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Effect of ENSO and the MJO on Western North Pacific Tropical Cyclones

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Abstract. Prior work has suggested that Rossby wave accumulation in the lower troposphere may be an important mechanism for the development of synoptic-scale disturbances in the western north Pacific in northern summer. This work examines the intraseasonal and interannual variability of wave accumulation by computing the barotropic wave activity flux divergence at 850 hPa for different phases of the Madden-Julian oscillation (MJO) and El Niño/southern oscillation (ENSO). Indirectly, and without ruling out other influences, the results suggest a physical mechanism behind previously identified relationships between tropical cyclogenesis statistics and these two modes of variability (MJO and ENSO).

Introduction

Observational studies have documented relationships between the statistics of tropical cyclones in the western North Pacific (WP) and longer-timescale climatic fluctuations, such as the Madden-Julian oscillation (MJO)[*Liebmann et al.*, 1994] and El Niño/Southern Oscillation (ENSO) [*Lander*, 1994; and references therein].

One necessary ingredient for tropical cyclogenesis is the prior existence of enhanced low-level synoptic-scale vorticity [*Zehr*, 1992], such as associated with a "tropical depression type" (TD-type) disturbance in the WP [*Reed and Recker*, 1971; *Nitta and Takayabu*, 1985; *Lau and Lau*, 1990, 1992; *Takayabu and Nitta*, 1993; *Dunkerton*, 1993; *Dunkerton and Baldwin*, 1995; *Chang et al.*, 1996; *Sobel and Bretherton*, 1999] (for a review of earlier work see *Wallace* [1971]). Recent work has suggested that TD-type disturbances amplify in the WP due to Rossby wave accumulation in the lower troposphere, caused by the strong large-scale convergence there [*Holland*,, 1995; *Sobel and Bretherton*, 1999]. The position and intensity of this large-scale convergence are modulated by the MJO and ENSO, and so one can expect that the lower tropospheric Rossby wave accumulation will be similarly modulated. The occurrence of tropical cyclogenesis in the WP may also be similarly modulated through the associated variation in the number of suitable synoptic-scale precursor disturbances.

Sobel and Bretherton [1999] used activity flux defined by *Plumb* [1986], which they computed assuming layer-wise barotropic disturbances propagating on the 850 hPa time-mean flow, to quantify the rate of wave accumulation. Here we present a similar analysis on subsets of the data representing different phases of the MJO and ENSO. Arguments similar to ours (though using different language) regarding the relationship of the MJO to tropical cyclones in the eastern north Pacific have also been made recently [*Maloney and Hartmann*, 2000; *Hartmann and Maloney*, 2000].

Data and method

We use the 850 hPa wind fields from the National Center for Environmental Prediction/ National Center for Atmospheric Research (NCEP/NCAR) reanalysis data set[*Kalnay et al.*,, 1996], from the period 1979-95. From each year we use data during May 15 - November 15, twice daily. A regression analysis shows that TD-type disturbances propagate approximately according to linear, barotropic vorticity dynamics when diagnosed from a single-level analysis at 850 hPa [*Sobel and Bretherton*, 1999]. Sensitivity tests (not shown) indicate that similar results are obtained by analogous calculations at other lower tropospheric levels.

The barotropic version of Plumb's wave activity flux is defined as

$$M = \frac{p\overline{\zeta'^2}\cos\phi}{|\nabla\overline{\zeta}_a|} \quad (1)$$

where the overbar represents a time average and prime a deviation therefrom, ϕ is latitude, p pressure, ζ the relative and ζ_a the absolute vorticity. Under linear, WKB dynamics, M satisfies the conservation relation

$$\frac{\partial M}{\partial t} + \nabla\cdot(\mathbf{M}_R + \overline{\mathbf{u}}M) = S_M. \quad (2)$$

where, assuming the $\overline{\zeta_a}$ contours are approximately zonal,

$$\mathbf{M}_R = p\cos\phi[\frac{1}{2}(\overline{v'^2} - \overline{u'^2}), -\overline{u'v'}]$$

and $\mathbf{u} = (u, v)$ is the horizontal velocity. S_M is a source or sink term, which can include baroclinic effects and other neglected processes as well as forcings per se. In the "almost plane-wave limit" the group velocity property is satisfied

$$\mathbf{c}_g = \mathbf{M}_R/M + \overline{\mathbf{u}}$$

with $\mathbf{c}_g$ being the group velocity. Expanding the flux divergence term in (2) in this limit,

$$\nabla\cdot(\mathbf{c}_g M) = \mathbf{c}_g\cdot\nabla M + M\nabla\cdot\mathbf{c}_g \quad (3)$$

The first term on the RHS, being equivalent to an advective term, does not change the wave packet's amplitude along a

