Final conference
Rome October 11 2016

project ARCA

ARCTIC
PRESENT CLIMATIC CHANGE
and PAST EXTREME EVENTS

Snow spectral albedo variation as a tool for arctic environmental monitoring

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ARCA project

ARCA Task: *Continuous Vis-Near Characterization of snow-ice surface in Ny-Ålesund* (RiS project 10241)

Involved people:

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Involved Project:

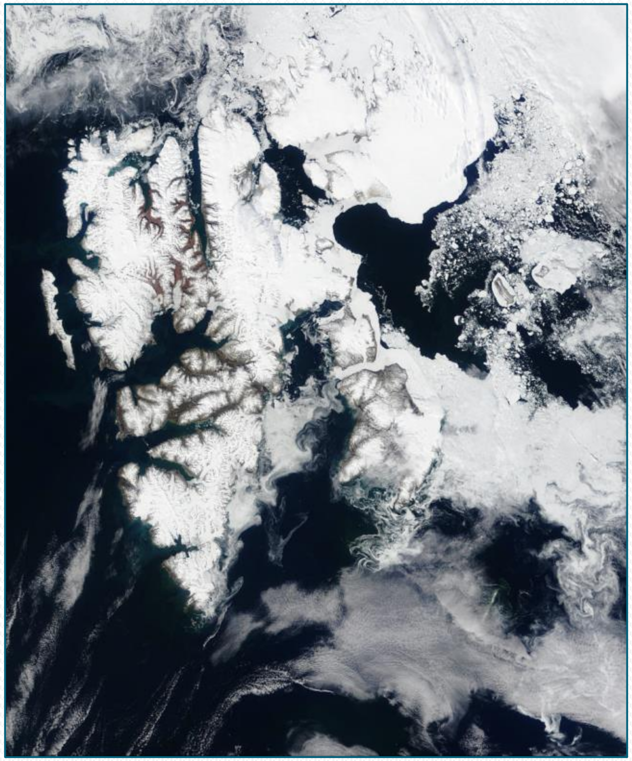
Study of the Radiative Regimes over the Antarctic Plateau and beyond [STRRAP-b]

Arctic environment

In the Arctic and Subarctic regions, nival-glacial processes are active all over the year and have an extensive impact on the ecosystem: snow and ice are the most relevant features, but they are strictly linked to the morphological features of the region and to the meteo-climatic conditions that create a network of multi-dependent interactions.

Snow cover is extremely sensitive to small variations in weather conditions, such as the presence of wind or changes in air temperature.

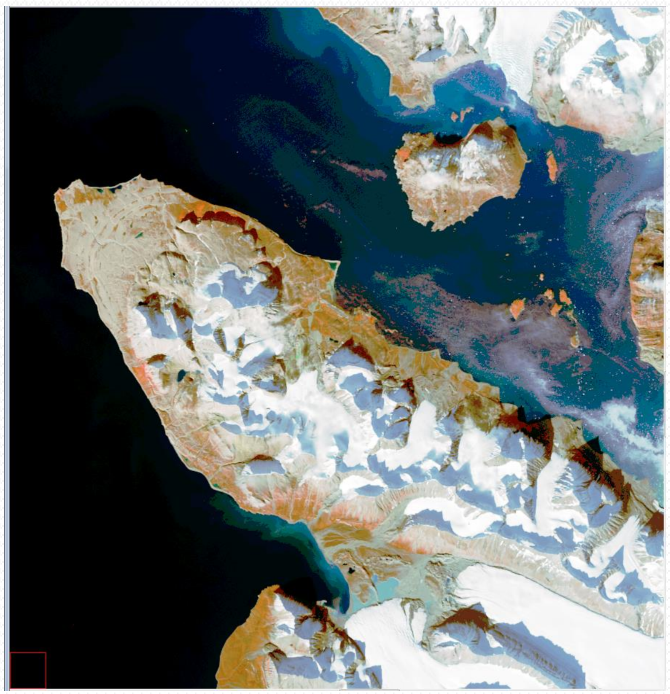
The monitoring of the snow cover is mandatory to the comprehension of environmental processes and climate changes in polar areas.



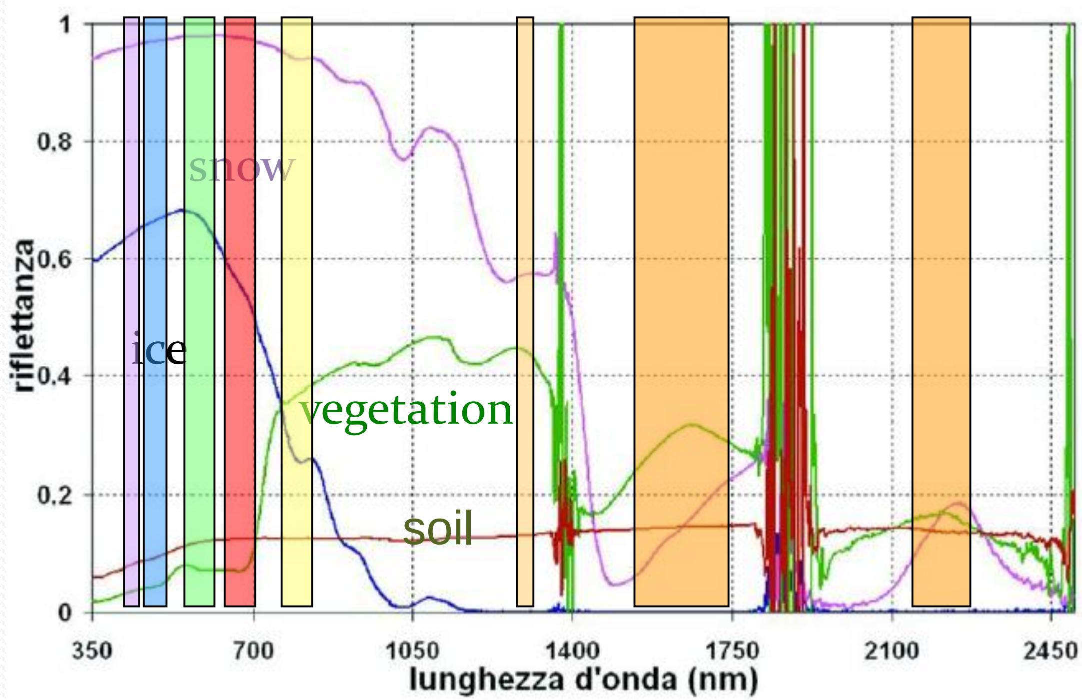
The snow cover in polar areas as well as in mountainous areas can be effectively monitored with satellite data.

Satellite data

Monitoring Earth with satellite passive sensors is possible because the surfaces spectral behaviours is strictly connected with chemical and physical proprieties of each type of surface.



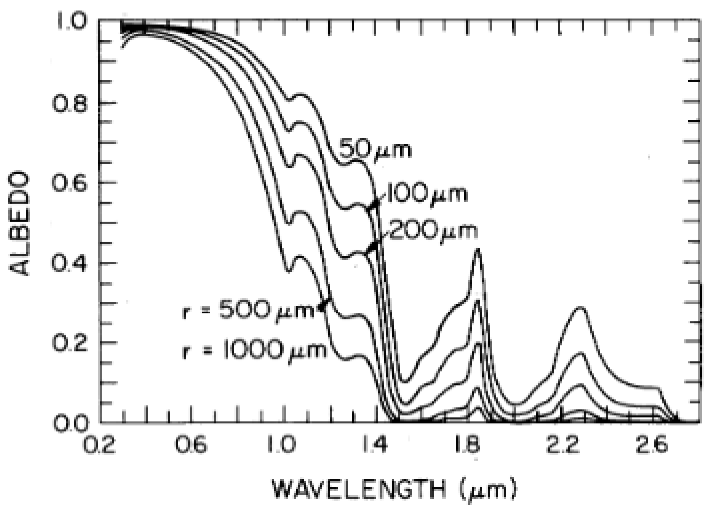
Landsat 8 OLI bands



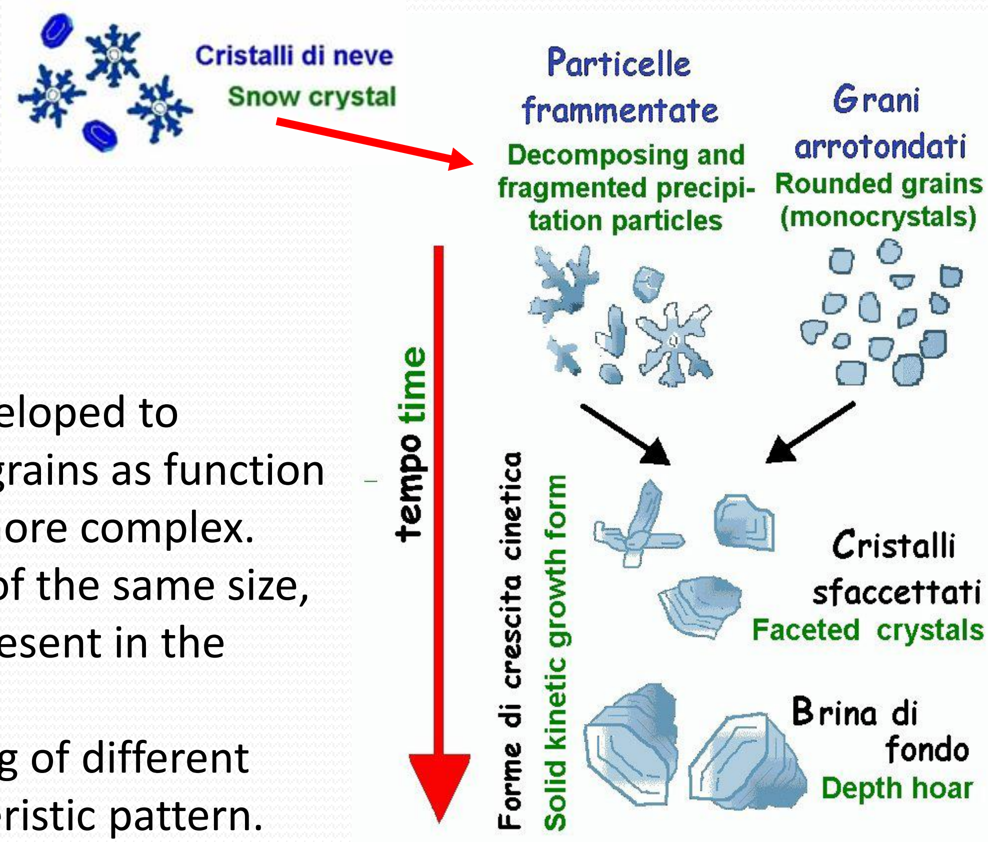
Satellite sensors are designed to collect the solar radiation reflected by the surfaces, in specific spectral ranges, selected to define/describe the investigated surfaces.

