Mechanisms of Summer Subtropical Southern Indian Ocean Sea Surface Temperature Variability

The Importance of Meridional Humidity Advection

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Background

We reexamine the mechanism responsible for a type of subtropical Indian Ocean sea surface temperature variability (see Fig. 1 for an example) that is known to correlate with rainfall over certain regions of Africa that depend on rainfall for their economic well being.

Recent studies have determined that zonal wind speed anomalies are important to the formation of this type of SST variability. Reexamination of the mechanism, using ocean mixed layer modeling (see Fig. 2), analyses of operational air-sea fluxes (see Fig. 3), and consideration of simple atmospheric boundary layer physics (see Figs. 7 and 8) has shown that meridional wind anomalies are crucial to the formation of the SST variability considered here. A novel mechanism that is simply dependent upon meridional wind anomalies is presented.

1 SST Anomaly

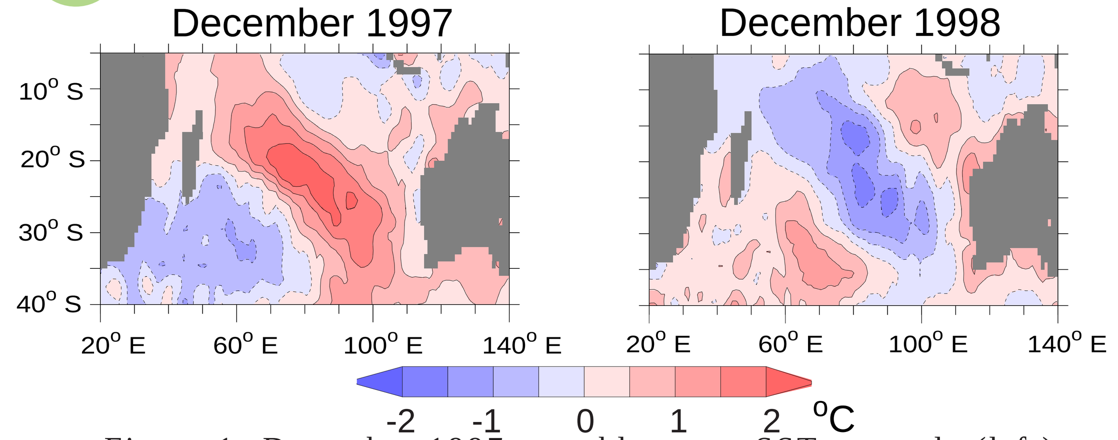


Figure 1: December 1997 monthly mean SST anomaly (left). December 1998 monthly mean SST anomaly (right). Reference period 1990-2004. Data from NOAA OISST.

The warm SST anomalies are largely caused by abrupt (2-4°C/mon), coherent warming that occurs on scales of roughly 2500 km (see Fig. 2). The shape and magnitude of these warming regions are reasonably well reproduced by a mixed layer model driven with surface fluxes of heat and momentum.

2 Monthly Temperature Tendency (November)

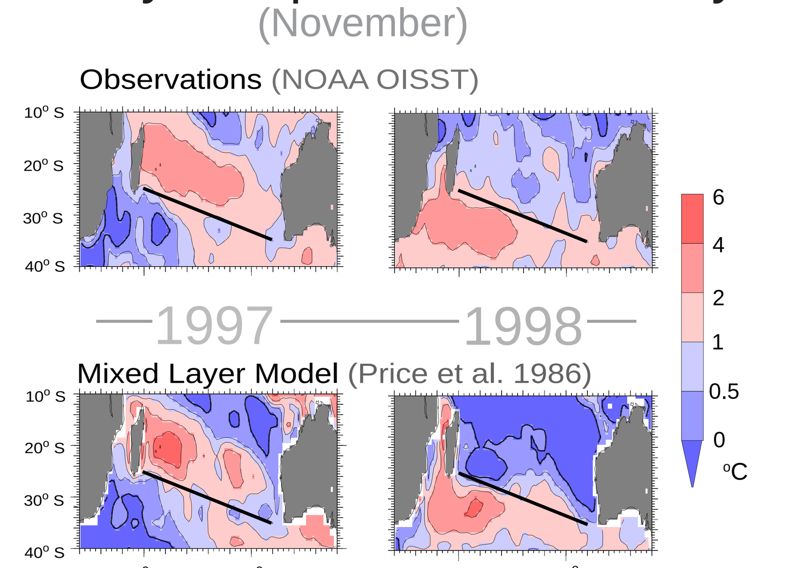


Figure 2: The observed temperature change during November 1997 (upper left) and November 1998 (upper right). The November temperature change estimated by a mixed layer model using NCEP surface fluxes (1997 bottom left; 1998 bottom right)

