

# DEVELOPMENT OF A FORECAST EQUATION TO PREDICT THE SEVERITY OF THUNDERSTORM EVENTS IN NEW YORK STATE

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## Abstract

*Forecasters across the country routinely make subjective assessments of convective potential for their forecast area based on the values of various atmospheric parameters and indices. If convection does form, forecasters must decide whether it will be severe or non severe; and, will the main threat from severe thunderstorms be large hail, strong straight line winds, tornadoes, or all three. The values which trigger certain decisions may vary from person to person depending on a forecaster's location and experience. The results may not be consistent. This paper describes the development of an equation that would provide objective statistical guidance for determining convective potential in New York State. Although the equation itself can only be applied in a narrow geographical area, the method used to develop this equation can be applied elsewhere.*

## 1. Introduction

Issuing tornado and severe thunderstorm warnings is one of the primary missions of the National Weather Service (NWS). The identification of the meteorological conditions that produce tornadoes and severe thunderstorms is the initial step in the warning process. LaPenta and Maglaras (1993) began a multi-step process to recognize the general atmospheric conditions that produce thunderstorm events of various intensities by examining the atmospheric conditions on 24 days that produced tornadoes in New York State from 1989 to 1992. In the second step, LaPenta (1995) examined 111 days with severe weather in New York State, 37 of which produced tornadoes. In that study an analysis was carried out to differentiate the general atmospheric conditions that produce tornadic thunderstorm events, major severe thunderstorm events, and minor severe thunderstorm events. The data on the tornadic and severe thunderstorm events were obtained from *Storm Data* (U.S. Department of Commerce 1989-1995).

In this study, a statistical analysis was carried out to develop an equation to make conditional forecasts of the severity of a thunderstorm event on a day when thunderstorms occur. The purpose of this equation was to provide objective statistical guidance to forecasters, using many of the methods and tools forecasters had been using for years to make subjective assessments of the potential for severe convection. The equation's objective output would be based on the forecaster's assessment of the general atmospheric conditions expected at the time of the event. The analysis that was performed used thun-

derstorm data from LaPenta (1995) as part of the developmental sample. These data included 37 days with tornadic thunderstorm events, 37 days with major severe thunderstorm events, and 37 days with minor severe thunderstorm events. In order to include a sample of non-severe thunderstorm days, that data set was expanded to include an additional 37 days where thunderstorms occurred, but no severe weather was reported.

## 2. Methodology

For the developmental sample, a day was classified as tornadic if at least one tornado occurred in New York State. A day was considered to be severe if severe thunderstorms were observed in New York State, and tornadoes were not observed anywhere in the northeastern United States (New England, New York, New Jersey, and Pennsylvania). If severe thunderstorms without tornadoes were observed in New York, but tornadoes were observed elsewhere in the northeastern United States, that day was not included in the study. This was done to prevent a day from being classified as non-tornadic, when tornadoes occurred in areas adjacent to New York. The severe thunderstorm events were divided into two equal groups. Major severe weather events were categorized as those days that produced 10 or more reports of severe weather in the northeastern United States. Minor severe weather events were categorized as those days that produced less than 10 reports of severe weather. Finally, non-severe weather events were defined as those days with thunderstorms in which severe weather was not reported anywhere in the northeastern United States.

For each of the 148 days in the study, a vertical atmospheric sounding was constructed to approximate the synoptic scale atmospheric conditions at the time of the event. Actual atmospheric soundings from across the northeastern United States were examined, and the sounding that was considered to be most representative of the airmass over the location where tornadoes, severe or non-severe thunderstorms occurred was selected. This sounding was then modified using the Skew-T Hodograph Analysis and Research Program (SHARP) Workstation (Hart and Korotky 1991) for observed surface temperature, dewpoint temperature, and wind from a surface observation site near the location of the thunderstorms. On a few occasions, additional subjective modifications were made if significant thermal advection aloft was evident, or changes to the vertical wind profile were warranted due to wind speed and/or direction changes aloft. The storm motion was determined primarily from radar observations. However, on the few occa-

sions when radar data were not available, the storm motion was estimated or obtained from the text of NWS warnings and statements.

