11A.5 THE ROLE OF MULTIPLE MESOSCALE CONVECTIVE SYSTEMS IN A NON-DEVELOPING TROPICAL DISTURBANCE OBSERVED DURING THE TROPICAL CYCLONE STRUCTURE-2008 (TCS-08) FIELD EXPERIMENT

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1. INTRODUCTION

During the Tropical Cyclone Structure-2008 (TCS-08) field program in the western North Pacific, tropical cloud clusters that were identified as potential precursors to tropical cyclone formation were monitored and tracked. During the two-month field program, approximately fifty such systems were observed. Of these, only twelve reached or exceeded tropical depression (TD) status, which illustrates that the vast majority of tropical cloud clusters fail to undergo tropical cyclogenesis. Understanding why so few of these tropical disturbances actually develop is an important aspect to the tropical cyclogenesis question, which is one of the main components of the TCS-08 field campaign (Elsberry and Harr 2008). For as Gray (1982) pointed out, for us to understand the process of tropical cyclogenesis, we must also be able to explain why more often then not, genesis does not occur.

One such non-developing tropical cloud cluster that initially appeared a likely candidate for further development was TCS025. This tropical disturbance was closely monitored from 24 August until 3 September when it was no longer deemed a candidate for further development. During its evolution, TCS025 went through several phases where observations and model forecasts suggested further development was likely. Due to its relatively close proximity to Guam, five aircraft missions were conducted to observe TCS025; three reconnaissance flights with the USAF WC-130J, and two with the Navy Research Lab (NRL) P3. Both aircraft deployed GPS dropwindsondes (Hock and Franklin 1999) during each flight, and the NRL-P3 was able to observe the three-dimensional convective structure of TCS025 with its onboard dual Doppler ELDORA radar (Hildebrand et al. 1996). During the first NRL-P3 flight (RF05) between 0030 - 0630 UTC 28 August and the second USAF WC130J flight between 2000 UTC 27 August - 0500 UTC 28 August, the TCS025 disturbance contained several mesoscale convective systems (MCSs) (Figure 1).

This paper will summarize preliminary results of an ongoing study of the mesoscale elements of TCS025 and the synoptic-scale features that affected its evolution. The ELDORA Doppler radar coverage during the first NRL-P3 flight is arguably more representative of the convective structure of TCS025 compared to the data obtained during the second NRL-P3 flight, and will therefore be the primary focus of this study. The remainder of this paper is divided up as follows: part two provides a synoptic overview of the lifecycle of TCS025, part three analyzes in-situ data collected during aircraft missions conducted on 28 August and compares the observed mesoscale structure of TCS025 with numerical simulations, and part four concludes.

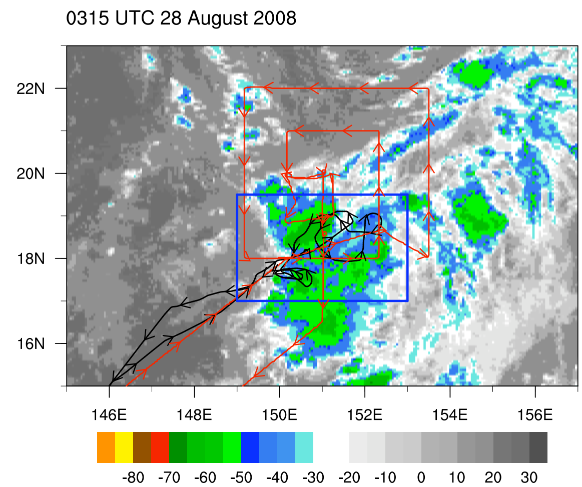

Figure 1: Flight track of the first NRL-P3 (black) and second USAF WC-130J (red) observation flights of TCS025 overlaid on geostationary MTSAT1R IR cloud-top temperature (°C) roughly corresponding to the halfway point of the NRL-P3 flight. The blue box denotes the observational area shown in Figure 5.

2. SYNOPTIC OVERVIEW OF TCS025

The TCS025 disturbance was first identified at 2100 UTC 24 August from satellite imagery as a cluster of convection about 600 km to the northeast of Guam that formed in an area of upper-level diffluence between two tropical upper-tropospheric trough (TUTT) cells to the north. Convergence near the eastern extension of the monsoon trough appears to have been associated with the development of deep moist convection. After the initial round of convection subsided, deep convection redeveloped late on 24 August and into the early part of 25 August as evidenced by the cold cloud-top temperatures observed by satellite IR imagery. By 1130 UTC 25 August, convection had organized into a broad MCS centered at 22°N and 152°E. This MCS quickly moved to the southeast and dissipated, leaving only weak and relatively disorganized convection by 0000 UTC 26 August.

