Observation techniques of spectral, narrowband and broadband albedos of snow surface

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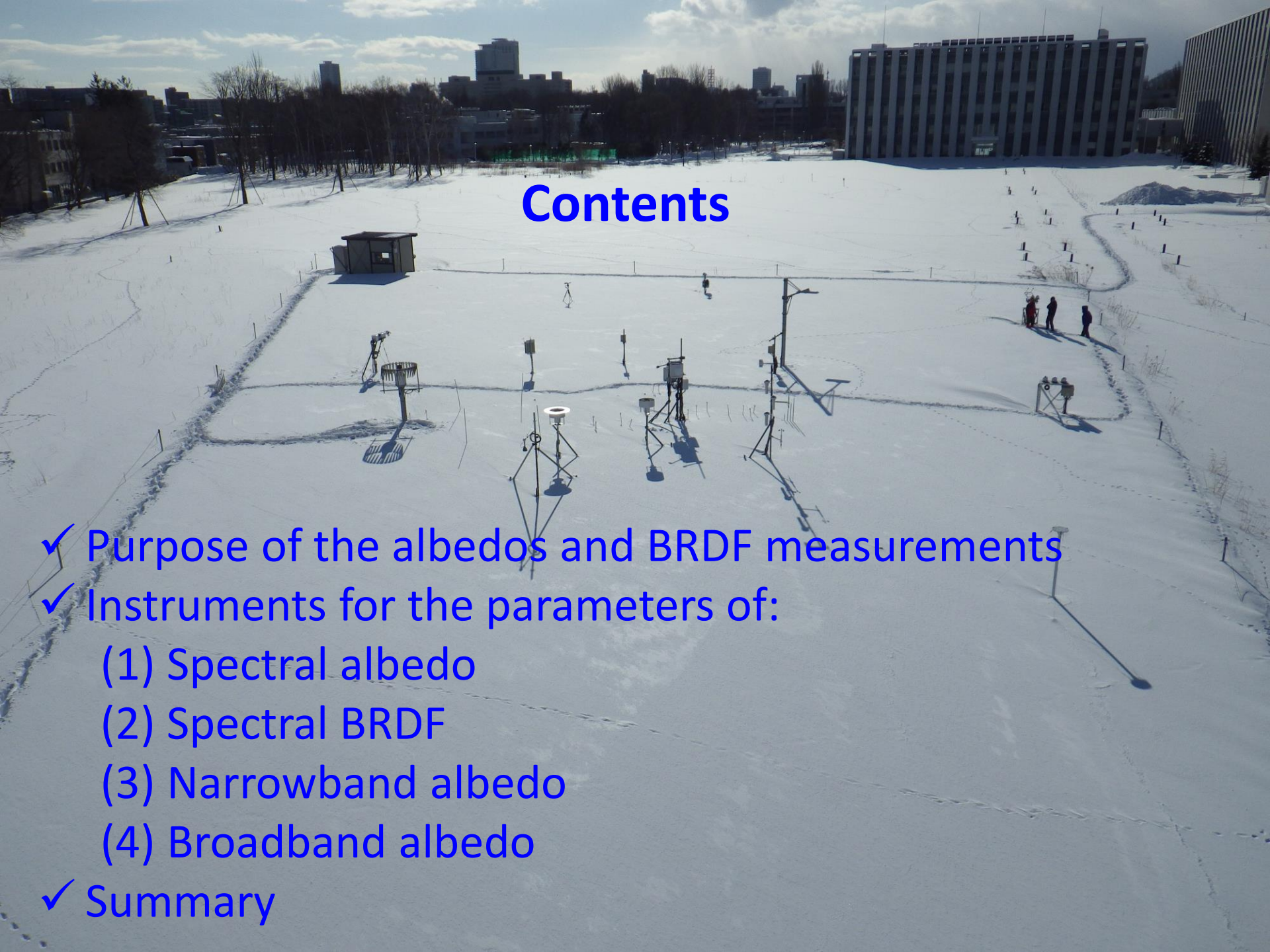

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- ✓ Instruments for the parameters of:
  - (1) Spectral albedo
  - (2) Spectral BRDF
  - (3) Narrowband albedo
  - (4) Broadband albedo
- ✓ Summary

Purpose of the albedos and BRDF* measurements

(*Bidirectional Reflectance Distribution Function)

- **Spectral albedo: Optical properties of snow**
  - ✓ Spectrally detailed radiative transfer model
  - ✓ Snow microphysics
  - ✓ Snow metamorphism model

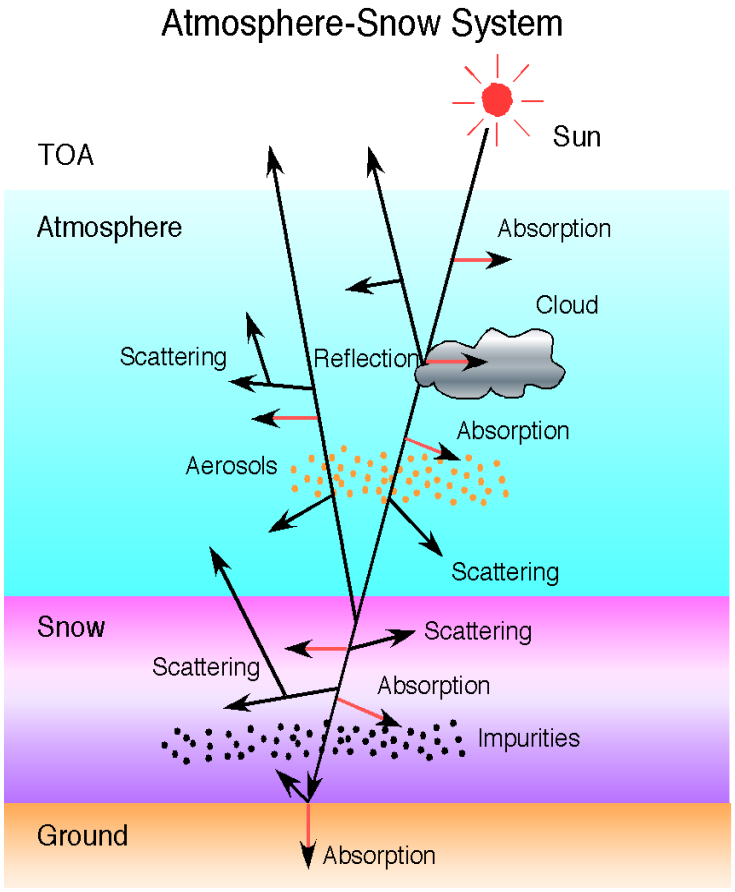
- **Spectral BRDF: Satellite remote sensing of snow parameters**
  - ✓ Inversion and look-up table (LUT) method used in algorithm

- **Narrowband albedo: Remote sensing of snow parameters**
  - ✓ Inversion, LUT and empirical method used in algorithm

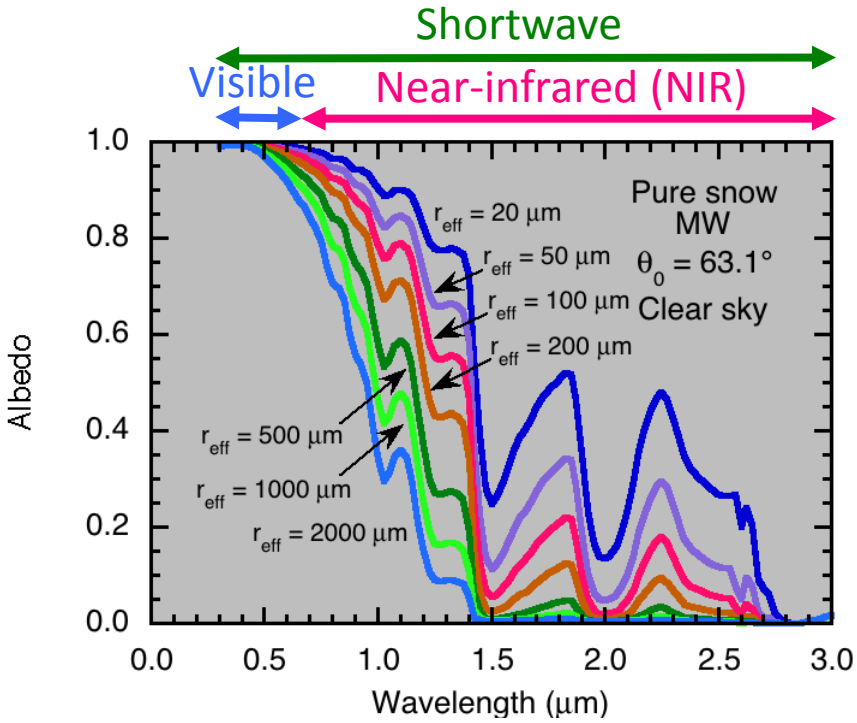
- **Broadband albedo: Glaciological and climate studies**
  - ✓ Albedo parameterization
  - ✓ Physically based snow albedo model
  - ✓ Snow metamorphism model

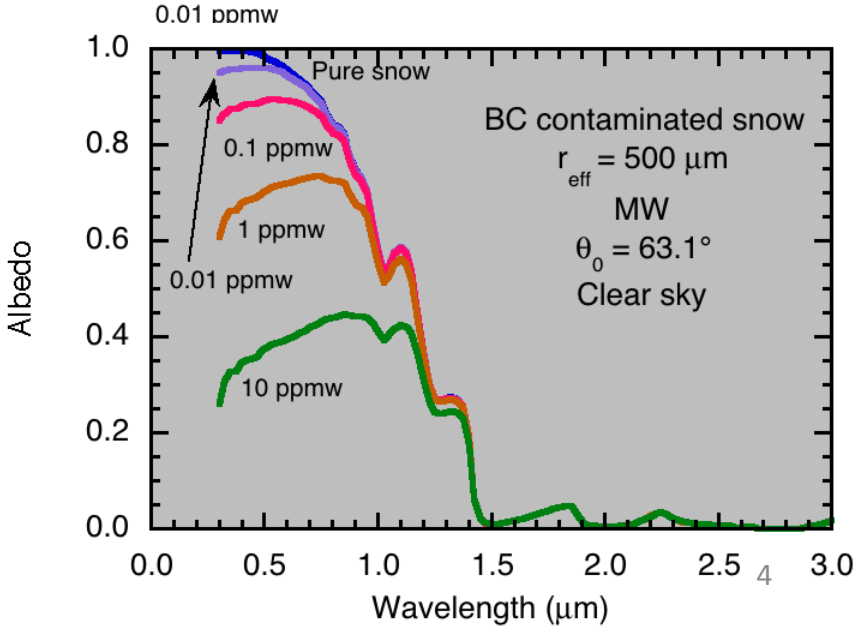
Radiative transfer model for the atmosphere-snow system

✓Visible and NIR albedos depend on snow impurities and grain size, respectively.



