JP1.10 PROBABILISTIC FORECASTS OF SEVERE LOCAL STORMS IN THE 0-3 HOUR TIMEFRAME FROM AN ADVECTIVE-STATISTICAL TECHNIQUE

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1. INTRODUCTION

The United States' National Weather Service (NWS) has routinely issued forecasts for severe local storm phenomena since the late 1950's. These forecasts include convective outlooks for 24-h periods, severe weather watches covering several thousand km^2 for the 1-6 h timeframe, and local warnings for specific storms covering areas of ~1500 km^2 for up to one hour.

Automated statistical guidance for for the preparation of these forecasts exists in several forms. Centrally-produced Model Output Statistics (MOS) forecasts for 6-60 h serve as guidance for convective outlooks (Hughes 2001), and probabilistic nowcasts based on automated interpretation of local radar data serve as monitoring and guidance products for short-range warnings (see, for example, Stumpf et al. 1998; Kitzmiller and Breidenbach 1995).

Though centralized guidance for the 2-6 h period, based on manually-digitized radar data, surface observations, and output of the Limited-Area Fine Mesh (LFM) model was routinely produced from 1978 through 1996 (Charba 1979), issuance was suspended with the retirement of the LFM model. We have developed a new short-range guidance system that automatically produces forecasts of severe storm probability, conditional on the occurrence of thunderstorms, based on radar reflectivity, lightning, surface observations, and numerical model output. It is an extension of the operational advective-statistical (ADSTAT) forecast system that currently produces 0-3 h probabilistic forecasts of rainfall amount and lightning (Kitzmiller et al. 2001). The forecasting system itself is intended to provide automated monitoring of remote-sensor observations, in situ observations, and NWP model output for the development of threatening convective weather.

2. FORECAST PRODUCTS

The four ADSTAT severe weather products are the probabilities of:

- hail $\geq$ 2 cm diameter at the surface;
- wind gusts $\geq$ 90 km hr^{-1}, or wind damage to structures or large trees;
- tornadoes,
- any combination of these three phenomena, which we refer to hereafter as "general severe weather."

The probabilities are conditional on the occurrence of thunderstorms, rather than absolute values. This convention permits users to assess the potential for severe weather in situations where thunderstorms are rare but any storms that can develop are likely to be severe. The absolute event probability can be derived as the product of the conditional probability and the lightning probability.

The forecasts are valid within boxes of a map grid with a mesh length of ~40 km covering the conterminous United States, hereafter referred to as the forecast grid. Forecasts are issued twice per hour, at 00:15 and 00:45, and cover the 3-h periods beginning at 00:30 and 00:00, respectively. They are currently produced on a workstation computer within NWS headquarters in less than one minute of real time.

3. DEVELOPMENTAL DATA

The statistical development sample described here was created from data during the period 1996-2000. Because conditional severe storm climatology exhibits significant diurnal, seasonal, and geographic dependence, the sample was stratified in several ways. To account for diurnal effects, eight "initial times" were considered, starting at 0230 UTC and continuing at 3-hour intervals through 2330 UTC; the corresponding valid periods were 0300-0600 UTC through 0000-0300 UTC. In practice, the equations derived in this manner can be applied at any time near the nominal initial time. The development sample was further stratified into warm and cool seasons (April-September and October-March, respectively), and into nine geographic regions.

Historic radar reflectivity analyses were derived from a 2-km national reflectivity mosaic reduced to 10–km resolution. In real time, the analysis is derived from Radar Coded Messages (RCM's) transmitted from individual WSR-88D sites (Kitzmiller et al. 2002). The reflectivity observations are automatically quality-controlled to identify and remove echoes from birds and insects, anomalous propagation, and ground clutter. The nominal time for the historic observations was 00:15 in the hour.

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Cloud-to-ground (CG) lightning data were incorporated by determining strike rates over a 15–minute period (00:05-00:20) within the 10-km grid boxes. The strike rates were reduced to categories by dividing nonzero strike counts by 10 and adding 1.

Historic radar data were provided by the Global Hydrology Resource Center (GHRC) at the Global Hydrology and Climate Center, Huntsville, Alabama. Historic lightning observations were provided by NASA Marshall Space Flight Center through GHRC.

