The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2256-11

Workshop on Aerosol Impact in the Environment: from Air Pollution to Climate Change

8 - 12 August 2011

Aerosol regional radiative effects and climatic impact modeling over Africa

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Study of aerosol regional climate impact over Africa

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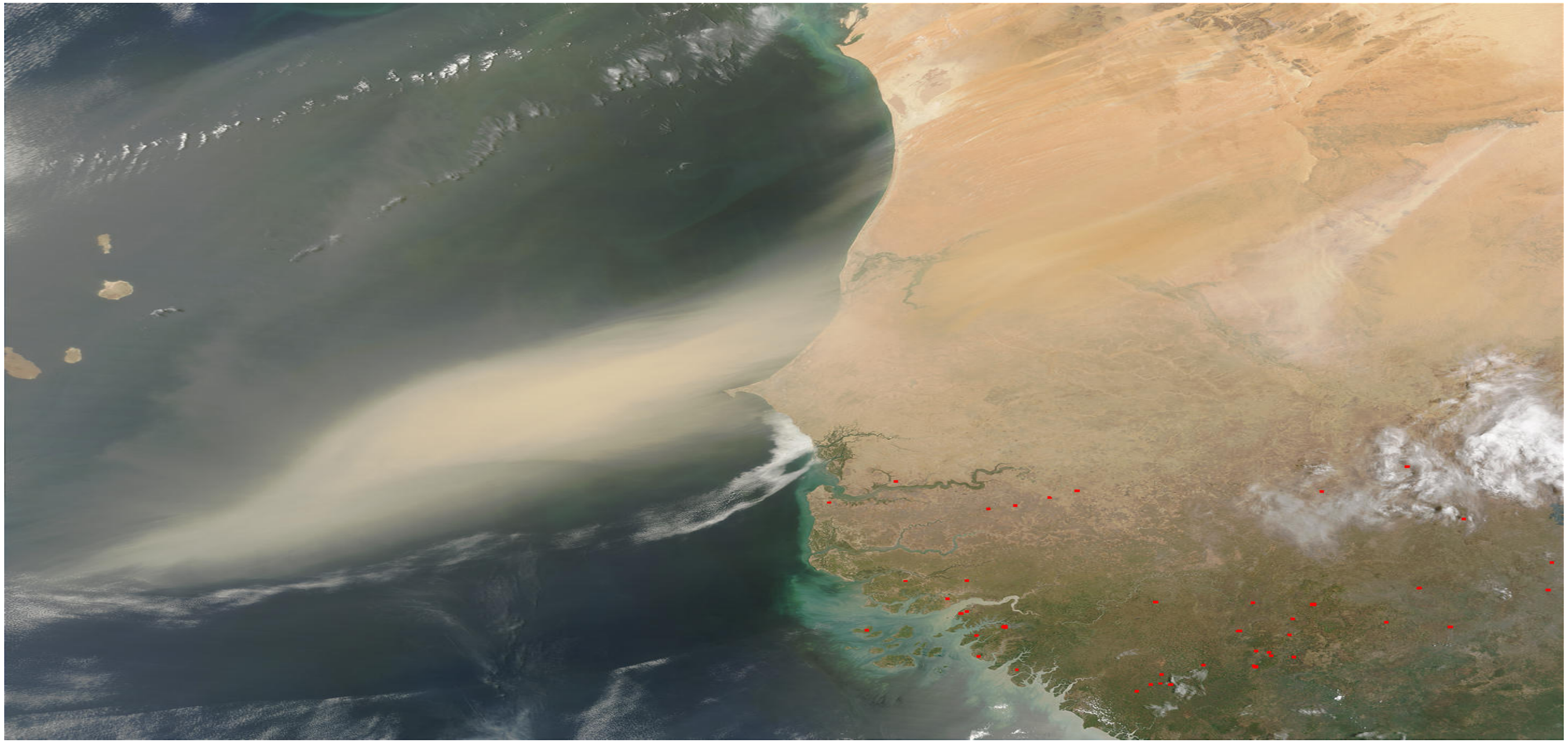
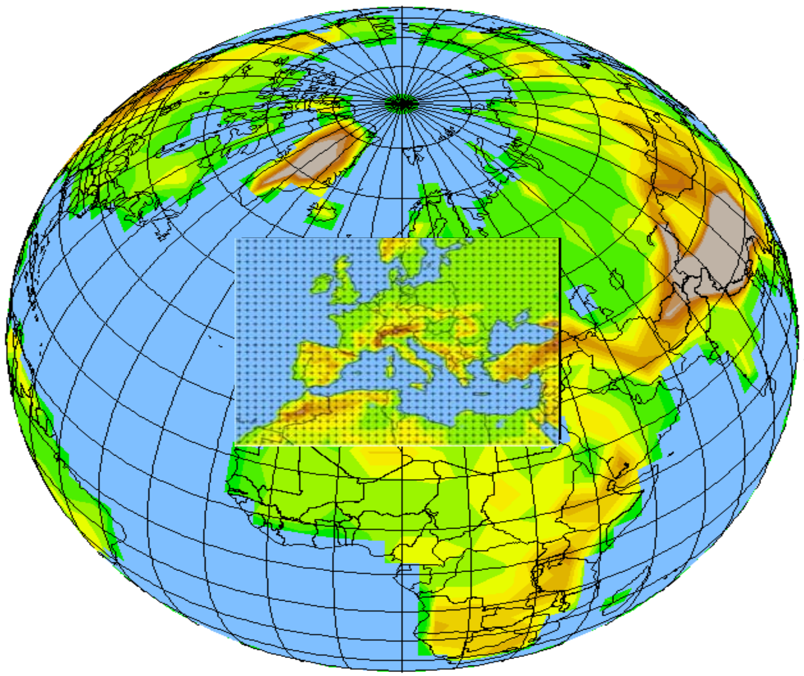


M. Mallet, F. Malavelle, N. Elguindi, F. Giorgi, A. Zakey, A. Konare …

Regional Climate Model



High resolution limited area models adapted to climatic simulations.

Forced by analysis or GCM outputs.

RegCM (ICTP/ESP, Trieste, it)

Giorgi and Mearns (1999), RegCM special issue of JGR (1999)

…

RegCNET

Special Issue of Theor., Apl., Clim., sep 2006

Aerosols in RegCM

- **Tracer model / RegCM3**

$$\frac{\partial \chi}{\partial t} = -\overline{V}\cdot\nabla\chi + F_H + F_V + T_{CUM} + S_\chi - R_{w,ls} - R_{w,cum} - D_{dep} + \sum Q_p - Q_l$$

Transport ($-\overline{V}\cdot\nabla\chi + F_H + F_V + T_{CUM}$)

Primary Emissions (S_χ)

Removal terms ($R_{w,ls}$, $R_{w,cum}$, D_{dep})

Physico – chemical transformations ($\sum Q_p - Q_l$)

- **Particles and chemical species considered**

SO_2 ⇔	SO_4^{--}	BC (soot)		OC (total organic carbon)		DUST (4 bins)				SEA SALT	
Aqueous and gazeous conversion (Qian et al., 2001)		*Hydrophilic (20% at emission)*	*Hydrophobic* (80%at emission) ⇒	*Hydrophilic (50%at emission)*	*Hydrophobic(50%at emission)* ⇒	0.01-1 µm	1-2.5 µm	2.5-5 µm	5-20 µm		

In dev. (RegCM4) gas-phase chemistry / aerosol dynamics

Dust aerosol on-line module in the ICTP RegCM3 model

No cloud microphysics interaction !

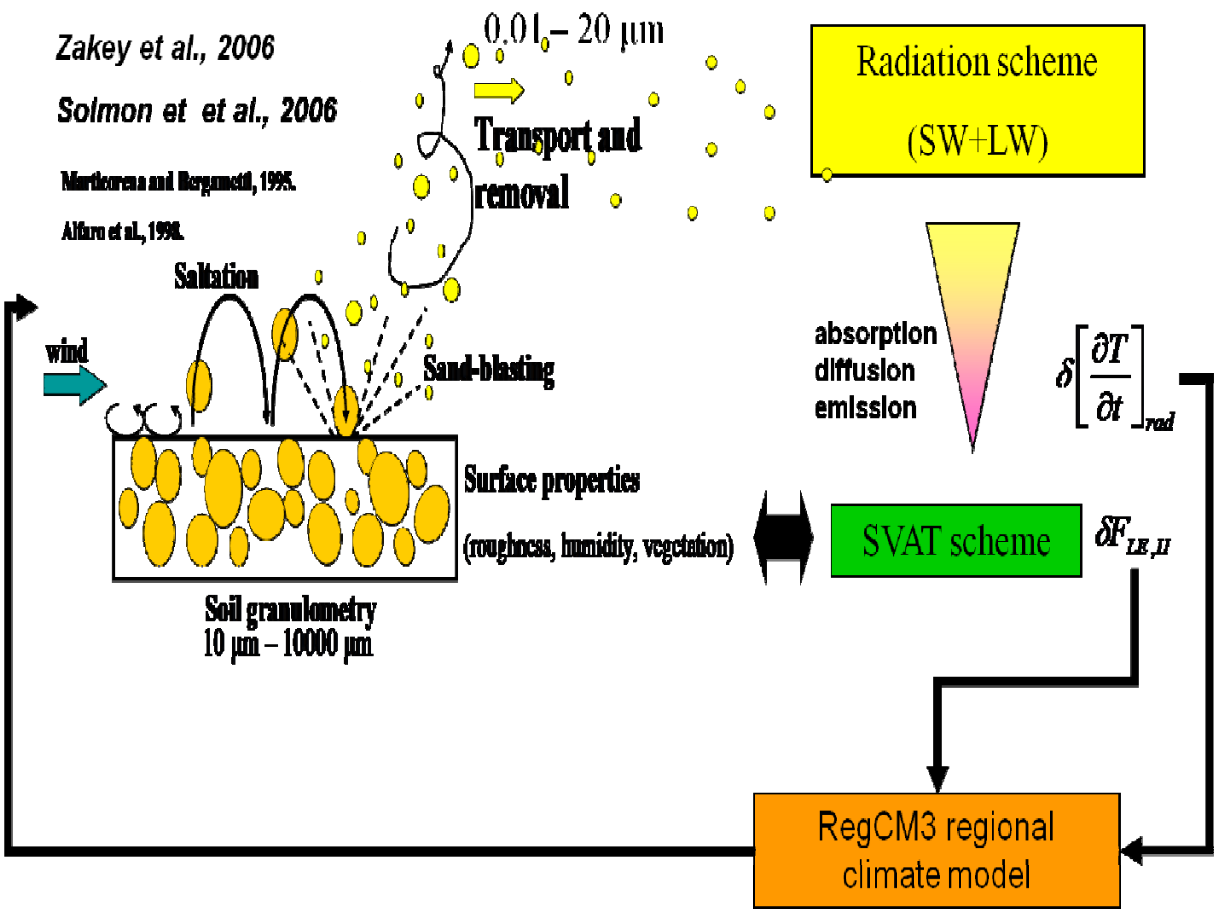
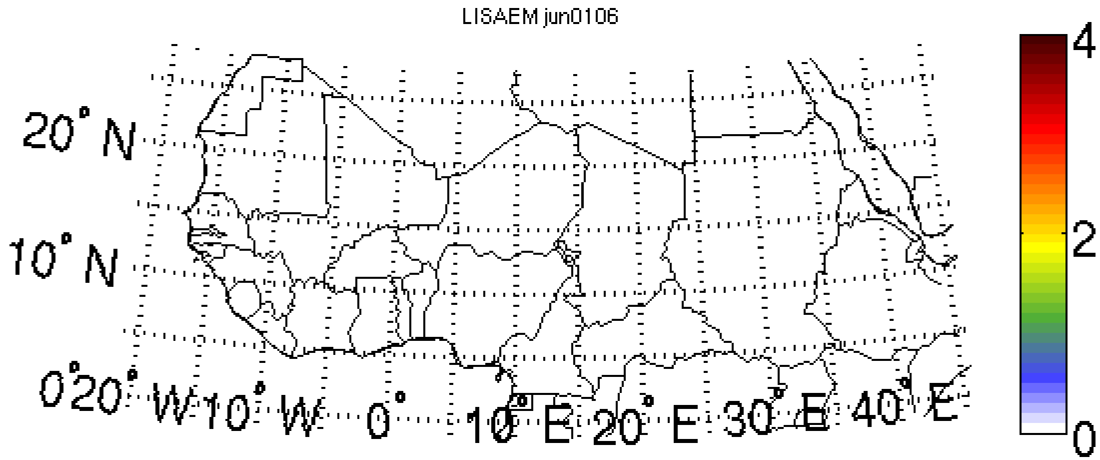
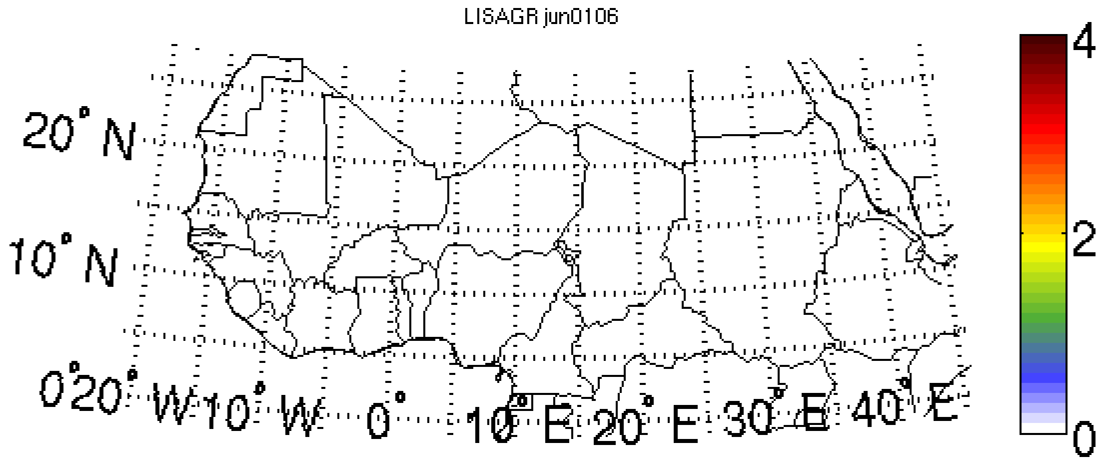


