SNOW COVER CLIMATOLOGY FROM METEOSAT-8

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Abstract

The Global Climate Observing System (GCOS) was established in 1992 to ensure that the observations necessary to address climate-related issues are defined, obtained and made available to all potential users. The Swiss GCOS Office at the Federal Office of Meteorology and Climatology MeteoSwiss is responsible to coordinate all climate relevant measurements on the national level in Switzerland. Given the long tradition of ground-based in-situ measurement networks in Switzerland since the middle of the 19th century, these data provide a unique opportunity to analyze the development of the climate over the last 150 years, in particular the regional climate change in the Alpine region.

Snow properties are important parameters for the Alpine climatology. Traditionally, they have been measured by nearly 250 in-situ stations in Switzerland. The complementary use of satellite data for snow cover mapping (eg. NOAA AVHRR since 1985) has shown the added value of the satellite data for the snow analysis. However, the low time frequency of the NOAA satellites compared to Meteosat-8 implies a lower probability of cloud-free pixels to be classified as ‘snow’ vs. ‘no snow’. Therefore, an operational processing chain has been implemented at MeteoSwiss to derive snow cover maps from Meteosat-8 every 15 minutes. This processing chain is operational since November 2005.

In this paper, the role of satellite data in the emerging integrated observing system GCOS is shown. The added value of satellite-based measurements is highlighted at the example of integrated snow cover observations of the Alpine region. For this purpose, the operationally derived MeteoSwiss snow cover product from each day of the winter 2005/2006 and 2006/2007 has been analyzed in comparison to in-situ stations, as well as to a combined ground- and satellite-based product (NOAA AVHRR, in-situ stations) for a few cases. The benefit of the satellite information in addition to the in-situ measurements is particularly visible during melting periods, eg. in spring, to capture the complex snow cover distribution.

1. INTRODUCTION

For the understanding of the climate system, continuous long-term, systematic observations are needed on the national, regional and global scale. The Global Climate Observing System (GCOS) was established in 1992 to ensure that the observations necessary to address climate-related issues on all three spatial scales are defined, obtained and made available to potential users. Primarily, the GCOS observations should assist Parties in meeting their responsibilities under the UN Framework Convention on Climate Change (UNFCCC), and also provide the systematic and sustained observations needed by the World Climate Research Programme (WCRP) and the Intergovernmental Panel on Climate Change (IPCC). In 2004, a 10-years GCOS Implementation Plan in support of the UNFCCC was compiled (WMO, 2004). The Implementation Plan describes a feasible and cost-effective path toward an integrated observing system which depends on both in-situ and satellite-based measurements.

In Switzerland, the climate relevant measurements are coordinated by the Swiss GCOS Office at the Federal Office of Meteorology and Climatology MeteoSwiss. Given the long tradition of ground-based in-situ measurement networks in Switzerland since the middle of the 19th century, these data provide a unique opportunity to analyze the development of the climate over the last 150 years, in particular the regional climate change in the Alpine region (Seiz and Foppa, 2007).

The Swiss GCOS Office is also exploring new measurement techniques and methods for improving the long-term monitoring of the Essential Climate Variables (ECVs; see eg. WMO, 2004) in Switzerland, in particular from satellites. The estimation of snow parameters such as snow extent, snow depth and snow water equivalent are vital for winter tourism as well as for the management of water resources. Accurate monitoring of regional snow cover is a key component in the study of climate and global change. This paper presents a pilot study of satellite-based snow cover climatology from Meteosat Second Generation (MSG) satellites for the two winters 2005/06 and 2006/07. In Chapter 2, a short overview of satellite-based snow cover mapping is given. Chapter 3 describes the methodology of the operational snow cover mapping from Meteosat-8 and Meteosat-9, respectively, and the results for the last two winters. Chapter 4 presents the other snow cover products operationally available in Switzerland.

2. SATELLITE-BASED SNOW COVER MAPPING

The launch of civil satellites in the 1960s opened a new era of snow cover mapping. With optical sensors as well as active and passive microwave systems, it is possible to estimate snow cover extent on regional and even continental spatial scales (Armstrong and Brodzki, 2001). Examples of fine-scale sensors that currently exist to map the spatial extent of snow cover from regional to global scales include SPOT-HRV (Systeme Probatoire d' Observation de la Terre-High Resolution Visible imaging system) or Landsat TM (Thematic Mapper), while relatively coarser scale sensors include MODIS (Moderate Resolution Imaging Spectroradiometer) and AVHRR (Advanced Very High Resolution Radiometer). Reviews exist that compare approaches for detecting snow cover (Dozier and Painter, 2004; Pietroniro and Leconte, 2005) and for generating snow cover maps based on data attained from these satellites (Hall et al., 2002; Vikhamar and Solberg, 2003). Regardless of the satellite system used, remote sensing of snow-covered ground in mountain areas is challenging. Mountainous topography introduces systematic geometric distortion; furthermore, cloud cover and vegetation disturb or even prevent the satellite-based retrieval of snow cover on the ground.

