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MODELING CLIMATE VARIABILITY IN TROPICAL ATLANTIC ATMOSPHERE

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1. Introduction

The climate of the tropical Atlantic undergoes strong fluctuations on a variety of time-scales ranging from seasonal through decadal. These climate fluctuations are associated with massive disruptions of populations as well as changes to the environment. There is now strong evidence that a significant part of this variability is the result of, or is modified by, local air/sea interaction within the tropical Atlantic sector.

At the present time, detailed physical mechanisms responsible for this climate variability are still unclear including the atmospheric response to changing boundary conditions. Here we examine the seasonal and interannual variability of a class of atmospheric general circulation models (AGCMs) for their response to sea surface temperature (SST) variations in the tropical Atlantic sector. Our focus is less on the behavior of a particular model - we can expect models to evolve - and more on those common features of the simulations that reveal our level of understanding of the dynamics of the tropical Atlantic atmosphere.

2. Models

We examine all five currently available AGCMs obtained from the AMIP II archive as well as an additional 50-year long simulation kindly provided by the NASA Seasonal to Interannual Prediction Project. We focus on monthly fields of surface wind stress, surface flux, precipitation, humidity, SST (similar for all models), and air temperature. For comparison to observations we use surface wind stress and heat flux estimates COADS. To examine seasonal and interannual modes of variability, use rotated principal component analyses. In these analyses, three variables, SST and zonal and meridional wind stress for each model integration (not the ensemble average), are combined into one matrix to calculate the principal components using Singular Value Decomposition.

3. Mean and Seasonal Cycle

Climate variability contains a strong seasonal component in the tropical Atlantic. Here we begin by examining the model representation of the time mean state and its seasonal cycle. It is found that most of the time-mean errors lie outside the equatorial area with an overestimation of wind stress in all simulations except UKMO. However, the simulated 10m winds are in reasonable agreement with observational data except JMA, which underestimates the winds in the southern tropics. Thus we conclude the wind stress errors in the simulations are due to the different drag coefficients used in each model. The errors in latent heat also show systematic overestimation in most of the simulations.

In our examination of surface winds we allow for slow variations in the seasonal cycle by presenting a rotated principal component analysis on the full monthly data. The first mode representing the annual cycle explains between 40-59% of the wind variance. The wind patterns are quite similar among simulations, although generally stronger than observed (by ~ 0.25 dyn/cm^2).

4. Interannual variability

The first pattern we obtained from SVD corresponds to the Atlantic Niño whose explained variances range from 14-17%, slightly stronger than observed during this period (12%). An examination of the seasonality of this pattern shows that for all simulations the maximum explained variance occurs in boreal summer, consistent with COADS. All simulations show a relaxation of the equatorial trade winds in the west by > 0.1 dyn/cm^2. Most simulations show strengthening of the southeast trade winds in the southeast, consistent with an enhancement of the North African Monsoon, and the northeast trade winds in the north, reflecting a strengthening of the summer subtropical high-pressure system.

The second pattern we obtained corresponds to the dipole-like interhemispheric mode. The surface wind field shows a strong cross-equatorial component blowing onto a warm northern hemisphere in response to warming SSTs in the northern tropics, with a relaxation of the northeast trade winds and a weaker strengthening of the southeast trade winds (figure 1). The simulations also reveal a pattern of surface winds similar to that observed with explained variances ranging from 11-13%, slightly less than observed

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during this period (15%). The weakest wind anomalies, significantly weaker than observed, occur in three simulations, JMA, UKMO, and NSIPP. An examination of the seasonality of this pattern shows that all simulations have maximum explained variance in boreal spring (MAM), in agreement with COADS.

Latent heat flux anomalies associated with the interhemispheric patterns are the most important term driving decadal SST variations in this region (*Carton et al., 1996*). An earlier examination of the NCAR CCM3 (*Chang et al., 2000*) pointed out the presence of a zone of positive feedback in the western tropics and negative feedback in the east. We find similar behavior in four of the remaining simulations, NCAR, NCEP, UKMO, and ECMWF. All four differ from COADS, which shows an expanded region of positive feedback and little negative feedback. In the other two simulations, JMA and NSIPP, a broad region of negative feedback is evident, with no corresponding region of positive feedback, suggesting in particular that coupled models using these AGCMs may be unable to reproduce the dynamics of the interhemispheric mode.

We decompose the latent heat anomalies into anomalous wind-driven and anomalous humidity-driven latent heat flux components. The observed anomalous wind-driven component dominates the humidity-driven component over much of the ocean, reversing sign in the Southern Hemisphere. In contrast the simulations show only weak zones of positive feedback associated with wind-driven latent heat flux because of the relatively weak wind anomalies associated with the interhemispheric pattern and because of the strong seasonal cycle of relative humidity in the boundary layer over much of the basin. The largest zone of positive feedback occurs in UKMO, while JMA has no positive feedback. The humidity-driven component is larger than observed for most simulations, but is large mainly in the northeast and acts as a negative feedback. The cause of the discrepancy between the observed and simulated humidity-driven component of latent heat flux appears to lie in problems with continental moisture.

