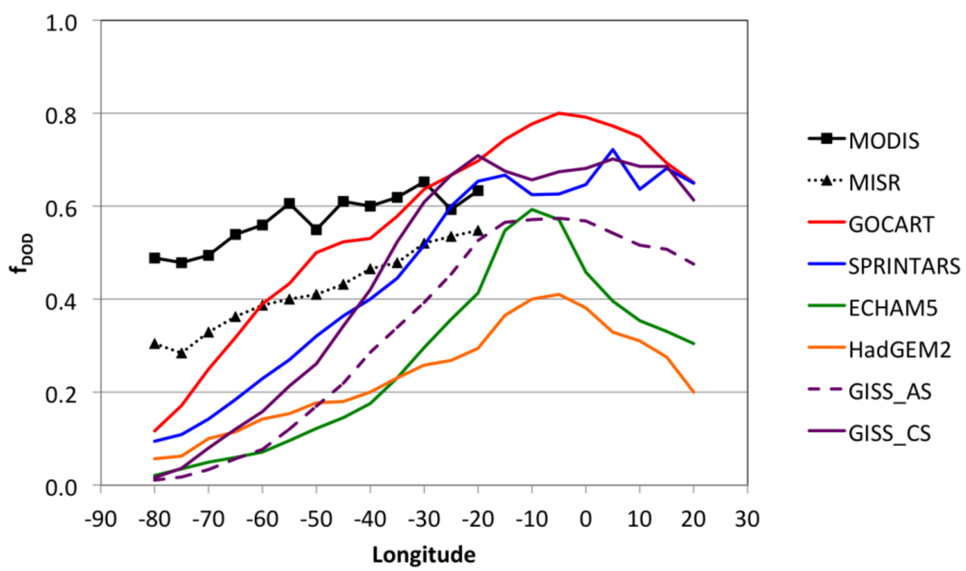
Distribution of DOD: Observation and Models



- Satellites agree on east-to-west gradient of AOD and DOD.
- Models show large discrepancy with satellite and between models. Best AOD agreement appears on the Atlantic Ocean.
- All models underestimate DOD.

