Model for Road Icing Forecast and Control

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ABSTRACT

A technique is developed for diagnosing different types of ice, frost and rime phenomena based on the classification of processes causing ice generation on the road. Based on this technique, an algorithm to forecast and diagnose glazed frost on the road has been worked out, which is realized as a model program demonstrating the potentials of the technique involved. According to this technique, glazed frost on the road is forecasted in two steps. As a first step, the road temperature is forecasted with sufficient lead-time. Secondly, based on the forecasted road temperature values and some other parameters, a diagnostic analysis and forecast of glazed frost events is performed.

The model program is run with a certain set of sensors available at an automated road weather station (RWS) and meant for automated information systems to prevent glazed frost by using de-icing liquid.

A technical problem has been solved, enabling data scanning in an interface suitable for examination, and software has been developed for personal computer to distinguish the corresponding types of events in the course of road weather station measurements.

The verification of the model during two winter seasons at two automated road weather stations has demonstrated satisfactory results. The relative faultless diagnoses of the events concerned amounted to 83% for the winter of 1996/1997 and 79% for the winter of 1997/1998.

Keywords: forecast model, diagnose of ice, de-icing liquid, road icing control

1. INTRODUCTION

Current approaches to developing automated systems of prophylactic road de-icing maintenance imply the availability of an efficient model of slipperiness forecast optimized for a particular area. The effort to reduce de-icing agents consumption and thus to decrease the adverse effects on the environment induces the upgrading of the model employed.

This paper presents a model for diagnosing and predicting road icing and packed snow formation based on measurements of automated road weather stations (RWS). The first version of the model BEST-98 by N. Bezrukova and E. Stulov [2] was validated using measurements from automated RWS of the Swedish company Telub in the two winter seasons of 1996/1997 and 1997/1998 and upgraded in 1999 by the authors in the new version of BEST-2000. In 2002 and 2003, the model was modified and adjusted for the automated road weather stations of the German Lufft Company. This modification consisted in considerable improvement of the meteorological forecasting and diagnosing block and the development by M. Khalili of a chemical block governing de-icing agents dispensing [3]. Additional introduction of the chemical block extended the scope of application of the new program complex ICE_2003 to include both conventional road maintenance and use in automated systems of road icing forecast and control.

2. ICE LOADING IN MOSCOW REGION

The cold season of Russia's European part is characterized by atmospheric circulation processes leading to variable weather, frequent air mass changes accompanied by precipitation phase changes close to and below 0ºC. All this makes ice loading and rime formation typical of cold season's weather in this area [1].

Moscow area is characterized by the following types of ice and rime phenomena, when slipperiness is generated: ice, glazed frost, atmospheric glazed ice, granular and crystalline rime, radiation rime frost, hoar-frost, packed snow. For motor transport, such phenomena as glazed frost, atmospheric glazed ice, hoar-frost, and packed snow are the most dangerous ones.

Ice coating ("black ice") includes such events as freezing 'wet', freezing water covering (including water from melting snow), freezing rain or freezing drizzle, rainwater freezing on a cold surface, and freezing dew.

Frost includes events such as frost due to radiative cooling, frost during periods with increasing air temperature, but still cold road surface, frost due to warm advection, supercooled fog water (granular rime), fog water, and freezing on a cold surface.

Snow includes wet snow and snow packed by traffic.

The authors have fulfilled climatic zoning for the road network of Moscow Region and the neighboring ones [1]. Based on the classification by types of ice, frost and rime phenomena, typical combinations of air temperature, humidity, dew-point temperature, type and amount of precipitation, all of them responsible for the above diversity of ice formations and slipperiness on the road, have been formalized. Model graphs of the variation of parameters for basic types of ice/snow/hoar-frost deposition are plotted in Fig. 1 using long-term observational data on atmospheric ice deposition presented in the [7] and [9].

