USE OF SATELLITE-BASED PRODUCTS WITHIN THE NATIONAL CLIMATE OBSERVING SYSTEM (GCOS 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 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.

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. This helps to improve the monitoring of so-called Essential Climate Variables and to link satellite-based products with long-term in-situ observations from various Swiss institutions to generate integrated climate data products for Switzerland. In this paper, the use of different satellite derived products is presented for climatological pilot studies of the atmospheric and terrestrial domain in Switzerland.

1. ATMOSPHERIC DOMAIN

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 assesses the future prospects of climate measurement series (Seiz and Foppa, 2007). Furthermore, the 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 (Seiz et al., 2007; Foppa et al., 2008; MeteoSwiss, 2008).

In this paper, we present preliminary results of long-term satellite-based data series over Switzerland in comparison to ground-based observations, for the ECVs cloud cover, snow and fire disturbance. These three pilot studies provide valuable information on the usability of global satellite products for climatological analysis in Switzerland, to complement the existing long-term, high-quality ground-based observations.

2. ATMOSPHERIC DOMAIN

The atmospheric domain includes ECVs of (a) the near surface, (b) the upper air atmosphere, and (c) the atmospheric composition. Atmospheric observations from space have evolved significantly over the last decades thanks in part to new measurement techniques (e.g. sounders, microwave scatterometers, limb-viewing measurements, lidar) (CEOS, 2006). However, some of them are not yet transitioned to operational missions or measurements are not adequate enough to generate long-term climate data records to use for climate trend analysis.

Cloud cover

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). Furthermore, the EUMETSAT Satellite Application Facility on Climate Monitoring (CM-SAF) provides – among other products - various cloud products from NOAA AVHRR and MSG SEVIRI over Europe for the period 2004-present (Schulz et al., 2009).

Atmospheric products have also been derived from the 36-channel MODerate resolution Imaging Spectroradiometer (MODIS) onboard Terra and Aqua since more than eight years (King et al., 2003). 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 (King et al., 2003; Platnick et al., 2003): pixel-level retrievals (Level-2 products) and global gridded statistics at a resolution of 1° (Level-3 products). The Level-2 MODIS Cloud Mask product (MOD35) is a daily, global product generated at 1km and 250m spatial resolution, which is then applied to the Level-2 MODIS Cloud Product (MOD06) to screen for clouds. This product combines infrared and visible techniques to determine both physical and radiative cloud properties. The Level-3 Atmosphere Products (e.g. MOD08) contain statistical datasets from the Level-2 products, summarized over a 1° by 1° global equal-angle grid. The Level-3 product derived from Cloud Mask related data (MOD35) is actually read from the cloud product (MOD06), therefore the Level-2 Cloud Mask (MOD35) is never read (directly) into Level-3 (Hubanks et al., 2008). The Level-3 products are temporally aggregated into daily, eight-day and monthly files.

To assess the usability of cloud coverage from satellite sensors for Swiss climatological studies, the Level-3 parameter ‘Monthly Cloud Fraction’ from MODIS onboard Terra (i.e. MOD08 product) and Aqua (i.e. MYD08 product) was analysed for the area over the MeteoSwiss GCOS Upper Air Network (GUAN) station Payerne (6°56’E, 46°48’N). The data used were from MODIS Collection 5 (C5) (Hubanks et al., 2008). The MODIS monthly timeseries (MOD08/ MYD08 pixel with Payerne) from March 2000 to December 2008 were then compared to another satellite-based data set (i.e. CM-SAF) as well as to monthly means of ground-based cloud observations (Synop) from Payerne. For the comparison, a 3x3 box average, centred at Payerne, of the CM-SAF monthly cloud cover product (March 2005 to December 2008; 15 x 15 km spatial resolution; day and night) was used. The monthly Synop Payerne timeseries are based on synoptic observations made every three hours by a local observer and given in octas (0 octas = clear sky, 8 octas = fully covered sky). Figure 1 shows the intercomparison of MODIS Terra (Day&Night), MODIS Aqua (Day&Night), MODIS Terra (Day), MODIS Terra (Night), CM-SAF (3x3 box average) and Synop Payerne for the period March 2000 to December 2008.

