Water Phase

Harri Hohti, Finnish Meteorological Institute

Klaus Stephan, DWD

Introduction

OPERA rainrate product is known to underestimate precipitation in winter. One of the reasons is that Marshall-Palmer equation is used to convert Z to R everywhere. In this project, a specific ZR equation is used at areas where it snows.

Analysis of water phase of surface precipitation from NWP model input for OPERA composite area

Post-processing team and operational aviation forecasters of FMI have developed an algorithm for "potential precipitation type" derived from basic model quantities by HIMAN system of FMI. The brief documentation can be found on https://github.com/fmidev/himan/blob/master/doc/plugin-preform_hybrid.md. The algorithm is under continuous development and update cycle.

The algorithm is originally developed for precipitating areas of NWP models, but the model precipitation is not used in this "potential" version, which is a continuous field over the model area, basically telling what would be the type of precipitation if there would be any. This kind of field is needed because of spatial differences of precipitative areas between model prediction and radar observation.

Forecasters in FMI use the algorithm operatively, and precipitation type analysis is produced for ECMWF, HIRLAM and HARMONIE models. Experiences has been presented at AMS conference in January 2017:
https://ams.confex.com/ams/97Annual/webprogram/Paper298049. Html

The output format is GRIB2 and it's read using "eccodes" library of ECMWF.

Correct operational ODC rain rate composite for snow events

Currently the potential precipitation type field consists discrete values for each type class. Because of this and the model grid being more coarse than the radar composite resolution, some modifications to the field is needed.

During the projection conversion from GRIB2 "lonlat" projection to Odyssey's "laea" projection the resolution of the field is increased to 2 km/pixel by taking the value from nearest neighbouring model grid point. The projection conversion is done by using the USGS PROJ4 library. The output format options are ODIM HDF5, GeoTIFF and PGM.

As shown in the status report from Klaus Stephan at March 2017 Exeter meeting, the field still contains too much precipitation classified as sleet. Therefore it was decided to handle the sleet class as snow, and use adjustable gaussian smoothing across the sleet-snow border. The classes of drizzle, freezing drizzle and freezing rain are handled as rain. The information of sleet excess has been relayed to the developers of the algorithm. According to the report it was also decided that temporal interpolation between hourly snow probability fields is not necessary at this point of the development.

For the conversion from Odyssey rain rate composite the smoothed potential precipitation type now represents the probability of dry snow. This will be useful interpretation also with the future probabilistic approach of ensemble models. This quantity is used as a measure of wetness of snow to interpolate parameters a and b from Z(R) to Z(S) relations within transition zones from rain to snow. As a first guess this is done linearly because of unknown behaviour of the parameters a and b with sleet.

The nearest prediction field in time for each Odyssey rain rate composite is used for correction process.

The output format is ODIM HDF5 with datasets of corrected rain rate and dry snow probability. The conversion parameters for Z(S) are added as metadata attributes zs_a and zs_b. The interpolation method is added as a comment attribute. GeoTIFF output is also available.

Verification of operational ODC rain rate composite and corrected ODC rain rate composite against several synop stations and optionally verification of NWP forecast quality when assimilating the two composites.

Only the qualitative verification has been done in aforementioned report by Klaus Stephan. Quantitative verification will follow after the decision of Z(S) relation parameter values (e.g from Microphysical Properties of Snow and Their Link to Ze-S Relations during BAECC 2014, von Lerber et al. Journal of Applied Meteorology and Climatology 56 (6), 1561-1582)

The modified rain rate and snow probability fields will be available for verification from FMI's FTP service or similar for the winter 2017-2018. The test phase of operational production started at 19th of September 2017 in FMI.

Archived GRIB2 files are available from HIRLAM and HARMONIE models since 17 Feb 2016, and from ECMWF since 19 Sep 2017.

Adaptation of ODC software if necessary

The implementation of the software to Odyssey will be done in OPERA 5.

The software is using only free software libraries (proj, gdal, eccodes, hdf5) and the HIMAN postprocessing system of FMI will also be published later as free software, so there won't be any property right limitations of installation.

Accumulation comparison should be done only after OD4 implementation, or offline with OD4 software and archived data.

Description of data fetch, processing chain and software

The operative HIMAN system of FMI produces the potential precipitation type data about four hours after model run start. From HIRLAM the data is available four times a day and from ECMWF twice a day.

The existence of new model data is checked every time the radar composite is fetched from Odyssey (polling cycle of Odyssey data is one minute). The script for polling the Odyssey data calls the script containing the calls to binary code to modify the rain rate data.

If new model data is found, the GRIB2 file is read and hourly model fields are converted to snow probablity (PS) fields in Odyssey projection and resolution. These files are kept until next model data is found.

The software used for PS processing:

GRIB2 read and conversion to PGM image and optionally to HDF5: C-code using eccodes and hdf5 librariers

Projection conversion to Odyssey projection: C-code using proj and hdf5 libraries. Optional output to GeoTIFF with gdal library.

Gaussian smoothing of PS files in PGM format: ImageMagick "convert" tool. Uses smoothing for 30 pixel (60 km) radius and deviation of 5 as default. This is fully adjustable. Specific C-code for this task is also available if needed.

The nearest PS file in time is used to modify the rain rate values as a function of PS

The software used for rain rate modification:

C-code for reading and writing the Odyssey rain rate composite with hdf5 library. Creates two lookup tables for PS values from 0 to 100 % for R to S conversion interpolation (this speeds up the rain rate modification per each Odyssey composite pixel). The rain to snow conversion parameters zr_a, zr_b and zs_a, zs_b are set as environmental variables for this software.

The software is also able to change the default Marshall-Palmer relation for rain of Odyssey rain rate composites to more suitable one if needed.

The resulting modified ODIM HDF5 files are archived in FMI's archiving system for further use, e.g. to be fetched from other OPERA countries for testing.

Remarks

- The current Odyssey rain rate files doesn't contain the zr_a and zr_b parameter attributes. The Marshall-Palmer ones 200 and 1.6 are assumed as default values in the software.
- The zs_a and zs_b parameters for snow are not defined in ODIM data model specification.
- Terminology needs clarification. In the FMI's post-processing the term "potential precipitation form" is used, but "type" and "phase" are also used elsewhere.
- Decision is needed whether the corrected rain rate dataset should be added to existing HDF5 rain rate file, the uncorrected dataset to be replaced or to create totally new file.

Sofware package

Software will be available as separate package with documentation via OPERA web site

Implementation plan for operative use in Odyssey

For the production of potential precipitation type there is three alternative solutions:

Production in FMI with HIMAN postprocessing and data transfer to Odyssey

Installation of HIMAN to e.g. ECMWF and data transfer from there

Extraction of algorithm from HIMAN and programming a standalone software. This solution needs the data fetch of several model quantities from many vertical model levels.

During the verification phase the first one is easiest to implement, as the process is already operational.

The other parts of the sofware are easy to install to Odyssey. Only three short C-code programs has to be installed. The input files needed are the rain rate composite in ODIM HDF5 format and the potential precipitation type in GRIB2 format (or snow probability field in Odyssey projection in PGM or HDF5 format if available from some other source). Conversion parameters for rain and snow must be set as environmental variables or given as arguments.

