2. Data and Methodology

2.1. List of Inland Reintensifying TCs

Potential cases of inland reintensifying TCs from 1950 through 2010, identified herein as "candidate cases," are identified using the National Hurricane Center (NHC) best track dataset at 6-h time intervals (0000, 0600, 1200, and 1800 UTC; available at http://www.nhc.noaa.gov/pastall.shtml). Candidate cases included TCs whose tracks may have ended, as analyzed by the NHC best track, over land or where the NHC best track indicates a TC strengthened inland.

Archived surface analyses, produced by the then National Meteorological Center (NMC) that became the National Centers for Environmental Prediction (NCEP), and displayed on 35-mm microfilm at the University at Albany Science Library are used to review surface analyses produced during the inland passage of TCs identified as candidate cases that occurred from 1962 through 1995. Candidate cases that occurred prior to 1962 and after 1995 are assessed using *Daily Weather Maps* stored in an online archive by the National Oceanic and Atmospheric Administration (NOAA) Central Library Data Imaging Project (available at http://docs.lib.noaa.gov/rescue/dwm/data_rescue_daily_weather_maps.html). National Weather Service (NWS) Digital Facsimile (DIFAX) surface maps archived by Colorado State University (available at http://ldm.atmos.colostate.edu/) are used in conjunction with the NOAA *Daily Weather Maps* to evaluate candidate cases occurring after 2000.

The four times daily (0000, 0600, 1200, and 1800 UTC) 2.5° × 2.5° National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) Reanalysis dataset (Kalnay et al. 1996) is used to examine synoptic-scale flow patterns within which the candidate TC cases were embedded. Higher-resolution, four times daily (0000, 0600, 1200, and 1800 UTC) 1.125° × 1.125° 40-yr ECMWF Re-Analysis (ERA-40) (Uppala et al. 2005) and four times daily (0000, 0600, 1200, and 1800 UTC) 0.5° × 0.5° NCEP Climate Forecast System Reanalysis (CFSR) (Saha et al. 2010) datasets are used to analyze mesoscale details of each candidate TC case. The ERA-40 and NCEP CFSR datasets contain 23 and 37 levels, respectively, on constant pressure surfaces. Candidate cases that occurred prior to 1979 are analyzed using the ERA-40 dataset, while cases since 1979 are analyzed using the NCEP CFSR dataset.

Using information obtained from the previously mentioned observational and reanalysis datasets in this chapter, subjective criteria are implemented for each candidate TC case to create a list of inland reintensifying TCs. To ensure that these candidate TC cases were not undergoing ET or influenced by ocean surface sensible and latent heat fluxes, the following subjective criteria are used to evaluate each candidate TC case:

- A vertically stacked, warm-core structure has to be maintained or enhanced during reintensification.
- The minimum central mean sea level pressure (MSLP) has to decrease by 2 hPa and/or the maximum sustained wind speed has to increase by 5 kt in a 6-h period.
- The central circulation (i.e., eye) of the candidate TC case has to remain over land during reintensification.
- The 500-hPa wind speed has to be less than or equal to 30 kt over the TC center.

Vertical cross sections taken from north to south through the center of each candidate TC, displaying PV and potential temperature, are created to evaluate whether a vertically stacked, warm-core structure was maintained or enhanced as a candidate TC traveled over land. The vertically stacked, warm-core structure of each candidate TC is subjectively determined to be maintained or enhanced during reintensification if the bowing down of isentropes is apparent in the central axis of a vertical or near-vertical PV tower associated with each candidate TC, which is indicative of a warm-core structure. For each candidate TC, NHC best track data and archived surface analyses are used to determine whether the second and third listed criteria are met. The last criterion is determined by analyzing 500-hPa wind maps produced from the ERA-40 and NCEP CFSR datasets for each candidate TC.

