

Probabilistic 0-12 h forecasts of (severe) thunderstorms for the purpose of issuing a weather alarm

Maurice Schmeits, Kees Kok, Daan Vogelesang and Rudolf van Westrhenen

Introduction

To improve severe weather forecasting, KNMI has started a special programme, in which a number of research and non-research projects are included. One research project, KOUW (Probabilistic forecasts of thunderstorms for the purpose of issuing a weather alarm), is described here. Another one, MESOMOD, is described elsewhere in this report¹⁾. The non-research projects of the programme are aimed at better tuning of severe weather information to the needs and wishes of the user, at a clear and consistent communication to the user and media, and at a more dedicated role of the forecaster. In this chapter the most important results of the KOUW project are presented. Because the skill of severe thunderstorm warnings was unsatisfactory, the KOUW project was initiated. The goal of this project was to

develop a probabilistic forecast system for (severe) thunderstorms to be used by forecasters as a tool to decide whether a weather alarm should be issued.

Method

In this project the technique of Model Output Statistics (MOS)²⁾ has been used to derive logistic regression²⁾ equations for the (conditional) probability of (severe) thunderstorms in the warm half-year (from mid-April to mid-October) in The Netherlands. The MOS technique consists of determining a statistical relationship between a predictandⁱ (i.e. the occurrence of a thunderstorm in this case) and predictorsⁱⁱ from numerical weather prediction (NWP) model forecasts and possibly from observations. For 12 regions of about 90x80 km² each (Figure 1) and for forecast projections up to

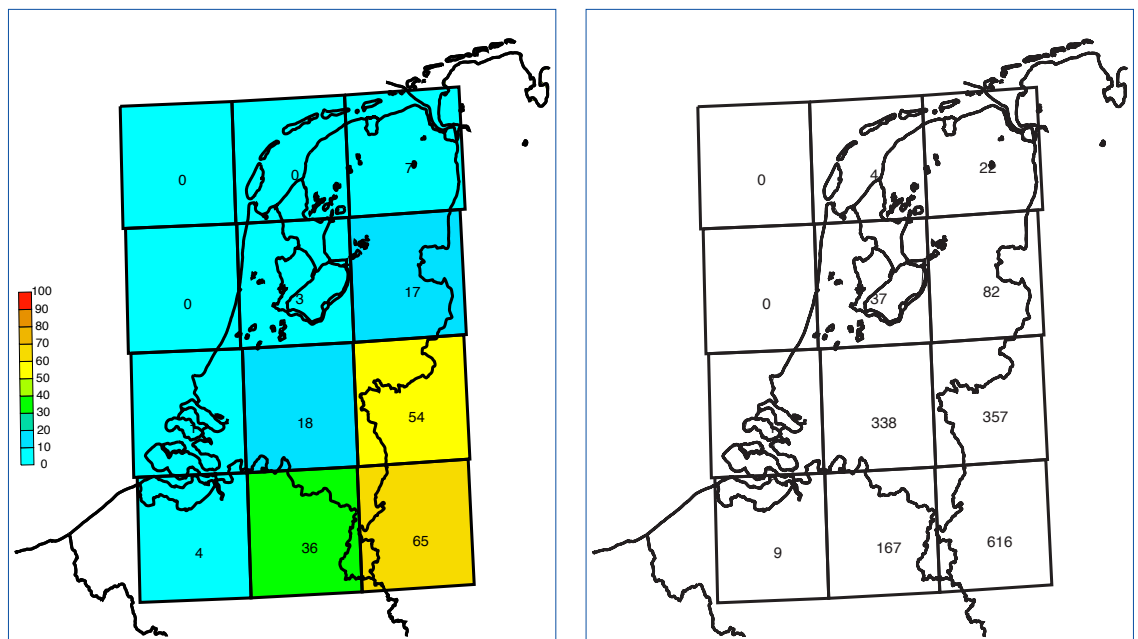


Figure 1. Left panel: 6-12 h conditional probability forecast (%) of maximum lightning intensity ≥ 200 discharges/5 min. valid for 15-21 UTC on June 25, 2006. The forecast is based on the 09 UTC run of the MOS system. Right panel: Maximum 5-min. lightning intensity, as detected by the SAFIR network, during the same period.

