

STATISTICAL MODELS FOR 1-2 DAY WARM SEASON LIGHTNING PREDICTION FOR CANADA AND THE NORTHERN UNITED STATES

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ABSTRACT: Tree-based statistical models for prediction of lightning occurrence in three-hour intervals were developed and tested with independent data from the North American Lightning Detection Network for Canada and the northern United States. The forecasts show positive skill to 48 hours over this large geographical region.

INTRODUCTION

Since February 1998 the North American Lightning Detection Network (NALDN) provides continuous lightning detection for Canada and the northern United States to about 65°N in the northwest and 55°N in the northeast. Location of detectors in the network is shown in Orville et al. (2002). The Meteorological Service of Canada (MSC) receives lightning flash reports for Canada plus the northern region of the United States to 35°N east of 100°W, and to 40°N west of 100°W. Major patterns of lightning occurrence for 1998-2000 were analyzed by (Burrows et. al., 2002(a)) for the northern United States and Canada, and by Orville et al. (2002) for the entire NALDN. Complex patterns were revealed in both studies, showing strong latitudinal, seasonal, and diurnal dependencies, and significant influence by topography and land-water boundaries.

Canada is a vast country where little or no information about the occurrence of lightning was available over many areas until the advent of the lightning detection network. There is a need for improved thunderstorm prediction guidance for Canadian forecasters. A starting point is to build statistical models that relate observed lightning to predictors generated by the GEM operational numerical weather prediction model run at the Canadian Meteorological Center (Coté et al., 1997).

DATA AND MODELING METHODS

Total lightning flash reports in three-hour periods May to September 2000 and 2001 were transformed to a grid of approximately 22km. Reports 0-10 km from a grid point were assigned a weight of 1, neighbouring points at 10-20 km distance received a weight decreasing linearly to 0 at 20 km. We refer to the gridded data as flash report density (FRD). Its sum over all grid points is about twice the number of actual reports since neighbouring grid points receive partial weights. Cloud to ground flashes were not separated from cloud to cloud flashes.

During the course of this study we found that a range of FRD can be associated with similar predictor values, thus transformation to categories is useful. FRD for non-zero lightning occurrence has approximately an exponential to log-normal distribution (Burrows,2002(b)). FRD was transformed into 11 categories of flashes per three hours: (1) 0-.01, (2) >.01-.50, (3) >.50-1.0, (4) >1.0-2.7, (5) >2.7-7.4, (6) >7.4-20, (7) >20-55, (8) >55-148, (9) >148-403, (10) >403-1097, (11) >1097-2981. Boundaries of categories 4-11 are the successive values of e^1 to e^8 . We found that significantly more reduction of variance could be achieved in statistical models for the transformed FRD predictand than for non-transformed FRD. For reference, FRD category ranges can be arbitrarily described as: ZERO (1), ANY (2-11), CHANCE (2), OCCASIONAL (3-6), FREQUENT (7-11), and RAPID (9-11), where the category range is indicated inside the brackets. Note that FREQUENT lightning includes the RAPID lightning flash categories.

Guidance for predictors came from our knowledge of physical processes and from several previous studies (e.g. Reap and MacGorman (1989), Price (2000)). Predictors associated with moisture, convection, lift, or climatological controls were matched with the FRD fields. Basic predictors are shown in Table 1. For meteorological predictors the three-hour mean, three-hour maximum value (or minimum value in some cases), and three-hour change were calculated. Thus a basic predictor such as the difference between the geopotential heights at 500 hPa and 1000 hPa yielded three separate predictors. Forecast precipitation fields were not used because only 6-hour accumulations were archived and we expected precipitation forecasts may change significantly in a future version of GEM with a different convective parameterization scheme.

Archived output fields for May-September 2000 and 2001 for 0000 UTC and 1200 UTC GEM model runs were linearly interpolated to intermediate 3-hour times, then predictors were calculated and matched with the predictand at all grid points. To circumvent GEM model spin-up error in the initial hours of integration, 00-hour GEM forecast data was replaced with 12-hour forecast data from the previous run. Predictors for the 0-3 hour and 3-6 hour forecasts are calculated with data interpolated from the previous run's 12-hour forecast and the

Table 1. Candidate predictors for tree-based models. Where the maximum, mean, and change for a three-hour period could be calculated, this is indicated by [MxAvCh].

Predictor. [time operator].	
Bouyant convective energy (CAPE) calculated from surface. [MxAvCh].	Geopotential height at 1000 hPa, 500 hPa. [MxAvCh].
Convective inhibition calculated from surface. [MxAvCh].	Layer thickness for 500-1000 hPa, 700-1000 hPa, 850-1000 hPa, 700-850 hPa). [MxAvCh].
Storm-relative helicity. [MxAvCh].	Vertical Motion at 700 hPa. [MxAvCh].
Maximum column wet-bulb potential temperature.	Depth of ascent and descent in hPa for 250-1000 hPa, 700-1000 hPa layers. [MxAvCh].
Convective index: Showalter, Lifted. (MnAvCh).	Pressure, temperature, and height of the tropopause. [MxAvCh].
Severe weather index: SWEAT, Severe Storm. [MxAvCh].	Thickness in km from 0° C to the tropopause and to potential cloud top. [MxAvCh].
Precipitable water for total troposphere. [MxAvCh].	Potential cloud top height. [MxAvCh].
Precipitable water 700 hPa to 400 hPa. [MxAvCh].	Topography elevation.
Dewpoint temperature at surface, 850 hPa, 700 hPa. [MxAvCh].	Land-water fraction (0 to 1).
Temperature at 850 hPa, 700 hPa, 500 hPa. [MxAvCh].	Vegetation type category
MSL pressure. [MxAvCh].	