Currently, there are a limited number of sensors which can be used for operational and real-time applications at a regional to continental scale. This includes polar orbiting optical earth observation instruments such as AVHRR (Advanced Very High Resolution Radiometer), MODIS (Moderate Resolution Imaging Spectroradiometer), MERIS (Medium Resolution Imaging Spectrometer), AATSR (Advanced Along Track Scanning Radiometer) and VEGETATION. In addition, geostationary satellite systems such as GOES (Geostationary Operational Environmental Satellites) and MSG (Meteosat Second Generation) provide snow cover information on a potentially high temporal resolution.

Operational snow cover monitoring techniques have been developed and successfully demonstrated for Norway using NOAA AVHRR data (Solberg and Andersen, 1994). During the melting period, the Finnish Environment Institute (SYKE) operationally estimates fractional snow cover at 5 km grid cells from NOAA AVHRR and MODIS over 5000 drainage basins covering whole Finland (Antilla et al., 2005). The National Operational Hydrologic Remote Sensing Center (NOHRSC) publishes daily fractional snow cover maps for the U.S as well as hemispherical snow products based on a variety of satellite imagery (AVHRR, GOES, SSMI, etc.) at a spatial resolution of 4 to 24 km (NOAA/NESDIS/OSDPD/SSD, 2004; Ramsey, 1998). The National Snow and Ice Data Center (NSIDC) distributes the MODIS global snow products available at different spatial resolutions for different users (Scharfen et al., 2000; Hall et al., 2002) with a current lag between time of observation and availability of products of a few days.

The disadvantage of polar-orbiting sensors is their low temporal resolution. Until recently, geostationary satellites did not possess all spectral channels that are of interest for snow mapping. In 2002, the first Meteosat Second Generation (MSG) satellite was launched by EUMETSAT. This geostationary satellite, named Meteosat-8, carries the Spinning Enhanced Visible and Infrared Imager (SEVIRI), which has improved spectral, spatial and temporal resolution with respect to its predecessors onboard of the previous Meteosat satellites. SEVIRI is the first geostationary satellite sensor with similar channels as the polar-orbiting sensors NOAA AVHRR and MODIS. It thus offers an unprecedented data set with adequate spectral and very high temporal resolution (i.e. 15 minutes), which allows the monitoring of dynamic processes and detection of short-term changes. The advantage of the high frequency for masking clouds over snow surfaces has for example been demonstrated by Romanov et al. (2000, 2003).

3. SNOW COVER MONITORING FROM MSG

Since October 2005, a new data processing chain is operational at the Federal Office of Meteorology and Climatology MeteoSwiss to derive snow cover data from the SEVIRI instrument of the operational MSG satellite. The resulting snow cover map is subsequently used in the snow analysis of the regional NWP model of MeteoSwiss, COSMO. The methodology for the snow cover retrieval from MSG is described in detail in De Ruijter de Wildt et al. (2007), including comprehensive comparison with other satellite (MODIS snow product) and in-situ data.

Figure 1 shows the extracted mean snow cover amount over Europe for the two winters 2005/06 and 2006/07. Also included is a quality index which is a function of the updating period (i.e. age of the pixel information). It is obvious that the two winters have been completely different in terms of snow cover. The winter 2005/06 started with an early increase of mean snow cover at the beginning of December which then stayed more or less constant over the whole winter. In 2006/07, there was not much snow until January, and also later in the winter, the mean snow cover has stayed much smaller than the previous winter. The corresponding quality index shows a few peaks of up to 7 days in winter 2005/06. These periods are caused by some missing data. In winter 2006/07, the maximum age of pixels has been significantly reduced. However, there are still some periods with a mean pixel age of 3-4 days, caused by several overcast days. One reason for the rather high cloudy periods is the setup of the snow algorithm. It is tuned to avoid any misclassification of snow, i.e. to assign a pixel as ‘snow’ when it is actually ‘cloudy’, so the threshold in the cloud classification has been set very conservatively. This setup is optimal for NWP application, where any misclassified ‘snow’ pixel can have a large negative influence on the snow analysis within the model and subsequently the temperature fields and forecasting skills. For climatology, there might be an improvement of the usable information with another setup of the retrieval.

