A conceptual framework for time and space scale interactions in the climate system

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Abstract Interactions involving various time and space scales, both within the tropics and between the tropics and midlatitudes, are ubiquitous in the climate system. We propose a conceptual framework for understanding such interactions whereby longer time scales and larger space scales set the base state for processes on shorter time scales and smaller space scales, which in turn have an influence back on the longer time scales and larger space scales in a continuum of process-related interactions. Though not intended to be comprehensive, we do cite examples from the literature to provide evidence for the validity of this framework. Decadal time scale base states of the coupled climate system set the context for the manifestation of interannual time scales (El Nino/Southern Oscillation, ENSO and tropospheric biennial oscillation, TBO) which are influenced by and interact with the annual cycle and seasonal time scales. Those base states in turn influence the large-scale coupled processes involved with intraseasonal and submonthly time scales, tied to interactions within the tropics and extratropics, and tropical–midlatitude teleconnections. All of these set the base state for processes on the synoptic and mesoscale and regional/local space scales. Events at those relatively short time scales and small space scales may then affect the longer time scale and larger space scale processes in turn, reaching back out to submonthly, intraseasonal, seasonal, annual, TBO, ENSO and decadal. Global coupled models can capture some elements of the decadal, ENSO, TBO, annual and seasonal time scales with the associated global space scales. However, coupled models are less successful at simulating phenomena at subseasonal and shorter time scales with hemispheric and smaller space scales. In the context of the proposed conceptual framework, the synergistic interactions of the time and space scales suggest that a high priority must be placed on improved simulations of all of the time and space scales in the climate system. This is particularly important for the subseasonal time scales and hemispheric and smaller space scales, which are not well simulated at present, to improve the prospects of successfully forecasting phenomena beyond the synoptic scales.

1 Introduction

It is well known that a background or climate base state can affect the climate system response to various forcings. This idea has mainly been developed in regard to specific time or space scales. An example illustrative of results from numerous modeling studies in Fig. 1 shows the response in midlatitudes to a tropical disturbance in a modeling study by Lau et al. (1988). For the GCM climatological “wavy” base state at top, the response in midlatitudes is characterized by an alternating series of troughs and ridges suggestive of synoptic scale events that would have implications for midlatitude forecasting. However, if the midlatitude base state is quite different (Fig. 1, in this case a basic state at rest) the midlatitude response to the tropical disturbance is almost devoid of any smaller scale features that could influence weather events. Thus the background base state directly influences the climate system response to specific forcings, in this case from the tropics.

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Another example of a climate system response dependent on a background or base state from observations is shown in Fig. 2. The panel at the top shows a midlatitude circulation pattern termed the West Pacific Oscillation (WPO) by Barnston and Livezey (1987). The correlation of this particular pattern to tropical Pacific SST anomalies for all data analyzed by Livezey and Mo (1987) is shown in Fig. 2b. There is some linkage with the tropics in Fig. 2b, but these connections are amplified (Fig. 2c) during El Nino-Southern Oscillation (ENSO) event conditions (correlations for ENSO years only). However, during non-ENSO event years the linkage is weaker (Fig. 2d). The implication is that for certain SST conditions in the tropical Pacific, for example during a warm ENSO event, there is a stronger connection between the tropics and midlatitudes (considering that warmest SSTs are associated with areas of enhanced convection) than in other years. That is, there appears to be a base state set up in association with tropical SST patterns that preferentially enhances the linkages between tropics and a particular midlatitude circulation pattern during ENSO years that does not happen in other years. Also note in Fig. 2 that the correlations in the western equatorial Pacific, which are consistent in all three lower panels, do not depend on ENSO because the SST there already is above the threshold for deep convection (about 28°C). Meanwhile the correlations centered around 135°W, where mean SSTs are below 28°C, vary considerably with ENSO.

We can extend the idea of background base states influencing the manifestation of various climate phenomena by proposing a conceptual framework for understanding these interactions. The central concept is that longer time scales and larger space scales set the base state for processes on shorter time scales and smaller space scales, with these scales then being able to act back...