CONTRIBUTION OF SATELLITE OBSERVATIONS TO THE NATIONAL CLIMATE OBSERVING SYSTEM (GCOS SWITZERLAND)

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Abstract

The Global Climate Observing System (GCOS) is designed to meet national and international needs for systematic climate observation. Its goal 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, for example, the Parties to the United Nations Framework Convention on Climate Change (UNFCCC), in the fulfillment of their obligations to the convention.

Switzerland has a long tradition in climate observation. An inventory report of the National Climate Observing System compiled in 2007 by the Swiss GCOS Office at MeteoSwiss provided an overview of the most valuable long measurement series of ECVs and identified series at risk of discontinuation. The most important systematic observations concern the surface (e.g., radiation), upper air (e.g., water vapour), atmospheric composition (e.g., trace gases, aerosols), hydrology (e.g., lake surface temperature), cryosphere (e.g., glaciers, snow), and biosphere (e.g., forest fires). The report also highlighted the ever-increasing importance of satellites for global climate observation, in support of conventional observation networks. Over recent decades, there has been a significant increase in both the number and the quality of satellite-based observations of ECVs. Despite the apparent challenges for satellite remote sensing in Switzerland, namely the complex topography, the number of projects using satellite-based observations has steadily increased.

This paper provides an overview of activities relying on satellite data within the National Climate Observing System (GCOS Switzerland). Comparative analyses of satellite- and ground-based time series of the ECVs snow cover and cloud cover are presented, demonstrating that through a combination of various observation techniques, high-quality climate products in support of GCOS Switzerland may be generated.

INTRODUCTION

The Global Climate Observing System (GCOS) was established two decades ago, in the context of the United Framework Convention on Climate Change (UNFCCC), to ensure that the observations necessary to address climate-related issues are defined, obtained and made available to all potential users. Primarily, the GCOS should assist the Parties in meeting their responsibilities under the UNFCCC, as well as provide the systematic observations needed by the World Climate Research Programme (WCRP) and the Intergovernmental Panel on Climate Change (IPCC).

GCOS encompasses all domains of the climate system (atmosphere, oceans, and the land surface) and is built upon a wide range of measurement techniques, one of which is satellite-based Earth observation. Over recent decades, satellites have become an increasingly important component of Earth observation; they provide information on remote areas, which are often difficult to access and, as a result, are only marginally represented in conventional observation networks. There is global consensus that satellites are a critical component of the current and future integrated global climate observing system (WMO, 2010).
Effective national coordination is needed to ensure the continuous success of GCOS at global scale. In Switzerland, this task is undertaken by the Swiss GCOS Office at the Federal Office of Meteorology and Climatology MeteoSwiss. The Swiss GCOS Office is the national focal point for climate observation and coordinates all relevant measurements of Essential Climate Variables (ECVs) from research institutes, federal offices and universities (Seiz and Poppa, 2011). A key activity of the Swiss GCOS Office is the promotion of emerging measurement techniques (e.g., satellite Earth observation), which may be used to complement existing observation networks, or to provide continuous observations where traditional measurements are at risk of being discontinued (Seiz et al., 2011).

Despite the apparent challenges associated with the analysis of satellite data over the complex topography of Switzerland, various Swiss institutions are involved in a number of national and international activities aiming at the provision of consistent satellite data sets of various ECVs in the atmospheric and terrestrial domains. These include, among others, the

- derivation of time series of global radiation from geostationary satellite data post-1983 at MeteoSwiss. These analyses are conducted in the framework of the EUMETSAT Satellite Application Facility on Climate Monitoring (CM SAF);
- ESA CCI "Ozone", focusing on the generation of global data sets of ozone tailored for the use by the climate research community, with MeteoSwiss being actively involved in validation activities;
- ESA CCI "Greenhouse Gases" (GHG), combining global satellite data with model information to identify sources and sinks of carbon dioxide and methane. The Swiss Federal Laboratories for Materials Science and Technology (Empa) is involved in the validation of satellite retrievals with in-situ measurements;
- comparison of different algorithms for the retrieval of aerosol information from space within the ESA CCI "Aerosol", with contributions by the Paul Scherrer Institute to the validation activities;
- generation of time series of Lake Water Surface Temperature (LWST) of selected Swiss lakes based on historical NOAA AVHRR data at the Institute of Geography, University of Bern;
- ESA CCI "Glaciers", led by the Institute of Geography, University of Zurich, which uses high spatial resolution satellite data to establish a global glacier inventory in support of the World Glacier Monitoring Service (WGMS);
- analysis of geolocation accuracy of medium spatial resolution satellite sensors over Switzerland by the Institute of Geodesy and Photogrammetry at the Swiss Federal Institute of Technology (ETH) in Zurich.

