Contribution of vegetation changes to dust decadal variability and its impact on tropical rainfall asymmetry

Presented by

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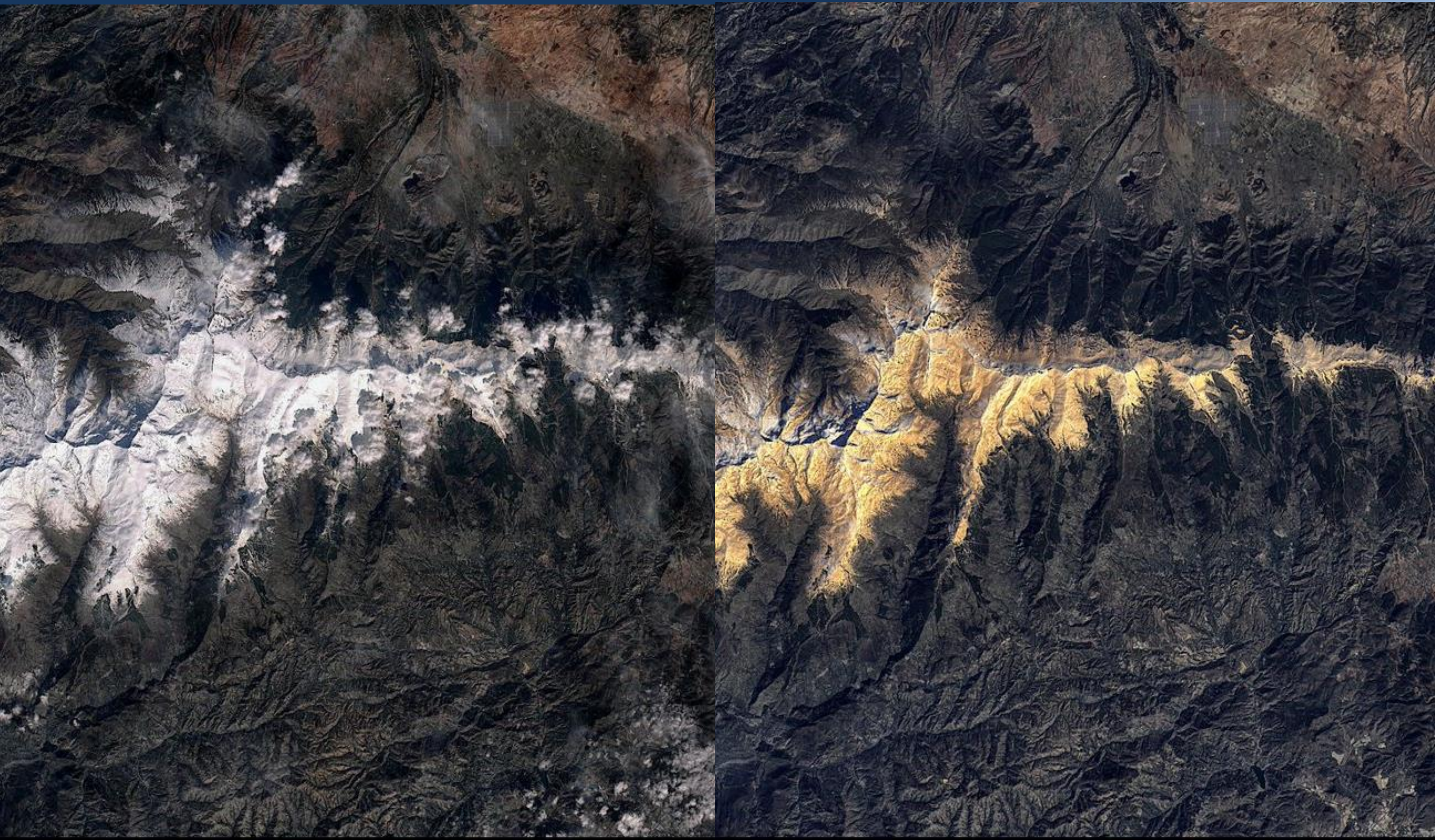
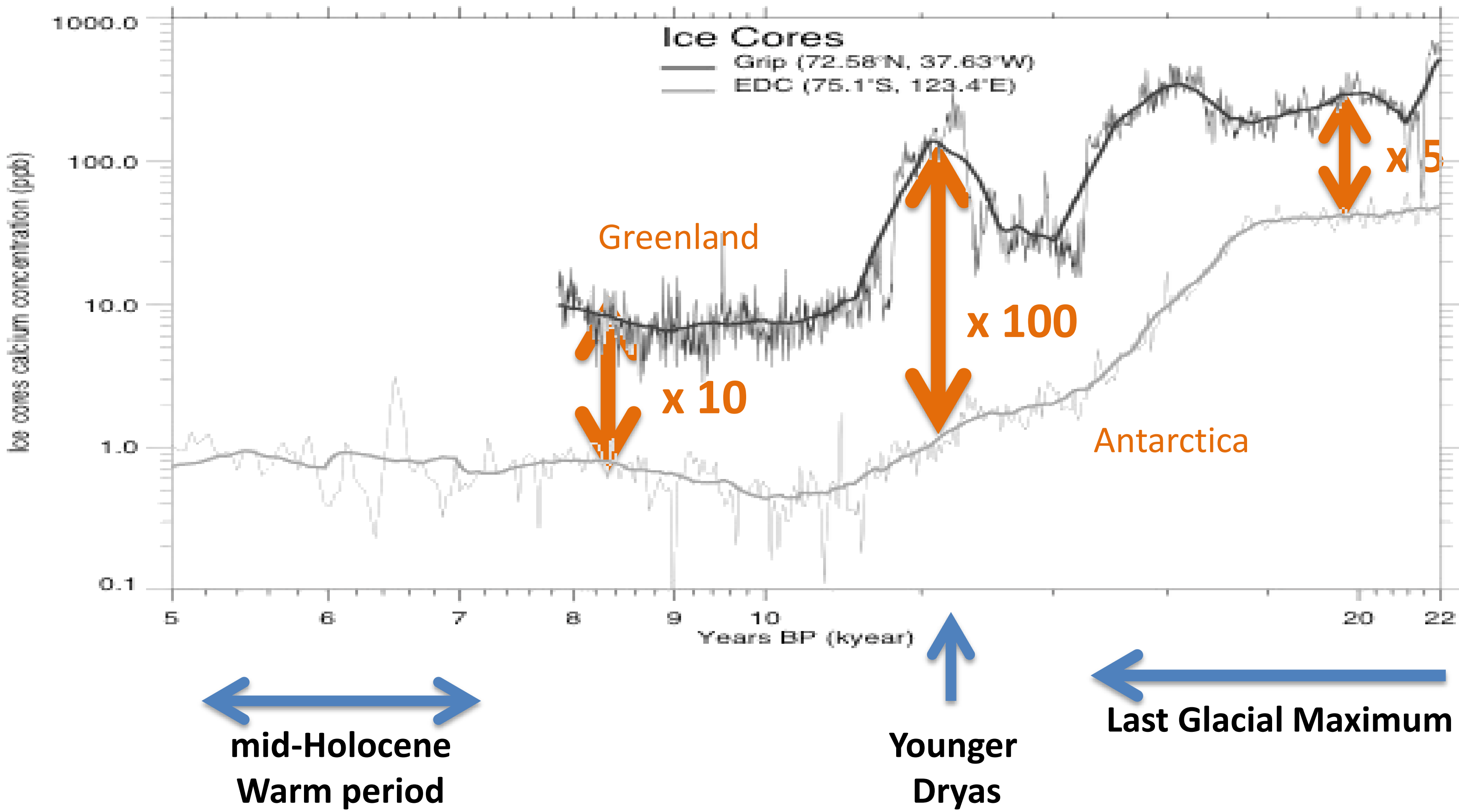
Saharan dust plume over Spain: Feb 2017

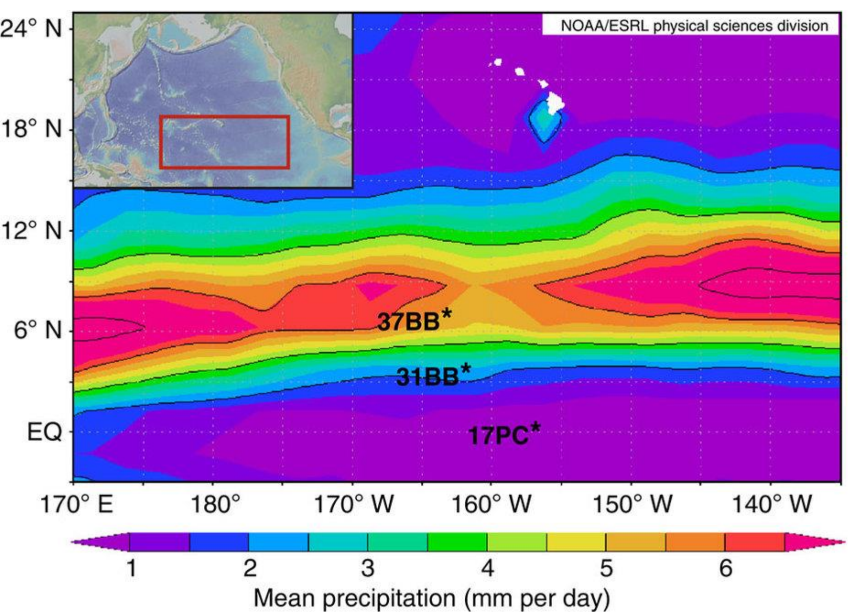
Sierra Nevada: before and after Sahara dust on Feb 2017

