Intercomparison of satellite products and in-situ analysis for snow

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Abstract
In this paper, we compare satellite snow products from NOAA/NESDIS, NASA and Land-SAF and analyses of snow by two NWPs, HIRLAM and ECMWF. Our study concentrates in the spring 2006. We can only compare the consistency between products, because there is no ground truth available as all in-situ measurements are already used in the NWP analyses and no independent data was left for verification. When compared against NOAA/NESDIS, the biggest discrepancies are with HIRLAM and Land-SAF analyses. However, new version already exists for Land-SAF and work for snow analyses for HIRLAM is on-going.

INTRODUCTION
Snow cover and snow depth are important parameters for numerical weather prediction and hydrological models, especially during the melting period in spring time. Duty meteorologists are also interested in snow cover and snow depth information. Traditionally analyses of these parameters are based on in-situ observations. However, in-situ observations suffer from limited spatial representativeness and the dissemination of no-snow observations can be limited. Lately satellite based observations of snow have emerged. Satellite based snow products have much better spatial coverage, but methods are often based on visible channels and suffer from clouds and limited sun light during polar winter. Methods based on microwave instruments are not limited by clouds but suffer from much coarse spatial resolution. In this study we compare snow products from satellite instruments, and NWP snow analyses with, and without, satellite observations.

DATA
Our study concentrates in the spring 2006, starting from Day 32, February 1st and ending at Day 151, 31st May. We compare satellite snow products from NOAA/NESDIS, NASA and Land-SAF, and analyses of snow by two NWPs, HIRLAM and ECMWF. NOAA/NESDIS (Figure 1) is a partly manual analysis of snow and ice using a variety of sources, including both microwave and shortwave instruments, such as MODIS instrument onboard Terra and Aqua satellites (NOAA/NESDIS/OSDPD/SSD. 2004). The snow analysis from NASA (Figure 2) is based only on the MODIS instrument (Hall et. al. 2002) and the Land-SAF snow cover analysis (Figure 3) is based on the SEVIRI instrument onboard METEOSAT satellites (http://landsaf.meteo.pt/). Analyses based on shortwave channels of MODIS and SEVIRI suffer from the clouds, while NOAA/NESDIS, which uses also microwave instruments, is less influenced by them. ECMWF (Drusch et. al. 2004) uses both in-situ observations and NOAA/NESDIS snow analysis (Figure 4). HIRLAM (HIRLAM 2005), on the other hand, does not use any satellite products for its analysis (Figure 5). The coverage of analyses varies: ECMWF and MODIS analyses are global in coverage, NOAA/NESDIS covers the northern hemisphere, the version of the Finnish HIRLAM we used in this study covers area of approximately Northern Europe, and Land-SAF uses a geostationary satellite instrument and is thus constricted by the field of the view of the instrument.

Products are in operational use, except Land-SAF, which is still actively developed and deemed to be in the pre-operational phase. Please note that since the spring 2006 new versions of product may have been released, especially a new version of Land-SAF snow product has been released, but, unfortunately, old data has been not re-processed.
QUALITATIVE AND QUANTITATIVE COMPARISON

For the comparison we had to reproject all products to same projection, for this Lambert Cylindrical Equal Area was chosen as it makes comparisons of areas meaningful. The reprojection (Figure 6) was done with resolution 5000 meters which is close to the original resolution of HIRLAM data. Another complication is that NWP analyses are of snow depth and of equivalent of snow, not of snow cover. To transform snow depths to snow covers, we simply classified all snow depth greater than zero as snow. This may result a small overestimation of snow in our comparisons. MODIS analyses have the fractional snow area for each grid point. This we converted to snow cover if snow area was greater than 20 per cent. This may result a small underestimation of snow in our comparisons. There is a slight difference between MODIS Terra and Aqua analyses, but in this study we only considered Terra analyses. In addition, we used only 12 UTC NWP analyses in comparisons.

Please note that there is no ground truth available. All in-situ measurements are already used in the NWP analyses, so no independent data is left for verification. If we were able to rerun the analyses, we could do the crossvalidation by keeping some observations out of the analyses and comparing these observations against analyses. However, we did not have the resources to do this. We will compare other products against NOAA/NESDIS snow product, as NOAA/NESDIS gives a quite stable snow cover, is not obscured by clouds, is basis for ECMWF snow, and uses MODIS data as input. Unfortunately, this also means that only HIRLAM and Land-SAF products are really independent.

An example (Figure 7) shows a comparison of products for Day 99, 9\textsuperscript{th} April. ECMWF and NOAA/NESDIS agree for the most part, and ECMWF mostly adds snow compared to NOAA/NESDIS. Land-SAF has large areas in Scandinavia where it does not detect snow. MODIS looks quite similar but visual comparison is difficult as the area is very much obscured by clouds. HIRLAM has an unrealistic circular area of snow in the Baltic region. This is a well known problem of Crossman method and is caused by the lack of observations reporting no snow.

For more quantitative comparison we first need meaningful measures to be used. The results of comparison between two analyses can be shown in a 2\times2 contingency table. We call A the number of
Figure 2: An example of the daily MODIS global climate modeling grid snow product, the upper image is from MODIS on-board Terra (code MOD10C1) and lower is from MODIS on-board Aqua (code MYD10C1). Snow-free areas are coloured in green, snow in white, cloud in red, sea in blue and unprocessed areas are in black. The whole globe is available but only Northern hemisphere shown here.

