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Real-time estimation of surface precipitation type merging weather radar and automated station observations

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ABSTRACT

One of the major problems affecting road safety conditions during the cold season in mid-latitudes is the possible presence of snow or ice on the ground. This is particularly critical in regions with mild winters such as in the Mediterranean basin where snow, especially at low altitudes, is a relatively rare phenomenon and vehicles are normally not equipped with winter tyres. Based on earlier developments in Finland and Norway during the last decade, a method to estimate surface precipitation type (snow, sleet, rainfall) that combines information from weather radar and automated surface observations is described. The method can be regarded as a three-step process. Firstly, a temperature and relative humidity analysis is derived from a network of standard surface automated stations. The analysis takes into account not only surface observations but also terrain height to estimate local vertical gradients in the interpolation process in complex orography. Secondly, an estimation of surface precipitation type is obtained through an empirical formula that provides the conditional probability of snow as a function of temperature and humidity, assuming that precipitation is present. This allows to build a two dimensional field of surface precipitation type. Thirdly, the surface precipitation type is combined with quality controlled weather radar data which provide an areal description of the spatial distribution of the precipitation field. This process is updated every six minutes, when new radar data are updated. The resulting product is presented to end-users in a customized way (GIS, specific visualization tool, etc.).

Keywords: surface precipitation type, weather radar, complex orography

1 INTRODUCTION

The presence of snow or ice over highways and roads can be a serious problem affecting normal circulation and safety conditions during the cold season and is regularly monitored in central or northern Europe to support winter snow clearance or salting operations. In other areas with mild winters, such as in the Mediterranean basin, snow or ice on ground may be particularly critical, especially at low altitudes and densely populated regions, where snow is a relatively rare phenomenon and vehicles are normally not equipped with winter tyres.

Different previous studies have shown the importance of a number of factors such as surface temperature or the presence of ice or snow over the road surface and slippery conditions having a potential impact on increasing the traffic accident rate – see for example [1-2]. Local conditions may be precisely monitored by *in situ* road surface sensors but this becomes an expensive solution if large regions must be under surveillance. One alternative approach to estimate the presence of different precipitation types over a wide area has been using weather radar data, for example in Finland [3], Switzerland [4-5], or Norway [6-7] (see Figure 1). This is not an straight-forward task as, in general, weather radar systems cannot distinguish precipitation type (for example rain from snow), except for polarimetric radars which only until recent years are becoming available for operational applications, e.g [8]. Therefore, the use of radar data supplied by ordinary, single-polarization, weather radar systems to estimate precipitation type requires additional information which usually is obtained either from networks of ordinary automated surface observations, or from Numerical Weather Prediction data, or a combination of both.

