# Precipitation Distribution Associated with Landfalling Tropical Cyclones

## 1. Introduction

Several recent storms have highlighted the importance of understanding the effect of the interaction of landfalling tropical systems with mid-latitude features such as cold upper-level troughs and baroclinic zones. Floyd (1999) proved to be a particularly difficult forecast challenge as most of the hazardous weather warnings as the storm approached the coast focused on the potential for wind damage. However, flooding proved to be by far the most significant threat to life and property in association with Floyd as more than 50 cm of rain fell over sections of North Carolina with widespread amounts exceeding 20 cm stretching from the Piedmont region of North Carolina into southeastern New York (Lawrence et al. 2001).

Atallah and Bosart (2003) provide a detailed case study of Floyd and indicate that the precipitation distribution and intensity associated with Floyd resulted from its interaction with a potent mid-latitude trough and subsequent extratropical transition. This paper will attempt to generalize the results of Atallah and Bosart (2003) and will focus on the dynamical basis for understanding the expected distribution, aerial extent, location, and intensity of precipitation relative to the track of the tropical cyclone prior to and subsequent to landfall for numerous cyclones.

## 2. Data and Methodology

All gridded fields for use in the composites are taken form the National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research's (NCAR) Reanalysis taken from 00 and 12 UTC (Kalnay et al. 1996). The first time period, or t=0, for each of the composites is defined as the first time that the storm exhibits a left of track (LOC) or right of track (ROC) precipitation distribution. The storm is then composited relative to a reference storm track. In order to be included in any of the composites, each storm had to meet the following criteria: 1) the storm had to make landfall along either the Gulf or Atlantic coasts of the United States, 2) the storm had to display a poleward component in its track, 3) the storm had to pass far enough inland that precipitation measurements could be made in all quadrants of the storm.

## 3. Results

Fig. 1 shows potential temperature ($\theta$) and wind on the dynamic tropopause (DT) as well as the 850-700 hPa relative vorticity. The utility of this schematic is that $\theta$ is conserved on the DT for frictionless and adiabatic conditions. Therefore, diabatic effects (e.g. latent heat release) can be inferred in regions where $\theta$ is not conserved.

At time t=0 in the LOC composite, a strong ridge – trough couplet is evident along the eastern seaboard (Fig. 1a). The composite cyclone already lies in the equatorward jet entrance region of a fairly pronounced jet streak ahead of the trough. Over the next 12 h, diabatically induced ridging occurs preferentially over New England (Fig. 1b) in a region of heavy precipitation (not shown). Note the northwestward propagation of the 345 K isentrope from southeastern to northwestern New York. This preferential ridging results in a reconfiguration in the tilt of the midlatitude trough, and a collapse in the wavelength of the ridge – trough couplet, indicative of an increase in the magnitude of the vorticity gradient.

By time t=24, the core of the relative vorticity center associated with the composite TC has become embedded in the strong $\theta$ gradient along the east coast (Fig. 1c). The tilt of the midlatitude trough is now negative, and the associated magnitude of vorticity advection increases. The movement of the TC into the $\theta$ gradient and high wind shear indicates the storm has undergone extratropical transition (ET) 24 h after first exhibiting a left of center precipitation distribution.

In contrast, the storm in the ROC composite makes landfall insulated by a $\theta$ ridge (Fig. 1d). A weak midlatitude trough is located several hundred kilometers to the north/northwest of the TC. Over the next 12 h, a $\theta$ ridge builds over the Ohio Valley as the 350 K isentrope propagates northward over the Ohio Valley during this time (Fig. 1e). The preferential ridging over the Ohio Valley has the effect of creating a ridge – trough couplet. As the $\theta$ gradient strengthens in response, the storm is brought into closer proximity of a developing jet streak.

Finally, by time t=24 the TC becomes begins to move across the $\theta$ gradient towards cooler values (Fig. 1f). At this point the structure is reminiscent of a weaker version of the LOC t=0 composite. It should be noted that about half the storms in the ROC composite underwent ET after this point, with a corresponding shift in the precipitation from right of to left of track.

## 4. Conclusions

The LOC precipitation distribution is a consequence of the landfalling TC interacting with a vigorous midlatitude trough. This often results in ET and a strong extratropical cyclone. In contrast, the TC in the ROC composite is initially isolated from any significant midlatitude systems. Eventually, diabatically enhanced downstream ridge development can produce a more amplified trough – ridge couplet leading to a more vigorous interaction.

## 5. References


Atallah, E. H. and L. F. Bosart, 2003: Extratropical Transition and Precipitation Distribution: A Case Study of Floyd (1999). *Mon Wea Rev.*, **131,** p. 1063–1081.