Table 1. Standard Dust SW Optical Properties for the RegCM Radiation Scheme Visible Band[a]

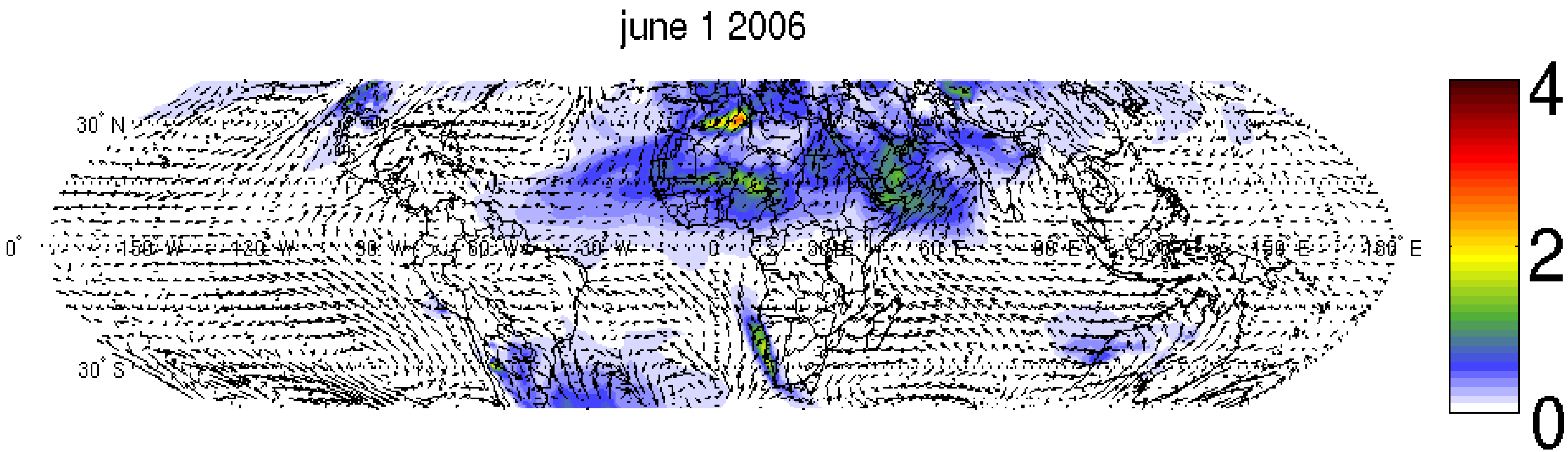
Dust Bins Size Diameter (µm)	K_{ext} ($m^2.g^{-1}$)	g	SSA
0.01–1	2.45	0.71	0.95
1–2.5	0.85	0.76	0.89
2.5–5	0.38	0.81	0.80
5–20	0.17	0.87	0.70

[a]350–640 nm. See Table S1 for details. A sensitivity study is performed by modifying standard SSA bin values of +5 and −5%.


LISAEM jun0106
20° N
10° N
0°
20° W
10° W
0°
10° E
20° E
30° E
40° E
4
2
0

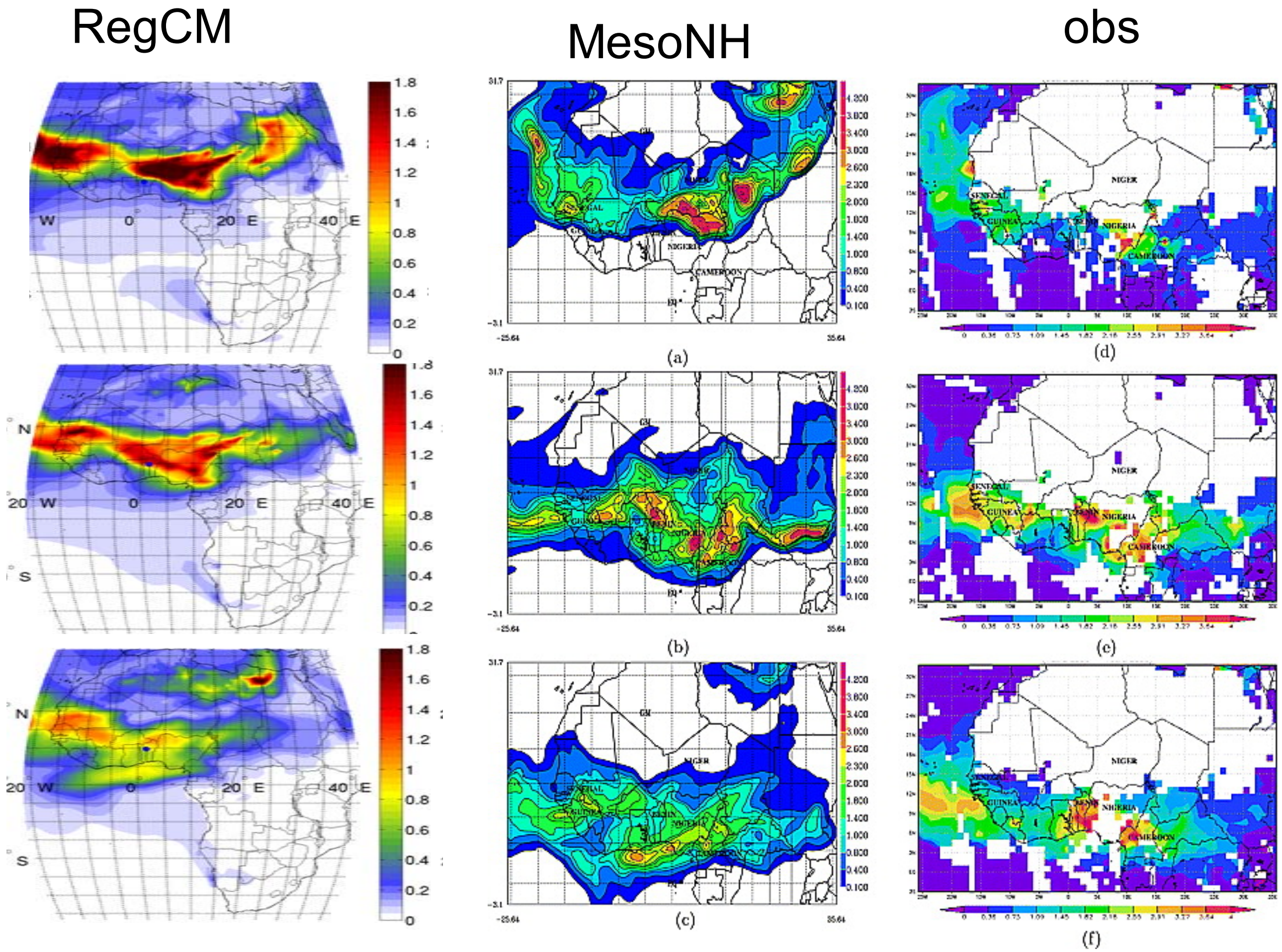

LISAGR jun0106
20° N
10° N
0°
20° W
10° W
0°
10° E
20° E
30° E
40° E
4
2
0

Tropical band configuration model (RegCM4)



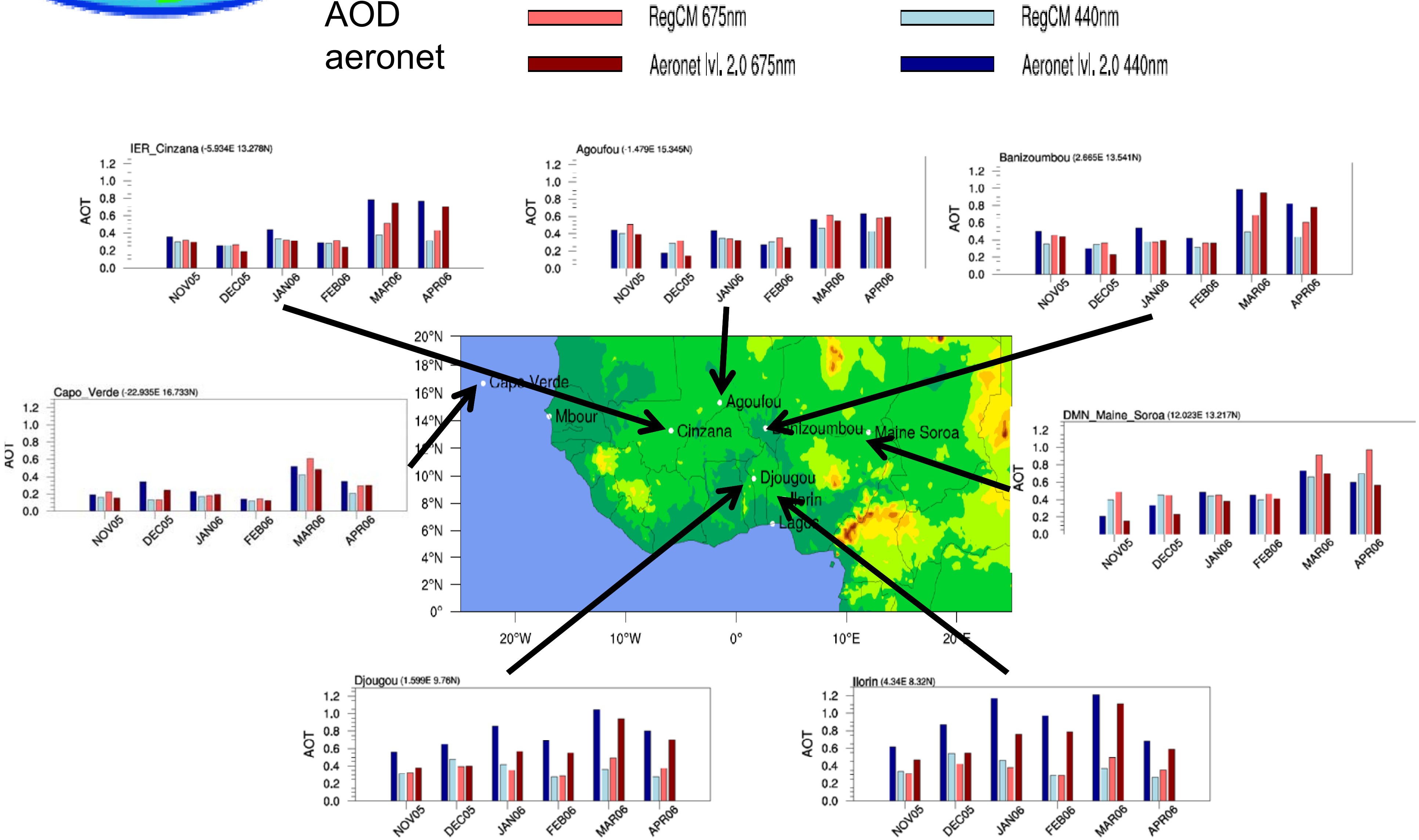
Simple (but fast) aerosol module

8-12 march 2006 (AMMA SOP)



