Snow albedo measured by FIGIFIGO

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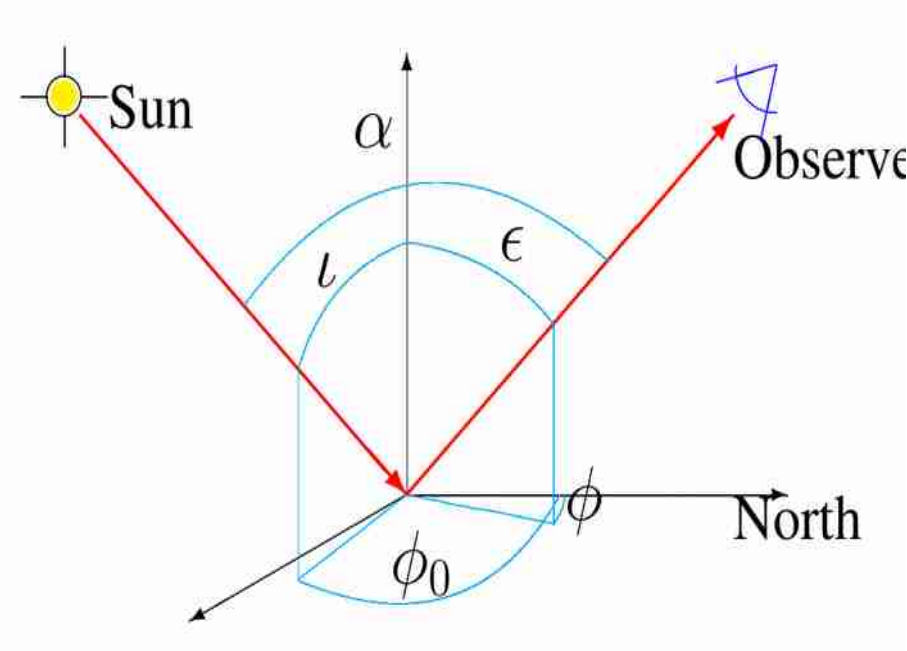
Motivation

- Quantitative remote sensing of Earth and planets
- Physical modelling of reflectance
- Testing models by experimental data
- Going to exciting field trips
- Innovating new observation techniques
- Snow is one favourite target, because
  - very important for Finland and globally,
  - reasonably understandable,
  - still challenging.
- (But most of our funding is for other purposes, and snow mostly moonlight research)