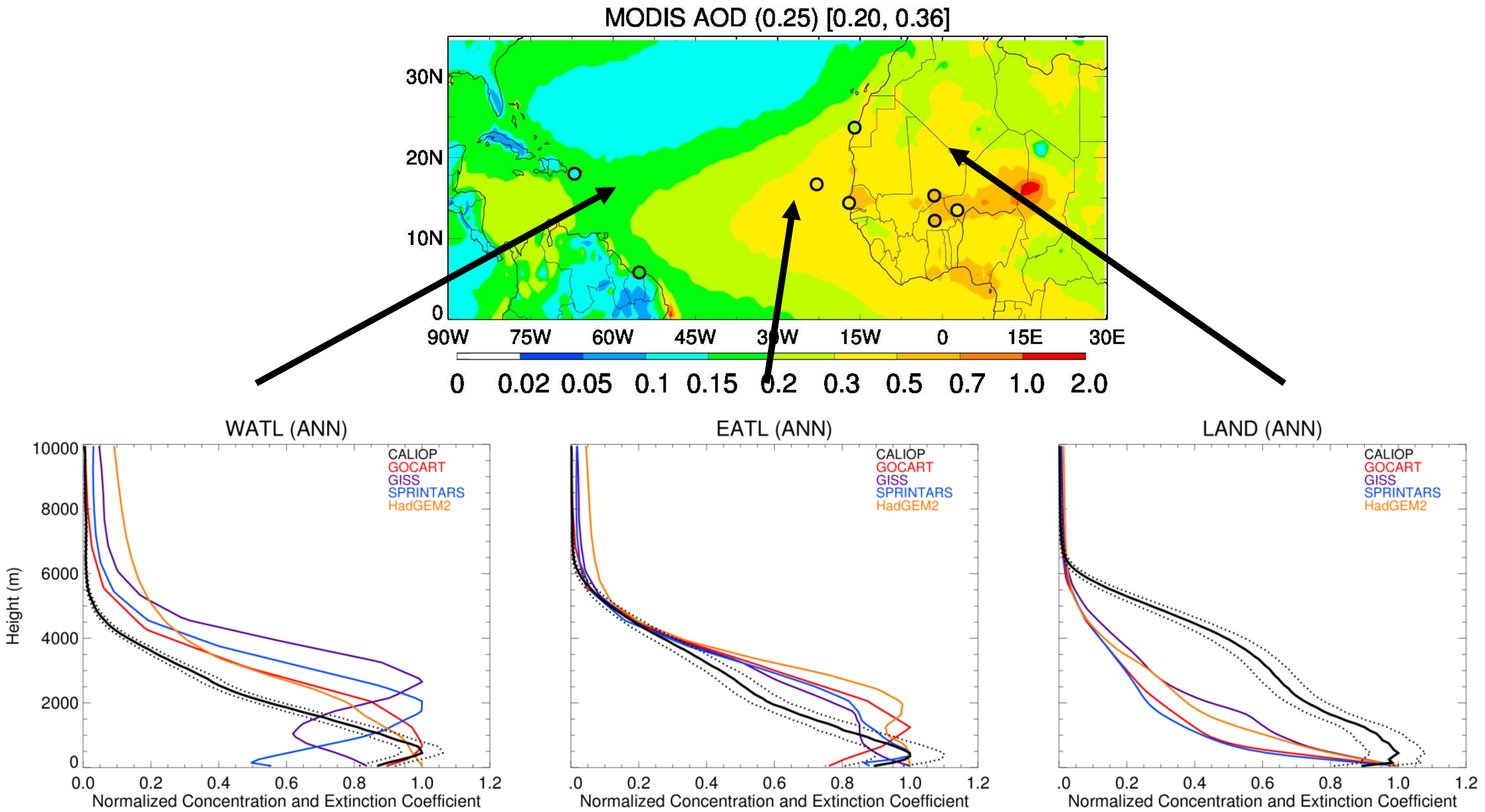
Distribution of f_DOD: Observation and Models



