SATELLITE-BASED CLIMATE PRODUCTS FOR ALPINE STUDIES WITHIN THE SWISS GCOS ACTIVITIES

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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 has the task of coordinating all climate relevant measurements in Switzerland. These include observations of both the atmospheric and terrestrial domain. In 2007, the Swiss GCOS Office published the first complete inventory of Swiss climate measurement series. The report also includes an assessment of the sustainability of these long-term climatological data series as well as of the international data centres hosted by Switzerland.

Satellite data contribute to the determination of atmospheric and terrestrial Essential Climate Variables (ECV) for Switzerland. Although satellite data have a relatively short data record compared to in-situ time series, they provide essential complementary information for various applications in the fields of climate monitoring. This paper presents existing satellite-based atmospheric and terrestrial products for climate monitoring in Switzerland and gives an outlook on future opportunities.

1. INTRODUCTION

In recent decades, observations of climate and climate change have become increasingly important. GCOS was established in 1992 to ensure that the observations necessary to address climate-related issues are defined, obtained and made available to potential users. In 2004, a 10-year GCOS Implementation Plan was compiled in support of the UNFCCC (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. It includes the definition of a set of Essential Climate Variables (ECVs) covering the entire climate system, such as the atmospheric, oceanic and terrestrial domain. Actions on satellite-based observations were explicitly described in the so-called ‘Satellite Supplement’ (WMO, 2006) of the Implementation Plan. The Committee on Earth Observation Satellites (CEOS) responded in 2006 to the GCOS Implementation Plan (CEOS, 2006).

Switzerland has a long tradition of climate observation, ranging from temperature and precipitation series of more than 150 years to glacier measurements since the end of the 19th century. Climate relevant measurements are coordinated by the Swiss GCOS Office at the Federal Office of Meteorology and Climatology MeteoSwiss. The first complete inventory of Swiss climate measurement series, compiled in 2007, also assess the future prospects of climate measurement series (Seiz and Foppa, 2007). Furthermore, the Swiss GCOS Office fosters the exploration of new measurement techniques and methods, in particular through the use of data obtained from Earth observation systems, to improve long-term monitoring of ECVs in Switzerland. Satellite data provide comprehensive and objective information about different climate variables and are therefore a suitable complement to ground based measurements.

This paper presents the applications of various satellite-based products of different ECVs across the terrestrial as well as the atmospheric domain and gives an overview of ECVs with a prospectively high potential for space-based climatology in Switzerland. For each investigated ECV an overview of global achievements in the field of satellite-based climatology is given, followed by preliminary case studies that include Earth observation data from various satellite sensors. This data is derived from global products and apportioned to the regional scale of Switzerland.

2. ATMOSPHERIC DOMAIN

Various ECVs from the atmospheric domain depend upon, or significantly benefit from, satellite observations. The most important systematic observations concern the surface and upper air climate, Earth radiation budget, water vapour, atmospheric trace gases, aerosols and pollen. The application of space-based information of those ECVs strongly depends on the variable's requirements for the satellite's and sensor's characteristics, as well as on sustained, overlapping and continuous coverage. While Earth observation data of certain ECVs already complement in-situ observations (cloud cover, radiation) to a satisfying degree, others show great potential but are yet to be postponed for the next generations of satellite sensors. In the following part, results from a first retrieval of cloud coverage and radiation from earth-observation data over Switzerland are shown.

Clouds

Clouds play an essential role in the Earth's radiative energy balance and hydrological cycle. Efforts have been made during the last years to generate homogeneous and continuous long term cloud information for climate studies. On a global scale, the results of the WCRP International Satellite Cloud Climatology Project (ISCCP) represent the most comprehensive cloud climatology analysis based on satellite data collected since 1983, which will be re-processed in the near future (Schiffer et al., 1983; Rossow et al., 2004). On a continental scale, the European Cloud Climatology (ECC) project has evaluated data from the NOAA Advanced Very High Resolution Radiometer (AVHRR) for the period of 1983-2003 across Europe (Meerkötter et al., 2004).

