Dust Induced Atmospheric Absorption Modifies Tropical Precipitations in Global Climate Models

Session: Science Talks Session A

Yves Balkanski, Rémy Bonnet, Olivier Boucher,
Ramiro Checa-Garcia and Jérôme Servonnat

Laboratoire Des Sciences du Climat et de l'Environnement, Gif-sur-Yvette, France

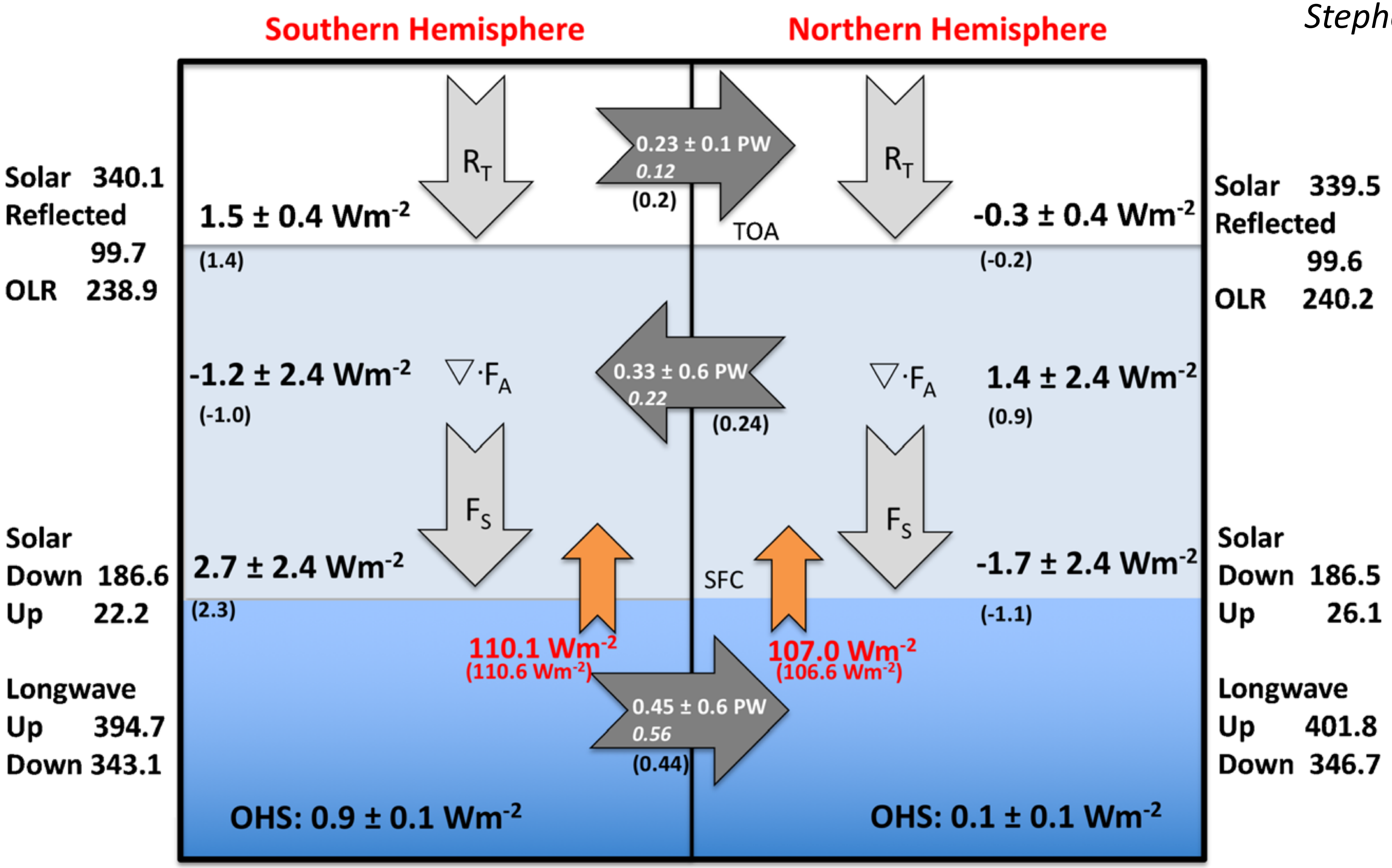
Institut Pierre Simon Laplace, Paris, France

Plan

- Earth heat budget and position of the ITCZ
- Previous published experiments
- Estimating dust absorption / role of iron oxides / role or large particles
- Analysis of tropical precipitations
- How can we improve tropical precipitations?