Validation report

The new procedure was tested during winter season 2017/2018. SNOW corrected and original OPERA composites are compared in different ways:

- comparison of the 3-monthly accumulated precipitation rate (OPERA domain)
- comparison of daily snow amount based on a snow analysis of DWD of a snowy day
- applying both composites for data assimilation into COSMO-DE model for December 2017 (mid Europe)

Figure 10 and Figure 13 show the amount of snow in Europe during December 2017 and January 2018. They are based on a snow analysis for a global NWP model running at DWD. As one can see, lots of snow events occurred, where the new procedure is expected to change the estimated precipitation amount of OPERA composite. In a first step of validation both composites were accumulated over three month. Figure 1 shows the amount of precipitation during December 2017 until February 2018 contained within operational OPERA composites. One can recognize the well known deficits of the composite:

- a lot of hotspots (maximum sum is about 32607 mm within 3 month!) caused by ground clutter or RLAN interference or inconsistency in data processing (Romania)
- very low precipitation amount, caused by climatological reason (Spain) but also caused by observing issues (northern Europe)

Some of the found underestimations are expected to be minimized by the new snow recognition procedure. Figure 2 shows the differences in 3-monthly precipitation sum. Overall an increasing of precipitation is found, but there are also areas of decreasing precipitation. This is due to the fact, that compositing routine where the snow recognition was tested, was slightly newer than the one which was running in winter 2017/2018. Therefore, the “corrected” precipitation rate is less than original one when original rate being less than 0.11 mm/h (reflectivity limit about 7.7

dBZ). As far as we know, there is no further difference between the routines, which means that all increasing rates are due to the snow recognition. Precipitation rate is mainly increased in mountainous regions, but also slight effect can be found in area of lower altitude, like in northern Germany. The increase in precipitation rate over Scandinavia is surprisingly low and not very homogeneous. It seems that the limitation in reflectivity is a bit counterproductive, as mainly no reflectivity seems to be left to be increased with the applied Z-S relation. Figure 2 also reveals, that the new procedure will also increases the amount of the erroneous hot spots (i.e. RLAN interferences) of about 19540 mm. Figure 3 illustrates the time series of the differences, which again emphasizes the effect of overall increasing the precipitation rates.

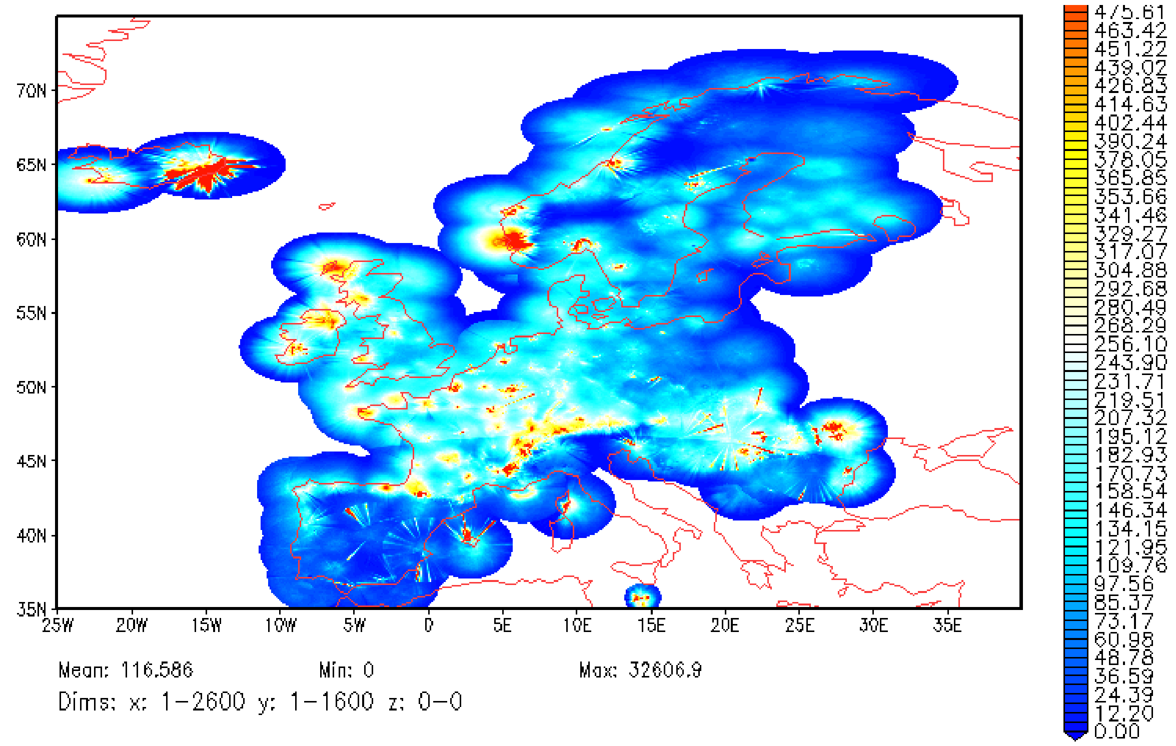

Figure 1: Accumulation of precipitation in mm over three month (Dec. 2017- Febr. 2018) for the operatinal OPERA composite

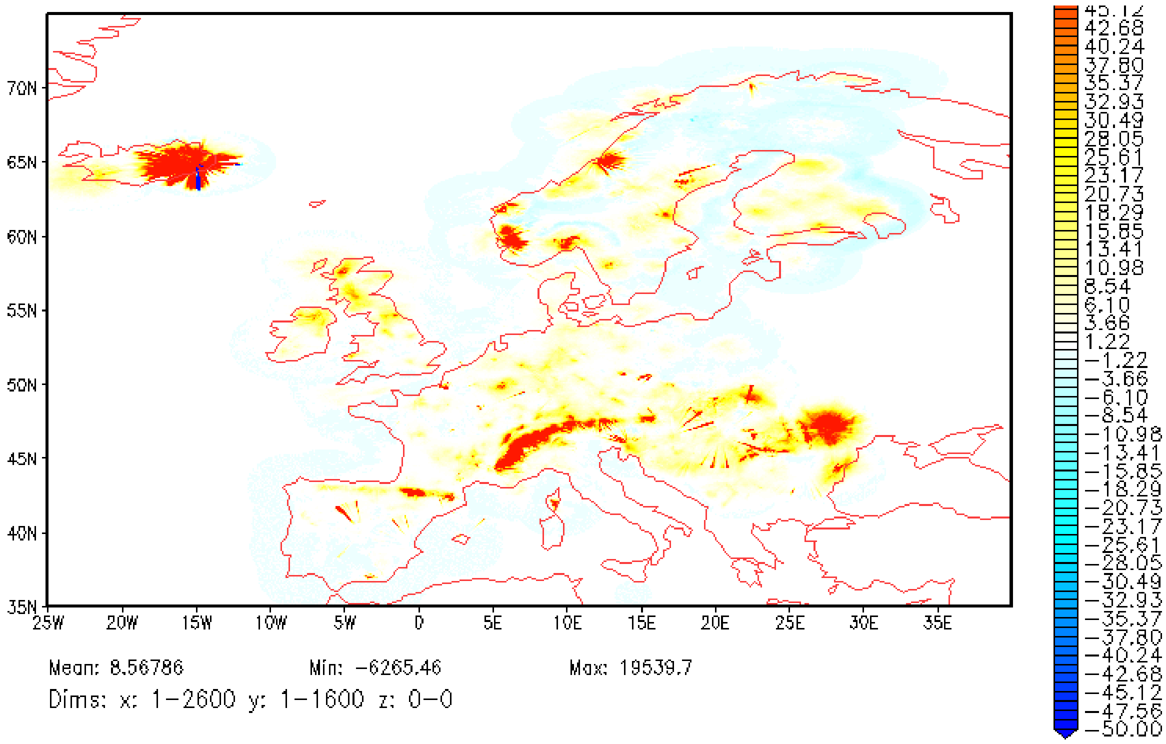

Figure 2: Differences in 3-monthly precipitation sum in mm between snow-corrected and operational OPERA composite