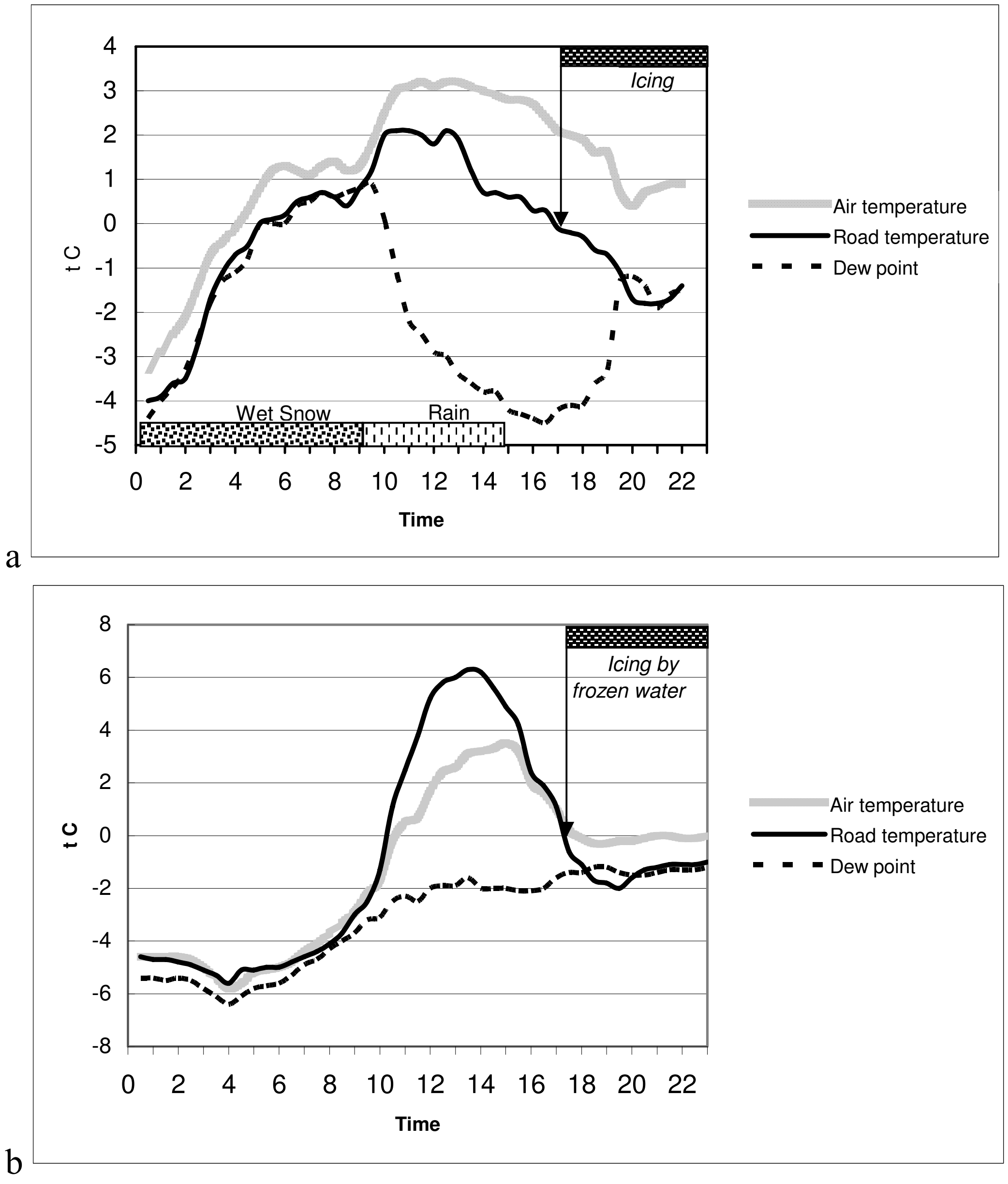


Fig. 1 a, b. Model graphs of the variation of parameters for basic types of ice when slipperiness is generated: snow deposition (a), frozen water (b).