Aoki et al. (1999, JMSJ)



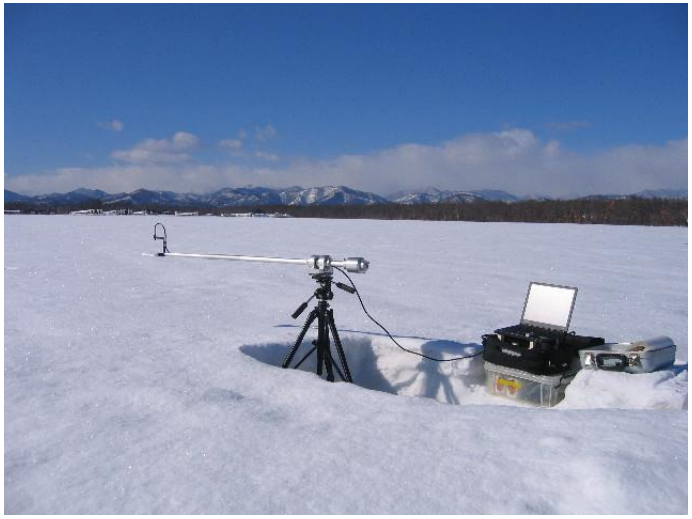


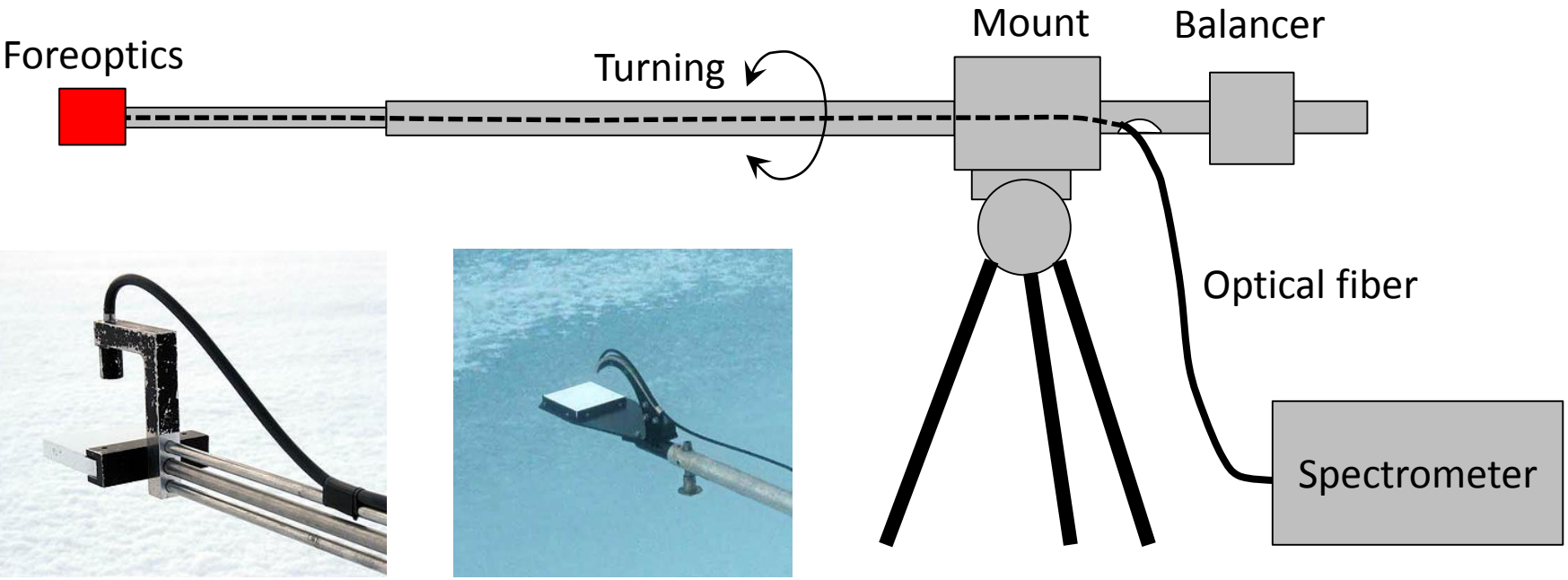
(1) Spectral albedo $a(\lambda) = \frac{F^{-}(\lambda)}{F^{-}(\lambda)}$

Spectrometer + foreoptics:

Foreoptics =

- ✓ White reference standard (WRS)
- ✓ Transparent diffuser (cosine corrector)
- ✓ Integrating sphere





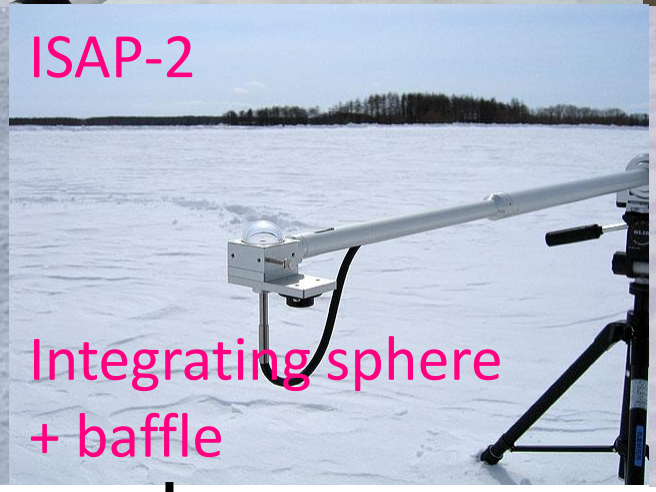
Aoki et al. (2000, JGR)

Grenfell and Perovich (2008, JGR)

