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Department of Atmospheric Sciences Ph.D. Dissertation Defense Announcement

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Ph.D. Dissertation Title:

El Niño/Annual Cycle Combination Mode Dynamics

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Date: Tuesday, March 24, 2015
Time: 10:00 AM
Location: Marine Sciences Building, MSB 100

Abstract:

The intricate interaction between the El Niño-Southern Oscillation (ENSO) and the annual cycle has been a long-standing problem in climate science. Here I demonstrate that the nonlinear atmospheric interaction between the Western Pacific warm pool seasonal cycle and ENSO creates a previously overlooked mode of Indo-Pacific climate variability. This combination mode (C-mode) is characterized by near-annual and sub-annual timescales (combination tones) and contributes substantially to the observed low-level atmospheric circulation and precipitation anomalies. The meridionally anti-symmetric warm pool annual cycle is the cause for the characteristic meridionally anti-symmetric C-mode response, while the linear ENSO response is quasi-symmetric with regard to the equator.

Several climate phenomena are shown to be manifestations of the C-mode: (i) zonal South Pacific Convergence Zone (SPCZ) events, (ii) the southward shift of anomalous westerlies at the end of the calendar year during El Niño events, (iii) the anomalous low-level Northwest Pacific Anticyclone (NWP-AC), and (iv) prolonged low sea-level events in the Southwest Pacific (El Niño Taimasa).

The NWP-AC bridges the impacts of ENSO to the Asian Monsoon system. Previous research highlighted the importance of thermodynamic air-sea coupling for the genesis and persistence of the NWP-AC. However, I show that the phase transition information for the anomalous Northwest Pacific circulation originates solely from the atmospheric C-mode. Air-sea coupling only contributes amplification and persistence to the C-mode response.

The ENSO/annual cycle interaction outlined here can be elegantly viewed as a frequency cascade, which transfers power from the interannual band to higher frequencies (combination tones). This extended ENSO response is not only characterized by different timescales but also by unique circulation and rainfall patterns. Importantly, this high frequency climate variability is purely deterministic in its nature and hence as potentially predictable as ENSO and the seasonal cycle themselves. Finally, the frequency cascade and combination mode frameworks are universal concepts that can be used to understand many nonlinear interactions between different timescale phenomena in the climate system and dynamical systems in general.