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Lawrence, M. B., L. A. Avila, J. L. Beven, J. L. Franklin, J. L. Guiney, and R. J. Pasch, 2001: Atlantic hurricane season of 1999. *Mon. Wea. Rev.,* **129** p. 3057–3084.



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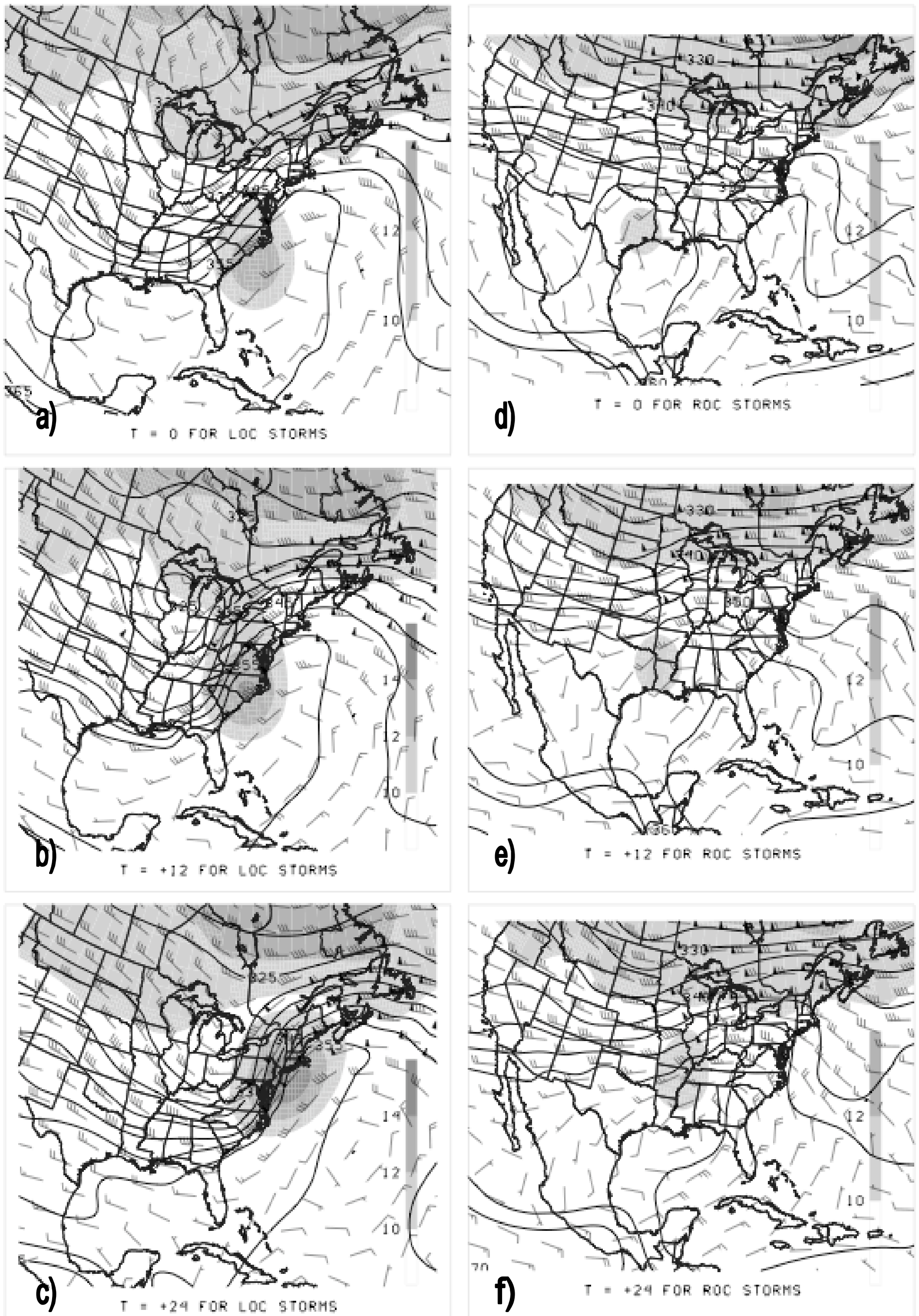


Figure 1. 850-700 hPa relative vorticity (shaded every 2 x $10^{-5}$ $s^{-1}$starting at 10 x $10^{-5}$ $s^{-1}$), θ (black lines, contoured every 5 K) on the dynamic tropopause (defined by the 1.5 PVU surface), and winds (black barbs – knots convention) on the dynamic tropopause for a) t=0 loc composite, b) t=12 loc, c) t=24 loc, d) t=0 roc, e) t=12 roc, and f) t=24 roc.

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