2.2. Multiscale Analyses

To conduct the multiscale analysis of TC Camille, reanalysis and observational datasets are used to diagnose the synoptic and mesoscale processes associated with the storm-related inland flooding. The 1.125° × 1.125° ERA-40 dataset is used to generate synoptic-scale charts and to calculate diagnostic quantities that are produced using the General Meteorology Package (GEMPAK; desJardins et al. 1991).

The evolution of precipitation across west-central Virginia that occurred with the passage of TC Camille is tracked using hourly radar summary charts. These radar summary charts, originally hand drawn and produced by the NMC, were obtained from the National Climatic Data Center (NCDC) and then further analyzed by the author. To be more visually appealing, the radar summary charts have been adapted from their original format and are reproduced following a key created to interpret the radar summary charts (Fig 2.1).

Surface data in Surface Airways Observations (SAO) format obtained from the NCDC Integrated Surface Database (http://www.ncdc.noaa.gov/oa/climate/isd/index.php) are plotted in GEMPAK and hand analyzed to track the surface evolution of the inland flooding event associated with TC Camille. The surface analyses include surface temperature and dew point, wind, and MSLP. A caveat for the surface analyses is that a lack of observations across west-central Virginia during the inland flooding event led to an uncertainty in the mesoscale details of the surface analyses.

The multiscale analysis of TC Danny uses a similar combination of reanalysis and observational datasets as for the TC Camille case to diagnose the synoptic and mesoscale processes associated with the inland reintensification event. The gridded 0.5° × 0.5° NCEP CFSR dataset is used to generate synoptic-scale charts and calculate diagnostic quantities similar to the TC Camille case. Unfortunately, using two datasets with different spatial resolutions limits the capability of making exact comparisons between the TC Camille and TC Danny cases. Since the NCEP CFSR dataset only goes back to 1979, this dataset could not be used for the TC Camille case. The TC Danny case could have been conducted using the lower-resolution ERA-40; however, high-resolution details produced by the NCEP CFSR are more realistic than the ERA-40 as illustrated in Fig. 2.2. Figure 2.2a, derived from the ERA-40 dataset, depicts a weak vertical structure of TC Danny for 1800 UTC 24 July 1997, whereas Fig. 2.2b, obtained from the NCEP CFSR reanalysis, shows a more realistic vertical structure for TC Danny as evident in surface wind speeds of approximately 15 m s^{-1} on the southern side of the TC at 1800 UTC 24 July. When comparing the reanalysis depiction of the surface wind with the observed 20 m s^{-1} maximum sustained wind speed in the NHC best track data at 1800 UTC 24 July, the NCEP CFSR underestimates the surface wind speed. The ERA-40 does not depict a surface wind at or above 15 m s^{-1} around the circulation of TC Danny, which makes the NCEP CFSR more appropriate to use for the TC Danny analysis.

Structural changes in convective and stratiform precipitation around TC Danny are documented prior to and during its inland reintensification using Weather Surveillance Radar–1988 Doppler (WSR-88D) base reflectivity datasets obtained from NCDC (http://www.ncdc.noaa.gov/nexradinv/) for multiple WSR-88D locations: Birmingham, Alabama (KBMX); Atlanta, Georgia (KFFC); Greer, South Carolina (KGSP); Columbia, South Carolina (KCAE); and Wakefield, Virginia (KAKQ) . The radar data are then plotted using Gibson Ridge Level 2 Analyst software (GR2Analyst; software can be downloaded at http://www.grlevelx.com/gr2analyst/). Visible and infrared satellite imagery obtained from the Unidata–Wisconsin datastream is used in conjunction with the radar data to facilitate the TC Danny analysis.

Standard hourly Automated Surface Observing System (ASOS) observations are obtained from an archive at the University at Albany, and are plotted in GEMPAK and hand analyzed to track the surface evolution of TC Danny and its environment as it reintensified inland. Similar to the TC Camille analysis, surface analyses include surface temperature and dew point, wind, and MSLP.

Diabatic heating rates are calculated from 1.0° × 1.0° NCEP CFSR 3-D Diabatic Heating Data 6-h forecasts (Saha et al. 2010) and used to monitor the evolution of the vertical heating distribution prior to and during the inland reintensification of TC Danny.

