10-YEARS SATELLITE-BASED SNOW COVER CLIMATOLOGY OF SWITZERLAND

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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. Primarily, the GCOS observations should assist Parties in meeting their responsibilities under the UN Framework Convention on Climate Change (UNFCCC) as well as provide the systematic observations needed by the World Climate Research Programme (WCRP) and the Intergovernmental Panel on Climate Change (IPCC).

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 (GCOS Switzerland). The first inventory of climate measurement series in Switzerland highlights, among others, the long-term in-situ snow measurement series in Switzerland dating back to the end of the 19th century (Seiz and Foppa, 2007, 2011). Although satellite data have a relatively short data record compared to in-situ series, they provide complementary information, especially on the spatial distribution and variability of snow.

In this paper, we focus on the procedure to derive a snow cover climatology from October 2000 to September 2010 from the Moderate Resolution Imaging Spectrometer (MODIS) on board Terra. A new cloud gap-filling technique was implemented by post-processing of the MODIS MOD10C1 snow product. Based on this new methodology of forward and backward gap-filling, it was possible to determine the annual snow days over Switzerland from 2000 to 2010. Subsequently, the 10-years time series of annual snow days were compared with in-situ snow observations and further analyzed on a monthly and daily basis to demonstrate the potential of our annual snow day product.

1. SNOW COVER MONITORING IN SWITZERLAND

Snow cover represents a significant geophysical variable for the climate system through a range of complex interactions and feedback mechanism related to its physical properties (IPCC, 2007). High priority is therefore given in the Implementation Plan of the Global Climate Observing System (GCOS) to maintain and strengthen snow cover in-situ observations, ideally supplemented with other observing systems (WMO, 2010).

The estimation of snow parameters such as snow extent, snow depth, and snow water equivalent plays a vital role in the Swiss Alps for winter tourism as well as for the management of water resources (eg. Abegg et al., 2007). Ground-based monitoring of snow cover has a long tradition in Switzerland, and a number of studies have been published over the last years, focusing on its temporal variability and long-term trend (eg. Scherrer and Appenzeller, 2006; Marty, 2008). Most of these studies focused on the spatiotemporal variability of snow days. In general, a snow day is defined as a day with a snow depth larger than a certain threshold (WMO, 2009).

Ground-based observations provide measurements on a specific point, whereas satellite data give an area-wide information. For Switzerland, polar-orbiting NOAA AVHRR data (Foppa et al., 2004) and geostationary Meteosat SEVIRI data (De Ruyter de Wildt et al., 2007) have been used for retrieval of the snow cover extent and pilot climate datasets (Seiz et al., 2007; Foppa et al., 2008). The study reported here is placed in the context of the satellite activities within the National Climate Observing System of Switzerland (GCOS Switzerland) (Seiz et al., 2011). The paper describes a proposed methodology to derive a 10-years snow cover climatology over Switzerland based on annual snow days from October 2000 – September 2010.

2. MODIS SNOW PRODUCT AND POST-PROCESSING

Within our study, the MODIS/Terra Snow Cover Daily L3 Global 0.05 Deg Climate Modeling Grid (CMG) Version 5 (MOD10C1) product was used, for the period from 1 October 2000 to 30 September 2010. In the MOD10C1 product, a binning algorithm maps MOD10A1 daily snow cover data at 500 m resolution into a grid of a 0.05 degree (CMG) and calculates snow and cloud percentages, Quality Assessment (QA), and a confidence index based on the mapping results (Riggs et al., 2006).

Several techniques have been developed over the last years to reduce the cloud cover pixels from optical sensor products (eg. MODIS products). They include one or a combination of different approaches, such as spatial or temporal filtering, temporal composites of maximum snow cover, prior cloud-persistence and combining Terra and Aqua MODIS (eg. Wang et al., 2009; Hall et al. 2010).

We applied a post-processing technique to fill data gaps in the MOD10C1 product caused by clouds. This two-step methodology included a re-classification of the MOD10C1 product followed by a new forward and backward gap-filling approach (Foppa and Seiz, 2011).

