SNOW ANALYSIS USING MSG DERIVED SNOW MAP

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An extended snow analysis system is developed at MeteoSwiss, by combining the Cressmann analysis used at DWD and a new MSG derived snow mask developed by M. de Ruyter de Wildt.

1 RECENT PROGRESSES

Main progresses since 2005 COSMO General Meeting are:

- Routine production of MSG derived snow mask on aLMo7 domain, at standard Meteosat 8 resolution (5-6km over the Alps). Routine production of associated quality flag. See Appendix A.
- Validation of MSG derived snow mask for winter 2005/2006 by comparison with in-situ data, MODIS snow map and AVHHR snow map; a consistent high quality is observed. See Appendix A.
- Derivation of MSG derived snow mask on aLMo7 domain, at HRV resolution (1.5-2km over the Alps). The elements used in this process are the standard resolution cloud mask, the temporal stability of HRV pixels, and the spatial consistency with the standard resolution snow mask.
- Version 2.0 of DWD snow analysis code. Correction of some bugs, tuning of the Cressmann analysis and re-write of snow mask usage are the characteristics of this version. See Appendix B.
- A snow analysis test suite has been run from November 17th, 2005 to May 1st, 2006.

2 TEST SUITE WINTER 2005/2006

A full aLMo7 assimilation cycle has been run. A daily update of the snow analysis has been computed at 6 UTC, using Meteosat 8 derived snow map and in-situ observations available at that time. The snow map was taken from the running composite valid for the same day (i.e. future information has been used); a scale of 7 days was defined to modulate the quality flag in function of the time of last information refresh. Only snow depth from SYNOP observations were available at the time of the experiment, providing a sub-optimal coverage of the region of interest. Evaluation of the results is based on a daily subjective cross-comparison with other snow analysis: snow analysis from ECMWF interpolated on aLMo7 mesh, snow analysis from DWD.

Main findings:

- New product has the most spatial details: snow map information generates more realistic small scale structures by adding or removing snow patches (see figure 1).
- New product and DWD analysis produce a better temporal evolution of snow cover than the ECMWF product.
- There are hints of improved snow height in Alpine region after tuning original DWD analysis (see figure 1).
- The major weakness of the new product is the strong negative impact of satellite information observed in long overcast periods associated with snow fall on bare soil (see figure 2). The 7 days time scale defined to modulate the quality flag in function of the time of last information refresh is evidently much too large and should be reduced to 1 day or less.

3 QUALITY FLAG

The dependence of the quality flag on the time of last information refresh will be modified; the goal is to quickly make the satellite information obsolete when bare soil has been observed (in one day or less, to solve the previously mentioned problem), but also to use the satellite information longer the higher the height of the observed snow.

The quality q_i of the snow map pixel *i* will be defined as

$$q_i = 1 - (t_i / t_{i,max})$$

where: t_i is the time since last information refresh,
$t_{i,max}$ is a time scale, depending on the snow depth at last time of refresh

The value of $t_{i,max}$, which should represent a lower bound to the temporal validity of the satellite information, will be based on the estimation of the daily snow melt expressed in the snow analysis software (formula AB(T) in grpeva.F).

4 OUTLOOK

After implementing the proposed modifications of the quality flag, part of the winter 2005/2006 test suite will be re-run. If the previously mentioned problem is solved, the new system will be in production for aLMo7 from November 2006 onwards.

The high resolution snow map will be validated against in-situ observations. A high resolution snow analysis will be calculated for aLMo2, and then for a stand alone soil model computed on a 2.2km mesh covering the aLMo7 domain (MeteoSwiss is implementing a measurement driven soil moisture analysis and a tile/mosaic approach in aLMo).

A sub-pixel snow cover product is also being developed and should be available early next year. This development is not available in any EUMETSAT SAFs, and it should be pretty straightforward to include partial snow cover information in LM soil model.

In the longer run, more in-situ snow depth observations will be collected and an attempt to complete the Cressmann analysis with a local estimation of the snow depth in function of the height will be made. This last method, based on a regression analysis of locally available observations, was proven successful in a previous study of M. de Ruyter de Wildt.