3. FORECAST MODEL DESCRIPTION

Russia is lacking a regular network of road weather stations, although a certain progress has been made in its development: the ring motor road around Moscow has been equipped with seven stationary automated road weather stations. However, there is still no regular data exchange between the stations of different subordination and prognostic divisions of the Weather Service. As a first step in developing the model, the authors had to solve the problem of road icing/slipperiness forecast by automated RWS measurements at a single point. This required forecasts timely enough for road treatment with de-icing agents using motor vehicles. For the 1st class road maintenance, a forecast must be issued 1 to 1,5-2 hours in advance [8].

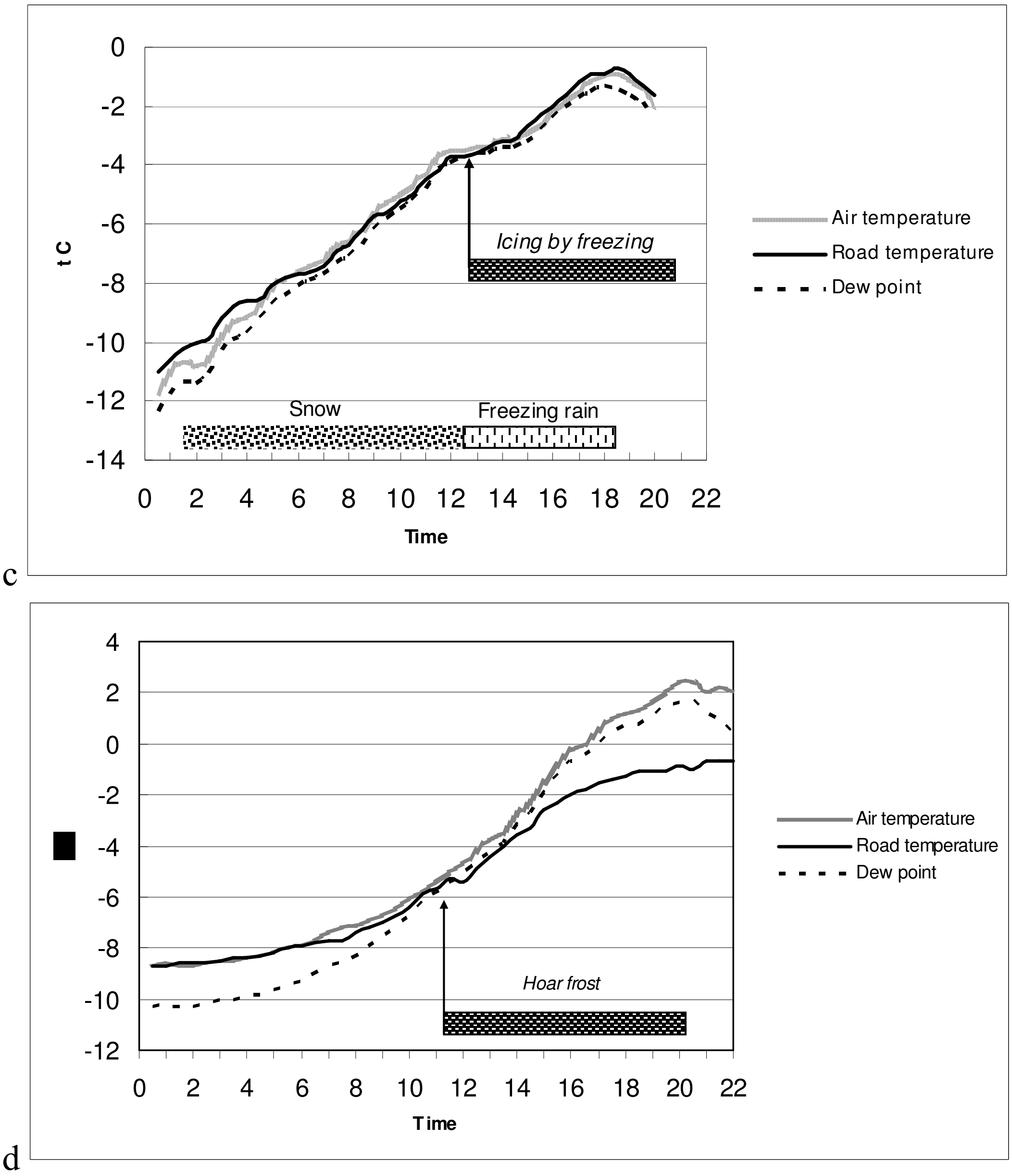


Fig. 1 c, d. Model graphs of the variation of parameters for basic types of ice: freezing rain (c), frost (d).

In lots of models, the moment of ice formation on the road is predicted by road temperature (T_r) approaching dew-point (T_d) within a hazardous range close to 0ºC. The critical temperature difference $\Delta T = T_r - T_d$ is commonly taken to be 0.25 – 0.5ºC. This method, straightforward, but crude enough, leads to numerous false alerts and misses of slipperiness events that are not associated with the above temperature difference, as in case of snowfalls. Apart from ice, the traction coefficient on road slopes is reduced on snow compacted by motor vehicles at temperatures close to 0ºC. Note that the contribution of snow to road slipperiness is especially pronounced on the European territory of Russia. A more reliable prediction of road state may build upon identification of typical ice loading characteristic of a given area, using RWS measurement. Each type of ice and rime phenomena in the model is considered as a complex of weather elements with certain values and a certain dynamics of the values variation. The model ICE_2003 includes:

- a classification of typical models of ice events;
- road surface temperature forecast;
- a scheme of automated search and identification of such events in analyzing measurement data and their prognostic values;
- a system of predicting road ice formation.

Slipperiness forecast is produced in two steps.

The 1st step: road surface temperature is predicted by the developed schemes of road temperature forecast, only using data from automated RWS sensors. The most important is the prediction of road surface temperature change as the temperature approaches the freezing point.

Inertial forecast for a period from 30 min. to 2 hour is only applied at a smooth temperature change resulting from warm /cold advection. With an abrupt change in this process when the role of diurnal temperature variation increases, the probability of errors within ranges close to extremes rises sharply, the changes in the prognostic curve then falling behind real measurements. The model allows for diurnal temperature variation by distinguishing its two basic types such as: *advection type* where time variation of meteorological elements is due to the air mass changing; *air-mass type* where changes in meteorological elements occur due to diurnal temperature variation. The advection type model is applied for inertial forecast.

