Influence of Surface Processes over Africa on the Atlantic Marine ITCZ and South American Precipitation

Samson M. Hagos and Kerry H. Cook

Cornell University

I INTRODUCTION

Because of its economic and social impact on the population of the neighboring regions, the dynamics of Atlantic marine ITCZ (AMI) merits the recent efforts to understand its various aspects. In addition to its direct interaction with the local ocean surface, the AMI is also sensitive to remote influences like ENSO. The role played by the surface features of the adjacent land, however, has not received as much attention. Cook et al. (2004) examined the nature of the intercontinental teleconnections between Africa and South America in a GCM. In their simulations, Africa influences South American precipitation more than South America does Africa. The strongest intercontinental forcing occurs during austral summer (January) when the presence of Africa introduces a large (about 40 %) suppression of rainfall over the Nordeste region of Brazil, and more modest rainfall enhancements on the northern coast and over the South Atlantic Convergence Zone (SACZ).

To explore the degree to which variability over the tropical Atlantic and South America may be related to processes over the African continent, this study addresses the following questions:

i. What is the influence of African topography on the climatology of the AMI and South American precipitation?

ii. How does variability in surface wetness over Africa influence the AMI?

II. MODEL AND EXPERIMENTS

- The GFDL R30 L14 atmospheric GCM with moist convection adjustment parameterization is used.
- SST, albedo, soil moisture and solar angle are fixed at their climatological January values.
- Each simulation begins with an isothermal dry atmosphere at rest. The integration length is 2000 days with the first 200 days removed as a spin up period.

Table of Experiments

Experiment	Soil Moisture	Topography
Control	Climatological	Full Global
Flat Africa	Climatological	African topography removed
Asymmetric	Wet Northern equatorial Africa (Fig. 1a)	Full Global
Symmetric	Dry Equatorial Africa (Fig.1b)	Full Global