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Another area of deep convection formed on 26 August while the TUTT cell to the east-northeast of TCS025 continued to move westward closer to the convection associated with TCS025. Deep convection developed on the southeastern edge of TCS025, but quickly moved to the south-southeast, "fanning" out in the east-west direction, and merged with convection directly associated with the TUTT cell. Meanwhile, the TUTT cell to the west-northwest remained nearly stationary and outside of the direct influence of TCS025. Late on 26 August, another MCS formed near 20°N and 150°E, but dissipated quickly under the influence of strong northerly vertical wind shear.

Convection remained quite disorganized and weak until after 1200 UTC 27 August when the westward-moving TUTT cell was positioned immediately to the north-northeast of the low-level disturbance associated with TCS025 (Figure 2). Two prominent MCSs developed shortly thereafter, one of which formed near 20°N and 150°E, which was very close to the location of the MCS development the day before. This MCS, like others previously, moved to the south under the influence of strong northerly shear. Although its intensity fluctuated, it remained a coherent structure until early on 28 August during the first NRL-P3 and second USAF WC-130J flights, and was thus an area of focus during the aircraft missions. The other MCS formed along the western edge of a band of deep convection further to the southeast and also moved southward under the influence of the strong northerly shear associated with the TUTT cell to the north-northeast.

As the westward-moving TUTT cell passed to the north of TCS025, convection remained disorganized and weak until about 1800 UTC 28 August when two areas of deep convection developed: deep convection formed near 18°N and 154°E, close to the convergence associated with the eastern side of the low-level circulation, and deep convection formed further to the northeast in a region characterized by upper-level divergence associated with the westward moving TUTT cell (Figure 3).

By 1200 UTC 29 August, the two areas of deep convection merged as the region of upper-level divergence associated with the TUTT cell had moved to the west while the low-level trough was beginning a rapid acceleration to the north under the influence of a deepening low-level ridge to the south. At 0000 UTC 30 August 30 (Figure 4), deep convection was present near the center of the low-level circulation and a cyclonically banded cloud structure became evident in satellite IR imagery. However, an analysis of low-level geopotential height from the European Center for Medium-Range Weather Forecasts (ECMWF) Year of Tropical Convection (YOTC) dataset revealed that the low-level trough was weakening as it moved to the north, even though the upper-level synoptic pattern looked