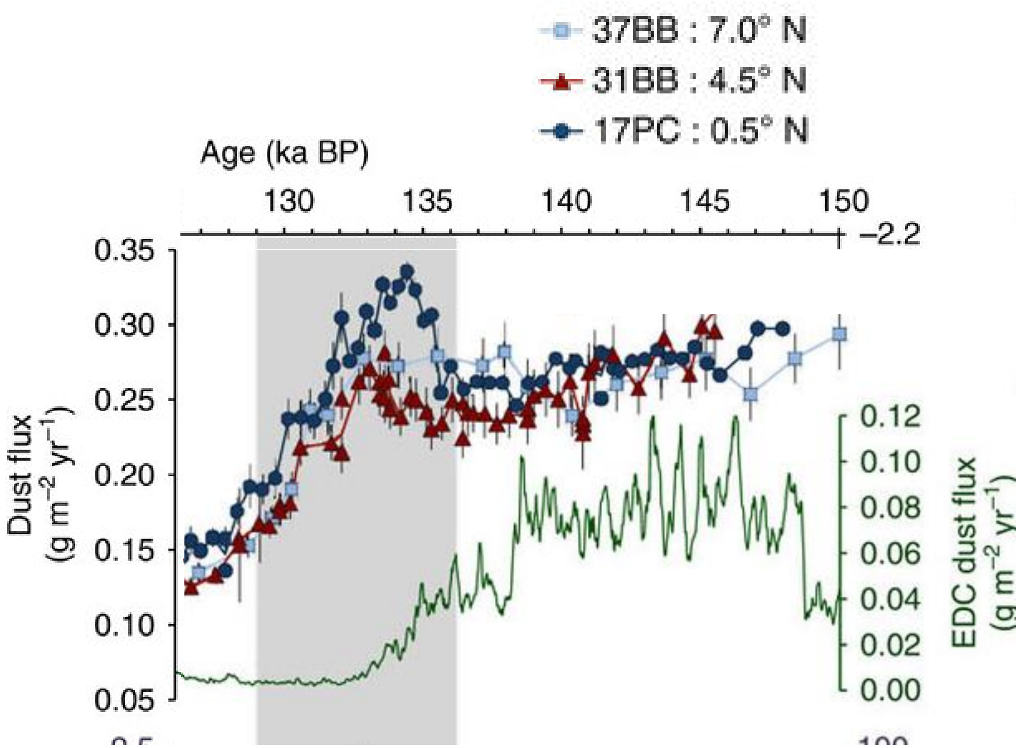


Decadal to millennial scale dust variability



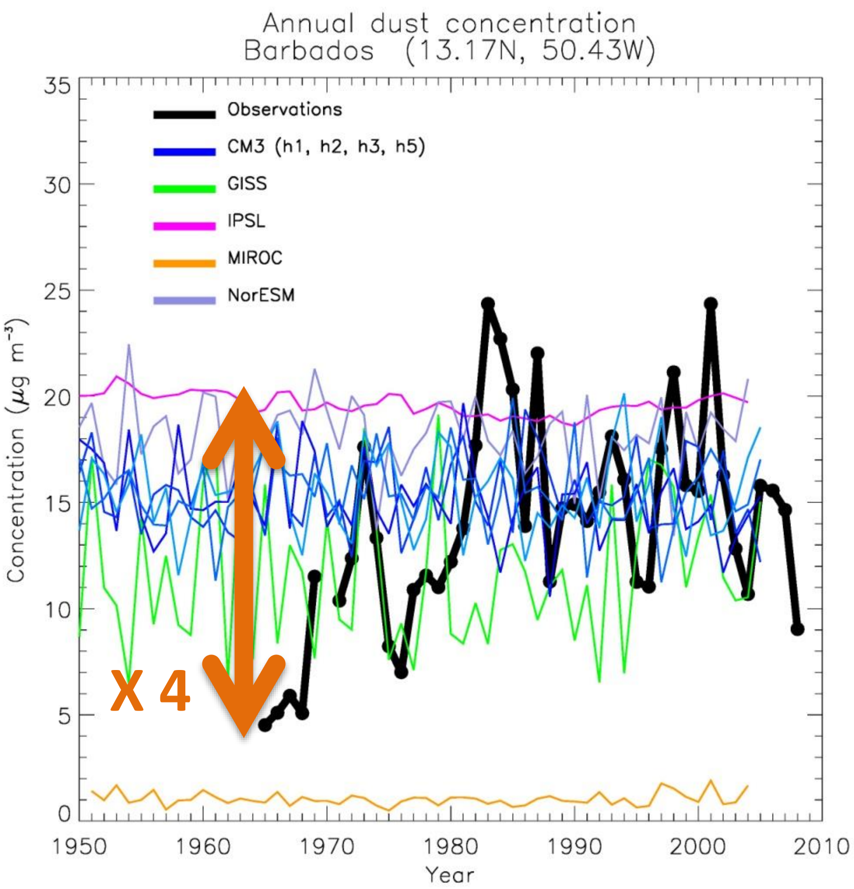
Southward displacement of tropical rainfall during deglaciation (135k-129 kyr)

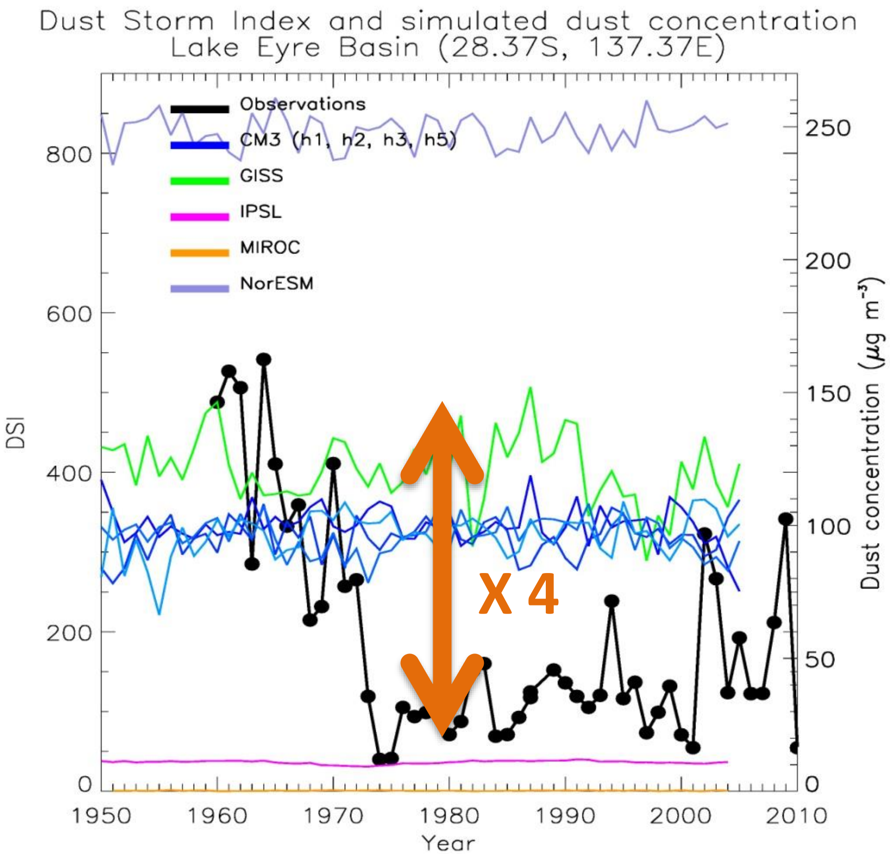




Jacobel et al. "Large deglacial shifts of the Pacific Intertropical Convergence Zone." *Nature communications* 7 (2016).

Dust decadal variability with climate models





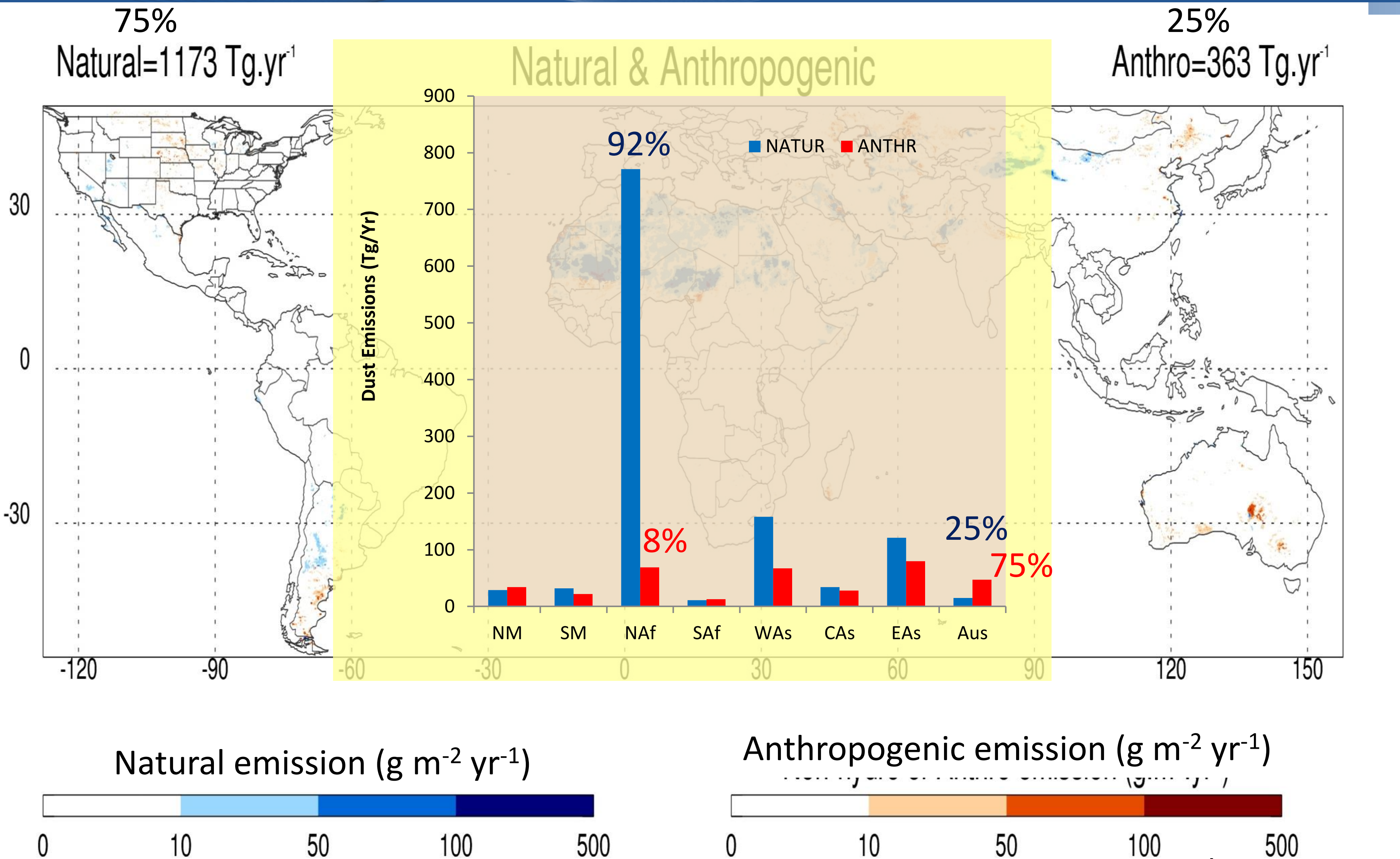
There is a large spread of results between CMIP5 surface dust concentrations, but they have all a common lack of decadal variability

Objectives

What is the contribution of vegetation changes in observed dust decadal variability?

What is the radiative effect on tropical rainfall of dust hemispheric asymmetry?

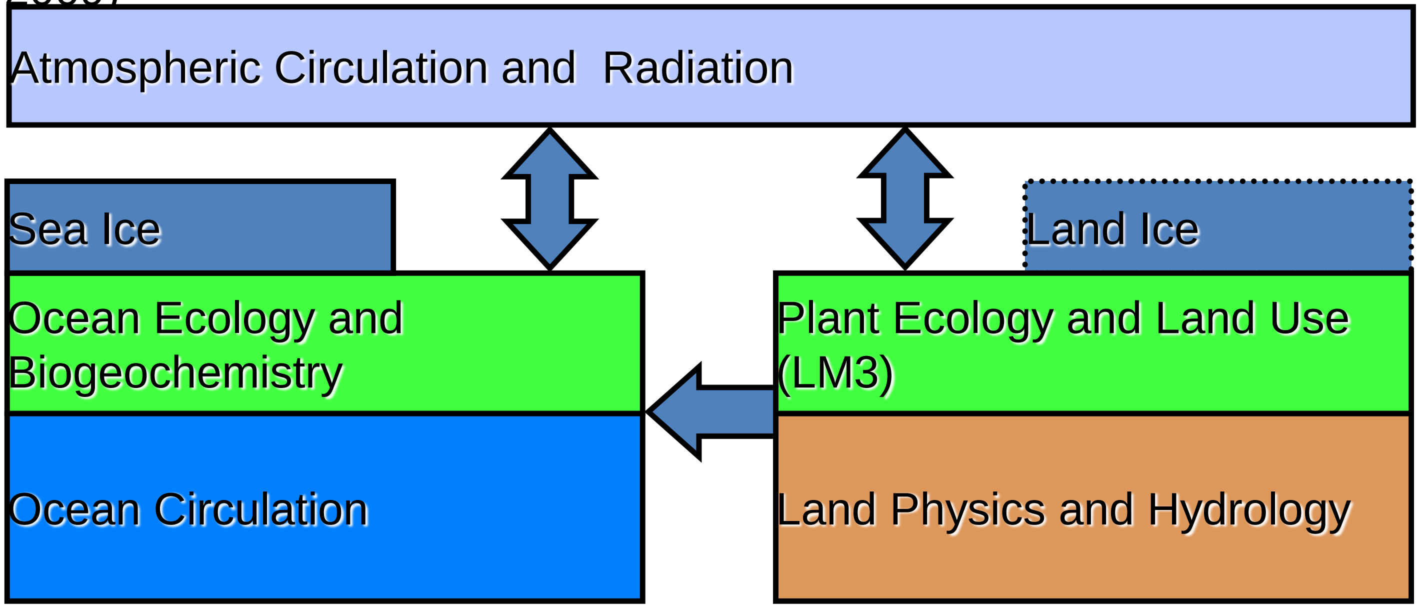
Satellite based contribution of anthropogenic dust



