Dust Induced Atmospheric Absorption Improves Tropical Precipitations

Plenary Session 4 - new modeling results

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Plan

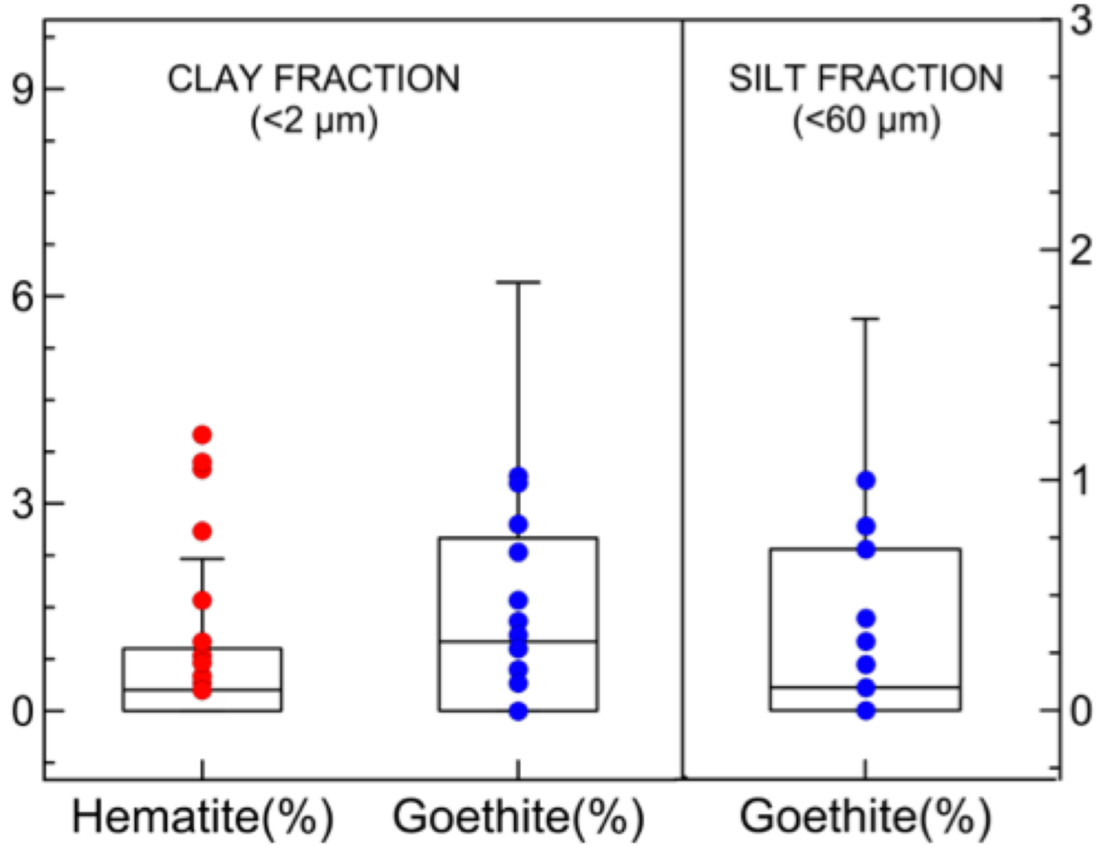
- Estimating dust absorption / role of iron oxides / role or large particles
- Analysis of tropical precipitations
- Is it thermodynamics, dynamics or the phasing of the Atlantic Decadal Variability that is improved?

Previous work on dust/precipitation connection

- Dust absorption triggers precipitation over the Sahel (Miller et al. 2004, 2011 & 2014; Solmon et al., 2008; Yoshioka et al. 2009)
- Dust influences the forecasts of the African Easterly Jet (Tompkins et al., 2005)
- Dust could explain the outgoing Longwave radiation anomaly observed in July 2003 over the Sahara (Haywood et al. 2005)

- This study introduces the following new approach:
  - ➢ Dust absorption is estimated from dust mineralogy, based upon iron oxide observations over Sahel
  - ➢ We account for the absorption from very large dust particles (10 < D < 100um)
  - ➢ Precipitation are compared with observations in terms of changed patterns over the Sahel, the North Atlantic and the West Indian Ocean.
  - ➢ ESMs struggle to improve tropical precipitations (Fiedler et al. 2020), here we quantify the improvements in precipitation over the 3 regions above

Goethite and hematite mass fractions (%) measured in the CESAM aerosol chamber for dust samples from major source areas



Di Biagio et al., 2019

Computation of the refractive index computed for a mineral assemblage

- We account for six minerals: Kaolinite, Illite, Montmorillonite, Quartz, Calcite et hematite
- An optical model is used in which we vary the iron oxide content to represent respectively: 0.9 1.5 2.7 5.0 10 et 15% of the total volume of the particles.

Step 1: Each mineral is associated with a VOLUME content of respectively: 0.9 1.5 2.7 5.0 10 et 15% using the Maxwell-Bruggeman approximation

Step 2: The combination kaolinite-hematite is associated with illite_hematite

Step 3: The combinaison kaolinite-illite-hematite is associated to montmorillonite-hematite

Step 4: The combinaison kaol-illi-montmo-hema is associated to quartz_hematite

Step 5: The combinaison kaol-illi-montmo-hema-quartz is associated to calcite_hematite

Step 6:: The refractive index of kaol-illi-montmo-hema-quartz-calcite-hematite is obtained