Aerosol optical depth

AOD
aeronet

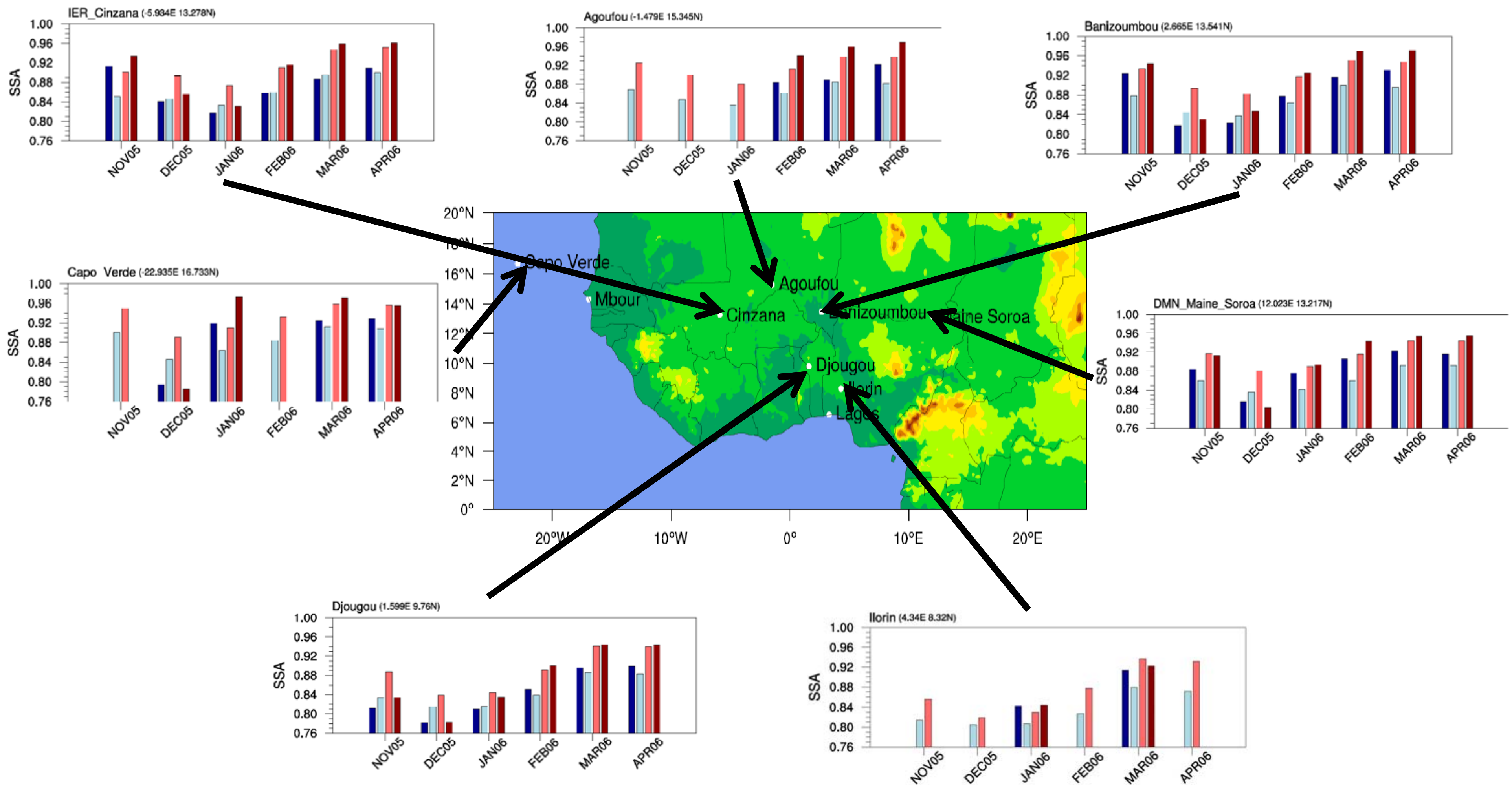


Malavelle et al., 2011 using Dust + biomass burning

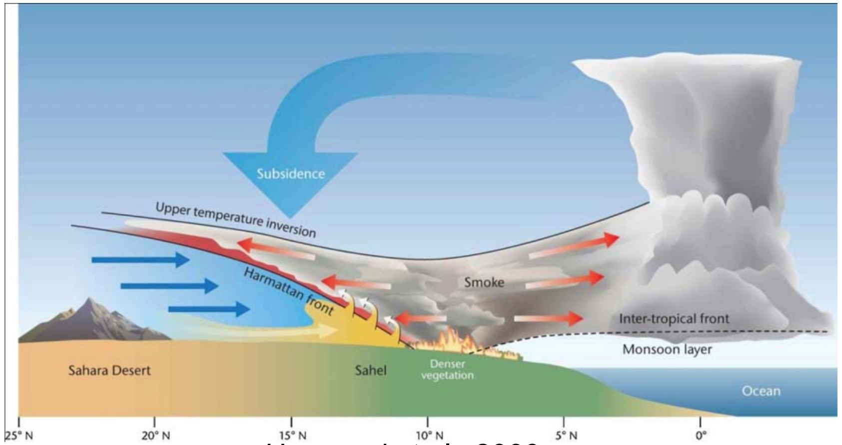
Bulk single scattering albedo

Bulk SSA aeronet

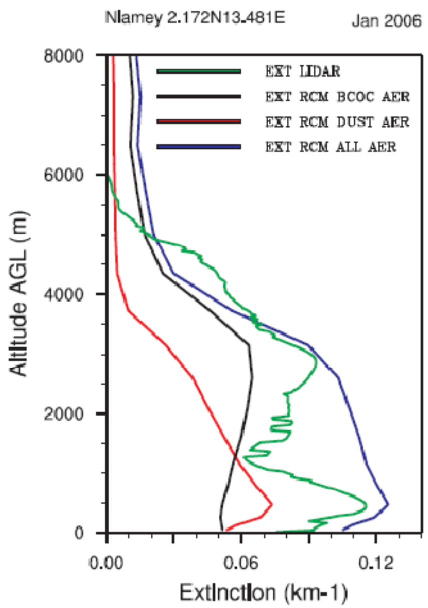
RegCM 675nm
RegCM 440nm
Aeronet lvl. 2.0 675nm
Aeronet lvl. 2.0 440nm

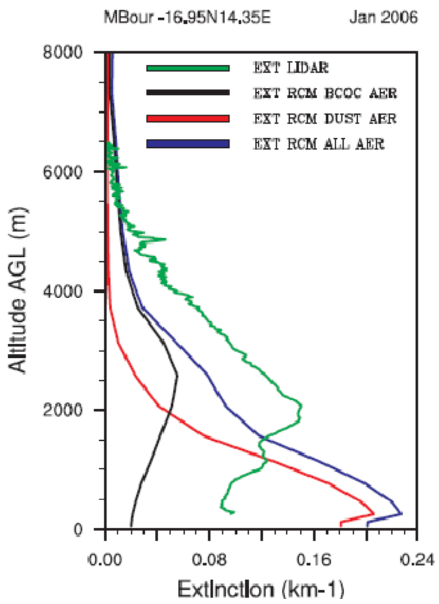


Vertical stratification



Haywood et al., 2009



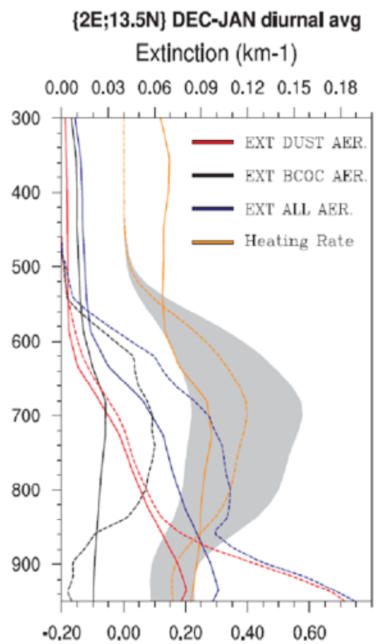


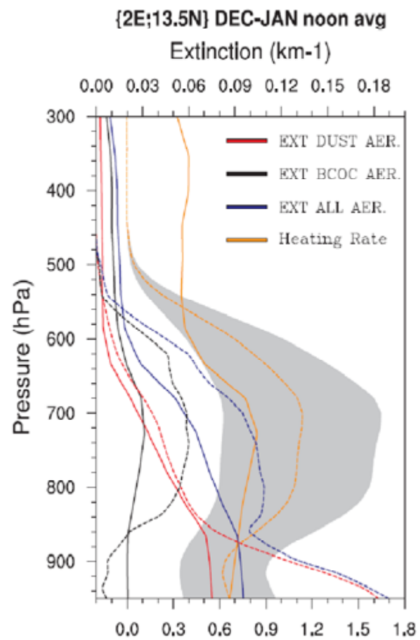
Implications for aerosol radiative heating rate vertical distribution.

Comparison of aerosol heating rates at niamey:

From measurments and detailed radiative transfer model.

From RegCM





Regional climate Applications …

Study of the Impact of Saharan dust on west African regional climate using a regional climate model.

The Abdus Salam
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Role of dust on precipitation in Sahel (significant feedback in drought persistence ?)

Many studies have been published recently based on :

Climate models (e.g. Yoshioka et al., 2007; Konaré et al., 2008; Solmon et al., 2008; Rodwell and Jung 2008; Lau et al., 2009, Perlwitz and Miller, 2010 ….].

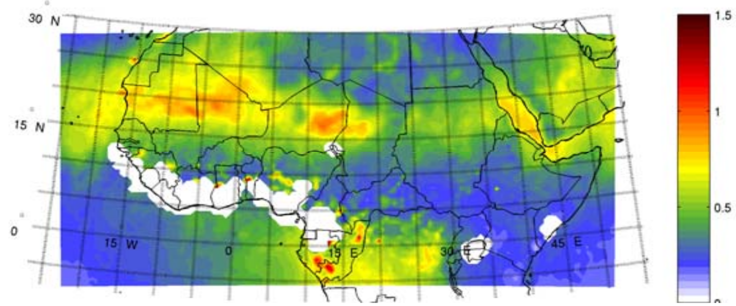
Mesoscale models (e.g. Chaboureau et al. 2007, Mallet et al. 2009, Vogel, Zaho et al., 2011 …**)**

Satellite observations (eg., Kluser and Holzer-Pop, 2010**)**

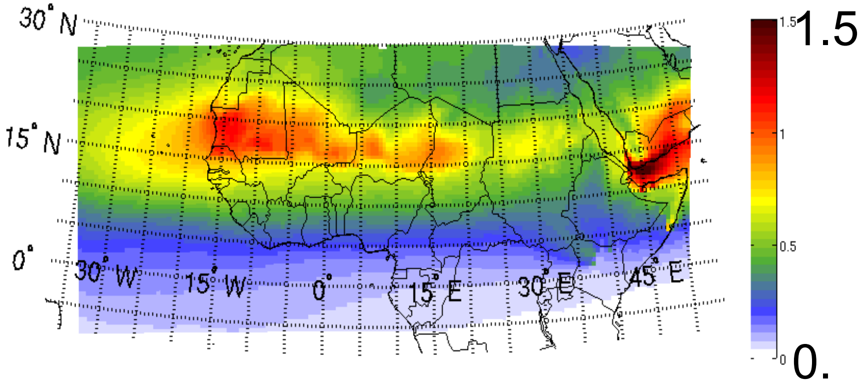
Sometimes ‘Contrasted’ results

Observations

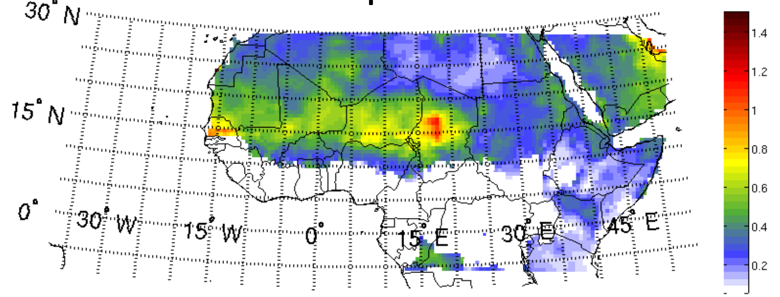
MISR AOD



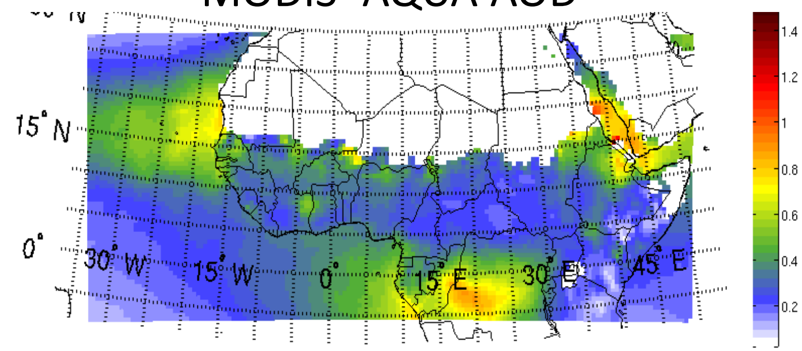
RegCM AOD JJA 2003-2006



MODIS- Deep blue AOD



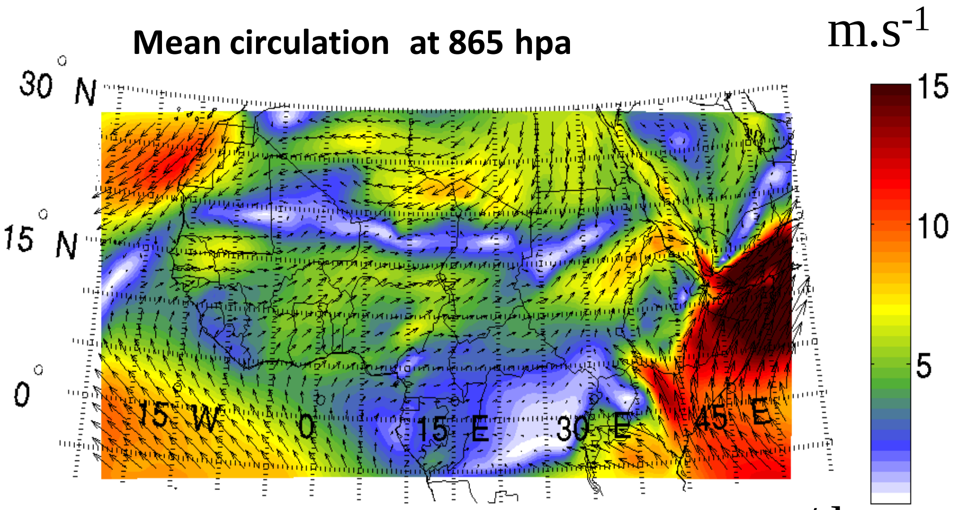
MODIS- AQUA AOD



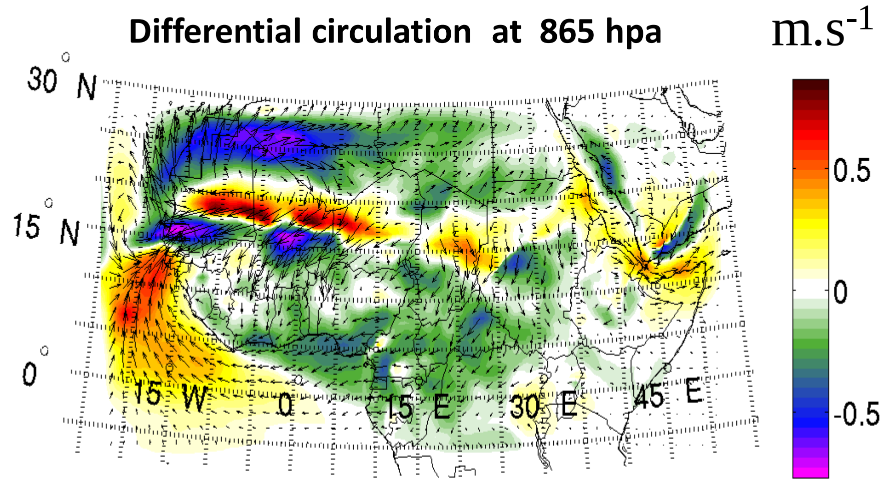
Average dynamical and precipitation response to dust over the WAM region

