The Role of the African Topography in the South Asian Monsoon

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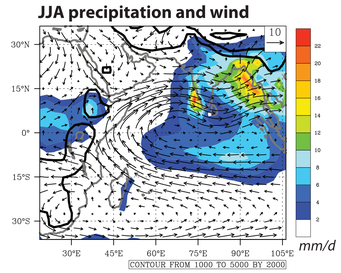
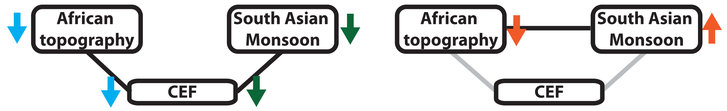
Motivation



Shading:
GPCP precipitation (mm/d)
Vector :
NCEP 850hPa wind (m/s)
Black Thick Contours :
Surface height (m)

- The South Asian Monsoon precipitation, the **cross equatorial flow (CEF)**, and the African topography located to the west of the CEF are closely related.

Previous Research



Krishnamurti et al. 1976; Sashegyi and Geisler 1987; Rodwell and Hoskins 1995

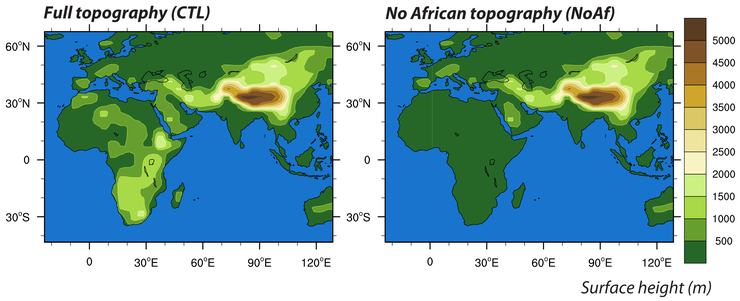
Findlater 1969; Halpern and Woiceshyn 2001

Chakraborty et al. 2002, 2006, 2009; Slingo et al. 2005

- The impact of the African topography on the South Asian Monsoon precipitation remains debated.
- In this study, we explore more comprehensively the role of the African topography in the South Asian Monsoon and clarify mechanisms.

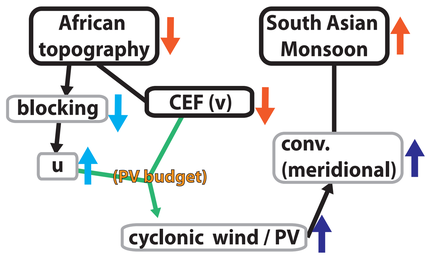
Model Setup

- GFDL AM2.1
- Resolution : 2.5 degrees x 2 degrees
- Two experiments with different surface height: **CTL** and **NoAf**



Summary

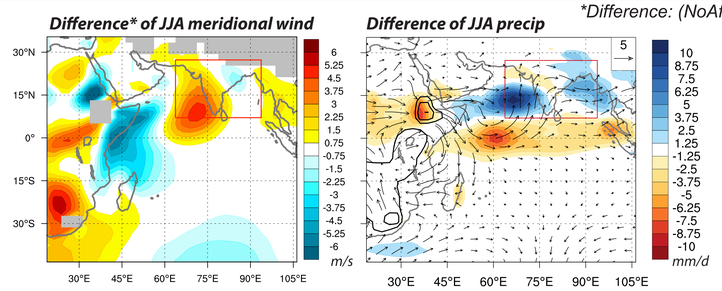
- In our simulations, when the African topography is removed, the South Asian Monsoon precipitation increases even if the CEF weakens.
- After the topography is removed :
  - The u increases because of decreased blocking effect.
  - Based on moisture budget, the stronger convergence term, primarily due to larger meridional convergence, is the largest contribution to the stronger precipitation.



- A cyclonic wind anomaly is related to the stronger meridional wind and convergence in its eastern flank.
- Our results are qualitatively consistent with theoretical stationary wave patterns but further analysis based on 3-D full-physics is required
- The latitudes of the initial locations of air particles reaching the Arabian Sea are higher and therefore contribute to the larger PV there.

