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Intercomparison of satellite- and ground-based cloud fraction over Switzerland (2000–2012)

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ABSTRACT

Satellite data provide the opportunity for systematic and continuous observation of cloud cover over large spatial scales. In this paper, we describe the generation of 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 clearly reflected seasonal variations in cloud fraction over Switzerland. A comparison with cloud fraction observations at four Synop stations (Chur, Locarno/Monti, Payerne, Zurich/Kloten) revealed an agreement of monthly mean mid-morning cloud fraction (MMCF) within ±1 octa (i.e., 12.5%). Relative to Synop observations, MMCF was positively biased by 0.3–5.0%, except at Payerne (−2.5%). Linear correlation coefficients ranged from 0.878 to 0.972. Results were similar for monthly mean early-afternoon cloud fraction (MACF). Cloud fraction was found to be higher in the early-afternoon when compared to mid-morning, except at Payerne and Zurich/Kloten in fall, which is explained by typical daytime cloud cover patterns in Switzerland. Analysis of daily mid-morning cloud fraction showed that largest discrepancies were observed in partly cloudy conditions, which is mainly explained by differences in observation times and observation geometry. Our results demonstrate that the newly processed cloud fraction data sets from the MODIS sensor can play an important role in complementing traditional Synop observations in support of systematic cloud cover monitoring within the National Climate Observing System (GCOS Switzerland).

1. Introduction

Clouds modulate the Earth's radiation budget through a complex system of feedbacks and thereby play an important role in the terrestrial climate system (Trenberth et al., 2007). As a result, in the context of climate change there has been increasing interest in the determination of cloud cover and its spatial and temporal variability. Recognizing the importance, the Global Climate Observing System (GCOS) has defined cloud properties as an Essential Climate Variable (ECV) in its Implementation Plan (IP) for climate observation (WMO, 2004, 2010) to ensure that clouds are observed systematically and continuously.

Traditionally, cloud cover is observed from the ground by human observers. In Switzerland, a network of these so-called Synop observations is available with data records dating back to the 19th century at some locations and has been used in long-term studies on cloud cover (Auer et al., 2007). However, Synop observations suffer from a number of limitations, e.g., they may contain inconsistencies due to changes in observation location and time and be subject to observer biases (Begert et al., 2007). In addition, Synop

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observations are constrained to the location of the observer and their value for climatological studies in a given region critically depends on the density of the observation network. This is especially true for spatially heterogeneous areas such as Switzerland due to the complex topography, with climatic conditions rapidly changing over small horizontal scales. Finally, the continuity of surface observation networks of cloud cover is at risk, as stated in the recent update to the GCOS IP (WMO, 2010).

Spaceborne observations provide the opportunity to obtain continuous and spatially integrated information on cloud cover, based on the analysis of the spectral signature within the field of view of a given satellite sensor. The usefulness of a satellite sensor for cloud detection thereby critically depends on its spectral characteristics, given that specific spectral bands are required to discriminate clouds from different land surface types, e.g., snow cover. Over the recent decades, satellite observations have become increasingly important and are recognized as an important means to complement traditional ground-based observations within GCOS (WMO, 2006, 2011).

When using satellite-based data of cloud cover, characteristics of the underlying satellite (i.e., polar-orbiting vs. geostationary Earth orbit) as well as sensor specifications (e.g., spectral, spatial, or temporal resolution) need to be considered carefully. For example, sensors onboard geostationary satellites, such as the Spinning Enhanced Visible and Infrared Imager (SEVIRI) carried by the satellites of the Meteosat Second Generation (MSG) series, typically offer frequent temporal sampling of the Earth's full disk and enable the detection of the diurnal cycle of cloud cover (Derrien and Le Gleau, 2005); however, information on the polar regions is limited due to the observation angles increasing at high latitudes. In contrast, sensors onboard polar-orbiting satellites, such as the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the Terra and Aqua satellites, provide daily global coverage at higher spatial resolution, but at the expense of a lower temporal resolution (up to four daytime overpasses over Switzerland in the case of MODIS). In addition, data availability is of key importance. For instance, while the Advanced Very High Resolution Radiometer (AVHRR) has been in orbit for more than three decades and provides unique global information for climatological analyses of cloud cover, MODIS data have only been available since 2000. However, MODIS is a newer generation satellite sensor compared to AVHRR and offers improved cloud detection capabilities due to better spectral coverage (Salomonson et al., 1989), as well as better calibration and geometry (Xiong and Barnes, 2006).

