EVALUATION OF REGIONAL-SCALE SNOW ALBEDO CHARACTERISTICS DURING WINTER SEASON FROM 2003 TO 2014

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ABSTRACT

Snow is a very important component of the climate system. It can influence the energy budget of the atmosphere and hydrological system significantly. The main goal of this paper is to use remote sensing and geographical information system techniques to analyze the spatial and temporal variations in regional scale and to find the relations between meteorological parameters and the snow albedo for the future modeling in snow albedo study. The results revealed spatial and temporal variation throughout different months during the winter season. In addition, the Pearson correlation coefficient analysis showed partial correlation between snow albedo and meteorological variables, which can be used to model snow albedo in some hydrological studies.

Index Terms— snow albedo, temporal variation, spatial variation, meteorological parameters, MODIS

1. INTRODUCTION

Snow is one of the most important components in the climate system due to its influence on land covers and surface characteristics such as surface temperature [1]. Snow albedo is the fraction of solar energy reflected from the snow surface back into space as shortwave radiation [2]. Snow albedo measurements are critical for various climate models, such as snowmelt runoff models, snow water equivalent model, and energy balance model [3].

Given that huge areas of the Earth, especially in the high latitude areas, are covered by snow and ice, analysis of snow albedo's dynamic changes and characteristics in global and regional scales have been become noticeable [4]. In the past, people can only use the ground based radiometer to measure the snow albedo, which caused numerous technical problems such as the sensor shorter than some high objects and the scale of study was too small [5]. Recent decades, researchers started using the data acquired from satellite-borne sensors such as the Advanced Very High Resolution Radiometer (AVHRR) to derive snow albedo [6]-[8]; however, the accuracy of the snow albedo was very low. Since 1999, the Moderate Imaging Spectroradiometer (MODIS) sensors were launched, which improved the cloud detection capabilities and significantly enhanced the accuracy of generating the snow albedo value [6]. MODIS snow products had been done on validation in many studies, which root mean square errors were all under 0.075 [6][9][10].

The snow albedo shows temporal variations which is dependent on a wide variety of sources. The snow surface characteristics, snow depth, meteorological conditions, and sensors accuracy can all affect snow albedo value [5]. Routine measuring of the meteorological factors are more common than measuring the albedo in most hydrological researches [5]. In addition, snow albedo shows spatial variations in regional or global scales. The main purpose of this particular study is to use remote sensing and geographical information system techniques to analyze the spatial and temporal variations of the snow albedo in the study area and to discover the relations

2. STUDY AREA AND DATA

In this case, the study area is the corridor of the Highway 400 located in South Ontario, Canada, including the part of the Greater Toronto Area (GTA) and Simcoe County in Ontario, Canada, see Fig.1. This area is located between Lake Ontario and Georgian Bay which has 10720.3 km^2 and Lake Simcoe is surrounded in this study area. Since the study area is surrounded by the Great Lakes, the average winter snowfall is around 121.5 cm, and under the lake-effect there are usually two or more heavy snowfalls of each winter.

All satellite snow products are provided by National Snow and Ice Data Center, USA [11]. These datasets were originally acquired by sensors MODIS/Terra and MODIS/Aqua. This paper selected the data which are less than 20% cloud cover of the study area during December, January and February from 2003 to 2014. The spatial and temporal resolutions are 500 m and daily, respectively. The snow albedo keeps in as an integer array which the value range is 0 to 100 (%) [6]; and non-snow features are also mapped using different data values. This data set was applied several processes including cloud removing, atmospheric correction, and a DISORT (Discrete Ordinate Radiative Transfer) for anisotropic correction [3]. The meteorological data used in this study include monthly mean temperature (°C), monthly total snowfall (cm), monthly total precipitation (mm), and snow on the ground on the last day (cm). All these datasets were acquired from Climate Canada.

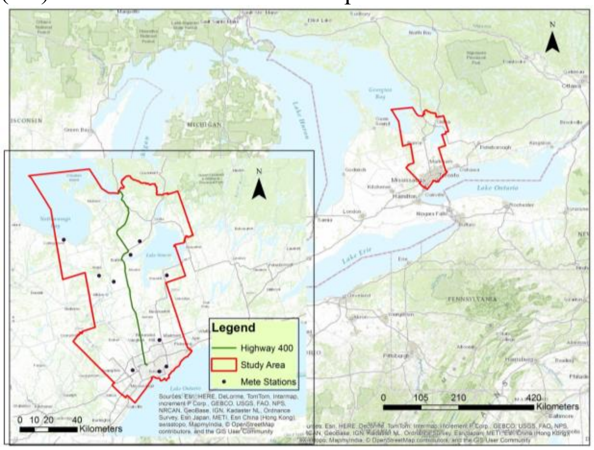

Fig. 1: Study area in southern Ontario

3. METHOD

3.1. Data pre-processing

This study used 10 separate meteorological stations' data from 2003 to 2014. Some stations' data were recorded daily; therefore, the monthly data were calculated based on the daily data by the mean or the sum of each category. The MODIS products were re-projected from SIN projection into NAD1927 UTM Zone 17N project coordinate system. Then the Hierarchical Data Format-Earth Observing System (HDF-EOS) format was converted into Geotiff format, and extracted the target area from the study area boundary. These two steps were completed by IDL coding.