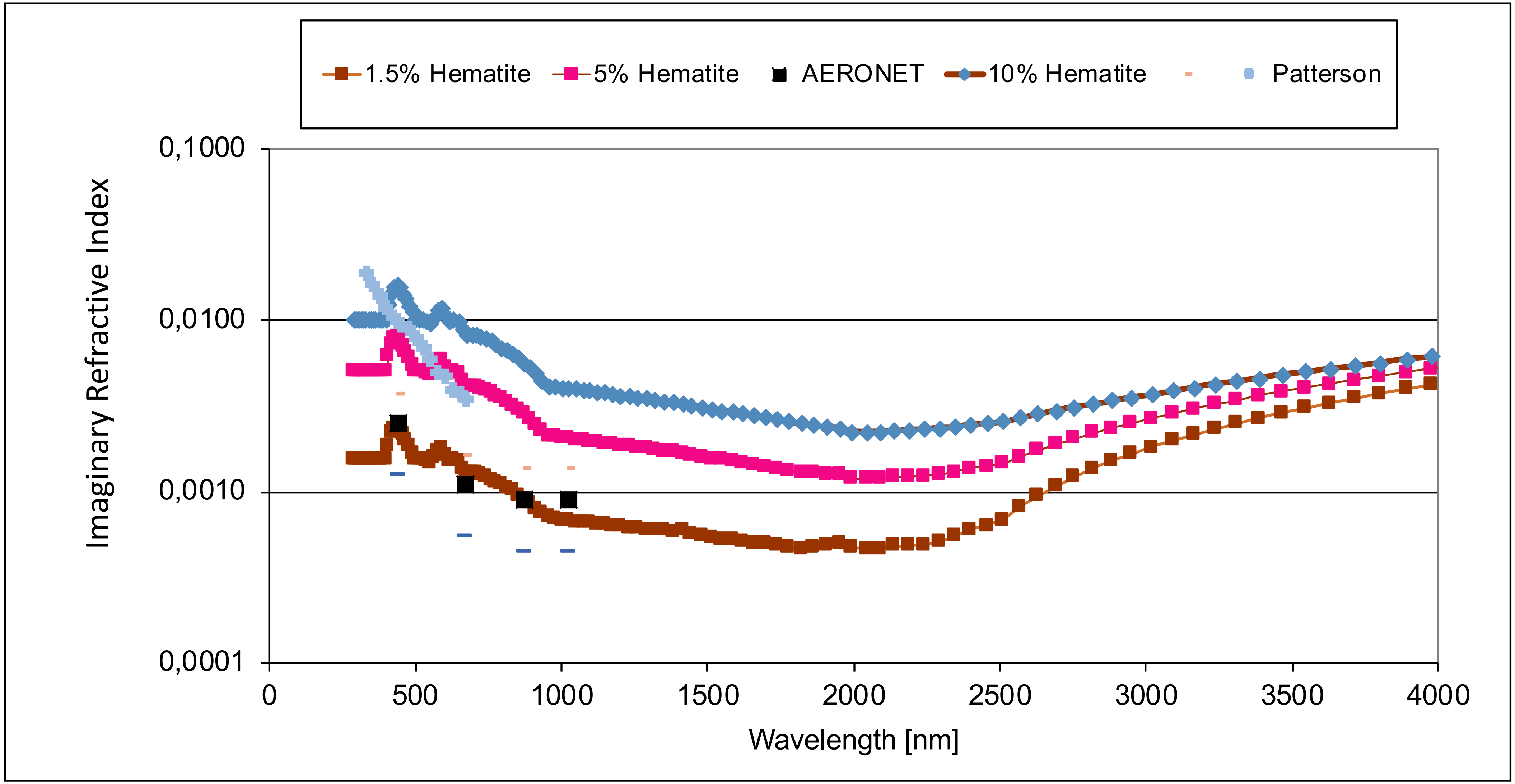
Absorption increase (imaginary part of ref. index) as a function of hematite content

