

A Study of Tropical Atlantic Variability with a High-resolution, Regional Coupled Climate Model

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Some important challenges in the study of Tropical Atlantic Variability (TAV) are (i) the prevalence of large systematic biases in the simulation of the tropical Atlantic state in global coupled models, (ii) the lack of adequate horizontal resolution in the deep tropics, and (iii) quantification of the relative importance of dynamic and thermodynamic atmosphere-ocean coupling.

We have developed a regional coupled model of the Atlantic basin, based on the MOM3 ocean model from GFDL, to address the above challenges. The regional coupling approach helps to mitigate the biases in the coupled tropical Atlantic simulation by allowing us to specify the observed SST in other ocean basins, particularly in the eastern equatorial Pacific, and thus capturing remote effects such as the influence of El Niño-Southern Oscillation (ENSO) on TAV accurately. The smaller spatial extent of the regional ocean model also allows us to use significantly higher horizontal resolution for the same cost as a lower resolution global coupled model. We employ this regional model as part of a hierarchy of coupled models, with different degrees of atmosphere-ocean coupling, to test the following hypotheses:

1. In the Atlantic intertropical convergence zone (ITCZ) region, atmospheric convection is affected more by thermodynamic coupling than by dynamic coupling.
2. Along the equator, dynamic coupling is more important than thermodynamic coupling.
3. Improved horizontal resolution will lead to better simulation of the narrow meridional scales associated with the ITCZ and the ocean currents, allowing models to better represent the interactions between the gradient mode, the ITCZ and the equatorial "Atlantic ENSO" mode.

We use the NCAR atmospheric general circulation model, CAM3, in the following configurations: uncoupled, thermodynamically coupled to a slab ocean model and fully coupled to the MOM3 regional ocean model in the Atlantic domain. By comparing the simulated TAV in the different model configurations, we test the hypotheses listed above. We also carry out ensemble hindcast experiments to assess the seasonal predictability of TAV, including hindcast experiments to coincide with the observing period of the proposed Atlantic Marine ITCZ process study.

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Variability in Tropical Depression Formation in the Eastern Atlantic and the Eastern Pacific

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Over the last ten years, an average of three tropical depressions per year have formed in the Atlantic east of 35° W. In the superficially similar region of the eastern Pacific, the rate of tropical depression formation is more than 5 times greater. Given that east Pacific storms are widely thought to form primarily from African easterly waves, which also presumably move through the monsoon trough area of the eastern Atlantic, it is a mystery as to why more such waves do not amplify into tropical depressions, and from there into tropical storms and hurricanes in the Atlantic.

Some hints as to the origin of this suppression comes from the research of William Gray, Chris Landsea, and their colleagues into the natural variability of Atlantic hurricanes. Three major factors appear to affect the frequency of such cyclones: (1) Sahelian rainfall, (2) the phase of ENSO, and (3) the phase of the quasi-biennial oscillation (QBO). In particular, a wet Sahel, La Niña, and westerly 30 hPa stratospheric winds are correlated with increased Atlantic storm activity. The latter two conditions are thought to reduce vertical wind shear in the regions of tropical cyclogenesis, a situation known to favor storm formation. Drought in the Sahel is also thought to increase shear in the eastern Atlantic, but may also have other effects, such as modification of easterly wave structure and more import of dry air.

The EPIC2001 project and other work by Maloney and Hartmann as well as Molinari and colleagues have documented variability in the east Pacific, a variability manifested strongly in changes in tropical storm generation. The predominant intraseasonal switch in this region is the phase of the Madden-Julian oscillation (MJO). EPIC2001 was unique in that it provided intensive in situ observations of tropical cyclogenesis and resulted in a hypothesis for the mechanism whereby the MJO affects this process. It also showed that the variability implied by periodic tropical storm production rectifies strongly onto climate time scales, both in the ocean and in the atmosphere.

Given the highly variable nature of the suppression of tropical storm activity by variable environmental factors in the eastern Atlantic, it would seem important to understand how these suppression mechanisms work there. A process study in this region could throw light on this issue, especially in the context of east Pacific observations, where the suppression of cyclogenesis is much weaker.

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Does local air-sea coupling matter in the Atlantic?

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Air-sea interaction involves the exchange of both momentum and heat between the atmosphere and the ocean. Dynamic air-sea interaction, which relates to the momentum exchange, is believed to play the dominant role in the interannual variability of the equatorial ocean, especially in phenomena such as the El Niño-Southern Oscillation (ENSO). However, thermodynamic heat exchange can also play a significant role in air-sea interaction. The role of this thermodynamic interaction in explaining season-to-interannual variability becomes increasingly important as one moves away from the equatorial ocean towards the extratropical regions.

The role of dynamic and thermodynamic air-sea interaction in the Atlantic basin is analyzed in three separate contexts: (i) extratropical variability; (ii) interhemispheric gradient mode; and (iii) Atlantic Niño. Observed variability is compared to simulated variability in a hierarchy of general circulation models with different degrees of air-sea coupling. It is argued that in the extratropics, the presence (or absence) of air-sea coupling does not significantly affect atmospheric variability above the boundary layer. This is consistent with a number of theoretical and modeling studies which suggest that the atmospheric response to midlatitude sea surface temperature (SST) anomalies is rather weak. The midlatitude SST variability itself can be explained primarily as the passive thermodynamic response to internal atmospheric variability, using the reduced thermal damping mechanism.

Much of the SST variability in the subtropical Atlantic may also be explained as the passive response to remote forcing associated with ENSO and the North Atlantic Oscillation. However, in the deep tropics, it is shown that thermodynamic air-sea interaction leads to amplification and increased persistence of surface wind variability. This effect is anisotropic, being stronger in the meridional component than in the zonal component of the surface wind. These features cannot be explained by the isotropic reduced thermal damping mechanism, and indicates a possible role for the wind-evaporation-SST (WES) feedback in the deep tropics. The importance of local air-sea coupling is further demonstrated using predictability experiments starting from observed SST initial conditions. These experiments show that thermodynamic air-sea interaction results in significant forecast skill for lead times of up to six months.

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