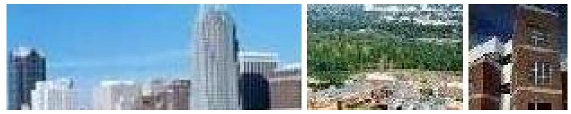
Forecasting Predominate Precipitation Type Trends (TREND)

National Weather Service, Raleigh NC



Updated 2008/01/24

Introduction

Numerous studies have shown that winter storms in this region contain mixed precipitation types and difficult to forecast events. Keeter et. al. (1995) provides an excellent review of the precipitation type forecast problem across the southeastern United States along with the extensive variability of winter events that occur in this region. Keeter and Green (1981) noted that more than half of the measurable frozen precipitation cases during a seven-year period at Charlotte, North Carolina, consisted of mixed precipitation types. Moyer (2001) showed that 86 percent of winter events during a 40 year period at Greer, South Carolina contained two or more precipitation types.

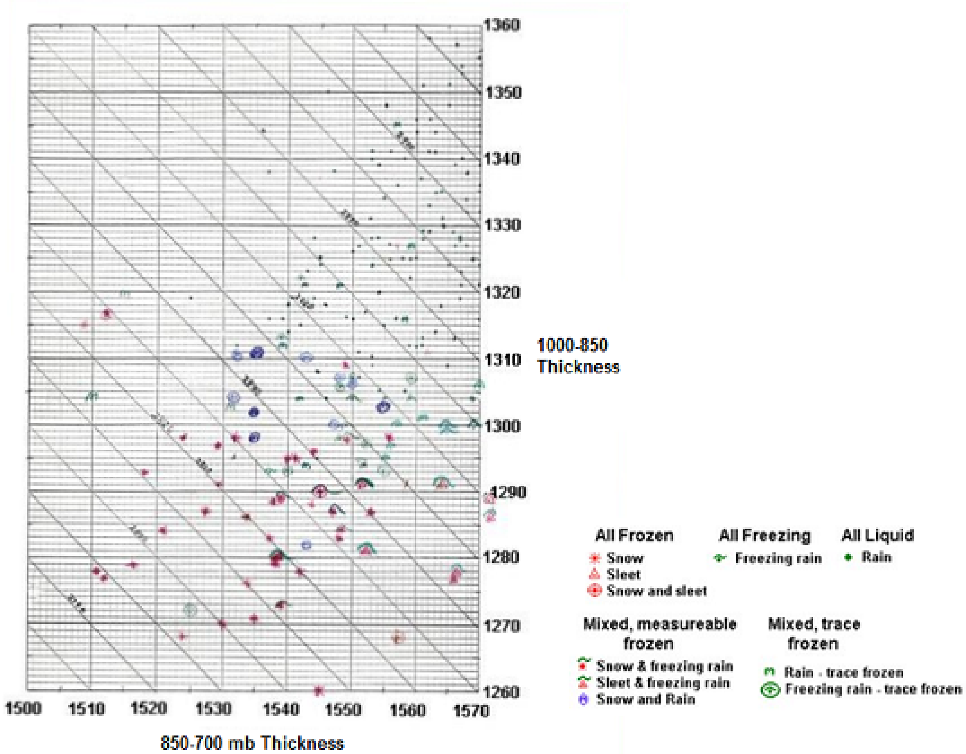
The TREND Technique using the Partial Thickness Predominant P-type Nomogram is a proven methodology for forecasting the predominant precipitation type during a six-hour period during winter storms in the Carolinas and Virginia. The Partial Thickness Universal Nomogram evolved from site-specific nomograms created according to the experimental design and developmental strategies described in Keeter and Cline (1991).

This reference document contains a thorough review of the TREND technique with a discussion of the technique, how it is used, its limitations, along with a new method to visualize the nomogram and some selected real time nonmogram plots. The table below provides an index and links to the various topics discussed.

What is TREND

TREND works best when used in conjunction with other components in the precipitation type forecast process. Extensive case studies of winter storms in the Carolinas have shown a high degree of correlation between geographical p-type distributions, patterns of cyclogenesis, composites of partial thickness, sounding profiles, and single station p-type analysis.

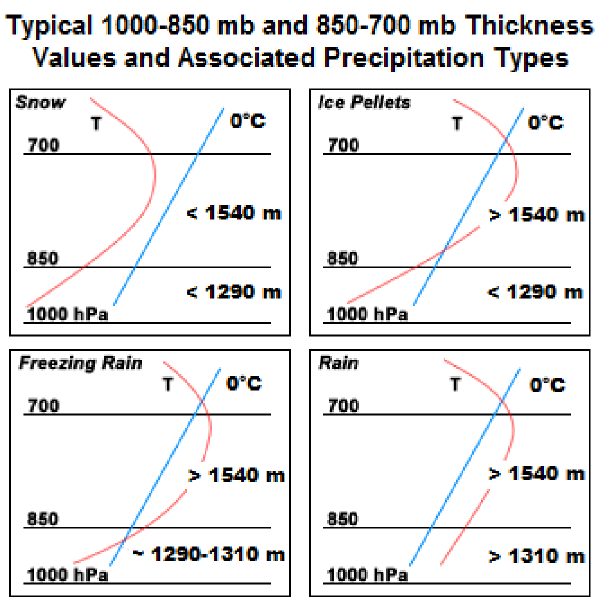
As an empirical technique, TREND was developed by correlating observations of precipitation type(s) and sounding data, both taken at Greensboro (GSO) North Carolina. Only measurable precipitation events were included. Special six-hour soundings were often taken during winter storm events. The collection of data has been ongoing since the winter season of 1970 - 71. It is a technique for predicting the predominant (i.e. greatest impact) precipitation type.



