The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2148-22

Fifth ICTP Workshop on the Theory and Use of Regional Climate Models

31 May - 11 June, 2010

Studying the climatic impacts of Saharan dust with RCMs: Advantages, limits and sensitive issues

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Climatic impact of saharan dust

A regional climate modelling approach

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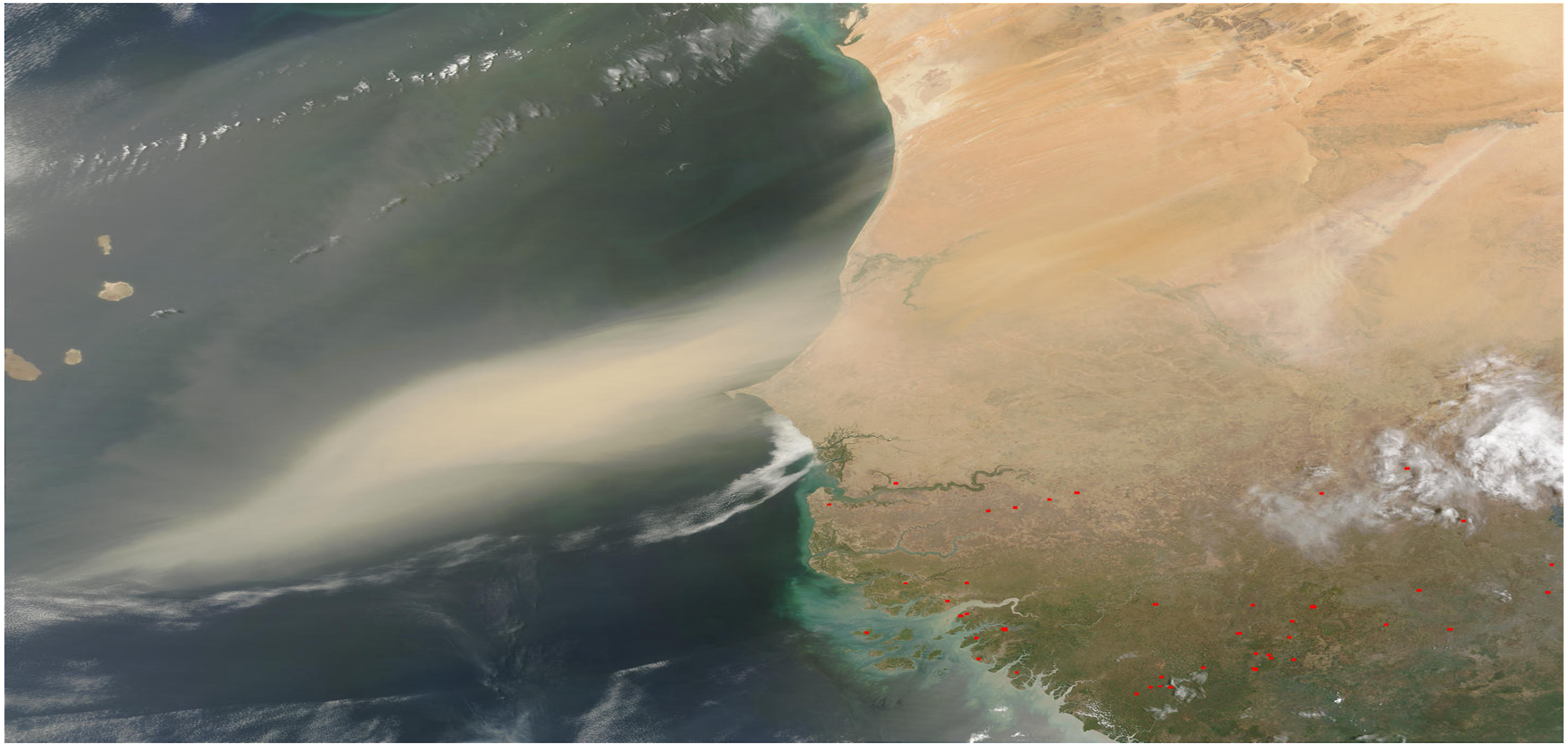
(2) Laboratoire d’Aérologie Toulouse

(3) Abidjan University, Ivory Coast.

(4) Niamey University, Niger.



Key questions :

Role of dust on precipitation in Sahel (positive or negative feedback in drought persistence ?)

Impact of dust on MCS, AEWs, tropical cyclones developments

Paleoclimate

Ecosystems and Health impacts

Many studies have been published recently based on :

Climate models

Mesoscale models (dust event simulations) ⇨ 'Contrasted' results

Satellite observations

⇨ Regional climate approach

Continental domain

Oceanic domain

Dust aerosol on-line module in the ICTP RegCM3 model

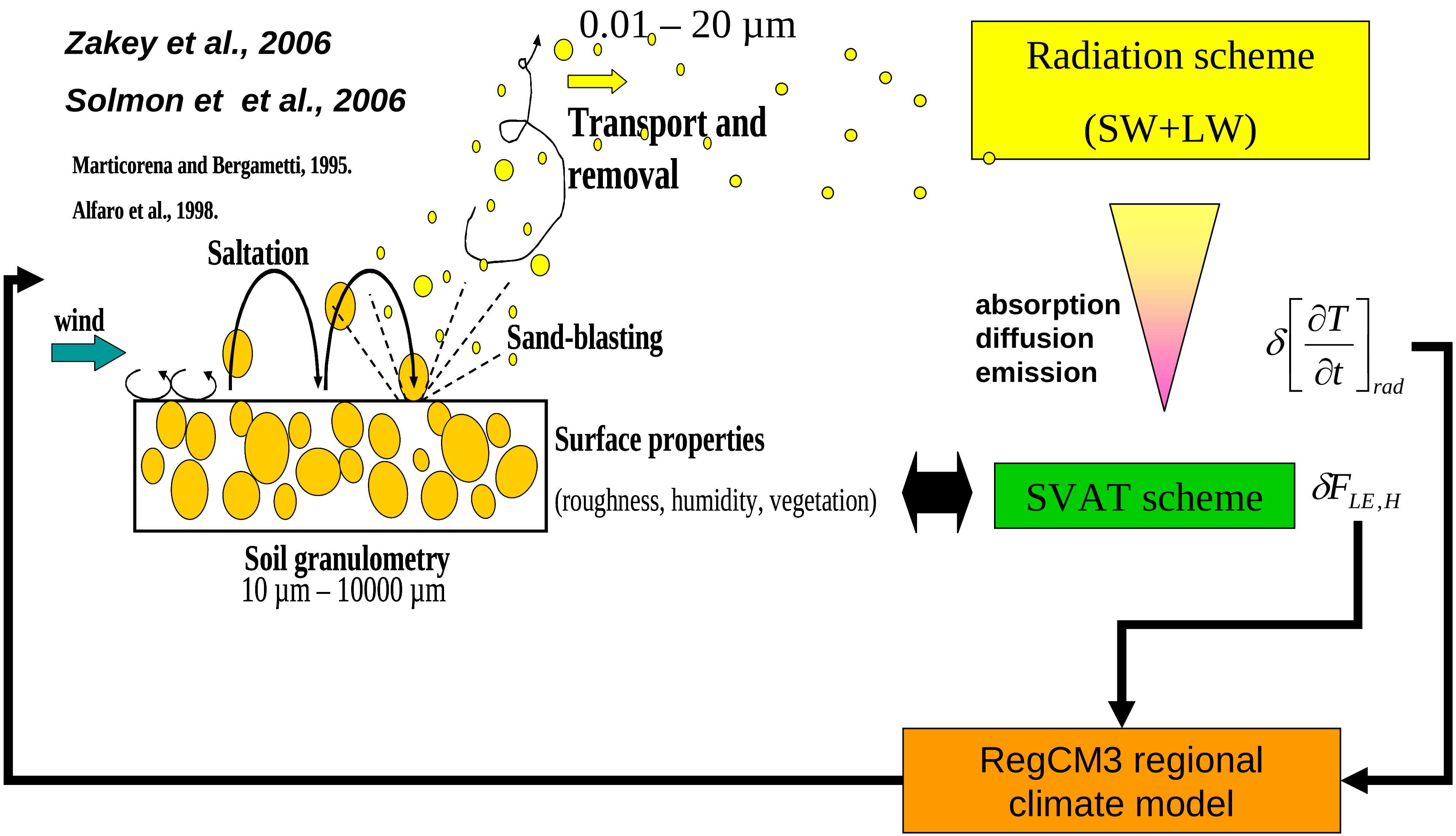
No cloud microphysics interaction !

Zakey et al., 2006

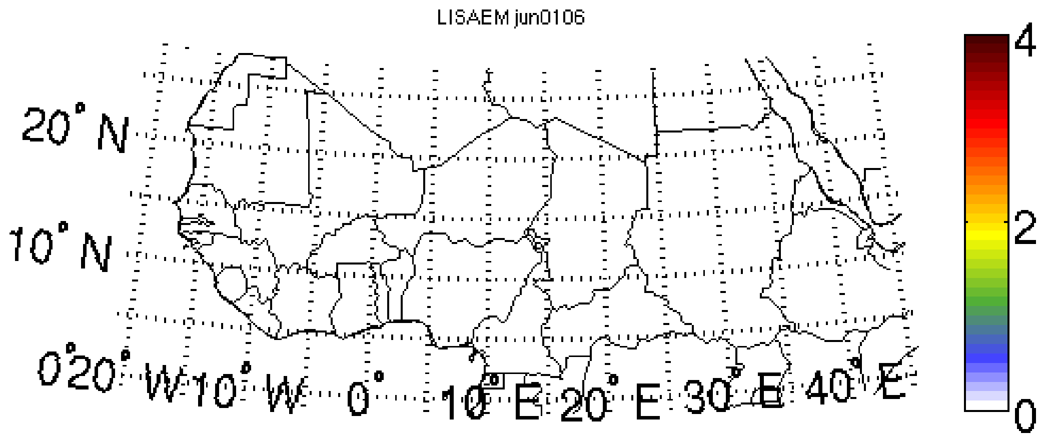
Solmon et et al., 2006

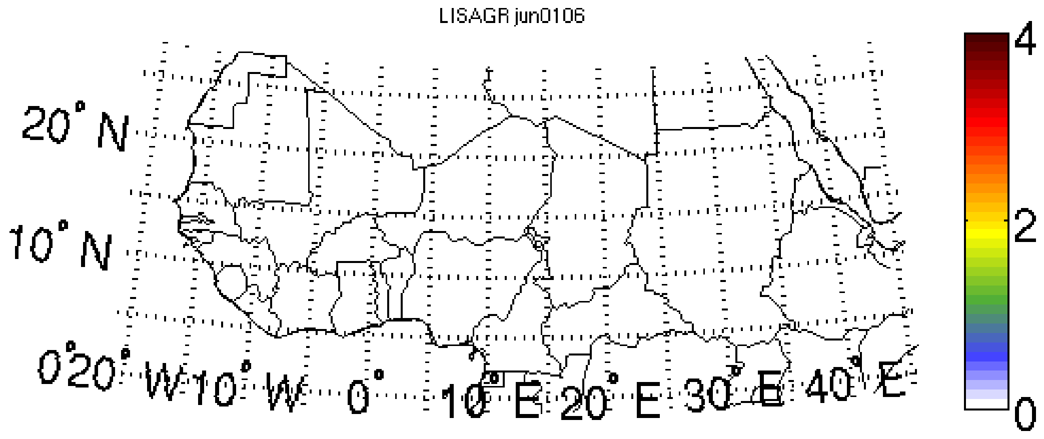
Marticorena and Bergametti, 1995.

Alfaro et al., 1998.



AOD





In this study : Grell + FC, Resolution of 60 km !

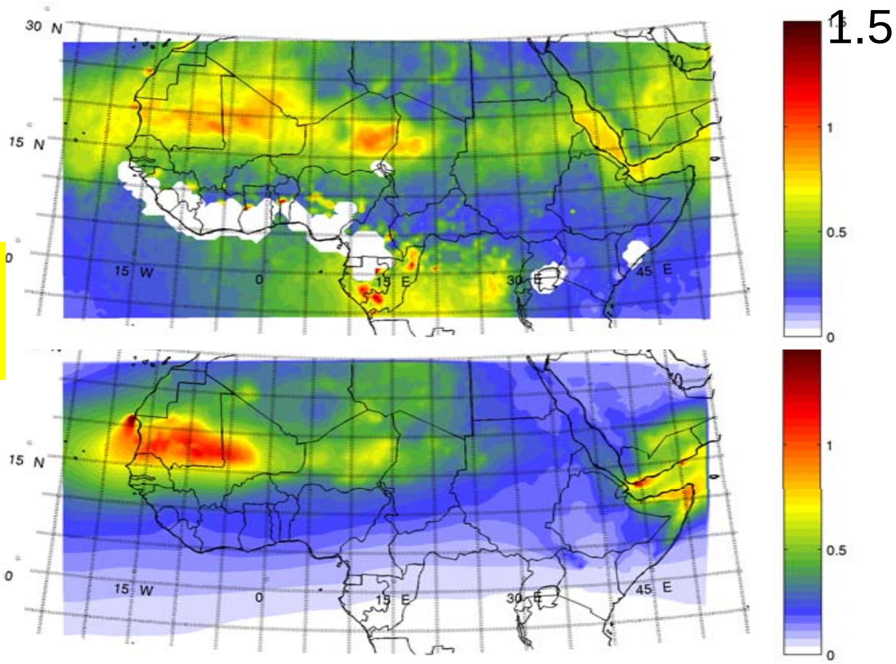
Comparison with observations

MISR AOD

JJA

(2000-2006)