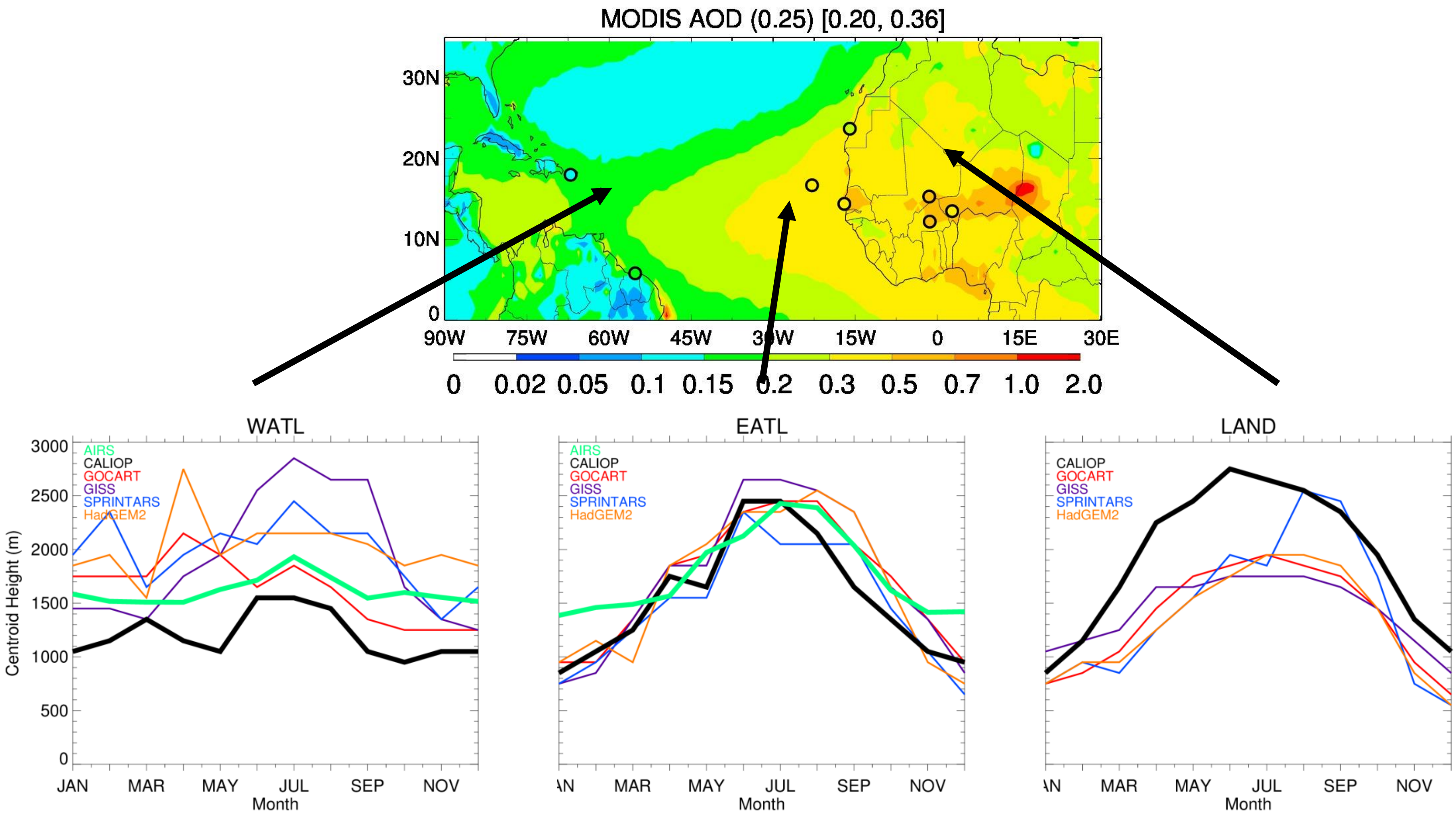


- f_DOD=DOD/AOD
- Satellites agree on east-to-west gradient f_DOD.
- Models show large difference with satellite and diversity.
- Models show stronger f_DOD gradient.

Vertical Distribution of DOD: Profile



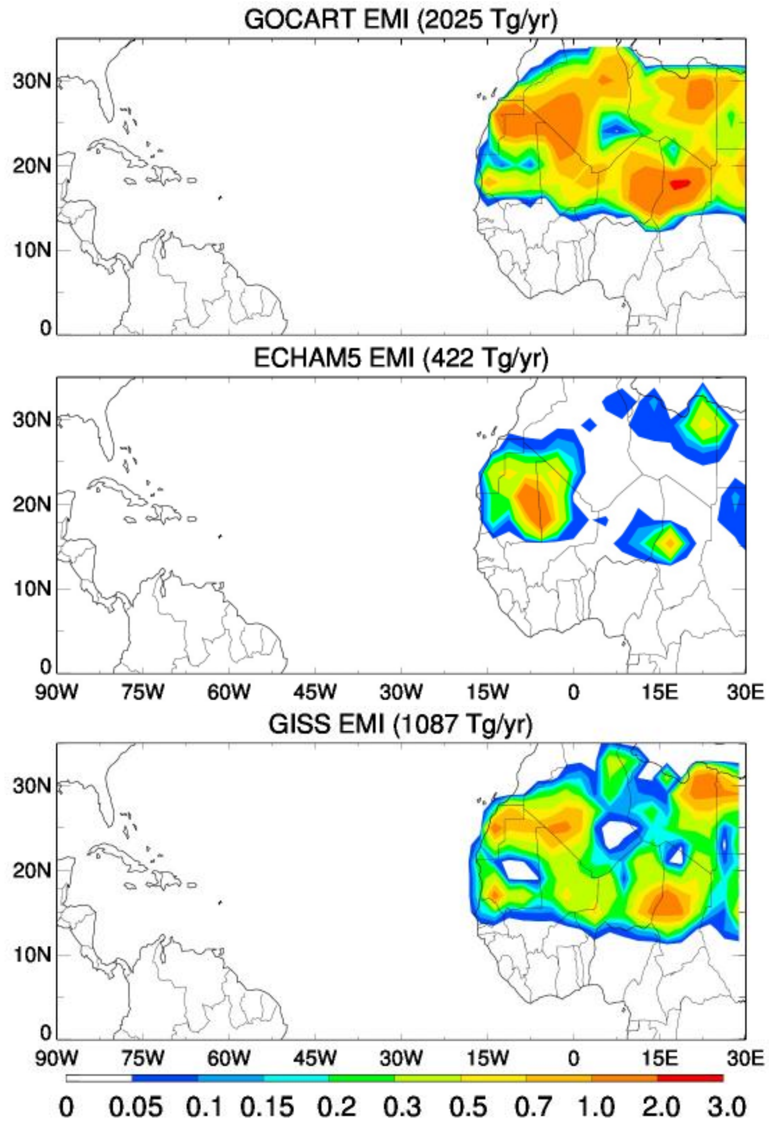
Vertical Distribution of DOD: Centroid Height