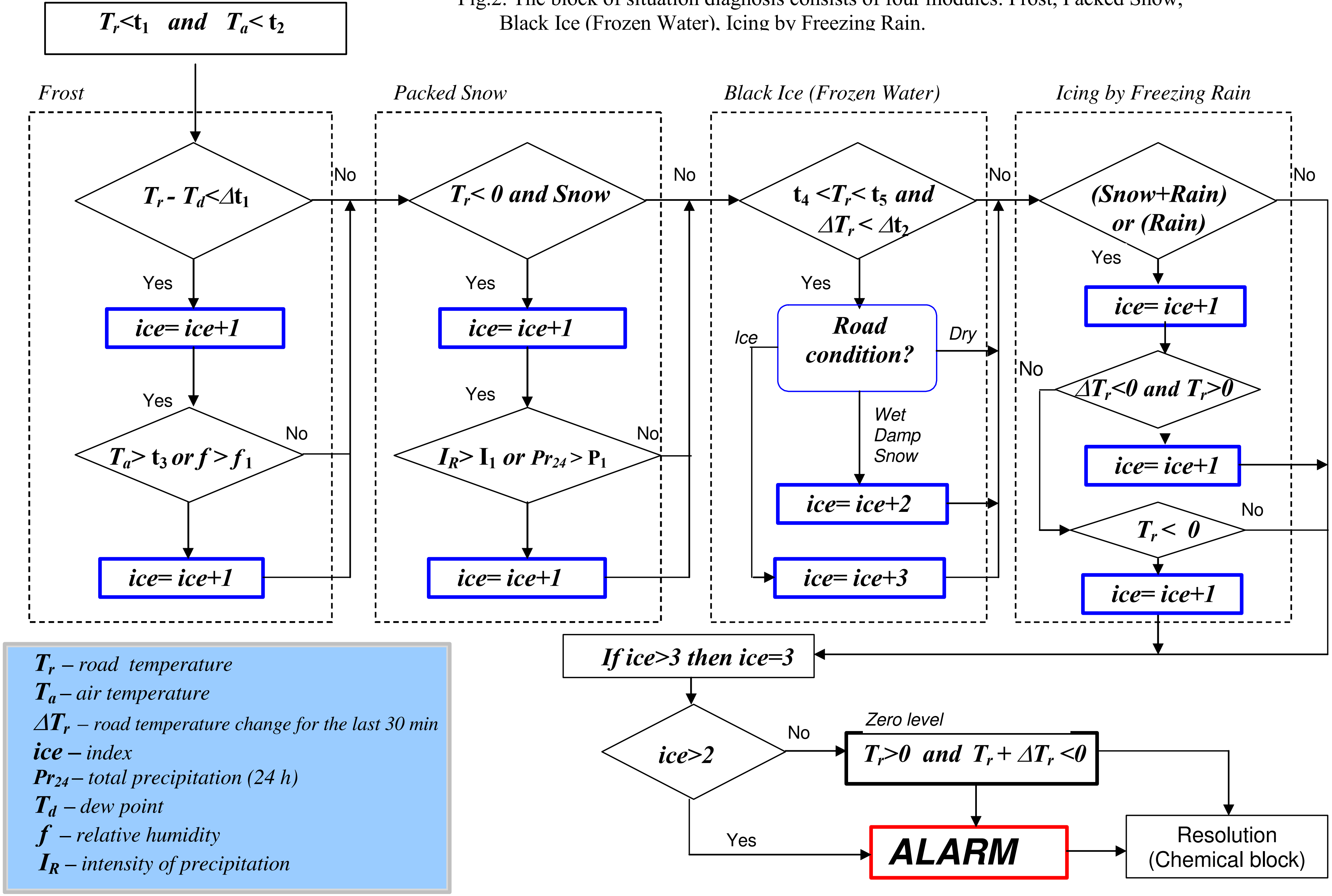
To inertial predict road icing 30 to 120 min. in advance, RWS must have sensors to measure road surface and air temperatures, relative humidity, precipitation type and intensity, and road surface state. To predict more reliably for over 1 hour in advance, the model allows the use of an approximate solution of the heat balance equation. However, additional sensors are required to measure wind speed and direction, temperature at depths of 5 and 30 cm, radiation balance in the range of 0.3 – 40 μ, and atmospheric pressure. The data of RWS measurements presenting input data are given in Table 1.

The 2nd step: Based on prognostic road temperature values, a diagnose of ice formation on road surface is produced.

№	Measurement data and parameters	Dimensional representation	Measurement data and parameters using for…						
			Identification (ID)	Forecast Block	Diagnosis Block				Chemical Block
					Hoar Frost	Packed Snow	Glazed Frost Frozen Water	Icing by Freezing Rain	
1-2	ID station, ID sensor	-	●						
3	Status	0 or 1	●						
4-6	Date, time	date, time	●						
7	T_a	0,1°C		●	●	●	●	●	
8	T_r	0,1°C		●	●	●	●	●	●
9	T_{-5cm}	0,1°C		○					
10	T_{-30cm}	0,1°C		○					
11	Relative humidity	0,1%		○	●				
12	Wind direction	1°		●					
13	Wind speed	0,1 m/s		○					
14	Precipitation type in code numbers	snow, rain, none				●	○	●	
15	Precipitation intensity	0,01mm/min				●			
16	Atmospheric pressure	100 Pa							
17	Net radiation	1 W/m^2		○					
18	Road condition in code numbers	dry, damp, wet snow, ice, frost, freezing wet, residual salt					●		●
19	Concentration	0,1%							●
20	Freezing temperature	0,1°C							●
21	Water film	0,001 мм							●

