AUTOMATED ROAD ICE NOWCASTS AND INTERNET/INTRANET APPLICATION

J. Shao and P. J. Lister

Vaisala Ltd., 349 Bristol Road, Birmingham B5 7SW, UK
Tel: (+44) 121 683 1200, Fax: (+44) 121 683 1299
Email: jianmin.shao@vaisala.com, jonathan.lister@vaisala.com

1. Introduction

In western Europe and many other countries, winter is characterised by cold and wet weather, resulting in road surface covered frequently by snow and ice and hence dangerous driving conditions for road users. One of the most effective and least expensive measures to tackle the problem is to use a numerical road ice prediction model together with pre-salting practice. Accurate and timely forecasts of when and where road surfaces will freeze are important for highway engineers responsible for winter road maintenance. To fulfil this task, an automated short term (3 to 6 hours ahead) road ice prediction model was developed (Shao & Lister 1996) and has been used in real time operation since then.

At the same time, computer networks have been growing explosively. The growth of the local Intranet and global Internet has an important impact on business and economy. Data networks have made telecommuting available to companies as well as individuals, and have changed business models.

This paper describes a technique to improve model forecasts by automatically tuning physical parameters required by the model and an application of Intranet/Internet for information gathering and information dissemination for winter road maintenance.

2. The model

The ice prediction model used in this study is based on unsteady one-dimensional heat conduction within the road sublayers, together with calculation and projection of initial and boundary condition for the model. The governing equation of the model is

$$C\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}(k\frac{\partial T}{\partial z})$$

where, C is the heat capacity, κ is the thermal conductivity, and T(z,t) is the temperature at time t and depth z. It is assumed that the road surface and its underlying sublayers are horizontally homogeneous so that heat transfer in a lateral direction can be neglected.

To run the model, an initial condition, and upper and lower boundary conditions are needed. The initial thermal condition prescribes the temperature profile within the road sublayers. The lower boundary condition (usually at a 1 m depth) is treated as a climatological constant. The upper boundary condition is, however, described by an energy balance equation

$$(1-a)S+L+H+LE+G=0$$

where, S is the solar irradiance, α is the surface albedo, L is the net longwave irradiance, H and LE are the sensible and latent heat flux densities, and G is the ground conductive heat flux density.

The model is run by ingesting sensor measurements at the forecast site for the previous 24 hours, together with site physical parameters (such as latitude, longitude, emissivity, sky view factor, surface roughness length, thermal conductivity, heat capacity, etc.). Tables 1 and 2 show respectively the inputs and parameters necessary to run the nowcasting model. It can be seen from the tables that the model requires only a limited number of meteorological inputs and physical parameters.

One valuable feature of the nowcasting model is that unlike many other models that require human intervention (e.g., for providing meteorological inputs), the model depends only on sensor measurements and is fully automatic. It will generate, three or six hours ahead, forecasts of road surface temperature and surface state (dry, wet, icy, snow, etc.) once sensor data are available or updated. The model can easily be re-run every time that new observations are available; however in typical practical applications nowcasts are generated when the road surface temperature falls below a given threshold.

3. Auto-tuning

Of many physical parameters required by the model, emissivity (E) and roughness length (RL) of road surface are the most important ones for the model to achieve desired accuracy of forecast. Model sensitivity tests showed that a moderate (say 10%) change of E or RL would cause significant deterioration of model forecast.

In the past, the value of emissivity and roughness length were chosen from laboratory experiments in published literatures and local ground conditions at the forecast site. While laboratory values are accurate and representative, it is impractical to adopt a laboratory-derived emissivity value to all forecast sites because road materials and road surface characteristics vary widely from one site to another. On the other hand, it is impossible to make good estimate of roughness length at individual forecast sites without personally visiting the sites. Therefore, some physical parameters (such as emissivity and roughness length) are traditionally fed to the model with certain degree of error. A feasible way to solve the problem is for the model itself to dynamically and robustly search for optimum values of the selected parameters.