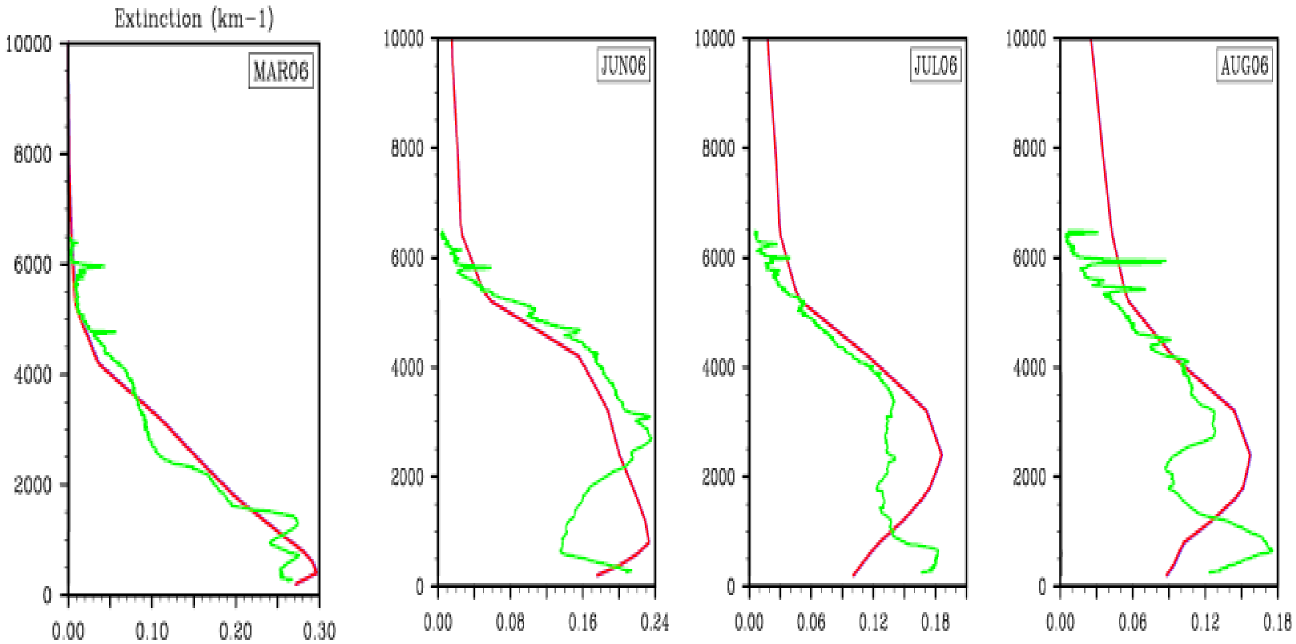
RegCM AOD



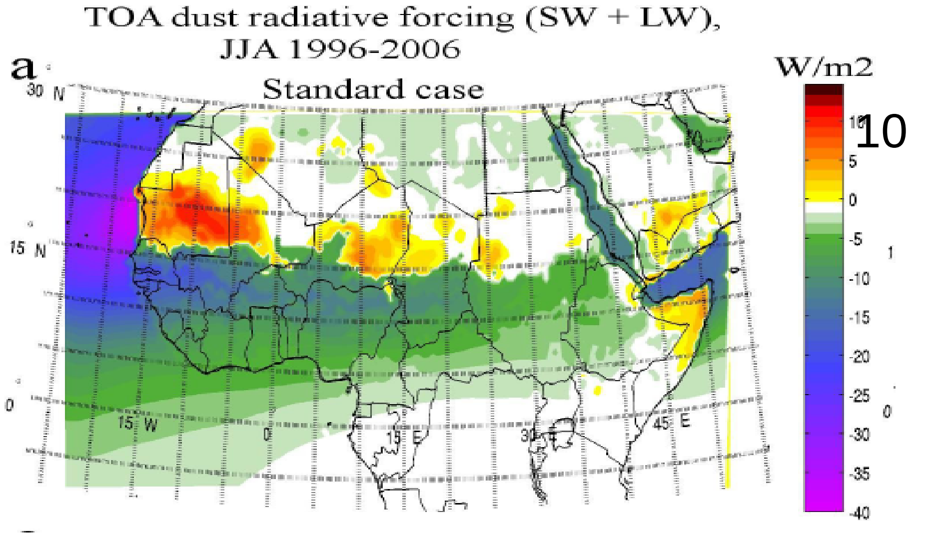
RegCM

Lidar

M'Bour

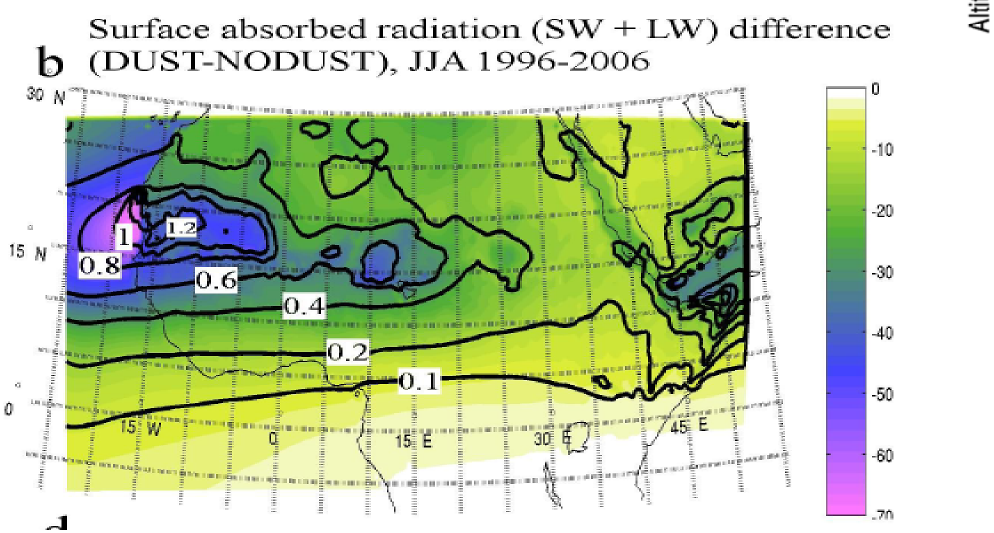


Dust radiative forcings



10

-40

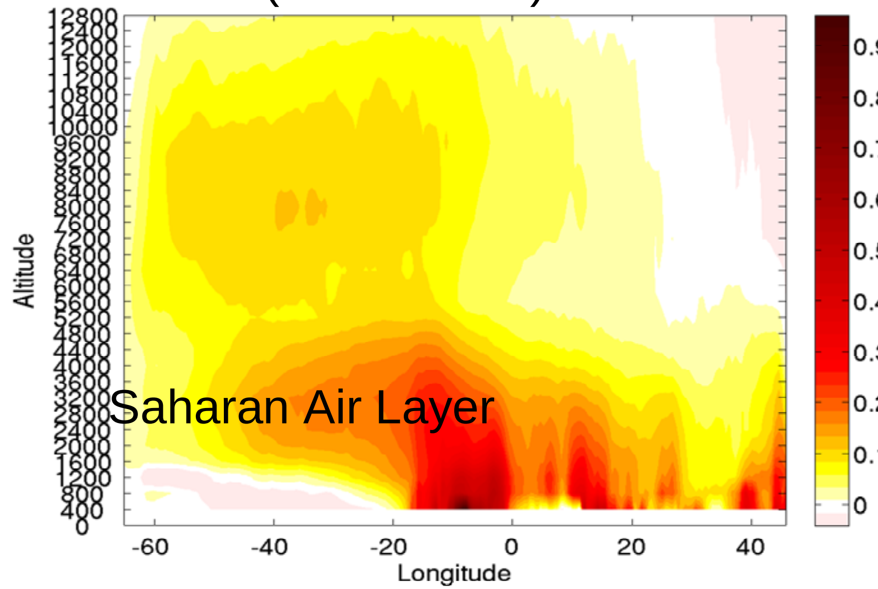


-70

Compares well with Li et al., 2004
(TOA) : -35 W/m2/AOD ,(SRF) -65 W/m2/AOD

Diabatic heating (96-06)
dif (dust-nodust)

K/day

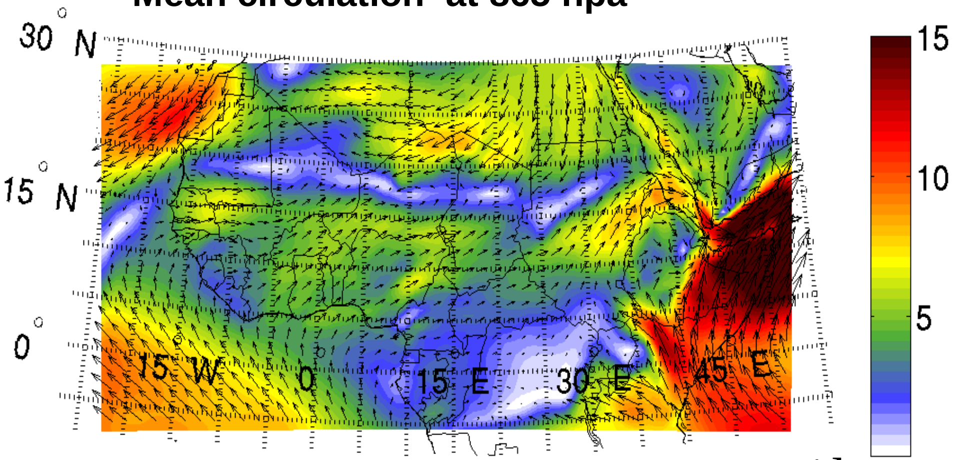


Zhu et al., 2007, Wong et al., 2009 estimate heating rates 0.2-0.4 K/day in the SAL

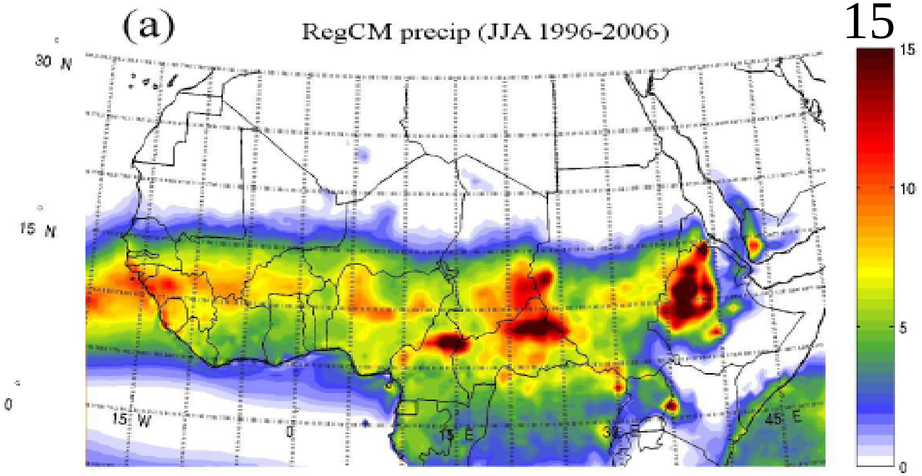
Average dynamical and precipitation response to dust over Sahel

(NODUST, JJA 1996-2006)

Mean circulation at 865 hpa $m.s^{-1}$



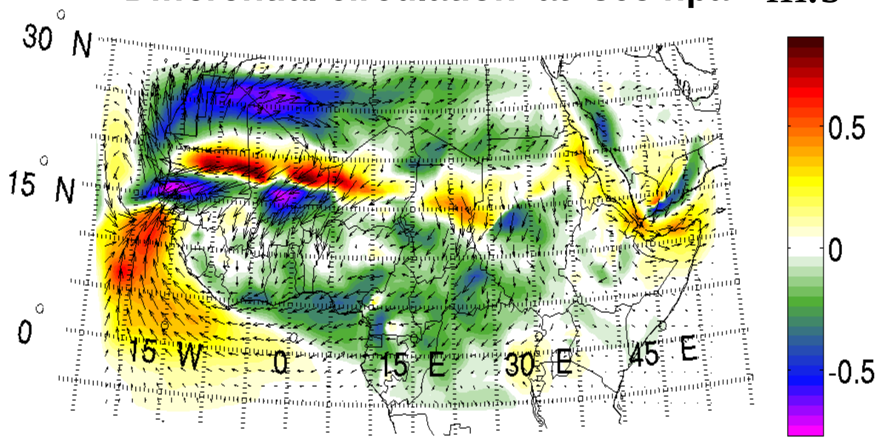
mm/day



Res = 60 km

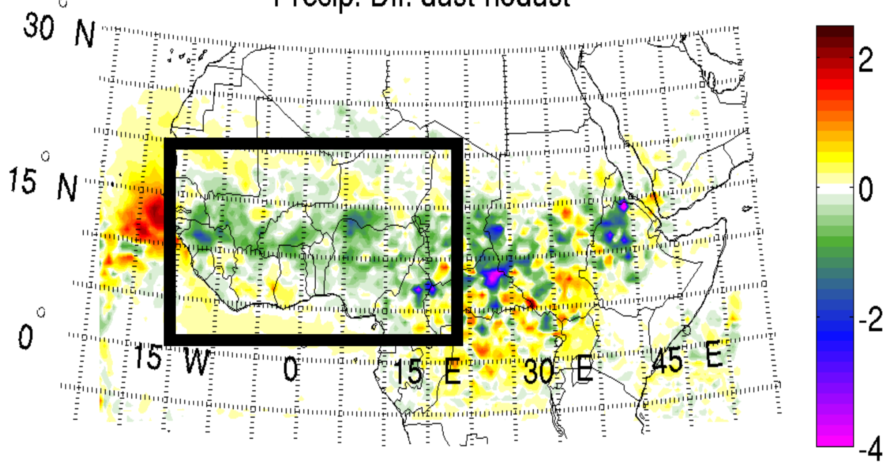
(DUST -NODUST, JJA 1996-2006)

Differential circulation at 865 hpa $m.s^{-1}$



mm/day

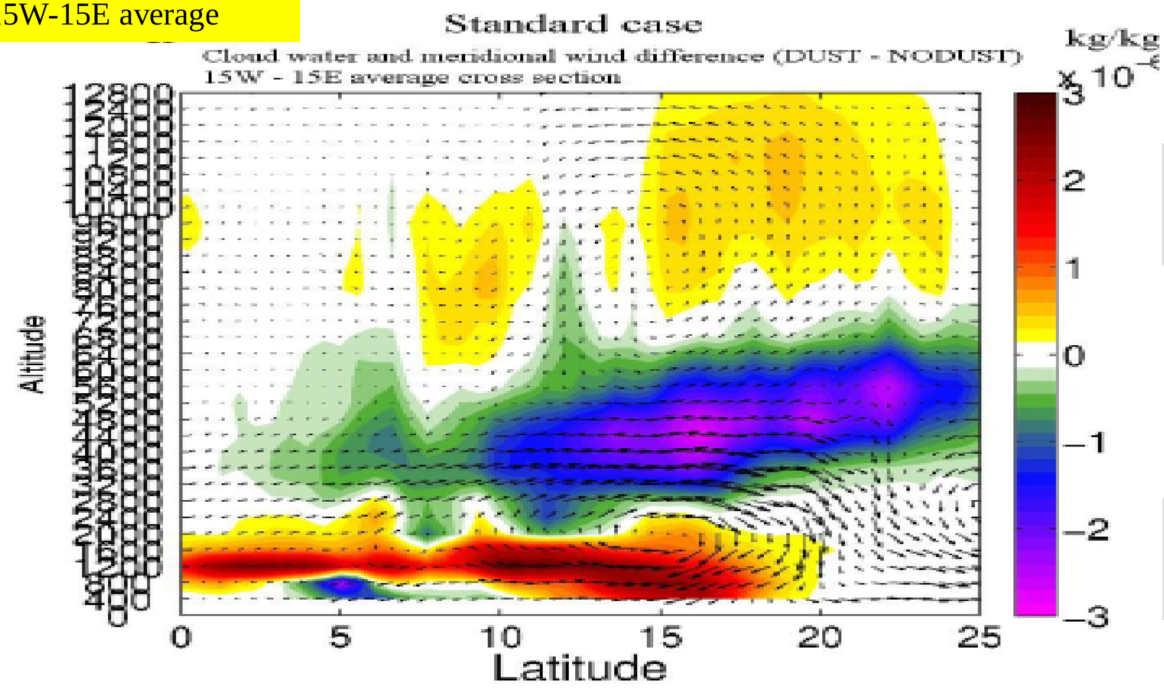
Precip. Dif. dust-nodust



Cloud water, meridional circulation and precip. difference (DUST-NODUST)

