importance of CSI in producing the observed banding and its impact on the overall precipitation amount and distribution (e.g., Emanuel 1985; Sanders and Bosart 1985a, b; Nicosia and Grumm 1999; Nicosia et al. 1999; McCann 1999; Schultz and Schumacher 1999). The ability to distinguish in real time between environments that are conducive to slantwise convection (i.e., associated with CSI) and those that favor upright convection (i.e., associated with conditional instability) will allow forecasters to issue more timely and precise short-range forecasts of the amount and distribution of heavy precipitation.

In addition to banded precipitation features associated with extratropical cyclones, a critical forecasting problem in the northeastern US involves the configuration and evolution of the rain-snow boundary, both in an elevation-dependent and geographical sense. The former is concerned with so-called elevation storms and the latter with coastal fronts (e.g., Bosart et al. 1972; Bosart 1975; Riordan 1990; Nielsen and Neille 1990; Riordan et al. 1995; Fritsch et al. 1998). Elevation storms occur where the critical thickness defining the rain-snow boundary is located over regions where terrain elevation varies significantly (e.g., the 4 October 1987 storm; Bosart and Sanders 1991). More precise determination of the location of the rain-snow boundary will result in improved forecasts of the type, amount, and distribution of precipitation, thereby mitigating the disruptive societal impact of these inland events. Cool-season coastal fronts commonly occur in southern New England and the New York City/Long Island area, and often delineate the rain-snow boundary and the axis of heavy precipitation. In the vicinity of the rain-snow line in coastal front cases, the axis of heavy precipitation may be observed in conjunction with mesoscale circulations forced by differential diabatic cooling associated with melting snow (e.g., Szeto et al. 1988a, b). Understanding the nature of vertical circulations associated with the rain-snow boundary in coastal fronts is a significant heavy precipitation forecasting problem that would appear to be an ideal candidate for the application of novel visualization packages that take advantage of existing diagnostic procedures.

**Proposed Operational Forecasting Product:**

We propose to develop a Web-based user-driven visualization package applicable to regional-scale short-range model guidance and suitable for diagnosing dynamical and thermodynamic mechanisms that contribute to the character and type of precipitation associated with extratropical cyclones affecting the northeastern US. In regard to the character of precipitation, the diagnostic package will take advantage of the graphic capabilities of Vis5D to delineate in three dimensions the respective thermodynamic stability regimes that distinguish between upright and slantwise convection, as well as stratiform precipitation. In order to isolate the regions where precipitation would be expected to occur in a model forecast, the diagnostic package will emphasize the three-dimensional distributions of upward vertical motion and water substance in conjunction with the indicated stability regimes. In regard to the type of precipitation, the diagnostic package will indicate the topology of the 0°C isosurface in relation to topographic and frontal features. We will develop the capability to interpret the detailed configuration of the 0°C temperature isosurface, with the goal of isolating signatures for the occurrence of snow, sleet, freezing rain, and rain. Additional thermodynamic parameters will be displayed, such as the 0°C wet-bulb temperature isosurface, to indicate the potential for the transition from liquid to frozen precipitation. Furthermore, parameters of microphysical significance may be considered, such as the atmospheric volume simultaneously exhibiting temperatures in the range of -12 to -16°C (where ice crystal production is optimized) and upward vertical motions exceeding preselected threshold values. Finally, the proposed diagnostic package will offer the capability of animating the three-dimensional displays of the foregoing diagnostic parameters, thereby providing forecasters with an “inside look” at the evolution of the critical processes and features determining the formation, character, and type of precipitation.

(ii) convectively dominated warm-season heavy precipitation events:

- Determine to what extent various large-scale circulation anomalies interact to control the frequency and occurrence of warm-season continental anticyclones and understand how these features provide efficient moisture conduits to initiate and sustain organized deep convection in the northeastern US.

