

# VARIATIONS IN INTENSITY OF THE WESTERLY MONSOON-LIKE FLOW FROM THE TROPICAL ATLANTIC & SUMMER RAINFALL OVER EQUATORIAL AND TROPICAL SOUTHERN AFRICA

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**Abstract:** An EOF of the onshore flow of moisture along the west coast of southern Africa using NCEP-DOE AMIP-2 re-analyses suggests two dominant modes of variability that are linked to (a) variations within the circulation linked to the mid-latitude westerlies and the South Atlantic anticyclone, (b) the intensity of the westerly flow from the tropical Atlantic. The second mode, referred as the Equatorial Westerly mode, contributes the most to moisture input from the Atlantic onto the subcontinent at tropical latitudes. This mode appears to be associated with large-scale rainfall anomalies over the upper lands surrounding the Congo basin in January-February, with potential impacts on land hydrology persisting until April-May to the east of the Great Rift valley. It is preceded in November-December by a strengthening/weakening of the South Atlantic anticyclone. Enhanced (reduced) advection of moisture over the Congo basin is accompanied by increased (inhibited) convection processes. In the positive phase of this mode, the excess water vapour is channelled from the Congo basin to the east and southeast at surface, while the southern extension of the African Easterly Jet (AEJ) could play a role in transporting more moisture southwards at mid-tropospheric levels, leading to above-normal rainfall. During its negative phase, often related to ENSO, an eastward shift of the ascending branch of the Walker-type circulation is found to reduce convection and thus rainfall over the upper lands surrounding the Congo basin. In conclusion, the study of water vapour transport may help in explaining southern African rainfall variability and thus, more globally, in assessing issues such as climate predictability as well as potential impacts on the hydrological cycle over the continent, in particular for tropical regions which are of the less documented.

## Introduction

Within tropical areas of southern and central Africa, rainfall regimes are largely dependent on deep convection processes and water vapour convergence at different tropospheric levels. Considered as the main sources of moisture for the subcontinent, the Oceans exert controls on the large scale circulation, thus impacting rainfall and the water cycle. The South Atlantic has been regarded for long as a secondary source of moisture but recent studies have shown its substantial importance to southern African climate variability (Cook et al., 2004 ; Reason and Jagadeesha, 2005a).

We present here a multivariate analysis of zonal moisture fluxes along the west coast of southern Africa. Strong connections are found between rainfall over the surrounding uplands of the Congo basin, and moisture input from the tropical Atlantic in January-February.

## Data & Method

➤ **S-EOF analysis** on zonal moisture fluxes computed from 2.5° resolution NCEP R2 dataset (Kanamitsu et al., 2002) and averaged along the west coast of southern Africa from 1979 to 2000.

➤ **Heterogeneous and lagged correlations** between leading modes of variability in zonal moisture fluxes and, -rainfall estimates at a 0.5°x0.5° spatial resolution from the CRU TS 2.0 dataset (Mitchell et al., 2004), -land hydrology parameters, NDVI version 3 (Myeni et al., 2002) and NOAA NCEP CPC soil moisture (Fan and van den Dool, 2004).

➤ **Composite analysis** on Hadley SSTs, ERA-40 SLPs, zonal moisture fluxes, 850 mb winds and vertical velocity from NCEP R2.

## Impacts on rainfall

The Equatorial Westerly mode seems to modulate, in January-February, rainfall regimes over the uplands surrounding the Congo basin (i.e. from east DRC and northwest Tanzania down to south Angola) with impacts on land hydrology persisting until April-May to the east of the Great Rift valley (Figure 4).

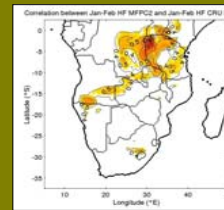
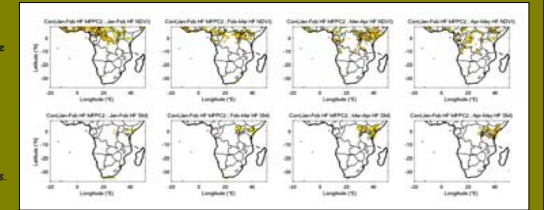


Figure 4: (Left) Heterogeneous correlations between HF zonal moisture flux PC2 and CRU rainfall in January-February over the 1979-2000 period. (Right) Lagged correlations between January-February HF zonal moisture flux PC2 and NDVI (top) as well as soil moisture (bottom) from January-February (far left) to April-May (far right) over the 1982-2000 period. The loadings presented are significant at 95% level using Monte Carlo simulations.