Impact on Jet and Precipitation

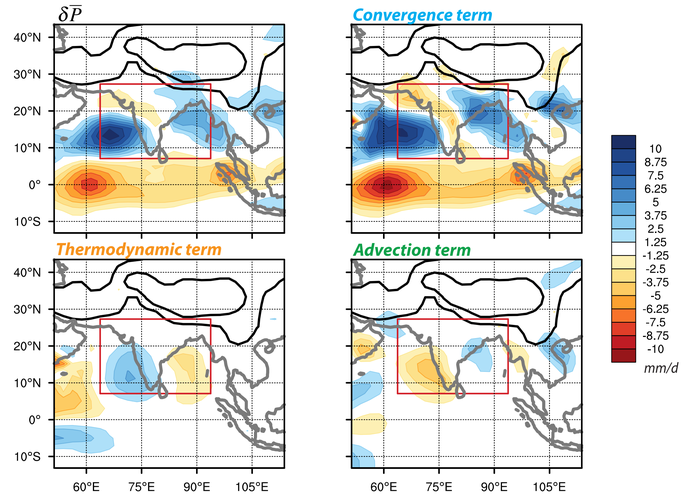
*Difference: (NoAf - CTL)



- The CEF is weaker when the African topography is removed.
- The South Asian Monsoon precipitation within the Indian region (red box) increases.

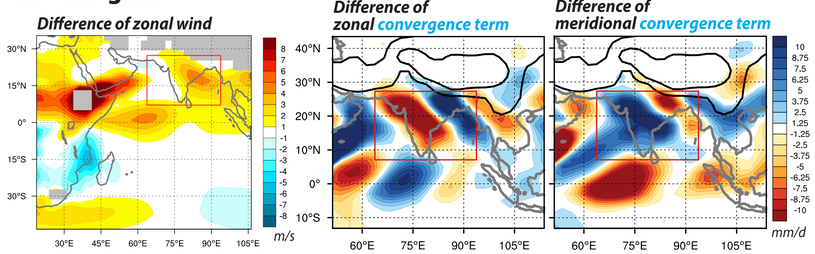
Moisture Budget

$$\delta\overline{P} = \delta\overline{E} - \langle\overline{q}\nabla\cdot\delta\overline{\mathbf{v}}\rangle - \langle\delta\overline{\mathbf{v}}\cdot\nabla\overline{q}\rangle - \langle\nabla\cdot[(\delta\overline{q})\overline{\mathbf{v}}]\rangle$$

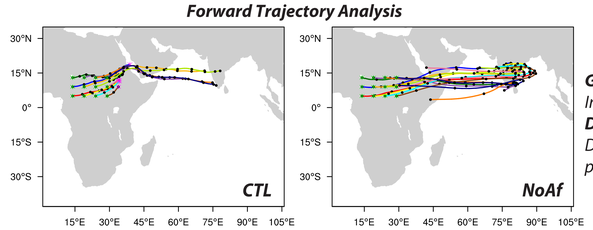


- The stronger precipitation near India is mainly accounted for by convergence term.

Blocking Effect



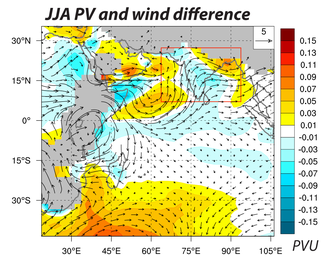
Forward Trajectory Analysis



Green asterisks:
Initial points
Different colors:
Different starting points

- The blocking effect is reduced when the African topography is removed.
- The increasing convergence is mainly contributed by the stronger meridional component of the total convergence. This is different from the mechanism proposed by Chakraborty et al. 2002, who hypothesized that the stronger zonal wind causes stronger convergence.

