MONITORING PRECIPITATION INTENSITY AND TYPE – COMBINED USE OF RADAR AND TEMPERATURE MEASUREMENTS

by

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Abstract

Two new products developed for road authorities and other customers of the Norwegian Meteorological Institutes Market Division are presented and verified in this paper: A precipitation type forecast and a radar precipitation type product. The HIRLAM model is used to forecast the precipitation types rain, sleet and snow. The operational HIRLAM-forecasts are biased towards predicting too many cases with snow. The paper shows that additional calculations of snow melting based on temperature and humidity in the lowest model layer reduce this error. For the radar product, the precipitation type is estimated from synoptic observations of 2m-temperature and dew point temperature. The observations are interpolated in space using a Digital Elevation Model (DEM) after deriving local vertical temperature gradients. A precipitation type datset is derived and combined with the actual radar precipitation intensity image. The radar product is verified against observed precipitation types at the synoptic stations for the winter season 2002/2003 (October to March). The percentage correct is 85%. The Probability of Detection is 0.9 for rain and 0.91 for snow. A comparison of estimated and forecasted precipitation types is carried out for January 2002 against an independent set of precipitation stations in Southern Norway. The results confirm the good quality of the radar product and show that the adjustment of HIRLAM precipitation type to real topography improves the forecast.

Introduction

Road managers have been using radar reflectivity images and precipitation forecasts from the HIRLAM atmospheric model for several years. The radar provides detailed information about the spatial distribution of precipitation in real time. For the management of winter snow clearance and salting, information about the type of precipitation is of great value. In the region Helsinki in Finland, where radar products have been available for several years, the cost savings are in the range of 200 000 EUR each winter (Koistinen and Saltikoff, 1998). Two new products developed at the Norwegian Meteorological Institute are evaluated in this paper: The forecast of precipitation type from the HIRLAM model, and radar precipitation intensity images with precipitation type information.

Gelöscht: .¶

In the HIRLAM model, precipitation distributed on snow and rain has been available from the condensation schemes for many years, but has not been available to customers. In a number of cases the model is forecasting snow when rain is observed at ground level. This is related to the mainly positive difference between model orography and the real topography, particularily in the valleys and the fjords. The approach presented here uses the temperature and humidity in the lowest model layer to predict melting of snow on the way from the model's lowest layer to the real topography. The precipitation type estimation for the radar product uses a different approach. Where the humidity and temperature information is taken from theHIRLAM model for the precipitation type forecast, observations from synoptic stations are used for the radar product.

Data and methods

Precipitation type from HIRLAM

The operational atmospheric model at the Norwegian Meteorological Institute is HIRLAM 5.2 with a resolution of 20*20 km and 40 levels. The method for extrapolating precipitation type to real topography is based on Golding (1989), and applied at the Norwegian Meteorological Institute by Ødegaard (1997). Melting of snow below the model surface is applied using the following equation:

$$\frac{\partial P}{\partial z} = -0.0028 T_w P \qquad (1)$$

T_w is the wetbulb temperature, P is the precipitation rate. The wetbulb temperature is used, because the melting of snowflakes is assumed to be delayed by evaporation from the snowflakes in subsaturated conditions. To compensate for the cooling of air caused by melting of snow, the vertical gradient varies in the range 0.1-0.6K/100m depending on precipitation rate. For high precipitation rates, the gradient of the wetbulb temperature is small. The wetbulb temperature used in the model is the mean of the wetbulb temperature in the lowest model layer and the wetbulb temperature extrapolated to station height.

A 30h forecast is run at 00 UTC for each day. The 6h accumulated precipitation at +12, and +18, and the 12h accumulated precipitation at +30h are used in this comparison. The precipitation type (pt) is calculated from accumulated rain (r) and snow (s) in mm. The result is a number between –1 and 1 on a continuous scale where precipitation type pt>0.33 is interpreted as snow, 0.33>=pt>=-0.33 is interpreted as sleet and pt<-0.33 is interpreted as rain.

$$pt = \frac{(\mathrm{s} - \mathrm{r})}{(\mathrm{s} + \mathrm{r})} \qquad (2)$$

The radar precipitation type product

The radar precipitation type product is based on the operational precipitation intensity data set derived from PseudoCAPPI data. Here, data from two of the four Norwegian C-band weather radars is used, the radars Oslo and Hægebostad in Southern Norway. The Marshall-Palmer relationship is used for converting from radar reflectivity to precipitation intensity, and a gauge adjustment is performed to improve the quantitative accuracy. The gauge adjustment method is under development, the most recent documentation of the method can be found in (Gjertsen and Dahl, 2001) and (Gjertsen, 2002). To derive precipitation type, observations of 2m-temperature (T) and dew point temperature (T_d) from synoptic stations are used in real time. T_d is converted to relative humidity (RH). A test for observation errors is not yet implemented.

