Available online at www.sciencedirect.com
ScienceDirect
Remote Sensing of Environment 109 (2007) 29–41
Remote Sensing of Environment
www.elsevier.com/locate/rse

Operational snow mapping using multitemporal Meteosat SEVIRI imagery

Martijn de Ruyter de Wildt [a,b,*], Gabriela Seiz [b], Armin Gruen [a]

[a] Institute of Geodesy and Photogrammetry, Swiss Federal Institute of Technology (ETH) Zurich, ETH-Hoenggerberg, 8093 Zurich, Switzerland
[b] Federal Office of Meteorology and Climatology MeteoSwiss, Krahbuhlstrasse 58, PO Box 514, 8044 Zurich, Switzerland

Received 23 June 2006; received in revised form 3 December 2006; accepted 5 December 2006

Abstract

The Spinning Enhanced Visible and Infrared Imager (SEVIRI) onboard Meteosat Second Generation is the first geostationary satellite instrument with all visual and infrared channels that are important for snow mapping. In this paper, we present an algorithm for deriving snow cover maps from SEVIRI data that makes use of the unique combination of adequate spectral resolution and very high frequency. The short interval of 15 min between images makes it possible to extend traditional spectral classification with a detection of changes between images. This improves the detection of clouds and cloud shadows in instantaneous images, because these often display more variation in time than the surface. It therefore allows a more accurate mapping of surface snow cover, as is shown by a validation of the results with ground observations and other satellite data. The accurate classification of each single image allows the generation of temporal composite snow maps in near real-time, which is for example of interest for numerical weather prediction models. When compared to many in situ measurements from the winter of 2005/2006, the accuracy of the algorithm is 95%.

Keywords: Snow cover; Clouds; Meteosat; SEVIRI; Multitemporal; Change detection

1. Introduction

Snow cover influences several processes that occur at or near the Earth's surface. It affects the exchange of energy and moisture between the surface and the atmosphere and is an important aspect of the hydrological cycle. Furthermore, snow cover extent is an indicator of climatic change and affects many human activities. Information about the surface snow cover is therefore important for studies and applications in many disciplines, including numerical weather prediction (NWP), hydrology and climatology. A valuable tool for detecting snow cover is satellite remote sensing, because it allows us to monitor large areas of the Earth at regular time intervals. Many different authors have studied remote sensing of snow and developed algorithms for this purpose. Most authors have studied binary (snow–no snow) snow cover (e.g. Dozier, 1989; Gesell, 1989; Hall et al., 2002), but in recent years the detection of subpixel snow cover has increasingly gained attention (e.g. Painter et al., 2003; Romanov et al., 2003; Salomonson and Appel, 2004; Vikhamar and Solberg, 2003).

The most frequent observations are acquired by geostationary satellites, which monitor an entire hemisphere with very high temporal frequency in near real-time. Until recently, however, geostationary satellites did not possess all spectral channels that are of interest for snow mapping. In 2002, the first Meteosat Second Generation (MSG) was launched by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). This geostationary satellite, named Meteosat-8, carries the Spinning Enhanced Visible and Infrared Imager (SEVIRI), which has improved spectral, spatial and temporal resolution with respect to its predecessors onboard of the previous Meteosat satellites. SEVIRI is the first geostationary satellite sensor with similar channels as polar orbiting sensors like AVHRR and MODIS (Fig. 1). It thus offers an unprecedented data set with adequate spectral and very high temporal resolution, which allows the monitoring of dynamic processes and detection of short-term changes. This is of

* Corresponding author. Institute of Geodesy and Photogrammetry, Swiss Federal Institute of Technology (ETH) Zurich, ETH-Hoenggerberg, 8093 Zurich, Switzerland.
E-mail address: ruyter@geod.baug.ethz.ch (M. de Ruyter de Wildt).

0034-4257/$ - see front matter © 2007 Elsevier Inc. All rights reserved.
doi:10.1016/j.rse.2006.12.008