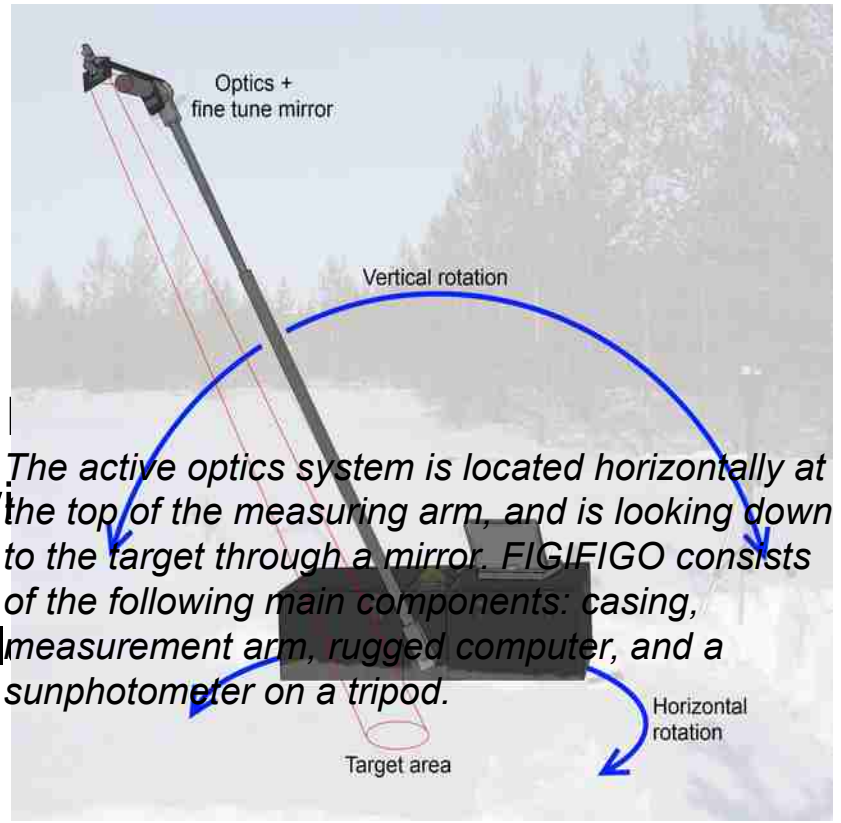
Basics

- Bidirectional reflectance factor (BRF)
  - Observed reflectance depends on 4 angles (3 with symmetric targets)
  - R=I/I_Lambert
  - $I(\varepsilon,\Phi)=\cos\iota/\pi\ R(\varepsilon,\Phi,\iota,\Phi_0)\ F0(\iota,\Phi_0)$
  - To model polarisation, **I**=[I,Q,U,V] and **R**= 4*4 matrix
  - Degree of linear polarisation P=-Q/I
- Albedo is an integral of BRF over the hemisphere



FIGIFIGO

- FInnish Geodetic Institute's FIeld Goniospectrometer
- Current model from 2006, first one 1997
- Measures BRF in full hemisphere
- Automated zenith turn, manual azimuth turn
- ASD FieldSpec Pro FR
  - 350-2500 nm
  - Field of view 5-25 cm
- Optionally also linear polarisation
- Portable, mounting time 10 minutes, weight 40 k
- Fast, 10 to 30 minutes for full BRF without or wi polarisation
- Accuracy at best about 1% in lab, 2% in the fiel but in practice about 5%



The active optics system is located horizontally at the top of the measuring arm, and is looking down to the target through a mirror. FIGIFIGO consists of the following main components: casing, measurement arm, rugged computer, and a sunphotometer on a tripod.

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FIGIFIGO in action

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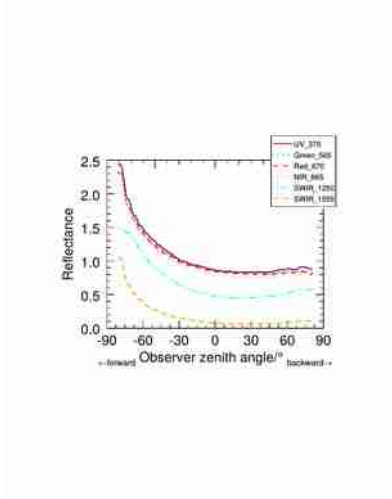
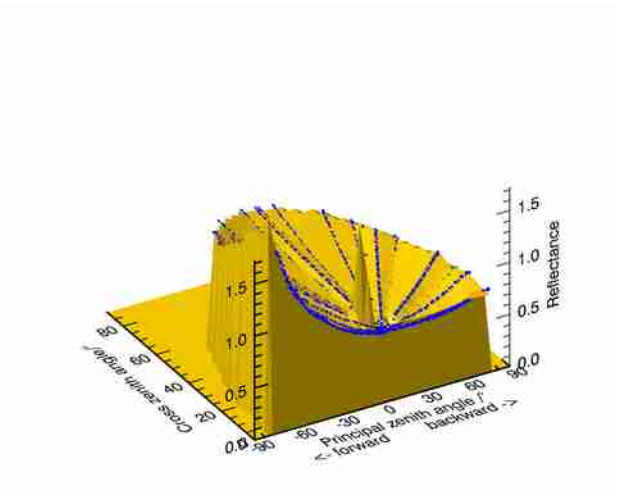
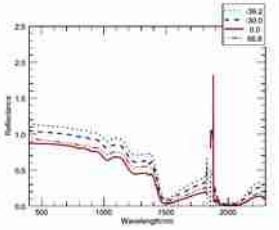
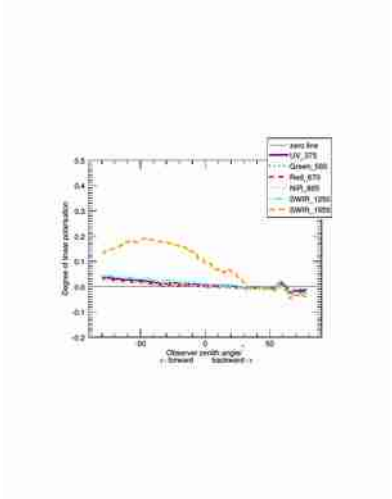
FGI reflectance library

