STRENGTHENING THE ROLE OF SATELLITE OBSERVATIONS WITHIN GCOS SWITZERLAND

Gabriela Seiz, Fabio Fontana, Nando Foppa

International Affairs Division, Swiss GCOS Office
Federal Office of Meteorology and Climatology MeteoSwiss, Kraehbuehlstrasse 58, 8044 Zurich, Switzerland

Abstract

The goal of the Global Climate Observing System (GCOS) is to ensure that observations of all Essential Climate Variables (ECVs) as defined in the GCOS Implementation Plan are obtained and made available to interested users. In Switzerland, the Swiss GCOS Office at the Federal Office of Meteorology and Climatology MeteoSwiss is responsible for the coordination of climate observation at the national level, as a contribution to the global system. An important task is the promotion of new measurement techniques and methods, such as Earth observation from space, to complement conventional observation networks.

Focusing on the area of Switzerland, the paper highlights studies on inter-annual variations of cloud cover (2000-2012) based on Moderate Resolution Imaging Spectroradiometer (MODIS) data, Lake Surface Temperature (LST) for several lakes in Switzerland (1989-2011) based on historical Advanced Very High Resolution Radiometer (AVHRR) data, and snow cover days between 2000 and 2010 based on the MODIS snow cover product. With regard to future validation exercises, the studies emphasize the importance of high quality ground-based observations, including the detailed station characterization and compilation of metadata. Such information is a prerequisite to assess product uncertainties and to increase confidence of users in satellite-derived products.

Insight gained from these types of applications will be very valuable for the development of high quality climate products. The Swiss GCOS Office will therefore continue to promote satellite-based data for climatological analyses in Switzerland, as a contribution to the National Climate Observing System (GCOS Switzerland).

INTRODUCTION

The goal of the Global Climate Observing System (GCOS) is to ensure that observations of all Essential Climate Variables (ECVs) as defined in the GCOS Implementation Plan are obtained and made available to interested users (WMO, 2010; WMO, 2011). Observations cover the entire climate system: atmosphere, oceans, and the land surface, and are based on a wide range of measurement techniques including Earth observation satellites. By providing observations of ECVs at the global scale, Earth observation satellites can complement conventional observation networks, and provide continuous observations where traditional measurements are at risk of being discontinued (Seiz et al., 2011).

To ensure the success of GCOS at the global scale, effective national coordination mechanisms are needed, making sure that efforts at the national level are consistent with the global system. In Switzerland, which has a long tradition of climate observation, the task of coordinating the National Climate Observing System (GCOS Switzerland) is undertaken by the Swiss GCOS Office at the Federal Office of Meteorology and Climatology MeteoSwiss (Seiz and Foppa, 2011). An important activity is the promotion of new measurement techniques and methods, such as Earth observation from space. Over recent years, space-based climate observation activities in Switzerland have increased in number, both in the atmospheric and terrestrial domain. A number of Swiss institutions are involved in national and international activities aiming to provide consistent satellite data sets of various ECVs. These include, among others, contributions to the European Space Agency (ESA) Climate Change Initiative (CCI) projects on clouds, ozone, greenhouse gases, aerosols, glaciers, soil moisture; global radiation from geostationary satellites as a contribution to the EUMETSAT Satellite Application Facility on Climate Monitoring (CM SAF); Swiss GCOS Projects on geolocation accuracy and Lake Surface Temperature (LST) of Swiss lakes. In addition, the potential contribution of satellite observations to GCOS Switzerland is highlighted by the Swiss GCOS Office through its Enabling Activities (Foppa and Seiz, 2012; Fontana et al., 2013).

With regard to the contribution of satellites to the National Climate Observing System (GCOS Switzerland), the paper highlights inter-annual variation of cloud cover (2000-2012), LST analyses for several lakes in the period 1989 to 2011, and snow cover days between 2000 and 2010.

CLOUD COVER

In light of the important role of cloud cover in the climate system, analysis of its spatio-temporal variations has attracted increasing interest over recent decades. As a result, cloud properties have been defined as a GCOS ECV to ensure that clouds are observed systematically and continuously (WMO, 2010). Systematic and continuous observation of cloud cover over large spatial scales is possible by means of satellite data. Moreover, satellite observations may be used to complement existing Synop observation networks, and are becoming particularly useful considering the negative trend in the number of Synop observation sites.

Given the high spatial variability of cloud cover due to the complex topography of the Swiss Alps, we generated two new high spatial resolution (0.05°) daytime cloud fraction data sets over Switzerland. The data sets are based on the Terra and Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) cloud mask products. The data sets cover the period from March 1, 2000 to February 29, 2012 (Terra/MODIS) and July 1, 2002 to February 29, 2012 (Aqua/MODIS) and represent mid-morning and early-afternoon cloud cover over Switzerland.