Satellite data validation require ground truth field data

Snow surface characteristics



Snow grains can rapidly change themselves following meteo-climatic conditions and time.



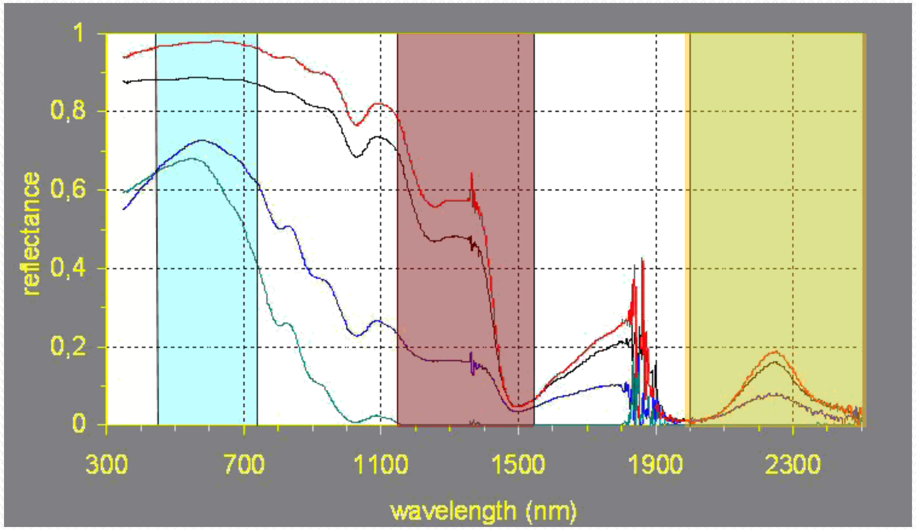
Since 80s, several models have been developed to evaluate the spectral behaviour of snow grains as function of their radius. Natural surfaces are far more complex. Snow grain are not spherical and not all of the same size, and different types of grain are usually present in the same surface.
Snow surface is generally a delicate mixing of different grains that scatters the light in a characteristic pattern.

Satellite data: NDSI

Due to the differences between snow, ice and cloud spectral behaviour, satellite can be used to derive snow cover maps as well as snow types distribution map.
The most common spectral parameter used in remote sensing for the investigation in snowed areas is the Normalized Difference Snow Index (NDSI).

NDSI= (RVis-RSwir)/(RVis+RSwir)

The NDSI was originally proposed for snow mapping from Landsat multi-spectral images and now it is currently implemented in the NASA EOS data chain.
The index was developed at first for discriminating snows cover and clouds, but it is now used to map systematically pixels that have a fraction of snow cover higher than 50 %.

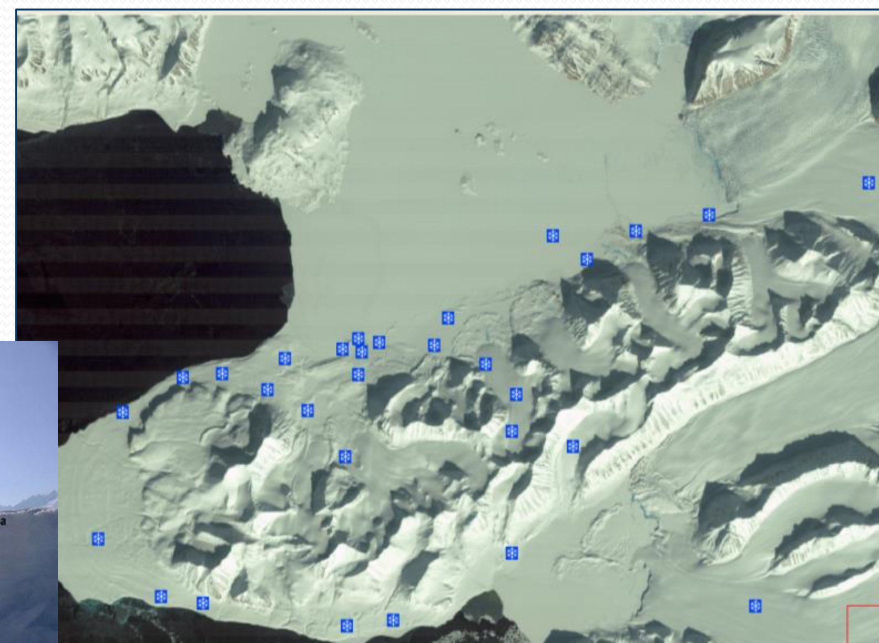


Field surveys

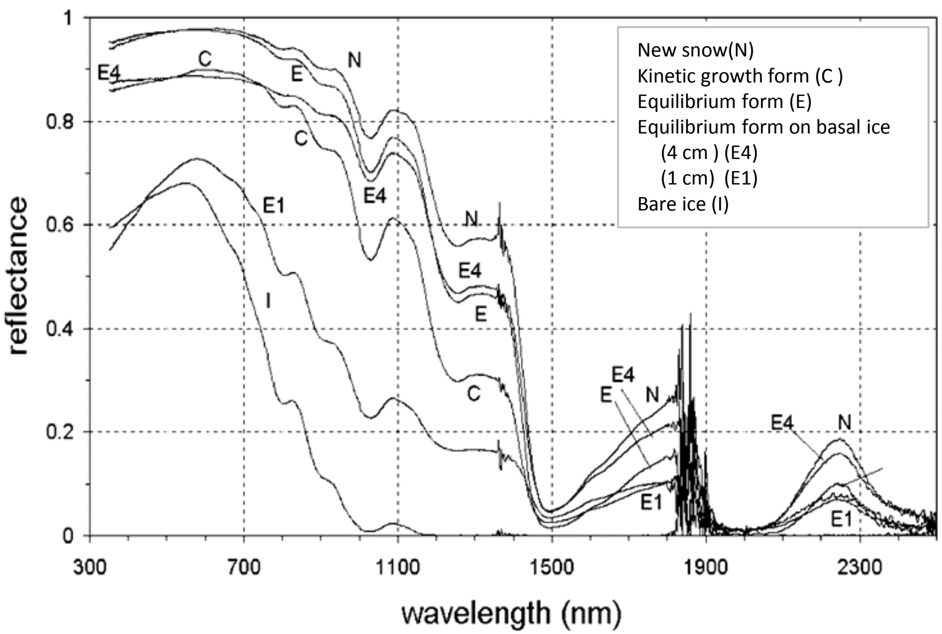
To better understand correlation between the radiometric data and physical properties of the snow is important to use field data

For this reason in the last years field surveys were carried out all along Brøgger peninsula (Svalbard Is.)

Spectroradiometric measurements, in the spectral range between 350 and 2500nm were coupled with detailed nivometric observations.



Snow reflectance data

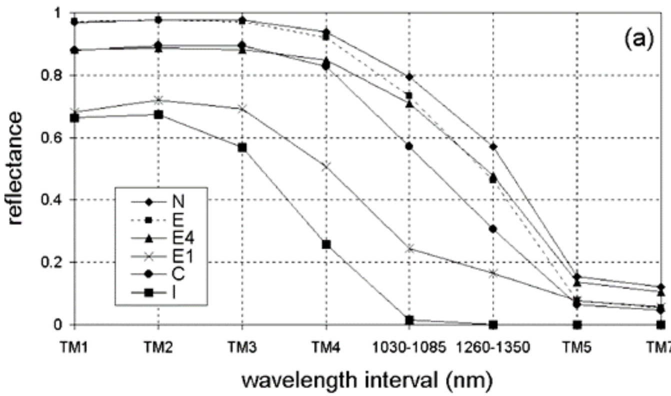


The reflectance of pure snow in the visible (Vis) range of the electromagnetic spectrum (400–700 nm) shows a value of approximately 1.0 and its decrease depends mostly on the amount of impurities.

