Characterization of the temporal-spatial variability of trans-Atlantic dust transport based on CALIPSO lidar measurements

Hongbin Yu – UMD & NASA GSFC

Mian Chin, Huisheng Bian, Tianle Yuan, Joseph Prospero, Ali Omar, Lorraine Remer, David Winker, Yuekui Yang, Yan Zhang, Zhibo Zhang, Chun Zhao

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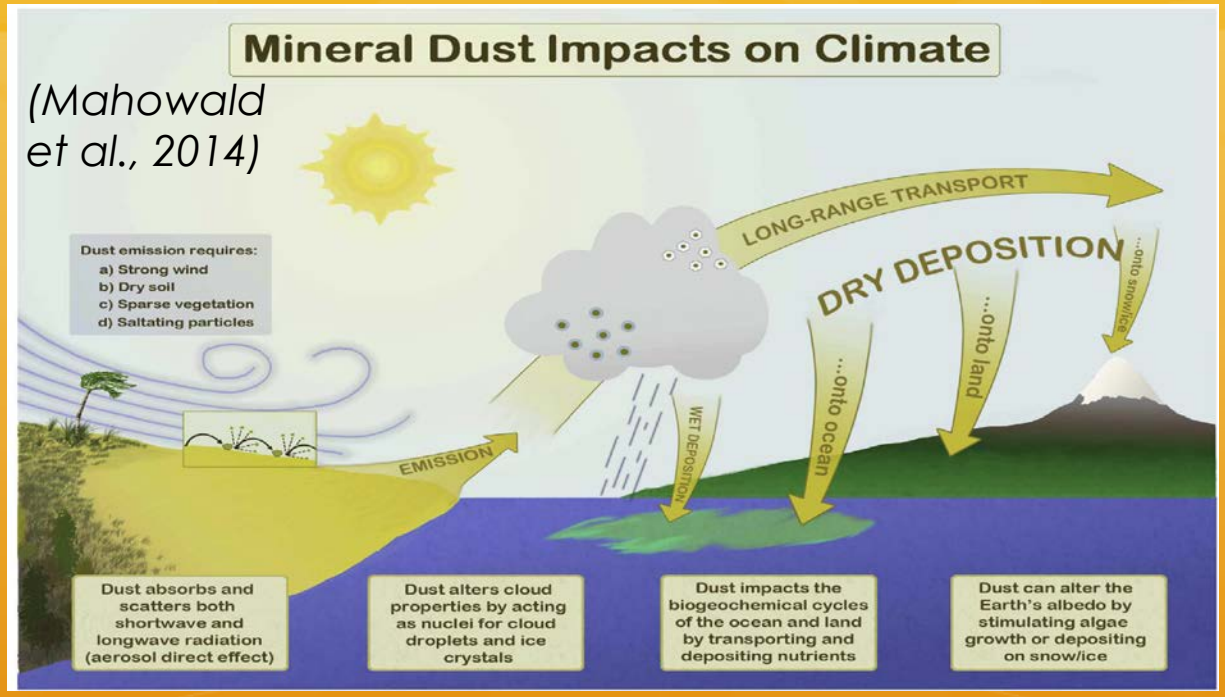
Dust – A Core Theme of Earth System Science



- Dust emissions and transport are affected by climate.
- Dust can adversely affect the health of human beings.

All these impacts are far-reaching, because of dust long-range transport (LRT).

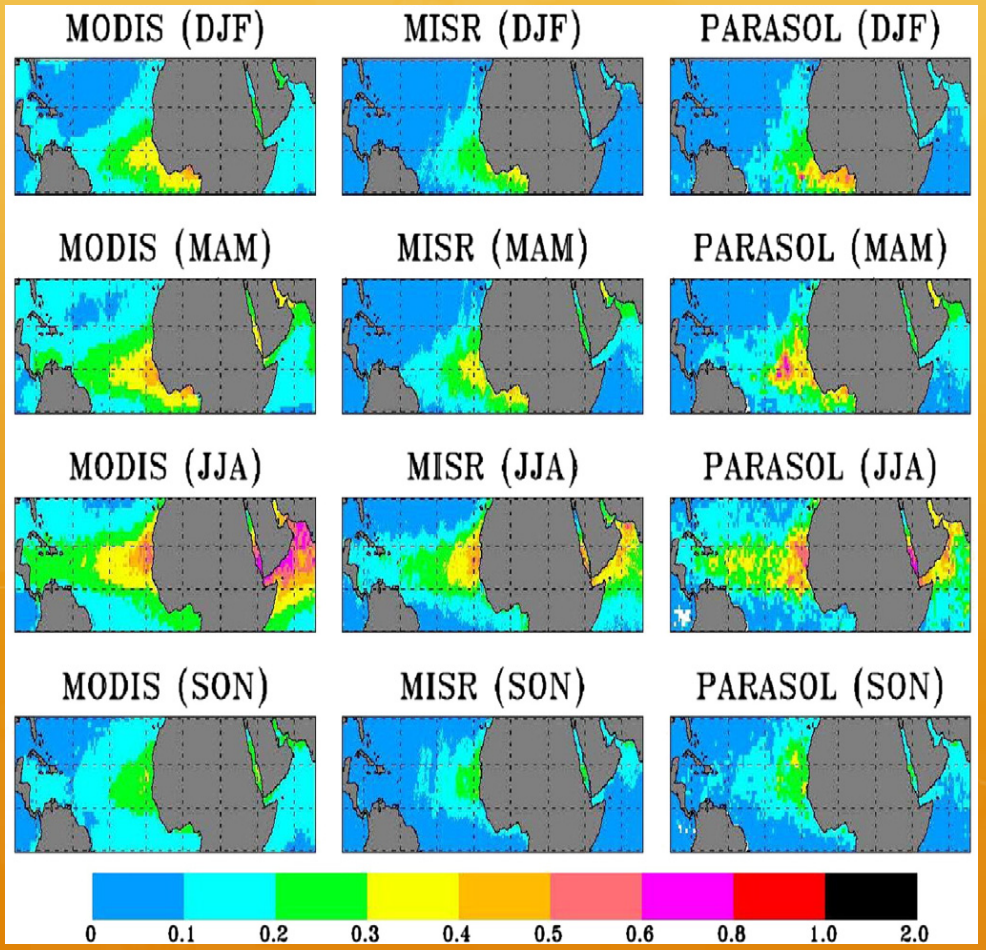
Role of Satellites in Studying Dust LRT

- ✓ Routine sampling
- ✓ Over a global scale
- ✓ Lasting for years & decades

Satellite observations can provide

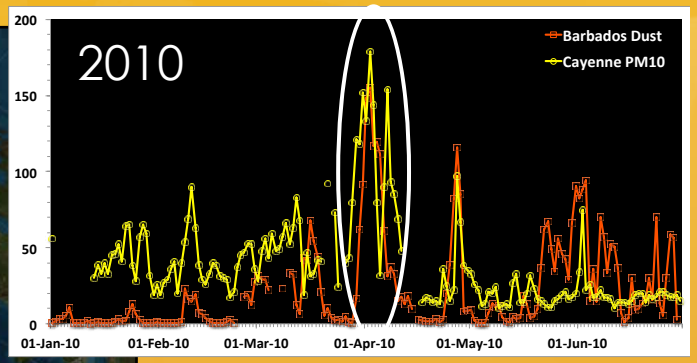
- details of dust episodes
- variations on intra-seasonal, seasonal, and inter-annual time scales

Satellite-derived Dust Optical Depth



Yu, H., L. A. Remer, R. A. Kahn, M. Chin, and Y. Zhang (2013). Satellite perspective of aerosol intercontinental transport: from qualitative tracking to quantitative characterization, *Atmos. Res, 124*, 73-100.