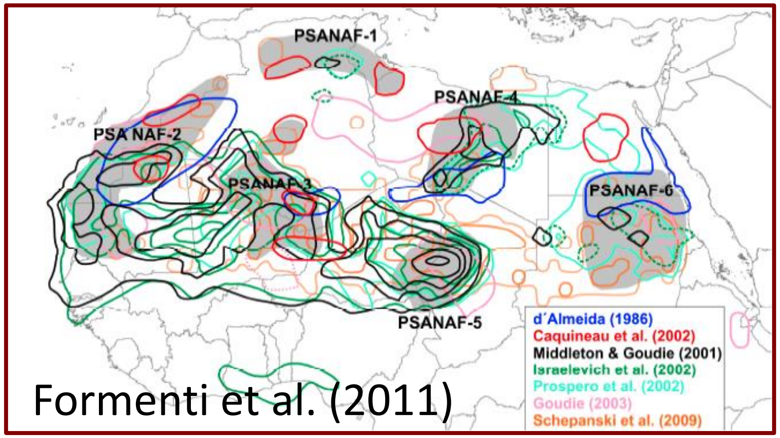


What’s the cause of the model uncertainty?

- Emission
- Dry/Wet removal (absolute and relative)
- Meteorology (wind, precipitation, seasonality…)
- Optical parameters
- Particle size and composition
- Chemistry