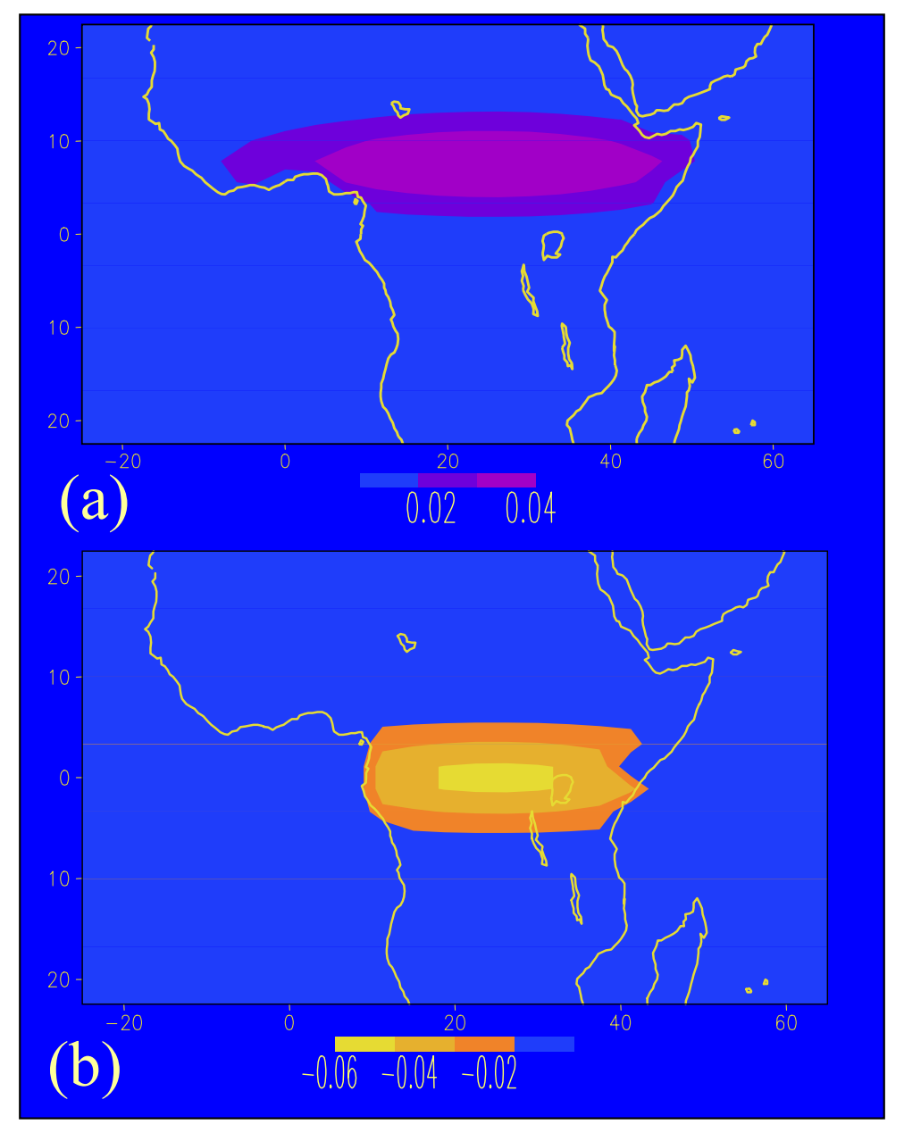

Fig.1 Prescribed soil moisture perturbation (normalized by saturation value).
(a) *Asymmetric* and (b) *Symmetric.*

The pair of experiments, "*Asymmetric*" and "*Symmetric*", evaluate the sensitivity of the AMI to variations in surface wetness over tropical Africa and the equatorially asymmetric and symmetric circulations associated with them.