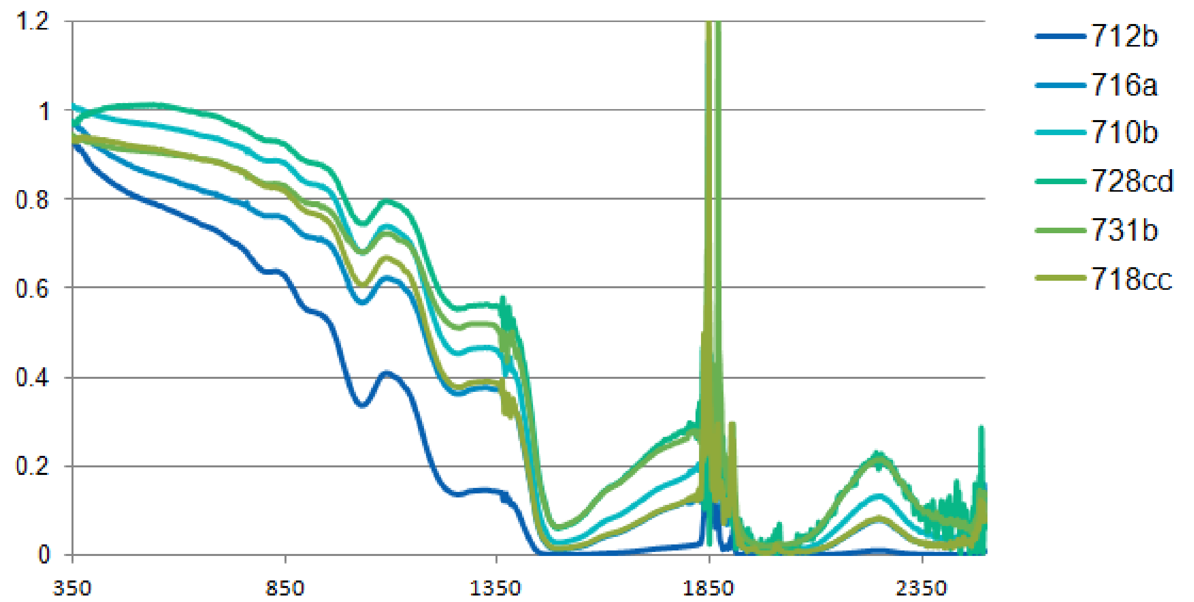
On the other hand, in the short-wave infrared (SWIR 700–2500 nm) snow reflectance decreases rapidly and it is mostly controlled by the snow grain size.

Ice reflectance values are lower all along the spectral range and above 1000 nm are negligible.

These features are clearly visible also observing reflectance data in satellites ranges.

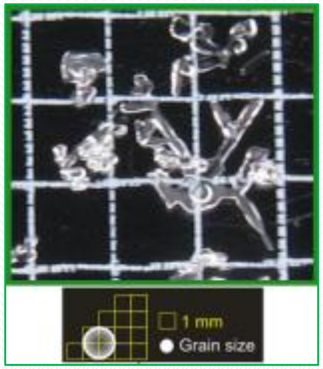


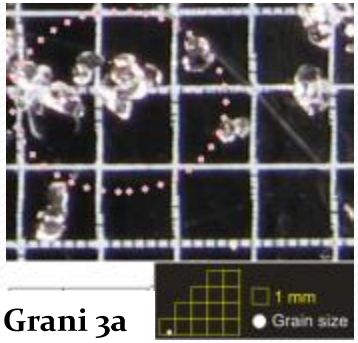
Reflectance vs snow grains shape and size



target	Grain	%	Φ mm
712b	3b	100	0,8
716a	3a 7a	50 50	0,5 1,0
710b	3a	100	0,6
728cd	2a 7a	80 20	1,0 1,0
731b	1f 1r	50 50	0,6 1,2
718cc	7a 3b	80 20	1,0 0,5

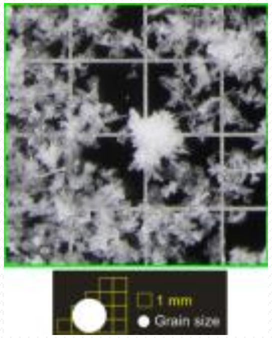
Grani 2a





Grani 3a

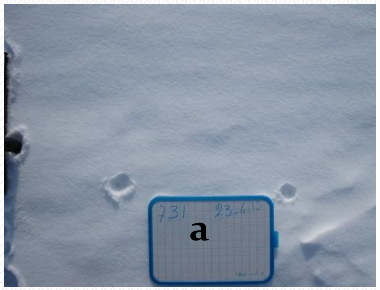
Grani 1f

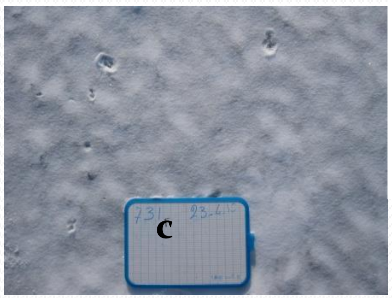


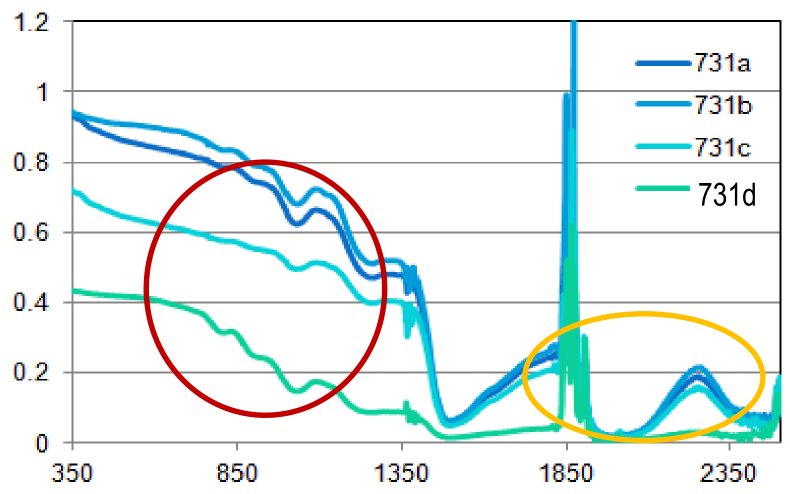
http://www.snowcrystals.it

Snow evolution can be recognized observing the reflectance values variations in SWIR range.
Spectra were collected in the same site in different days

Reflectance vs snow thickness and roughness







The reflectance of the target increases with the thickness of the snow layer.

Drifted snow

Grain	%	Φ cm
1f	**0,5**	**0,6**
1r	**0,5**	**1,2**

The reflectance of the target is strongly dependent on roughness.

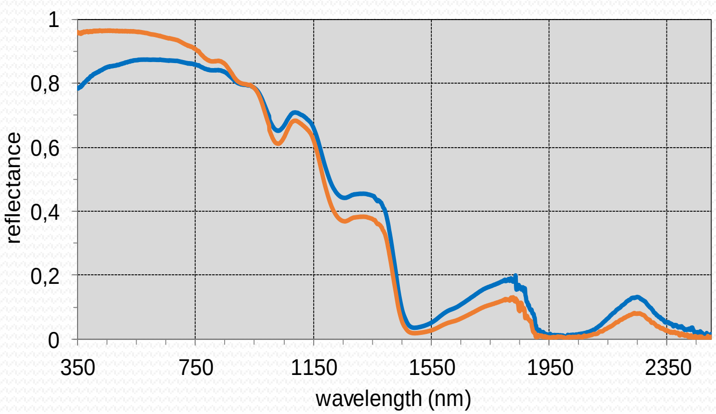
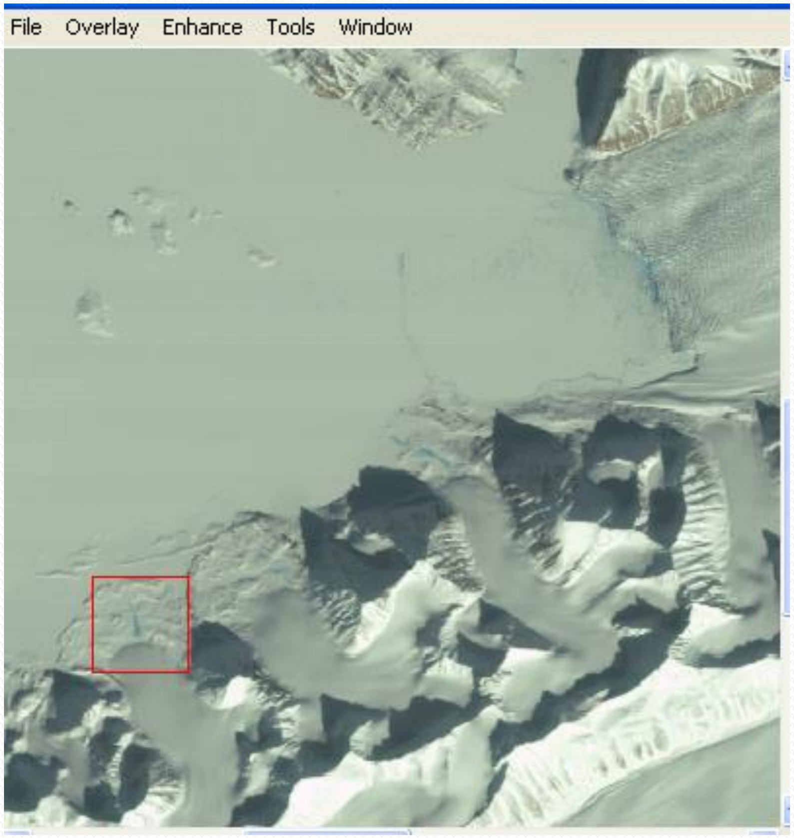
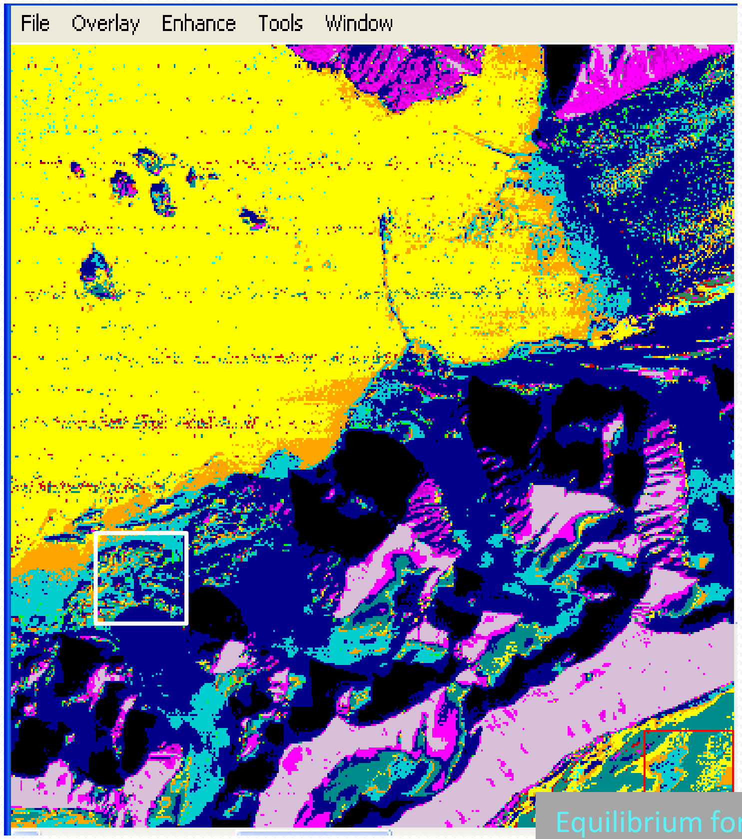


