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# TROPICAL CYCLOGENESIS WITHIN A KELVIN WAVE

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## 1. INTRODUCTION

Equatorial waves significantly influence tropical cyclogenesis in many basins (Frank and Roundy 2006). For example, the Madden–Julian oscillation (MJO) produces large envelopes of convection and low-level cyclonic vorticity that favor cyclogenesis (Liebmann et al. 1994). Equatorial Rossby waves, mixed Rossby–gravity waves, and tropical depression-type disturbances can also strongly influence the formation of tropical cyclones, which tend to move westward at similar speeds to these waves.

Kelvin waves are believed to be less important for cyclogenesis than other equatorial wave types (Frank and Roundy 2006). Kelvin waves occur particularly close to the equator where the weaker Coriolis force may not support cyclogenesis. These waves also move eastward at about 15 m $\text{s}^{-1}$, so an incipient storm may not reside within the wave for long enough to be strongly influenced by it.

Despite these obstacles, Bessafi and Wheeler (2006) found that Kelvin waves can produce a 2-to-1 modulation of cyclogenesis in the south Indian Ocean. The idealized Kelvin wave solution features alternating zonal wind anomalies on the equator. The resulting low-level equatorial westerlies can enhance off-equatorial cyclonic vorticity for cyclogenesis. Roundy (2008) also observed that the cyclonic circulations persist even after the Kelvin-wave convection dissipates. He hypothesized that these residual circulations could act as tropical cyclone precursors.

This study examines a case from June 2002 during which two tropical cyclones formed in association with a series of Kelvin waves. The equatorial westerly anomalies associated with these waves preconditioned the low-level environment for cyclogenesis. To the author's knowledge, this is the first case study of tropical cyclogenesis in association with Kelvin waves.

## 2. DATA

The Kelvin waves are investigated using the Tropical Rainfall Measuring Mission (TRMM) multisatellite precipitation analysis (TRMM product 3B42, Huffman et al. 2007). The 850-hPa winds associated with the waves are examined with the European Centre for Medium-Range Forecasting (ECMWF) interim reanalysis (ERA-interim).

To identify the waves, the rainfall data are filtered for the Kelvin band as in Wheeler and Kiladis (1999). Schreck et al. (2010) demonstrated that the large rainfall rates associated with tropical cyclones can significantly alter equatorial wave-filtered fields. The storm-related anomalies are removed before filtering following their method.

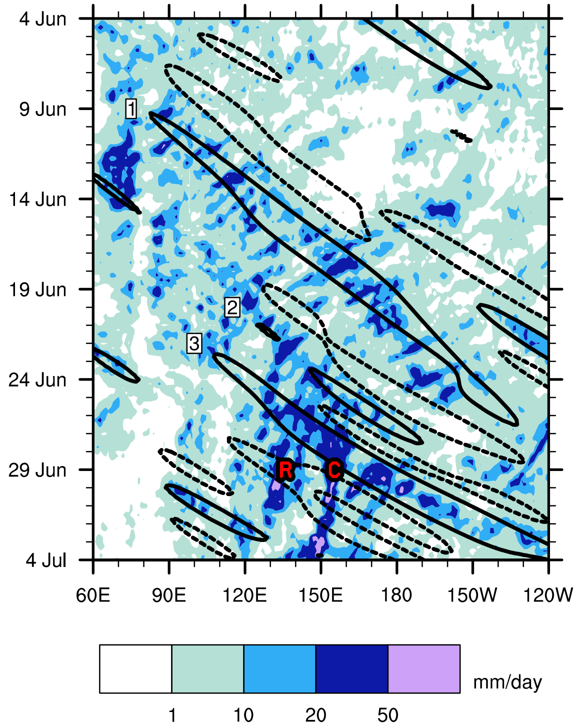

Figure 1. Time–longitude section of unfiltered rainfall (shading) and Kelvin filtered rainfall (contours), averaged from the equator to 15°N. Kelvin-filtered anomalies are contoured at ±3 mm $\text{day}^{-1}$ with negative contours dashed. The "R and C" denote genesis locations of Rammasun and Chataan, respectively.

