Remote Sensing of Environment 143 (2014) 192–203

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Monitoring snow cover using Chinese meteorological satellite data over China

Juntao Yang [a], Lingmei Jiang [a,*], Jiancheng Shi [b], Shengli Wu [c], Ruijing Sun [c], Hu Yang [d]

[a] State Key Laboratory of Remote Sensing Science, Research Center for Remote Sensing and GIS, and School of Geography, Beijing Normal University, Beijing 100875, China
[b] State Key Laboratory of Remote Sensing Science, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing 100101, China
[c] National Satellite Meteorological Center, Beijing 100081, China
[d] Earth Science System Interdisciplinary Center, University of Maryland, College Park, MD 20742, USA

ARTICLE INFO

Article history:
Received 31 May 2013
Received in revised form 26 December 2013
Accepted 27 December 2013
Available online 29 January 2014

Keywords:
FY-2D/E VISSR
FY-3B MWRI
Snow cover
Geostationary satellite
China

ABSTRACT

Snow cover plays an important role in hydrological processes and global climate change research. Geostationary satellites with high temporal resolution provide multiple observations in one day, which highlights their potential for monitoring real-time snow-cover information. In this paper, data from the Chinese meteorological satellites Fengyun-2D (FY-2D), Fengyun-2E (FY-2E) and Fengyun-3B (FY-3B) was used for snow-cover mapping over China. A new method of detecting snow-cover information is proposed, that combines the Visible and Infrared Spin Scan-Radiometer (VISSR) on board the geostationary satellites FY-2D and FY-2E and the Microwave Radiation Imager (MWRI) on board the polar orbiting satellite FY-3B. The snow cover estimated from Fengyun satellites was compared by the Moderate Resolution Imaging Spectroradiometer (MODIS) snow-cover products (MOD10A1 and MYD10A1), and Interactive Multisensor Snow and Ice Mapping System (IMS) snow-cover products. The Fengyun satellite snow-cover images and IMS snow-cover products were validated with meteorological station observations for the 2010–2011 and 2011–2012 winter seasons. The influence of elevation and land-cover types on the accuracy of snow retrievals was also analyzed. The results showed that the combined use of FY-2D and FY-2E VISSR data reduced cloud obscuration by 30.47% compared to the MODIS products. The validation demonstrated that the accuracy of the final multi-sensor snow-cover images was 91.28%, which is similar to that for IMS snow-cover products. This work indicates that combined data from geostationary satellites and passive microwave remote sensing monitored snow cover over China to a high level of accuracy.

1. Introduction

Seasonal snow cover plays an important role in hydrological processes, surface radiation and climates. Snow-cover mapping has been utilized in operational snowmelt, runoff forecasting, data assimilation and the calibration or validation of various hydrological models (Gao, Xie, Lu, Yao, & Liang, 2010). In situ observations are the traditional source of information on the snow cover. However, it does not fully satisfy the needs of the modeling community (Romanov & Tarpley, 2007). With a growing number of satellite platforms, satellite remote sensing technology has been used to monitor snow cover at both regional and global scales. It has become possible to monitor snow cover in near real time.

Both optical and passive microwave imagery can be used to extract snow cover information. The Advanced Very High Resolution Radiometer (AVHRR) on board the National Oceanic and Atmospheric Administration (NOAA) polar orbiter, the Moderate Resolution Imaging Spectroradiometer (MODIS) on board the Terra and Aqua satellites, the Special Sensor Microwave Imager (SSM/I) on board the Defense Meteorological Satellite Platform (DMSP), and Landsat Thematic Mapper (TM) have been widely used to monitor snow cover (Allen, Durkee, & Wash, 1990; Dozier & Painter, 2004; Grody & Basist, 1996; Hall, Riggs, Salomonson, DiGirolamo, & Bayr, 2002). Monitoring snow cover using optical imagery with high spatial resolution is seriously hampered by cloud cover because of the similar spectral reflectance of snow and some types of clouds (Liang et al., 2008; Wang, Xie, & Liang, 2008). MODIS snow-cover products composed over eight days may be used to reduce cloud obscuration. However, timely snow-cover mapping is required to identify disaster regions and in hydrological applications. Therefore, various approaches have been proposed to reduce cloud obscuration by altering the cloud mask, separating cloud-masked pixels, and applying spatial–temporal or multi-sensor combinations (Gao et al., 2010; Hall, Riggs, Foster, & Kumar, 2010; Parajka & Blöschl, 2008). Passive microwave remote sensing presents the advantages of penetrating cloud cover and obtaining more snow-cover information. However, the coarse spatial resolution of passive microwave data is still its main limitation. In addition, current passive microwave snow algorithms cannot detect wet and shallow snow. The wet snow cover and

* Corresponding author at: State Key Laboratory of Remote Sensing Science, Research Center for Remote Sensing and GIS, and School of Geography, Beijing Normal University, Beijing 100875, China.
E-mail address: jiang@bnu.edu.cn (L. Jiang).

0034-4257/$ – see front matter
http://dx.doi.org/10.1016/j.rse.2013.12.022

serious cloud obscuration in southern China has indicated the limitation of using optical or passive microwave remote sensing data separately.