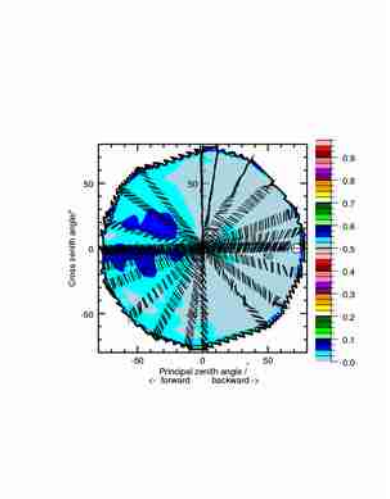
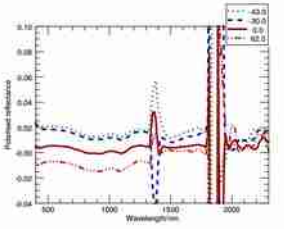
- webdav://webdisk.kotisivut.com/fgi/Reflectance_Library/
  - Username: BRFuser, password: BRFuseri
- All data are free for normal scientific use
- Currently the library contains BRF/HDRF measurements of over 150 samples
  - Snow – wet and dry, new and old, natural and contaminated
  - Gravel, Sand
  - Volcanic stuff
  - Vegetation
  - Asphalts, concrete
- *Status still experimental, needs some efforts to use*
- A pdf datasheet is produced from each library file
  - Shows contents of the file
  - Describes the reflectance properties of the sample

Sample data plots (principal, cake, spectral, same with polarisation)




Reflectance
Cross zenith angle/°
Principal zenith angle /°
<- forward
backward ->





Cross zenith angle°
Principal zenith angle /°
<- forward
backward ->


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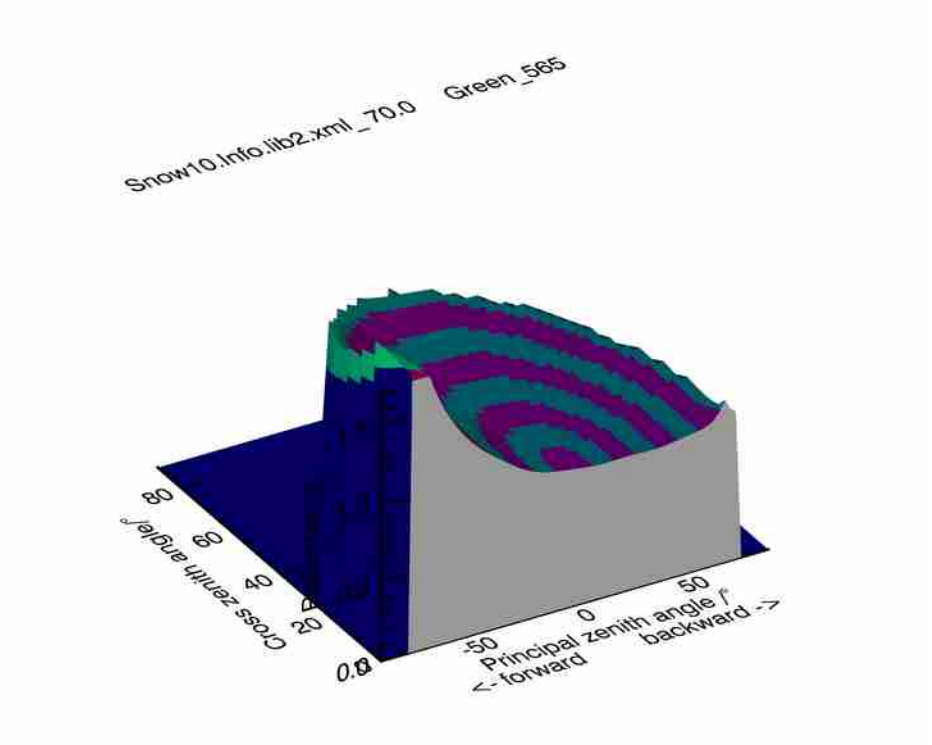
BRF to Albedo