Figure 3: An example of the daily Land-SAF snow product in the native satellite projection. Snow-free areas are coloured in green, two snow classes in white and gray, sea in blue and "no data" is in black.

Figure 4: An example of the ECMWF snow depth analysis. The whole globe is available but only Northern hemisphere shown here. The colour scale is from maximum snow (white) to no snow (black).
cases where both analyses reported snow, D cases where neither of analyses reported snow, B when only the NOAA/NESDIS analysis reported snow and C when only the second analysis reported snow. There is an extensive literature of different measures calculated from the contingency table, but for this study it is enough to focus on

\[ \text{BIAS} = \frac{(A+B)}{(A+C)} \]

and

\[ \text{PC (Proportion Correct or Hit rate)} = \frac{(A+D)}{(A+B+C+D)}. \]

In the best case, when BIAS equals 1, there is an equal amount of snow in both analyses. When BIAS is less than 1, there is less snow in NOAA/NESDIS analysis and when BIAS is more then 1, there is more snow in NOAA/NESDIS analysis. When there PC equals 1, there is a total agreement between analyses, and when PC equals 0, there is a total disagreement.

We also split area by height to “Lowlands” (height <600 m) and “Highlands” (height >600 m). In Figure 8 the results of the measures are shown. Before the snow starts to melt, i.e., during about the first 80 days, most of the analyses agree with NOAA/NESDIS quite well. The exception is the Land-SAF snow analysis: in the Lowlands NOAA/NESDIS sees about twice as much snow as Land-SAF and PC is around 0.6, and in Highlands BIAS and PC behave quite erratically.

After the melting starts, the differences between models are more evident. As seen in Figure 7, ECMWF adds snow to NOAA/NESDIS analysis: BIAS is less than one after the melting starts, more in Lowlands than in Highlands. The agreement is reasonable, some problems can be seen at the end of period in Highlands.

Terra MODIS has the smallest BIAS and the best agreement with NOAA/NESDIS most of the time, not surprising because it is used in NOAA/NESDIS analysis. For MODIS the most problematic time is at the end of the melting period, in Lowlands BIAS has high values that vary greatly from day to day and in Highland the agreement between analyses is at the lowest. Note that all analyses agree very well at the end of the period in the Lowlands, because at this point virtually all snow as melted away from Lowlands and all analyses report no snow.
In Lowlands HIRLAM agrees rather well with NOAA/NESDIS, but BIAS is quite variable during the melting period, changing from more than one to less than one day to day. As mentioned above, these erroneous rapid changes in snow cover are most likely caused by the use of Cressman method and the lack of no-snow observations. In Highlands the agreement is worse as the snow starts to melt, after that BIAS starts to climb and PC drops to around 0.5. This indicates that HIRLAM detects much less snow in the Highland areas compared to NOAA/NESDIS.

LANDSAF, as mentioned above, has the worst agreement with NOAA/NESDIS snow. BIAS is more than one for all the period and is especially large at the end of the spring. Spuriously, the agreement between NOAA/NESDIS and snow increases in Lowlands, but this is probably only caused by melting of the snow, as mentioned above. At the end of the spring, the agreement in Highlands is quite low, PC around 0.5, as was for HIRLAM. Actually the agreement between NOAA/NESDIS and all others is quite low at this point, which suggests that NOAA/NESDIS analysis has problems in these circumstances.

**CONCLUSION AND OUTLOOK**

Comparison of different snow analyses is hampered by the fact that we have no ground truth, so we can only compare the consistency between products. These is further hampered by the fact the NOAA/NESDIS, MODIS and ECMWF analyses are not independent. Still, some observations can be made. The NOAA/NESDIS and ECMWF (partly based on NOAA/NESDIS) analyses are quite similar, ECMWF mostly adds snow to NOAA/NESDIS analysis. Terra MODIS snow and NOAA/NESDIS snow are also quite consistent as MODIS is one of the inputs for NOAA/NESDIS analyses, but MODIS is greatly hampered by clouds. The biggest problems were found in HIRLAM and Land-SAF analyses: Based only on in-situ measurements and using the Cressman method for the analyses, HIRLAM behaves rather erratically during the snow melting season and could benefit from satellite observations. The pre-operational LANDSAF product has problems with the snow in Northern Europe and needs further work.

However, these problems are already known and being worked on. Further LANDSAF snow cover development is on-going in Finnish Meteorological Institute (Siljamo 2007). In addition to this, another snow analysis development has started in Finnish Meteorological Institute, in the context of Hydro-SAF (Lahtinen 2007). The snow analysis for HIRLAM is also being further developed in Spain (Cansado 2004).
Figure 7: Comparison between different products in Day 99, 9th April 2006. All comparisons are NOAA/NESDIS against other products. Other products are (from top to bottom) ECMWF, Land-SAF, Terra MODIS and HIRLAM. Colour codes are grey for snow in both analyses, green for no snow in either analyses, purple for snow only in NOAA/NESDIS and yellow for snow only in the other analyses. Clouds are coloured in red, where applicable.

REFERENCES


Figure 8: BIAS and PC as the function of time for different comparisons for two topography classes, “Highlands” and “Lowlands”. All comparisons are NOAA/NESDIS against other products. Other products are ECMWF (green points), Land-SAF (black points), MODIS (red points) and HIRLAM (blue points).

NOAA/NESDIS/OSDPD/SSD. 2004, update 2006.IMS daily Northern Hemisphere snow and ice analysis at 4 km and 24 km resolution. Boulder, CO: National Snow and Ice Data Center. Digital media