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# Unmanned continuous reflectance monitoring of snowed surfaces

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## Introduction

The monitoring of the cryosphere is mandatory to the comprehension of climate changes in polar areas. Snow cover, in fact, is extremely sensitive to variations in weather conditions (Callaghan et al. 2011;Valt&Salvatori 2016), such as the presence of wind or changes in air temperature. Furthermore, the analysis of the snowed surfaces, coupling remote sensed images and field data, can offer the best option to monitor the cryosphere changes through time. The availability of ground-truth observations concerning the spectral albedo, in the wavelength between 400 and 2500nm, can support remote sensing analysis not only to derive the spatial distribution of snow/ice covers, but also to supply information about their physical characteristics (Pope & Rees 2014; Domine et al.2006). The reflectance of pure snow in the visible (Vis) range of the electromagnetic spectrum (400–700 nm) shows, in fact, a value of approximately 1 and its decrease depends mostly on the amount of impurities. On the other hand, in the short-wave infrared (SWIR-700–2500 nm) snow reflectance decreases rapidly and it is mostly controlled by the snow grain size (Warren&Wiscombe 1980;Wiscombe & Warren 1980). This different behavior of the reflectance in the Vis range and in SWIR range supports the discrimination between snowed surfaces and other matrices, their characterization in terms of snow grain size and shape (Nolin 2010; Salzano et al. 2008; Painter et al 2003), and the detection of liquid water in the first layer of the snow pack (Meinander et al.2013). The continuous monitoring of the snowed surface offers an effective tool to gather integrated information about the evolution of cold regions in response to daily/hourly variations. However, the availability of continuous observations in polar areas is limited, especially considering the difficulty of obtaining a multi or hyperspectral images without cloud cover. While measurements of broadband albedo are performed continuously from different polar observatory, observations on the spectral albedo are still limited, for logistical reasons, to short periods. Even in Ny Ålesund, where the data collected by the scientific community are numerous and well diversified, continuous monitoring of spectral albedo was a gap. In the framework of the ARCA project, and in cooperation with the PNRA program with the STRRAP-b project, the authors developed an activity devoted to implement the CCTower facilities, with an innovative instrument aimed to obtain continuous spectral albedo measurements of the snow surface.

## Field activities

The activities carried out since 2014 to nowadays can be summarized in two principal phases. The first phase of the project started in 2014: a portable spectroradiometer Fieldspec 3 was specifically adapted to work continuously with of a tilting system realized to supported the collection of asynchronous hyperspectral measurements. The system was installed at the CCtower (about 8 meters above the ground) in May and the measuring campaign covered the period from May 25th to July 5th 2014, when the weather conditions were considerably variable. It collected radiant energy through a Remote Cosine Receiver (RCR) for measuring the spectral radiation between 350 nm and 2500 nm with a maximum resolution of 1 nm. Single spectral measurements were acquired performing one 180-degree rotation cycle every 15 minutes in order to collect downwelling and upwelling fluxes with the same measuring system. Standard deviation obtained by triplets of spectra

provided information on sky stability, hence, determining the possibility to perform accurate determination of the spectral albedo. Moreover, the background noise spectrum (dark measurements) was acquired every hour. The instrumental setup was completed by a weather protected fish-eye D-LINK (DCS 6010-L) commercial web-camera, mounted on the same rotating platform. This hemispheric webcam captured images of sky and ground conditions every 15 minutes and supported the description of the experiment in terms of cloud and snow cover/roughness characterization. In addition to that, it provided a quality check of the rotating support position detecting the position of specific targets (Salzano et al. 2016).
During the second period the developed instrument (SnowIce CReM) was deployed in order to obtain multi-bands albedo at 860, 1240 and 1640 nm (fig.1a,1b,). These bands were selected in order to support also the estimation of the Normalized Difference Snow Index (NDSI). This parameter, defined as the ratio between (Vis-SWIR) and (Vis+SWIR), is usually computed by remote sensed data for investigating snowed areas. The SnowIce CReM instrument consisted of 3 twins sensors collecting simultaneously the upwelling and the downwelling radiances in the selected wavelengths ranges. This instrument was deployed at the CCTower during the 2015 field campaign together with the Fieldspec in order to check the performance of the system. The radiometric measurements of both apparatus (Fieldspec and SnowIceCReM) were hemispheric, in the 350-2500nm wavelength range. While the first apparatus obtained asynchronous spectral albedo, the second one provided synchronous spectral albedo on bands selected considering sensors deployed on satellites. The same quality check approach was used also for the organization of both dataset. In September 2015 a mast close to the CCT was prepared and the SnowIceCReM apparatus was moved in that position in order to record spectral measurements of undisturbed snow surface. SnowIceCReM is actually running at Ny Alesund since April 2015 and the data analysis of the melting seasons is an ongoing activity

