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Detecting nocturnal clouds with surface temperature data

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Abstract. With radar tracking algorithms, precipitation can be predicted up to three hours. Especially in road weather forecasts, however, surface temperature and cloudiness are other important objectives. Low surface temperatures while or after rainfall may cause slipperiness, and clearing is one effect pushing temperatures below the freezing level. Cloudiness and the difference between air and surface temperature both are parameters of the radiation balance. In this contribution, we show the relationship between them, proved at several stations all over Switzerland. We found a quadratic correlation coefficient of typically 60%. One has to be careful in formulating a single equation for all stations, but we conclude that temperature difference is a signature for nocturnal cloudiness.

We investigated nocturnal cloudiness for a case from winter 2002 in the canton of Lucerne in central Switzerland. There, temperature differences detected from an ultra-dense combination of two networks with together 55 stations were converted to a cloud map. A comparison between precipitation seen by radar, cloud map and surface temperatures shows that there are similar structures in all data. But not each area with high temperature difference is associated with clear sky. Especially in precipitation areas and with temperatures near the freezing point, we could identify other important effects (e.g. advection or the influence of melting heat) giving suggestions for ongoing work.

1 Introduction

Road weather forecasting is one of the key topics of today's meteorology. Worst cases in road weather are those who lead to unexpected slipperiness, caused by snowfall, rain falling on supercooled ground or freezing rain water after (post-frontal) clearing. With radar tracking algorithms, one can nowcast precipitation, but it is still difficult to decide whether the precipitation is rain, freezing rain or snow. A key parameter for this decision is the surface temperature, depending most of all on **radiation** and **advection**. The aim of this work is to find a better way to forecast the surface temperature.

Slipperiness often comes along with **cloud effects** like clearing. The changes from overcasted to cloudy or clear sky and back lead to the biggest problems for road weather forecast. We intend to investigate the relationship between cloudiness and surface temperature and, if possible, to quantify the influences. We're using air and surface temperature data of a dense network in Switzerland and combine them with information from **radar** and satellites. Because most critical cases occur at night, and due to the cease of solar radiation as a complicating factor, we decided to concentrate on nocturnal events.

In the next section, we will list the different types of data included in our study and summarise our methods to analyse these data. After that, we show a number of cases with warm and cold fronts leading to slipperiness. We will concentrate on two cases in February 2002 to discuss the complex spatial connection between cloudiness, precipitation and air and surface temperature in the mountainous region of Lucerne in central Switzerland. Finally, we summarise the main results of the study and give an outlook on further and ongoing work.

2 Procedure

2.1 Data

Three data sets are used in this study: The radar composite of MeteoSwiss, the ANETZ data and a road weather measurement system operated by the road inspection office of the canton of Lucerne in central Switzerland. All over Switzerland, there are three C-band radars owned by MeteoSwiss. Every five minutes a full volume scan is taken and a composite image of whole Switzerland is created, showing the maximum reflectivity value above each point. These reflectivity values are classified in 16 levels of intensity. The spatial range of this composite data set is $2 \times 2\,\mathrm{km}^2$ (Joss and Lee, 1995).

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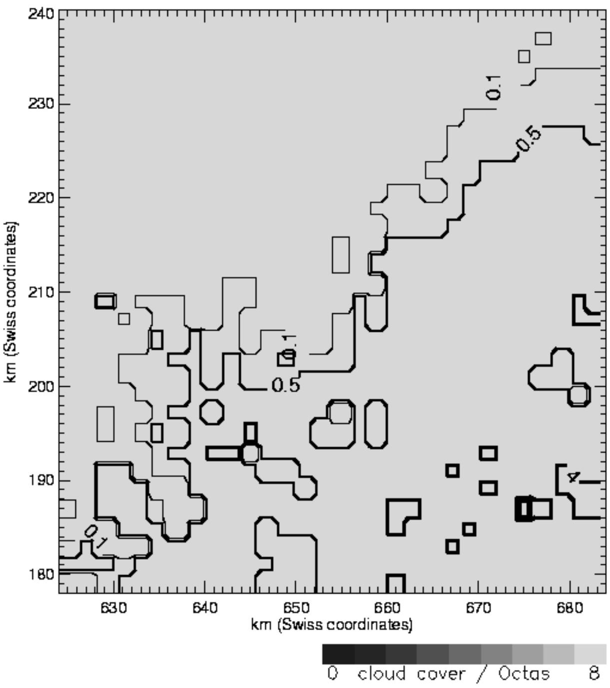

