Validation of methods to detect winter precipitation and retrieve precipitation type

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1. Introduction

Weak or moderate precipitation in winter, e.g. snowfall or freezing rain, may have dramatic consequences on traffic. Therefore, there is a need to see and foresee weak and moderate winter precipitation with adequate techniques. A key instrument for this is the weather radar (e.g., Atlas, 1990), in spite of several deficiencies:

1. The inability to identify precipitation type (e.g., rain or snow)
2. The difficulty to detect winter precipitation, especially in mountainous areas, due to shadowing and clutter effects and due to the small height above ground of precipitating clouds.

The first point can be overcome with polarisation radars (Atlas, 1990). However, these next-generation radar systems are not yet available for operational use. We proposed a much simpler method to identify precipitation type as rain, melting snow or snow (Schmid et al., 2002). Profiles of air temperature and dew point temperature are generated from ground data at various altitudes. These data are converted into fractions of snow within total precipitation mass (Koistinen and Saltikoff, 1998). Specific thresholds of this fraction define the height and thickness of the melting layer. This method to identify precipitation type is referred to as the KSS-method (<u>K</u>oistinen/<u>S</u>altikoff/<u>S</u>chmid) hereafter.

For operational applications, it is important to know the performance of methods measuring and nowcasting precipitation in winter. In Switzerland, radar image data and short-term radar image forecasts are widely used for road maintanance (Schmid, 2000). Products resulting from the KSS-method (e.g., a radar image showing the height of the melting layer, see Schmid and Mecklenburg, 2001) have become popular, and the customer responses are very positive. However, an objective and quantitave validation of the KSS-method is missing up to now, mainly due to missing direct measurements of the type of precipitation.

This situation can be overcome with the Vaisala road weather measuring network, operated by the canton of Lucerne (Mathis, 2000). The type of precipitation is registered by an optical sensor. Hence, the data from this sensor are suitable for validation of the radar information and the KSS-method. This is the main purpose of this study. For „predicting“ precipitation and it’s type, we use the radar images from MeteoSwiss (covering Switzerland and the neighboring regions) and ground network data of temperature and humidity (the so-called ANETZ, also operated by MeteoSwiss). The Lucerne data are used for validation. In the next section, we describe the data and procedures. After that, the main results of the study are shown. We end up by summarizing our findings and by discussing their consequence for future studies and operations.