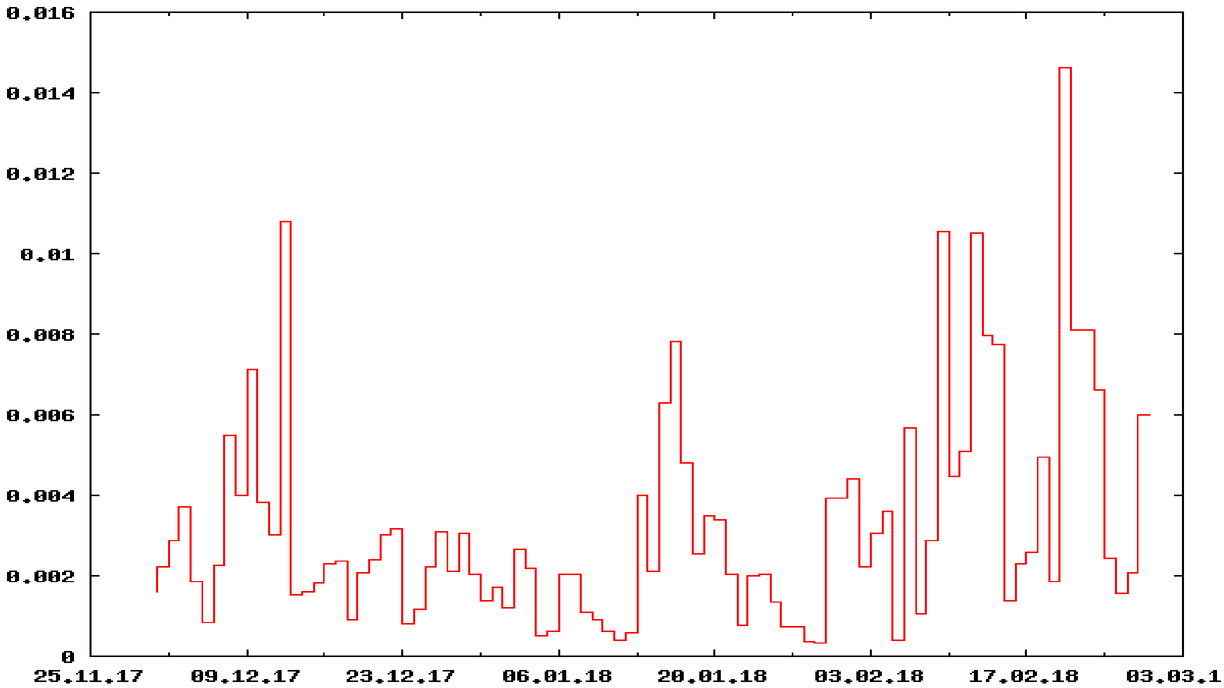

Figure 3: Time series of differences of daily precipitation sums in mm between snow-corrected and operational OPERA composites

Figure 4 highlights the differences in daily precipitation between snow-corrected and operational OPERA composite at December 10th 2017. Large positive differences can be found over central Europe, southern UK and eastern Romania, a smaller increasing of precipitation rate over Finland. Most areas of the positive differences are in good agreement with areas of positive changes in accumulated snow amount over the same day (see Figure 5). Please note, that the snow analysis applied here, is calculated once a day, taking satellite information and model background into account. The difference of such snow coverage only tells how much snow has change at a daily time scale. Sub-daily changes are not represented. Snow which was falling 3 UTC and 3 UTC of the next day but melted completely afterwards, will not appear in Figure 5. To get a more detailed validation hourly data has to be applied for, which we think is beyond the scope of this review. In the appendix charts of accumulated snow and charts of differences in precipitation amount of the two procedures for December 2017 and January 2018 are included. The color scale in all those figures was chosen for an easier comparison between patterns in differences of precipitation and snow height.

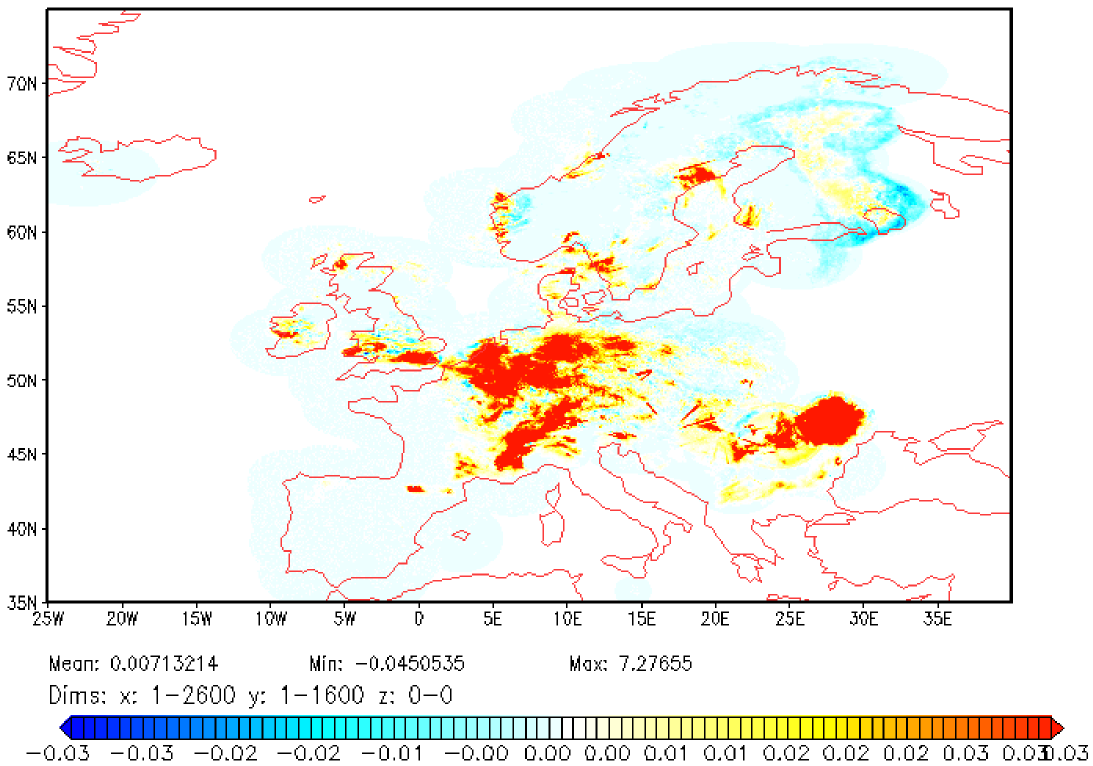

Figure 4: Differences in daily precipitation in mm between snow-corrected and operational OPERA composite for December 10th

