AiMT Advances in Military Technology
Vol. 3, No. 2, December 2008

Prediction of Ice Formation on Earth's surface

K. Dejmal[1] and V. Répal[*2]

[1] *Department of Military Geography and Meteorology, University of Defence, Brno, Czech Republic*
[2] *Department of Military Geography and Meteorology, University of Defence, Brno, Czech Republic*

The manuscript was received on 30 April 2008 and was accepted after revision for publication on 18 September 2008.

Abstract:

"The Road meteorology" is a branch of an applied meteorology, which deals with the meteorological elements and phenomena in the light of their influence over running of communication namely the major roads and motorways on a given territory. Road meteorology tries to solve the theoretic problems pair with the meteorological support of the road maintenance.

Keywords:

Icing, prediction, road meteorology, criteria of successfulness

1. Introduction

"The Road meteorology" is a branch of an applied meteorology, which deals with the meteorological elements and phenomena in the light of their influence over running of communication, namely the major roads and motorways on a given territory inclusive of bridges and tunnels constructions. Road meteorology tries to solve the theoretic problems pair with the meteorological support of the road maintenance.

The most significant element is the network of the specialized measurement which provides actual data along the main roads and it is possible this one to mark like a Road weather information system. Among the measurements belong values of the classical weather elements and also special temperatures measuring and measuring of road surface. It is evident that increasing attention is applied to dangerous sections, in the light of the production of black ice, frost, drifting snow etc. Most widespread station on territory of the Czech Republic is weather-station "Rosa" of Vaisala production. We have got a data series from winter season from years 2002-2005 with measured period of 12 minutes from road meteorological stations Bystřice nad Olší, Cheb Estakáda, Cheb Jindřichov, Chrlice, Kocourovec, Mirošovice, Nová Ves, Ostrov u Stříbra, Poříčany, Rozvadov, Rudná, Rudná Okruh, Velký Beranov. For statistical processing were used measured values of following quantities:

- Air temperature in 2 m above ground level [°C];

- Dew point temperature [°C];
- Temperature in 5 cm under road surface [°C];
- Relative humidity [%];
- Road surface temperature [°C];
- Freezing point [°C];
- Road state.

2. Evaluation Of Method Used For Prediction Of Ice Formation Adding

Occurrence of ice formation was evaluated by the Robitsch's method (calculation according to Řezáčová [1] and calculation according to Červený [2]) and Luers design method of estimation of water-vapour content [3]. These methods were chosen pursuant to requirements leading to maximal objectification, i.e. to eliminate human factor. [4]

In Robitsch's method by Řezáčová (abbreviation REZ) the procedure is based on calculation and comparison water-vapour pressure with respect to the water droplets for given dew point temperature and maximum water-vapour pressure with respect to the ice for given air temperature in standard level.

$$E_w(t) \cdot RH \cong E_w(t_d) > E_i(t) \tag{1}$$

where

E_w… maximum water-vapour pressure with respect to the water for given temperature,

E_i… maximum water-vapour pressure with respect to the water for given temperature,

RH... relative humidity.

If the equation (1) comes true, then in such given conditions the ice formation is predicted on Earth's surface.

In Robitsch's method by Červený (CER), the technique is based on calculation of relative humidity of air for given temperature, when is air in respect to the ice saturated. If real relative humidity (acquired from measurement) is greater than one calculated is analysed ice. Calculated relative humidity:

$$F_i = \frac{E_i}{E_w} \cdot 100\% \tag{2}$$

In Luers's method (LUR) we directly work with characteristic of moistures [4]. In method is counted entire amount of all stages of water which could be deposited as a icing (*vl*) in layer above surface and comparison of results with value 0,11 g/m. Estimation of *vl* is based on calculation of humidity mixing ratio

$$vl = (1/2.87) \cdot (w_0 - w_1) \cdot \frac{p}{T}, \tag{3}$$

where

e…vapour pressure with respect to the water for given temperature of air,

p…constant atmospheric pressure on sea level, p = 1013.25 hPa,

$w_{0/1}$…humidity mixing ratio in 2 m and in layer adjacent to ground accordingly,

T...constant temperature of air on sea level [K] [4].