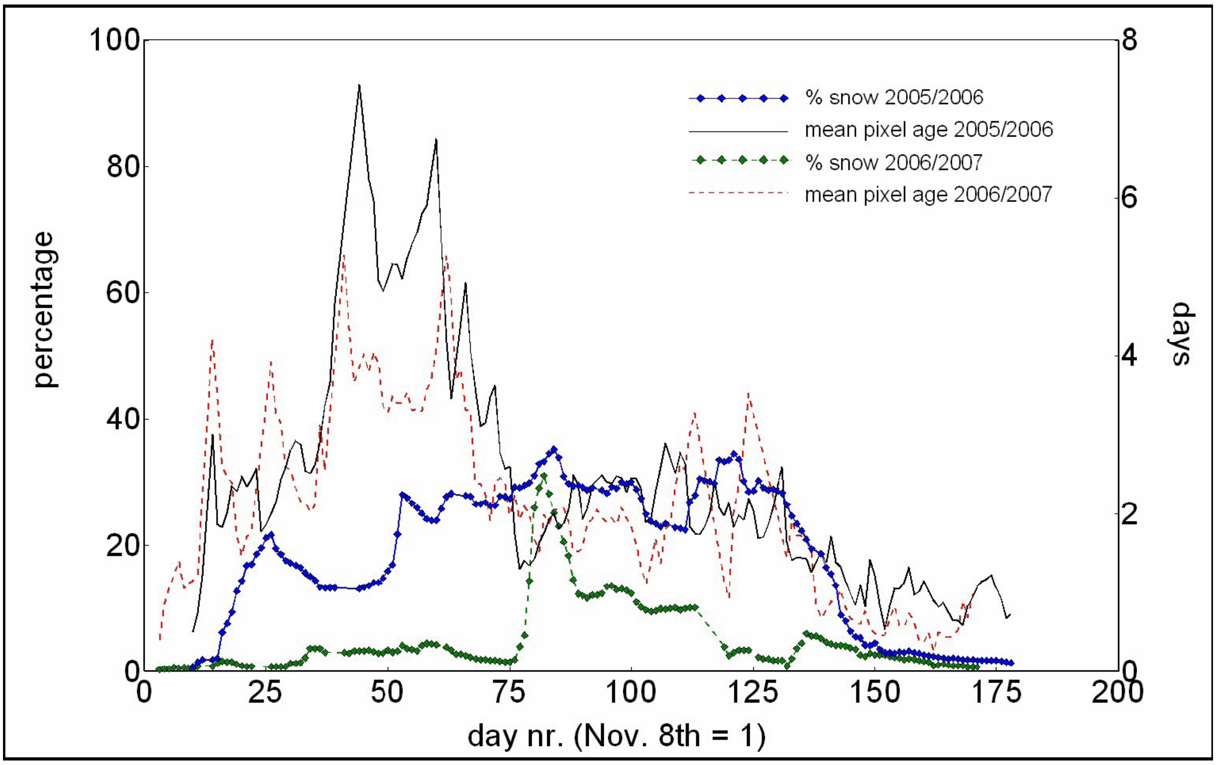

Figure 1: **Results from the operational snow cover mapping from Meteosat-8 for the winters 2005/06 and 2006/07.**

4. OTHER SNOW PRODUCTS IN SWITZERLAND

Monitoring snow depth in the Swiss Alps has a long tradition. These measurements provide a basis for avalanche forecasting, hydrological snowmelt runoff modelling, long-term changes in snow depth and are an important resource of information for winter tourism. Additionally, snow depth determines to a large extent the land surface albedo and thus is critical for radiation balance calculations.

The Swiss Federal Institute for Snow and Avalanche Research in Davos (SLF) provides daily information about the avalanche situation and the snow conditions in the Swiss Alps. In addition to avalanche text bulletins, country-wide maps for avalanche danger, snow pack stability, new snow depth and snow depth are primary products of the institute's snow information.