TREND is best suited for those areas of the country (e.g., southern United States) where mixed precipitation often occurs or where even small amounts of frozen and/or freezing precipitation can have a significant sociological impact. The TREND technique was developed with empirical data taken from Greensboro North Carolina with a station elevation at 897 ft MSL. It is best suited for those locations whose station elevation is less than 1500 feet MSL

The TREND technique specifies and verifies the occurrence of p-types continuously over six-hour intervals. This design is in contrast to the more traditional approach where p-type is specified and verified for a point in time such as direct NWP output or MOS. By employing a six-hour interval, the technique accounts for trends in the evolution of p-types and maximizes the capture of measurable frozen and freezing precipitation during mixed precipitation events (e.g. measurable snow with rain vs. trace snow with rain).

A layer's thickness, or depth, is proportional to its average virtual temperature. The thickness can represent a thermal field through a layer in the troposphere. The greater the relative thickness of the layer, the warmer the thermal field. Typically in the Carolinas, the1000-850 mb thickness characterizes the strength of the surface based cold air, while the 850-700 mb thickness characterizes the degree of warm air gliding atop the cold dome. Specific partial thickness values can be reliable indicators of subfreezing, above freezing, near freezing isothermal, and varying magnitudes of melting and subfreezing.



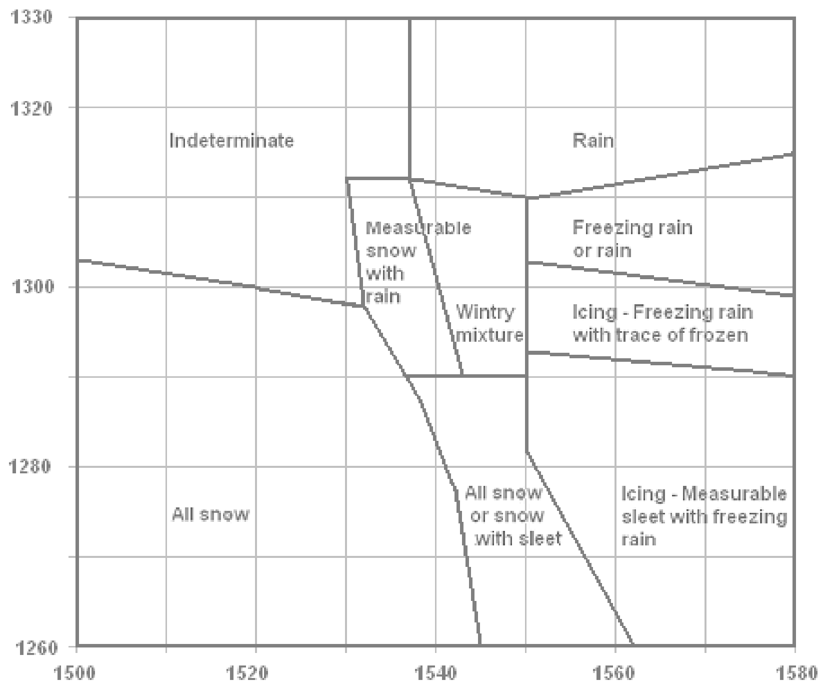
adapted from COMET

When used with real-time RAOB data, TREND can provide p-type specificity for use in short term forecasts. When used with NWP data, TREND provides forecasts of p-type trends over intervals of six-hours.

TREND’s Predominant P-type Nomogram

The nomogram shows the distribution of p-type trends as a function of partial thickness values. Close examination of precipitation events over the past 30 years accounts for the boundaries on the nomogram separating the various p-type trend areas. Mid level thickness values increase from left to right along the x axis. Low level thickness values increase from bottom to top along the y-axis.

The last revision to the predominant p-type nomogram (winter 2006/2007) was focused on the central region of the nomogram where many events occur with weak thermal advection and/or surface based melting layers that can result in near freezing isothermal layers. This part of the nomogram requires the forecaster to be especially aware of the so-called secondary p-type factors that can become larger players for controlling precipitation types. These factors include evaporation, melting, precipitation amounts, and precipitation rates.



TREND’s 6 hourly predominant p-type categories include:

- All snow
- All snow or snow/sleet mix
- Icing – measurable sleet with freezing rain
- Icing – freezing rain mixed with trace frozen
- Freezing rain or rain
- Rain
- Measurable snow with rain
- Wintry mixtures

Changes to or mixing with other p-types are in part determined by noting which predominant p-type category the thickness values are trending toward. When the partial thickness values are located near an adjacent p-type category and are trending toward that adjacent category, forecasters should reflect this trend in their 6 hourly forecast of p-type.

Visualization of Vertical Temperature Profile(s) from Partial Thickness

Observations of partial thicknesses and the corresponding vertical thermal structure seen from observed soundings show a strong. Listed below are partial thickness values and their associated thermal interpretations. The thermal interpretations are useful for projecting the distribution of precipitation types from plan views of observed or forecast partial thickness values.

While, the same thickness layer value can be associated with more than one vertical temperature profile, some valuable generalities do apply. To maximize your skill in using TREND, you should know what the most likely vertical temperature profiles can be for a given range in thickness values. By employing the thermal interpretations associated with the partial thickness values indicated below, you can visualize the most likely vertical temperature profile. This allows the user to determine the geographical distribution of p-types from a plan view plot of partial thickness values.