To assess ability of single methods to forecast ice formation on roads were used criteria CSI (Threat score – critical success index), POD (probability of detection), FAR (false alarm ratio), BIAS (systematic errors), HSS (Heidke skill score), EQS (Hansen and Kuipers discriminant) [5] and own characteristic meaning percentage of successful forecasts (NGOOD) based on use of contingent tables. Value 0 and 1 accordingly represent, that event fail, or occurred, whereas first figure features reality, i.e. detection of ice formation by sensor, and second figure prediction of ice formation.

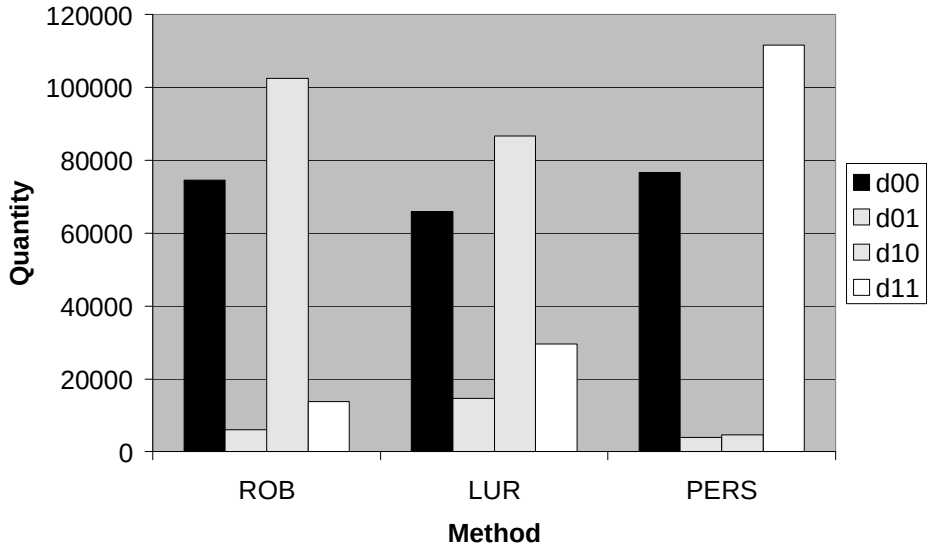

Fig. 1 Quantity of all possible occurrences (forecast vs. observation).

Supporting narrative used in all graphs:
ROB – Robitsch method, LUR – Luers method, PERS – persistent forecast;
HSS – Heidke skill score, CSI – critical success index, POD – probability of detection, FAR – false alarm ratio, BIAS – bias score, NGOOD – proper prediction, EQS – equitable score;
d00…Correct Negatives, d01…False Alarms, d10…Misses, d11…hits.

From graphs 1 and 2 results follows that the best forecast is attained by simple repetition of prognoses, i.e. persistent prediction (PERS), which is misguided, because if icing occurs and sensor detects icing e.g. for six hours, whereas interval following is about twelve minutes, will be successfulness of such prognoses by simple repetition thirty times successful and only twice poor. According to the criteria in graphs the using of single methods will not provide forecast in sufficient quality. Nevertheless different values of statistical criteria achieved by evaluation based on different quantity describing state in ground layer atmospheres directly urge to their mutual combination. Those methods therefore might be combining at prognoses of ice formation, so it is possible forecast ice formation with higher accuracy. For this purpose was used method of linear regression.

