Connections Between Mid-latitude and Tropical Climate Variability in the Pacific: the Role of the Seasonal Cycle and Subtropical Air-Sea Interaction

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Introduction:

Recent research has identified a mechanism by which winter mid-latitude atmospheric variability can affect tropical climate through associated changes in the tropical and subtropical trade winds. These trade wind fluctuations alter the underlying sea surface temperature, exciting coupled feedbacks in the tropics and subtropics that persist through the spring and summer. This sequence of events, dubbed the "seasonal footprinting mechanism" (SFM) appears to be an effective means of initiating interannual El Niño – Southern Oscillation (ENSO) variability, and in generating tropical decadal variability. A schematic of the SFM is illustrated in Figure 1.

Despite the identification of the SFM in models and in nature, numerous questions remain about its role in generating tropical climate variability. What role do realistic ocean processes play in altering the strength and persistence of tropical variability that is generated through the SFM? How strong are the coupled feedbacks that generate the tropical response? What is the ocean's dynamical response to tropical variability generated through the SFM? Does the SFM enhance tropical ENSO predictability?

Project Goals:

The present proposal has three specific goals:

1. Simulate the physical processes that compose the SFM, and identify the role of various oceanic physical processes in altering the structure, persistence, and predictability of tropical variability generated through the SFM.
2. Identify the specific geographical regions where mid-latitude atmospheric variability is most effective at generating a tropical response.
3. Examine the effect of mid-latitude atmospheric variability on the evolution and predictability of tropical ENSO variability.

More generally, this proposal aims to better understand the nature of air-sea interactions in the tropics and subtropics; to explore the role of seasonality in Pacific interannual and decadal variability; and to better quantify the processes that give rise to Pacific climate variability and predictability on interannual to decadal time scales.

Methodology:

We propose ensemble experiments using a hierarchy of coupled general circulation models with differing ocean physics. The coupled models are forced with anomalous heat and momentum fluxes (representing forcing from mid-latitude atmospheric variability) during the winter months, then allowed to freely evolve during the ensuing spring and summer. Model results will be compared with observations to ensure their reality, and to better quantify observed air-sea interactions in the subtropics and tropics. An example of the model forcing and response is shown in Figures 2 and 3, and described in their captions.

Three sets of experiments are proposed. The first set of experiments involves the atmospheric model (we will be using the NCAR CAM) coupled to (i) a 50m slab ocean, (ii) a more physically realistic mixed layer ocean model (MLM), and (iii) the oceanic component of CSM. As explained above, the ocean models (coupled with the atmosphere) will be forced with anomalous surface heat and momentum fluxes during the boreal winter months, and allowed to freely evolve during the following seasons. This first set of experiments will explore how oceanic processes affect interactions between mid-latitude atmospheric variability and tropical coupled processes. The second set of experiments involves forcing the CAM+MLM model with the same heat and momentum flux anomalies as in the first set of experiments, except that forcing in the tropics will be masked. We will run a series of experiments that mask out the tropical forcing at increasing latitudes, to determine the equatorward extent of mid-latitude forcing necessary to excite a coupled response in the tropics. In the last set of experiments, we intend to investigate the mid-latitude atmosphere's influence on developing ENSO variability by applying the heat and momentum flux forcing to an intermediate coupled model prior to a warm, cold, or neutral ENSO year. If time permits, we will repeat this experiment with the full CSM.

Results and Accomplishments:

We are just beginning this research, so there are no results yet.

Publications resulting from this research:

We are just beginning this research, so we have not published any papers yet.

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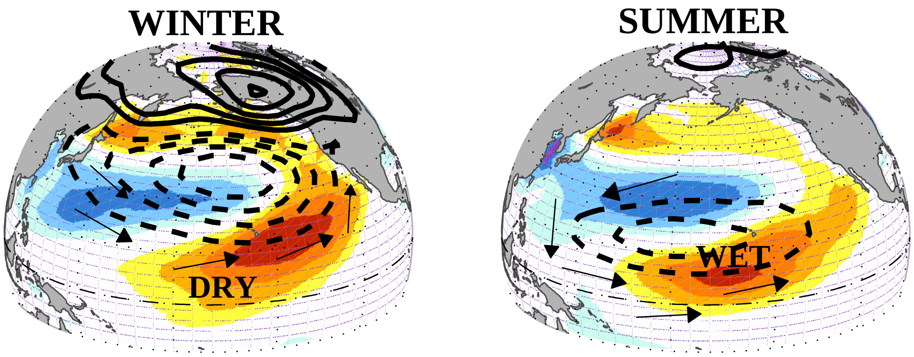
Figures:



A. Atmosphere imparts SST footprint onto the ocean during the winter months

B. SST footprint persists into the following summer, when it forces atmosphere

Figure 1. Schematic of the seasonal footprinting mechanism (SFM). Taken from Vimont et al. (2001). During winter (left panel) mid-latitude atmospheric variability (SLP: solid and dashed contours denote positive and negative anomalies, respectively) imparts an SST footprint onto the ocean (shading; warm colors positive, cool colors negative). During the following summer (right panel), the SST footprint forces a residual atmospheric circulation (SLP contours, as above) that includes zonal wind stress anomalies along the equator (vectors). Precipitation anomalies are denoted by text (DRY and WET).