This searching procedure is called auto-tuning and is described in Figure 1. First, the model reads in meteorological inputs from sensor measurements. It then takes a small step variation of one parameter from its standard value and generates a ‘hindcast’ or retrospective forecast for the previously observed few hours with varied parameter. After this, the model compares its forecast to actual sensor measurement, and finds the optimum value for the parameter by choosing the minimum forecast error.

4. Internet application

The emergence of Internet and Intranet technology is rapidly changing the way that meteorological applications are constructed, including:

- How meteorological data are collected, organized and computed;
- How meteorological forecasts are delivered, propagated and displayed.

Traditionally, meteorological data are observed and collected at local climatic or weather stations. The data are transferred to a central unit (e.g., the UK meteorological Office) for processing and computing. The processed and forecast data are then distributed to a wide variety of different users via a wide variety of different communication channels.

The Intranet/Internet technology, however, has changed and is going to further change the structure of meteorological application. The new approach automatically pulls together roadside weather information through the Internet, processes the information by distributed computers through the Intranet, triggers model reaction, and displays the information and forecast products at a specified Web site. Compared to traditional meteorological applications, distributed Web applications in meteorology have the advantages of:

- Reduced burden of computation resources on the traditional central unit;
- Lower cost due to less human involvement;
- Helpful tools for forecast model validation and evolution;
- User convenience, i.e., a use can get access to both the observation data and forecast data at whenever and wherever he/she wants to;
- Fast access and gathering of observation data;
- Timely access to forecast data;
- Various capabilities for information dissemination via fax, pager and e-mail notification;
- Flexibility for further design, evolution and innovation of the web applications.

Figure 2 illustrates how the web applications are performed for winter road maintenance. With aid of the Internet/Intranet tools, data collection, forecast generation, statistical report production and information dissemination become much more controllable and easier to achieve.

5. Test results

Operational Nowcasts for a large number of different forecast sites across the UK were introduced from the start of winter 1999 / 2000. At the same time, real time performance verification reports were made available via an Intranet / Browser user interface. The number of forecast sites varied from 55 to 108 on monthly basis due to variation of weather conditions. In order to avoid unnecessary updates, the model is designed to generate forecasts only when the surface temperature at the initial time drops below a customer selected threshold (typically in the range 1°C to 3°C for a 3 hour nowcast). This means that in cold months (e.g., December, January and February), there will be more forecasts than in warm months.

To investigate the effects of auto-tuning on nowcasts two stations were selected. Garrowby (HU007) is located on the A166, about 12 miles east of York. Garrowby was chosen as a station with reasonably typical although slightly below average verification figures. On the other hand, Friars Walsh (A6014) on the A5 north of London has historically been a problematic station for nowcasting and had some of the worst verification figures before auto-tuning.

The tests were divided into two parts: in the first part nowcasts were generated whenever possible regardless of surface temperature, in the second part nowcasts were only generated when the surface temperature fell below a 3°C threshold.

Test results are given in Table 3a for 3-hour nowcasts and Table 3b for 6-hour nowcasts. Both tables clearly demonstrate that the auto-tuning mechanism led to simultaneous reductions of bias, standard deviation and absolute error in most cases. Encouragingly the most significant improvements were noted at the previously problematic Friars Wash station.

The overall results of 3-hour nowcasts at real time for all forecast sites are presented from 1st November to 31st March for two winters: winter 1999/2000 and winter 2000/2001. Each pair of model forecasts of road surface temperature (T_s) was compared against actual sensor measurements at the test sites. The error of temperature forecasts is expressed by bias (forecast minus actual) and standard deviation (SD). The forecast of ice (when $T_s \leq 0°C$) and no-ice (when $T_s > 0°C$) was compared with sensor measurements and its accuracy is expressed in percentage (%). The results of the comparison are summarized in Table 4.

It is seen from the table that

- The model has a near-zero bias for temperature forecast;
- The forecast of temperature is generally better in December and January than in March;
- The accuracy of forecast of ice/no-ice is around 90%.