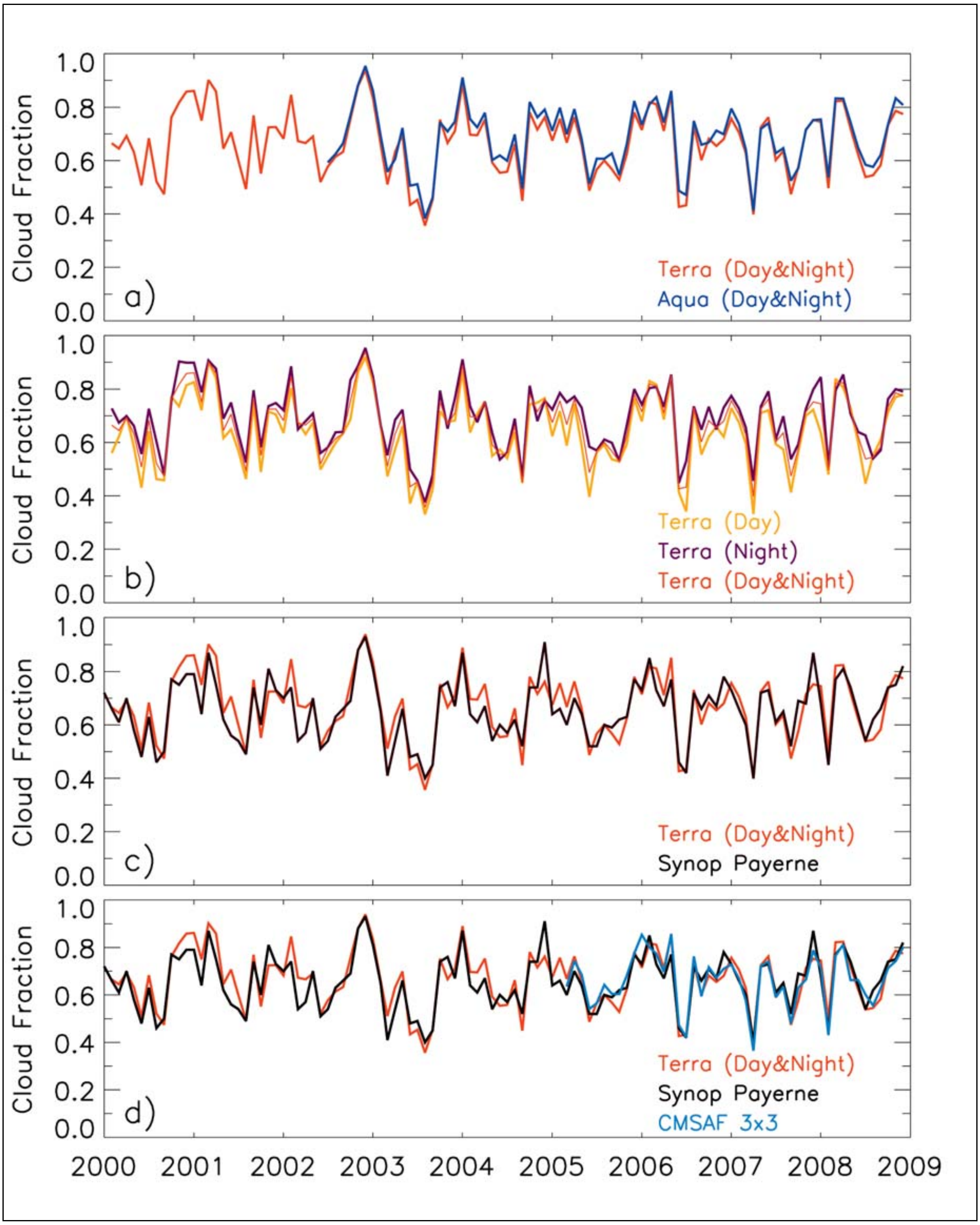

***Figure 1*: Comparison of MODIS Terra (MOD08) and Aqua (MYD08) cloud fraction product with the CM-SAF cloud fraction product and ground-based synop observations. a) MOD08_Day&Night vs. MYD08_Day&Night, b) MOD08_Day&Night vs. MYD08_Day&Night, c) MOD08_Day&Night vs. Synop Payerne, and d) MOD08_Day&Night vs. CM-SAF 3x3 box average vs. Synop Payerne.**

In general, there is a very good agreement between the MODIS cloud fraction product derived from Terra (i.e. MOD08) and Aqua (i.e. MYD08) (Figure 1a), with Aqua being slightly higher throughout the year. This small difference can be attributed to the time of satellite overpass. The effect of the diurnal cycle is also reflected in the comparison of the MOD08 Day_only with the MOD08_Night_only product (Figure 1b). Again, the two timeseries are consistent with each other, with the night values slightly higher than the day values. This day-night difference is also described in Kotarba (2009).