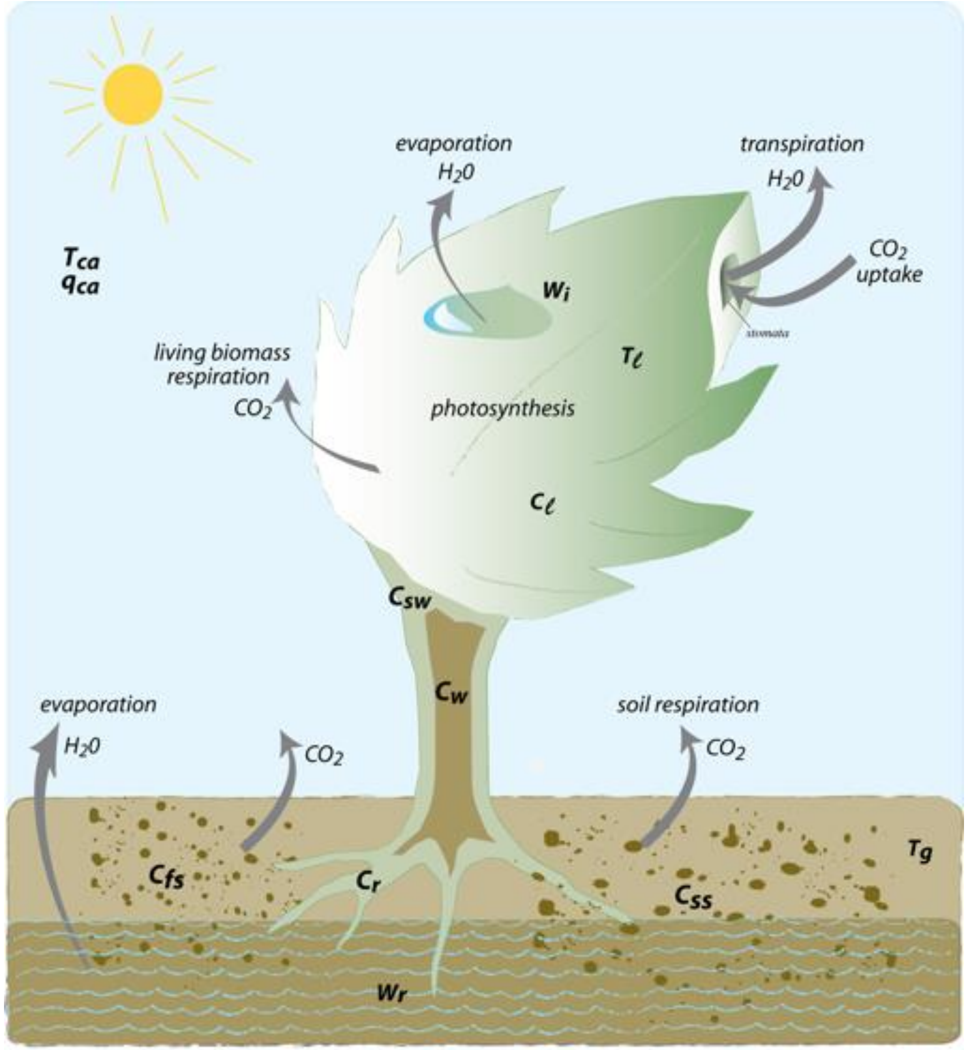
Ginoux et al., RoG, 2012

GFDL CM3

GFDL Coupled Models version 3 (Donner et al., J. Climate, 2011)
- 2x2.5 degree resolution
- 48 levels in the atmosphere
- Chemistry: MOZART (Horowitz et al., 2003)
- Aerosols: Sulfate (MOZART), OC, BC, Seasalt Chin et al., 2002), Dust (Ginoux et al., 2001)
- Dynamic vegetation and land surface model (Shevliakova et al., 2009)



LM3 Structure



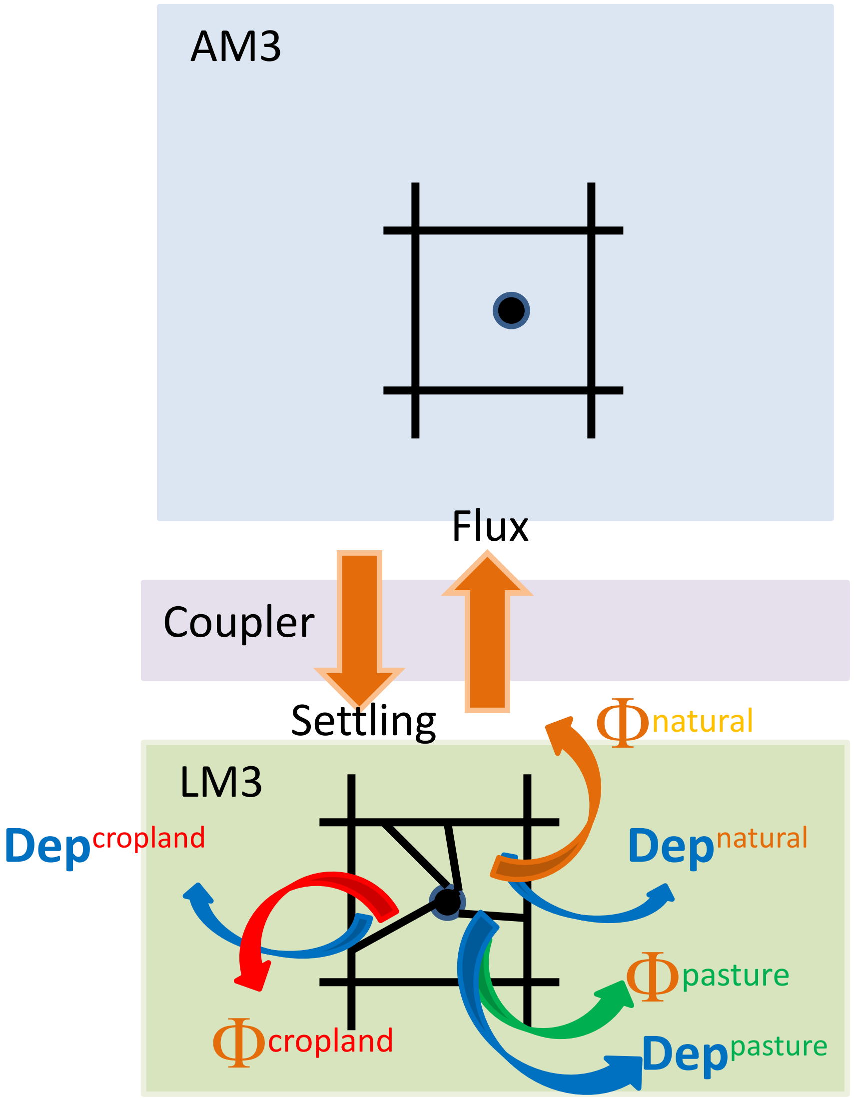
- 5 vegetation types
- 5 carbon pools
- 2 soil carbon pools

- efficient energy and water balance
- mechanistic photosynthesis model
- 20 layers in soil for heat and water
- vertically resolved water uptake
- dynamic river model

- Energy/water balance (30 min)
- C allocation (1day)
- Phenology (1month)
- Fire (1year)
- Biogeography (1 year)
- Land use processes (1 year)

Shevliakova et al., 2009

Implementing dust emission in LM3



- Dust emission and deposition are calculated within each sub-grid tiles (natural, secondary vegetation, pasture and cropland) of LM3,
- Settling and convective fluxes are exchanged between the atmosphere and the canopy,
- The emission parameters were tuned to match present day dust properties with observations

Dust emission

For each tiles, dust emission, dry (settling+turbulent) and below cloud scavenging are calculated using the physical parameters of the corresponding tile.

$$\text{Emission} = C\ L\ S\ U^2\ (U - U_{te})\ \ [\text{kg m}^{-2}\ \text{s}^{-1}]$$

$C = 10^{-9}$ kg m^{-5} s^2

L = exp(-LAI-10.*SAI)

S=[0-1] from GOCART topographic depression (Ginoux et al., 2001)

U : friction velocity [m s^{-1}]

$U_{te} = U_t\ (1.2+0.2*\log_{10}(w+1e^{-5}))^2$

Ut = 0.25 (Bare soils), 0.35 (pasture), 0.8 (cropland) [m s^{-1}]

Model setup & Methodology

Setup

CM3 (2^ox2.5^o, 48 levels) is run from 1950 to 2010 with simplified chemistry for sulfate (>3 times faster: 20yr/day)

I.C.: IPCC AR5 CM3 for 1950

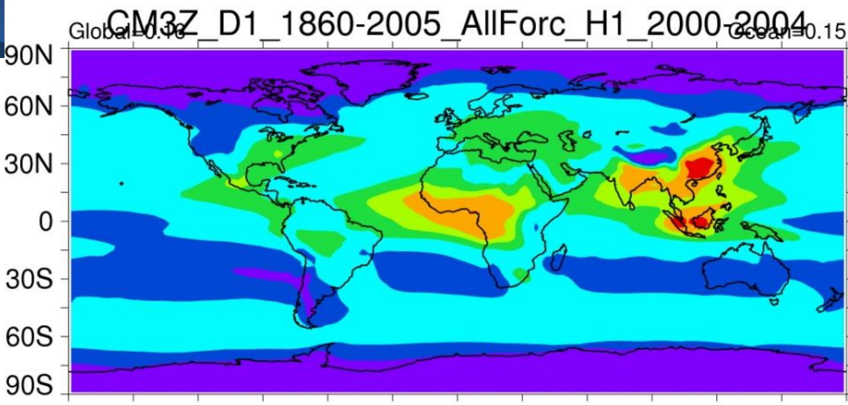
B.C: exact same forcing as IPCC AR5

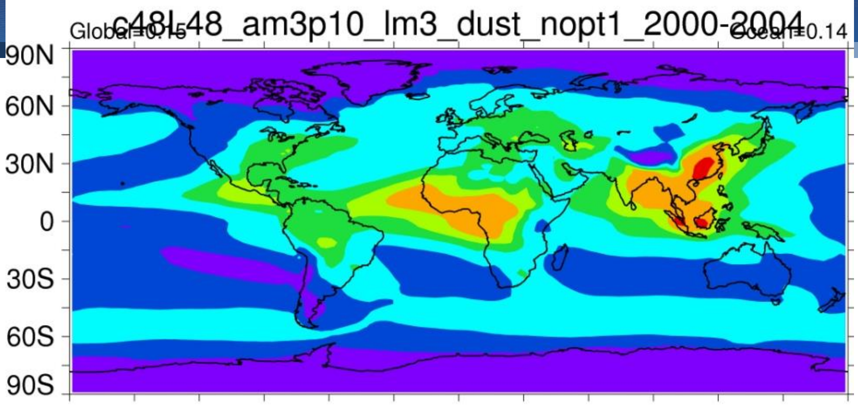
Ocean: No ocean model, observed sea surface temperature (HadSST).

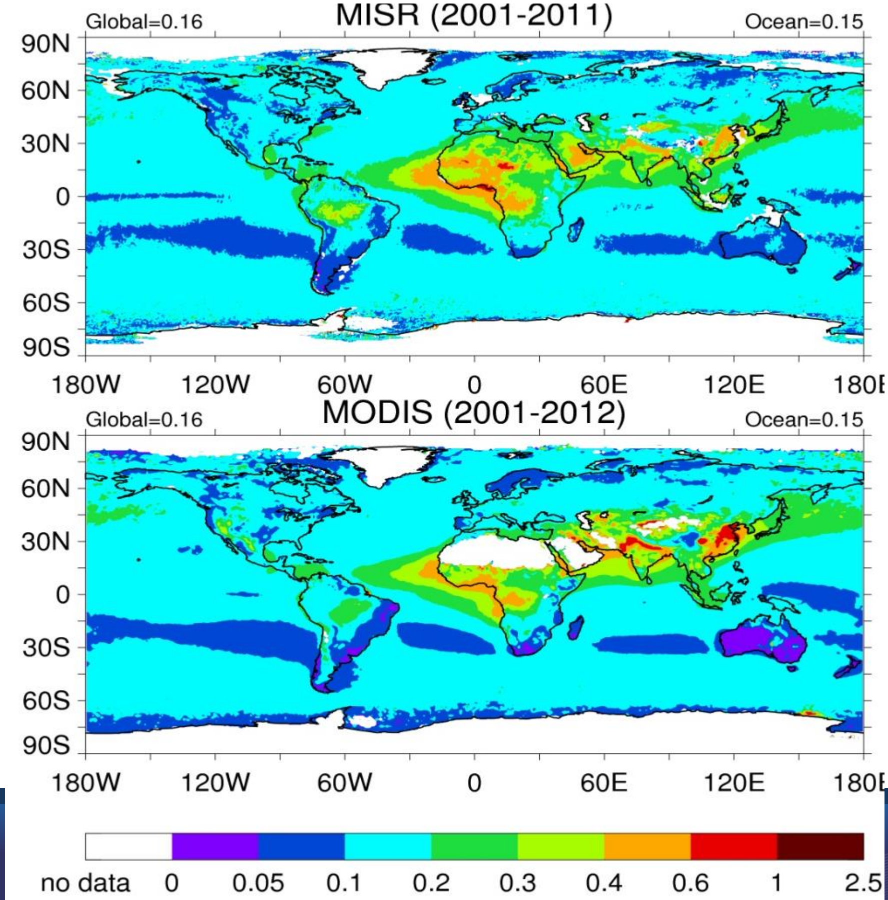
Methodology

1. Determine best estimated values of all dust emission parameters by changing these values in short simulations (2000-2004) then comparing the results with observations: dust concentration (U Miami and IMPROVE), lidar extinction (MPLNET), and AOD (AERONET, MODIS, MISR)
2. Use these parameters to run **1950-2010** with wind components forced towards NCEP re-analysis
3. **1860-2010** simulation without forcing wind components

