Regional climatic impact of dust aerosol over west Africa

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ICTP

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A. Konaré , S. Ibrah

LA

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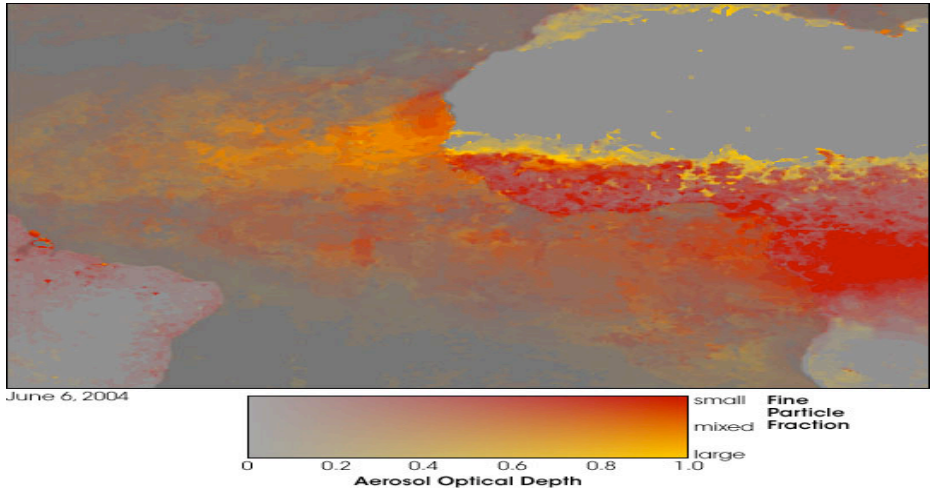
C. Liousse

« Aerosol regional climatic impact in Africa »

Motivations

- Large and increasing emissions and burdens in Africa
- Aerosol forcing important at regional (and for global) scale
- Diversity of emissions and complexity of tropical atmospheric chemistry (Natural and anthropogenic compounds)



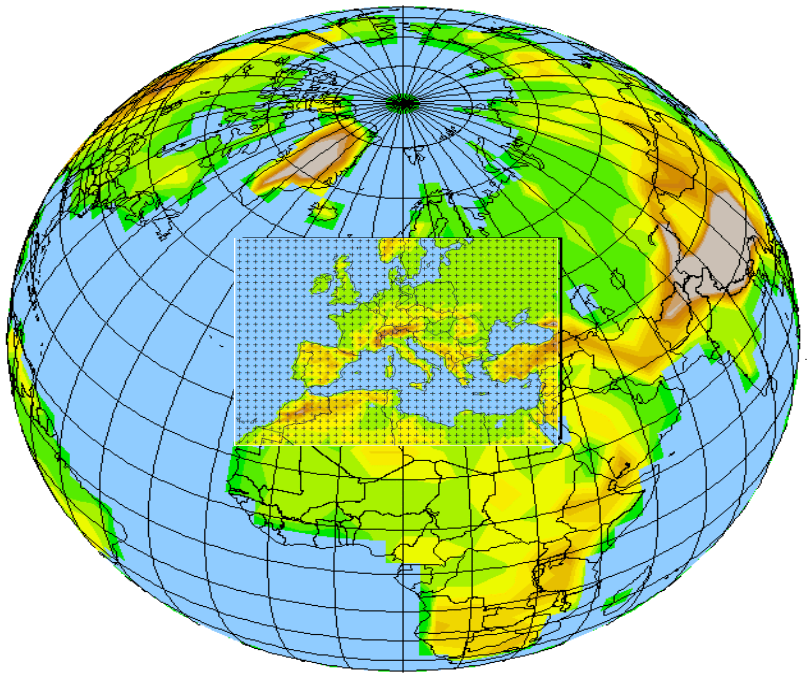
MODIS

AOD

- Sensitivity of societies and ecosystems to environmental change
- **AMMA experiment (2005-2010)**

A modelling approach …

Regional Climate Model



High resolution limited area models adapted to climatic simulations.

Forced by analysis or GCM outputs.

RegCM (ICTP/UNESCO, 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** **(Solmon et al., 2006; Zakey et al., 2006)**

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

Transport | Primary Emissions | Removal terms | Physico – chemical transformations

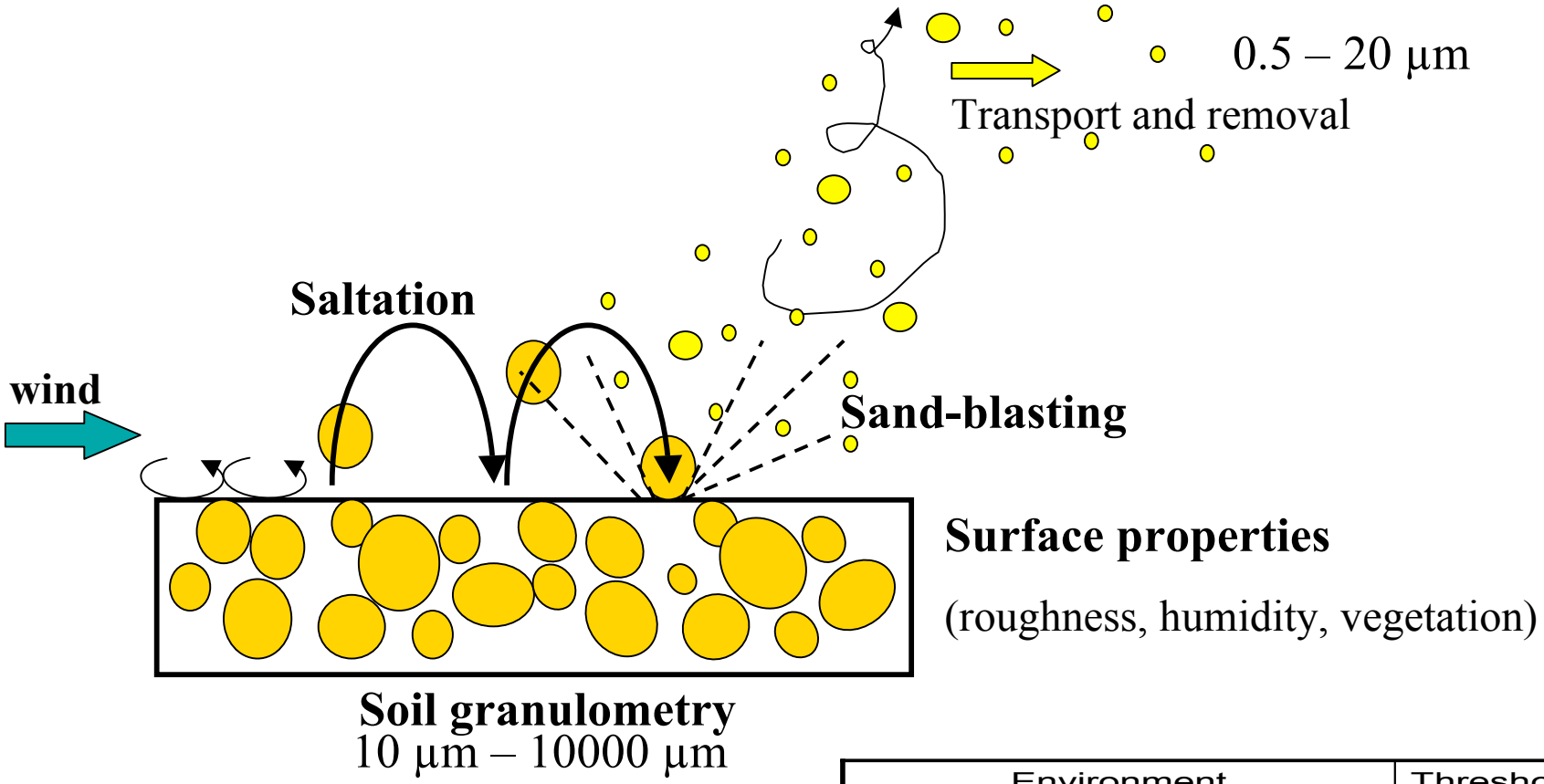
- **Particles and chemical species considered**

SO_2	SO_4^{--}	BC (soot)		OC (total organic carbon)		DUST (4 bins)			
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 ì m	1-2.5 ì m	2.5-5 ì m	5-20 ì m