current run's 6-hour forecast, while predictors for the 6-9-hour and 9-12-hour forecasts are calculated with data from the current run's 6-hour and 12-hour forecasts. Thus forecast models valid at 00-03, 03-06, 09-12, 12-15, 15-18, 18-21, and 21-24 hours UTC were built with archived 6-hr and 12-hr forecasts from 0000 UTC and 1200 UTC GEM runs. Under the assumption that GEM model variance is unchanged after 12 hours, these models can then be applied in any 24-hour period using GEM model output valid for the projection time (e.g. 0-24 hours, 24-48 hours, or longer). This approach was called "time-offset model output statistics" in Burrows (1985).

Data for each three hours were stratified into 5 degree latitude-longitude boxes due to the large geographical area. Separate models were built for each box for each 3-hour period. If desired, forecasts for longer time intervals than 3 hours can be made by using the maximum probability of the three-hour forecasts in the period.

Statistical prediction models were derived with the tree-based regression algorithm of Classification and Regression Trees (CART) (Brieman et al., 1984). This non-linear, non-parametric procedure finds a decision-tree data-partitioning structure that minimizes residual variance of the predictand by clustering groups of similar training data into a set of "nodes". Partition functions can be a linear combination of predictors or a single predictor. Briefly, an "honest" tree-structure is found as follows: Beginning at the root node, training data is divided into left and right descendent nodes by searching through all values of all predictors until a threshold value is found that gives the minimum residual variance after the split (weighted by case populations in the 2 descendent nodes). Partitioning of descendent nodes continues along each tree branch until no further reduction of variance can be achieved. The entire tree is then "pruned from the bottom up" using independent validation data until a tree remains which fits the validation data with the least error. Predictors need not be orthogonal, thus there is no need for data dimension reduction (e.g. principal component transformation). In fact this will often prove detrimental because it can hide local predictand-predictor correlation that might be used to further reduce variance in the sub-set of data partitioned locally into a node. If the predictand is treated as continuous, a probability distribution for the categories of a categorical predictand can be assigned to each terminal node using the sub-set of training data that was partitioned into the node, or the continuous predictand data partitioned into a node can be transformed to categories after it is partitioned.

RESULTS

Forecasts are being tested with independent data from 2002. Figure 1 shows a 21-24 hour forecast for the probability of occurrence of any category of lightning valid 2100 UTC to 2400 UTC, 26 June, 2002. Heavy solid lines are .75 probability contours, dashed lines are .25 probability contours. Small grey crosses mark grid points where lightning was observed. Dash-dot lines denote 5 degree latitude-longitude boxes where a forecast could

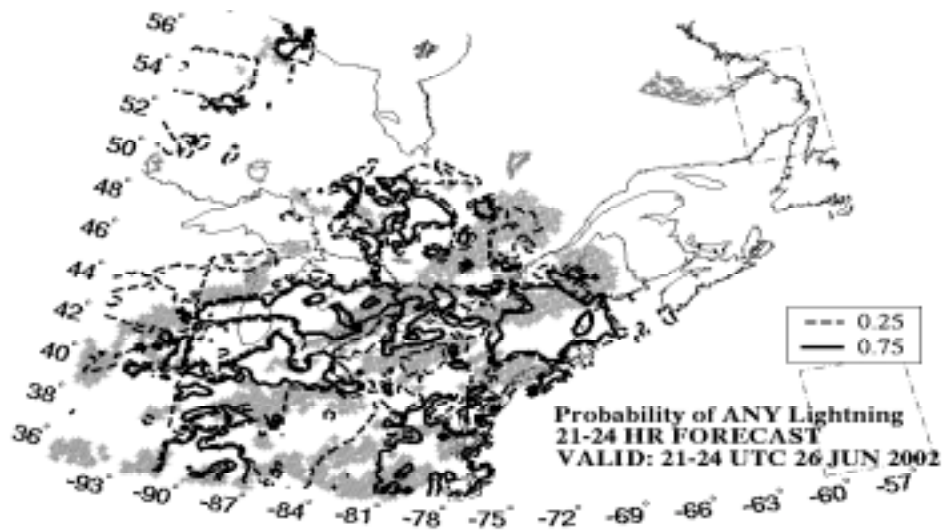


Figure 1: 21-24 hour forecast of probability of lightning occurrence valid 2100-2400 UTC, 26 June, 2002.