Because there are only one–two observations per day of polar-orbiting satellites, substantial cloud obscuration is the main limitation of daily optical snow cover products. In daily snow-cover mapping, the most effective method of reducing cloud obscuration is to increase the number of observations within a day. Geostationary satellites provide frequent observations, which allow for monitoring an entire hemisphere at temporal resolution in close to real time (Wildt, Seiz, & Gruen, 2007). Current operational geostationary satellites include Geostationary Operational Environmental Satellites (GOES), Meteosat Second Generation (MSG), Multi-functional Transport Satellite-2 (MTSAT-2) and Fengyun-2 (FY-2). GOES data for snow-cover mapping was used by Romanov, Gutman, and Csiszar (2000, 2003), who made a daily composite image and obtained daily snow-cover images. For MSG, Wildt et al. (2007) used temporal differences between images to produce daily snow-cover maps. Siljamo and Hyvärinen (2011) developed a new snow algorithm for MSG, based on scatterplots and classification rules. Oyoshi, Takeuchi, and Yasuoka (2007) used MTSAT data for snow-cover mapping and found that the maps were consistent with those from AVHRR and MODIS. FY-2C satellite data was used by Li, Yan, and Liu (2007) to derive snow-cover information using different threshold criteria. Currently, most methods for snow-cover detection based on geostationary satellite data utilize spectral-based threshold algorithms. Cloud obscuration can be reduced by utilizing multi-temporal geostationary satellite data. Currently, daily snow-cover monitoring techniques that use either optical sensors on polar orbiting satellites or passive microwave sensors cannot provide accurate daily snow-cover images with low cloud obscuration. Therefore, the combined use of optical sensors on board geostationary satellites and passive microwave sensors will provide more surface information without cloud obscuration.

In daily snow-cover mapping, the most effective method of reducing cloud obscuration is to increase the number of observations within a day (e.g., see Wang et al., 2008). In addition, multi-sensor technology can also be used to obtain more accurate information on snow cover. This paper describes a snow-cover mapping algorithm that uses data from two geostationary satellites (FY-2D, FY-2E) combined with passive microwave data derived from polar-orbiting meteorological satellite FY-3B. Despite the different observation times and locations for FY-2D and FY-2E, the data from both satellites was utilized to monitor snow cover with less cloud obscuration during in the period of one day, with the observation frequency reduced to half an hour.

In Section 2, the Fengyun satellite data, ground observations and other snow-cover products are compared. Section 3 presents the methodology, including data pre-processing, development of a snow-cover algorithm, and techniques for reducing cloud obscuration. Section 4 details the comparison and validation of FY-2D/E, MODIS and IMS snow-cover products, and the conclusion appears in the final section.

2. Data

2.1. In situ measurements

The China Meteorological Administration (CMA) provides daily meteorological observations for the whole of China, including snow depth, and minimum, maximum and mean air temperatures, along with other information. In this study, a total of 699 meteorological stations over China were used in the validation. Snow depth observations were also used in the development of a snow-cover algorithm. Global 30 Arc-Second Elevation (GTOPO30) is a global digital elevation model (DEM). The spatial resolution of GTOPO30 is approximately 1 km (USGS, 1996). Fig. 1 is a map showing the locations of the meteorological stations, and the DEM derived from GTOPO30 is overlaid on the map.

2.2. Satellite data

The FY-2 series are first-generation Chinese geostationary meteorological satellites. Currently, the FY-2D and FY-2E satellites are operational, and FY-2F is on standby. FY-2D was launched at central

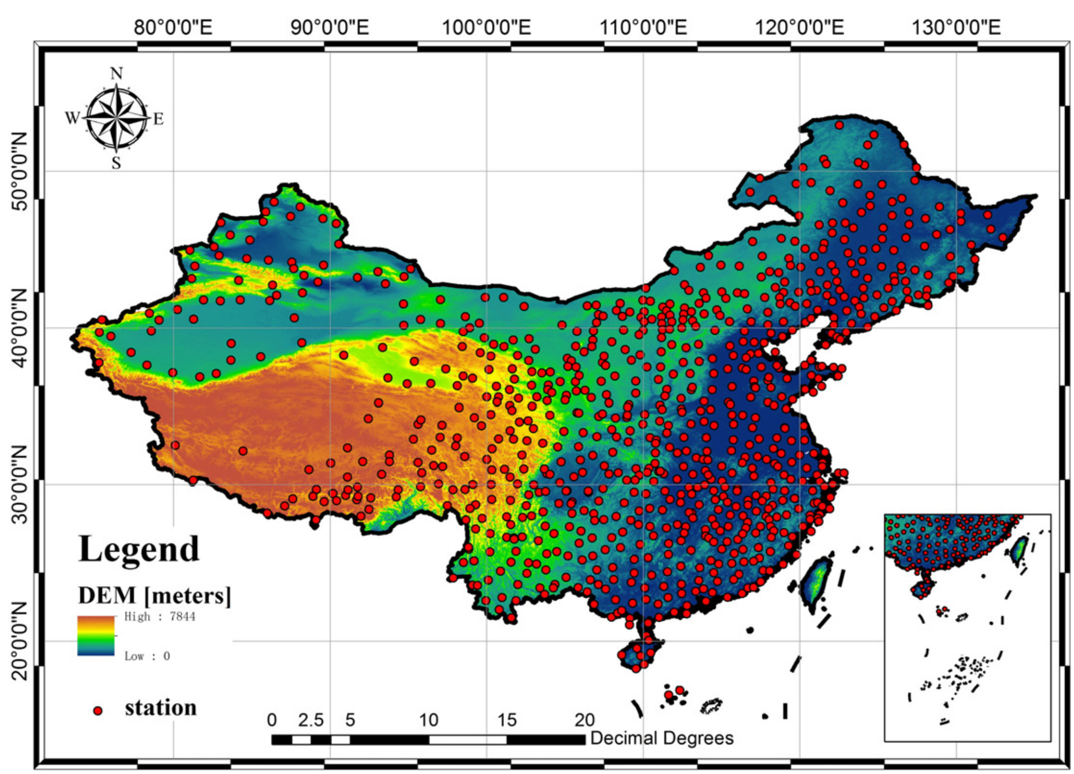

Fig. 1. Meteorological stations and DEM of China.