A digital elevation model (DEM) from US Geological Survey is used to interpolate T and RH between the synoptic stations. The DEM is transformed to the radar data resolution and geometry (1*1 km, polar stereographic). Local vertical profiles for T and RH are derived for each raster element in the radar data set using a local linear regression with the DEM height as the indepent variable. Input data to the regression are the ten closest synoptic stations within a predefined search radius (200 km in the actual implementation of the model).

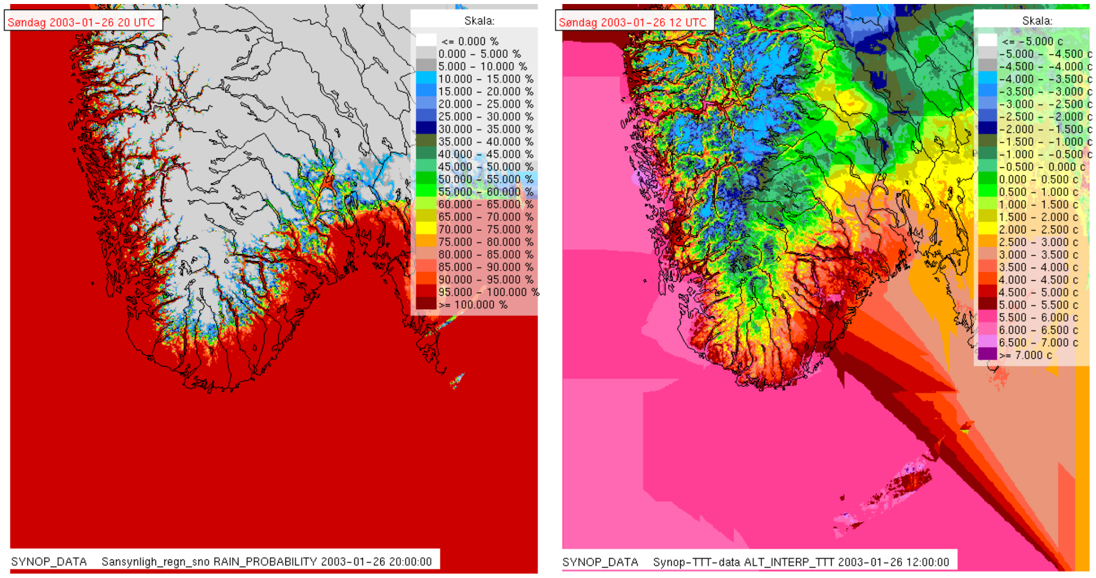

Figure 1 – Probability of rain and temperature interpolation for 26.1.2003.

Each raster element is then assigned a value for T and RH according to the DEM-height. When T and RH are available as raster datasets, the probability of rain is derived using the equation by Koistinen and Saltikoff (1998):

$$p(rain) = \frac{1}{1 + e^{(22 - 2.7T - 0.2RH)}} \qquad (3)$$

Examples of the T and p(rain) datasets are shown in *Figure 1*. The probability of rain is converted to precipitation type and overlaid with the actual radar precipitation intensity image every 15 minutes. The precipitation types are displayed in different color scales as shown in *Figure 2*. The images are generated both as composites and single site products.

The ground reference

For verification, the results from HIRLAM and the precipitation type estimation are compared to precipitation types observed at stations from the synoptic and the precipitation station network. Observations of actual weather from the synoptic network (00, 06, 12, 18h UTC) are used for the verification of the radar product for the winter season 2002/2003. The data is used after a conversion to the classes rain, sleet, snow. These are the same stations used for the generation of the T and RH data sets, therefore, no information about the accuracy of the temperature interpolation is obtained. A seperate verification is therefore performed on data from the network of precipitation stations. These stations report with a delay and are therefore not used in the processing of the radar product.. All stations covered by the two radars are used (around 280). The precipitation stations report daily at 06, 12 and 18 UTC.