3.2. Generating monthly snow albedo products

Since the study area is often cloudy in the winter, several months' snow product data were partially missing under the high cloud-effect situation (e.g., no data available in December 2007 and 2008). If a given month had two or three images, the snow albedo data were composited by averaging the images. This operation also removes clouds from the images. By averaging the snow albedo values for those images, we obtained the monthly snow albedo products by every year, and the mean snow albedo products of January, February, and December for 10 years. Lastly, the mean snow albedo value of 10 stations in January, February, and December was obtained. The snow albedo values used were taken from the coordinate that corresponded to the weather station at Shanty Bay, Ontario via MODIS, which had complete meteorological data of that location during those 10 winters. In this case, we assumed that the weather station only measured the nearby area's meteorological data. This procedure was completed by programing in the MATLAB environment.

3.3. Variation analysis and statistics analysis

The meteorological data and snow albedo data were integrated into ArcGIS for spatial analysis. The contours of mean temperature and snow on the ground were generated by Kriging interpolation and contour extraction. Statistical analysis was applied to the obtained data. The relation between each meteorological variable and snow albedo - the Pearson correlation coefficient (denoted as r) [12], and two-tailed significance test (denoted as p) was carried out. We chose the weather station at Shanty Bay, Ontario as the test site since this station collected a complete meteorological parameters dataset. The snow albedo value, where is on the station's pixel, was generated from the monthly snow albedo product retrieved by this study as one data set.

4. RESULTS AND DISCUSSIONS

4.1. Spatial analysis

After analyzing the monthly mean data from 2003 to 2014, the snow albedo was classified into 5 levels, as shown in Fig. 2. It is clear that there were some spatial distributions of the entire area.

Firstly, the mean snow albedo values in areas with heavy human activities are usually kept below 0.53. For instance, the City of Toronto and the City of Barrie had significantly lower snow albedo in the winter. This illustrates a thinner snow layer, which could be the result of increased human activities. The snow albedo level is also affected by the ground surface temperature and land cover type. Consequently, as the firn process accelerates, the snow albedo tends to decrease.

Secondly, during the winter season, the data on Lake Simcoe displayed a significant variation. As shown in Fig. 2, the mean snow albedo values in December on Lake Simcoe were mostly under 0.65 without considering the missing data caused by cloud. In January and February, the snow albedos were mostly between 0.66-1. This could be explained by the relatively mild temperature on Lake Simcoe in December, which only froze the Lake's surface. However, the temperature in January and February was low enough to freeze a much bigger portion of the lake; therefore the Lake's surface temperature was significantly lower. The firn process is slowed down after snow, and low human activity on the lake area meant that the snow was relatively pure. As the result, the snow albedo on Lake Simcoe was high during these two months.

Lastly, as shown in Fig.2, the snow albedo on Georgian Bay was lower than the snow albedo in Lake Simcoe overall. Despite some missing data from December, the results still showed an increase in snow albedo in January and February compared to December. Georgian Bay is a much bigger body of water compared to Lake Simcoe. Therefore, due to the heat-sink property of water, it could retain more energy/heat during the early months of winter. In December, the thin layer of ice on Georgian Bay caused quick snow firn, which was translated into the low snow albedo. However, the water loses energy throughout the winter, and water temperature decreased in January and February. As the result, the snow albedo increased in these two months.