Presribed emission inventories

On line emissions

Dust emission parameterization

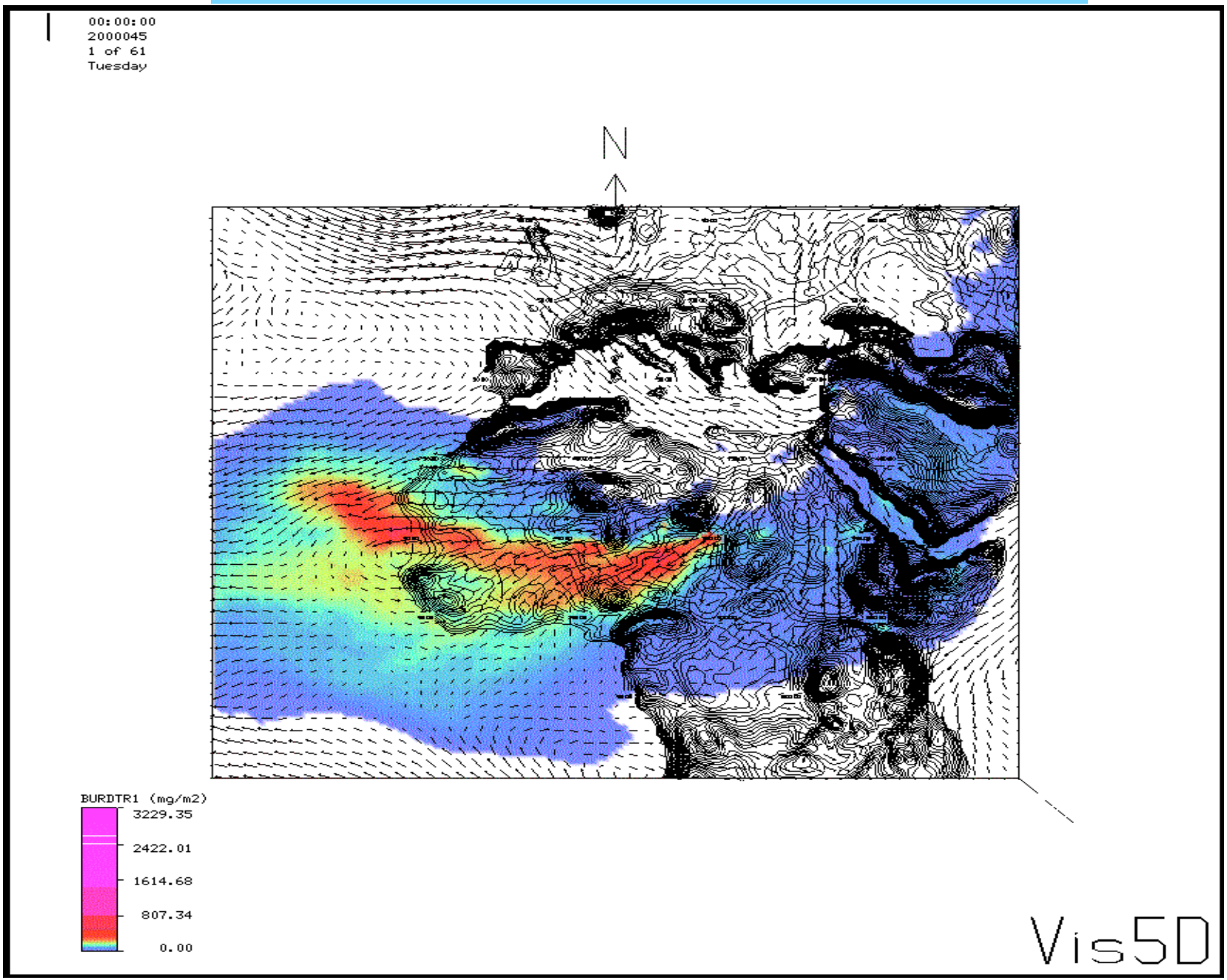


RegCM

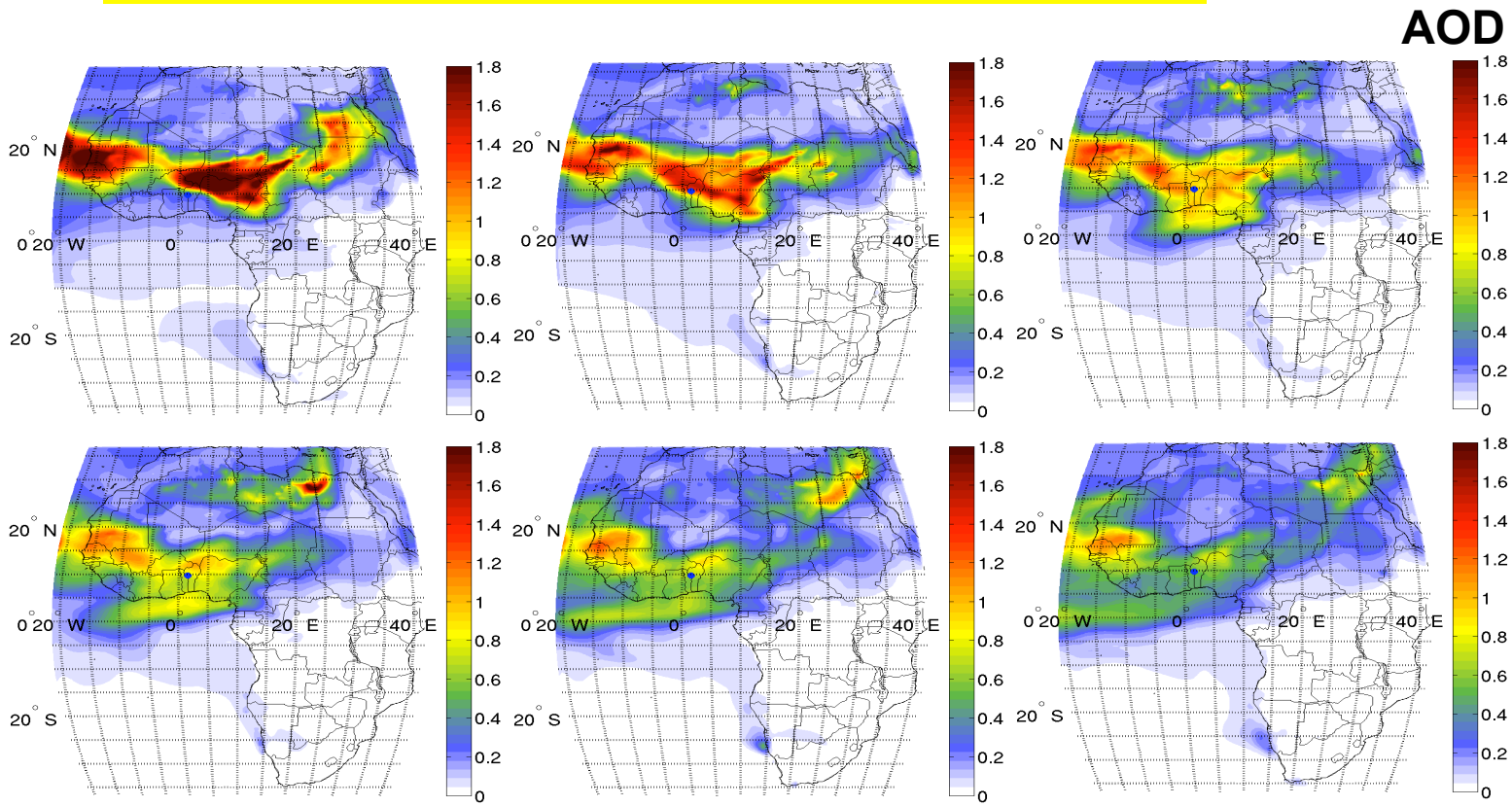
Zakey et al., 2006

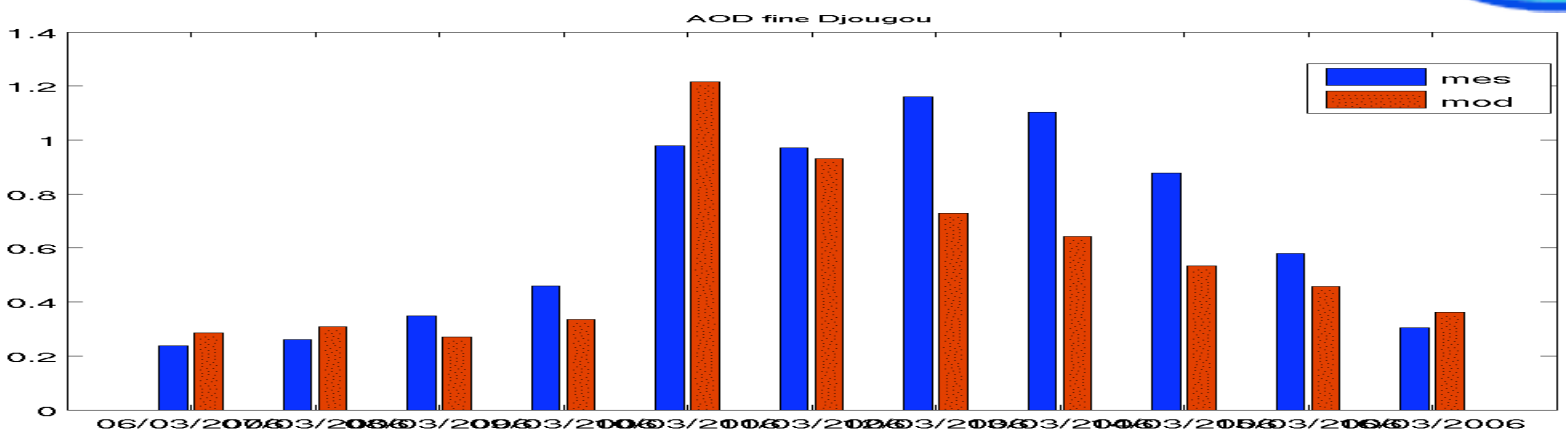
Environment	Threshold wind (mph)
Fine to medium sand in dune covered regions	10-15
Sandy areas	20
Fine material, desert flat	20-25
Alluvial fans and crusted salt flats (dry lake beds)	30-35
Well developed desert pavement	40

RegCM Dust simulation (February 2000)



DUST event March 2006 9-14 (AOD day av)





Seasonnal validation summer 2000

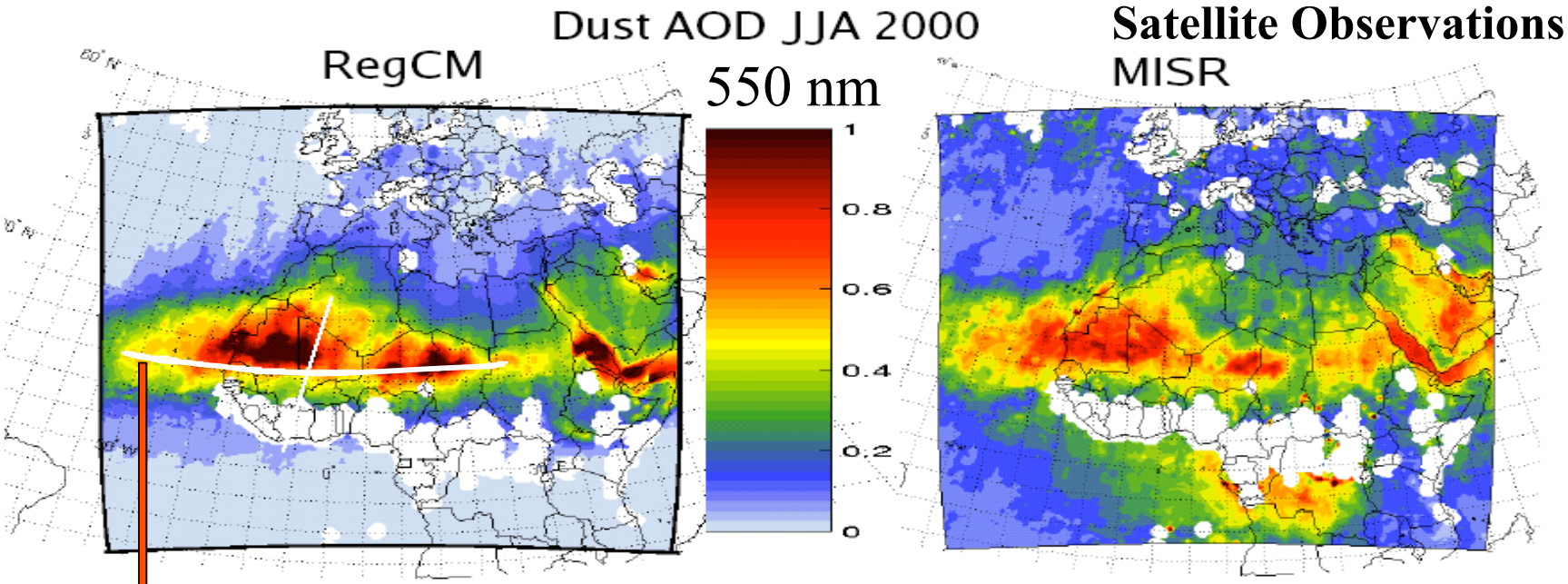
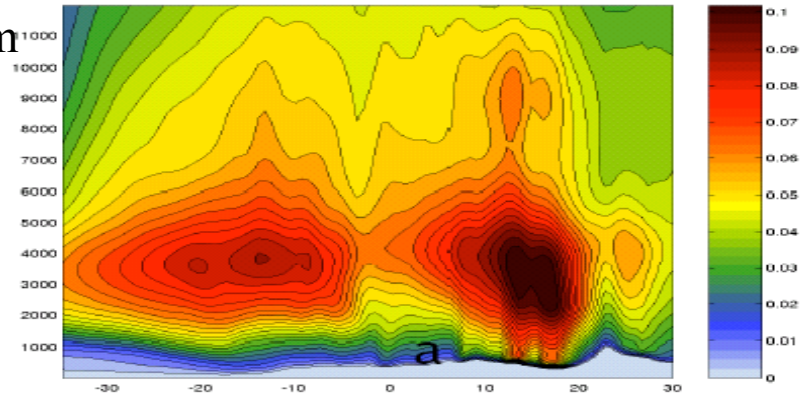


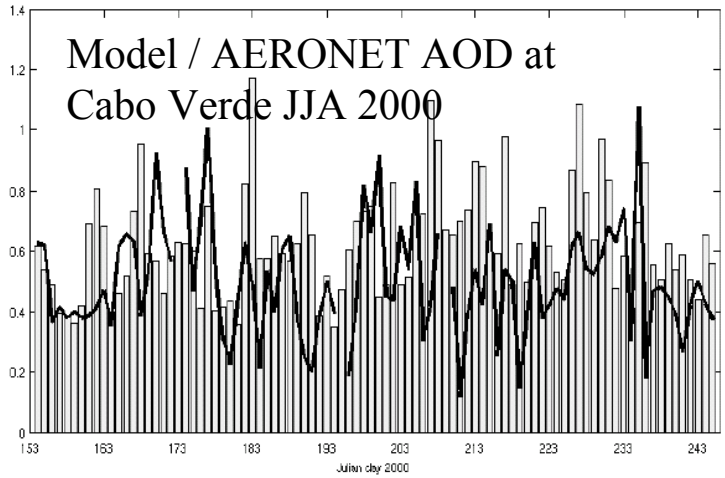
Fig. 10

Vertical cross section

11 km

4 km





Key questions :

Dust storm forecasting.

Dust impact on meso-scale weather system (African Easterly Wave).

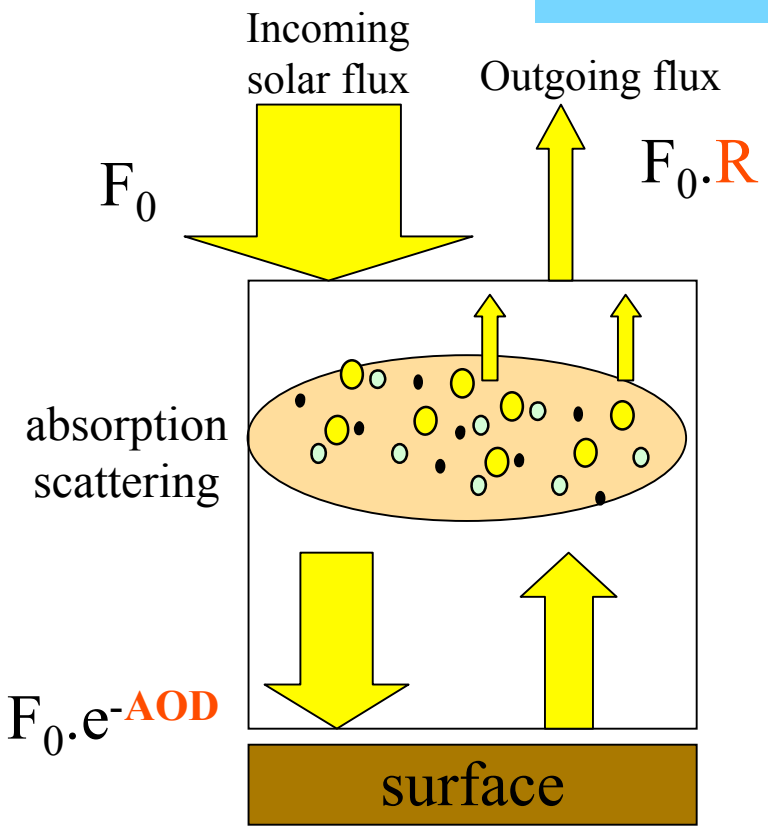
Dust impact on hurricane development over Atlantic.

Role of dust aerosol in the regulation of Sahelian climate ?

Biogeochemical and health impacts …

This study focus on **dust direct and semi-direct effects**

Dust Short Wave radiative forcing



TOA SW Radiative forcing : difference of outgoing fluxes without and with aerosol

All other atmospheric and surface variables being fixed.

> 0. = warming of the system

< 0. = cooling of the system

SRF SW Radiative forcing : difference of net flux at the surface

Always < 0. = cooling of the surface

Aerosol optical depth AOD describes the aerosol extinction due to the sum of absorption and scattering effects.

Scattered fraction R : depends on surface albedo, incident radiation angle , AOD, **absorption and scattering properties of aerosols**

Dust Refractive index

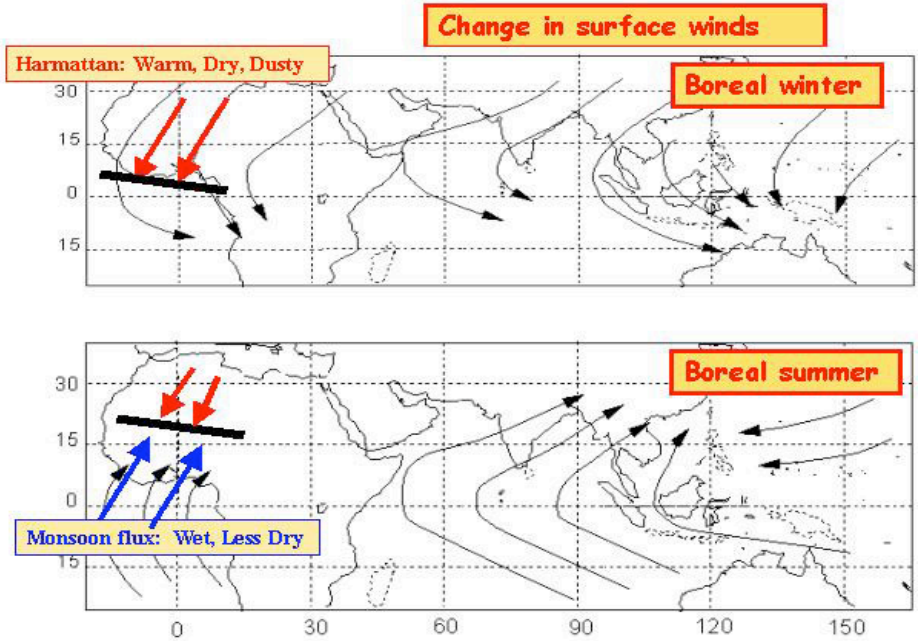
Mie theory

Extinction cross section (Qext, $m^2 \cdot g^{-1}$)

Single scattering albedo (SSA)

Asymetry parameter (g)

