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Six-hour Thunderstorm Probability Forecasts for Kansas-Oklahoma and the Northeast United States

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FIRST BULLETIN ON THIS SUBJECT

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This bulletin, prepared by Mr. Ronald M. Reap of the Techniques Development Laboratory (TDL), describes the Model Output Statistics (MOS) 6-hour thunderstorm probability forecasts for the Kansas-Oklahoma region and the Northeast U.S. that have appeared on the AFOS system since April, 1989. The forecast equations were derived from developmental samples containing cloud-to-ground lightning strike predictand data and predictors from the operational LFM and LFM-based trajectory models. Lightning data for the Northeast U.S. were obtained from the lightning detection network operated by the State University of New York at Albany (SUNYA); lightning data for Kansas-Oklahoma were obtained from the network operated by the National Severe Storms Laboratory (NSSL).

Information on storing these thunderstorm probability forecasts is available in AFOS Change Notice No. 462. These forecasts are transmitted once per day on AFOS around 0300 UTC. At this time, this forecast guidance is **not** available to external users.

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SIX-HOUR THUNDERSTORM PROBABILITY FORECASTS FOR KANSAS-OKLAHOMA AND THE NORTHEAST U.S.

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1. INTRODUCTION

This bulletin describes the 6-hour (hr) thunderstorm probability forecasts for Kansas-Oklahoma and the Northeast U.S. that have been transmitted on the National Weather Service's (NWS's) AFOS system since April, 1989 (consult AFOS Change Notice No. 462 for details). The forecasts, sent daily around 0300 UTC, are valid for projections of 6-12, 12-18, 18-24, and 24-30 hours (hrs) following 0000 UTC initial data time. They give the probability of two or more cloud-to-ground lightning strikes occurring during a 6-hr period within grid blocks that are approximately 47 kilometers (km) on a side (at 60 deg N). The approximate geographical areas for which the forecasts are generated are shown by the sample forecasts in Figure 1.The new forecasts are similar in form to the 6-hr thunderstorm probability forecasts based on lightning location data that were implemented on AFOS in 1986 for the western U.S. (NWS, 1986; NWS, 1987).

2. METHOD

Extensive evaluations (Reap, 1986; Reap and MacGorman, 1989; Reap and Orville, 1990) of cloud-to-ground lightning strike reports from automated networks across the U.S., including Kansas and Oklahoma and the northeast U.S., have clearly revealed the ability of the lightning data to accurately delineate convective activity within these regions. As a result, thunderstorm forecast equations were derived by applying screening regression techniques to relate the lightning predictand data to large-scale meteorological predictors obtained from numerical forecast models. The high temporal and spatial resolution of the lightning predictand data combined with the 6-hr forecast intervals provides more information on the diurnal variation of thunderstorm activity than was possible with previous developmental samples.

3. DEVELOPMENT

3a. Predictor/Predictand Sample

Probability equations for projections of 6-12, 12-18, 18-24, and 24-30 hrs following 0000 UTC were derived from developmental samples consisting of lightning predictand data and predictors from NMC's LFM model and TDL's LFM-based three-dimensional trajectory model. The lightning data set contains nearly 2 million reports of cloud-to-ground lightning flashes from the detection network operated by the State University of New York at Albany (SUNYA) and 5 million lightning reports from the National Severe Storms Laboratory (NSSL) network. For a detailed description of the SUNYA network refer to Orville et al. (1983); for the NSSL network refer to Reap and MacGorman (1989).

The lightning data in the SUNYA predictand sample were obtained for the two warm season periods from March 11 to September 30, for both 1985 and 1986. Lighting frequencies in the 6-12, 12-18, 18-24, and 24-30 hr periods following 0000 UTC were 3.8, 3.9, 10.0, and 6.8 percent, respectively. Lightning frequency is the fraction of 47 km grid blocks in the total sample with two or more flashes to ground. The maximum frequency of 10 percent for the 18-24 hr projection reflects the late afternoon maximum in thunderstorm activity found throughout most of the U.S., including the Northeast.

The developmental sample for the Kansas-Oklahoma region was stratified according to the geographical areas shown by Region 1 and Region 2 in Figure 1. Lightning frequencies in the 6-12, 12-18, 18-24, and 24-30 hr periods after 0000 UTC were 8.8, 5.5, 10.9, and 11.6 percent, respectively, for Region 1, and 6.8, 7.0, 14.6, and 9.3 percent, respectively, for Region 2.