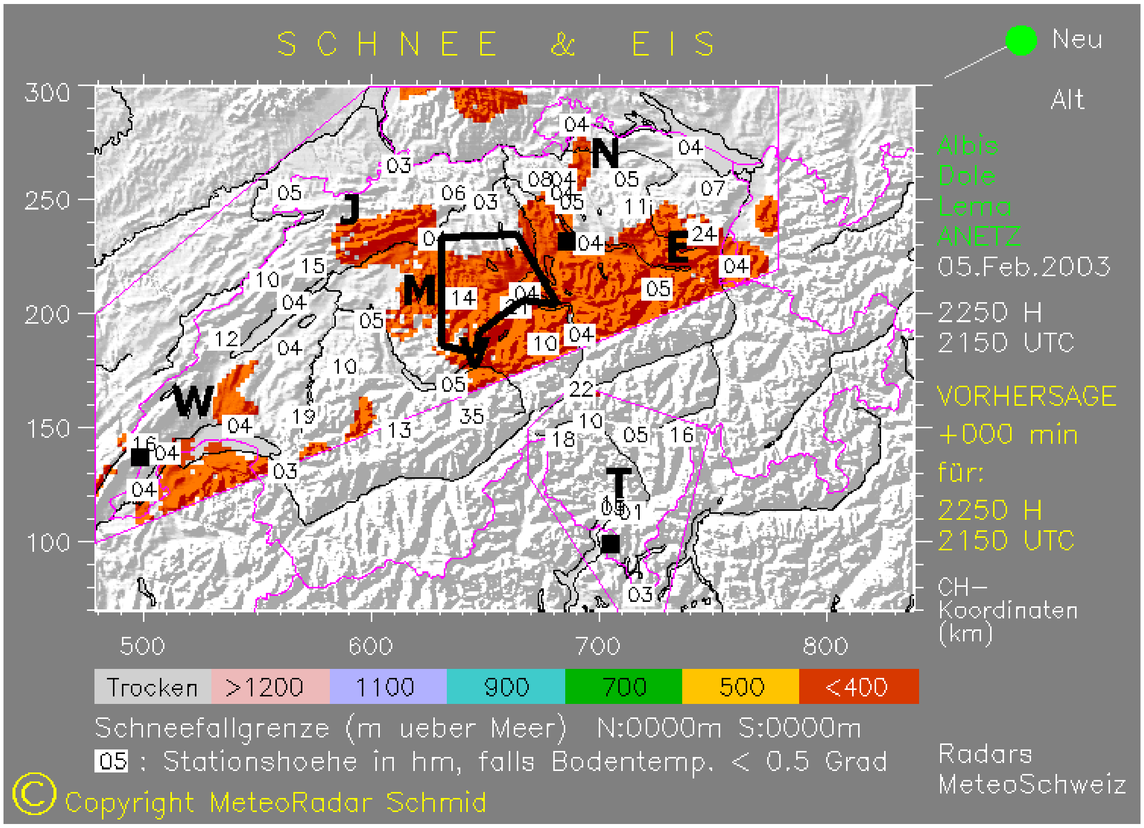

Fig. 1: Example of the product "snow and ice", showing a map of radar echoes and coloured with the height of the melting layer between 400 and 1200 m MSL. In addition, the map shows white boxes of all ANETZ stations whose temperature near ground (typically 5 cm above ground) is below 0.5^{0}C. The numbers within the boxes indicate the height of the station in Hectometers (e.g., "05" = 500 -600 m MSL). The height of the melting layer and the associated ANETZ stations are only shown in two regions, one in the north, and one in the south of the alps. These regions are divided into 7 sectors, whose centers are indicated with letters W (western Switzerland), J (Jura mountains), M (Swiss midland), V ("Voralpen" = prealps), N (Northern Switzerland), E (Eastern Switzerland) and T (Ticino area). A group of ANETZ stations is defined for each region and used for retrieving the melting layer, following the procedure outlined in the text. The Vaisala ground network of 52 stations, used for verification in this study, is located within the canton of Lucerne in Central Switzerland, bounded schematically with a black line in the figure. The black squares mark the locations of three weather radars operated by MeteoSwiss.

2. Data and procedures

a. Radar data

Three C-band weather radars are operated by MeteoSwiss in Switzerland. Black squares indicate their locations in Fig. 1. The radar data are merged to a composite image covering Switzerland and the neighboring regions. The atmospheric volume from 0 to 12 km MSL is scanned every 5 min by 20 revolutions of the radar antenna. The maximum of registered intensity within each vertical column is projected to the plane of the radar image. In order to handle evaporating precipitation, we use the radar data near ground to correct the projected maximum under specific circumstances. The radar measurements are converted into logarithmic rainfall intensities and digitized to 16 intensity levels. A sophisticated procedure is used to handle clutter and shielding effects within the radar image (Germann and Joss, 2002). In general, the ability of the radar to see precipitation depends on the orographic pattern. In the interior of the Alps, the viewing range of the radars is inhibited by mountains reaching 4800m MSL. In the Swiss midlands north of the Alps and the Ticino area south of the Alps, the visibility is quite good. For this reason, we reduce our study area to the regions north and south of the Alps.