Forecasts of upper-air winds, temperature, humidity, and various stability indices from the operational Eta model (Rogers et al. 1996) were also submitted as candidate predictors. These fields are regularly archived on an 80-km grid at 6-h intervals by the Meteorological Development Laboratory.

Forecasts of radar reflectivity and lightning strike rate were made by advecting the corresponding initial-time fields at the velocity of the forecasted 700-500 mb mean wind vector. Candidate predictors derived from the advection forecasts included maximum reflectivity and maximum lightning strike rate during each of the three hours in the forecast period, the maximum reflectivity and lightning strike rate during the entire 3-h forecast period, and forecasted areal coverage by high-intensity radar echoes.

The statistical predictands were derived from the official log of severe local storm reports collected from the public, trained spotters, civil defense personnel, and official observing stations. The reports are forwarded to the NWS Office of Climate, Water, and Weather Services for final screening. Storm observations were assigned to boxes of the forecast grid based on their reported latitude and longitude. The predictand is considered to be 1 if one or more events was reported and 0 otherwise.

To construct the statistical development sample, predictor values and the corresponding predictands were drawn from forecast grid boxes over which lightning or severe weather was observed during the valid period. Furthermore, we wished to include only cases from locations were there was a good expectation that any severe weather was actually reported. Therefore, only data from grid boxes in which at least 55 severe weather events were reported 1973 and 1995 were included in the development sample. This corresponds to the median number of reports received in all forecast grid boxes.

4. PROBABILITY EQUATIONS

The conditional probability of severe weather over a locality, given that thunderstorms occur, appears to be dependent chiefly on static instability and wind speed in the mid-troposphere. Thus, predictors such as Total Totals index, lifted index, and 500-mb wind speed were commonly selected by the screening regression procedure. We found that percentage areal coverage by high-reflectivity radar echoes ($\geq$ 45 dBZ) and vertical wind shear were often selected, as well.

An example of the probability equations, specifically that for any severe weather during the 2100-2359 UTC valid period during the warm season over the Northern Plains region, appears below. It is typical of many equations in that it contains both environmental wind and stability information from Eta forecasts and surface observations and some information from radar reflectivity:

$$P(SVR) = -11.6 - 2.04\ LI + 0.59\ WSPD500 + 0.18\ TAI - 0.42\ LI_{SFC} + 13.60\ COVR45dbz \quad (1)$$

where P(SVR) is the probability in %. Two of the predictors are based solely on Eta-model forecasts: LI is the Eta-forecasted 'best' lifted index between the boundary layer and the 500-mb level in °C, and WSPD500 is the 500-mb wind speed in m s^{-1}. Two predictors are based on a combination of surface observations and Eta forecasts: TAI is the 'thermal advection index' between the surface and the 700-mb level in s^{-1} (Kitzmiller and McGovern 1989), an index proportional to the wind speed and degree of vertical veering of the wind between the surface and the 700-mb level, and LI_{SFC} is the lifted index between the surface and the 500-mb level, calculated with surface information from hourly observations and an Eta forecast of the 500-mb temperature. The remaining predictor, COVR45dbz is based on radar reflectivity. It is the percentage of the area within the 40-km grid box forecasted to contain $\geq$ 45 dBZ echoes during the valid period. In the development sample the relative frequency of severe events was 12.4 %, and this equation explained 6.5 % of the predictand's variance.

Probability forecasts specifically for wind, hail, and tornadoes explain a smaller fraction of the predictand variance in part because the event relative frequency is smaller.

In operations, it is necessary to account for missing radar data in the reflectivity mosaic, since both permanent and temporary coverage gaps exist over the United States. Probabilities derived from only Eta-model and lightning predictors are used within such coverage gaps.

5. STATISTICAL PROPERTIES OF THE FORECASTS

The probability forecasts derived in this manner appear to be reliable and sufficiently accurate to be useful in forecasting operations. When the terms in (1), which was developed from data during the 1996, 1997, 1999, and 2000 warm seasons, were applied to cases from the 1998 warm season, the mean probability forecast (11.9% of all thunderstorm cases) was fairly close to the observed relative frequency of severe weather (12.2%). The mean absolute severe storm probability (0.67%) was also close to the observed relative frequency (0.88%).