Tuning LM3DU dust emission with observations

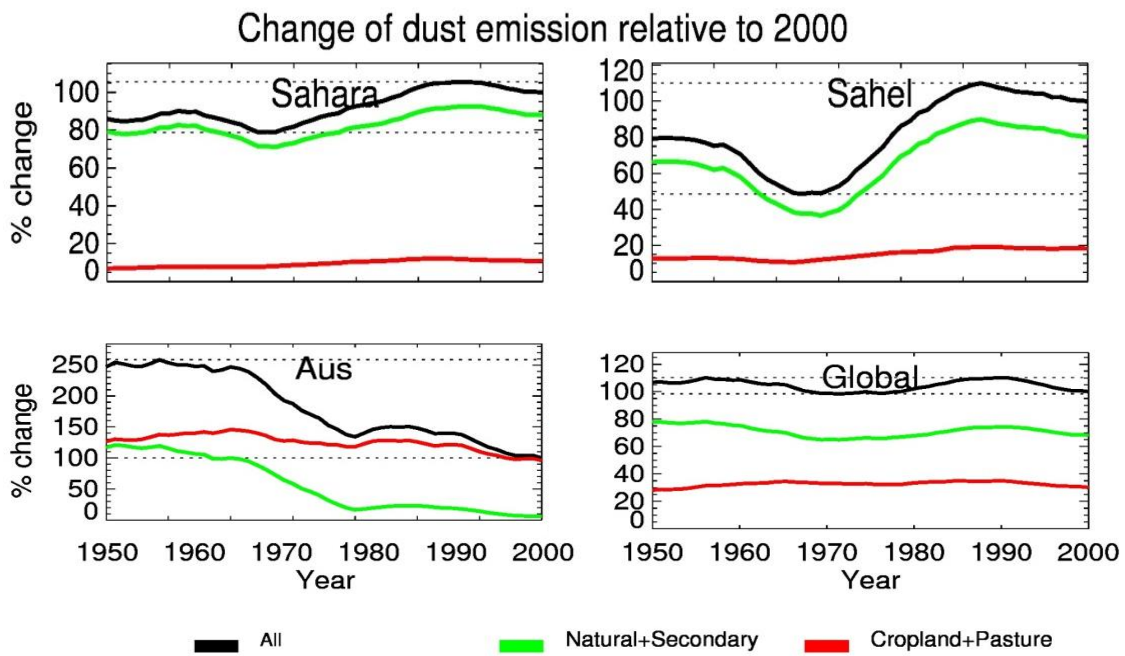






The tuning of all parameters of dust emission has been done by comparing dust concentration and optical depth with observations using simplified chemistry and short (5 years) simulations

Changes (%) of dust emission relative to 2000: Natural/Anthropogenic

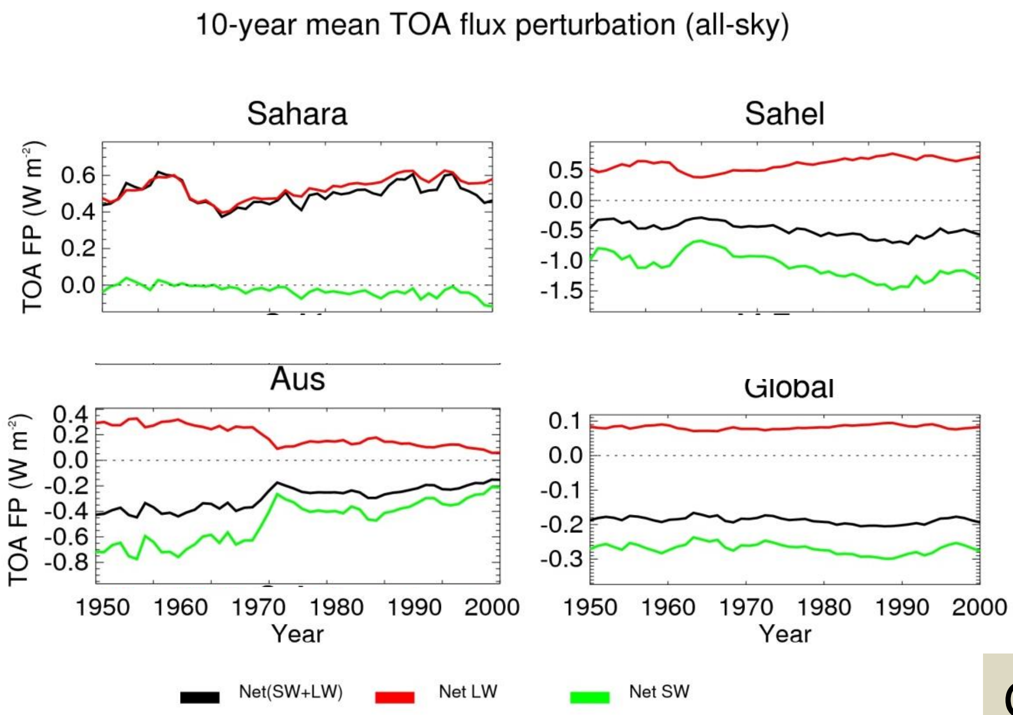


Sahara and Sahel: minimum in 1960s due to vegetation change, anthro dust slightly increase

Australia: natural emission have decreased by 2.5, while anthropogenic dust is stable

Global: only 10% change over 60 years.
Anthro dust ~25% (same as Ginoux et al., RoG, 2012)

TOA Flux Perturbation (W/m²)



LW+SW LW SW

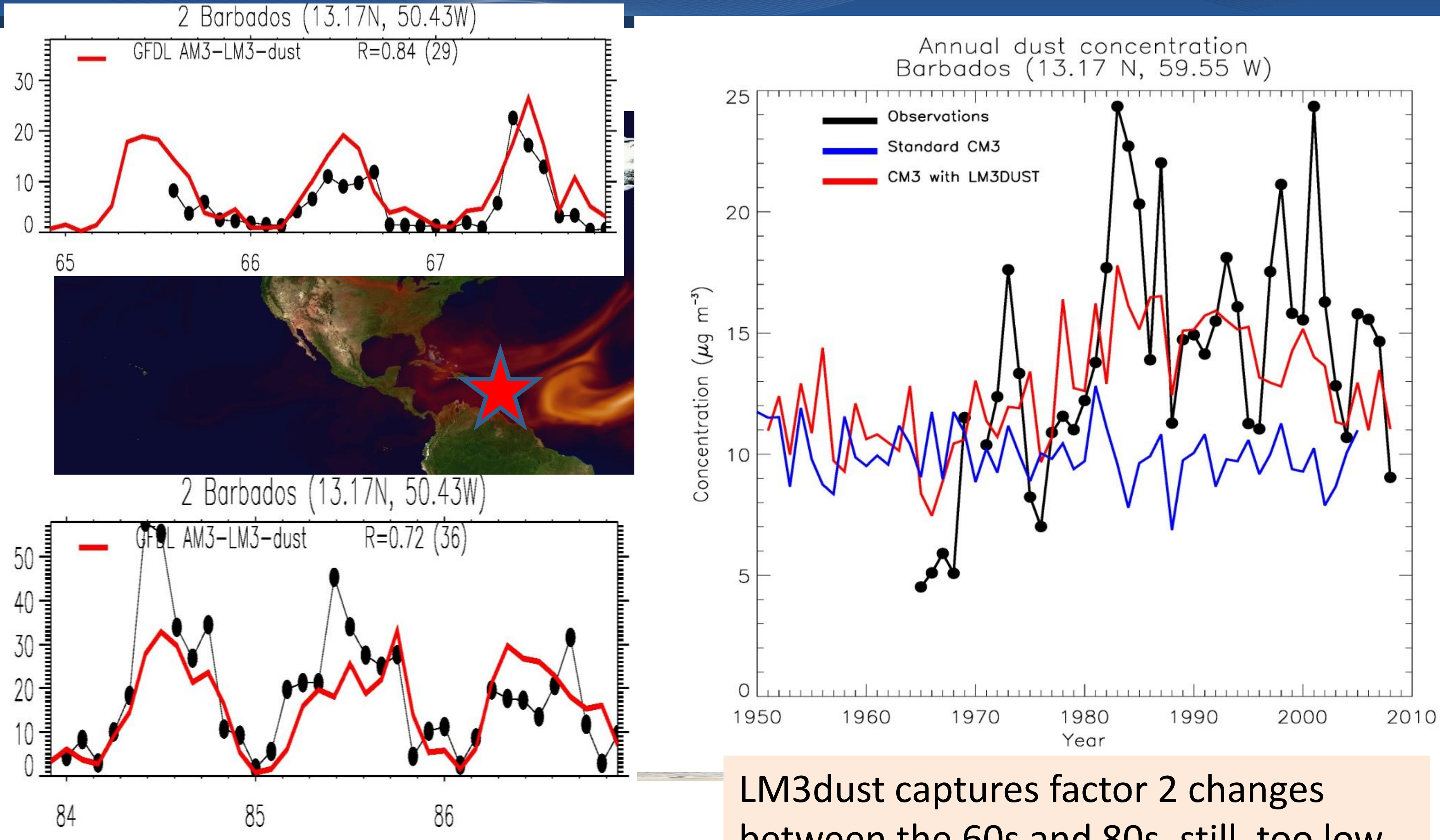
Sahara: highest warming due to LW absorption

Sahel: highest cooling due to scattering

Australia: 50% reduction of radiative cooling

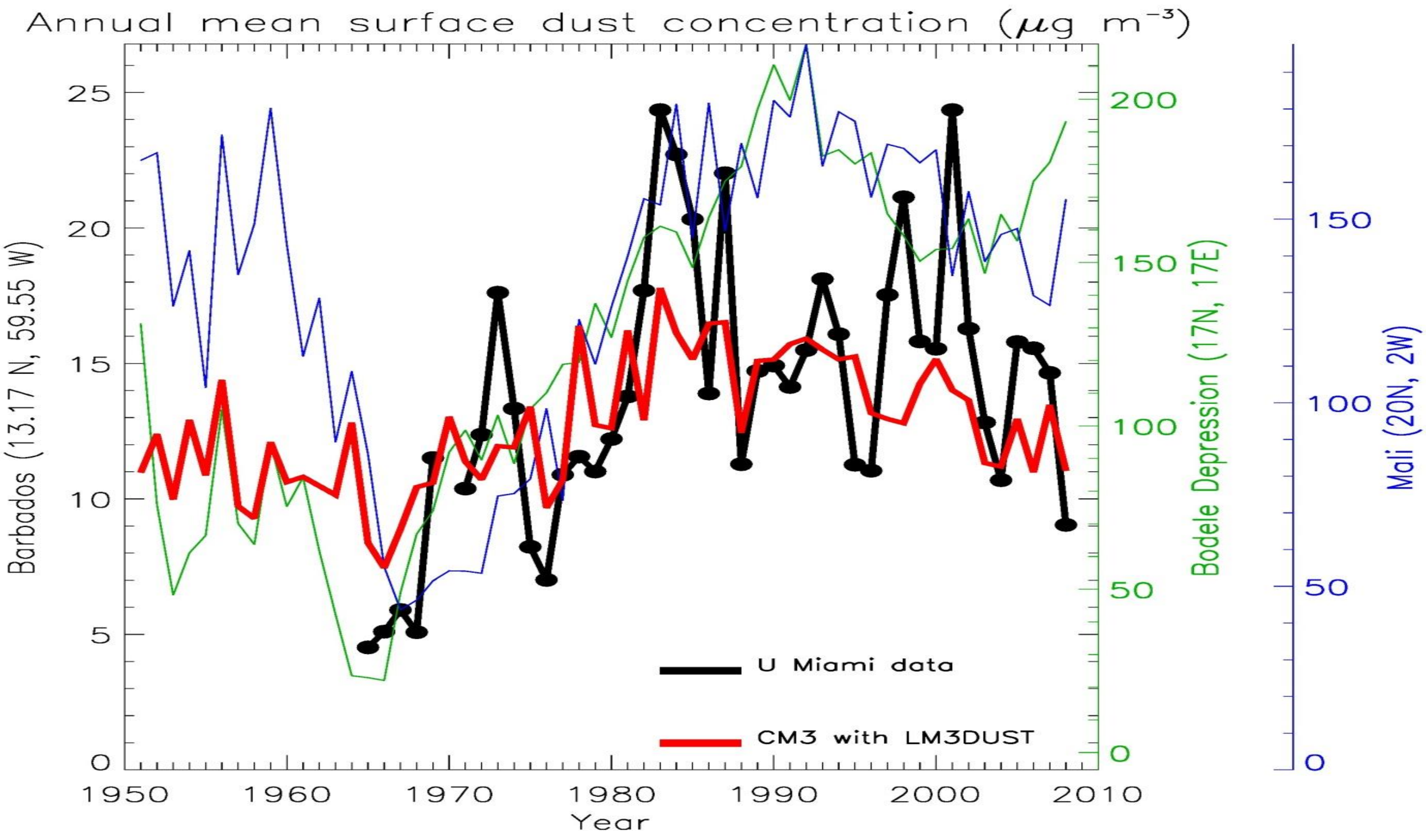
Global mean RF TOA (All-sky) 2000:
Present study: **-0.22** W/m²
Miller et al. (2004): -0.18 W/m²
Miller et al. (2006): -0.4 W/m²
Yoshika et al. (2007): -0.6 W/m²
Takemura et al. (2009): -0.01 W/m²