Atmospheric products such as the cloud cover fraction derived from the 36-channel MODerate resolution Imaging Spectroradiometer (MODIS) onboard Terra and Aqua have been delivering information on the Earth's atmosphere for a period of eight years. MODIS on Terra was launched in late 1999 with data stream beginning in late February 2000, followed by Aqua in May 2002. MODIS features spectral and spatial resolution in key atmospheric bands in order to expand the capability to globally retrieve cloud properties. The MODIS atmosphere products are archived into two categories: level-2 products (pixel-level retrievals) and level-3 products, which contain statistical datasets from the level-2 products, summarized over a 1°x1° global equal-angle grid for daily, eight-day and monthly temporal periods.

To assess the usability of cloud coverage from satellite sensors for Swiss-wide climate studies, the level-3 parameter 'Cloud Fraction' from MODIS onboard the Terra spacecraft was analysed on a monthly base. Geographical boundaries from 46°N to 48°N and from 6°E to 10°E were applied to the global product, covering the area of Switzerland. It is widely known that the Alps, acting as a 'natural barrier', influence large-scale weather systems and trigger local mountainous phenomena. Thus, the largest differences in weather and climate occur between the northern and southern part of Switzerland. It was therefore chosen to compare the cloud fraction of the alpine and south alpine region with the corresponding cloud coverage of the lowland region. The resulting time series covers the period from March 2000 to June 2008 (Figure 1). In evidence is the annual fluctuation of the cloud fraction. A comparison between alpine and lowland region shows that during the winter months cloud coverage has always been higher for the lowland region than for the alpine and south alpine region, especially in December and January. This distinctive feature corresponds well with prevalent weather conditions for the considered time period, measured at various ground stations across Switzerland (Reports on Atmospheric Conditions, MeteoSwiss Archive). The extreme hot and dry summer of 2003 is reflected in a remarkably low cloud coverage, which is in concordance with results from the ECC (Meerkoetter et al., 2004). Also noteworthy is the exceptionally sparse cloud coverage in April 2007.