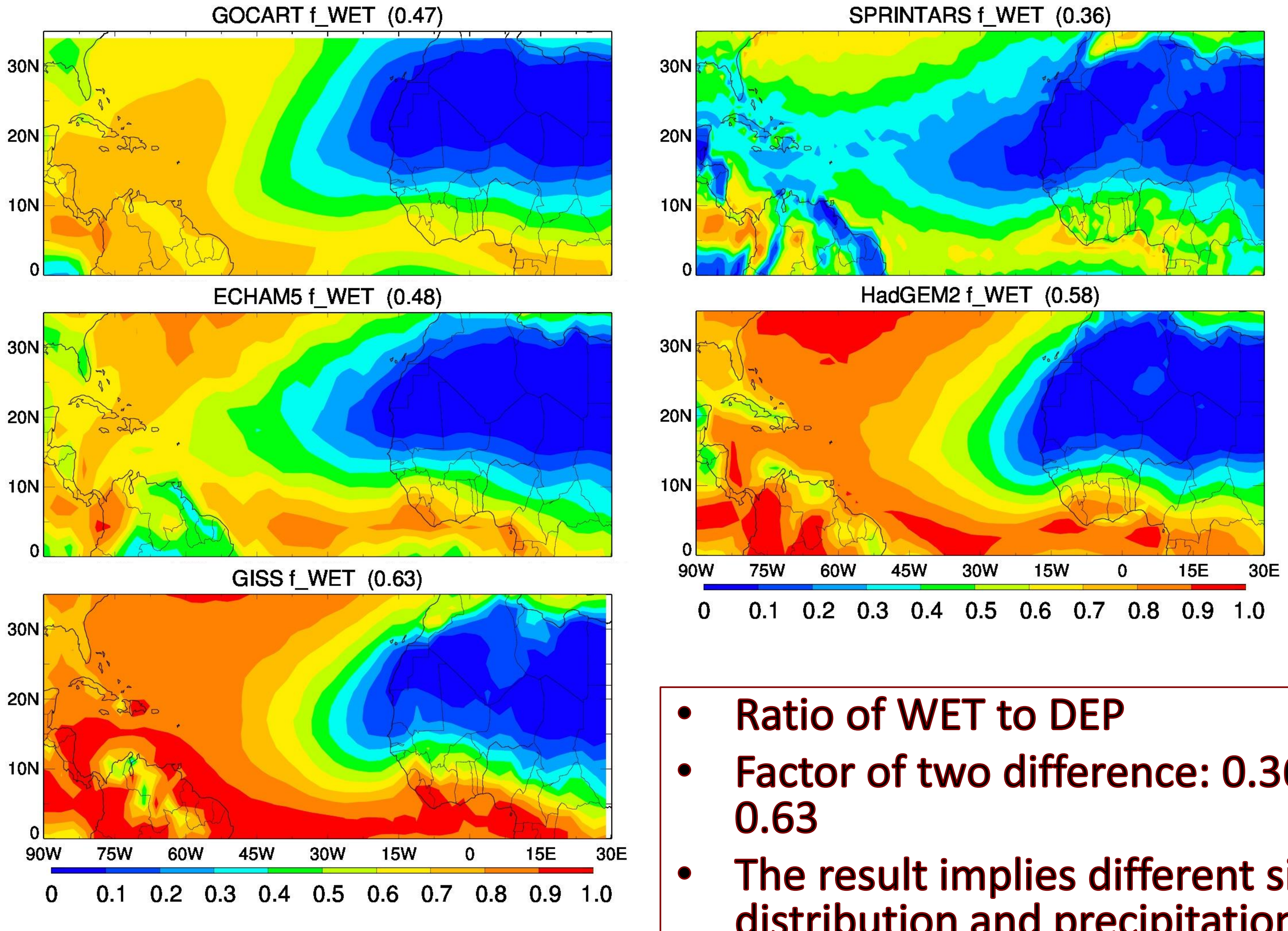
Distribution and Magnitude of Emission