Patterson-Volz
$\omega_{0,550nm}$=0,90

Hematite 10%
$\omega_{0,550nm}$=0,852

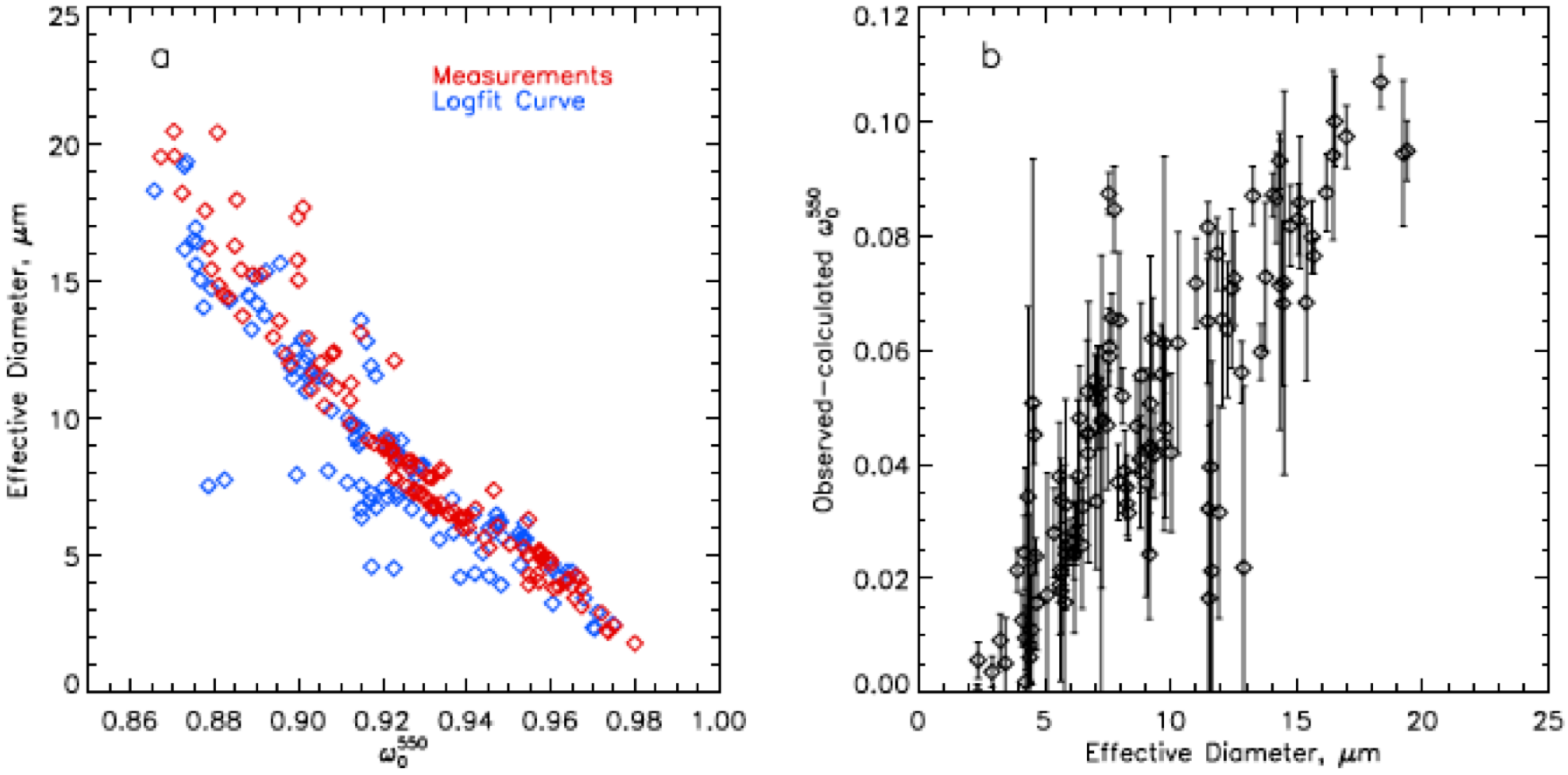
Hematite 5%
$\omega_{0,550nm}$=0,910

Hematite 1,5%
$\omega_{0,550nm}$=0,968

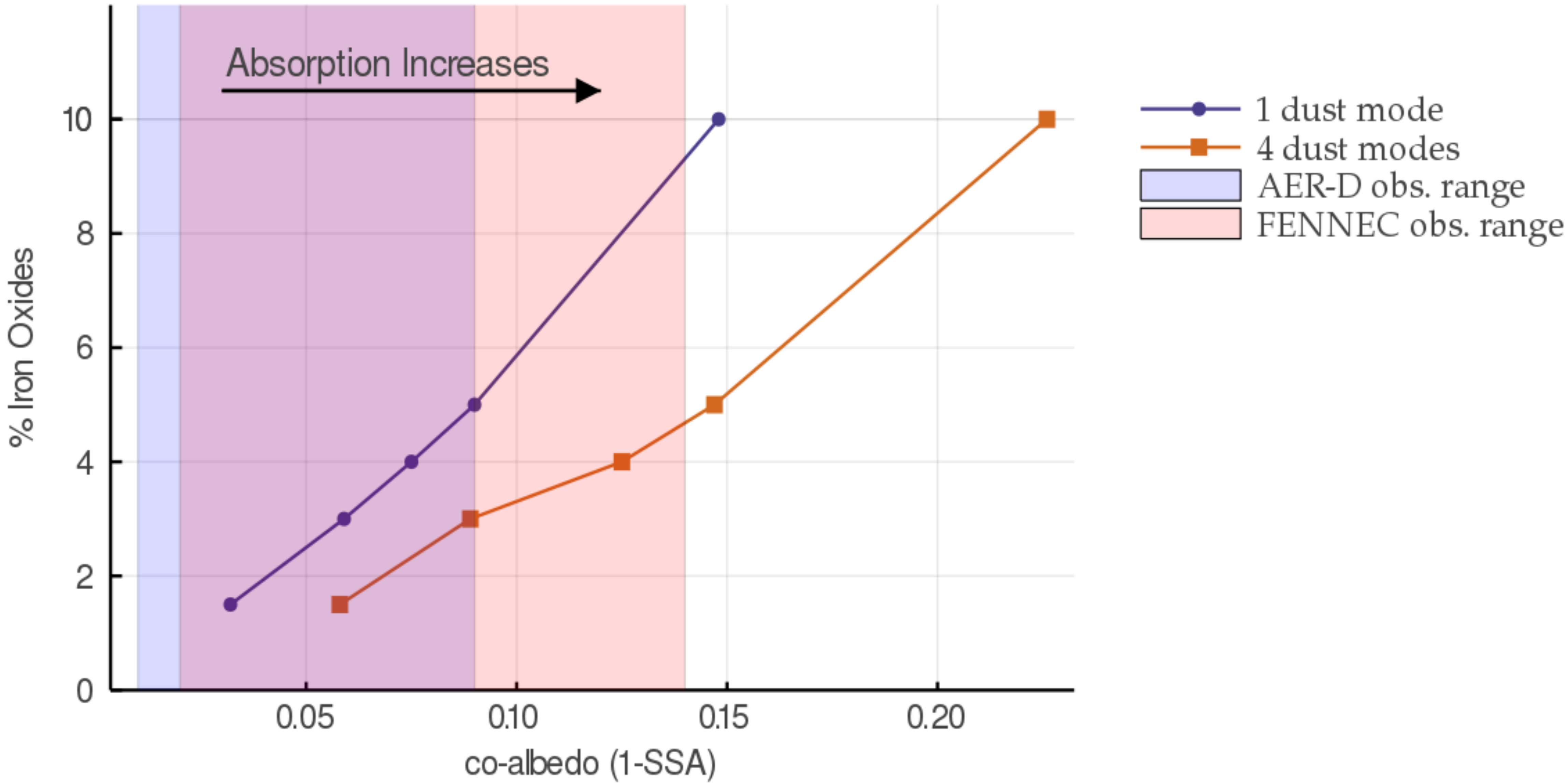


Observations of Dust Single Scattering Albedo (SSA) as a function of particle size during the AER-D campaign

Ryder et al., 2013



Absorption Increase when large particles (D > 10μm) are accounted for



Description of the simulations

- Dust size distribution is modeled either using 1 mode (MMD=2.5 um, σ=2.0) or 4 modes (MMD= 1, 3.5, 7 and 22 μm respectively).
- Simulations with 1 mode have a volume content of 5% iron oxide (hematite + goethite), simulations with 4 modes have a 3.0% iron oxide content.
- We made long simulations with the fully coupled model IPSLCM6 for 100 years (1915 to 2014)

We show results for the last 30 years (1985-2014) of simulation and compare the precipitation obtained with a control simulation with NO Dust

JJAS Average Dust SW+LW Radiative Effect for 3.0% Iron Oxide

top panel: Top-of-Atmosphere, middle panel: Atmospheric absorption; bottom panel: Surface

TOA over Sahel= +8.1 $W.m^{-2}$

(SW=+4.4 / LW=+3.7 $W.m^{-2}$)