**NCEP’s Hydrometeorological Prediction Center (HPC)**

An example of the large-scale control of the precipitation distribution and amount can be found in the occurrence of persistent upper-level continental anticyclones over the interior of North
Transient mesoscale disturbances found in conjunction with these anticyclones can be associated with significant episodic organized mesoscale convection. Organized mesoscale convection can assume the form of mesoscale convective systems (MCSs), mesoscale convective complexes (MCCs), mesoscale convective vortices (MCVs), and derechos. Examples documented locally (e.g., Bosart et al. 1998, 1999) include the significant organized convective events that occurred over parts of the northeastern US in mid-July 1995, in late May and early June 1998, in September 1998, and in early July 1999. In the case of continental anticyclones, transient mesoscale disturbances can sometimes circumnavigate the anticyclone over periods of days to weeks. Bosart et al. (1998, 1999) noted that when equatorward-moving mesoscale disturbances on the eastern periphery of the anticyclone turn southwestward and then eventually westward, they could join other westward-moving disturbances of tropical origin in the deep easterlies on the equatorward periphery of the anticyclone. They further demonstrated that when these westward-moving mesoscale disturbances turned poleward in the southerly flow to the east of the Rockies, new organized deep convection (e.g., MCSs/MCCs) was triggered as the disturbances aloft approached and merged once again with the fast westerlies on the poleward side of the entrenched anticyclone. The “reactivation” of these mesoscale disturbances to the east of the Rockies occurred in a region favorable for instability, moisture, and lift, which were reinforced by the tendency of the southerly flow to turn upslope in response to diurnal heating over the elevated terrain to the west.

The multiple mesoscale disturbances rotating anticyclonically around the persistent continental anticyclone create the so-called “ring-of-fire” effect (a favorite term of meteorologists on The Weather Channel), because each transient disturbance is associated with an organized cloud and precipitation signature readily seen in satellite and radar imagery. The isolation of time-mean (5-10 day) cloud and precipitation anomalies enables the “ring-of-fire” effect to be clearly seen. Also at issue is to what extent large-scale circulation anomalies such as the NAO/PNA and/or La Niña/El Niño (or a combination thereof) control the frequency of warm-season continental anticyclones. Subtle differences in the location and structure of these anticyclones, and in the strength and position of the fast westerlies poleward of them, can have a significant impact on the convective precipitation signal (and the likelihood of heavy rains) over the northeastern US. This behavior is especially true in northwesterly flow convective outbreaks when limited moisture availability might be balanced by extreme instability (very steep lapse rates) in the presence of a jet-entrance region on the poleward periphery of the anticyclone. Conceptual models need to be developed to help forecasters recognize the potential for anticyclonic flow patterns aloft that are associated with severe weather outbreaks and damaging heavy rain events. We expect that this approach will be successful based on its application to other important weather situations. Examples include derecho events east of the Rockies (e.g., Bentley and Mote 1998) and mid-Atlantic flash floods events (e.g., Pontrelli et al. 1999), where subtle differences in moisture availability and instability are important.

Proposed Operational Forecasting Product:

The envisioned conceptual models will emphasize large-scale flow regimes associated with persistent continental anticyclones associated with severe weather outbreaks and damaging heavy rain events. In the present project, we will be concerned with those extreme events that tend to occur on the northeastern periphery of these upper-level anticyclones. This project will focus on the anomalous behavior of the time-mean upper-level anticyclone commonly found over central North America in summer. It is hypothesized that a variety of warm-season heavy precipitation systems, such as severe convection over the northeastern US, are modulated by variations in the central position, amplitude, and configuration of the upper-level continental anticyclone. The procedure to be followed in developing these conceptual models is to: 1) perform 30+ years of analyses of summertime upper-level (i.e., 200 hPa) monthly and intraseasonal time-mean and anomalous flow patterns over North America in order to document the behavior of the continental anticyclone; 2) relate anomalous anticyclone behavior to the observed large-scale flow anomalies and to the various indices that objectively define large-scale flow regimes; 3) identify all instances of significant organized severe convection (e.g., MCSs, squall lines, derechos, and tornadic convection) over the northeastern US over the 30+ year period; 4) stratify and categorize events with respect to the observed large-scale flow anomalies and to the various indices that objectively define the behavior of the upper-level continental anticyclone; 5) relate anomalies in thermodynamic stability, moisture, and wind shear, all of which strongly influence the detailed evolution of convection, to the various severe convective events identified in step (4). As in the cool-season large-scale project, this series of steps
will culminate in graphical, Web-based conceptual models that will provide important guidance to the forecaster in regard to the potential for severe convection under the prevailing and expected large-scale flow regimes.