The partial thickness values shown below are in meters. The thickness value(s) of the 1000/850 layer is shown first, followed by the thickness value(s) for 850/700 mb layer

Layer below freezing
< 1290 < 1540

Layer above freezing
> 1320 > 1580

Small melting layer or near freezing isothermal segment
1290's AND 1540's

Typically, significant melting layers
>1305 AND 1550's

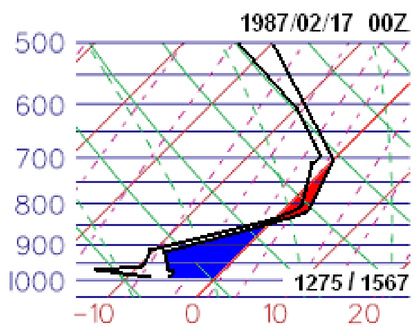
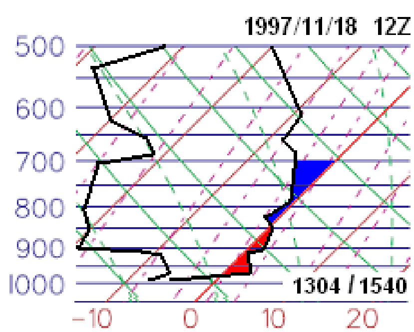
Typical deep (> 100 mb) near freezing isothermal layer
1295-1305 AND 1545-1557

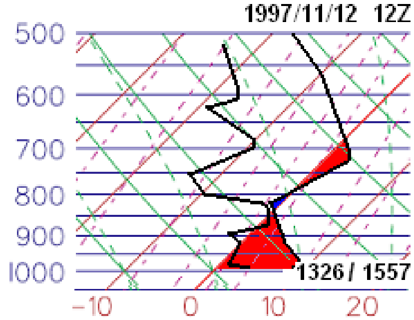
Maximum thicknesses observed with a very deep (180 mb) near freezing isothermal layer at GSO on 1997/01/22 producing 12 inches of wet snow
1299 1556

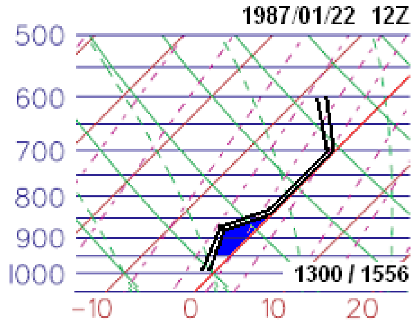
Large inversions with prominent melting "warm noses" above surface based sub freezing "cold noses"
< 1280 AND > 1560

Shallow surface based sub freezing cold layer
1310-1320

Steep lapse rate, very cold above a surface based melting layer
> 1300 AND < 1530

1000-850 mb	**850-700 mb**	**RAOB Imagery**
1275 m (prominent cold nose)	**1567 m** (prominent warm nose aloft)	
1304 m (significant layer above freezing)	**1540 m** (layer below freezing)	
1326 m (layer above freezing)	**1557 m** (significant portion above freezing)	

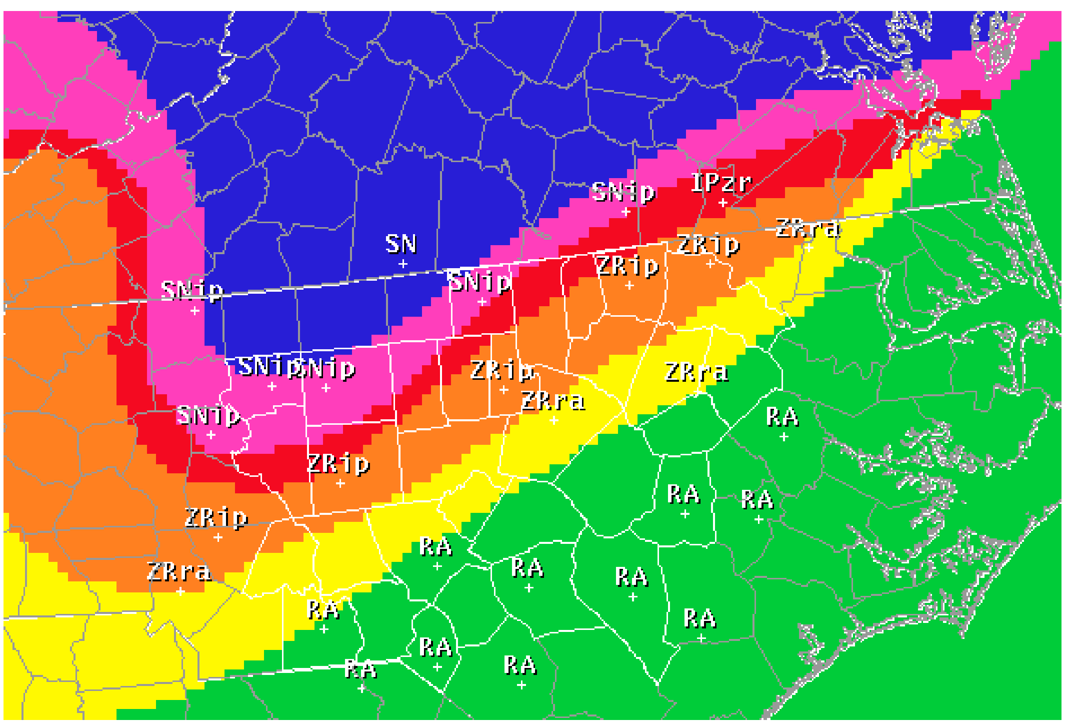


1300 m (near freezing, isothermal)	**1556 m** (near freezing, isothermal)	