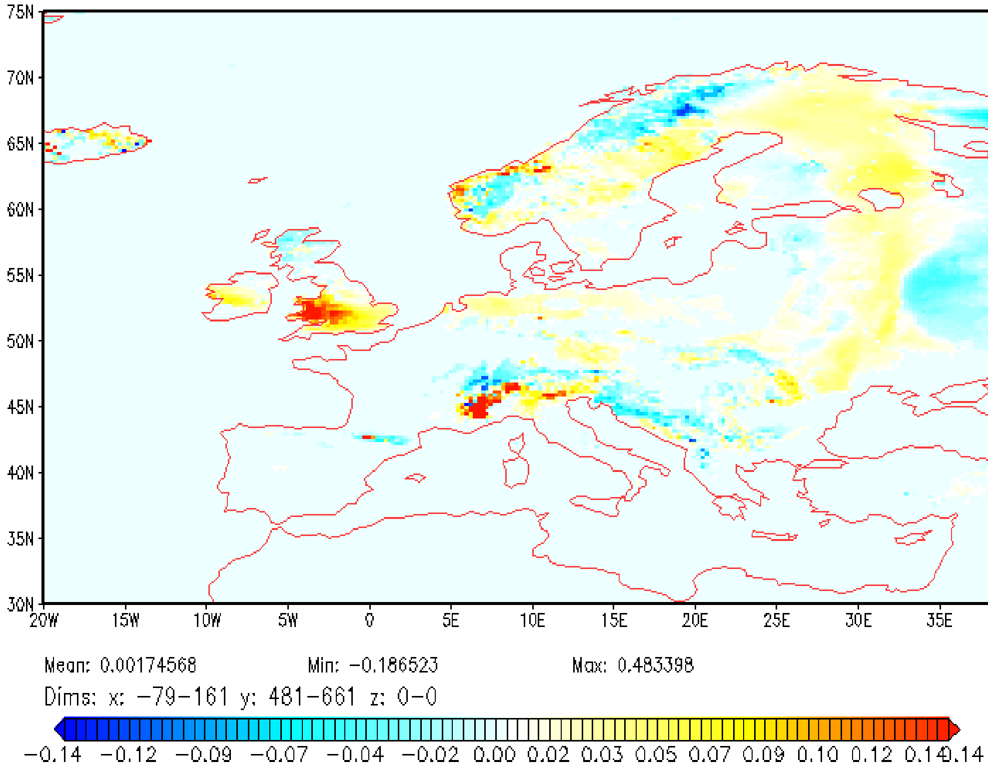

Figure 5: Changes of snow height in m at December 10th

The effect of snow recognition procedure can also be validated by applying both composites as input for a data assimilation experiment. DWD is running a short range NWP model COSMO covering central Europe, which is able to assimilate radar derived precipitation rates by incorporation of the so called latent heat nudging approach. The model thermodynamic state is adopted in such a way, that the simulated precipitation rate get closer to the observed one. Due to the improvement in simulated precipitation other forecast elements (i.e. screen level temperatures) are expected to be improved, too. This approach is running operationally for more than 10 years. To investigate the benefit of the snow recognition for data assimilation both, original and corrected OPERA composite are assimilated into COSMO model during December 2017, as it is done operationally. Verification of model results against SYNOP stations and radio soundings were conducted over this monthly period. In Figure 6 to Figure 8 exp_10634 stands for an experiment where the snow-corrected composite was applied and in exp_10632 the original OPERA composite was applied for data assimilation.

The overall impression is, that the results of both experiment are quite similar. However, the experiment with snow-corrected data tends to be slightly better, esp. for screen level dew point temperature (see Figure 6) and atmospheric wind (see Figure 7). Please note that the verification is done over central Europe for a complete month of different weather conditions. Focusing at the snowy period in this region (as it happened to be the first days of December) the improvement of assimilating snow-corrected precipitation rates are much more pronounced. This is shown in Figure 8 for a verification against SYNOP stations.

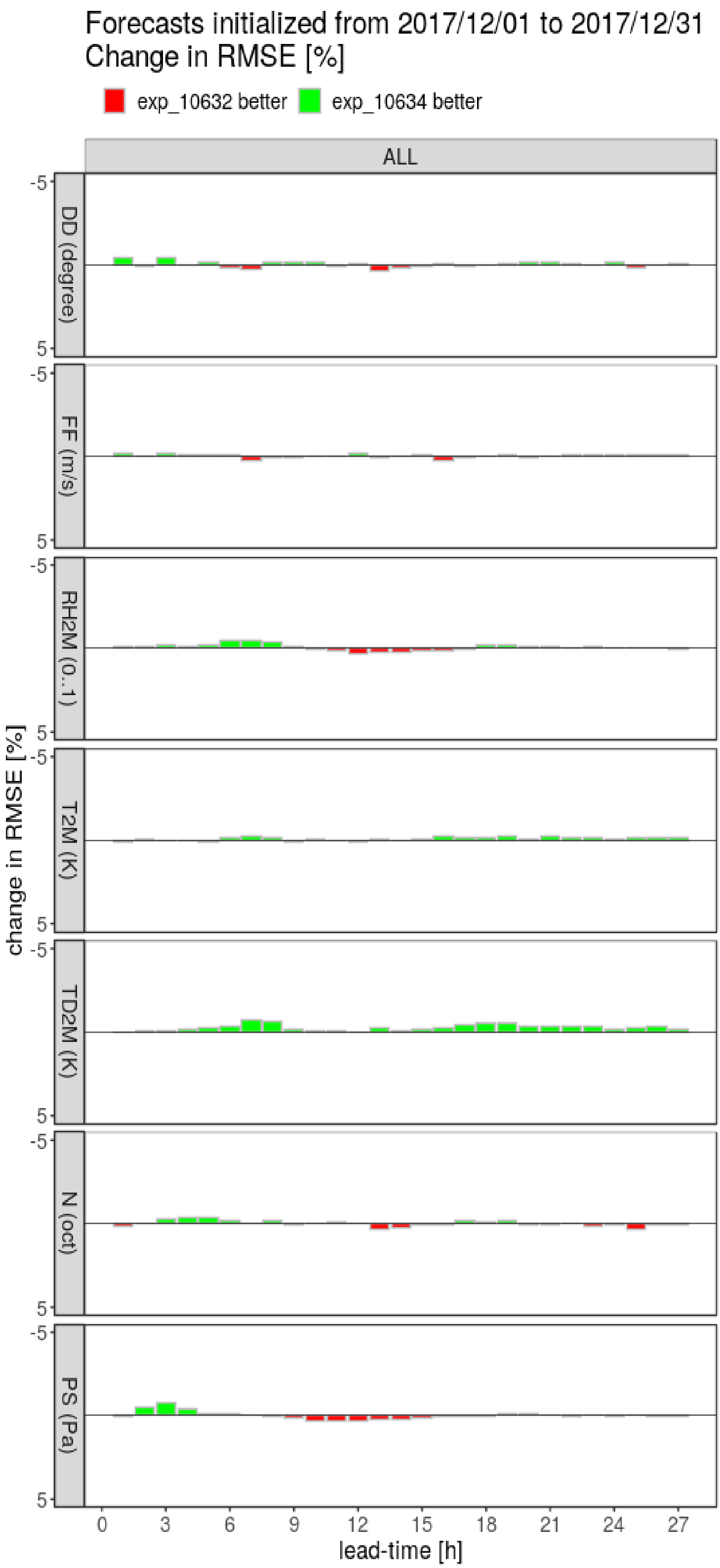

Figure 6: Verification (improvements in RMSE) against SYNOP station of COSMO model forecast in December 2017 comparing the application of snow-corrected and operational OPERA composite within data assimilation (via latent heat nudging). Green colour: model forecasts using snow-corrected composites are better, red colours: using operational composites leads to better forecasts.