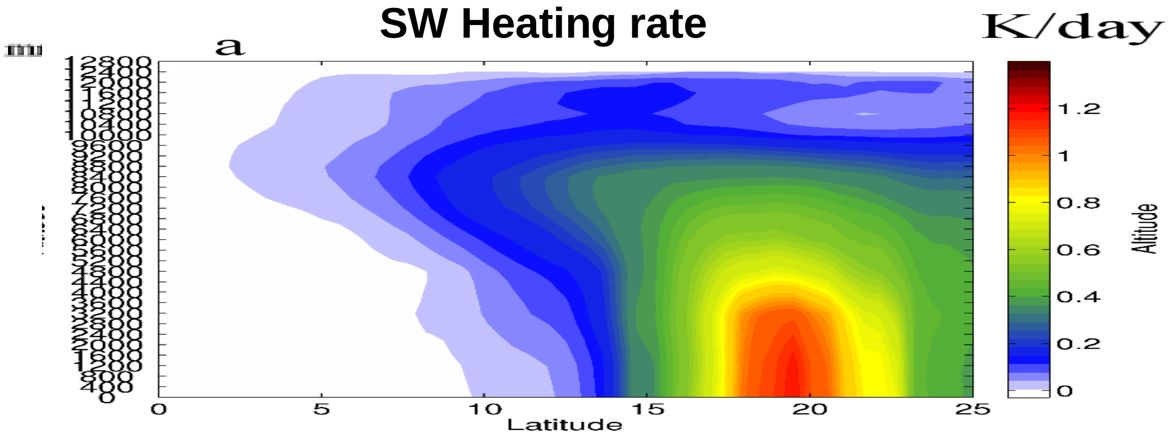
15W-15E average

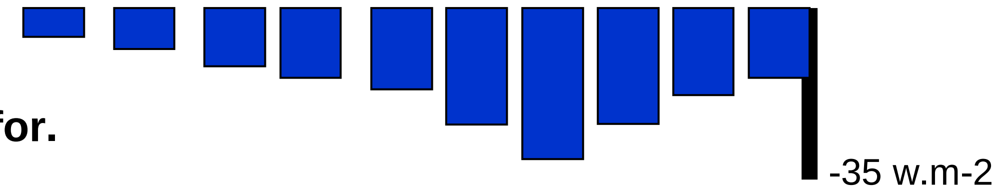
Solmon et al., 2008



2 : ‘Elevated heat pump’ effect (Lau et al., 2009)

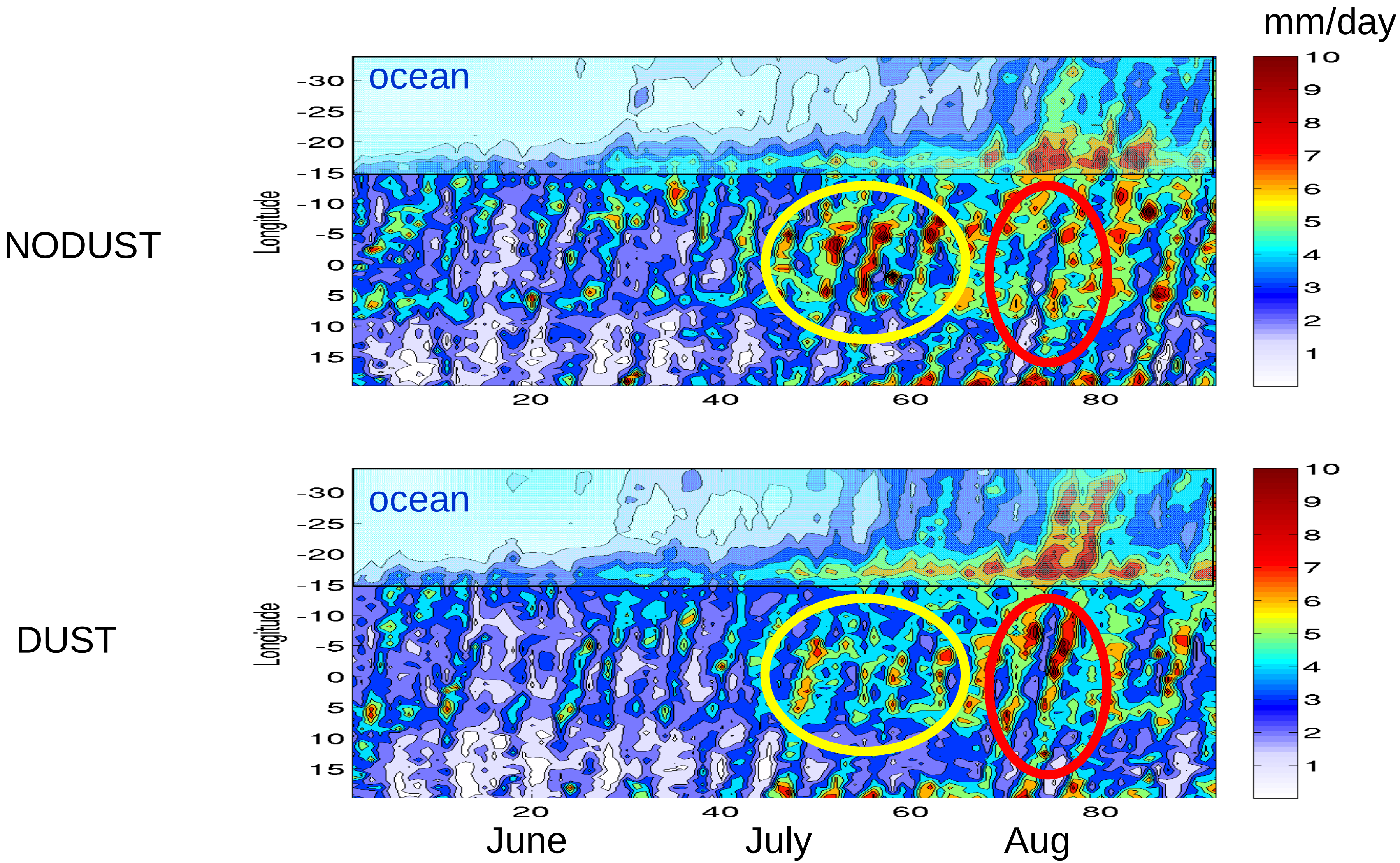
1: Weakening of the ‘monsoon pump’





srf rad. for.

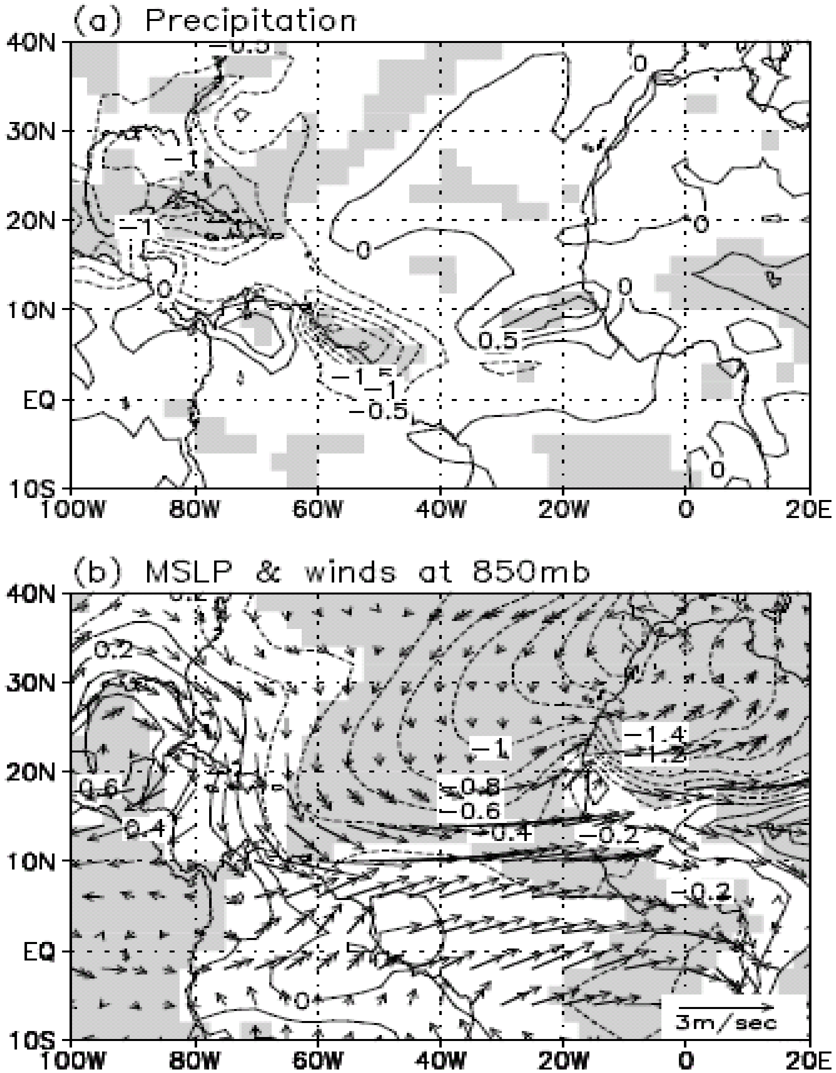
Seasonnal evolution of dust impact on precipitation (JJA 1996-2006)



10-22 N meridional average

Comparison (and contradiction !) with recent GCM studies …

Lau et al., 2009 (angeo special issue)



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

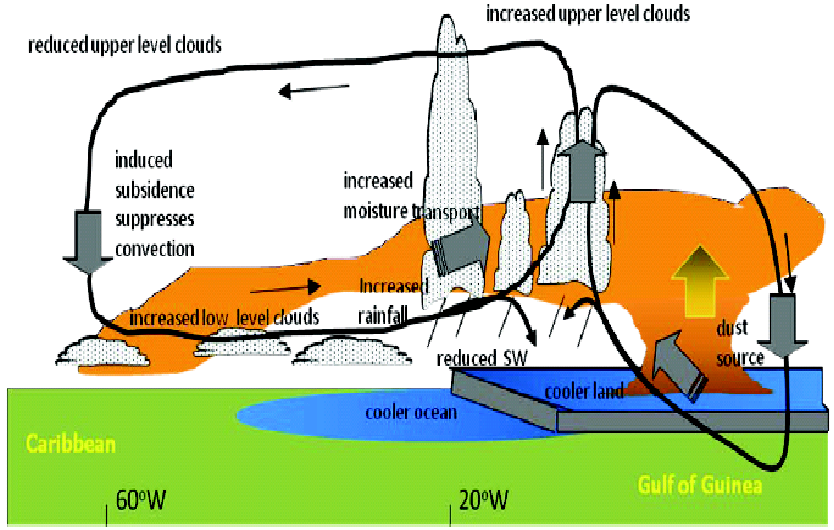


Fig. 10. Schematic diagram showing Saharan dust induced anomalous Walker-type and Hadley-type circulations, and accompanying chan… in components of the atmospheric water and energy cycle, across West Africa, the Atlantic and the Caribbean.

Sud et al., 2009 (angeo special issue)

"Intercomparisons of circulation, diabatic heating, and precipitation difference fields showed large disparities among the AR and AI simulations, which raised serious questions about the proverbial AR assumption, commonly invoked in regional climate simulation studies". *abstract*

" we infer that AR approximations are unrealistic for assessing the real world aerosol anomaly scenarios that operate essentially under essentially AI ".

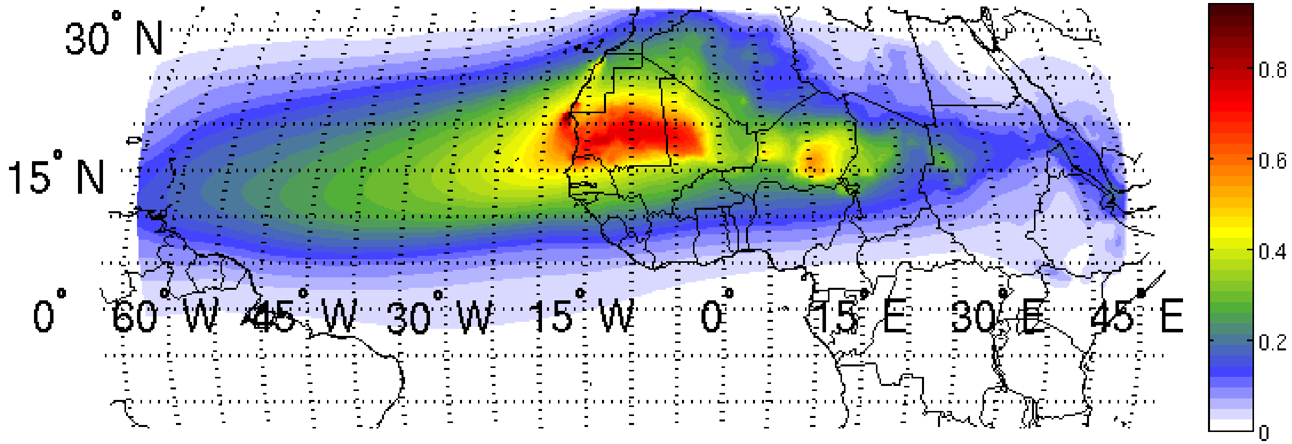
Since we have many processors, we are going to extend our domain !