## Water vapour transport

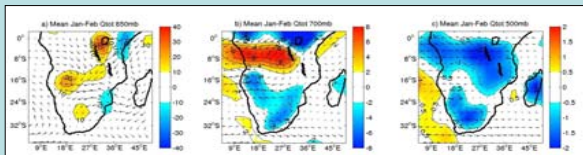


Figure 1: Mean January-February moisture fluxes (streamlines in  $g \cdot kg^{-1} \cdot m \cdot s^{-1}$  with arrows scaled at 1 unit/degree of latitude) together with contours of moisture convergence (in  $g \cdot kg^{-1} \cdot s^{-2}$ ) at 850 mb (a), 700 mb (b) and 500 mb (c). Positive values contour areas of moisture divergence at given levels.

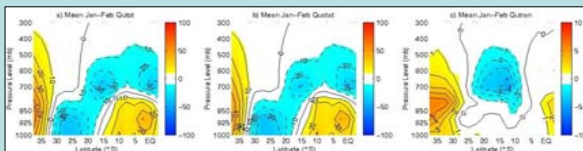


Figure 2: Mean vertical structure (a) of zonal moisture fluxes along the west southern African coast (in  $g \cdot kg^{-1} \cdot m \cdot s^{-1}$ ) for January-February together with its stationary (b) and transient (c) components. Positive values correspond to westerly fluxes while negative values refer to easterly fluxes.

Moisture from the oceanic basins appears to converge at tropical latitudes within the summer position of the ITCZ (Figure 1), particularly to the east of the Congo basin, around 30°E where an area of pronounced convergence can be identified at 850 mb. Centered at about 17°S over the Bie plateau is a local feature known as the Angola low. Stronger divergence at 700 mb over south Angola suggests substantial convection mechanisms there, but less deep within the air column. A third low-level convergence zone is found to the south of Botswana at about 25°E corresponding with the subtropical heat-low location in summer (Preston-Whyte and Tyson, 1988).

During summer, some key features are highlighted in zonal moisture fluxes along the west coast of southern Africa (Figure 2):

➤ **From the Equator to 15°S**, a westerly monsoon-like flux is present at surface and low levels. At mid-tropospheric levels, overlying this westerly flux, is found the southern extension of the African Easterly Jet (AEJ) as described in Hastenrath (1985).

➤ **To the south (between 17°S and 32°S)**, prevails an easterly flux linked to the trade winds driven by the South Atlantic anticyclone.

➤ **South of 32°S**, a westerly flux associated with the mid-latitude circulation is occupying the tropospheric air column. The transient analysis suggests latitudinal variations within this flux associated with mid-latitude perturbations at mid-tropospheric levels.

## Variability along the west coast

Due to abrupt shifts in the computed zonal moisture fluxes (not shown), they were filtered at 8 years and EOFs techniques were applied to their high-filtered (HF) component along the west coast of southern Africa using the covariance matrix (Figure 3).

➤ **The first mode**, contributing to about 25% of the variance explained, is typical of the migration in latitude of the circulation linked with the mid-latitude westerlies and South Atlantic anticyclone. Loadings are particularly strong from the surface up to 600 mb and are balanced in the subtropics at upper tropospheric levels.

➤ **The second mode**, representing about 11% of the variance explained, characterizes the monsoon-like westerly moisture flux in the tropics, from the equator to about 15°S. It has a simultaneous loading at surface between 20°S and 30°S. In the following we will refer to this component as the **Equatorial Westerly mode**.

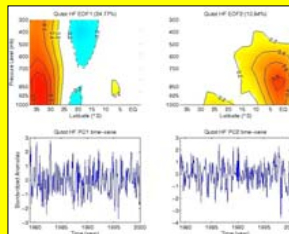


Figure 3: Spatial patterns (top) and temporal variability (bottom) as represented by the first two EOF leading modes in HF zonal moisture fluxes along the west coast of southern Africa.

## Associated atmospheric dynamics

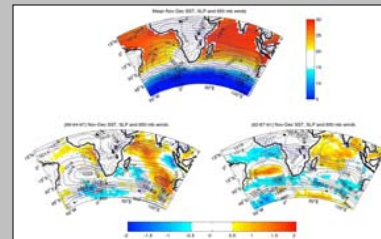


Figure 6: Mean (top), and November-December composites prior to positive/negative January-February events (bottom left/right) linked to the Equatorial Westerly mode for SLPs (contours), SSTs (color) and 850 mb winds (streamlines) significant at 90% confidence level of Student t-test.

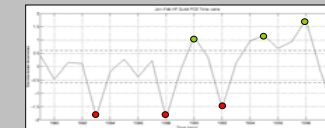


Figure 5: January-February expansion coefficient for the Equatorial Westerly mode. Green (red) dots indicate selected positive (negative) events.