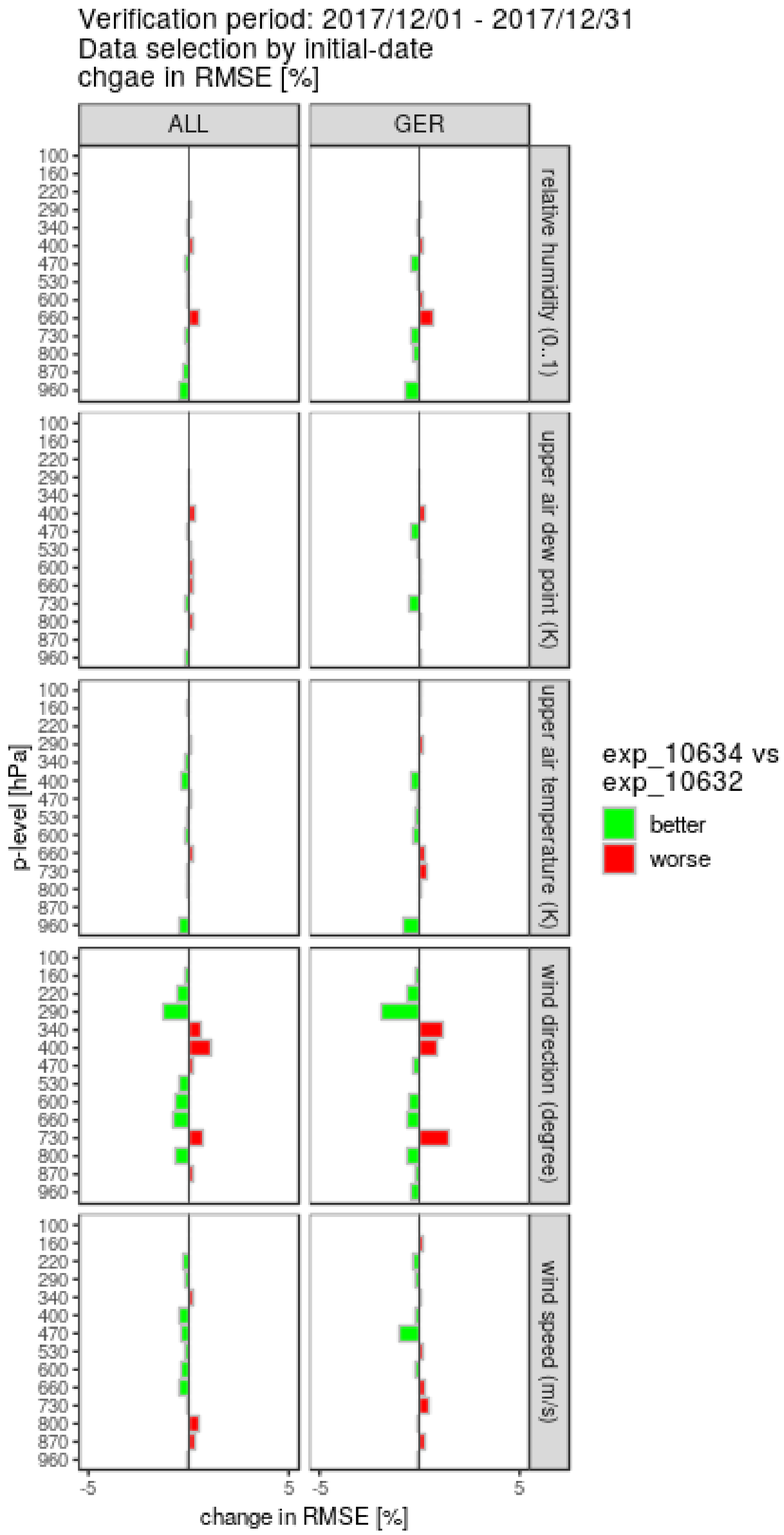

Figure 7: Verification (improvements in RMSE)against Radio Soundings of COSMO model forecast in December 2017 comparing the application of snow-corrected and operational OPERA composite within data assimilation (via latent heat nudging). Green colour: model forecasts using snow- corrected composites are better, red colours: using operational composites leads to better forecasts.

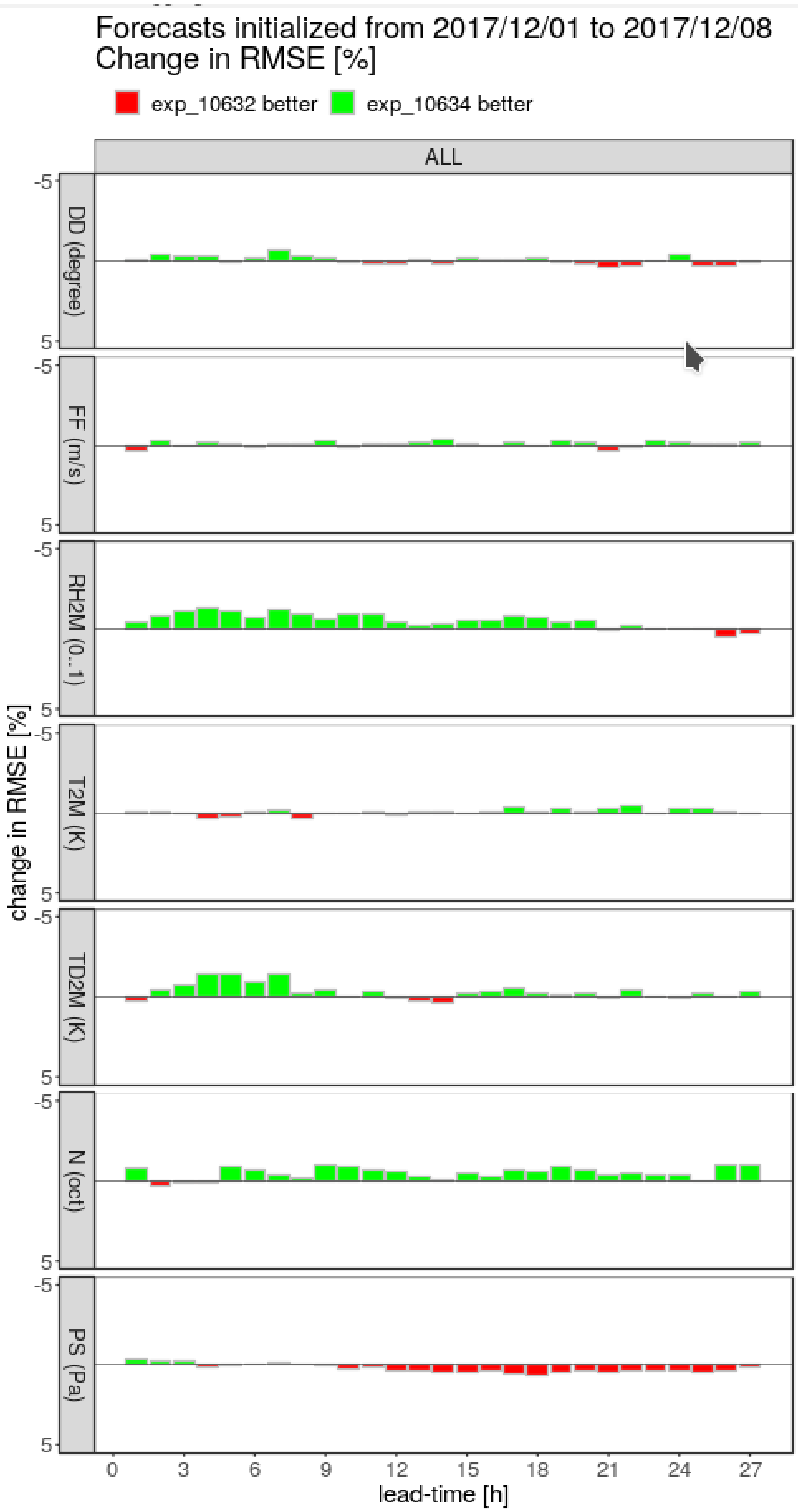

Figure 8: Verification (improvements in RMSE) against SYNOP station of COSMO model forecast over first 8 days in December 2017 comparing the application of snow-corrected and operational OPERA composite within data assimilation (via latent heat nudging). Green colours: model forecasts using snow- corrected composites are better, red colours: using operational composites leads to better forecasts.