CALIOP – 3D View of Dust Transport



Data courtesy of Joe Prospero

Image courtesy of Kelly Elkins, NASA GSFC SVS

- 3D distributions of aerosol backscatter and extinction – more realistic transport height
- Particulate depolarization ratio – separating dust from non-dust aerosol
- Above-cloud aerosol (ACA) profile – new information additional to clear-sky aerosol (CSA)

Objectives

We use CALIOP 8-year (2007-2014) record of aerosol observations (nighttime data only) to:

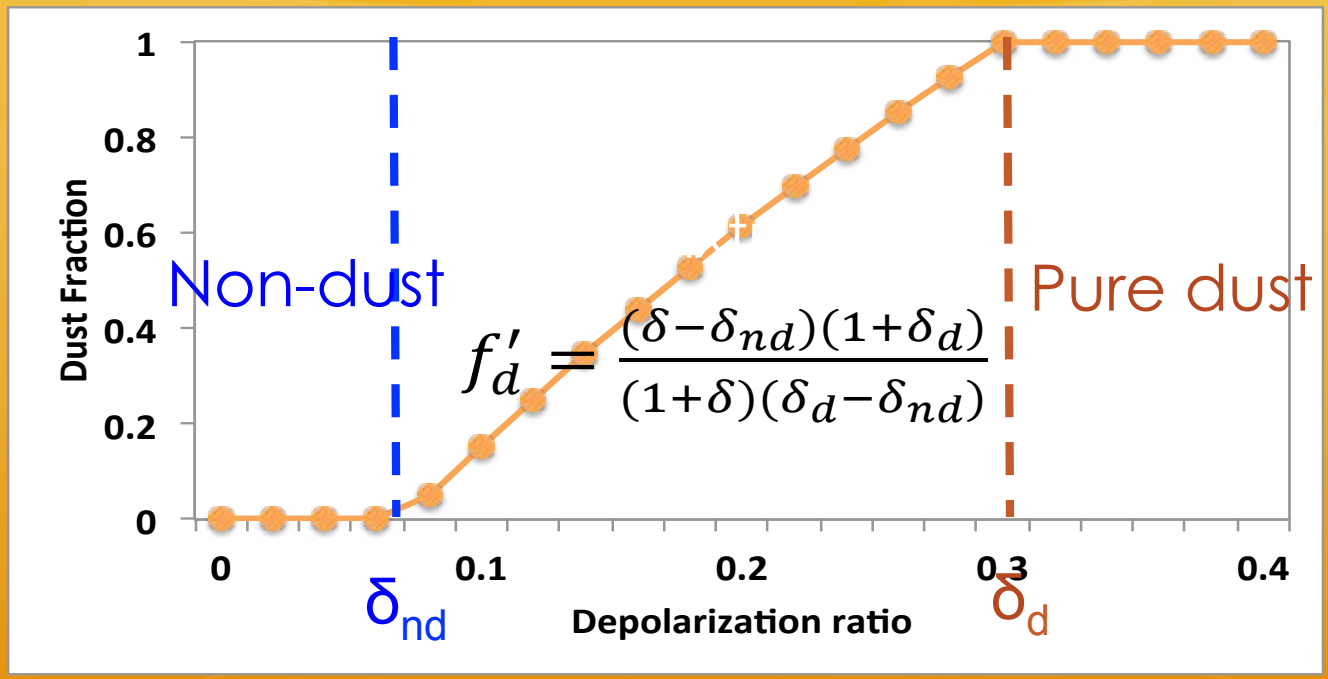
- Characterize seasonal and interannual variability of 3D dust transport across the Atlantic.
- Estimate the amount of dust imported to the great Caribbean Basin.

The 2007-2013 analysis has been published:

1. Yu et al., 2015. "Quantification of Trans-Atlantic Dust Transport from Seven-year (2007-2013) Record of CALIPSO Lidar Measurements." Remote Sens. Environ 159 232-249 [10.1016/j.rse.2014.12.010]

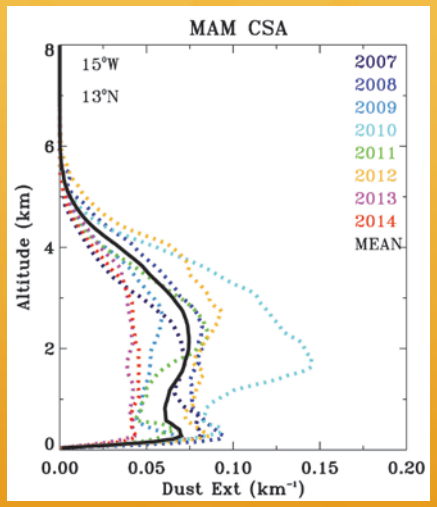
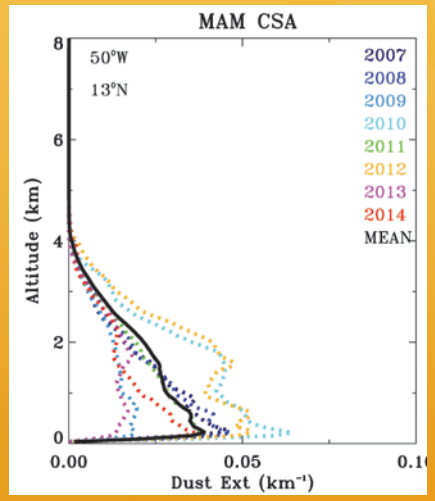
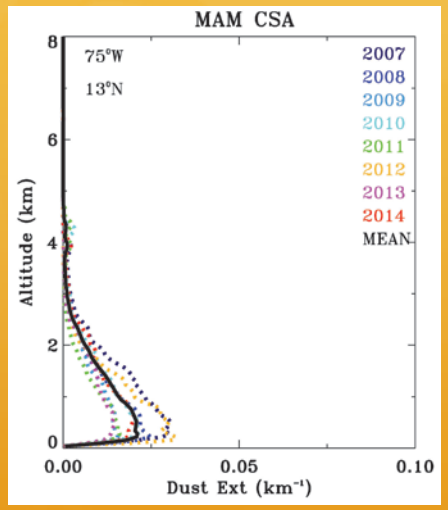
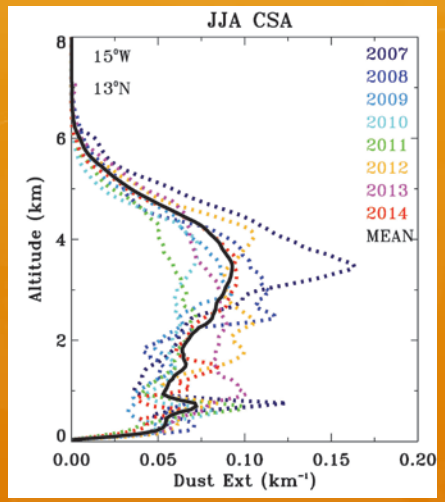
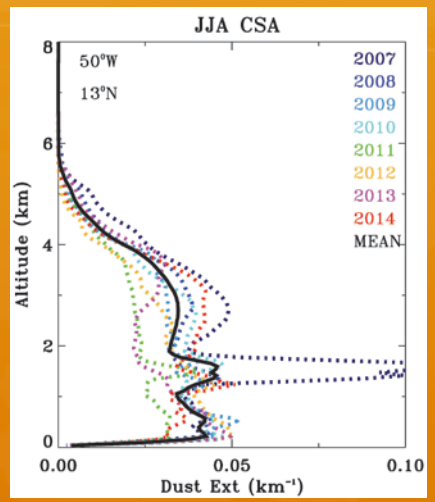
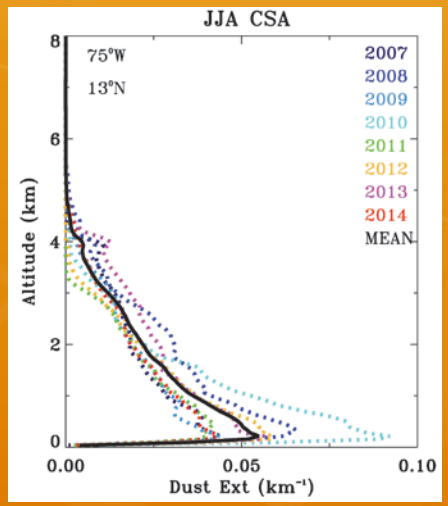
2. Yu et al. 2015. "The Fertilizing Role of African Dust in the Amazon Rainforest: A First Multiyear Assessment Based on CALIPSO Lidar Observations ." Geophysical Research Letters 42 1984-1991 [10.1002/2015GL063040]

Separating Dust from non-dust aerosol



- **Lower-bound Dust Fraction (LDF):** $\delta_d = 0.30$, $\delta_{nd} = 0.07$
- **Upper-bound Dust Fraction (UDF):** $\delta_d = 0.20$, $\delta_{nd} = 0.02$
- **We use an average of LDF and UDF as the best estimate.**

Dust Extinction Profiles – 8 years

	African Coast	Upwind of Barbados	Caribbean Sea
Spring			
Summer			

Estimate of Dust Mass Flux from CALIOP Measurements

Dust backscatter/ extinction profile from CALIOP

(CSA & ACA)

Extinction (1/m) =
Mass Conc. (g/m^3) * MEE (=0.37 m^2/g)

MEE (Mass Extinction Efficiency)