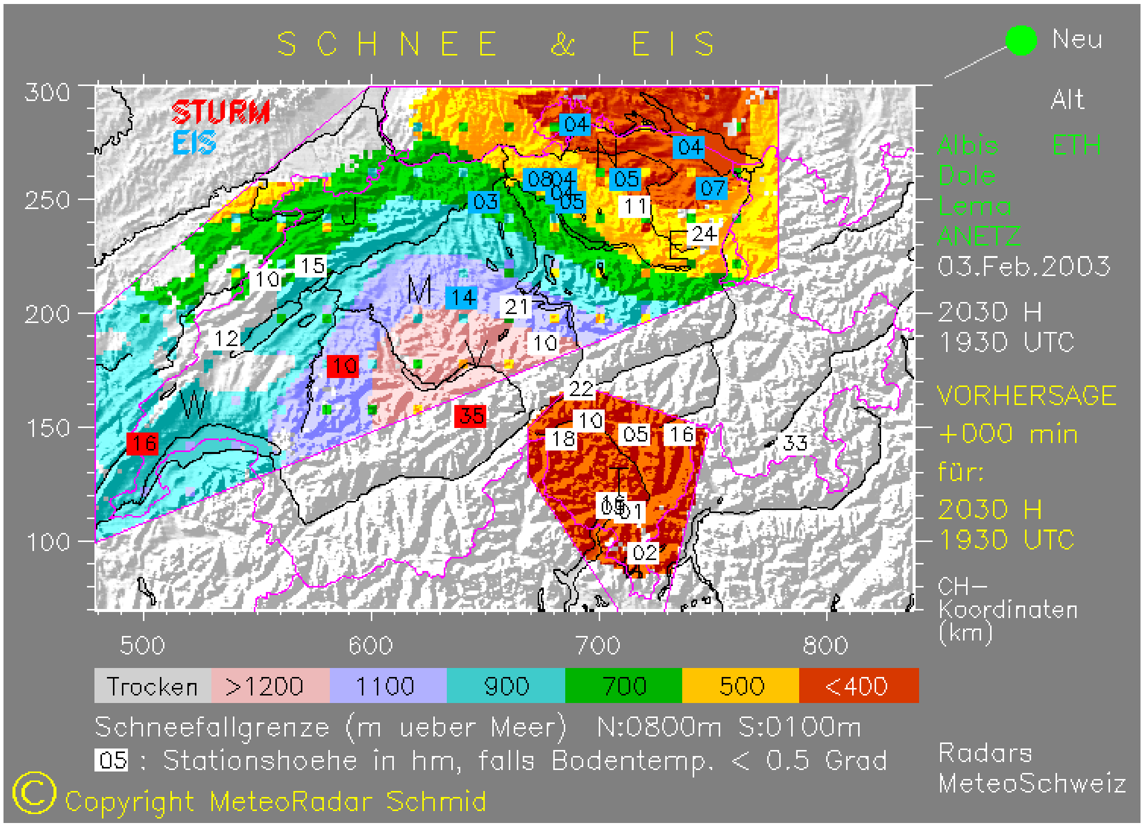

Fig. 2: Same as Fig. 1 but for a situation with variing height of the melting layer over a short horizontal distance. Blue stations ("grey" in grey-scale) indicate liquid water on the ground, together with surface temperatures below 0.5^{0}C. Red stations ("dark grey" in grey-scale) have wind gusts larger than 100 km/h.

b. ANETZ data and the KSS method

MeteoSwiss operates a network of 72 ground stations, measuring various meteorological parameters with a time resolution of 10 min. We use air temperature and dew point temperature. The two experimental regions north and south of the Alps are divided into seven sectors. In each sector, a sufficient number of stations can be found covering a height range from 200 up to 2000 m MSL. Hence, individual profiles of air and dew point temperature can be constructed for each sector. Above 2000 m, few stations can be used to expand the profiles to higher altitudes. Fig. 1 gives an overview of the two experimental regions and the centers of the seven defined sectors (labelled by letters W, J, M, V, N, E and T). The air and dew point temperature data are converted into fractions of snow within total precipitation mass, following the method by Koistinen and Saltikoff (1998). The melting layer and it's thickness is obtained by using these thresholds of snow fraction: 20%, 50% and 80%. The resulting heights are assumed to be valid for the centers of the seven sectors, and standard procedures are used to interpolate the height values in between.

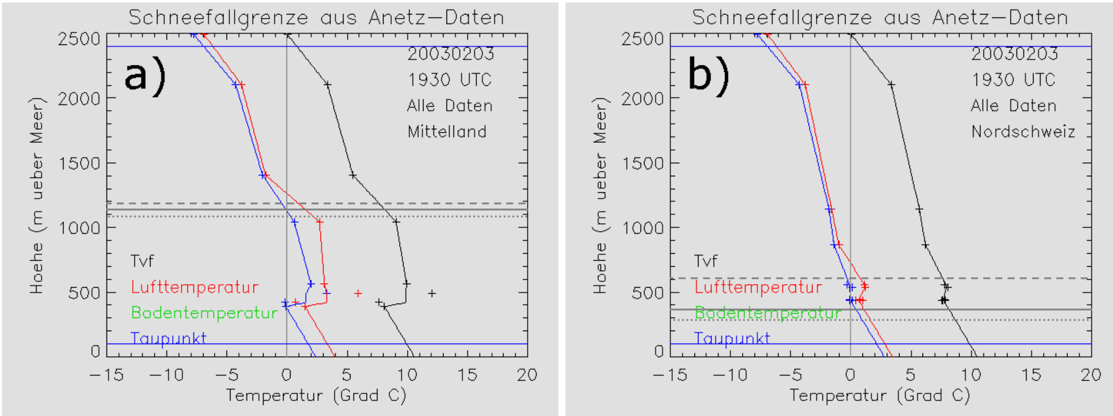

Fig. 3: Profiles of air temperature (red, in the middle)) and dew point temperature (blue, to the left)), for the "Mittelland" (a) and "Northern Switzerland" (b). The black profile (to the right) is an internal quantity, used for calculation of the melting layer height (solid horizontal line). The dashed and dotted horizontal lines mark the upper and lower boundaries of the melting layer.