A: Dust impact on African Monsoon: SW forcing only

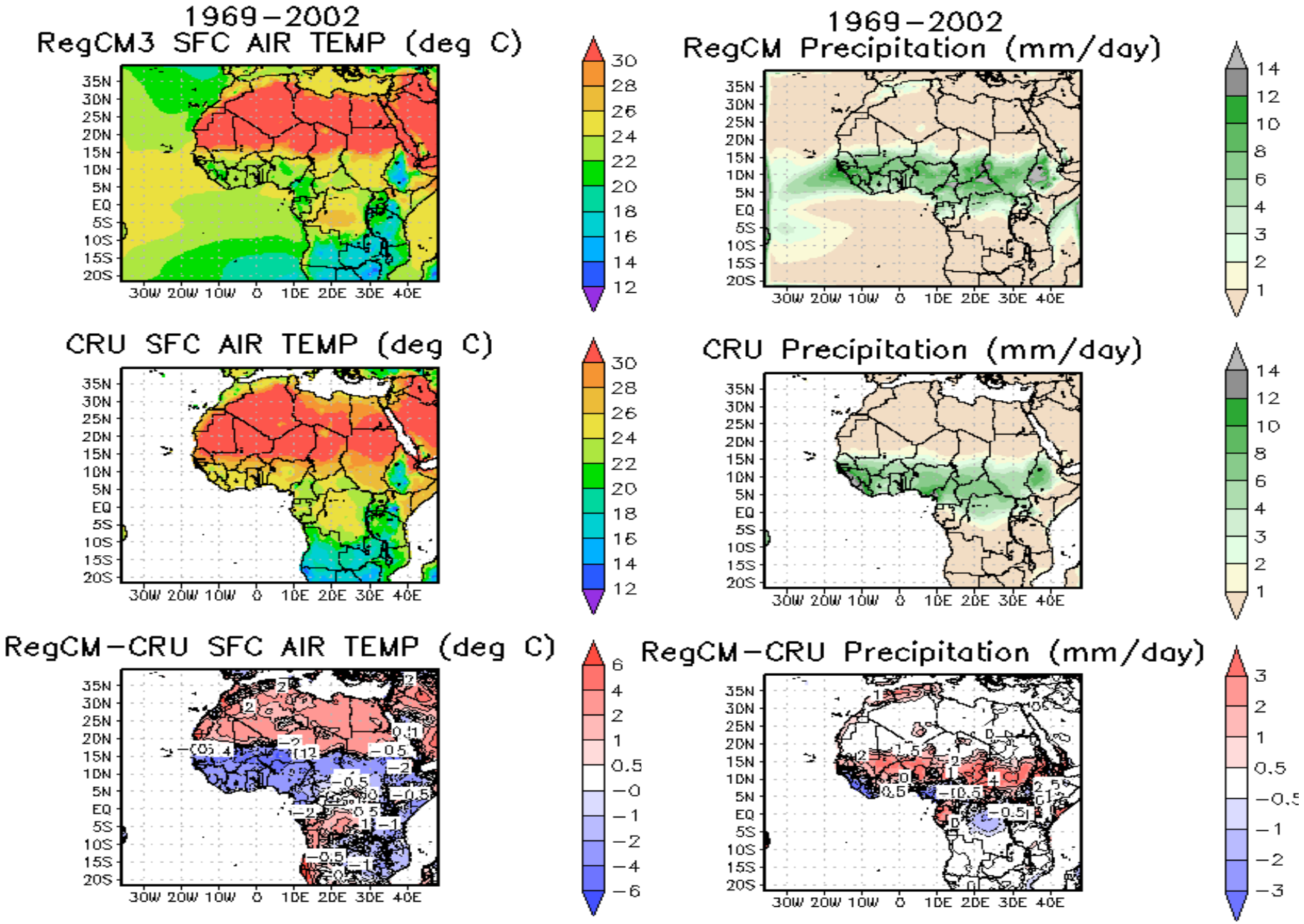


Experiment

RegCM

Control simulation : NODUST
Dust simulation : DUST Short Wave radiative impact
Simulation Period : 1969 to 2006, 60 km resolution
Boundary conditions : NCEP reanalysis
38 summer (JJAS) averages are discussed

Basic model climatology



Simulation of West African Regional Climate : jet dynamics.

JJAS 69-06

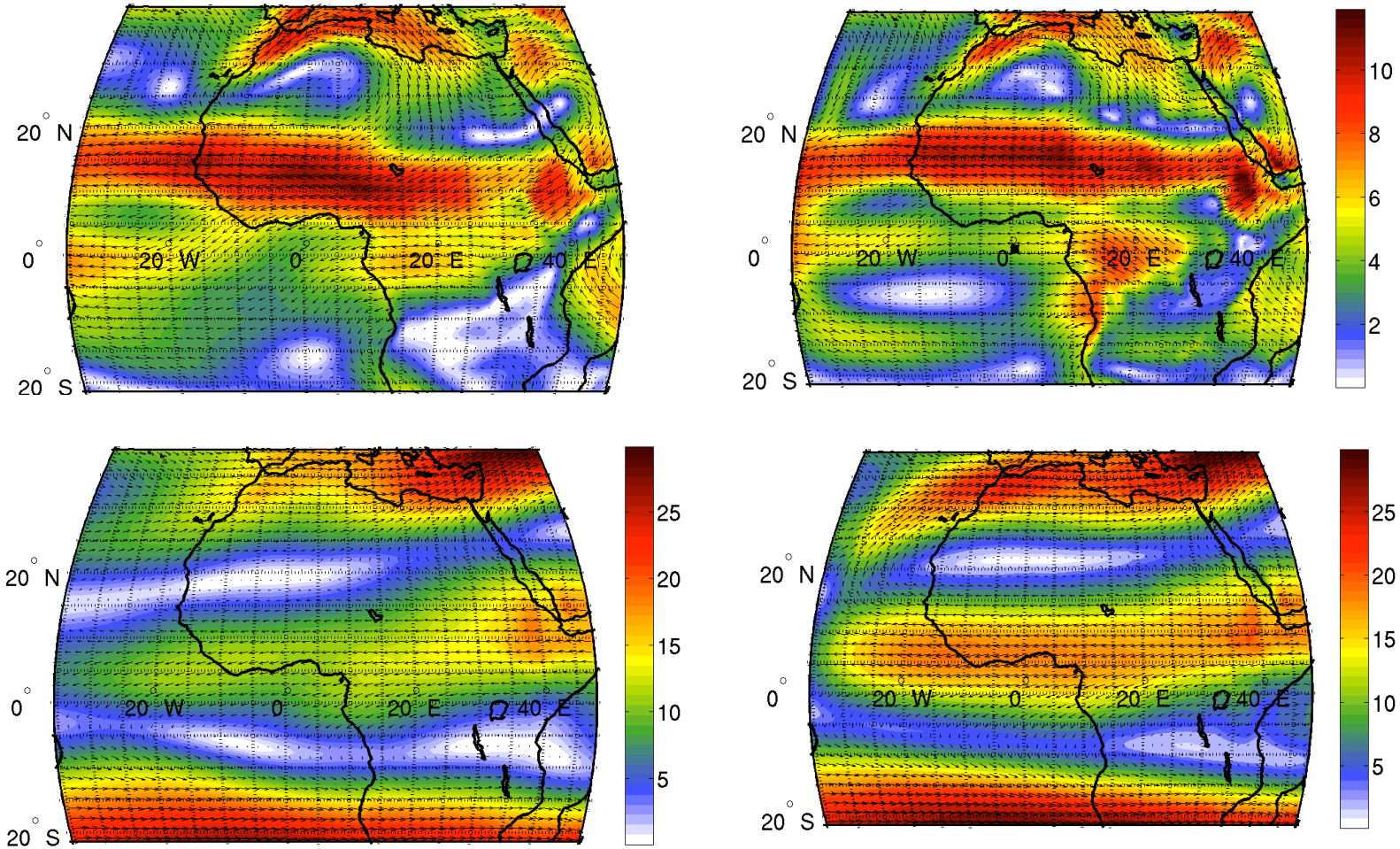
NCEP

RegCM (NODUST)

m.s-1

AEJ (670 hpa)

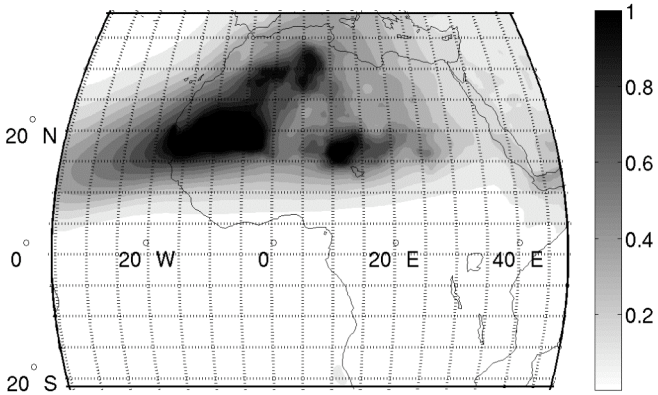
TEJ (195 hpa)



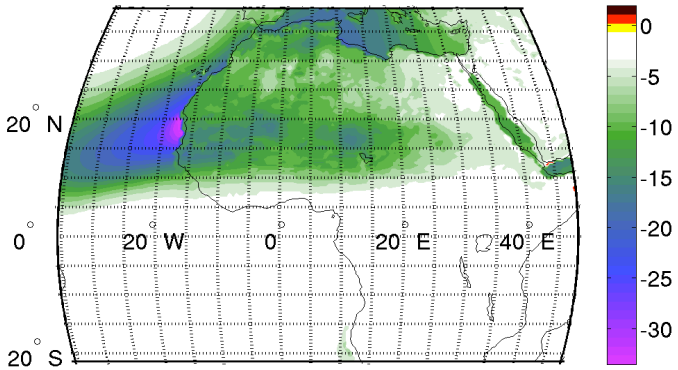
DUST SW radiative Forcing.

JJAS 69-06

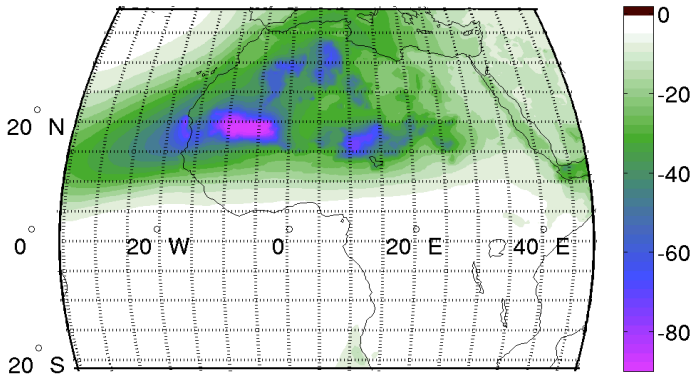
AOD



TOA (w.m-2)

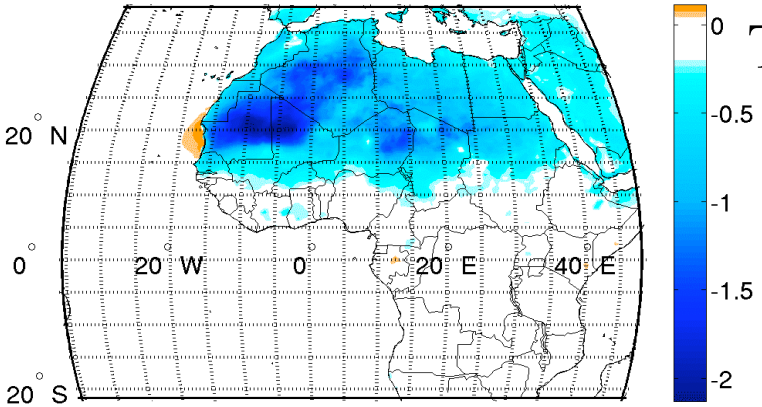


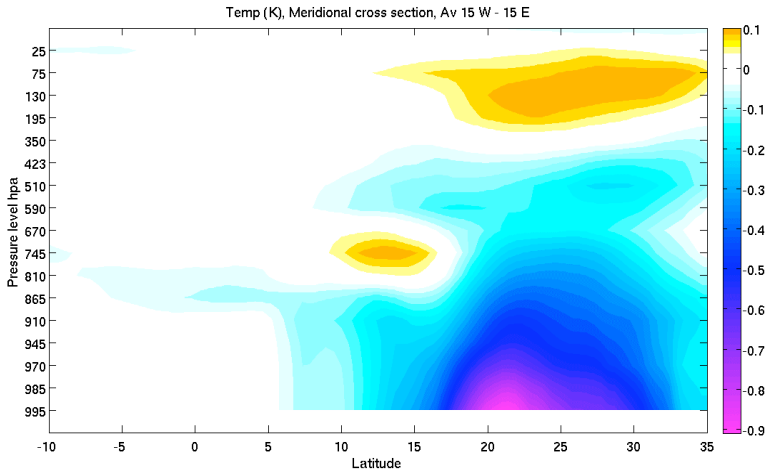
SRF (w.m-2)