The limited spatial and temporal sampling by the NWS radiosonde network and the highly variable nature of the atmosphere make it difficult to create soundings that accurately represent the state of the atmosphere at the time of a particular event. If temporal and spatial restrictions are too strict, it will be difficult to come up with a statistically significant number of cases (Brooks et al. 1994). The goal of this study was to evaluate the general conditions that produce non-severe, severe and tornadic thunderstorms, using information that is routinely available to forecasters. In order to maximize the size of the data set, strict temporal and spatial constraints were not placed on the use of observed soundings. Atmospheric conditions at the time of an event, or series of events, were approximated to the best degree allowed given data limitations. However, some events were eliminated, if the lack of observed data made analysis of the event unrealistic. Brooks et al. (1994) discuss in detail the use of, and limitations of, such an approach.

The developmental data were stratified in the following manner. Days with tornadic events were assigned a value of one. Days with major severe weather events were assigned a value of two. Days with minor severe weather events were assigned a value of three, and days with non-severe weather events were given a value of four.

The Statistical Correlation and REgression program (SCORE) (Wooldridge and Burrus 1995) was used to perform a regression analysis. Based on the findings from LaPenta (1995), only nine variables and indices were offered as predictors to the SCORE program. These predictors were the sweat index, convective available potential energy (CAPE), bulk Richardson number, energy-helicity index (EHI) (Hart and Korotky 1991), storm speed (SPD), storm relative helicity (s-rH) (Davies-Jones et al. 1990), 0-6 km mean wind speed, 0-3 km storm-relative inflow, and the maximum wind speed in the sounding (MWND).

From the 148 thunderstorm days, 26 days were randomly selected to be used as an independent data sample. Hence, these cases were excluded, and the remaining 122 days were used as the dependent data sample for the regression analysis. The independent sample included six days with tornadic events, seven days with major severe weather events, six days with minor severe weather events, and seven days with non-severe events. The equation was also tested operationally during the 1995 spring season. These operational tests will also be examined.

### 3. Discussion of the Perfect Prog Approach

The method of developing a regression equation from a sample of observed data, then applying this equation using output from a numerical model in order to make forecasts of a particular variable, is known as the perfect prog approach (Klein and Lewis 1970). One of the benefits of the perfect prog approach is that the equation can be applied using output from any numerical model, or it can be applied using data from an actual RAOB. The biggest limitation to the perfect prog approach is that it does not

account for error or bias in the numerical model because the equation was not developed using model data. For example, if a numerical model typically overforecasts the strength of the low-level wind flow at a given location, or the model overforecasts instability at longer range projections, then these biases will not be statistically accounted for by the regression equation. Thus, systematic errors of the model will also become systematic errors in any forecasts from the equation. However, if a forecaster is aware of model errors or biases for their area, he or she can subjectively adjust the model forecast sounding using the SHARP workstation, thereby reducing the impact of this major limitation to the perfect prog approach.

### 4. Regression Analysis Results

Table 1 shows the correlation of the nine predictors used with the total sample of 148 thunderstorm days. The s-rH was the most highly correlated, while the EHI and CAPE were second and third, respectively. The MWND in the sounding was the least correlated.

**Table 1. Correlation of the nine predictors with the predict-and data sample.**

STORM-RELATIVE HELICITY (s-rH)	-0.6051
ENERGY-HELICITY INDEX (EHI)	-0.5688
CONVECTIVE AVAILABLE POTENTIAL ENERGY (CAPE)	-0.5341
SWEAT INDEX	-0.4608
STORM SPEED (SPD)	-0.4577
0-6 km MEAN WIND	-0.4423
0-3 km RELATIVE STORM INFLOW	-0.3833
BULK RICHARDSON NUMBER	+0.1694
MAX WIND IN THE SOUNDING (MWND)	-0.1426

Based on numerous applications of the SCORE program, it was determined that the best possible equation (one which maximized the number of correct forecasts on independent data) was a five-term equation, which included the s-rH, CAPE, EHI, storm speed, and MWND as the predictors. Even though the MWND was the least correlated predictor, it was included in the equation because it was the only predictor which provided information about wind flow in the middle and upper troposphere. Flow at these levels can be important in determining thunderstorm intensity. For example, Johns and Doswell (1992) note that bow echoes which can produce damaging winds at the surface are associated with mid-level winds that are moderate or strong. Also, Davies-Jones (1986) lists one of the conditions that favors tornadoes as moderate to strong winds that veer with height, with large values in a narrow horizontal band (jet stream) at altitudes above 6 km. The equation is shown in Table 2. The correlation of this equation to the dependent sample was 64.4 percent.