Hemispheric heat budgets and cross-equatorial heat transports

Stephens et al., 2016

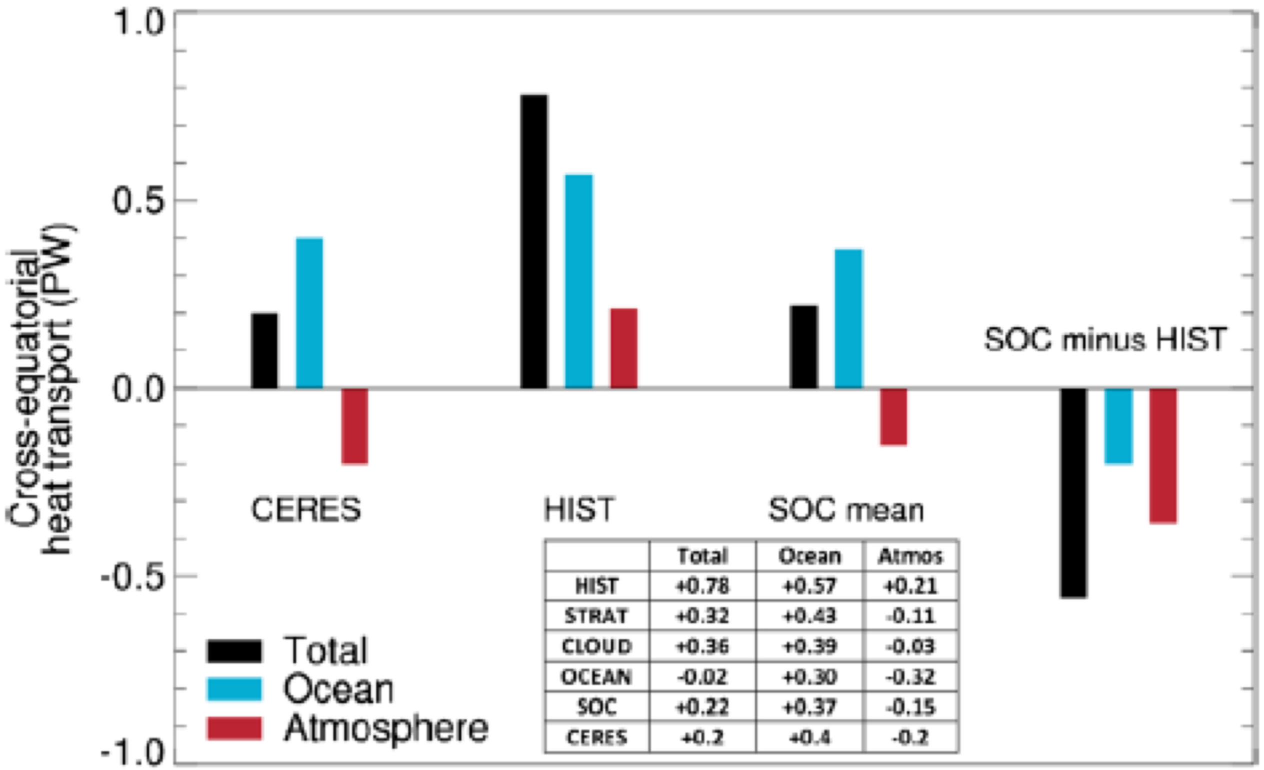


Previous studies

- Links between hemispheric energy imbalance and precipitation asymmetry

Stephens, …, Haywood, et al., 2016

Haywood et al. (2016) studied how albedo biases (that translate into TOA energy budget) were linked to cross-equatorial energy transport (of energy or moisture). The symmetry in albedo is obtained through 3 different means: adding stratospheric aerosols (STRAT), changeing the ocean albedo (OCE) or changing cloud microphysics (CLOUD). This Figure contrasts the mean of these 3 experiments (SOC-mean) with the historical simulation from HadGEM