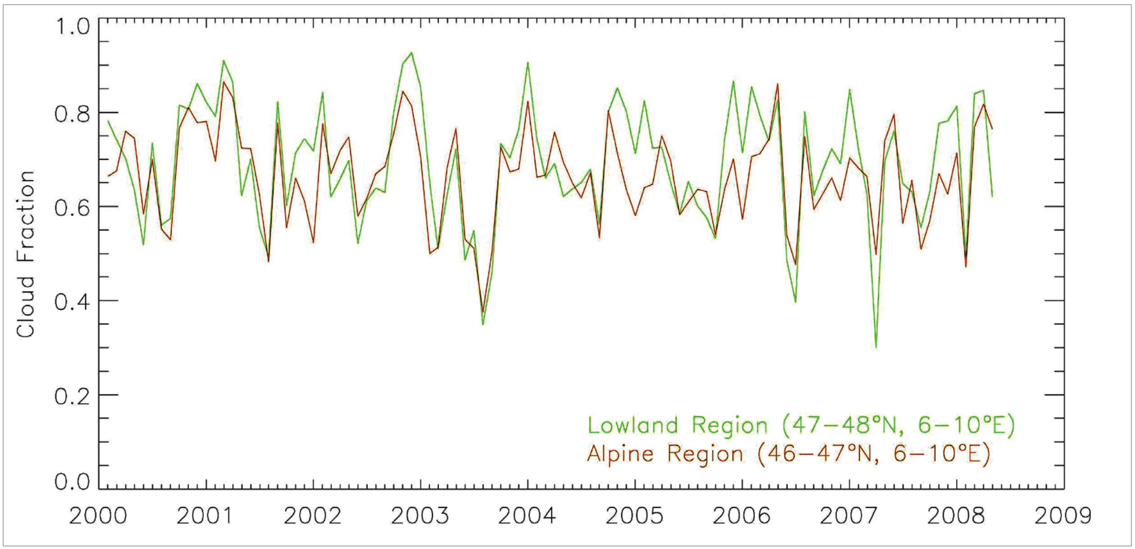

***Figure 1*: Time series of the Cloud Fraction over Switzerland for the alpine and lowland Region.**

Radiation

The Earth's radiation budget is greatly influenced by surface conditions and atmospheric properties, and therefore directly reflects changes in the climate system. Hence, determining and understanding radiation fluxes is essential to atmospheric modelling and climate studies. The Eumetsat Satellite Application Facilities for Climate Monitoring (CM-SAF), a joint project involving several European meteorological services, has the objective to monitor climate variables, such as radiation, using satellite data. A variety of radiation products is derived from European satellite data, notably Meteosat Second Generation (MSG), and validated specifically for the alpine region, which is distinguished by its rather disparate surface conditions and radiative climates (Dürr and Zelenka, 2008).

In order to account for the alpine terrain of Switzerland, Dürr and Zelenka (2008) adapted the existing HELIOSAT-algorithm (Cano et al., 1986; Beyer et al., 1996, Hammer et al., 2003), which converts reflectance measured by the 'visible' channel of Meteosat to global radiation at the ground, by implementing a highly sensitive snow detection algorithm in combination with an algorithm for cloud detection over snow-covered areas. Furthermore, a precise georeferencing, orthorectification and normalization with respect to the sun zenith angle of the alpine region were crucial to obviate systematic errors that are apparently caused by mountainous terrain. The results obtained from this enhanced algorithm now provide a sound basis for long-term climate studies of the alpine radiation budget.

3. TERRESTRIAL DOMAIN

The terrestrial domain is subdivided into biosphere, cryosphere and hydrosphere. These sub-systems of the climate system include individual ECVs whose characterization, observation and monitoring strongly benefit from large and small scale satellite coverage. Others, notably permafrost, ground water, river discharge or water use, do not qualify for investigation with orbital data and, hence require new measurement techniques and better spatial resolution than today's sensors provide.

Snow cover

In addition to playing a key role in the climate system, snow cover is a vital economic factor in sectors such as tourism, water management, hydropower, agriculture and transport. Satellite systems such as MODIS, MERIS and NOAA AVHRR deliver space-borne information on snow cover extent: particularly NOAA AVHRR provides operational and near real-time data to determine the snow cover extent over the European Alps (Foppa et al., 2007). Furthermore, geostationary Meteosat Second Generation offers very high temporal information on snow area extent, which is generated in near real-time by the Federal Office of Meteorology and Climatology MeteoSwiss for assimilation in the mesoscale NWP model COSMO (De Ruyter de Wildt et al., 2007). This product has been used for pilot studies on snow cover climatology for Europe within the Swiss GCOS activities at MeteoSwiss (Seiz et al., 2007). The implemented near real-time snow cover mapping algorithm allows the construction of a running composite snow map, which for each pixel always displays the most recent cloud-free situation. This means that in the running composite, all pixels are cloud-free and that the time of last update varies per pixel. Figure 2 shows the extracted mean snow cover amount over Europe derived from all land-based pixels in the running composite snow map for the three winters 2005/06, 2006/07 and 2007/08. It is obvious that all three winters were variable in terms of snow cover amount showing differences in the evolution of the main accumulation and ablation period. Data gaps mainly result from missing data in the real-time processing of Meteosat SEVIRI data.