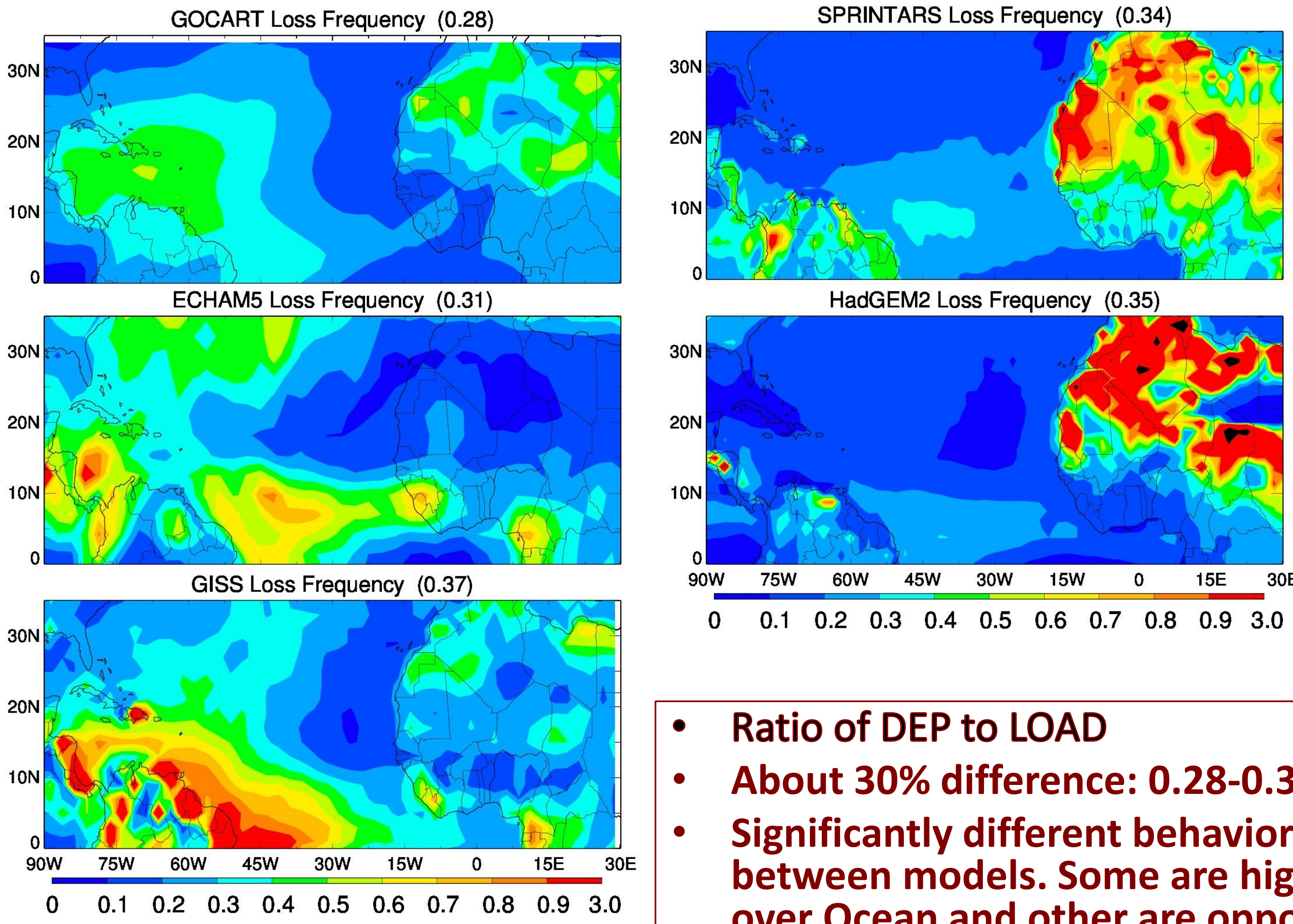
Formenti et al. (2011)