- Usually BRF shape is smooth
- Can be inter and extrapolated by a polynom, and integrated over the hemisphere in good accuracy
- Need large zenith angles (>70 degree)
- Still, forward scattering often difficult



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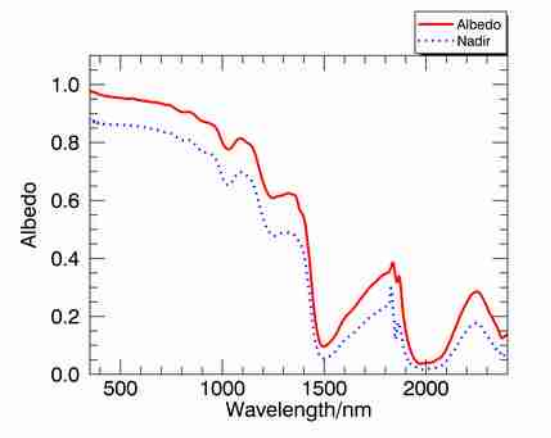
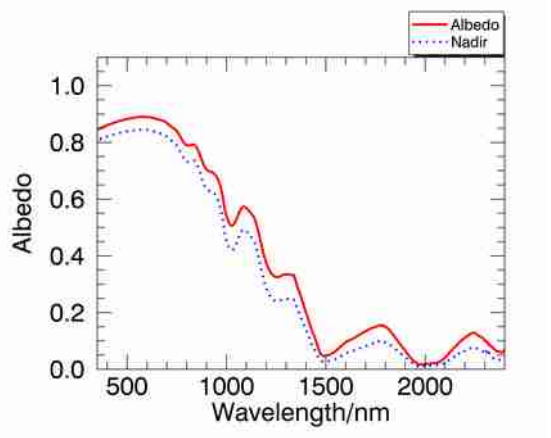
What albedo tells