The example in Fig. 1 shows a winter situation with snowfall down to the ground in some regions north of the alps. To illustrate the procedure furthermore, we show in Fig. 2 a second example with a variing height of the melting layer over a short horizontal distance. Fig. 3 shows, at the same date and time, two profiles of temperature and dew point temperature for sectors M and N. The melting layers in Fig. 3 are marked with a solid horizonal line, and the melting layer boundaries are marked with dashed and dotted lines, respectively.

Based on that information, one can retrieve precipitation type at any location and height as "snow" or "rain", simply by comparing the height of the given location with the height of the melting layer. Since the ground network data are available in time steps of 10 min, on can update this information every 10 min. This is done operationally since January 2001.

c. Vaisala data and validation

A dense network of 52 RWIS stations, manufactured by Vaisala, is operated by the canton of Lucerne since 1996. The stations measure in time steps of 15 min a number of parameters that are relevant for road weather (air temperature, surface temperature, below-surface temperature, wetness of ground, and others). Here, we use the data of the optical sensor PWD11, registering 16 types of precipitation (Table 1). An unequivocal identification of precipation type is not possible in all cases. Just "precipitation" (codes 1-3) is identified when detection of rain, snow or graupel is not possible. Just "rainfall" or "snowfall" (codes 10 or 20) is identified when discrimination among the three intensity classes is not possible. Note that the three intensity classes are not clearly linked to precipitation intensity, normally measured in units of mm/h.

For validation, we identify all registrations of precipitation type within a two-month period (Jan./Feb. 2003) from the Vaisala data for each station and time. All unknown precipitation types (code –99) are thrown away. In a second step, we search the closest temperature/humidity profile, and we use these profile data for "prediction" of precipitation type. In a third step, we select the radar value above the station for the time of interest. With this procedure, we obtained a sample of 99745 cases. Precipitation of any type was registered in 11339 cases (11%) by the Vaisala network, the rest was "dry".

Table 1: Precipitation types registered by the optical sensor PWD11, manufactured by Vaisala.

Precipitation type	Numeric code
Dry	0
Weak precipitation	1
Moderate precipitation	2
Heavy precipitation	3
Rainfall	10
Weak rainfall	11
Moderate rainfall	12
Heavy rainfall	13
Drizzle	14
Snowfall	20
Weak snowfall	21
Moderate snowfall	22
Heavy snowfall	23
Weak graupel	31
Moderate graupel	32
Ice bellets	34
Unknown	-99

3. Results

a. Validation of the KSS-method

A contingency table for judging the performance of the KSS-method to discriminate between rain and snow is shown in Table 2. The table shows an excellent result. The KSS-method is able to find the correct precipitation type in 92 % of all cases. This result is hard to improve furthermore. Inspection of the two groups with a wrong identification leads to the following result: predicting snowfall in case of rain occurs more frequently than the opposite. This has a favorable effect in practice. A short-term snow forecast is provided in cases of a continuously sinking melting layer. This is preferable to the opposite, at least for road maintanance. For this reason, we see no need to perform a fine-tuning of our method, at least not at the moment.

In summary: the threshold between snow and rain, as found in Finland (Koistinen and Saltikoff, 1998), is valid in Switzerland as well. This is not the case in Norway, as recently discussed by Gjertsen et al. (2003). There, the thresholds of snow fraction have to be shifted in order to obtain the best possible performance. The reasons for this discrepancy between the three regions are unknown at the moment. Climatic differences in precipitation physics or differences in the observations and procedures are possible explanations.

Table 2: Contingency table for validation of the KSS-method to discriminate between rain and snow. Two months of data (Jan./Feb. 2003) are evaluated.