ⁱ Definition of predictand: quantity to be forecast

ⁱⁱ Definition of predictor: quantity that has forecasting value for the predictand

12 hours in advance (with 6-hour periods), we have developed these equations using several potential predictor sources. These sources not only consisted of combined (postprocessed) output from two NWP models, as in our previous study³⁾, but also contained an ensemble of 18 members of advected radar and lightning data for the 0-6 h projections⁴⁾. As a source for the predictands, reprocessed lightning data from the SAFIR network^{5,6)} have been used. The system was made pre-operational at KNMI in the spring of 2006 and produces an update every 3 hours during the warm half-year.

Predictand definitions

Two predictands are defined, based on (reprocessed) SAFIR^{5,6)} lightning data. Herewith, both horizontal and vertical lightning discharges are taken into account. One predictand is defined as the probability of a thunderstorm (i.e. > 1 discharge in a 6-h period in a 90x80 km² region). The other predictand is defined as the conditional probability of a severe thunderstorm (with maximum intensity thresholds of 50, 100 and 200 discharges/ 5 min. in a 6-h period in a 90x80 km² region) under the condition that > 1 discharge will be detected in the same 6-h period in the same region. The two highest thresholds are only available for the 12-18, 15-21 and 18-00 UTC periods. The absolute probability of a severe thunderstorm can be computed by multiplying the conditional probability of a severe thunderstorm by the probability of a thunderstorm (> 1 discharge). Note that the predictand definition for severe thunderstorms is different from the one used in the operational severe thunderstorm forecast system³⁾.

Weather alarm criterion

The current weather alarm criterion for severe thunderstorms (≥ 500 discharges/ 5 min. in any area of 50x50 km²) is met only twice a year on average. For such a rare event it is impossible to derive skilful statistical equations. Therefore, we have investigated what the maximum intensity threshold is that renders a skilful system. This has led to the above mentioned predictand definitions. Not only the intensity thresholds in the KOUW-system are lower than the weather alarm threshold, but the area size is also a factor of 3 larger. The area size is larger, because the thunderstorm frequency would otherwise

become so low (in the night and morning) that there would be too few thunderstorm cases left to derive statistical equations. On the other hand, the 90x80 km² regions in the KOUW-system are specified a priori, while the weather alarm criterion is defined for any area of 50x50 km².

Predictors

New compared to the operational thunderstorm forecast system³⁾ is the use of an ensemble of 18 members of advected radar and lightning data as potential predictor sources for the 0-6 h projections⁴⁾. The lightning and radar images of 02.40, 05.40, 08.40, 11.40, 14.40, 17.40, 20.40 or 23.40 UTC have been used as initial conditions. Subsequently, both the lightning and the radar image are advected using the HIRLAM 700 hPa wind vectors together with vectors computed from previous radar images. Apart from these basic vectors, also vectors that are 25% longer and 25% shorter have been used and vectors whose direction deviates by +10 and -10 degrees, respectively. This leads to a total number of 18 ensemble members.

The remaining potential predictor sets consist of 17 thunderstorm indices, computed from the 22-km HIRLAM reforecasting dataset, ECMWF (postprocessed) direct model output (resolution: 0.5 degree) and the (co)sine of the day of the year. The dataset used to develop the application consists of July 2002 to July 2005 data (warm half-years only) with independent verification datasets consisting of July to mid-October 2005 and mid-April to mid-October 2006 data, respectively. Because the severe thunderstorm sample size is too small for each region separately, all 12 regions have been pooled in the severe thunderstorm forecast system.