Image processing

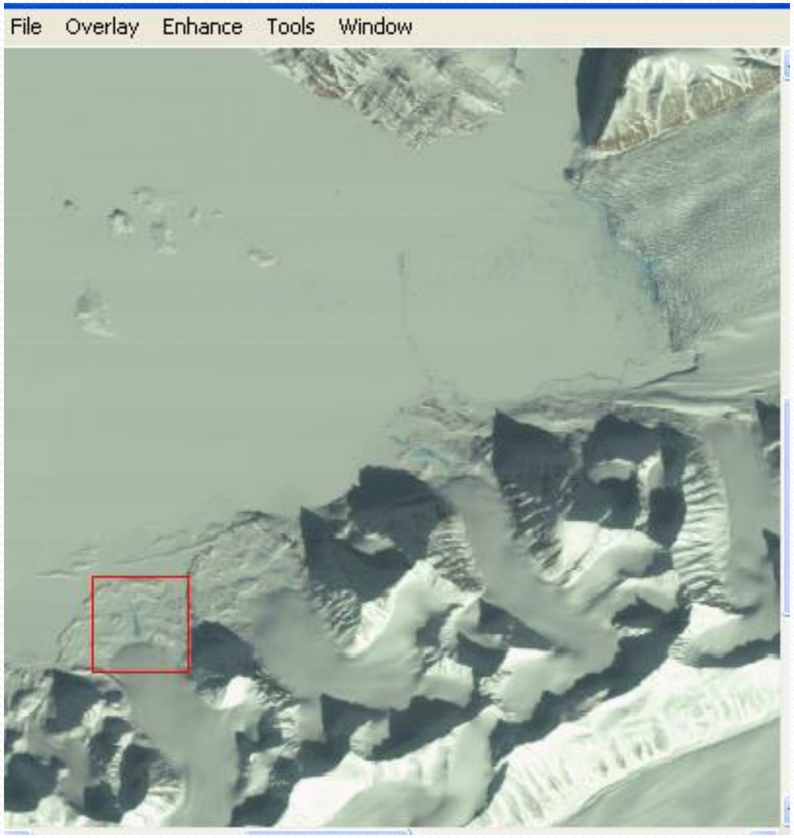


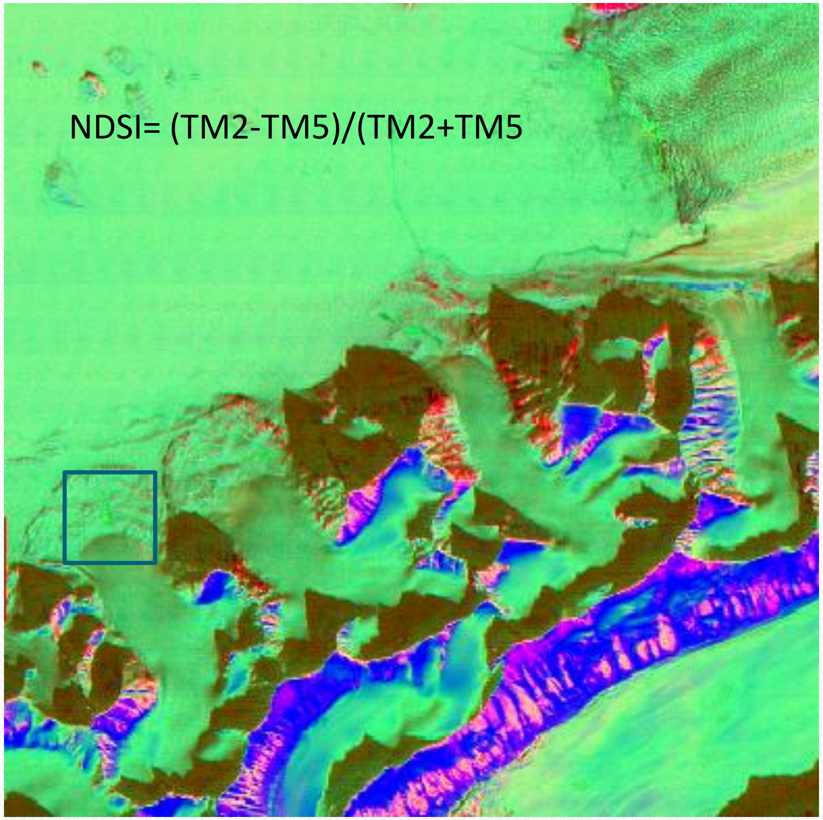


Equilibrium form
Equilibrium form**(4cm)**
Equilibrium form**(1cm)**
Kinetic growth form

Following the previous considerations on the snow cover spectral characteristics, field data has been used to process a Landsat images to discriminate different snow and ice surfaces.

Image processing: NDSI





This index emphasize the differences in snow cover distribution and multitemporal NDSI images, with the validation of field data, can be used to mark the beginning of the melting season.

Melting season monitoring

In the Arctic Region, melting is a rapid process and its monitoring requires high temporal frequency radiometric data either from satellite sensors or from field surveys

This kind of data are difficult to acquire for:

Satellite data are often affected by a high cloud coverage. Frequent revisitation rate satellite have not a suitable spatial resolution, while high resolution satellite revisitation rate is too low for these latitudes

Field campaigns are scheduled in advance and so they cannot be perfectly overlapped to the melting season

For these reasons, the availability of continuous observations in polar areas is limited, even in Ny Ålesund where many instruments are installed from different research stations

ARCA activity

In the framework of ARCA project we decided to fill this gap implementing a experimental system to continuously monitor snow spectral variations during the whole melting season.

As testing site we selected the CNR CCT, not only for logistic reasons, but also for the morphological asset of the area and the limited interactions with the inhabited area.
The CCT area is also well detectable on remote imagery.

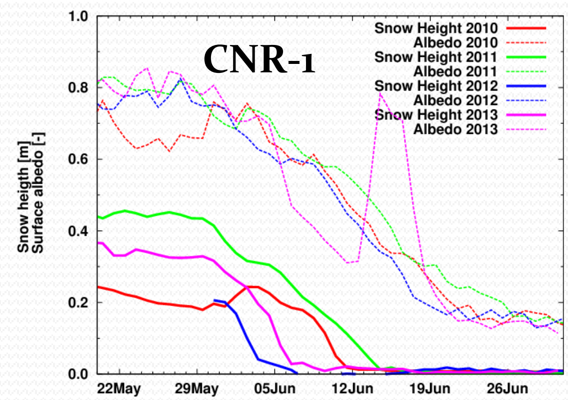
CCT data

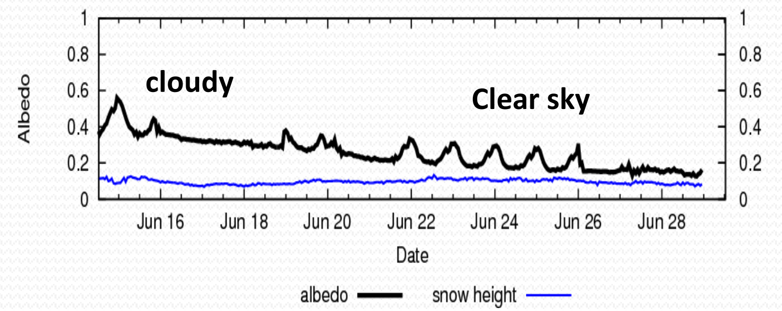
Broad band albedo values supplied by CCT instruments are related to the snow height.
But snow height is a single measure point where albedo it is a wide surface integrated data.
Broad band albedo is therefore a marker of the snow cover modification but does not supply a detailed information about the fraction of surface covered by snow.