Surface dust concentration

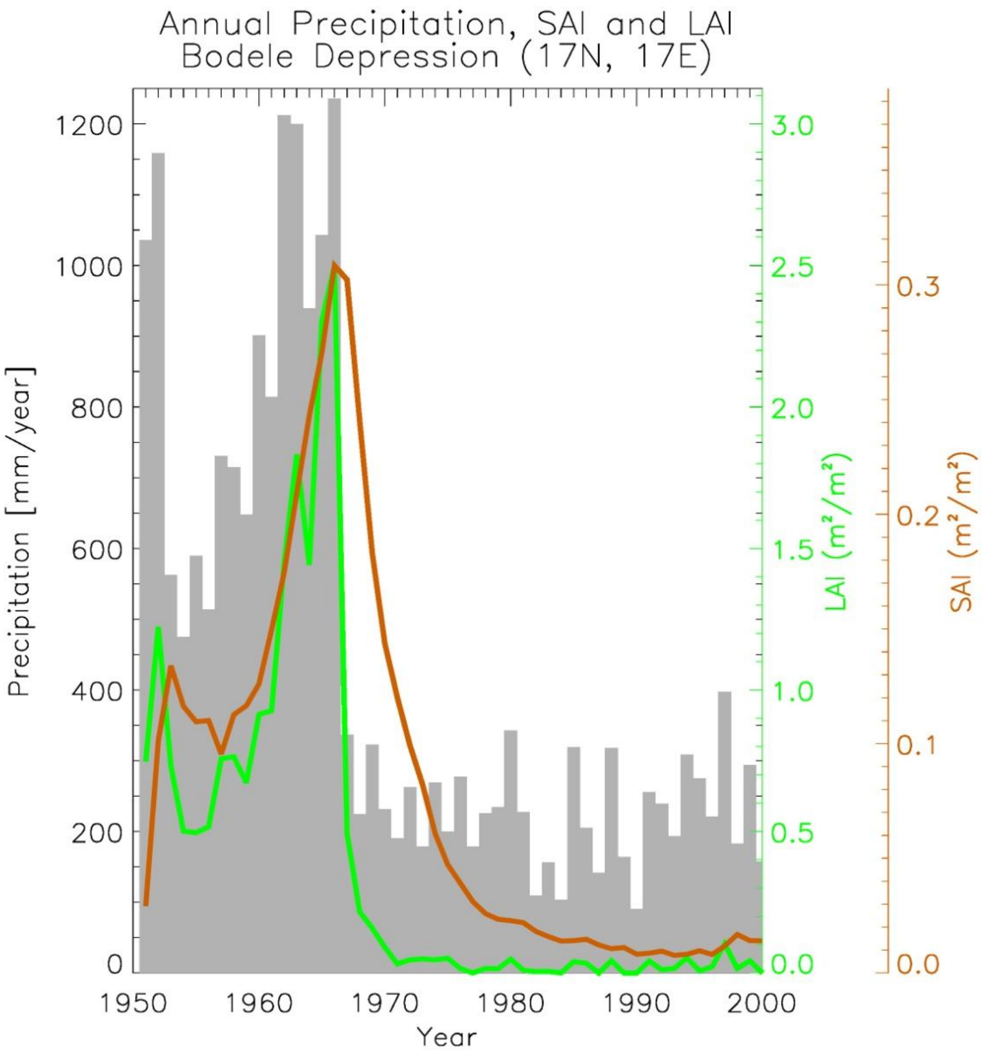


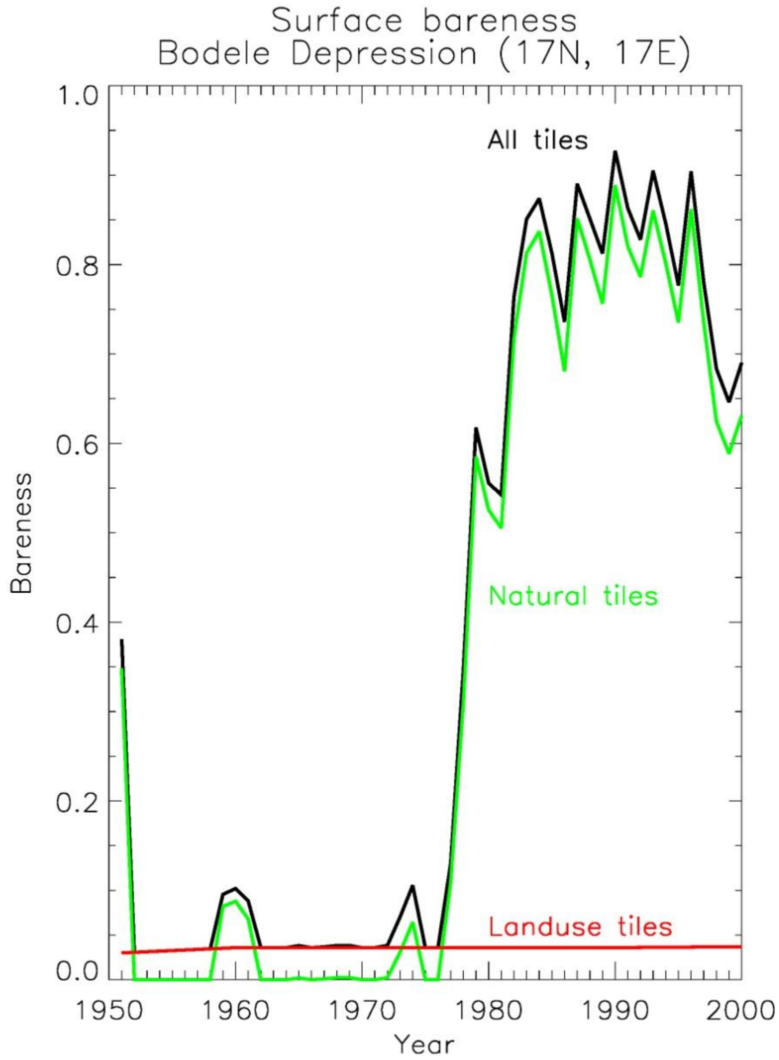
LM3dust captures factor 2 changes between the 60s and 80s, still too low in summer during the 80s

Surface dust concentration

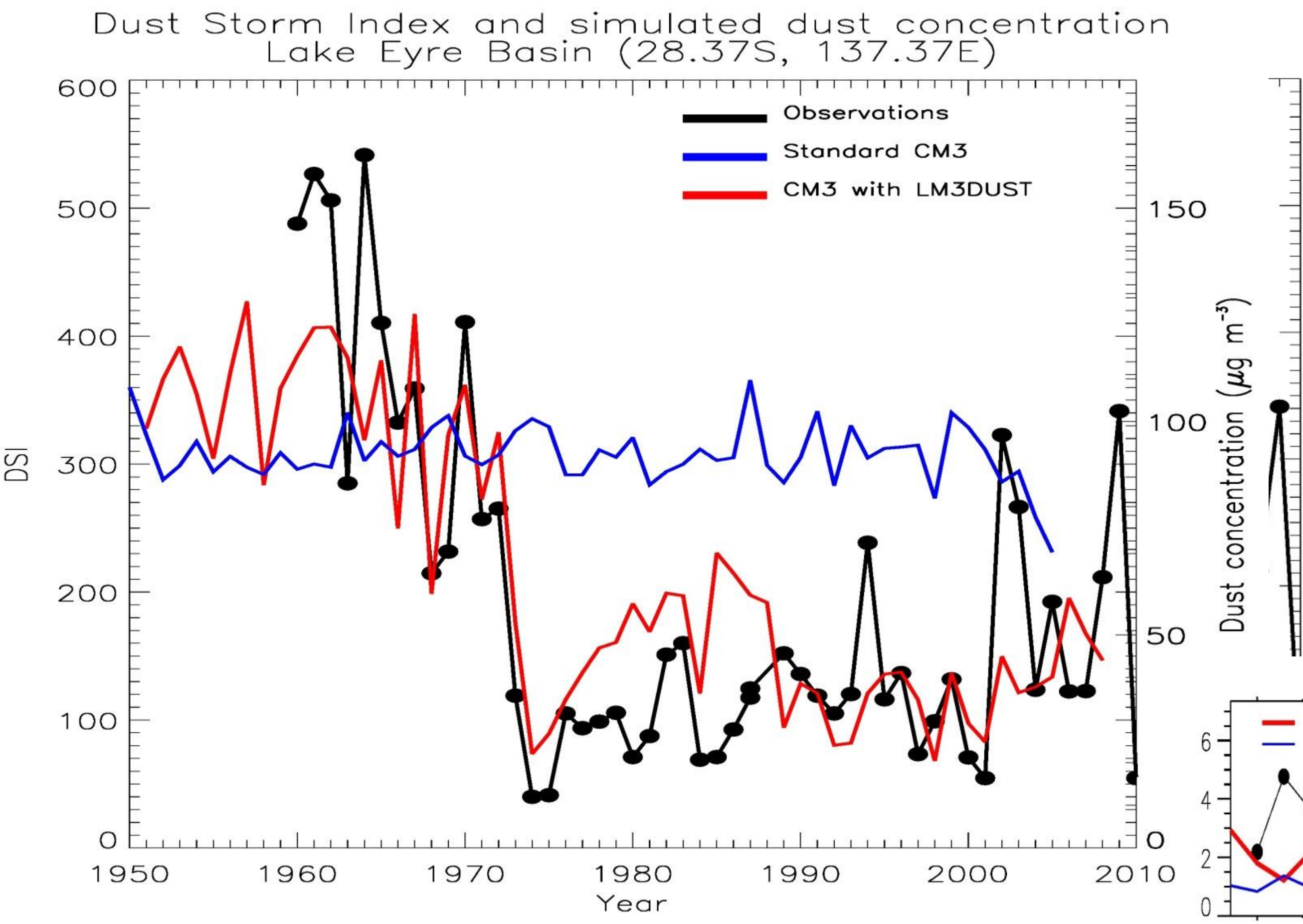


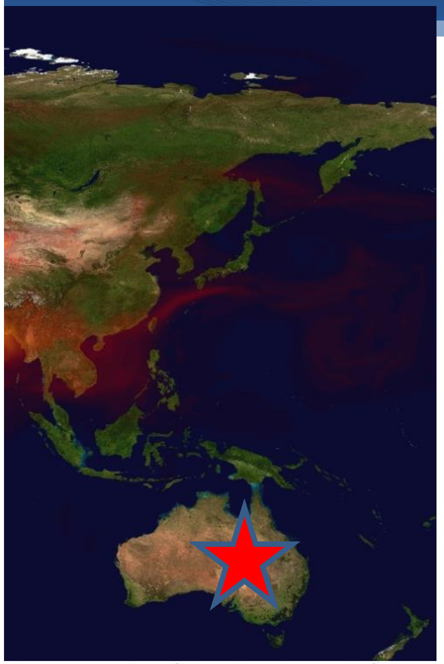
Time series of precip, SAI, LAI and bareness