Snow depth is measured at 250 snow and weather stations in Switzerland, mainly in the Alpine region. These point measurements are used by the SLF to interpolate area-wide snow depth maps for Switzerland. The resulting snow depth map is calculated on a grid cell size of 1 x 1 km over Switzerland. The method performs strongly in regions with a dense network of snow stations, however, the spatial interpolation of point measurements cannot provide a true spatial product as from aerial- or space-based data. The Remote Sensing Research Group at the University of Bern, Switzerland, produces daily snow cover maps using NOAA AVHRR data covering the area of the whole European Alps. The derived AVHRR snow product provides information at sub-pixel resolution. The snow fraction algorithm takes into account potentially mixed pixels covering different land cover types (Foppa et al., 2004; Foppa et al. 2007). At SLF, the operational and near real-time AVHRR sub-pixel snow product has been included into the spatial interpolation process as an additional source of snow information (Foppa et al., 2006). In fall and spring the quality of the satellite snow cover data is improved compared to mid-winter, due to the illumination conditions of the northern hemisphere. The aim of merging in-situ snow depth data with satellite data is to take advantage of these oppositional trends which lead to an improved snow depth interpolation, mainly at the snow/no-snow borderline and/or during melting periods.

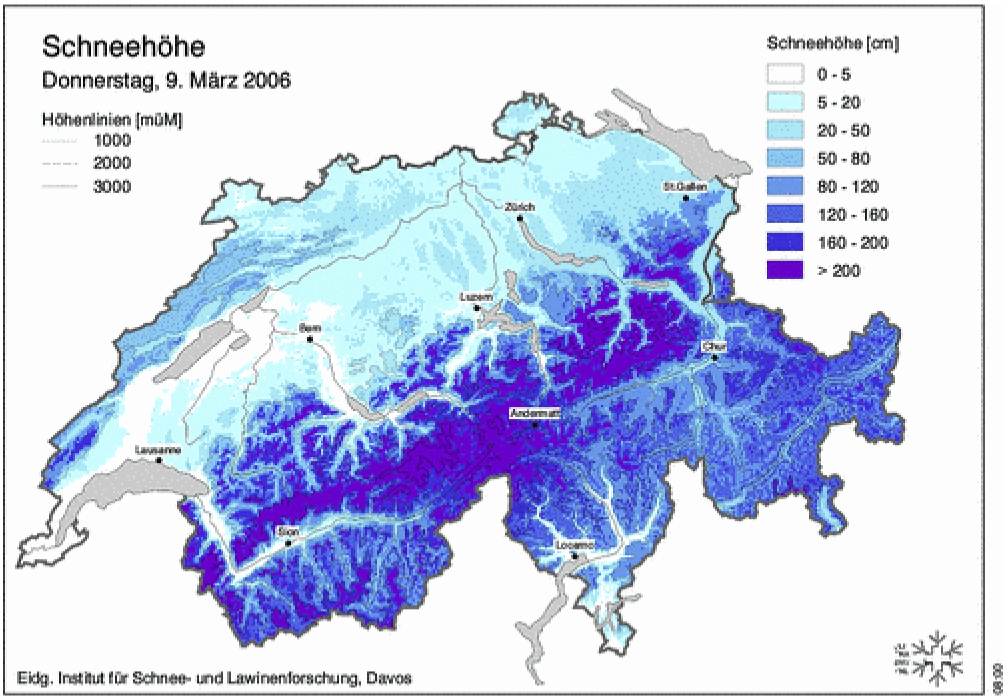

Figure 2: **Daily snow depth product of Switzerland from the Swiss Federal Institute for Snow and Avalanche Research in Davos (SLF), based on both in-situ and satellite data.**

5. CONCLUSIONS AND OUTLOOK

This paper has presented the role of the Swiss GCOS Office for exploring the potential of satellite data for the long-term monitoring of Essential Climate Variables in Switzerland. The example of snow cover has been chosen. The snow cover product from Meteosat-8 (and Meteosat-9, respectively), which is operational at MeteoSwiss since November 2005, has been systematically analysed for the two winters 2005/06 and 2006/07. In general, the satellite-based results give a good overview of the snow cover situation in Switzerland. However, the restriction of the method to cloud-free situations leads to the problem of long time periods with no update of the snow information. Despite the use of every 15 min time step of MSG, the updating period (i.e. age of the pixel information) can be up to 3-4 days. This pixel age information has consequently been included as quality indicator in the processing chain.

In the winter 2007/08, the snow cover product will be further analysed and compared with other Swiss products described earlier in this paper. Thereby, emphasis is given to improve the mean pixel age, eg. by adapting the retrieval strategy in terms of cloud classification. Furthermore, it will be studied, how to optimally combine geostationary and polar-orbiting satellite information, as well as in-situ data, for snow cover monitoring. Finally, a strategy will be outlined how to extend the snow cover data record of Switzerland back to the start of NOAA AVHRR data in 1985.

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