Climatic Change Tower **basic setup :**

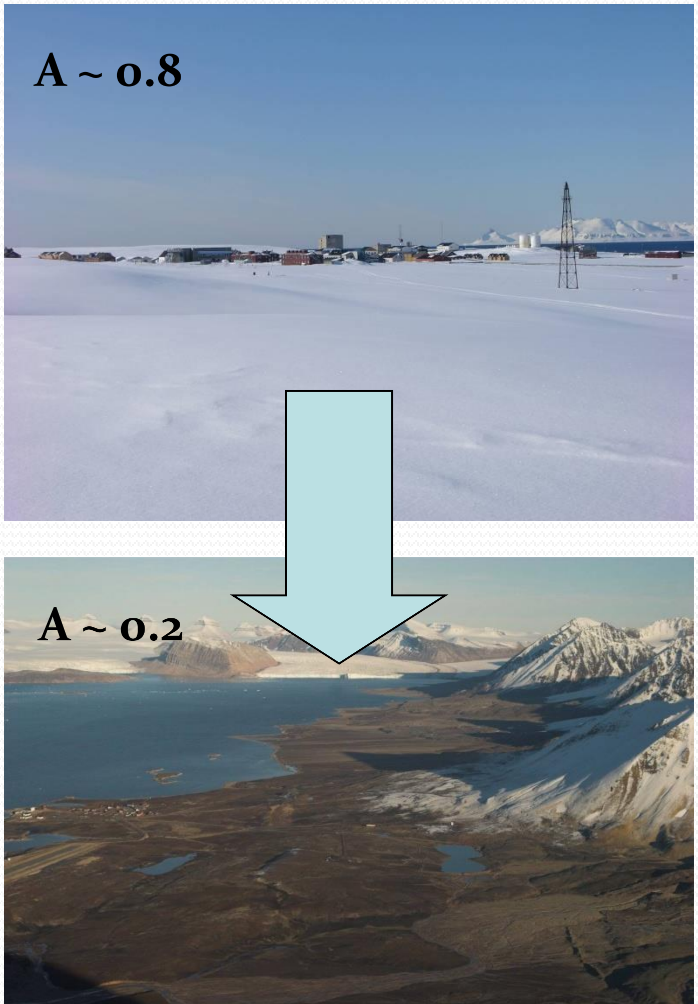
- Four T,RH and wind levels
- Net Radiometer CNR-1, and ventilated CM11, CG4 for upwelling components
- Snow height (sonic) and skin temperature (IR camera)
- Sonic anemometers and KH20
- Real time data
- Internet connected

- 32 mt alu tower installed in 2009





Broad band vs Spectral albedo



Broad band albedo is thus a key tool for radiative balance studies and for climatic models but only partially suitable for remote sensing image analysis because it marks the snow cover modification but does not supplies a detailed information on the fraction of surface covered by snow and on the snow surface characteristics.
These information are significant environmental parameters to describe e. g. permafrost and vegetation seasonal evolution.

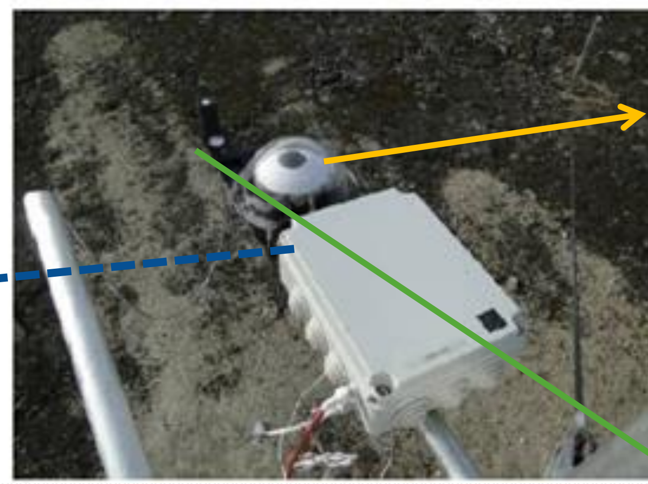
Continuous Vis-Near Characterization of snow-ice surfaces

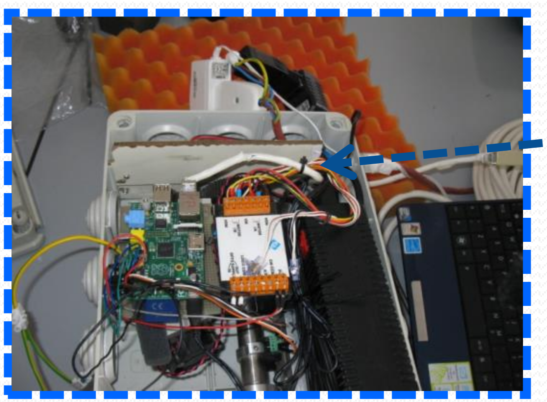
Therefore, ARCA task (*Continuous Vis-Near Characterization of snow-ice surface in Ny-Ålesund* RiS project 10241) has been focused on improving our knowledge of the melting period from a radiative point of view by means of:

- Monitoring the spectral reflectance within the 350-2500nm range with a commercial handheld field spectrometer (*ASD FieldSpec3*)
- Studying the connections between spectral and broadband albedo (spectral-to-broadband parameterization)
- Investigating how the sky status affects the albedo, in terms of cloud cover and turbidity.
- Testing of a system for the remote operation of the spectroradiometer

First step

The first step continuous monitoring system consists of the commercial instrument (ASD FieldSpec 3) equipped with a rotating platform and a wide angle sky camera. The system is designed to, continuously and automatically, acquire incoming and reflected radiation. Via internet, data are real time recorded and made available to remote analysis.



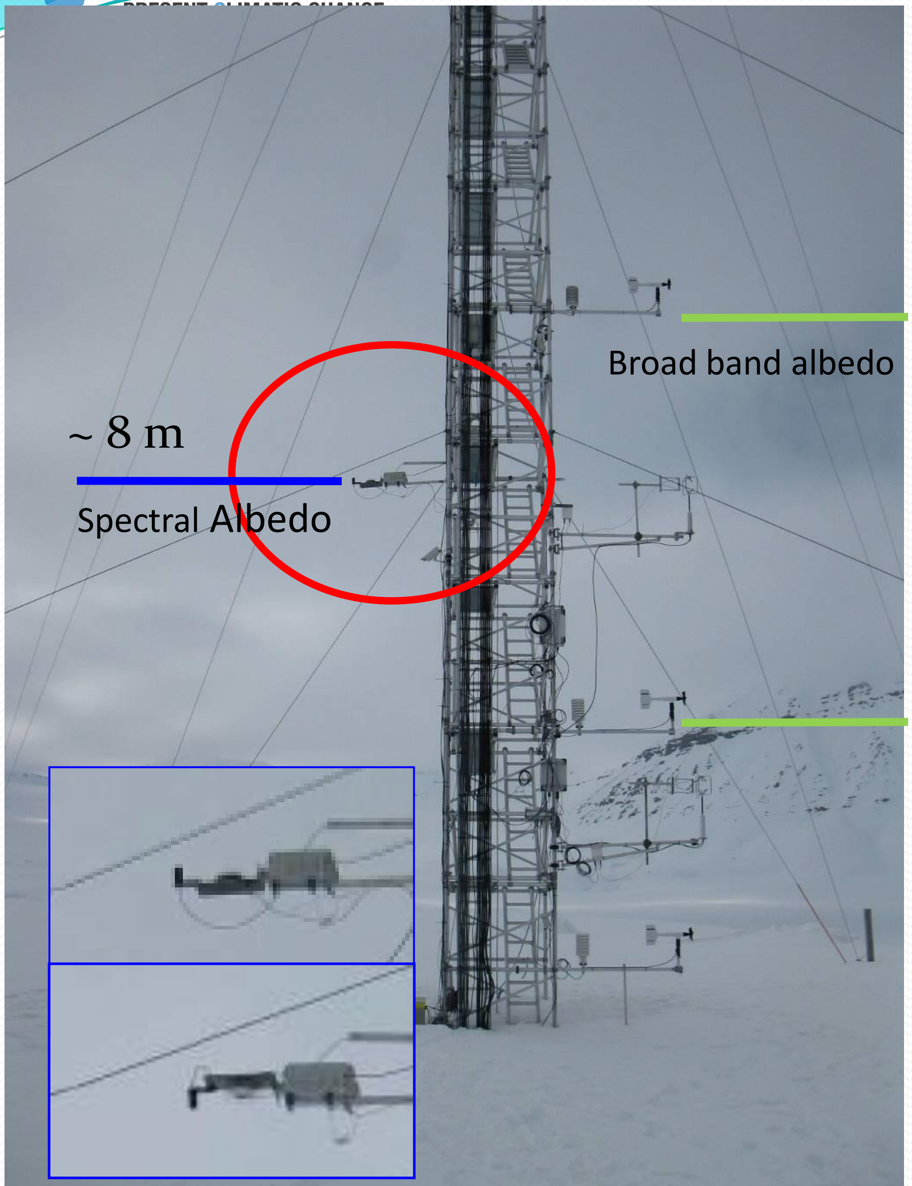


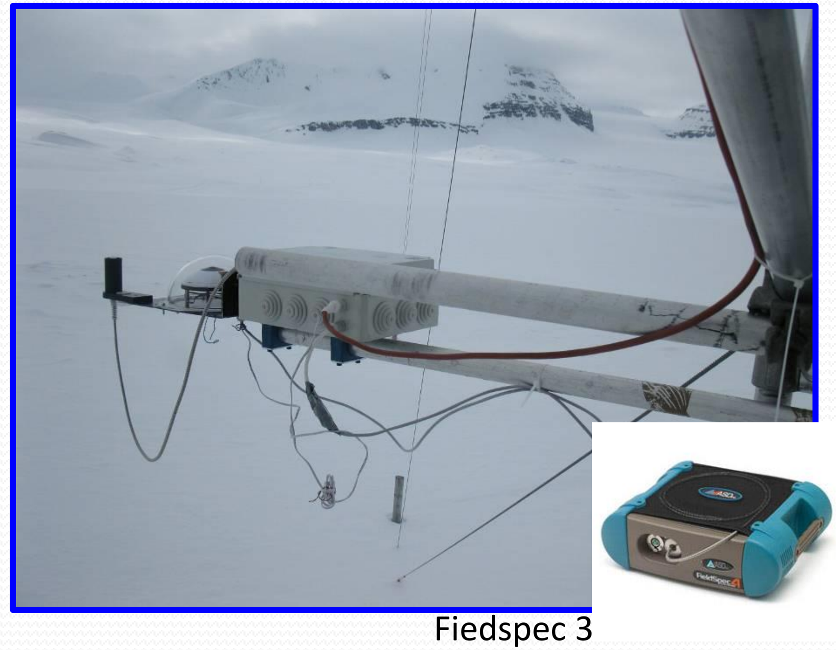
Rotating platform carries the sky camera ann the fieldspec sensor(optical fibre)