III RESULTS

(a) Influence of Circulations Associated with African Topography

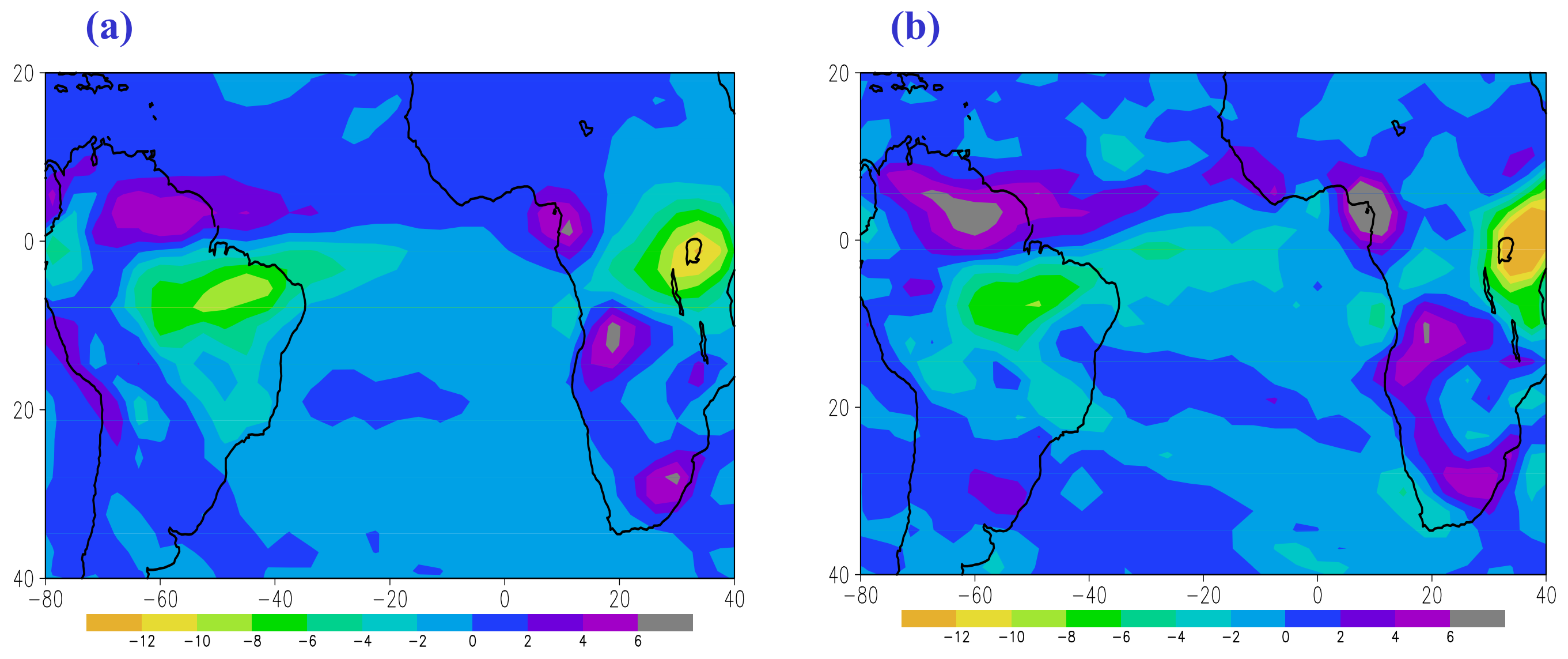

Fig. 2 (a) Precipitation and (b) column moisture convergence from *Control* minus *Flat Africa* (mm/day).

The influence of African topography is particularly large over the northeastern parts of South America and the western equatorial Atlantic where the rainfall is reduced by about 6mm/day (about 80 %) due to the effects of circulation generated by the African topography (Fig.2a). These circulations also shift the AMI about 5^0 north, increasing precipitation over the northern edge of the continent. There is little influence from African topography over South America south of about 20^0S.

Comparison of the anomalous rainfall and the vertically-integrated moisture convergence (Figs. 2a and b) shows that differences in the latter account for most of the rainfall anomaly over the western Atlantic and South America. Since most of the atmospheric moisture is at low levels, this implies that anomalous structure in the low-level wind fields is closely associated with the precipitation anomaly shown in Fig. 2.