Results

Only latent heat anomalies have the magnitude and shape necessary to drive these SST anomalies. A perturbation analysis of the standard bulk parameterization of latent heat flux has shown that the total normalized latent heat flux anomaly (anomaly/climatological mean) is approximately equal to the sum of two parts; the normalized wind speed and ∇q anomalies (∇q = near surface humidity - surface saturated humidity). A pattern similar to the one seen in the SST and latent heat flux anomalies is usually most evident in the ∇q anomaly (see Fig. 3).

3 Components of Monthly Latent Heat Flux Anomalies (anomaly / climatology)

Total ≅ Humidity Component + Wind Speed Component

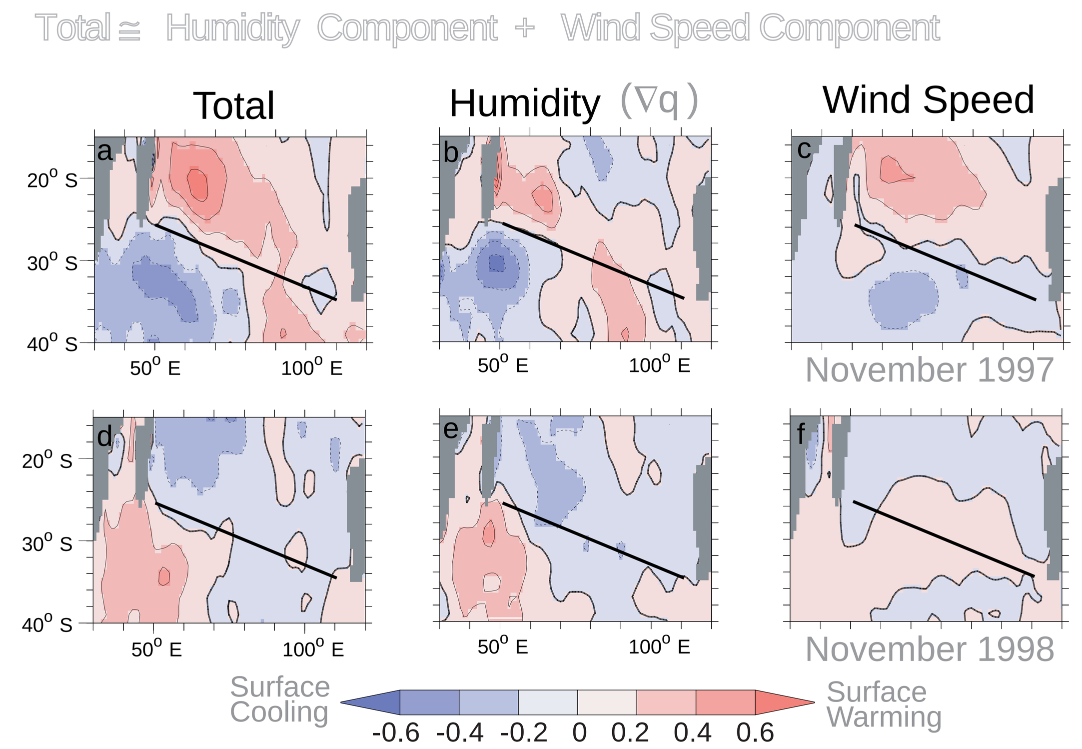


Figure 3: November 1997 mean normalized latent heat flux anomaly (a), normalized ∇q anomaly (b) and normalized wind speed anomaly (c). Anomalies are normalized by their climatological monthly means. (d), (e) and (f) are the same as (a),(b) and (c), respectively, except for 1998.

Visual inspection of SLP and near surface wind fields suggest that conditions that are favorable to warming are created within the western/central flank of the subtropical anticyclone (Fig. 4).