D-Link

sky camera (fish eye)

FieldSpec sensor.
The instrument is on the CCT





Fiedspec 3

Net Radiometer CNR-1

Continuous monitoring was active from May to September 2014

Image analysis

During this period, sky-facing and ground-facing views were acquired every 15 minutes.
Those images have been used

- to verify the correct position of the *FieldSpec* sensor
- to define the sky cloud coverage, analysing the central area that exclude the peripheral area and the tower (sky facing images)
- to derive the percentage of snow covered area (ground facing images)

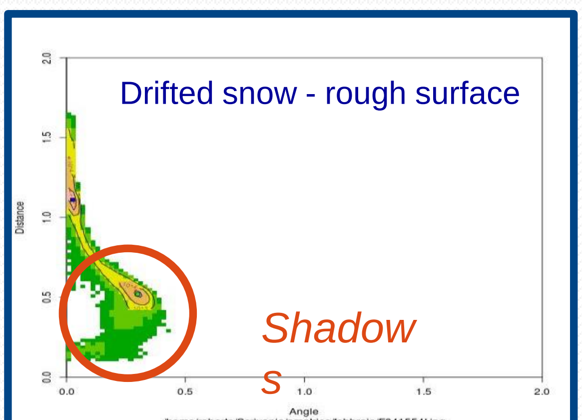
Image analysis

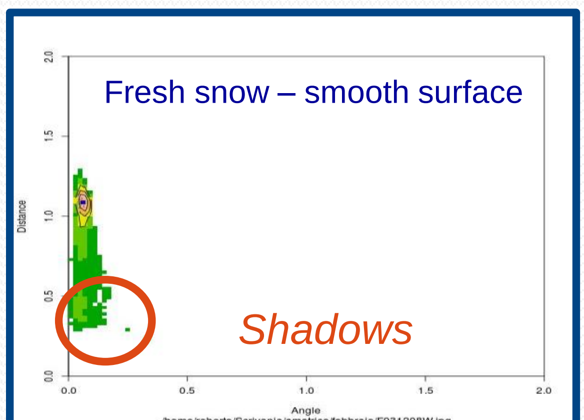
Image type	number
Sky instead of snow	165
Sky on the left	360
Sky on the right	394
Snow instead of sky	3956
Agreement	7916
Total	**12791**

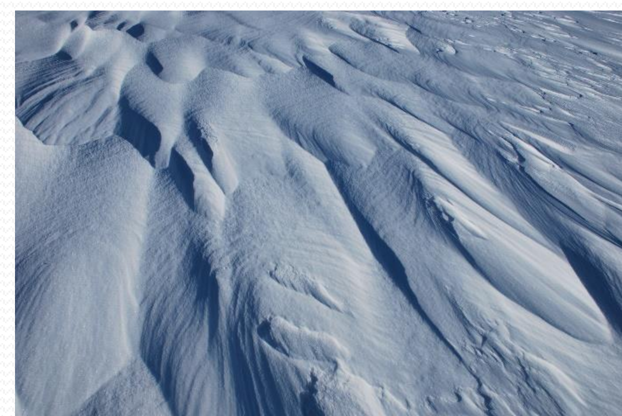
Good quality ground facing images have been used for snow cover analysis.

The multitemporal image series analysis has allowed the definition of the roughness of the surface, following the evolution of the shadows.

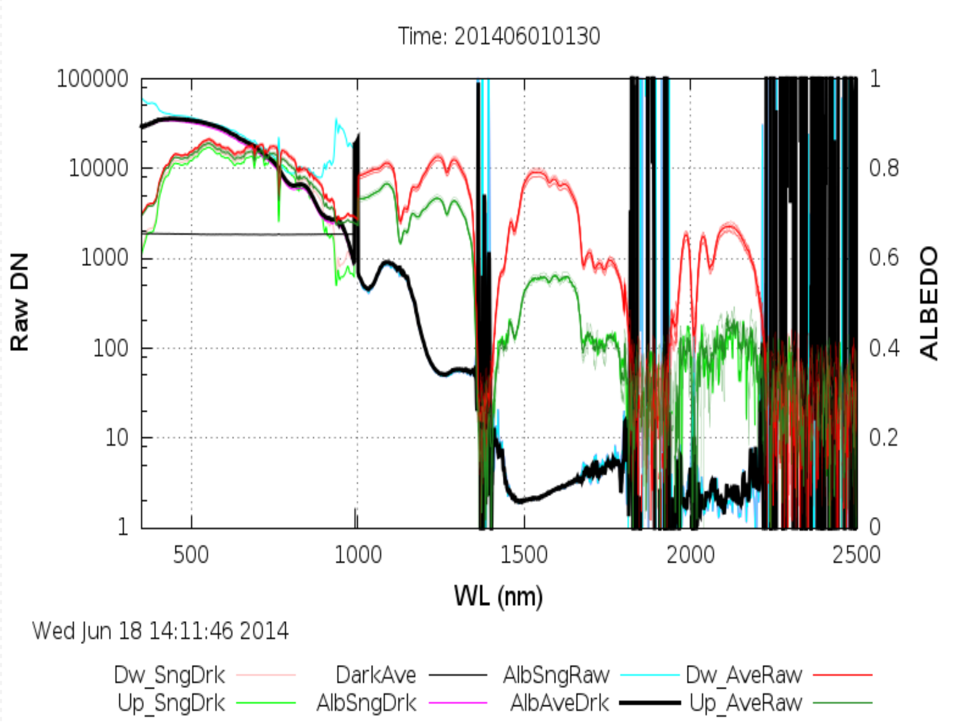
The surface morphology of the snow cover, in fact, is driven by the wind action and air temperature and influences critically the spectral signature of the cover.