Furthermore, there is a good agreement of the MODIS Terra cloud fraction product with the Synop Payerne data (Figure 1c). In general, satellite-based cloud cover algorithms tend to overestimate cloud coverage with respect to ground-based synop observations. For example, Kotarba (2009) describes a higher cloud coverage from MODIS of about 4% in summer and 7% in winter when compared to synoptic cloud observations. CM-SAF cloud fractional cover also tends to overestimate the actual cloud fraction due to the binary cloud mask algorithm (Schulz et al., 2009). This slight overestimation is also visible in our results – the effect seems however to be averaged out in the Day&Night product and on this coarse spatial resolution. The differences between satellite-based data and ground-based observations will be further evaluated by additionally analyzing the higher resolution MODIS MOD06 cloud fraction product.

Finally, the CM-SAF timeseries agree very well with the MODIS Terra and Synop Payerne data (Fig 1d). Again, there are larger differences in some of the monthly values (eg. early 2006) which will be further evaluated by analyzing the higher resolution MOD06 cloud fraction product, as well as the effect of the time difference between the satellite overpass time and the synop observation times. As further ground-based comparison data, Partial Cloud Amount (PCA) timeseries estimated by the APCADA algorithm (Automated Partial Cloud Amount Detection Algorithm) (Dürr and Philipona, 2004; Ruckstuhl and Philipona, 2008) will be used in our cloud cover analysis. The PCA is thereby calculated every 10 minutes, based on longwave downward radiation, temperature and relative humidity measurements at specific radiation stations in Switzerland.

3. TERRESTRIAL DOMAIN

The terrestrial domain is subdivided into the (a) hydrosphere, (b) cryosphere, and (c) biosphere. Considerable improvements in the quality of terrestrial satellite-based products have been achieved over the last years (CEOS, 2006). Advances mean that these sub-systems can be observed and characterized systematically using satellite information. Individual ECVs, notably permafrost, ground water, river discharge or water use, do not qualify for investigation with space-borne data and, hence require new measurement techniques and better spatial resolution than today's sensors are able to 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 continental Europe derived from all land-based pixels in the running composite snow map for the four winters from 2005 to 2009. It is obvious that all four 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. An upcoming reprocessing of the SEVIRI data set for the entire period with a focus on the Swiss Alps will certainly highlight snow cover changes at the regional scale. The pre-operational LandSAF snow cover product based on MSG/SEVIRI will provide valuable information for further intercomparison studies.

