11B.2 DISTAL AND SYMPATHETIC SURFACE TROUGH DEVELOPMENT INDUCED BY TUTT CELLS: A CASE STUDY

Billy D. Ward Jr.*
NOAA/NWS, Barrigada, Guam

Mark A. Lander
University of Guam, Mangilao, Guam

1. INTRODUCTION

A developing tropical disturbance, that became Typhoon Krosa, moved from north of Chuuk through the Marianas during the period 01 to 04 October 2001. This tropical cyclone (TC) began as an exposed low-level circulation with relatively little convection until it reached the base of a warm surface trough located just to the east of the Marianas. Data shows that this low-level warm trough was one of two surface troughs that developed in association with two TUTT cells that coupled and formed a negatively tilted upper level trough located over and to the northwest of Guam. Of the two surface troughs, one was a distal reflection (see definitions) of a TUTT cell, and the other was the warm trough that was associated with deep convection stretching northward from the incipient Krosa (then north of Chuuk). The warm trough was located to the east of the NNW-SSE axis formed by the two TUTT cells. It has long been known that TUTT cells in the western Pacific and cut-off cold lows in the North Atlantic can play a role in TC formation. Hebert and Poteat (1975) describe the Atlantic case of conversion of a sub-tropical cyclone to a TC. The years 2000 and 2001 in the North Atlantic were notable for several Hurricanes that developed from cut-off lows in the subtropics, for example: Hurricane Michael (17L 2000), Hurricane Noel (16L 2001) and Hurricane Olga (17L 2001).

Research by Sadler (1978) indicates that TUTT cell-related TC genesis takes place not directly under the TUTT cell, as it does in Hebert and Poteat's scenario of the distal formation of subtropical cyclones associated with cold lows in the Atlantic; but rather, takes place under the diffluent anticyclonically curved flow east of the TUTT cell (Fig. 1). Tropical cyclogenesis and development influenced by an adjacent upper trough (or low) is herein designated as "sympathetic". TC-trough interaction has been studied extensively by John Molinari and colleagues at SUNY, Albany (e.g. Hanley 1999). He and others often use Hurricane Opal (15L 1995) as an example of TC rapid intensification influenced by interaction of a TC with an upper trough. Opal, however, interacted with troughs in the mid-latitude westerlies, whereas Typhoon Krosa formed in the deep tropics of the western North Pacific and rapidly developed while interacting with a TUTT cell.

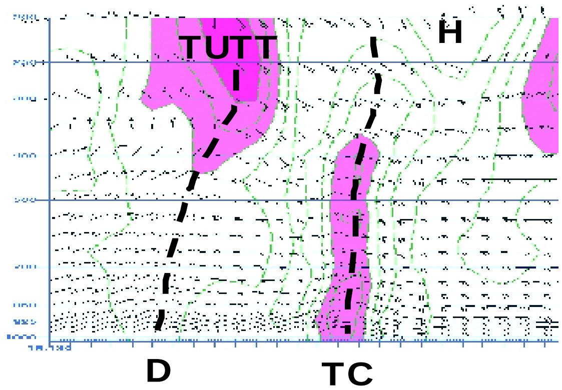

Figure 1. AVN vorticity cross-section from 10N 130E to 15N 155E at 0600 UTC 03 OCT 2001) shows no direct vorticity link between the TUTT cell and associated surface trough (maximum cyclonic vortcity is shaded). Rather, it provides further credence to our newly formed term "Sympathetic surface cyclogensis" where vorticity within the TUTT cell is maximum in the upper troposphere and decreases with decreasing altitude (dashed line D-TUTT) and vorticity within the TC is maximum near the surface and decreases with height (dashed line above TC). "H" indicates upper high.