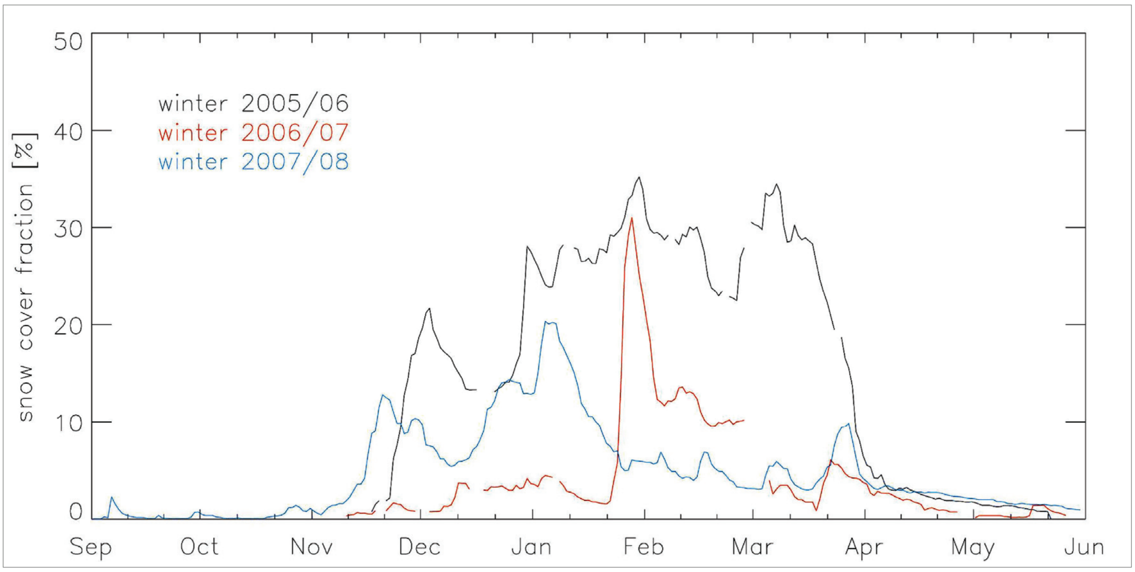

***Figure 2*: Snow cover extent over Europe for the winters 2005/06, 2006/07 and 2007/08.**

Glaciers

The predominantly negative mass balance of Alpine glaciers over the past 25 years is one of the clearest signals of a significant increase in the Earth's surface temperature. Multi-spectral satellite data provide a sound basis for glacier inventories on a regional and global scale in order to describe and monitor the development of glaciers around the world. In response to the demands defined in the GCOS Implementation Plan (WMO, 2004) and the CEOS Response to the GCOS Implementation Plan (CEOS, 2006), the European Space Agency (ESA) initiated the GlobGlacier project within its Data User Element (DUE) programme. GlobGlacier aims to combine well established techniques for mapping glacier snow lines and indicators for mass balances with archived satellite data from existing databases (World Glacier Inventory, World Glacier Monitoring Service WGMS), including optical (ASTER/SPOT) as well as interferometric SAR data (e.g. from ERS1/2) (Paul et al., 2008). Based on these satellite data and the subsequent derivation of inventory data using Geographical Information Systems (GIS), the automatic glacier classification algorithms are also applied worldwide, e.g. in the Global Land Ice Measurements from Space (GLIMS) initiative (Bishop et al., 2004). Long time series of volume changes provide a valuable data set for combining mass balance models with remote sensing data for spatio-temporal extrapolation of isolated measurements.

Vegetation

Time series of satellite-derived vegetation parameters such as the absorbed photosynthetically active radiation estimates (fAPAR), the leaf area index (LAI) and the normalized difference vegetation index (NDVI) are used in various climate studies for Switzerland (Jolly et al., 2005; Stöckli and Vidale, 2004). Data records from AVHRR on board the NOAA platforms provide long-term series. With the launch of

MetOp, the series will extend to a unique historical time series of over thirty years. But despite the long-term data series, caution is advised when using AVHRR NDVI data for vegetation analyses as there are a number of spatial, temporal and radiometric problems in the data (calibration, aerosols, viewing geometry). The 8 km bi-monthly AVHRR NDVI product of the Global Inventory Modelling and Mapping Studies (GIMMS) accounts for varying solar zenith angles due to the orbital drift of the afternoon NOAA platforms (Pinzon et al., 2005; Tucker et al., 2005). The preference of the GIMMS NDVI data sets over other (e.g. Pathfinder AVHRR Land PAL) data is motivated by the correction of different effects not related to vegetation changes (Fensholt et al., 2006) concluded from their inter-comparison study that the accuracy of the AVHRR GIMMS NDVI is higher than the AVHRR PAL NDVI and, consequently, GIMMS NDVI should be used for analyses of long-term trends in regional or continental scale NDVI. Figure 3 shows the time series of the NOAA AVHRR GIMMS NDVI for the European Alps (40N – 50N / 0E -20E) from 1981-2006. Interannual and seasonal variability of the vegetation are represented by monthly means of spatial averaged NDVI data for three selected months (April, August, November).

