NOWCASTING THE RISK OF SNOWFALL AND FREEZING RAIN WITH RADAR AND GROUND DATA

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Abstract

A reliable forecast of the danger of snowfall or freezing rain is required for an optimal planning of snow or ice removal on the roads. Risk forecasts in the time range 0-2 hours would be especially useful. Salt could be distributed, or special actions to prevent accidents or traffic breakdowns could be initiated in time. Up to now, forecast procedures are mainly based on local ground measurements of temperature, humidity and precipitation. Forecasts on the onset and evolution of precipitation are normally delivered by weather services or by monitoring systems presenting weather maps, model forecasts, satellite or radar data. Few attempts have been made up to now to **combine** local data and short-term forecasts of precipitation based on satellite or radar data in a proper nowcasting system.

In this contribution, we present a new concept to combine various risk factors to the desired risk forecasts of snowfall or freezing rain. The risk factors are:

[1] The probability that precipitation stronger than a given level of intensity will occur in the subsequent 1-2 hours. This risk factor is obtained with ***RainCast***, a fully automated radar nowcasting procedure developed at ETH.

[2] The probability that this precipitation will be snow or supercooled rain. This probability is determined using ground measurements of temperature, humidity and precipitation. In a hilly or mountainous region one has the possibility to use pseudo-profiles of temperature and humidity for calculation of this risk factor if the measuring stations are distributed over various layers in altitude.

[3] The probability that liquid precipitation will fall an a frozen surface.

The resulting nowcasting procedure is called ***RainCast+***. Various forecast products can be distributed to the users: forecast images, local risk forecasts and warning messages. The procedure allows selection of the desired warning regions and warning criteria in a highly flexible manner. The skill of the forecasts, based on a statistical analysis of large data samples, is promising. The system is now being installed for operational use in Switzerland north of the Alps.

1. Introduction

A reliable forecast of critical weather (e.g., snowfall or freezing rain) is required for an optimal planning of snow or ice removal on the roads. Risk forecasts in the time range 0-2 hours would be especially useful. Salt could be distributed, or special actions to prevent accidents or traffic breakdowns could be initiated in time. Up to now, forecast procedures are mainly based on local ground measurements of temperature, humidity and precipitation. Forecasts on the onset and evolution of precipitation are normally delivered by weather services or by monitoring systems presenting weather maps, model forecasts, satellite or radar data. Few attempts have been made up to now to **combine** local data and short-term forecasts of precipitation based on satellite or radar data in a proper nowcasting system (e.g., Rasmussen et al. 2001)

In this contribution, we present a new concept to combine various risk factors to the desired risk forecasts of snowfall or freezing rain. In addition to forecasts based on local measurements, we also use forecasts of precipitation based on radar images. The system **COTREC/RainCast**, developed at ETH, is a fully automated nowcasting technique which is presently used in Switzerland for various applications. In the next section, we will summarize the radar extrapolation technique and the algorithms to obtain the desired risk forecasts. After that, we illustrate the new algorithms with a snowfall and a freezing rain event from winter 2000/2001. A final section will summarize the main results of the study and give an outlook on further work.

2. The algorithms

a. COTREC/RainCast

The radar extrapolation technique is an extension of TREC ("**T**racking **r**adar **e**choes by **c**orrelation"), introduced by Rinehart and Garvey (1978). The radar image is divided into squared boxes. Each box is compared with the same box in a subsequent radar image. The box in the second image is shifted on a regular grid until the best match (maximum correlation) between the radar patterns in the two boxes is found. Hence, the motion and the change in intensity of the radar echoes can be calculated for each box. This information is used for the extrapolation. The technique has been optimized by various authors. Li et al. (1995) introduced COTREC: a method to improve the motion vectors with a variational technique. Mecklenburg et al. (2000) found optimal model parameters (e.g., the box size) for various precipitation types. Schmid (2000) improved the extrapolation technique and introduced RainCast: the operational version of COTREC which fulfils the following requirements:

1. Good and robust forecast quality for various weather types.
2. Short computation time an a modern PC.

The statistical properties of the forecast errors are converted into local risk forecasts (Schmid et al. 2001). The risk for the occurrence of precipitation (p_r hereafter) can be calculated for each desired location and time period, depending on the variations of echo motion in the vicinity of that location. Risk forecasts of hail, floods, snowfall, freezing rain, lightning or heavy wind can be obtained as well. Warning messages can be issued to interested users if the calculated risk factor reaches a pre-defined level. In this manner, it is possible to use the machine (instead of humans) for permanent or long-term monitoring tasks.