**Positive/negative events** linked to the Equatorial Westerly mode (selected from Figure 5) appear to be preceded in November-December by a strengthening/weakening of the South Atlantic anticyclone (Figure 6). The warming/cooling found in the eastern tropical Atlantic suggests the advection of warmer and moister/cooler and drier air over the subcontinent at these latitudes.

Enhanced/reduced advection of moisture over the Congo basin is accompanied by favoured/inhibited convection (Figure 7). In the **positive phase** of this mode, the excess water vapour is channelled from the Congo basin to the east/southeast at surface, while the southern extension of the AEJ could play a role in transporting more moisture southwards at mid-tropospheric levels (Figure 8), leading to above-average rainfall. During its **negative phase**, often related to ENSO, a shift eastwards of the ascending branch of the Walker circulation acts to reduce convection and thus rainfall.

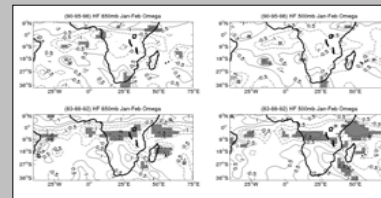


Figure 7: (1990, 1995 and 1998) and (1983, 1988 and 1992) composites (top and bottom) for NCEP R2 HF vertical velocity at 850 mb (left) and 500 mb levels (right) in January-February (shaded areas are significant at 95% confidence level of Student t-test).

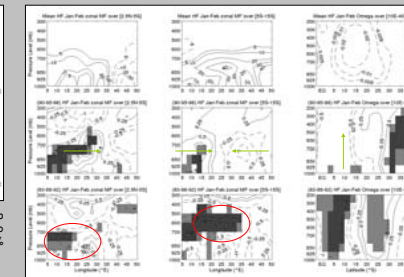


Figure 8: Mean (top), positive/negative composites (middle/bottom) for HF zonal moisture fluxes averaged over [2.5°N-5°S] (left), and [5°S-15°S] (middle), with positive (negative) values corresponding to westerly (easterly) orientated fluxes, together with NCEP R2 HF vertical velocity (right) averaged over [10°E-40°E] in January-February with dark and light shaded areas representing 95% and 90% confidence level of Student t-test respectively.

## Discussion & Future work

This 3D investigation of variability in moisture fluxes from the tropical Atlantic into southern Africa helped provide further elements of description in terms of summer rainfall variability over the subcontinent, in particular for the tropics which are of the less studied. These results are subject to limitations linked to the validity of rainfall estimates over these regions, mass-imbalance in the re-analyses but also the short period of study. Moreover we only considered zonal moisture transport while its meridional component could be of importance. Further work could be of interest concerning some features such as the southern extension of the AEJ. Connections with known modes of ocean-atmosphere variability could bring further information, while atmospheric model simulations could help emphasize overlying processes. This study has focused on the atmospheric part of the hydrological cycle and a next topic would be to examine the possible mitigation/aggravation of the effect of precipitation through land hydrology.

References: Cook, C.J.C., Reason, and B. Hewitson (2004). Wet and dry spells within particularly wet and dry summers in the South African summer rainfall region, *Clim. Res.*, 17-31; Fan, Y., and H. van den Dool (2004). Climate prediction center global monthly soil moisture dataset at 0.5° resolution for 1948 to present, *Jour. Geophys. Res.*, 109; Hastenrath, S. (1985). *Climate Circulation in the Tropics*, 455 pp., D. Reidel Publishing Company; Kanamitsu, M., W. Ebisuzaki, J. Woollen, S.-K. Yang, J. Hnilo, M. Fiorino, and G. L. Potter (2002). NCEP-DOE AMIP-2 re-analysis (R2), *Bull. of the Atmos. Met. Soc.*, Nov., 1631-1643; Mitchell, T. D., T. R. Carter, P. D. Jones, R. Hulme, and M. New (2004). A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: the observed record (1950-2000) and 16 scenarios (2001-2100), Tyndall Centre Working Paper, 55; Myeni, R.B., S. Hoffman, V. Knyazikhin, J.L. Privet, J. Glasby, Y. Tian, Y. Wang, Y. Zhang, G. Smith, A. Lotsh, M. Friedl, J.T. Monette, P. Votav, R. Nemani and S. Running (2002). Global products of vegetation leaf area and fraction absorbed PAR from year one of MODIS data, *Rem. Sens. Env.*, 83, 214-231; Preston-Whyte, R., and P. Tyson (1988). *The Atmosphere and Weather of Southern Africa*, 334 pp., Oxford Univ. Press, Cape Town; Reason, C.J.C., and D. Jagadeesha (2005a). Relationship between South Atlantic SST variability and atmospheric circulation over the South African region during austral winter, *J. Climate*, 18, 3339-3355.