Visualization of the Location and Orientation of P-type Boundaries

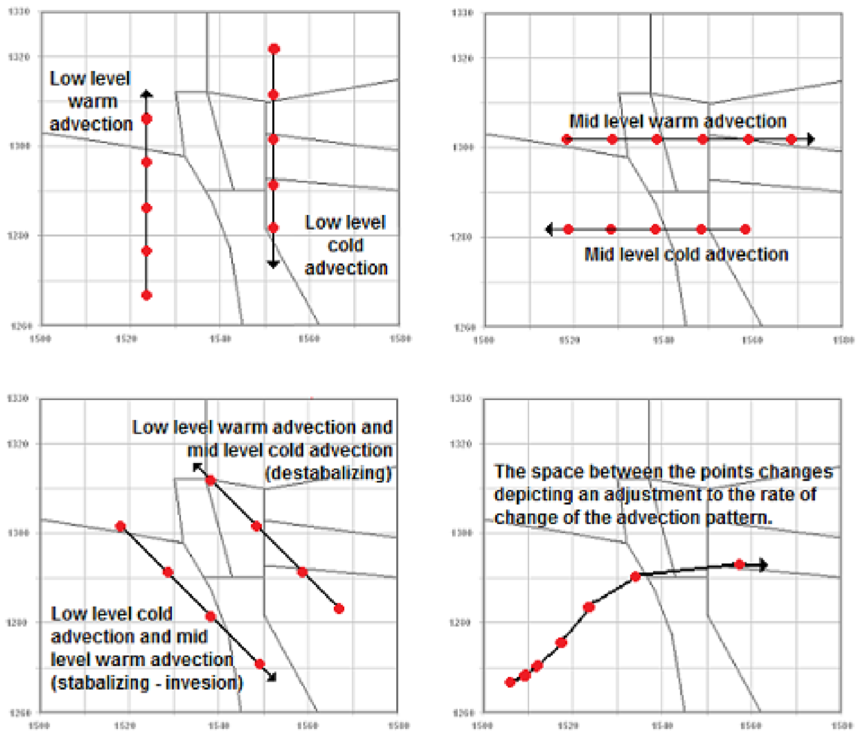
One advantage of the TREND technique is the increased ability to visualize the location and movement of precipitation type boundaries across wide areas in plan view. In the example shown below, the plot of partial thickness values would help the forecaster visualize the likely location of precipitation type boundaries in a complex situation. In addition, viewing this type of display in a time-lapse mode would also allow forecasters to visualize the evolution of the atmospheric thermal environment; for example, the advance or retreat of cold air at low or mid levels

The image below was produced via the GFE "PType Nomogram Tool" created by Patrick Moore from WFO GSP. The "PType Nomogram Tool" uses grids of 1000-850mb thickness and 850-700mb thickness to create a discrete grid that shows a plan view of where all grid boxes reside within the Partial Thickness Predominant P-type Nomogram. This smart tool is available on this Smart Tool Repository.



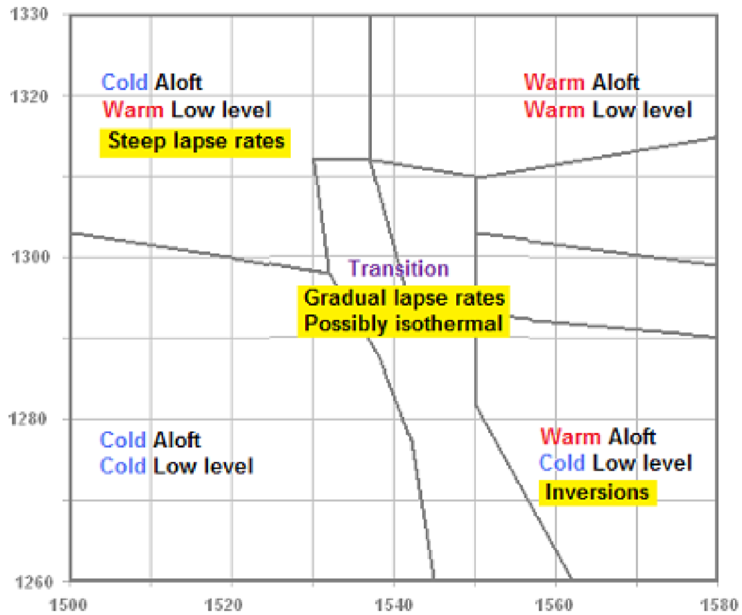
Visualization of Atmospheric Processes

Another application of the TREND technique is shown below. Viewing the time-evolution of partial thickness values at a particular site can give the forecaster insight into what kind of atmospheric processes are at work. The direction, slope, and speed of motion following changes in the partial thickness values, represented by the red circles in the images below, indicate the model's various solutions for thermal advection. In general, increasing (decreasing) partial thickness values indicate warm (cold) air advection. A vertical (horizontal) slope to the motion indicates low level (mid level) advection only. The greater (smaller) the spacing between the red circles, the more rapid (slower) the rate of thermal advection. Using the nomogram in this manner allows the forecaster to compare the model's solutions for thermal advection in the low and mid layers.



