10A.7b GENESIS OF TYPHOON CHANCHU (2006) DURING THE MJO: FORMATION AND SYNOPTIC EVOLUTION OF A TILTED VORTEX

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1. INTRODUCTION

Few tropical cyclones (TCs) develop prior to June in the Western North Pacific (WNP) basin, which lacks climatological foci for tropical cyclogenesis (TCG) prior to the onset of the Asian monsoon. Instead, trade easterlies dominate the WNP during the spring months, and the rare TCs that do develop during this pre-monsoon environment are often associated with anomalous westerly equatorial winds that modulate the formation of TC precursor disturbances (Ritchie and Holland 1999). This is the case for the present study of Typhoon Chanchu, which developed in early May 2006 (see Fig. 1).

The Madden-Julian Oscillation (MJO; Madden and Julian 1994) is the dominant mode of intraseasonal variability globally, and during its active phase near-equatorial WWBs converge with easterly trades, not only enhancing deep convection, but also facilitating the growth of cyclonic disturbances. Barotropic energy conversions associated with zonal convergence and cyclonic shear (Maloney and Hartmann 2001) can account for the formation of such disturbances, which can serve as precursors to TCG (Aiyyer and Molinari 2003). In some situations, WWBs can modulate the development of twin TCs that are roughly symmetric about the equator (Lander 1990).

Dickinson and Molinari (2002) showed that within the area of active convection associated with the MJO, westward-propagating mixed Rossby-gravity (MRG) waves can develop and serve as precursors to TCG. The MRG waves exhibit a westward vertical tilt because of the easterly vertical shear during the MJO (Frank and Roundy 2006). Dickinson and Molinari (2002) further found that pre-TCG deep convection develops not near the circulation centers of the waves, but to their north. As the westward-tilted MRG waves "transition" to tropical depression (TD) type waves, deep convection develops closer to their centers as they move northwestward away from the equator, and they can undergo TCG. However, the northward translation and "transition" of such incipient tilted equatorial disturbances to off-equatorial upright TCs still remain mysteries central to the issue of TCG during the active MJO.

So while previous studies have established the relationship between the MJO, WWBs, and TCG, little is certain about the mechanisms by which they interact. Specifically, how does convection interact with the incipient vortex leading to TCG? In this presentation, we begin to address these issues by examining the synoptic-scale processes involving the MJO, WWBs, and precipitation processes during the genesis of Typhoon Chanchu (2006).

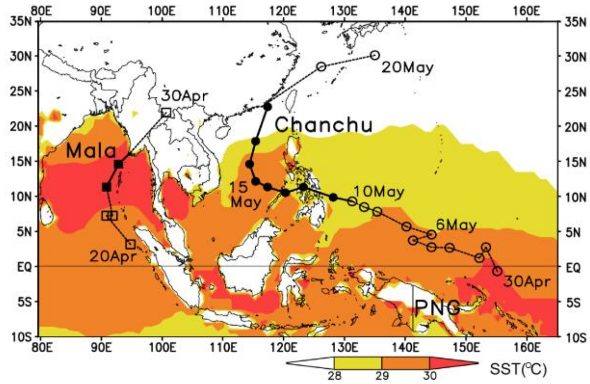

Figure 1: Observed track of Typhoon Chanchu from 30 Apr – 20 May 2006, obtained by following the 900-hPa circulation center from the NCEP FNL.

2. DATA AND METHODOLOGY

In the present study, we utilize available observational data and an 11-day, cloud-resolving regional simulation to investigate the near-equatorial formation and ultimate TCG of Chanchu. The Climate Prediction Center (CPC) MJO index is used to diagnose the phase of the MJO (not shown), and the NCEP Final Analysis (FNL) at 1º x 1º resolution is used to understand the formation, structure, and evolution of the incipient disturbance.