Conclusion

Applying a snow recognition to improve QPE of OPERA composite shows significant differences, when compared to the original composites. The validation conducted within that project reveals that the snow-correction is mainly done at snowy regions. If the used model-based indicator indicates snowy conditions at a certain point of composite the precipitation rate is enhanced, disregarding of observation's quality. Therefore undetected clutter will be increase, too, deteriorating the quality of the composite. However, in most cases the increasing of precipitation rate is in according to snow accumulation information.

Snow-corrected composites were tested as input for data assimilation into a SRNWP model, showing its ability of improving the forecast quality.

Appendix

In the following figures are added to emphasis the performance of the snow recognition procedure, showing accumulated precipitation of operational composites (December 2017, see Figure 9, January 2018, see Figure 12), accumulated height of snow (Figure 9 and Figure 12 for Dec.'17 and Jan.'18, resp.) and differences in monthly precipitation sums between snow-corrected and operational composites (Figure 11 and Figure 14 for Dec.'17 and Jan.'18, resp.)

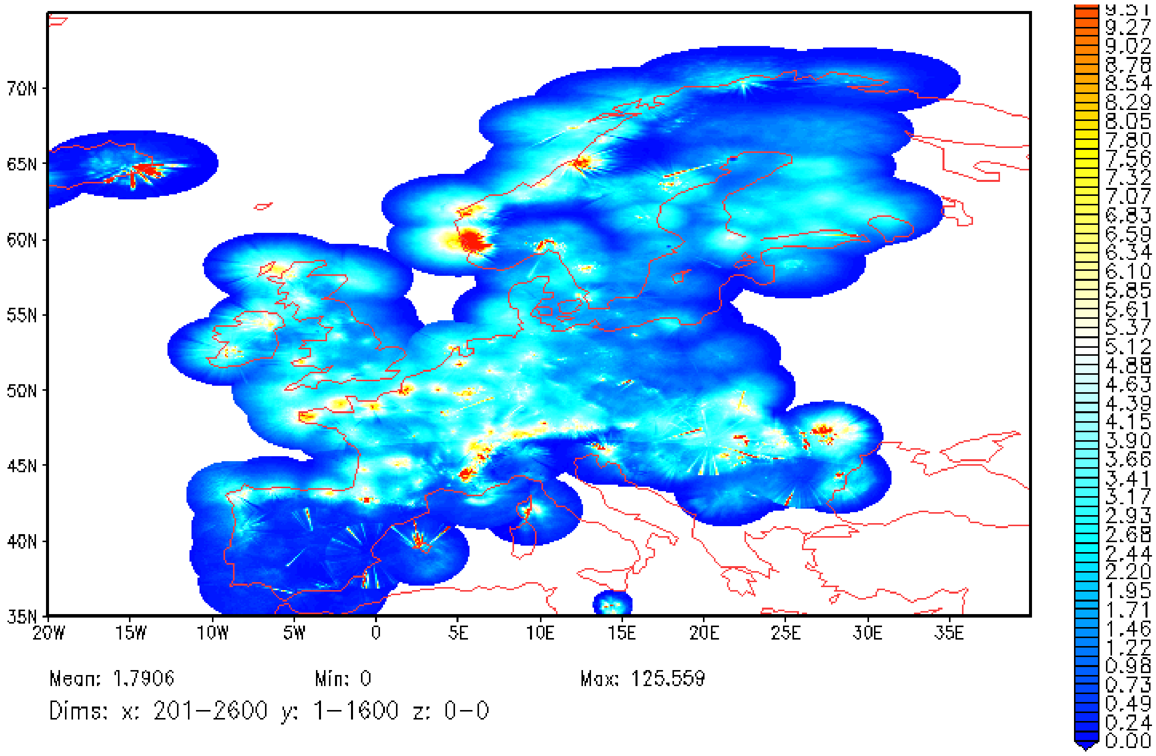

Figure 9: Accumulation of precipitation in mm for December 2017 of the operational OPERA composite

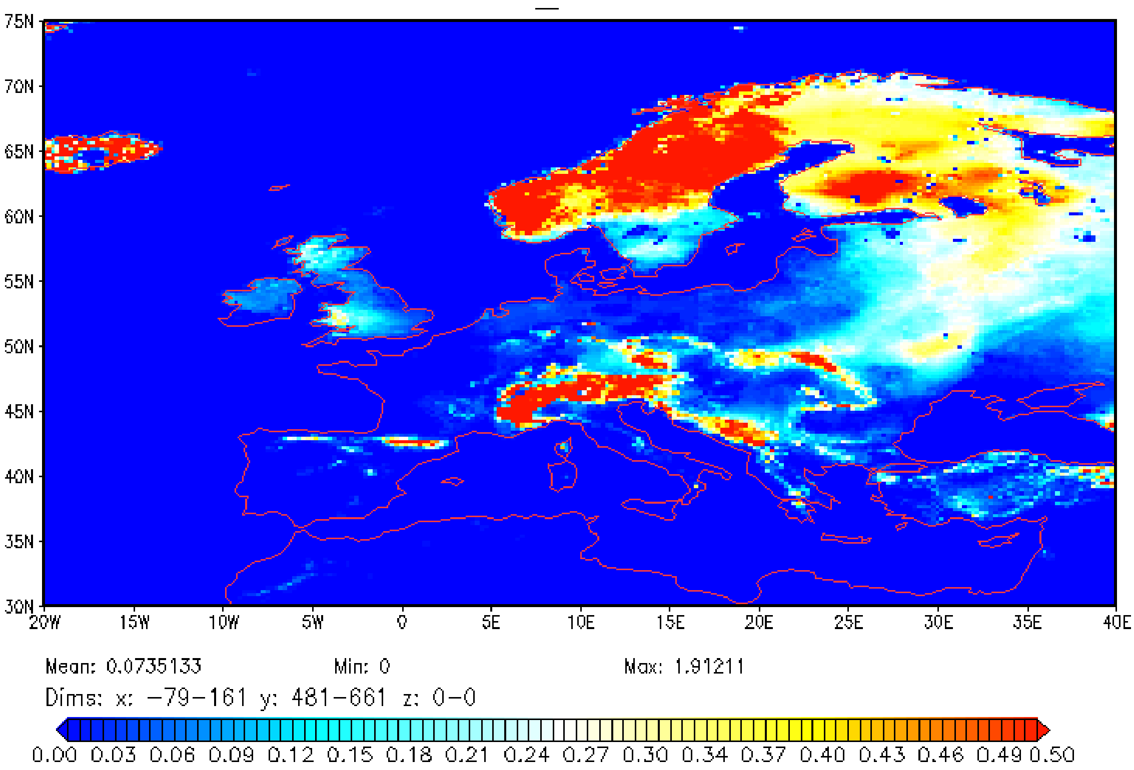

Figure 10: Accumulated snow_heights in m (without melting effects) for December 2017