Fig. 1. 6 February 2002, 22:00 UTC. Image of calculated cloud cover and radar precipitation in the Lucerne region. Thickness of lines and precipitation intensity (in mm/h) are corresponding.

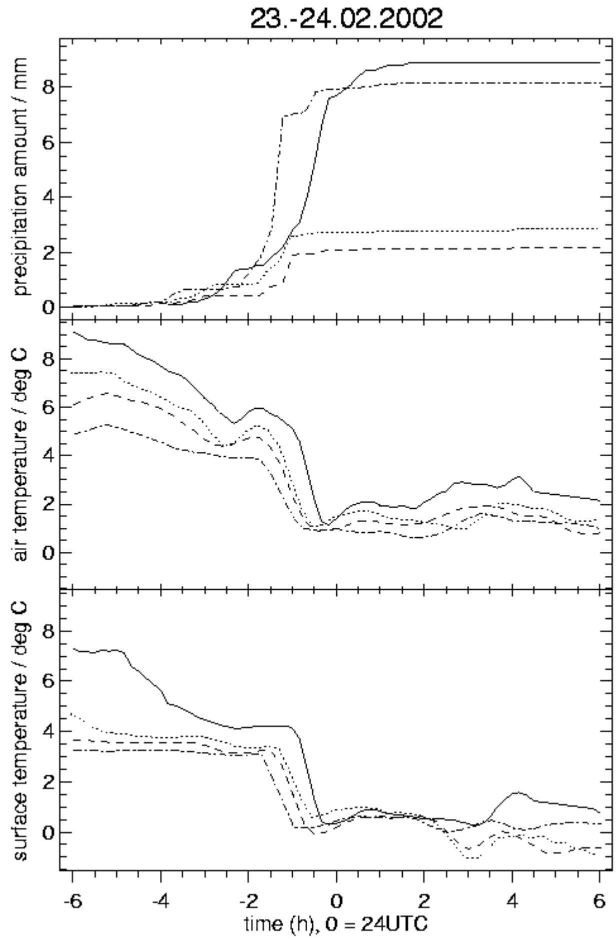

Fig. 2. Time series of air and surface temperature and precipitation amount from 23 February 2002, 18:00 UTC till 24 February 2002, 06:00 UTC. The four stations shown are the ANETZ station of Lucerne (solid, 456 MSL, 665/210 km) and the stations in Neuenkirch (dotted, 151 MSL, 657/219 km), Oberkirch (dashed, 520 MSL, 650/224 km) and Roggliswil (dash-dotted, 540 MSL, 633/230 km) of the Vaisala network.

Another measurement system operated by MeteoSwiss is the ANETZ, covering 72 meteorological stations all over Switzerland. At each station almost all parameters of interest, such as air and surface temperature (temperature in 2 m above ground and in 0.05 m above ground), pressure, rain rate, humidity, wind direction and speed and ground temperature (temperature in 6 cm below the surface) are measured in a temporal resolution of 10 minutes. Additionally, 33 of these stations do have direct observations of cloudiness, which are available every six hours. The observers estimate cloudiness in Octas, assigning clear sky with zero Octas and overcasted sky with eight Octas of clouds.

To study small-scale phenomena like clouds, one needs a measurement network as dense as possible. In the canton of Lucerne a Vaisala network with 52 stations within an area of $50 \times 40\,\mathrm{km}^2$ has been installed. Placed on the side of cantonal routes, every station measures every quarter of an hour the most important road weather parameters like air and surface temperature, humidity, visibility, rain rate and road condition (Mathis, 2000).