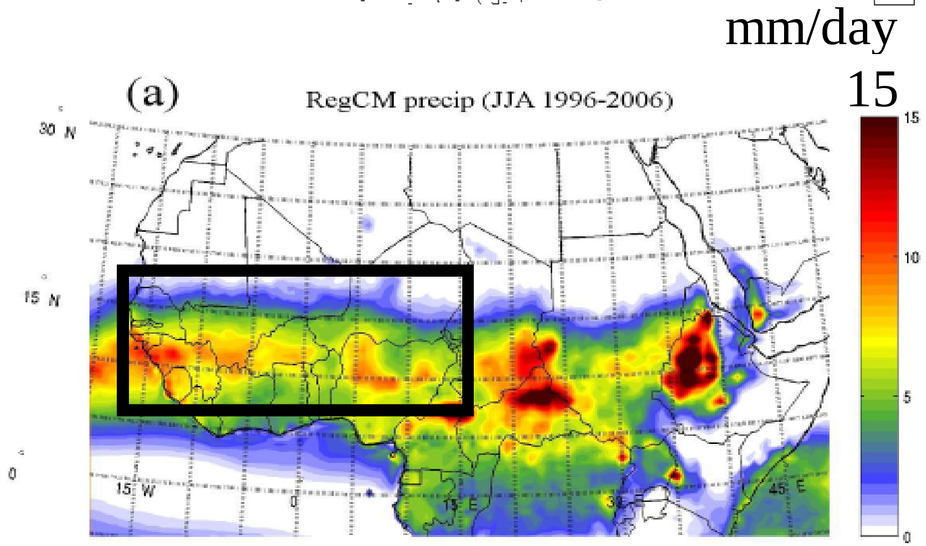
Res = 60 km

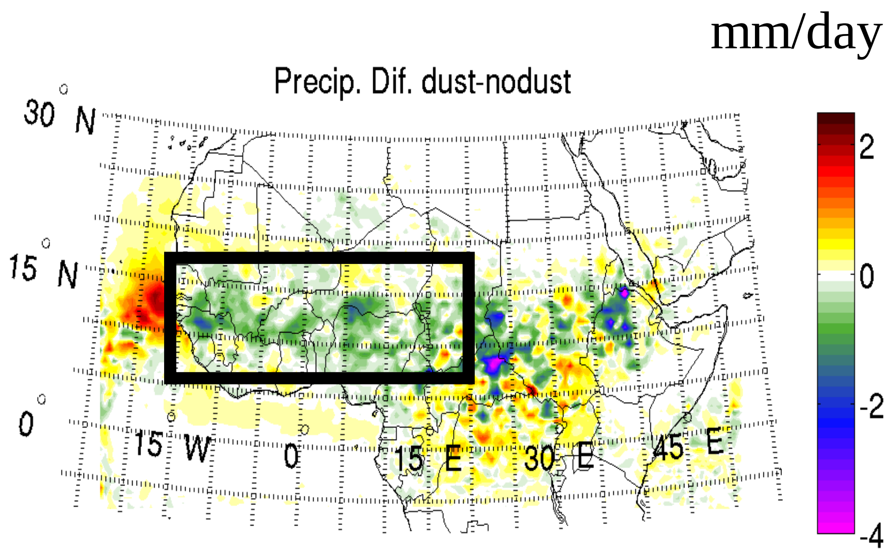
(NODUST, JJA 1996-2006)



(DUST -NODUST, JJA 1996-2006)

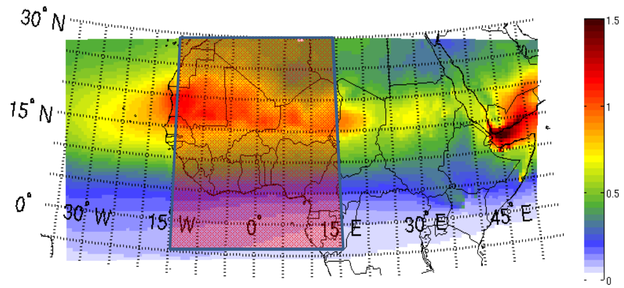


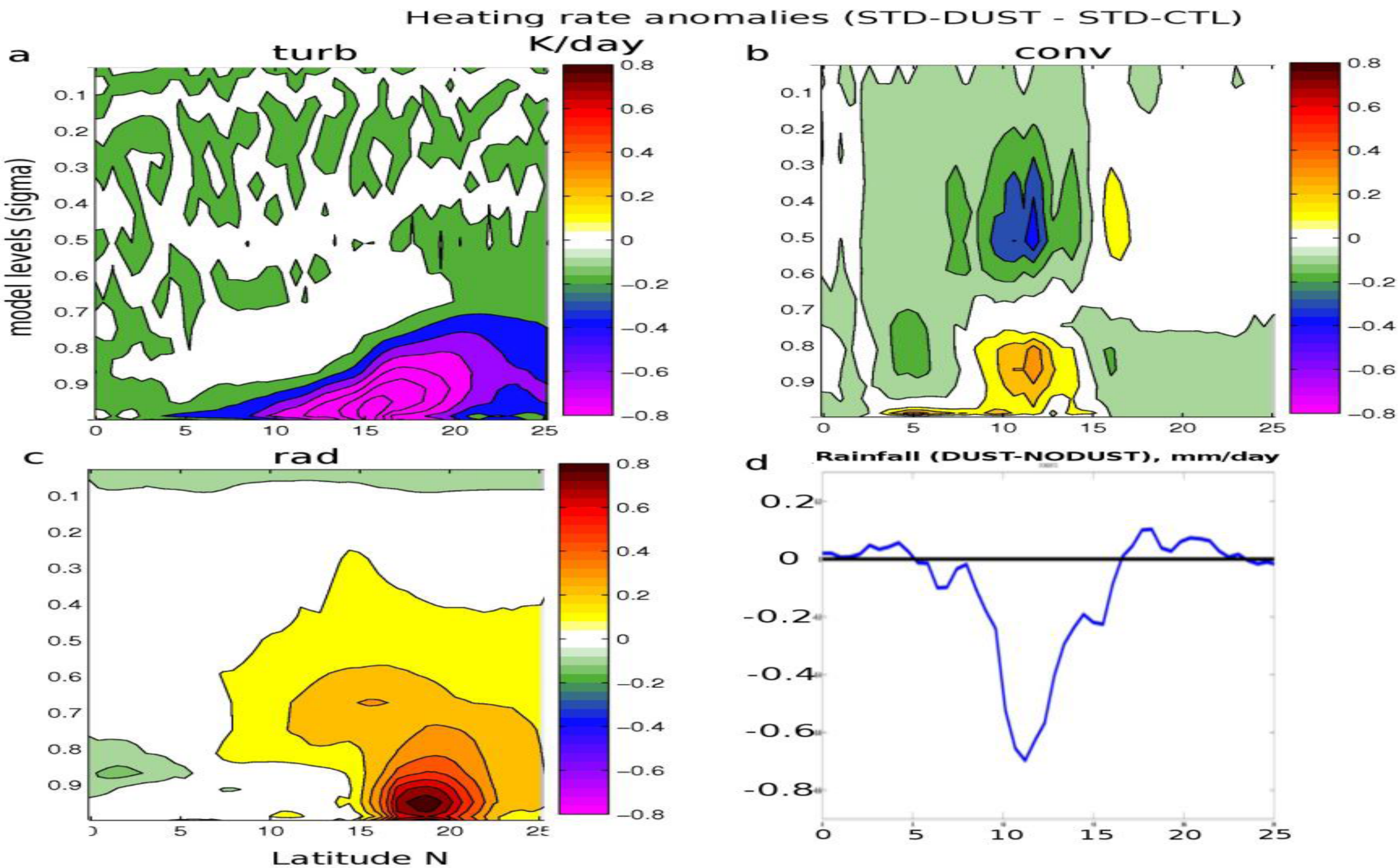




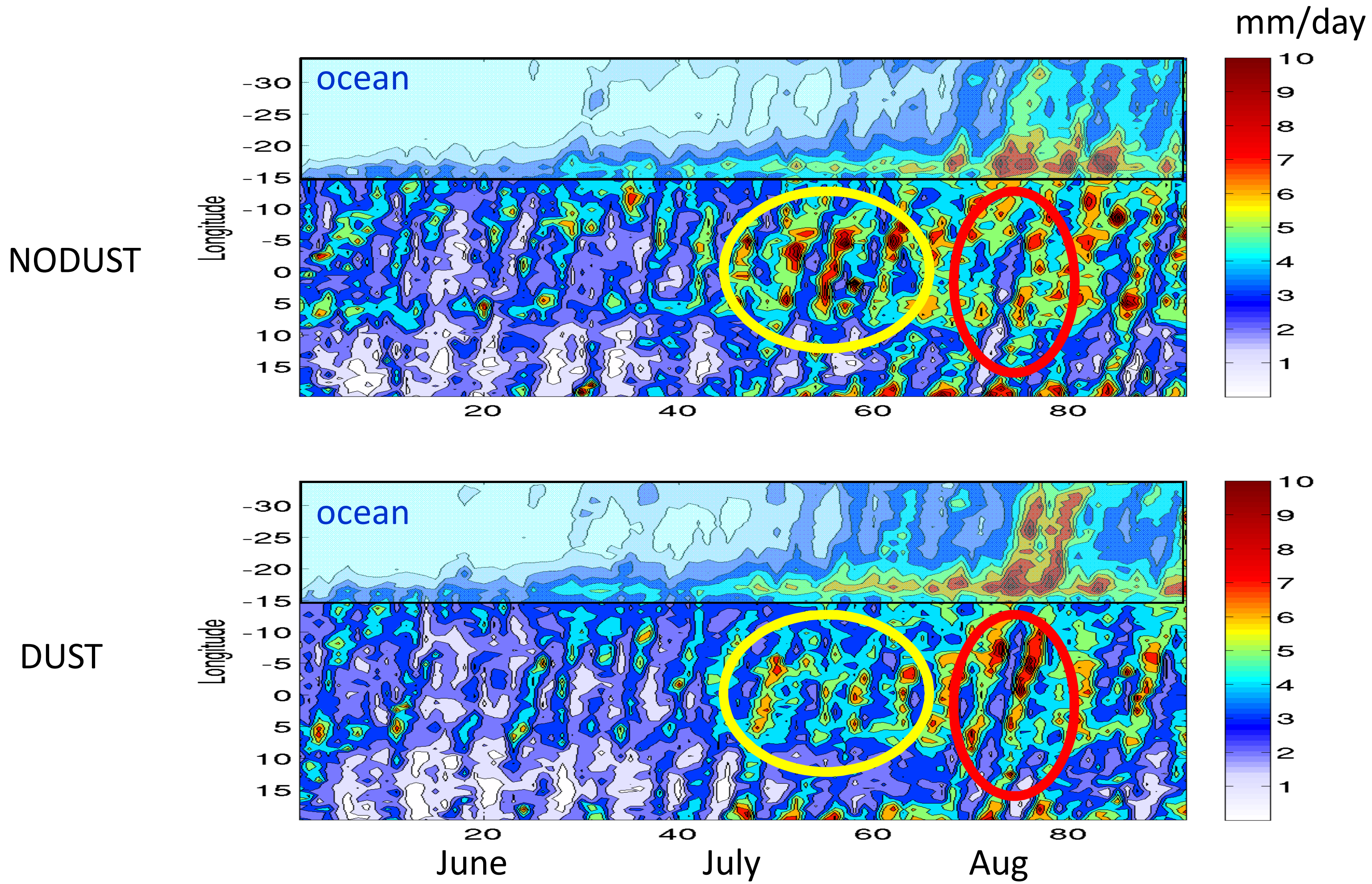
Dust perturbation analysis on heating rates (JJA 1996-2006)

$$\delta\left[\frac{\partial T}{\partial t}\right]_{rad} = \left[\frac{\partial T}{\partial t}\right]_{rad}^{dust} - \left[\frac{\partial T}{\partial t}\right]_{rad}^{nodust}$$





Seasonal evolution of dust impact on Sahel precipitation (STD - JJA 2006)



10-22 N meridional average

1) Discuss the climatic response to dust aerosol over WAM and Sahel (precip).