Distribution of WET Fraction



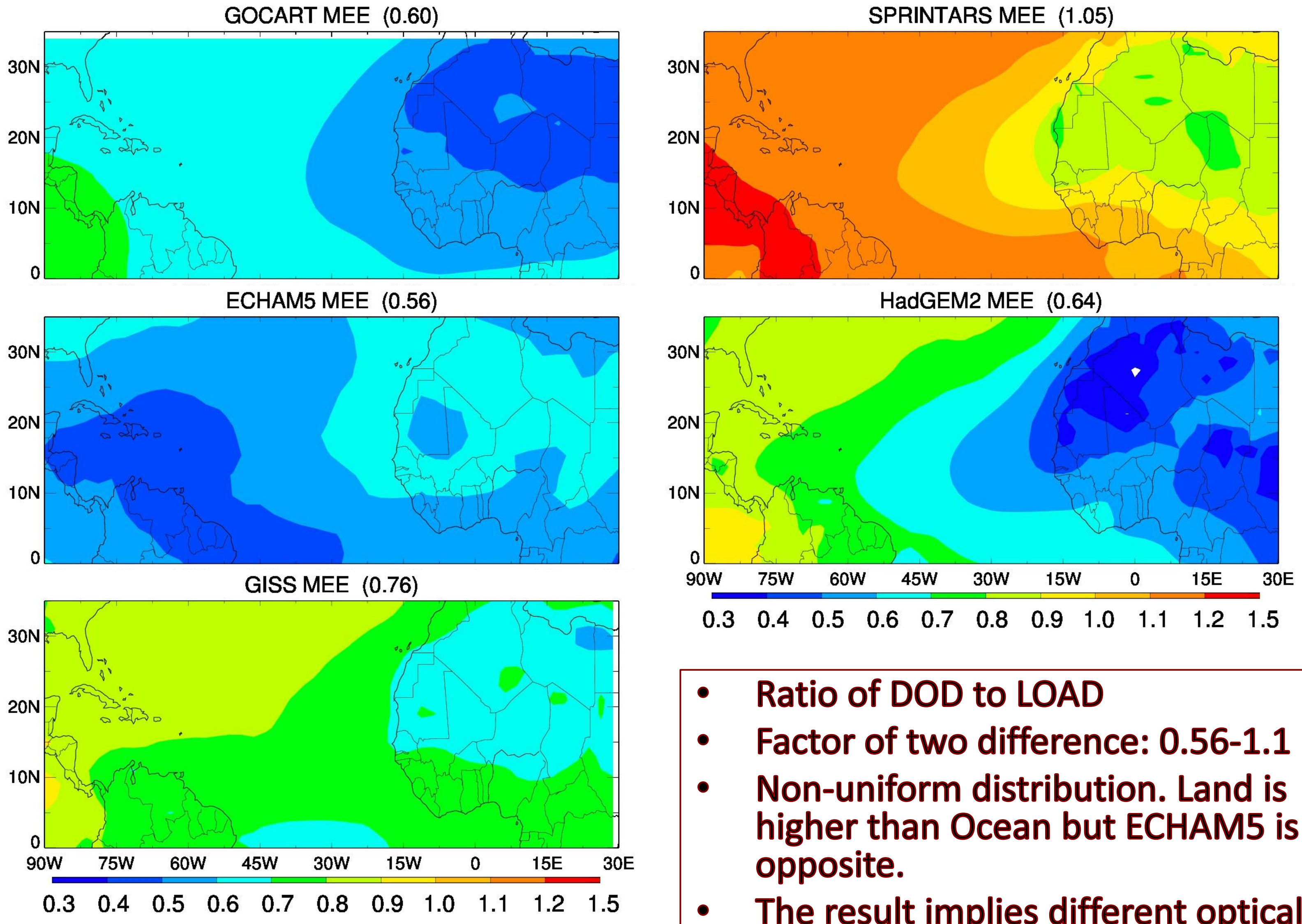
- Ratio of WET to DEP
- Factor of two difference: 0.36-0.63
- The result implies different size distribution and precipitation during transport.

Distribution of Loss Frequency (~1/Lifetime)