	KSS - rain	KSS - snow	Total
Vaisala - rain	3311	790	4101
Vaisala - snow	59	6939	6998
Total	3370	7729	11099

b. Validation of precipitation seen by radar

In a second test, we judge the ability of the radar to discriminate between “precipitation” and “no precipitation”. Table 3 shows that decisions about the occurrence of precipitation based on radar are erroneous in many cases. Radar-seen precipitation may be wrong in 35% of all cases. Evaporation of precipitation between radar and ground is probably one important error source. On the other hand, 65% of all precipitation events seen on the ground remain undetected by the radar. In order to understand these two findings, we perform further stratifications of the data shown in the third line of Table 3 (“Vaisala – precipitation”). The results are given in Table 4.

Table 3: Contingency table for judgement of precipitation detection by radar.

	Radar - dry	Radar - precipitation	Total
Vaisala - dry	86245	2161	88406
Vaisala - precipitation	7331	4008	11339
Total	93576	6169	99745

Table 4 : Number of precipitation events seen with the Vaisala network, stratified according to precipitation type.

	Radar - dry	Radar - precipitation	Total
Weak precipitation	111	127	238
Moderate precipitation	0	1	1
Heavy precipitation	0	1	1
Rainfall	50	5	55
Weak rainfall	1399	2330	3729
Moderate rainfall	1	154	155
Heavy rainfall	1	7	8
Drizzle	127	27	154
Snowfall	132	13	145
Weak snowfall	5474	760	6234
Moderate snowfall	21	582	603
Heavy snowfall	0	0	0
Weak graupel	0	0	0
Moderate graupel	0	0	0
Ice bellets	15	1	16
Total	7331	4008	11339

Tabel 4 shows that “weak snowfall”, "snowfall" and "drizzle" are hardly detectable by radar. Only 12% of all events with weak snowfall can be seen by radar. Two unfavourable effects come together and inhibit the detection of weak snowfall with radar. First of all, the sensitivity of a radar to see “dry” particles (such as snowflakes or snow crystals) is lower than for “wet” particles, such as melting snowflakes or raindrops (Atlas, 1990). Second, snowclouds are often shallow and only visible near the ground, but the radar beam near the ground is either shadowed by hills or mountains, or contaminated by clutter echoes. In Jan/Feb 2002 an unusually high number of days with fog, low stratus and easterly flow occurred. Weak snowfall may develop within fog and low stratus clouds. Sometimes, human sources for ice nuclei can be identified, leading to so-called “industry snow”.

For “weak rainfall”, the detection rate is much better and reaches 62%. Even better results are found for “moderate snowfall” (detection rate with radar 97%), and almost every event of “moderate and heavy” rainfall can be seen by radar (detection rate 99 %).

4. Conclusions and Outlook

In this study, we tested a simple method based on temperature and humidity measurements to discriminate between rain and snow (the so-called KSS-method), and we validated the ability of radar measurements to detect winter precipitation over hilly terrain. The following main results are found:

a) The KSS-method works fine and provides the correct precipitation type in 92% of all cases.

b) The detection rate of a radar for weak snowfall is low (12%), but the radar is able to detect the majority of all cases with weak rainfall. Moderate snowfall, and moderate and heavy rainfall are detected in almost all cases by radar.

The first finding allows a real-time monitoring of the melting layer which has several applications, for instance: interpretation of precipitation observations with radar, improving precipitation estimates on ground, and nowcasting snowfall or freezing rain.

The second finding calls for further efforts assessing the detection of weak snowfall. Either, radar systems with a better sensitivity are installed, or, a dense network of proper sensors on the ground is operated. A possible solution could be the use of X-band radars, having better properties for clutter suppression and detection of weak precipitation than C-band radars. Considering ground stations, it is also possible to operate a dense network of precipitation sensors, being able to register precipitation with a good resolution in time (typically 5-10 min). The information about the type pf precipitation (rain or snow) can be obtained with the KSS-method, based on a less dense network of stations measuring air temperature and humidity. However, the KSS-method, as discussed in this study, is only usable in hilly or mountainous terrain.

For future, we plan to expand our data sample for validation. Sensor data about the type pf precipitation are available since 1999. Hence, the data from several winters can be used for validation. We also plan to validate short-term forecats of winter snowfall, based on our extrapolation technique COTREC/RainCast (Schmid, 2000). We believe that short-term forcasts of moderate snowfall are reliable since the detection rate of moderate snowfall with radar is close to 100%. Finally, there is also a need to develop and validate methods identifying and nowcasting freezing rain. Similar concepts as outlined in this contribution can be used for this purpose.

Acknowledgements

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