The equation was evaluated on the test sample of 26 cases. As shown in Table 2, if the forecast was greater than or equal to 3.5, then a forecast of a non-severe weather day was made. If the forecast was greater than or equal to 2.5 but less than 3.5, then a minor severe weather event was forecast for that day. If the forecast

**Table 2. The forecast equation to predict the severity of thunderstorm events, and the associated threshold values.**

SEVERITY (S) =	4.943709
+	(-.000777 x CAPE)
+	(-.004005 x MWND)
+	(+.181217 x EHI)
+	(-.026867 x SPD)
+	(-.006479 x s-rH)
If S is $\geq 3.5$	... forecast a non-severe event
If S is $\geq 2.5$ but $< 3.5$	... forecast a minor severe event
If S is $\geq 1.5$ but $< 2.5$	... forecast a major severe event
If S is $< 1.5$	... forecast a tornadic event

was greater than or equal to 1.5 but less than 2.5, then a major severe weather event was forecast. Finally, if the forecast was less than 1.5, then a tornadic event was forecast. The test results showed that the equation was able to correctly forecast the type of thunderstorm event 16 out of 26 times. Of the 10 incorrect forecasts, nine were incorrect by only one category.

An analysis of these independent test results was done in order to determine if the forecasts were better than random chance. The Heidke skill score for these forecasts was 0.48 (random chance would produce a score of zero, while a perfect score would be one). In addition, we used the Chi-Square distribution to test the results for significance, and it showed that the results were significant at the 95 percent confidence level.

### 5. Operational Use of the Forecast Equation

For several years, forecasters have used the SHARP workstation to modify actual atmospheric soundings in order to make subjective assessments of convective potential. First, based on their assessment of the general atmospheric conditions expected at a given time, they would determine the likelihood of thunderstorms forming. Second, they would determine the potential for any thunderstorms that did form to become severe. More recently, output from numerical model forecast soundings has become available to field forecasters. Using the SHARP workstation, forecasters can now analyze model forecast soundings and make subjective assessments of the potential for convection, and they can do so as much as 48 hours in advance. The forecaster can accept the model sounding or make modifications to it for model biases or local effects. Operationally, it is generally more useful to use SHARP derived data from model forecast soundings as input to the equation. Model soundings provide objective assessment of temperature, moisture and wind profiles valid for the exact time the forecaster is interested in. Observed RAOBS can be used to provide input into the equation. However, since observed RAOBS are typically used to forecast potential severe weather 6 to 12 hours after the RAOB observation time, they may require extensive subjective modification.

The thunderstorm equation was developed using a sample of modified soundings, constructed to approximate the general synoptic scale atmospheric conditions

at the time of the event. Output from the SHARP workstation is used as input to the equation in order to make an objective conditional forecast of severe weather potential. The equation provides guidance for the second step in the process of determining overall convective potential, namely, will any thunderstorms that do form be non-severe, severe or tornadic.

### 6. Operational Tests of the Forecast Equation

The first operational and independent test of the thunderstorm severity equation was performed during the midnight shift of 4 April 1995. The National Centers for Environmental Prediction (NCEP) numerical models predicted a strong cold front would move across eastern New York and western New England that afternoon. The cold front was associated with a very intense surface low that was forecast to move down the Saint Lawrence Valley. Behind the cold front, surface temperatures were forecast by the NCEP numerical model statistical guidance to fall from the 50s (°F) into the teens (°F) by early evening. Ahead of the cold front a strong pressure gradient existed, but the southerly wind was not expected to reach high wind warning criteria. The strong southerly flow did transport unseasonably warm and humid air into the region, and it was expected that this relatively warm and humid air mass would produce some weak instability (CAPE values from numerical model forecast soundings were between 200 and 300 J Kg<sup>-1</sup>). However, the strong winds and shear associated with this intense storm and cold front were sufficient to cause the forecasters on duty to anticipate the development of severe thunderstorms during the afternoon.