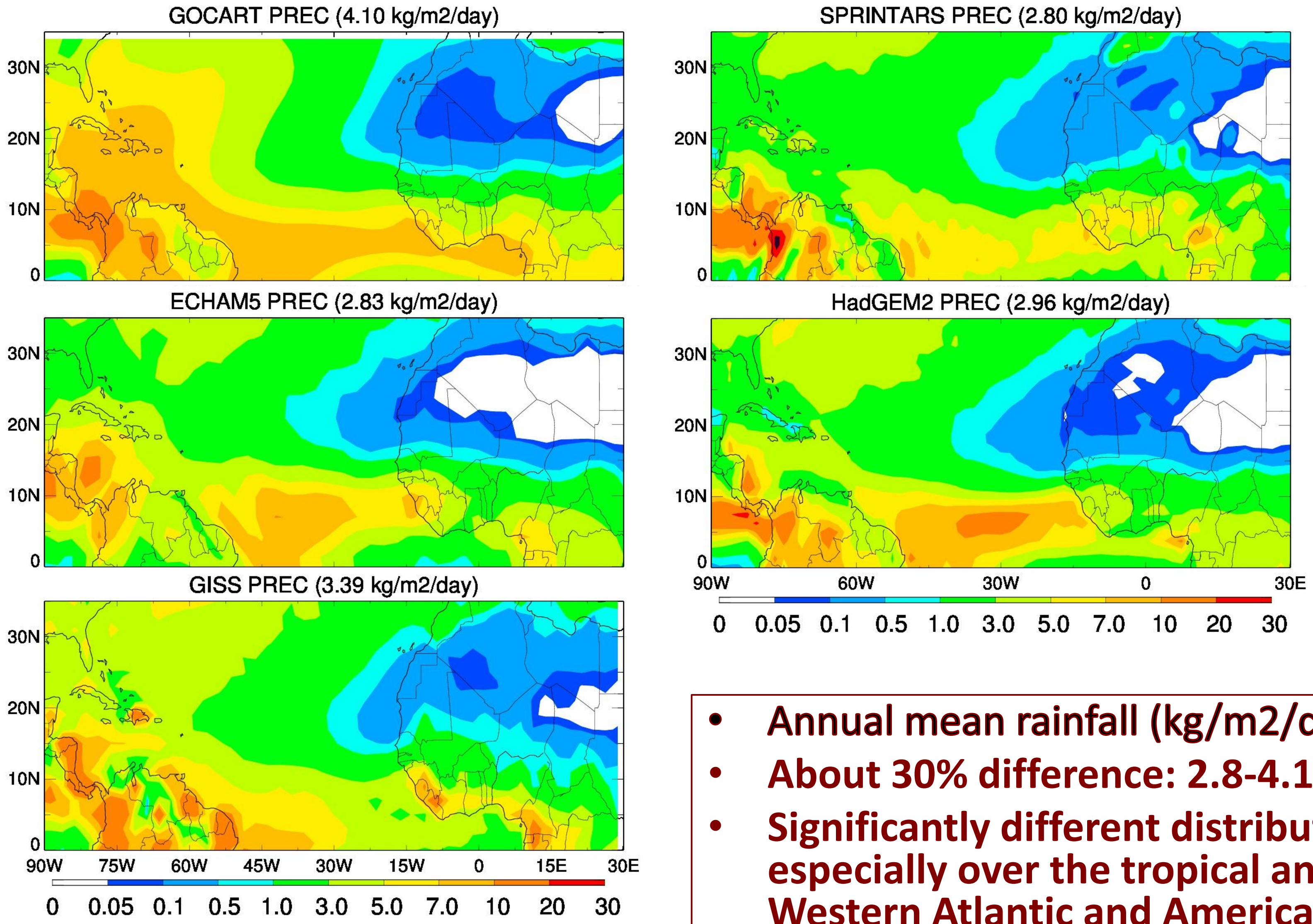
- Ratio of DEP to LOAD
- About 30% difference: 0.28-0.37 s^{-1}.
- Significantly different behavior between models. Some are higher over Ocean and other are opposite.

Distribution of Mass Extinction Efficient (m^2/g)



- Ratio of DOD to LOAD
- Factor of two difference: 0.56-1.1
- Non-uniform distribution. Land is higher than Ocean but ECHAM5 is opposite.
- The result implies different optical property tables and size distribution during transport.

Meteorology - Distribution of Rainfall



- **Annual mean rainfall (kg/m2/day)**
- **About 30% difference: 2.8-4.1**
- **Significantly different distributions especially over the tropical and Western Atlantic and America.**
- **Aerosol modeling is dependent to Meteorology.**

Summary

- North African dust is studied using observations (2000-2005) (AOD, DOD, and f_{DOD}).
  - Satellites agree in distribution, seasonality, and longitudinal gradient
- AeroCom models are compared with observations and between models (AOD, DOD, and f_{DOD}).
  - Strong spatiotemporal variation and inter-annual variation
  - Large diversity in AOD and the larger diversity in DOD and f_{DOD}
  - Large differences in vertical distributions
- There are large differences in distribution and magnitude of normalized parameters.
  - Loss frequency, Wet deposition fraction, Mass extinction efficiency
- Dust simulation is highly meteorology dependent such as wind and precipitation.
- More observation is essential to improve models.