6. Summary

The concept and results represented in this paper are encouraging. The paper shows that

- An auto-tuning mechanism introduced in this paper improves the estimates of key physical parameters and thereby reduces the bias, standard deviation and absolute error of Nowcasts. The mechanism is particularly helpful at problematic sites;
- Because of less human involvement and wider range of potential users, costs of data collection and information dissemination will be hopefully lower and efficiency will be higher;
- Road weather information can be easily accessed by relevant users by simply logging on to the Internet at a remote location. For example, a winter road maintenance manager can get forecast information via Internet connect from his/her home.

Reference

Shao, J. and P. J. Lister, 1996: An automated nowcasting model of road surface temperature and state for winter road maintenance. *J. Appl. Meteorol.*, **35**, 1352-1361.

Figure 1. Schematic description of auto-tuning for automatic road ice prediction

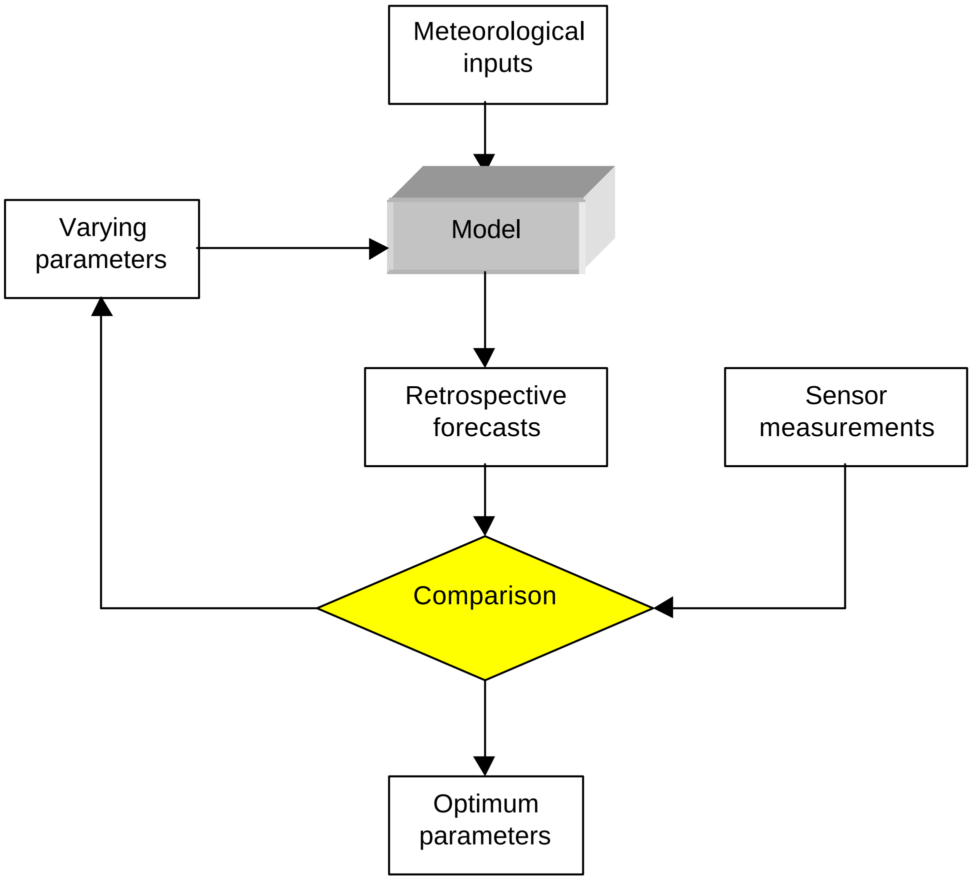

Figure 2. Application of Internet/Intranet in winter road maintenance

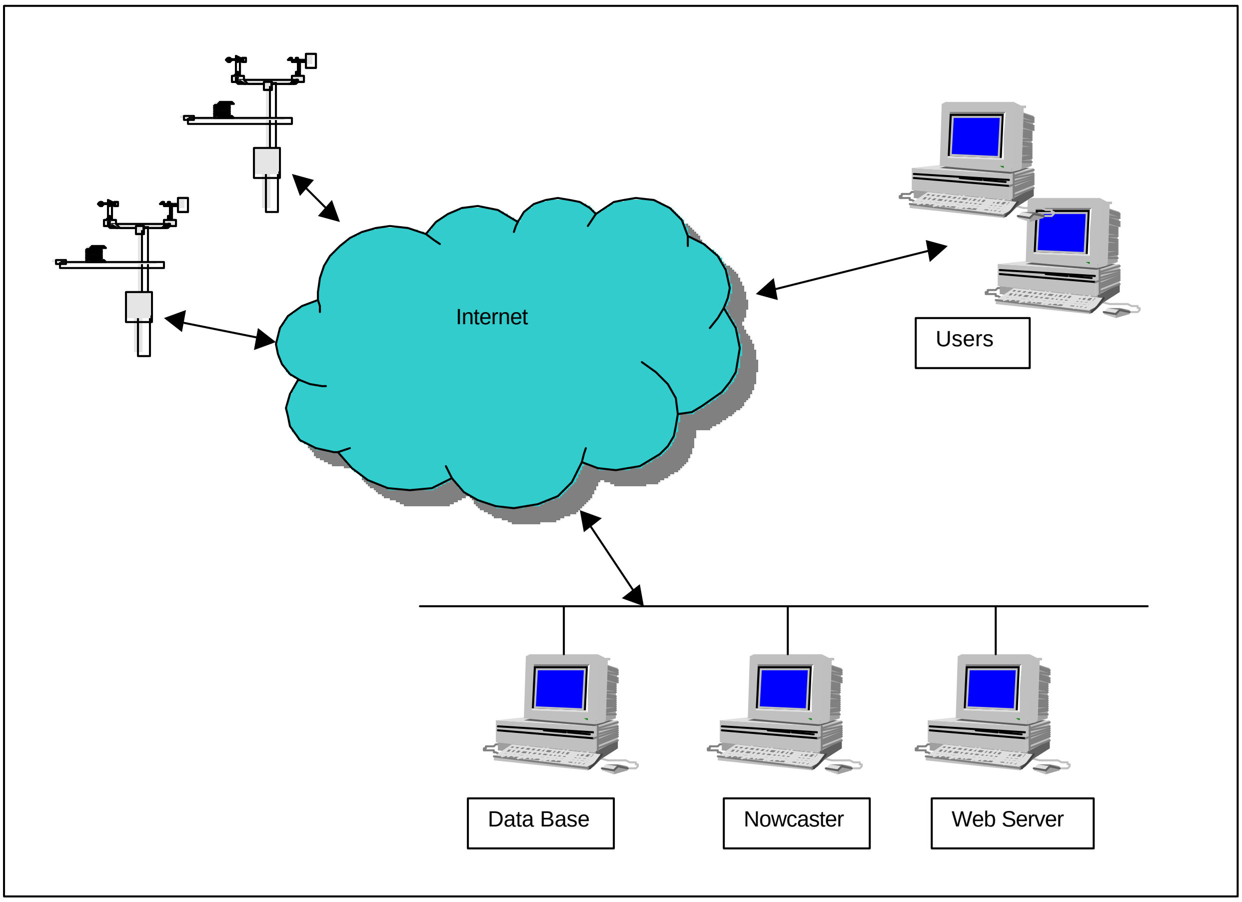

Table 1. Meteorological inputs required by the nowcasting model

Meteorological inputs:
Air temperature for the last 24 hours;
Dew point temperature for the last 24 hours;
Wind speed for the last 24 hours;
Current precipitation status at the initial forecast time;
Road surface temperature and state at the initial forecast time;
Road depth temperature(s) at the initial forecast time.

Table 2. Physical parameters required by the nowcasting model

Physical parameters:
Latitude and longitude;
Climatic soil temperature at 1 m depth in winter;
Mean surface air pressure in winter;
Sky view factor (1 for total sky visibility, and 0 for none);
Emissivity of road surface (0 to 1);
Roughness length of road surface;
Thermal conductivity of road materials;
Heat capacity of road materials.