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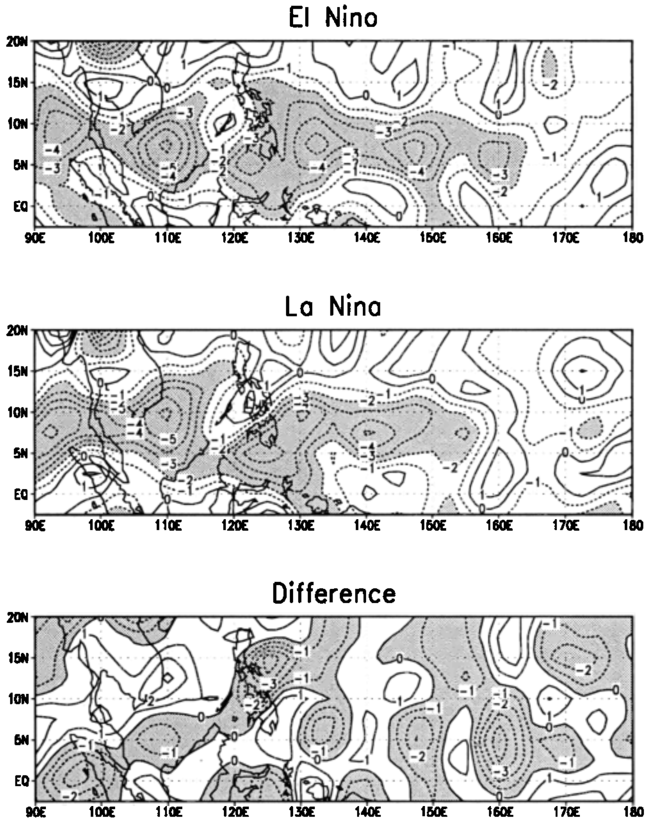

Figure 1. Group velocity divergence at 850 hPa for years in which the SOI is less than (top) or greater than (middle) -0.2, and the first minus the second (bottom), in units of $10^{-6}s^{-1}$.

trajectory defined by the group velocity. The second does change the amplitude (neglecting S for the sake of argument), defining a local growth time scale $-(\nabla \cdot \mathbf{c}_g)^{-1}$. Of course, if $S = 0$ there is no amplitude change integrated over the wave packet, if amplitude is measured by M. However, there can be a net increase in the eddy kinetic energy associated with nonmodal barotropic conversion from the mean flow.

In this study, the overbar (and therefore primes) are not computed by an average over the whole data record, but by averages during different phases of ENSO or the MJO. The different phases of ENSO are defined by the southern oscillation index (SOI)[*Chelliah*, 1990], averaged for the months June-October. A threshold value of -0.2 was used, with calculations performed separately on years having a June-October averaged SOI either below or above that value; -0.2 was chosen because it divides the data exactly in half. The phases of the MJO are defined by the index of *Maloney and Hartmann* [1998]. The index is defined only during MJO "events", which in total constitute 54% of our data record. Only that fraction of the data is used for the MJO calculations below.

The perturbations are filtered in time to isolate synoptic frequencies; the filter has full power between 2-6 days and falls to half power at 1.5 and 11 days. The filter may not remove all influence from tropical cyclones themselves, leading to some potential bias, though this should be minimal along the eastern portion of the disturbance "storm track" where most disturbances have not yet undergone cyclogenesis [*Sobel and Bretherton*, 1999].

Results

ENSO

The top two panels of Figure 1 (a and b) show the group velocity divergence calculated for years in which the average SOI over the season is positive and negative, respectively. In both cases a longitudinally oriented tongue of substantial convergence, indicating local amplitude growth through wave accumulation, exists around 5-10N. The assumption of linear barotropic vorticity dynamics holds to a reasonably good approximation only along this tongue, particularly the portion east of the Philippines. Fortunately, this is also the region where disturbance amplification occurs [*Sobel and Bretherton*, 1999]. The bottom panel (c) shows the difference between the two, figure 1a minus figure 1b. This plot indicates that during El Niño years (SOI < -0.2) the magnitude of the wave activity flux convergence averaged over the tongue is slightly larger than in La Niña years. However, the main difference is that the higher values extend somewhat further east during El Niño years, as evidenced by the maximum in (c) centered on 5N, 160E.

While some studies have indicated a relationship between WP tropical cyclone frequency and ENSO, the majority (including, to our knowledge, the most recent) do not. However, the typical location at which cyclogenesis occurs has been found to shift eastward during El Niño years [*Lander*, 1994]. The eastward extension of the large group velocity