Effect on average temperatures, DUST -NODUST

T10



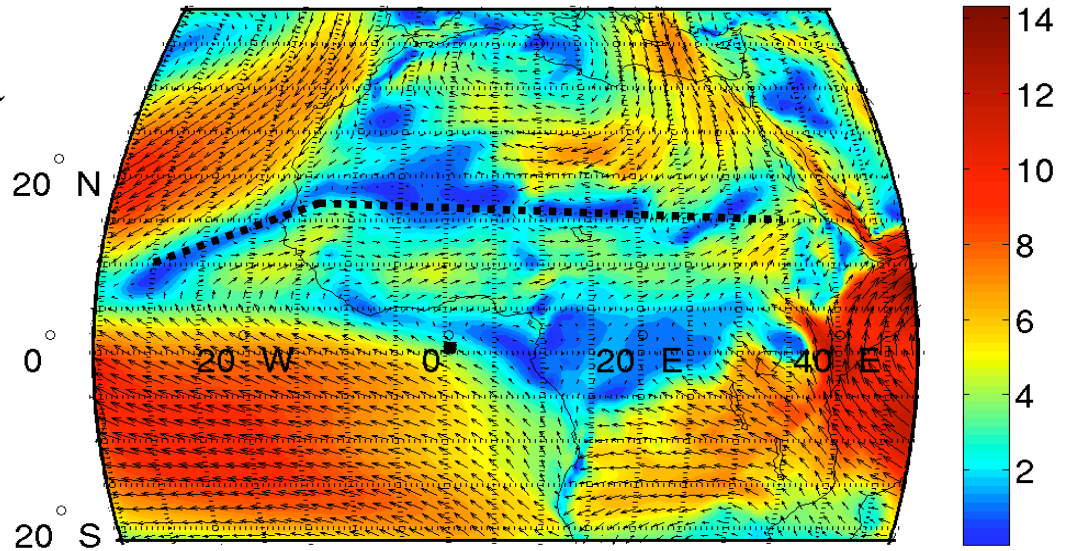


Dust impact on mean monsoon circulation

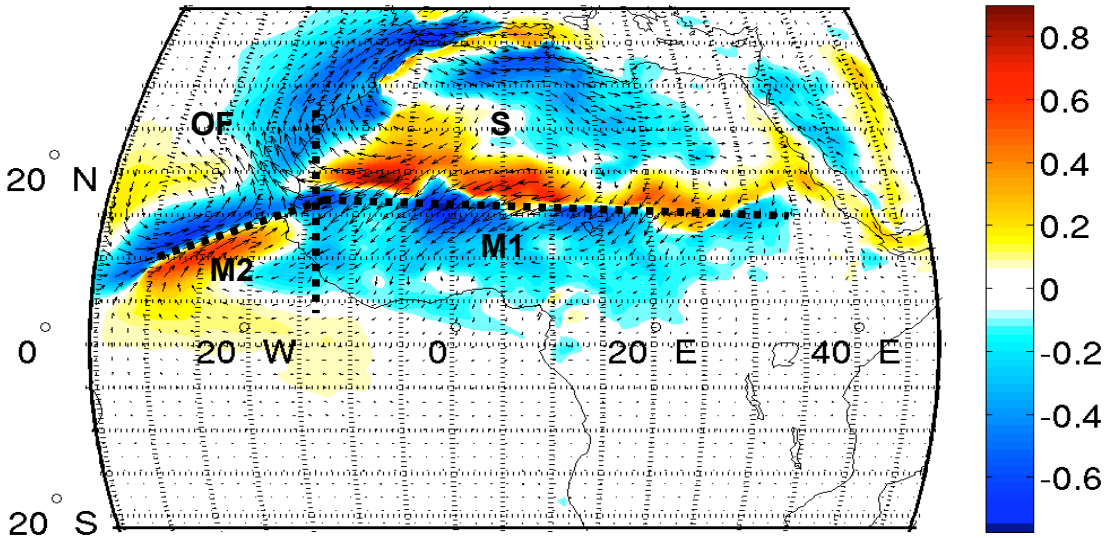
JJAS 69-06

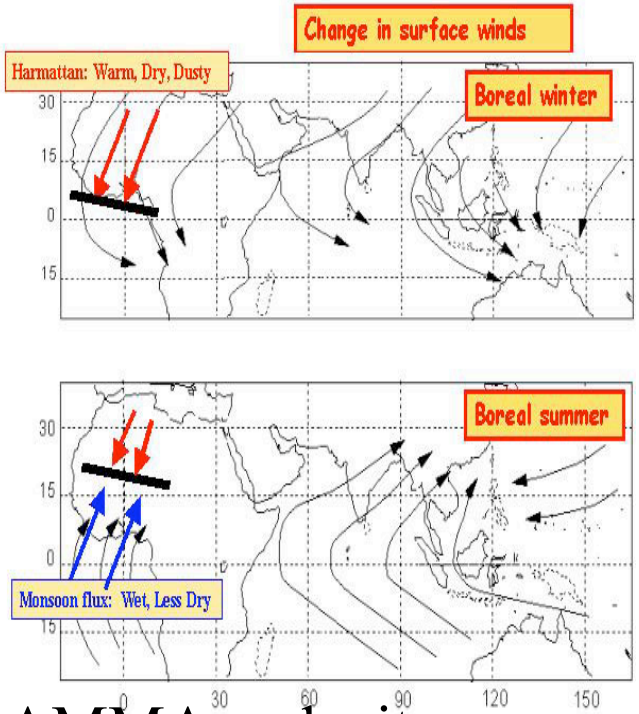
Wind field (m.s-1) at 865 hpa

(NODUST simulation JJAS 69-2002)

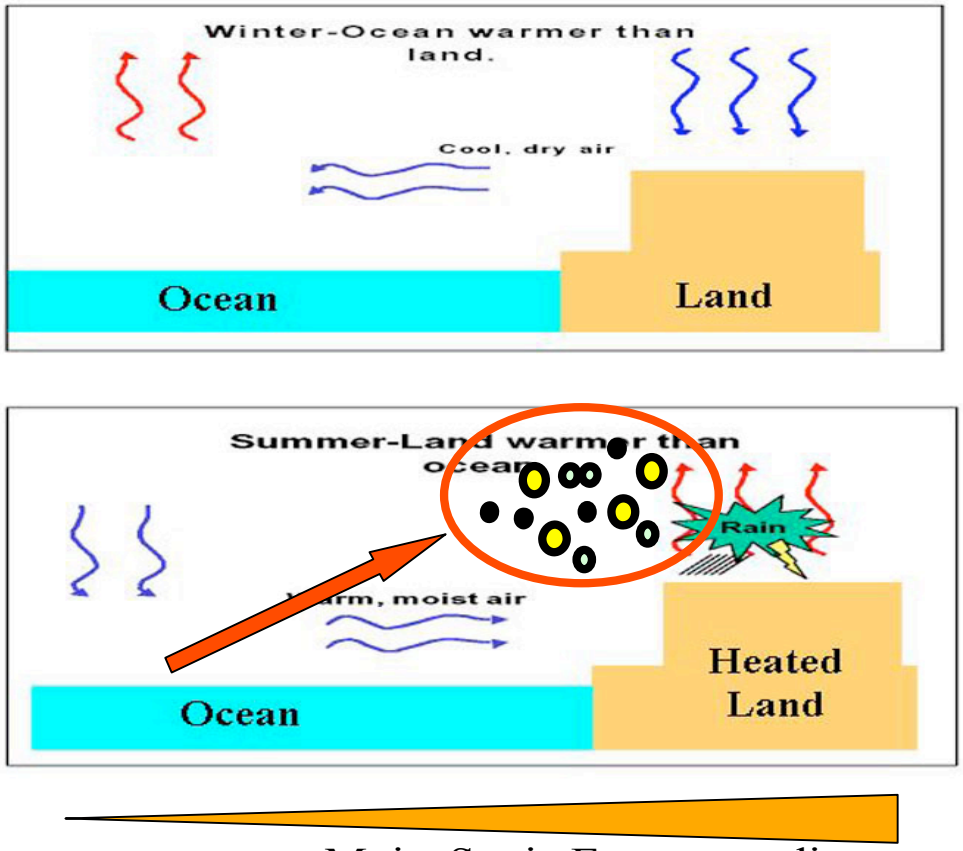


Differential circulation
(DUST – NODUST)





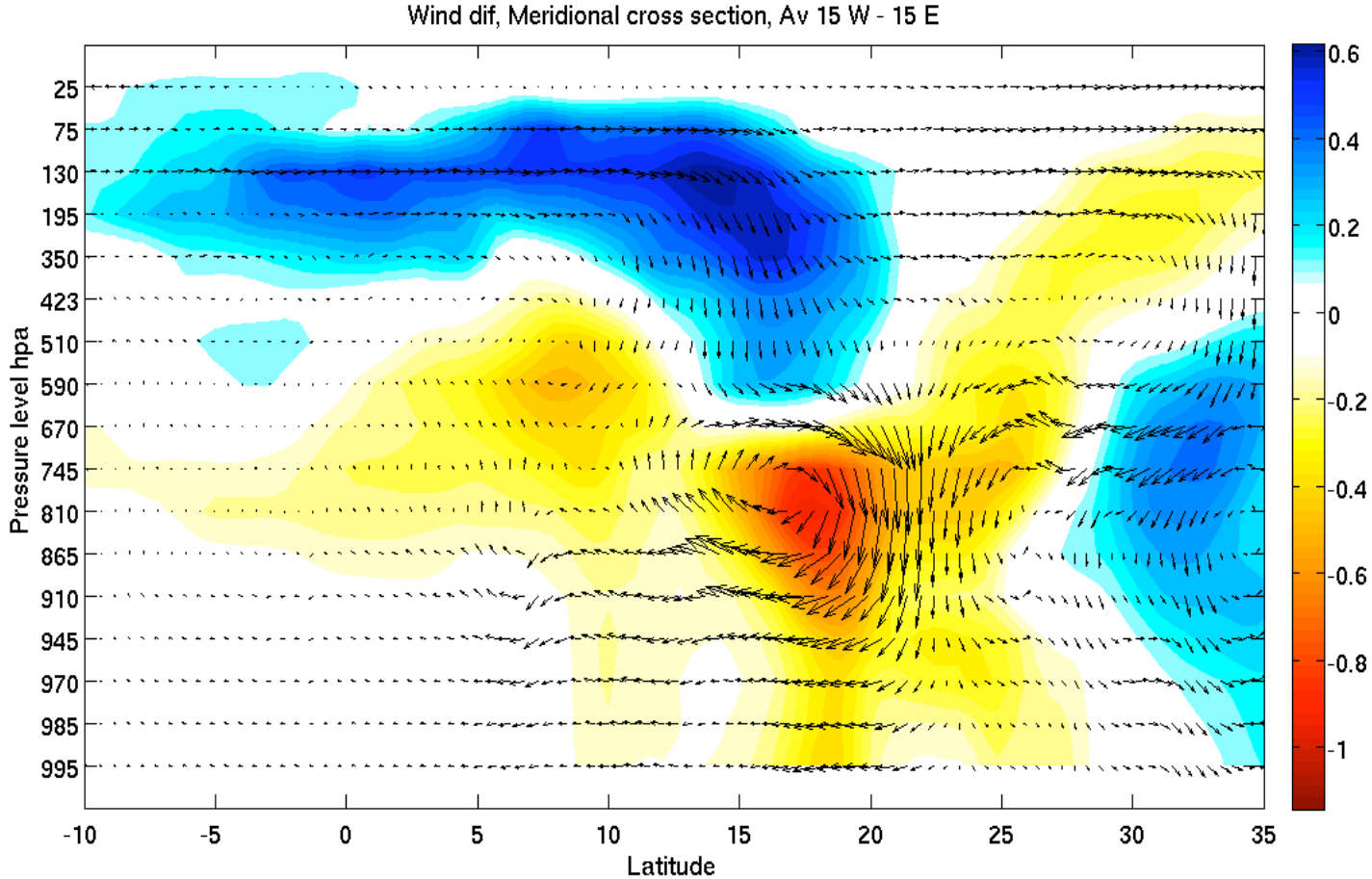
AMMA web site



Moist Static Energy gradient

Decrease of Moist Static Energy gradient

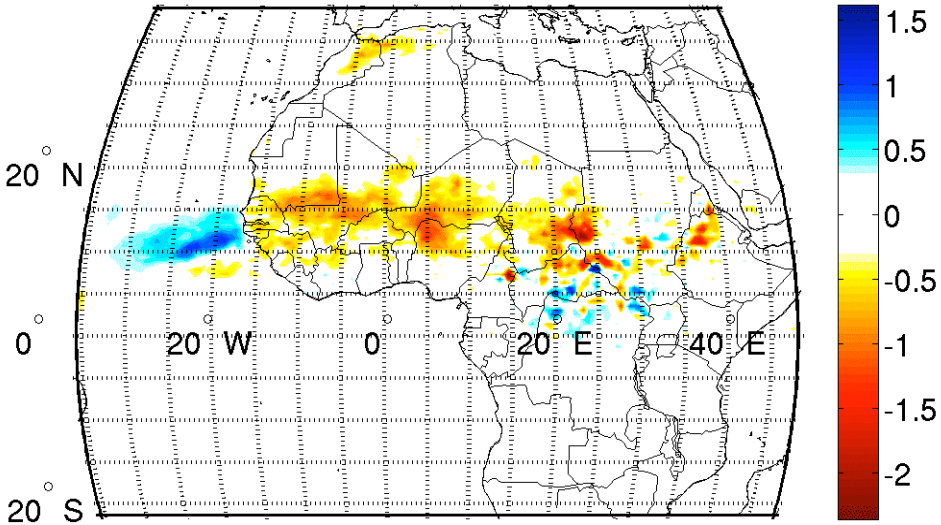
Dust impact on mean Monsoon and jet dynamic



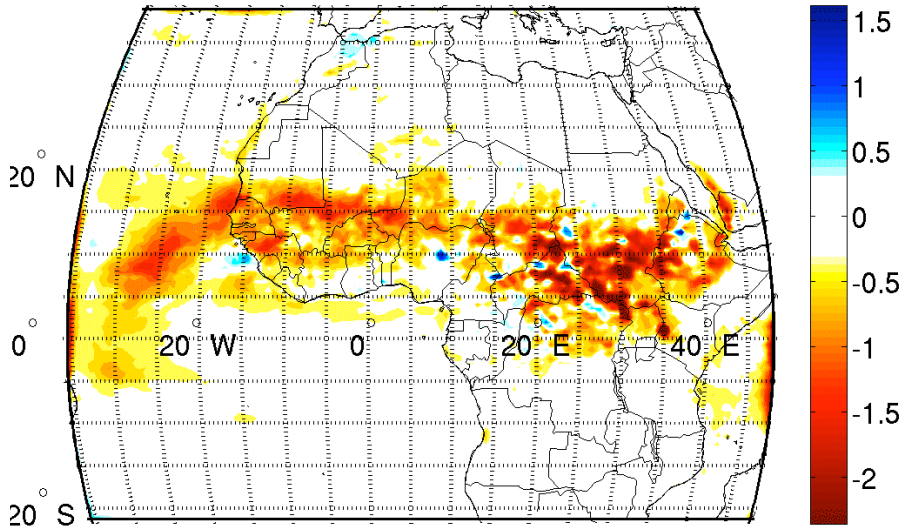
Effect of dust on wind field (JJAS, 1969-2006): Meridonal cross section of differential circulation between DUST-NODUST, averaged between 15W and 15E.
Colors show the differential zonal wind component (warm colors show an intensification of Easterly circulation and cold colors a decrease of Easterly circulation)
Arrows show the meridional and and vertical differential wind components.

Dust impact on mean precipitation and comparison with dry year mode.

mm.d-1



DUST - NODUST



DRY _ WET Years

Based on WMO standardized mean Sahel rainfall

Conclusion on dust SW forcing effect

Dust shortwave radiative forcing leads to a significant weakening of monsoon penetration driven by a strong surface cooling over the Sahelian region.

This reduction of Sahelian precipitations are associated with a strengthening of the AEJ and a weakening of the TEJ.

These are patterns observed during dryer years suggesting that dust could be a positive feedback in maintaining dry conditions over Sahel. These results in line with some recent global studies (e.g. Yoshioka et al., 2007) but in contradiction with others .

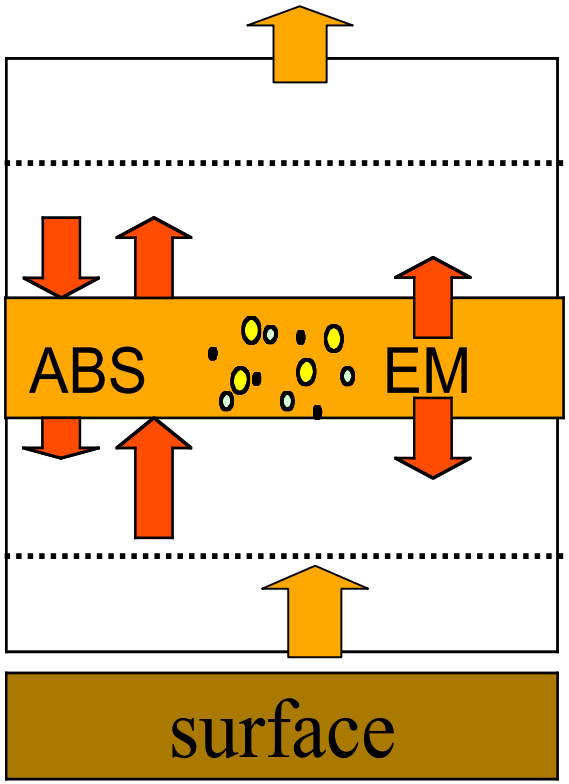
Limits of the study:

The main limit of this study is the lack of LW dust effect.

Over the ocean, SST are forced and do not react to dust radiative forcing.

