Special Section Guest Editorial: Progress in Snow Remote Sensing

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Snow plays an important role in the energy and water balance of drainage basins in alpine regions. Contribution of snowmelt to runoff is one of the important water resources in mountainous regions, in addition to rainfall and glacier melt. Snow stores at least one-third of the water usage for irrigation and growth of crops worldwide. Snow covered area and snow depth/water equivalent estimations are important parameters for regional climate change studies, agriculture, and water resource management. Traditional *in situ* measurements provide critical snow observations in limited areas and for calibration and validation (cal/val) of remotely sensed estimation of snow parameters. Satellite-based snow measurements have revolutionized the monitoring of spatiotemporal variations of snow cover and snow depth/water equivalent in complex natural conditions at regional and global scales.

This special section provides a picture of state-of-the-art research in snow remote sensing, algorithm development and improvement, and snow modeling and application. It includes 20 papers that cover four major topics: snow cover and snow depth/snow water equivalent (SWE) mapping using optical and passive microwave remote sensing (10 papers), algorithm developments for snow cover and glacier mapping (6 papers), snow cover and snow melt-runoff modeling (3 papers), and one review paper. Many of the papers are extended versions of materials that were presented in the first Snow Remote Sensing of China Workshop (Lanzhou, China, August 2013). The review paper "Remote sensing for snow hydrology in China: challenges and perspectives" by Wang et al. (CID 084687) provides a detailed summary of the development of snow remote sensing, snow parameters retrieving and applications in China since the 1980s. In particular, since 2007, two major large-scale field-based experiments: (1) Watershed Allied Telemetry Experimental Research (WATER) in the Heihe River Basin of Northwest China and (2) Cooperative Observation Series for Snow Properties in three major snowfall regions (Northwest China, Northeast China and the Tibetan Plateau), have been initiated and have obtained many first-hand data for algorithm development and validation of remotely sensed snow parameters retrievals. One particular application of remote sensing snow products in China is the early warning system of snow-caused livestock death (disasters) in pastoral areas. The system is a unique application and development, particularly for undeveloped high mountainous areas such as the Tibetan Plateau (TP), where mean elevations are over 4000 m and there is little or no infrastructure and industry.

There are 10 papers about snow cover and snow depth/SWE mapping and applications. Of these, 5 papers use optical remote sensing, primarily MODIS snow cover products; 4 papers use passive microwave remote sensing; and one paper evaluates the accuracy of the U.S. National Ice Center's Multisensor Snow and Ice Mapping System (IMS) snow cover product in China. Two papers by Chen et al. and by Li and Ke present applications of different MODIS snow cover products for northeast China. Both find an increased trend of snow covered area (SCA) in the most recent 10 years, primarily correlated with the recent decreased tendency of air temperature in the region, although there is a clear long-term increased trend of air temperature since 1960. The recent decreasing trend in air temperature in the region is interesting and deserving of further

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investigation as pointed out by Chen et al. (CID 084685). Chen et al. (CID 084694) examine the Nam Co basin of the TP for interrelations among climate factors, snow, grassland vegetation, and lake water and finds a decreasing tendency of snow cover (although insignificant) in the basin. This is consistent with the recent decreased trend of precipitation in the cold season, although precipitation shows a clear and significant increased trend in the cold season since the 1960s, due to a significant temperature increase in the same time period. Chu et al. examine the snow cover time series using the MODIS Terra 8-day snow cover product (2001–2013) for the entire TP and finds that the SCA reaches maximum in the spring season (22% of the area) and there is an overall decreasing trend in all seasons except in autumn, with a more obvious decrease in summer. Tang et al. extract snowline altitude (SLA) over the TP using MODIS fractional snow cover data (2001–2013) and finds that the SLA in the interior of the TP is higher than that in the peripheral mountainous area and there is no obvious trend of SLA change in the examined period.