Sahel area: 16W:36E, 10N:20N

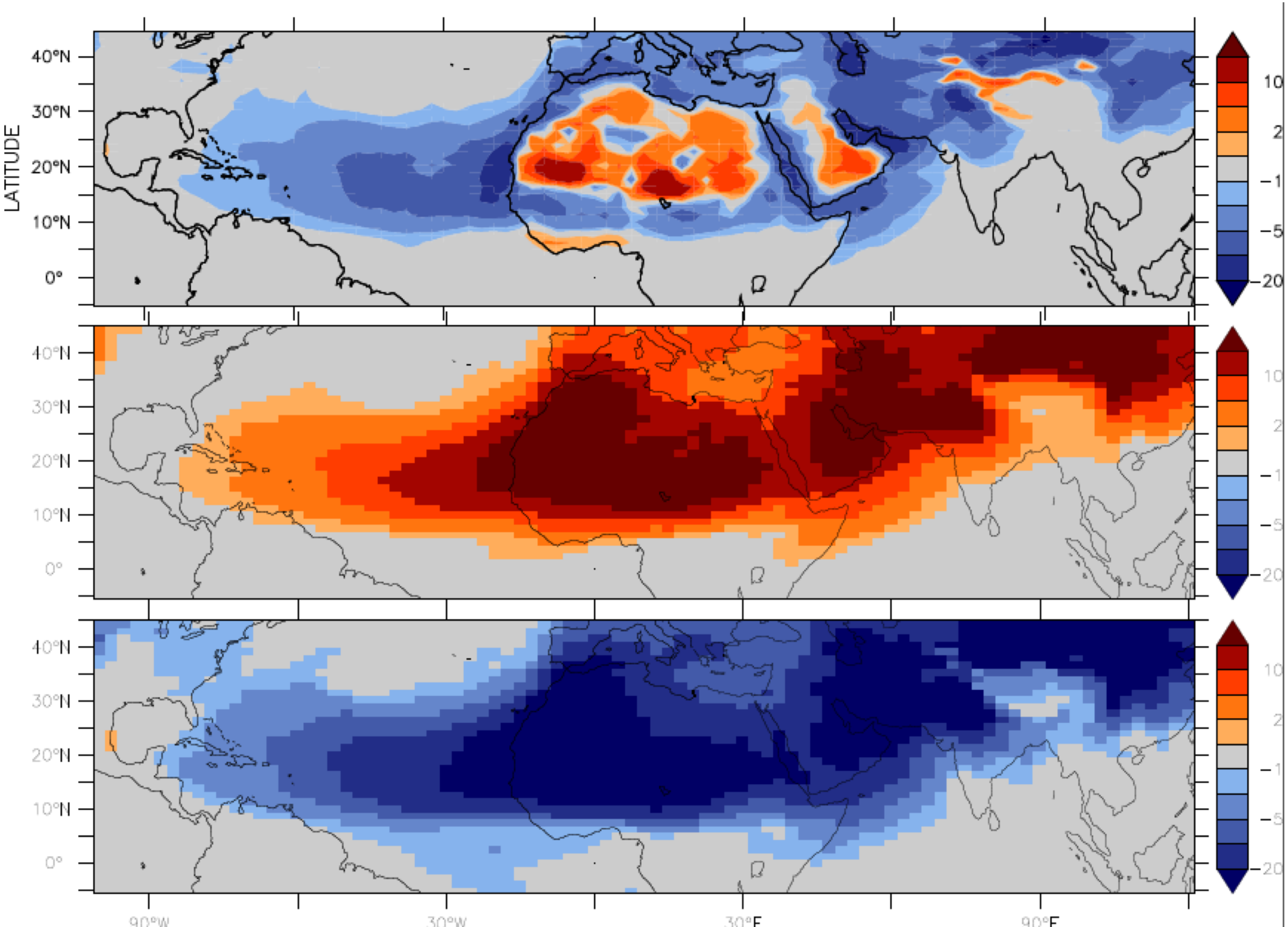
Atm. Absorption = +25.8 $W.m^{-2}$

(SW=+36.0 / LW=-10.2 $W.m^{-2}$)

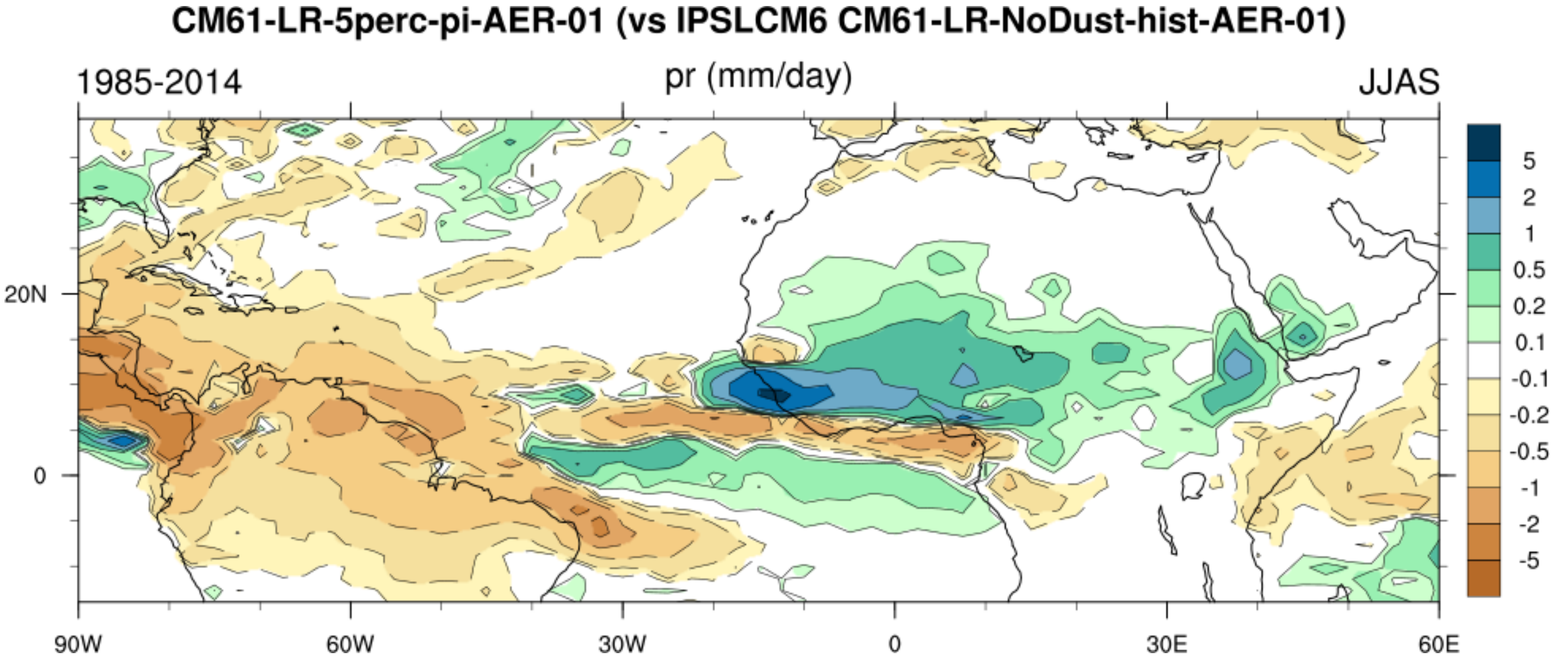
(Sahel area)