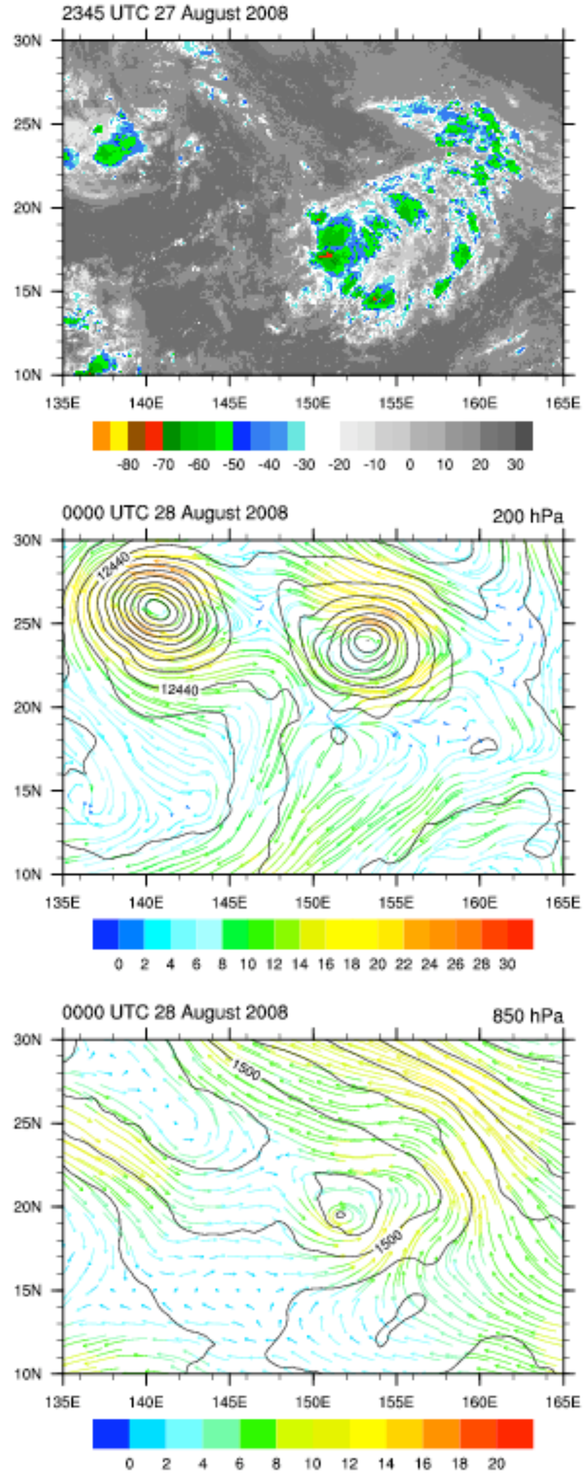

Figure 2: Geostationary MTSAT1R IR imagery for 2345 UTC 27 August 2008 (top) and geopotential height (m) and horizontal wind vectors (m s^{-1}) (middle) and 850 hPa geopotential height (m) and horizontal wind vectors (m s^{-1}) (bottom) from the ECMWF YOTC Analysis at 0000 UTC 28 August 2008.

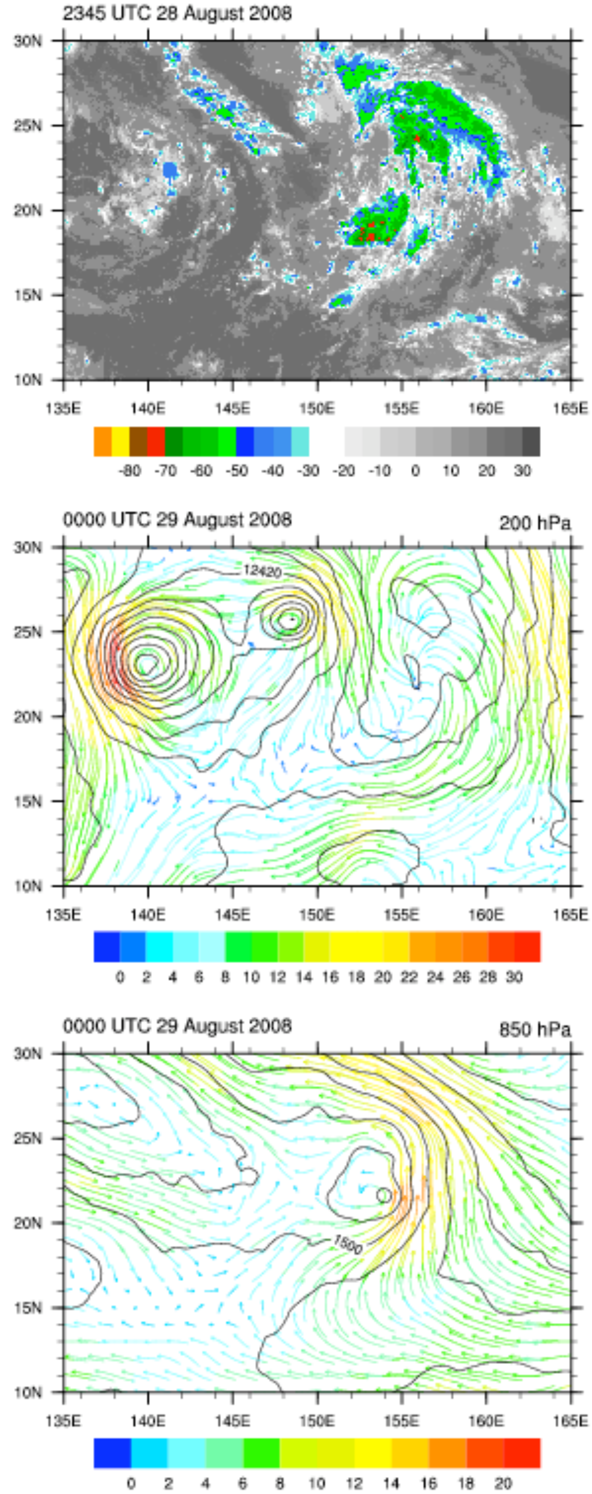

Figure 3: As in Figure 2, except for MTSAT1R IR imagery at 2345 UTC 28 August 2008 and ECMWF YOTC Analysis at 0000 UTC 29 August 2008.

