

Influence of the Stratospheric QBO on ENSO Variability

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Abstract

A hypothetical mechanism is described whereby the Quasi-Biennial Oscillation (QBO) of Zonal winds in the equatorial stratosphere actively modulates the timing of El Niño-Southern Oscillation (ENSO) events. The mechanism involves the meridional redistribution of deep convective activity throughout the tropical Pacific warm pool region in response to variable wind shear processes which are linked to the opposing phases of the QBO. Hydrostatic conditions favoring deep convective activity within approximately $\pm 7^\circ$ of the equator develop in response to the easterly shear phase of the QBO. At the same time, deep convection is inhibited in the monsoon-convergence zones farther off the equator ($8\text{--}18^\circ$ latitude) during the east phase of the QBO. The opposite trends occur during the westerly shear phase of the QBO wherein deep equatorial convection is suppressed while off-equator monsoon convection is enhanced. It is shown that during the east phase of the QBO, the Pacific regional pressure and circulation anomalies which arise in response to QBO-linked trends in convective activity are consistent with conditions leading to warm ENSO events (*i.e.*, El Niño). If the heat content of the warm pool is sufficient, a warm event will occur. Conversely, conditions favoring the development of cold (or La Niña) events tend to occur in association with the westerly phase of the QBO. Although several aspects of the hypothetical mechanism remain tentative, extensive empirical results present a compelling argument for the QBO as an active and fundamental component of ENSO variability.

1. Introduction: Problems of ENSO predictability

Reliable prediction of significant El Niño-Southern Oscillation (ENSO) events remains an important long term research goal for improved extended range weather forecasting. In this report, it is proposed that the ENSO cycle may be significantly influenced by subtle trends in tropical convective activity which occur in association with the Quasi-Biennial Oscillation (QBO) of zonal wind and temperature anomalies in the equatorial stratosphere. We present evidence that such convective trends occur in response to several QBO-linked processes. These processes include variations in: (1) the distribution of geopotential heights in the equatorial upper troposphere and lower stratosphere, (2) the horizontal ventilation of the lower stratosphere over deep tropical convective cells penetrating the tropopause and (3) the reflection versus absorption of upward propagating wave energy from these developing convective cells. Each of these processes varies in response to conditions linked to trends of QBO-induced vertical wind shear and likely feedback into intense convective activity.

The duration of full ENSO cycles typically varies

from three to seven years, entailing the accumulation and comparatively rapid release of heat energy in the ocean surface layer of the western equatorial Pacific. Easterly trade winds in the tropical Pacific tend to move warm surface layer water westward. Ocean upwelling processes along the equator which are linked to the divergence of this westward drift maintain comparatively cold Sea Surface Temperatures (SST) throughout much of the central and eastern equatorial Pacific. The deep layer of comparatively warm ($>28^\circ\text{C}$) surface water which accumulates in the West Pacific is the so called West Pacific "warm pool". The West Pacific warm pool is the principal area of tropospheric mass flux into the stratosphere, primarily through the concentrated effects of deep convective clouds penetrating the tropical tropopause. Termed the "stratospheric fountain" by Newell and Gould-Stuart (1981), this vast region is at the center of the ascending branch of the Pacific Walker circulation.

Any process which significantly alters deep convective activity in the warm pool must also influence the regional Walker and Hadley circulations and hence, the Southern Oscillation. Therefore, the proposed mechanism linking the QBO to ENSO is based on the contention that contrasting amounts of vertical wind shear and static stability imposed

by the east and west phases of QBO act to significantly alter the regional scale distribution of deep convective activity over the warm pool region. If contrasting trends in the distribution of deep tropical convection are linked to the phase of the QBO, then the resulting tropospheric circulation anomalies which they promote will occur over large areas. These trends also persist over interannual time scales which should be more than adequate to force concurrent changes in the regional tropospheric circulation. As shown in the following section, the distribution of these effects varies such that the QBO east phase trends to promote the development of El Niños (warm SST events) whereas the QBO west phase promotes La Niña (cold) conditions.