Visualization of Atmospheric Stability

The nomogram also represents a stability diagram. The upper left (lower right) quadrant of the nomogram represents an unstable (stable) atmosphere with steep lapse rates (strong inversions) typical of many northwest (southwest) flow aloft synoptic patterns. The mid portion of the nomogram moving from the upper left to lower right quadrant is characterized by gradual lapse rates giving way to weak inversions. Between the two quadrants centered near a 1000-850 thickness value of 1300 and a 850-700 mb value of 1550 is an area that can be indicative of deep near freezing isothermal soundings capable of supporting so-called warm, heavy snow.



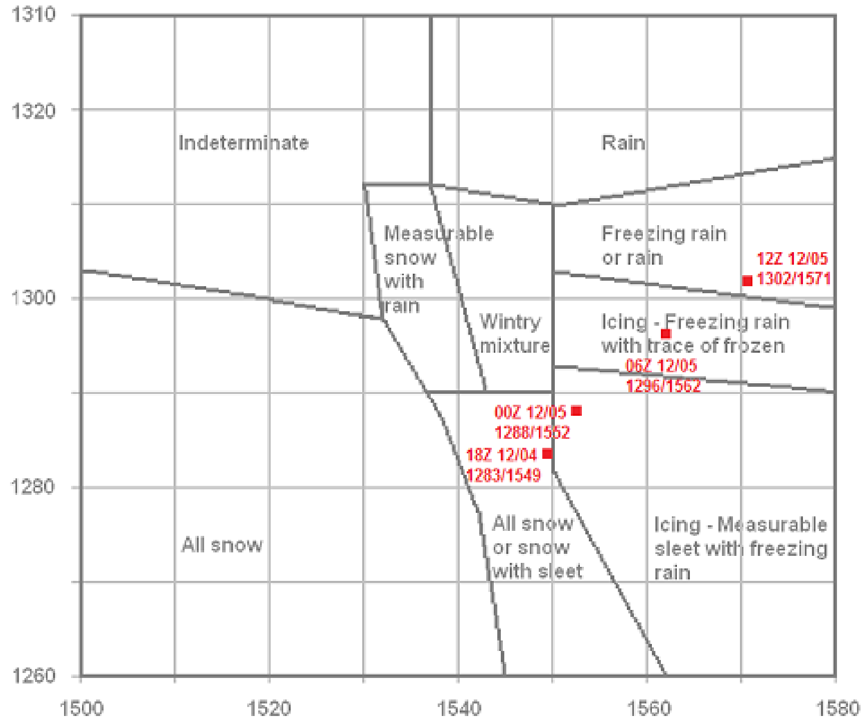
Illustrating the Interconnectivity of Winter Storm Factors

Partial thickness values, predominant 6 hour p-types and their likely vertical thermal structures are well correlated. Winter storm physical processes can be inferred by plotting changes in the 6 hourly partial thickness values. Large changes in 6 hourly partial thickness values as seen on the plotted nomogram are indicative of strong horizontal thermal advection (e.g. onset of strong cold air damming resulting in a large decrease in the 1000/850 layer). Small changes indicate weak horizontal thermal advection and may be associated with other physical processes such as melting or the release of latent heat of condensation.

Physical process signals via the nomogram can then be used to alert forecaster to pay special attention to a specific p-type forecast issue (e.g. potential for near freezing isothermal layers when horizontal thermal advection is weak.) Displaying partial thickness values in a plan view is helpful for anticipating the geographical p-type distributions associated with the various patterns of cyclogenesis and the evolution of cold air damming. The TREND technique nomogram is well suited for showing differences and trends in NWP solutions.

The plotting of 6 hour p-type events also provides the user in with climatological information. Events that lie well removed from the locus of the majority of events are climatologically infrequent. The prediction of a p-type event by the NWP models well removed from the climatology of the most cases can signal a relatively rare and significant event. Or it may indicate that the NWP models are in error with respect to their predicted partial thickness values and/or the projection of sufficient moisture and lift to generate an event.