Table. 1. Measured input data used in the model (○ - parameters employed to forecast T_r using the heat balance equation.).

Fig.2. The block of situation diagnosis consists of four modules: Frost, Packed Snow, Black Ice (Frozen Water), Icing by Freezing Rain.



T_r – road temperature

T_a – air temperature

ΔT_r – road temperature change for the last 30 min

ice – index

Pr_{24} – total precipitation (24 h)

T_d – dew point

f – relative humidity

I_R – intensity of precipitation

4. DIAGNOSINC AND FORECASTING ROAD ICING

In analyzing a current situation, the following parameters and their combinations are used: T_a, T_r and T_d, which are air, road, and dew-point temperatures, respectively, relative humidity f, road temperature change ΔT_r, for the last 30 min, type and intensity I_R of current precipitation and their amount Pr_{24} for the last 24 hours.

The diagnostic scheme (Fig. 2) builds on a principle of a stepwise filter distinguishing situations with conditions typical of different types of icing phenomena. Depending on the extent of situation hazard, the time concerned is assigned a conventional index of ***ice*** formation 0, 1, 2, 3…. When the index ***ice*** is equal to or more than 2, an ***"alarm"*** signal is given.

The scheme is run on condition that $T_r < \mathbf{t}_1$, $T_a < \mathbf{t}_2$ (Table. 2). The critical $\mathbf{t}_1$ value is selected taking into consideration the sensor's precision, possible temperature decrease within the next 30 min. At $\mathbf{t}_1 > 2{,}0°C$, ice formation on road surface is thought unlikely. Consecutively, block by block, conditions for possible formation of one or another type of road icing are examined.

Parameter	Range of values	Unit
$\mathbf{t}_1$	0,5…2,0	°C
$\mathbf{t}_2$	3….6	°C
$\mathbf{t}_3$	-5….-10	°C
$\mathbf{t}_4$	-2,0….-0,5	°C
$\mathbf{t}_5$	0….1,0	°C
$\Delta\mathbf{t}_1$	0….1	°C/hr
$\Delta\mathbf{t}_2$	-0,1 ….-1,0	°C/hr
f_1	85 — 95	%
$\mathbf{I}_1$	0,3….0,5	mm/hr
$\mathbf{P}_1$	1….5	mm/24hr

Table.2. Parameter changes as shown on the scheme in Fig.2.

The block of diagnosing frost checks for the condition of direct water vapor sublimation on the road, i.e., a possibility of dew-point temperature exceeding road temperature.

The block of packed snow diagnosing is run in the presence of solid precipitation at road temperature below 0°C, in case of heavy precipitation at $I_R > \mathbf{I}_1$ or when the integral amount of precipitation for the last 24 hours $Pr_{24} > \mathbf{P}_1$.

The block of "black ice" diagnosing distinguishes situations that may lead to the freezing of precipitation that fell out before (including water from melting snow) due to road cooling tendency during the last measurement interval and the coincidence of two conditions: $\mathbf{t}_4 < T_r < \mathbf{t}_5$ and $\Delta T_r < \Delta\mathbf{t}_2$.

The block of diagnosing ice coating formed from supercooled rainwater (freezing rain, freezing drizzle) checks the combinations of conditions characteristic of supercooled liquid precipitation from clouds. As it is impossible to determine temperature based on RWS data, all cases with liquid or mixed-type precipitation at road temperatures below $\mathbf{t}_1$ are considered hazardous. In using model forecast road/air temperatures, the whole set of diagnosing blocks are run in a forecast mode.