Sahel Surface = -17.7 $W.m^{-2}$

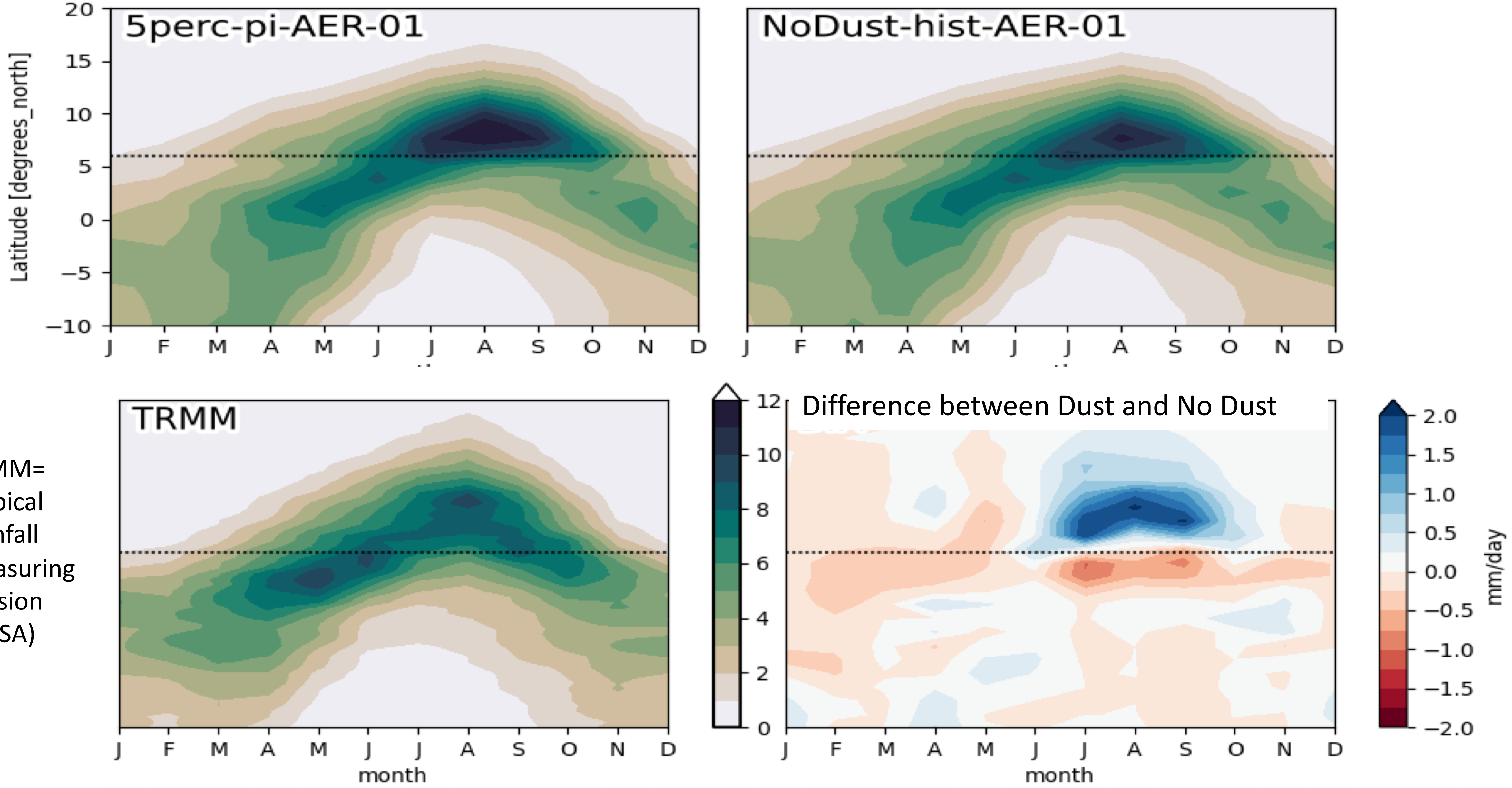
(SW=-31.6 / LW=+13.9 $W.m^{-2}$)



Precipitation change – Absorbing Dust versus No Dust JJAS (1985-2014)



Hovmoller diagram of precipitation (averaged from 10°W to 10°E) showing the monthly northward migration over Western Africa



TRMM= Tropical Rainfall Measuring Mission (NASA)

Comparison Between Simulated Precipitation and GPCP observations for JJAS (1985 to 2014)

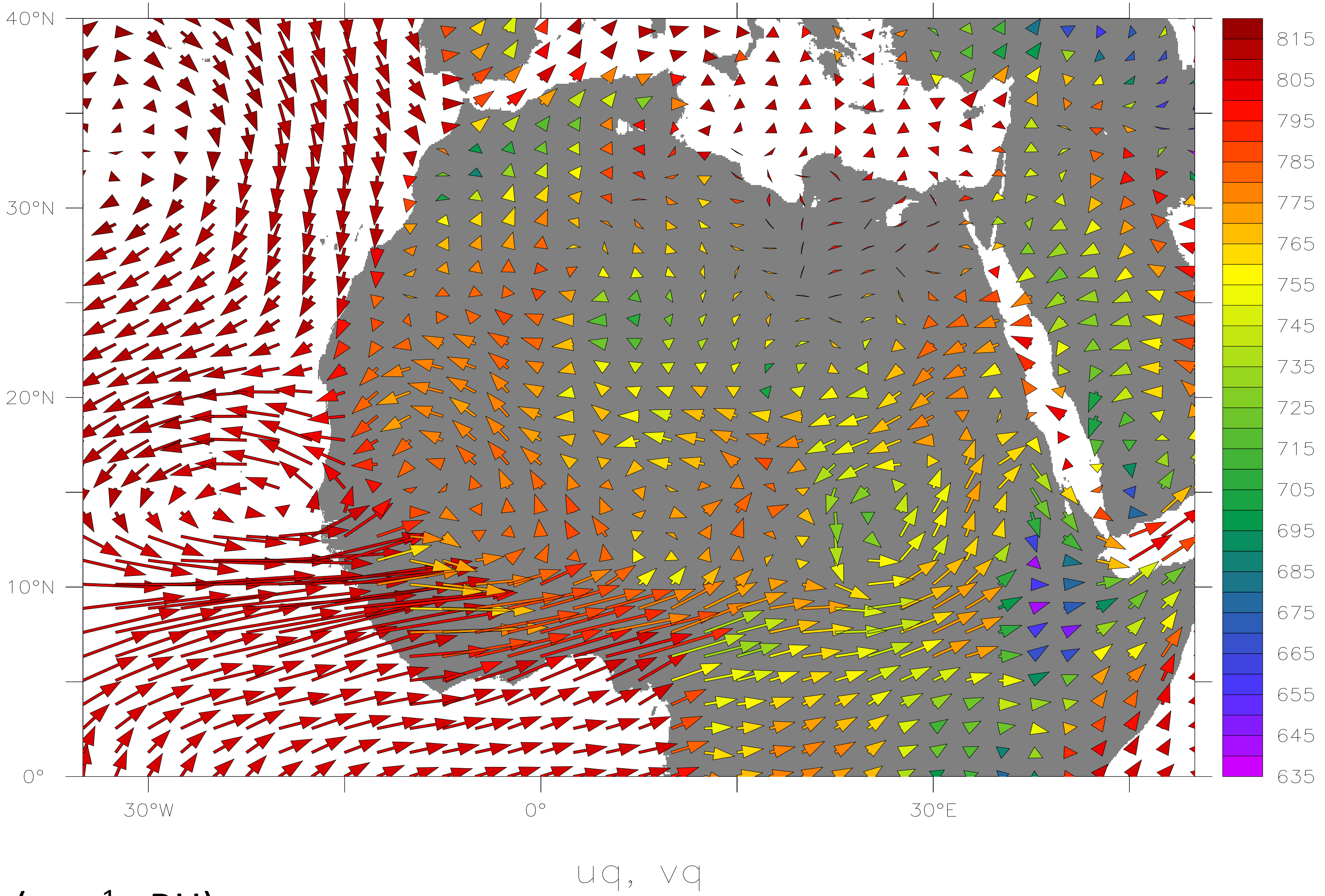
Light blue and light red: 5 to 15% change