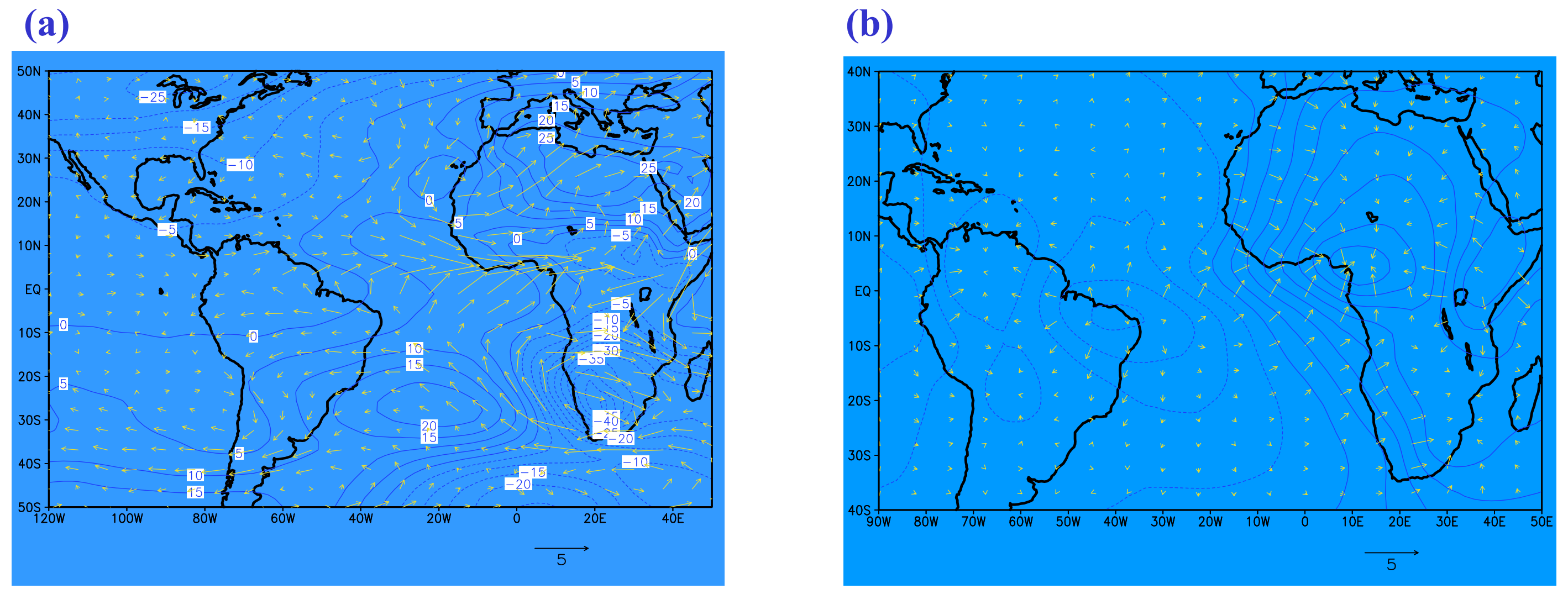

Fig. 3 (a) Wind (m/s) and geopotential (m) and (b) Irrotational Wind (m/s) and velocity potential at 866mb from *Control* minus *Flat Africa.*

An anomalous low and diabatic heating of up to 2K/day (not shown) are associated with the topography of southern Africa. This heating introduces a region of high geopotential over the southern Atlantic Ocean. This is similar to the observed anomalous high over the eastern South Pacific in association with the South American monsoon heating, and over the eastern North Atlantic due to the Asian monsoon.

The irrotational part of the anomalous wind shown in Fig. 3b has a significant southerly component crossing the equator. The center of convergence (ascent) is located on the western coast of central Africa, and the divergence center (descent) is over the northeastern tip of South America (the Nordeste region of Brazil). Thus, African topography generate an anomalous overturning circulation over the Atlantic Ocean with the down branch about 8 degrees south of the equator.

(b) Influence of Circulations Associated with Perturbations in African Soil Moisture