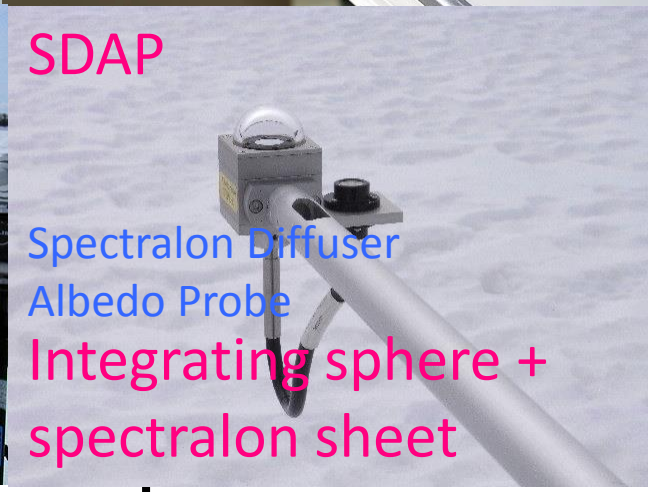
White reference standard

Cosine corrector

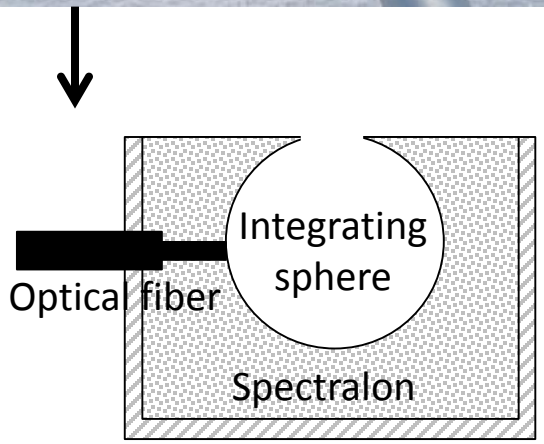
Integrating sphere

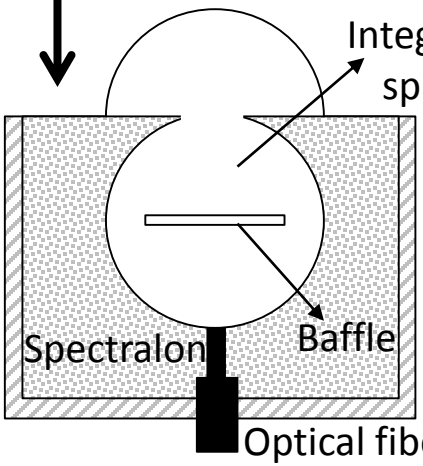


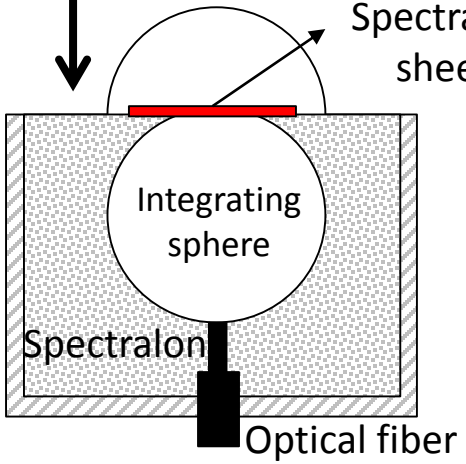
Integrating sphere
+ baffle



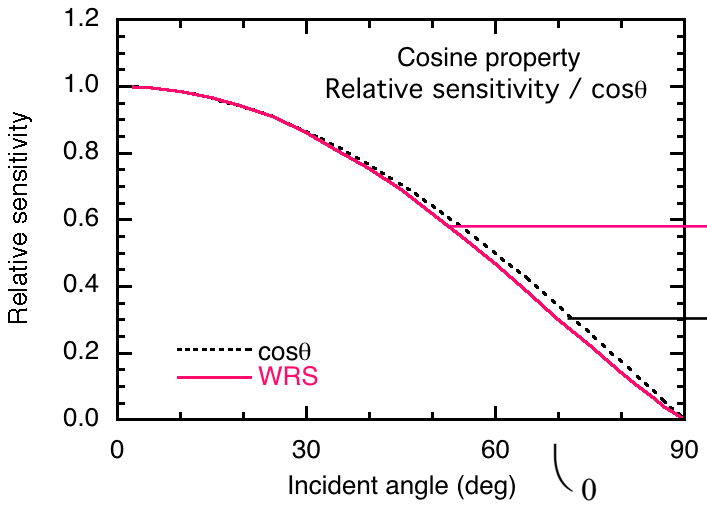
Integrating sphere +
spectralon sheet







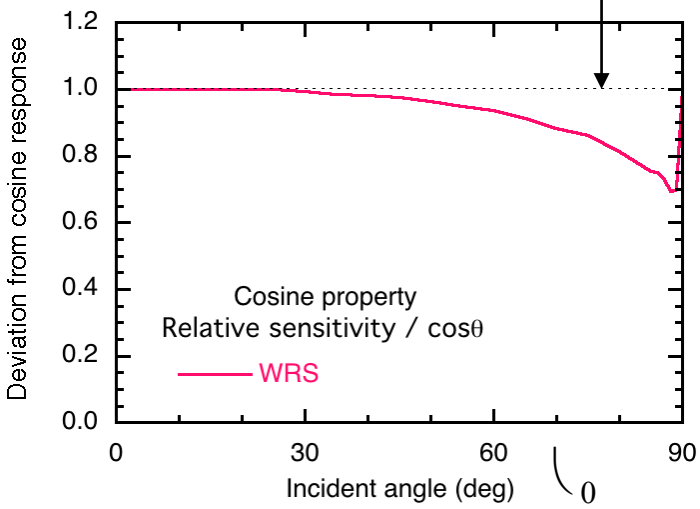
Calibration of cosine response

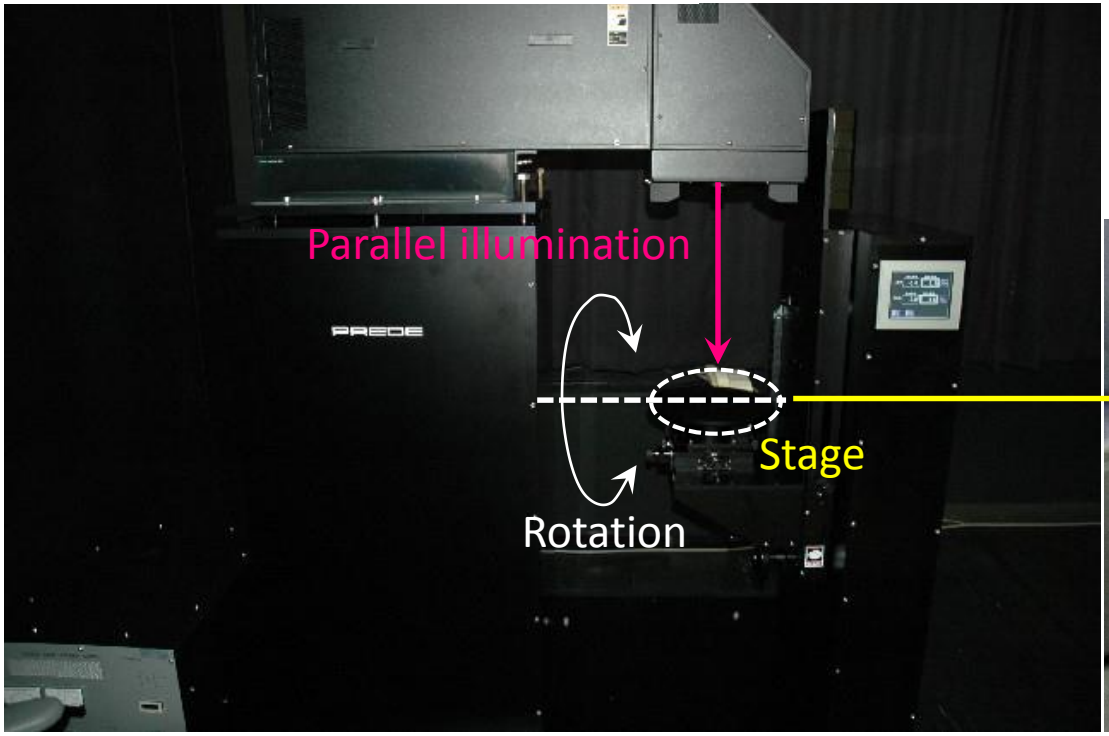


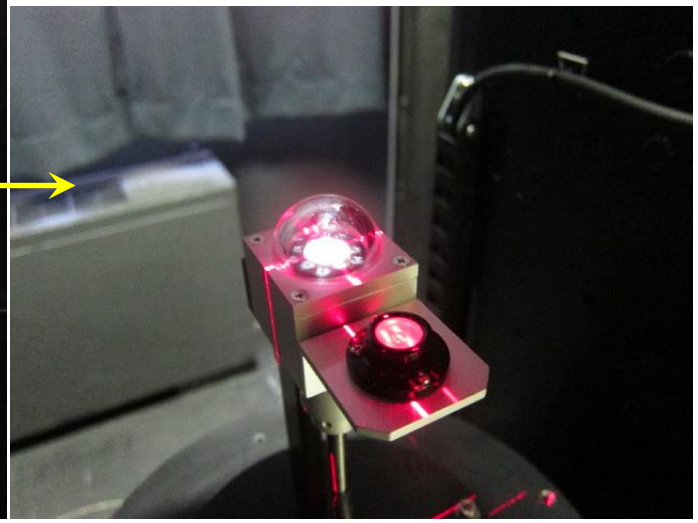
Cosine response

$$= \frac{prove(q)}{\cos q}$$

Perfect cosine response







Correction for measured radiant flux density

Corrections are made for the direct (f_{dir}) and diffuse (f_{diff}) components of radiant flux measured.

$$\bar{F}_{true} = \bar{F}_{obs}\left(\frac{f_{dir}}{c_{dir}(q_0, f_0)} + \frac{f_{diff}}{c_{diff}}\right),$$

$$\bar{F}_{true} = \frac{\bar{F}_{obs}}{c_{diff}}.$$

where c_{diff} is calculated by assuming isotropic radiation,

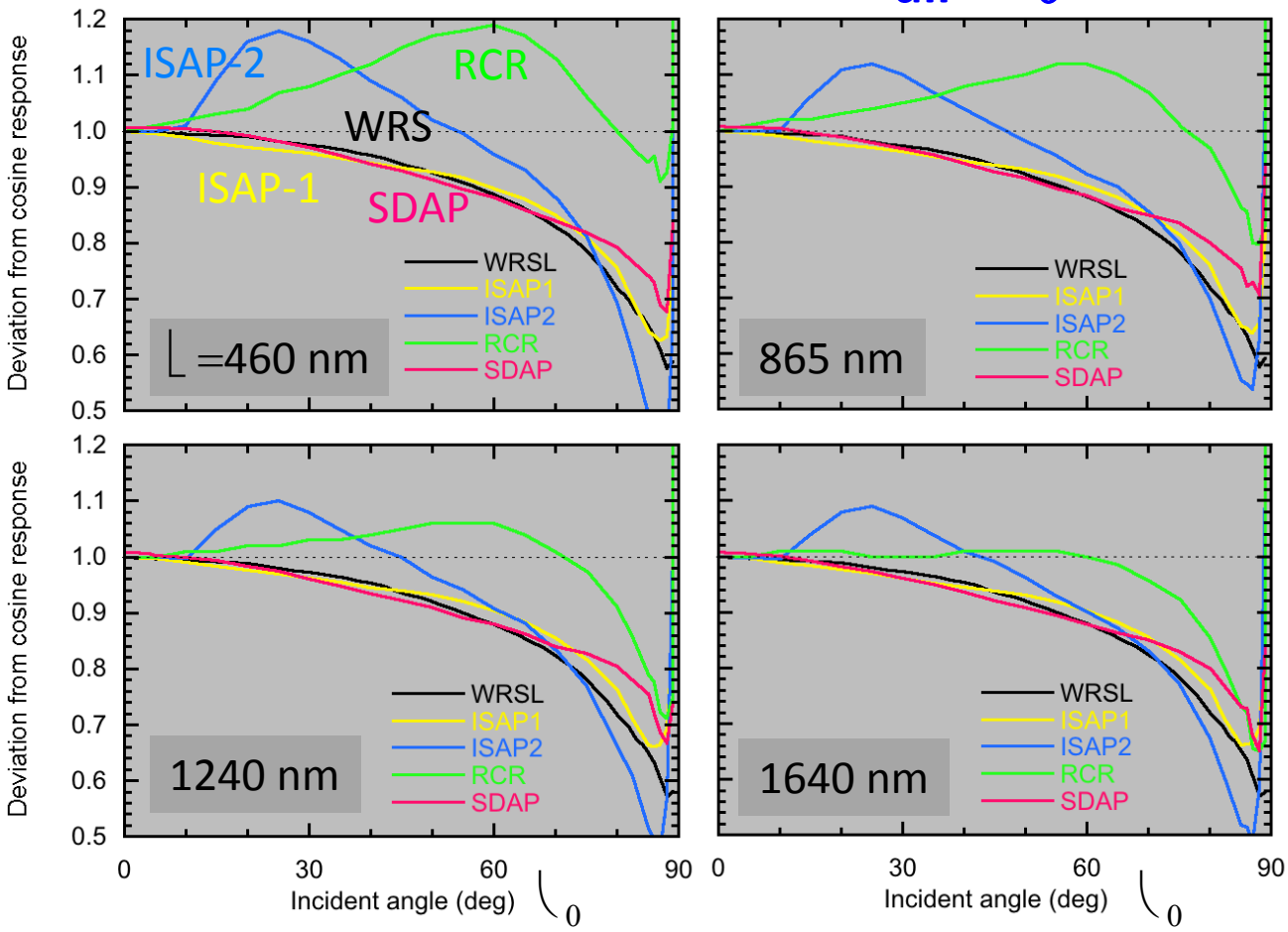
$$c_{diff} = c_{isotropic} = \frac{1}{p}\int_0^{2p}\int_0^{p/2} c_{dir}(q,f)\cos q \sin q\, dq\, df.$$

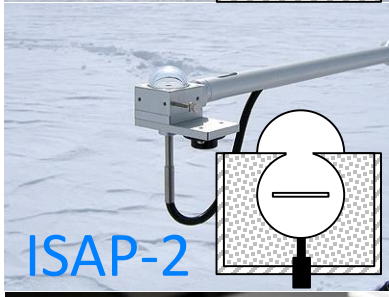
In case of WRS,

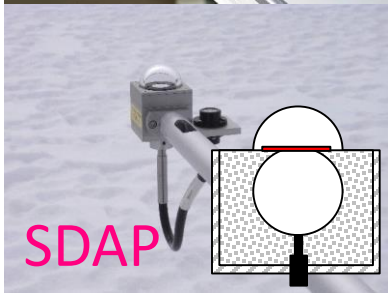
$$c_{diff} = c_{isotropic}(1 - \bar{f}_{arm}),$$

$$\bar{f}_{arm} = \frac{1}{p}\int_0^{2p}\int_0^{p/2} f_{arm}(q,f)\cos q \sin q\, dq\, df.$$

