Available online at www.sciencedirect.com
ScienceDirect
Remote Sensing of Environment 111 (2007) 337–345
Remote Sensing of Environment
www.elsevier.com/locate/rse

Northern Hemisphere five-year average (2000–2004) spectral albedos of surfaces in the presence of snow: Statistics computed from Terra MODIS land products

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Received 22 August 2006; received in revised form 18 February 2007; accepted 18 March 2007

Abstract

In this paper, we present five-year (2000–2004) climatological statistics of Northern Hemisphere spectral white-sky albedo for the 16 International Geosphere–Biosphere Program (IGBP) ecosystem classes when accompanied by the presence of snow on the ground. These statistics are obtained using validated, high quality Moderate Resolution Imaging Spectroradiometer (MODIS) land surface albedo (MOD43B3) data flagged as snow in the associated Quality Assurance (QA) fields. Near Real-Time Ice and Snow Extent (NISE) data are used as an additional discriminator of snow extent. Statistics are provided for the first seven MODIS bands, ranging from 0.47 to 2.1 μm, and for three broadbands, 0.3–0.7, 0.3–5.0 and 0.7–5.0 μm.

The statistics demonstrate that each ecosystem classification has a discernible spectral albedo signature when accompanied by snow on the ground. This indicates that winter canopy and the underlying surface radiative properties are impacted by the presence of snow overlying these surfaces. For example, the 0.47 μm albedo of winter snow-free evergreen needleleaf forests increases from 0.03 to 0.36 in the presence of snow, compared to an increase of 0.04 to 0.76 for croplands. In general, the albedo of snow-covered ecosystems with some winter canopy has lower albedos than ecosystems with little to no winter canopy; for example the 0.47 μm albedo of snow-covered mixed forests is 0.39 compared to 0.87 for barren/deserts and 0.95 for permanent snow.

These statistics can be used within land surface models in a stand-alone mode, to prescribe albedo values in atmospheric General Circulation Models (GCMs), or be incorporated into research and operational projects. They are intended to provide researchers with representative spectral albedo values of IGBP ecosystems in the presence of snow that are derived from validated satellite data.
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Keywords: Moderate Resolution Imaging Spectroradiometer (MODIS); Radiative transfer; Remote sensing; Satellite applications; Spectral surface albedo; Terra; Vegetation; Ecosystem; Modeling; Snow

1. Introduction

The ratio of reflected to incident radiation, or albedo, of a surface in the presence of snow can be influenced by several characteristics. During periods that coincide with snow coverage, the vegetation is either at or near the full dormant (winter) state; however, the remnants of the vegetative canopy can protrude from the surface. As such, differences in dormant snow-free surface conditions for the various land surface classifications result in distinct ecosystem spectral signatures (see for example Moody et al., 2005). However, the presence of snow, the location of the snow (on or below winter canopies), and the condition of the snow (i.e. snow state, morphology, age, depth, type, and contamination, among others) can dramatically alter these spectral signatures.

Proper representation of the impact of snow on the snow-free surface albedo thereby becomes critical for Earth system remote sensing, energy budgeting, and modeling projects that depend on surface radiative properties for accurate observations and

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0034-4257/$ - see front matter © 2007 Elsevier Inc. All rights reserved.
doi:10.1016/j.rse.2007.03.026

calculations of Earth and atmosphere properties. As such, the goal of the present study is to employ validated remote sensing data to provide researchers with representative albedo values for the various ecosystems while they are in the presence of snow. To accomplish this, we utilize validated observations of land surface classification (MOD12Q1, Friedl et al., 2002) and land surface albedo (MOD43B3, 16-day product, Schaaf et al., 2002) that are readily available from the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard NASA's Terra (King & Herring, 2000) satellite.

The analysis is not straightforward, however, as some of these snow and surface properties can change quite dramatically over a 16-day period of MODIS albedo observations. Additionally, MOD43B3 albedo observations are by nature a temporal average of changing conditions, except in very limited regions of continuity. Further complicating matters, correlating albedo observations with these snow and surface properties is hampered by the limited availability of high-resolution temporal and spatial data. This includes a limited number of highest quality MOD43B3 snow albedo observations over both a 16-day period and even over the course of a full year.

Instead, this work provides albedo values for surfaces in the presence of "average" snow conditions by computing ecosystem-dependent multi-year Northern Hemisphere statistics (Jin et al., 2002). Such statistics are an amalgamation of the differing snow conditions that occur during the course of the snow season for each ecosystem type. This is accomplished by using all of the highest quality MOD43B3 observations (discerned to be snow) in the Northern Hemisphere over nearly five years (March 2000–December 2004).