Impact on the Larger-scale Circulation

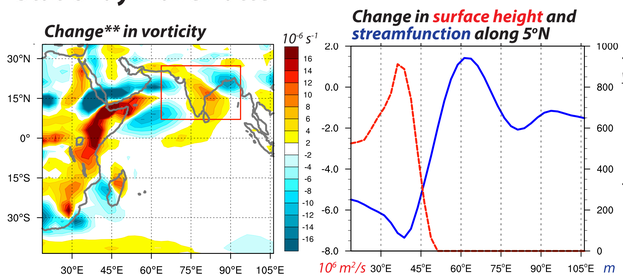


Shading:
PV anomaly (PVU)
Vector :
850hPa wind anomaly (m/s)

- A cyclonic wind anomaly is located over Arabian Sea.
- The southerly anomalies in the eastern flank of the cyclonic wind anomaly might be related to larger meridional convergence there. Therefore, we want to explore what induces the cyclonic wind anomaly over the Arabian Sea when the African topography is removed.
- The positive vorticity and potential vorticity (PV) anomalies are consistent with the cyclonic wind anomaly.

Stationay Wave Pattern

*Change**: (CTL-NoAf), change when adding topography*



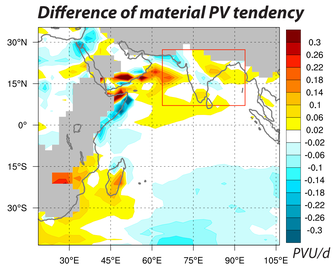
- ***Stationary Rossby wavelength:***
  - Theoretical:
    $\lambda_s = \sqrt{\frac{\overline{u}}{\beta}}$ ~21.6 degs
  - Simulated: ~30 degs
- ***Shift***
  - Theoretical:
    $\lambda_s/4$ ~ 5.4 degs
  - Simulated : ~ 3 degs

- While qualitative consistency exists between our results and the simplified models of stationary wave dynamics, a more quantitative understanding of the cyclonic anomaly over the Arabian Sea requires consideration of the 3D full-physics PV dynamics.

Potential Vorticity Budget

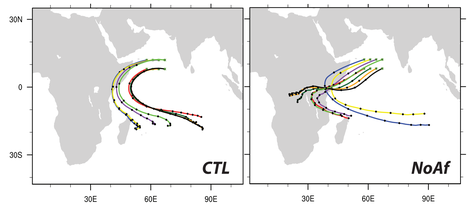
$$\frac{DP}{Dt} = \frac{1}{\rho}\boldsymbol{F}_\eta\cdot\nabla\theta + \frac{1}{\rho}\boldsymbol{\eta}\cdot\nabla\dot{\theta}$$

frictional term (ft) heating term (ht)



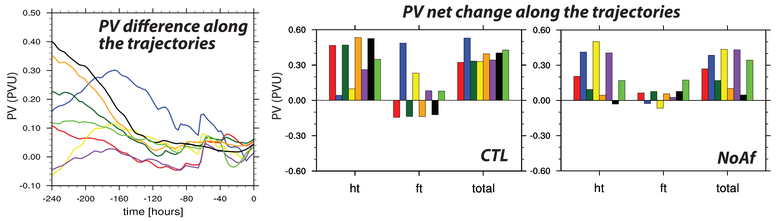
- Negative difference of the material PV tendency is right to the east of the African topography. Positive difference of the material PV tendency is over the Arabian Sea.
- Since the material tendency is the tendency along the particle, the trajectories of the flow need to be considered as well.

Backward Trajectory Analysis



- The particle movements have more southerly component in the NoAf simulation over Arabian Sea.
- The flow comes from a more organized CEF in CTL, but in NoAf, some of the particles come from Africa and others come from higher latitude compared to those in CTL.

Integration of PV Tendency



- The positive PV difference between NoAf and CTL over the Arabian Sea is related to the higher latitude of the initial locations in the NoAf compared to those in CTL.
- The weaker CEF and the weaker blocking effect of the African topography of the westerlies over Africa might be related to these different initial locations.