Profile of Dust Mass Concentration (m)

(CSA & ACA)

$$FLUX_{ALL} = FLUX_{CSA}\,(1 - f_{ACA}) + FLUX_{ACA}\,f_{ACA}$$

MERRA reanalysis wind field

Dust Mass Flux

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

(CSA & ACA)

CSA: Clear-Sky Aerosol

ACA: Above-Cloud Aerosol

Sources of Uncertainty

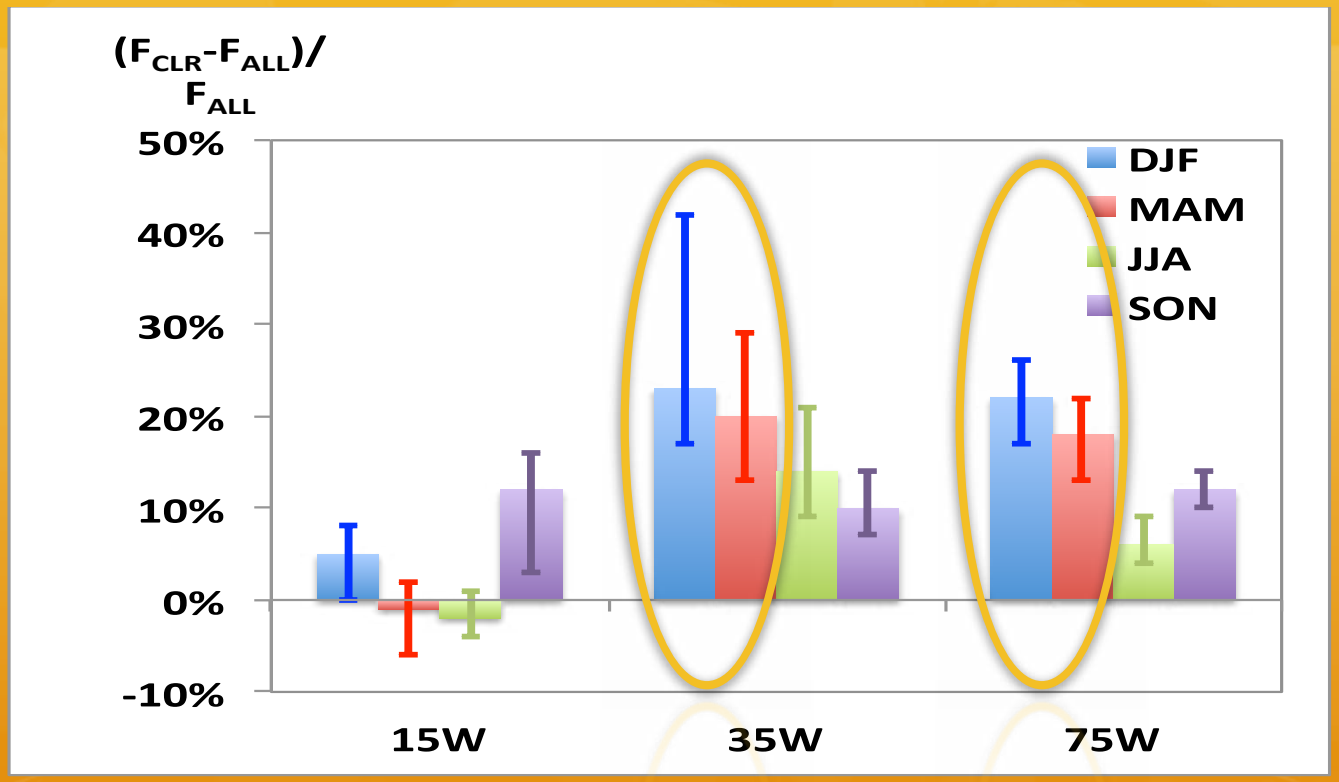
- Dust and non-dust separation: ± (15~34)%
- Unchanged size: ±15% *(Maring et al., 2003)*
- CALIOP AOD low-bias: -30% *(Omar et al., 2013; Liu et al., 2014)*
- Low dust MEE/ high mass bias: +30% *(Ansmann et al., 2012)*
- Vertical profile shape: *probably small,* ±10%