5 ACKNOWLEGDEMENTS

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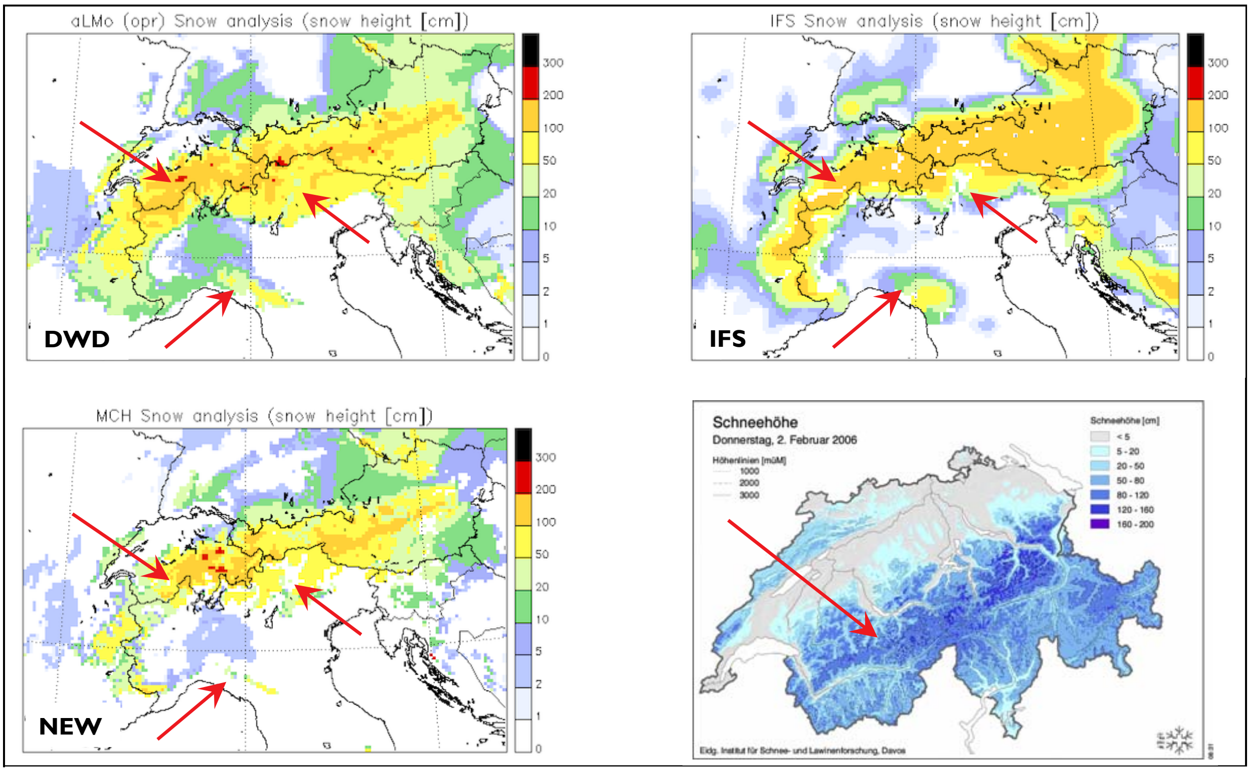
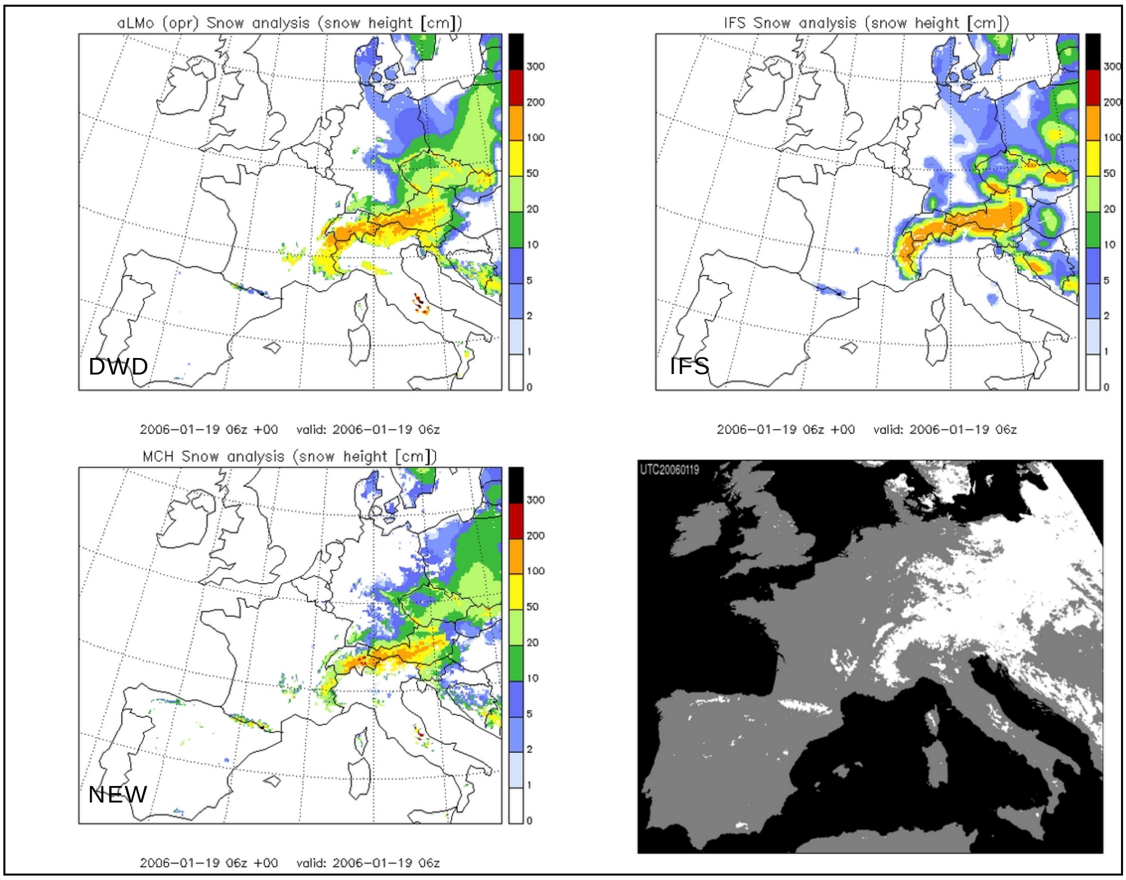