2) Discuss the sensitivity of the signal to different modelling conditions

ICTP RegCM – 60km – NCEP2 - JJA 1996-2006

Standard	Control simulation: STD-CTL Dust activated: STD-DUST	BATS surface scheme, Grell convection
Extended Domain impact	Control simulation: EXT-CTL Dust activated: EXT-DUST	BATS surface scheme, Grell convection
Aerosol Sea Surface Temperature feedback impact	Control simulation: same as EXT-CTL Dust activated: SST-DUST	BATS surface scheme, Grell convection Dust impact SST
Convection scheme impact	Control simulation: CONV-CTL Dust activated: CONV-DUST	BATS surface scheme, Emmanuel convection
Land surface scheme impact	Control simulation: CLM-CTL Dust activated: CLM-DUST	CLM3.5 surface scheme, Grell convection
Dust optical properties 1 impact (absorbing case)	Control simulation: STD-CTL Dust activated: ABS-DUST	BATS surface scheme, Grell convection DUST SSA -5%
Dust optical properties 2 impact (diffusive case)	Control simulation: STD-CTL Dust activated: DIF-DUST	BATS surface scheme, Grell convection DUST SSA +5%

Limits of the regional climate model : Boundary conditions

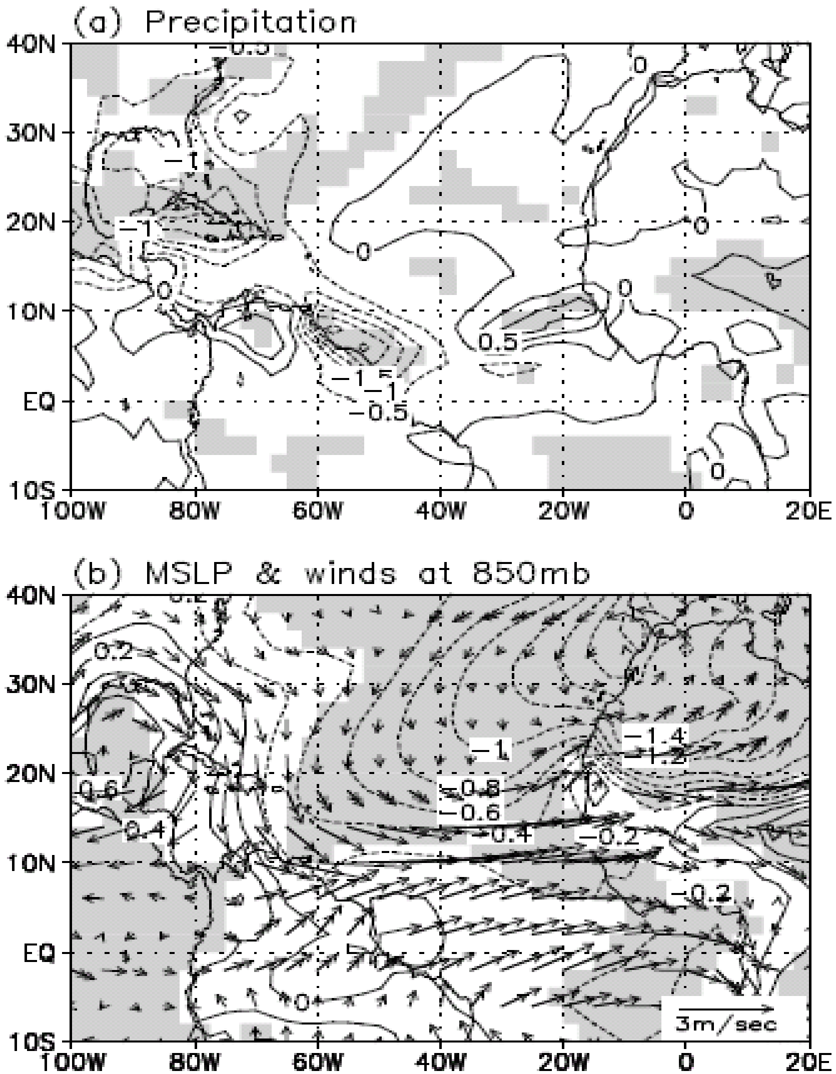
•GCM based analysis of Rodwell and Jung, 2008 (QJRMS) discuss local and remote effects of Saharan aerosol forcing

•B.Co = ‘Loss’ of the aerosol induces anomaly at the boundary. Do not take into account remote feedbacks induces by the aerosol perturbation.

• B.Co. is an infinite source of energy, moisture

•How can that affect the simulated precip anomaly by regional climate model for Sahelian region ?

Lau et al., 2009 (angeo special issue)



K. M. Lau et al.: Response of the atmospheric water cycle to Saharan dust radiative forcing 40

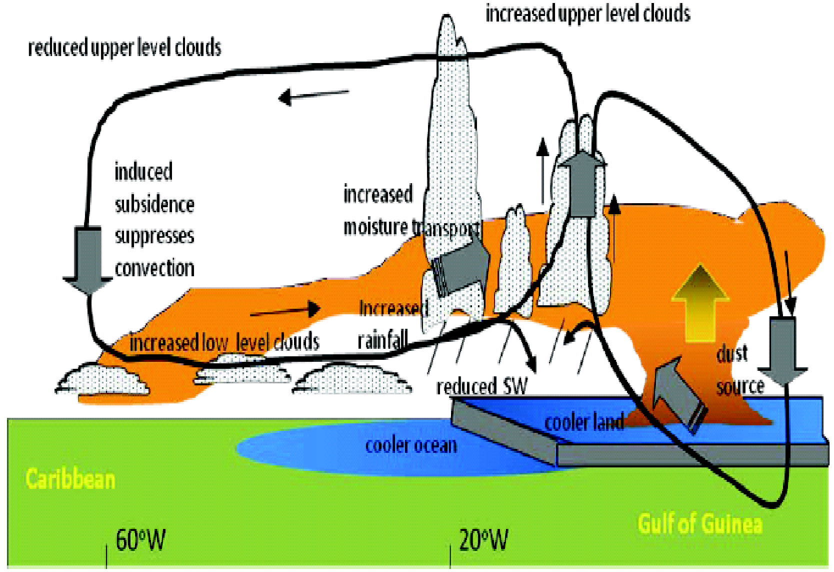
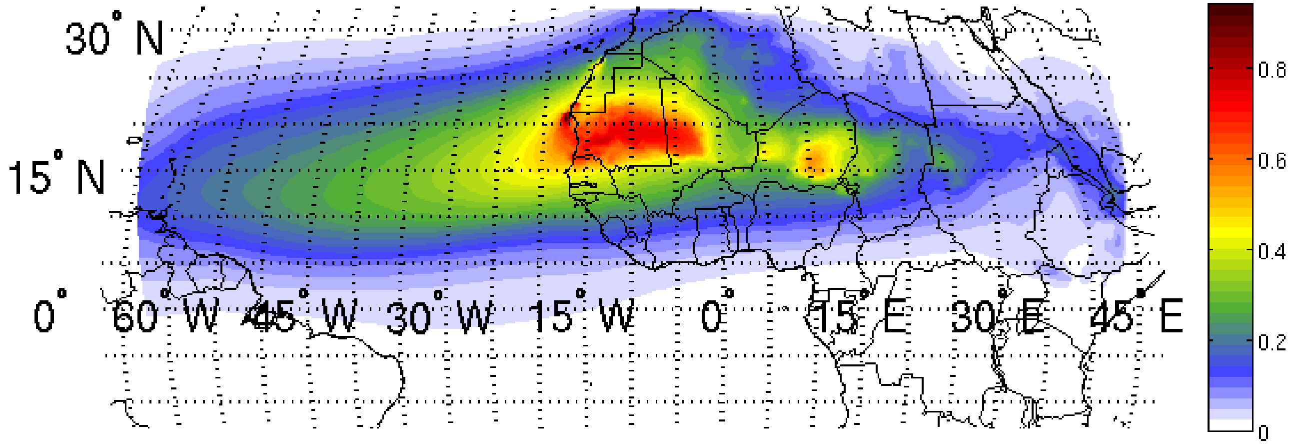


Fig. 10. Schematic diagram showing Saharan dust induced anomalous Walker-type and Hadley-type circulations, and accompanying chan in components of the atmospheric water and energy cycle, across West Africa, the Atlantic and the Caribbean.

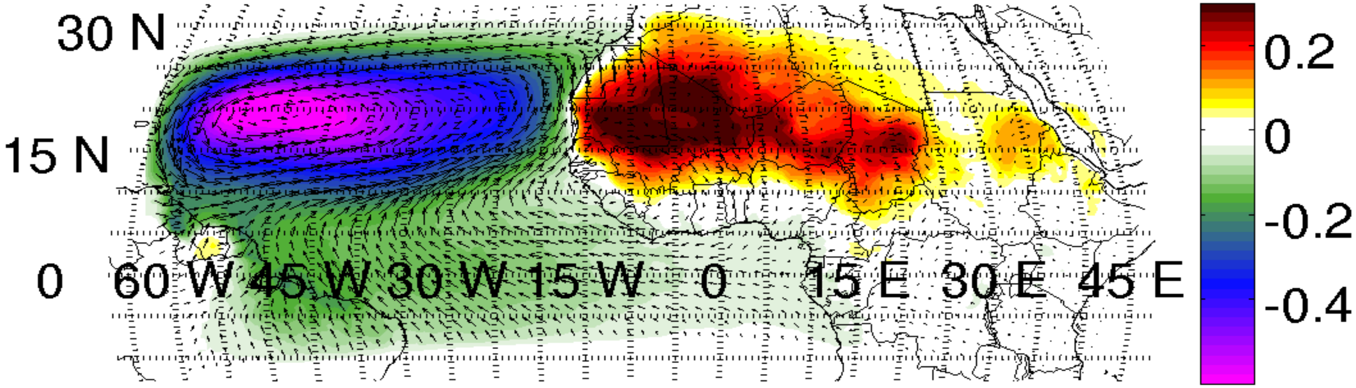
Opposite response over sahel
Other GCM bases studies find also different pattern (Yoshioka et al., 2007, Miller et al., 2004 …)