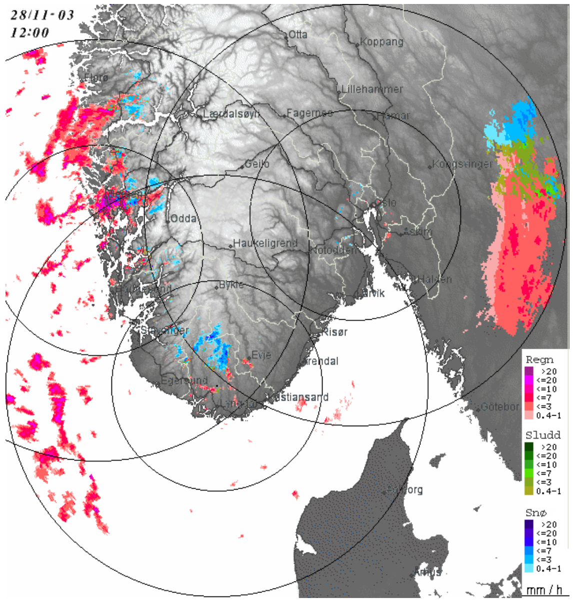

Figure 2 – Precipitation type composite for 28.11.2003, 12:00 local time

The weather including precipitation type is described with three symbols covering the period since the last observation. The symbols are given numerical values 1, 0 and –1 according to the coding of the HIRLAM product. When determining the value for a single observation period, the observation codes for the period are averaged. The radar product is coded accordingly, i.e. precipitation is accumulated for the periods 6-12, 12-18 and 18-06 UTC. For periods where precipitation is observed, the type is calculated as the mean of the precipitation types estimated during the period.
Ground observations of precipitation type are subjective. It is not clearly defined how much of the snowflake is melted in sleet, or when sleet goes over to rain. Averaging the observation codes for 6 or 12 hours is therefore not the same as using the mean precipitation type from a 6h or 12h period from HIRLAM, or averaging the precipitation type estimation from the radar product. The results presented in the following sections have to be interpreted being aware of these limitations.

Verification of the radar product against synoptic stations

In this section, the accuracy of the precipitation type estimation is verified against observations of actual weather at the synoptic stations for the months October 2002 – March 2003. Only cases where both radar and station observe precipitation are used. The quantitative accuracy of the radar precipitation product is not subject of this verification. The actual weather type is read from a climate data base and classified into the precipitation types rain, snow and sleet.

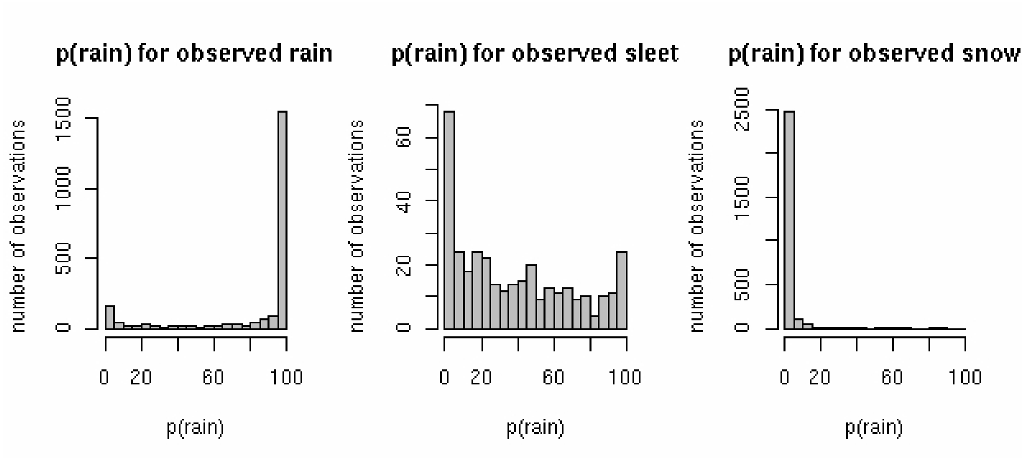

Figure 3 – p (rain) for observed precipitation types.

Figure 3 illustrates the distribution of p(rain) derived from *eq. (3)* for observed rain, sleet and snow. Snow and rain show clear peaks on each side of the spectrum, but there are cases where rain is observed despite very low probability. This is most likely due to temperature inversions not modeled correctly by the vertical temperature profile regression. Sleet is observed for all p(rain) and shows no clear maximum. There are however many cases where sleet is observed for low probability of rain. Also in this case, temperature inversions are a possible cause. .

Table I FAR and POD for precipitation types.