Cosine response $c_{dir}(\theta_0)$

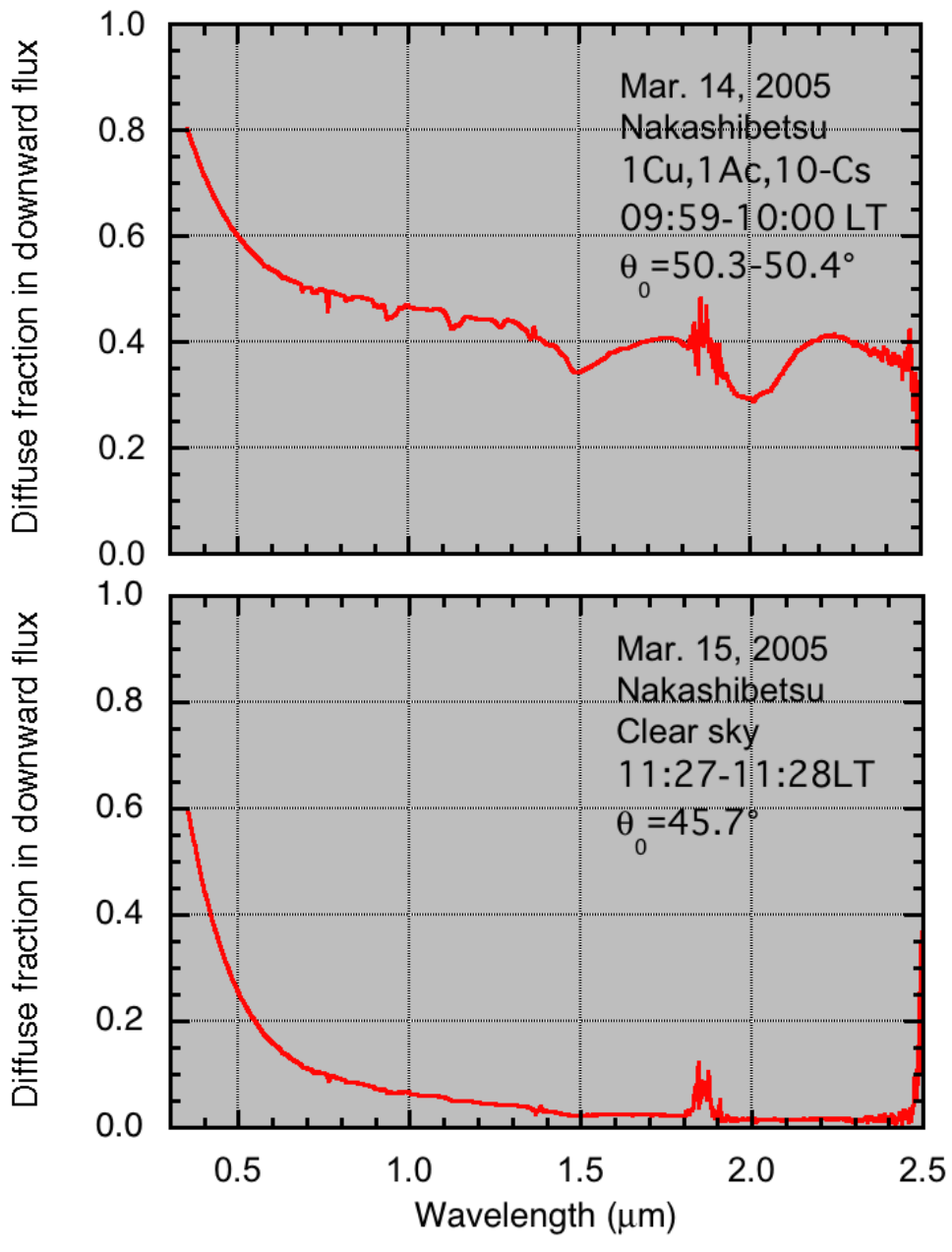


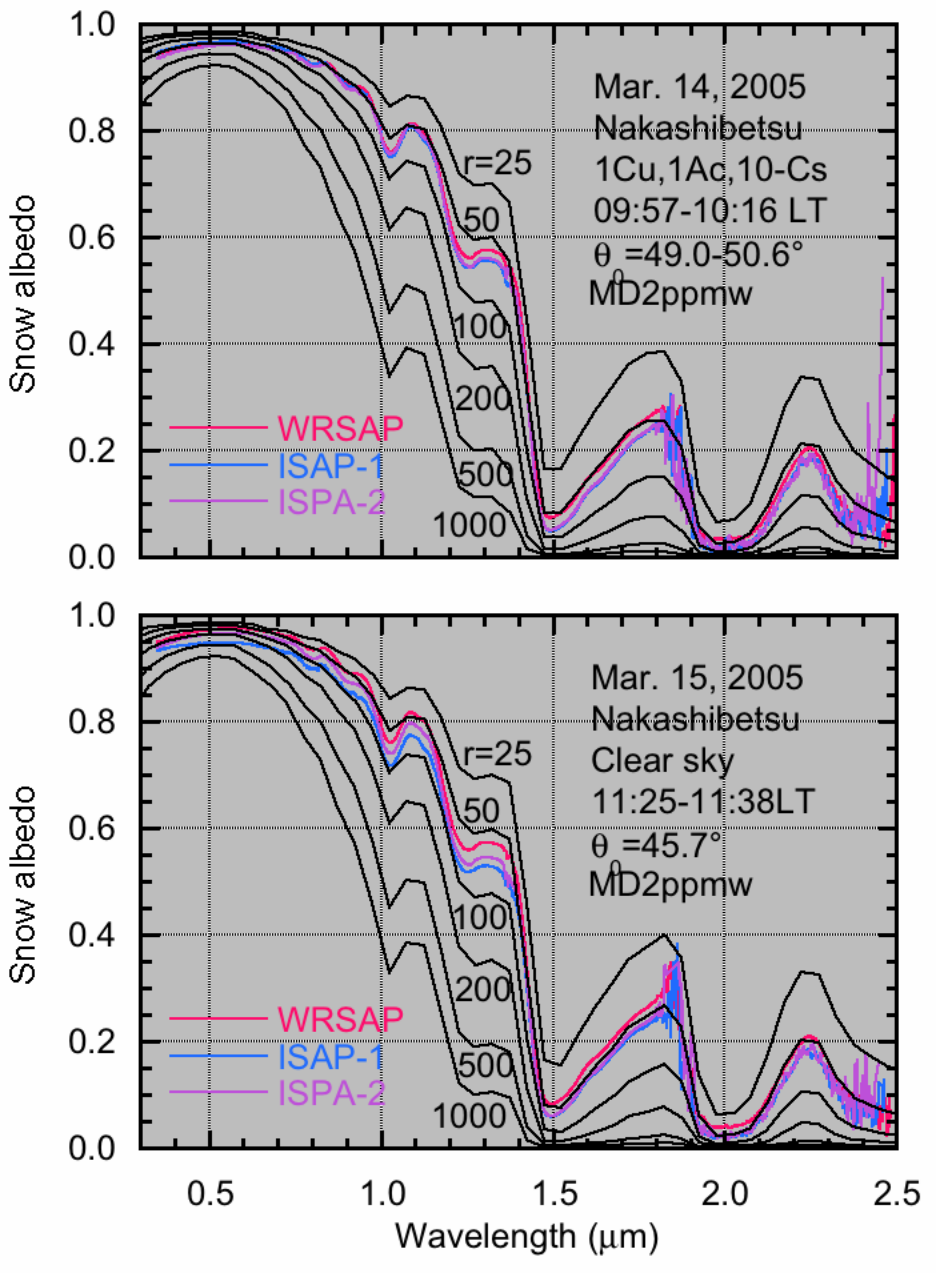




- ✓ WRS, ISAP-1 and SDAP have the similar cosine response and are independent on wavelength, whereas ISAP-1 has an azimuth angle dependence.
- ✓ ISAP-2 and RCR have an excessive sensitivity for some parts of θ_0.
- ✓ RCR's cosine response varies depending on the wavelength.

Spectral albedos by WRS, ISAP-1 and ISAP-2



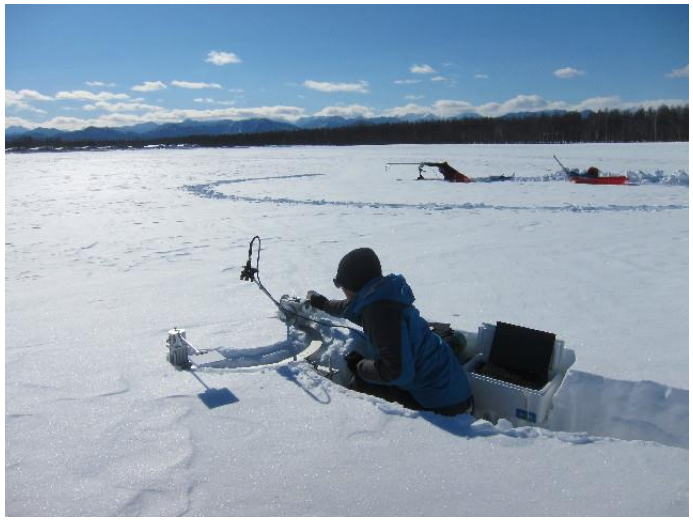


Cosine response of the probes

- ✓ WRS, ISAP-1 and SDAP have the similar cosine response to each other which are independent on the wavelength, whereas ISAP-1 has an azimuth angle dependence.
- ✓ ISAP-2 and RCR have an excessive sensitivity for some part of θ.
- ✓ RCR's cosine response varies depending on the wavelength.
- ✓ Absolute sensitivity: WRS > ISAP-1 > ISAP-2 > SDAP ~ RCR.
- ✓ From the viewpoint of easy correction and accuracy, WRS and SDAP are the best choice among these devices.

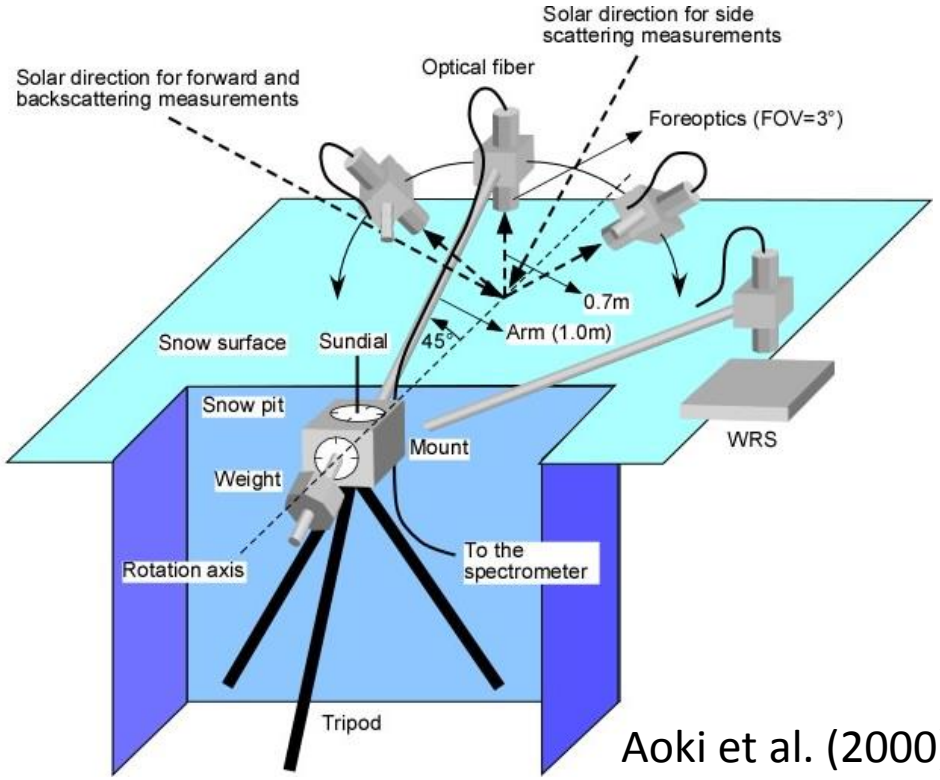
(2) Spectral BRDF (HDRF)

$$HDRF_l(q_0, f_0, q_r, f_r) = \frac{p I_l^-(q_r, f_r)}{m_0 F_{l\,\mathrm{dir}}^-(q_0, f_0) + F_{l\,\mathrm{diff}}^-}$$