The diabatic heating rates are calculated in a 3°×3° box centered on the central circulation of TC Danny. A visual depiction of this computational box around TC Danny is shown for 0600 UTC 24 July 1997 (Fig. 2.3). The diabatic heating rate calculation includes a shallow convective heating rate, a deep convective heating rate, and a large-scale condensation heating rate (Saha et al. 2010). A caveat to using the NCEP CFSR diabatic heating dataset is that the forecasted placement of convection may be incorrect (M. Janiga 2012, personal communication). A visual check of the forecasted placement of convection shows that it approximately resembles the convection observed around TC Danny during its inland reintensification, which gives confidence in the diabatic heating rate calculations.

The “PV thinking” perspective (e.g., Hoskins et al. 1985; Morgan and Nielsen-Gammon 1998) is used to assist in the diagnosis and interpretation of the TC Danny and TC Camille cases. The utility of using a PV perspective is twofold: (1) identifying sources of diabatic heating that may lead to generation (destruction) of lower- (upper-) tropospheric cyclonic (anticyclonic) PV and reduction of wind shear aloft, and (2) evaluating vertical and horizontal interactions between PV anomalies to diagnose synoptic and mesoscale processes. The analyses for TC Camille and TC Danny calculated Ertel PV, which is conserved following flow that is adiabatic and frictionless, and is evaluated as

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Changes in PV can be evaluated by using the Lagrangian rate of change of PV, and is approximated as [adapted from Martin 2006, his Eq. (9.23)]:

where is the diabatic heating rate. A qualitative assessment of Eq. (2) is used in the TC Danny case to infer changes in PV based on changes in with pressure. Where increases (decreases) with decreasing pressure, a corresponding increase (decrease) of PV ensues. Calculations of the irrotational wind are produced as a supplementary tool for the PV analysis in the TC Danny case to document the influence of the upper-tropospheric divergent outflow associated with regions of diabatic heating on the upper-tropospheric distribution of PV.

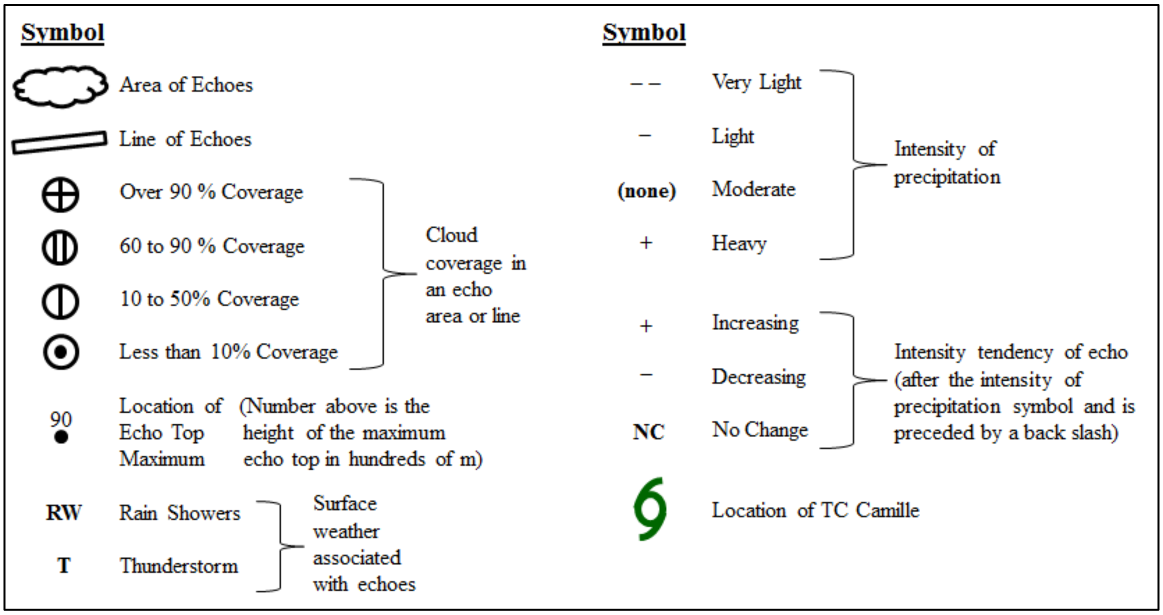

Fig. 2.1. Key displaying the symbols used for the adapted radar summary charts.