Extended domain, 60 km resolution

JJA 1996-2006

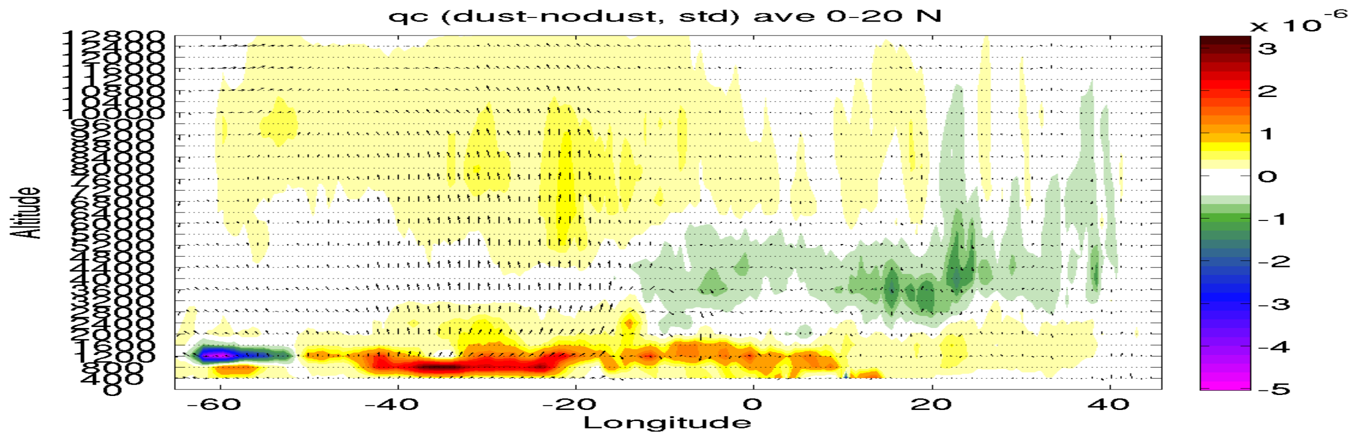


AOD

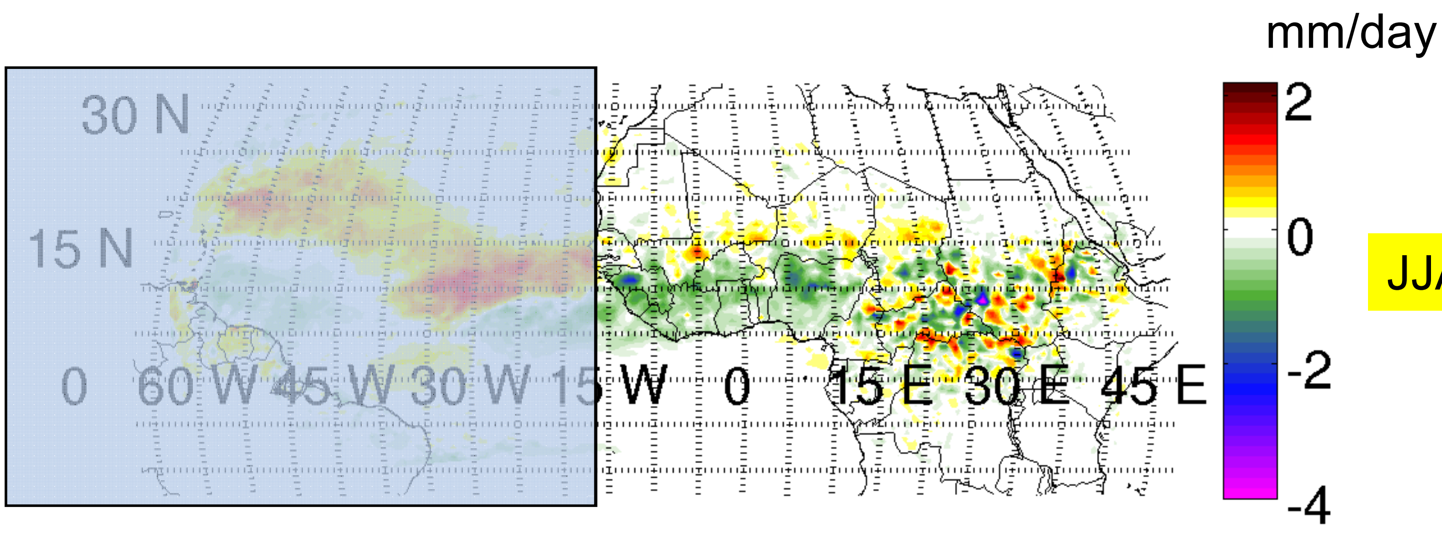


Psea

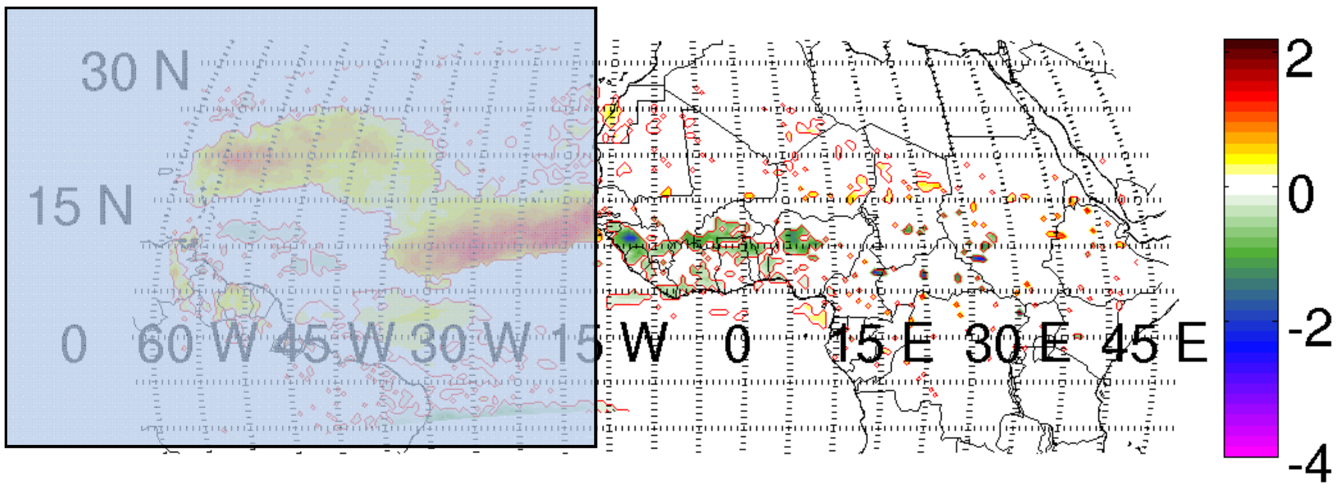
(cb dust – nodust)



Qc and vertical circulation (dust – nodust)



JJA 1996-2006



JJA 1984-2006

+ 95 % sig.

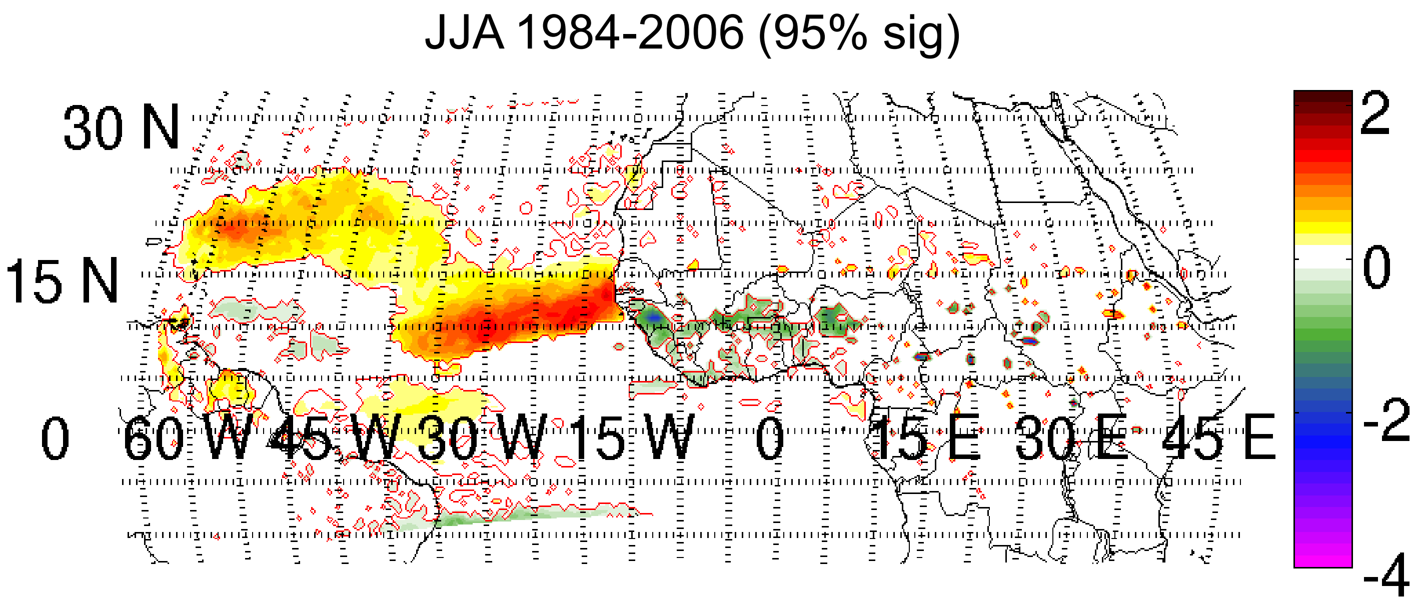
Precipitation anomaly over Sahel consistent with standard.

Perspective: using the tropical band option

Limits of the regional climate model approach : prescribed SST

No energy balance at the surface (ocean is a infinite source of energy, moisture)

Dust Radiative forcing effect over the the ocean ?



Over ocean only diabatic heating contribution is efficient since SST are forced (only diurnal variation is accounted for).

Can it affect results obtained over the Sahel ?

Can we trust RegCM climate/dust simulations over the ocean ?

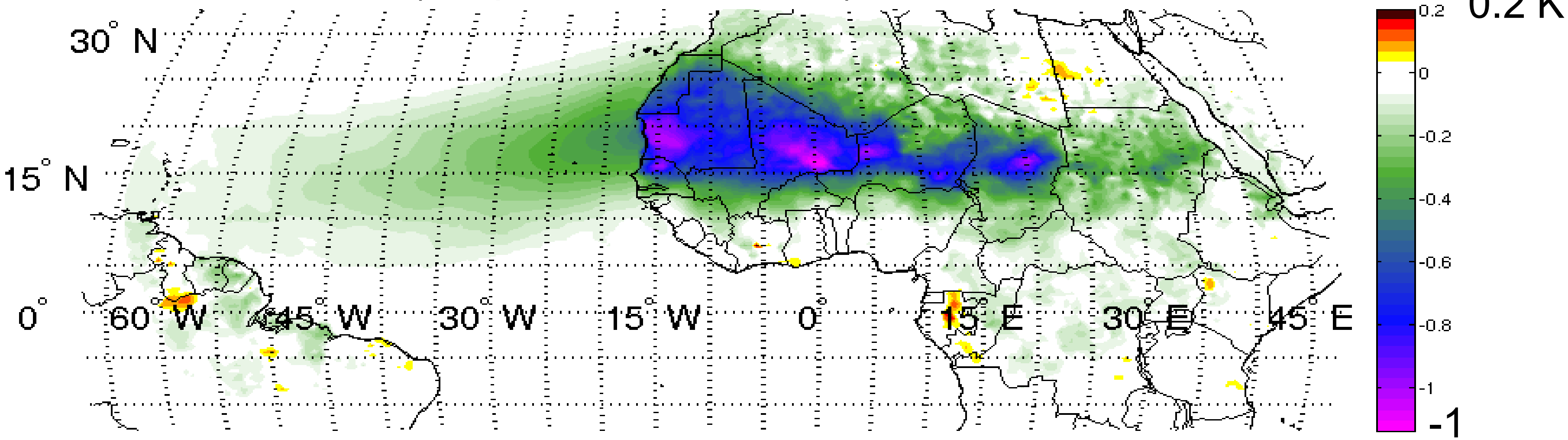
Seasonal cooling of the ocean mixed layer

Simple experiment : SST* = SST - 0.8 x AOD

as a result of less SW absorbed in ocean mixed layer due to dust extinction

(consistent with ***Avila et al., 2007***, ***Evan et al., 2009***, ***Yoshioka et al.,2007 studies using observation and coupled ocean models***)

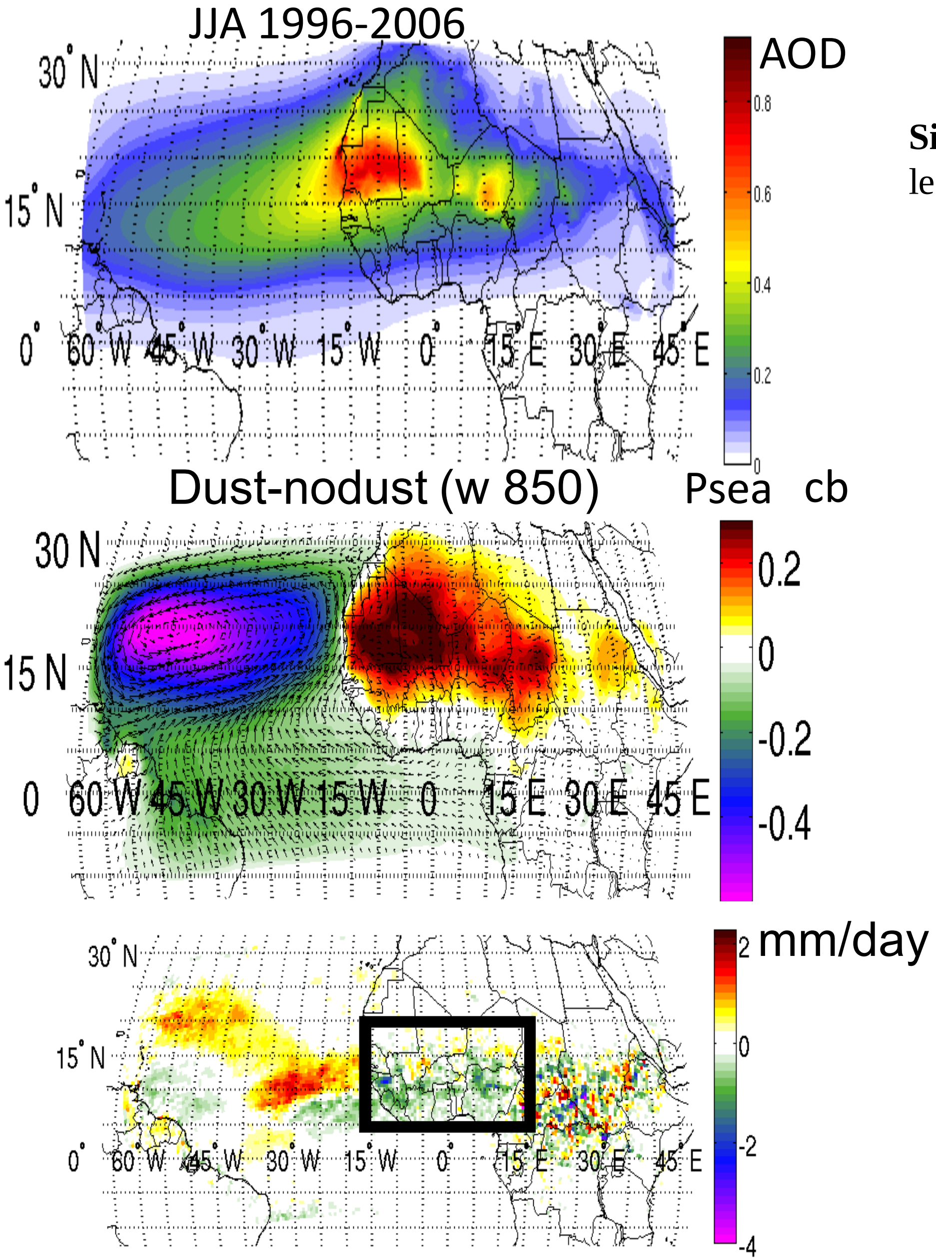
T2m (temperature difference)



Limits of the hypothesis: It is not a real energy budget !