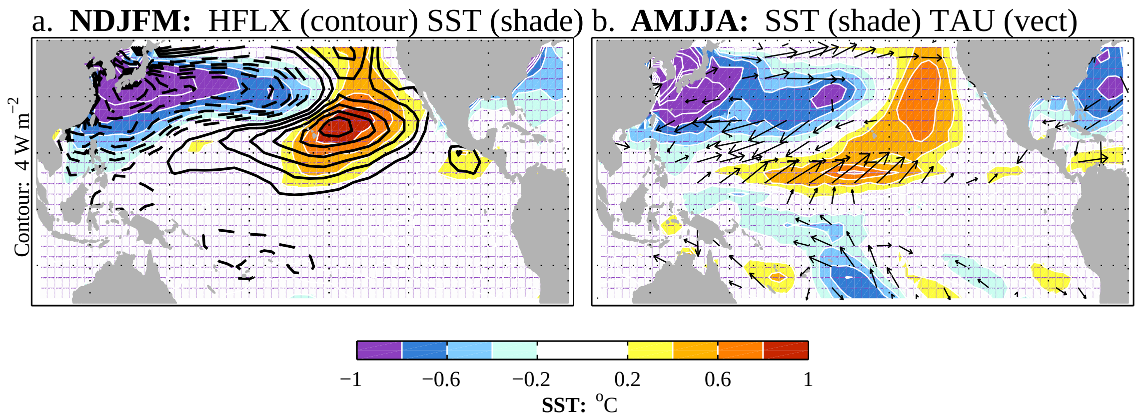


Figure 2. Ensemble mean difference from the “test run”, in which CCM3 is coupled to the 50m SOM. During winter (left panel) the coupled model is forced at the surface by heat flux anomalies (contours in left panel: solid positive, negative dashed, contour interval 5 W m^{-2}). The heat flux anomalies produce SST anomalies (shading in left panel) that persist into the summer (right panel, shading). Summer SST anomalies force a residual atmospheric circulation (wind stress vectors in right panel). Of note is the development of warm SST anomalies along 10°N in the right panel, which appears to arise via coupled feedbacks.

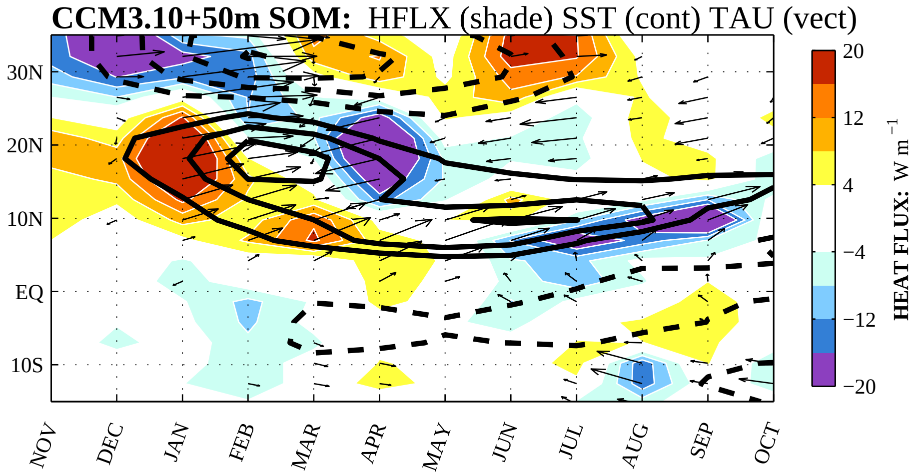


Figure 3. Zonally averaged (150°E-135°W) ensemble mean difference from the “test run” of CCM coupled to the 50m SOM. In January, the heat flux (shading) around 17°N generates the SST footprint (contour interval 0.2°C; solid and dashed contours denote positive and negative SST anomalies, respectively). The SST footprint peaks in February and March, and forces surface wind stress anomalies (vectors). Note that around 10°N, the SST footprint and the wind stress anomalies both continue to amplify through June, despite cessation of the imposed heat flux forcing at the end of March. This development suggests the presence of coupled feedbacks between the SST footprint and the tropical atmospheric circulation.