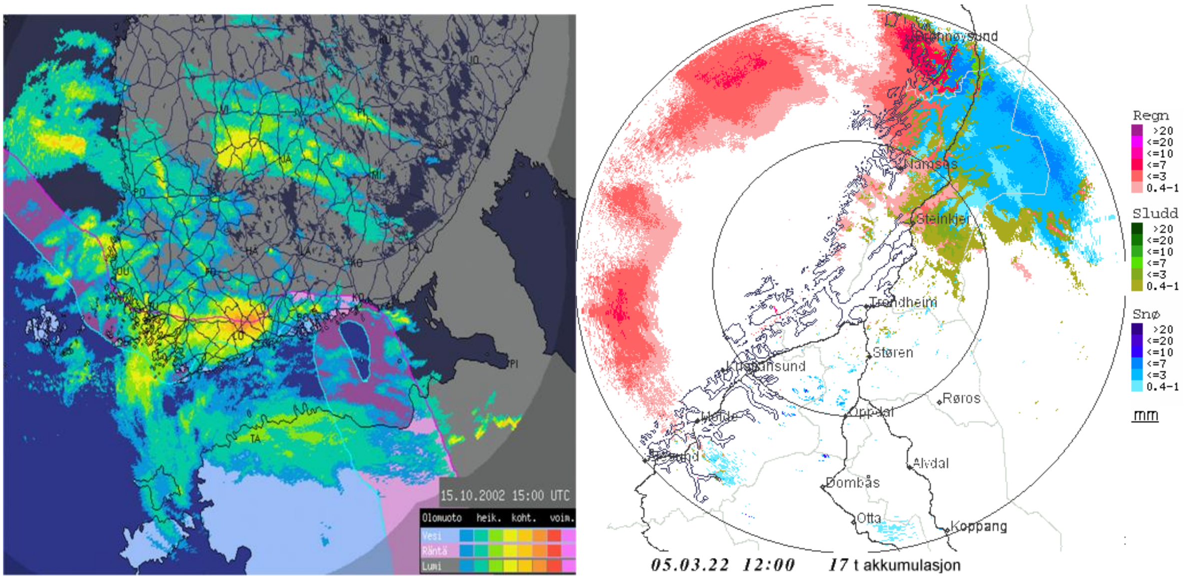

Figure 1. Examples of surface precipitation type products over Finland (left) and Norway (right) showing different precipitation types: rain (blue background/reddish colours), sleet (purple background/greenish colours) and snow (grey background/blueish colours). Source: Finnish Meteorological Institute (left) and Norwegian Meteorological Institute (right).

The aim of this study is to describe the implementation of a surface precipitation type (SPT) product over Catalonia (NE Spain), in the Iberian Peninsula. This region is characterized mostly by a Mediterranean climate, with mild winters, particularly along the coast where most population and transport networks (highways, railways, speed train lines) are concentrated. Snow on ground is common on the mountains, especially in the Pyrenees (with peaks above 3000 m and a dozen of sky resorts), mostly on the North, but it is rather rare over lower areas, such as the metropolitan area of Barcelona. Low altitude heavy snowfalls in Catalonia may have a large impact such as the recent cases on 14-15 December 2001 [9-10], 28-29 January 2006 [11], or 10 March 2010 [12-15].

2 METHODOLOGY

The methodology of the surface precipitation type product is based essentially on [7] and can be described as a three-step process:

- Temperature and relative humidity analysis, obtained from a network of standard surface automated stations. Both the temperature and humidity analysis take into account not only surface observations but also terrain height to estimate local vertical gradients in the interpolation process in complex orography, very relevant in some parts of the region.

- Estimation of surface precipitation type, calculated through an empirical formula that provides the conditional probability of snow as a function of temperature and humidity, assuming that precipitation is present. This allows to build a two dimensional field of surface precipitation type, provided that precipitation exists.

- Combination of quality controlled weather radar data, which provide an areal description of the spatial distribution of the precipitation field, with the surface precipitation type field, used as a mask for each hydrometeor type.

The first version of this product was implemented at the Meteorological Service of Catalonia (SMC) in 2005 to examine some case studies and became operational in 2006. The following subsections describe in more detail the development and implementation of each step, using data both from the SMC automated surface observation stations and radar data (see Figure 2).

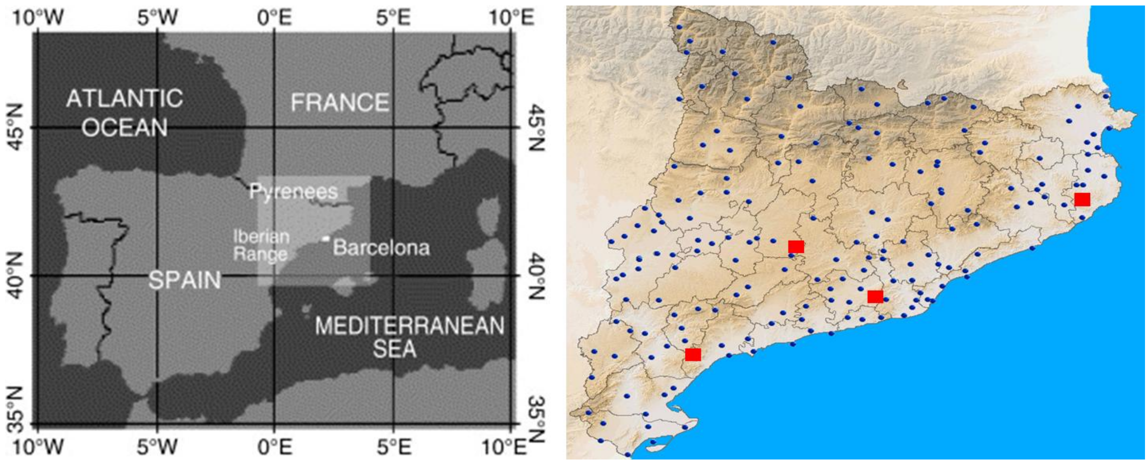

Figure 2. Position of Catalonia in NE Spain (left) and distribution of the automated meteorological observation stations network (blue dots) and C-band Doppler weather radar systems (red squares) of the Meteorological Service of Catalonia (right).