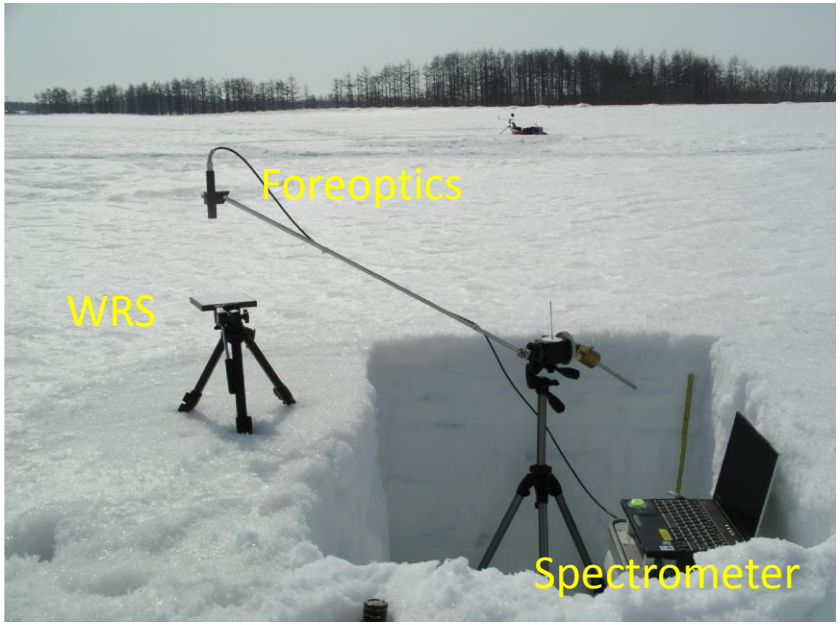


Spectrometer + goniometer + foreoptics

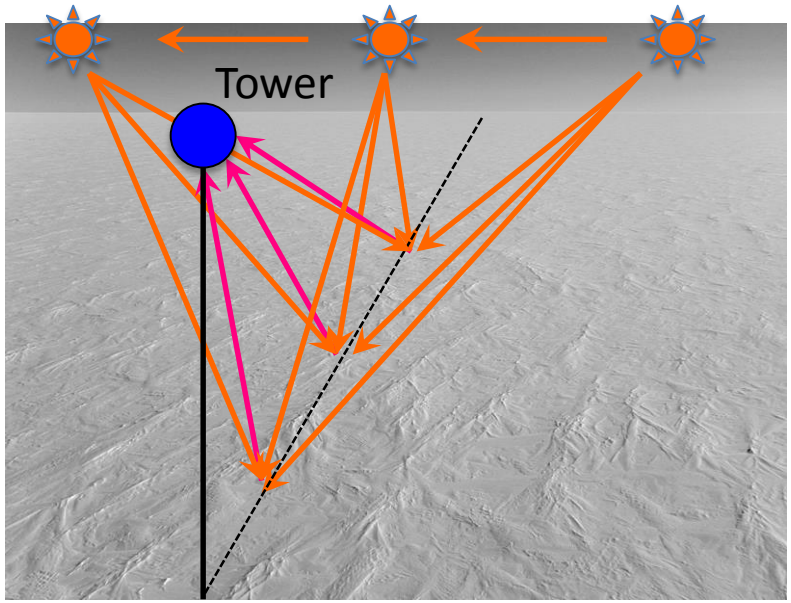
- ✓ Point measurement (Painter and Dozier, 2004)
- ✓ Zenith angle scan at South Pole (Grenfell et al., 1994; Hudson et al., 2006)
- ✓ Below (Aoki et al., 2000; Kuchiki et al., 2012)



Aoki et al. (2000)

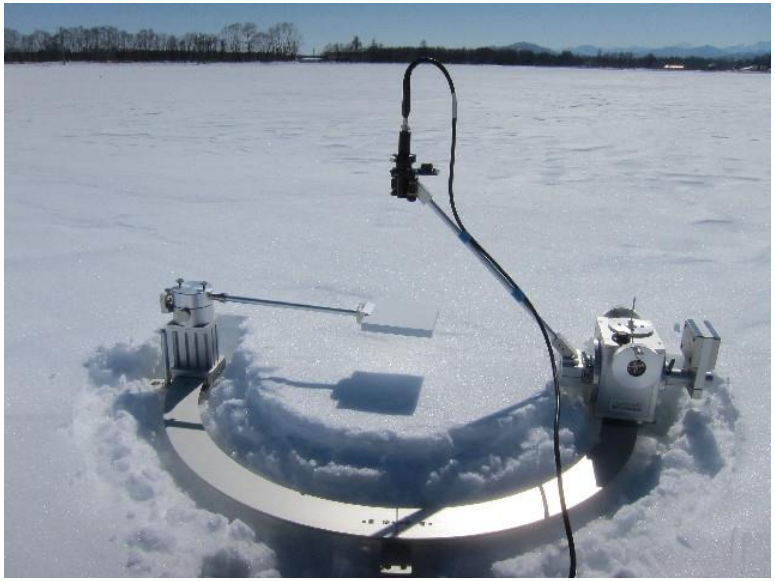


Painter and Dozier (2004)



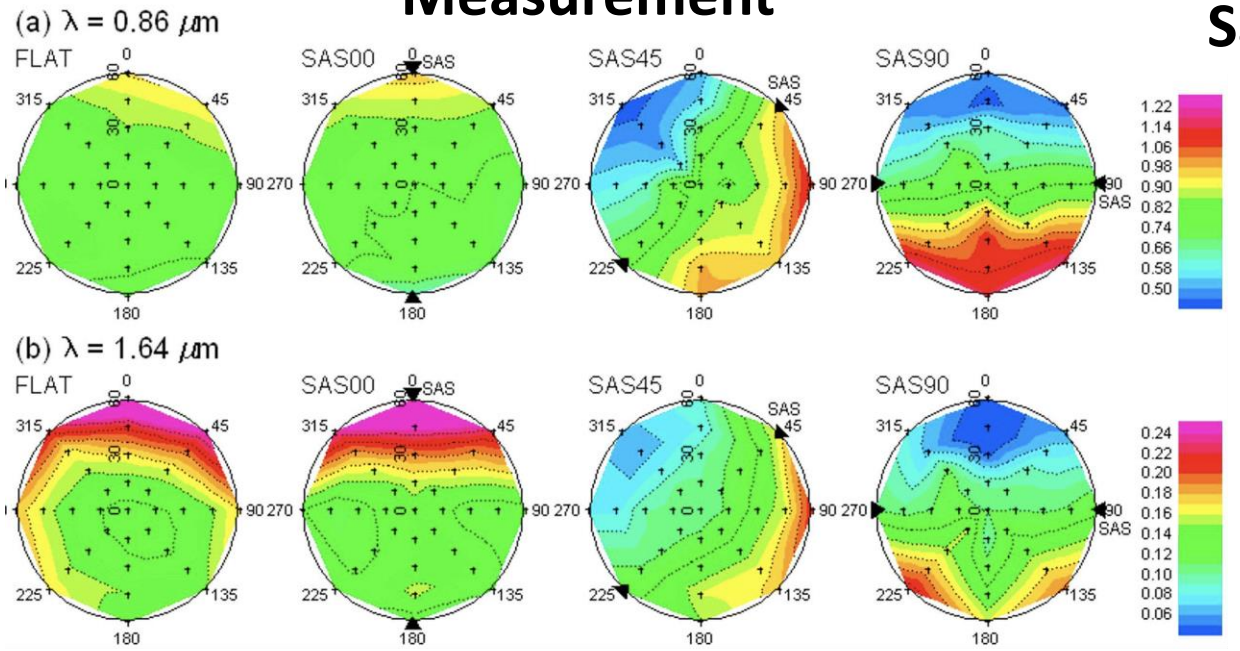
Hudson et al. (2006)

Kuchiki et al. (2012)