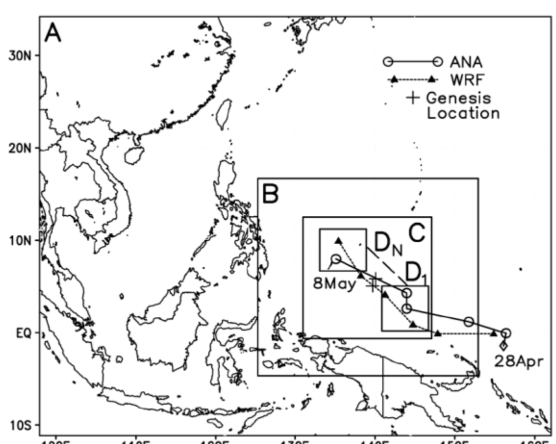

Figure 2: WRF model configuration for the quadruply-nested (domains A – D) simulation, including the observed and simulated tracks.

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To gain insight into the processes not resolvable by the FNL, the WRF-ARW model is employed at the finest horizontal resolution of 2 km. Fig. 2 shows the organization of the WRF simulation, which is quadruply nested at horizontal resolutions of 54 km (domain A) down to 2 km (moving domain D). The three outer domains remain stationary throughout the simulation, which is initialized (terminated) at 0000 UTC 27 Apr (8 May) 2006. FNL fields are used as initial and boundary conditions, and no artificial data is used during the simulation.

3. RESULTS

3.1 Observed Structure of Pre-Chanchu Vortex

Fig. 3a shows the mean horizontal structure of the WWB and its associated dual vortices that developed during the pre-genesis phase of Chanchu. The peak WWB occurred near 2°S, and the two lower-tropospheric cyclonic vortices formed at the interface of the westerly and easterly flow. The across-WWB structures (Fig. 3b) show that easterly winds dominated the WNP basin, except within the WWB. The WWB and associated vortices were confined below 400 hPa with the peak magnitude near 900 hPa.

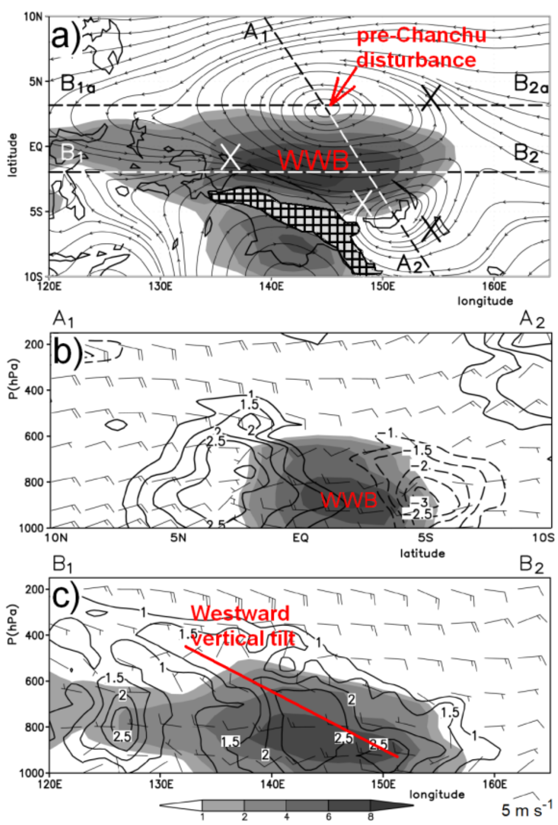

Figure 3: (a) 900 – 800 hPa layer-mean horizontal streamlines and WWB (shaded, m s^{-1}), averaged during Apr 30 – May 5 2006. "X" symbols denote low-level confluence regions. In (b) and (c), as in (a), but for vertical cross sections through the mean WWB, with relative vorticity (x 10^{-5} s^{-1}) contoured.

An along-WWB vertical cross section clearly shows a westward tilt of the WWB with height (Fig. 3c). At 900 hPa, the leading edge of the WWB extended to near 158°E, but only to 138°E at its uppermost location. The westward vertical tilt explains the observed development of a closed 600-hPa circulation (not shown) over 1000 km to the west of the 900-hPa circulation. The coherent vorticity structure north of the WWB (Fig. 3c) suggests also the existence of a coherent westward vertically-tilted vortex, which developed in the presence of large-scale easterly vertical shear (Fig. 3b).