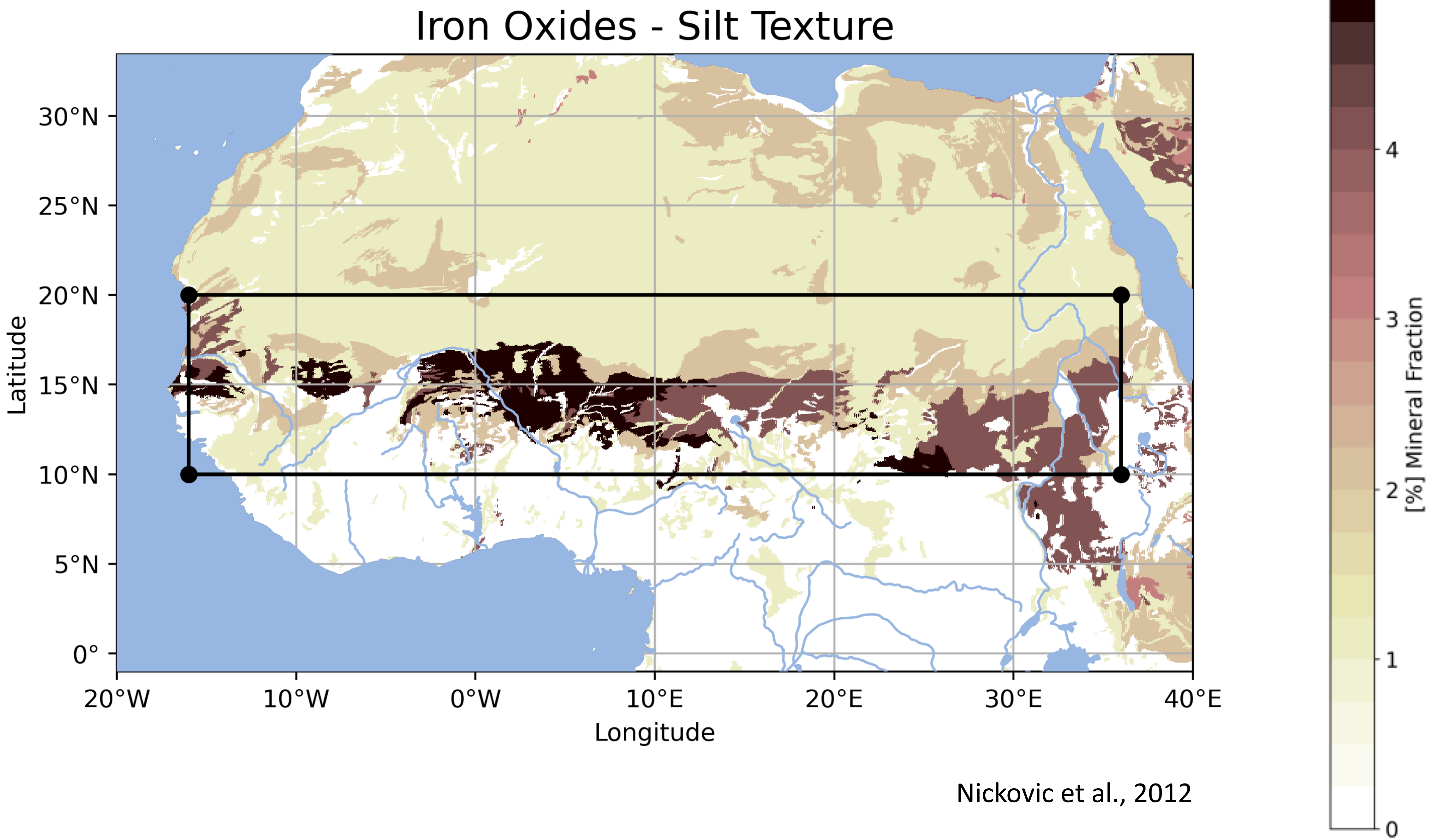
	Total	Ocean	Atmos
HIST	+0.78	+0.57	+0.21
STRAT	+0.32	+0.43	-0.11
CLOUD	+0.36	+0.39	-0.03
OCEAN	-0.02	+0.30	-0.32
SOC	+0.22	+0.37	-0.15
CERES	+0.2	+0.4	-0.2

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, in the shortwave the iron oxide dominates
  - ➢ We account for the absorption from very large dust particles ($10 < D < 100\mu m$)
  - ➢ Precipitation are compared with observations over the Sahel, the North Atlantic and the West Indian Ocean.
  - ➢ ESMs struggle to improve tropical precipitations (Fiedler et al. 2020