Fgure 1: Snow analysis on 02.02.2006. Clockwise form upper left panel: DWD product, ECMWF product, analysis from Swiss Federal Institute for Snow and Avalanche Research Davos, and new product discussed in this paper. Note the East-West gradient observed in the Swiss Alps which is better reproduced in the new product. Note the small scale structures in region of Garda Lake and Apennin.



Fgure 2: Snow analysis on 19.01.2006. Clockwise form upper left panel: DWD product, ECMWF product, MSG derived snow mask for that day (composite map), and new product discussed in this paper. Note the large snow patch over North-Eastern Germany not present in the new product; the snow map shows bare soil over this region (in grey), but the corresponding satellite information is old due to overcast situation (not shown).

APPENDIX A: SNOW MAPPING WITH VERY HIGH-FREQUENCY METEOSAT-8 (MSG) SEVIRI DATA

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1 . INTRODUCTION

Meteosat SEVIRI is the first geostationary satellite instrument with channels at all bandwidths that are of use for snow mapping. It thus offers an unprecedented data set of high spectral and temporal resolution that can be used for snow mapping in near-real time. The unique combination of high spectral and temporal resolution can furthermore be used to analyze the temporal behavior of pixels. In general, using temporal information to improve image classification is referred to as (digital) change detection. For an overview of change detection methods in many different fields of image analysis, the reader is referred to Radke et al. (2005). The use of change detection in earth observation is reviewed by Coppin et al. (2004). Here we use change detection to improve the discrimination between ice clouds and snow, which have partly overlapping spectral signatures and can be difficult to distinguish with spectral information alone.