Huuuhhhh *

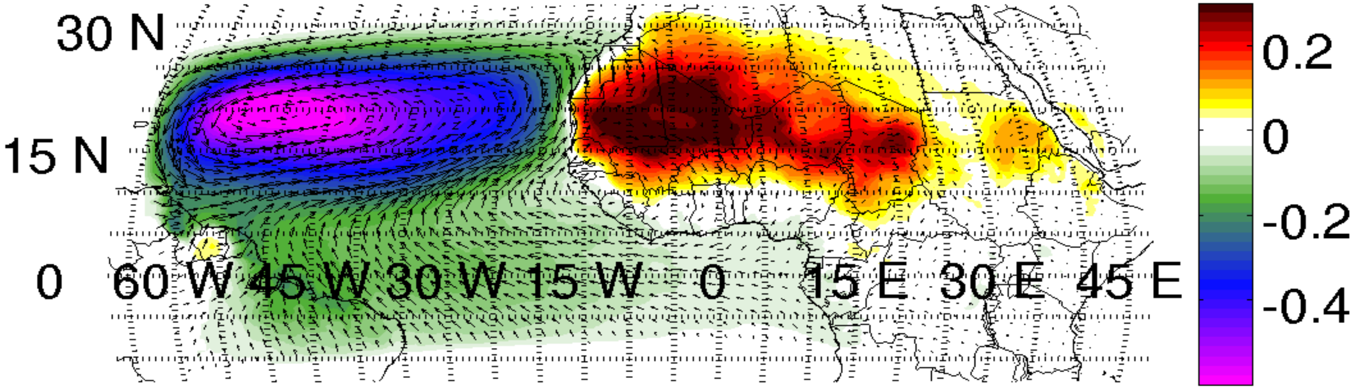
*you guys do what you want

Extended domain, 60 km resolution

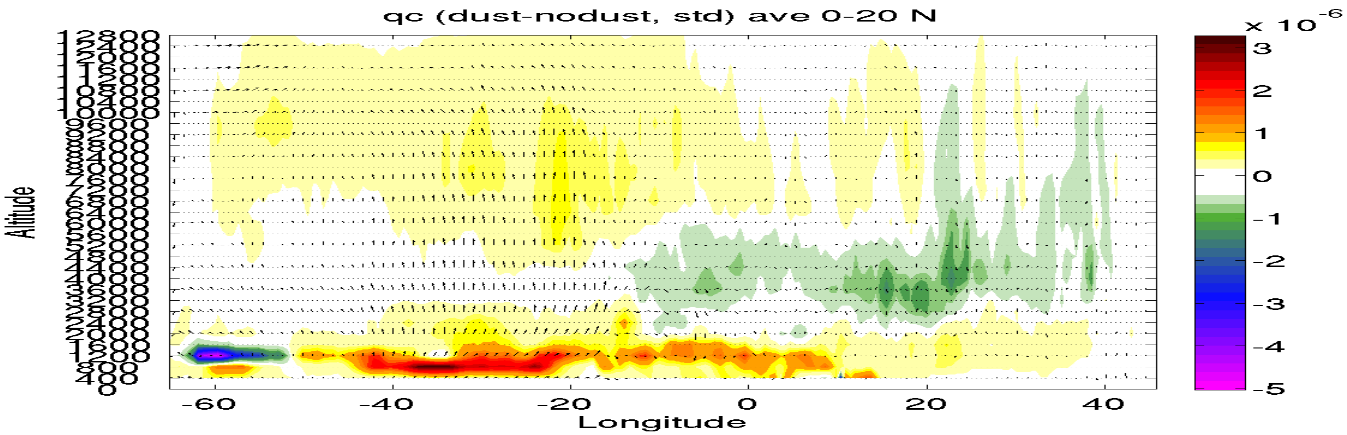
JJA 1996-2006



AOD

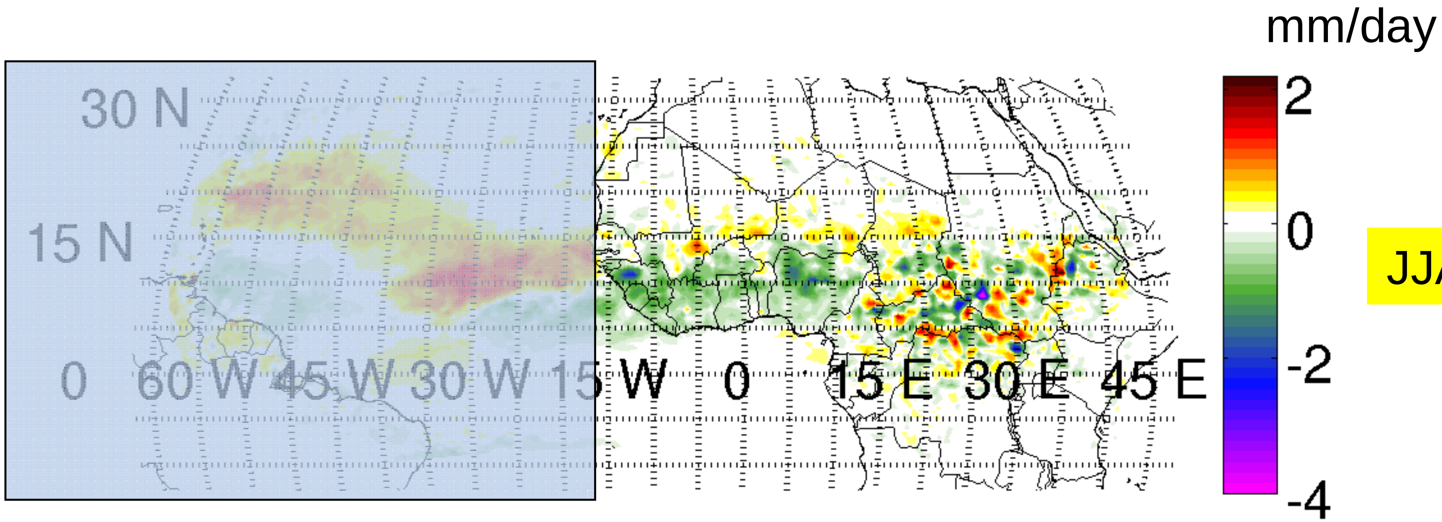


Psea (dust – nodust)

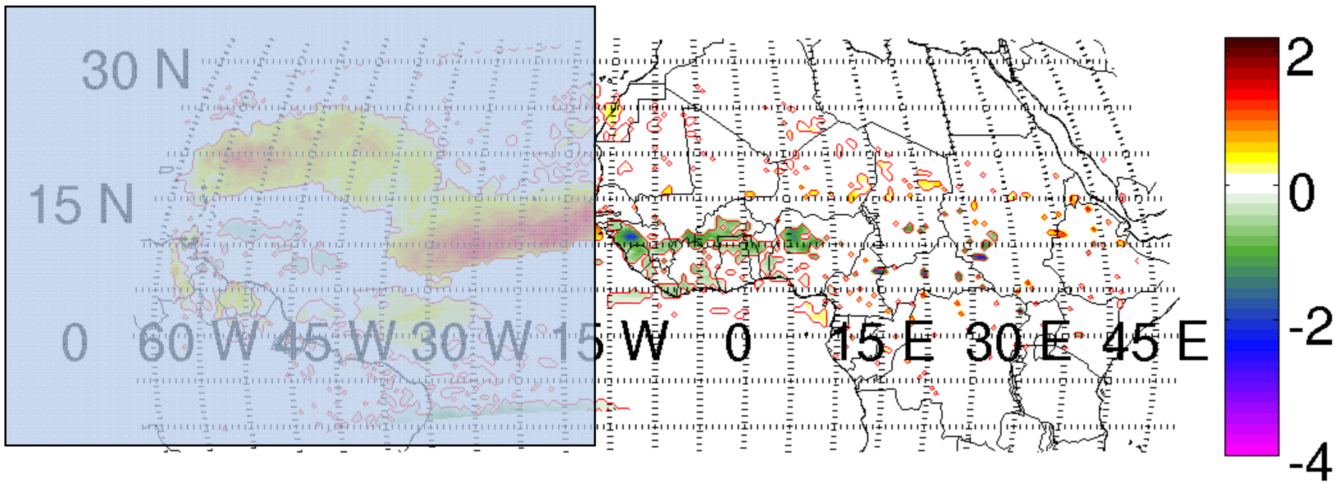


Qc + vertical circulation (dust – nodust)

Does this change precipitation anomaly over Sahel ?



JJA 1996-2006



JJA 1984-2006

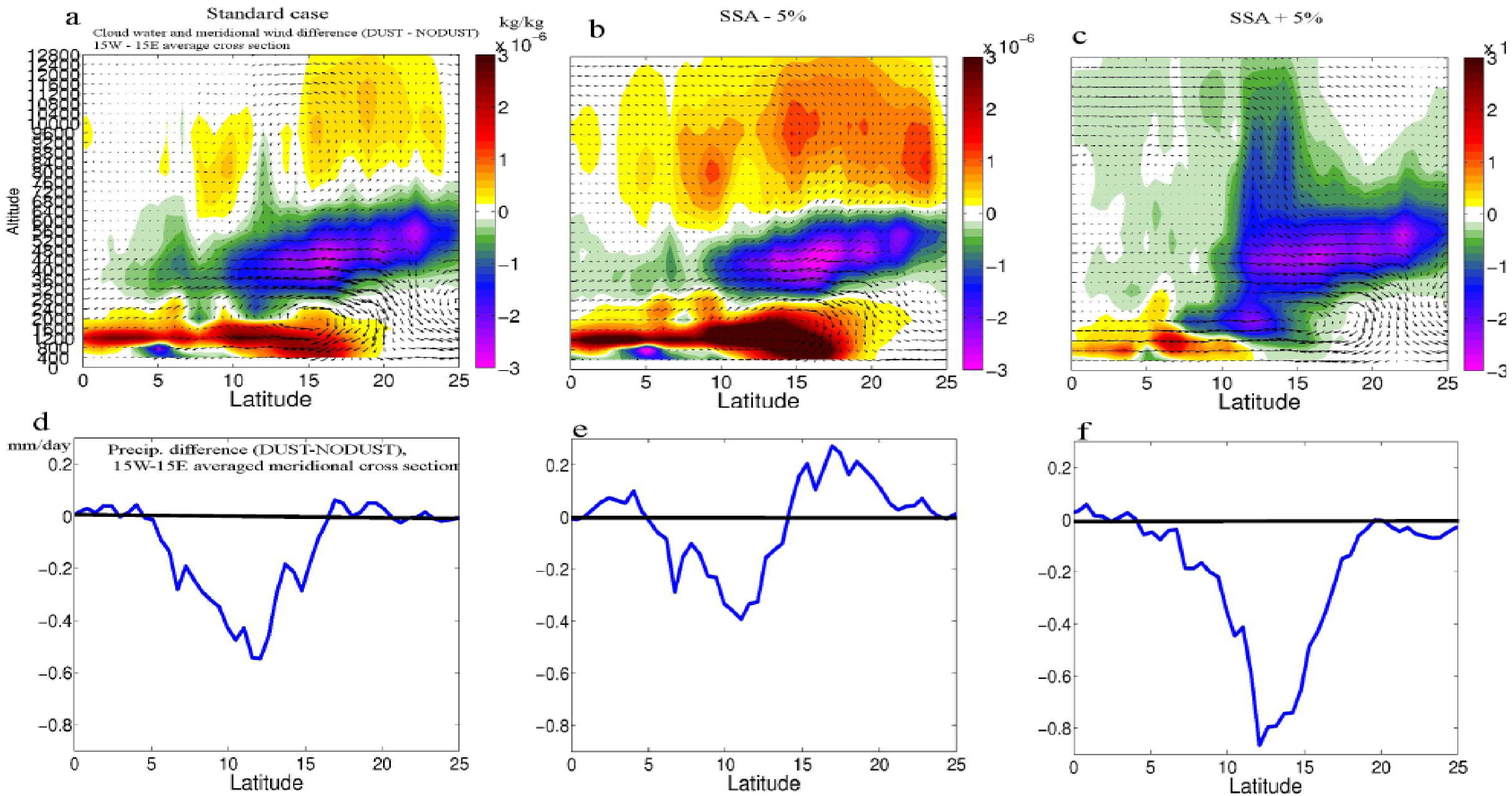
+ 95 % sig.

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.

Image

SSA ~0.95 (fine dust) **SSA ~0.90** **SSA ~0.99**



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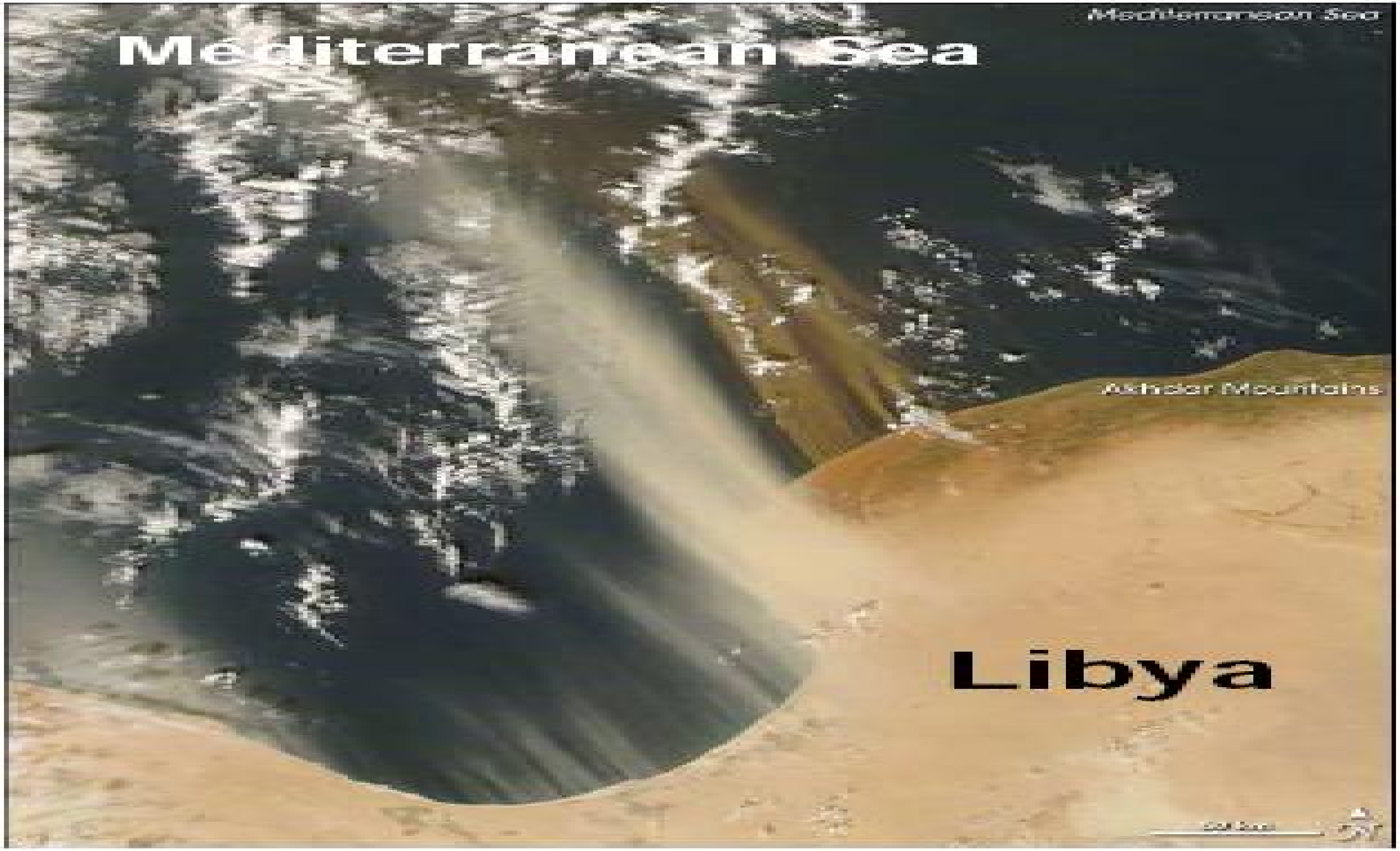


Source NASA

Any evidence of dust climatic signal over Sahel from observation ?