After a selection process⁴⁾, the most important predictors in the thunderstorm forecast system turned out to be the percentage of the total number of advection ensemble members with ≥ 4 discharges (0-6 h projections only), the ECMWF 6-h convective precipitation sum, the HIRLAM Jefferson index, the HIRLAM CAPE of the most unstable level and the HIRLAM Boyden index (see Table 1 for definitions of the thunderstorm indices). The most important predictors in the severe thunderstorm forecast

*Because the skill of severe thunderstorm warnings was unsatisfactory,
the KOUW project was initiated*

Thunderstorm index	Definition
Boyden index	$0.1(Z_{700} - Z_{1000}) - T_{700} - 200$
Bradbury index	$\theta_{w600} - \theta_{w850}$
Jefferson index	$1.6 \times \theta_{w925} - T_{500} - 11$
Convective available potential energy (CAPE)	$g \int_{LFC}^{LNB} \frac{T_v(\text{parcel}) - T_v(\text{environment})}{T_v(\text{environment})} dz$

Table 1. Definitions of a number of thunderstorm indices, where z is the (geopotential) height, T is the temperature ($^{\circ}\text{C}$), θ_w is the potential wet-bulb temperature ($^{\circ}\text{C}$), g is the acceleration due to gravity, LNB is the level of neutral buoyancy, LFC is the level of free convection, and T_v is the virtual temperature (K).

system turned out to be the HIRLAM Bradbury index, a number of predictors from the ensemble of advected lightning data (0-6 h projections only), the ECMWF 3-h convective precipitation sum and the HIRLAM Jefferson index. In the logistic regression²⁾ equations for the three different thresholds (50, 100 and 200 discharges/ 5 min.) the same predictors are used, but of course with different regression coefficients. The equations contain minimally 2 and maximally 5 predictors. The maximum number of predictors has been set to 5, because more than 5 predictors often appeared to result in overfitting.

Example case: June 25, 2006

Figure 1a shows an example of a probabilistic forecast of severe thunderstorms for 15-21 UTC on June 25, 2006 and Figure 1b shows the observed maximum 5-min. lightning intensity for the same period. In the morning the system already showed high probabilities of severe thunderstorms, especially in the south-eastern regions (Figure 1a). It is found that the 200 discharges/ 5 min. threshold was exceeded in 3 regions (Figure 1b). Inside the Netherlands the

weather alarm criterion has not been reached, but just outside (within the most south-eastern region in Figure 1b) it has. In fact this was the only case in 2006 in which the weather alarm criterion was met anywhere within the total area of the 12 regions. Of course, (probability) forecasts cannot be verified using only one single case, so objective verification results for the independent datasets are presented here.

Verification

We conclude from the verification results for 2006 (Figure 2) that the overall skill of the MOS thunderstorm forecast system (> 1 discharge) is good compared to the 2000-2004 climatology. The average Brier skill score (BSS)²⁾ of the 6 land regions (EMN, MMS, EMS, WXS, MXS and EXS)³⁾ shows a clear diurnal cycle with the highest skill in the afternoon (12 and 15 UTC) and evening (18 UTC). The average BSS²⁾ of the 6 coastal regions (WXN, MXN, EXN, WMN, MMN and WMS)³⁾ shows a diurnal cycle as well, but with a smaller amplitude and a phase shift of approximately 12 h. This can be partly explained by the smaller and

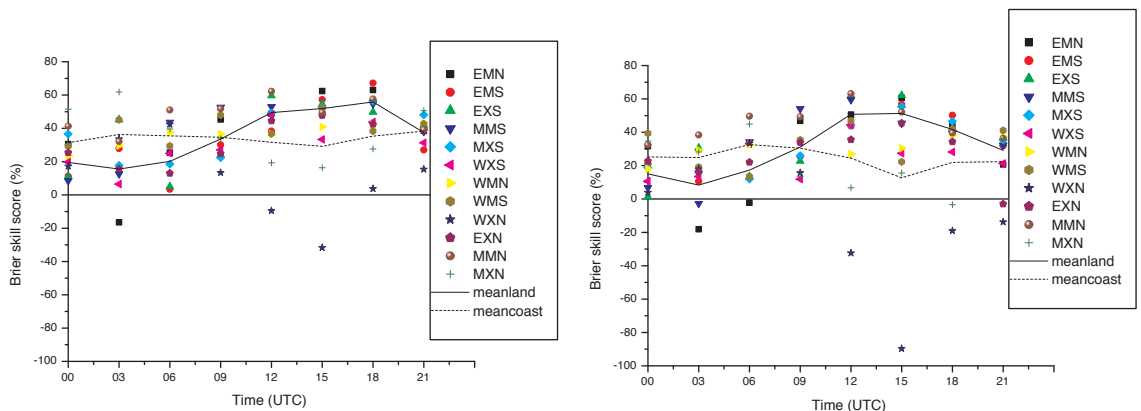


Figure 2. Brier skill score (BSS)²⁾ with respect to the 2000-2004 climatology, as a function of central verification time for the 8 runs of the MOS thunderstorm forecast system (threshold: 1 discharge) for all 12 regions (indicated by the different symbols). The solid (dotted) line represents the average BSS for the 6 land (coastal) regions (see text). The verification period is from 16 April to 15 October 2006. The left panel shows the 0-6 h forecasts and the right panel the 6-12 h forecasts.