Out of the two ground-based networks one can make a combined data set contributing at least air and surface temperature with a time scale of 15 minutes. In or near the area of the canton of Lucerne there are five ANETZ-Stations. Two of them are placed at the top of the mountains Pilatus and Napf and therefore do not deliver comparable information. The other three stations are located in Lucerne (LUZ, 456 MSL, 665/210 km in Swiss coordinates), Wynau (WYN, 422 MSL, 626/234 km) and Engelberg (ENG, 1035 MSL, 674/186 km). The vertical range of the Vaisala network reaches from Gisikon (410 MSL, 672/220 km) up to Sörenberg (1130 MSL, 645/186 km).

2.2 Methods

2.2.1 Radiation theory and temperature difference

The search for a relation between cloudiness and surface temperature leads to a flashlight onto radiation equation theory. Several authors (e.g. Albisser, 1983; Chapman et al., 2001) claim, that the short-wave and long-wave radiation balance has the greatest influence on air and surface temperature (T_{air} and $T_{surface}$) and especially on the temperature difference $T_{diff} = T_{air} - T_{surface}$. Since short-wave radiation is zero in nocturnal cases, radiation balance depends on long-wave radiation. Without clouds, the long-wave emission of the ground is not compensated by irradiation, all en-

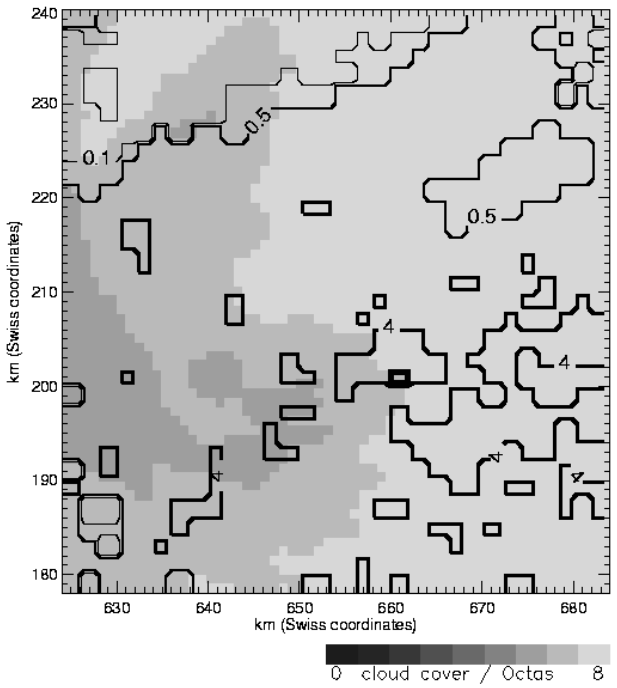

Fig. 3. 23 February 2002, 24:00 UTC. Map of calculated cloud cover and radar precipitation in the Lucerne region. Thickness of lines and precipitation intensity (in mm/h) are corresponding.