Dark blue or red: >15% change

Regions	**IPSL-CM6A-NoDust vs. GPCP**			**IPSL-CM6A-Dust 3.5% iron oxide vs. GPCP**			**Precipitation Change Absorbing Dust vs No Dust**
	Bias	Rmse	Correlation	Bias	Rmse	Correlation	
Globe	0.277	1.61	0.821	0.276	1.62	0.819	-0.1%
N. Atlantic (50W-20W; 0-30N)	0.625	1.43	0.952	0.499	1.25	0.956	-3.9%
N. Africa (18W-40E; 0-35N)	0.029	1.67	0.883	0.235	1.56	0.916	7.5%
Sahel (16W-36E; 10N-20N)	-1.18	1.51	0.951	-0.775	1.07	0.965	20.9%
West Indian Ocean (50E-70E; 10S-15N)	1.33	1.74	0.815	1.26	1.58	0.865	-2.1%
Eq. Pacific (120E-90W; 10S-10N)	0.313	3.67	0.704	0.326	3.68	0.709	0.1%
Western Europe (0-50E; 35N-60N)	-0.298	0.748	0.708	-0.319	0.705	0.766	-1.3%

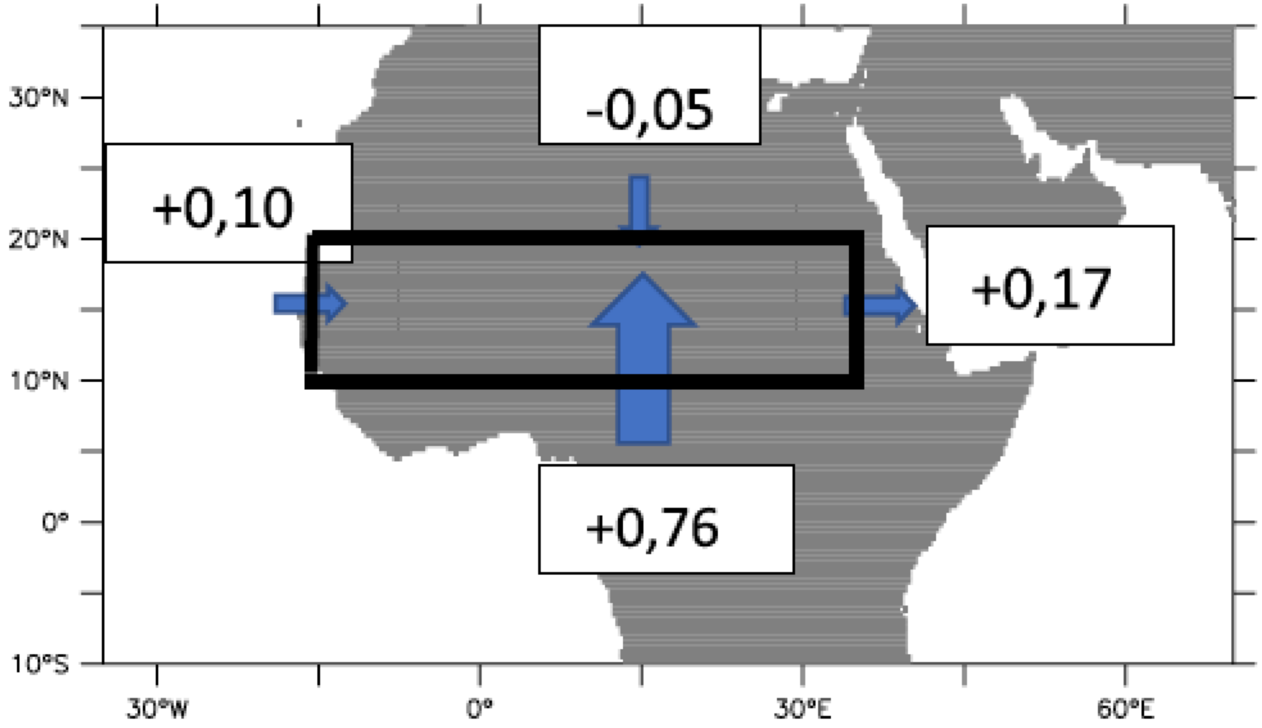
Change in Humidity Transport (uq,vq) at 800mb over Oceanic Surfaces

Model JJAS 1985-2014



→ 35 (m s^{-1} . RH)

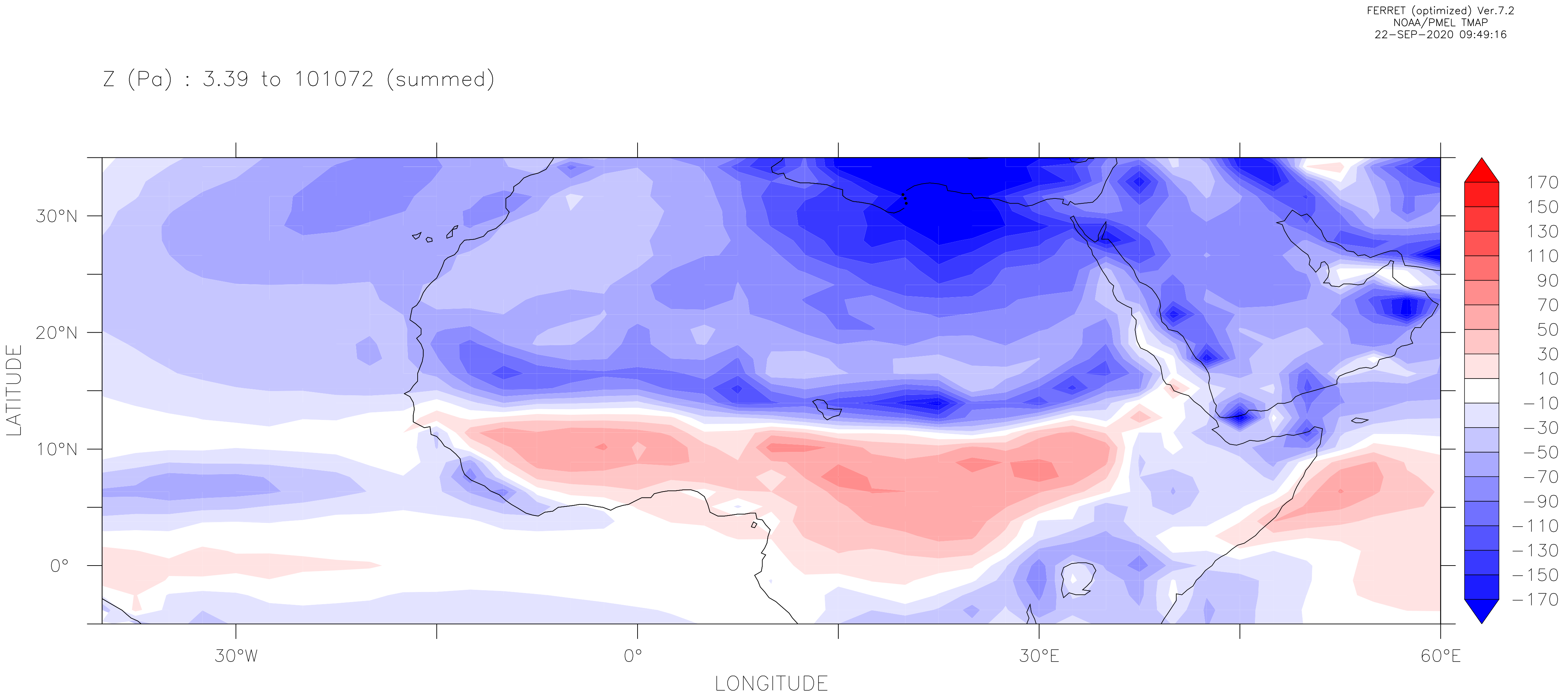
Water budget over Sahel (mm day^{-1}) up to 200mb