Dust Long Wave radiative forcing

Atmospheric layers absorb and emit (grey body) in thermal radiation range.
Radiative equilibrium between layers



TOA LW Radiative forcing : difference of outgoing fluxes without and with aerosol

All other atmospheric and surface variables being fixed

> 0. = relative warming of the system (in most situation)

(LW trapping by dust)

SRF LW Radiative forcing : difference of net flux at the surface

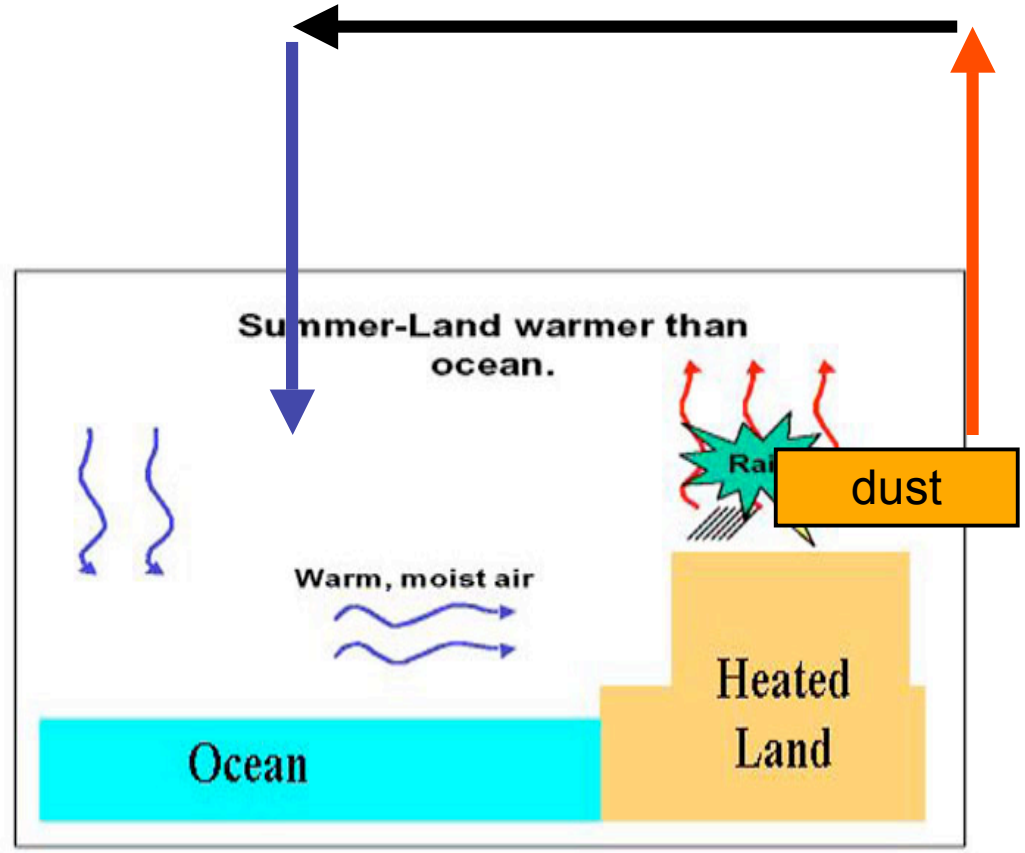
Always > 0. = relative warming of the surface (e.g at night time)

LW dust relative warming could cancel the dust SW cooling effect over bright surfaces
Which is now the climatic impact ?

Elevated heat pump hypothesis ?

Monsoon strenghtening by dust … An opposite conclusion to the previous result !

Lau et al. 2007, Miller et al. 2004.;



Could we obtain elevated heat pump effect over West Africa within the regional model ?

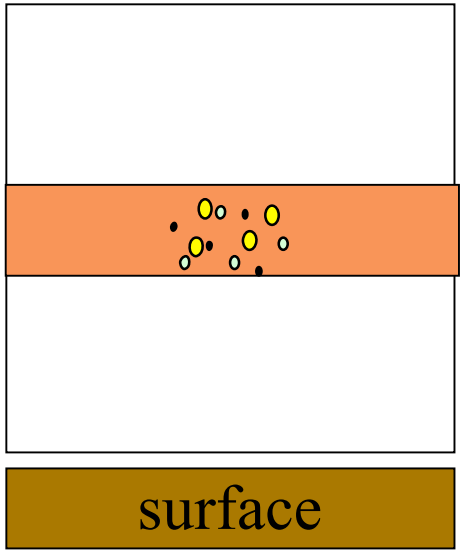
Introduction of the dust LW effect in RegCM

CCM LW radiation package

Absorptivity

Emissivity

$1 - e^{-D.Qa.DP(z)}$



DP(z) , 'dust path calculated' from the dust scheme

Qa (wl) = 0.1 $m^2.g^{-1}$

From Mie Theory

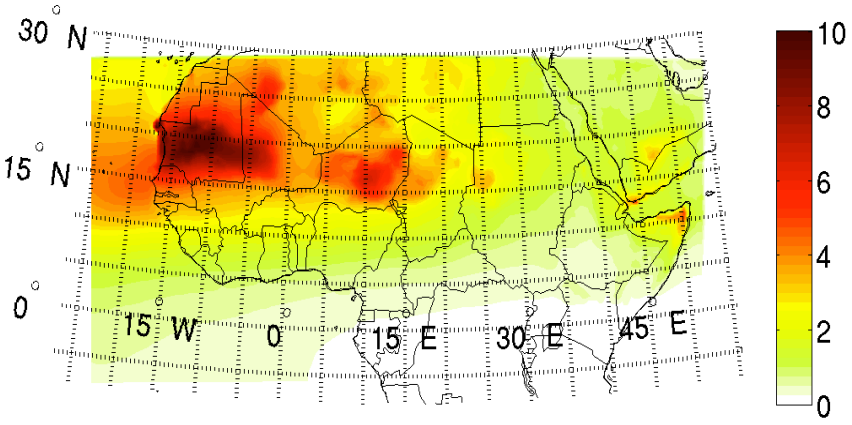
LW scattering is not explicitely included in the radiation scheme

CASE STUDY : Simulation JJA 2000-2004

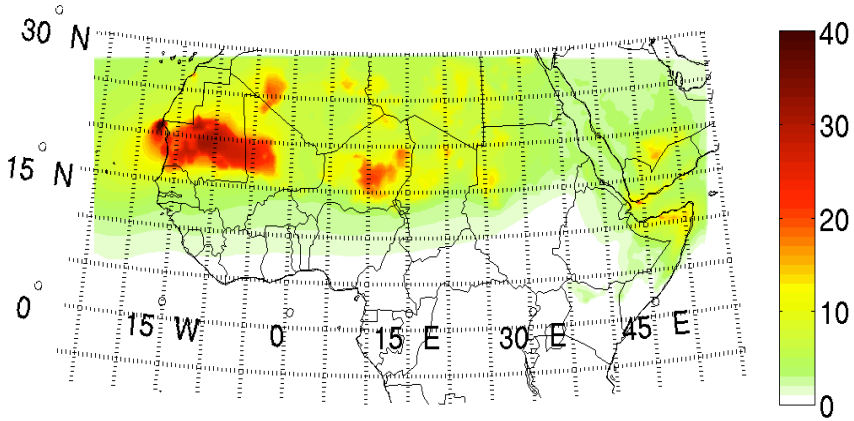
Dust Long Wave radiative forcing

TOA

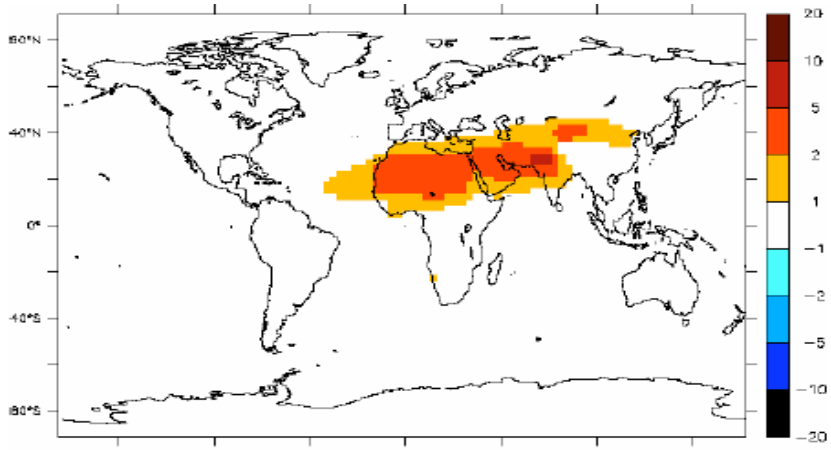
LW only (JJA 2000-2004)



SRF

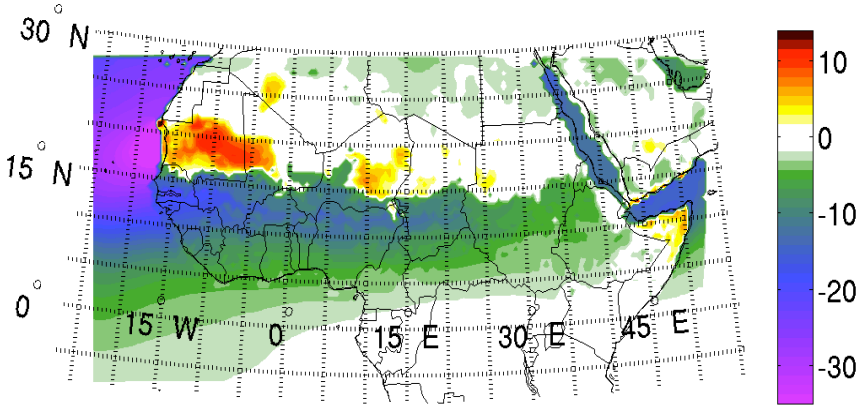


Depends strongly on surface temperature and burdens

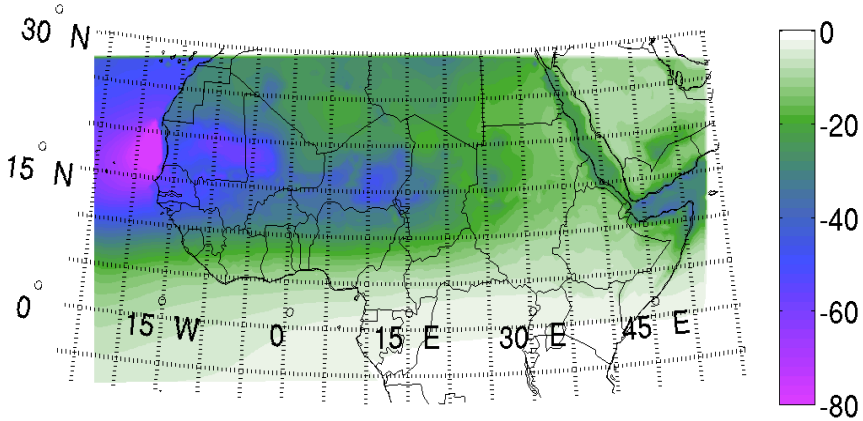


TOA LW forcing from Balkanski et al. 2007

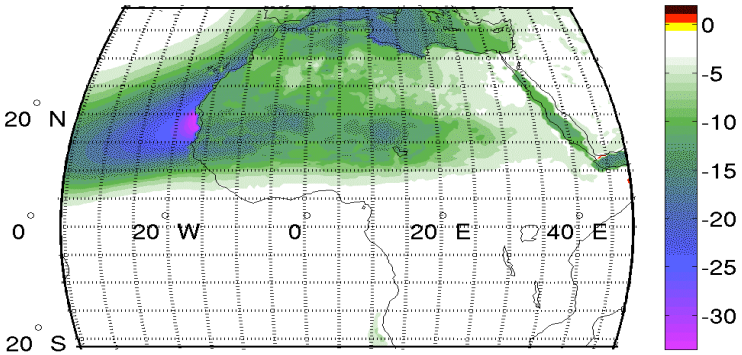
NET (SW + LW) TOA forcing



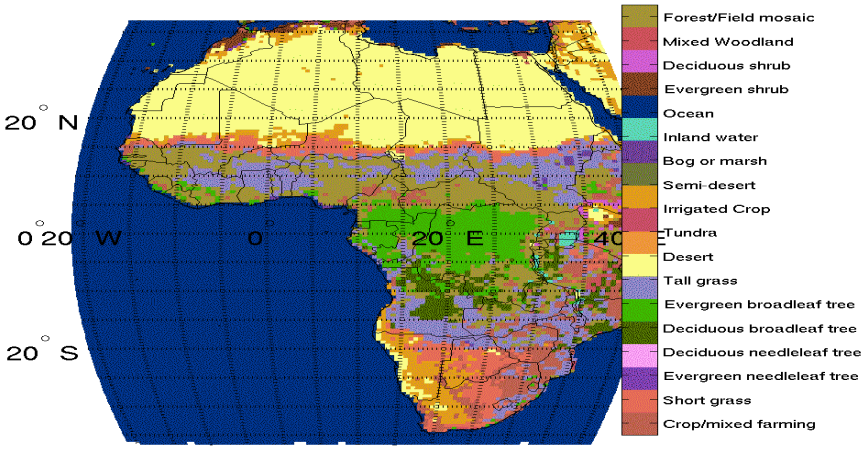
NET (SW + LW) SRF forcing



(30 year simulation discussed in part A, SW only)



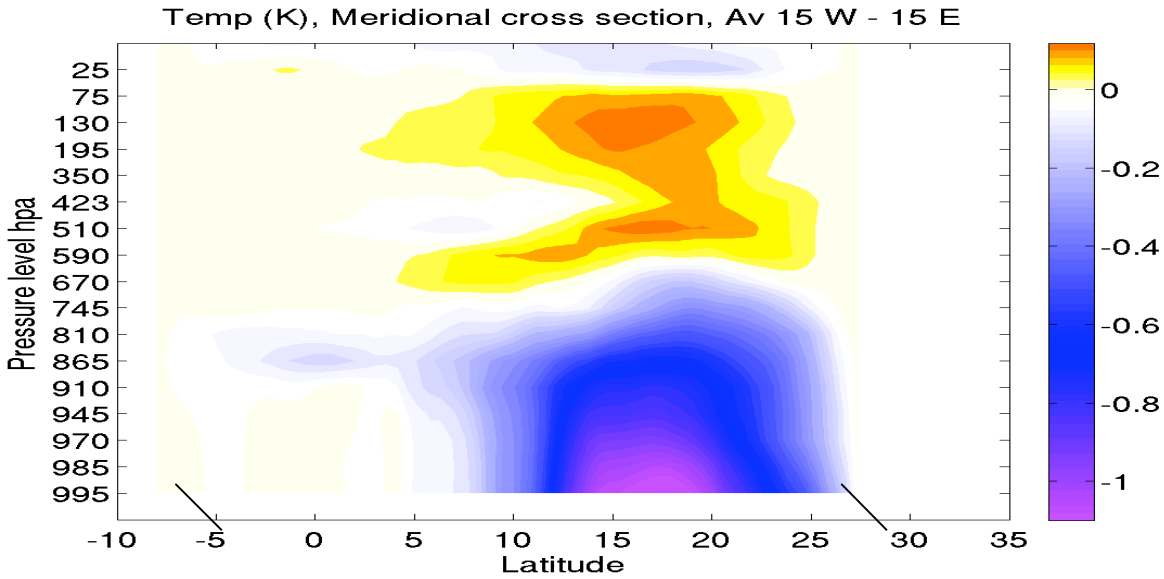
Land use



How will react the monsoon system ?