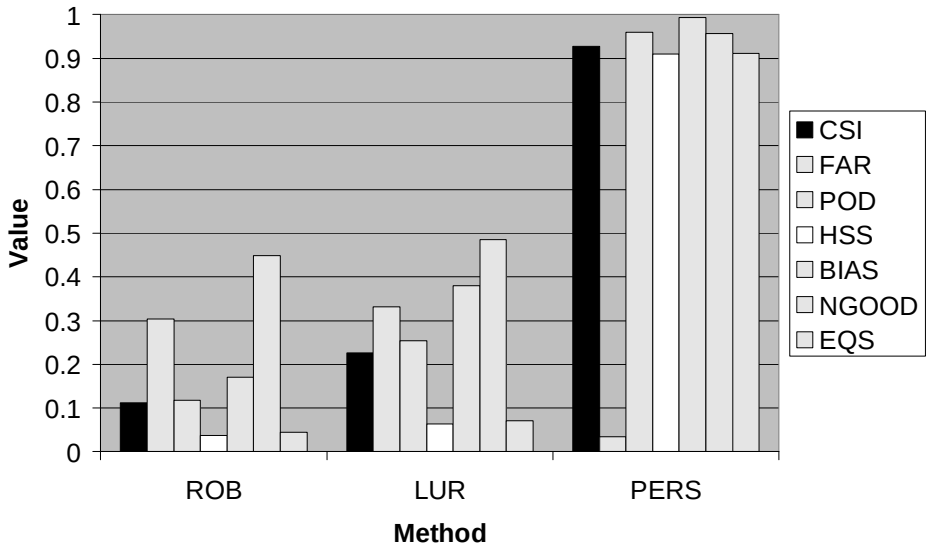

Fig. 2 Evaluation with reference to criteria of successfulness of single methods

3. Exploitation Of Linear Regression

Linear regression was extract o pursuant to two years of teaching. Third year was then used for testing of prognoses.

As an autonomous variables were considered values 0 or 1 given by measurement of sensor, i.e. 0, when sensor did not detect an icing, 1, when icing was detect by sensor. Coefficients of linear regression equation were derived through the use of method of the smallest squares. Results of prognoses then will be value 0 or 1 in cases, when icing will be occurred or not.

3.1. Prediction Of Ice Formation According To Single Methods And Their Combinations

In linear regressions were used following combinations of predictors:

- $R(vl, vc = RH - F_i, vr = E(t_d) - E_i(t))$ – equation of linear regression based on quantities used in methods ROB (REZ, CER) and LUR;
- $R(vr)$, resp. $R(vc)$, resp. $R(vl)$ – independent equations of linear regression based on singling methods;
- $R(t, t_d)$, resp. $R(t, t_d, t_f)$ – equation of linear regressions derived on combination of following parameters, e.g. combination of air temperature and dew point temperature, respectively on both of these parameters and temperature of road with the condition, that temperature surface would be smaller or equal to temperature of freezing (endeavour to filter off the influence of salting).

In graph are the regression method termed by $R(xxx)$, whereas the contemplated regresses are state in brackets.

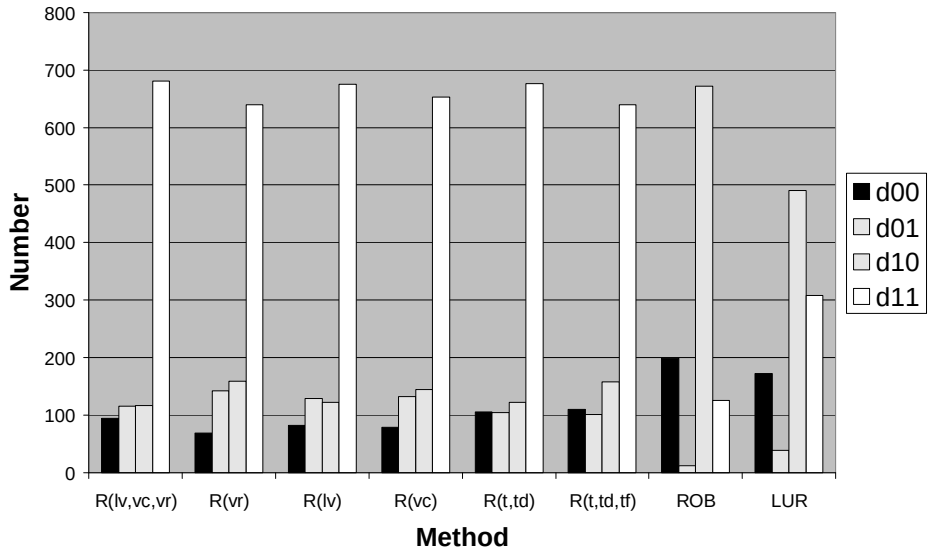

Fig. 3 Absolute frequency of ice formation prediction in the carriage way according to single method and their combinations