The paper details on a number of activities as mentioned above, namely the Swiss GCOS projects on geolocation accuracy and LWST, and the enabling activities of the Swiss GCOS Office in the field of cloud cover and snow cover over Switzerland.

**ASSESSING THE GEOMETRIC ACCURACY OF FUNDAMENTAL CLIMATE DATA RECORDS**

With regard to the use of satellite-based data sets in climate studies, requirements for accuracy and stability of Fundamental Climate Data Records (FCDRs) were defined and described in the document “Systematic Observation Requirements for Satellite-Based Data Products for Climate” (WMO 2006) and recently updated to reflect the latest advances in science (WMO 2011). For example, this so called Satellite Supplement to the GCOS Implementation Plan (WMO, 2004, 2010) details the requirements for radiometric and geometric accuracy of FCDRs. While former has been and still is an active and critical research area within the remote sensing community (e.g., Heidinger et al., 2003), only relatively few studies have so far addressed the issue of geometric accuracy (e.g., Khlopenkov et al. 2010), even though geometric distortions in satellite imagery may cause systematic errors in climate data sets (Fontana et al., 2009).

In a new project recently launched by the Swiss GCOS Office in collaboration with ETH Zurich, geometric accuracy of FCDRs will be analysed with regard to the generation of long-term data sets of snow cover and LWST over Switzerland. It is planned to consider data from following three moderate
spatial resolution satellite sensors: Spinning Enhanced Visible and Infrared Imager (SEVIRI) onboard the Meteosat Second Generation (MSG) satellites, Advanced Very High Resolution Radiometer (AVHRR) onboard the National Oceanic and Atmospheric Administration (NOAA) as well as EUMETSAT Metop satellites, and Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the Terra and Aqua satellites.

The focus of the project is on the geographic area of Switzerland, which imposes additional challenges due to the geometric distortions caused by the elevated topography of the Swiss Alps. Work will include analyses of the absolute geolocation accuracy (relative to reference imagery) and relative accuracy (between consecutive images and between spectral bands).

TIME SERIES OF LAKE WATER SURFACE TEMPERATURE

Knowledge about spatio-temporal variations in LWST are of interest for various applications, such as numerical weather prediction, water quality monitoring, modeling of lakes’ physical properties, and for climate change studies (Oesch et al., 2005, and references therein). Information on LWST in Switzerland is available for various lakes from in-situ data, which are available at hourly (e.g., Lake Constance) to monthly intervals (e.g., Lake Sempach). To date, however, there is no nationally coordinated measurement network for in-situ LWST (Seiz and Foppa, 2007). The contribution of satellites to the observation of the ECV “Lakes” in Switzerland has so far been limited to an operational LWST product based on AVHRR data from the University of Bern (Oesch et al., 2005). The University of Bern hosts a comprehensive archive of AVHRR data at 1 km spatial resolution over Europe, including historical satellites of the NOAA series post-1989.

In the framework of a GCOS Switzerland project in collaboration with the University of Bern, time series of LWST are derived for a number of lakes in Switzerland based on this long-term archive. In-situ data from various institutions is available for the entire time period and is used for validation. Three retrieval algorithms are investigated: the Sea Surface Temperature (SST) algorithm operational at the NOAA National Environmental Satellite, Data, and Information Service NESDIS (NLSST), the algorithm developed in the framework of the NOAA Pathfinder Project (PFSST), and an algorithm recently developed at the University of Bern (RTSST). While the NLSST and PFSST algorithms are designed for global application, the RTSST algorithm is tailored for the area of Switzerland and relies on the Radiative Transfer Code RT-TOVS (Saunders et al., 2012) and ancillary input data on the atmospheric state to account for regional conditions. Preliminary analyses revealed a strong correlation between satellite- and ground-based measurements for all three algorithms, whereas the results for the regionally tailored algorithm were more consistent when compared to the NLSST and PFSST algorithms. Moreover, analyses showed that LWST may also be retrieved for small lakes with a size in the order of a few square kilometers only, e.g., Lake Sempach, with good correlations with in-situ measurements. Time series of LWST for a number of Swiss lakes will be made available to the public at the end of the project (December 2012) on the webpage of the Remote Sensing Research Group (RSGB) at the University of Bern.

