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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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)
- Satellite observations

‘Contrasted’ results

Continental domain

Regional climate approach

Oceanic domain
Dust aerosol on-line module in the ICTP RegCM3 model

No cloud microphysics interaction!

Zakey et al., 2006
Solmon et al., 2006
Marticorena and Bergametti, 1995.
Alfaro et al., 1998.

Dust module in RegCM3

10 µm – 10000 µm

0.01 – 20 µm

Transport and removal

Sand-blasting

Saltation

Wind

Soil granulometry

10 µm – 10000 µm

Surface properties

(roughness, humidity, vegetation)

RegCM3 regional climate model

SVAT scheme

δ

δF_{LE,H}

Radiation scheme

(SW+LW)

Absorption
diffusion
emission

δ

δ\left[ \frac{\partial T}{\partial t} \right]_{\text{rad}}
In this study: Grell + FC, Resolution of 60 km!
Comparison with observations

MISR AOD

JJA
(2000-2006)

RegCM AOD

RegCM
Lidar
M’Bour

Extinction (km⁻¹)

Red lines represent RegCM, green lines represent Lidar, and blue lines represent M’Bour.
Dust radiative forcings

Compares well with Li et al., 2004
(TOA) : -35 W/m^2/AOD , (SRF) -65 W/m^2/AOD

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

Diabatic heating (96-06)
dif (dust-nodust) K/day

Saharan Air Layer
Average dynamical and precipitation response to dust over Sahel

( NODUST, JJA 1996-2006)
Mean circulation at 865 hpa

( DUST - NODUST, JJA 1996-2006)
Differential circulation at 865 hpa

RegCM precip (JJA 1996-2006)

Res = 60 km
Cloud water, meridional circulation and precip. difference (DUST-NODUST) 15W-15E average

1: Weakening of the ‘monsoon pump’

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

Solen et al., 2008
Seasonnal evolution of dust impact on precipitation (JJA 1996-2006)

NODUST

10-22 N meridional average

DUST
Comparison (and contradiction!) with recent GCM studies …

Lau et al., 2009 (angeo special issue)

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

Sud et al., 2009 (angeo special issue)

Since we have many processors, we are going to extend our domain !
Extended domain, 60 km resolution

JJA 1996-2006

AOD

Psea (dust – nodust)

Qc + vertical circulation (dust – nodust)
Does this change precipitation anomaly over Sahel?
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.

SSA ~0.95 (fine dust)

SSA ~0.90

Image SSA ~0.99
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
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 ($\delta_{COV}$), cloud top temperature ($\delta_{CTT}$), ice phase fraction ($\delta_{IPF}$), liquid phase effective radius ($\delta_{Re(liquid)}$) and warm rain likelihood ($\delta_{WRL}$) within the Harmattan flow of the monsoon season.

<table>
<thead>
<tr>
<th>sensor</th>
<th>dust load</th>
<th>$\delta_{COV}$</th>
<th>$\delta_{CTT}$</th>
<th>$\delta_{IPF}$</th>
<th>$\delta_{Re(liquid)}$</th>
<th>$\delta_{WRL}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODIS</td>
<td>moderate</td>
<td>$-20.84%$</td>
<td>$+14.07,K$</td>
<td>$-16.90%$</td>
<td>$-2.39,\mu m$</td>
<td>$-0.27$</td>
</tr>
<tr>
<td></td>
<td>heavy</td>
<td>$-14.73%$</td>
<td>$+12.06,K$</td>
<td>$-14.15%$</td>
<td>$-3.16,\mu m$</td>
<td>$-0.35$</td>
</tr>
<tr>
<td>SEVIRI</td>
<td>moderate</td>
<td>$-21.31%$</td>
<td>$+12.37,K$</td>
<td>$-15.78%$</td>
<td>$-$</td>
<td>$-$</td>
</tr>
<tr>
<td></td>
<td>heavy</td>
<td>$-21.68%$</td>
<td>$+14.89,K$</td>
<td>$-22.88%$</td>
<td>$-$</td>
<td>$-$</td>
</tr>
</tbody>
</table>
### Response to dust forcing vs. Precipitation bias.

#### Region (15W-15E average)

<table>
<thead>
<tr>
<th>Region</th>
<th>5 N – 10 N</th>
<th>10 N – 17 N</th>
<th>17-N 20 N</th>
</tr>
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<tbody>
<tr>
<td><strong>OBS</strong></td>
<td>CRU</td>
<td>TRMM</td>
<td>CRU</td>
</tr>
<tr>
<td>Bias (mm/day and %)</td>
<td>-1.23 (-20.3 %)</td>
<td>-1.23 (-24%)</td>
<td>+1.09 (+20%)</td>
</tr>
<tr>
<td>(DUST – NODUST) (mm/day and %)</td>
<td>-0.18 (-3.0 %)</td>
<td>-0.19 (-3.8 %)</td>
<td>-0.42 (-7.9%)</td>
</tr>
<tr>
<td>Improvement?</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
</tbody>
</table>
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

With diurnal cycle

NO diurnal cycle

Precip. Dif. dust-nodust

With diurnal cycle

NO 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)

Limits of the hypothesis: apply instantaneous forcing during dust episode
Robustness of Sahel drying signal

Over the Ocean: Where is the truth?
consistent with lower cyclonic activity during ‘anomalous’ high dust season
( Lau and Kim, 2007 comparing 2005 and 2006)
Wilcox et al., 2009 GRL (using modis and TRMM observation)

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!
MODIS
‘Deep blue’
AOD

MAR 2006

RegCM
AOD
Simple SST experiment: \( \text{SST}^* = \text{SST} - 0.8 \times \text{AOD} \)
as a result of downward SW attenuation at the surface
(consistent with \textit{Evan et al., 2009, Yoshioka et al., 2007 studies using coupled ocean models})
With SST correction: dust induced cyclonic anomaly but less precipitation over the ocean...
**Response to dust forcing vs. Precipitation bias.**

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*Response images from (a) RegCM precip (JJA 1996-2006), (b) Precip difference DUST-NODUST (JJA 1996-2006), (c) RegCM - CRU (JJA 1998-2002), (d) RegCM - TRMM (JJA 1998-2006).*
## Climate sensitivity to dust absorption properties

<table>
<thead>
<tr>
<th>Dust bins size (μm)</th>
<th>0.01-1</th>
<th>1-2.5</th>
<th>2.5-5</th>
<th>5-20</th>
</tr>
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<tbody>
<tr>
<td><strong>K_{ext} (m^2.g^{-1})</strong></td>
<td>2.45</td>
<td>0.85</td>
<td>0.38</td>
<td>0.17</td>
</tr>
<tr>
<td><strong>g</strong></td>
<td>0.71</td>
<td>0.76</td>
<td>0.81</td>
<td>0.87</td>
</tr>
<tr>
<td><strong>SSA</strong></td>
<td>0.95</td>
<td>0.89</td>
<td>0.80</td>
<td>0.70</td>
</tr>
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Cloud water, meridional circulation and precip. difference (DUST-NODUST)
15W-15E average

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

1: Weakening of the ‘monsoon pump’

Solmon et al., 2008