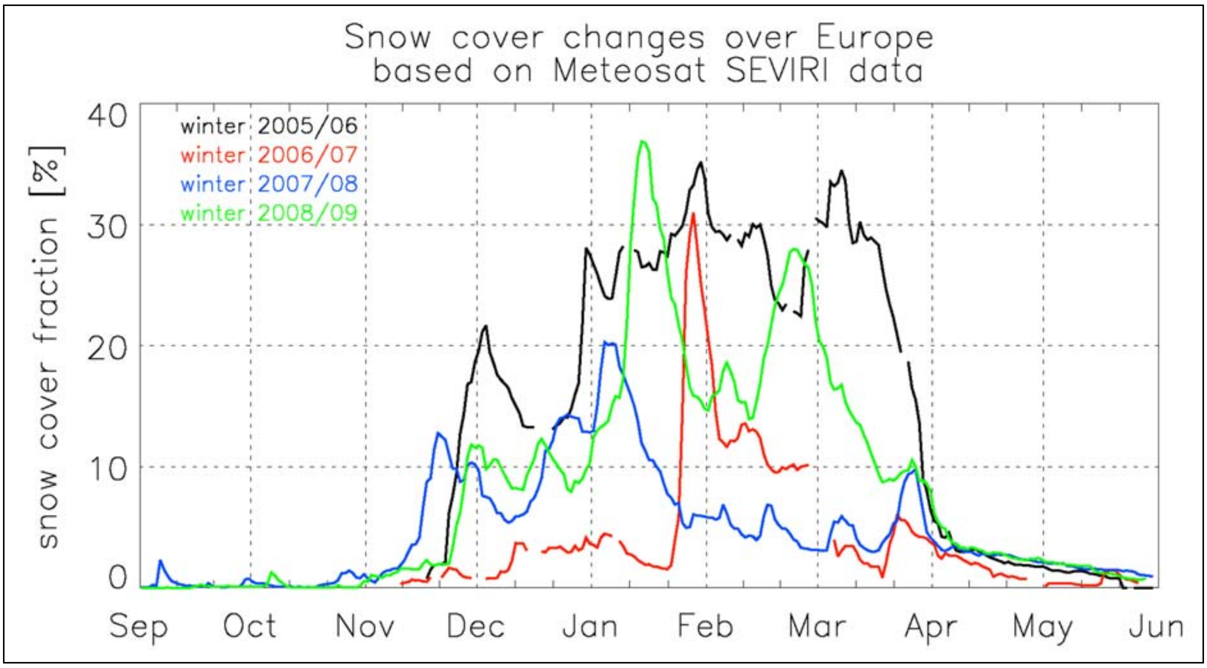

***Figure 2*: Snow cover extent over Europe for the winters 2005/06, 2006/07, 2007/08 and 2008/09.**

Fire disturbance

The emissions of greenhouse gases and aerosols from fires are important climate forcing factors and are therefore essential for modelling of the climate system and its global carbon cycle. Fire activity is an indicator of land cover and land use change affecting the ecosystem. In regions where the fire regime is climate-driven, climate variability and change may have already caused changes in fire activity. The GCOS fire disturbance ECV consists of burnt-area maps and active fires. Satellite sensors can monitor global fire patterns and have increased the understanding of fire emissions, land use change, and fire risk (Hawbaker et al., 2008). Major long-term global records of active fires have been generated by ESA (ATSR World Fire Atlas) and NASA (TRMM and MODIS). Geostationary fire monitoring has been undertaken using MSG SEVIRI (EUMETSAT Active Fire Monitoring FIR) and GOES (Wildfire Automated Biomass Burning Algorithm WF-ABBA).

In our pilot study, we focus on the MODIS active fire global product based on a contextual algorithm (Giglio et al. 2003, 2006). The fire detection rates are compared between the two sensors (i.e. MODIS sensor onboard Terra and Aqua, respectively) and ground-based fire statistics for the southern part of the Swiss Alps for the period 2000 to 2008. The MODIS Terra and Aqua 8-day fire-mask composite product (MOD14A2, MYD14A2) at 1-kilometer resolution (version 5) acquired from NASA's Warehouse Inventory Search Tool (WIST) was used. Ground-based observations of forest fires and forest fire statistics are made available through a Swiss national database. This forest fire database in Switzerland provides data from several cantons and will be upgraded in the near future to allocate systematically recorded, harmonised and coherent forest fire statistics from all cantons in Switzerland (see http://www.wsl.ch/swissfire/index_EN). In the presented comparison, the ground-based statistics is based on several cantons with a total area approximately 15% smaller than the area of the MODIS data (MODIS data area: 45.8°N-46.8°N, 7.0°E-10.5°E). Due to the similar fire characteristics and fire regime, the presented comparison seems to be adequate for this preliminary study (personal communication M. Conedera).