4 Monthly SLP and Wind (10m)

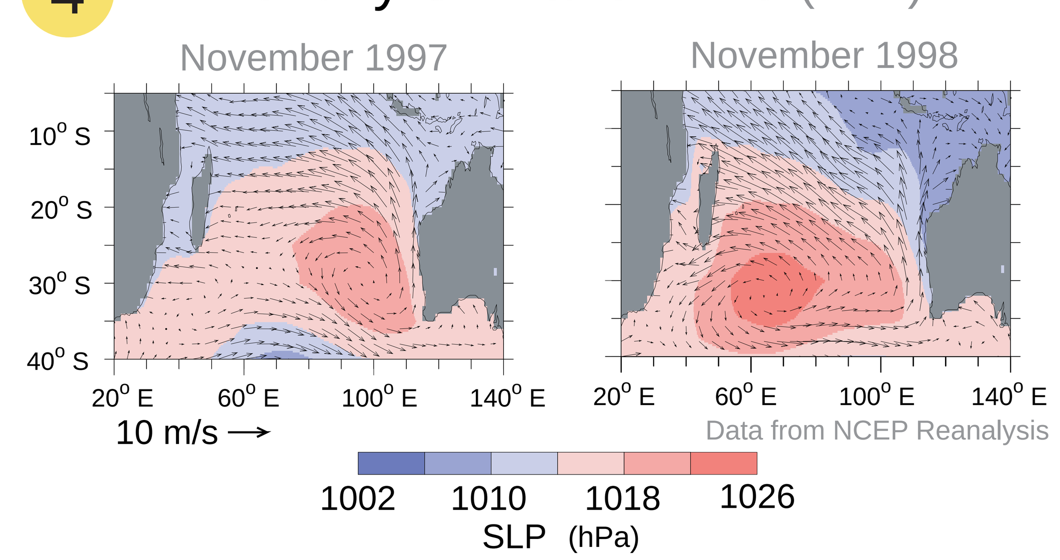


Figure 4: November 1997 mean SLP (color field) and 10m winds (left). November 1998 mean SLP and 10m winds (right).

A simple index for anticyclone position is significantly correlated with SST and latent heat flux variability. This index also correlates well with meridional wind and advective surface humidity variability, suggesting that atmospheric advection drives these anomalies (see Fig. 5)

5a Index Averaging Regions

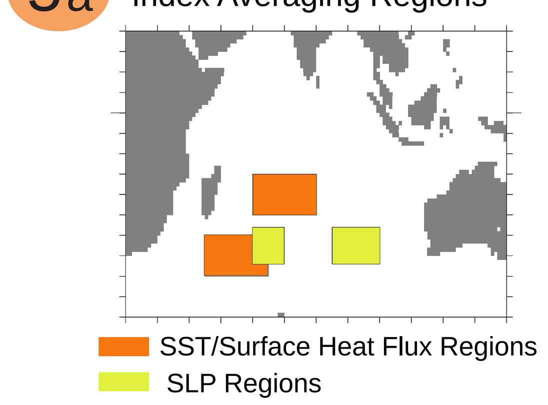


Figure 5a: Area averaging regions for SLP (yellow) and SST,latent heat flux, meridional wind and humidity advection (orange). Indices are formed by differencing two regions of the same type.