Using the SHARP workstation, we examined the 18-h NCEP nested-grid model (NGM) sounding for Albany, NY (ALB), and the 20-h NGM model sounding for Poughkeepsie, NY (POU). These soundings were from the 0000 UTC 4 April 1995 NGM model run. The model soundings were modified by inserting surface temperature values in the mid or upper 50s (°F) and surface dewpoints in the lower 50s (°F). Table 3 shows the SHARP derived values of the five predictors used in the equation

**Table 3. Case study from 4 April 1995.** The first operational test of the thunderstorm severity equation. Data from the 18-h NGM model sounding from the 0000 UTC 4 April 1995 run was examined by using the SHARP program for the locations of Albany (ALB) and Poughkeepsie (POU), NY. The calculations of S for ALB and POU are also included.

ALB	POU
CAPE - 297 J Kg <sup>-1</sup>	CAPE - 218 J Kg <sup>-1</sup>
MWND - 95 kt	MWND - 95 kt
EHI - .22	EHI - .22
SPD - 42 kt	SPD - 42 kt
s-rH - 120 m <sup>2</sup> s <sup>-2</sup>	s-rH - 184 m <sup>2</sup> s <sup>-2</sup>
<b>CALCULATIONS FOR S:</b>	
CNST CAPE MWND EHI SPD s-rH	
ALB = 4.94 + (-.23) + (-.39) + (.04) + (-1.13) + (-.78)	= 2.45
POU = 4.94 + (-.17) + (-.42) + (.04) + (-1.13) + (-1.19)	= 2.07

for both ALB and POU. CAPE values were between 200 and 300 J Kg<sup>-1</sup>, the MWND was around 100 kt, the EHI was 0.22 at both ALB and POU, the storm speed was 42 kt at both ALB and POU, and the s-rH was around 150 m<sup>2</sup> s<sup>-2</sup>. Table 3 also shows the contribution of each term in the equation to the final forecast value. For ALB the forecast was 2.45 (a borderline major severe event), at POU the forecast was 2.07 (a major severe event).

A look at each term in the equation reveals that the storm speed and the s-rH were the most important factors in the forecast for a major severe weather event on this day. Recall, this forecast is conditional on the occurrence of thunderstorms; however, the likelihood of thunderstorms on this day was considerably less than 100 percent.

The forecast of surface dewpoints in the low 50s (°F) verified, but the surface temperature reached the low and mid 60s (°F) near POU. Thunderstorms formed that day from ALB south. These thunderstorms produced scattered reports of severe weather in the ALB area, but from central Pennsylvania, to the southern Catskill Mountains, northern New Jersey, Long Island, the mid-Hudson Valley (POU area), and into southern New England, there were widespread reports of wind damage. The location of each severe weather event is plotted in Fig. 1.

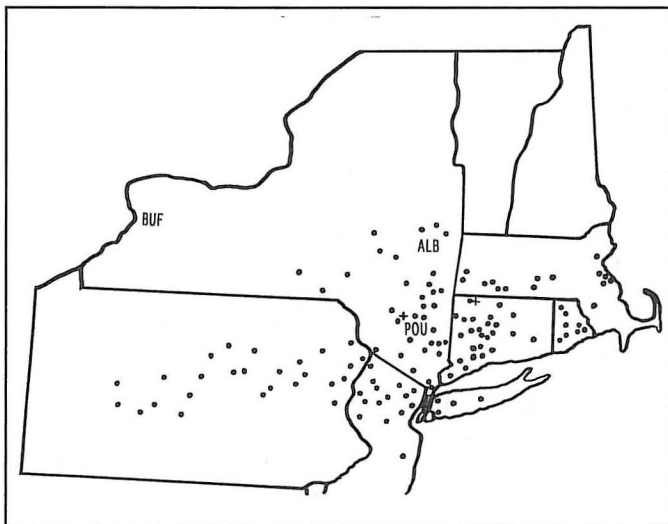


Fig. 1. Location of each severe weather event reported in the Northeast United States on 4 April 1995. Dots indicate wind reports. Crosses indicate hail reports. Also shown are the locations of Albany (ALB), Poughkeepsie (POU), and Buffalo (BUF), New York.