2.1 Temperature and humidity analysis

The original temperature and humidity surface analysis described in [6] was produced from synoptic stations, updated every 3h. The implementation here described makes use of a more dense network of 165 automatic meteorological stations covering the extension of Catalonia (Figure 2), ca. 32000 square km, with data updates every hour. The interpolation scheme was originally adapted from [6], which used a digital elevation model to incorporate height variations (both in temperature and moisture). At each analysis grid point (2 km x 2 km), a radius of influence was considered and all observations under that radius were used to derive a local lapse rate value, which was then used to estimate the local value of temperature and humidity by linear regression. This method is fast, relatively simple and provides a broad view of the situation as shown for the 2001 snowfall event using radius of 50 km. However this method may introduce unrealistic effects such as spurious thermal inversions due to warmer coastal stations strongly influenced by the Mediterranean Sea.

To improve the analysis, alternative interpolation methods were tested with 1 year of data. The one that yielded best results was a multiple linear regression analysis with anomaly correction. This method consists in a multiple regression using altitude, latitude, and distance to the sea as variables - the last variable had a threshold limiting the influence up to 50 km inland. At each observation point the anomaly, i.e. the difference between the observed and analysed value, is computed. A field of anomalies is then built and subtracted to the analysed field in order to include local effects. Three stations showed high systematic bias in the anomaly field (above three standard deviations) and were removed from the anomaly correction. The mean error over all the stations was 1.2ºC obtained with a leave-one-out cross validation approach. Complementary, additional cases with specific meteorological conditions were examined, including typical winter nights, cold morning after strong nocturnal radiation cooling, days with strong sea breeze, fog, snowfall, or hot summer days to assess to behaviour of the method trough a range of conditions. Individual hourly mean errors in those events ranged between 0.7 ºC and 1.6ºC (see Table 1 for details).

Date Hour [UTC]	*Event*	*Mean Error [ºC]*	*St. Dev. [ºC]*	*Min. Error [ºC]*	*Max. Error [ºC]*
20110101 00:00	Winter night	0.832	0.797	0.018	4.057
20110622 13:00	Strong breeze	0.881	0.949	0.014	6.698
20101204 07:00	Cold morning	1.334	1.304	0.006	7.978
20091211 12:00	Fog	1.553	1.382	0.036	6.389
20100308 12:00	Snowfall	0.675	0.598	0.008	3.820
20100827 13:00	Summer noon	0.949	0.971	0.001	4.761

Table 1. Summary of error statistics of hourly temperature multiple linear regression analysis with anomaly correction for selected events.

2.2 Probability of precipitation type

The implementation of the surface precipitation type product at SMC used an empirical formula that provides the probability of precipitation type, assuming precipitation exists, given a value of temperature and relative humidity. This formula was originally fitted using two years of synoptic observations of those variables and present weather observations recorded in Scandinavia as detailed in [3]. In particular it is formulated as the probability that precipitation is rain and it is given by:

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

where temperature *T* is in Celsius and relative humidity *RH* in %. Values where *p(rain)* > 0.66 indicate rain, values with *p(rain)* < 0.33 indicate snow, and values in between are assigned to sleet. Note that for the sake of simplicity precipitation type is restricted to these three possibilities, despite present weather synoptic codes include a much wider range of classes (drizzle, drizzle and rain, rain, sleet, snow, etc) - for more details see for example [7],[16]. The probability *p(rain)* is defined for any value of temperature and humidity though precipitation is unlikely in dry conditions (Figure 3).