- New vs old (grain size)
- Cleaner vs dirtier
- Wet vs dry

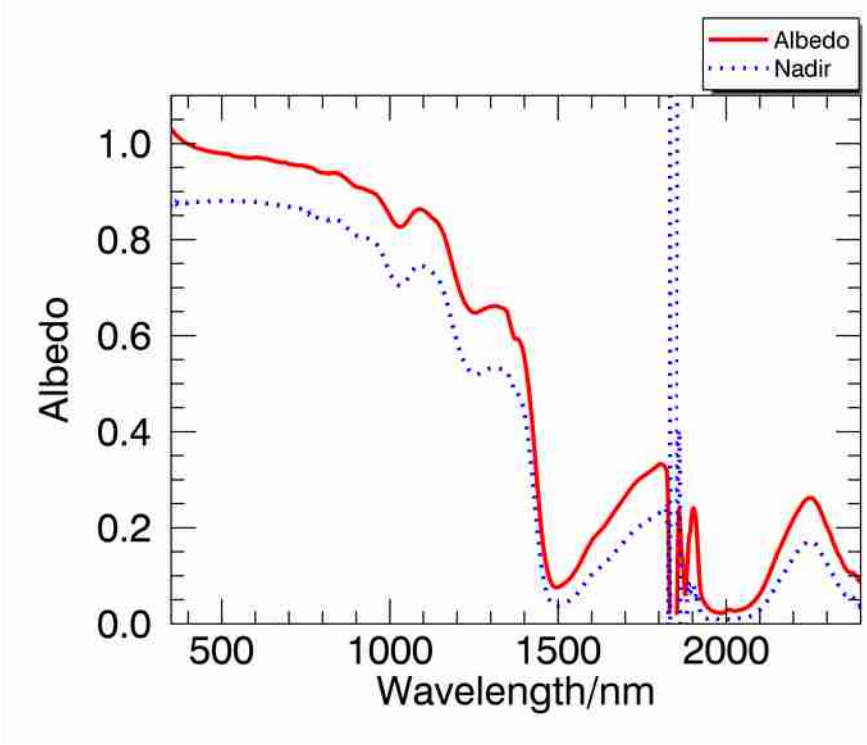
New – old, spectrum

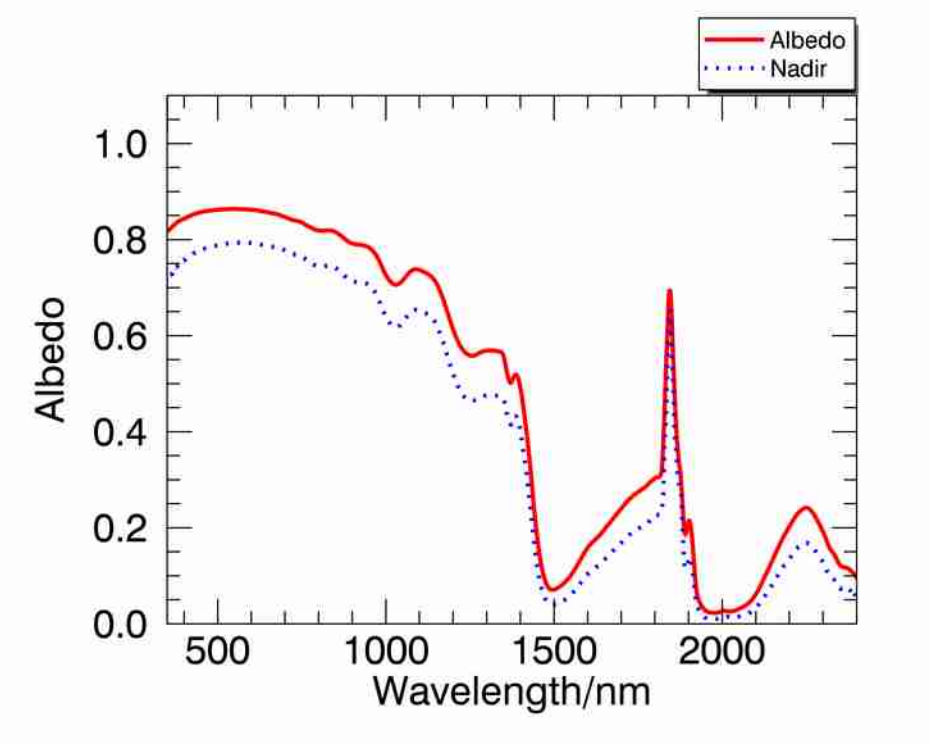