Overall known uncertainty: ± (45~70)%

Unquantifiable sources

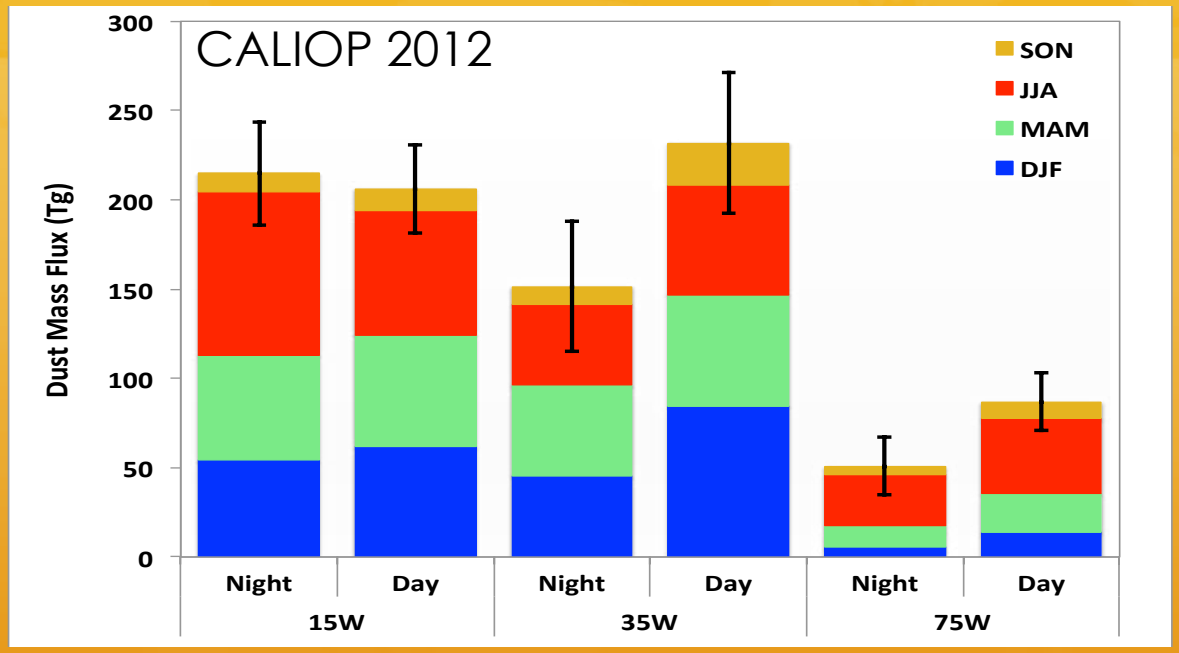
☒ Below-cloud dust ☒ Diurnal variation

Clear-sky vs. all-sky



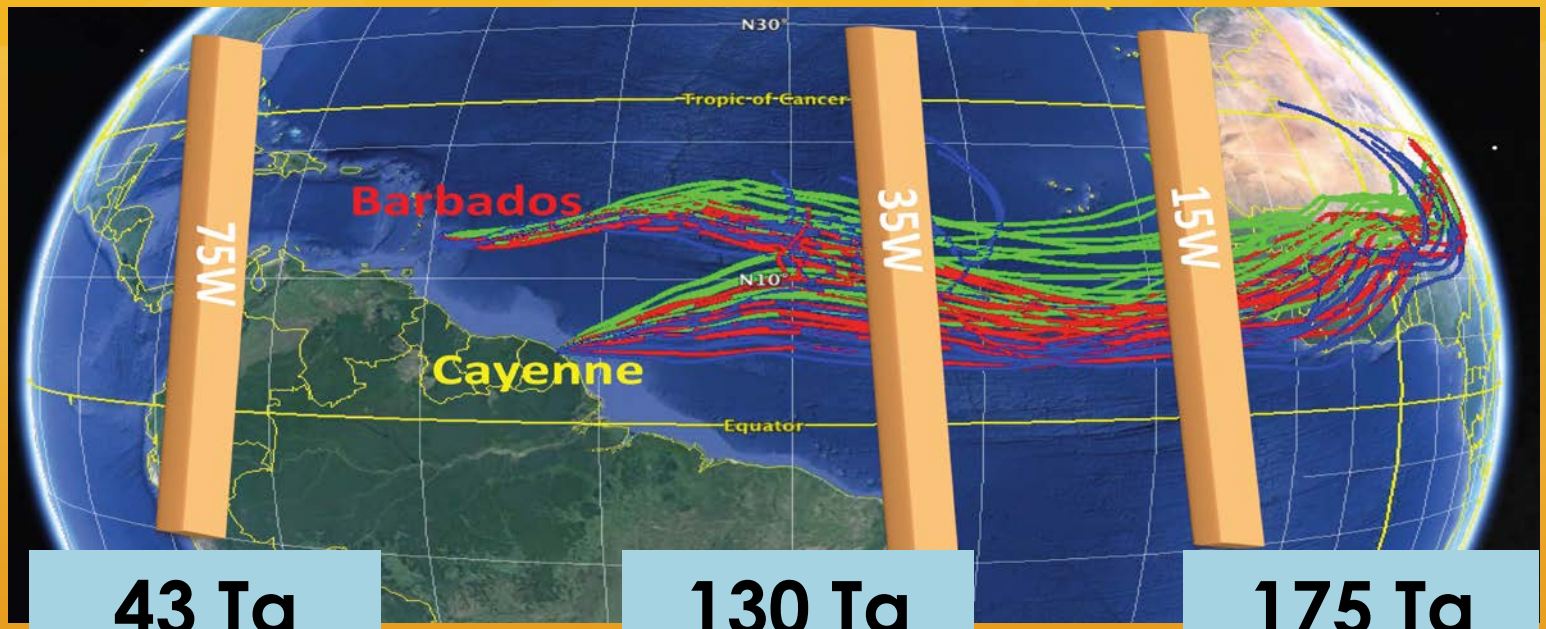
- The relative difference between using clear-sky & all-sky measurement is about 20% in regions remote from the source in winter & spring.
- *<u>Caveat:</u> we don't have below-cloud aerosol observation to offer a conclusive assessment . (maybe ground-based lidar)*

Daytime vs nighttime

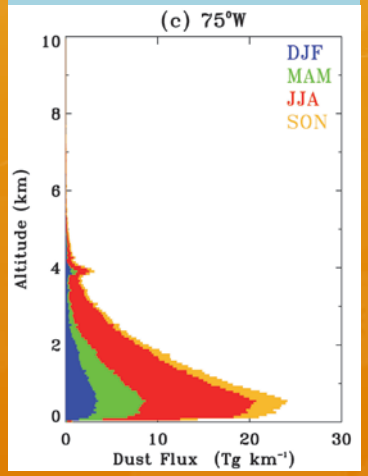


- But we can't attribute the day-night difference to physical processes, because CALIOP daytime and nighttime data have different quality.
- AERONET AOD in trans-Atlantic dust route shows small daytime variations *(Smirnov et al, 2002; Zhang et al., 2012)*