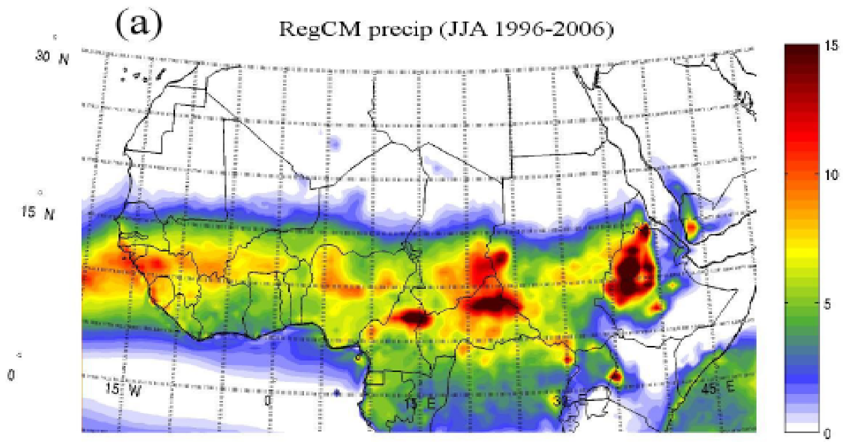
Kluser et al., 2010 (ACPD) propose a statistical study of dust impact on cloud cover property and rain likelihood using MODIS (deep blue) and SEVIRI clouds and dust product.

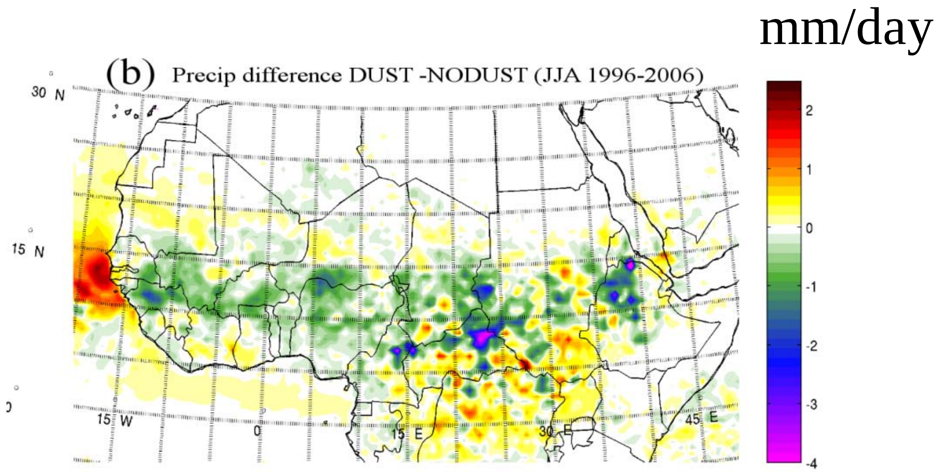
The observed increase in cloud top temperature in the monsoon season's Harmattan air mass can be explained by suppression of initial convection by boundary layer stabilisation and due to the entrainment of very dry air warmed by solar heating. This effect indicates that strong dust activity during the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

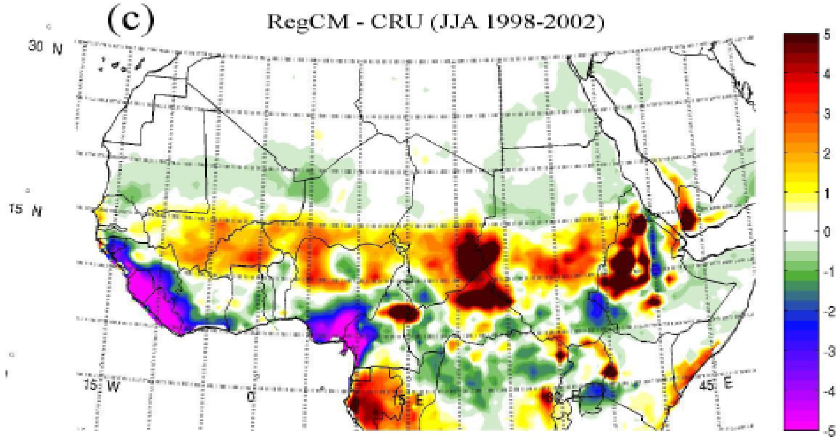
Table 1. Net dust effects on cloud cover (δ_{COV}), cloud top temperature (δ_{CTT}), ice phase fraction (δ_{IPF}), liquid phase effective radius ($\delta_{Re(liquid)}$) and warm rain likelihood (δ_{WRL}) within the Harmattan flow of the monsoon season.

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%	–	–

Response to dust forcing vs. Precipitation bias.





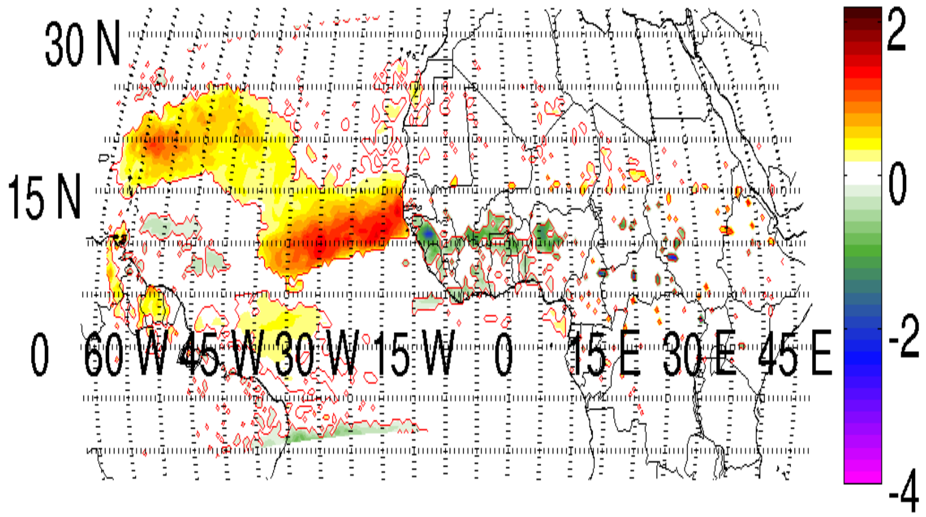


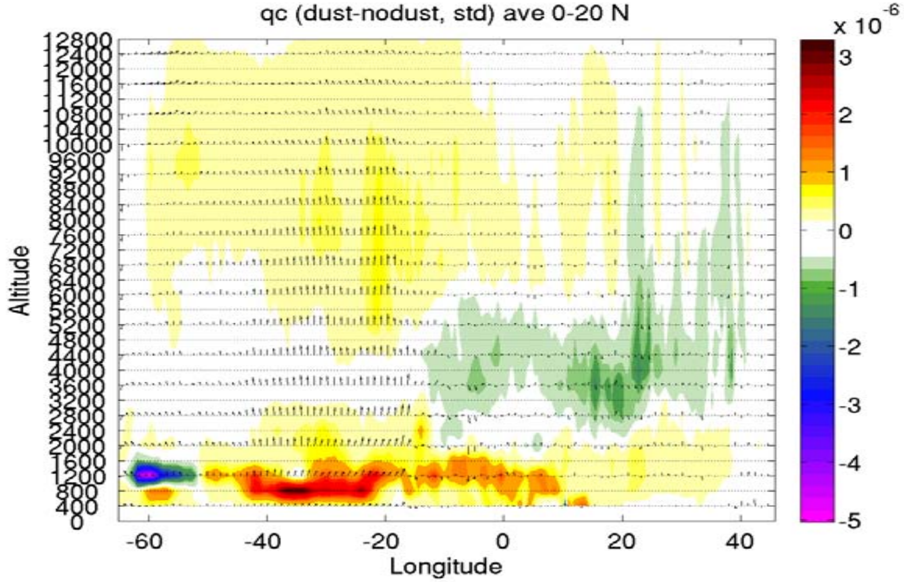
Region (15W-15E average)	5 N – 10 N		10 N – 17 N		17-N 20 N	
OBS	CRU	TRMM	CRU	TRMM	CRU	TRMM
Bias (mm/day and %)	-1.23 (-20.3 %)	-1.23 (-24%)	+1.09 (+20%)	+0.06 (+1.4%)	-0.23 (-41%)	-0.41 (-92%)
(DUST –NODUST) (mm/day and %)	-0.18 (-3.0 %)	-0.19 (-3.8 %)	-0.42 (-7.9%)	-0.28 (-6.1%)	+0.04 (+7.4 %)	+0.05 (+11.3%)
Improvment ?	no	no	yes	yes	yes	yes

Precipitation anomaly over the ocean ?

Cloud cover

JJA 1984-2006 (95% sig)



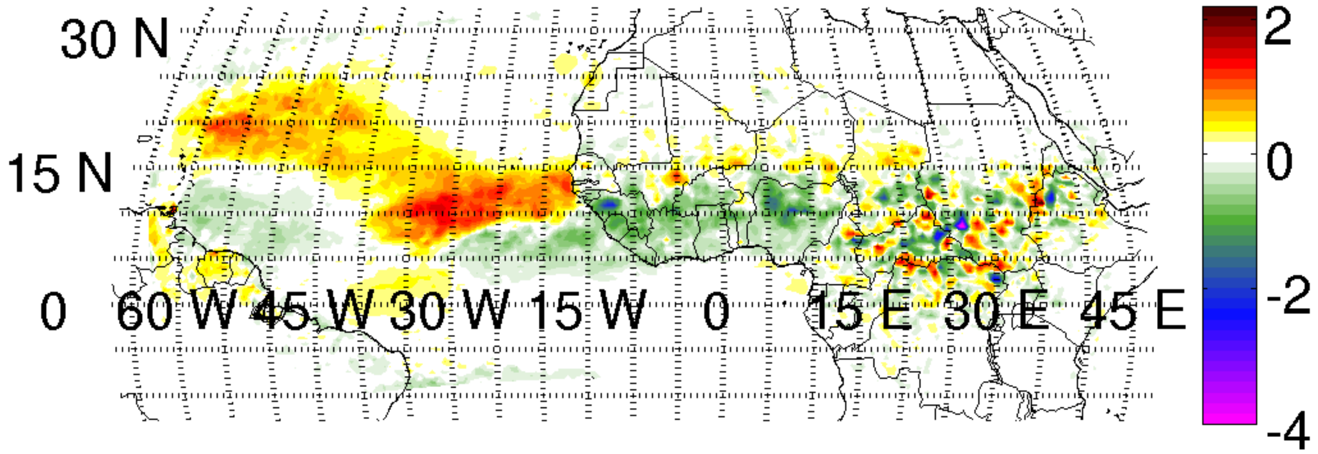


Possibly an over estimated elevated heat pump effect : Over ocean only diabatic heating contribution is efficient since SST are forced.

Can it affect results obtained up to now over the Sahel ?

Can we trust climate/dust simulations over the ocean ?

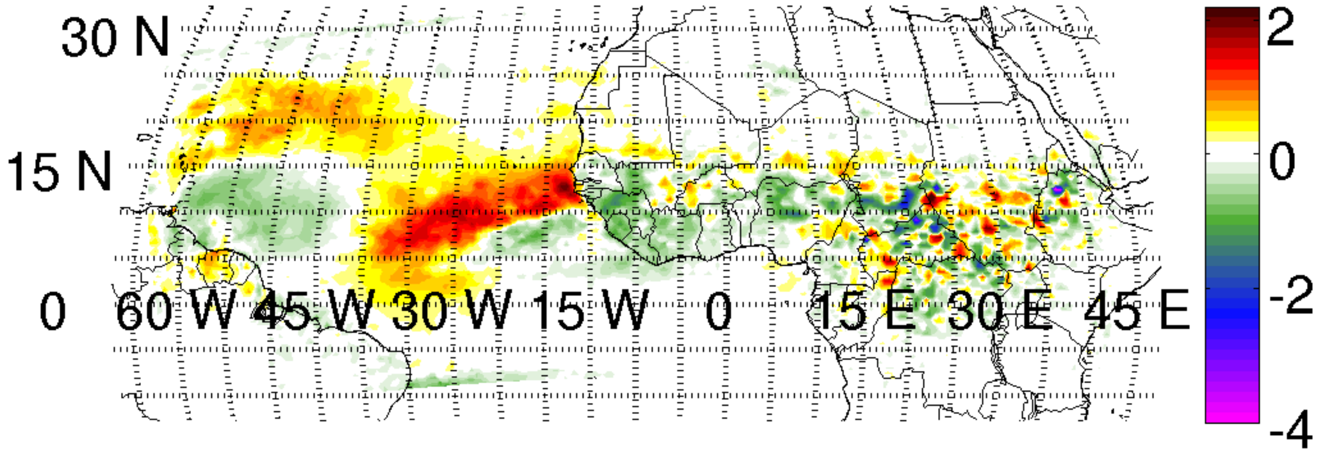
Use of the interactive diurnal cycle of skin temperature in control simulation and dust simulation