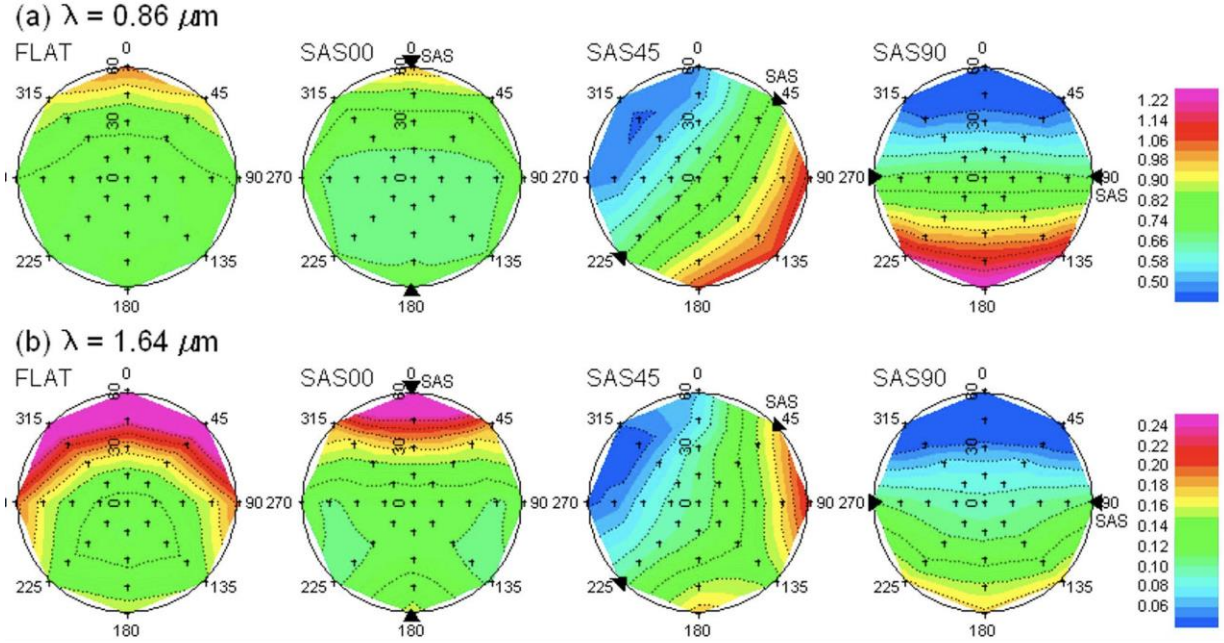


Our new system

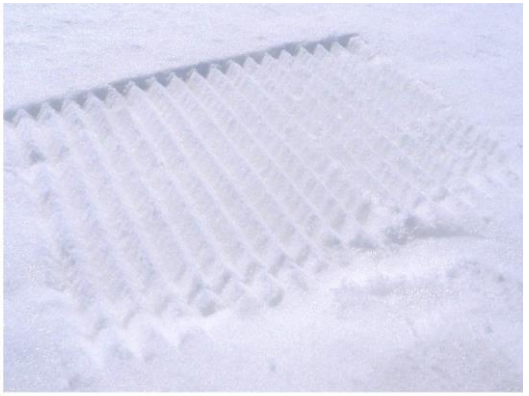
Measurement

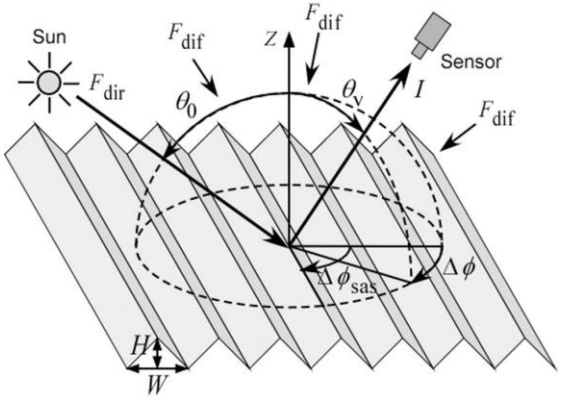


Simulation

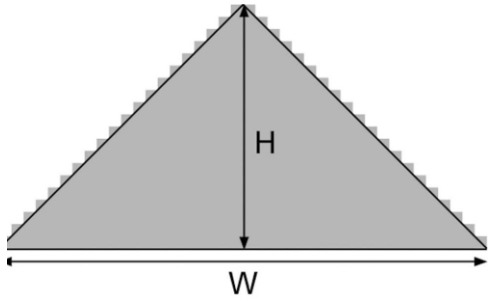


Sastrugi-like roughness





Sastrugi model

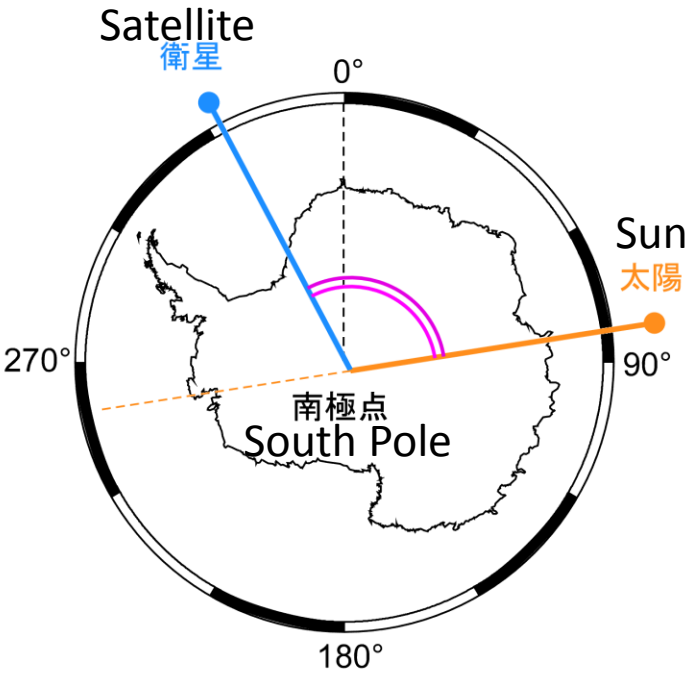


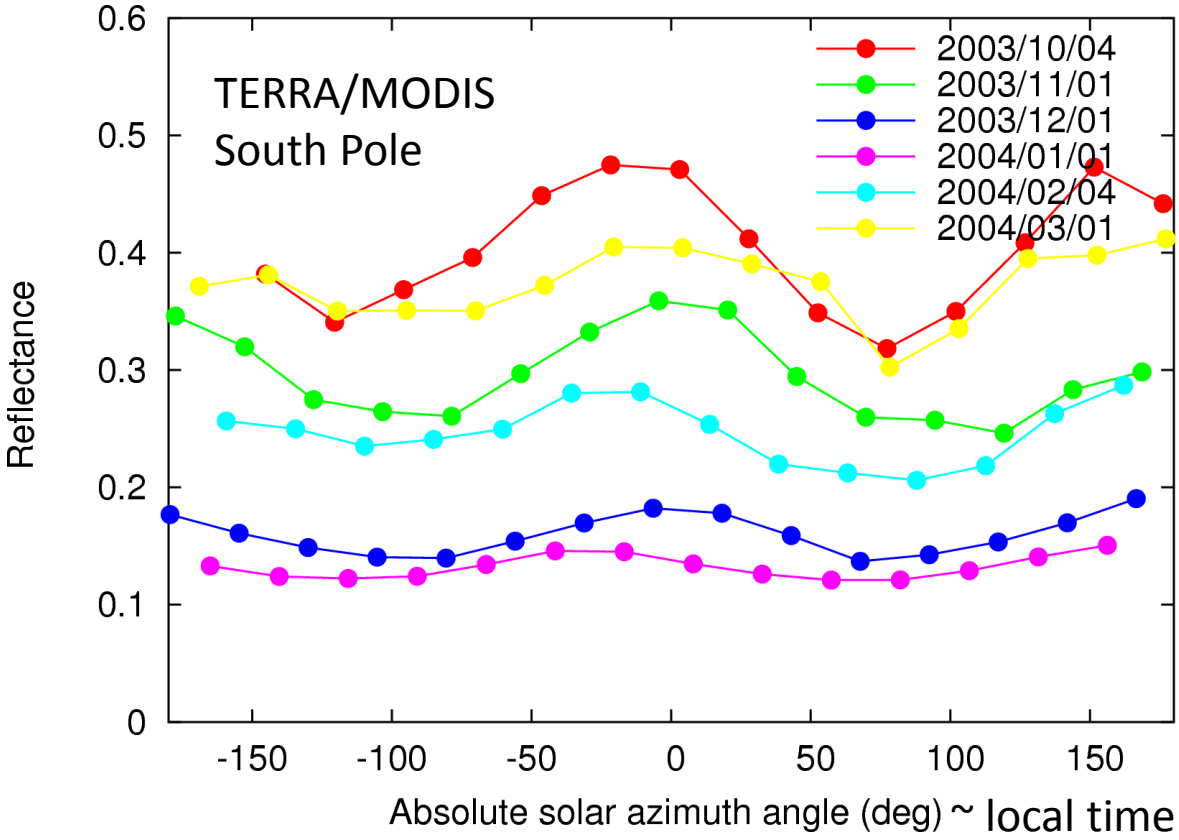
Kuchiki et al. (2012, JGR)

Diurnal variation of reflectance at South Pole

✓Solar zenith, satellite zenith and relative azimuth angles are almost constant throughout a day.

✓Two-cycle in diurnal variation of reflectance is observed.

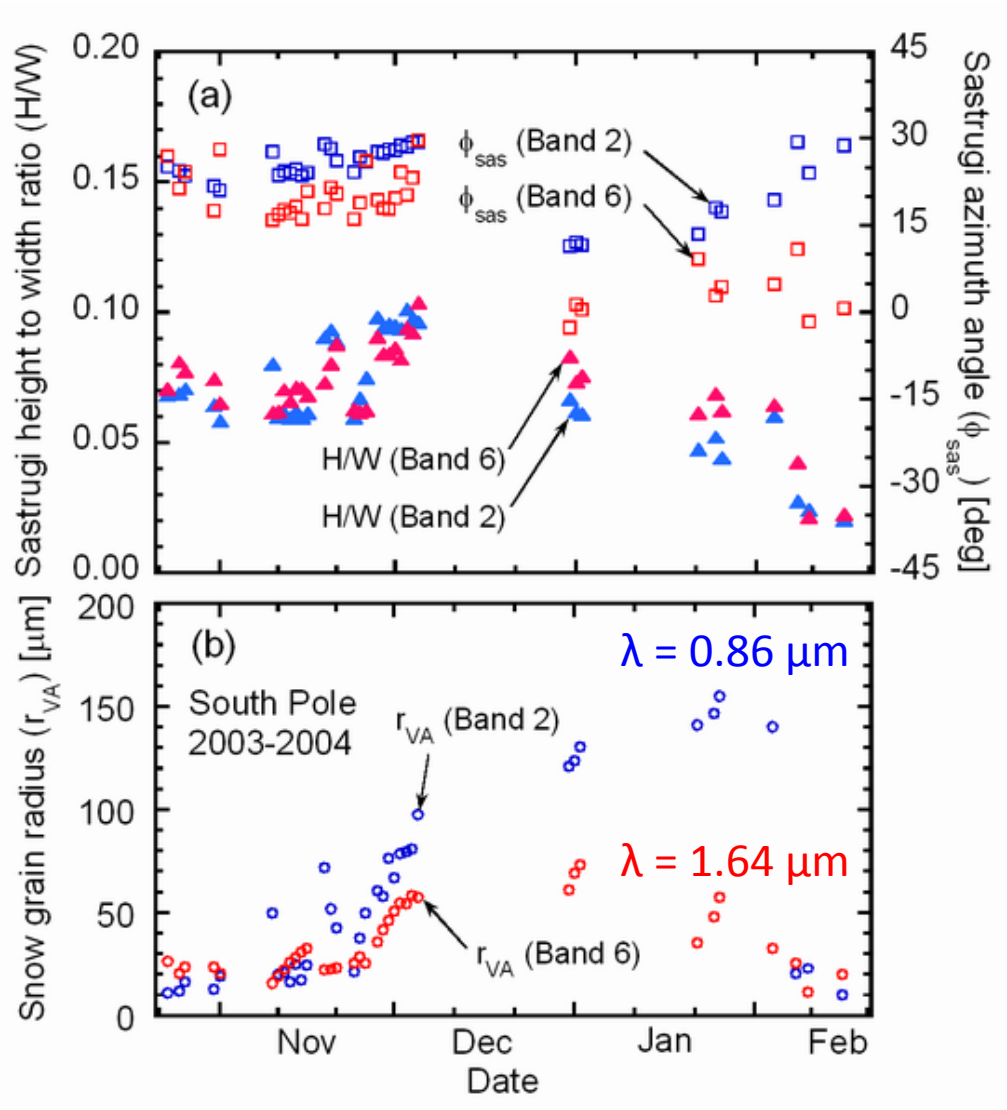


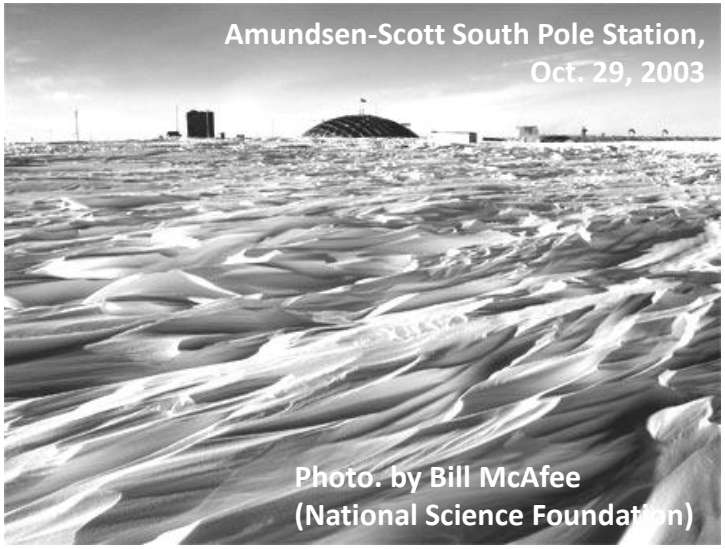


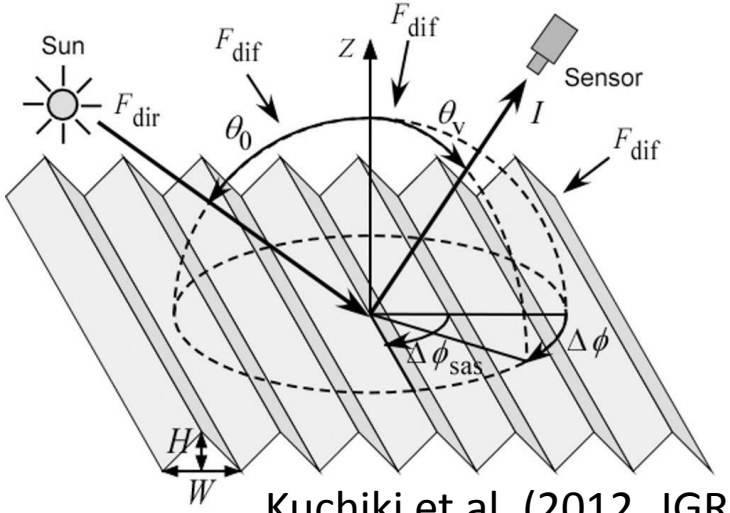
Sastrugi at South Pole

Snow grain size, sastrugi height to width ratio, and direction at South Pole retrieved from satellite