In short, the development of Chanchu could be traced back more than a week prior to its classification as a TD. It formed at the leading portion of the WWB associated with the eastward propagation of the MJO, and its associated vortex exhibited a westward tilt in the vertical. During the week between the initial formation of the tilted vortex (30 Apr) and genesis (~7 May), the tilted vortex remained coherent. The subsequent subsections describe the results of the cloud-resolving simulation of this pre-genesis portion of Chanchu's life cycle that is performed to replicate the above-observed evolution and gain insight into the processes by which the vertically tilted WWB-vortex could transition into an intense typhoon.

3.2 Simulated Structure of Pre-Chanchu Vortex

The track of the simulated disturbance (Fig. 2) compares well to that observed, but with a notable difference in the initial speed of the disturbance. The simulated storm tracks initially to quickly westward, and thus it moves off of the equator about two days prior than observed. Associated with the early northward translation, the simulated disturbance undergoes genesis about two days earlier than observed. However, that the simulation captures the development and general week-long evolution of the weak disturbance lends credibility to the simulation of the large-scale fields.

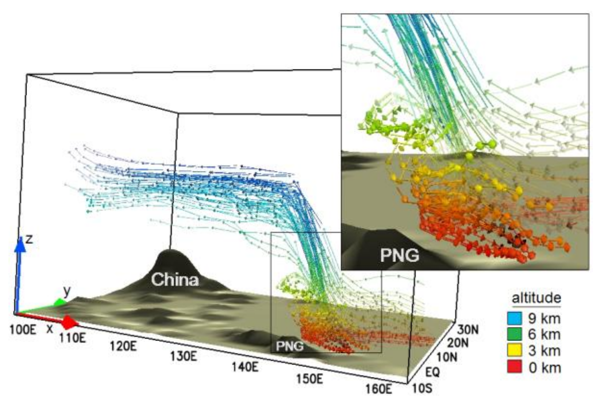

Figure 4: Simulated streamlines showing the vertical tilt of the pre-Chanchu disturbance and upward motion occurring exclusively to the northern, downtilt-right, side of the vortex.

Of interest is that the simulation captures quite well the westward vertical tilt of the incipient vortex

(Fig. 4). In addition to a westward tilt, simulated upward motion occurs almost exclusively to the north, hereafter the downtilt-right side, of the vortex. On the downtilt-left side of the vortex, flow remains free from significant vertical displacements.

The thermal structure of the vortex (Fig. 5) provides some insight into the tendency for precipitation to remain on the downtilt-right. The vortex is characterized by a warm (cool) anomaly uptilt (downtilt), which is likely established by shallow convection and subsidence heating of the incoming easterly flow. The cool anomaly likely arises due to the relatively cool outflow from precipitation. Once the thermal dipole is established, the structure can be maintained due to persistent generation (suppression) of precipitation by isentropic ascent in the downtilt-right (-left) environment. Additionally, the downtilt-left environment remains unfavorable for precipitation due to the cyclonic advection of low-level cool air.

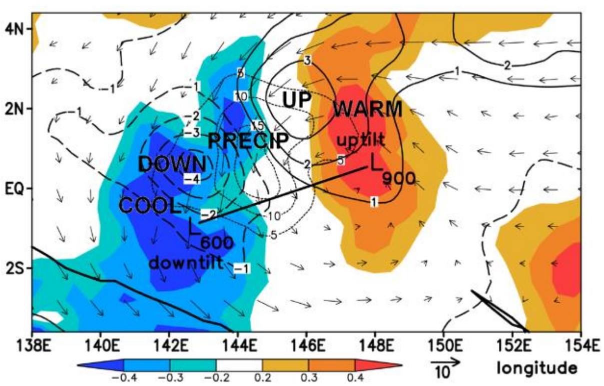

Figure 5: Simulated potential temperature anomalies (shaded, K), vertical motion (heavy contours, cm s-1), and dBZ (light contours) on 30 Apr, near the time of vortex formation.