INTERANNUAL VARIATIONS OF SNOW COVER DAYS FROM 2000-2010

Snow cover represents a significant geophysical variable for the climate system and therefore high priority is given in the GCOS IP 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 an important role in the Swiss Alps for various applications. Hence, 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 (e.g., Scherrer and Appenzeller, 2006; Marty, 2008).

For Switzerland, polar-orbiting NOAA AVHRR data (Foppa et al., 2004; Hüsler et al., 2012) and geostationary Meteosat SEVIRI data (De Ruyter de Wildt et al., 2007) have been used for generating pilot climate datasets on snow cover. Within the activities of the National Climate Observing System (GCOS Switzerland) inter-annual variations of snow cover days (SCD) over Switzerland were derived.
from 2000 to 2010 based on data from the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the Terra satellite. The purpose is to examine the spatiotemporal variation of snow conditions on a yearly basis. A cloud gap-filling technique is implemented by post-processing the MOD10C1 product to derive the number of days with snow cover. The data set spans the period from 1 October 2000 to 30 September 2010 (V005) (Riggs et al., 2006). Further details on the methodology of the cloud gap-filling technique and the validation based on in-situ measurements over Switzerland is given in Foppa and Seiz (2012).

Figure 1 shows the SCD maps based on MODIS, binned into 15 classes on a 25-days interval. The SCD maps highlight the number of snow days for the period of 1 October to 30 September for the selected years 2006/2007 and 2008/2009, representing different snow conditions (Foppa and Seiz, 2012). It is clearly visible that the satellite-derived SCD product reflects the topography of Switzerland with a larger number of snow days in higher altitudes and less days with snow cover in the Swiss midlands and in Southern Switzerland. The inter-annual spatial variations are most apparent on the Swiss Plateau whereas in the Central Alps the year to year variability is marginal. The year 2006/2007 is outstanding with a relatively small number of days with snow particularly on the Swiss Plateau. In contrast, in 2008/2009 a relatively large number of days with snow in the Swiss lowlands was observed.

Figure 1: Satellite-derived number of snow cover days per year over Switzerland for the years 2006/2007 and 2008/2009.

Figure 2 shows monthly variations in SCD and differences between MODIS and in-situ derived SCD from October 2000 to September 2010 at Samedan (Foppa and Seiz, 2012). The Samedan site is located in the Central Swiss Alps at 1708 m a.s.l. and is part of the so-called National Basic Climatological Network for Snow (NBCN-S), which represents the main climatological regimes in Switzerland and varying altitudes (Wüthrich et al., 2010). In our study, we defined snow cover days (SCD) as days with a snow depth of at least 1 cm, which is the definition also used operationally at MeteoSwiss.
Figure 2: Temporal variability of the monthly number of snow cover days and the differences (MODIS – in-situ) from 2000–2010 for the alpine site Samedan.

Overall, the monthly variations from MODIS and in-situ correspond quite well. Periods with complete snow cover (December, January, February, March) are generally captured by MODIS in every year. A somewhat weaker agreement is found during the transition periods in fall (October, November) and spring (April, May). Analyses at both annual and monthly basis show that the number of snow days is overestimated by our post-processed MOD10C1 product compared to in-situ SCD. For the alpine site Samedan, the relative error (MODIS – in-situ) averaged over the 10 years is around 8%.

For further discussion of the spatiotemporal variability of snow days on a regional to local scale, other higher spatial resolution products from MODIS or other sensors might be used. Longer records of satellite data such as from NOAA AVHRR might provide more significant long-term information on the change and variability of snow days over Switzerland although other challenges would arise. Additionally, the use of high temporal resolution data such as from geostationary satellites (e.g., Meteosat) could be of interest for the development of a combined gap-filling approach.