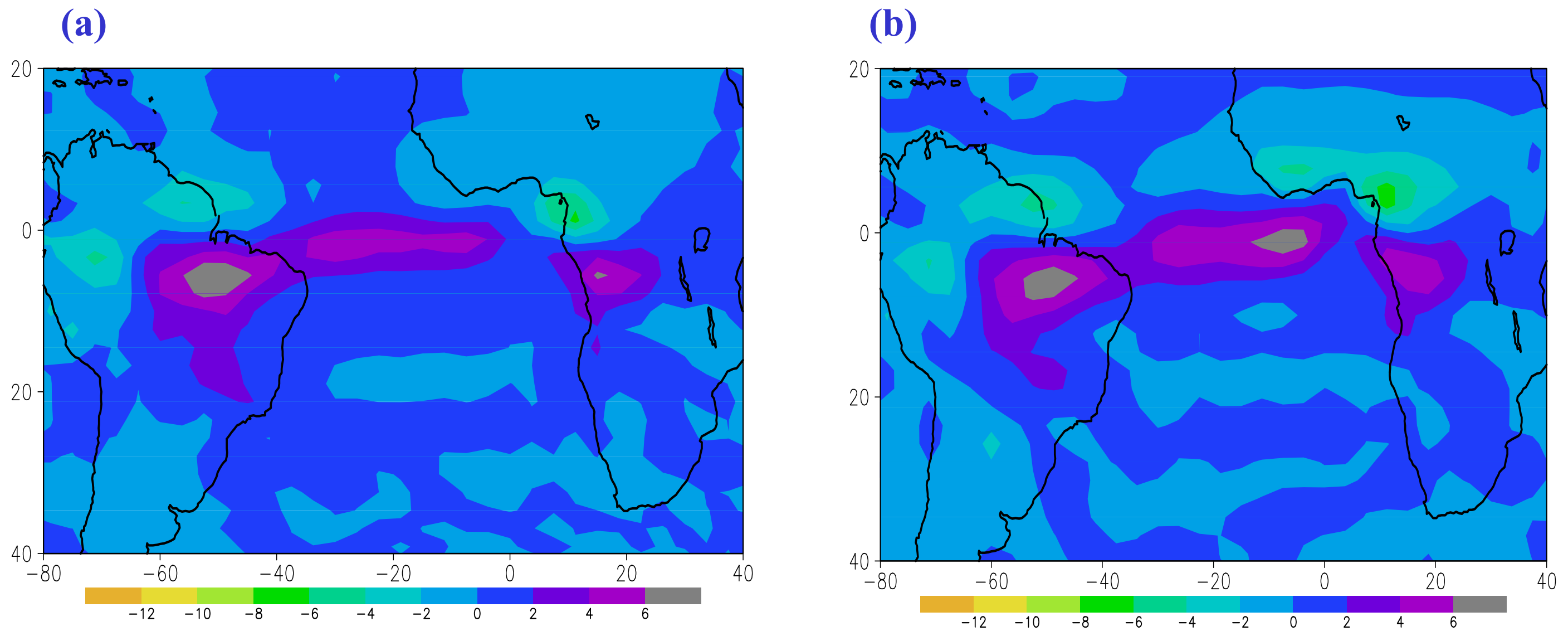

Fig. 4. (a) Precipitation (mm/day) and (b) vertically integrated moisture convergence (mm/day) for *Asymmetric* minus *Control*. The contour interval is 1mm/day.

The imposition of asymmetric soil moisture anomaly over Africa in the GCM (Fig. 1a) leads to a southward shift of the AMI and the precipitation over northeastern South America (Fig. 4a). The Nordeste region gains an average of about 3mm/day of precipitation (about 40% of the climatological value), while northern parts of the continent become about 2 mm/day drier. The moisture budget analysis shows that, as above, the column moisture convergence accounts for most of the precipitation anomaly and is closely related to the low-level wind convergence. Note especially the southward shift and strengthening of the moisture convergence maximum that marks the AMI in the central and western Atlantic (Fig. 4b).

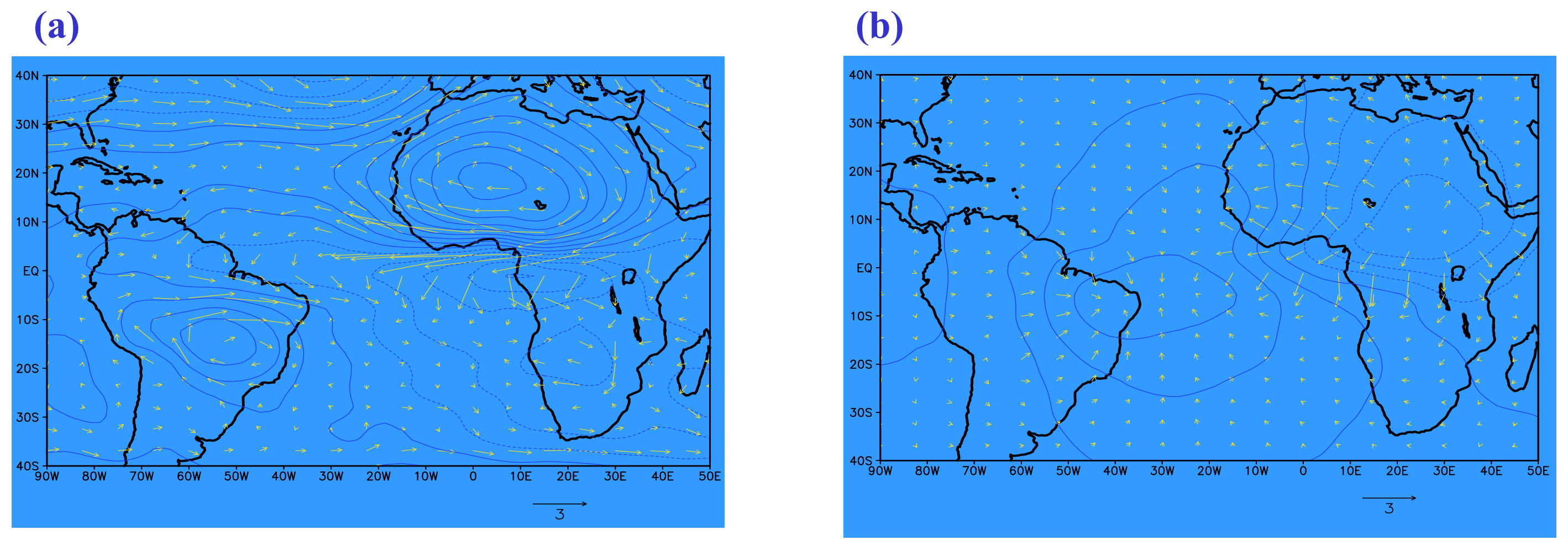

Fig. 5. (a) Wind (m/s) and streamfunction and (b) irrotational component of the horizontal wind from minus at 866 hPa. Vector scale is in m/s.