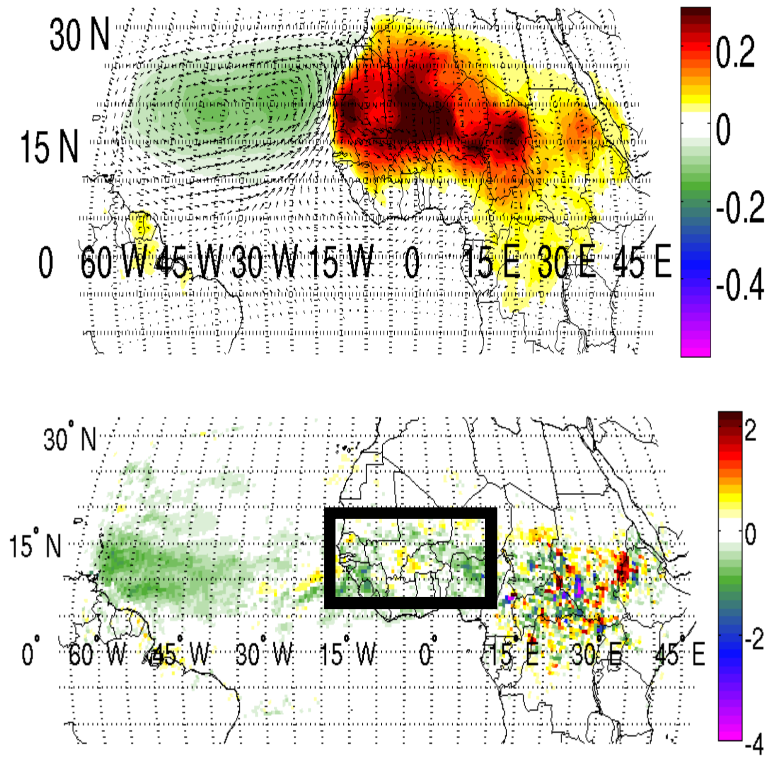
SST anomaly is applied instantaneously

Extended domain experiment



SST response experiment

Simple experiment : SST* = SST - 0.8 x AOD as a result of less SW absorbed in ocean mixed layer due to dust extinction

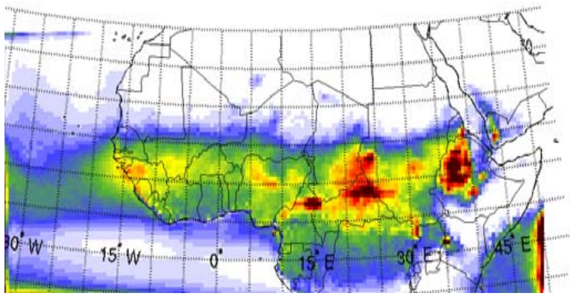


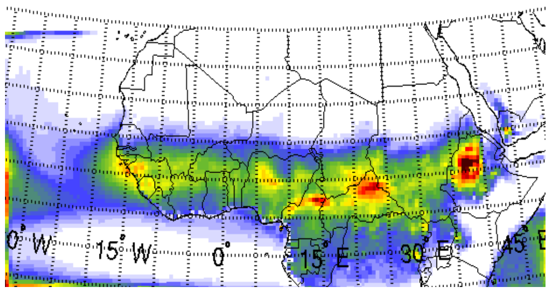
Robustness over of the signal over Sahel

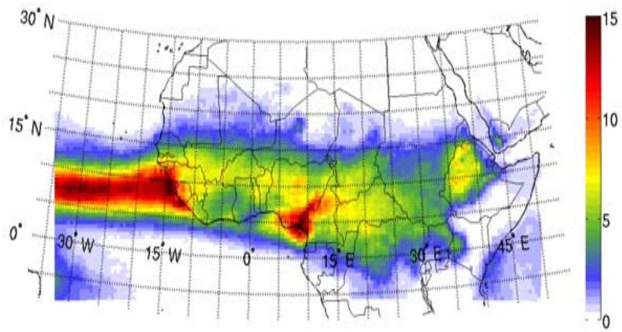
Consistent with Yue et al., ACP 2011 over the ocean

Land surface scheme experiment

STD- BATS CLM3.5 TRMM mm/day

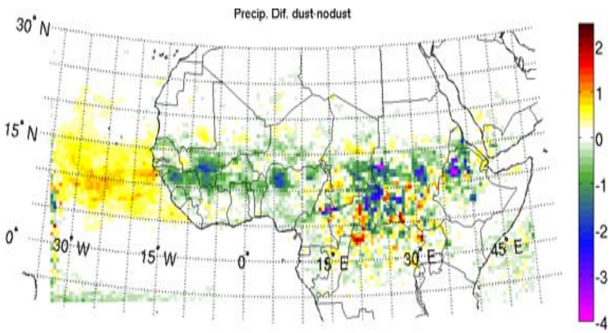




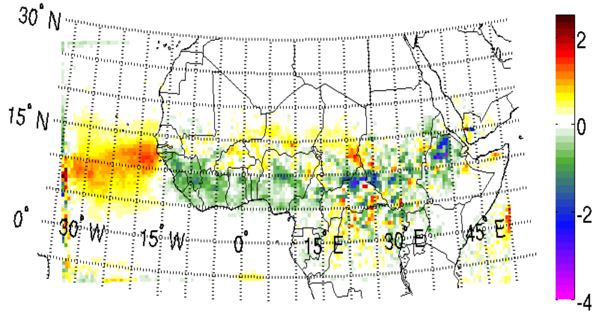


JJA 1996-2006

Precip (DUST – CTL)

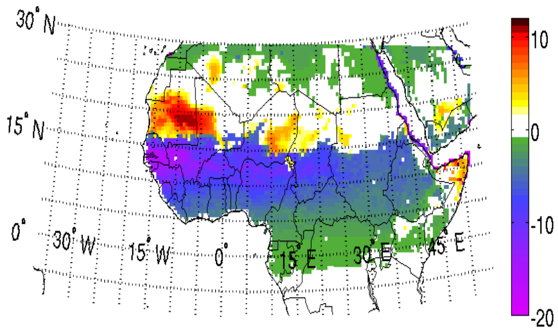


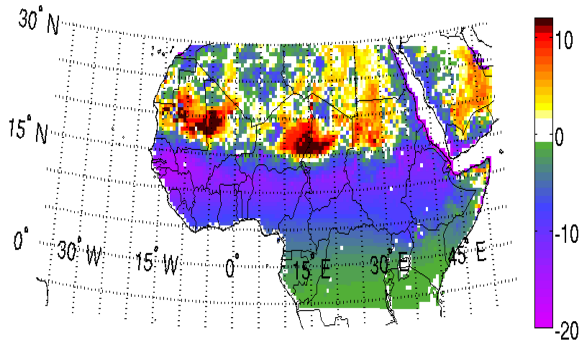
Precip (DUST – CTL)



Southward shift of the signal

TOA Rf (SW+LW) W.m2



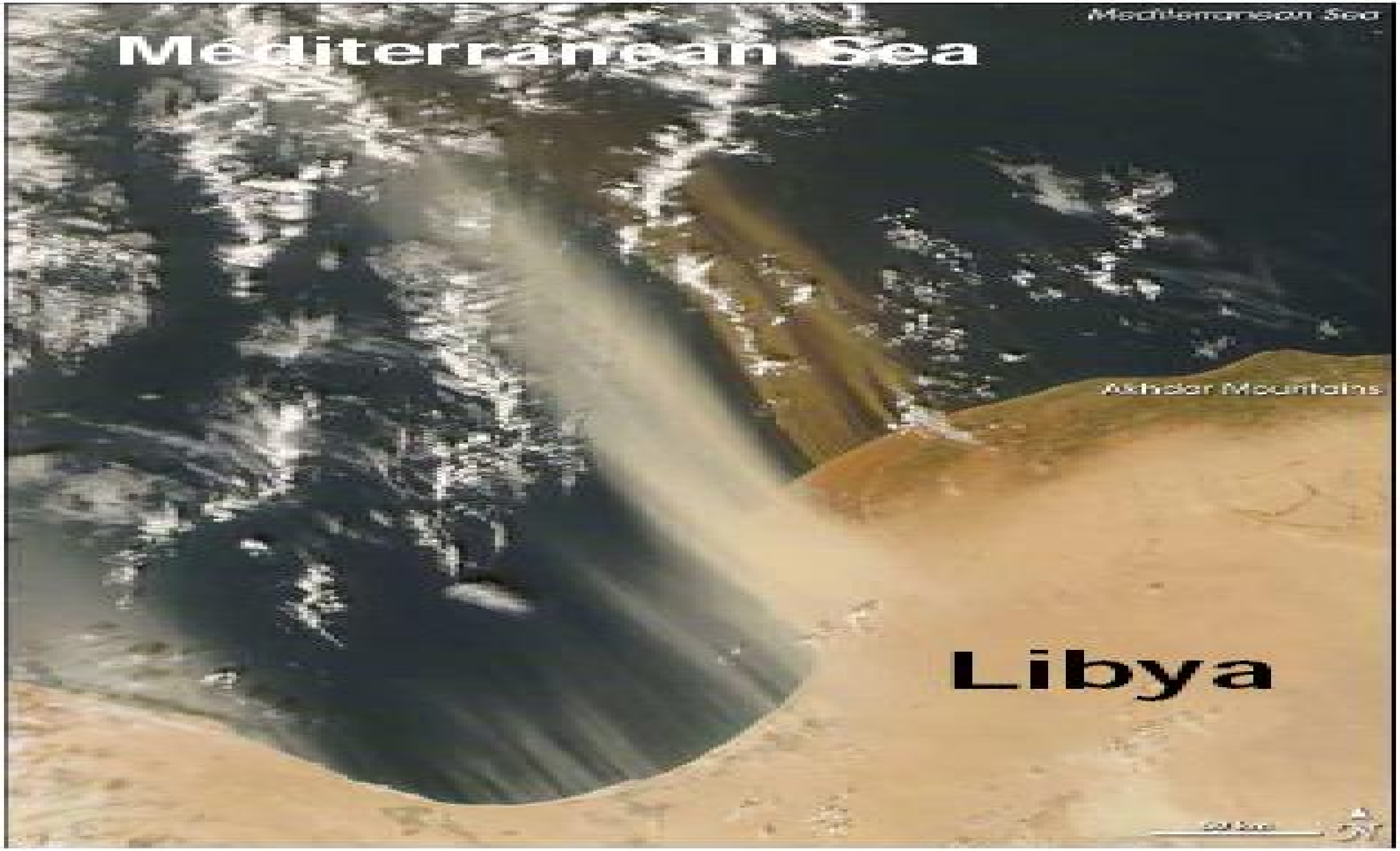


Impact of surface albdeo modulating radiative forcing

Dust emis feedback
evapotranspiration

Climate sensitivity to dust absorption properties

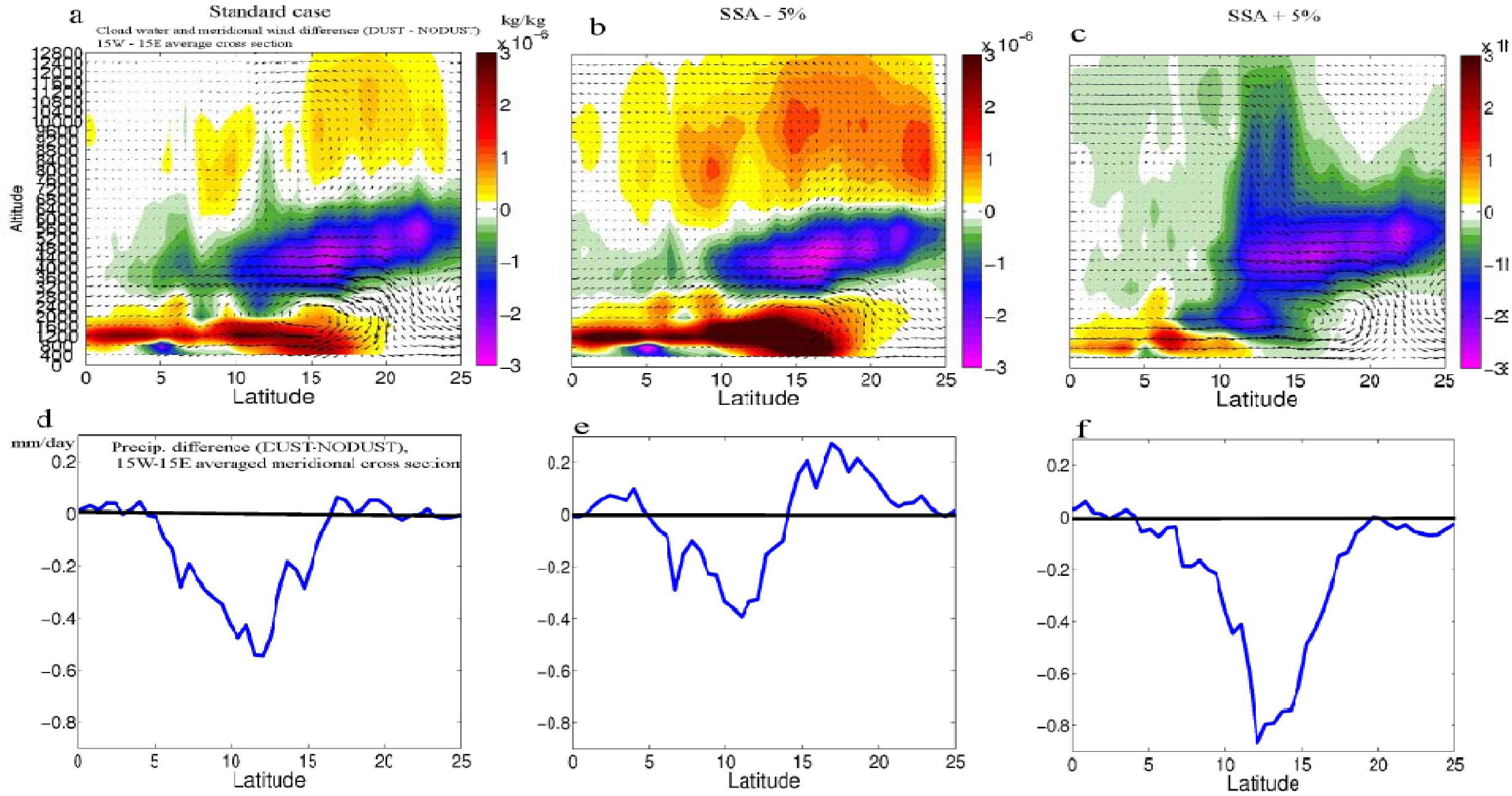
Variability of measured values of dust SSA values (mineral composition, coating, aerosol size distribution ..) : impacts on the climatic response ?