different diurnal cycle in the occurrence of thunderstorms in the coastal regions compared to the land regions. The Brier skill scores for the 6-12 h forecasts (Figure 2b) are generally smaller than those for the 0-6 h forecasts (Figure 2a), as expected. Apart from the fact that the skill of a forecast system decreases with increasing forecast projections, the loss of the most important predictor for the 0-6 h projections (i.e. the percentage of the total number of advection ensemble members with ≥ 4 discharges) is expected to play a role as well. Finally, the Brier skill scores of this new thunderstorm forecast system are

generally higher than those of the operational system³⁾ (not shown).

Severe thunderstorms were relatively rare in the warm half-year of 2006. Because the period July to mid-October 2005, in which their frequency was about the same as in the 2000-2004 period, was more representative, we have verified the MOS system for severe thunderstorms over both periods. In Figure 3 reliability diagrams²⁾ are shown for the 0-6 h forecasts of 5 runs of the MOS severe thunderstorm forecast system based on the lowest threshold

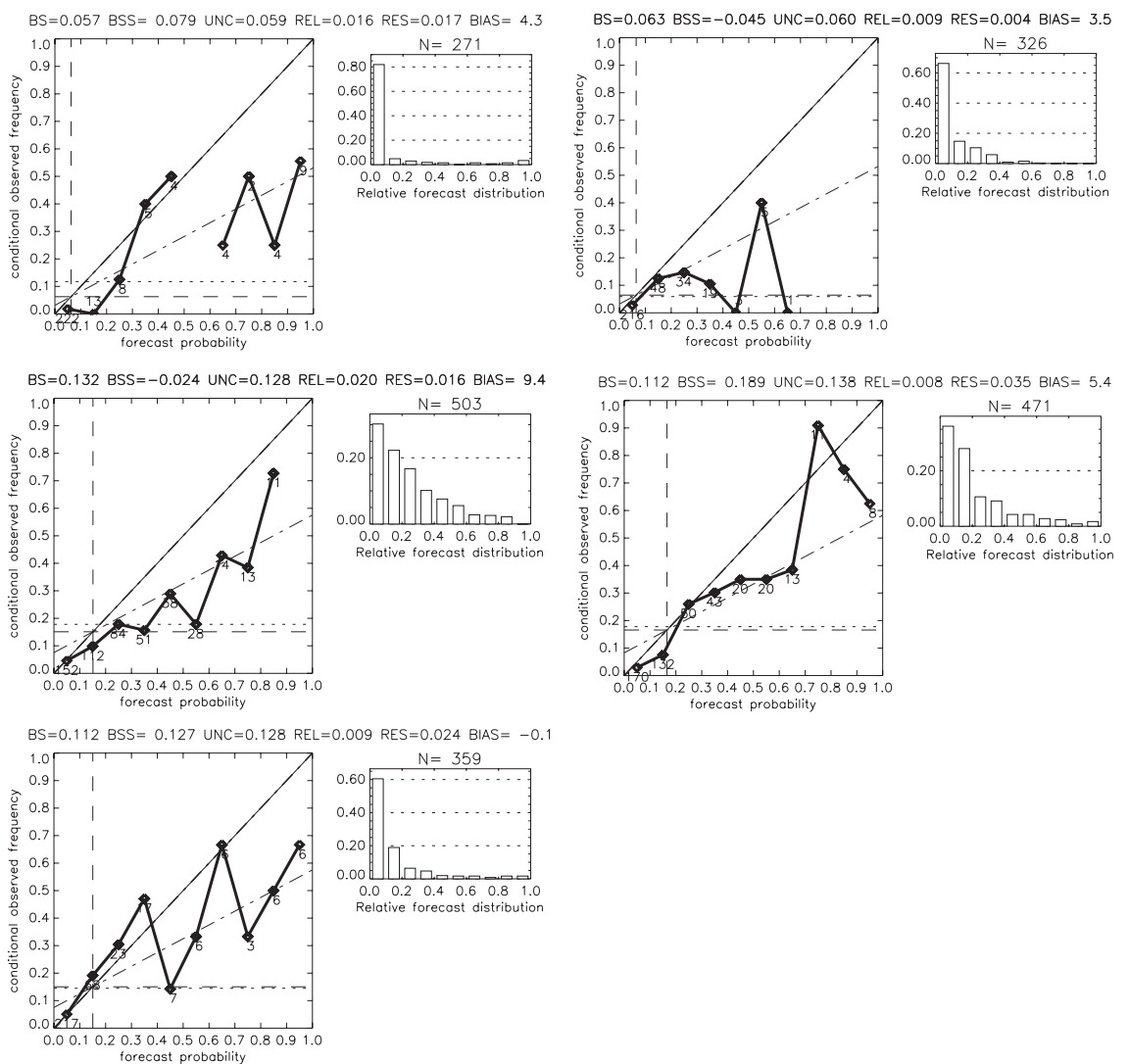


Figure 3. Reliability diagrams²⁾ for the 0-6 h forecasts of 5 runs of the MOS severe thunderstorm forecast system for the threshold of 50 discharges/5 min. The verification period is from 1 July to 15 October 2005 and from 16 April to 15 October 2006. In these diagrams the observed frequencies are shown as a function of forecast probabilities. The histograms indicate the frequency of the forecast probabilities. Valid for 00-06 UTC (upper left panel), 06-12 UTC (upper right panel), 12-18 UTC (middle left panel), 15-21 UTC (middle right panel) and 18-00 UTC (lower panel).