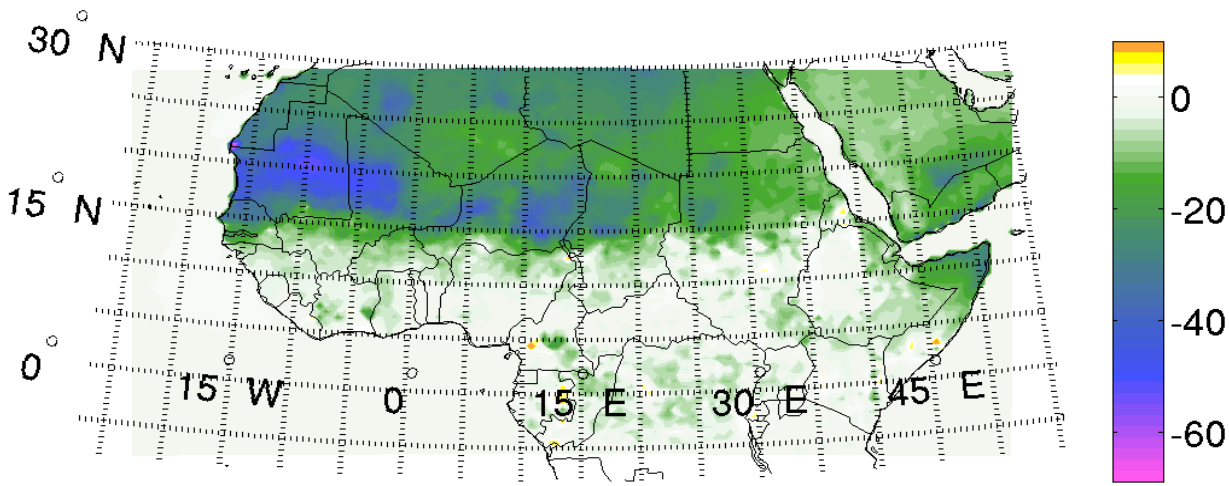
Can we obtain elevated heat pump effects ?

Temperature difference JJA (DUST_NODUST)



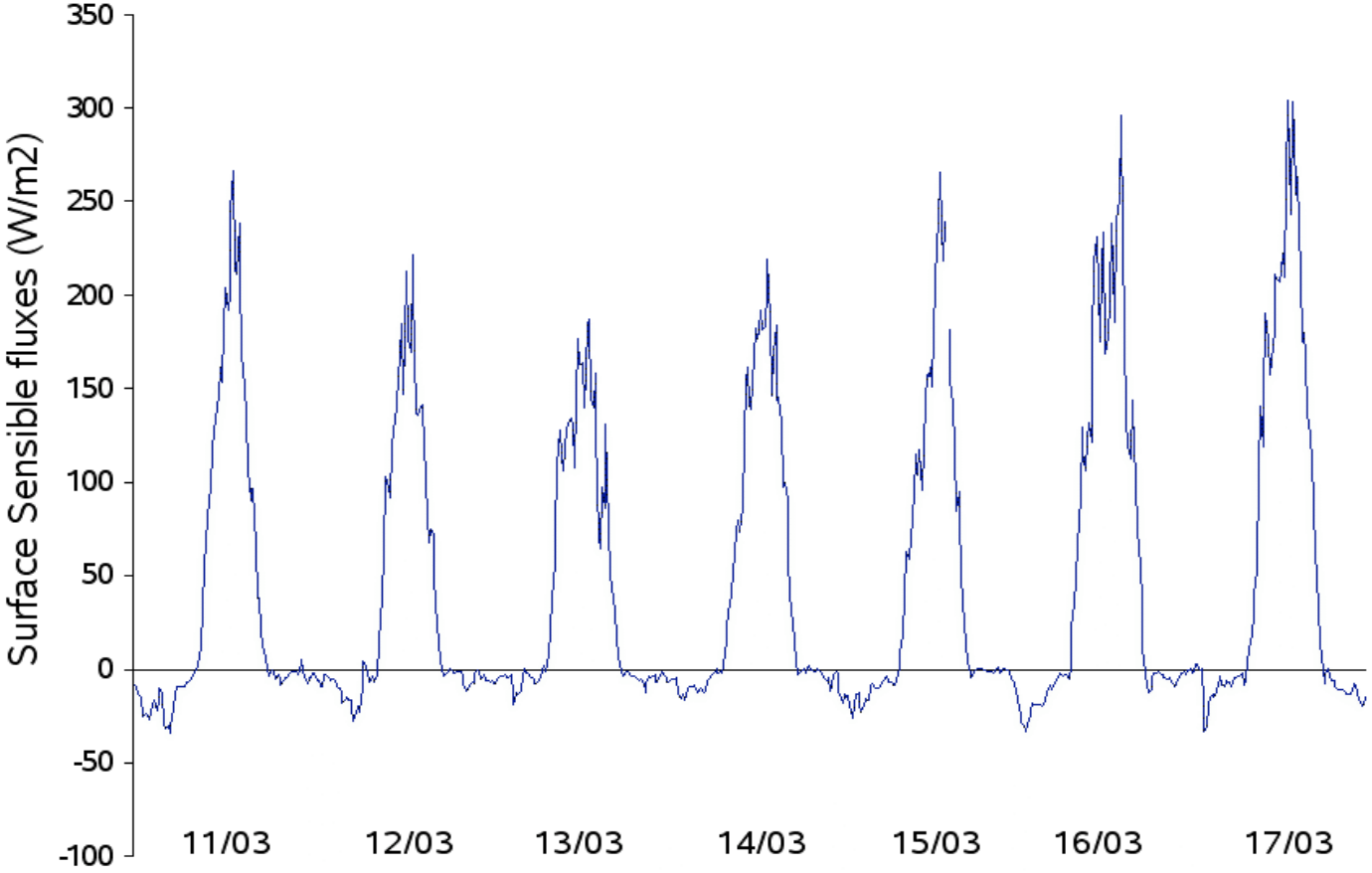
Cooling of the Lower troposphere despite a positive TOA …

Sensible heat flux difference (DUST-NODUST)



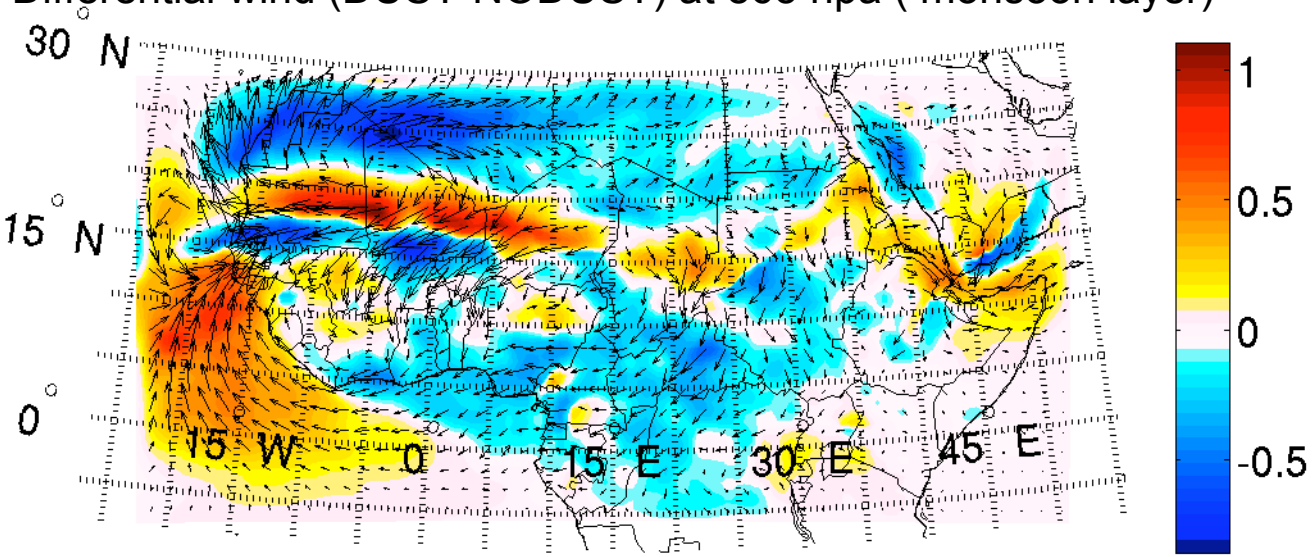
Role of the surface feedback to the SRF forcing

Measured Impact of dust on sensible heat flux during the March 2006 SOP



Dynamic response of the monsoon …

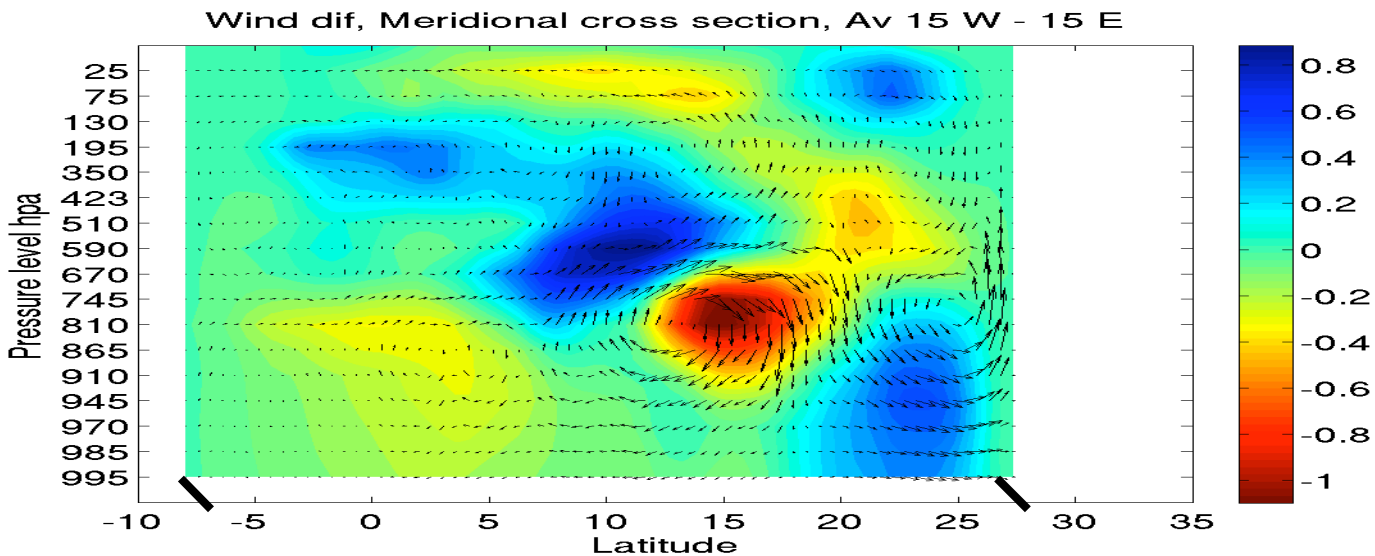
Differential wind (DUST-NODUST) at 865 hpa (monsoon layer)



Reduction of the mean monsoon flux

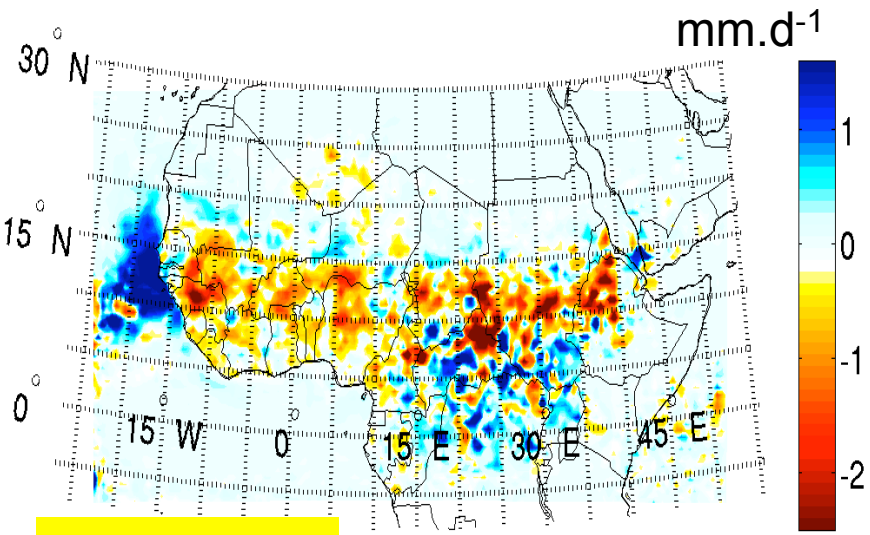
Intensification of the convergence west of 15W

Cyclonic circulation strentghening west of Senegal

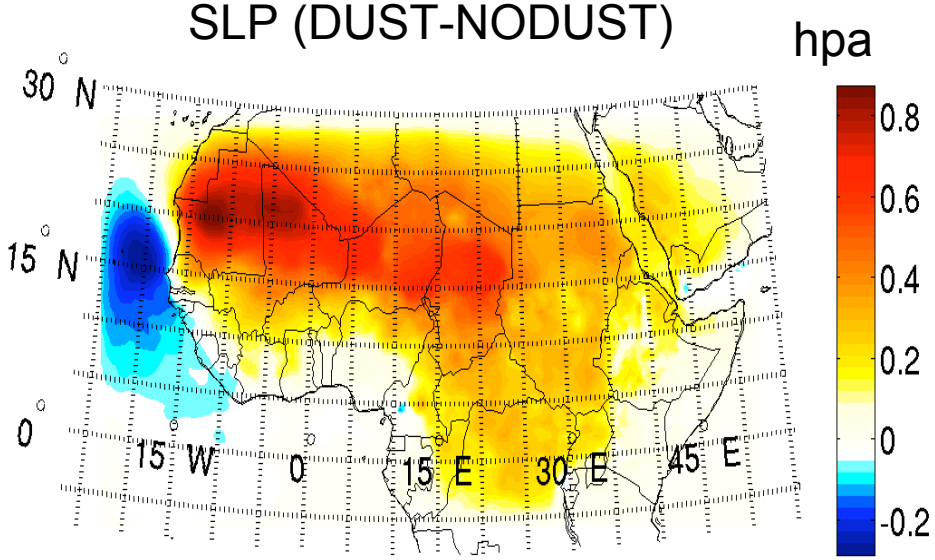


Still an intensification of AEJ and a weakening of TEJ

Impact on mean precipitation



SLP (DUST-NODUST)



Conclusions

Still a reduction of precip on Sahel despite the tropospheric LW heating effect.