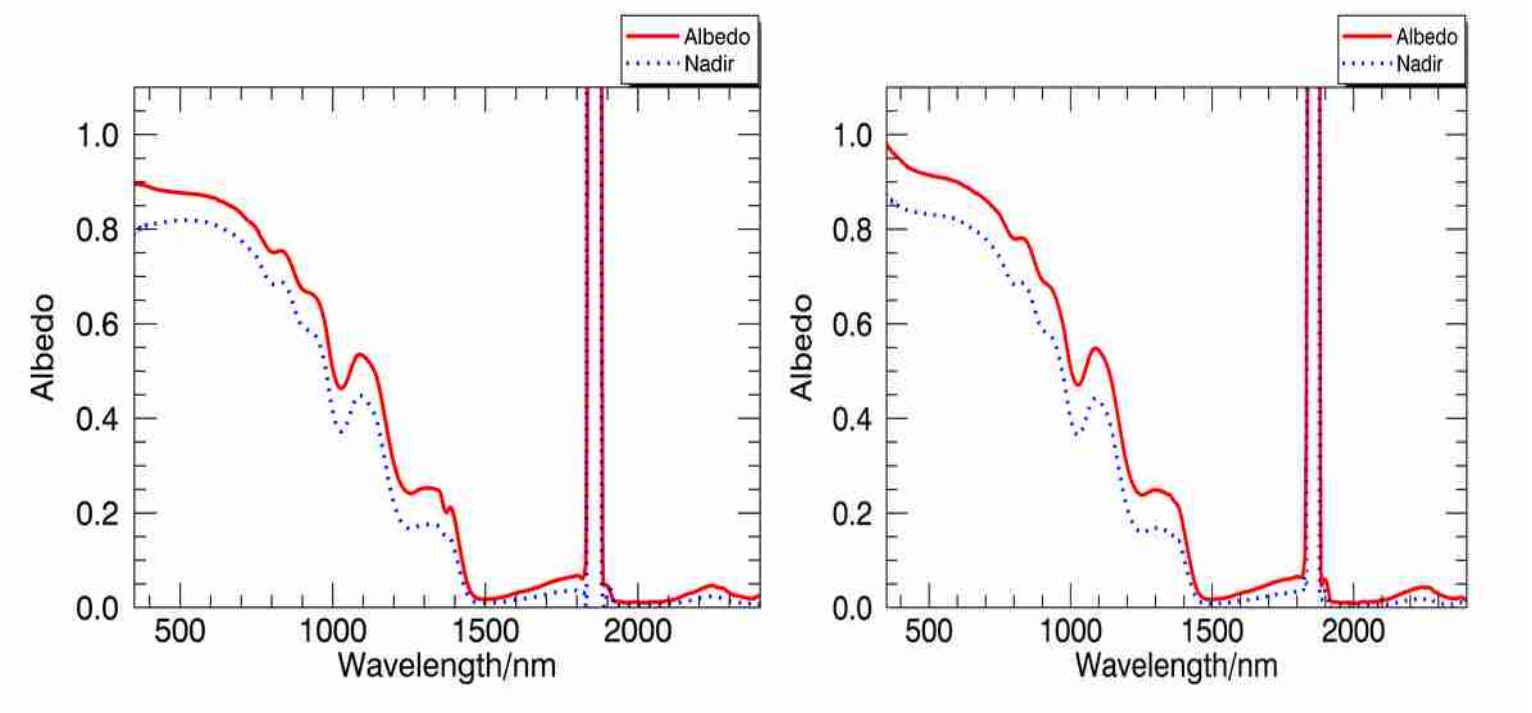
- New snow has much smaller grains, and less absorption
- Also small differences in anisotropy and polarisation