5. **Conclusion**

We examine climate variability in the tropical Atlantic sector as represented in six Atmospheric General Circulation Models. On annual mean, most simulations overestimate wind stress away from the equator although much of the variability can be accounted for by differences in drag formulations. Most models produce excessive latent heat flux as a consequence of errors in boundary layer humidity.

Next we consider interannual variability, focusing on two tropical patterns (Atlantic Niño and interhemispheric modes). We find the models are roughly similar. However, all models fail to reproduce the wind-latent heat feedback believed to be essential to interannual variability in this basin. The cause of this failure appears to lie in problems with continental moisture.

References

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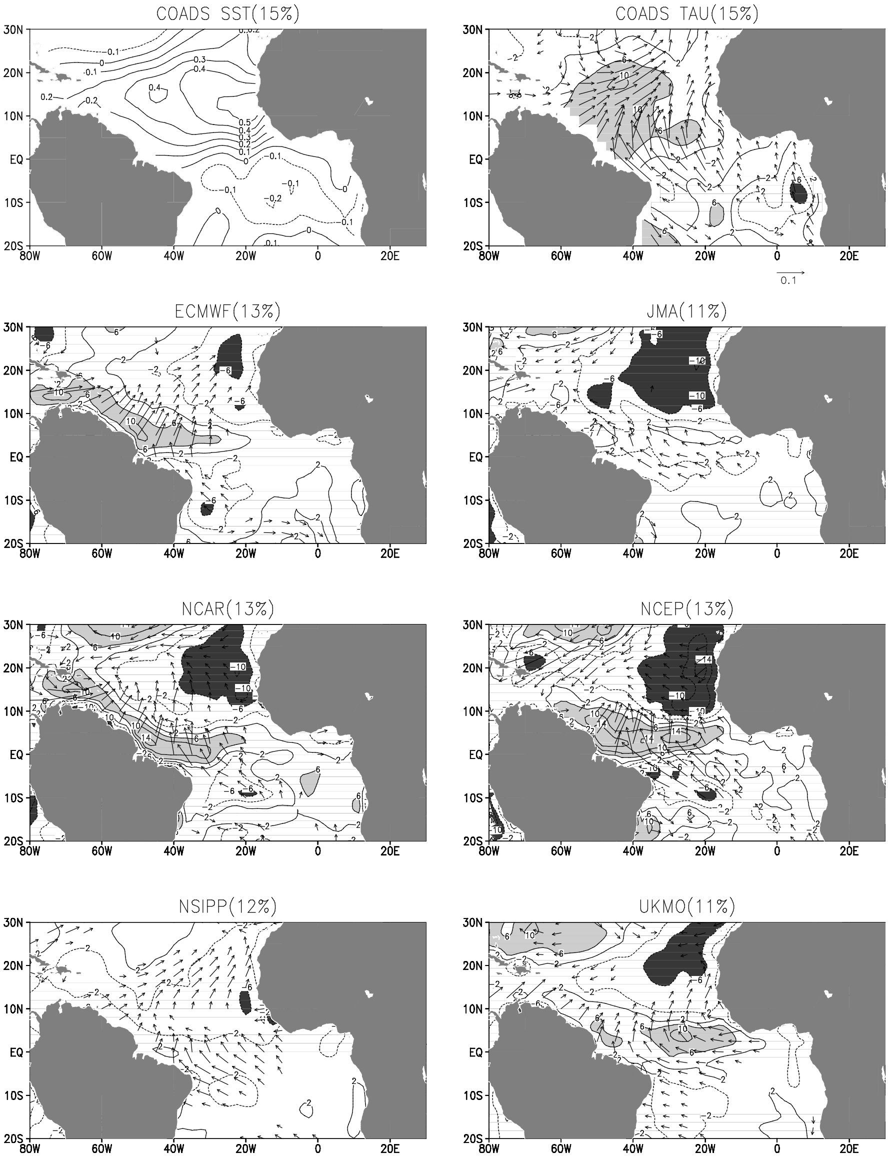

COADS SST(15%)

COADS TAU(15%)

ECMWF(13%)

JMA(11%)

NCAR(13%)

NCEP(13%)

NSIPP(12%)

UKMO(11%)

Figure 1: Wind stress anomalies (vectors) of interhemispheric mode from principal component analysis of March-May data and regression of latent heat (contours) on the rotated time coefficient of this mode. Units are dyn/cm^2 for wind stress. Contour interval for latent heat is 4 W/m^2 and zero contours are not drawn. Latent heat anomalies larger than ±6 W/m^2 are shaded. Positive values indicate ocean gains heat. Only wind stress differences larger than 0.02 dyn/cm^2 in amplitude are plotted. Explained variances are shown in parenthesis.