Importance of surface forcing which drives a cooling of lower troposphere.

Precip reduction could be even more effective with LW because of an enhanced warming of Higher troposphere (convection inhibition)…

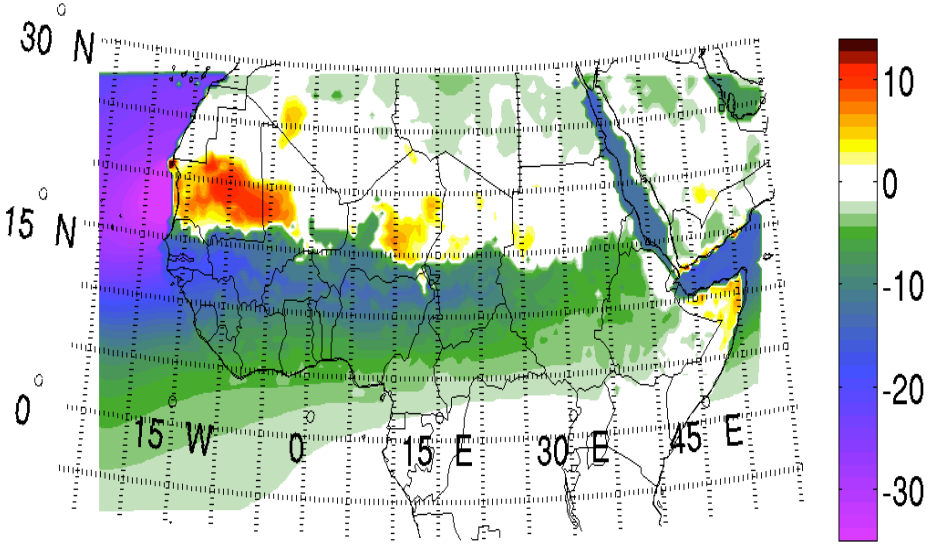
No elevated heat pump effect over Sahel on <u>climatic time scale.</u> No ocean feedback in the present study.

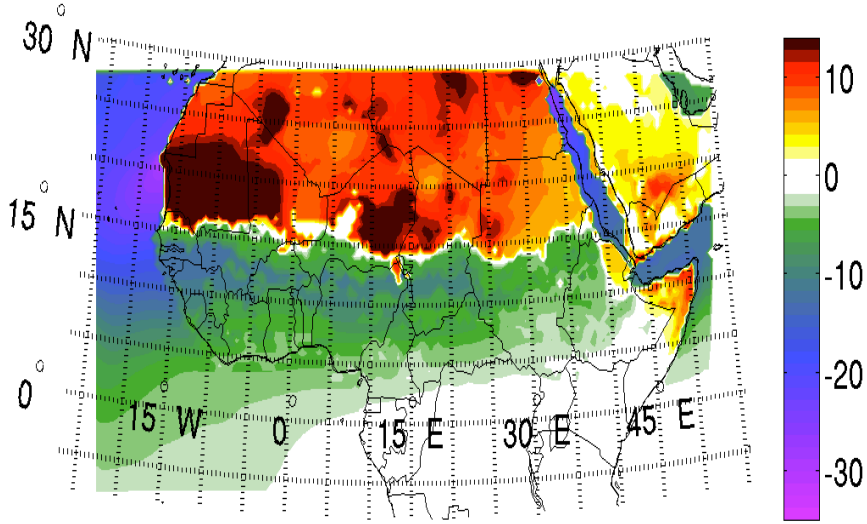
Interesting signal of enhanced low pressure system activity (west of Senegal): Impact of dust on African Easterly Wave activity ?

Added value of RCM compared to GCM on this domain

Optical properties of aerosols in this domain : A very sensitive issue

TOA net forcing (JJA 2003) W.m^{-2}





Dust SSA = 0.945

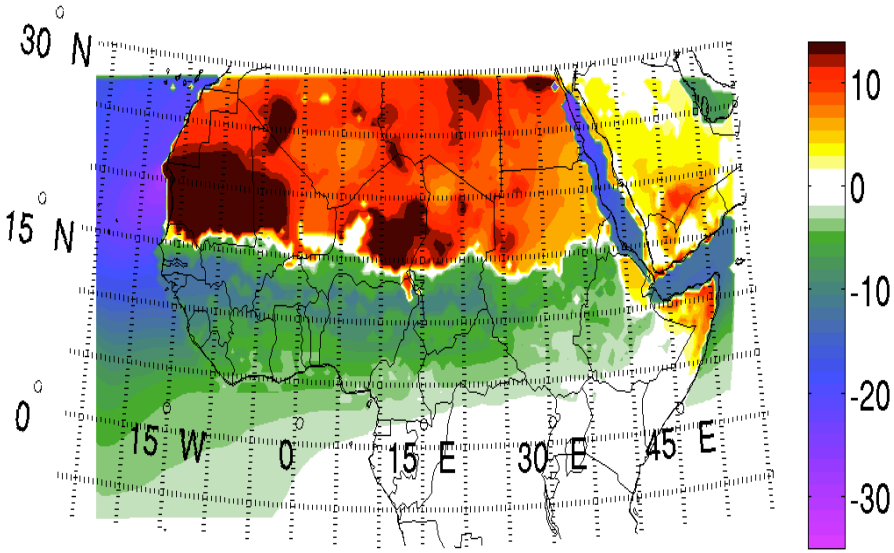
default in regcm

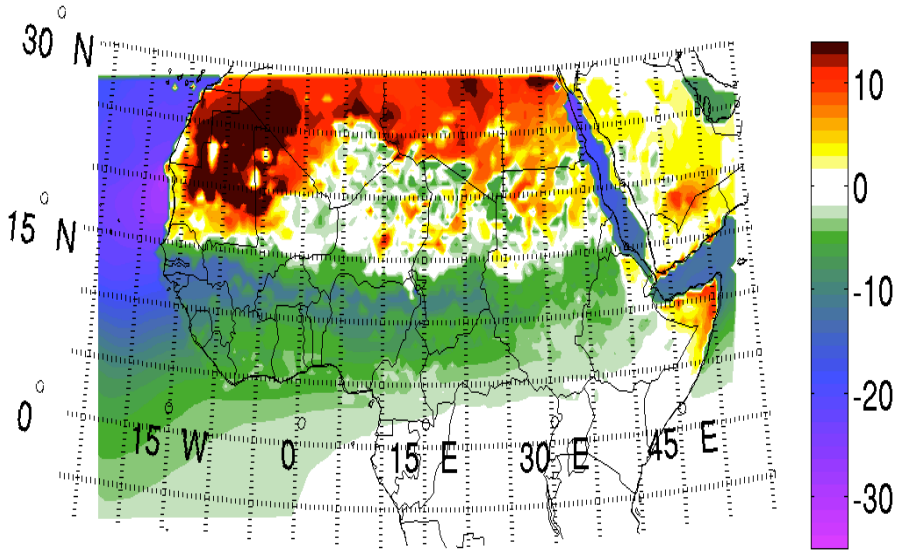
Dust SSA = 0.88

= more absorbing dust

Interesting feedback on dust radiative forcing : Soil color change with precip ..

TOA net forcing (JJA 2003 , wet year)





Dust SSA = 0.88

Bare soil albedo = fixed

Dust SSA = 0.88

Bare soil albedo modified by precip !

(default in RegCM)

… Still some work to do

- Longer simulations with LW effects are required.
- Variability of dust emissions and climate response, role in drought persistence.
- Role of land use change / dust emission. Significance of the signal ?
- Dust response to future climate scenarios
- Impact of on regional dynamic and mesoscale weather system (intensity and frequency). Use of Meso-scale and Regional Climate model.

Improvement of the RegCM dust scheme:

New land surface scheme. Source function in some region.

Dynamic issues : vertical transport.

More constraints on optical properties from regional measurements (AMMA …)

Dust mineral content

Heterogeneous chemistry

Effect of aerosol mixture (DUST, OC , BC …) on West African regional climate ?

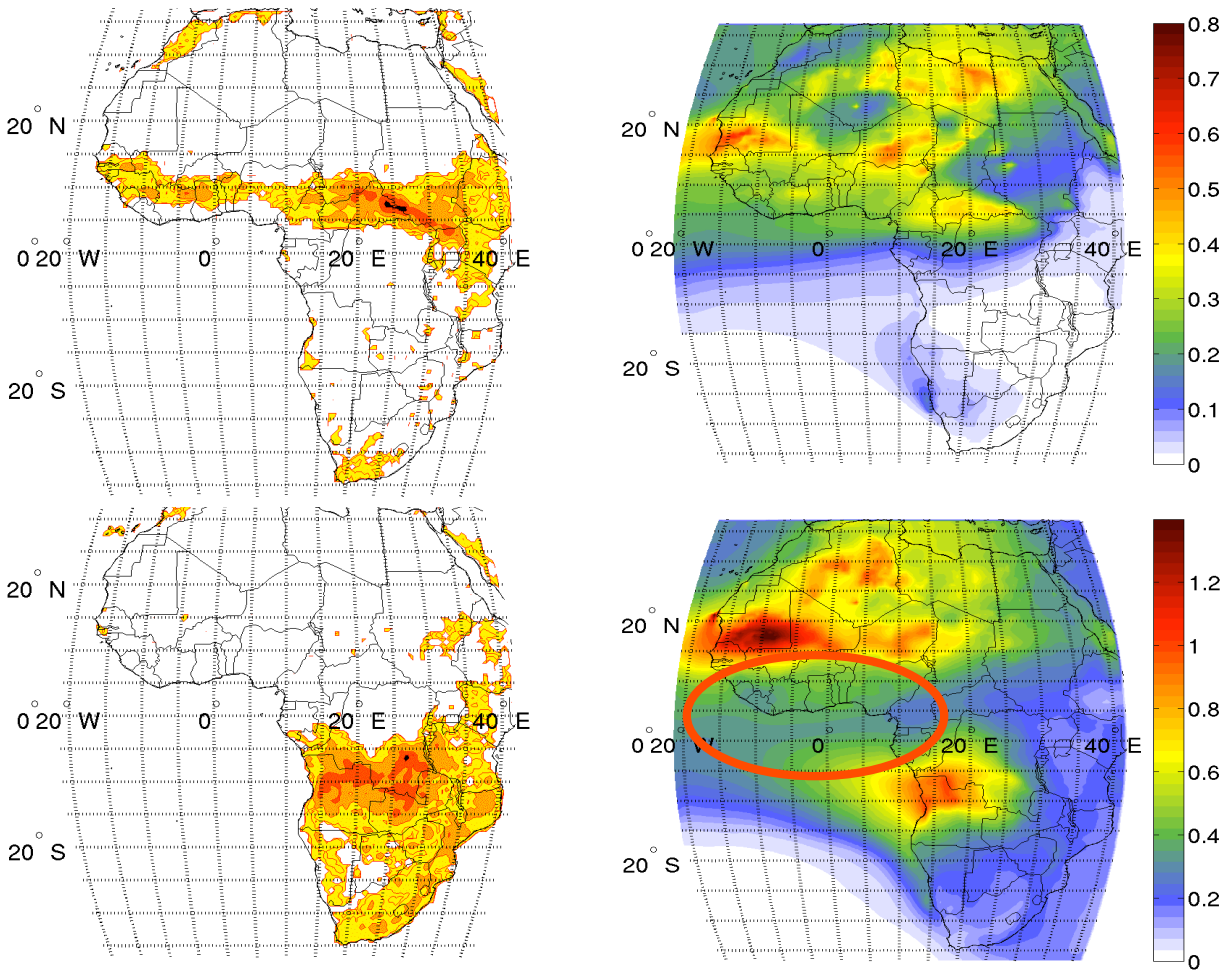
Seasonal BC (DJF – JJA 2006) emissions

contour =[0 0.01 0.1 1 5 10 15] mg.m-2.day

RegCM AOD

DJF

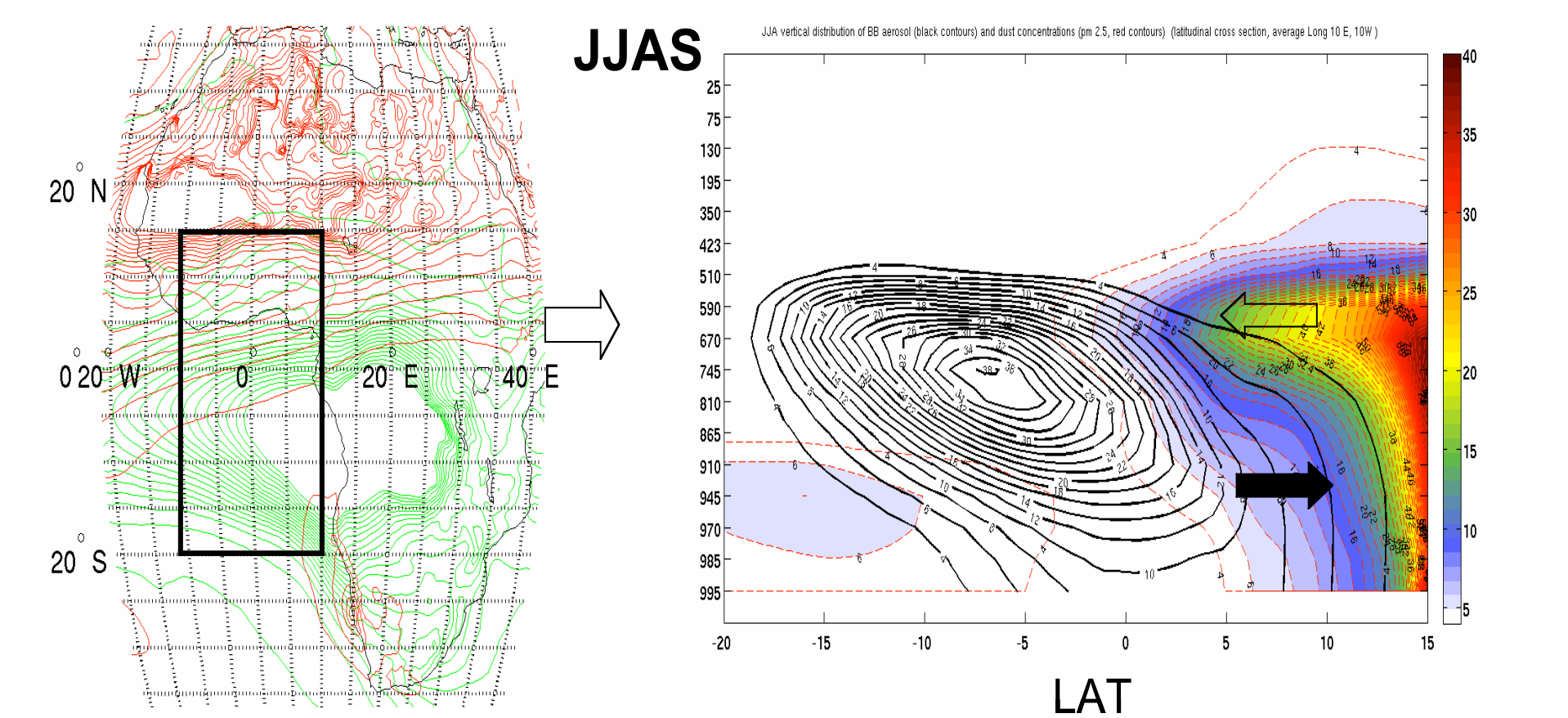
JJAS



Climatic signal of BB aerosol ?