Cleaner vs dirtier snow soot deposition





Dry vs wet

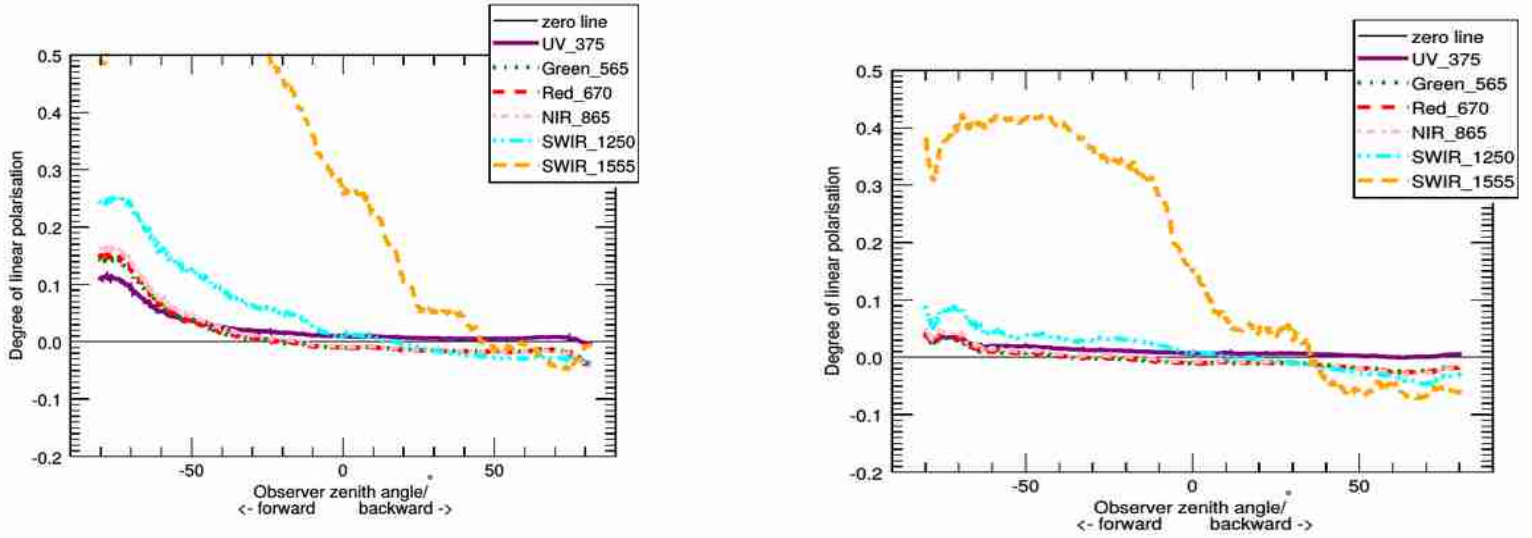


- Small differences, difficult to quantify, most differences are due to other factors

More dependencies

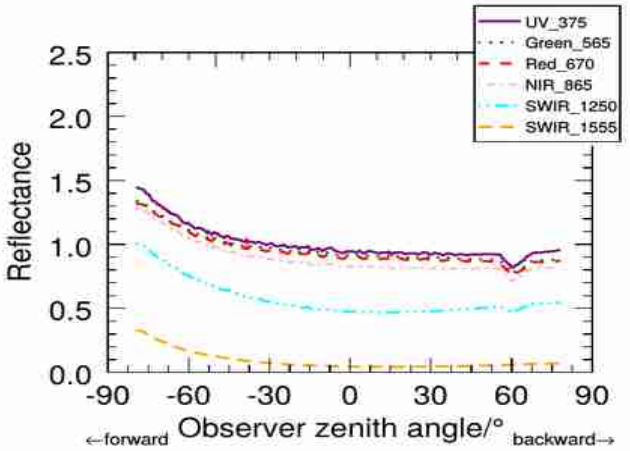
- Snow albedo depends on
  - Grain size
  - Grain shape
  - Snow pack thickness
  - Underlying ground
  - Density
  - Surface roughness
  - Wetness
  - etc
- But mostly uninvertible from albedo data alone, need more measurements
  - fast overview of other signals next