5b SST/SLP Indices

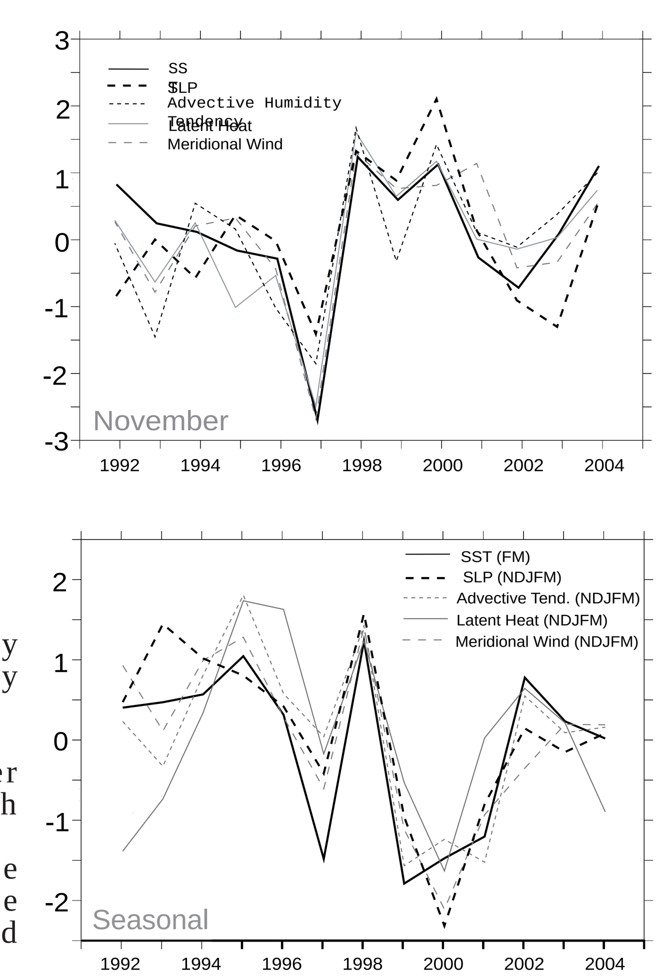


Figure 5b: Southwestern minus central basin differences of 30-day mean SST, SLP, advective humidity tendency and meridional wind anomalies (upper panel). The means are centered on 15 November for all variables except SST, which is centered on 30 November. Timeseries are normalized to have unit variance. Lower panel is the same, except that SST is averaged from Feb. through Mar. and the other variables are averaged from Nov. through Mar.

Composite averages based on the extrema of this SLP index clearly show a bi-modal pattern of anticyclone variability (Fig. 6, upper panel). Composite differences show that the anomaly pattern of interest is seen in latent heat flux, meridional atmospheric advection and SST variability (Fig. 6, lower panel).