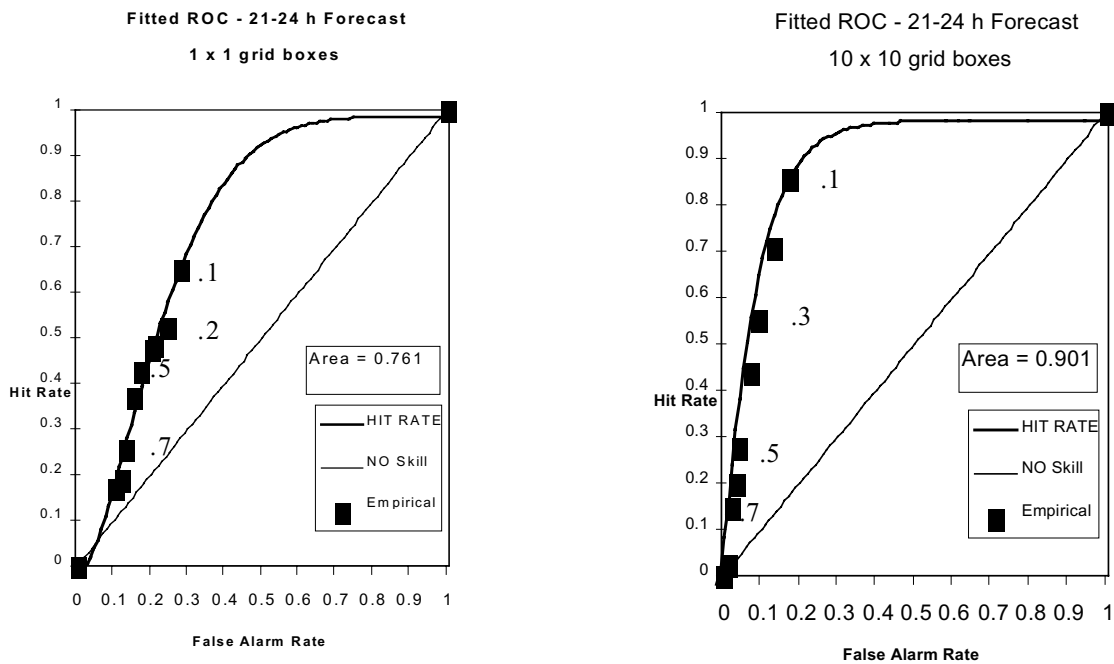


Figure 2: Relative operating characteristic (ROC) graphs for the lightning forecasts in Fig. 1. Verification probability threshold values in increments of .1 are plotted as small squares. Some threshold values are labeled.

not be made due to lack of training data. There are several distinct areas of lightning seen in Fig.1. Overall, the position of the general area where lightning was observed was well forecast, however there are errors in predicting details within this area. The “puddling” effect in the regions forecast to have high probability of lightning may be partly due to the piecewise-continuous CART fit of the learning data.

To quantify forecast accuracy by signal detection, Figure 2 shows two relative operating characteristic (ROC) graphs for the prediction in Fig.1. The left graph is point-by-point verification, the right box is verification on 10*10 point boxes (squares with sides approximately 220km). The predictand is a binary YES/NO lightning forecast. The ROC curves are fitted to the empirical values, which ranged from .1 to .9. The points on the ROC curves (solid line) are the hit rate and false alarm rate that would be achieved for threshold probability, in increments of .10. (e.g. for a threshold of .3, a forecast of .3 or above is YES lightning, less than .3 is NO lightning). Some verification threshold probability values are plotted beside the curve. A good forecast has a high hit rate and a low false alarm rate. The ROC curves are fitted to empirical values, which ranged from .1 to .9. The 45° line is a reference ROC for a no-skill forecast with equal hits and false alarms. The larger the area under the fitted ROC curve, the better the forecast. We see in Fig. 2 there is positive skill in the forecasts verified point-by-point (left graph), (e.g. verifying even with a threshold probability value of .10 gives a hit rate of .65 and a false alarm rate of .28). Demonstrated accuracy improves considerably when we verify the same forecasts in equal-area squares of 10*10 grid points. The forecast is the mean probability of lightning occurrence for the 100 points in a square. A hit is counted if lightning occurred anywhere in the box. Now a forecast of lightning for a threshold value of .10 has a hit rate of .86 and false alarm rate of .17. An area above .75 for a ROC graph indicates a good forecast. Discussion of ROC verification is in Stanski et al. (1989).

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CONCLUSION

We built statistical models with just 2 years of training data for warm season prediction of probability of lightning occurrence in three-hour intervals, valid over a large geographical region. The models were tested to a 48-hour projection for several days in 2002 and found to display reasonable accuracy overall. Comprehensive tests with more independent data are still underway at the time of writing. Best results were generally obtained for the period 1800 to 0600 UTC. This is likely due to a well-known diurnal variation in lightning activity, and to greater GEM model error in resolving the boundary layer at night and early morning. Verification results thus far indicate the forecasts will have utility for public forecasts, since these generally apply to large regions. The models have been installed at the Canadian Meteorological Center to provide forecasts of thunderstorm probability for automated public forecast generation software. Better GEM models in the future and a planned increase in the time resolution archived data hold the promise for better models in the future. We are investigating other model generation methods such as logistic regression and neural networks.

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