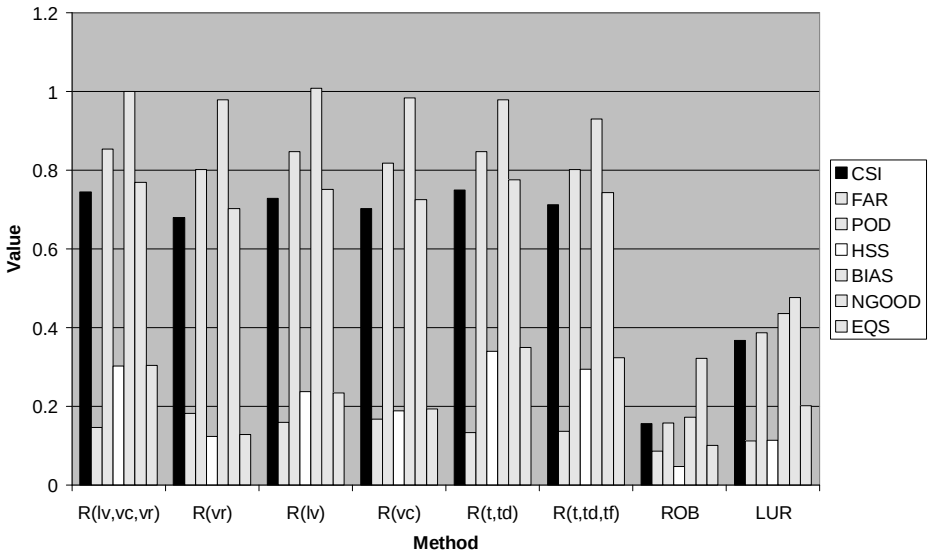

Fig. 4 Criteria of successfulness of ice formation in the carriage way centre according to single methods and their combinations

For the comparison there are in graph 3 and 4 state also results of regression analyses coming from measured values in terms, when icing occurred. In spite of fact, that we take absolute accuracy values of temperature, dew point temperature and road surface temperature, not their prediction, the results of regression analyse of combination

singling methods are sufficiently good. It can be manifested by combination of single methods we achieved higher successfulness at prognoses of ice formation than by single methods.

4. Conclusion

The main outcome is simple forecast model of prognoses of ice formation based on comparison single empirical methods for the ice formation forecast in the free atmosphere and methods based on regression model. Results of prognoses is value 1, which means an icing will occur, or 0, when appropriate method will ice formation reject. Method are ordered according to their long-term successfulness assessed by single criteria (CSI, POD, FAR, BIAS, HSS, EQS), that is as well possible before calculation determined. This procedure leads to a prognosis that is not dependent upon subjective guesswork of meteorologist, because to users isn't given any possibility to influence prediction work. The issue has been also theoretically described and partly solved in doctoral thesis.

Problems reaching without doubts behind limits of this work due to improve the quality of prognoses of ice formation are quality of input data. Accuracy of prognoses of thermal and moisture characteristics coming into the calculation then will have a direct influence on prediction of ice formation thereby will presage limits of quality of prediction.

References

[1] ŘEZÁČOVÁ, D. and ŠKOLOUD, O. Evaluation of air sounding information by software TEMP-GRAF. *Meteorological Bulletin*, 1993, vol. 46, no. 2, pp. 71-77 (CHMI, Praha) ISSN 0026-1173.

[2] ČERVENÝ, J. Icing on the aeroplanes (in Czech). *Meteorological Bulletin*, 1950, vol. 4, no. 1-2, pp. 19-21 (CHMI, Praha) ISSN 0026-1173.

[3] LUERS, JK. *One-dimensional icing forecast model. Technical description*. Dayton (Ohio, USA) : University of Dayton Press, 1988.

[4] RÉPAL, V. *Objectification of icing forecasting for meteorological support of operation* (in Czech) [Ph.D. thesis]. Brno : University of Defence, 2007, 82 p.

[5] MURPHY, AH. and DANN, H.. Forecast evaluation. In AH. Murphy and RW. Katz (eds.) *Probability, Statistics, and Decision Making in the Atmospheric Sciences*. Boulder and London : Westview Press, 1985, pp. 379-437.