Meteosat-8 was launched in 2002 by EUMETSAT, the European Organisation for the Exploitation of Meteorological Satellites. It is currently positioned at 3.4° W at an altitude of 36,000 km. It carries the Spinning Enhanced Visual and Infrared Imager (SEVIRI), which continuously monitors the entire hemisphere with a frequency of 15 minutes. It has twelve spectral channels (Table 1), most of which can be used for monitoring the surface and the lower atmosphere. The signals that are measured by the solar channels (1, 2, 3 and 12) are expressed as reflectances (r). The signals that are measured by the terrestrial channels are expressed as brightness temperatures (BT). The resolution is 3 km at the sub-satellite point and 4 to 7 km over Europe.

channel	central wave-length (µm)	description
1	0.64	visual
2	0.81	visual
3	1.6	near infrared
4	3.9	solar + terrestrial infrared
5	6.2	infrared (water vapor absorption)
6	7.3	infrared (water vapor absorption)
7	8.7	infrared
8	9.7	infrared (ozone absorption)
9	10.8	infrared
10	12.0	infrared
11	13.4	infrared (CO_2 absorption)
12	HRV	high resolution visual broadband

Table 1. The twelve channels of SEVIRI.

2 . DETECTION OF SNOW AND CLOUDS IN INSTANTANEOUS IMAGES

As a basis for cloud and snow detection, we use several spectral threshold tests that are in common use (e.g. Dozier,, 1989; Allen et al., 1990; Baum and Trepte, 1999; Hall et al., 2002; De Ruyter de Wildt et al., 2006). Figure 3a shows that most clouds can be distinguished from snow by making use of the visible reflectance (0.64 µm), the near-infrared reflectance (1.6 µm) and several brightness temperatures. Spectral classification of this image gives good results, but fails to detect clouds that are not very cold and contain ice crystals (figure 3b). These clouds have similar spectral properties as surface snow and ancillary information is required to identify them. Many snow mapping algorithms use the anticipated or forecasted surface temperature, with which the threshold for thermal separation of surface snow and ice clouds can be fine-tuned to current meteorological conditions. Here we use the high temporal frequency of SEVIRI to detect these clouds. Most clouds display a more variable behavior in time than the surface. At each pixel, this behavior can be quantified by computing the standard deviation of a short time series of pixel values. The optimal length of the time series was found to be five images, i.e. the current image, the two preceding images and the two succeeding images.

Figure 3c displays the temporal standard deviation in three of the SEVIRI channels as an RGB combination. The occurrence of different colors in this figure shows that the temporal variability is not necessarily equally high in all channels. When we label pixels that display a high temporal standard deviation in one or more of the SEVIRI channels as cloud, most clouds are detected (figure 3d). However, many clear-sky pixels with clouds in their proximity are also labeled as clouds. These clear-sky pixels may be cloudy one or two images earlier or later, and therefore display a high variation in time. The temporal cloud mask is therefore not applied to all pixels, but only used to check pixels that may have been erroneously classified by the spectral tests. This concerns not only undetected ice clouds, but also cloud shadows. Both are characterized by relatively high Normalized Differential Snow Index, $(r_{0.64}-r_{1.6})/(r_{0.64}-r_{1.6})$. Figure 3e displays the final classification result.

