Application of the Marsupial Paradigm to Tropical Cyclone Formation from Northwestward Propagating Disturbances

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Introduction

Dunkerton et al. (2009) recently proposed a new paradigm for the formation of a tropical cyclone within the critical layer of a tropical easterly wave. Through a survey of 55 named storms over the Atlantic and East Pacific during 1998-2001, they showed that the critical layer of the wave is important to tropical storm formation, and that the intersection of the trough axis and the critical surface of the wave -- the center of the cat's eye in the wave critical layer -- is the preferred location for tropical cyclone formation.

Based on the marsupial paradigm, Wang et al. (2009) proposed a real-time forecast method to predict the track of the possible genesis locations within zonally propagating waves using global model operational data. They showed that the genesis location of a tropical storm can be predicted using global model forecast data up to three days in advance with less than one degree error when and if genesis occurs.

Motivation

Northwestward propagating waves, which include tropical-depression disturbances and Rossby wave train over the western North Pacific and tropical easterly waves turning northwestward over the West Atlantic, play a role in tropical cyclogenesis over the western oceans.

The method proposed in Wang et al. (2009) is no longer applicable when the meridional propagation speed of the precursor disturbance is not negligible compared to the zonal propagation.

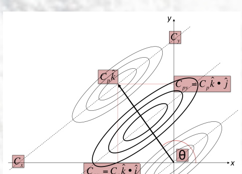

Fig. 1 A schematic showing the wave propagation speed. The thick and thin contours represent positive and negative perturbations associated with a wave, and the dashed lines represent the constant phase lines.

Nakri (2008)

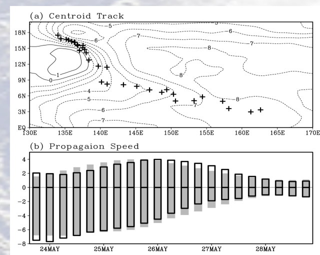

Fig. 2 (a) The vorticity centroid track of the pre-Nakri gyre-pouch during 06 UTC May 22 to 06 UTC May 30, and (b) the zonal (negative positive values) and meridional (positive values) components of the propagation speed of the vorticity centroid derived for an 8° × 8° box (gray bars) and for the pre-Nakri gyre-pouch (thick black bars).

- The parcel trajectories show that there is a closed Lagrangian circulation similar to what is depicted by the translated streamlines, in contrast with the open wave pattern in the Earth-relative frame.
- The wave's gyre-pouch captures the moisture gradient on its northern and western boundaries.
- Genesis of Nakri occurred near the center of the moist, convectively active gyre-pouch.

Results

Nakri formed at 14Z May 27, 2008 over the western North Pacific.

The critical latitude for 2D propagating waves is defined as

$$\hat{k}\bullet(\vec{V}-C_p\hat{k})=0$$

where the wave-relative flow is zero in the direction of the wave propagation.

The "trough axis" should be modified as

$$\hat{n}\bullet(\vec{V}-C_p\hat{k})=0$$

That is, the relative flow in the direction perpendicular to the wave propagation direction is zero along the modified trough axis.

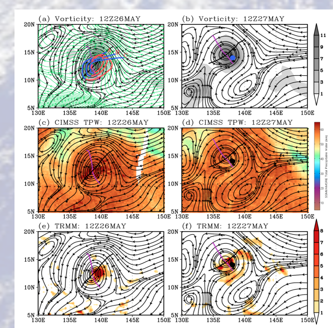

Fig. 3 Relative vorticity (upper), CIMSS total precipitable water(middle), and TRMM rain rate (bottom) superimposed on 850 hPa streamlines (black) in the frame of reference moving at the same speed with the wave. The thick black curve represents the modified wave trough axis, and the thick purple curve represents the critical surface. Green streamlines in (a) are in the Earth-relative frame. A, B and C label the trajectories of three air parcels. The black dot in the right panels represents the genesis location.

Erika (2009)

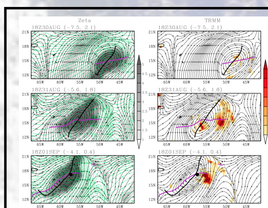

Fig. 4 Relative vorticity (left) and TRMM rain rate (right) superimposed on streamlines (black) in the co-moving frame of reference and the resting frame (green).

- Despite persistent deep convection and "winds to around tropical storm strength" (NHC) on August 30 -31, formation of Erika was not declared till Sep 1 because it lacked a well-defined low-level center of circulation in the Earth-relative frame.
- If viewed in the wave co-moving frame of reference, a well-defined low-level closed circulation with abundant moisture and strong cyclonic relative vorticity had formed more than two days before the disturbance was declared as a tropical storm.

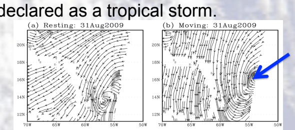

Fig. 5 Streamlines of surface flow from QuikSCAT on 31 August for the pre-Erika disturbance: (a) Resting frame; (b) co-moving frame.

A Few Other Examples

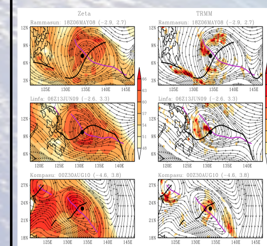

Fig. 6 GFS total precipitable water (TPW) (left) and TRMM (right) superimposed on the translated streamlines at the genesis time for Rammasun (2008) (top), Linfa (2009) (middle), and Kompasu (2010) (bottom). The black dot indicates the genesis location.

These cases show that

i) the wave pouch of a northwestward propagating disturbance is a region of strong rotation and weak deformation;

ii) the pouch has high moisture content;

iii) convection becomes organized within the pouch, and tropical storms formed near the center of the wave pouch.

Our diagnoses suggest the marsupial framework can apply to tropical cyclone formation from northwestward propagating disturbances.

Summary

- A wave-tracking algorithm is developed for northwestward propagating waves which, on occasion, play a role in tropical cyclogenesis over the western oceans.
- To obtain the Lagrangian flow structure, the frame of reference is translated obliquely with the precursor disturbance. Trajectory analysis suggests that streamlines in the obliquely translated frame of reference can be used to approximate flow trajectories.
- Diagnoses of meteorological analyses and satellite-derived moisture and precipitation fields show that the marsupial framework (Dunkerton et al. 2009) for tropical cyclogenesis in tropical easterly waves is also relevant for northwestward propagating disturbances as are commonly observed in the tropical western Atlantic, Gulf of Mexico and western North Pacific.

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