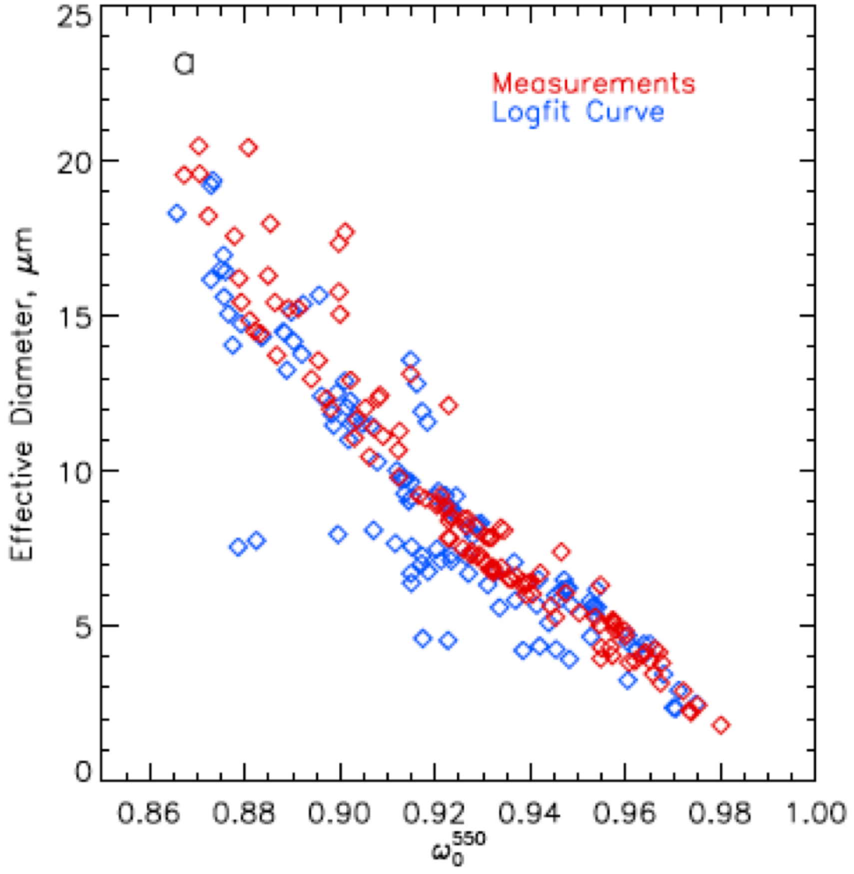
Iron Oxide Content Over Sahel

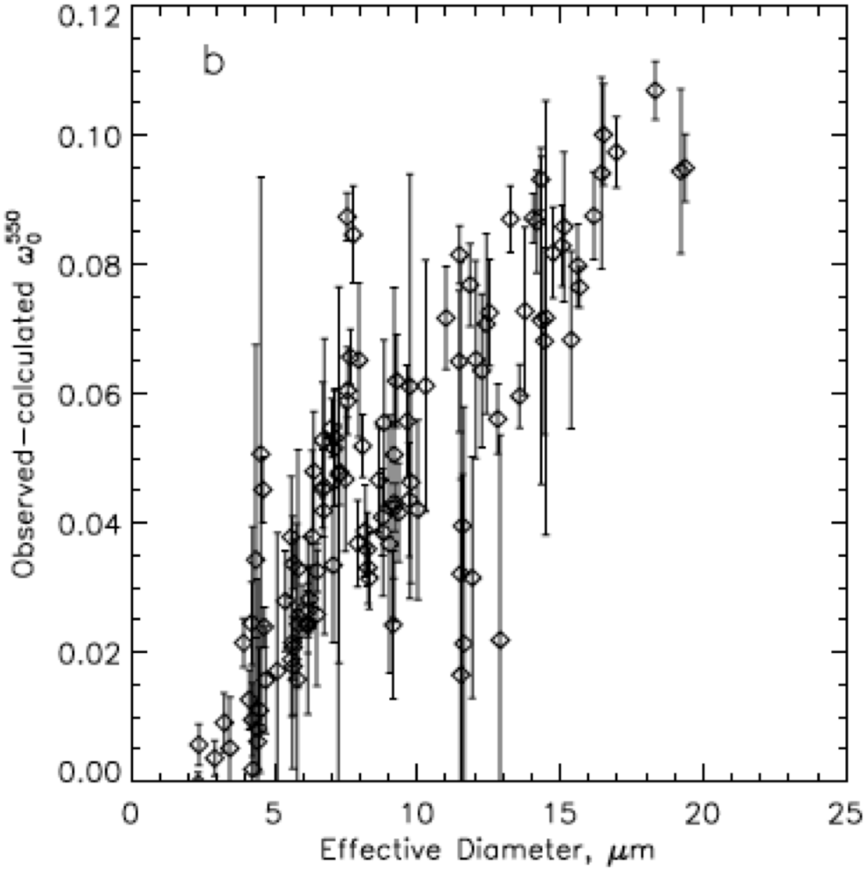


Nickovic et al., 2012

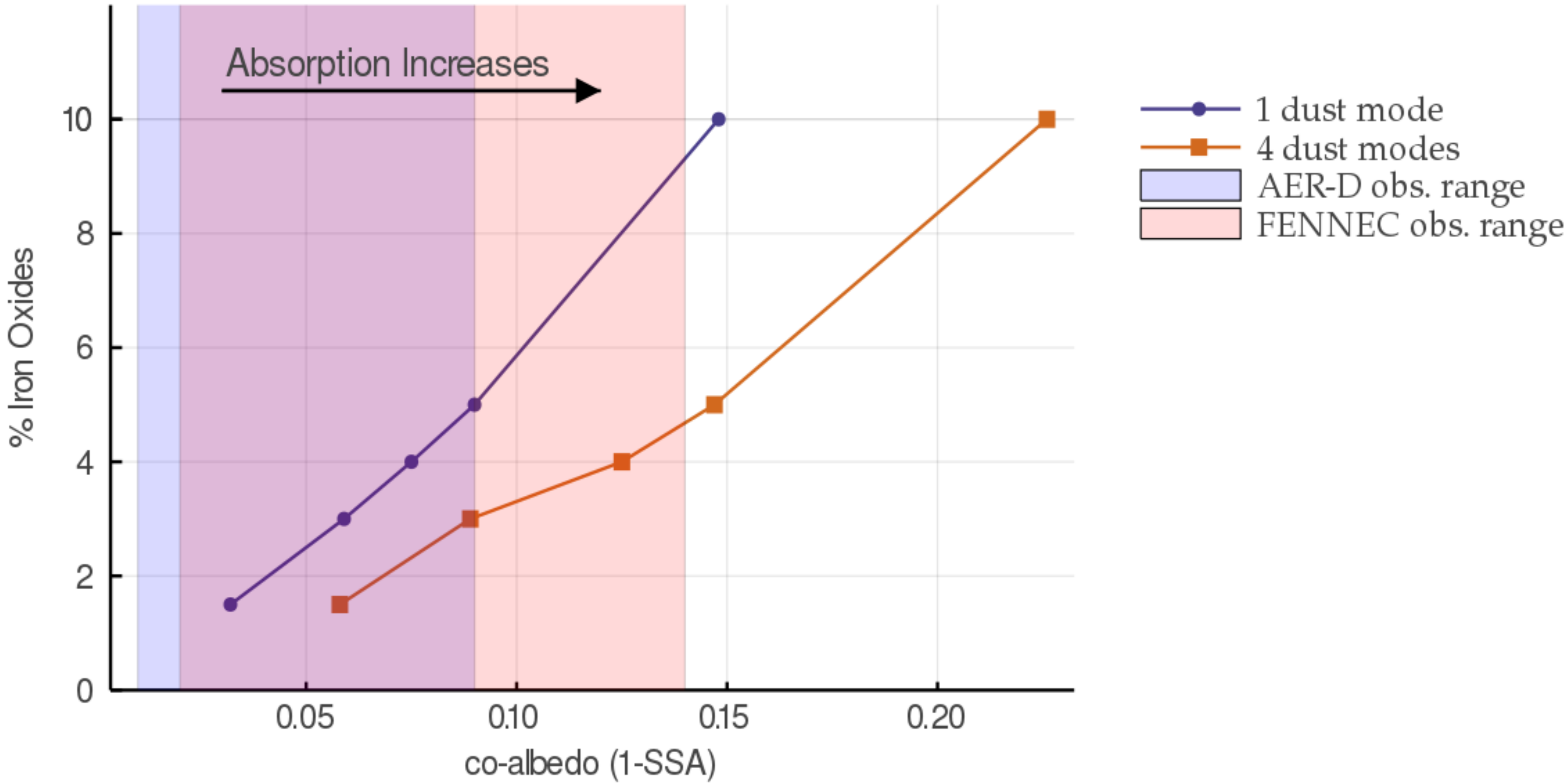
Observations of Dust Single Scattering Albedo (SSA) as a function of particle size during the AER-D campaign

Ryder et al., 2013





Absorption (550 nm) Increase For Large Particles (D > 10μm)



Comparaison Of Absorption For A Content Of 5% Iron Oxide And Dust Particles Of Diameter < 10 μm, And 3% Iron Oxides And Dust < 100 μm

Region	DOD at 550nm (Dust Optical Depth)	Height	Global Radiative Perturbation (Wm^{-2})		
			SW	LW	Net
Sahel 15W:35E; 10N:20N	1mode 5% iron oxide	TOA	+2.89	+2.30	+5.19
		Atm. Absorption	+19.4	-2.90	+16.6
		Surface	-16.6	+5.20	-11.4
	4modes 3% iron oxide	TOA	+4.11	+1.87	+5.98
		Atm. Absorption	+19.9	-3.21	+16.7
		Surface	-15.8	+5.09	-11.7

Description Of The Simulations

We made 2 long simulations with the fully coupled model IPSLCM6 for 100 years from 1915 to 2014

Simulation 1 with Sahel Dust

Simulation 2 with No Dust

We show results for the last 30 years (1985-2014) of simulation

Results for precipitation compare the simulation with Dust to the simulation without Dust