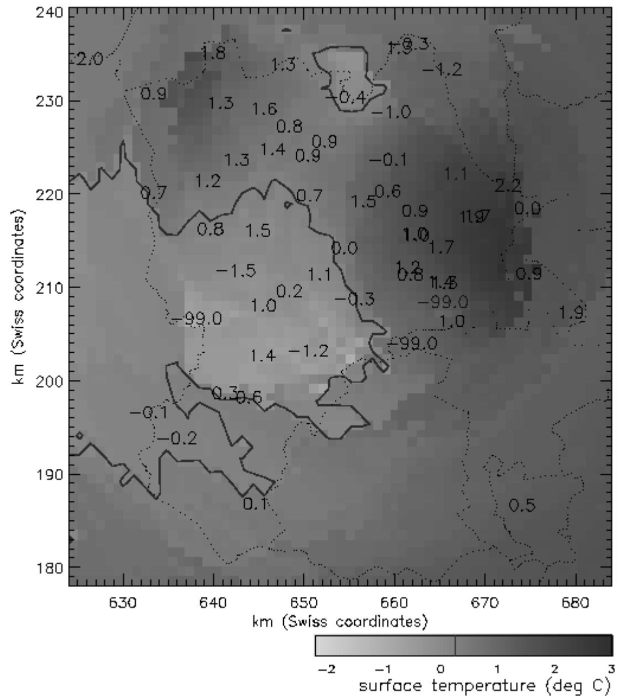

Fig. 4. 23 February 2002, 24:00 UTC. Map with air temperature (numbers at the place of each station) and interpolated surface temperature (background colors) in the Lucerne region. The black line indicates the 0.25°C borderline in surface temperature.

ergy is taken from ground or from the air near ground, and T_{diff} increases. At cloudy sky, the long-wave emission of the ground and the irradiation of clouds is of the same range. Therefore $T_{surface}$ or T_{diff} remain relatively unaffected by radiation. The other parts of the energy balance, such as the turbulent fluxes of latent and sensible heat, heat of fusion and the heat flux to soil, are normally considered to be small. However, their contributions exist and should be kept in mind. Another relevant point in this context is the advection both of the air we observe and of clouds influencing the radiation balance. That's why we decided to do this work in two dimensions.

2.2.2 Relation between clouds and ground temperatures

Is there a functional relationship between cloud cover N and temperature difference T_{diff}? As shown in Sect. 2.1., there are nocturnal observations of cloud cover and corresponding measurements of T_{diff} at 33 ANETZ stations and for several winters. We tested the relationship with a linear regression and found a typical correlation coefficient of 0.6 to 0.8. This is similar to the results of Albisser (1983), who also studied the influence of wind speed in this context and found none significant effect.

For each of the stations with both, observations of cloud cover and measurements of T_{diff}, one can formulate an equation of the type $N = a + b \cdot T_{diff}$ to get the cloud cover, calculated in Octas, out of the temperature difference in K. But due to the special properties of each measuring station, the two parameters a and b vary from station to station (e.g., b is between -5 and -1.5 Octas/K). To get a spatial map of cloudiness from temperature data only, one has to find a method to use a generalised functional relationship for all stations. This is of special relevance to include the stations of the Vaisala network in Lucerne, which do not have observations of cloud cover and so have to be linked to a station with known relationship. For this, we register the distribution of T_{diff} over a short but representative time scale at each station. A period of 14 days appeared to be a good choice. Afterwards, one can adapt the different distributions of all stations in a statistical way to the distribution of a station with known relationship. Now, one single equation is usable, independently from the special situation at each station, and independently whether or not cloud cover is observed at more than one station in a specified area.

In this study, we choose the ANETZ station of Lucerne (LUZ) as representative for the whole area. We transform every temperature difference from all the other stations to the data from Lucerne. The used equation for Lucerne is $N = a + b \cdot T_{diff}$, with $a = 9.4$ Octas and $b = -2.2$ Octas/K. Values out of range (i.e. not between 0 and 8 Octas) are corrected.

2.2.3 The radar rain component

It is obvious, that a precipitation event is normally coupled with 8 Octas of cloud cover. Even in convective precipitation