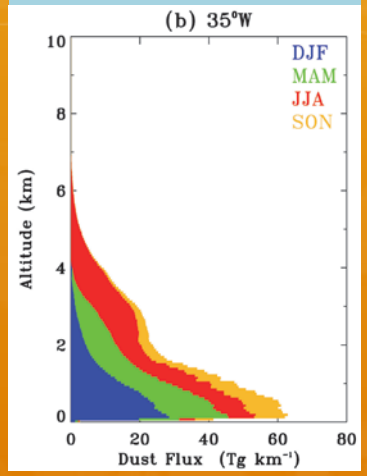
8-year average dust flux & profile



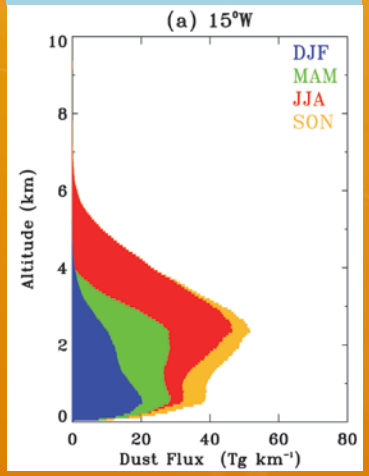
43 Tg



130 Tg

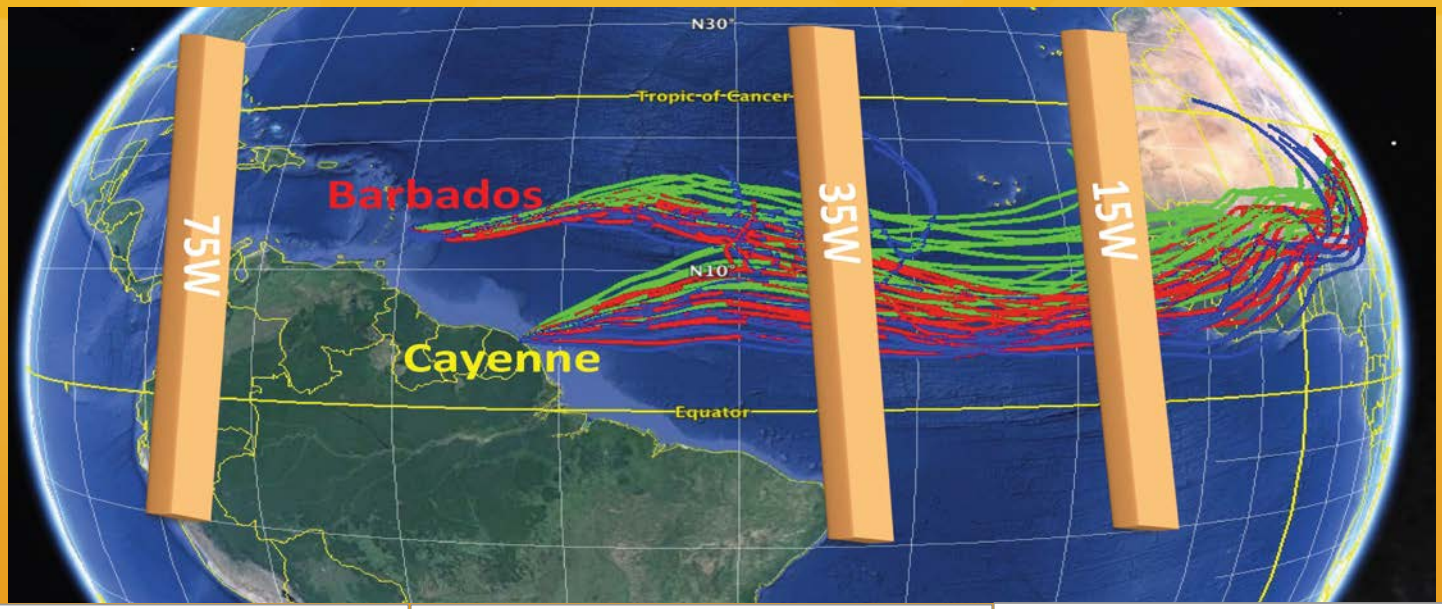


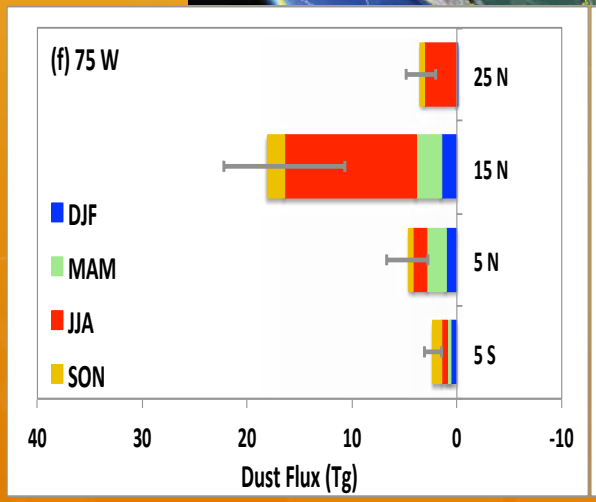
175 Tg

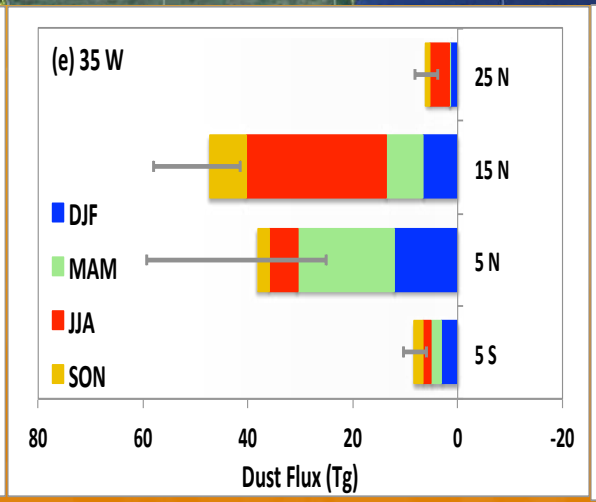


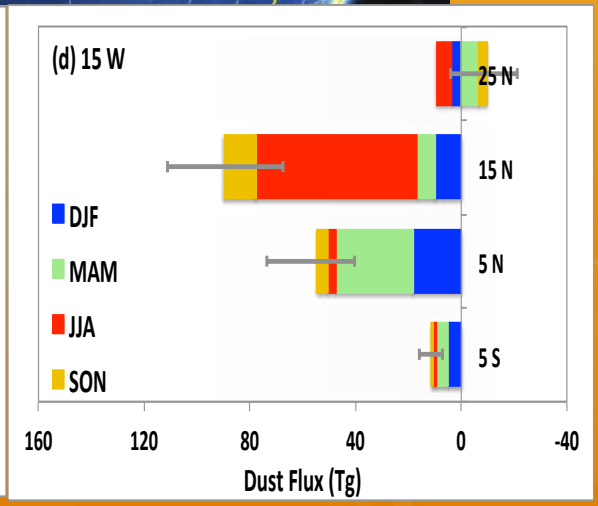
1 Tg = 1 million tons

Meridional Distribution



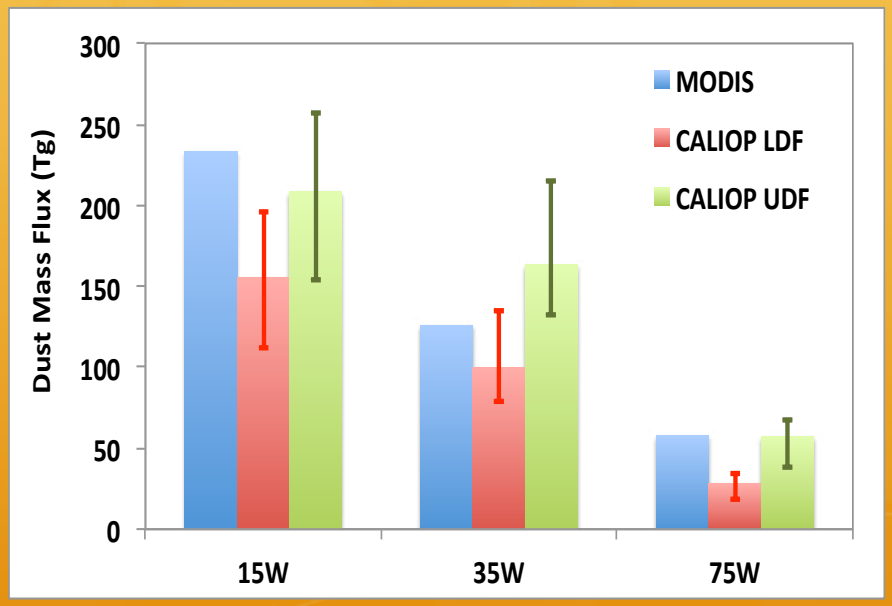






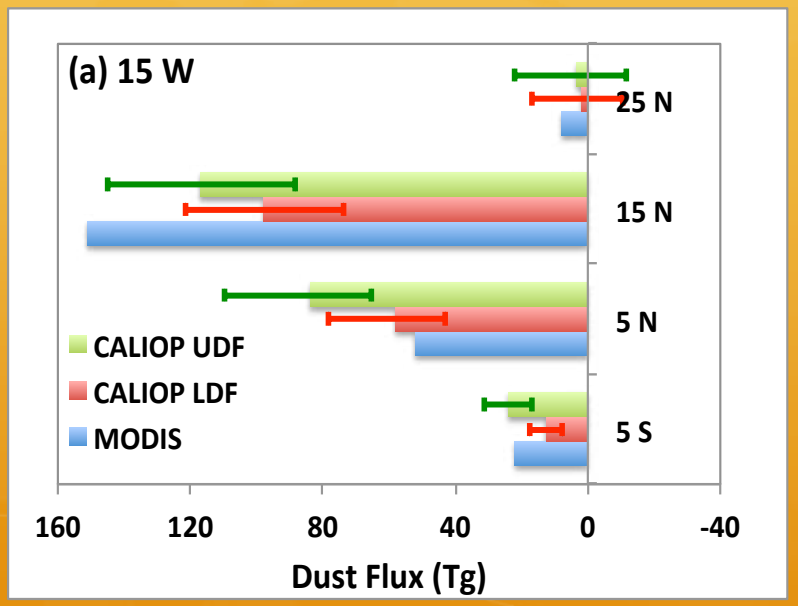
CALIOP vs. MODIS

10S-30N Integrated



MODIS-based dust mass flux (Kaufman et al., 2005) generally agrees well with CALIOP upper-bound estimate.

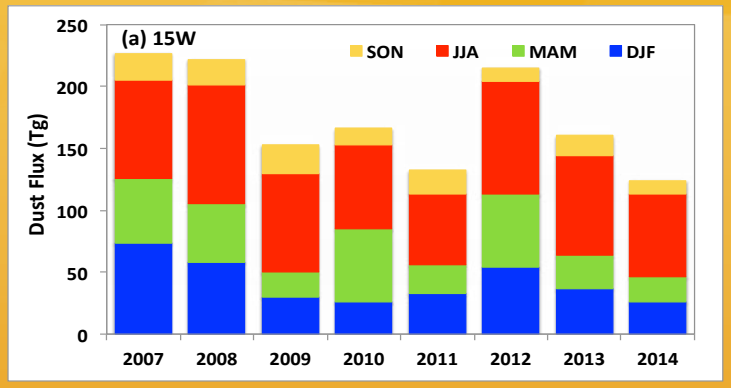
Meridional Distribution

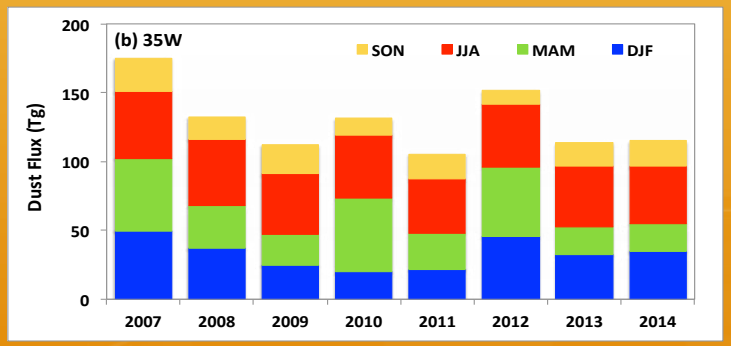


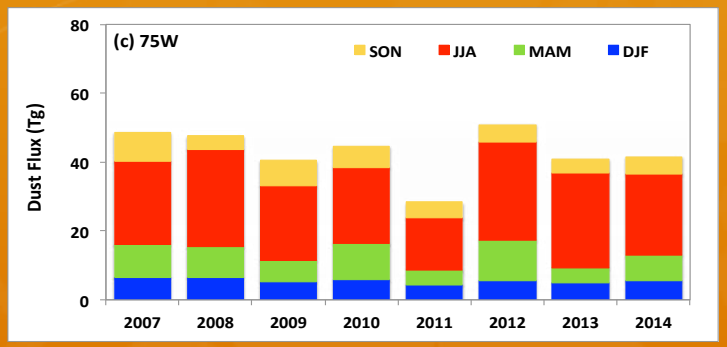
Larger differences in the meridional distribution.

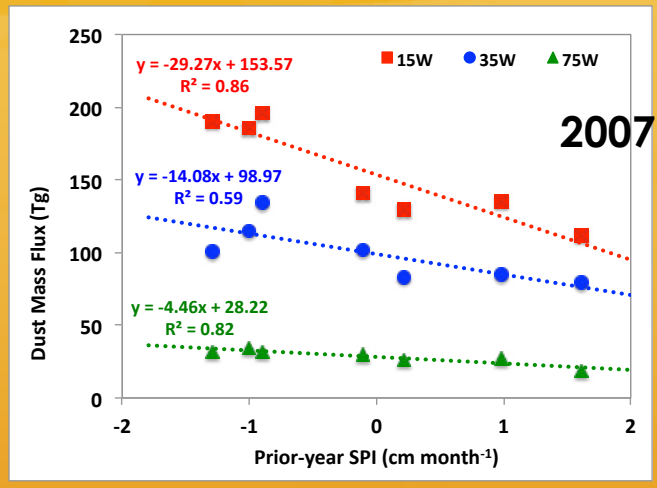
Error bar indicates the range over the 8-year period.