RainCast is now in operation in Switzerland for various applications. Forecast products and automated warning messages are distributed by an ETH-spinoff company ("MeteoRadar Schmid", for details see http://www.meteoradar.ch/). The software is installed on a Linux machine. Radar images and other meteorological data are available from MeteoSwiss and maintenance services. Risk forecasts and warning criteria are calculated and distributed to the customers every 5 minutes.

b. RainCast+

New algorithms to handle the risks of snowfall and freezing rainwater are being developed within an extension of the existing RainCast system. This extension is called **RainCast+** since additional data are introduced and combined with the existing RainCast procedures. Hereafter, we summarize the algorithms to estimate the risks for snowfall and freezing rainwater.

Snowfall. Identification of precipitation type (rain, snow, graupel, hail) with radar is only possible with dual-polarization radars. Such radar systems are expensive and presently used for research purposes only. Therefore, additional data should be considered for discrimination between rain and snow in an operational environment. A mountainous orography allows it to consider ground measurements of air temperature and humidity at various altitudes. The fraction of snow mass (p hereafter) in precipitation can be estimated following a procedure given by Koistinen and Saltikoff (1998). Based on their suggestion, one can define a "snow temperature" t_s (^{o}C) as follows:

$$t_s = t + rh \cdot 0.074 \qquad (1)$$

Here, t is air temperature (^{o}C), and rh is relative humidity (%). The fraction of snow mass p (being a quantity between 0 and 1) is a non-linear function of t_s:

$$p = \frac{1}{1 + \exp(22 - 2.7 \cdot t_s)} \qquad (2)$$

The fraction of snow in precipitation can be calculated for any altitude with the help of Eqs. 1 and 2 if the profiles of temperature and relative humidity are known. Of special interest is a forecast of the risk of snowfall (p_s hereafter) in the subsequent hours. For this, one needs a forecast of the risk of precipitation (p_p) and a forecast of p. Given the two forecasts, one can obtain an estimate of p_s:

$$p_s = p_p \cdot p \qquad (3)$$

The forecast for p_p is provided by RainCast, and a forecast of p is presently obtained by an extrapolation of the time series of t and rh into the future with an autoregressive time series model.

Freezing rain: The same method can be used to obtain a forecast of freezing rain. An important additional quantity is ground temperature t_g, and an extrapolation of t_g into the future. The standard deviation of the extrapolated t_g should be estimated as well, in order to obtain an estimate of the risk (p_0 hereafter) that ground temperature is below the freezing level. The risk for freezing rain (p_f hereafter) can be estimated as follows:

$$p_f = (1 - p_s) \cdot p_0 \qquad (4)$$

Freezing rainwater after rainfall or wet snowfall: Another danger is a clearing sky after rainfall at a temperature near the freezing level. Radiational cooling may lead to ice-slipperiness. Two factors are important to foresee such a situation: the wetness of roads, and the temperature trend based on cloud cover. The first factor can be estimated either directly from ground sensors, or indirectly by accumulating the rainwater seen with radar and by considering evaporation of the fallen rainwater. The second factor is difficult to predict. A reliable forecast of ground temperature is only possible by considering the motion and evolution of cloud fields. Radar images cannot help a lot since the radar sees precipitation but not non-precipitating clouds. Satellite images have deficiencies as well: IR-images are often unable to discriminate between ground and cloud tops during winter. Therefore, alternative methods are searched to estimate cloud cover. One possibility is to use surface temperature, together with air temperature, as an indirect indicator of cloud cover. A network of stations can provide information about the motion of cloud fields. We are presently investigating the possibilities to monitor cloud fields with a dense ground network measuring surface and air temperature.

3. Case studies

a. A freezing rain event

Hereafter, we discuss two examples from last winter in northern Switzerland. The first example is a freezing rain event which occurred in the evening of 1 January 2001. The time series of ground temperature and precipitation in Fig. 1a indicate a ground temperature below and at the freezing level. Since the freezing level in the free atmosphere is at about 700m above ground (not shown here), it is expected that precipitation is liquid and may freeze when getting into contact with the supercooled ground. Weak precipitation occurred at 2210h for a couple of minutes, and stronger precipitation started one hour later. At that time, ground temperature was still very close to zero degrees. Therefore, freezing of rainwater at some locations is possible. The thick vertical line in Fig. 1a indicates the time when the danger of freezing rain is evident.