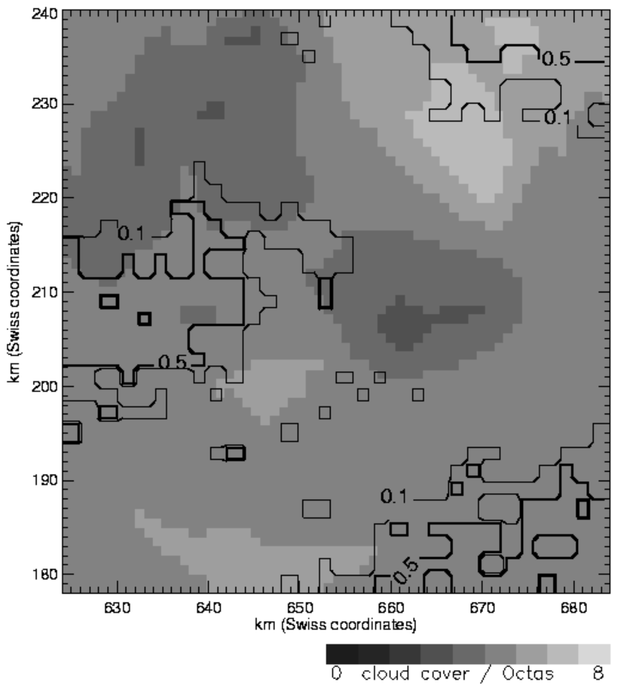

Fig. 5. 24 February 2002, 04:00 UTC. Map of calculated cloud cover and radar precipitation in the Lucerne region. Thick of lines and precipitation intensity (in mm/h) are corresponding.

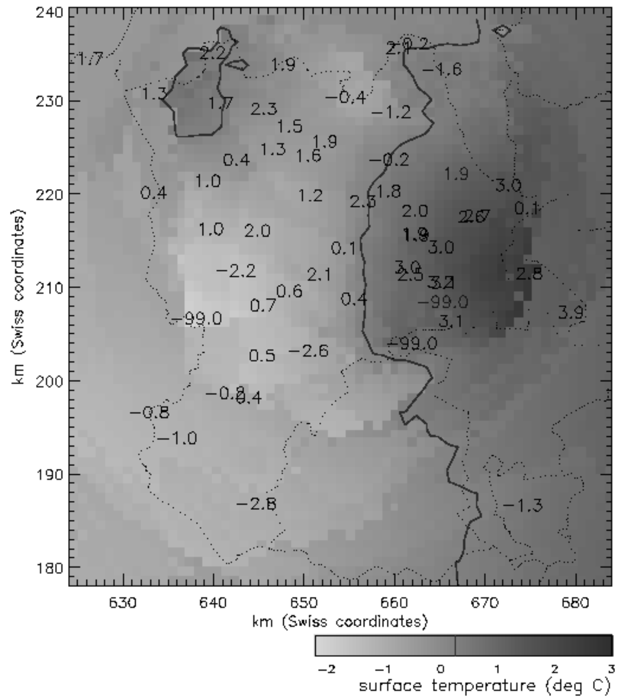

Fig. 6. 24 February 2002, 04:00 UTC. Map with air temperature (numbers at the place of each station) and interpolated surface temperature (background colors) in the Lucerne region. The black line indicates the 0.25°C borderline in surface temperature.

situations, large parts of the sky will be covered with the precipitating clouds. In the Swiss radar composite image with its resolution of $2 \times 2\,\mathrm{km}^2$ and its time range of five minutes, one can in many cases decide by eye, if a precipitation event is convective or not. In the ambient up to 5 km of a convective precipitation cell, we expect a cloud cover lower than 8 Octas to be possible.

Since radar gives a detailed picture of precipitation, we choose to compare our results concerning cloud cover with radar precipitation data, in order to find out if there are any problems, or, hopefully if we can see an interesting case of clearing after a nocturnal rain event. In comparison with the air temperatures near ground, we can identify precipitation seen by radar as snow or rain.

3 Results

In the last few winters we could observe several cases of interest. Often, cold fronts leaded to unexpected snow and slippery conditions. But also warm fronts and freezing rain on supercooled surface are observed. This variety of cases is figured in Table 1 and discussed in Sect. 3.3. Before this overview, we intend to give a more detailed look on two cases in February 2002.