The paper by Dai and Che presents daily snow depth time series, derived from SSM/I and AMSR-E and archived at the West Data Center in China, for northern China from 1987–2011 and finds snow depth decreased in the beginning and end of the snow season in all climate zones, while large variations are found during the middle of the snow season. This dataset is also used to examine the spatiotemporal variations of SCA, snow cover days, and cumulative snowfall of northern China. Li et al. (CID 084692) show a case study in Heilongjiang Province (China) of using the new Chinese meteorological FengYun (FY3B) satellite (similar to AMSR-E) for snow depth retrieval (based on Chang's algorithm) and validation using *in situ* measurements. They find that Chang's algorithm, developed for open areas, tends to underestimate the snow depth in forested regions, while underestimating and overestimating snow depth in earlier phase and later phase of snow cover in cropland, respectively. Liu et al. examine the accuracy of the two Northern Hemisphere SWE products, from the National Snow and Ice Data Center (NSIDC) and GlobSnow from the European Space Agency, using 7388 *in situ* stations data and finds that the GlobSnow SWE performs better for SWE values of 30–200 mm, while the NSIDC SWE performs better for SWE values of less than 30 mm. Struzik presents a first look of the snow depth product of AMSR2 from the new Japanese Global Change Observation Mission-1st Water (GCOM-W1) satellite and finds its descending product is better than its ascending product over Poland and is overall a better product (and higher resolution) than other SWE products currently available. Chen et al. (ID 084680) validates the accuracy of IMS snow cover products (daily cloud free and 4 km) in southern China using Landsat images and finds the agreement is greater than 85% over flat surfaces, while less than 75% (with 50% overestimate of snow cover) in forested mountainous areas.

There are 6 papers covering the advancement and improvement of algorithms for snow cover and glacier mapping. Du et al. present an object-based image segmentation method to map glacier change using Landsat images from 1977 to 2013 and show the glacier area in Tianshan Mountains decreased 21.5% since 1977. Gu et al. presents an unmixing method using component brightness temperatures of four land cover types (farmland, grass, bare, and forest) from the FY3B satellite to retrieve snow depth and snow cover information, with a 10–17% improvement of snow depth retrieval as compared with Chang's algorithm and NASA96 algorithm and a retrieving accuracy of 86% for SCA. Pettinato et al. present a change detection method (based on Shannon's information theory) to extract SCA from the newly launched COSMO-SkyMed satellites (X-band SAR system) and finds that the method is very promising in case of large snow covering on multitemporal single-look SAR images at very high spatial resolution, due to its intrinsic low sensitivity to speckle noise. Wang et al. (CID 084681) present a new cloud-removal approach, through backward replacements of daily combinations of Terra and Aqua MODIS snow cover products, to produce daily cloud-free snow cover images with 91% snow cover agreement. Zhang et al. present an improved end member extraction algorithm for fractional snow cover extraction from the MODIS reflectance product and finds that the results are better than the MODIS standard fractional snow cover product that is derived from empirical equations. Zhu et al. present a support vector machine-based decision tree algorithm to extract snow cover of mountainous areas from high resolution optical imagery (ZY-3 satellite, China). The proposed method (basically an object-based classification method) successfully extracts snow in sunlight and snow in shadow and overcomes the

difficulty in topographic correction for high resolution imagery due to lack of high resolution topographic data.

There are 3 papers dealing with snow cover modeling. Li et al. (CID 084696) use the ensemble Kalman filter to combine the remotely sensed snow cover and snow depth information with distributed SnowModel to simulate the snow distribution for the TP. The root-mean-square-error of the assimilated snow depth is in the range of 0.002–0.008 m as compared with the station measurements ($r = 0.61 - 0.87$) and the snow depletion curve is found to be the most important parameter for the successful simulation over the TP where snow is patchy and thin. With the MODIS 8-day snow cover product as input, the snowmelt runoff model (SRM) is used by Shahabi et al. to simulate runoff in Central Zab Basin of Iran and the results match well with the measured runoff ($R^2 = 0.90$ and volume difference of 0.15%). Wu et al. model the spring snowmelt using the Utah Energy Balance (UEB) model for a small watershed in northwest China and find the modeled SWE matches well with measured SWE with a mean relative error of 7.2%.

We wish to express our deep appreciation to all authors and reviewers for their high-quality contributions and enthusiastic efforts to this special section. Our sincere thanks also goes to the JARS staff, who worked very hard and were timely in handling the review process and in answering questions raised during the session initiation, paper submission, and review processes.