**Preliminary results**

The experimental surveys produced a large number of observations during each melting season. The total number of image pairs (facing to the sky and to the ground) acquired in the 2014 campaign, for example, was 1728. The images were processed and the cloud cover was defined in order to select the spectra that can be used to compute snow reflectance data set; we considered a threshold of 90% of cloud-covered sky for the definition of the diffuse light condition and a cloud index of 10% for the identification of cloud-free sky where direct irradiation is dominant. The radiometric data are presented in fig. 1 according to snow and meteorological data provided by the CCTower. From a qualitative point of view, each melting season is characterized by different phases with specific melting ratios influenced by the skin temperature $T_{skin}$ and the snow height. These phases can also be recognized analyzing the behavior of the radiometric values re-sampled or centered in the MODIS bands range (B4: 545–565 nm and B6: 1628–1652 nm). The SWIR albedo pattern (B4) can be interpreted looking at the relationship between these spectral features and the specific surface area of the snow cover, the surface roughness and the presence of impurities in snow. The evolution of the NDSI was strictly related to the snow aging that could be described by the snow depth reduction in the first part of the season. In addition to that, steep increments can occur in correspondence to precipitation events or to strong-wind conditions. The raw data of the 2015 campaign, confirm this connection between spectral data and meteo-climatic conditions of the snow cover. Precipitations, wind speed and ground-temperature gradient are key parameters that if correlated to the detected spectral features can support the inference between spectral reflectance and metamorphism of the snow cover. From this perspective the activity must be completed by a strong effort in calibrating our systems at different sun-elevation angles in order to assess the daily variations of the spectral albedo. Further work will be performed to couple the observed NDVI index with the pattern derived by multitemporal images of Ny Alesund area.

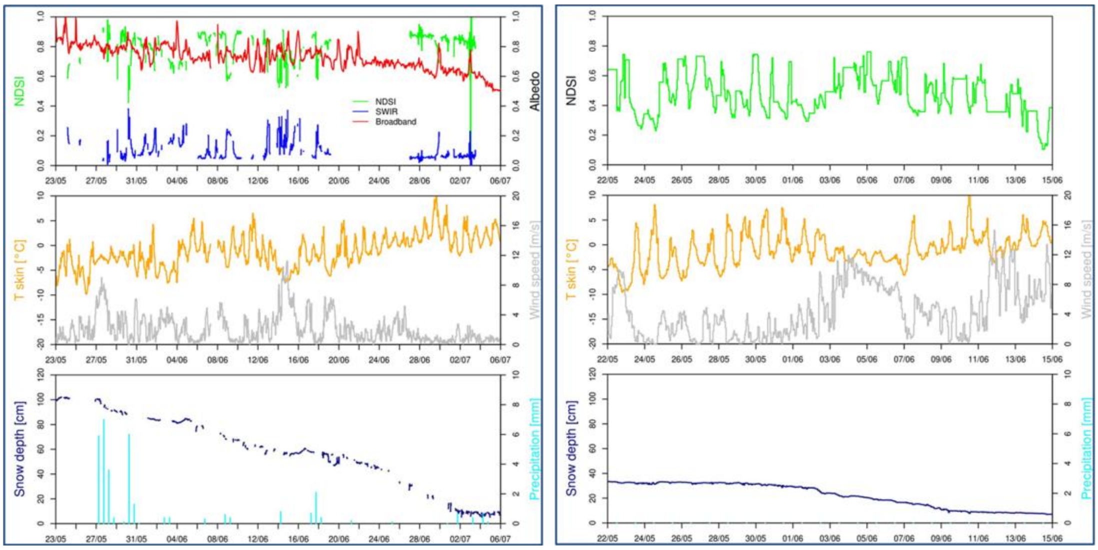


***Figure 1:*** *Preliminary result for the melting season 2014(right) and 2015 (left)*

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