3.1 Case I: 6 February 2002

February 6 was a grey and rainy winter day in Switzerland. In the evening hours, a large precipitation area combined with a cold front crossed the canton of Lucerne from Northwest towards Southeast. The precipitation intensity detected by radar was relatively homogeneously between 1 mm/h and 4 mm/h. Air temperature decreased in consequence of the cold front between 19:00 UTC and 20:00 UTC from 3°C to 2°C, detected at Lucerne ANETZ station. At the stations higher in the mountains, the temperature remained below the freezing point the whole day through. The precipitation was measured as snow, e.g. in Sörenberg (1130 MSL, 645/186 km). In the sector between 600 and 800 MSL, e.g. in Schwanderholz (690 MSL, 648/209 km), precipitation conditions changed from rain to snow within the early evening. In the following 12 hours, temperatures didn't change significantly at any of the 55 stations in the two networks. Surface temperatures are about the same range as air temperatures.

In Fig. 1 the result of our calculation for 22:00 UTC is shown. The temperature difference indicates overcasted sky in the whole area. At the chosen time, the canton of Lucerne has been crossed about half by the precipitation area detected with radar.

This result is consistent with the found relationship.

3.2 Case II: 23 to 24 February 2002

In the morning of 23 February, a warm front crossed Switzerland without great amount of precipitation. Temperatures raised in Lucerne from 3°C to 8°C at 04:00 UTC. Late in the evening, between 23:00 UTC and 24:00 UTC, they de-

Table 1. Several cases of slipperiness in Switzerland in the last few winters

Date of event	Place of observation	Weather character and effects	Reference
27/01/99, 06:00 UTC	Northern Switzerland	Cold front with snowstorm and freezing rain	Schmid (2000)
01/01/01, 23:00 UTC	Zürich-Kloten	Freezing rain on supercooled ground	Schmid et al. (2002)
03/01/01, 04:00 UTC	Lucerne and St. Gallen	Warm front with postfrontal clearing, and therefore freezing of remaining rain water	www.meteoradar.ethz.ch/ schnee/schnee.html
08/01/01, 20:00 UTC	Lucerne	Cold front with rain and snow	Schmid et al. (2002)
13/12/01, 22:00 UTC	Zürich	Cold front with freezing rain and snow	
06/02/02, 22:00 UTC	Canton of Lucerne	Rain and snow	Case I in Sect. 3.1
10/02/02, 02:00 UTC	Canton of Lucerne	Cold front similar to 24/02/02, but without freezing anywhere	
23 to 24/02/02, 00:00 UTC	Canton of Lucerne	Cold front with snow and rain	Case II in Sect. 3.2
26/02/02, 20:00 UTC	Canton of Lucerne	Cold front with above 0°C in cold air	Similar to Case I

creased again from 6°C to 1°C, due to the approaching cold front. The front propagated from West to East, as one can see in Fig. 2 (stations listed from East to West).

Figure 2 shows, that temperature drops at all stations even in the flat part of canton Lucerne into the critical range near freezing point. Therefore, the precipitation at the four plotted stations, especially in Roggliswil, is assumed to be snow after the arrival of the cold front. At higher places, e.g. in Sörenberg, temperature decreases much slower, starting at a lower level but still at +3°C and with rain. After midnight, a little bit later as in the northern part of the canton, the advected cool air mass pushed the temperatures below the freezing point, indicating snowfall up to the ground.

Figure 3 is of the same type as Fig. 1, showing the situation at 24:00 UTC on 23 February. The precipitation event covers almost the whole area. Only in the north-western corner of the map it is dry. From there, precipitation intensity increases continuously to the south-eastern part of the region. But against all expectations, there are parts of the map which are not indicated as fully overcasted. Searching for a reason, a look to Fig. 4 may be helpful. This figure shows air temperature (numbers at the place of each station) and interpolated surface temperature (background colors). In the middle of the map, roughly about 650/205 km there is an area with surface temperatures below the freezing point. The cold air did not yet reach the more southern part of the canton, while in the northern and eastern part the orography is not high enough to push temperatures below 0°C. The southern part of the area with snow falling on freezing ground (within the thick line in Fig. 4) seems to correspond pretty well with the region indicated with 6 Octas of cloudiness in Fig. 3. Especially the fine structures around Wiggen (790 MSL, 636/193km) are almost exactly the same in both figures.