$$1./\boldsymbol{\rho_w}\mathbf{g}\ \int_0^{ps}\langle \boldsymbol{qu}\rangle \mathrm{dp}$$

where $\langle \boldsymbol{qu}\rangle$ represents the monthly mean,
g is the acceleration due to gravity, ρw is the density of water and
ps is the surface pressure.

JJAS Difference in MSE (W.m^{-2}) caused by dust absorption (integrated from surface to top-of-atmosphere)

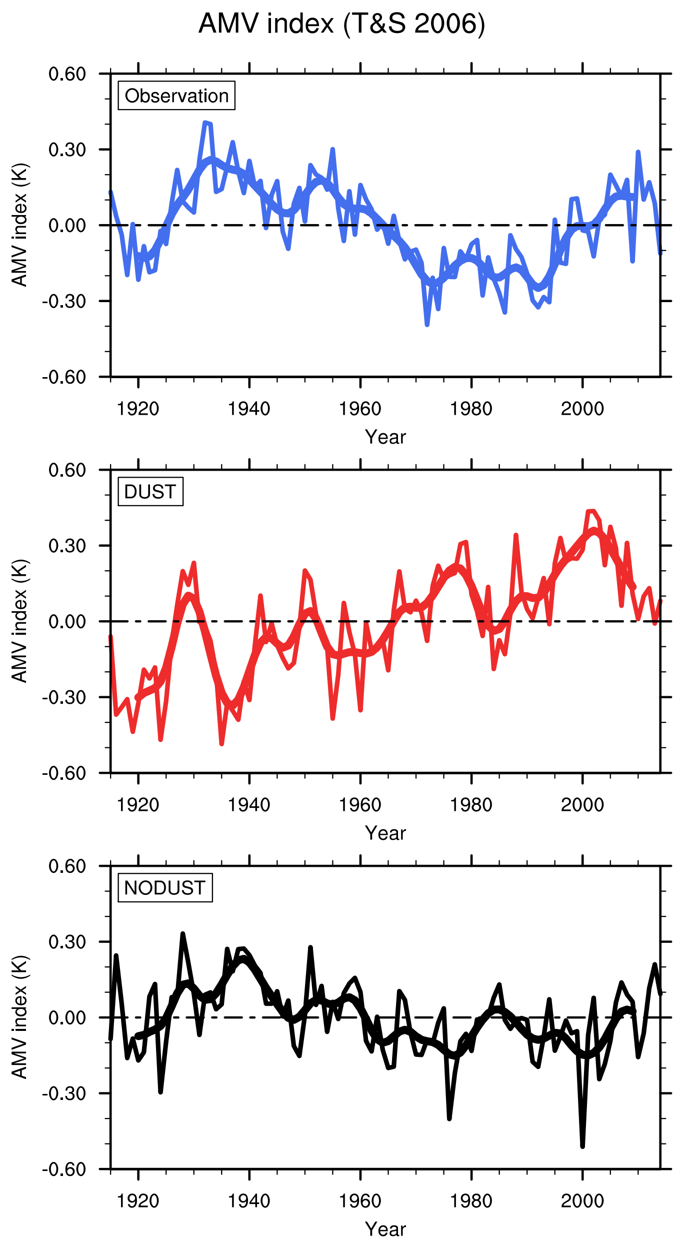


$$\delta\left(\langle\omega\rangle\frac{\partial\langle MSE\rangle}{\delta p}\right)$$