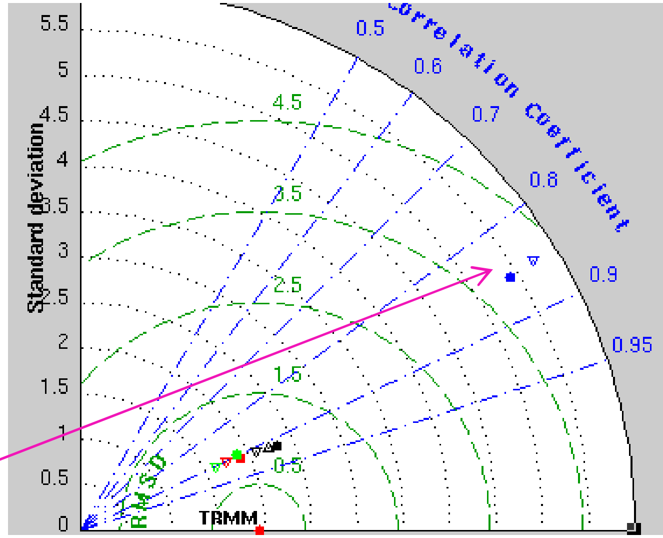
Source NASA

Climate sensitivity to dust absorption properties
(solmon etal., 2008)

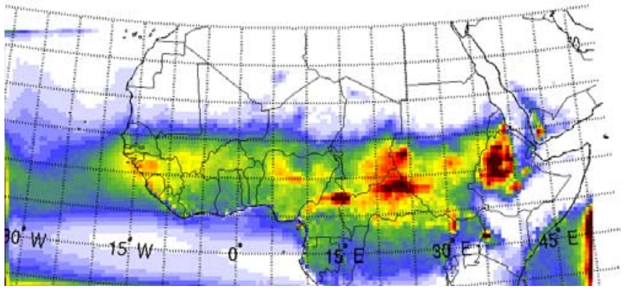
Standard case	More absorbing dust	Very diffusive dust
SSA ~0.95 (fine dust)	**SSA ~0.90**	**SSA ~0.99**



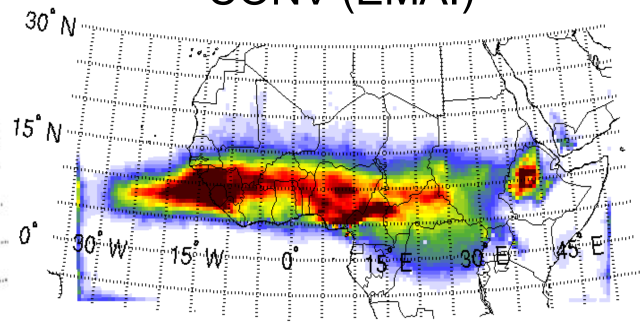
Convection experiment



STD- Grell

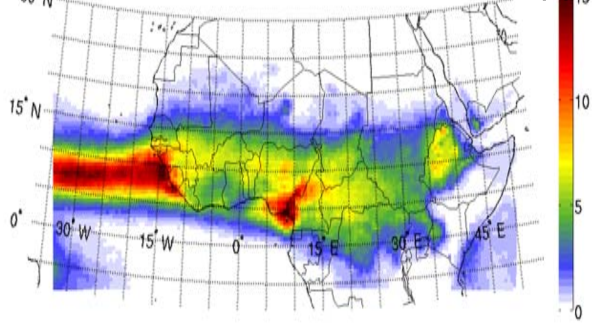


CONV (EMA.)

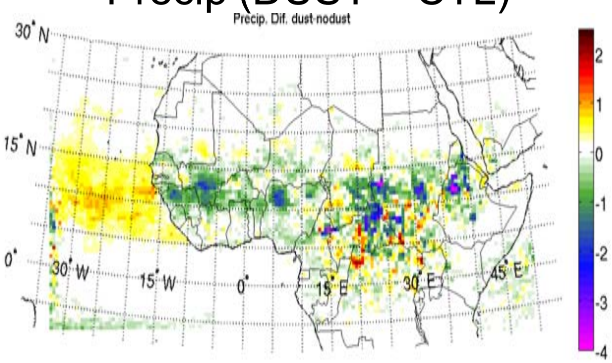


TRMM

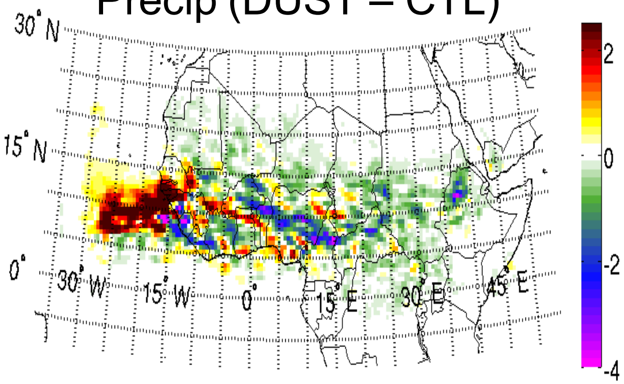
mm/day



Precip (DUST – CTL)

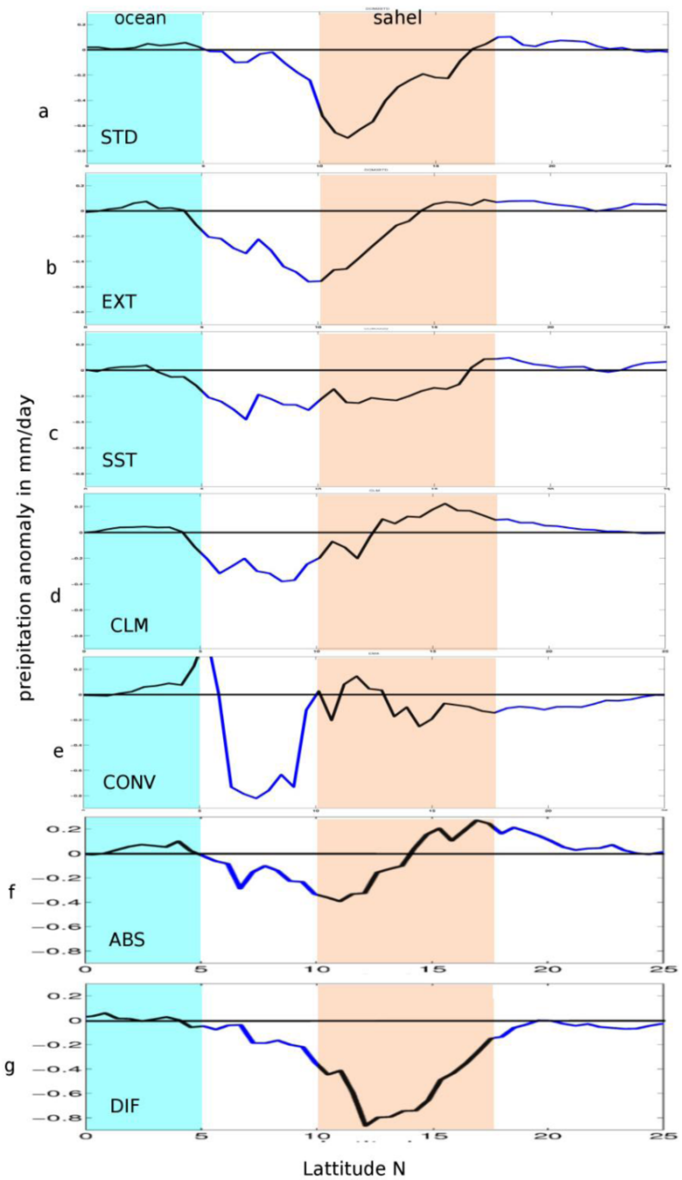


Precip (DUST – CTL)



Noisy signal in the monsoon region / Overall drying pattern dominant over land

Mer. cross sec. of precip. ano. (dust-ctl jja 96-06, mm/day)
(av 15W-15E)



Experiment	Precip anom.(%) (10-17N av.)	Precip anom. (%) (15-17.5 N av.)
STD	-6.8	-7.5
EXT	-3.2	+3
SST	-3.3	-1.6
CLM	+3.7	+25.6
CONV	-1.3	-9
ABS	-0.9	+27.4
DIF	-11.4	-49.1

•Dipole type response consistent and robust over land , drying dominant.

•Northern Sahel = the most sensitive region to different simulation conditions

Any evidence of dust climatic signal over Sahel from observation ?

➡

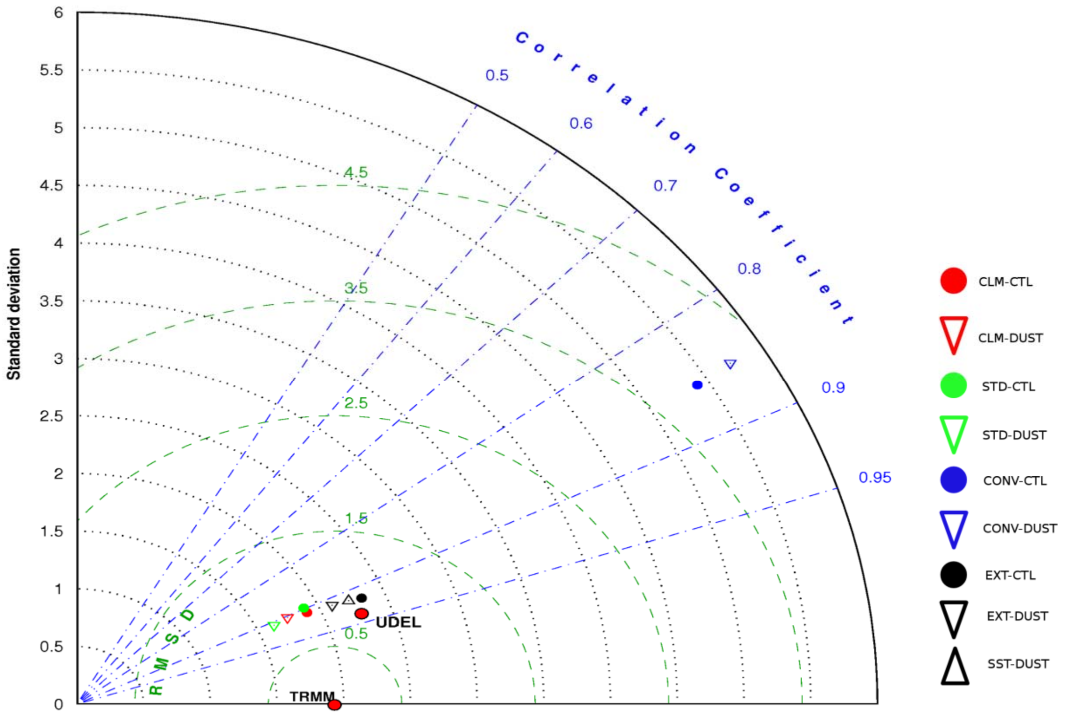
Kluser et al., 2010 (ACP) propose a statistical study of dust impact on cloud cover property and rain likelihood using MODIS (deep blue) and SEVIRI clouds and dust product.

The observed increase in cloud top temperature in the monsoon season's Harmattan air mass can be explained by suppression of initial convection by boundary layer stabilisation and due to the entrainment of very dry air warmed by solar heating. This effect indicates that strong dust activity during the Sahelian monsoon season significantly affects convective intensity within the region.

Table 1. Net dust effects on cloud cover (δ_{COV}), cloud top temperature (δ_{CTT}), ice phase fraction (δ_{IPF}), liquid phase effective radius ($\delta_{Re(liquid)}$) and warm rain likelihood (δ_{WRL}) within the Harmattan flow of the monsoon season.

sensor	dust load	δ_{COV}	δ_{CTT}	δ_{IPF}	$\delta_{Re(liquid)}$	δ_{WRL}
MODIS	moderate	−20.84%	+14.07 K	−16.90%	−2.39 µm	−0.27
	heavy	−14.73%	+12.06 K	−14.15%	−3.16 µm	−0.35
SEVIRI	moderate	−21.31%	+12.37K	−15.78%	–	–
	heavy	−21.68%	+14.89K	−22.88%	–	–

Improvement of dust simulations vs nodust over Sahel?



Rather limited impact but … Potential importance for High resolution , Impact on prec.diurnal cycle

Persectives:

On-line vs climato.
Decadal variability (collab A. Evan)
Other impacts (Biogeo, Health…)

Conclusion

•Regional precipitation responses depend on coexisting differential circulations patterns induced by the dust radiative forcing at different tropospheric levels.

•Surface and lower troposphere cooling induces a decrease of the monsoon pump intensity whereas atmospheric diabatic warming over the source areas trigger an elevated heat pump effect resulting in enhanced convection over northern Sahel.

•The net regional impact of dust on average precipitation results from these coexisting effects. Drying is dominant over Sahelian region except for a limited band over northern Sahel which sees enhanced precipitations.

•These signal showed a cerain robustness with regards to different modelling configuration or physics options for the sahelian region

•However physics option might influence locally this pattern. Importance of SSA and convective scheme.

• A proper energy budget is necesary over the ocean regions.

Related studies Impacts of biomass burning aerosol over southern Africa .
Tummon et al., 2010, JGR.

Thank You