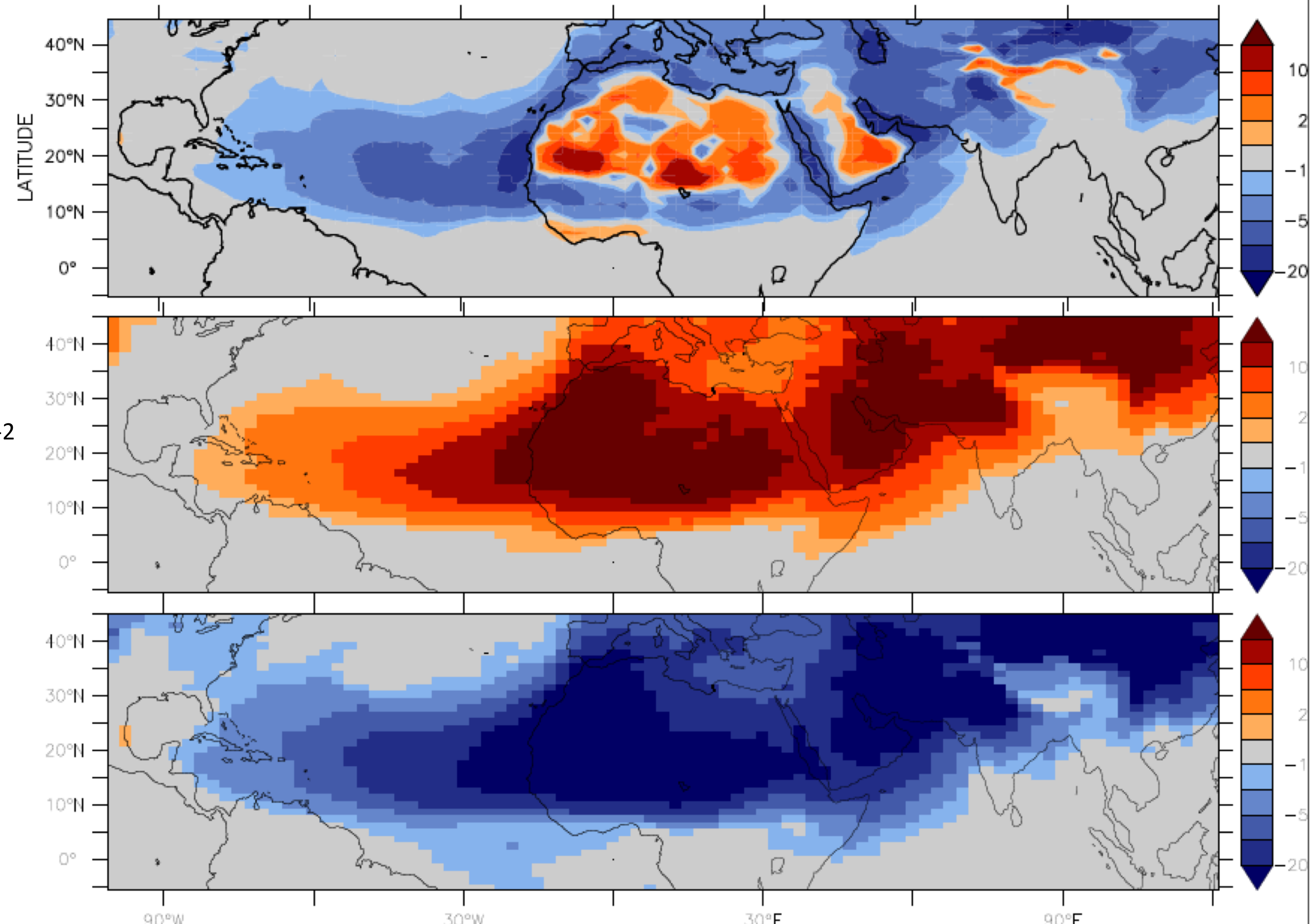
Averaged JJAS Dust Radiative Effect (SW+LW) for 3.0% Iron Oxide

Sahel Region (10°N:20°N; 15°W:35°E)