The resulting statistics of surface albedo in the presence of snow provide researchers with reasonable and representative spectral albedo values at seven discrete wavelengths between 0.47 and 2.1 μm, and three broadbands, 0.3–0.7, 0.3–5.0, and 0.7–5.0 μm that are derived from validated satellite data. The statistics may be used as a stand-alone lookup table, or incorporated into remote sensing retrievals by matching conditions to a lookup table of these average snow conditions. They may also be an excellent source for model validation.

This paper explores the techniques and datasets used to compute the statistics of the surface albedo in the presence of snow and proceeds by providing background on albedo applications and data sources (Section 2), an overview of the methodology, including a description of the data used and conditioning and statistical calculations (Section 3), and finally a discussion of the resulting data (Section 4), and potential applications (Section 5).

2. Background

The albedo of a surface in the presence of snow is a key parameter for remote sensing of atmospheric cloud properties and plays a central role in global energy budget and climate forcing issues (Dickinson, 1992; King et al., 2004; Platnick et al., 2003; Roesch et al., 2002; Viterbo & Betts, 1999). Various climatic and ecosystem models, at a variety of scales, use snow-free albedo maps with superimposed snow properties (extent, type, albedo, etc.) (Barnett et al., 1989; Bonan, 1996; Cess et al., 1991; Dickinson et al., 1986; Dickinson, 1988; Molotch & Bales, 2006; Molotch et al., 2004; Verseghy, 1991; Yang et al., 1999). Remote sensing projects depend on the knowledge of surface radiative properties for accurate observations of Earth and atmosphere properties.

Aircraft and satellite observations of snow-covered land surfaces have been undertaken for many years; various techniques have been used to derive albedo over a variety of land cover types (see for example, Dozier, 1989; McFadden & Ragotzkie, 1967; Robinson & Kukla, 1985). There have also been extensive efforts to model the effects of various influencing factors (snow state, contamination, etc.) on the albedo of snow-covered surfaces (Davis et al., 1997; Dozier et al., 1981; Grenfell & Warren, 1994; Nolin & Dozier, 2000; Warren & Wiscombe, 1980; Warren, 1982; Wiscombe & Warren, 1980; Painter and Dozier, 2004).

There have also been some remote sensing, ground, and laboratory validation projects that have provided observations under a variety of conditions (Arnold et al., 2002; Betts & Ball, 1997; Brest & Goward, 1987; Grenfell & Perovich, 2004; Greuell & Oerlemans, 2005; Hall et al., 1993; Klein & Stroeve, 2002; Liang et al., 2002, 2005; O'Brien & Munis, 1975; Salomonson & Marlatt, 1968; Stroeve et al., 2005). These studies have shown that the albedo of surfaces in the presence of snow can vary dramatically, and therefore must be taken into account in radiative transfer calculations.

While the MOD43B3 product is currently the only validated source of global high-resolution snow-covered surface albedo data, the MOD10 Terra MODIS product suite (Hall et al., 2006, in press) can be used as an additional source for daily snow-coverage and snow albedo products. The MOD10 snow albedo data are an initial effort and currently only designated as "provisionally validated," but the snow-covered area data product is very mature and is validated to stage 2. In the future, it would be beneficial to use the validated MOD10 snow-covered area data to crosscheck the MOD43B3 data for the presence of snow as the MOD10 product's spatial resolution is 500 m, and includes sub-pixel snow cover information.

6. Summary

In this paper, we present five-year Northern Hemisphere spectral albedo statistics (mean, standard deviation, and coefficient of variation) for the 16 IGBP ecosystem surfaces when accompanied by snow. These statistics are computed for each of the 10 MOD43B3 narrowband and broadband wavelengths. The analysis demonstrates that each ecosystem classification has a discernible spectral albedo signature when accompanied by snow on the ground. This indicates that winter canopy and underlying surface radiative properties are impacted by the presence of snow overlying these surfaces.

It is the intention of the authors to provide researchers with representative spectral albedo values of IGBP ecosystems in the presence of snow that are derived from validated satellite data. It is anticipated that these statistics will be incorporated within land surface models in a stand-alone mode, to prescribe albedo values in atmospheric General Circulation Models (GCMs), or be incorporated into research and operational projects.