2. Satellite imagery and AVN data fields

Satellite imagery shows the beginnings of TC Krosa located to the east of Guam at 0425 UTC 03 October (Fig. 2). Cloud lines merging into Krosa show a well-developed circulation located within the monsoon trough. AVN 1000 hPa analysis data from 0000 UTC, 03 October 2001 show the monsoon trough oriented southwest to northeast from near 5N130E to Krosa near 13N147E. By 1200 UTC Krosa had rapidly exploded into a well-developed TC and continued a northwestward track up through the Marianas becoming a tropical storm by 1800 UTC 03 October. Satellite imagery from 2225 UTC 03 October (Fig. 2) shows a well-developed tropical storm. This is a great example of rapid intensification of a TC from a weak tropical depression to a tropical storm in less than 12 hours. For most of its life Krosa was an exposed low-level circulation until it moved up into the warm trough located east of Guam. Around 0600 UTC, 03 October 2001 the upper level pattern over Krosa underwent a dramatic change. Sharply split westerly flow

* *Corresponding Author Address*: Billy D. Ward, Jr., Lead Forecaster, NOAA/National Weather Service Forecast Office, Barrigada, Guam. E-mail: Bill.ward@noaa.gov

east of the upper trough transitioned into an anticyclone centered over the area of convection located east of Saipan. This changed the winds aloft over the low-level center of the incipient Krosa from westerly to light easterly. The importance of this is that the shear was greatly reduced over the circulation as was noted by the sudden increase in convection in both radar and satellite imagery.

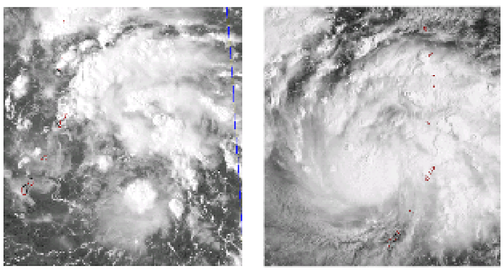

Figure 2. A weak tropical depression (left panel at 0425 UTC 03 OCT) becomes Tropical Storm Krosa in less than 18 hours (right panel at 2225 UTC 03 OCT).

Review of 250 hPa analysis data from 0600 UTC, 03 October 2001 shows a negatively tilted trough oriented NNW to SSE extending from a well defined TUTT cell northwest of the Marianas to almost over pre-Krosa. Negative tilt of a trough in the mid-latitudes indicates strong differential thermal advection (middle and upper level cool air advecting over low-level warm air advection) that increases thermodynamic instability. Severe weather outbreaks in the Central U.S. and intense cyclogenesis on the U.S. east coast are often associated with negatively tilted upper level troughs. It is not known if negative tilt of an upper trough in the subtropics provides similar instability favorable for major outbreaks of deep convection as happened in the Krosa case. The location of this trough and an upper level high located to the northeast of Guam created a well defined jet max of 45 knots 150 miles either side of a line from just northwest of pre-Krosa to near 24N 140E. This pattern coincided with a let-up of shear over the incipient Krosa and its subsequent rapid intensification.

3. Concluding remarks

Krosa provides a great case of rapid intensification of a TC commencing at the depression stage. A comprehensive data set (including VIS and IR satellite imagery, scatterometer data, water-vapor winds, synoptic data, and high-resolution AVN output) is available to define and monitor the entities that were associated with Krosa's formation and rapid intensification: the monsoon trough, a preexisting low-level vortex in the monsoon trough, a TUTT cell that evolved into a negatively tilted upper trough NW of the TC, and a warm surface trough (and its associated area of persistent deep convection) located east of the TUTT cell and north of the pre-Krosa vortex. We postulate relaxed shear, tropospheric moistening, and decreased stability east of a negatively tilted upper trough as key factors in Krosa's rapid development, but many questions remain.

Acknowledgements

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Definitions

DISTAL

Located far from the origin or line of attachment. Usage: "Cut-Off" or Distal Lows. Open trough (cyclonic curvature in open flow) to weak closed cell of low pressure on the surface; grows progressively stronger with height.

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SYMPATHETIC SURFACE CYCLOGENSIS

This is warm core trough development initiated by an upper trough (e.g. a TUTT cell. The potential vorticity of the upper trough or TUTT cell is maximum aloft and it weakens with decreasing altitude. The potential vorticity of the low level trough or vortex is maximum near the surface and weakens with height. In cross sections the potential vorticity of the upper low penetrates straight downward (and may reflect at the surface as a trough independent of the warm core vortex) and the potential vorticity of the lower trough penetrates directly upward. The PV anomalies associated with the two troughs do not connect (i.e., are not linked).

Reference: Lander and Ward; January 2002, Unpublished terminology

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