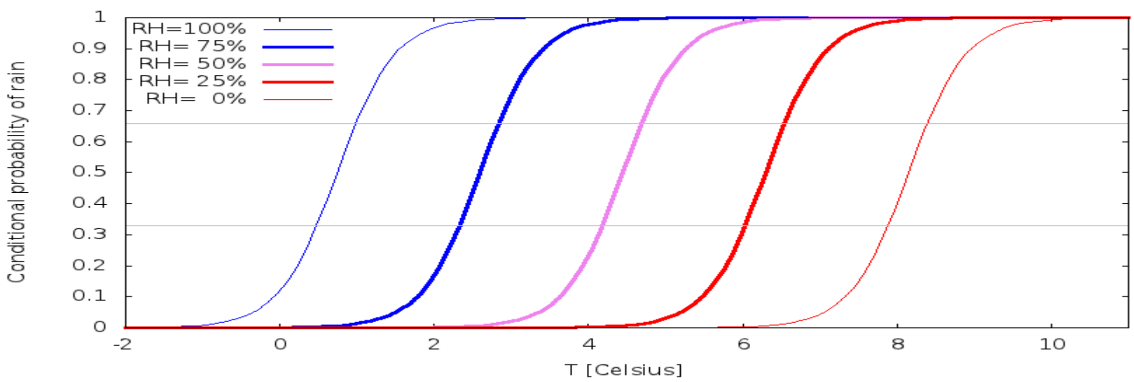

Figure 3. Conditional probability of rain as a function of temperature for different relative humidity values according to Equation (1). Probabilities of 0.33 (upper threshold for snow) and 0.66 (lower threshold for rain) are also plotted.

On the other hand, a different approach was taken by [16] when trying to parameterize precipitation type in global numerical weather prediction models. Based on 30 years of a global data set of synoptic observations (15000 stations) a probability function was fitted considering temperature and pressure:

$$F(T) = a \cdot [\tanh(b \cdot (T - c)) - d] \quad (2)$$

where parameters *a*, *b*, *c* and *d* depend on a number of factors such as precipitation type (rain, sleet or snow), continental or oceanic site, and yearly or seasonal periods. Different probability functions and values of the parameters are given in [16]. The pressure dependence becomes relevant for values below 700 hPa, as then lower air density implies slower snowfall speeds and the possibility of coexisting with higher temperatures.

Equations (1) and (2) were compared with a data set of about 220 synoptic stations over Spain and the Western Mediterranean area included in the rectangle 44ºN to 34ºN and 10ºW to 15ºE during the period April 2007 to March 2009 (2 years) [17]. The aim of the analysis was assessing their validity with independent observations and also determining if there were alternative thresholds to set the snow or rain type (0.33 and 0.66 respectively). The data set available contained 63900 observations of rain and 1800 observations of snow - sleet and other winter precipitation types were negligible, therefore the focus was on distinguishing between these two types. Several versions of F(T) were used (denoted P2, P3, ..) considering different parameters.
A verification analysis based on contingency table scores was performed with those versions and also with the probability of rain given by Equation (1), denoted here as P1. For example Figure 4 shows the behaviour of BIAS and Heidke Skill Score (HSS) for several probability of rain functions (P1, P2 and P3) under different thresholds.