Observed precipitation type	**False Alarm Rate**	**Probability of Detection**
Rain	0.15	0.9
Sleet	0.84	0.08
Snow	0.09	0.91

The probability of rain is a continous variable on a scale from 0 to 1. The class boundaries for rain, sleet, snow were found by balancing the False Alarm Rate (FAR) and Probability of Detection (POD) for snow and rain. The class boundaries used by Koistinen and Saltikoff (1998) lead to an overestimation of snow, equivalent to a high False Alarm Rate for snow. By adjusting the class boundaries, the FAR for snow and rain are reduced and the POD are increased.The total number of hits is 77% for the original class boundaries and 85% for the adjusted class boundaries.The POD for sleet is very low (0.08). Only 8% of the cases with observed sleet are classified correctly by the model. For observed rain, the model classifies correctly in 90% of the cases, for snow in 91%.

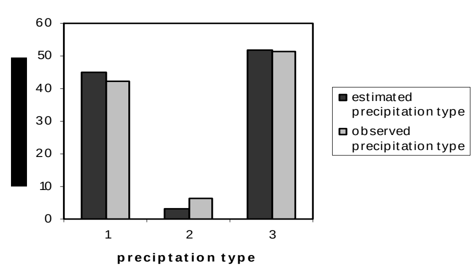

Figure 4 – Frequency histogram for estimated and observed precipitation types (1=rain, 2=sleet, 3=snow) October 2002 – March 2003.

Figure 4 shows the relative frequencies of estimated and observed precipitation types. Sleet is observed in 6.4% of the cases and is underestimated in the radar product. Rain is slightly overestimated, while the frequency of snow is around 50% for both observervation and estimation. The confusion matrix for the classification is shown in *Table II*. 5375 observation/estimation pairs are used.

Table II Confusion matrix for classification into precipitation types.

	Est. rain	**Est. sleet**	**Est. snow**	**Est. sum**
Observed rain	2037	43	178	2258
Observed sleet	235	29	81	345
Observed snow	178	81	2513	2772
Observed Sum	2450	153	2772	5375

Verification of forecast and radar product against independent precipitation stations

In this section, the adapted HIRLAM forecast (with melting of snow between model layer and real topography), and the estimated precipitation type are compared to observations from the network of precipitation stations for January 2002. In *Figure 5*, two time series for the stations Moss (131 m asl.) south of Oslo, and Madland (297 m asl.) on the Western Coast of Norway are shown as examples.

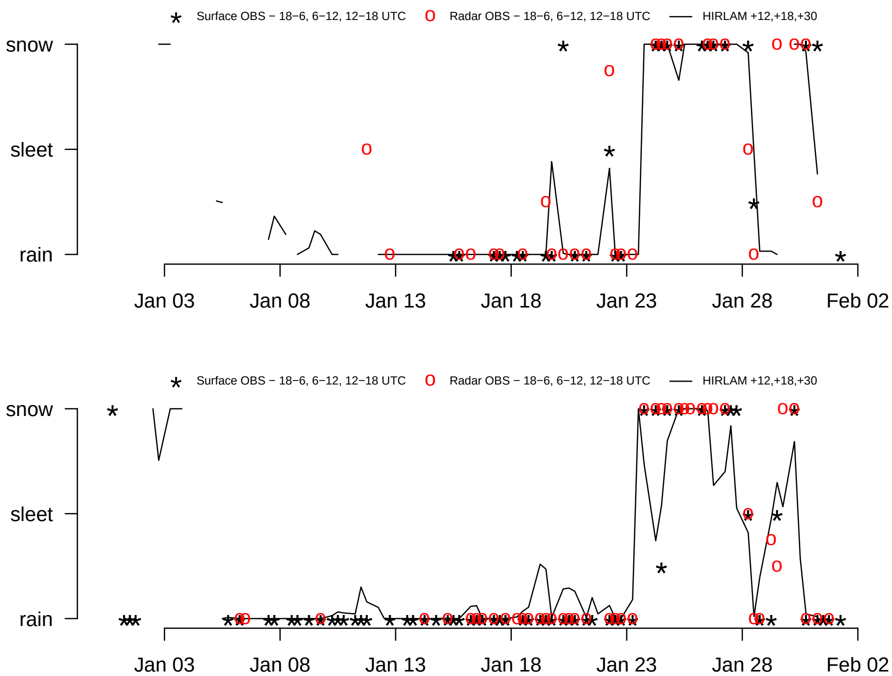

Figure 5 – Time series for stations Moss and Madland.