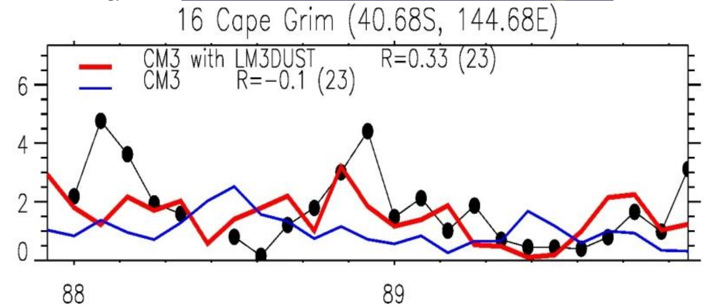




Comparison over Lake Eyre Basin (Australia)

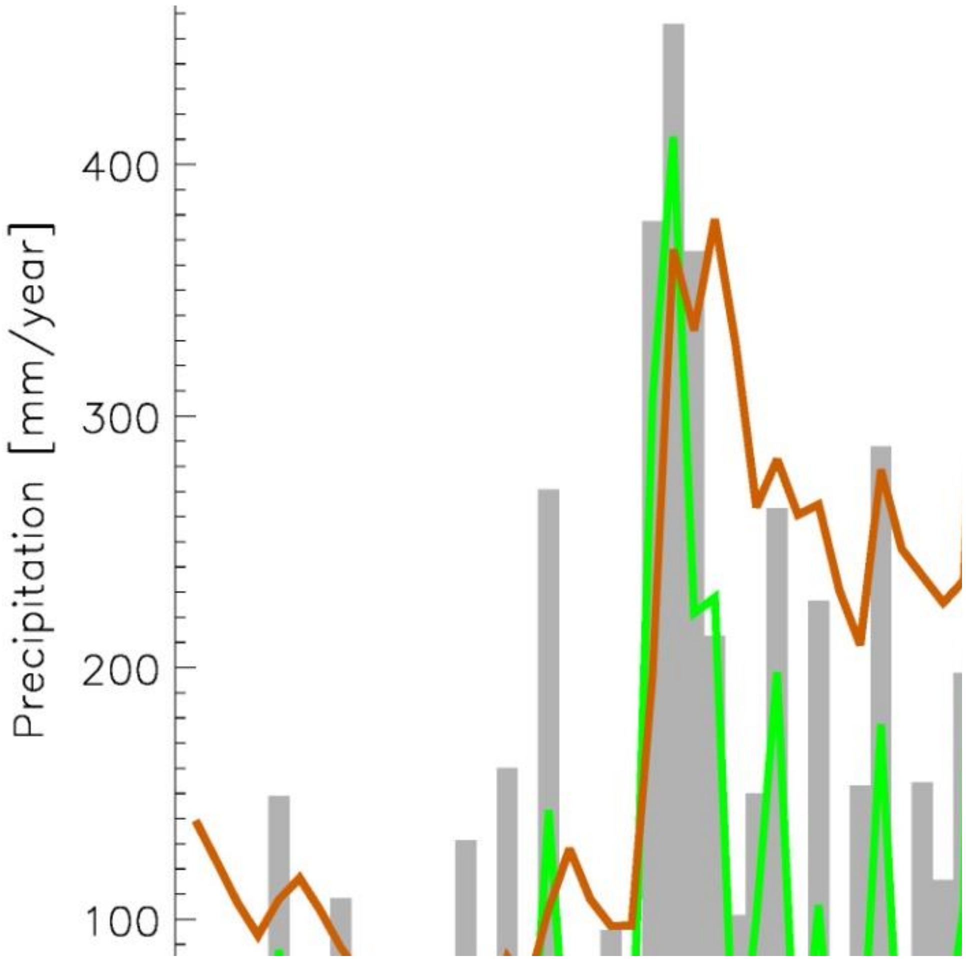


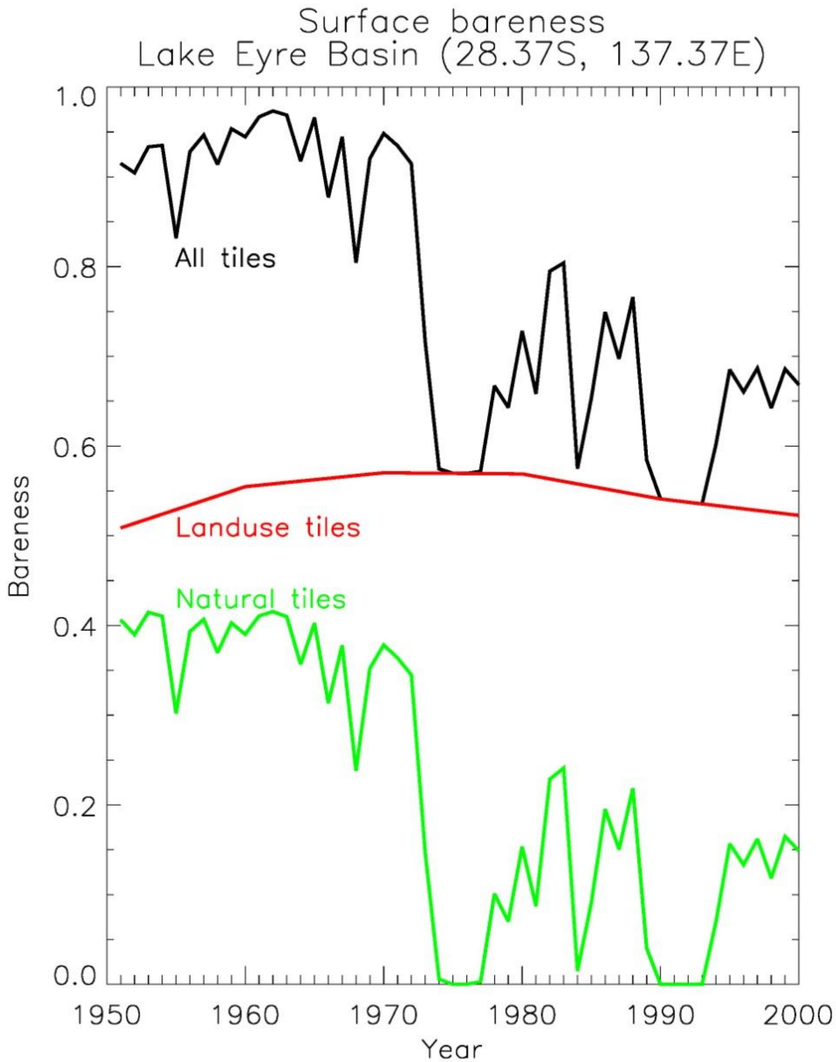




Following heavy precipitation in early 70s, surface dust concentration dropped by a factor 3 in agreement with Dust Storm Index.

Time series of precip, SAI, LAI and bareness





Compare dust variability due to: wind, soil moisture, vegetation

CM3 (2°x2.5°, 48 levels) is run 500 years for 3 experiments with emission depending on

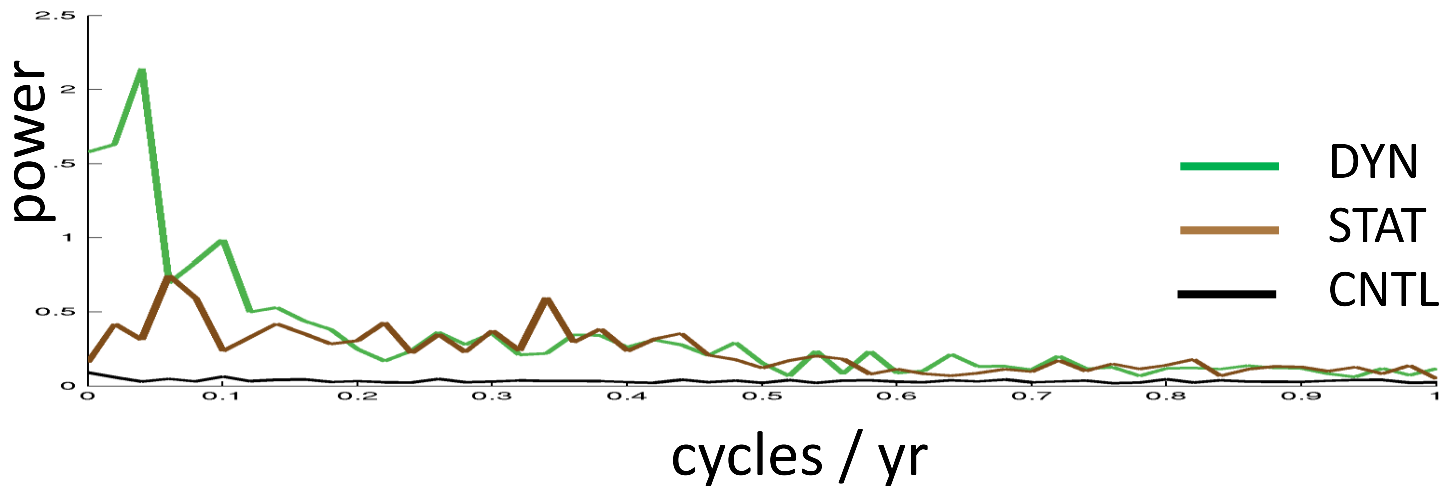
- Surface wind (CNTL)
- Surface wind + soil moisture (STAT)
- Surface wind + soil moisture + vegetation (DYN)

I.C.: IPCC AR5 CM3 for 1860

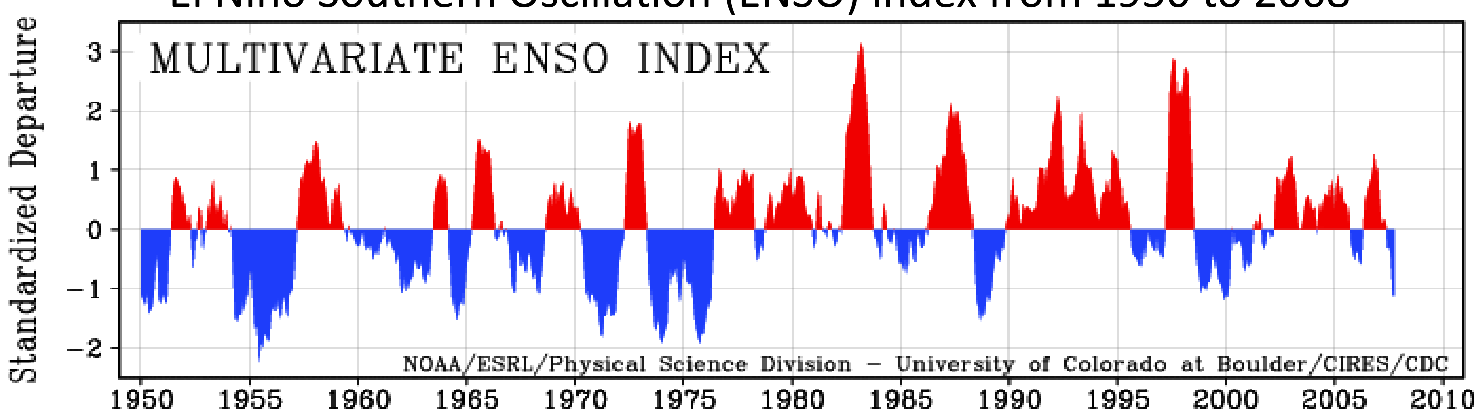
B.C: exact same forcing as IPCC AR5 1860

Ocean: MOM5 (1° resolution)