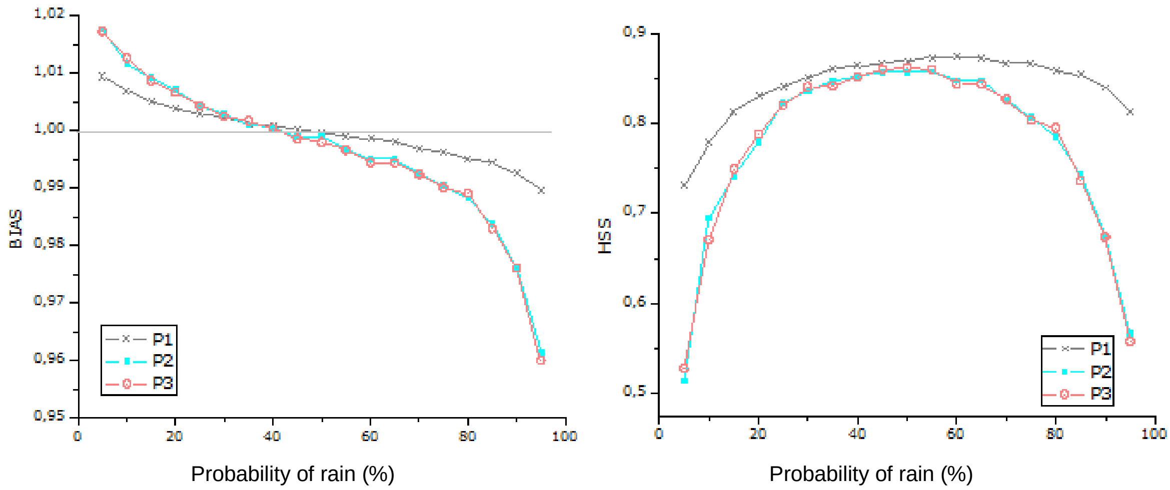

Figure 4. Bias (left) and Heidke Skill Score (right) plots for different probability of occurrence of rain versions calculated with P1 (Equation 1) and P2 and P3 (Equation 2). Adapted from [17].

Results indicated that P1, derived from Equation (1), was generally better than probabilities of rain and snow derived from Equation (2). Optimal thresholds to distinguish snow and rain were 0.60 and 0.30, a set of consistent values with the original probabilities (0.66 and 0.33) proposed in [3].

The operational implementation at SMC applies Equation (1) to the temperature and moisture analysis described earlier to produce a two dimensional grid covering Catalonia. This process is currently updated every 30 minutes.

2.3 Weather radar data

The surface precipitation field required for the SPT product is obtained from the radar reflectivity composite of the C-band Doppler radar network of the Meteorological Service of Catalonia (Figure 2). In the operational radar product generation scheme, a number of post-processing algorithms are applied in order to remove non-precipitating echoes (sea clutter, anaprop, etc.), correcting for beam blockage, vertical profile of reflectivity, etc. as originally described in [18-19]. Single radar polar volumes are available every 6 minutes and the composite produced with the corrected data is updated accordingly. Radar reflectivity is available in a 1 square km grid that is adapted to the probability of precipitation field (Figure 5).

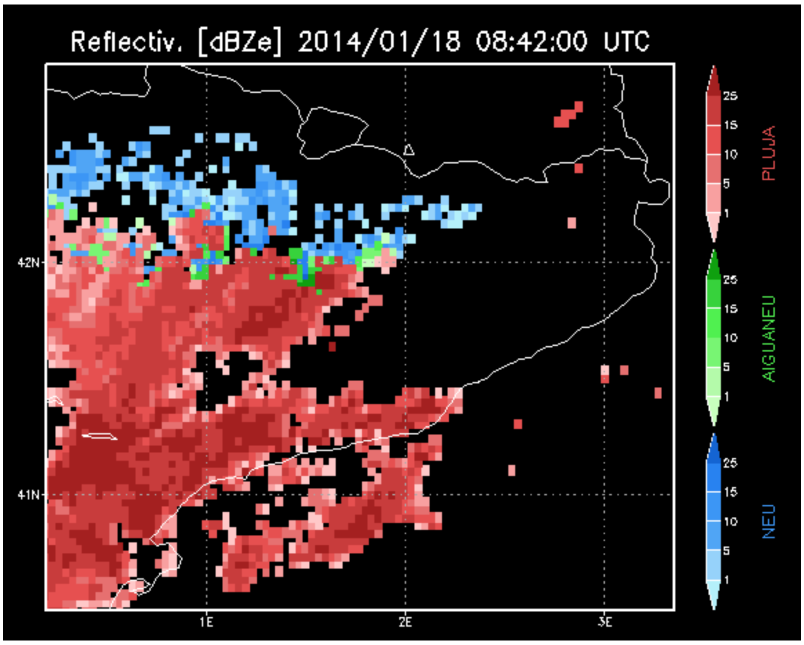

Figure 5. SMC operational surface precipitation type product, showing radar reflectivity for different precipitation types: rain (red), sleet (green) and snow (blue).

2.4 Surface precipitation type product

Two versions of the surface precipitation type product are currently in operation at the SMC. The first operational version started in 2006, is based on the three dimensional interpolation scheme analysis depends only on the interpolated variable and on orography (horizontal resolution of 1 km), shown in Figure 5. A second version is being produced using the multiple linear regression analysis with anomaly correction (with 200 m of horizontal resolution). The precipitation type mask is adapted to the radar composite resolution (Figure 6). The product is ready for delivery for both internal and external end-users in a variety of formats allowing integration in third-party systems such as GIS software packages.

