

# **Tropical Cyclone Distribution and Intensity Change in the Western Pacific Ocean**

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## **LONG-TERM GOALS**

The long-term goals of this research are to understand the processes that determine the spatial and temporal distribution of tropical cyclones in the western Pacific Ocean.

## **OBJECTIVES**

The primary objectives during the last year have been to address why tropical cyclones tend to occur in clusters in the Western Pacific Ocean, i.e., two or more storms in the same region, followed by two or more in a completely different region. Our efforts have centered on the role of equatorial wave modes, especially mixed Rossby-gravity and  $n=1$  Equatorial Rossby (ER) waves. We are also trying to reconcile the monsoon trough-centered paradigm of tropical cyclone genesis with paradigm involving westward-moving waves interacting with slowly varying background features like the Madden-Julian Oscillation (MJO).

## **APPROACH**

We believe the best way to address the questions above is with detailed synoptic case studies rather than composite or statistical studies. We make use of gridded analyses from ECMWF and of outgoing longwave radiation (OLR) data. Both data sets were filtered in time to isolate the slowly-varying background (representative of the MJO and other slowly varying features) from the time scale of waves and tropical cyclones.

In addition, a shallow water model was developed by Anantha Aiyyer to give insight into how the MJO, mixed Rossby-gravity waves, and tropical cyclogenesis are related. The slowly-varying background with an active MJO was simulated by integrating to steady state with an imposed mass sink. Linear model simulations with small-amplitude disturbances were carried out with this background state assumed fixed. Analytically defined mixed Rossby gravity wave trains were generated and allowed to interact with the background state.

Looking forward, key individuals beyond the PI are Senior Scientific Programmer David Vollaro, MS student Kelly Lombardo, and MS student Carl Schreck. PhD student Anantha Aiyyer, who contributed greatly in past years, completed his dissertation work in Fall 2003.

## Report Documentation Page

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## WORK COMPLETED 2002-2003

A paper was published in the *Journal of the Atmospheric Sciences* entitled "Mixed Rossby-gravity waves and western Pacific tropical cyclogenesis. Part I: Synoptic Evolution", by PhD student Michael Dickinson and Molinari.

A paper is in press in the *Journal of the Atmospheric Sciences* entitled "Evolution of mixed Rossby-gravity waves in idealized MJO environments" by PhD student Anantha Aiyyer and Molinari. This was an idealized numerical modeling study based on the observational study noted above.

M.S. student Kelly Lombardo has studied a remarkable sequence of events in the western Pacific during summer 1991. For three months,  $n=1$  equatorial Rossby waves dominated the basin, and 11 tropical cyclones formed, at least 7 of which appear to be directly associated with the waves.

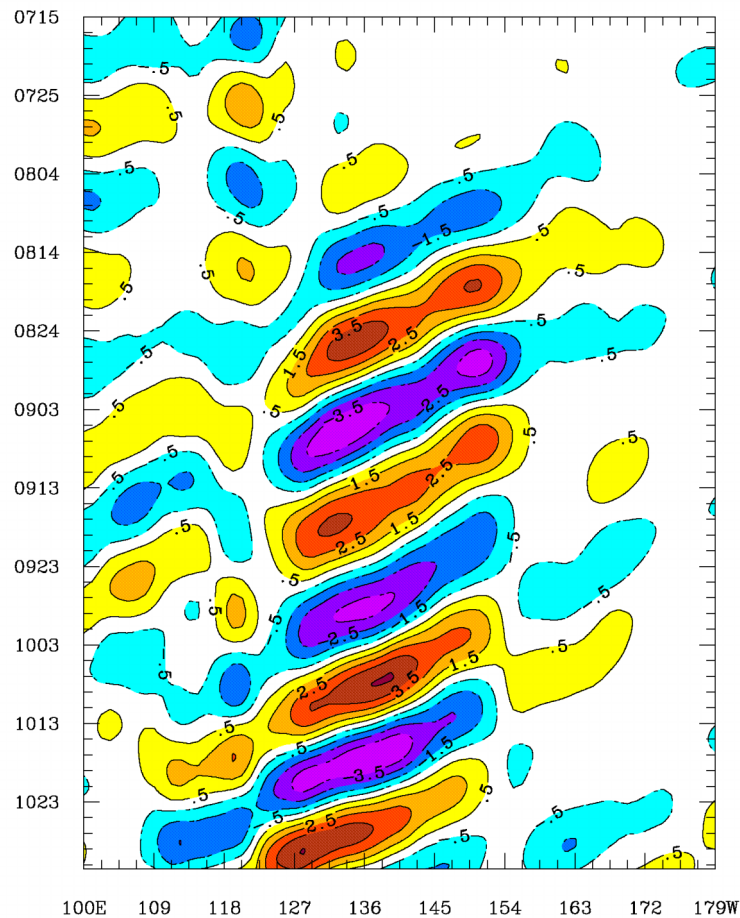
M.S. student Carl Schreck has examined 20 years of tropical cyclone tracks and filtered global model analyses and found several examples of tropical cyclogenesis associated with mixed Rossby-gravity waves. This represents a follow-up to the work by Dickinson and Molinari.