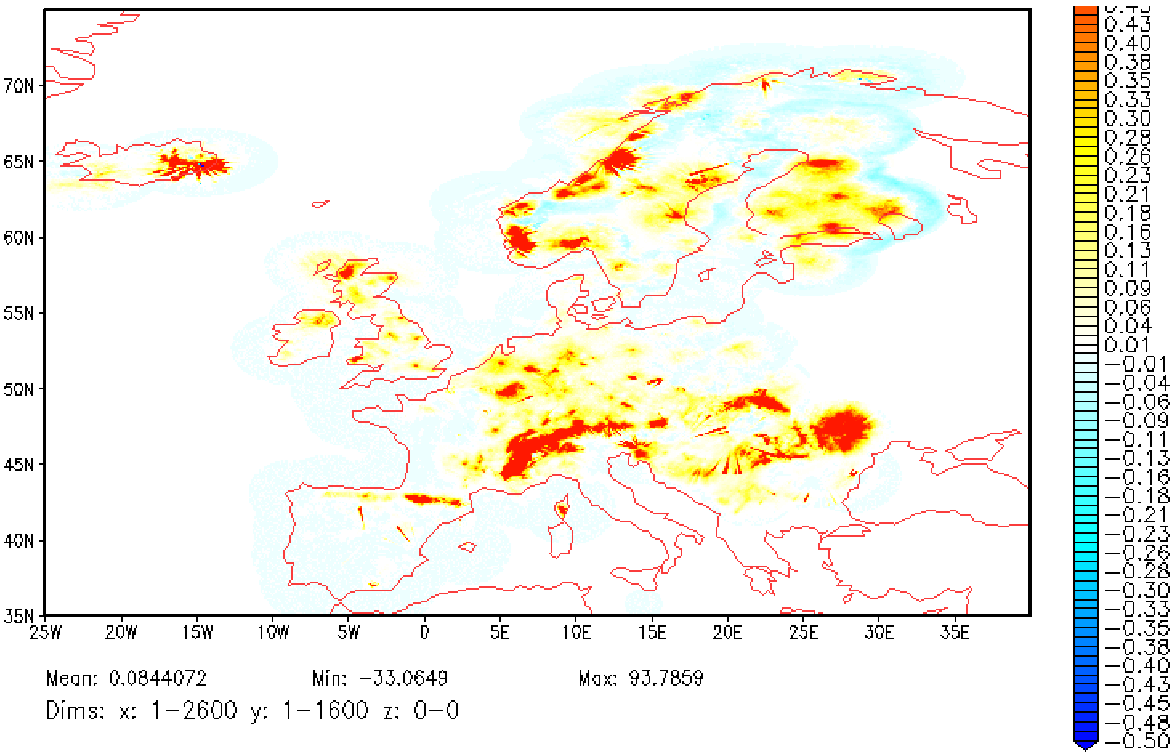

Figure 11: Differences in monthly precipitation in mm for December 2017 of snow-corrected and operational OPERA composites

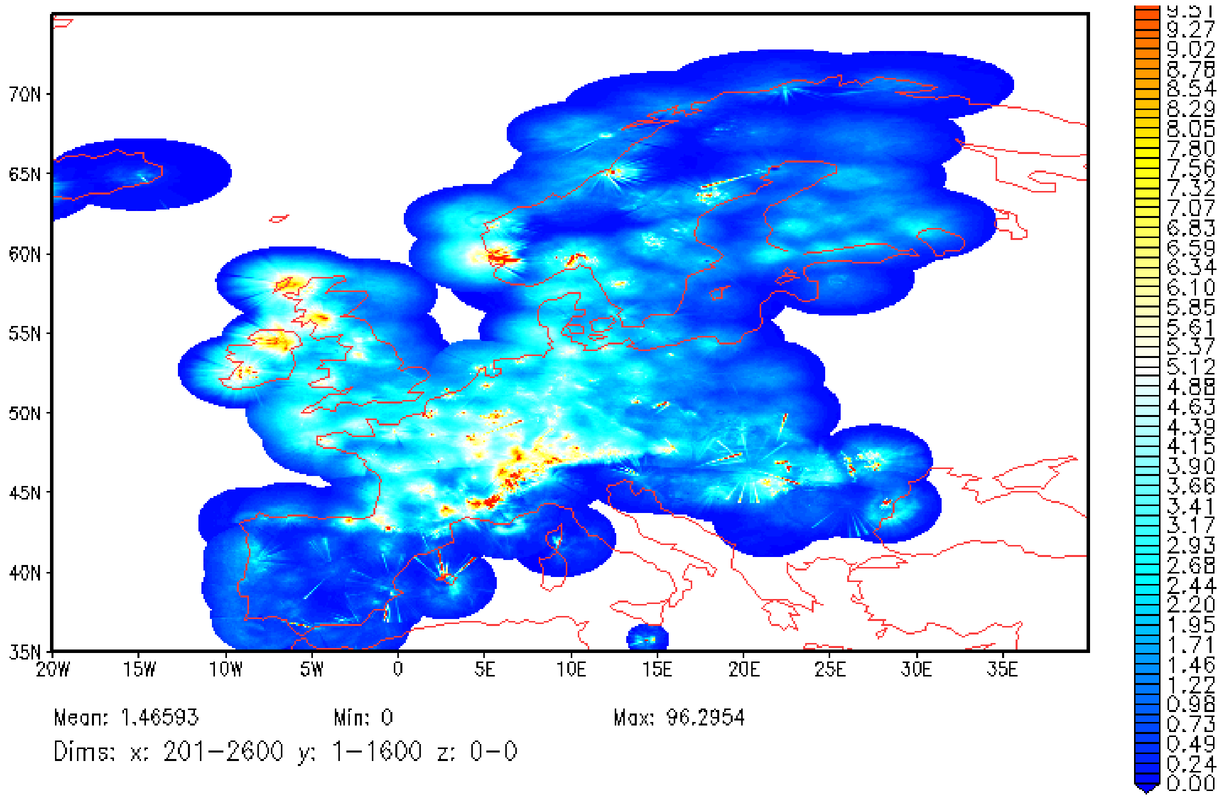

Figure 12: Accumulation of precipitation in mm for January 2018 of the operational OPERA composite