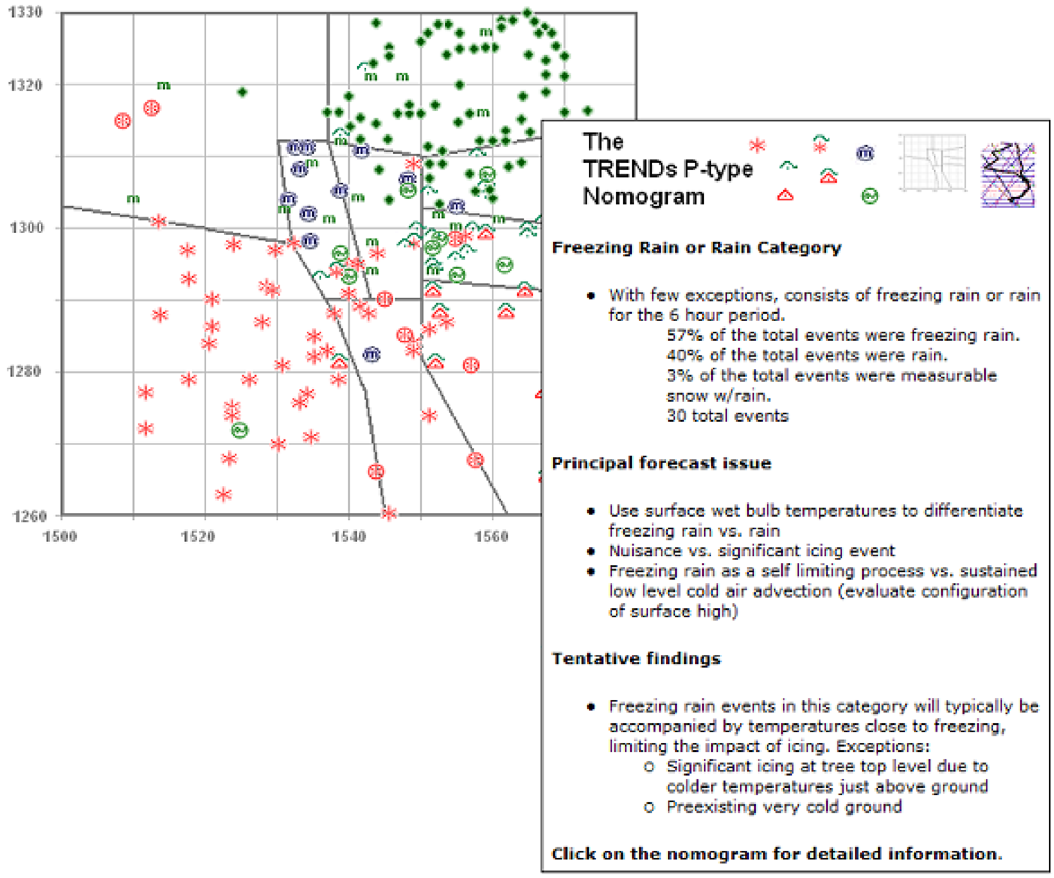
The image below shows the thickness values from the GSO soundings taken during the December 4-5, 2002 winter storm which produced between a half inch and one inch of freezing rain across portions of central North Carolina. The thickness values shown on the TREND technique's universal p-type nomogram are from 18Z on December 4, 2002, and 00Z, 06Z, and 12Z on December 5, 2002. As the nomogram predicted, precipitation at GSO began as measurable snow and sleet, followed by a changeover to measurable sleet with freezing rain, and finally to an all-freezing rain event.



Predominate P-Type TRENDs Nomogram Visualizer

The Predominate P-Type TRENDs Nomogram Visualizer was designed to allow users an easy to use, interactive reference for use with the Predominate P-Type TRENDs Nomogram. Simply move the cursor over the nomogram. As the cursor moves over different sections of the nomogram, generalized information about that portion of the nomogram is shown. Click on nomogram to display detailed information about that category of nomogram.

Click on the image below to open the Predominate P-Type TRENDs Nomogram Visualizer in a new window.



The TREND Technique is Only One Component in the Winter Storm Forecast Process

No p-type tool should be used as a sole source for resolving p-types. All p-type approaches have strengths and weaknesses. The TREND technique works best when used in conjunction with other components in the precipitation-type forecast process; such as the examination of model forecast sounding profiles to determine the dominant physical processes affecting hydrometeors.

Specific forecast issues that need to be investigated further with other precipitation type forecasting tools include:

<u>Are in-cloud temperatures cold enough to support frozen precipitation?</u>
- evaluate soundings

<u>Is there enough sustained low level cold air advection to support a wintry p-type problem?</u>
- evaluate the configuration characteristics of the supporting surface cold air high including the location and strength of the parent high, the orientation of the high's ridge axis, if cold air damming CAD), the CAD subtype and most likely CAD erosion scenario.
- determine if favorable 500 mb confluent flow for anchoring the surface high exists

<u>If cold air high is unfavorably configured to sustained low level cold air advection, consider other cold air supporting processes including:</u>
- Cooling from strong dynamics
- Cooling from melting requiring sustained heavy precipitation rates consider banding as a means to increase precipitation rate.
- Unfavorably configured surface high evolves into a favorably configured high via “hybrid” cold air damming.

<u>Is there the potential for evaporative cooling?</u>
- evaluate soundings

<u>How far south and east will wintry p-types extend?</u>
- evaluate surface wet bulb temperatures

<u>Will measurable snow predominate from a wintry mix?</u>
- evaluate low level wet bulb temperatures from soundings

<u>Is there is potential for deep near freezing isothermal layers?</u>
- evaluate sounding and check for factors favorable for their development, such as
  weak thermal advection (baggy highs, flat lows)
  northwest quadrant of mature cyclone

moderate to heavy precipitation rates & surface temperatures within several degrees of 0 C (precipitation banding)
near snow/rain boundary on the snow side

Is the ground warm enough to produce melting of snow as it falls?
- evaluate 4" subsoil temperatures

Factors Influencing P-type that TREND Does Not Directly Account For

TREND does not account for cloud microphysics issues

- If in-cloud temperatures are -10 C or colder, then cloud supports ice and frozen precipitation is possible.
- If in-cloud temperatures are warmer than -10 C, then cloud likely does not contain enough ice to support frozen precipitation.