As shown by Easterling and Robinson (1985), most of Kansas and Oklahoma (Region 1) is characterized by nocturnal storms in all seasons except winter, as reflected by the maximum lightning frequency of 11.6 percent for the 24-30 hr projection. Nocturnal convection within Region 1 is also characterized by relatively high lightning flash rates (Reap and MacGorman, 1989). The smaller region in southeast Oklahoma (Region 2) is characterized by a late afternoon maximum (14.6 percent) consisting mostly of negative ground flashes with relatively low flash rates (Reap and MacGorman, 1989).

The predictor sample included a standard set of over 100 basic and derived model predictors from the LFM and trajectory models (Reap and Foster, 1979). For this particular application, the regression procedure was followed until twelve predictors were selected for each forecast equation. To promote consistency in the forecasts, the four equations for a particular area employ a common set of twelve predictors for all four projections; only the predictor coefficients and equation constants change from one projection to another. The operational predictor sets selected by the screening regression procedure are shown in Table 1.

3b. Description of Predictors

The leading term in the operational equation for the Northeast (Table 1) is the convective or layer instability θ^* given by the lapse rate of equivalent potential temperature θ_e, where

$$\theta^* = \theta_e(700) - [\theta_e(\text{surface}) + \theta_e(850)]/2$$

and surface, 850, and 700 refer to the pressure levels (in millibars) at which θ_e is calculated. The second predictor in the equation for the Northeast combines the convective or layer instability with the net vertical displacement necessary to release it. In this case, the most significant net vertical displacement was that sustained over the last 12 hours of the trajectory model forecast by air parcels terminating at 700 mb. Among the more important predictors in the forecast equations for the Kansas-Oklahoma region are the boundary-layer moisture convergence, K stability index (George, 1960), and the 1000-500 mb mean relative humidity. The selection of predictors in all three forecast equations agrees with results from a study by Reap and MacGorman (1989) that found lightning cloud-to-ground flashes were strongly correlated with the low-level moisture flux and circulation, as characterized by favorable moisture convergence, cyclonic relative vorticity, and strong upward vertical motions in the lower layers.

3c. Verification

Typical examples of the accuracy and reliability (bias) for operational probability forecasts for the Kansas-Oklahoma region and the Northeast U.S. are shown in Figure 2. The verification statistics were computed from the dependent data sample, however, past experience has shown no significant degradation in the performance of the thunderstorm forecasts on independent data. As usual, the solid, bold diagonal line in Figure 2a represents perfect forecast reliability or zero bias. For most projections and categories, the 1987 probability forecasts (Fig. 2a) were highly reliable with only a slight tendency to underforecast in the 6-12 hr projection. The expected accuracy for the Northeast is shown in Figure 2b. For example, if the forecaster selects a probability threshold of 22 percent to delineate the area in which thunderstorms are expected to occur, then, on average, almost three-fourths of the observed thunderstorms would be within the 22 percent probability isoline, as shown by the POD = 0.72.

4. PRODUCT CONSIDERATIONS

4a. Sample Lightning Probability Forecasts

Sample 6-hr thunderstorm probability forecasts for the Kansas-Oklahoma region and the Northeast U.S. are shown in Figure 1. Also plotted are the number of reported cloud-to-ground lightning strikes during the given 6-hr period for grid blocks containing two or more strikes.

4b. Forecast Probability Product Description

While the forecasts in Figure 1 are shown in graphical form, the 6-hr probabilities are actually transmitted as gridded data, i.e., gridpoint values. Thus, the gridded data must be unpacked and contoured at each AFOS site by using an application program in order to obtain a graphical display similar to that shown in Figure 1. The unpacked gridded data are 24 x 19 arrays that are subsets of the LFM grid. The geographical areas encompassed by the unpacked arrays correspond to the areas shown by the sample forecasts in Figure 1. As previously noted, the mesh length of the 24 x 19 grid is one-fourth that of the LFM, or approximately 47 km at 60 deg N (about 41 km at 37.5 deg N).