Fig. 5a shows the full wind and streamfunction differences at 866 hPa associated with the wet surface conditions imposed over northern equatorial Africa (*Asymmetric* minus *Control*). In the Northern (winter) Hemisphere, there is a substantial acceleration of the tropical easterly flow over West Africa and the eastern Atlantic. Close to the equator, the flow anomaly has a strong northeasterly component over the Gulf of Guinea. The strongest differences in the wind occur over South America, where a pronounced cyclonic flow is associated with enhanced precipitation. This precipitation difference is shows a southward shift of the ITCZ (Fig. 4), and amplification by land surface feedbacks. The overall effect being the weakening of the Walker circulation (Fig. 5b).

Linear Model

To understand the physical processes involved in this response, the forcing over Africa is identified by examining the local effects of changes in surface wetness on the surface heating. The prescribed soil moisture perturbation changes the surface heat budget. Wet surface condition reduces the sensible heat and net upward longwave radiation fluxes, and increases the latent heat flux. These differences are accompanied by a cooling of the surface because the enhanced availability of moisture favors evaporation and heat transfer through the latent heat flux. The basic response of the atmosphere to such surface cooling is then studied using a simple linear model.

A two dimensional dynamical model of a hydrostatic, steady state perturbation of the atmosphere on an equatorial β - plane driven by differential heating and controlled by friction can be written as;

$$\varepsilon u - yv = -\frac{\partial \varphi}{\partial x} \qquad (1)$$

$$\varepsilon v + yu = -\frac{\partial \varphi}{\partial y} \qquad (2)$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial \omega}{\partial p} = 0 \qquad (3)$$

$$\omega = -\frac{pq}{S(p)} \qquad (4)$$

where u, v , and ω are the x, y and p components of velocity, φ is geopotential height, ε, S(p) and *q* are the friction coefficient, stability parameter and the heating rate, respectively. All the variables are appropriately made non-dimensional. For an asymmetric *q,* i.e horizontal structure similar to Fig. 1a, the model is solved using matrix inversion (Hagos and Cook 2005).