Whereas progress is being made in numerical simulations of El Niño and of the ENSO cycle, important questions remain concerning the specific combination of oceanic and atmospheric conditions that actually initiate the transition between distinct ENSO modes (see Phillander, 1990). Many researchers believe that inadequate knowledge of both the structural and quantitative factors governing the ocean-atmosphere heat budgets of the warm pool region are primary obstacles to more successful numerical forecasts of ENSO variability. Others maintain that a more detailed understanding of the organization of atmospheric convective processes in the warm pool holds the key to ENSO variability. Efforts are now underway (*e.g.*, the forthcoming TOGA-COARE field program) to acquire extensive heat flux data for the warm pool area.

It is our opinion that additional processes (such as the QBO) which are not currently under serious consideration may be important components of ENSO variability. The mechanism for the QBO-linked modulation of ENSO variability which is outlined in this report is based on the interpretation of empirical data for several aspects of ENSO variability which are otherwise not well explained. It is important to note (and we shall re-emphasize throughout this report) that the stratospheric QBO-troposphere-ocean interaction which is proposed here is likely neither necessary nor sufficient, in and of itself, to either cause or to completely inhibit ENSO events; therefore, it is not proposed that the stratosphere drives the troposphere. Rather, it is suggested that the QBO is an important interactive component influencing the timing of the major ENSO events in the tropical ocean-atmosphere system. Consequently, we also argue for the inclusion of likely QBO-linked effects in ENSO forecasting schemes.

Note also that in our discussion, the term "QBO" will refer strictly to the QBO of lower stratospheric zonal winds, temperature and geopotential height. Other biennial or quasi-biennial oscillations which have been observed in the troposphere and ocean

will be explicitly identified as they are discussed. The term "ENSO" will be used to refer to all aspects of the phenomenon although our primary ENSO index is anomalous variations of SSTs in the "Niño 3" (5°N to 5°S, 90 to 140°W) area of the equatorial East Pacific.

In the following section we briefly summarize prior related studies. The remainder of the report is organized as follows: In Section 2 we present a detailed discussion of physical mechanisms tying QBO-linked vertical wind shear, temperature and height fields to anomalous trends in tropical convection and ENSO variability. Empirical evidence of a QBO-tropical convection-ENSO association is presented in part 3. A summary which includes a review of questions related to ENSO variability which are better resolved by the proposed QBO modulation mechanism, is presented in part 4.

2. Related research

Studies of associations between the QBO and ENSO are relatively sparse. A few authors have suggested that variable, vertically propagating planetary wave energy flux linked to ENSO might affect the periodicity of the QBO (see Maruyama and Tsuneoka, 1988). However, the possibility that the QBO might somehow modulate ENSO variability has received little serious consideration (see Trenberth, 1976; Barnett, 1989, 1991; Enfield, 1990). Several recent studies have presented evidence of strong biennial components in ENSO linked data sets. Results presented by Lau and Sheu (1988), Barnett (1990, 1991), Rasmusson *et al.* (1990), Xu (1992), and Ropelewski *et al.* (1992), show biennial components in global data including precipitation, equatorial Pacific SSTs and broad scale tropical circulations. Most notably, Rasmusson *et al.* (1990) and Xu (1992) argue that these observed tropospheric biennial oscillations are distinct from the stratospheric QBO in that the tropospheric oscillations tend to be comparatively pure biennial signals (*i.e.*, 24 month periodicity), closely phase locked with the annual cycle, but occasionally reversing phase. Our view, as detailed below, is that when a quasi-biennial process (*i.e.*, the QBO) is actively modulating circulations with strong annual cycles (*i.e.*, the monsoons, intertropical convergence zones and tropical cyclone activity), then the characteristics of the resulting tropospheric "biennial" oscillations are precisely as those described by Rasmusson *et al.* (*i.e.*, 24 month oscillations, occasionally reversing phase). Consequently, the failure of rigorous spectra based comparative studies to find a clear QBO-ENSO tie is not surprising, especially in view of the additional complications of powerful ENSO feedback processes acting throughout the region on a highly variable interannual time scale.

Prior work by Gray (1984, 1988) and by Shapiro