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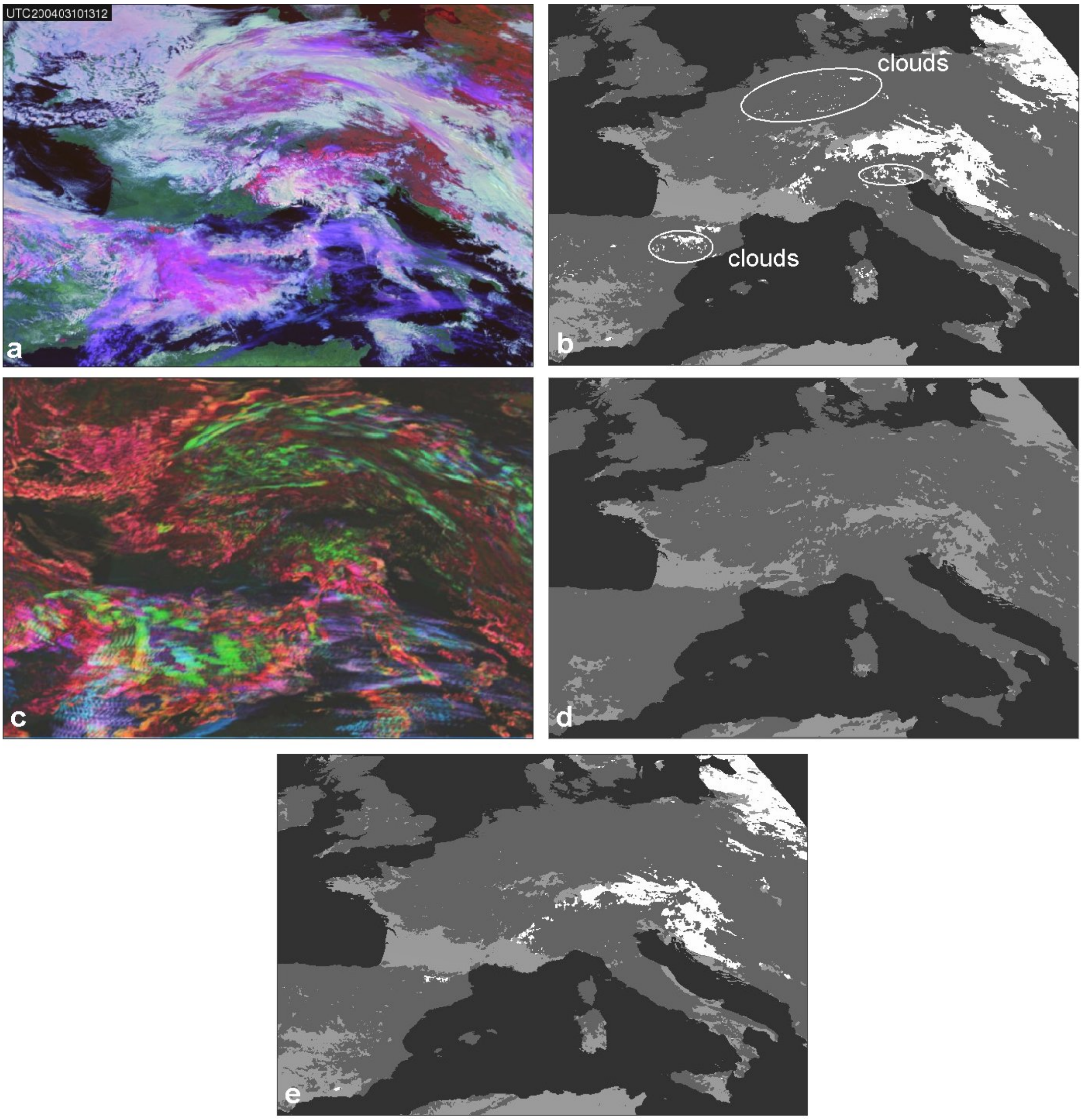

Figure 3. Images and results for March 10th, 2004, 13:00 UTC. a: RGB combination, made from $r_{0.64}$, $r_{1.6}$ and ($BT_{3.9}$-$BT_{10.8}$)/($BT_{3.9}$-$BT_{13.4}$). Snow appears red, snow-free land green, water clouds white and ice clouds purple or red. b: spectral classification result. Snow is white, snow-free land is light gray and clouds are dark gray. c: RGB combination of the temporal standard deviations in channels 1 (0.64 μm), 4 (3.9 μm) and 7 (8.7 μm). Black is minimum variation, white is maximum variation in all three channels. d: temporal cloud mask, obtained by stacking all single channel temporal cloud masks. e: final classification result.

3 . TEMPORAL COMPOSITING

Each satellite image is classified about 1.5 hours after it is acquired, and thus an instantaneous snow map is produced every 15 minutes. When a pixel is cloud free in an instantaneous snow map, the classification result for this pixel (snow or no snow), is transferred immediately to a running composite snow map (figure 4a). This means that in the running composite, the time of last update varies per pixel (this can be 1.5 hours ago, but also 2 weeks ago). A separate file contains a quality flag for each pixel, which primarily depends upon the time of the last update, and also on the solar zenith angle and the number of neighboring cloudy pixels (figure 4b). The running composite is continuously available under the same file name, and can be accessed whenever the latest snow information is required by another application.