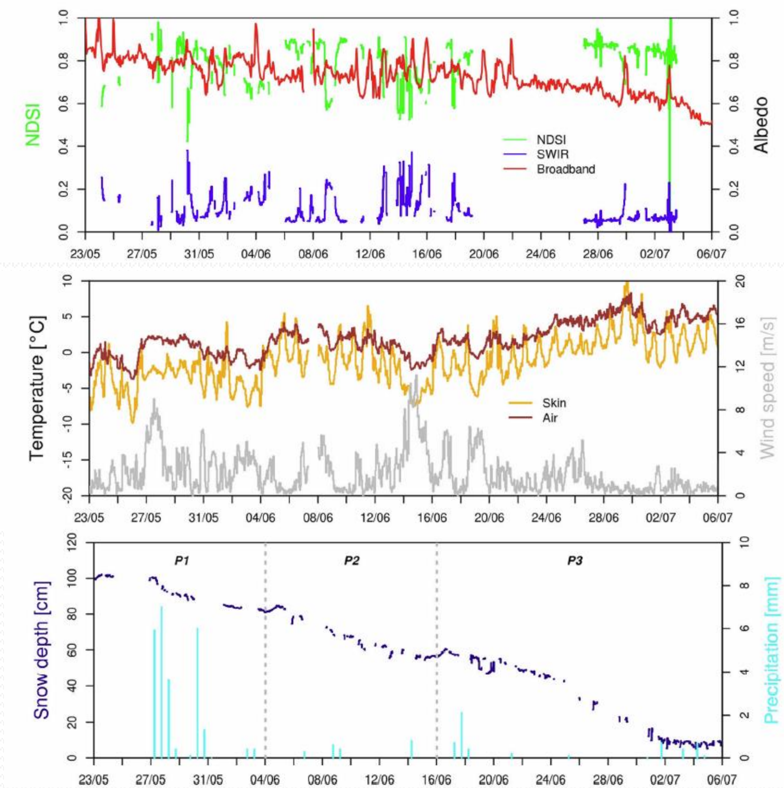


Spectral data analysis



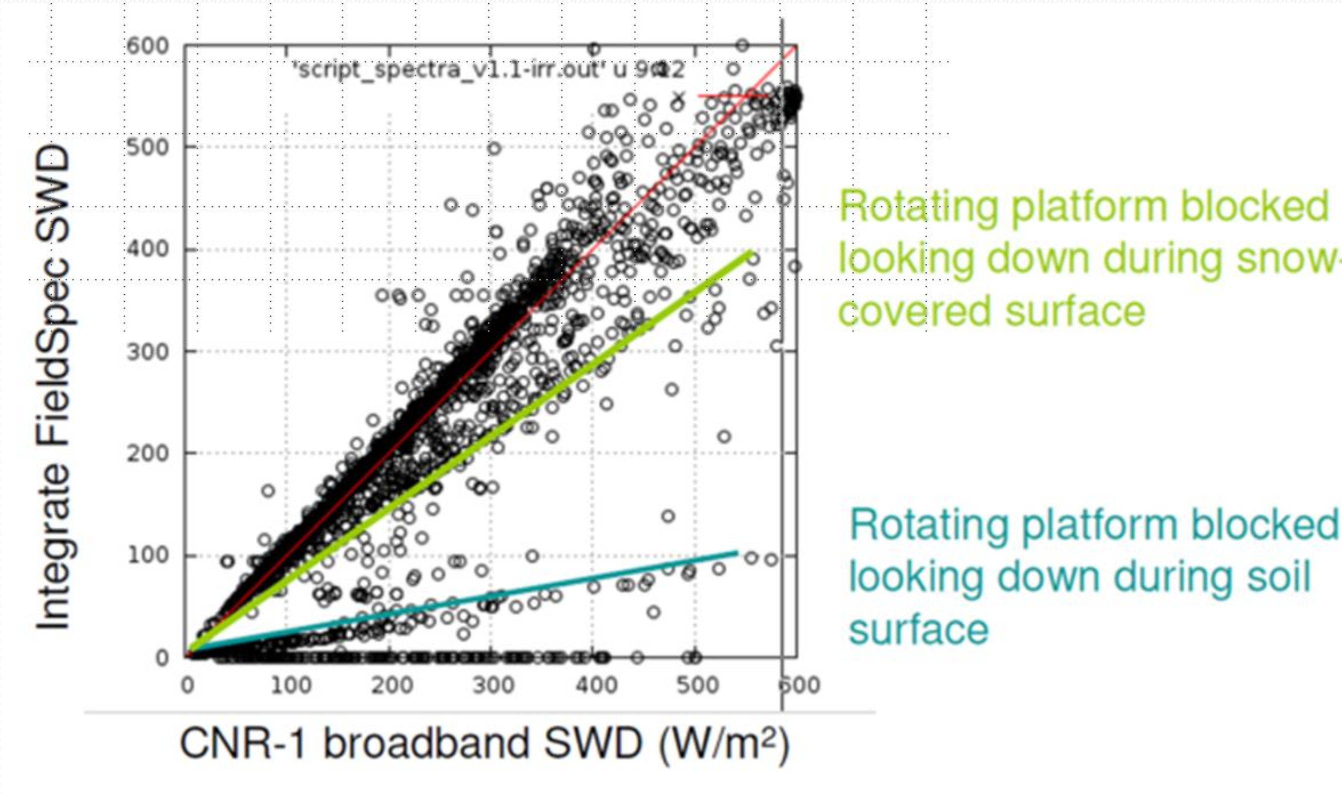
Spectrum obtained after a validation procedure.

Spectral albedo was resampled using MODIS intervals (545–565nm and 1628–1652 nm)



On the right, data are hourly averaged to reconstruct the evolution of the NDSI and SWIR albedo over the observed period in relation to broad band albedo and the main meteorological parameters obtained from CCT measurements (precipitation provided by e-Klima database).

Comparing the results

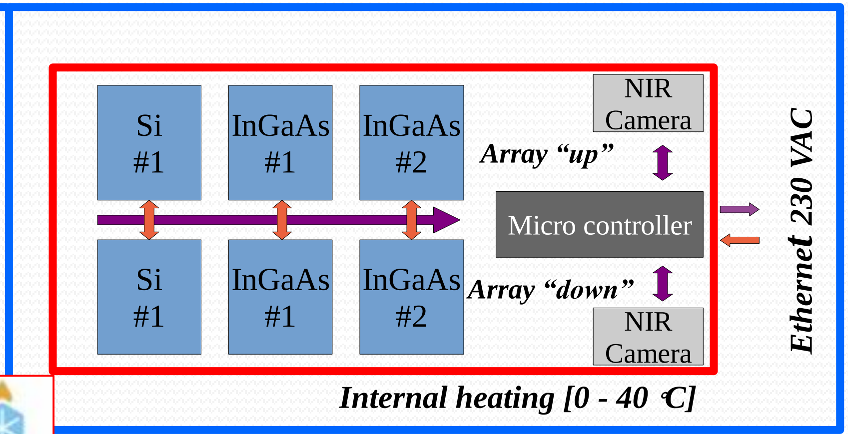


The comparison between *FieldSpec* integrated albedo and broad band albedo measured by CCT shows a very high correlation.
Outliers represent data acquired during malfunctioning of the rotation system.
The promising results and the mechanical difficulties suggested the design of a more efficient continuous monitoring system

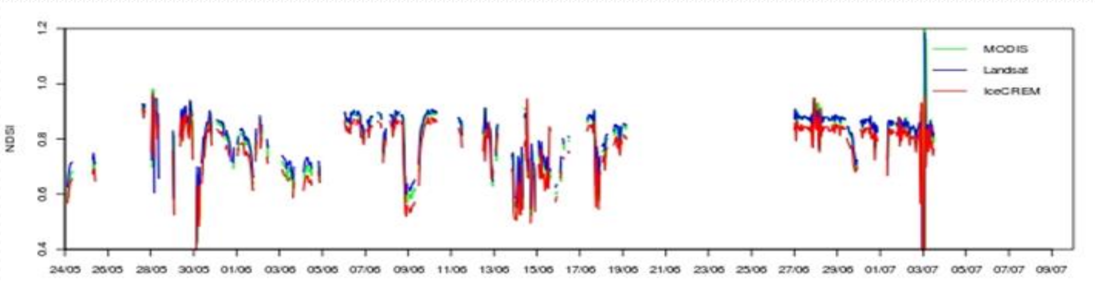
STEP 2: SNOWICECReM

In the second step of the activities a new instrument, (Snow Ice Continuous REflectance Monitor) consisting in 3 twins sensors collecting upwelling and downwelling radiances in three fixed band (860, 1240 and 1640 nm) was realized by our team *in house,* as well as the operational software.

The intervals were selected considering snow and ice spectral behavior, satellite image spectral range and the results obtained processing *FieldSpec* spectra.

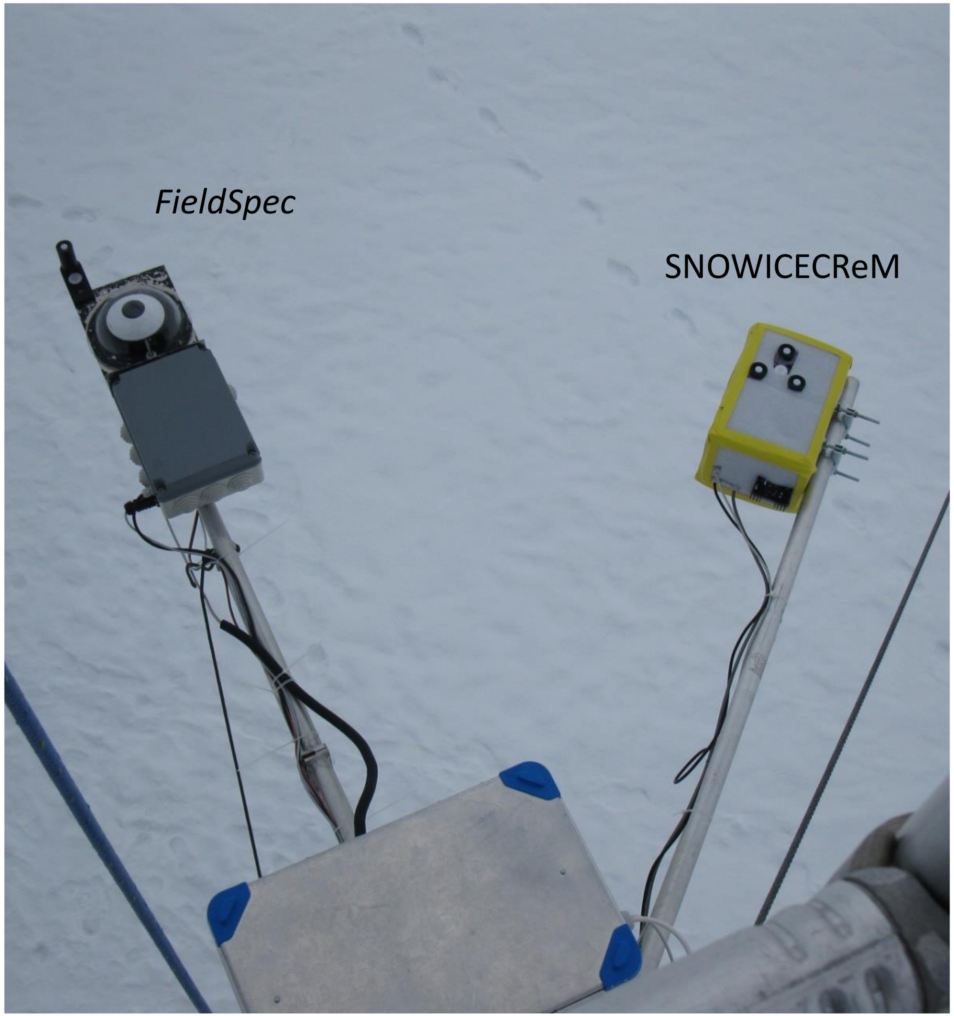


SNOWICEContinous Reflectance Monitor



Spring 2015: FieldSpec and SNOWICECReM

During 2015 springtime, SNOWICECReM has been placed on the CCT together with *FiledSpec* in order to control and validate its data acquisition.
The instrument is still working and also the winter season has not affected his functionality.
After a positive test period, a second instrument was realized and deployed to Dome C base in Antarctica.