JJA 1996-2006

NO diurnal cycle

Precip. Dif. dust-nodust



With diurnal cycle

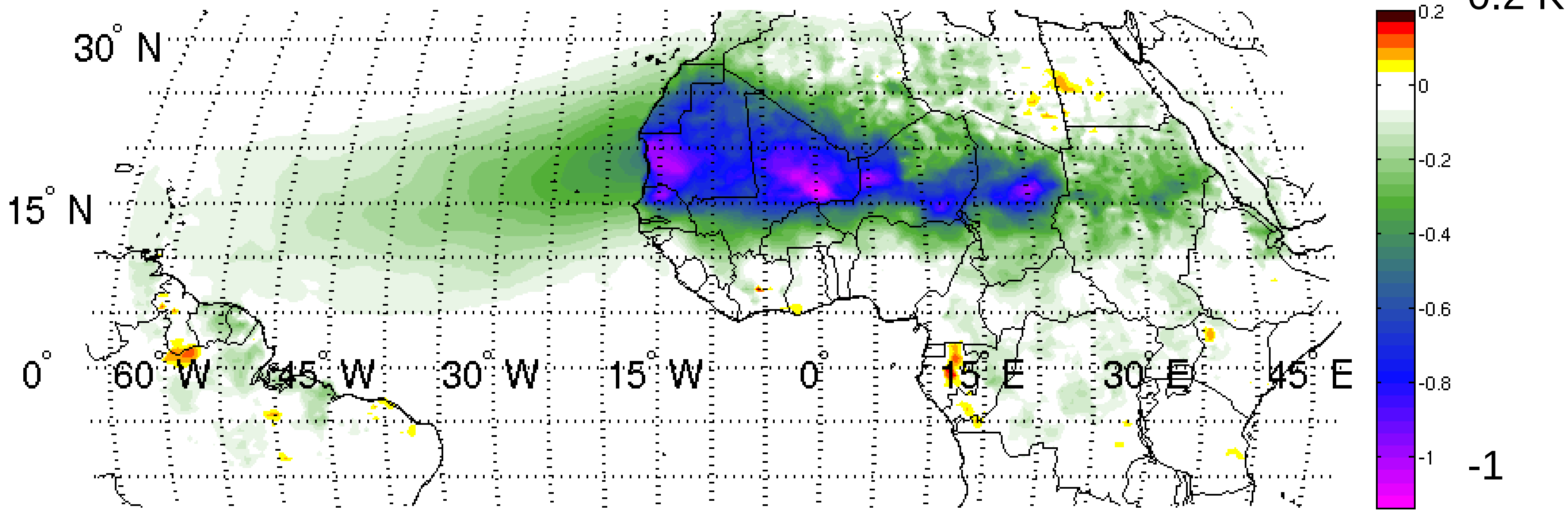
Beyond the diurnal cycle : Seasonal cooling of the ocean mixed layer

Simple experiment : SST* = SST - 0.8 x AOD

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

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

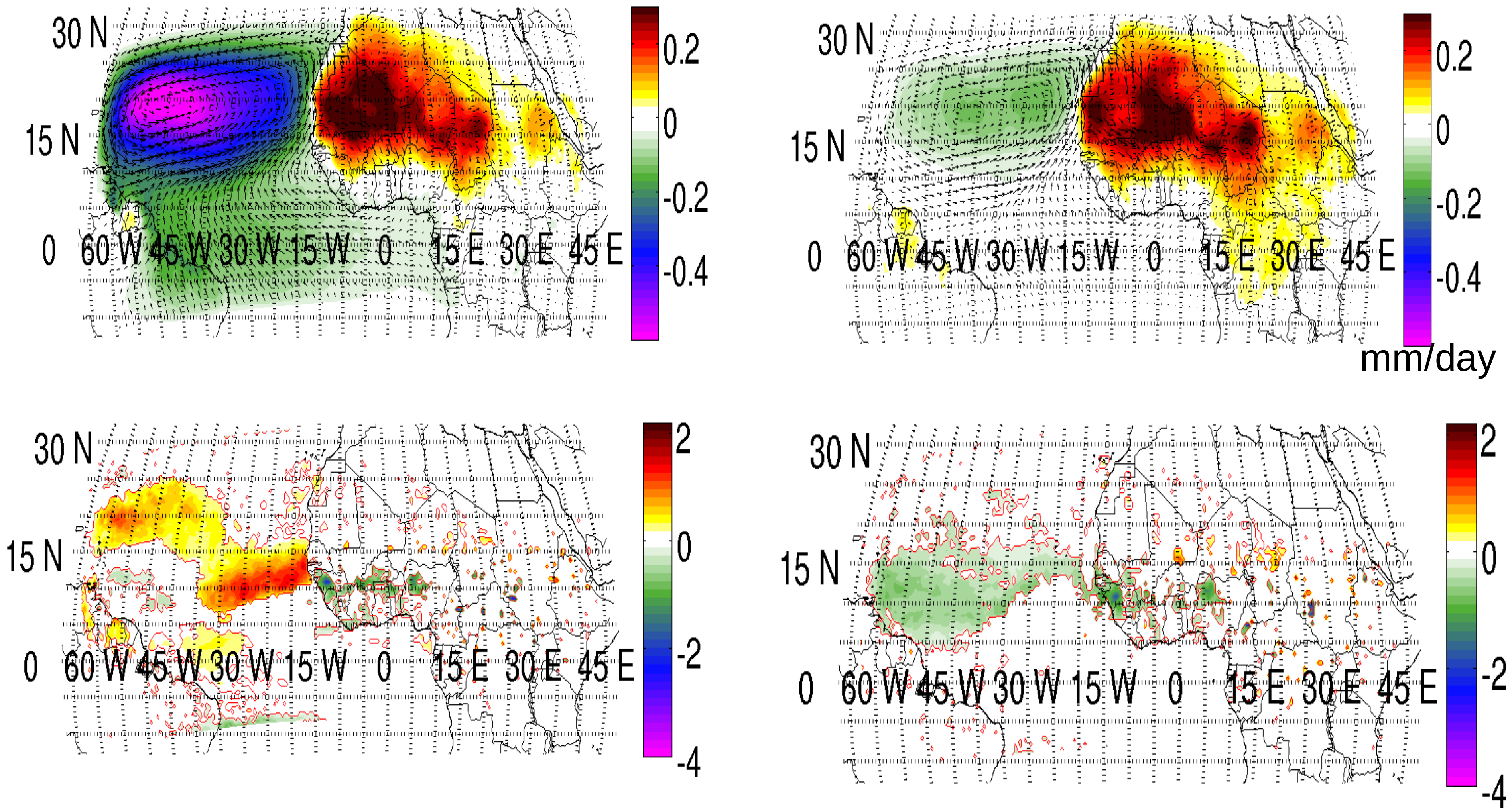
T2m (temperature difference)



Limits of the hypothesis: apply instantaneous forcing during dust episode

JJA 85-06

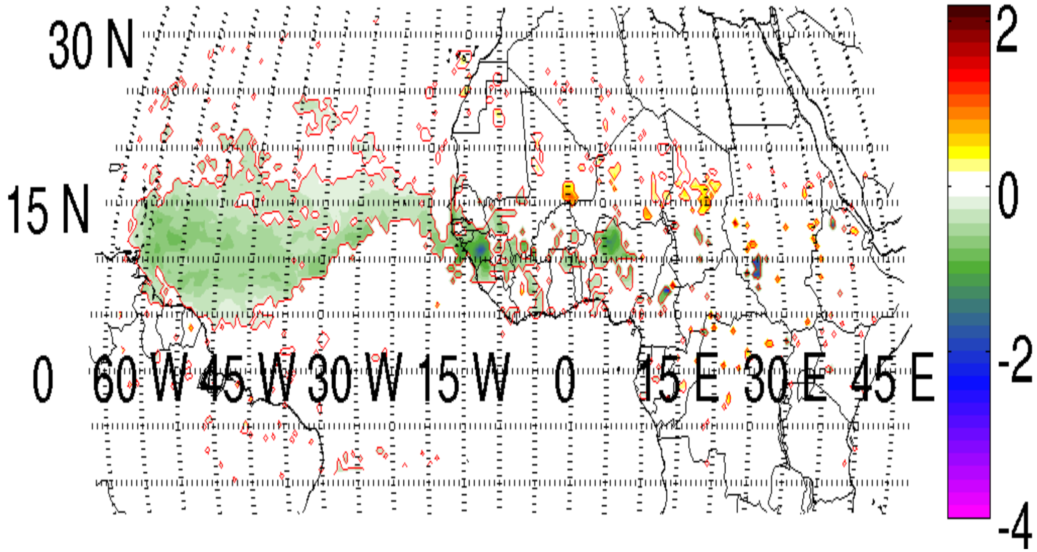
CTL (Diurnal cycle only) — 'mixed layer' experiment



Robustness of Sahel drying signal

Over the Ocean : Where is the truth ?

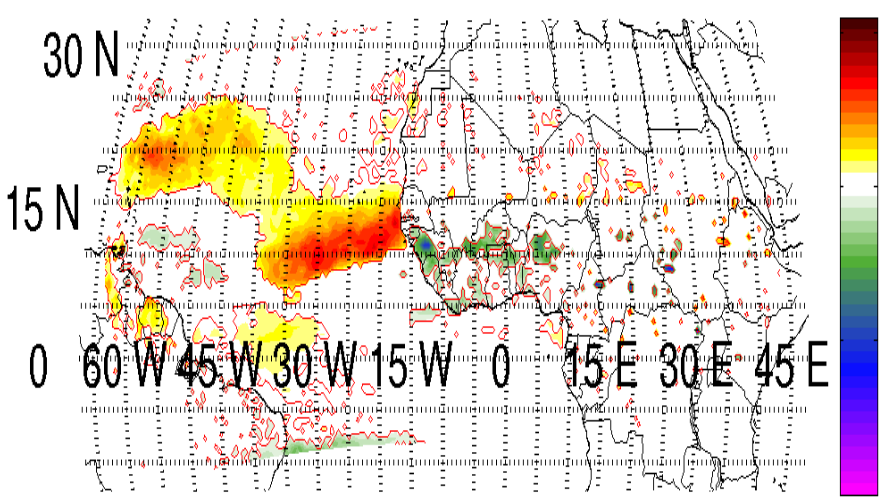
Type of response A :

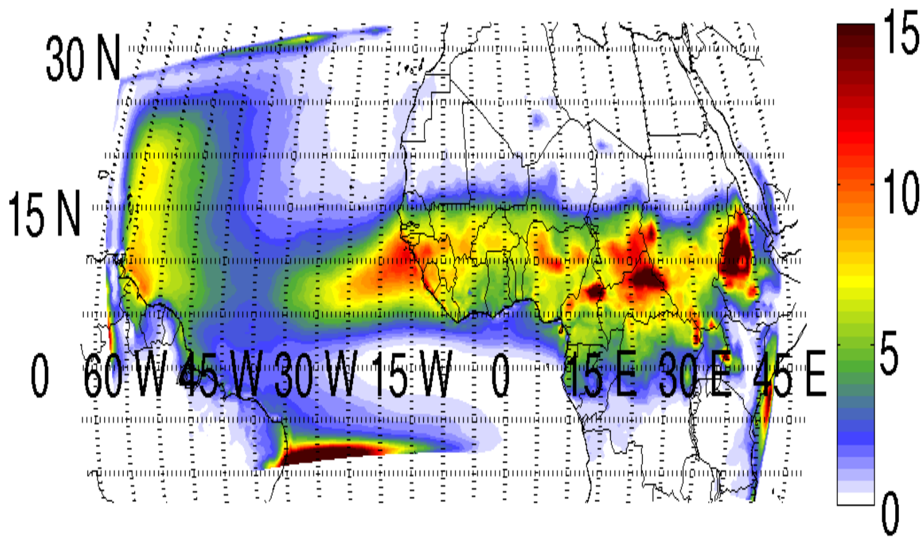


consistent with lower cyclonic activity during ‘anomalous’ high dust season

(Lau and Kim, 2007 comparing 2005 and 2006)

Type of response B :





Wilcox et al., 2009 GRL (using modis and TRMM observation)

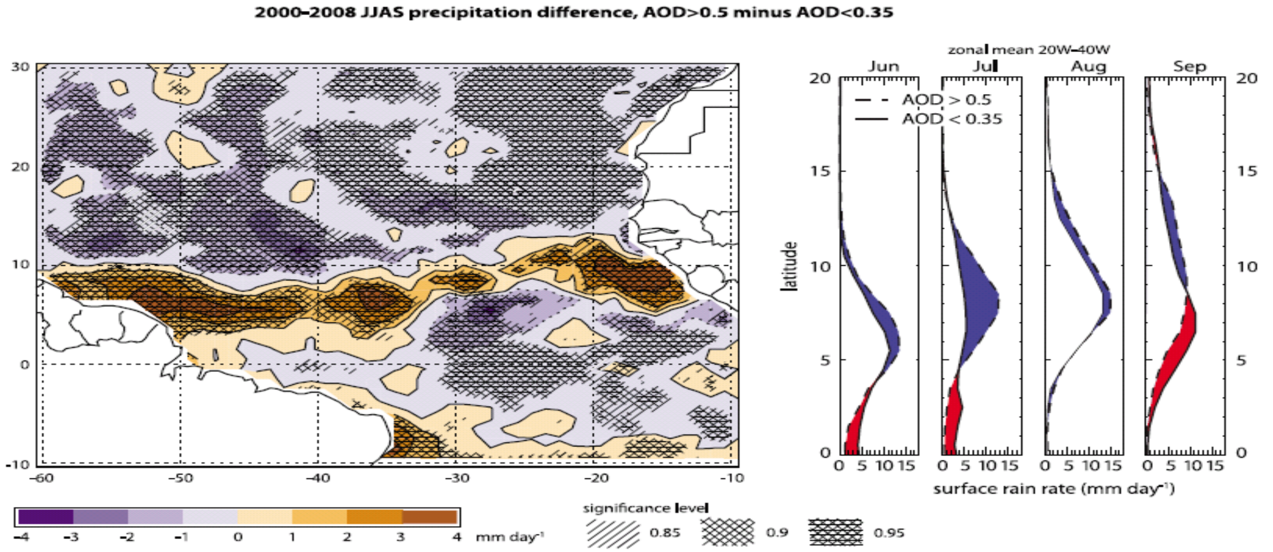


Figure 4. Difference in P (in mm d^{-1}) between dust outbreak conditions and low dust conditions. (left) Spatial distribution where the degree of hatching indicates level of significance of the difference compared to variability of pentad averages. The mean position of the ITCZ during the JJAS season is 8°N latitude. (right) Zonal-mean averaged 20° to 40° W by latitude of P during dust outbreak conditions (dashed) and low dust conditions (solid). Higher values during dust outbreaks denoted in blue, and lower values in red.

Saharan dust layer induce a northward shift of ITCZ

(the diabatic warming effect would be predominant)

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 and cloud formation in the higher troposphere over the Sahel.

•The net regional impact of dust on average precipitation results from these coexisting effects. On average, drying is dominant over Sahelian region except for a limited band over northern Sahel which sees enhanced precipitations. This signal is significant when changing domain and SST conditions. Model precipitation bias is positively impacted when dust are accounted for.

•The balance between these effects is very sensitive to the dust SSA which affects the intensity of precipitation decrease vs. increase as well as the latitudinal limit between these two responses.

•When SST are prescribed to the model, only diabatic warming is effective over ocean and more convection and precipitation are obtained in the dust outflow region. When SST are allowed to feedback (cooling of mixed layer due to decrease of incoming SW radiation) the response could be of opposite sign due a decrease of latent heat and moisture availability for deep convection. Needs ocean coupling !