The forecasts calculated at 2140h (thin vertical line in Fig. 1a) are shown in Figs. 2a and 3a, respectively. Fig. 2a shows a radar forecast image valid for 2240h, i.e. one hour ahead. This figure indicates that the location of Zürich-Flughafen is already covered by a precipitation echo. The local forecast (shown in Fig. 3a) indicates that the risk for weak or moderate precipitation increases substantially at 2200h, but does not reach 100%. The risks for snowfall and freezing rain increase as well but remain at a level of about 20%.

In summary: the increasing risk for precipitation and for freezing rain has been seen by the forecast model. The model also forecasts some risk for snowfall. Warning messages would have been issued by the model if the warning levels for the risks of snowfall and freezing rain are at 20%. Since the forecasts are updated every five minutes, it is expected that the forecasts become more and more accurate with progressing time.

b. A snowfall event

In the second example we discuss a snowfall event in central Switzerland. Fig. 1b shows weak precipitation at positive temperatures up to about 2000h in the evening. At that time, precipitation intensity increases substantially, and ground temperature reaches the freezing level at about 2030h local time. The type of precipitation apparently changed from rain to snow, and the snow survived at the surface after 2030 local time, hence causing snow slipperiness. The thick vertical line in Fig. 1b marks the time (2030h) when the local RWIS (Vaisala) issued an alarm message.

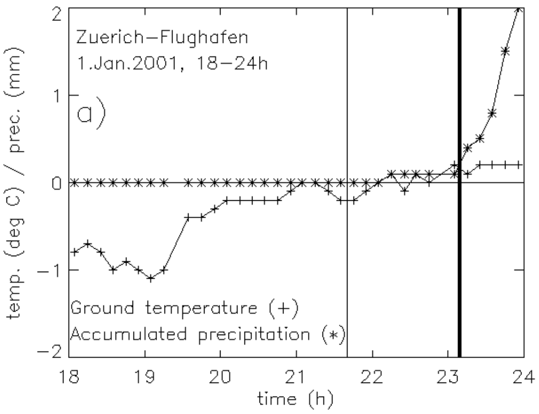

Fig. 1: Time series of ground temperature and precipitation accumulation, for Zürich Flughafen (Fig. 1a) and the Grosshofbrücke near Lucerne (Fig. 1b). The data for Fig. 1a are from the ANETZ, operated by MeteoSwiss, and for Fig. 1b from the Vaisala network, operated by the Canton of Lucerne. The vertical lines are explained in the text.

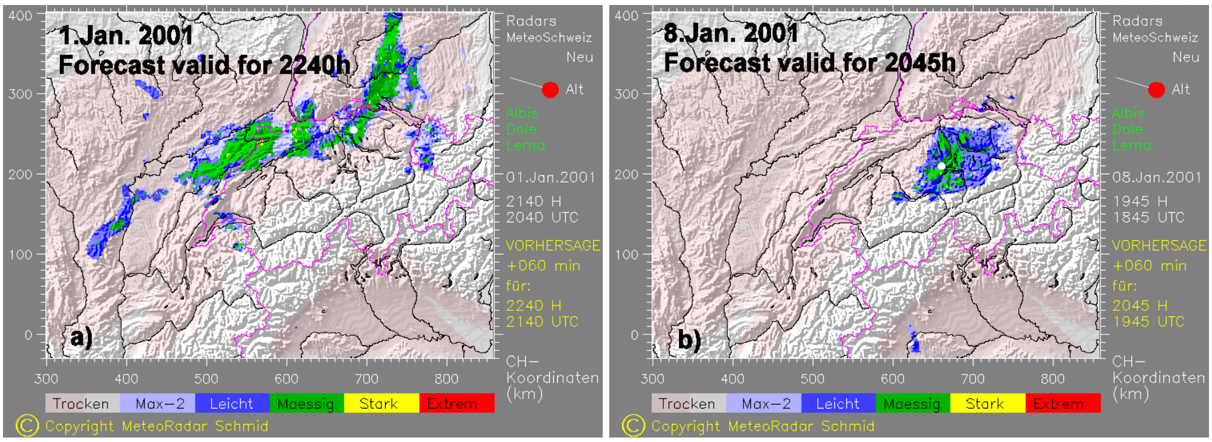

Fig. 2: Radar forecast images (1 hour), for Zürich-Flughafen (Fig. 2a), and for the Grosshofbrücke near Lucerne (Fig. 2b). The positions of the measuring sites are indicated with a white dot.