The eight fields of gridded thunderstorm probabilities are sent on AFOS as follows:

Northeast U.S.:

NMCGRDNE2 (06-12 hr projection)
NMCGRDNE3 (12-18 hr ")
NMCGRDNE4 (18-24 hr ")
NMCGRDNE5 (24-30 hr ")

Kansas-Oklahoma:

NMCGRDOK2 (06-12 hr projection)
NMCGRDOK3 (12-18 hr ")
NMCGRDOK4 (18-24 hr ")
NMCGRDOK5 (24-30 hr ")

4c. AFOS Applications TPN and TPO

The data are sent in binary form using the AFOS standard universal transmission format (UTF) and are not displayable on either the AFOS alphanumeric or graphics display monitors. Two AFOS applications programs have been developed by TDL that unpack, contour, and generate AFOS graphics for display of the above gridded data. The TPN program reads and creates graphics for the four gridded probability forecasts for the Northeast U.S., while program TPO reads and plots the data for Kansas-Oklahoma. Copies of these two programs and their documentation are available from TDL's AFOS applications library or from Regional Scientific Services Division.

5. FORECAST IMPLICATIONS

As is the case with all MOS forecasts, the probability forecasts for the Kansas-Oklahoma region and the Northeast U.S. are dependent on the accuracy of the numerical model forecasts used as input. Therefore, the guidance may have to be used with caution if the forecaster detects possible errors in the model predictions. Specific localized conditions and mesoscale features detected by radar, satellite, or ground-based observations also should be taken into account by the local forecaster.

6. REFERENCES

Easterling, D. R., and P. J. Robinson, 1985: The diurnal variation of thunderstorm activity in the United States. *J. Climate Appl. Meteor.*, **24**, 1048-1058.

George, J. J., 1960: *Weather Forecasting for Aeronautics*. Academic Press, New York, 673 pp.

National Weather Service, 1986: New 6-hr thunderstorm probability forecasts for the West. NWS Tech. Proc. Bull. No. 362, NOAA, U.S. Dept. of Commerce, 6 pp.

______, 1987: Verification of the thunderstorm probability equations. NWS Western Region Tech. Attachment No. 87-22, 2 pp.

Orville, R. E., R. W. Henderson, and L. F. Bosart, 1983: An east coast lightning detection network. *Bull. Amer. Meteor. Soc.*, **64**, 1029-37.

Reap, R. M., 1986: Evaluation of cloud-to-ground lightning data from the Western United States for the 1983-84 summer seasons. *J. Climate Appl. Meteor.*, **25**, 785-799.

______, and D. S. Foster, 1979: Automated 12-36 hour probability forecasts of thunderstorms and severe local storms. *J. Appl. Meteor.*, **18**, 1304-1315.

______, and D. R. MacGorman, 1989: Cloud-to-ground lightning: Climatological characteristics and relationships to model fields, radar observations, and severe local Storms. *Mon. Wea. Rev.*, **117**, 518-535.

______, and R. E. Orville, 1990: The relationship between network lightning locations and surface hourly observations of thunderstorms. *Mon.Wea.Rev.*, **118**, 94-108.