RCMs strengths:

On line emission scheme

Detail in mesoscale systems representation

Detail in soil emission processes (different dust tracers) and surface winds

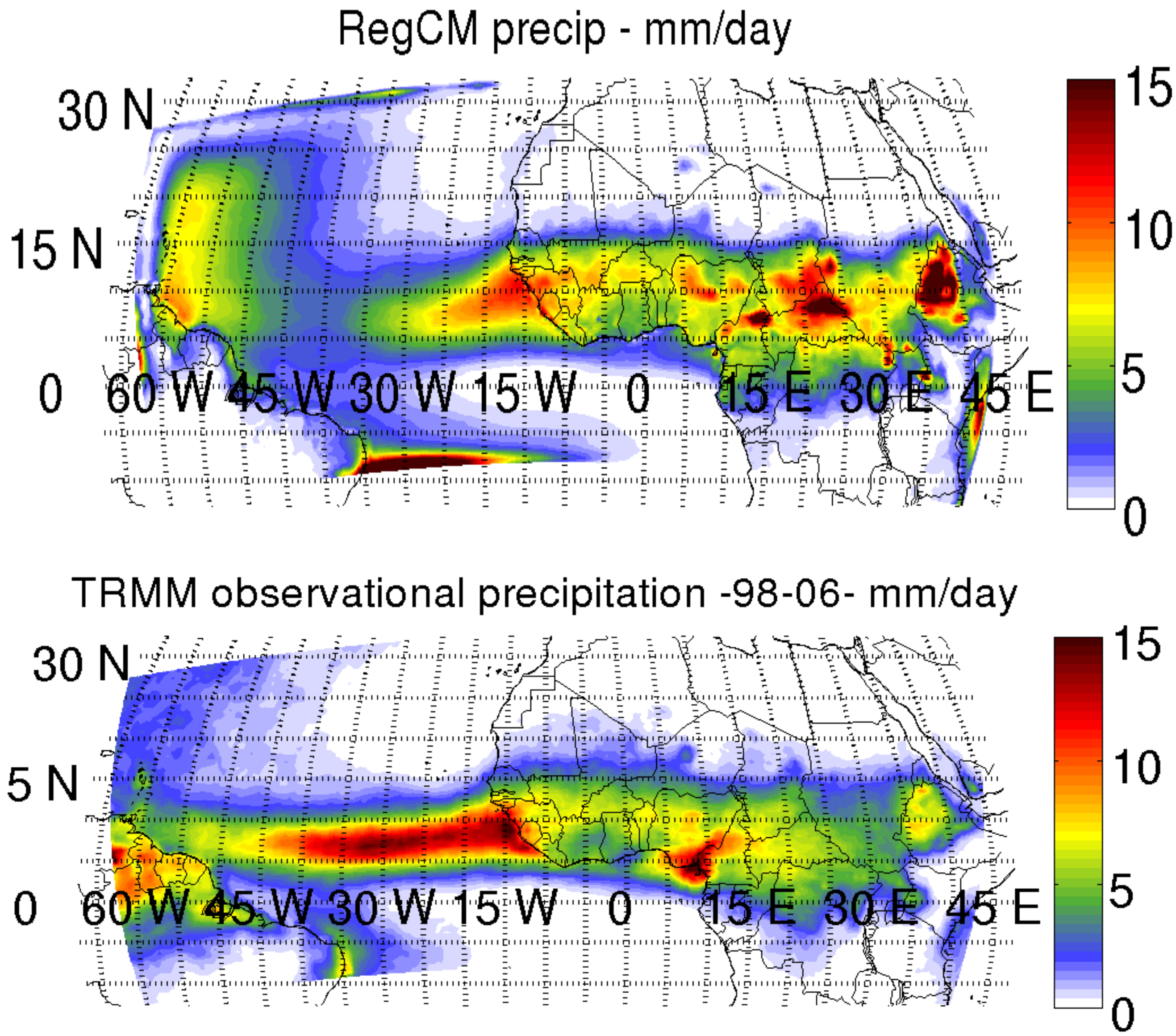
Cloud / aerosol interactions (transport and microphysics)

Limits:

Boundary conditions (need to perform domain sensitivity tests, use of big domains)

Lack of ocean feedback but hopefully not for long !

Thank you !


RegCM precip - mm/day
30 N
15 N
0
60 W
45 W
30 W
15 W
0
15 E
30 E
45 E
15
10
5
0
TRMM observational precipitation -98-06- mm/day
30 N
15 N
0
60 W
45 W
30 W
15 W
0
15 E
30 E
45 E
15
10
5
0

MODIS

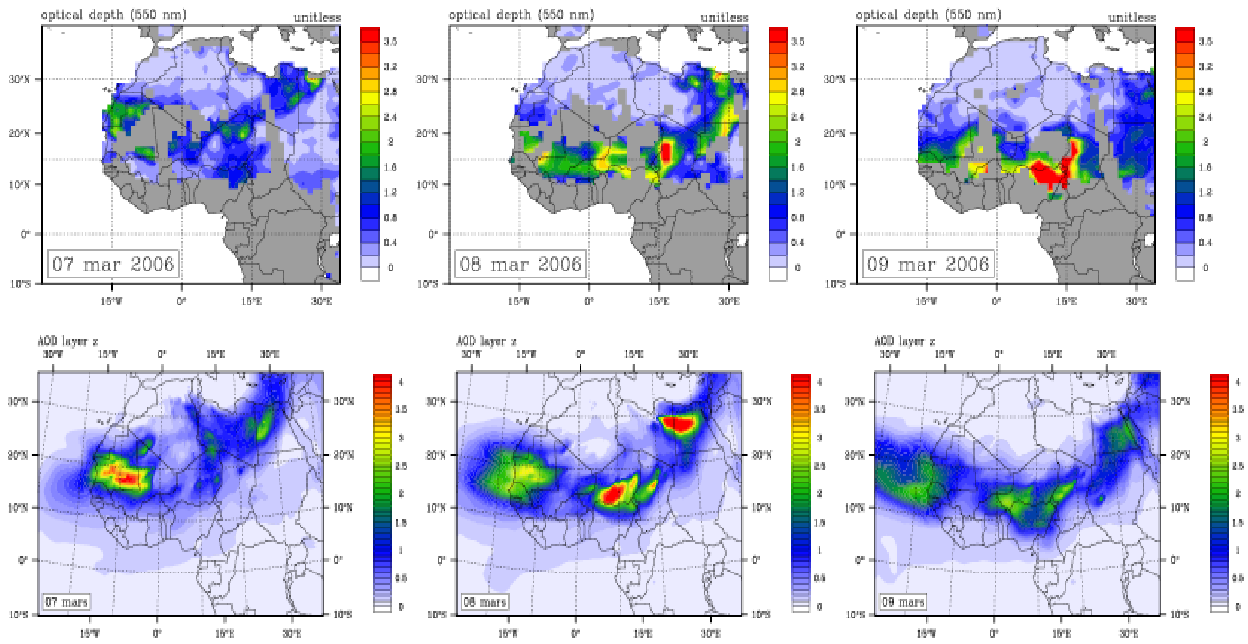
‘Deep blue’

AOD

MAR 2006

RegCM

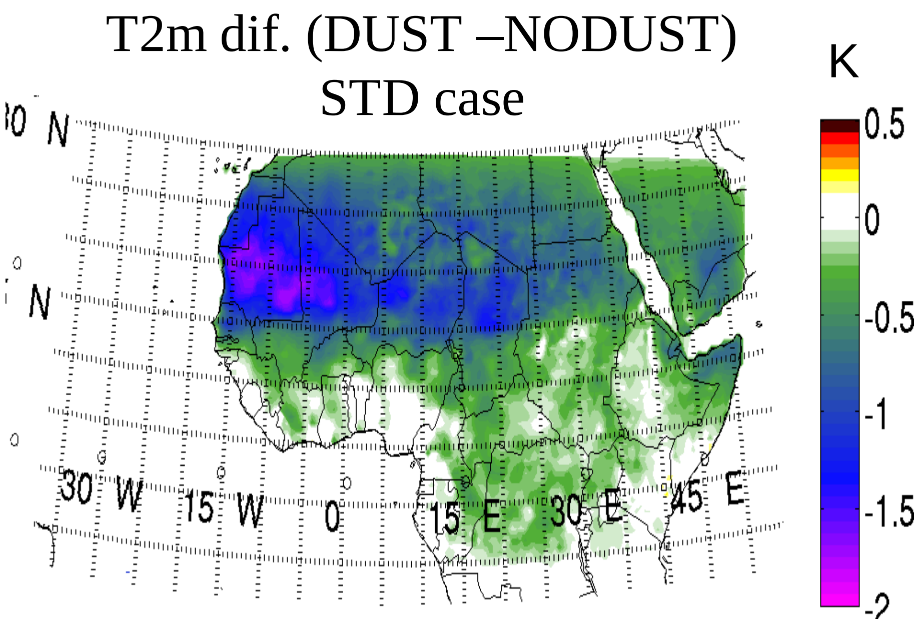
AOD

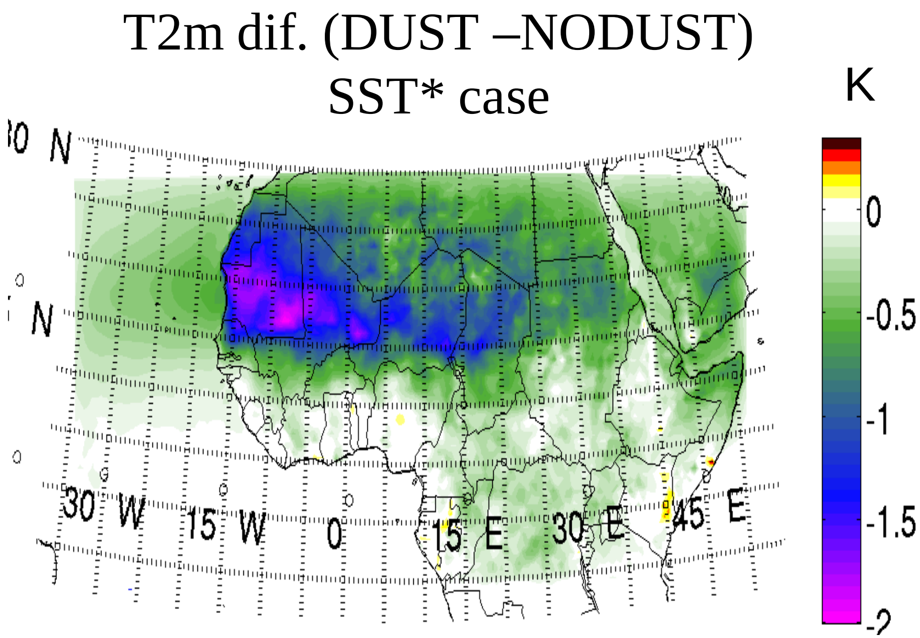


Simple SST experiment : SST* = SST - 0.8 x AOD

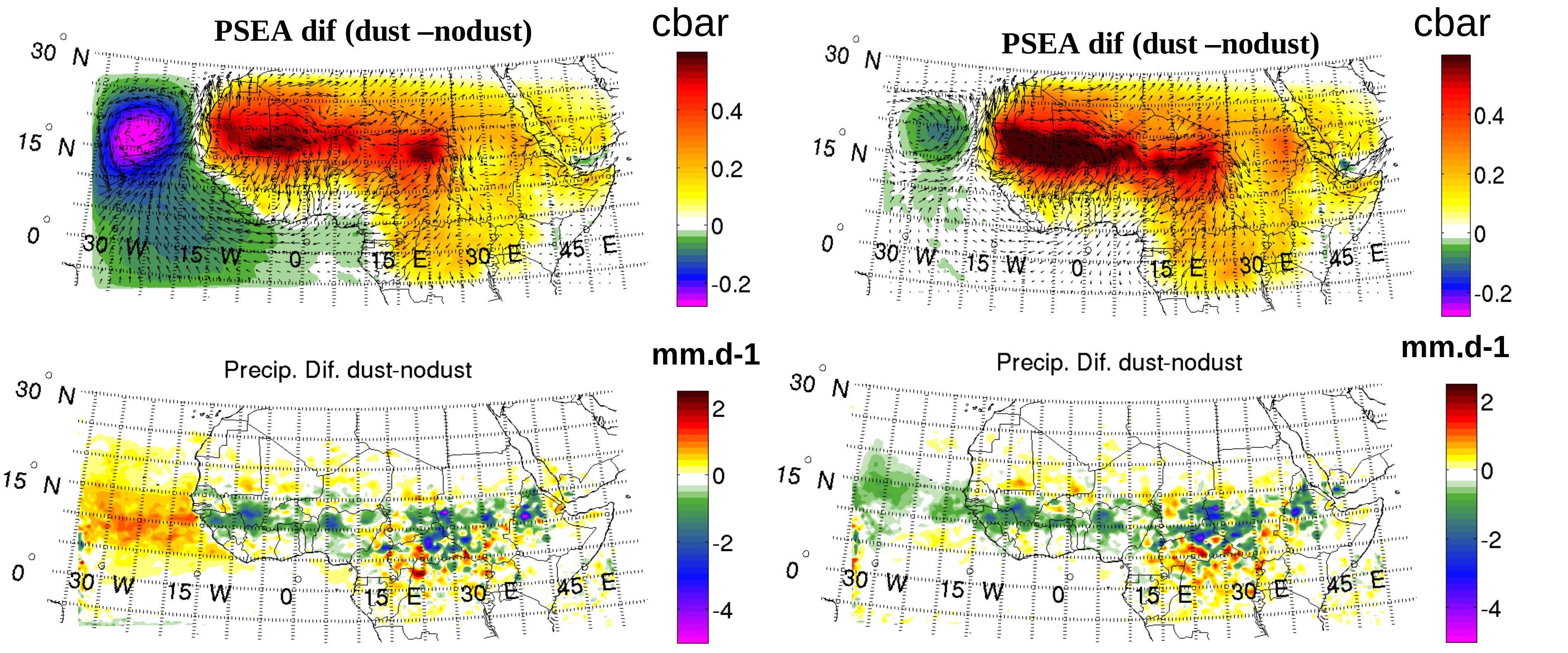
as a result of downward SW attenuation at the surface