3.3 Simulated Evolution of Pre-Chanchu Vortex

Throughout the several days prior to genesis, simulated precipitation remains confined to the downtilt-right side of the tilted vortex (Fig. 6 a-d). During this time, the low-level (midlevel) center moves northwestward (northeastward), effectively decreasing the vertical tilt of the vortex. Though not discussed herein, the observed fields exhibit a similar evolution during pre-genesis. At the time TCG begins (Fig. 6d), the low- and midlevel centers become vertically stacked. It is at this moment that the surface pressure begins a sustained fall. Note, however, that the peripheral circulations, including those in the vicinity of the primary spiral band, remain vertically sheared. As will be shown in the presentation, the precipitation likely serves as an attractor for the vortex centers through its generation of midlevel vorticity and surface pressure falls. This slow evolution culminates in genesis as an upright vortex.

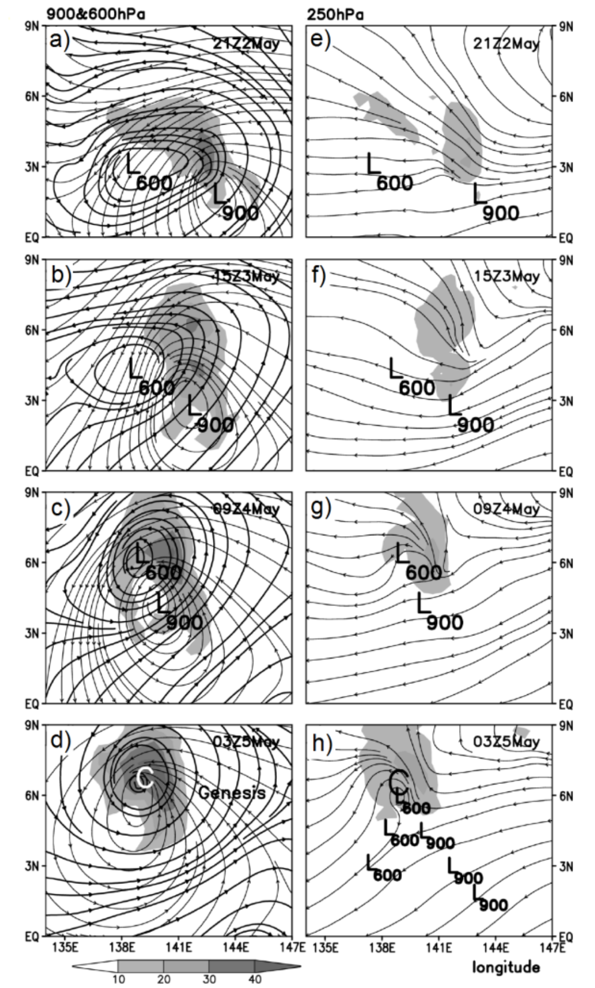

Figure 6: (a) – (d) Evolution of low- and midlevel streamlines with 850-hPa dBZ (shaded), during two days prior to genesis. In (e) – (h), as in left panel, but for 250-hPa.

4. SUMMARY AND CONCLUSIONS

The pre-genesis period of Typhoon Chanchu (2006) is diagnosed using available observations and reproduced in a cloud-resolving simulation using the WRF-ARW. It is found that the pre-cursor disturbance forms on the equator as a WWB propagates eastward. The disturbance exhibits a westward vertical tilt, which diminishes as the pre-Chanchu disturbance moves northward off of the equator. The simulation captures well this evolution, culminating in TCG as the vortex becomes upright.

The thermal structure of the vortex favors the persistence of precipitation exclusively on the downtilt-right side of the vortex. This precipitation facilitates the northward deviation and vertical alignment of the vortex, even in an environment of non-negligible vertical shear.

5. REFERENCES

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