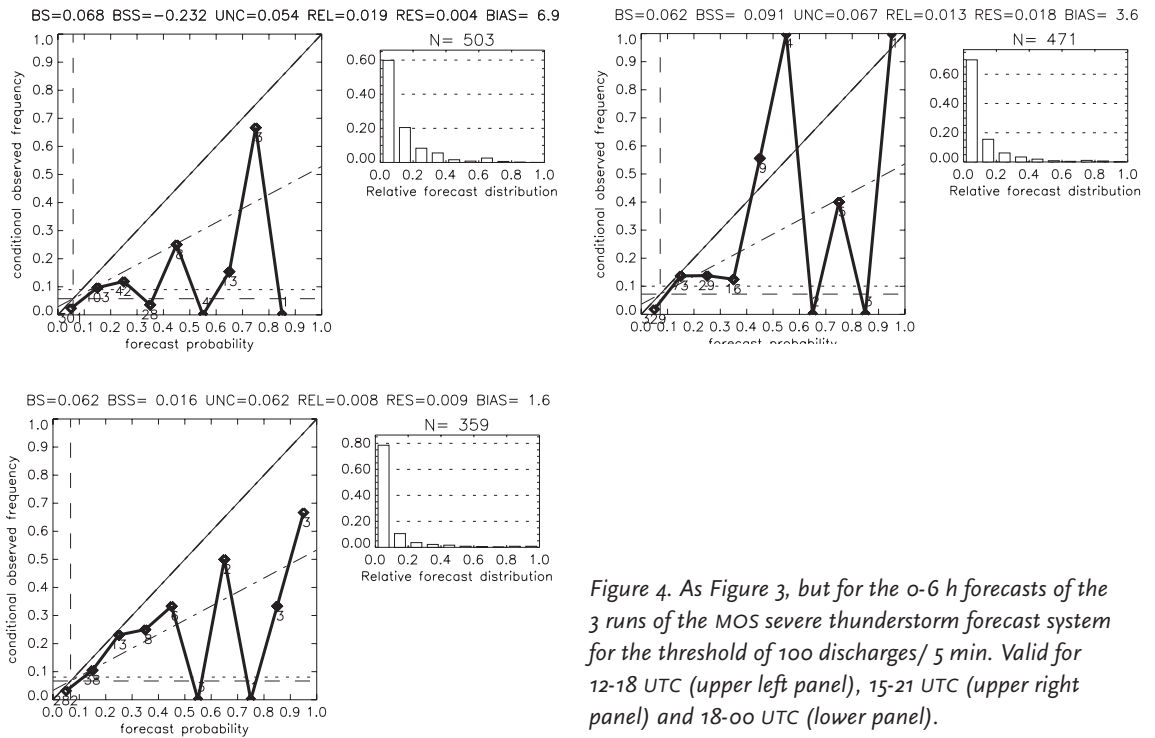


Figure 4. As Figure 3, but for the 0-6 h forecasts of the 3 runs of the MOS severe thunderstorm forecast system for the threshold of 100 discharges/ 5 min. Valid for 12-18 UTC (upper left panel), 15-21 UTC (upper right panel) and 18-00 UTC (lower panel).

Future developments in this MOS system may consist of even more extreme criteria for severe thunderstorms and the inclusion of advected MSG data as a potential predictor source for the 0-6 h projections

of 50 discharges/ 5 min. Figure 4 shows reliability diagrams based on the higher threshold of 100 discharges/ 5 min. The severe thunderstorm forecast system shows the highest skill in the evening (15-21 UTC) with the highest skill for the lowest threshold, as expected. The reliability diagrams for the period July to mid-October 2005 show a better overall skill than the diagrams for the warm half-year of 2006⁷⁾. Factors that may have contributed to the lesser skill in the warm half-year of 2006 are sampling effects, the increased ECMWF model resolution starting February 2006 and/or the low frequencies of severe thunderstorms. Nevertheless, the evaluation of the system by forecasters during the period May 24 2006 to mid-October 2006 was positive⁷⁾. Apparently, a forecast system can be much more useful in practice than the (harsh) objective verification results might suggest. We conclude from the verification results shown here (Figures 3 and 4) that the overall skill of the severe thunderstorm forecast system is reasonable compared to the 2000-2004 climatology, at least for the thresholds of 50 and 100 discharges/ 5 min. Conclusions for the higher