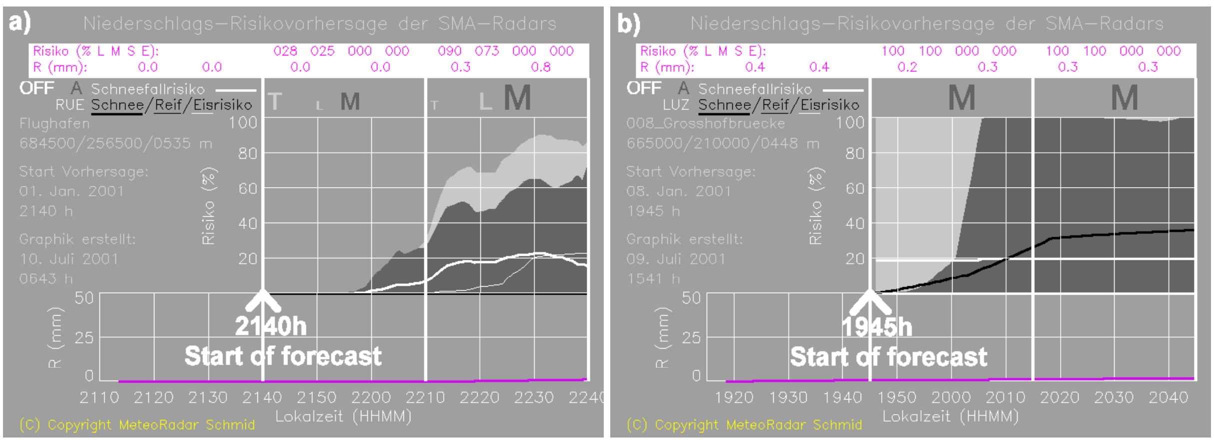

Fig. 3: local 1-hour risk forecasts of weak precipitation (light-grey), moderate precipitation (dark-grey), snowfall (thick white line), ice-slipperiness (thin white line) and snow-slipperiness (black line), for Zürich-Flughafen (Fig. 3a), and for the Grosshofbrücke near Lucerne (Fig. 3b).

The main reason for sending that message was the lowering ground temperature, reaching the freezing level. This message was apparently too late for preventive salting the roads. Therefore, we investigated how well the new RainCast+ system could foresee the danger. We calculated the RainCast-forecasts at 1945h, i.e. 45 min in advance. The results are shown in Figs. 2b and 3b, respectively.

The one-hour radar forecast (Fig. 2b) indicates moderate precipitation at the location of interest. The local forecast shown in Fig. 3b suggests that precipitation persists during the whole forecast period (1934-2034 h). This forecast is in a good agreement with the observation (Fig. 1b). The model also delivers the risks for snowfall (20%) and snow-slipperiness (increasing from 0 to about 35%). These forecasts are a bit conservative, compared to the reality. The reason is that the sinking temperature, as observed in Fig. 1b, is not adequately forecasted by the model. The forecast of temperature in the present version of RainCast is based on local measurements only. It is suggested that a refinement of the temperature forecast, including spatial data and numerical model forecasts, can improve the reliability of the RainCast-forecasts furthermore.

We can nevertheless state that the model gives realistic forecasts of the defined winter risks in the two case studies. We are evaluating further cases from last winter in a similar manner, in order to obtain statistically valid results.

4. Discussion and conclusions

In this study, we propose a new method to obtain better forecasts of critical road weather. The new technique combines radar forecasts of precipitation with forecasts of local parameters, such as air temperature, ground temperature and surface wetness. Risk factors of snowfall, freezing rain and slippery roads due to snowfall or freezing rainwater are calculated by combining individual risk factors estimated from two systems: local measurements and radar observations.

The forecast model, called RainCast+, has been tested for the first time in winter 2000/2001. The data are now being evaluated. In this contribution, we present an analysis of two specific events, highlighting the reliability of the calculated risk factors. A statistical evaluation of larger data samples is ongoing. Preliminary results can be summarized as follows:

1. The calculated risk factors of precipitation (based on the radar forecast) slightly overestimate the observed risk factors (Schmid and Mecklenburg 2001).

2. The standard deviation of forecasted ground temperature is about 1^{o}C for a 50 min forecast.

The second finding is not yet satisfying and should be improved. Up to now, the temperature forecast is simply an extrapolation of the past time series of temperature with an autoregressive model, without considering advective effects, such as the motion of airmasses or cloud fields. Therefore the next step is an improvement of the temperature forecasts by considering spatial data of temperature and cloud cover, possibly also numerical model forecasts.

The advantage of a road-weather forecast and warning system is evident and widely confirmed by many users of RWIS-systems. Consideration of **advection** in such systems means an important step towards more precise short-term forecasts. Advection refers to precipitation fields seen by radar, but also to cloud fields and surface air. The advection of precipitation fields is now implemented in RainCast+, whereas the advection of cloud fields and air temperature is considered in a future version of the system.

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