Megacities in West Africa, which impacts ?

Aerosol mixing

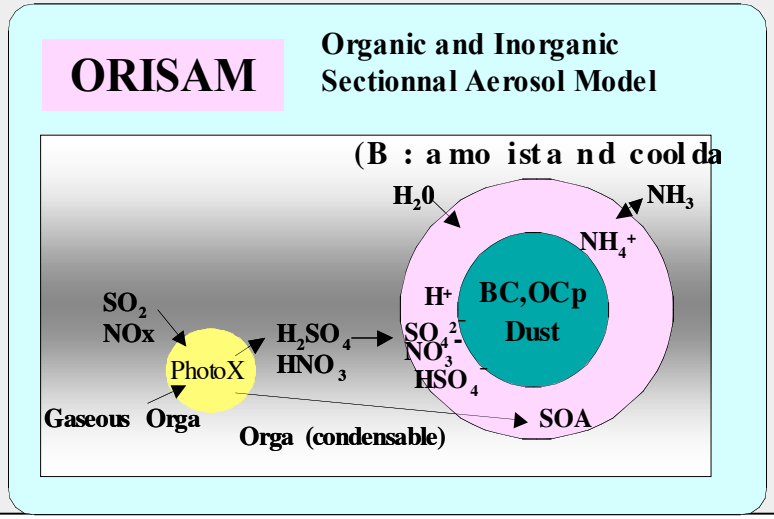


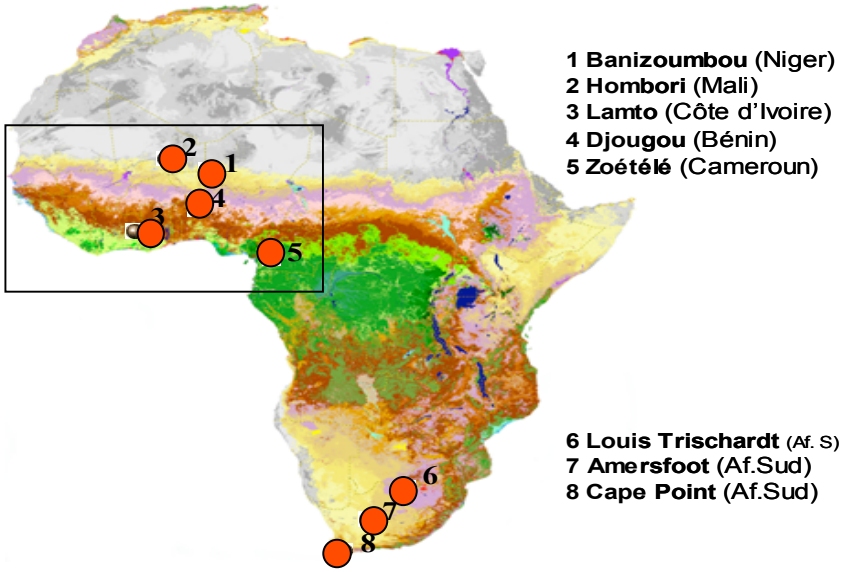
RegCM , dust + BB aerosols, JJAS 2005-2006

Mixing state and optical properties ? Needs more a more detailed chemstry scheme compatible with regional climate modelling

On going actvities at Laboratoire d'Aérologie

- Coating formation
- Coating composition (mineral dissolution, …)
- Optical and CCN properties





DEBITS IDAF activities

Validation and constraints

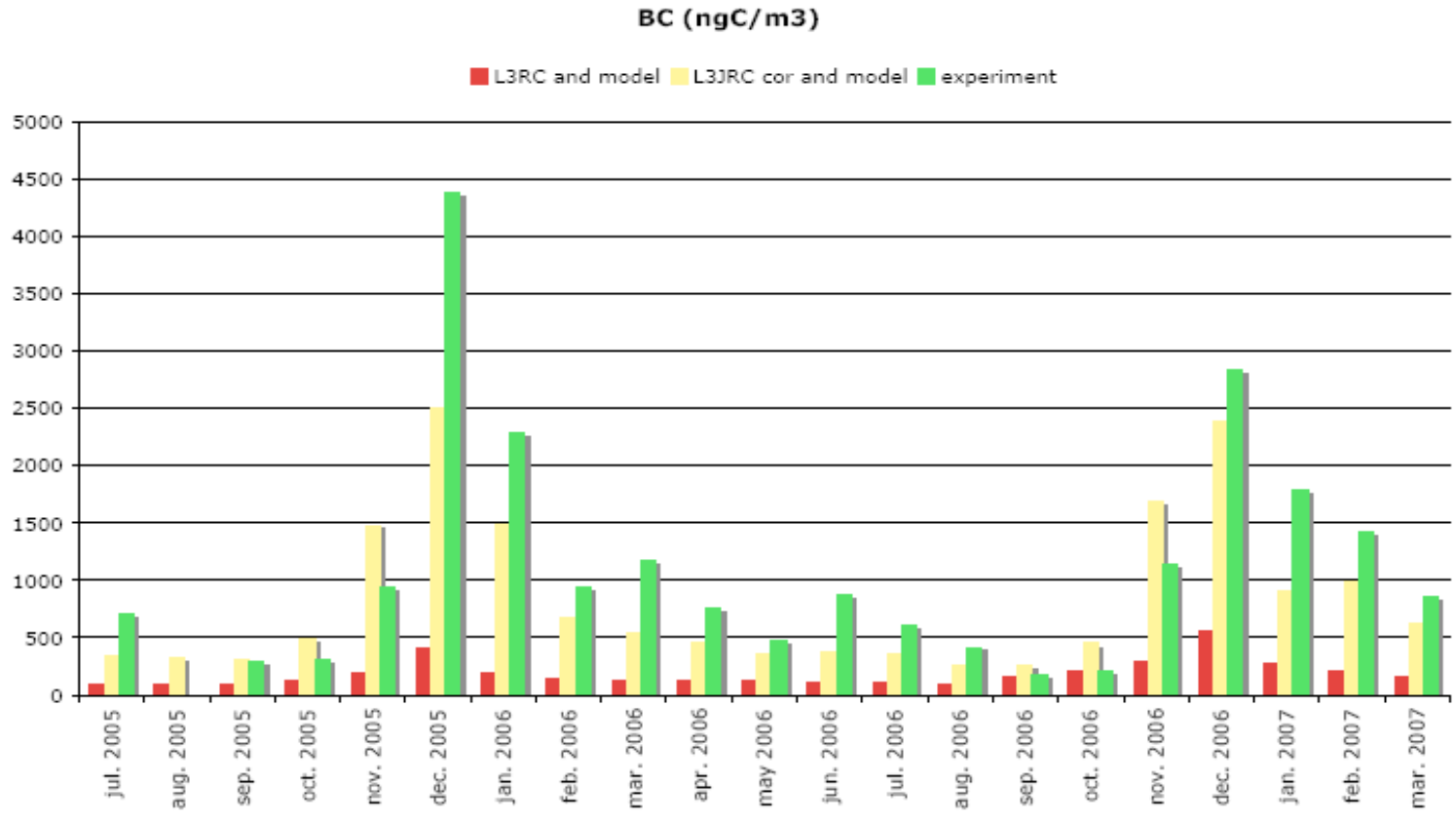
Regionalisation and impact studies

Promotion of modelling activities in Africa

RegCM

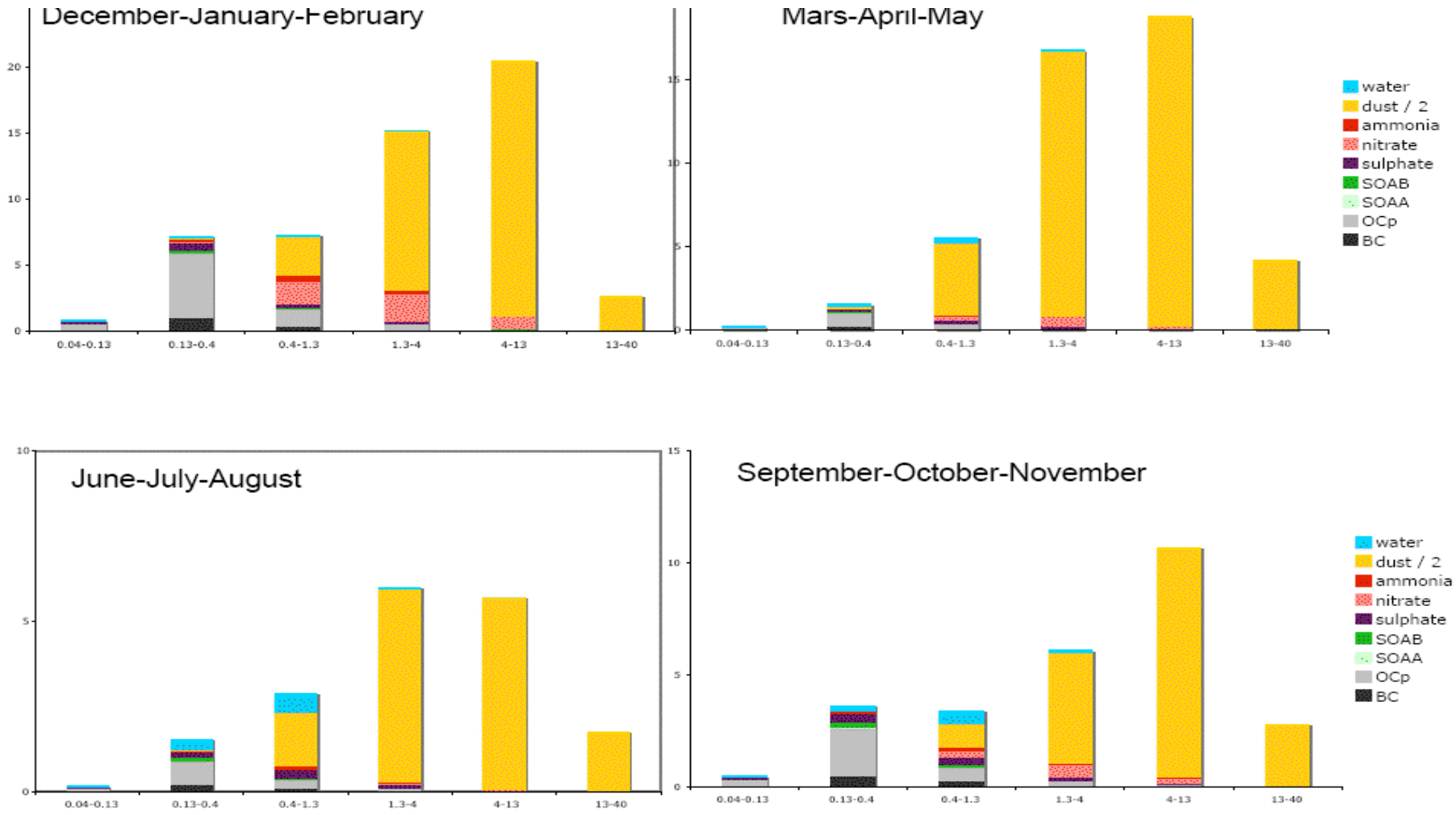
TM4 - ORISAM

Djougou (Benin)



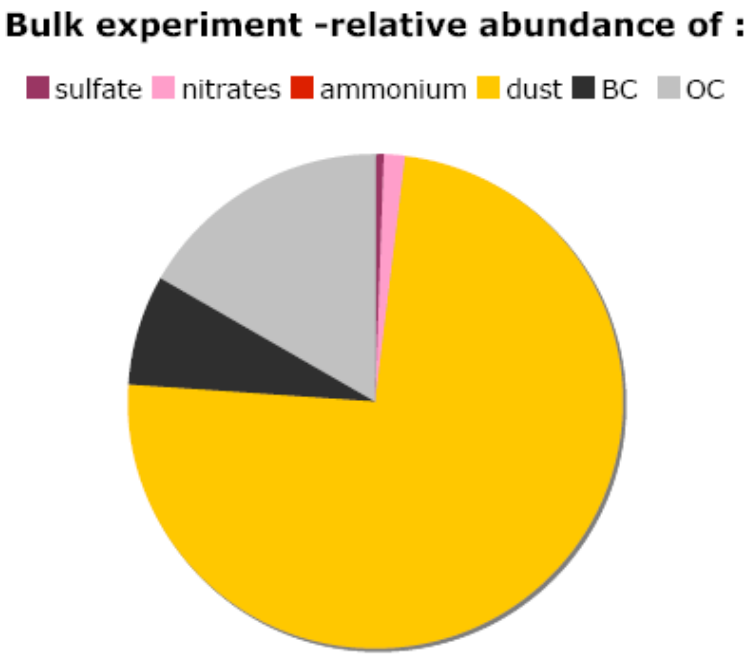
TM4 – ORISAM

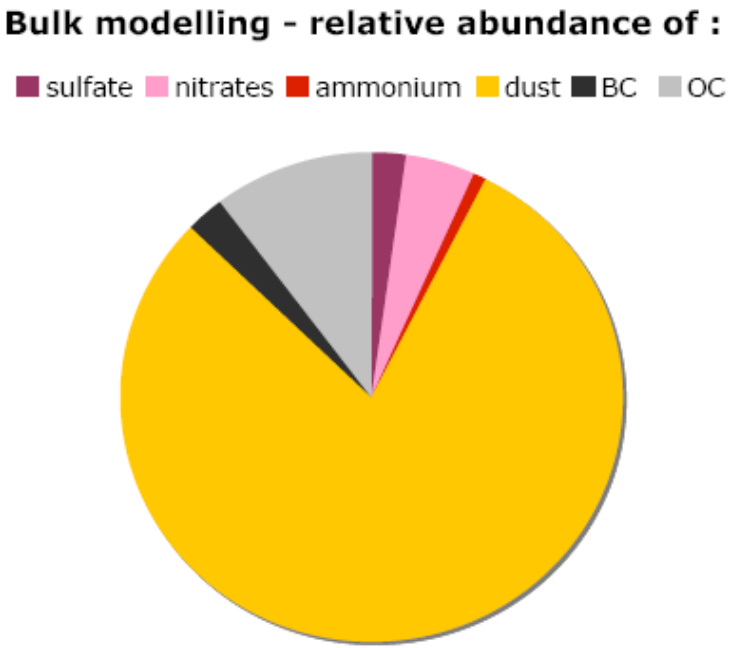
Djougou (Benin)



Djougou (Benin)

TM4 –ORISAM vs OBS





THANK YOU !