## RESULTS

The paper by Dickinson and Molinari (2002) described a sequence in July 1987, in which a large-amplitude MRG wave packet spawned three consecutive tropical cyclones in nearly the same location (near 10N, 145E). Each cyclone developed in association with a counterclockwise vortex that was initially part of the MRG packet, but then moved northwestward away from the equator. The packet developed under an active MJO, and later dispersed as the MJO moved eastward. The results suggest that tropical wave modes can act as pre-cursor disturbances to tropical cyclones in the western Pacific during times that the MJO is active.

The paper by Aiyyer and Molinari (2003) has shown that a background flow arising from a symmetric mass sink about the equator produced growing MRG waves only, but an asymmetric mass sink allowed growth of off-equatorial disturbances with the correct scale to be seedlings for tropical cyclones, even though the initial MRG waves had a 5000 km wavelength. The results support the observational study above, but show in addition that tropical cyclone precursors develop only when the MJO is asymmetric about the equator. This suggests that such events should be most common in Northern Hemisphere summer.

The study of  $n=1$  Equatorial Rossby (ER) waves has produced some surprising results. Figure 1 below shows a longitude-time (Hovmoeller) diagram of the  $v$ -component of the wind, bandpass-filtered to isolate ER waves, and averaged 5-20N, for summer 1991 in the western Pacific. It shows a long sequence of repeated passages of cyclones and anticyclones over nearly three months. The westward phase speed of these disturbances closely matches that of ER waves ( $1.8$  vs  $2.4 \text{ ms}^{-1}$ ), but does not match that of ordinary Rossby waves ( $5 \text{ ms}^{-1}$ ). The waves have a period close to 22 days.