INTERCOMPARISON OF SATELLITE AND GROUND BASED OBSERVATIONS OF CLOUD COVER

To improve our knowledge of the role of clouds in the climate system, systematic observations of cloud cover are a prerequisite. Continuous observations over large spatial scales are uniquely provided by satellite observations. With the aim of analysing daytime cloud cover patterns over Switzerland, we generated two new cloud fraction data sets at a high spatial resolution of 0.05° (Fontana et al., subm.), based on the standard MODIS cloud mask product between 2000 and 2012 (MOD35 for MODIS onboard the Terra satellite) and between 2002 and 2012 (MYD35 for MODIS onboard the Aqua satellite). The products are based on daytime observations and represent mid-morning (Terra MODIS) and early-afternoon cloudiness conditions (Aqua MODIS) over Switzerland. An intercomparison was performed with ground based observations of cloud cover (so called Synop observations) at four sites in Switzerland (Fontana et al., subm.). Intercomparison between different data sources is required to assess the consistency between data sets. Moreover, satellite observations may be used to complement existing Synop observation networks, given the negative trend in the number of Synop observation sites.

Figure 3 displays monthly mean mid-morning cloud cover over Switzerland for January and July 2006, as derived from Terra MODIS observations. In January, high mid-morning cloud fraction is observed over the Swiss Plateau due to persistent low-level stratiform clouds, which are often observed during that time of the year. Cloud fraction in January was found to be low over the elevated topography of the Swiss Alps. In summer, this pattern is reversed, with high cloud fraction observed over the Alps.
due to convective activity. The main inner-alpine valleys, which are typically characterized by high (low) cloud fraction in winter (summer), are clearly visible.

Figure 3: Monthly mean mid-morning cloud fraction over Switzerland in January 2006 (left) and July 2006 (right). The numbers denote the four intercomparison sites (1: Chur, 2: Locarno, 3: Payerne, 4: Zurich-Kloten).

Figure 4 shows a comparison of monthly mean mid-morning cloud fraction from Synop and Terra MODIS observations at Zurich-Kloten. Even though intercomparisons of satellite and Synop observations of cloud fraction are complicated by several factors, such as differences in observation geometries and times, limitations in the portion of the sky visible to the ground observer due to surrounding elevated topography, or uncertainties in cloud detection under certain conditions for both, ground observers and satellite sensors, a good agreement was observed over the 12-year period. For Terra MODIS, a correlation coefficient $c$ of 0.972 and a bias $d$ of 0.3% was obtained. Both data sets display a distinct seasonal pattern with high cloud fraction in winter and low cloud fraction in summer. The time series also reflect cloud cover anomalies, e.g., in summer 2003, when the contrast between wintertime and summertime cloud cover was particularly strong. In the same year, above long-term average temperatures were recorded in summer in major parts of Central Europe including the European Alps (Schär et al., 2004). Results for the comparison of early-afternoon cloud fraction were similar, showing an overall good agreement between Synop and satellite observations at all sites.

Further comparative analyses with other sources of cloud fraction information over Switzerland (i.e., other satellite-derived data sets as well as automated ground based observations) is needed. However, the study demonstrated that the newly generated high spatial resolution cloud fraction data sets may play an important role in complementing the existing Synop observation network in support of the National Climate Observing System (GCOS Switzerland).

Figure 4: Time series of monthly mean mid-morning cloud fraction at Zurich-Kloten from Synop (red) and MODIS observations (black) between 2000 and 2012.
CONCLUDING REMARKS

Efficient national coordination of climate observation is essential for the global success of GCOS. In Switzerland, it is the Swiss GCOS Office at MeteoSwiss that coordinates all climate relevant measurements. Activities include, among others, enabling activities in the area of satellite-based Earth observation, which aim at promoting the use of satellite data as a complement to existing traditional measurement networks.

Various Swiss institutions are involved in national and international projects on the generation of satellite-based data sets of ECVs. In collaboration with the Swiss GCOS Office, time series of LWST are generated at the University of Bern and validated with in-situ measurements. Another project in collaboration with the ETH Zurich focuses on the geometric accuracy of FCDRs from SEVIRI, AVHRR, and MODIS, to ensure that accuracy requirements as defined in the GCOS IP are met in satellite-based climate products over Switzerland.

Comparative studies of satellite- and ground-based observations in the atmospheric (i.e., cloud fraction) and terrestrial domain (i.e., snow cover) have demonstrated the potential value of satellite data for the National Climate Observing System (GCOS Switzerland). Good agreements between the different data sources indicate that high-quality climate products may be generated through a combination of various observation techniques. Accordingly, the Swiss GCOS Office will continue to promote satellite-based data for climatological analyses in Switzerland.

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