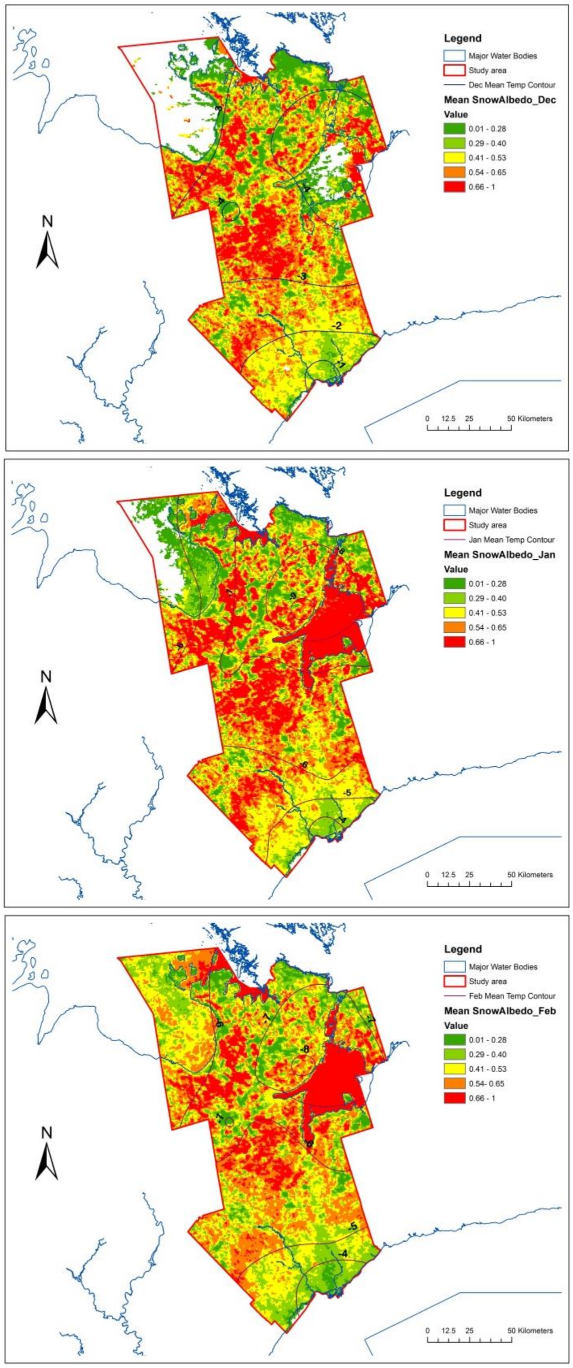

Fig. 2: Mean snow albedo of December, January and February from 2003 to 2014

4.2. Temporal analysis

As shown in Fig. 3, the average monthly snow albedo showed some temporal variation between December, January, and February. In this line diagram, the horizontal axis means snow albedo from 0.01-1, and the vertical axis is the area number of each snow albedo value. There was a decreasing trend from December to February in the range of 0.01-0.28, which is the only one the total number of area reduces in these levels. Other ranges, such as 0.29-0.4, 0.54-0.65, and 0.41-0.53 had significant increasing in this time series. The range 0.66-1 increased about 60% from December to January, and then there was a reduction in 30% area of total study area in February. This temporal variation may be related to the meteorological parameters varieties, since the snow albedo could be affected by snow surface characteristics and the atmosphere conditions [13].

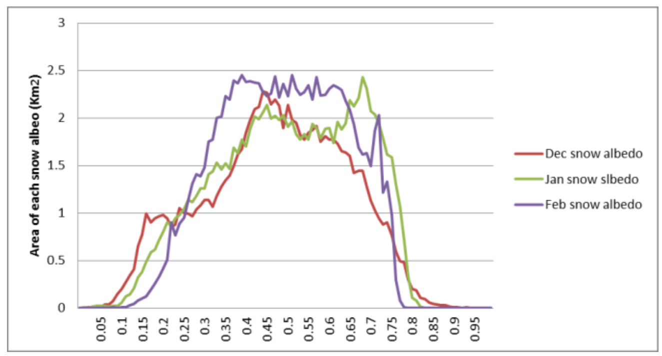

Fig. 3: Average monthly snow albedo distribution in winter time series

4.3. Statistical analysis

In this study, a Pearson correlation coefficient analysis was made to analyze the correlations between the snow albedo and various meteorological parameters. The results of this analysis are shown in table 1. There were two parts in this test. The correlation coefficient in this data set was around 0.4-0.5, which meant there was partial correlation between snow albedo and all four variables. In addition, the p values in all four scenarios were below 0.05. This result was consistent with that of [5]. However, for the second data set, there was no clear correlation between snow albedo and meteorological parameters except for total precipitation, in which r value was 0.403 and p value was 0.037. This low correlation might be the result of a large study area, which meant that the average value simply could not represent the entire area. There were also other factors that could influence the snow albedo. Therefore, pixel-based data-set was more reliable for correlation analysis than the study area's mean value. The result of this analysis allows for modelling of snow albedo from weather data, as the correlation between snow albedo and meteorological parameters was significant.

Table I. Pearson correlation coefficient pairs of snow albedo and meteorological parameters

	Total snow	Total precipitation	Mean temperature	Snow on ground
Shanty Bay Ontario weather station snow albedo	r=0.441	r=0.404	r=-0.568	r=0.443
	p=0.017	p=0.030	p=0.010	p=0.018

5. CONCLUSION

This study analyzed the spatial and temporal variations of snow albedo and concluded with the correlation analysis between snow albedo and meteorological parameters. The results show that the mean snow albedo values in areas with heavy human activities are usually kept in lower value. The lake areas have significant spatial variations. In terms of temporal variation, there has been an obvious increasing trend of snow albedo values from December to February. In addition, the Pearson correlation coefficient analysis show that snow albedo had partial correlations with the meteorological variables which could help model snow albedo in some hydrological studies. The whole procedure of data processing are quite efficiency for processing huge number of MODIS products, which can be applied into future researches.

There were a few factors that could be improved in this study. Firstly, the MODIS daily snow albedo data is not a representation of the daily mean value. Therefore, using the daily or hourly meteorological data might be more reliable for the purpose of this study. Secondly, only data from three months were analyzed. Some areas receive snow fall from November to March, and it could lead to a better time series research on snow albedo in the region if data from November to March was analyzed instead of December to February. Lastly, the meteorological data had many missing values and some of the data was estimated.

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