Today, cloud cover data records derived from various satellite sensors and covering time periods of at least one decade exist and have successfully been used in climatological studies at various spatial scales (Rossow and Schiffer, 1999; Stowe et al., 2002; Karlsson, 2003; Kotarba, 2009), including the area covering the European Alps (Kästner and Kriebel, 2001).

Intercomparison of different satellite-based data sets as well as intercomparison with ground-based observations is, however, required to ensure consistency between the data sets (Stubenrauch et al., 2012). Kästner et al. (2004) compared monthly mean daytime cloud cover from the Advanced Very High Resolution Radiometer (AVHRR) Alpine Cloud Climatology (ACC) data set at 15 km spatial resolution with Synop observations in Central Europe and described a good agreement between both data sets. The same study highlighted the high spatial variability of cloud cover in the European Alps. Meerkötter et al. (2004) presented the European Cloud Climatology (ECC) based on AVHRR data at 1 km spatial resolution and performed a comparison with Synop data in several regions of interest (ROI), including the European Alps. Overall, a good agreement within the limits of one octa (12.5% cloud cover) was observed, with linear correlation coefficients in the order of 0.8. However, the study compared cloud fraction averaged over the entire ROI, neglecting small scale variations in cloud cover. A comparison of the MODIS cloud product with lidar observations (Ackerman et al., 2008) revealed a good agreement, but also pointed out some limitations of the MODIS algorithm, e.g., cloud misclassification due to low contrast between clouds and cloud-free land. Li et al. (2004) compared the MODIS cloud product with Whole Sky Imager measurements and showed a reasonable agreement between both data sets, with MODIS tending to overestimate cloud fraction relative to the ground observations. Large discrepancies were explained with contradictory test results in the cloud retrieval algorithm. A good performance is also reported by Holz et al. (2008), who compared MODIS with CALIOP observations and found correlations of 85% (clear sky) to 88% (cloud covered). Seiz et al. (2009) compared the standard MODIS Level-3 Atmosphere Product (MOD08 and MYD08; Hubanks et al., 2008), which provides aggregated cloud fraction information at 1° spatial resolution, with daytime Synop observations in Switzerland. Despite the relatively coarse resolution of the MODIS product, a good agreement with Synop observations was reported at Payerne in western Switzerland. To give consideration to the high spatial variability of cloud cover within the complex topography of Switzerland, a new high spatial resolution (0.05°) daytime cloud fraction data set based on the Terra/MODIS cloud mask product (MOD35) was recently proposed by Seiz et al. (2011) and analyzed at a number of sites in Switzerland (Lugrin, 2011).

With the aim of generating a long-term MODIS cloud climatology over Switzerland in support of the National Climate Observation System (GCOS Switzerland; Seiz and Foppa, 2011), we present a detailed comparison of the newly generated MODIS cloud fraction data set with Synop observations over Switzerland for the period from March 2000 to February 2012, and extend the analyses to an equivalent data set generated based on Aqua/MODIS observations between July 2002 and February 2012. The data sets are based on daytime observations and represent mid-morning (Terra/MODIS) and early-afternoon cloudiness conditions (Aqua/MODIS) over Switzerland.

The paper is structured as follows: In Section 2, the data sets and processing steps are described. Results are presented in Section 3. Section 4 discusses the results and provides concluding remarks.

2. Data and methods

2.1. Cloud fraction from MODIS

The MODIS collection 5 MOD35 and MYD35 products were downloaded from the Level 1 and Atmospheric Archive and Distribution System (LAADS; http://ladsweb.nascom.nasa.gov/)