6 Composite Winds (10m) and SLP

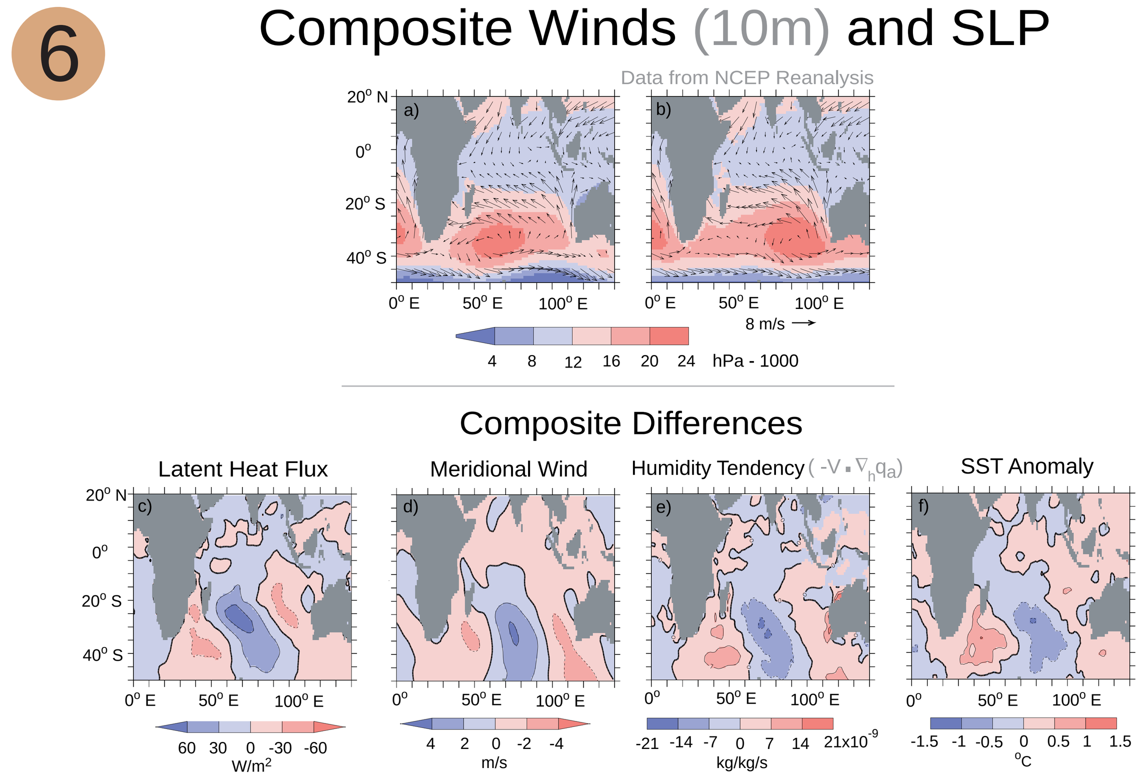


Figure 6: (a) Mean SLP and 10m wind composite during high western/low eastern SLP intervals. Intervals are 15 days long with 25 intervals per composite. Period 1992-2004. (b) Same as (a), except for low western/high eastern SLP intervals. (c) Composite difference of latent heat flux (high western minus high eastern SLP). (d) Composite difference of meridional wind speed. (e) Composite difference of advective humidity trend. (f) Composite difference of SST anomaly (lagged 1 week).

The way in which such latent heat flux anomalies are created was examined with a simple model for low level humidity. The humidity tendency in this atmospheric boundary layer model is determined by advection, air-sea flux and a generic removal of moisture (e.g. mixing with overlying air mass). Monte Carlo simulations show that the importance of ∇q variability in this model is consistent with the NCEP reanalysis, but estimated conservatively (see Fig. 7).

7 The Relative Importance of ∇q and Wind Speed Variability

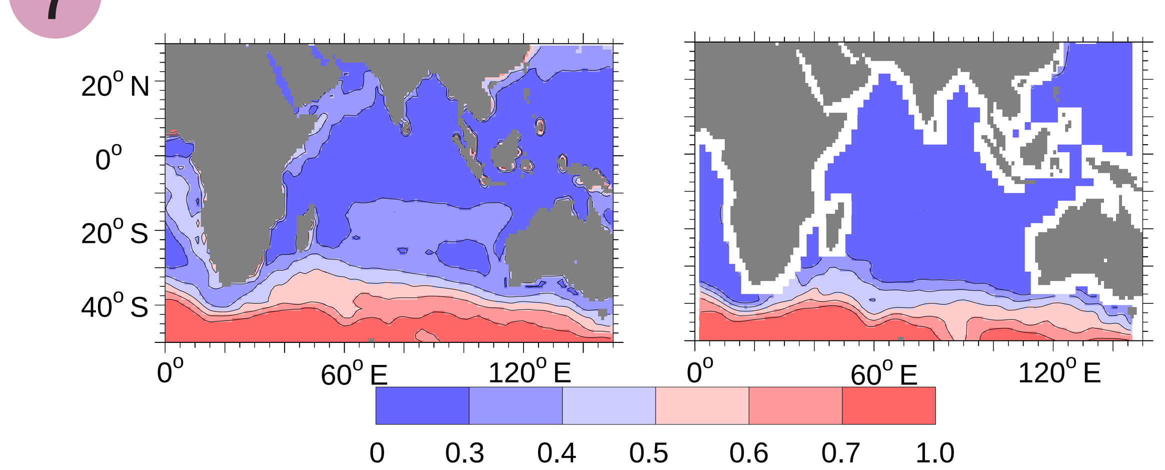
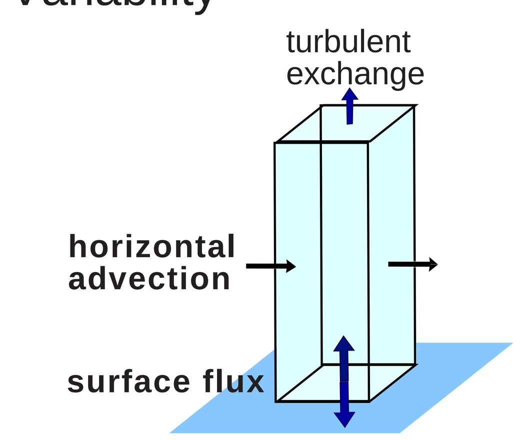


Figure 7: Probability that anomalies of ∇q are more important than of wind speed to latent heat flux variability. Left panel results from analysis of the NCEP reanalysis, right panel is from the idealized boundary layer model described here.



Atmospheric Boundary Layer Model Schematic : In this analytic model, changes in humidity are driven by wind anomalies, which cause variations in surface evaporation and horizontal advection.