The conditional nature of the thunderstorm severity equation was demonstrated by the case of 19 April 1995. This event was very similar to the event of 4 April 1995. A strong cold front was once again forecast to move across eastern New York and western New England during the afternoon with an intense surface low moving northeast, down the Saint Lawrence Valley. Surface temperatures were expected to rise into the mid 60s (°F) and dewpoints into the lower 50s (°F).

The SHARP workstation was used to examine the 20-h NGM model soundings for both ALB and POU. These soundings were from the 0000 UTC 19 April 1995, NGM

model run. Table 4 shows the SHARP derived values of the five predictors for ALB and POU, and it also indicates the contribution of each term in the equation to the final forecast. Actual values of the CAPE, MWND, EHI and storm speed, and their contribution to the final forecast of thunderstorm intensity for this event, were similar to the 4 April 1995, event. The only significant difference between this 19 April event and the 4 April event was the s-rH. For this event, the actual value of the s-rH (over 300 m<sup>2</sup> s<sup>-2</sup>), and its contribution to the final forecast of thunderstorm intensity (around 2.00), were about twice as high as for the 4 April event. For ALB the equation forecast 1.34, and 1.43 at POU, both marginal forecasts for tornadic events. The s-rH was the main factor in the forecast of a tornadic event, and its contribution to the final forecast value was more than all the other predictors combined.

Table 4. Case study from 19 April 1995. The same as Table 3 except data from the 20-h NGM model sounding from the 0000 UTC 19 April 1995 run.

ALB	POU
CAPE - 153 J Kg <sup>-1</sup>	CAPE - 302 J Kg <sup>-1</sup>
MWND - 90 kt	MWND - 90 kt
EHI - .26	EHI - .60
SPD - 40 kt	SPD - 40 kt
s-rH - 324 m <sup>2</sup> s <sup>-2</sup>	s-rH - 302 m <sup>2</sup> s <sup>-2</sup>
CALCULATIONS FOR S:	
CNST CAPE MWND EHI SPD s-rH	
ALB = 4.94 + (-.12) + (-.36) + (+.05) + (-1.07) + (-2.10) = 1.34	
POU = 4.94 + (-.23) + (-.36) + (+.11) + (-1.07) + (-1.96) = 1.43	

The conditional nature of the forecast means thunderstorms must occur for the equation to have applicability. Numbers produced by the equation have no meaning if thunderstorms do not occur. On this day, there was a possibility of convection due to the weak instability forecast. However, thunderstorms were not observed. The surface temperature and dewpoint forecasts verified just west of ALB and POU, but the Hudson Valley remained "socked in" with low clouds and light rain. Showers formed to the west of ALB and POU. The NWS weather surveillance radar (WSR-88D) indicated that the 30-40 dBZ cells which formed, appeared to shear apart and dissipate. The lightning detection display at the NWS office in Albany, and spotter reports, indicated that there were no lightning strikes. The radar observations and limited instability suggest that the weak updrafts could not be sustained in the strong environmental wind field.

The 19 April 1995 event is an example of what happens when instability is marginal and the wind field and shear are too strong. Despite nearly identical values of CAPE for both events, the higher s-rH values with the 19 April 1995 event made the convective environment less favorable for thunderstorm development, in agreement with Johns et al. (1993) and Johns and Doswell (1992). This case indicates how the thunderstorm severity equation might forecast a tornadic thunderstorm event, even when the chance of getting a thunderstorm is very low or non-existent.