Table 3a. Effects of auto-tuning on 3-hour nowcasts
(N=number of samples, SD=standard deviation °C, AE=absolute error °C)
Bold figures highlight improvements due to auto-tuning

Site	Month	Tuning	No Threshold				Threshold=3°C			
			N	Bias	SD	AE	N	Bias	SD	AE
HU007	27/10/00 to 08/03/01	No	20753	-0.01	1.07	0.69	11149	0.18	0.85	0.59
		Yes		0.07	**0.93**	**0.60**		**0.08**	**0.79**	**0.53**
A6014	Nov 2000	No	4374	-0.43	1.08	0.80	513	-0.52	1.09	0.77
		Yes		**0.0**	**1.05**	**0.70**		**-0.42**	**0.99**	**0.68**
	Dec 2000	No	4449	-0.46	0.86	0.68	1140	-0.43	1.00	0.70
		Yes		**0.03**	**0.81**	**0.53**		**-0.26**	**0.96**	**0.63**
	Jan 2001	No	5095	-0.39	0.98	0.73	2444	-0.44	0.98	0.73
		Yes		**0.0**	**0.97**	**0.65**		**-0.24**	0.99	**0.66**
	Feb 2001	No	3299	-0.44	1.34	0.93	728	-0.61	1.17	0.83
		Yes		**0.14**	1.36	**0.82**		**-0.35**	1.17	**0.75**
	All	No	17217	-0.43	1.04	0.77	4825	-0.47	1.03	0.74
		Yes		**0.03**	**1.02**	**0.66**		**-0.28**	**1.01**	**0.67**

Table 3b. Effects of auto-tuning on 6-hour nowcasts

Site	Month	Tuning	No Threshold				Threshold=3°C			
			N	Bias	SD	AE	N	Bias	SD	AE
HU007	27/10/00 to 08/03/01	No	37954	0.01	1.44	0.98	20298	0.12	1.22	0.85
		Yes		0.11	**1.31**	**0.90**		**0.02**	**1.16**	**0.80**
A6014	Nov 2000	No	8005	-0.54	1.58	1.20	933	-1.06	1.80	1.41
		Yes		**0.11**	1.61	**1.14**		**-0.92**	**1.69**	**1.26**
	Dec 2000	No	7971	-0.58	1.28	0.98	1973	-0.74	1.72	1.23
		Yes		**0.12**	**1.27**	**0.86**		**-0.49**	**1.69**	**1.12**
	Jan 2001	No	9394	-0.48	1.43	1.07	4532	-0.68	1.40	1.10
		Yes		**0.06**	1.46	**1.02**		**-0.40**	1.46	**1.03**
	Feb 2001	No	5955	-0.56	1.78	1.26	1319	-1.10	2.02	1.45
		Yes		**0.33**	1.84	**1.25**		**-0.73**	**1.88**	**1.29**
	All	No	31325	-0.54	1.50	1.12	8757	-0.80	1.61	1.22
		Yes		**0.14**	1.52	**1.05**		**-0.53**	**1.60**	**1.11**

Table 4. Overall results of 3-hour nowcasts in the UK during the winters 1999/2000 and 2000/2001

Winter 1999/2000:				
Month	No. of samples	Bias (°C)	SD (°C)	Accuracy (%)
November	30,310	-0.19	1.06	92.5
December	157,527	0.00	0.90	88.6
January	121,930	-0.02	1.02	88.2
February	127,012	0.11	1.14	87.4
March	41,463	-0.22	1.35	92.2
Winter 2000/2001:				
Month	No. of samples	Bias (°C)	SD (°C)	Accuracy (%)
November	57,468	-0.24	0.89	95.9
December	135,591	-0.20	0.82	91.7
January	113,941	-0.18	0.91	89.6
February	58,762	-0.14	1.10	88.7
March	69,669	-0.08	1.21	91.9