Diabatic Processes (evaporative cooling)

- TREND indirectly accounts for evaporative cooling
- Though typically a secondary factor in determining p-types, evaporation becomes a primary factor when horizontal thermal advection is weak.
- Horizontal thermal advection is typically weak when the MSL pressure pattern is ill defined and characterized by weak baggy highs and flat surface waves.
- Use soundings to evaluate the potential for evaporative cooling. The deeper and drier the sounding, the greater the potential for cooling from evaporation.
- Many of central North Carolina's snow events begin as rain. The evaporation of rain or the sublimation of snow into dry air can cool an existing melting layer to freezing or below.
- As evaporation and sublimation is taking place, the cooling realized can be as much as 5-10 degrees F within an hour.
- In order for evaporation to be an effective cooling mechanism, there must be enough precipitation to realize the cooling potential. In the drier air masses, the first 0.10 -0.25 inches of precipitation will likely evaporate before precipitation reaches the ground.
- When there is a sub cloud dry layer, low level wet bulb temperatures are an excellent means to fine tune the p-type forecast. Refer to the forecast soundings in BUFKIT and turn on the Tw profile.
- Once the air mass is saturated, the wet bulb temperatures are no longer an effective means for anticipating p-types. Instead use the ambient temperature.
- Prior to the onset of precipitation with a sub cloud dry layer, use the surface wet bulb temperatures to determine how far south and east the p-type threat area will extend. Also, use the wet bulb temperature profile in BUUFKIT to determine if the frozen or freezing precipitation is supported at the surface.
- Polar air masses are typically very dry through deep layers.
- These air masses are often characterized by vertical temperature profiles that approach an isothermal lapse rate through a significant layer. In the absence of significant horizontal thermal advection, these air masses are predisposed to the development of near freezing isothermal layers.

Diabatic Processes (melting)

- The TREND technique indirectly accounts for melting.
- Melting is a process that can cool the temperature to freezing.
- The effectiveness of melting to lower a temperature to freezing is dependent upon the precipitation rate as well as the depth of the melting layer.
- An empirical rule of thumb states that a 100 mb melting layer requires 0.2 inches of precipitation to erode. To determine the amount of precipitation needed to erode an existing melting layer use the equation below: (Depth of melting layer) (melting layer mean wet bulb temperature) 500 where the precipitation is in inches; the layer is in mb, and the wet bulb temperature is in degree C

- The deeper the melting layer, the less cooling realized from a given precipitation rate.
- As the precipitation rates increases (decreases), melting increases (decreases) and the snow level is lowered (raised). This explains why there can be relatively frequent changes between rain and snow as the precipitation rate change.
- Relative to evaporation, melting is a less effective means for cooling. Cooling from melting is typically an order of magnitude smaller than cooling from evaporation.
- Though typically a secondary factor for determining p-types, melting becomes a more important factor when horizontal thermal advection is weak.
- In a mature cyclone, horizontal thermal advection is weak since the atmosphere is now tending toward a barotropic state. For those situations where there is a weak melting layer preventing snow from reaching the ground, the northwest quadrant of a mature cyclone can be a favorable location where melting via increased precipitation rates can lower the snow level to the ground.
- The combination of weak highs and lows at the surface (i.e., weak horizontal thermal advection) and an active jet aloft is another scenario where increased snow rates can erode a marginal melting layer. This situation results in the infrequent pattern of snow islands embedded in a cold rain.
- In the long term, precipitation rates are hard to anticipate. In the short term for updates and nowcasts, you can use the WSR 88D to monitor precipitation rates and also the reflectivity products looking for evidence of the melting "bright band".
- Locations on the cold side near the snow/rain boundary are prone to enhanced snow fall associated with an ageostropic circulation restoring thermal balance to differential heating along the snow/rain boundary.
- Isothermal near freezing layers developed in response to melting and can be identified in the soundings only when other physical processes impacting the vertical temperature profile are weak.

Latent heat of freezing

- TREND does not account for the latent heat of freezing
- In the absence of sustained cold air advection, freezing rain is a self limiting process

- As temperatures near 30 degrees F, the ratio between liquid and ice accumulation is no longer 1:1. Once temperatures are 32 F, (point at which water freezes and ice melts), there is no longer any significant ice accumulation.
- Without a source of sustained low level cold air advection, temperatures increase to 32 F as supercool (< 32F) water droplets freeze.

Warmth of ground and road surfaces
- TREND does not account for surface temperatures
- Warm soil temperatures can melt snow as it falls, limiting accumulations.
- Use 4 inch soil temperatures (refer to agricultural observational network) to determine if soil temperatures are warm enough to limit snow fall accumulations.
- Monitor DOT and Airport Authority sites providing pavement temperatures to determine if surfaces are cold enough to support the accumulation of snow and ice.
- Be alert for those situations where surface temperatures are above freezing while tree top temperatures are cold enough to support the accumulation of ice.
- Recall that freezing rain is a "self limiting" process. If there is no source for sustained cold air advection, then the latent heat of freezing associated with freezing rain will gradually increase temperatures to the freezing. Once temperatures reach 32 degrees, ice no longer accumulates.

Atypical means for clouds to become cold enough to support ice
- Seeder – Feeder…Ice supporting cold cloud (-10 C or colder) moves over lower cloud composed of super cool droplets (warmer -10 C). Ice falls into and seeds lower cloud. Lower cloud must be within 5,000 ft of upper cloud or ice sublimates. Capable of supporting frozen precipitation for short periods of time.
- Elevated Convection…If elevated convection accompanies a warm cloud precipitation event, then convection seeds ice into the cloud. Capable of producing a "surprise" period of thunder snow or thunder sleet.
- Sub freezing surface based cold layer has a cold nose colder than -10 C beneath a warm melting layer. This cold nose can introduce ice into a cloud making snow and/or sleet possible.
- Vertical Motion…..A passing disturbance moves across an area of otherwise warm clouds consisting of super cool droplets. The enhanced vertical velocities lift and cool the cloud to temperatures cold enough to introduce ice. Process is capable of producing frozen precipitation from an otherwise non frozen event.