5. CHEMICAL BLOCK OF PROPORTIONING DE_ICING ACTIONS

The chemical block is based on a simple and clear model of freezing temperature dependence on the initial agent concentration and its further dilution (considering forecasted precipitation and actual liquid film thickness) following its deposition onto the road surface.

In the model, apart from road surface temperature, the amount of water on the road surface is also predicted, which is necessary in case of heavy precipitation for launching preventive actions.

	Output data	
№	Parameters	Dimensional representation
1-3	ID station, ID sensor, Status	N, N, 0 or 1
4-6	Date, time	date, time
7	Forecast value of T_r	0,1°C
8	Index ***"ice"*** intensity	1, 2, 3
9	***"alarm"***	0 or 1
10	Recommendations	1 g/m^2
11	Signal of emergency situation	0 or 1

Table. 3. Output computational model data.

The algorithm of issuing recommendations for salt dispersal over the road surface is aimed at preventive anti-ice road treatment in the zone of the system's responsibility. Also, the algorithm is to minimize the agent consumption. The recommendations are given in the form of surface densities (g/m^2) of the dispersed salt. The output computational model data are given in Table 3.

In issuing recommendations, the algorithm is guided by information about the road surface state at the road sensor location. Accordingly, the position of this sensor must specifically suit the zone of responsibility concerned. Besides, the distribution of agent over the road surface is assumed to be uniform.

In some cities, in order to reduce ecological loading, legal limitations on the amount of agent to be dispersed are introduced. If the predicted amount of agent per unit area to be used exceeds the adopted norm, a signal of emergency is applied and automated agent dispersal is stopped. This may occur due to a very low road surface temperature, a large amount of water on the road, or a combination of these factors. The program continues running and issuing recommendations for road maintenance services to switch to another de-icing technique. In such a case, it is recommended that conventional means of road maintenance, say, motor snow-removers, be employed.

6. MODEL EVALUATION

During the winters of 1996/97 and 1997/98, the model was being evaluated using data from two weather stations: RWS-102 of Road Maintenance Office (RMO-14) in Oktyabrsky, Moscow Region, and RWS-104 in Tver Region. The model diagnosis and the test 2-hr. forecast were compared with the regular records in the log of the RMO shift supervisor and hourly data from the nearest weather stations.

The model verification using the RWS-102 data indicated that the relative skill score of slipperiness diagnosing was 79% (Fig.3) in the winter 1997/98 when no precipitation measurements were available at the station and 83% (Fig.4) in the winter 1996/97, with false alerts of 13 and 15% and missed events of 8 and 2%, respectively.

The model verification using the RWS-104 data (Tver) showed faultless diagnosing in the winter 1997/98 to amount to 89%, with false alerts of 10% and missed events of 1%. The results of verifying the scheme run in a diagnosing regime show its suitability for use in a prognostic regime.

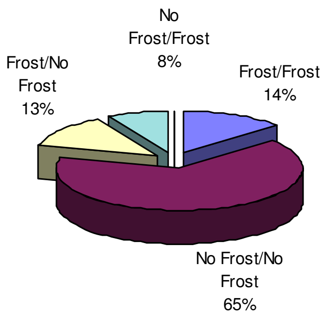


Fig. 3. Percentage of Correct Frost Diagnosis for 125 days of the winter 1997/1998.

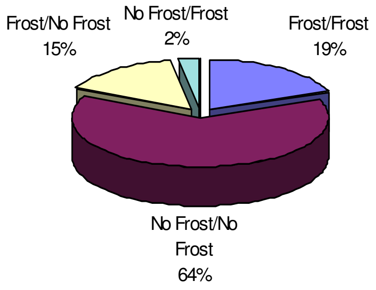


Fig. 4. Percentage of Correct Frost Diagnosis for 135 days of the winter 1996/1997.

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