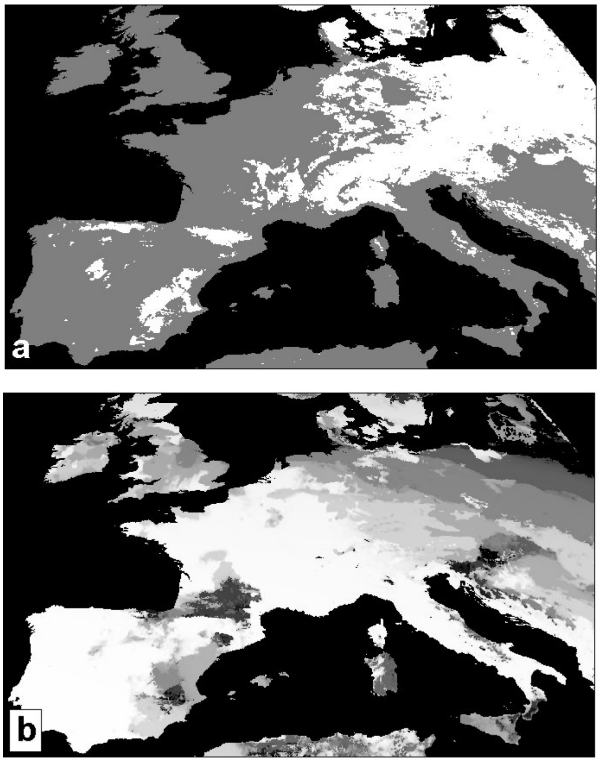

Figure 4. Running composite snow map (a) and corresponding quality map (b) at January 31st, 2006, 15:00 UTC. In the snow map, snow is white and snow-free land is light gray. In the quality map, white indicates maximum quality (1) and black minimum quality (0).

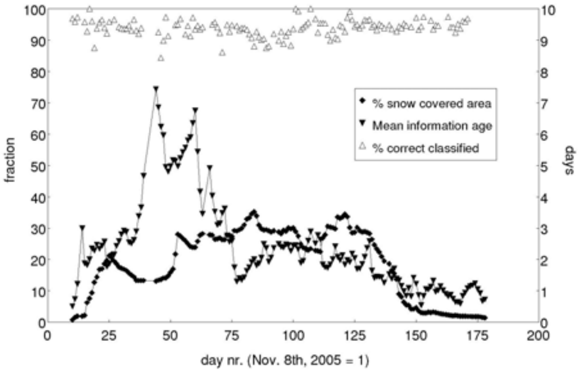

Figure 5. Results for the winter of 2005/2006. Shown are the percentage correctly classified cloud-free pixels, the average pixel age of the running composite snow map and the retrieved snow-covered area.

4 . VALIDATION AND RESULTS FOR THE WINTER OF 2005/2006

The algorithm has been operational since November 2005, and fully automatically produces snow cover maps in near-real time. A validation of instantaneous snow maps from the winter of 2005/2006 with 27,000 ground measurements made at more than 700 synoptic weather stations, showed that 94% of the cloud-free pixels are correctly classified (figure 5). Discrepancies between satellite pixels and ground measurements are caused by the differences in resolution, by dense vegetation that obscures snow cover and also by remaining undetected ice clouds. Results from the winter of 2005/2006 furthermore showed that, on average, each pixel in the running composite snow map was updated after 2.2 days (figure 5). The highest mean pixel ages of the running composite occurred between December 15th and January 15th (day number 38 - 69), when solar elevations were lowest and cloudiness was high. The highest mean pixel age, 7.44 days, occurred on December 21st, after some days of interrupted image availability. Figure 3 furthermore shows the extension of snow cover over the study area, which can be derived from the running composite snow map.

5 . CONCLUSIONS

The combination of adequate spectral resolution and high temporal frequency that is unique for SEVIRI, can be used to improve the discrimination between snow and ice clouds. Also, it allows the detection of surface snow cover in near-real time, cloud-cover permitting. Instantaneous snow maps can be combined into a running composite snow map, which for each pixel always contains the latest available surface information.

The algorithm presented here produces binary (snow or no snow) snow maps at normal SEVIRI resolution. Currently, we are developing a sub-pixel snow cover product and investigate possibilities of mapping snow in the High Resolution Visible (HRV) SEVIRI channel. This involves correcting the measured reflectance for the influence of surface topography, which can significantly affect the signal in the HRV channel.