Time series of cloud fraction over Switzerland clearly reflected the seasonal variation in cloud cover. Satellite-based monthly mean mid-morning as well as early-afternoon cloud fraction agreed within 12.5% when compared to traditional Synop observations at a number of sites in Switzerland (Fontana et al. 2013). Discrepancies between satellite- and ground-based observations were observed due to differences in observation times and geometry, as well as due to the complex topography limiting the range of sight of the ground observer.

LAKE SURFACE TEMPERATURE (LST)

Knowledge about spatio-temporal variations in LST are of interest for various applications, e.g. climate monitoring (Oesch et al., 2005). As a result, “Lakes” have been defined as a GCOS ECV (WMO, 2010). However, in Switzerland, in-situ measurements are carried out in an uncoordinated manner, and freeze and thaw dates of lakes are not systematically observed (Seiz and Foppa, 2007). Against this background and in line with the GCOS Implementation Plan (WMO, 2010), which explicitly encourages studies on satellite-derived LST, the goal of a recent Swiss GCOS Project at the University of Bern was to derive LST from satellite data over Switzerland.

A comprehensive archive of Advanced Very High Resolution Radiometer (AVHRR) data over Europe, hosted at the University of Bern (Hüsler et al., 2011), served as the basis for this study. AVHRR observations at a spatial resolution of 1 km and covering the period from 1989 to 2011 were considered, hence including historical observations of the NOAA satellite series as well as data from AVHRR onboard the EUMETSAT Metop satellites.

Validation with in-situ data revealed a strong correlation between satellite- and ground-based measurements, both for large lakes (e.g., Lake Constance) and lakes with a size in the order of a few square kilometers only, e.g., Lake Murten (Riffler and Wunderle, *in prep.*). Figure 1 shows LST derived from Metop-A AVHRR data at a number of lakes in Western Switzerland. The figure demonstrates that spatial and temporal variations in LST can be observed with AVHRR data, both for large and small lakes.

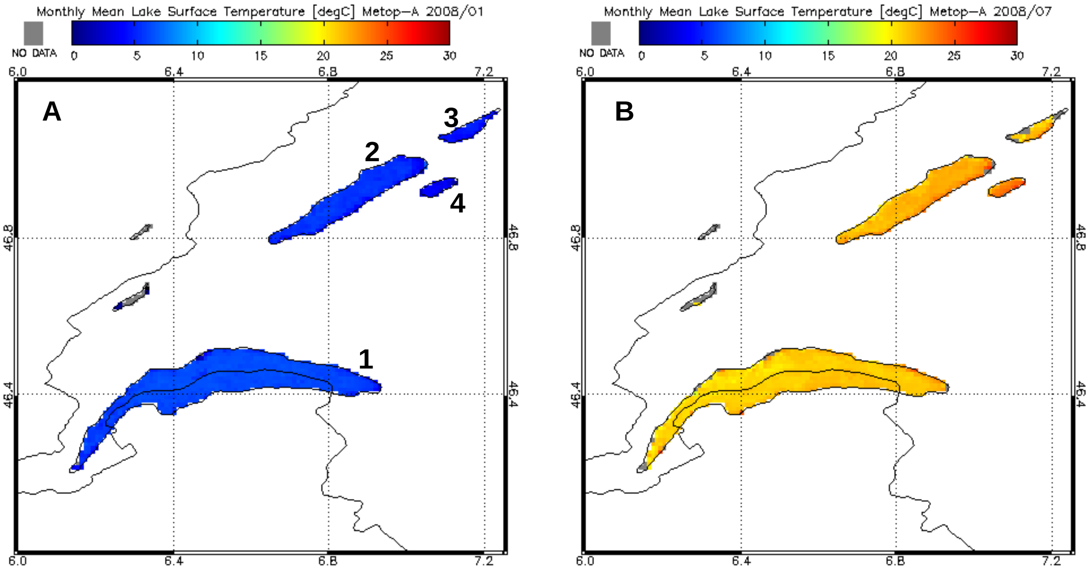

Figure 1: **Monthly mean LST for Lake Geneva (1), Lake Neuchâtel (2), Lake Biel (3), and Lake Murten (4) in Western Switzerland, for January (A) and July (B) 2008. Water temperatures are derived from Metop-A AVHRR data (Riffler and Wunderle, *in prep.*).**

In Figure 2, a time series of ΔLST is shown for Lake Constance (Station: Bregenzer Hafen) for the period 1989 to 2009. The seasonal variation in ΔLST, which is clearly apparent from Figure 2, results from the comparison of surface skin temperature (satellite-derived) and in-situ measurements, which are measured at a certain depth. As a result, the analyses reflects diurnal (and seasonal) variations in the vertical profile of water temperature. Time series of LST for a number of Swiss lakes is available to the public on the webpage of the Remote Sensing Research Group (RSGB) at the University of Bern.