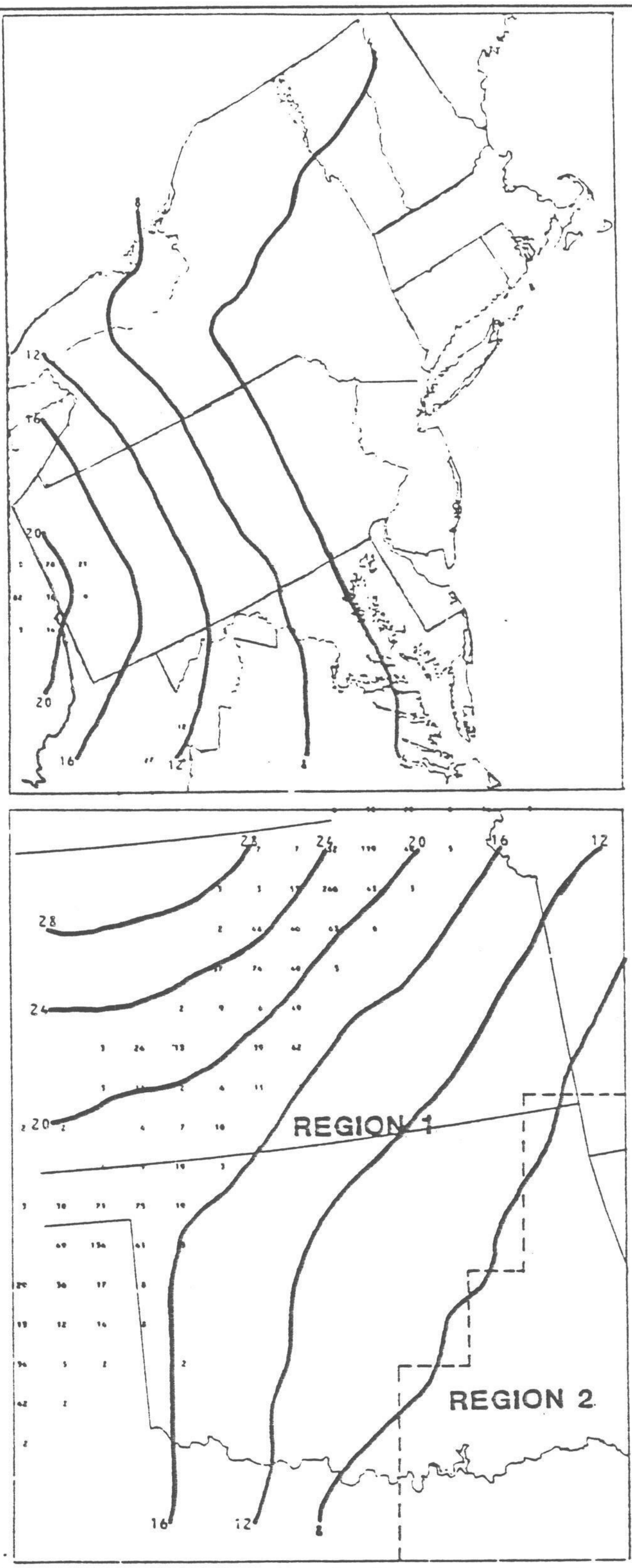

Figure 1. Probability of two or more lightning ground strikes during 18-24 h projection following 0000 UTC on June 4, 1986 for northeast U.S. (top) and 6-12 hr projection following 0000 UTC on May 26, 1987 for Kansas-Oklahoma region (bottom). Number of reported ground strikes is plotted for each 47 km grid block with two or more strikes. Region 1 and Region 2 designate geographical areas for which separate forecast equations were developed.