Experiments with this model show that the model-estimated latent heat flux anomalies (found from imposed wind speed anomalies and calculated humidity anomalies) are caused primarily by humidity anomalies that are driven by anomalous meridional humidity advection (see Fig. 8).

8 Model Estimated Monthly Latent Heat Flux Anomalies

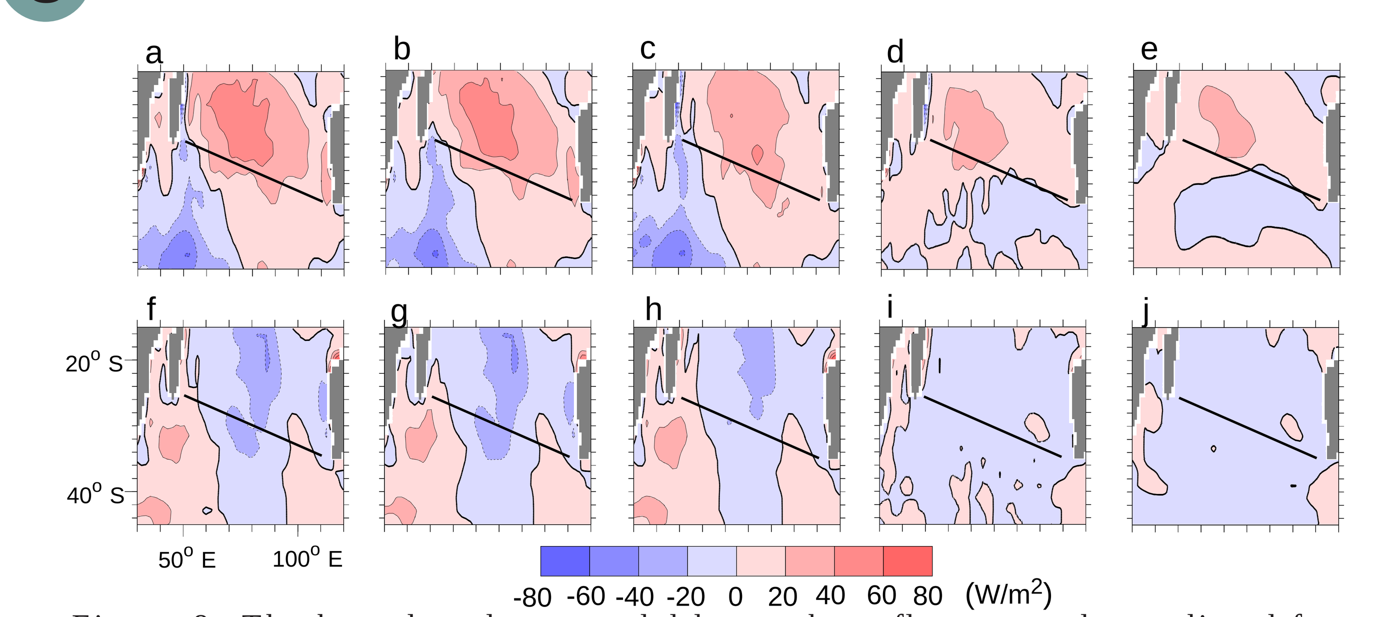


Figure 8: The boundary layer model latent heat flux anomaly predicted from the November 1997 10m wind anomaly (a). Other top row panels are the same as (a) except that; (b) zonal wind anomalies are neglected, (c) wind speed anomalies are neglected, (d) meridional wind anomalies are neglected, (e) humidity advection is neglected. The lower panels are the same as those above them, except for November 1998.

Conclusion

The southern subtropical Indian Ocean SST variability that is known to correlate with African rainfall is mainly caused by the following mechanism: (i) meridional wind anomalies advect water vapor and cause low level humidity anomalies which, (ii) cause latent heat flux anomalies that drive the SST variability of interest.

Zonal wind anomalies sometimes have important effects on SST variability (as previously reported), but results strongly suggest that the mechanism for this SST variability primarily depends upon meridional wind-dependent mechanism described here. These meridional wind anomalies appear to be dependent upon the (bi-modal) position of the subtropical anticyclone. The cause of this anticyclone variability is unknown.