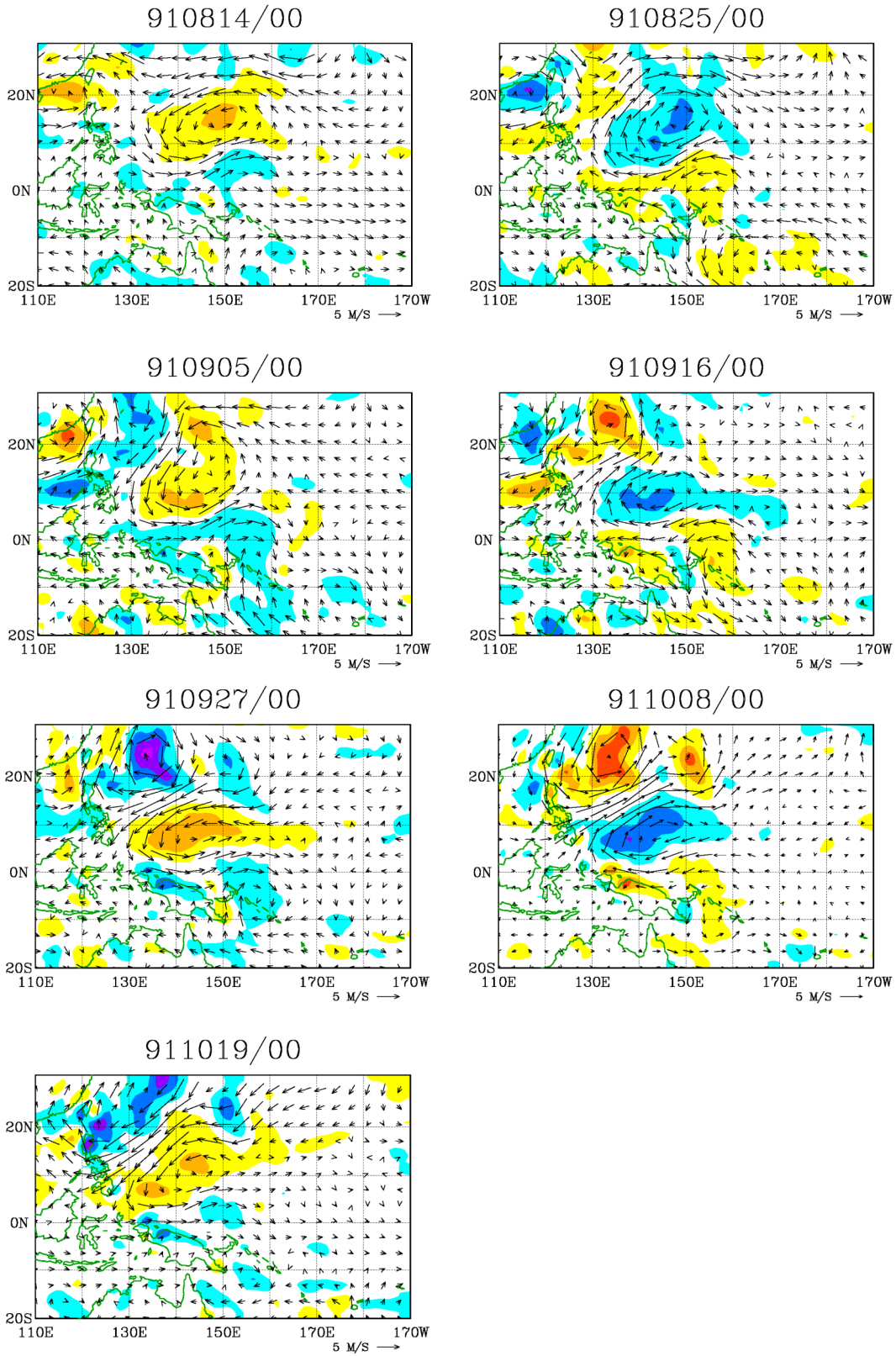


**Figure 1. Bandpass-filtered (15-30 d)  $v$  component of the wind, averaged 5N-20N, during the summer of 1991 in the western Pacific. Contour increment  $0.5 \text{ ms}^{-1}$ . This shows a sequence of  $n=1$  equatorial Rossby waves that lasts nearly three months.**

Figure 2 (next page) gives more insight into these disturbances. It shows the first month of the sequence, with one map every 11 days in order to capture the 22-day period. A remarkably regular pattern can be seen near 15N, 145-150E: first a large cyclone appeared, then 11 days later an anticyclone appeared in nearly the same location, then the pattern repeated. This occurred for nearly three months. Eleven tropical cyclones formed during the period, seven of which developed east or southeast of the cyclones, where pure ER waves favor upward motion. The disturbances moved northwestward with time. The results suggest that a northwest-southeast oriented wave packet existed for an extended period, with several tropical cyclones forming adjacent to the cyclonic circulations. This sequence of events will be studied in detail over the next year.

## IMPACT/APPLICATIONS

Both the mixed Rossby-gravity and Equatorial Rossby wave studies suggest that clusters of tropical cyclones can form in the western Pacific that are associated entirely with equatorial wave modes. Such possibilities are rarely if ever considered in current operations, and we believe improvements in one-two week forecasts of tropical cyclogenesis may be possible by taking advantage of this knowledge. We will be working over the next year to investigate how often this kind of event occurs, and how to identify it in real-time satellite images.



**Figure 2. Winds and relative vorticity at 850 mb every 11 days during the sequence of ER waves. Warm colors are positive vorticity, cold are negative. Although not apparent from the figures, the wave train moved northwestward, with cyclones and anticyclones alternating at a given location every 11 days.**

## **TRANSITIONS**

The equatorial wave mode studies are not yet ready for transition. We have concentrated our efforts on synoptic studies of these disturbances. We believe such studies are the best way to make transition of these results to operations possible.

## **RELATED PROJECTS**

We are conducting a study under NSF support of tropical cyclogenesis, and a study under NASA support of convection and dynamics of the hurricane core.

## **ONR-SUPPORTED PUBLICATIONS 2002-2003**

### **JOURNAL ARTICLES**

Corbosiero, K.L., and J. Molinari, 2003: The relationship between storm motion, vertical wind shear, and convective asymmetries in tropical cyclones. *Journal of the Atmospheric Sciences*, **60**, 366-376. [published, refereed]

Corbosiero, K.L., and J. Molinari, 2002: The effects of vertical wind shear on the distribution of convection in tropical cyclones. *Monthly Weather Review*, **130**, 2110-2123. [published, refereed]

Dickinson, M.J., and J. Molinari, 2002: Mixed Rossby-gravity waves and western Pacific tropical cyclogenesis. Part I: Synoptic evolution. *Journal of the Atmospheric Sciences*, **59**, 2183-2196. [published, refereed]

Aiyyer, A., and J. Molinari, 2003: Evolution of mixed Rossby-gravity waves in idealized MJO environments. *Journal of the Atmospheric Sciences*. [in press, refereed]

### **PREPRINTS**

Corbosiero, K.L., 2002: The relationship between storm motion, vertical wind shear, and convective asymmetries in tropical cyclones. Preprints of the 25<sup>th</sup> Conference on Hurricanes and Tropical Meteorology, American Meteorological Society, 29 April–3 May 2002, San Diego, CA, pp 321-322.

Lombardo, K., 2002: Development and breakdown of reverse monsoon troughs in the western Pacific. Preprints of the 25<sup>th</sup> Conference on Hurricanes and Tropical Meteorology, American Meteorological Society, 29 April–3 May 2002, San Diego, CA, pp 269-270.

Aiyyer, A., and J. Molinari 2002: Evolution of mixed Rossby-gravity waves in MJO type environments. Preprints of the 25<sup>th</sup> Conference on Hurricanes and Tropical Meteorology, American Meteorological Society, 29 April–3 May 2002, San Diego, CA pp 650-651.

Molinari, J., D. Vollaro, and K.L. Corbosiero, 2002: Genesis of a hurricane in a sheared environment. Preprints of the 25<sup>th</sup> Conference on Hurricanes and Tropical Meteorology, American Meteorological Society, San Diego, CA, pp 393-394.

### **HONORS/AWARDS**

Banner Miller Award, American Meteorological Society, 1999  
Excellence in Research Award, University at Albany, 1999