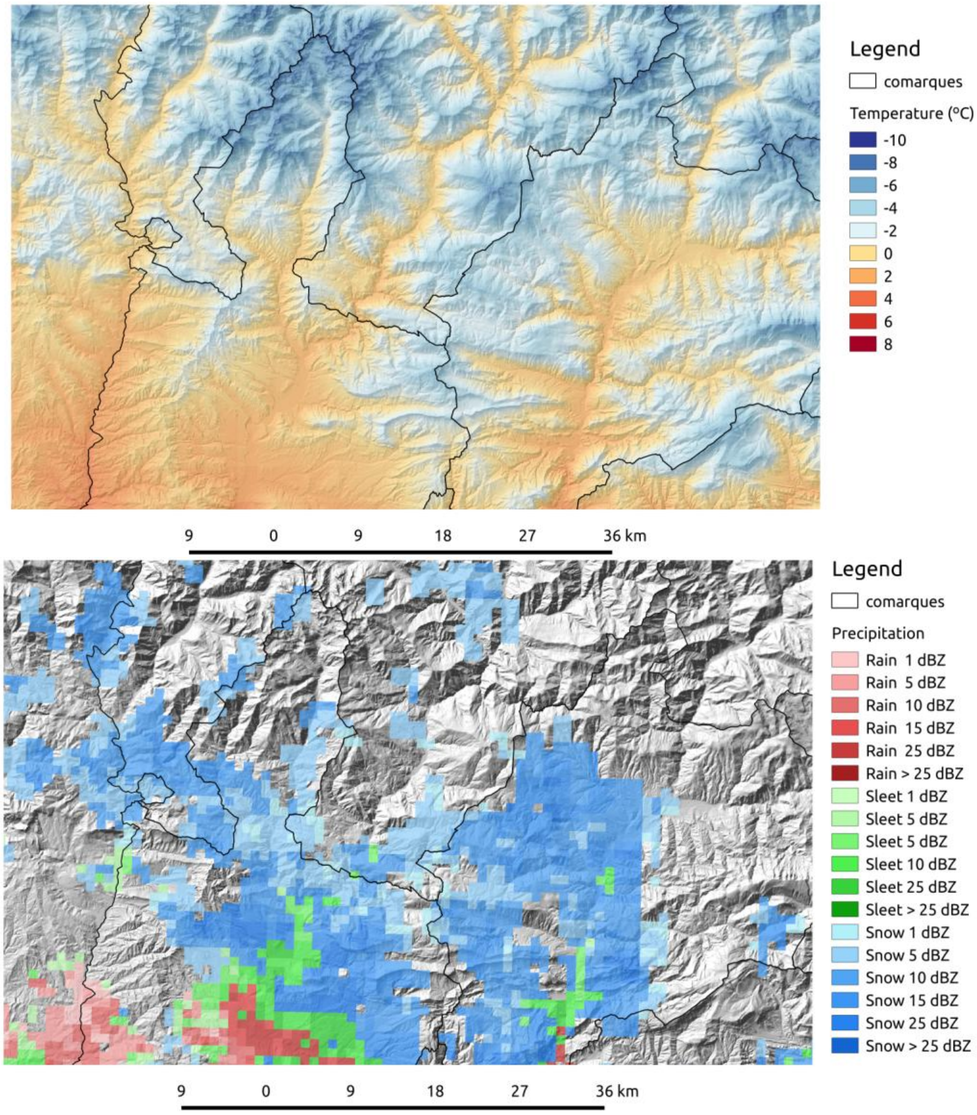

Figure 6. SMC improved temperature analysis using multiple linear regression with anomaly correction (top) and corresponding surface precipitation type product (bottom) – view corresponds to NW Catalonia, same date and time as Figure 5.

3 CONCLUSIONS

A surface precipitation type product based on surface temperature and relative humidity analysis and radar data observations implemented at the Meteorological Service of Catalonia has been described. The product has provided promising results and a reasonable behaviour so far, despite the limitations of the input data (station local effects, inherent problems with single polarisation radar observations of snow, etc.).

Currently this product is being used internally in general weather surveillance tasks and also is being evaluated for specific support to other winter traffic applications developed at the SMC [20-21]. Further work is expected to include a verification of the precipitation type product against *in situ* observations and of the temperature and moisture analysis with independent observations.

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