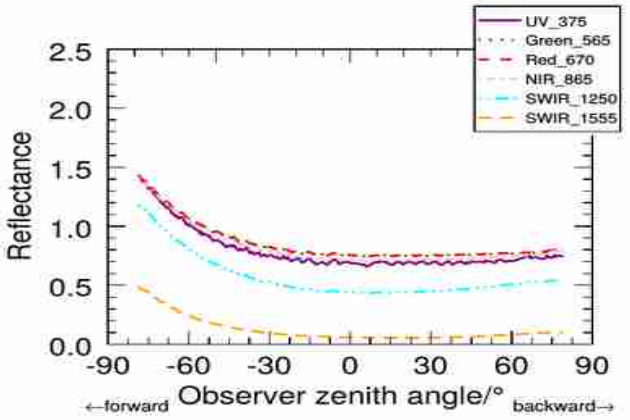
Dry – wet differences, polarisation



- Dry snow polarises more in the forward than wet snow
- Also small differences in the spectrum and aniotropy
- No signal alone sufficient

Natural-dirty, principal BRF





- All contaminants also darken snow in visual bands, but in NIR may be vice versa
- Sometimes backscattering can be even enhanced
- Depending on the properties of the contaminants, bowl shape may be enhanced or dampened
- Satellite observations may understimate albedo, on ground viewer overestimate

FIGIFIGO albedo measurements

- Pros
  - Almost full hemipsherical coverage
  - From a fixed spot
  - Well calibrateable
  - Much other data
- Cons
  - Only small area
  - Spot still elongates
  - Low temporal and spatial resolution
  - Too slow and complex for only albedo
  - Corrupts the snow around
  - Samples biased towards easy and accessible ones

Do we need more?

- Gonioradiometer measures small spot accurately but slowly
- Albedometer measures larger spot in higher temporal accuracy but lower angular accuracy, forward peak may be under or over estimated
- Satellite and UAV imaging cover larger areas, but need extrapolation to get albedo
- ***New multi sensor measurements producing albedo using physical models***
- ***Calibration chain using multiple steps and instruments and best available data***

Composite snow radiative transfer modelling

- From old work of 1987-1993 with small upgrades
- Composed of three components:
  - 1. The smallest wavelength scale dust, ripple and bubbles are modelled as randomly oriented ellipsoids or Gaussian particles, and solved using volume integral equation technique
    - Hours to days, but needed only once
  - 2. a small layer of densely packed Gaussian snow grains is solved using Monte Carlo ray-tracing, assuming Fresnelian reflection or transmission, and point scattering by from 1
    - 1 hour each case
  - 3. Combine a snow pack from different initialization layers using adding/doubling and interpolation
    - < minute
- Arbitrary size distribution using scaling
- Full polarisation
- Limited spectrum
- First attempts to validate the model after first mesurements proved only that first models were not only not correct, but not even wrong = not possible to validate, irrelevant parametrisation.
- After long work, we progressed to mostly wrong state (e.g. polarisation details), and partially even reasonably correct (e.g. albedo of clean snow and its dependece on grain size)

Future of reflectance measurements at FGI

- FIGIFIGO has been an excellent work horse, but is getting old
- Projects end now in August
  - We try to keep operational as long as possible with zero budget
  - We apply possible funding sources
  - On-line data distribution may disappear
- We are planning of much more advanced FIGIFIGO 2
  - Full polarisation, including circular
  - Four angle automatic, no manual intervention
  - Real time data processing and visualisation
  - Smaller laboratory and larger field configuration
  - Non elongating footprint
  - Less disruptive for snow and soil
  - Even more portable
- We actively develop unmanned aerial measurements with multiple sensors

Conclusions

- We know a lot of snow reflectance
- Still open
  - Effects of small impurities
  - Quantitative roughness
  - Grain shapes
  - Cause of enlargened forward polarisation
- Todo with models
  - Roughness and 3D structures
  - Crystal forms
  - Wave effects
- Todo with measurements
  - Presice polarisation, including circular (V) and illumination control
  - Backscattering
  - Natural and processed roughness
  - Mixtures, smaller and larger contamination ratios
  - Time series of metamorphism
  - Better characterization of snow from wavelength scales to topographic scales