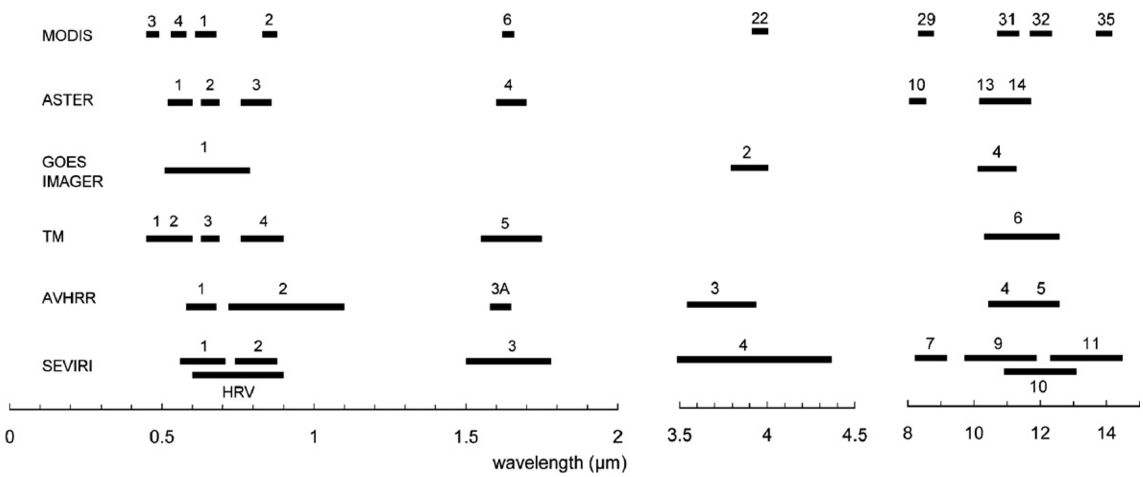

Fig. 1. Comparison of the spectral channels of several sensors that have been used for snow mapping (in random order). Only channels relevant for snow mapping are shown.

interest for cases where spectral information alone is insufficient for image classification, like the discrimination between snow and ice clouds (e.g. Hall et al., 1995). Such clouds can have similar reflectances, brightness temperatures and phase as snow and are sometimes difficult to distinguish from snow with spectral information alone.

In satellite remote sensing, change detection is generally used to study processes that occur at the earth's surface at rather long time scales of months to years (for an overview, we refer the reader to Coppin et al., 2004; Radke et al., 2005). In most of these studies polar orbiting sensors have been used, as these have repeat times of hours to weeks and offer a wide range of spatial and spectral resolutions. In contrast to the surface of the earth, clouds often display a dynamic behavior at time scales of minutes to hours, and only geostationary satellites have a frequency that is high enough to monitor this behavior. The advantage of the high frequency for masking clouds over snow surfaces has been demonstrated by Romanov et al. (2000, 2003). From many successive images of the Imager instrument on board of the Geostationary Observational Environmental Satellites (GOES), the authors made a daily composite image by retaining the warmest value of each pixel and then classified the daily composite. This procedure acts as a cloud mask because clouds are generally colder than the surface. As far as we know, there are no studies on using temporal information to detect clouds in instantaneous satellite images.

In this paper, we present a snow mapping algorithm that uses change detection in addition to pixel-based spectral classification. The algorithm classifies instantaneous SEVIRI images and can thus produce snow maps in near real-time. This is of importance for NWP models, which are typically initialized several times per day and require the latest information about the state of the atmosphere and the surface. In the near future the algorithm will deliver snow cover data to the operational NWP model of MeteoSwiss, the Alpine Model (aLMo).

2. Data

Meteosat-8 is currently situated at 3.4° W at an altitude of 36,000 km. SEVIRI monitors the entire visible hemisphere with a frequency of 15 min and has twelve spectral channels (Table 1). Channel 12 is a high resolution visible (HRV) channel that has a

Table 1
The twelve SEVIRI channels and average divergences of snow cover and clouds containing ice particles (with $r_{1.6}<0.5$)

Channel	Central wavelength (μm)	Description	Divergences for Eq. (2)				Divergences for Eq. (3)			
			3	5	7	9	3	5	7	9
1	0.64	Visible	0.616	0.683	0.699	0.693	0.712	0.749	0.752	0.74
2	0.81	Visible	0.614	0.679	0.688	0.671	0.702	0.734	0.731	0.709
3	1.6	Near infrared	0.632	0.656	0.644	0.618	0.737	0.729	0.702	0.671
4	3.9	Solar + terrestrial infrared	0.549	0.594	0.611	0.622	0.613	0.639	0.648	0.655
5	6.2	Infrared (water vapor absorption)	0.360	0.402	0.407	0.402	0.38	0.408	0.409	0.402
6	7.3	Infrared (water vapor absorption)	0.530	0.577	0.586	0.584	0.574	0.601	0.603	0.597
7	8.7	Infrared	0.621	0.665	0.667	0.658	0.678	0.700	0.693	0.679
8	9.7	Infrared (ozone absorption)	0.542	0.602	0.616	0.617	0.582	0.619	0.626	0.622
9	10.8	Infrared	0.604	0.646	0.649	0.642	0.657	0.679	0.674	0.662
10	12.0	Infrared	0.587	0.628	0.631	0.624	0.637	0.658	0.654	0.642
11	13.4	Infrared (CO_2 absorption)	0.550	0.599	0.608	0.605	0.588	0.619	0.621	0.615
12	HRV	High resolution visual broadband	0.705	0.747	0.741	0.715	0.731	0.767	0.759	0.733

Shown are the divergences for Eqs. (2) and (3), both with 3, 5, 7 and 9 images.