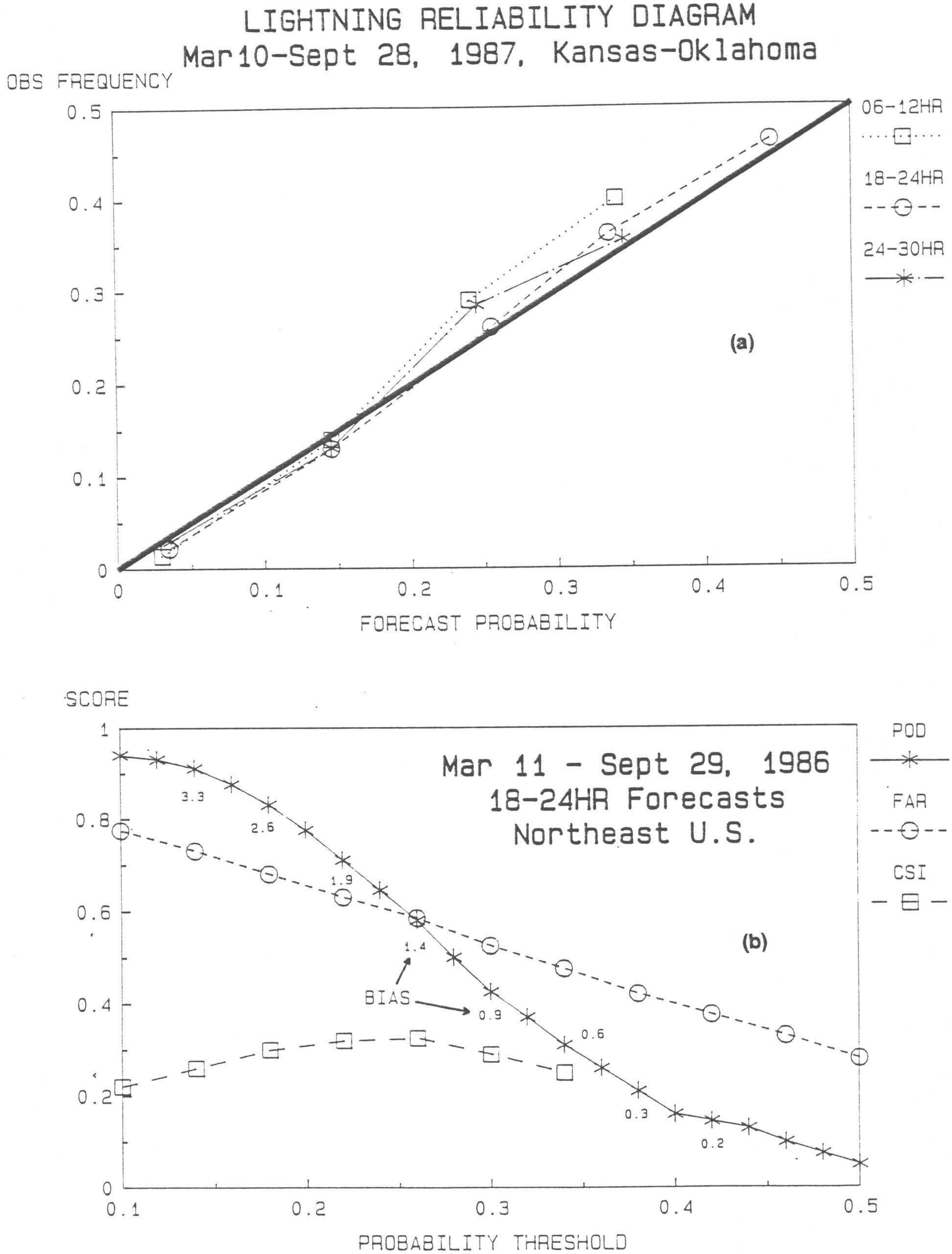

Figure 2. (a) Observed frequency of two or more lightning strikes per 47 km grid blocks as a function of forecast probability for 1987; **(b)** critical success index (CSI), false alarm ratio (FAR), and probability of detection (POD) for categorical thunderstorm occurrence based on various probability thresholds.

Table 1. Predictors in probability equations* for two or more cloud-to-ground lightning strikes during the 6-12, 12-18, 18-24, and 24-30 h projections following 0000 UTC. Equation for the northeast U.S. is based on data from March 11-September 30 for the years 1985-86. Equations for Kansas-Oklahoma are based on data from March 11-September 30 for the years 1985-88. Predictors are limited area fine mesh (LFM) model and/or trajectory (TJ) model forecasts.

Northeast U.S.			Kansas-Oklahoma (Region 1)			Kansas-Oklahoma (Region 2)		
Predictor	Projection	Model	Predictor	Projection	Model	Predictor	Projection	Model
Convective instability	24	TJ	Boundary-layer moisture convergence	24	LFM	Boundary-layer moisture convergence	12	LFM
Convective instability times 700 mb 12-h net vertical displacement	24	TJ	Boundary-layer moisture convergence	12	LFM	K stability index	24	LFM
Boundary-layer moisture convergence	12	LFM	1000-500 mb mean relative humidity	24	LFM	Convective instability times 700 mb 12-h net vertical displacement	24	TJ
Boundary-layer moisture convergence	24	LFM	Total Totals stability index	24	TJ	Boundary-layer moisture convergence	24	LFM
700 mb dew point	24	TJ	1000-500 mb mean relative humidity	12	LFM	K stability index	12	LFM
850 mb net vertical displacement	24	TJ	Surface pressure	24	LFM	700 mb dew point advection	24	TJ
Boundary-layer relative vorticity	24	LFM	Boundary-layer wind speed	24	LFM	500 mb wind speed	24	LFM
700 mb temperature	24	TJ	Boundary-layer "u" wind component	12	LFM	Convective instability	24	TJ
K stability index	24	LFM	500 mb wind speed	24	LFM	1000-500 mb mean relative humidity	24	LFM
500 mb "v" wind component	12	LFM	850 mb dew point depression	24	LFM	700 mb 12-h net vertical displacement	24	TJ
K stability index	12	LFM	Convective instability	24	TJ	850 mb temperature advection	24	LFM
200 mb "v" wind component	12	LFM	Convective instability times 700 mb 12-h net vertical displacement	24	TJ	850 mb dew point depression	24	LFM

*Equations developed for 6-12, 12-18, 18-24, and 24-30 h projections for each region employ a common set of 12 predictors selected during the screening analysis; only predictor coefficients and equation constants change from one projection to another.