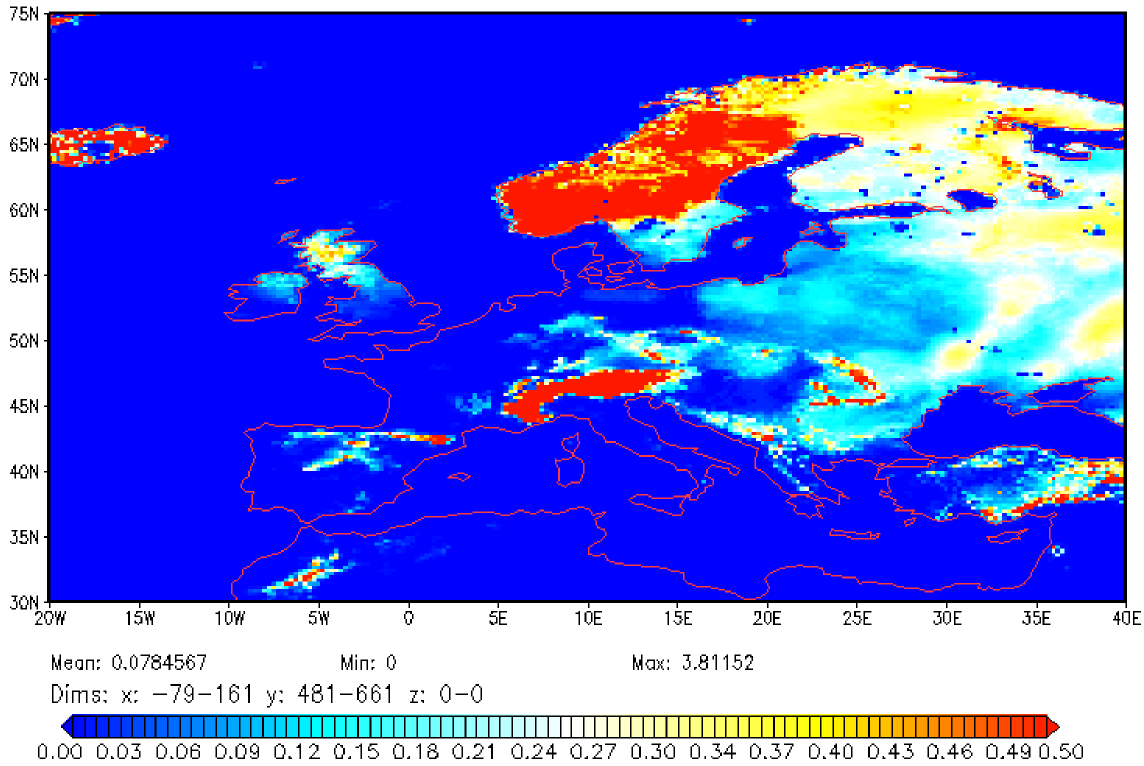

Figure 13: Accumulated snow_heights in m(without melting effects) for January 2018

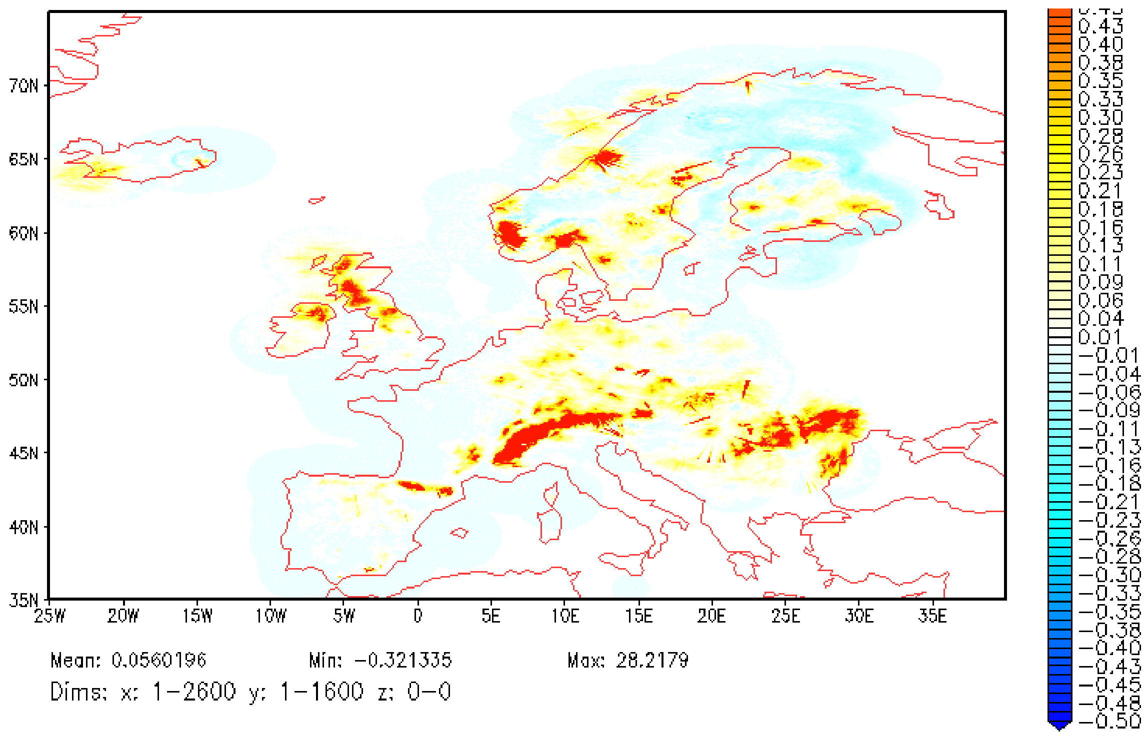

Figure 14: Differences in monthly precipitation in mm for January 2018 of snow-corrected and operational OPERA composites

Appendix A

Proposal for OD7:

Use of the **water phase of the hydrometeors** when deriving rain intensities (thus producing correct intensities also for snow). NOTE: this requires synoptic data and model fields as additional input.

The functionalities developed is expected to include:

- A quantitative precipitation estimation method built on model snow fraction output.
- Verification framework and metrics to measure improvement made by scheme on snow amount estimation.

  Deliverables: Software module with documentation
  Input/Output: Internal software interfaces

Prerequisites:

- Using ZS relation of FMI based on NWP forecasts (IFS, ICON,...)

The project will jointly be done by FMI and DWD.

The project will be divided in following parts:

1. Analysis of water phase of surface precipitation from NWP model input for OPERA composite area
2. Correct operational ODC rain rate composite for snow events
3. Verification of operational ODC rain rate composite and corrected ODC rain rate composite against several synop stations and optionally verification of NWP forecast quality when assimilating the two composites.
4. Adaptation of ODC software if necessary
5. Optional issues

Part 1: **2 MM Q4 2015:**

- Decision which NWP model will be used. This implies also the question of input data format to deal with. (FMI, DWD)
  - **0.5 MM Q4 2015**
- Choose best model predictors to estimate probability of snow. Start with the model predictors mentioned by FMI but investigation of additional predictors will be done. Based on best model predictors probability of snow is estimated for each composite point. (FMI, DWD)
  - **0.5 MM Q4 2015**
- Interpolation of model predictors onto OPERA composite in space and time. Several method will be investigated. Topography related issues might be stressed. (DWD)
  - **0.5 MM Q4 2015**
- At composite points showing an increased probability of snow rain rate is recalculated to reflectivity and ZS relation is applied, to correct for snow amount. (FMI)
  - **0.5 MM Q4 2015**
- add on: verification/validation of precipitation type with synoptic observations

Requires: composite data, model data, synoptic observation of present weather

Part 2: **3 MM during winter 2015/2016**

Verification of radar derived precipitation rate will be done against Finnish and German rain gauges over a certain period with and without snow events. The number of days containing precipitation should be significant. (DWD, FMI). It will also be possible to assimilate corrected and uncorrected OPERA composite into COSMO model and verify forecast quality against different observations. (DWD)

Requires: composite data and rain gauge data

Part 3: **1 MM, Q3 2016**

In case of positive results compositing software will be modified and tested in real time. (FMI)

Part 4: 2 MM, Q2 2016

4.1 Validation of model based decision with hydrometeor classification (DWD)

The snow probability calculated from model parameter will suffer for some uncertainties. It might be possible to validate it against hydrometeor classification obtained from dual-pol radar measurements and to tune thresholds of model predictors.

4.2 Further development of Z(S) relation (FMI)

See Lerber et al (2017) Microphysical Properties of Snow and Their Link to Ze–S Relations during BAECC 2014. J. Appl. Met. Clim (attached)

4.3 Accumulation comparison with specific Finnish rain gauge data (wind bias corrected) (FMI)

Annex 2.