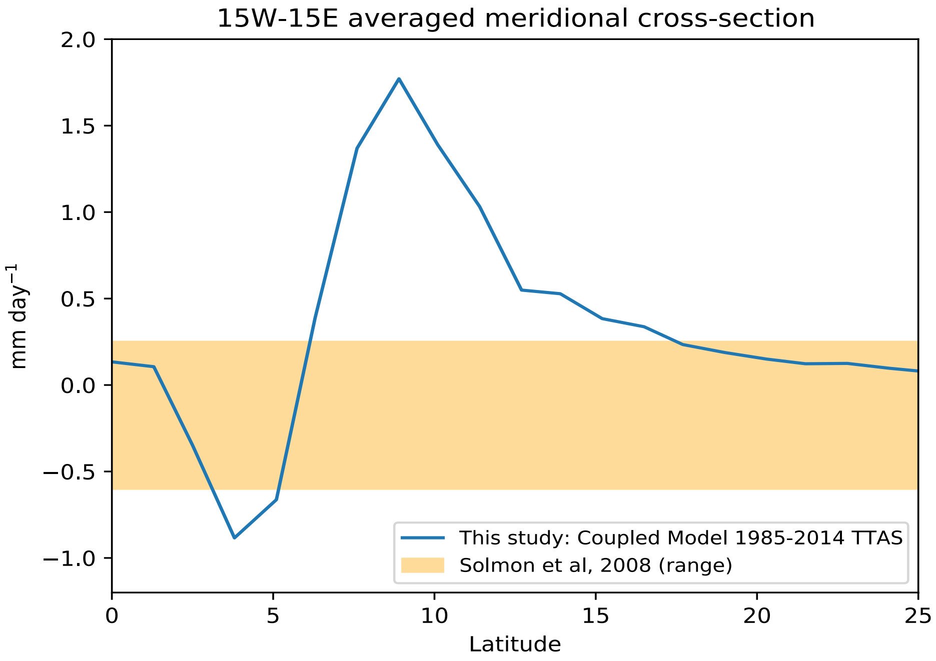
Energy Transported Vertically

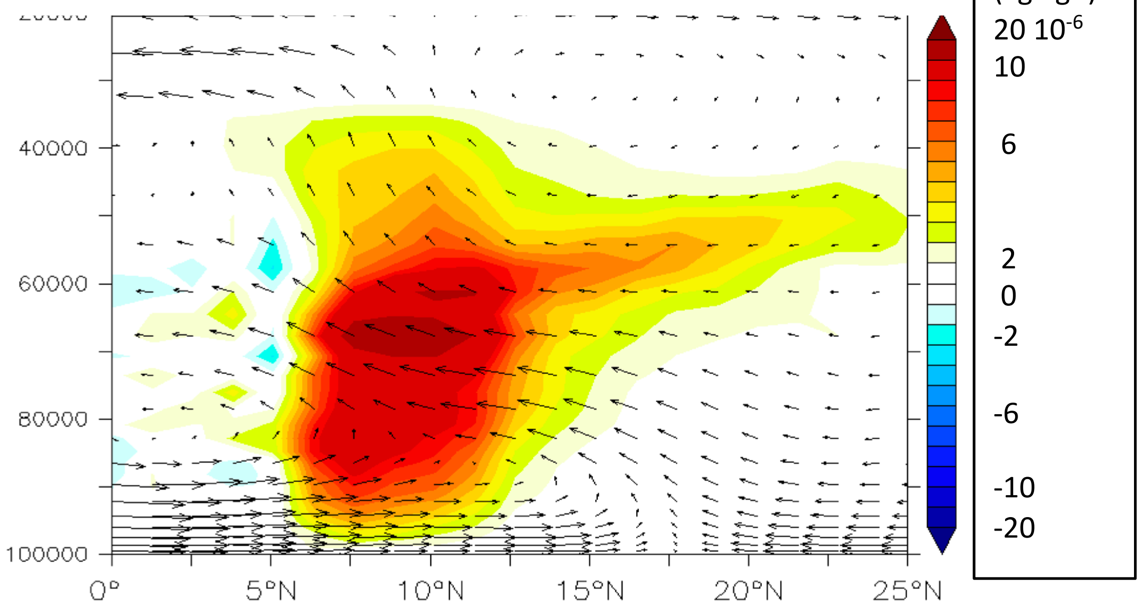
$$MSE = c_pT + gz + L_V\ ovap$$

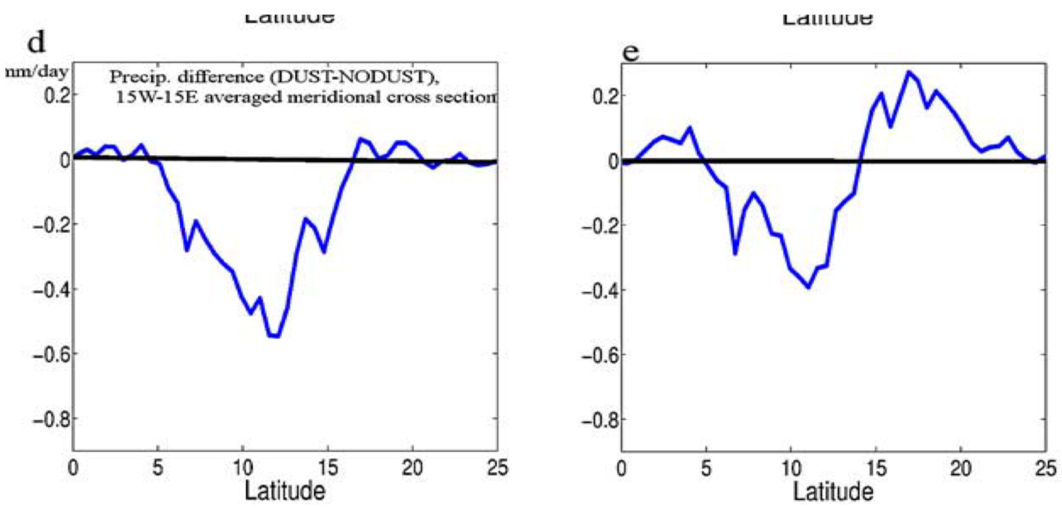
Atlantic Multidecadal Variability

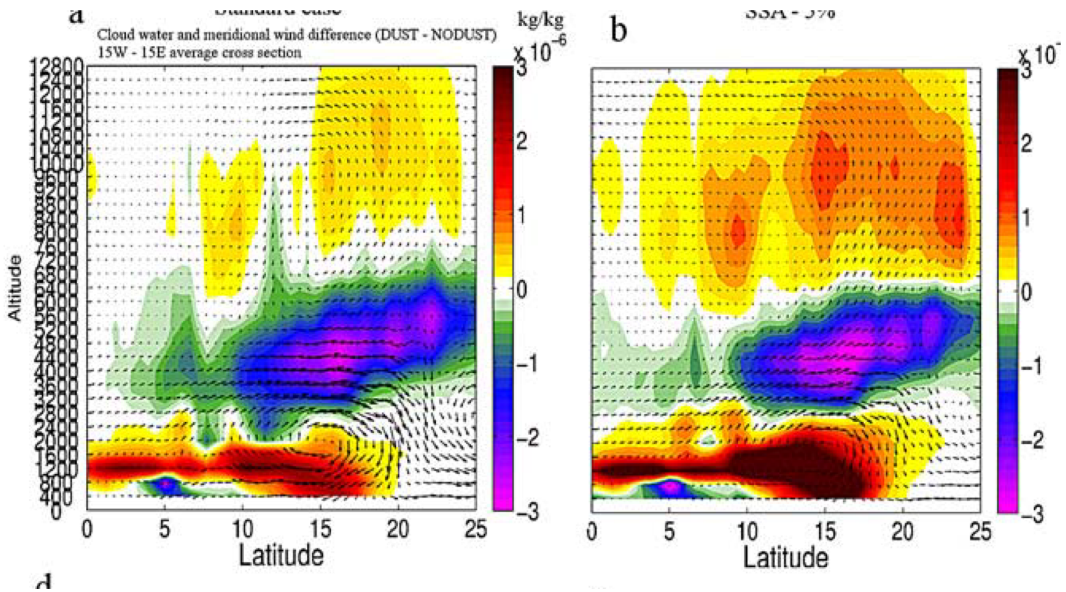


Top left: IPSLCM6 Zonal mean precip change for summer (JJAS), Top right liquid water mixing ratio (lwcon), bottom Solmon 2008 std case and -5% SSA.









Conclusions

- Dust absorption strongly influences Sahel precipitations
- We took a realistic iron oxide content of dust and accounted for large (> 10 μm), i.e more absorbing, particles
- A comparison with GPCP observations over the 1985-2014 period shows noticeable improvements on tropical precipitations over Sahel, tropical N. Atlantic and Western Indian Ocean. No improvement is seen over the tropical Pacific
- This improvement is triggered by thermodynamics that conditions the tropical atmospheric circulation over the Atlantic-Sahel region