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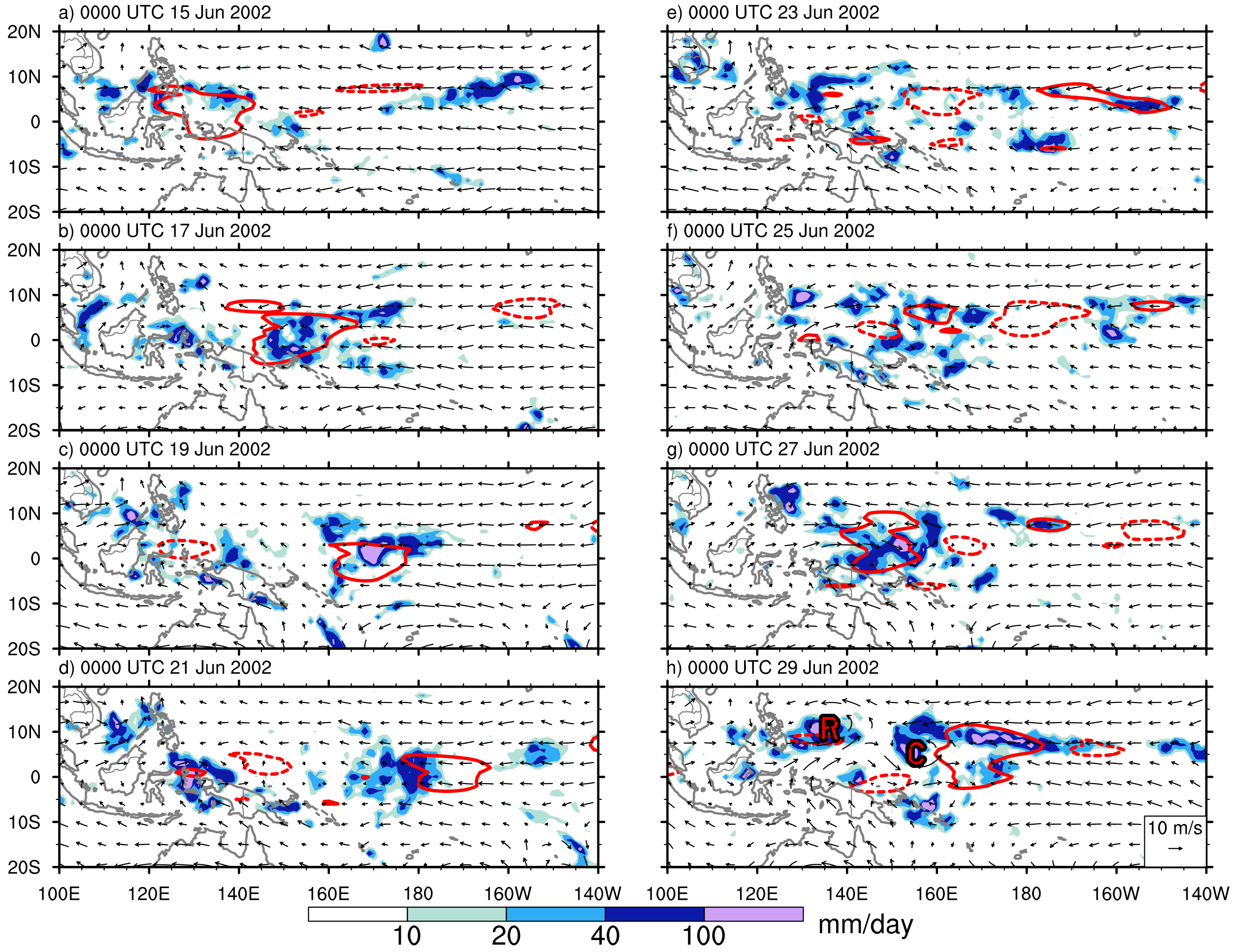

Figure 2. Evolution of unfiltered rainfall (shading), Kelvin-filtered rainfall (contours), and 850-hPa winds (vectors). Shown every two days at 0000 UTC from 15 June 2002 to 29 June 2002. Kelvin-filtered anomalies are contoured at ±8 mm day$^{-1}$ with negative contours dashed. The "R and C" denote genesis locations of Rammasun and Chataan, respectively.

## 3. RESULTS

Figure 1 shows a time–longitude plot of unfiltered (shading) and Kelvin-filtered (contours) rainfall rates. The convective phases of three Kelvin waves are identified by the numbers in Fig. 1. These waves occur within a broader envelope of enhanced convection associated with the MJO. Episodes of heavy rainfall (> 20 mm day$^{-1}$) occur within each convective wave. Between these waves, periods of reduced rainfall are also evident in the unfiltered data.

Figure 2 shows a series maps with unfiltered rainfall (shading), Kelvin-filtered rainfall (contours), and unfiltered 850-hPa winds (vectors). On 15 June (Fig. 2a), broad trade easterlies dominate the pattern in the Pacific. A notable exception is to the north of Australia where the winds are weak. These weak winds coincide with the enhanced convection of the first Kelvin wave.

Both the filtered and unfiltered rainfall data trace the eastward propagation of this convection (Figs. 2a–d). Near the equator, the trade easterlies retreat in the wake of the wave. This behavior is consistent with the idealized Kelvin wave. Ahead of the convection, the idealized wave produces low-level easterlies that enhance the trades. Behind the convection, westerly anomalies counter the background trades leaving nearly calm conditions.

The second wave is weaker, but it can be identified traveling eastward from 130°E on 21 June (Fig. 2d) to the dateline on 27 June (Fig. 2g). The easterly anomalies are less evident ahead of this wave. Because of the relatively calm conditions, however, the equatorial westerlies behind the wave can be seen in the total field. These equatorial westerlies, combined with the persistent easterlies farther north, produce a strip of cyclonic shear.

The third wave further enhances the westerlies (Fig. 2g,h). The depressions that will become typhoons Rammasun and Chataan develop within the cyclonic shear behind this wave (Fig. 2h). Chataan also forms on the western edge of the wave-enhanced convection.

## 4. DISCUSSION

The formation of two tropical cyclones is examined in association with a series of Kelvin waves. The initial environment features uniform trade easterlies (Fig. 2a). The Kelvin waves weaken the easterlies near the equator until they are supplanted with equatorial westerlies. The resulting strips of low-level cyclonic vorticity provide the favorable environment within which the tropical cyclones develop.

Kelvin waves are frequently observed within the convective envelope of the MJO (Straub and Kiladis 2003) as in this case. Previous studies have shown that the MJO significantly influences tropical cyclogenesis in many basins, but the role of the embedded Kelvin waves has not been examined until now. The MJO is a planetary scale feature with large envelopes of convection and low-level cyclonic vorticity. However, tropical cyclogenesis occurs at much smaller scales. Kelvin waves may bridge the gap between these scales to determine where and when tropical cyclones will develop within the MJO.

## 5. ACKNOWLEDGEMENTS

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