Users of the forecasts must ultimately make yes/no decisions based on the probability values, essentially converting the forecasts to categorical ones. The threshold probability defining the yes/no breakpoint can be adjusted to fit the user's particular needs. We can describe the utility of the yes/no forecasts in terms of commonly-used scores including probability of detection (POD), false alarm ratio (FAR), and bias (Schaefer 1990).

Scores for ADSTAT forecasts of general severe weather over the entire Plains region during the 1998 warm season, for the 2100-0000 UTC valid time, appear in Fig. 1. Note that absolute severe weather probabilities were examined here. The effects of varying the yes/no probability threshold show the manner in which POD, FAR, and bias are apparent. For example, if the yes/no threshold is set at 5%, then approximately 42% of the grid boxes with severe weather will be detected (POD is 0.42), and about 88% of the "yes" forecasts will be false alarms (FAR is 0.88). There will be approximately 3.7 times as many "yes" forecasts as there are severe events (bias is 3.7). If the yes/no threshold probability is increased, FAR and bias decrease, but POD decreases as well.

To provide a benchmark reference for these scores, we compared them to scores that might be obtained by treating the NWS Storm Prediction Center (SPC) watch status for a forecast grid box as a yes/no forecast. We examined archives of the SPC watches for 1998 and mapped those that were in effect at 2045 UTC and valid until at least 2200 UTC to the forecast grid. All grid boxes within either a severe thunderstorm or tornado watch were assigned a forecast value of one, all other boxes a value of zero. We found that the watch status as applied to this map grid and time period yielded a POD of 0.28, with an FAR of 0.86 and a bias of 2.25. By comparison, the ADSTAT absolute severe storm threshold probability of 9%, which also yielded a POD of 0.28, gave an FAR of 0.82 and a bias of only 1.6.

Though this result might suggest that the ADSTAT forecasts are superior to the SPC watches, it should be noted that the watch program is designed to notify the public of only significant, organized storm outbreaks (Ostby 1992). Therefore, watches are not issued for the minor storm events that affect only small areas, but which in aggregate produce a rather larger percentage of all severe storms during the warm season, particularly the summer months. Also, many events in this sample were probably covered by watches issued later. Still, the result illustrates the potential utility of the ADSTAT system.

6. EXAMPLE: FORECASTS AND VERIFICATION FOR 13 MAY 2002

On the afternoon of 13 May 2002, thunderstorms accompanied by an extensive outbreak of downburst wind events affected Kentucky and the mid-Atlantic States. Thunderstorm and severe storm probability forecasts for the period 1800-2100 UTC appear in Figs. 2-4. Thunderstorm probabilities (Fig. 2) were as high as 70% in advance of a developing line of storms that was moving rapidly eastward. Moderately unstable air and strong 500-mb winds were reflected in conditional severe weather probabilities near 25% over eastern Maryland and central Virginia (Fig. 3). Unconditional severe weather probabilities approached 20% over central Maryland (Fig. 4).

Nearly 70 severe storm reports, mostly for high wind events, were logged during the valid period. The events affected areas from central Virginia through central Maryland, with a less extensive outbreak in eastern Kentucky (Fig. 5).

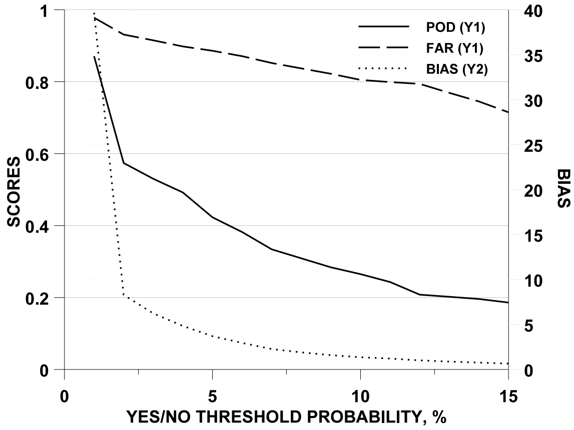

Figure 1. Categorical forecast scores for severe local storm forecasts, U.S. Plains region, during 1998 warm season.

7. FUTURE WORK

Real-time output from the ADSTAT forecast system is available on the World-Wide Web at: http://weather.gov/mdl/. Current plans call for operational dissemination of the severe weather forecast suite during summer of 2002, in Gridded Binary (GRIB) format, over the NOAA Satellite Broadcast Network. The forecasts will eventually be incorporated with the System for Convection Analysis and Nowcasting (SCAN, Smith et al. 1998).