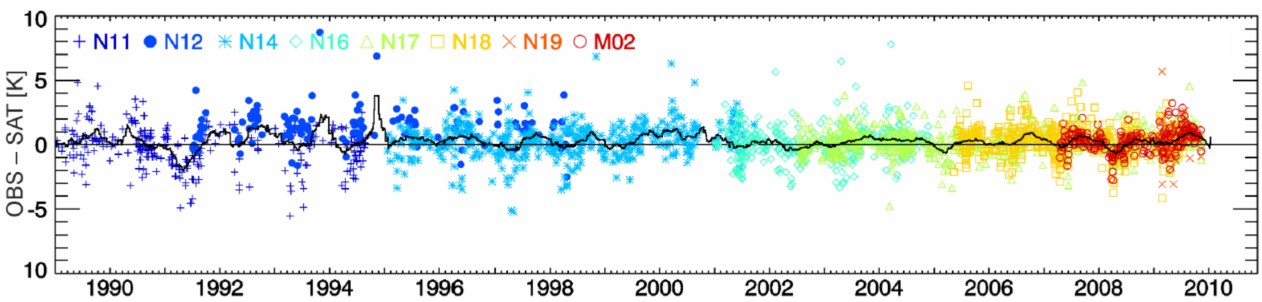

Figure 2: **Time series of the difference in LST between in-situ (OBS) and satellite-based LST at Bregenzer Hafen, Lake Constance (Riffler and Wunderle, *in prep.*). Symbols indicate the satellite used for LST retrieval (NOAA: N11-N19; Metop-A: M02).**

SNOW COVER

Snow cover plays a vital role in the climate system. As a result, high priority is given in the GCOS Implementation Plan to maintain and strengthen snow cover in-situ observations, ideally supplemented with other observing systems (WMO, 2010). In Switzerland, monitoring of snow cover has a long tradition, mainly based on in-situ observations (e.g. Scherrer and Appenzeller, 2006), but also using satellite data (Foppa et al., 2004; Hüsler et al., 2012; De Ruyter de Wildt et al., 2007).

Within the activities of GCOS Switzerland, inter-annual variations of snow cover days (SCD) in Switzerland were derived based on Terra MODIS data (Riggs et al., 2006). The data set spans the period from 1 October 2000 to 30 September 2010 at a spatial resolution of 5 km. The MOD10C1 product was post-processed using a cloud gap-filling technique to derive the number of days with snow in a year. Our gap-filling approach is similar to Hall et al. (2010), taking into account the temporal evolution of cloud cover. However, instead of tracking cloud persistence from the current day to previous days as it is mainly done in near-realtime applications, we introduced a so-called backward gap-filling method combined with the more common forward gap-filling (Foppa and Seiz, 2012).

For validation, a subset of well-characterized in-situ snow observation sites from the so-called National Basic Climatological Network for Snow (NBCN-S) was selected. These potential Swiss GCOS Snow stations were defined in the framework of a detailed analysis of 160 historical snow measurement series in Switzerland (Wüthrich et al., 2010). Figure 3a and 3b shows the geographical location of two potential Swiss GCOS Snow stations, both having different characteristics in terms of surrounding topography and land cover. Defining and carefully describing high quality ground-based observations is a prerequisite for the development and validation of consistent satellite-based snow products, especially over alpine terrain.