The result of the summary verification for operational HIRLAM (1st row), radar product (2nd row) and adapted HIRLAM (3rd row) is shown in *Figure 6*. For observed rain (1st column), the operational HIRLAM forecast is correct in 73% of the cases, the adapted HIRLAM is correct in 86% of the cases, the radar product in 87%. The HIRLAM forecast is clearly improved in the adapted model. For observed snow, the operational HIRLAM forecast is correct in 87% of the cases, the adapted HIRLAM in 84%, the radar product in 91%. Here, the operational HIRLAM performs slightly better than the adapted due to a general overestimation of snow. It is likely that the adapted HIRLAM melts too much snow in some cases. The class sleet is problematic, it is mixed with snow and rain in allproducts, with a bias towards snow. This is at least partly related to the fact that the definitions of sleet vary in the three data sets. The observed precipitation type "sleet" is not equivalent to the class "sleet" from HIRLAM or the radar product.
The results for the radar product are good. Also when verified against independent stations, the detection of snow and rain is around 90%. The percentage correct for the precipitation stations is 84.6% as compared to 85% for the synoptic stations. These results show that the temperature interpolation technique performs well.

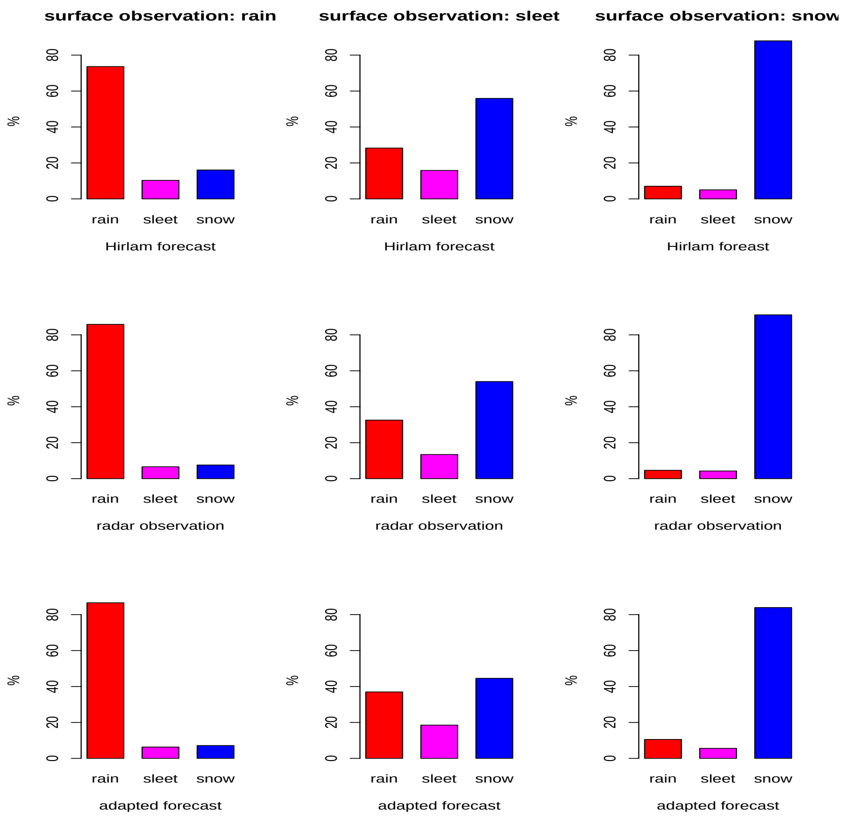

Figure 6 – Precipitation type distribution for all cases with observed rain/sleet/snow in January 2002. Row1: operational HIRLAM forecast, row2: radar estimation, row3: adapted HIRLAM forecast.

Conclusions

The verification of the adapted HIRLAM precipitation type forecast and the precipitation type product from synop- and radar data shows that the HIRLAM forecast improves with adjustment to real topography. The bias towards predicting too many cases with snow is removed. The detection of snow is slightly reduced, this might indicate that the model melts too effectively in some cases, possibly also cases with temperature inversions. An adjustment of the T-gradients is possible. The adapted HIRLAM model improves the forecast for locations in complex terrain where the operational HIRLAM forecasts too many cases with snow. The estimated precipitation type in the radar product is correct in 85% of occurrences when verified against synop– and precipitation stations. The classification of sleet is difficult. This is partly a matter of definition of class boundaries. In a next step, we plan to compare the quantitative accuracies of HIRLAM precipitation forecast and radar precipitation accumulations.

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