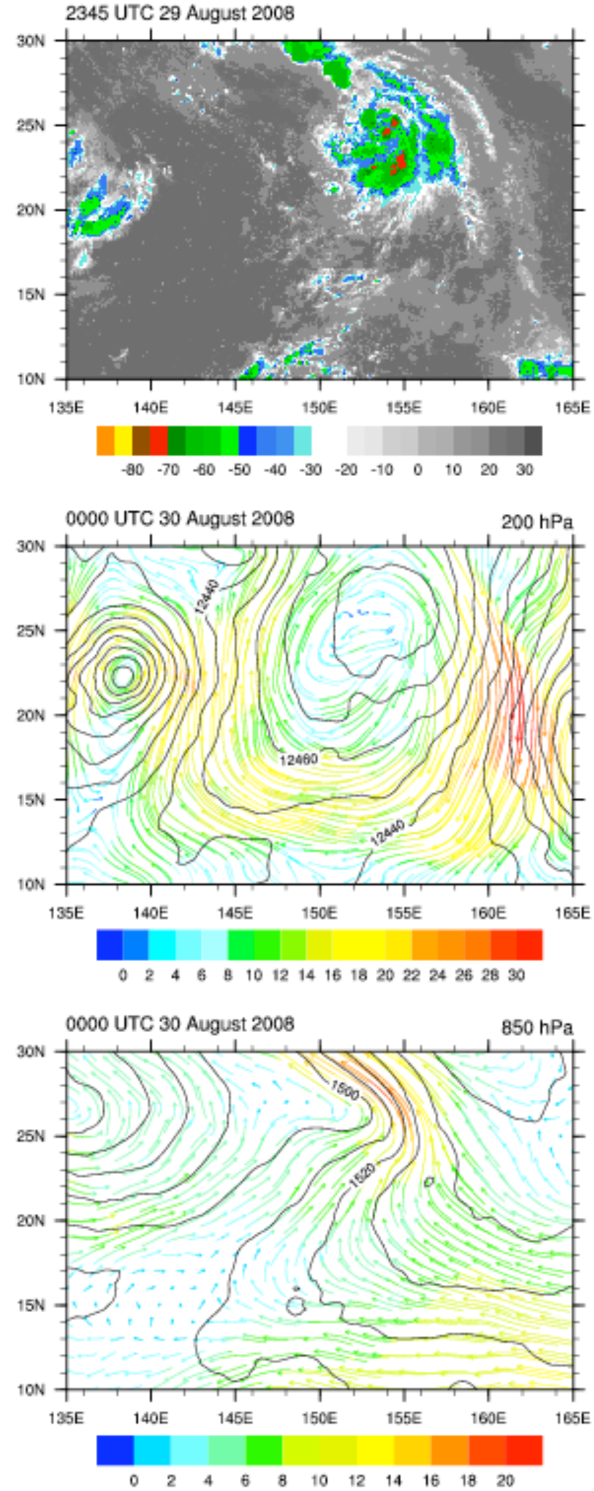

Figure 4: As in Figure 2, except for MTSAT1R IR imagery at 2345 UTC 29 August 2008 and ECMWF YOTC Analysis at 0000 UTC 30 August 2008.

favorable for further development. By 1200 UTC, banded cloud structures were evident to the northeast, but the inner-core convection had become very disorganized and weak, and by 1800 UTC, the cloud structure of TCS025 exhibited signs that it was beginning to shear apart. Convection continued to pulse, but strong northerly shear and the weakening low-level support limited further development.

In summary, convection associated with the low-level disturbance of TCS025 developed within a region of strong vertical wind shear between two upper-level TUTT cells. Persistent MCS development occurred throughout the lifecycle of TCS025, but due to strong northerly wind shear, deep convection remained relatively separate from the low-level disturbance during the early stages of evolution. As the TUTT cell located to the northeast of TCS025 moved westward and became situated north of the disturbance, a short period of time existed when vertical wind shear relaxed and upper-level divergence increased. During this time, a banded cloud structure became evident on MTSAT1R IR imagery and deep convection was observed close to the center of the low-level disturbance. However, further development was short lived as the low-level trough weakened while moving rapidly to the north and strong vertical wind shear again formed over the area.