threshold of 200 discharges/ 5 min. can only be reached when a dataset with more severe thunderstorm cases will become available. Finally, we would like to stress that the verification results for the independent dataset during the development were good for all thresholds (not shown).

Outlook

The pre-operational KOUW system will be extended to include the 12-48 h projections. Subsequently, this system will replace the operational (severe) thunderstorm forecast system³⁾. Future developments in this MOS system may consist of even more extreme criteria for severe thunderstorms⁴⁾ and the inclusion of advected MSG data as a potential predictor source for the 0-6 h projections.

-
- 1) Siebesma, A.P. and W.C. de Rooy, 2007. *An integral approach for the representation of turbulence, convection and clouds in weather and climate models*. This Biennial Report.
 - 2) Wilks, D.S., 2006. *Statistical methods in the atmospheric sciences, 2nd Ed.*, Academic Press, 627 pp.
 - 3) Schmeits, M.J., C.J. Kok and D.H.P. Vogelezang, 2005. *Probabilistic forecasting of (severe) thunderstorms in the Netherlands using model output statistics*. *Weather and Forecasting*, **20**, 134-148.
 - 4) Schmeits, M.J., C.J. Kok, D.H.P. Vogelezang and R.M. van Westrhenen. *Probabilistic forecasts of (severe) thunderstorms for the purpose of issuing a weather alarm in the Netherlands*. Submitted to *Weather and Forecasting*.
 - 5) Wessels, H.R.A., 1998. *Evaluation of a radio interferometry lightning positioning system*. KNMI Scientific Report WR 98-04.
 - 6) Noteboom, S., 2006. *Processing, validatie, en analyse van bliksemdata uit het SAFIR/FLITS systeem*. KNMI Internal Report IR 2006-01 (in Dutch).
 - 7) Schmeits, M.J., C.J. Kok, D.H.P. Vogelezang and R.M. van Westrhenen. *Kansverwachtingen voor onweer ten behoeve van uitgifte weeralarm (KOUW)*. KNMI Internal Report IR 2007-03 (in Dutch).