Power spectra of Australian dust emission

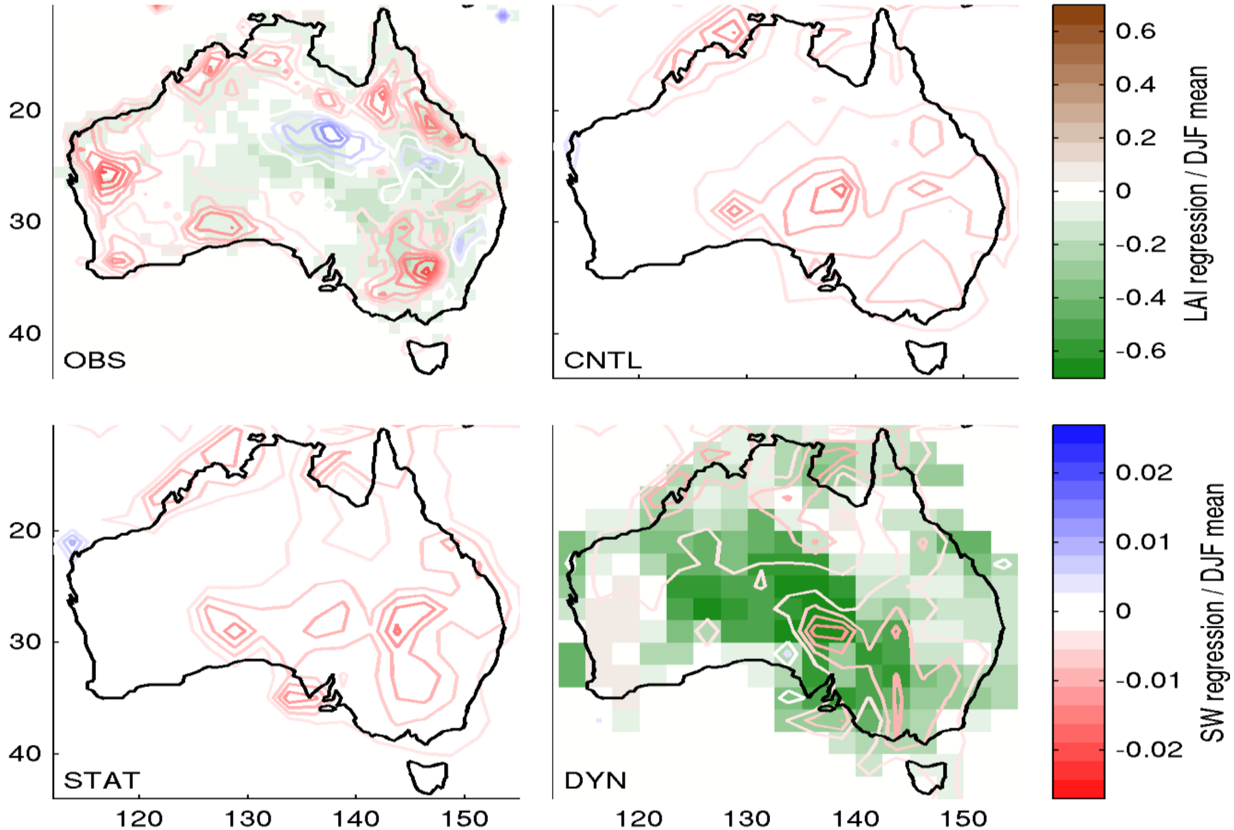


El Nino Southern Oscillation (ENSO) index from 1950 to 2008



Soil moisture & vegetation response to ENSO

MODIS leaf area index (2003–2014)
AMSRE soil moisture (2003–2011)



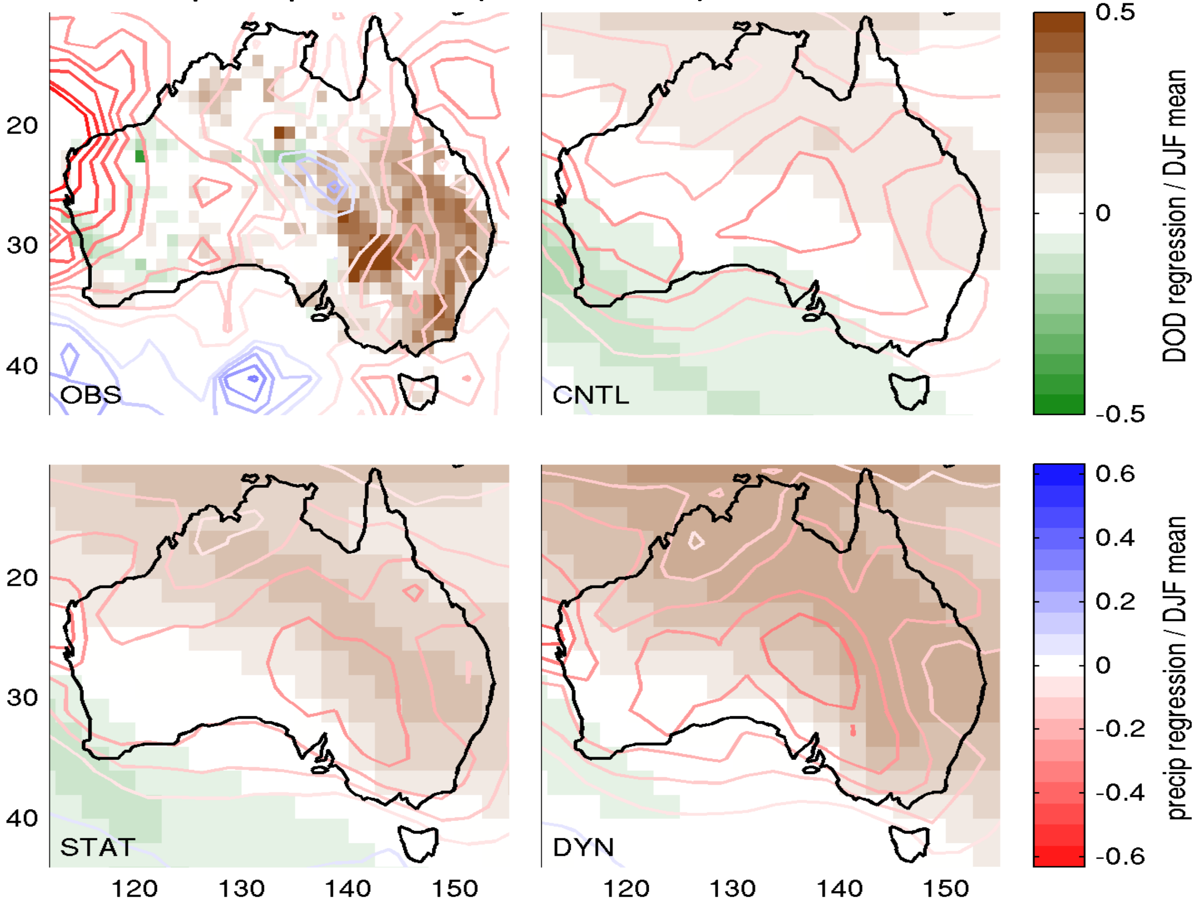
leaf area index (LAI) anomalies (shading)

soil moisture (SW) anomalies (contours)

Evans et al. "Climate-vegetation interaction and amplification of Australian dust variability." *Geophysical Research Letters* 43.22 (2016).

Dust Optical Depth Response to ENSO

MODIS Dust Optical Depth (2003–2014)
TRMM precipitation (1998-2012)



Dust Optical Depth (DOD) anomalies (shading)

Precipitation anomalies (contours)

Evans et al. "Climate-vegetation interaction and amplification of Australian dust variability." *Geophysical Research Letters* 43.22 (2016).

Objective 1: Conclusions

- Implementation of LM3 dust parameterization allows for dust emission to respond to changes in the land surface hydrology and vegetation. This allows the model to create low frequency variability in dust emission.
- Including the effects of soil moisture (STAT) allows the model to capture the relationship between ENSO and dust optical depth over Australia.
- Including the effects of vegetation changes strengthens the dust response, bringing it to the same level as observations.

Tropical rainfall response to dust hemispheric load asymmetry

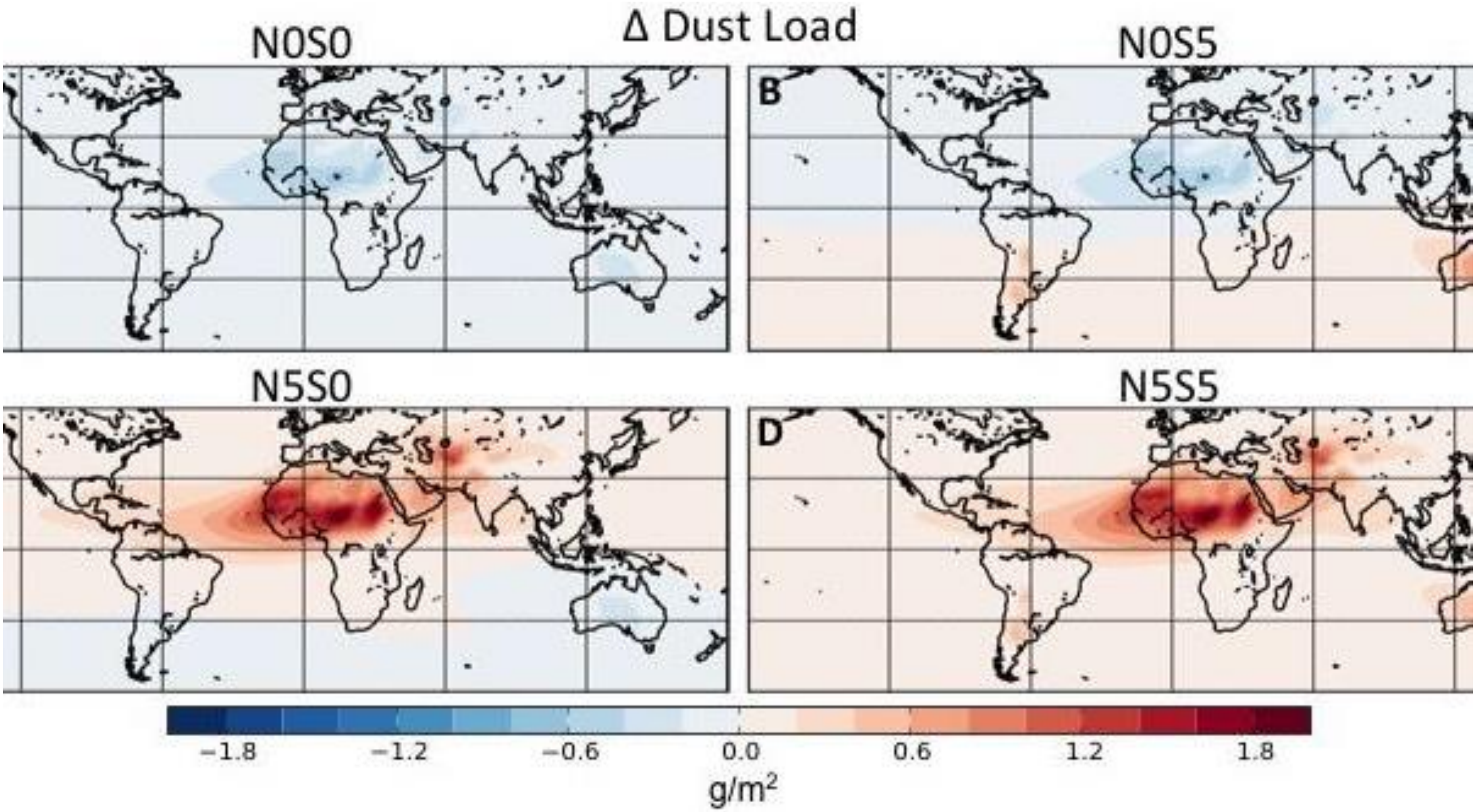
CM3 (2^ox2.5^o, 48 levels) is run 200 years for 10 experiments with emission multiplied by 0, 1 (Control), 2, and 5 for one hemisphere and both