On 10 May 1995, the equation was tested for an area outside the forecast area of responsibility for the NWS office in Albany. A warm and relatively humid air mass moved into western New York on the afternoon of 10 May. The airmass was forecast to become moderately unstable during the afternoon. The SHARP workstation was used to examine the 9-h NGM model sounding for Buffalo, NY (BUF). This model sounding was from the 1200 UTC 10 May 1995, NGM model run. A surface temperature of 80°F and a surface dewpoint of 58°F were input to the SHARP program (observed surface temperature and dewpoint readings were already near these values when the equation was tested). Table 5 shows the SHARP derived values for four of the five predictors used in the equation. Since echoes had already been detected by the BUF, WSR-74C radar, the storm speed was taken directly from the BUF radar reports. Table 5 also shows the contribution of each term to the final forecast value. The forecast for BUF was 2.37 (a major severe event). The high CAPE was the main factor in the forecast of a widespread severe event. The contribution of the CAPE to the final forecast value was more than all the other predictors combined.

**Table 5. Case study from 10 May 1995.** The first operational test of the thunderstorm severity equation outside of the immediate NWSFO ALB forecast area. Data from the 9-h NGM model sounding from the 1200 UTC 10 May 1995 run was examined using the SHARP program for the location of Buffalo (BUF), NY. The calculation of S for BUF is also included.

**BUF**

CAPE - 1895 J Kg<sup>-1</sup>

MWND - 40 kt

EHI - .57

SPD - 30 kt (FROM BUF RADAR REPORT)

s-rH - 37 m<sup>2</sup> s<sup>-2</sup>

**CALCULATION FOR S:**

	CNST	CAPE	MWND	EHI	SPD	s-rH
BUF =	4.94 +	(-1.47) +	(-.16) +	(+.10) +	(-.80) +	(-.24) = 2.37

Severe thunderstorms occurred in western New York that afternoon and evening. A few severe weather events were reported in or near the BUF county warning area. The severe weather was more widespread in western Pennsylvania. The location and type of each severe weather event are plotted in Fig. 2. Further studies will be needed to determine if the equation can be applied to areas in the northeast U. S., outside of New York. However, logic suggests that there should be applicability in areas immediately adjacent to New York, but no supporting data has been provided to determine how far across the state boundary this equation can be reliably applied.

At around 2231 UTC 29 May 1995, (Memorial Day) a supercell spawned an F2 tornado over Columbia County in eastern New York. It dissipated after being on the ground for about 25 minutes. Shortly after that the same supercell produced an F3 tornado in southern Berkshire County in western Massachusetts. This tornado was on the ground for 25 minutes and killed three people. In



**Fig. 2.** Same as Fig. 1, except for 10 May 1995.

addition to these tornadoes, there was widespread severe weather damage across much of southeast New York and southern New England.

A narrow wedge of warm and very humid air was forecast to move northeast into southeast New York and southern New England during the afternoon of 29 May 1995. This warm and very humid air mass was ahead of a strong cold front and upper-level trough that were forecast to move across the region late in the afternoon and during the evening. Forty-eight hours in advance of the frontal passage, the SHARP workstation was used to examine the 48-h NGM model sounding for ALB. This model sounding was from the 0000 UTC, 28 May 1995, NGM model run. A surface temperature and dewpoint of 73°F and 68°F, respectively, were input to the SHARP program.

Table 6 shows the SHARP derived values of the five predictors for ALB, and it also shows the contribution of each term in the equation to the final forecast value. The CAPE of 3565 J Kg<sup>-1</sup> was by far the most important factor in the forecast, but the contributions from the storm speed and s-rH were also very high. The final forecast value was 0.28 (a strong indication that the general atmospheric conditions would be favorable for the development of a tornadic event.)

**Table 6. Case study from 29 May 1995.** A case of a strong tornado event. Data from the 48-h NGM model sounding from the 0000 UTC 28 May 1995 run was examined using the SHARP program for ALB. The calculation of S for ALB is also included.

ALB

CAPE - 3565 J Kg<sup>-1</sup>

MWND - 60 kt

EHI - 4.14

SPD - 40 kt

s-rH - 205 m<sup>2</sup> s<sup>-2</sup>

CALCULATION FOR S:

CNST

CAPE

MWND

EHI

SPD

s-rH

ALB =

4.94 +

(-2.77) +

(-.24) +

(+.75) +

(-1.07) +

(-1.33) = 0.28

As discussed in section three, theoretically, the perfect prog approach is limited by its inability to account for model error and bias, and, generally, its use should be limited to 24 hours. However, operationally, arrangements for extra staffing, especially during a major holiday weekend, sometimes require the forecaster to assess the potential for severe weather beyond one day. If a forecaster is aware of the limitations to the perfect prog approach and can subjectively adjust the model forecast sounding for any model errors or bias, then the output from the equation can still be useful for determining if the general synoptic scale conditions will be favorable for the development of severe convection.