- Improve the prediction of the timing and location of heavy precipitation associated with landfalling tropical storms, as modulated by the complex terrain and physiography of the northeastern US.

WFO Gray, Maine (GYX), WFO Taunton, Massachusetts (BOX), and RFC Taunton, Massachusetts (TAR)

An important warm-season forecasting problem is how landfalling tropical storms contribute to terrain-modified heavy rain events (LaPenta et al. 1995; Marks et al. 1998; Fritsch et al. 1998). Examples are the “Saxby Gale” of October 1829 (Abraham et al. 1999), Agnes in June 1972 (e.g., Bosart and Carr 1978; Carr and Bosart 1978; DiMego and Bosart 1982a,b; Bosart and Dean 1991), David in September 1979 (Bosart and Lackmann 1995), Opal in October 1995 (e.g., Henderson et al. 1999), Fran in September 1996 (e.g., Johnstone and Burrus 1998), and Danny in July 1997 (Blackwell and Medlin 1998; Medlin and Blackwell 1999; Atallah and Bosart 1999). The quantitative precipitation forecast (QPF) problem posed by a decaying (or, in the case of David, reorganizing) tropical cyclone has always been a challenge. In the case of the northeastern US, there are additional complications that arise because of the complex terrain. These additional complications involve the timing of the heavy rains and the definition of the location of the heaviest rain (recent examples include Bertha 1996; Dennis 1999; and Floyd 1999). When the deep-layer directional shear (above 850 hPa) is relatively small, as might often be the case in a landfalling tropical cyclone, training echoes (whereby new deep convective cells repeatedly traverse old ground covered by previous cells) and heavy precipitation can be expected. The problem is exacerbated by the combination of weak flow aloft (which ensures slow-moving convective cells) and by the absence of baroclinicity (which ensures a tropospheric-deep unidirectional flow and training echoes). This situation was observed in conjunction with the landfall of tropical storm Dennis in September 1999, when heavy unforecast rains disrupted the morning rush hour in the New York City area well in advance of the storm, and again several days later in parts of the northeast (including the Albany area) when the very weak remnant of Dennis interacted with ambient tropical air in the presence of complex terrain.

Other scientific issues relate to understanding the distribution of terrain-modified precipitation when thermodynamically unstable air is forced against the mountains. One can ask to what extent the elevation dependence of precipitation is a function of the stability profile of the moist air mass and what is the role of convection in this process. Cloud microphysical processes may be playing a key role (drop size distribution in tropical air vs. more typical midlatitude air), and the height of the freezing level may also be important in relation to precipitation-growth mechanisms. A further issue is how the diurnal heating cycle over complex terrain helps to force mesoscale circulations that are often anchored to the terrain and result in excessive precipitation. Weak disturbances aloft can play an important role in triggering deep convection and flood-producing heavy rains, modulated by complex terrain, in ambient tropical air masses. These weak flow heavy rain events might provide an ideal testbed for assessing how complex terrain modulates deep convection in response to the diurnal heating cycle, given that the synoptic-scale forcing is so weak.

Proposed Operational Forecasting Product:

We propose to develop a checklist/decision tree to enable forecasters to refine the short-range QPF guidance provided by NCEP/HPC and the National Hurricane Center (NHC) in situations of anticipated tropical-cyclone landfall and subsequent inland movement over the northeastern US. This checklist/decision tree is designed to reflect three significant operational forecasting problems: 1) the preferred location of severe convection at the time of landfall; 2) the distribution and intensity of precipitation relative to the postlandfall tropical-cyclone track; 3) the question of tropical-storm regeneration or extratropical transition. The latter problem is especially critical because of the likelihood of significant inland and coastal flooding as well as accompanying high winds. The checklist/decision tree will consist of the following ingredients: the large-scale environment (e.g., upper-level baroclinic troughs and jet streaks); the mesoscale environment (e.g., vertical wind shear and thermodynamic stability profiles); boundary-layer and surface processes (e.g., diurnal heating cycle and orography); and microscale processes (e.g., cloud microphysics). Each of the foregoing