Terra/MODIS over the South Pole during Oct, 2003 – Feb, 2004







Kuchiki et al. (2012, JGR)

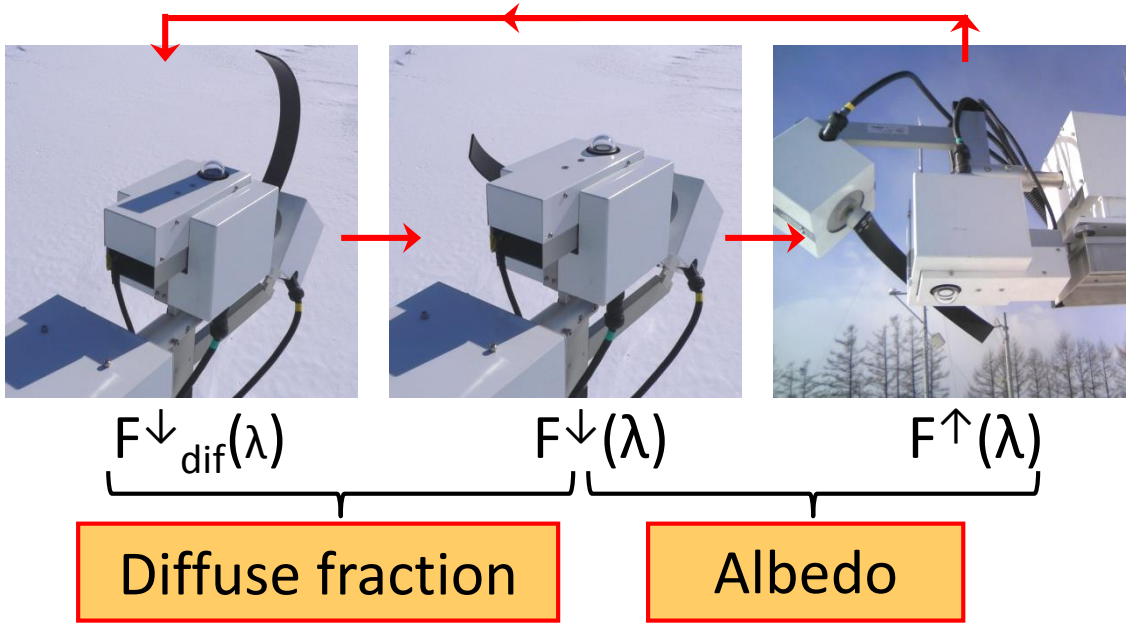
Spectral BRDF

- ✓ Spectral BRDF model is a key module in satellite remote sensing algorithm.
- ✓ For accurate BRDF measurements, accurate BRDF observation system composed by spectrometer, goniometer and foreoptics is needed.

(3) Narrowband albedo

$$a(\lambda) = \frac{F^{\uparrow}(\lambda)}{F^{\downarrow}(\lambda)}$$

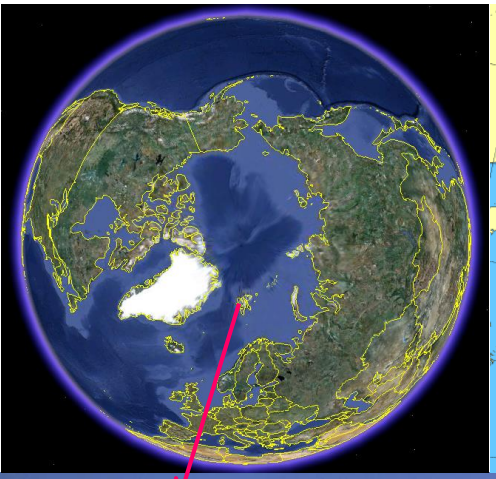
Grand-based Spectral radiometer for Albedo and Flux (GSAF)

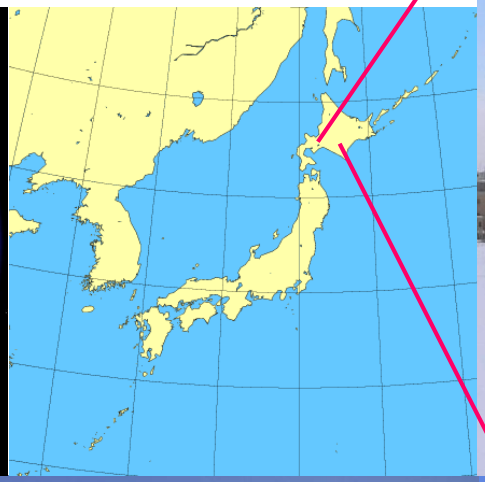


- ✓ Top layer snow grain size (Rs1), subsurface layer snow grain size (Rs2), and soot concentration in snow (Cs) can be retrieved from the spectral albedos at λ = 0.44, 0.87, and 1.23 μm channels of GSAF.
- ✓ GSAF is used not only for measurement of snow parameters but also for validation of remote sensing algorithms.

Kuchiki et al., (2009, Appl. Opt.)