6 . REFERENCES

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APPENDIX B: MODIFICATIONS TO SNOW ANALYSIS SOFTWARE

In this appendix the main modifications to the snow analysis software provided to MeteoSwiss by the DWD are described.

1 CODE STRUCTURE

Analysis of in-situ observations is coded in the file grpeva.F; use of the satellite derived snow mask to modulate the produced analysis is coded in file snwmsk.F.

2 MODIFICATIONS TO GRPEVA.F (VERSION 2.0)

- Bug correction: temporal scale in ZGEWTM reduced from 60 to 12 (time difference is expressed in hours and not in minutes).
- Bug correction: the presence of a snw_info file can trigger the use of NOAA data, even if none are present, with unpredictable results. As solution, the variable LUSENOAA in &NAMANA has been introduced (default is .false.).
- More selective vertical weight, with value 0.5 at cut-off:
  ZGEWH = SQRT(1.-0.75*(ZDH/ZHMAX)**2)
  ZHMAX = 0.3*ORO(MLON,MLAT)+120.
  Note: a symmetric weight is used to reproduce a linear dependency of snow depth with height (in presence of multiple observations).
- Horizontal weight flatter around observation location, with value 0.5 at cut-off:
  ZGEWD = (3*ZRMAX**4 - ZDD**4) / (3*ZRMAX**4 + ZDD**4)
- In case of a second scan, if there are enough snow depth reports, the new search radius is set to MAX(0.6*ZRMAX,50.)
- Minimal snow depth value after Cressmann analysis set to 10mm (instead of 5mm).

In this routine the meaning of the Cressmann weights is twofold: as a factor to define a snow depth value at the target point, and as the probability to have snow.

3 MODIFICATIONS TO SNWMSK.F (VERSION 2.0)

- Bug correction: projection from satellite mesh on model mesh was only correct for satellite mesh size significantly smaller than model mesh size; the algorithm has been re-written in a more general way and should support any satellite mesh which is regular enough
- For each model grid point, the surrounding satellite pixels are used to calculate the probability of having snow and no snow. The vertical weight used in this operation is now asymmetric with respect to the height difference between the grid point and the satellite pixel.
- Quality flag associated to snow mask is read in and used to calculate Probability(snow) and Probability(no snow) for each model grid point. The name of the file containing the quality information is defined by SNW_QUA in &NAMANA and should follow the same naming convention and format as the snow mask file. Allowed values are between 0 (not to be trusted) to 1 (best quality).
- Satellite information is only used when the two following constraints are satisfied:
  Prob(snow) + Prob(no snow) > min_prob_info
  |Prob(snow) - Prob(no snow)| > min_prob_dif
- For setting a snow depth when the snow mask indicates new snow, information from nearby in-situ analysis is looked for in a radius of 250km (this also helps having a smooth transition between regions where snow depth is defined by in-situ data and region where a default snow depth is used).
- Changed the threshold for the surface temperature above which satellite snow is not used, from 6°C to 15°C. With the previous value of 6°C, some snow which was clearly present in the satellite image, was not transfered in the snow analysis.
- Relevant parameters are declared at the beginning of the routine, and printed out for diagnostic
- To make the code more robust, look-up table is now calculated each time instead of being read from disk.

4 SOME SIGNIFICANT PARAMETERS

Many free parameters are used in the snow analysis; some of them, listed below, have a significant influence on the final product. The proposed values have been chosen on the basis of a case study (02.02.2006).

1. RMAX in &NAMANA	80km
2. SUFWGH in &NAMANA	1.5
3. Min allowed snow depth in grbeva.F	10mm
4. min_prob_info in snwmsk.F	0.2
5. sdavg_radius in snwmsk.F	250km
6. default_snow in snwmsk.F	100mm

Where:

1. Horizontal scale used in the Cressmann analysis (it was originally set to 200km).
2. Relative weight of snow depth observations, observed precipitation and first guess.
3. Minimum snow depth enforced after the Cressmann analysis has been performed (values below this threshold are set to 0.).
4. Probability threshold to use satellite derived snow mask.
5. Search radius for setting snow depth when snow is introduced following the use of the satellite derived snow mask.
6. Default snow depth when snow is introduced following the use of the satellite derived snow mask.