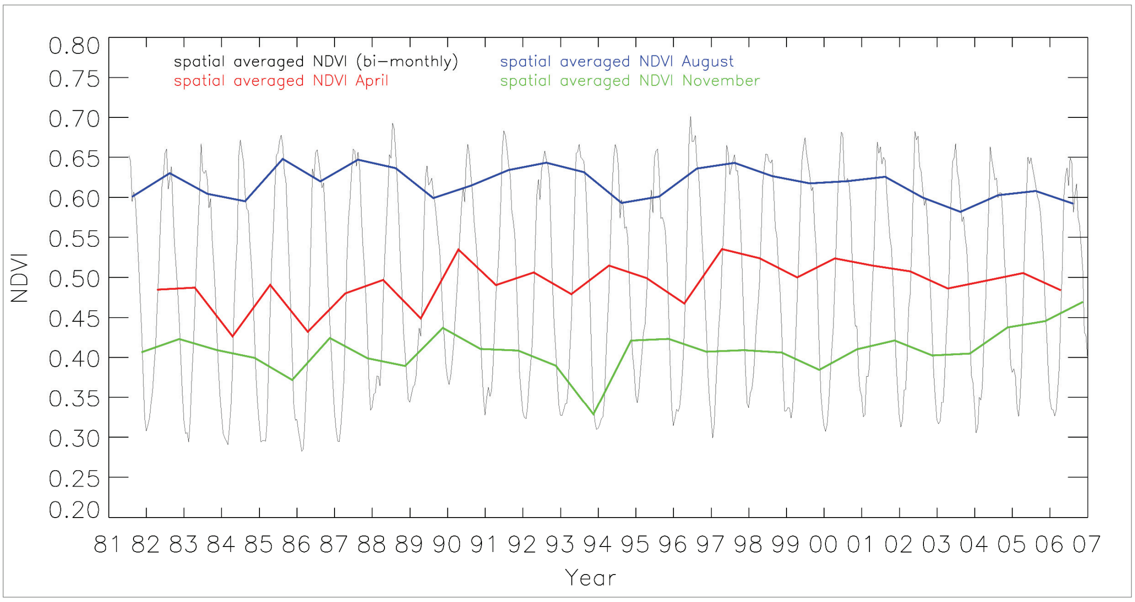

***Figure 3*: Changes in NDVI for the European Alps 1981-2006 based on NOAA AVHRR GIMMS data.**

Fire disturbance

Fire is a major agent of environmental change due to its driving force in land cover modification and its contribution to greenhouse gas emissions. Its quantification is therefore important for the ongoing study of climate change, which may affect the regional forest fire risk in Switzerland.

For a decade, ESA's satellites ERS-2 and Envisat have been continuously surveying fires burning across the Earth's surface. Fire maps for the entire globe based on this data are now available online in near real-time through ESA's ATSR World Fire Atlas (Arino et al., 2005). The data are based on results from the Along Track Scanning Radiometer (ATSR) onboard ESA's ERS-2 satellite, launched in 1995, and the Advanced Along Track Scanning Radiometer (AATSR) on ESA's Envisat, launched in 2002. This resource is the first multi-year global fire atlas ever developed and provides data approximately six hours after acquisition. The maps are generated monthly and cover the time period from September 1995 to present. In addition to the fire atlas, MODIS onboard NASA's Terra and Aqua satellites provides the Active Fire Product (i.e. MOD 14), which is a 1 km gridded global composite of pixels each assigned to a fire mask class (Justice et al., 2002).