Figure 3 shows the frequency of monthly forest fires according to their size based on in-situ observations and compared to (a) Terra and (b) Aqua (August 2003 onwards). For the analysis, all MODIS active fires of medium and high confidence classes based on the products definition (Giglio et al., 2003) were included. In the Alps, lightning-induced fires occur from May to October with a peak in July-August (Conedera et al., 2006). The fire seasonality shows another major peak in March-April when certain regions are affected by strong foehn winds (Zumbrunnen et al., 2009). For the time period 2000-2008, 80% of all fires are smaller than 1ha and only 5% larger than 10ha. The hot and drought period in summer 2003 caused a large number of forest fires and a high frequency of forest fires detected by Terra and Aqua. However, MODIS Aqua detects 15% more fires than Terra for the period 2003 to 2008. The difference in the detection rates between the two MODIS sensors might be related to their different overpass times (Hawbaker et al., 2008). Fire activity often peaks in the afternoon when weather conditions are most favorable for burning (Giglio, 2007) and Aqua's afternoon (13:30 UTC) overpass is closer to this peak. Other factors such as dense forest, dense smoke and cloud cover might influence the fire detection by MODIS (Csiszar et al., 2006). An accurate validation of the product is therefore required including studies on errors of commission and omission to interpret the MODIS active fire product over the Alps (Schroeder et al, 2008). This requires an accurate definition and congruent dimension of the area of interest for both data sources. The growing Swiss forest fire database can make a valuable contribution in understanding satellite-based fire products. On an international level, validation protocols and standards are planned under the CEOS Working Group on Land Product Validation in collaboration with the GOFC/GOLD (Global Observations of Forest and Land Cover Dynamics) technical panel of the Global Terrestrial Observing System (GTOS).

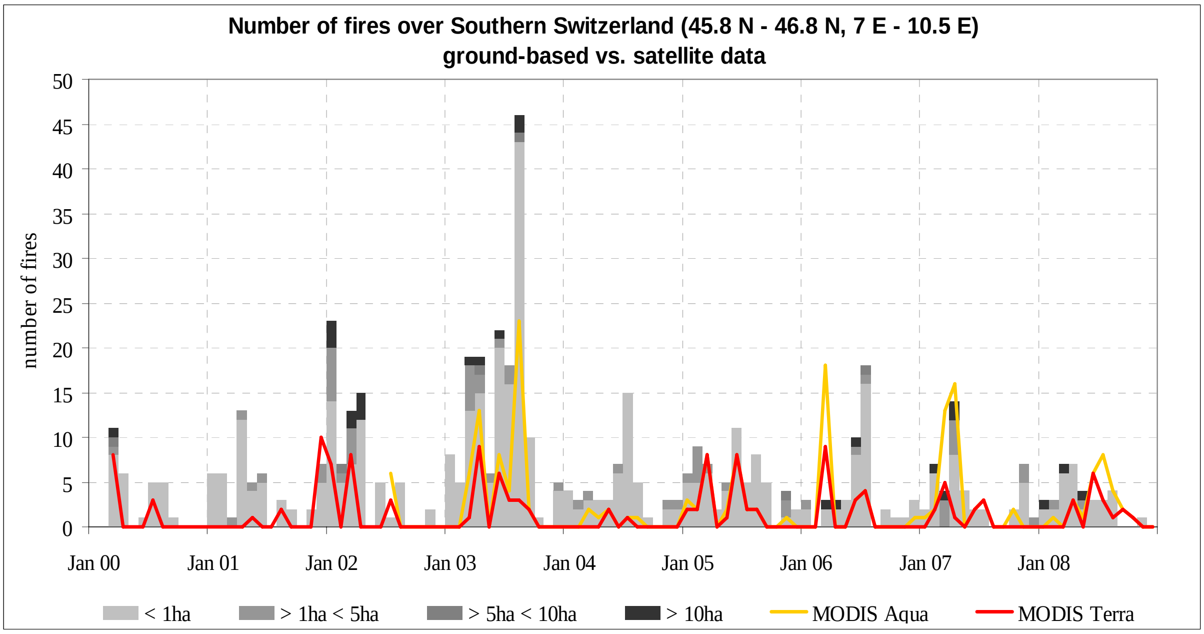

Figure 3: **Monthly fire counts detected by the MODIS Aqua and Terra and compared to ground-based fire statistics collected in Southern Switzerland.**

4. CONCLUSIONS AND OUTLOOK

The presented examples have shown first results of the use of satellite-derived atmospheric and terrestrial ECVs for climate studies in Switzerland. Even though the data products were mostly developed for applications at a global scale, the examples demonstrate that the products can also be used on 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 homogeneous 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 supporting the generation of long-term data records from satellite observations for climate analysis. In this respect, it is also important to stress the necessity of a thorough assessment of the error bars for the different satellite-based products.

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

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