## 7. Discussion

Based on forecaster comments, the thunderstorm severity equation provided useful guidance to the forecasters at NWSFO ALB during the 1995 convective season. It can perform well in cool season strong wind field/low instability cases, and also in warm season weak wind field/high instability cases. When the equation was used for cool season convective events, the biggest concern usually was whether or not **ANY** convection would form. For those events when thunderstorms **DID** form, the severity of those events was usually forecast well.

In the warm season, during periods of moderate or high instability, weak wind fields and short-lived air-mass thunderstorms, the forecast equation would typically forecast a minor severe event. However, the forecast for such weather regimes would indicate a major severe event with the presence of a moderate wind field.

In LaPenta and Maglaras (1993), the warm season in New York State was defined as the period from June through early September. The cool season was defined as the rest of the year. Using the same definitions here, the four case studies discussed in this paper would be considered cool season events. Thunderstorms did form in three of the four case studies, and the equation correctly forecast the intensity three out of three times, but one of the events was a borderline event with exactly 10 reports of severe weather. In the test sample there was a total of six cool season events, and the intensity was correctly forecast five times. The remaining twenty events were warm season cases, and eleven of these were correctly forecast. Of the nine incorrect forecasts, eight were incorrect by only one category. Five of the nine incorrect warm season forecasts were the result of tornadic events being forecast as major severe events.

The conditional nature of the equation necessitates a two step approach in its application. First, the forecaster must assess the likelihood that deep convection will develop. The output from this equation is not intended to provide any guidance with this forecast problem. Thus, if thunderstorms are not expected or do not form, the equation's output has no meaning. If analyses of observed data and numerical model output indicate thunderstorms are possible, or thunderstorms are already occurring, then the equation's output can be used as guidance in the second step of the forecast

process, which is to assess the possible severity of the thunderstorms. The first step, determining whether convection will occur and whether or not the equation's output will have any meaning, can be especially difficult in the cool season when wind fields are typically strong, but instability is often absent or marginal. For example, a strong cold front during the cool season will frequently be associated with strong wind fields and significant wind shear through the lower troposphere. Evaluation of the equation may result in a forecast of a major severe or tornadic event. In such cases widespread stratiform clouds and rain might be enough to inhibit any convection from forming; or the strong wind fields and associated low-level wind shear may be enough to overcome any weak instability and not allow air parcels to rise without being sheared apart. In some cases, the combination of weak instability and strong wind fields may be balanced just right and lead to the formation of tornadic thunderstorms, Johns et al. (1993), Johns and Doswell (1992). However, the forecast equation can still be useful for such events because it can alert and focus the attention of the forecaster to the potential for any convection that **DOES** form, to cause damage or even tornadoes.

When using the equation, either model forecast soundings or actual RAOB data can be used as input. Generally, the model forecast soundings are easier and more appropriate to use because the above ground level temperature, moisture and wind profiles are already valid for the exact time of forecast interest.

Based on personal experience, we have found that the storm motion calculated by SHARP is usually to the right of the observed storm motion, and the speed is slower than that observed. The forecast motion to the right of the actual motion results in s-rH values that are too high. This can lead to the forecast of a more significant thunderstorm event than actually occurs. For the purpose of using this equation, it is usually best to modify the SHARP output by using a storm motion that is 10 to 15 degrees to the right of the 0-6 km mean wind and use the 0-6 km wind speed.

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Kenneth LaPenta has been a Lead Forecaster at the NWS Forecast Office at Albany, New York since 1986. Prior to joining the NWS in 1975 he worked at the National Hurricane Research Laboratory in Coral Gables, Florida and with Stone and Webster Engineering Corporation in Boston, Massachusetts. He earned a B.S. in Meteorology in 1971, and a M.S. in Meteorology in 1973 from Saint Louis University. His primary research interests are the analysis and forecasting of severe storms in the northeast U.S.

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