I.C.: IPCC AR5 CM3 for 1860

B.C: exact same forcing as IPCC AR5 1860

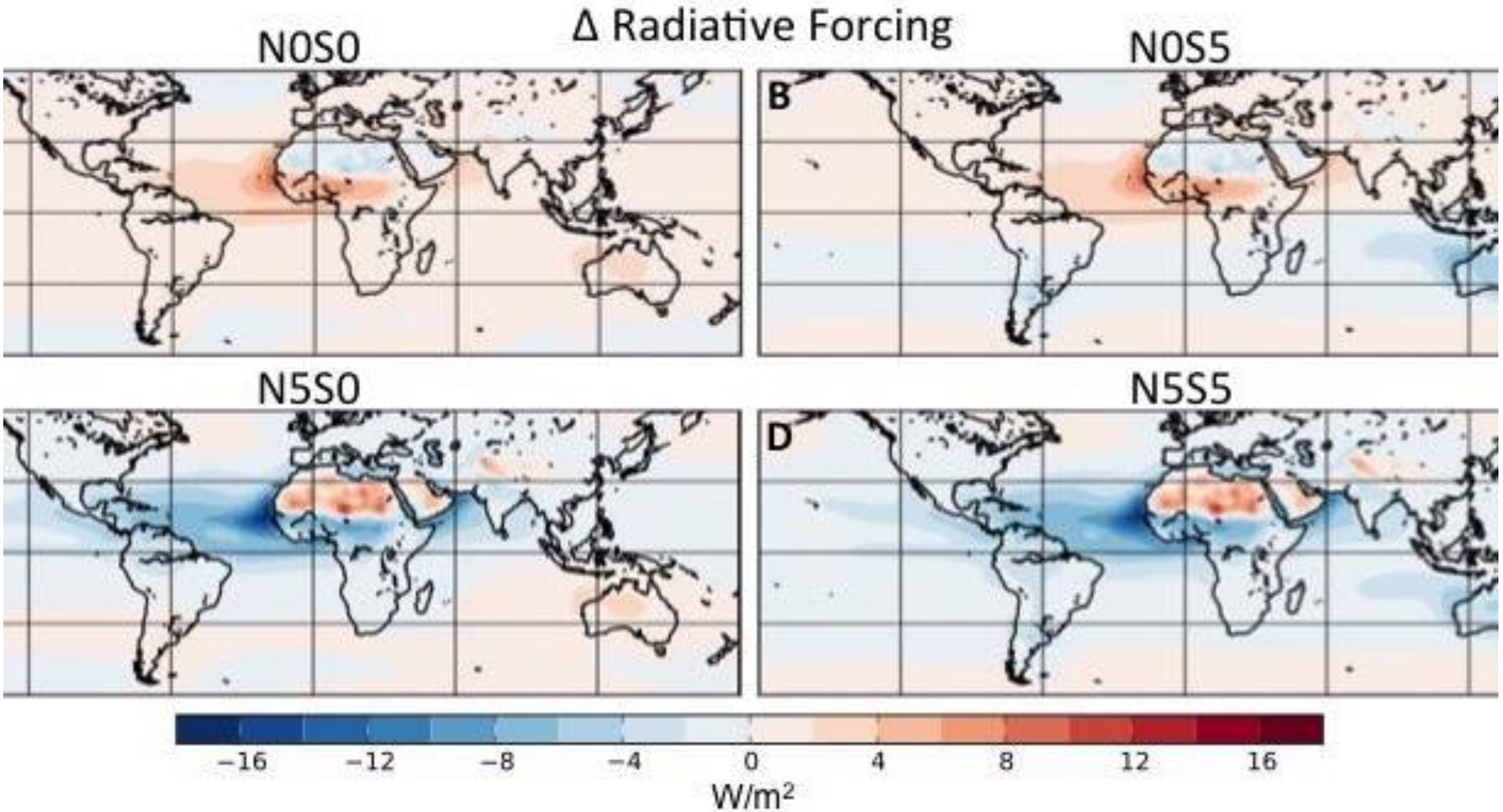
Ocean: MOM5 (1^o resolution)

Dust Loading



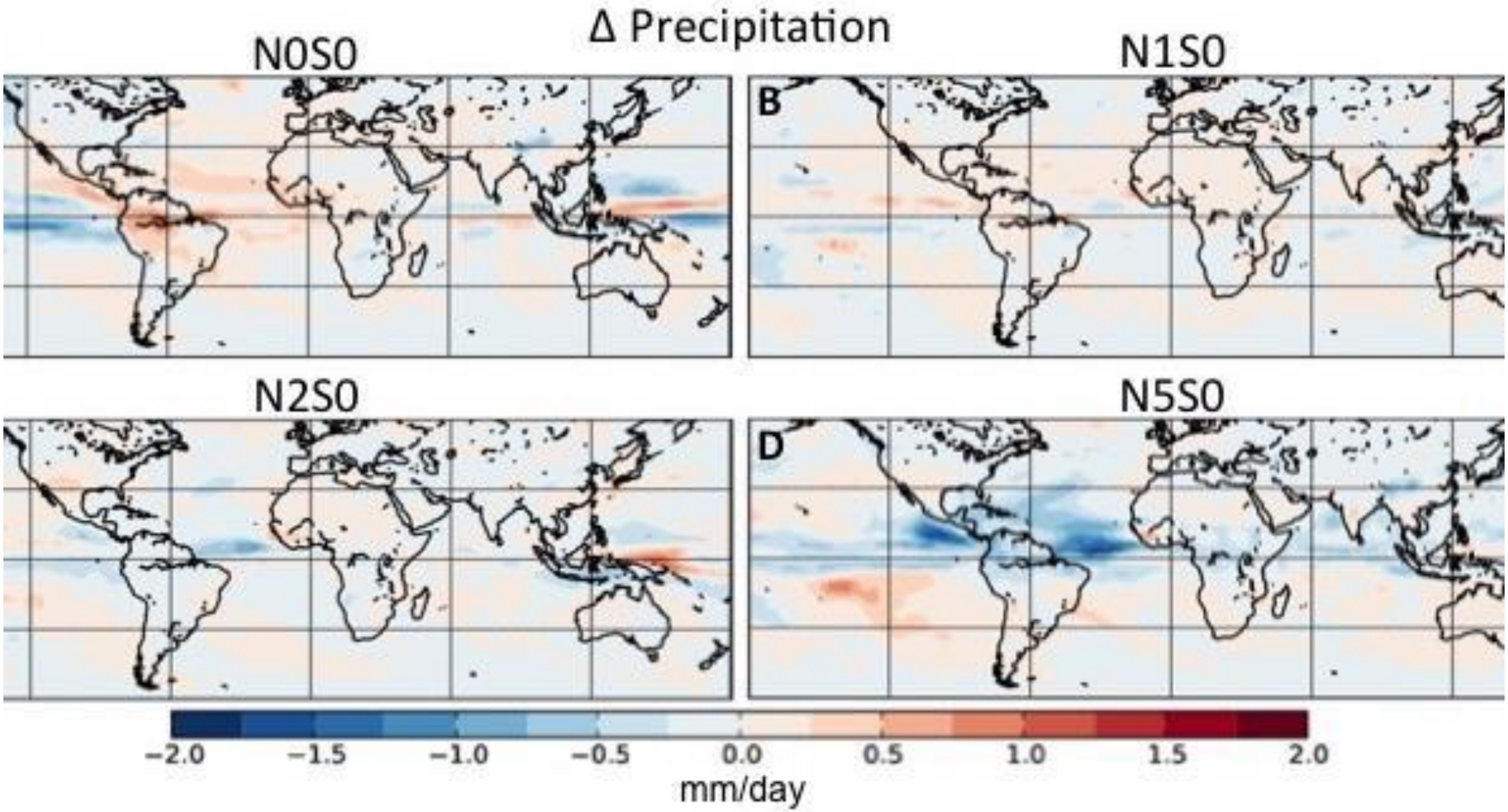
Dawson et al., “Variability of the Inter-tropical Convergence Zone related to changes in inter-hemispheric dust load”, to be submitted to *Geophys. Res. Lett.* (2017)

Dust Radiative Forcing



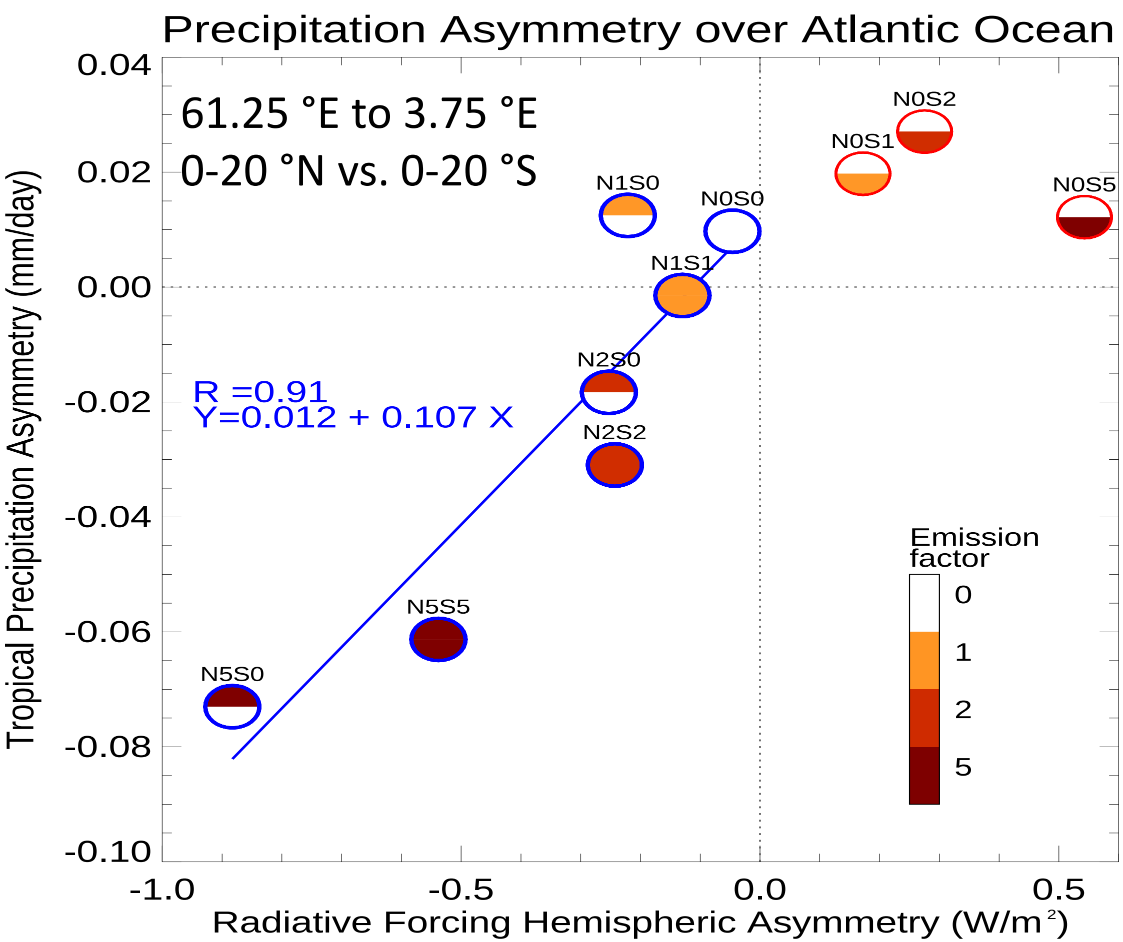
Dawson et al., "Variability of the Inter-tropical Convergence Zone related to changes in inter-hemispheric dust load", to be submitted to *Geophys. Res. Lett.* (2017)

Precipitation Change



Dawson et al., "Variability of the Inter-tropical Convergence Zone related to changes in inter-hemispheric dust load", to be submitted to *Geophys. Res. Lett.* (2017)

Tropical precipitation asymmetry and dust hemispheric radiative forcing



Dawson et al., “Variability of the Inter-tropical Convergence Zone related to changes in inter-hemispheric dust load”, to be submitted to *Geophys. Res. Lett.* (2017)

Objective 2: Results

- The larger dust emission and load in the Northern Hemisphere create a hemispheric asymmetry of radiative forcing which has been amplified on decadal to millennial scales.
- Asymmetric radiative forcing generates an inter-hemispheric transfer of energy and a shift in precipitation along the ITCZ, in agreement with observations.
- We found a linear relationship in the Atlantic between increasing dust emission in the NH and southward shift of tropical precipitation.

Acknowledgments

- Sergey Malyshev (Princeton U) and Elena Shevliakova (NOAA GFDL) were instrumental in implementing dust emission in LM3.
- Stuart Evans (postdoc at GFDL, PEI Princeton U) coupled CM3 with LM3 dust. He performed all the simulations, and helped with the analysis.
- Eliza Dawson (undergrad student at UW, summer internship at GFDL) did the analysis and figures relating dust radiative forcing with asymmetry in tropical rainfall.