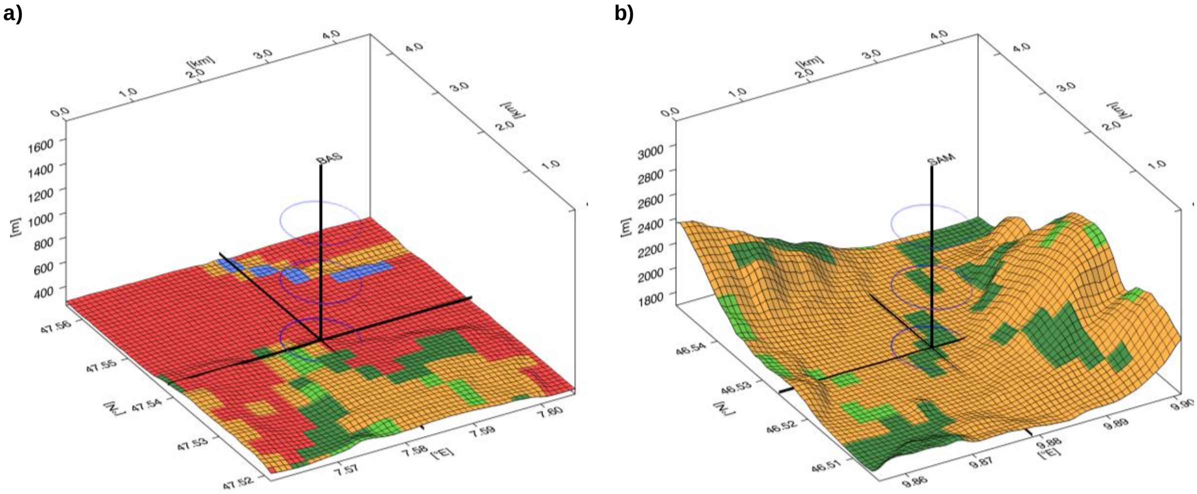

Figure 3: **Characteristics of two potential Swiss GCOS Snow station sites used for the intercomparison study: (a) Basel (Swiss Plateau) and (b) Samedan (Central Alps). The digital elevation model from the Shuttle Radar Topography Mission (SRTM) (Rodriguez et al., 2005) and a simplified GlobCover data set (Bontemps et al., 2010), distinguishing seven categories (urban=red, cultivated=orange, grassland=green, forest=dark green, water=blue, bare ground=gray, snow=white) was used. Circles indicate a 1 km radius around the sites.**

Skill scores comparing MODIS- and in-situ-derived SCDs were calculated using contingency tables (snow or no snow), on a daily basis (Wilks, 2011). Results suggest that the overall accuracy between the two data sets was high, at 0.88, 0.89, and 0.94 for the Basel, Samedan, and Lugano stations, respectively. Besides the overall accuracy, two additional statistics, the ‘probability of detection’ (POD) and the ‘false alarm ratio’ (FAR), should be considered in conjunction to take into account missed events and false alarms, respectively. SCD estimates agreed well at the alpine site of Samedan, indicated by a high POD and a low FAR. In contrast, a higher FAR at Basel and Lugano suggests there were more days where snow cover was observed by the satellite but was not observed at the ground.

Overall, the investigation revealed a good performance, particularly at the alpine site of Samedan, characterized by relatively homogeneous land cover (Fig. 3b) and a frequent occurrence of snow events. In contrast, higher discrepancies at the lowland sites in Basel and Lugano could be related to the low number of SCDs. Similar overall accuracies have been reported by Wang and Xie (2009) who analyzed the performance of MODIS-derived mean snow covered days with in-situ measurements for several years at 20 stations in China. More detailed analyses are, however, required in our study to determine under which conditions, e.g., altitude, climatological region, season and local topography, discrepancies are observed.

CONCLUSIONS AND OUTLOOK

Mountain regions are among the most vulnerable to climate variability and change. Earth observation satellites make an essential contribution toward the monitoring of the climate system over mountain areas worldwide. The number of applications relying on satellite data has recently increased in Switzerland. Today, Swiss institutions contribute to several international activities that aim to provide consistent satellite data sets of ECVs for climate studies, demonstrating the importance of satellite data as a complement to traditional measurement networks within the National Climate Observing System (GCOS Switzerland).

High quality ground-based observations of ECVs are of major importance, one considerable advantage being their role for the validation of satellite-based products. As an example, intercomparison of ground- and satellite-based cloud fraction as well as LST over Switzerland showed that satellite observations may be an important complement to conventional observational methods. However, detailed characterization of validation sites is required, including the compilation of metadata information (e.g. station history). This has been done for the potential Swiss GCOS Snow Stations, and is considered a prerequisite to assess product uncertainties and to increase confidence of users in satellite-derived products.

High quality in-situ data have been used hand-in-hand with MODIS-derived snow cover days over Switzerland (2000-2010). For further improvement of the cloud gap-filling technique, the development of blended satellite products including highest temporal resolution data, e.g. from geostationary Meteosat satellites, are envisaged. Additionally, with upcoming new Earth observation platforms (e.g. Sentinel-3), the continuation of optical sensors is ensured, bringing forth a large potential for snow retrievals and the continuation of times series of this ECV. Studies using combined ground- and satellite-based snow cover data over the Swiss Alps may further serve as an example for potential investigations over other mountainous regions, particularly for regions where ground-based observations are sparse.

Experience gained from this wide range of space-based climate observation applications will ultimately be valuable for the development of high quality climate products, to take full advantage of increasingly available data sources (incl. modeling). Accordingly, the Swiss GCOS Office, as the national focal point for climate observation in Switzerland, will continue to promote satellite-based data for climatological analyses as a contribution to GCOS Switzerland.

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