The re-classification of the MOD10C1 is based on thresholds defining a CMG grid cell to be re-classified as entirely cloud covered, snow covered or snow free. However, if snow percentage of a CMG cell is > 4% and cloud percentage ≤ 95%, the pixel value is then normalized, resulting in a snow fraction related to the cloud free land observed. The subsequent forward and backward gap-filling procedure is as follows: pixels, which are cloud covered on a specific day (i.e. day one) are replaced with the cloud free pixel information from the day before (i.e. day one – 1). Even though the number of consecutive days with cloud cover could accumulate over time, the gaps are filled with the same value provided from the latest cloud free grid cell. In accordance to this so-called forward gap-filling approach, we applied the same procedure in reverse direction, eg. 30 September 2001 to 1 October 2000. To derive the annual snow days, we calculated the mean of the annual number of snow days based on the forward and backward gap-filling procedure.

3. RESULTS

The derivation of the annual snow days from the MOD10C1 product is adequate for describing the inter-annual variability of the snow cover over Switzerland. Although the spatial resolution of the MOD10C1 is moderate (i.e. 0.05^{o}), topographic features such as the main alpine valleys are clearly apparent (Figure 1). As such, the post-processed MOD10C1 product provides valuable information to complement the sparsely distributed point observations on the ground.

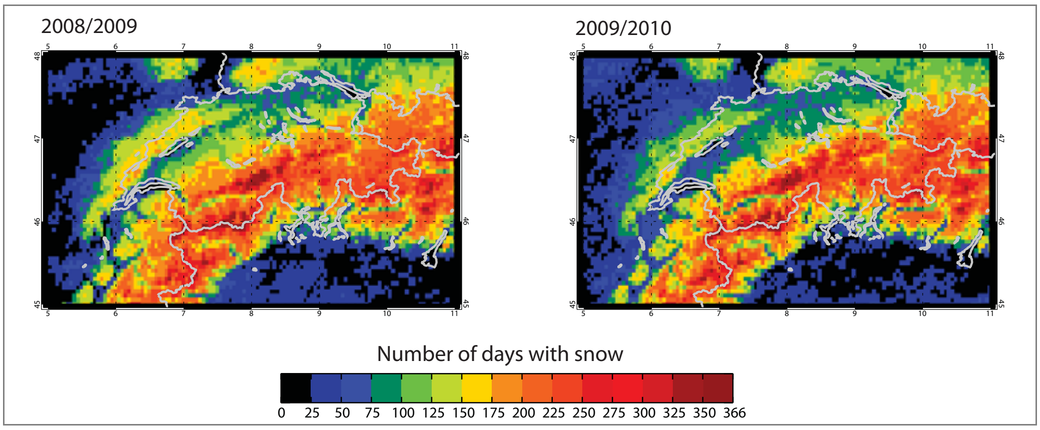

***Figure 1*: Satellite-derived annual snow days over Switzerland for the years 2008/2009 and 2009/2010.**

4. CONCLUSIONS AND OUTLOOK

The annual snow days were retrieved by applying a new gap-filling approach to reduce cloud cover obscuration. An accuracy assessment based on in-situ observation sites representing different climatological regimes in Switzerland has demonstrated the potential of this new methodology. For further discussing the spatiotemporal variability of annual snow days on a regional to local scale, other higher spatial resolution products from MODIS or other sensors might be used. The long-term record of satellite data such as from NOAA AVHRR and Metop might provide time-series of more than 20 years. Additionally, the use of high temporal resolution data such as from geostationary satellites (eg. Meteosat, see Boi, 2010) could be of interest for the development of a combined gap-filling approach. The Swiss GCOS Office will continue to foster the generation of satellite-based datasets of ECVs for the area of Switzerland by various institutions and use the combination with long-term in-situ measurements to generate integrated high-quality climate data products within GCOS Switzerland.

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