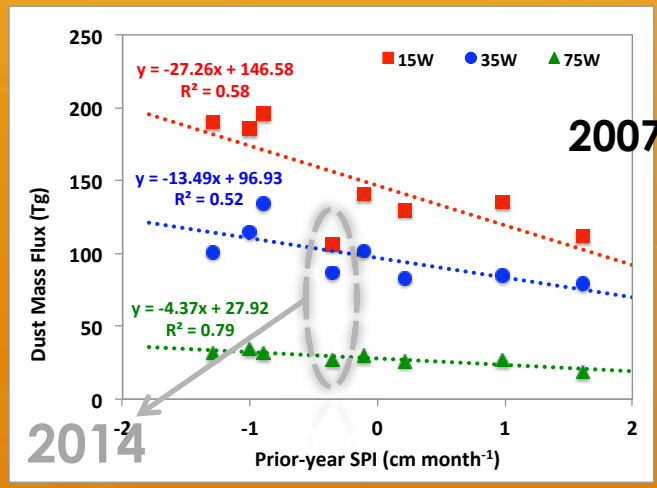
Interannual variation of dust transport vs. prior-year Sahel Rainfall





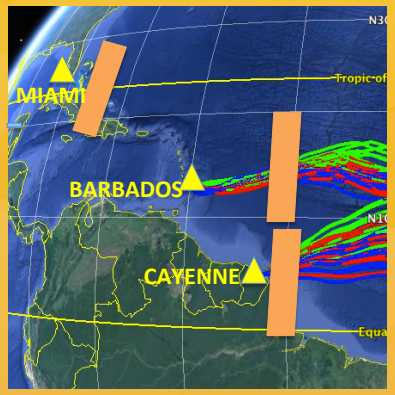


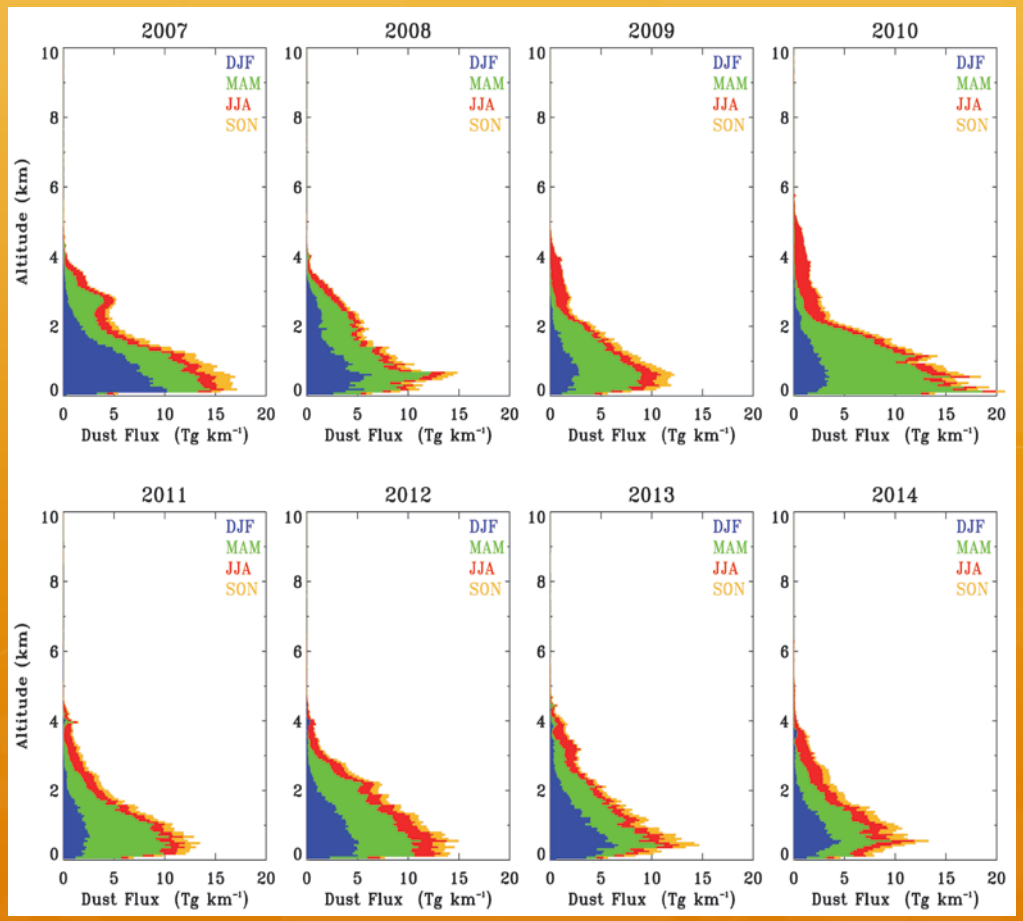


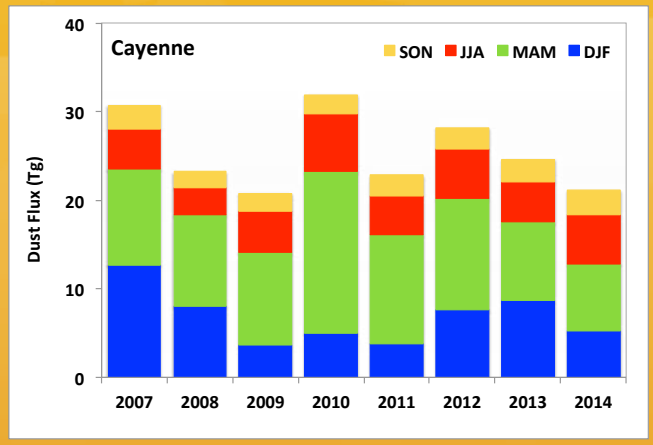


SPI - Sahel Precipitation Index (data from JISAO of NOAA & U. Washington)