3. COMPARISON OF IN-SITU OBSERVATIONS AND NUMERICAL SIMULATIONS

An analysis of dropwindsonde wind data from both flights reveals good agreement with the ECMWF YOTC analysis (0000 UTC 28 August) wind fields and the structure of the horizontal winds depicted by ELDORA radar from flight RF05. Before the ELDORA Doppler radar data were analyzed, the data were edited using an automated technique to remove ground echo, noise, clutter, and radar side-lobes. After the initial editing process, the data were then interpolated to a 1 x 1 x 1 km spaced Cartesian grid using the variational approach described by Reasor et al. (2009). The ECMWF YOTC analysis fields were available at 6-hour intervals on a 0.25-degree global domain with 20 pressure levels. Dropwindsondes deployed by the two aircraft span the times of each flight, but due to the relatively low flight altitude needed to operate the ELDORA Doppler radar, data from the NRL-P3 dropwindsondes were only available below ~700 hPa.

All three data sets reveal that TCS025 possessed a low-level circulation that tilted to the south-southeast (downshear) with height (Figure 5) near the eastern boundary of the monsoon trough. Winds along the southeastern side of the circulation appear to have been strongest at low-levels, whereas in the mid-troposphere, wind speeds were strongest to the west of the circulation center. This tilted circulation, which extended from the near-surface levels up through 400 hPa, existed well to the northeast of the area of deepest convection during the aircraft flights on 28 August. Vertical cross sections of ELDORA radar reflectivity (not