Type: **Multi-band**

Spectral Range: **840-1260-1640nm**

*Geometry: **Bi-hemispherical***

Collection: **Synchronous**

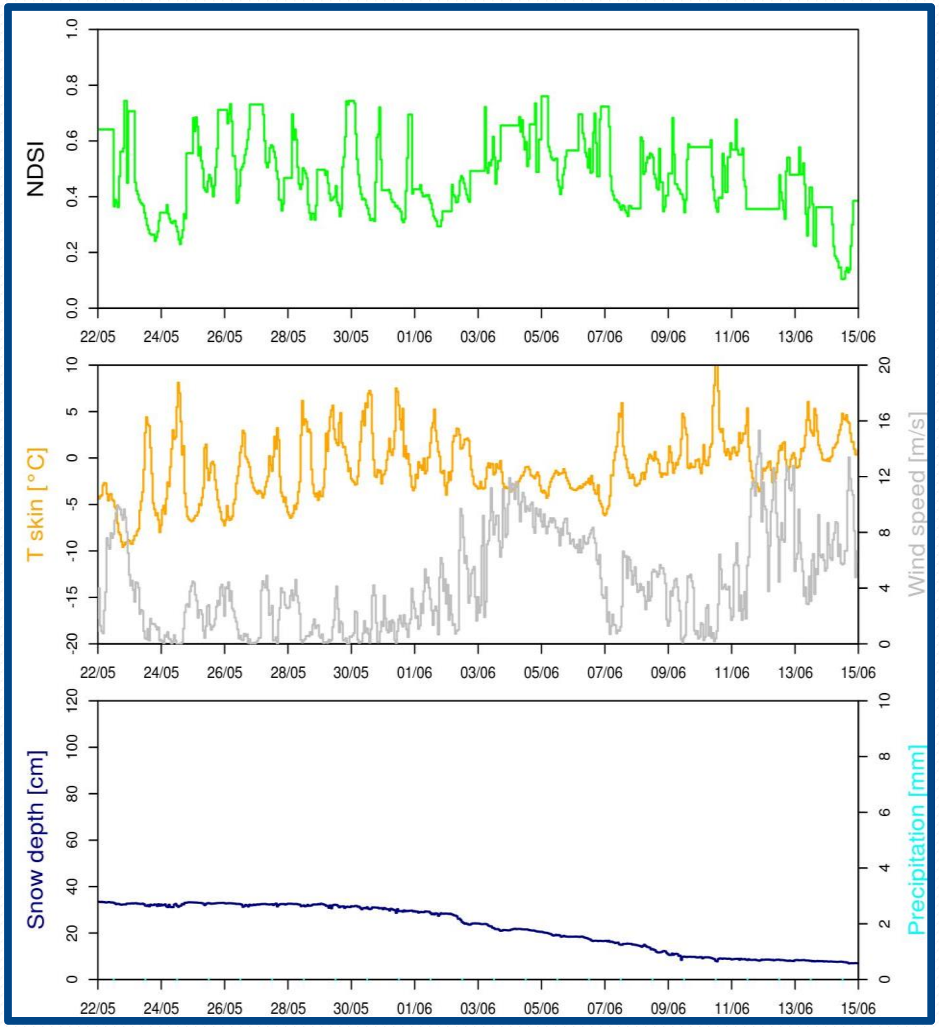
Foreoptics: **Six**

Rotation: **No**

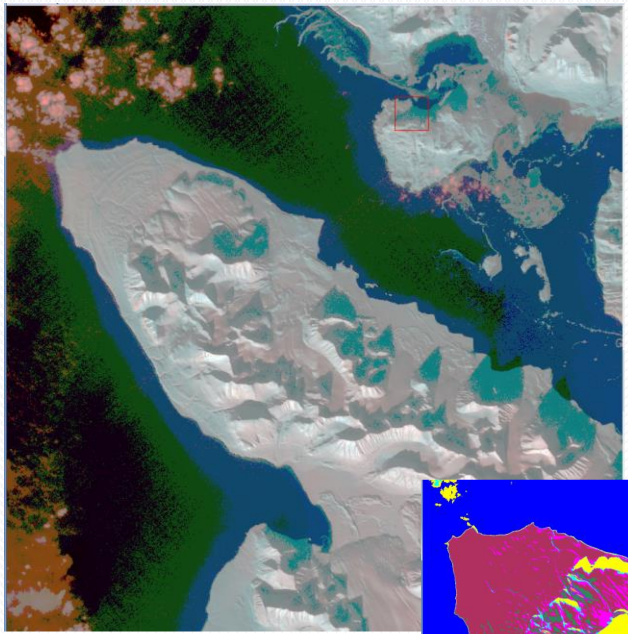
Hardware: **Si and InGaAs photodetectors**

Software: **Raspbian**

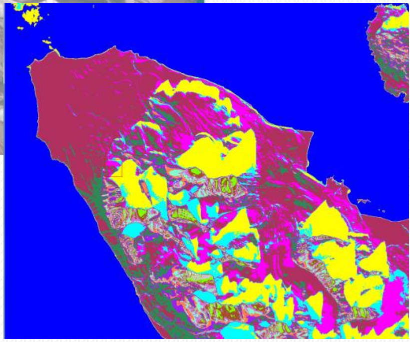
Preliminary results 2015



SNOWICECRem continuous spectral data can allow NDSI variations analysis.
These data will be merged to satellite images to describe snow cover surface characteristics at larger scale.



Landsat 8 - RGB 654

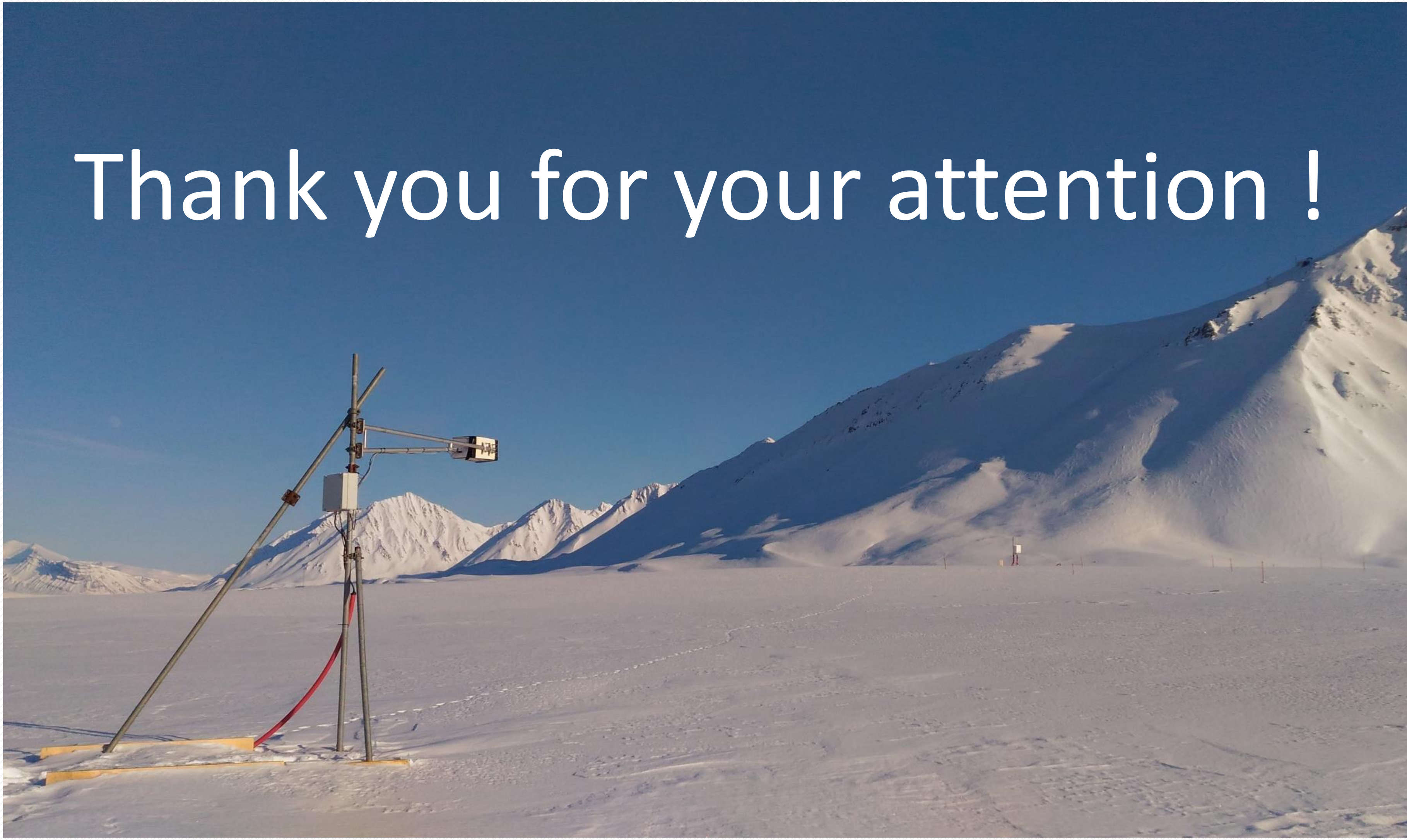


NDSI distribution map

In 2016, SNOWICECRem has ben moved to a new location to reduce the anthropic modification of the snow target.

Summary

- In ARCA project framework, a first attempt to associate snow metamorphism to snow spectral variations was carried out.
- A multi spectral device that can be deployed in polar regions for unmanned continuously monitoring of the spectral evolution of the snow cover has been realized
- SNOWICECRem is actually running at Ny Ålesund since April 2015 and the data analysis of the melting seasons is still an ongoing activity.
- We believe that SNOWICECRem can supply valuable continuous data, relevant both to radiative balance studies and satellite image processing devoted to environmental studies;


Thank you for your attention !