One of the chief shortcomings of the ADSTAT system in its present form is its limited use of radar data, with no input from volumetric reflectivity or Doppler information. Only limited capabilities for archiving such information on a national scale were available until late 2000. We plan to augment the historical predictor dataset with vertically-integrated liquid fields and Doppler mesocyclone information from 2000 onwards. Capabilities for operationally compositing and using these data are now expanding.

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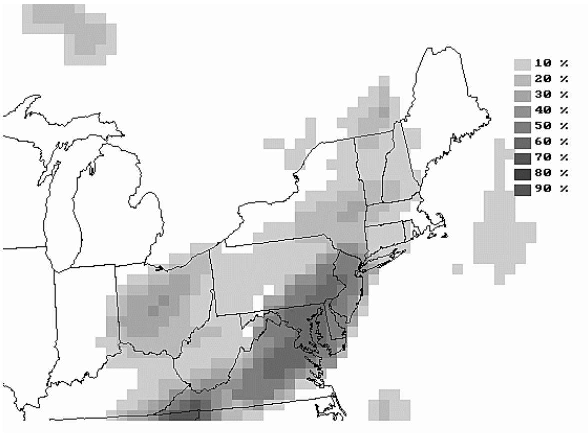

Figure 2. Lightning probabilities valid 1800-2100 UTC, 13 May 2002.

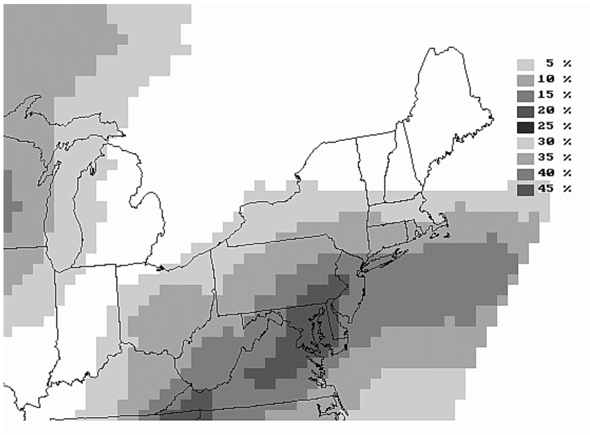

Figure 3. Probability of any general severe weather, conditional on lightning, valid 1800-2100 UTC 13 May 2002.

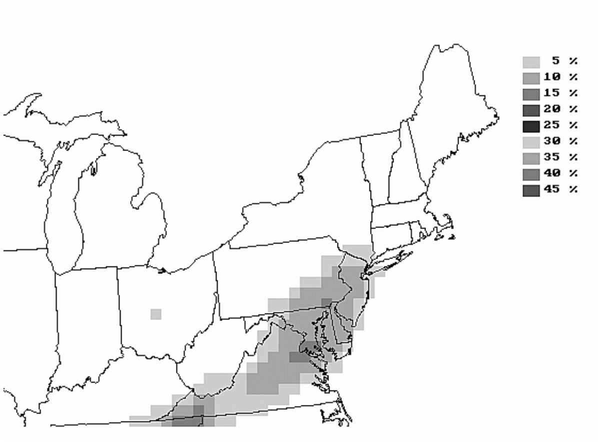

Figure 4. As in Fig. 3, except absolute severe weather probability calculated as product of lightning and conditional severe local storm probabilities.

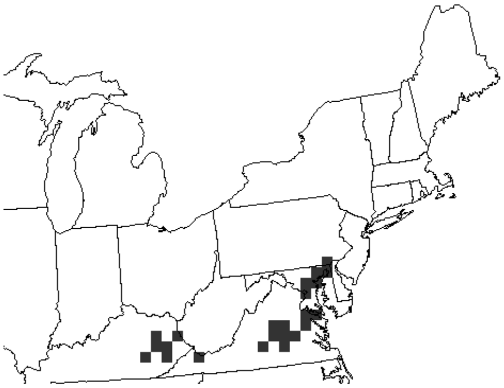

Figure 5. Grid boxes with severe storm events reported during the period 1800-2100 UTC, 13 May 2002.