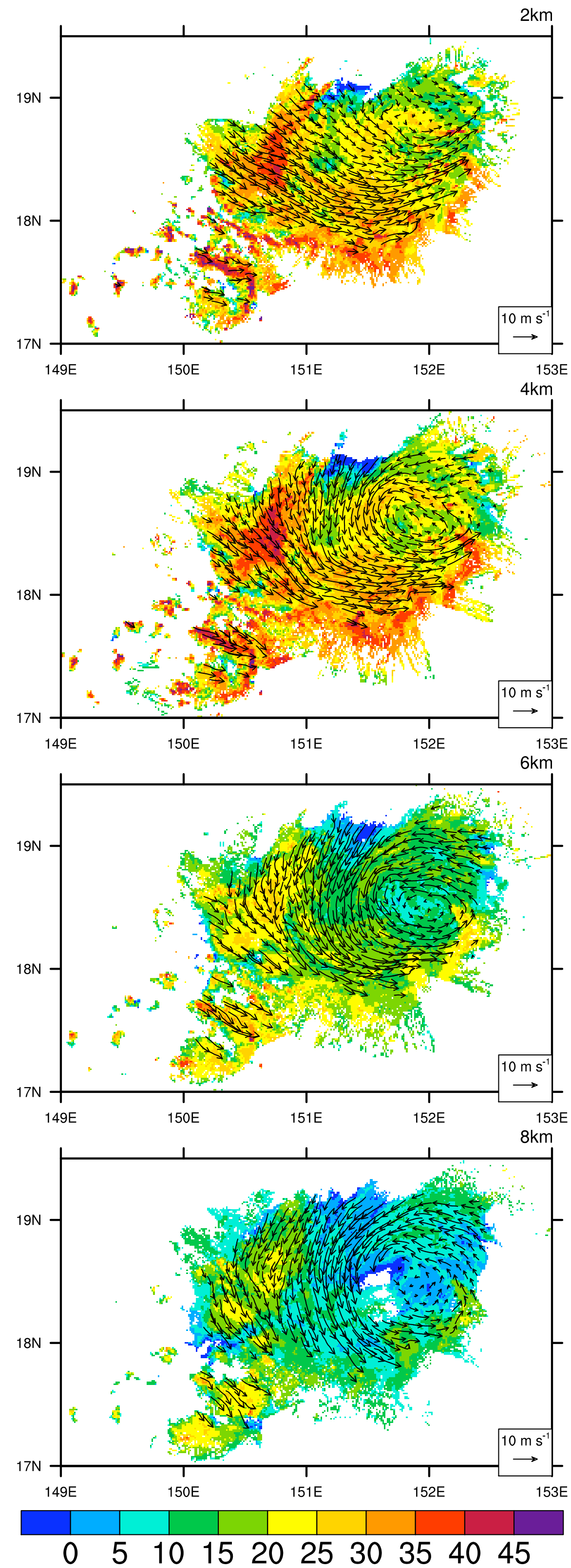

Figure 5: ELDORA Doppler radar reflectivity (dBZ) (shaded) and horizontal wind (vectors) at indicated height levels observed during the NRL-P3 RF05 flight on August 28.

shown) reveal that the area surrounding the circulation was predominantly characterized by stratiform precipitation during the NRL-P3 flight.

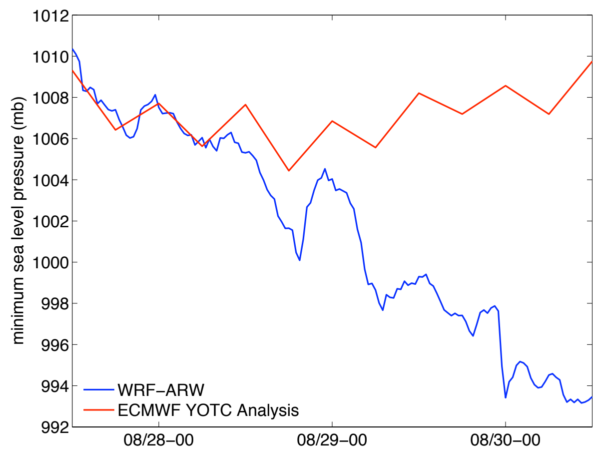

Figure 6: Minimum sea level pressure (mb) for the ECMWF YOTC Analysis (red) and WRF-ARW simulation (blue).

The MCS that initially developed near 20°N and 150°E around 1200 UTC 27 August (shown further to the south in Figure 1), was well removed from the observed circulation and was beginning to dissipate under the presence of strong northerly shear during the time of the NRL-P3 and USAF WC-130J observational flights. Throughout the lifecycle of TCS025, repeated MCS development and dissipation occurred in a similar fashion to that observed early on 28 August.

High resolution simulations (3-km grid spacing) of TCS025 using the Advanced Weather Research and Forecasting numerical model (WRF-ARW), with ECMWF YOTC Analysis data used for initial and lateral boundary conditions, tend to produce anomalous development and strengthening of TCS025 (Figure 6), while resolving the strength and location of the large scale synoptic features relatively well. A preliminary analysis suggests that the WRF-ARW simulations fail to capture the significant degree of vortex tilt that is observed in the in-situ data, and allow deep convection to develop too close to the center of circulation. One hypothesis is that the existence of deep convection close to the center of circulation may have acted to decrease the tilt of the circulation and increase low-level vorticity and moisture, allowing the simulated disturbance to develop further during the time period when conditions were otherwise favorable. However, additional simulations employing the assimilation of in-situ observations are needed to test this hypothesis.

4. SUMMARY

TCS025 was a non-developing tropical cloud cluster observed during the TCS-08 field campaign in the western North Pacific. TCS025 developed between two upper-level TUTT cells to its north and near the eastern-most extent of the monsoon trough. Several periods of MCS development and dissipation were observed during its existence. Strong northerly shear associated with the westward moving TUTT cell to the northeast pushed deep convection southwards away from the low-level forcing, which appears to have limited further development. Conditions became favorable for development late on 28 August and during 29 August as the TUTT cell passed to the north of TCS025 and vertical wind shear relaxed. However, any deepening was short lived as the low-level trough began to weaken and move to the north while vertical wind shear again increased over the area.

In total, five aircraft missions were flown to observe TCS025, three with the USAF WC-130J aircraft, and two with the NRL-P3 aircraft equipped with an ELDORA Doppler radar. An analysis of aircraft observations collected during the flights on 28 August reveals that the area of deepest convection associated with TCS025 remained well to the southwest of the low-level circulation which exhibited a significant downshear tilt with height. Numerical simulations using the WRF-ARW model tend to overdevelop TCS025, which is hypothesized to be the result of deep convection forming too close to the center of circulation, and the development of a circulation with less vertical tilt than observations would suggest.

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