A possible reason for this correspondence may be the fact, that snow falling on warmer surface lowers the surface temperature even without melting. Maybe in the mountainous regions there is residual snow from colder days. Snow or rain falling on it will freeze and lowers surface temperatures additionally. In areas with snowfall but surface temperatures above freezing point, melting heat can be another factor leading to a larger temperature difference.

As one can imagine in Fig. 2 by comparison of air and surface temperature at about 03:00 UTC on 24 February, there is postfrontal clearing with surface temperatures dropping below the freezing point at least at stations Oberkirch and Neuenkirch. But this signal is not definitely visible in our cloud maps (see Figs. 5 and 6 showing the situation at 04:00 UTC). In fact, the cloud amount decreases at this time in almost the whole area down to a level of 5 to 3 Octas, but a postfrontal precipitation event, detected by radar in the western half of the map between km 195 and km 220, does not raise these values in the raining area. In this case maybe the latent heat flux plays an important role in energy balance. Especially in the warmer part of the canton it is still possible that the surface temperature is influenced by melting heat.

In summary, we cannot relate varying temperature differences to cloud cover, without using radar information as well.

3.3 List of other cases

In Table 1 several other cases are listed. Some of them are already published by Schmid (2000) and Schmid et al. (2002) or are discussed in the internet. In all cases advection of air masses or advective motion of clouds, often combined with fronts, leaded to slipperiness in parts of Switzerland. The three cases at the beginning of 2001 show impressively that there are series of slippery events, and periods in between which are relatively free of slippery conditions.

4 Conclusions

Surface temperature is a highly critical parameter and its forecast is not easy. On the other hand, all studied cases of slipperiness are related to advection. Either cold air was advected or the post-precipitational clearing, caused by advective motion of precipitating clouds, leaded to radiative cooling. The way to describe the radiative and advective interaction between cloudiness and ground temperatures seems to be a good direction to learn something about predictability of surface temperature.

We found out that there is a general correlation between cloud cover and temperature difference, but it explains only about 60% of related variance. Whether the problem could be solved, that there is no simple equation for all stations, the general validity is not guaranteed.

In case studies, we showed that one can't trust the ground temperature information to detect clouds, if there was precipitation and especially if temperatures are around freezing point. It is necessary to consider all available other information about cloudiness, especially the precipitation information given by weather radar.

Because the advection not only of precipitation but mainly of cloud cover is relevant for the behaviour of surface temperature, we want to compare cloud structures identified from surface with satellite data in non-precipitational cases. In this way, one can find out if only precipitation make things worse or if there are other problems to solve. This work is in progress.

As shown, several factors depending on the rain or snow event should be taken into account because they do have influence on temperature difference. At least the two effects of latent heat flux and melting heat should be quantified. Therefore a simple energy balance model will be needed. With its help we intend to further improve our understanding of the phenomena, which in the end will lead to a high quality nowcasting information of forecasted surface temperature.

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References

Albisser, P., Abschaetzung der naechtlichen Gesamtbewoelkung mit Hilfe von ASTA-Daten, Working Reports of the Swiss Meteorological Institute, No 116, Zürich, 1983.

Chapman, L., Thornes, J.E., and Braley, A.V., Modelling of road surface temperature from a geographical parameter database. Part 2: Numerical, Meteorol. Appl. 8, 421-436, 2001.

Joss, J. and Lee, R., The Application of Radar-Gauge Comparisons to Operational Precipitation Profile Corrections, J. Appl. Meteor. 34, 2612-2630, 1995.

Mathis, A., Reengineering winter road maintenance: Decision making process, Proceedings of the 10th SIRWEC conference, Davos, 111-118, 2000.

Schmid, W., Nowcasting winter precipitation with radar, Proceedings of the 10th SIRWEC conference, Davos, 17-24, 2000.

Schmid, W., Mathis, A. and Keller, U., Nowcasting the risk of snowfall and freezing rain with radar and ground data, Proceedings of the 11th PIARC conference, Sapporo, aviable on CD-ROM, 2002.