Limitations

- TREND does not include trace precipitation events or nuisance sleet events in its data base. Nuisance sleet events are brief occurrences of sleet with no significant impact as surface temperatures are well above freezing. Such events are typically due to evaporative cooling occurring in dry layers aloft.

- TREND will under forecast freezing rain falling into a very shallow cold and dry arctic air mass. Evaluate the low level wet bulb temperatures when presented with the potential for freezing rain associated with a shallow cold and dry air mass.

- TREND does not account for cloud microphysics issues. Soundings must always be evaluated to determine if in-cloud temperatures are cold enough to contain sufficient ice for supporting frozen precipitation.

Real Time Predominant P-type Nomogram Plots and Partial Thickness Data

Text and Graphical Plots of Nomogram and Partial Thickness Data for Fixed Locations

Observed thickness values from KGSO, KRNK, and KMHX Text product
Observed thickness values plotted on the Predominate P-Type TRENDs Nomogram GSO | RNK | MHX

Current GSO Observed

Current GSO RUC Forecast

Current GSO NAM Forecast

Current GSO GFS Forecast

RUC Forecast thickness values plotted on the Predominate P-Type TRENDs Nomogram
GSO | RDU | FAY | VUJ | HNZ | RZZ | RWI | SOP | All RUC locations
CAE | GSP | CLT | AVL | HKY | DAN | ROA | RIC | FFC

NAM Forecast thickness values plotted on the Predominate P-Type TRENDs Nomogram
GSO | RDU | FAY | VUJ | HNZ | RZZ | RWI | SOP | All NAM-WRF locations
CAE | GSP | CLT | AVL | HKY | DAN | ROA | RIC | FFC

GFS Forecast thickness values plotted on the Predominate P-Type TRENDs Nomogram
GSO | RDU | FAY | VUJ | HNZ | RZZ | RWI | SOP | All GFS locations
CAE | GSP | CLT | AVL | HKY | DAN | ROA | RIC | FFC

Two Panel Printer Friendly NAM/GFS Forecast thickness values plotted on the Predominate P-Type TRENDs Nomogram
GSO | RDU | FAY | VUJ | HNZ | RZZ | RWI | SOP |
CAE | GSP | CLT | AVL | HKY | DAN | ROA | RIC | FFC

Plan View Analysis and Forecast Partial Thickness Charts

Courtesy of Dr. Michael Brennan and the N.C. State Meteorological Analysis and Prediction Laboratory

A large inventory of partial thickness charts including RUC analyses as well as NAM and GFS model forecasts across the Carolinas and the eastern CONUS is available from the Partial Thickness Charts Web Page.

RUC Analysis
The latest RUC analysis of 1000-850 mb thickness (blue) and 850-700 mb thickness (red) with observed present weather and wet-bulb temperature in Fahrenheit (green) is shown below. **(RUC analyses from previous hours available at the Partial Thickness Charts Web Page.)**

Current RUC Analysis

Click here to enlarge image

NAM and GFS Forecasts
The 12 hour forecasts from the NAM and GFS of the 1000-850 mb thickness (blue) and 850-700 mb thickness (red) with the precipitation forecast for the previous 6-hour period from the model (color shading) ending at the time displayed is shown below. **(Additional forecast**

times and a larger domain are available from the Partial Thickness Charts Web Page.)

24 Hour NAM Forecast

Click here to enlarge image

24 Hour GFS Forecast

Click here to enlarge image

Current Bufkit Data for the Carolina's and Mid Atlantic for use with the Predominant P-type Nomogram

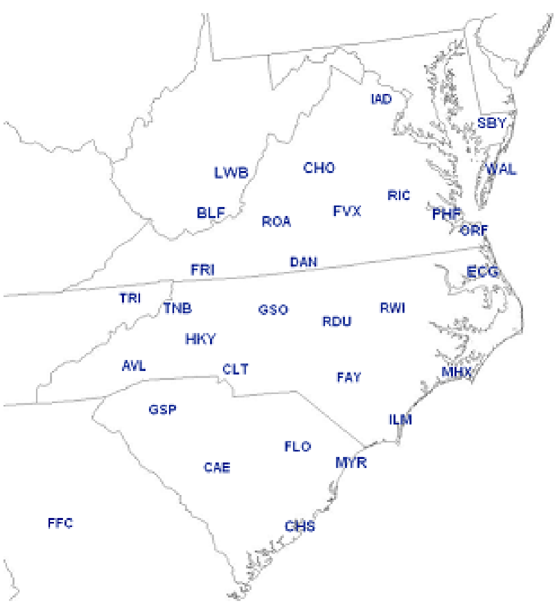
Bufkit data for the Carolinas and the surrounding region is provided as a service to our users and collaborative partners.

BUFKIT is a forecast profile visualization and analysis tool kit developed by the staff at the National Weather Service (NWS) office in Buffalo and the Warning Decision Training Branch (WDTB) in Norman, OK. BUFKIT is used in the public, private, and educational meteorological sectors in both the US and Canada. BUFKIT is available to anyone who is interested in the analysis of forecast hourly profiles. **Bufkit Software and Download Information**

The map below shows the locations where Bufkit is available from the NWS Raleigh.

A list of current files - sorted by date/time is available.

List of current files - sorted by name is available.



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Keeter, K. K., and J. W. Cline, 1991: The objective use of observed and forecast thickness values to predict precipitation type in North Carolina. *Wea. Forecasting*, **6**, 456-469.

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For questions regarding the web site, please contact *Jonathan Blaes*.