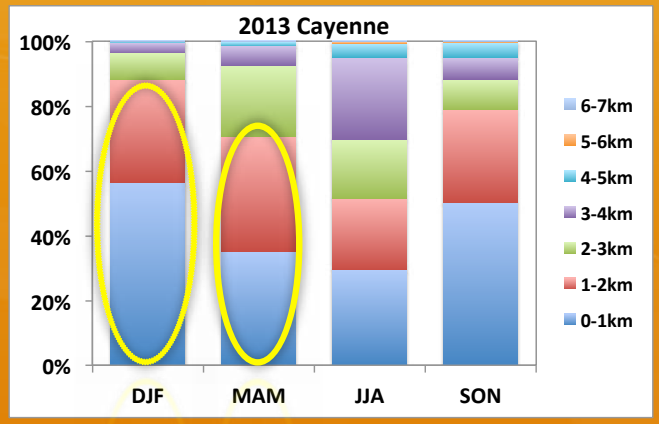
Dust Import into CAYENNE





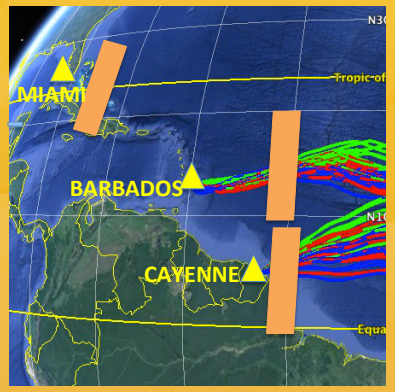


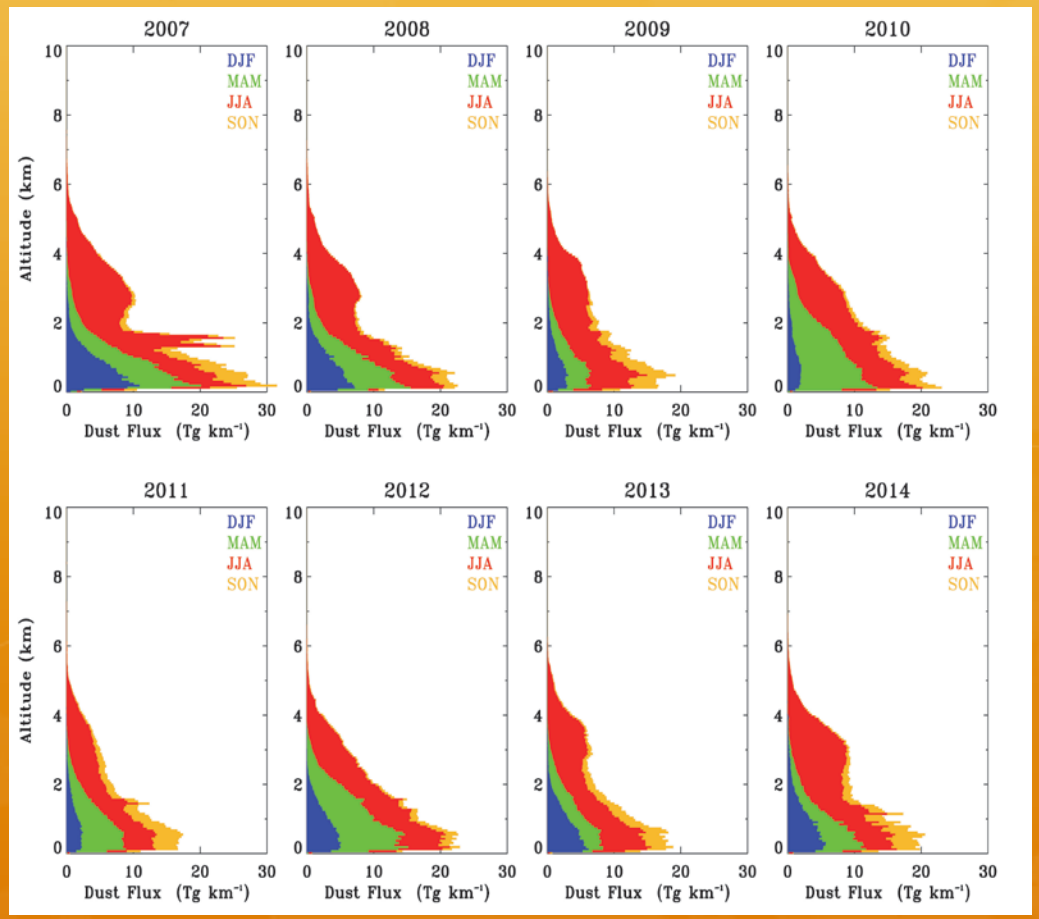
20~30 Tg, peak in spring (winter in some years)

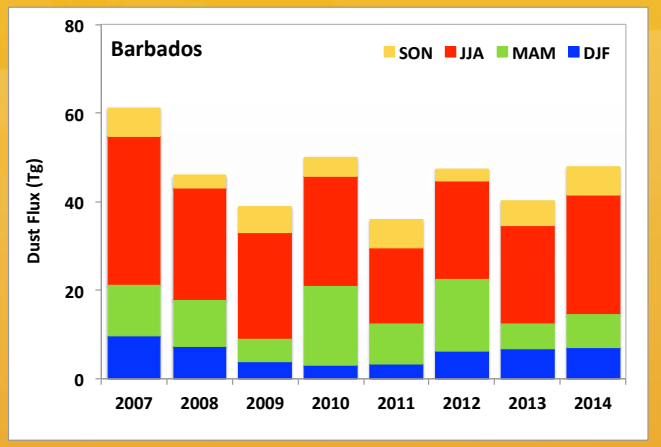


In spring/winter: 70 - 85% below 2 km

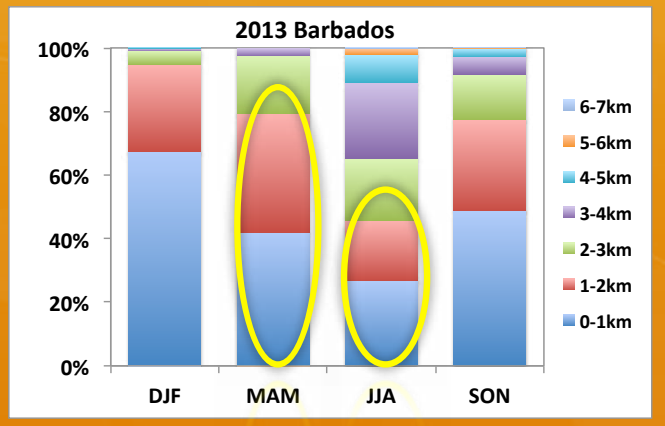
Dust Import into BARBADOS





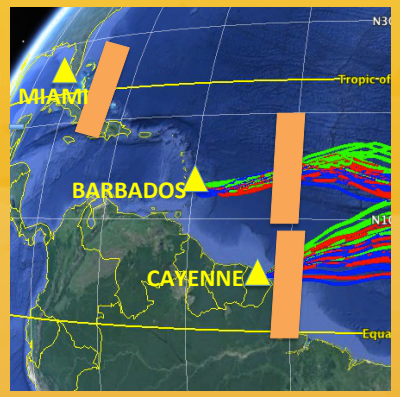


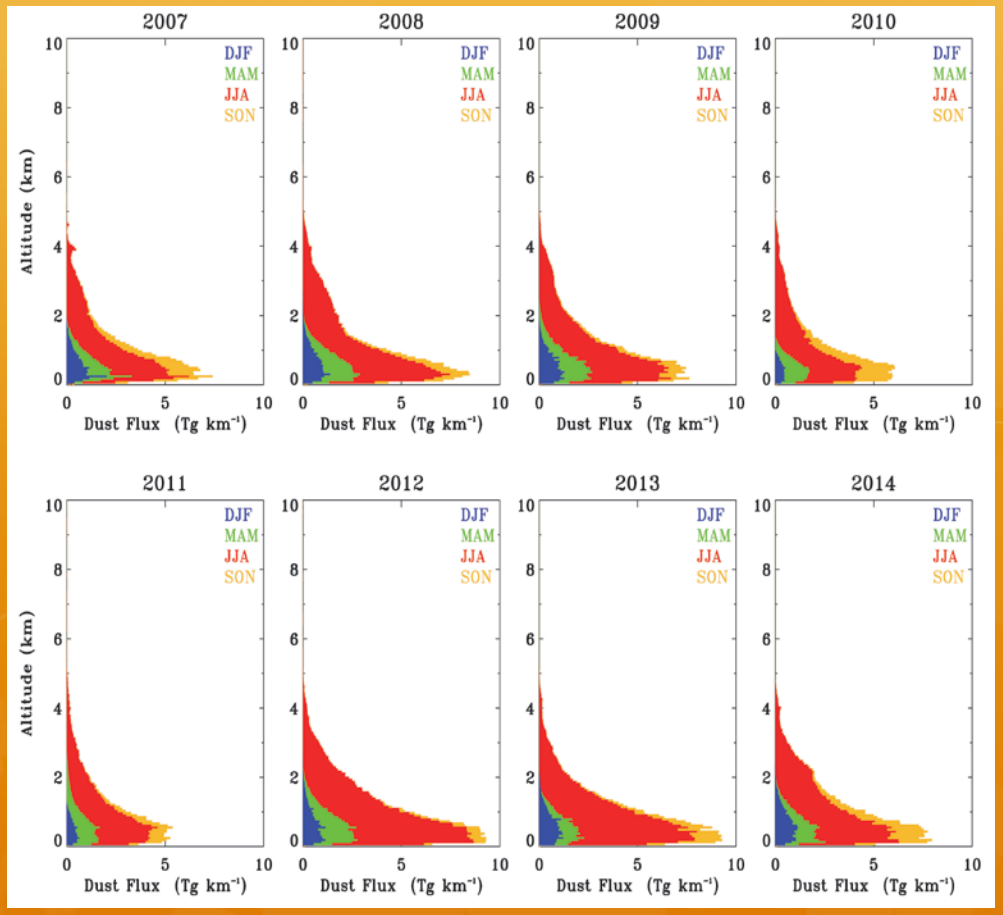
37~60 Tg, peak in summer (spring in some years)

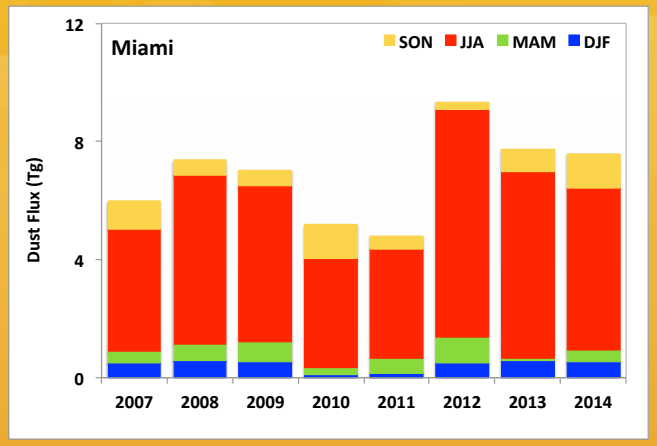


Below 2 km: 80% (spring), 42% (summer)