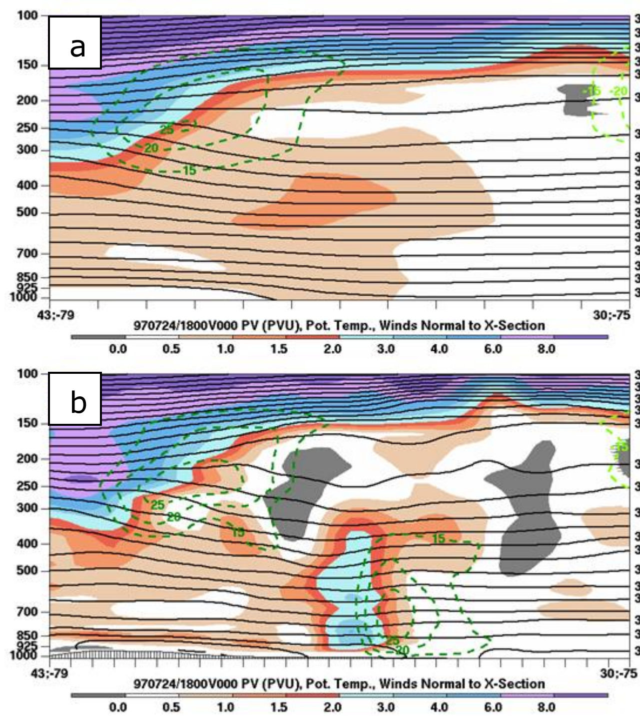

Fig. 2.2. Vertical cross section of PV (shaded every 1 potential vorticity unit [PVU; 10^{-6} $m^2 s^{-1}$ K kg^{-1}]), potential temperature (solid black every 4 K), and the wind component normal to the cross section (dashed green every 5 m s^{-1} starting at 15 m s^{-1}) at 1800 UTC 24 July 1997 using the (a) ERA-40 and (b) NCEP CFSR.

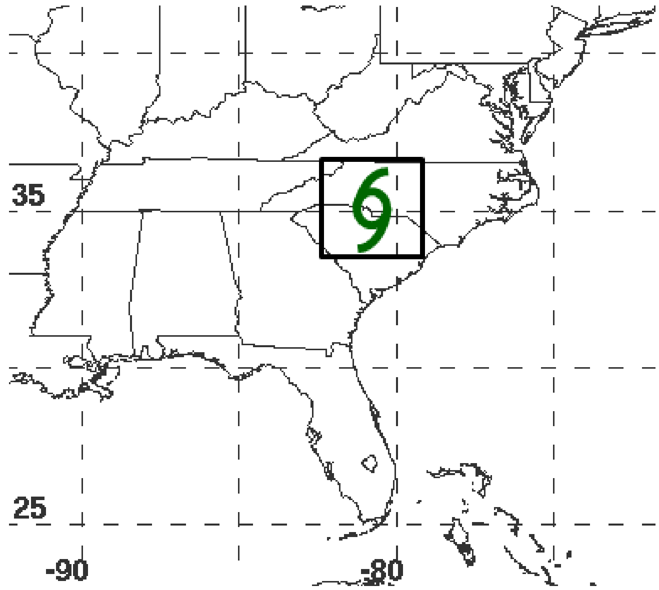

Fig. 2.3. A 3°×3° computational box centered on the central circulation of TC Danny (green TC symbol) at 0600 UTC 24 July 1997.