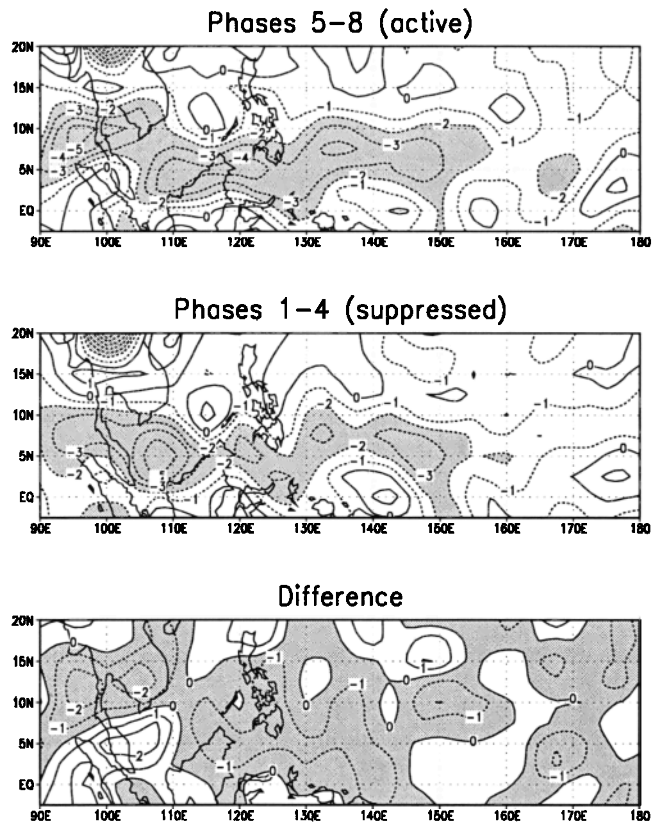

Figure 2. Group velocity divergence at 850 hPa composited over the active (top) and suppresed (middle) phase of the MJO, and the first minus the second (bottom), units as above.

convergence shown in figure 1 for El Niño years is consistent with these findings.

MJO

The top two panels of Figure 2 show the group velocity divergence averaged over two phases of the MJO. The first is defined by the average over phases 5-8 (active), and the second over phases 1-4 (suppressed), of the MJO composite events defined by *Maloney and Hartmann* [1998] (see their figure 15). While those authors used zonal wind anomalies at 850 hPa to define the anomaly phases, we define the active and inactive phases by the sign of the 20-80 day precipitation anomalies in the region of interest in the western Pacific (see Fig. 15 of *Maloney and Hartmann* [1998]). The difference plot (bottom panel) shows that convergence is larger in the active phase than the inactive by an amount of order $1 \times 10^{-6} s^{-1}$ averaged over the region of interest. This value represents a significant fraction (roughly 30-50%) of the total. The tongue of large convergence also shifts slightly northward in the active phase.

WP tropical cyclones have been found to be more frequent during the active MJO phase than during the suppressed phase, because of the existence of a larger number of precursor depressions rather than because of any increase in the percentage which undergo cyclogenesis [*Liebmann et al.*, 1994]. A larger rate of wave accumulation in the active MJO phase can explain this result. Given a fixed flux of wave activity into the WP, a larger wave activity flux convergence would on average lead to a larger local growth rate, and hence a larger number of TD-type disturbances reaching sufficient amplitude to be labeled "depressions".

Discussion

The wave accumulation argument assumes the preexistence of Rossby waves which propagate into the region. These Rossby waves are assumed to have larger spatial scales and smaller amplitudes than are typical of a TD type disturbance that can support cyclogenesis. One caveat is that the characterization of TD type disturbances as barotropic Rossby waves is dynamically incomplete. The TD type disturbances are associated with deep convection and thus with convergent/divergent circulations, though these have only a weak influence on their propagation characteristics. Also, the present argument ignores possible intraseasonal or interannual variability in the sources of these waves. These wave sources have not been conclusively identified, though planetary-scale equatorial Rossby waves have been diagnosed from outgoing longwave radiation data [*Wheeler and Kiladis*, 1999; *Wheeler et al.*, 1999]. Mature tropical cyclones themselves may also be an important source, since they radiate Rossby waves [*Davidson and Hendon*, 1989; *Holland,*, 1995; *Ferreira and Schubert*, 1997; *Sobel and Bretherton*, 1999].

The associations between tropical cyclones and modes of variability with larger space and time scales have been described in other terms, for example in terms of the position or strength of the monsoon trough [*Zehr*, 1992; *Harr and Elsberry*, 1995a, b]. Such descriptions have tended to be based on analyses that are statistical rather than dynamical in nature, and hence are not necessarily inconsistent with the arguments presented here. However, since the low-level flow convergence that in large part determines the group velocity convergence is associated with enhanced convection in the monsoon trough region, this enhanced convection may also increase the probability of cyclogenesis through other dynamical mechanisms not directly associated with synoptic-scale vorticity fluctuations.

Conclusions

NCEP/NCAR Reanalyses for the years 1979-95 and the 850 hPa level have been used to perform calculations of wave activity flux divergence similar to those of *Sobel and Bretherton* [1999], except that the calculations were performed on subsets of the data representing different phases of the MJO and ENSO. The main conclusions are:

- the tongue of large wave activity convergence associated with the storm track of TD-type disturbances in the northern summer WP extends further east during an El Niño year than during a La Niña year, and is stronger during the active phase of the MJO than during the suppressed phase;
- without ruling out others, these results suggest one possible physical explanation for prior results on observed tropical cyclone statistics, namely that the average genesis location moves eastward in an El Niño year, and that tropical cyclones are more frequent during the active MJO phase than the suppressed phase. If wave accumulation is an important mechanism for TD-type disturbance development in the WP, and the frequency of tropical cyclogenesis is to a significant extent rate-limited by the availability of such disturbances having sufficiently large amplitude, then our group velocity calculations would lead one to expect intraseasonal and interannual variations in tropical cyclone statistics such as are observed.

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