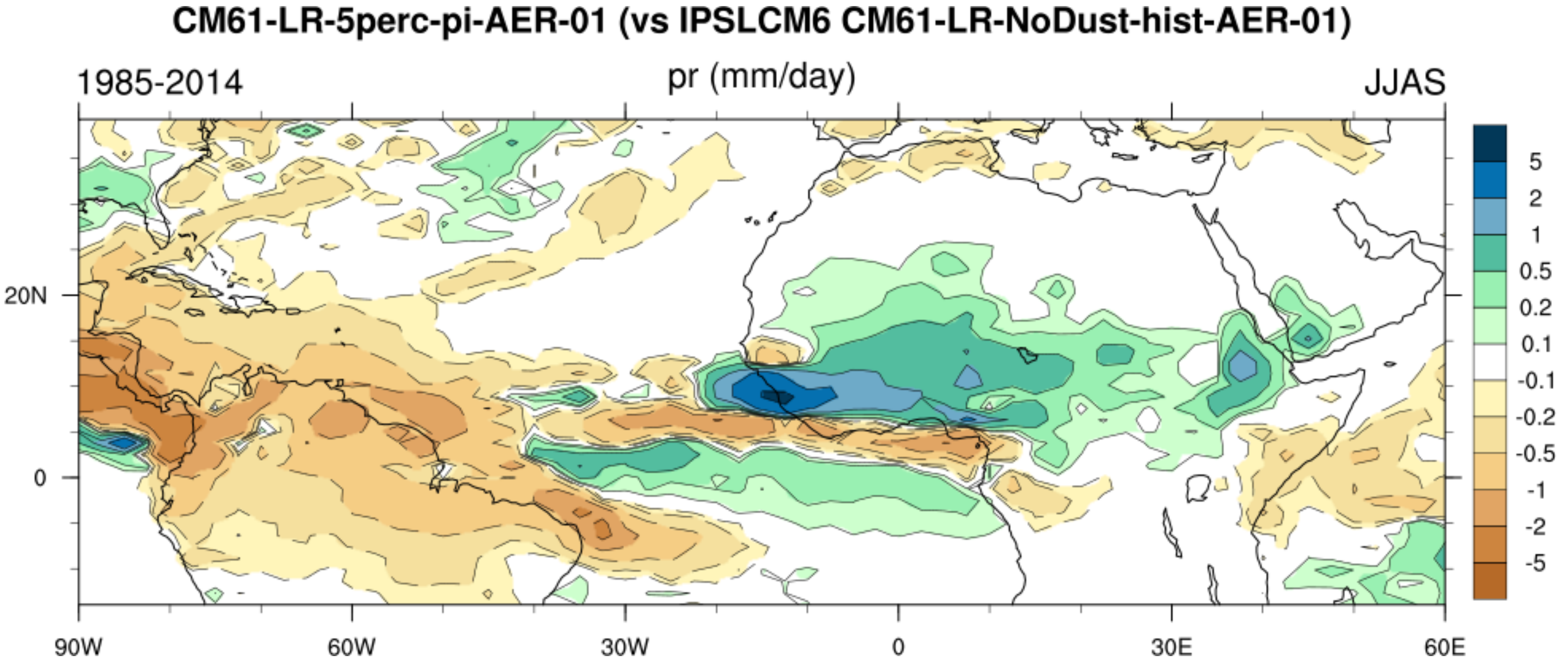
TOA = +6.0 W m^{-2}

Atm. Absorption = +16.7 W m^{-2}

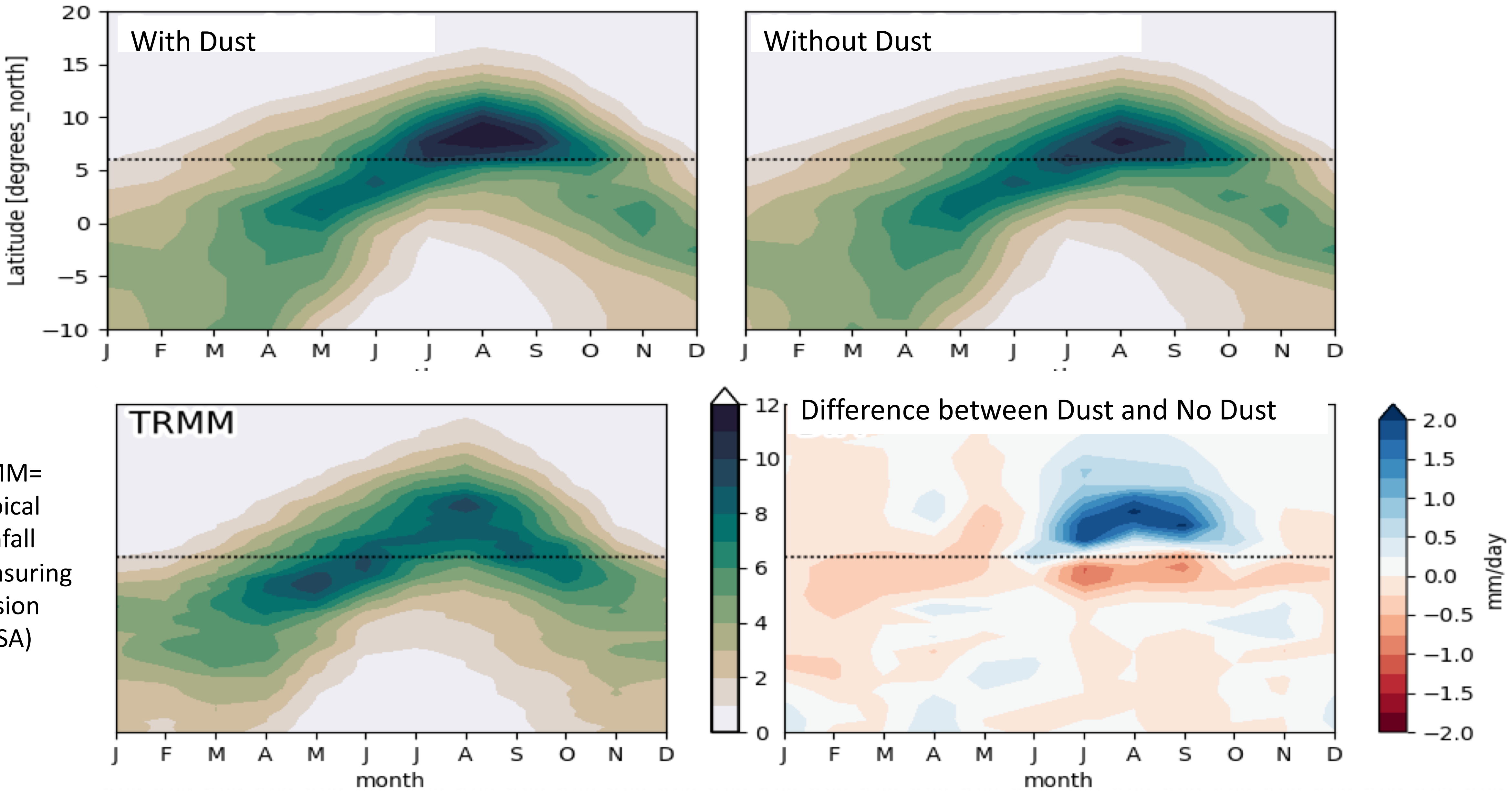
Surface = -11.7 W m^{-2}



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



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