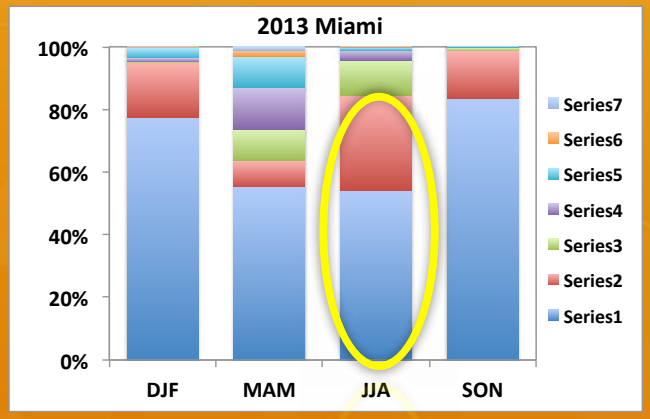
Dust Import into MIAMI





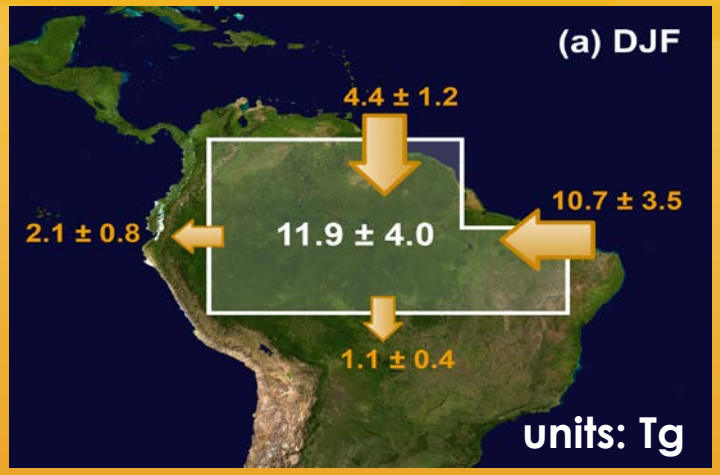


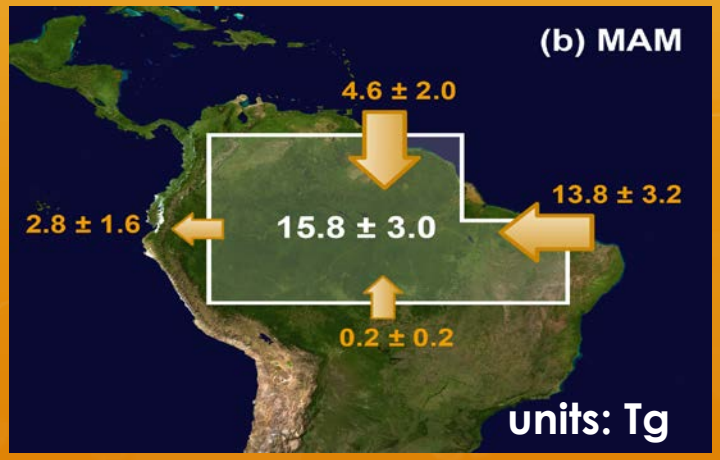
5-10 Tg, peak in summer



In summer: 85% below 2 km

Budget of Dust Flow into Amazonia





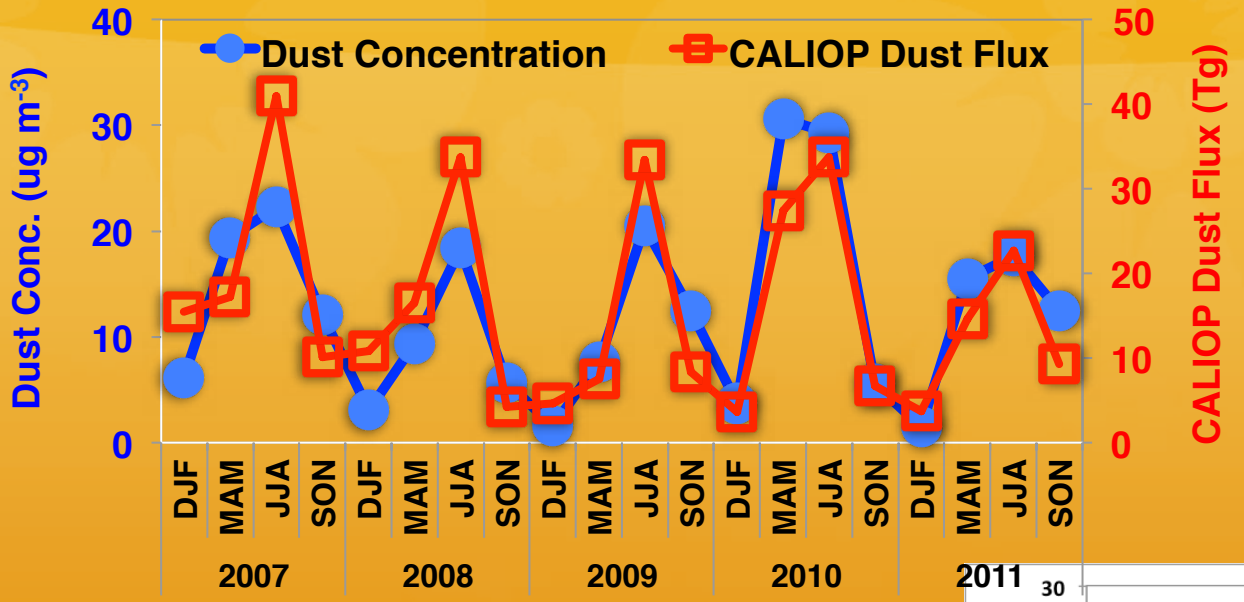
7-year average ± std dev.

DJF+MAM combined

- Total dust import from E & N: 34 Tg
- Fraction of meridional contribution: ~30%
- Dust deposition: 28 Tg

Source	Total Dust Deposition (Tg)	Dust Deposition Per Area (kg ha^{-1})
CALIOP	28 (8–48)	29 (8–50)
MODIS	50	n/a
In situ observations	13 (9–19)	190
GOCART model	26	27
WRF-Chem model	19	20
GEOS-Chem model	17	n/a

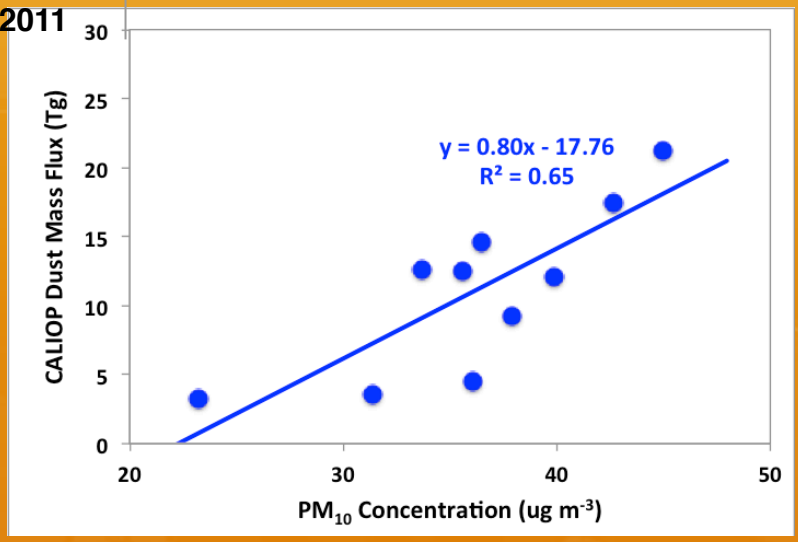
Correlation of Dust Flux with Surface Dust



Barbados

Cayenne

DJF & MAM only



Surface dust/PM_{10} concentrations at Barbados and Cayenne provided by J. Prospero.

Conclusions

We estimated from CALIOP 8-year record of aerosols:

- Yearly dust transport: 182 Tg (15°W), 132 Tg (35°W), 43 Tg (75°W), with a known uncertainty of ± (45-70)%.
- The interannual variation shows correlation with prior-year Sahel rainfall. *(2014 exceptional)*
- 28 Tg dust is deposited in the Amazon Basin, which is smaller than MODIS estimate of 50 Tg but higher than models/other observation (13-26 Tg).
- African dust brings phosphorous to the Amazon rainforest, which largely offsets the hydrological loss.

Thank you for your attention!

Questions?