Figure 4 shows the result of the MOD 14 Fire Product for Switzerland. The extraordinarily hot summer months of 2003 have become manifest in a remarkably high and broad peak of pixels detected and classified as fire. However, this product reflects the effective area of burning landmass, not the number of occurrences. Comparison with yearly statistics of the database on forest fires (Conedera et al., 1996) should therefore be made with caution.

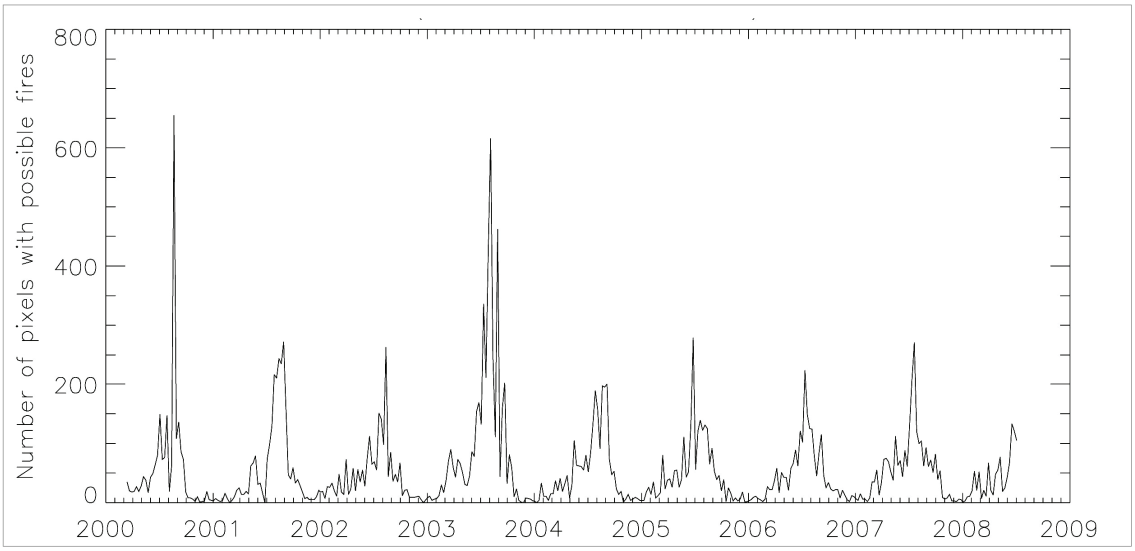

Figure 4: **Number of fire pixels for the time period of 2000 – 2008.**

4. CONCLUSIONS AND OUTLOOK

The presented examples have shown first results of satellite-derived atmospheric and terrestrial ECVs for climate studies in Switzerland. Even though the employed data products were developed for applications at a global scale, the examples have demonstrated that they can be adapted to the regional scale of Switzerland. The resulting time series of different ECVs provide the possibility of complementing long-term measurement series from ground-based stations in Switzerland. Therefore, the continuity of Earth Observation programmes of the corresponding sensors is vital to guarantee measurements of sufficient length. An adequate and periodical reprocessing of the long-term data sets is essential to provide consistent climate data records for regional applications. Initiatives such as the Global Space-based Inter-Calibration System (GSICS) play an important role in making long-term data records from satellite observations suitable for climate analysis.

Archived data sets and existing algorithms developed for near real-time use over Switzerland represent an interesting potential for future climate studies (e.g. near real-time aerosol optical depth maps for Switzerland based on Meteosat SEVIRI). Additionally, the high quality ground-based observations of various ECVs hold great potential for extensive calibration and validation studies over Switzerland (e.g. Dobson/Brewer ozone measurements, soundings and ground-based remote sensing data).

The future promises continuous progress in sensor development, which will open new possibilities for ECV data products. Switzerland, with its many unique observation systems and climate records, can thereby advance the integration of satellite data into comprehensive climate data records. The Swiss GCOS Office strives to foster the link between satellite-based products of ECVs with long-term in-situ observations from various Swiss institutions to generate integrated climate data products for Switzerland.

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