TRMM= Tropical Rainfall Measuring Mission (NASA)

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

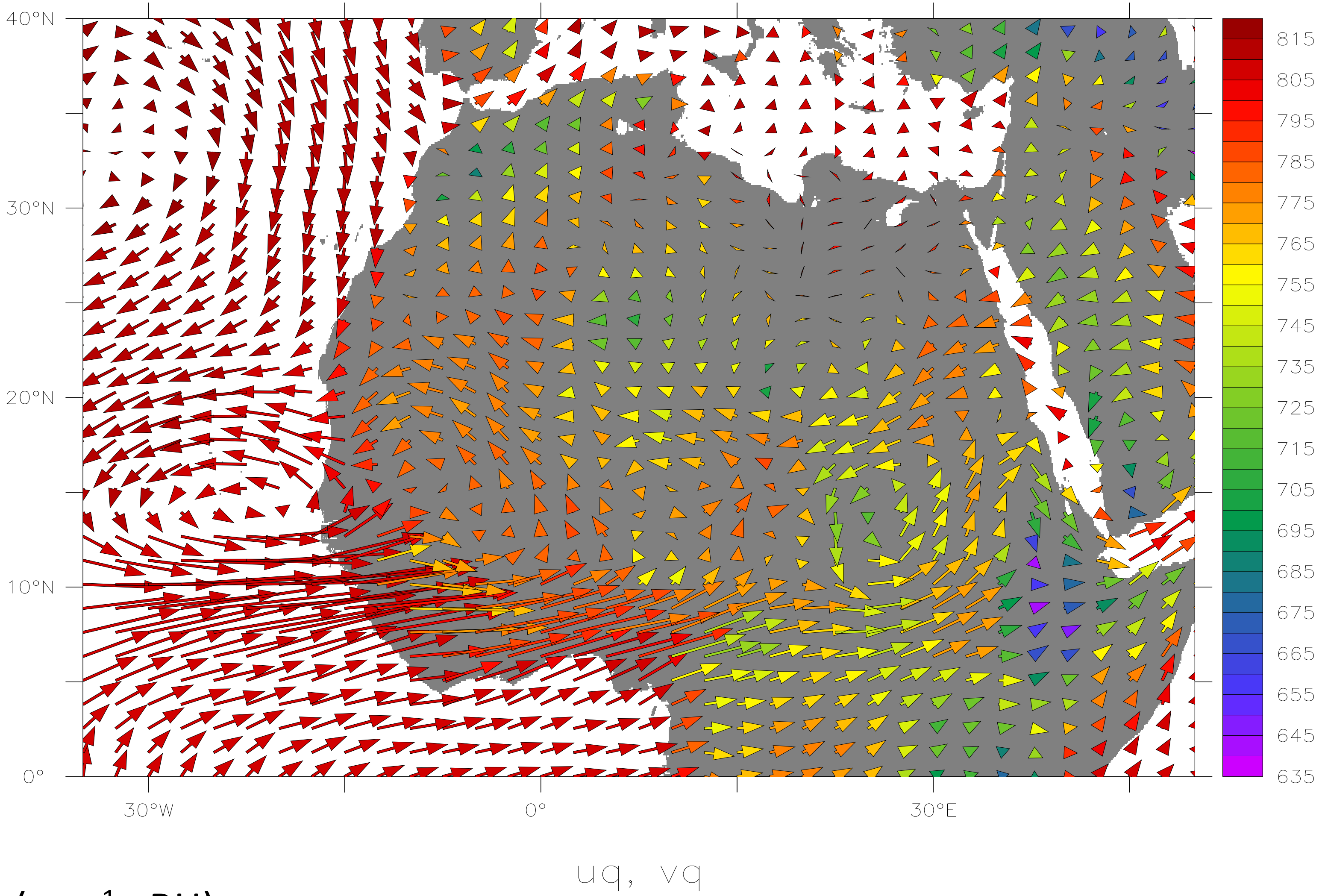
Light blue and light red: 5 to 15% change

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)

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