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

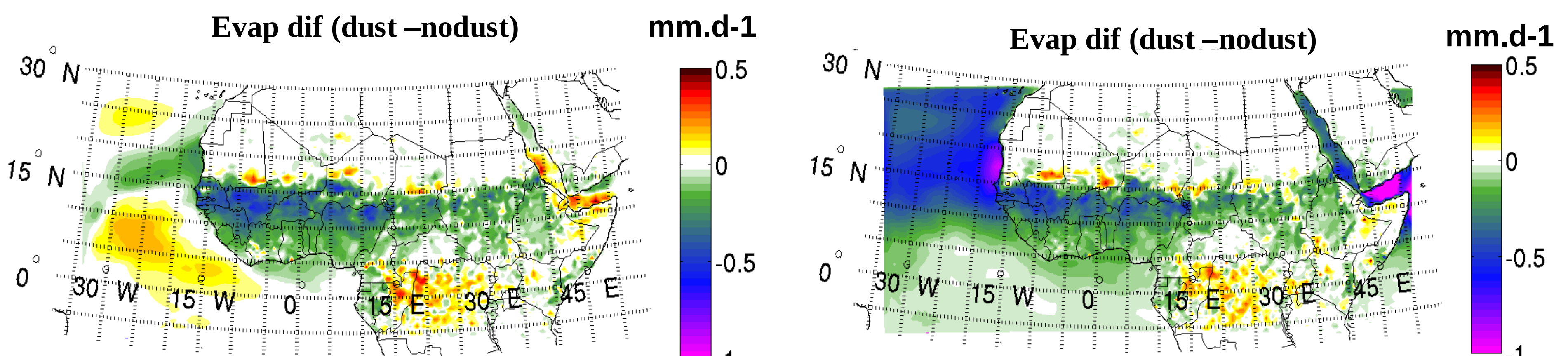




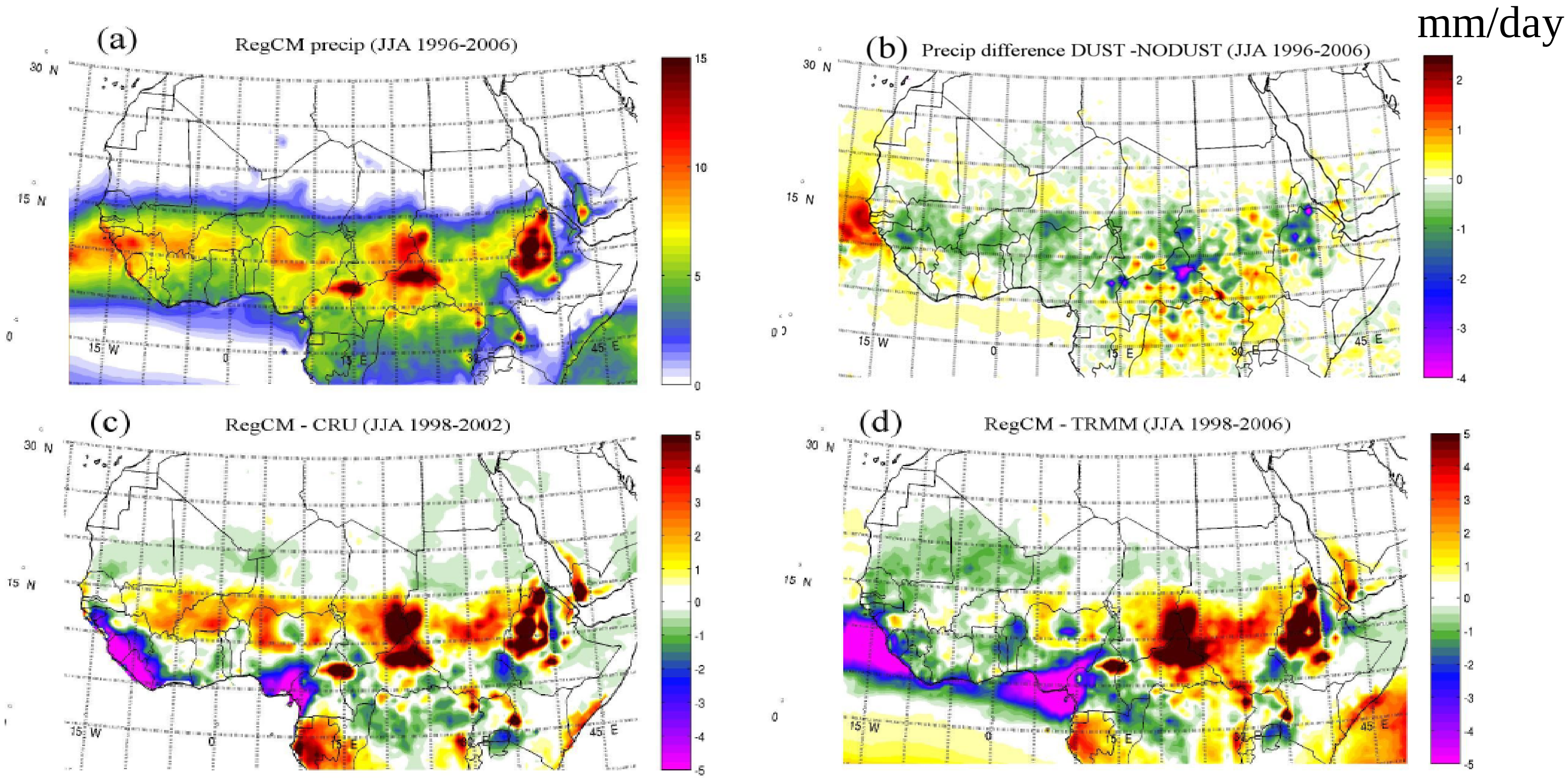
STD case | SST* case



With SST correction : dust induced cyclonic anomaly but less precipitation over the ocean …



Response to dust forcing vs. Precipitation bias.



Region (15W-15E average)	5 N – 10 N		10 N – 17 N		17-N 20 N	
OBS	CRU	TRMM	CRU	TRMM	CRU	TRMM
Bias (mm/day and %)	-1.23 (-20.3 %)	-1.23 (-24%)	+1.09 (+20%)	+0.06 (+1.4%)	-0.23 (+41%)	-0.41 (-92%)
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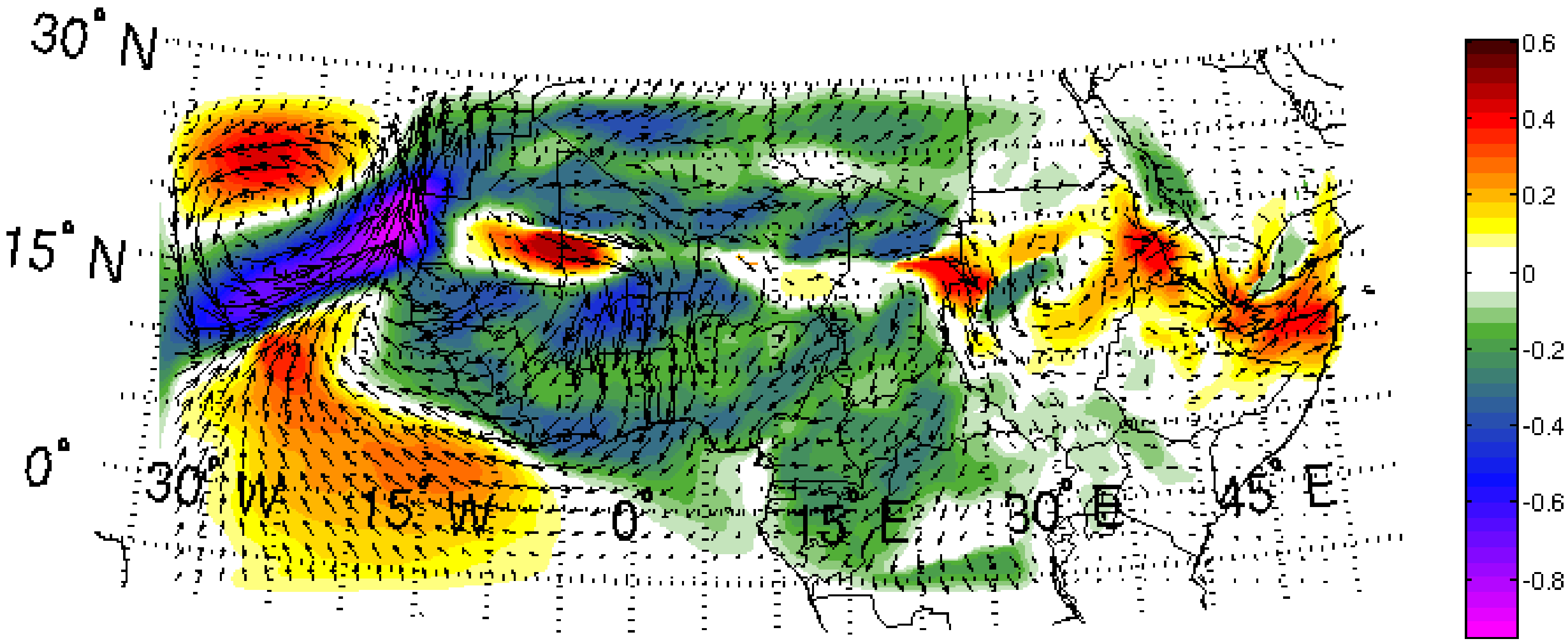
Improvment ?	no	no	yes	yes	yes	yes

Climate sensitivity to dust absorption properties

STD

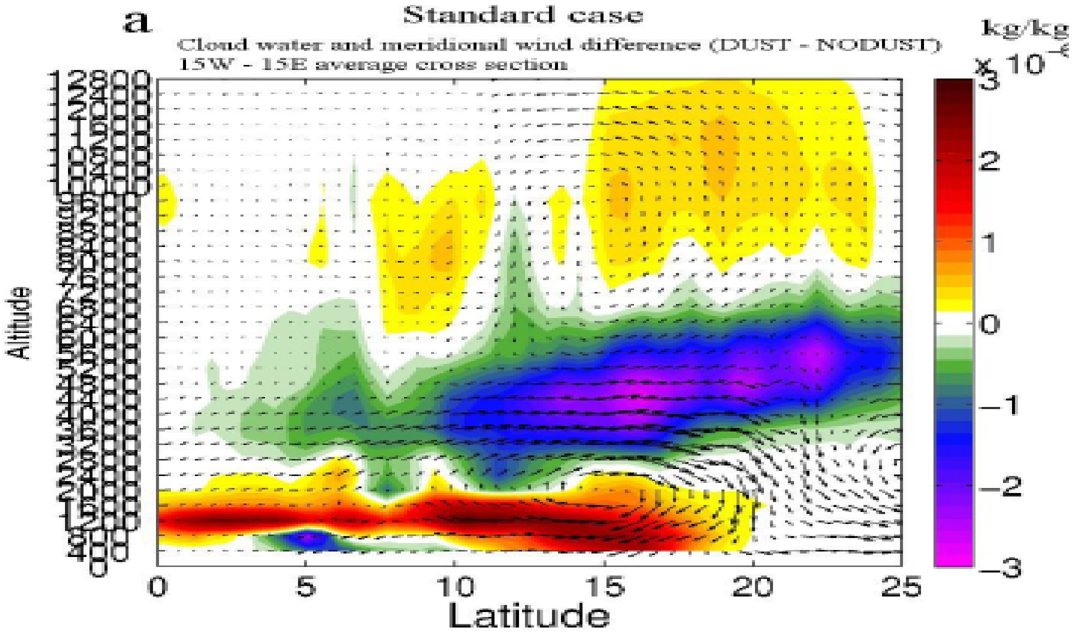
Dust bins size diameter (µm)	0.01-1	1-2.5	2.5-5	5-20
K_{ext} ($m^2.g^{-1}$)	2.45	0.85	0.38	0.17
g	0.71	0.76	0.81	0.87
SSA	0.95	0.89	0.80	0.70


30° N
15° N
0°
30° W
15° W
0°
15° E
30° E
45° E
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8

Cloud water, meridional circulation and precip. difference (DUST-NODUST)

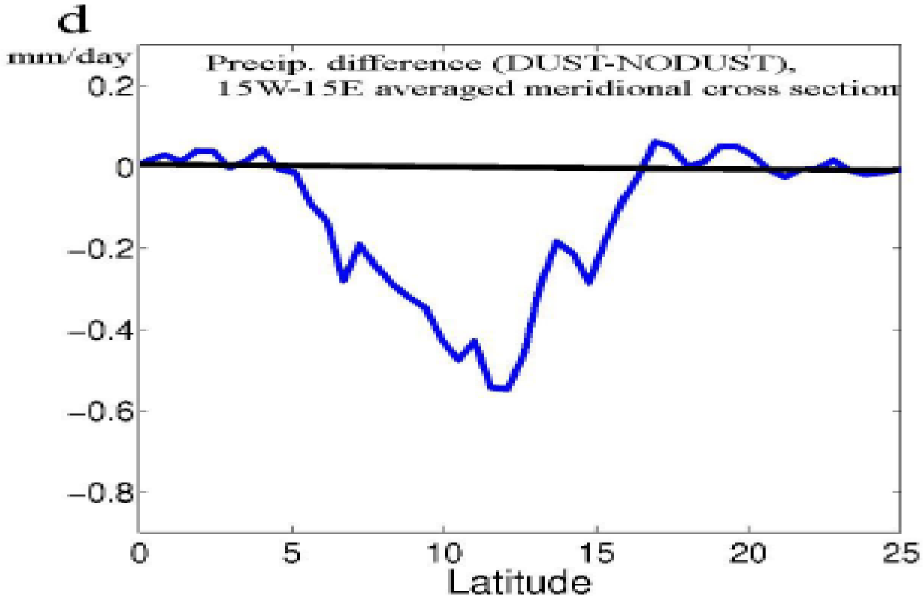
15W-15E average

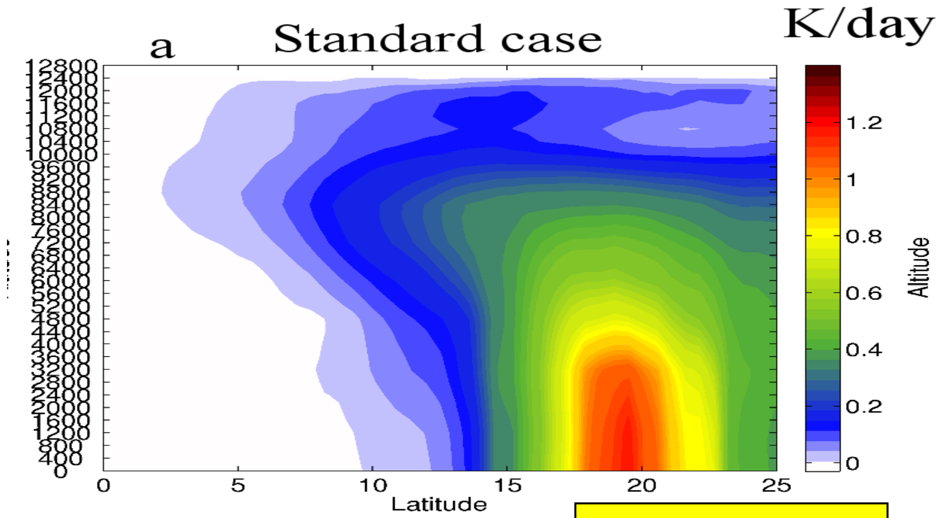
Solmon et al., 2008



2 : 'Elevated heat pump' effect (Lau et al., 2009)

1: Weakening of the 'monsoon pump'





+ higher surf ALB