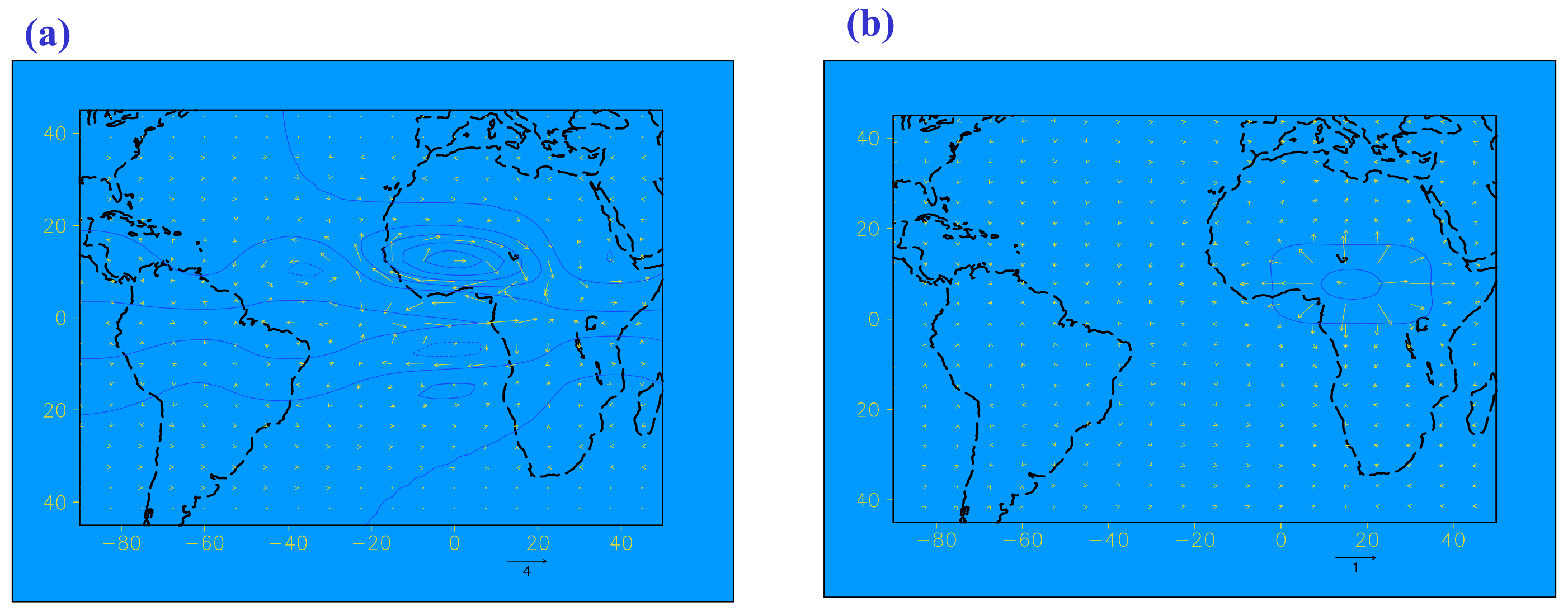

Fig. 6. (a) Full and (b) irrotational component of circulation from linear model with equatorially asymmetric forcing.

Comparison of Fig. 5a and 6a shows that response of the wind to the prescribed forcing can be explained by the linear theory of the tropical atmosphere. A surface cooling located off-equator shrinks the local column of air reducing its absolute vorticity. In the presence of small friction, parcels do this by moving equator-ward thereby introducing an anti-cyclonic circulation to the immediate west of the cooling region. Another important feature of equatorially asymmetric forcing is the cross equatorial flow. The low level divergence at the region of cooling is accompanied by a northerly flow along the equator (Fig. 5b and Fig. 6b). This northerly flow shifts the AMI southward, resulting in precipitation anomaly shown in Fig. 4a.

Because the circulation anomaly reflects the equatorial symmetry of the forcing, the *symmetric* forcing which involves soil moisture perturbation shown in Fig. 1b does not introduce significant cross equatorial flow and precipitation perturbation.

IV. CONCLUSIONS

Previous study shows that the climatological precipitation over South America, particularly the Nordeste region, is influenced by the presence of the African continent. Here the influence of African topography and surface wetness on the Atlantic marine ITCZ (AMI) and South American precipitation is investigated. Cross-equatorial flow over the Atlantic Ocean introduced by north-south asymmetry in surface conditions over Africa shifts the AMI in the direction of the flow. African topography, for example, introduces an anomalous high over the southern Atlantic Ocean and a low to the north. This results in a northward migration of the AMI and dry conditions over the Nordeste region.

The implications of this process on variability are then studied by analyzing the response of the AMI to soil moisture anomalies over tropical Africa. Northerly flow induced by equatorially asymmetric perturbations in soil moisture over northern tropical Africa shifts the AMI southward, increasing the climatological precipitation over northeastern South America. Flow associated with an equatorially symmetric perturbation in soil moisture, however, has a very weak cross equatorial component and very weak influence on the AMI and South American precipitation. This sensitivity of the AMI to soil moisture perturbations over certain regions of Africa can potentially improve the skill of prediction.

References

Cook, K. H. J. Hsieh and S. Hagos, 2004: The Africa/South America intercontinental teleconnection. *J. Clim* 17, 14

Hagos, S. M and K. H. Cook, 2005: Influence of Surface Processes over Africa on the Atlantic Marine ITCZ and South American Precipitation. Submitted to *J. Clim*

Acknowledgements: This research was supported by NOAA's US CLIVAR program (Award NA16GP1621).