GSAF measurements in Japan and Svalbard





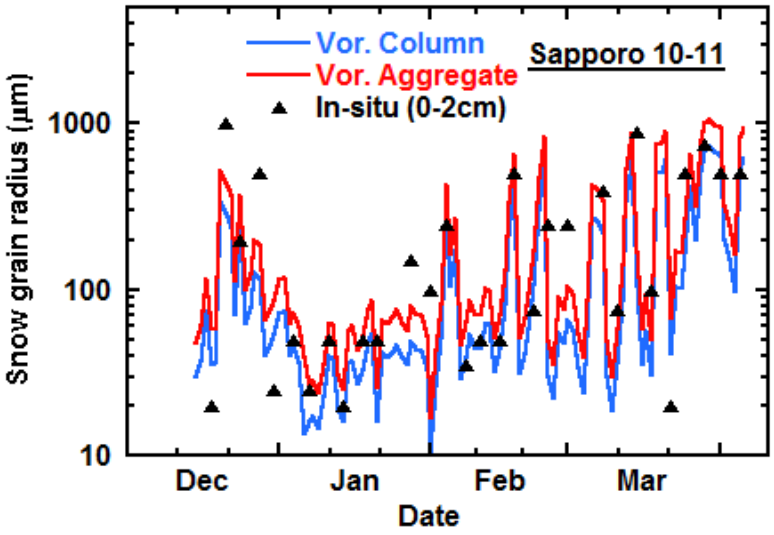
Sapporo, Hokkaido, since 2007

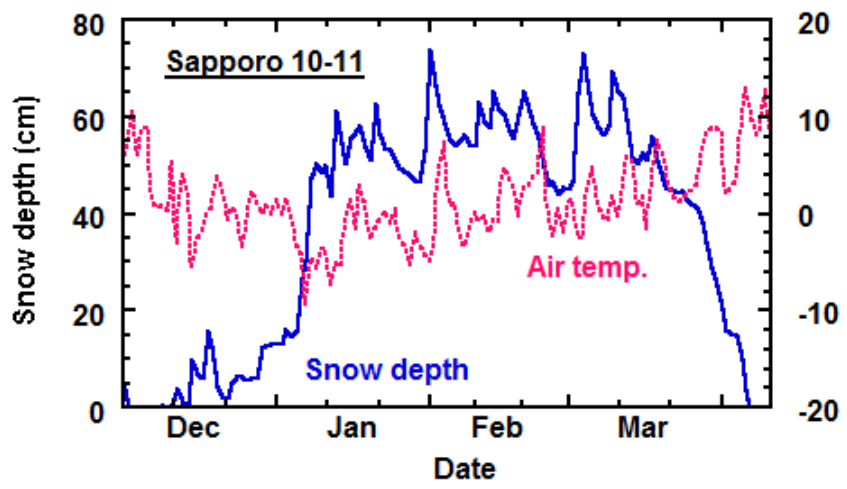
Ny-Alesund, Svalbard, since 2012

Memuro, Hokkaido, since 2007

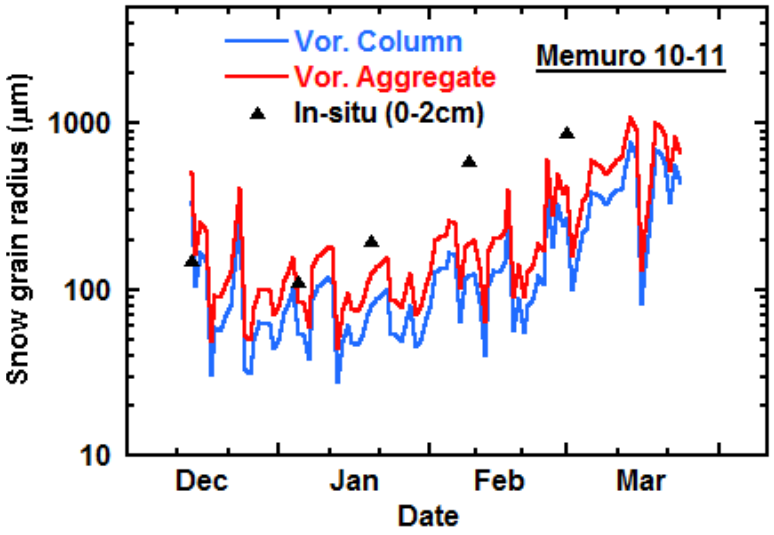
Top layer grain radius in 2010-2011

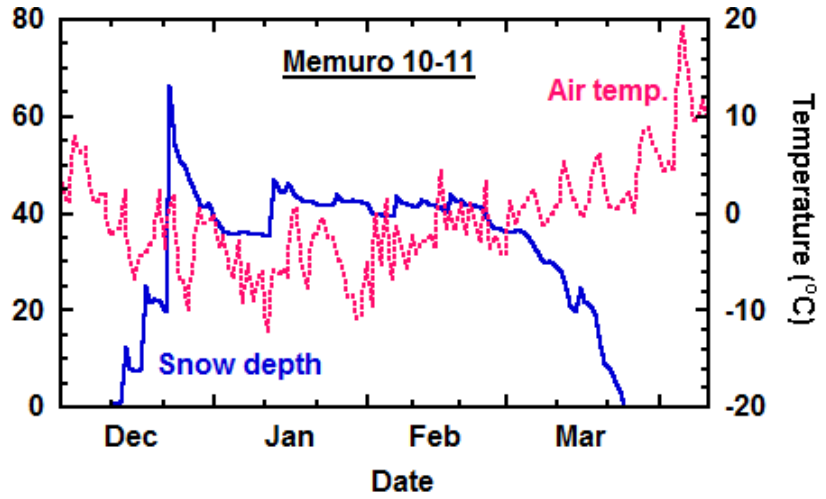
Sapporo

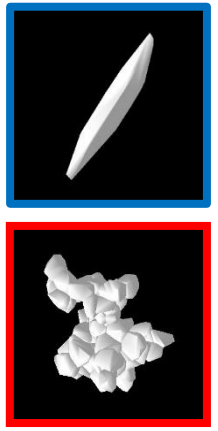




Memuro

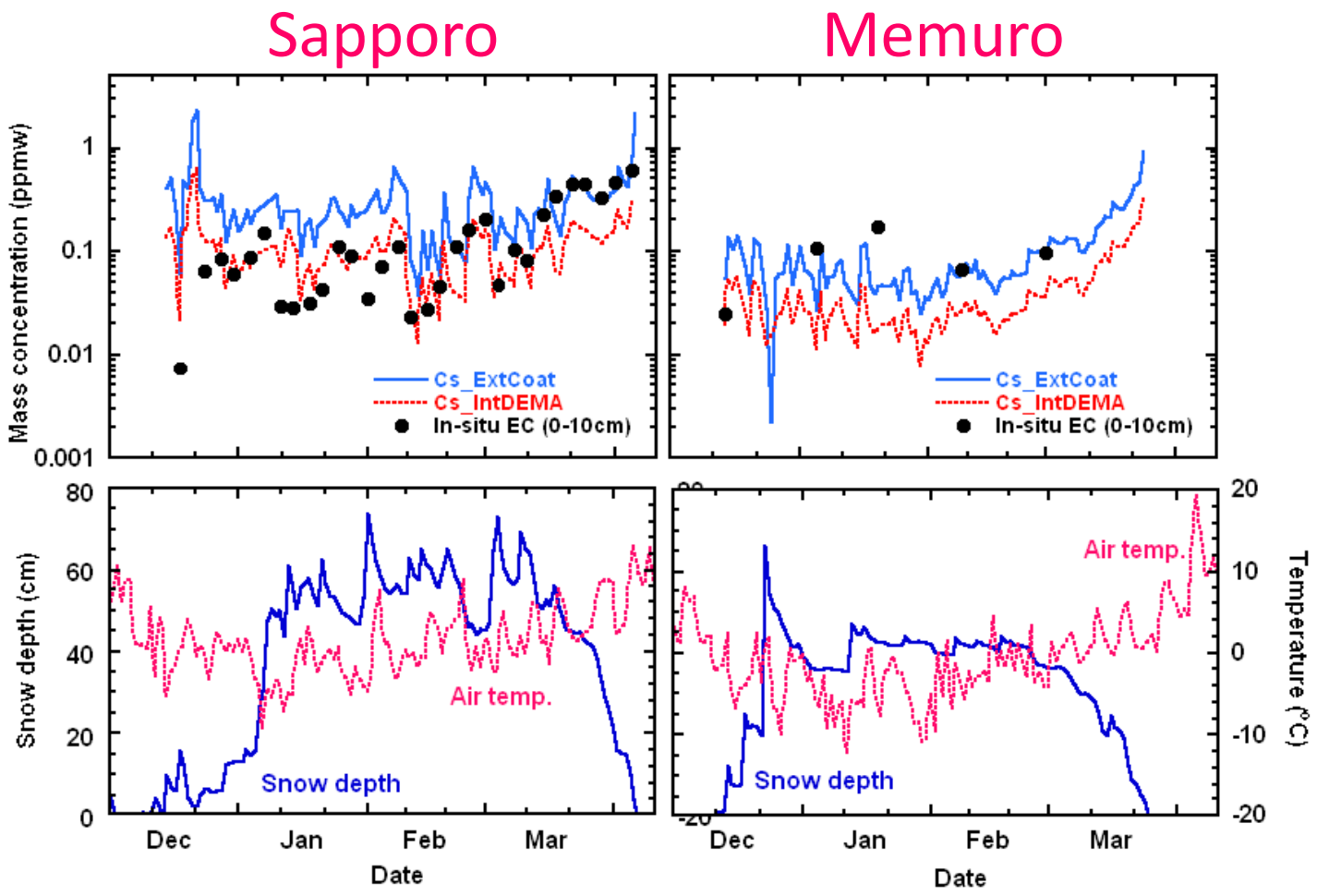






- Retrieved snow grain size: Vor. Column < Vor. Aggregate

Soot concentration in snow in 2010-2011



- Retrieved soot concentration: Ext. > Int.
- Int. agreed in accumulation season at Sapporo
- Ext. agreed at Memuro and in melting season at Sapporo

  --> dry/wet deposition and/or change in mixing state with snow metamorphism?

Narrowband albedo

- ✓ From narrowband albedo, snow parameters are retrieved without BRDF property of snow surface.
- ✓ This kind of narrowband albedo observation system can be used for snow parameter monitoring, improvement of snow parameter retrieval algorithm and radiative transfer model development such as snow shape model and impurity model in snowpack.

(4) Broadband albedo

$$a(\lambda) = \frac{F^{\uparrow}}{F^{\downarrow}}$$

- ✓ Broadband albedo is measured with a pyranometer.
- ✓ Issues on the measurement are frost, riming and dirt on glass dome, and snow on the instrument.
- ✓ Ventilation system is valid to protect those issues in case of downward radiation instrument.
- ✓ By employing a long horizontal pipe and a roof of the pyranometer, the albedo accuracy can be improved.

Physically based snow albedo model (PBSAM)
(Aoki et al., 2011, JGR)

A model to calculates broadband albedos and solar heating profile of snow from the profiles of snow grain size, snow impurity concentrations, snow water equivalent, etc.

Features

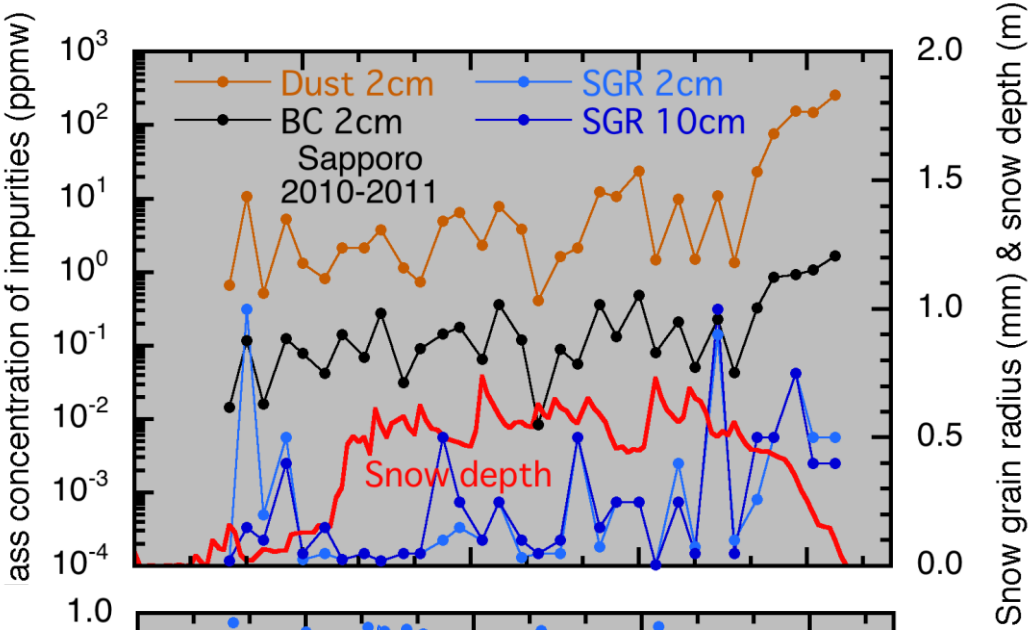
- ✓ Designed for use in GCM (e.g., MRI-ESM).
- ✓ Applicable to any snow depth, snow layer structure and solar illumination condition.
- ✓ Tunable several subbands applicable in broadbands.

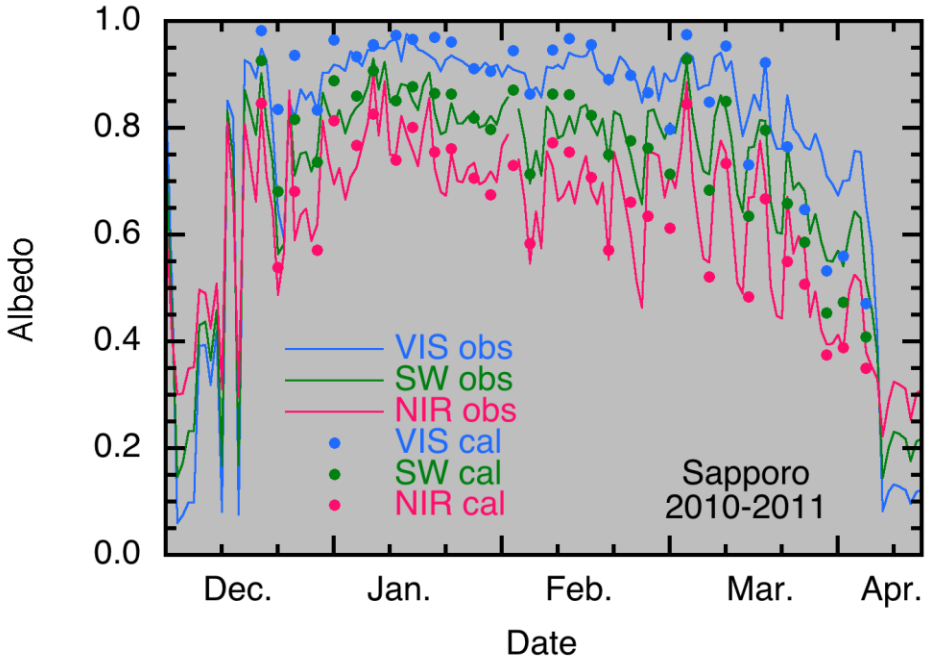
For studies …

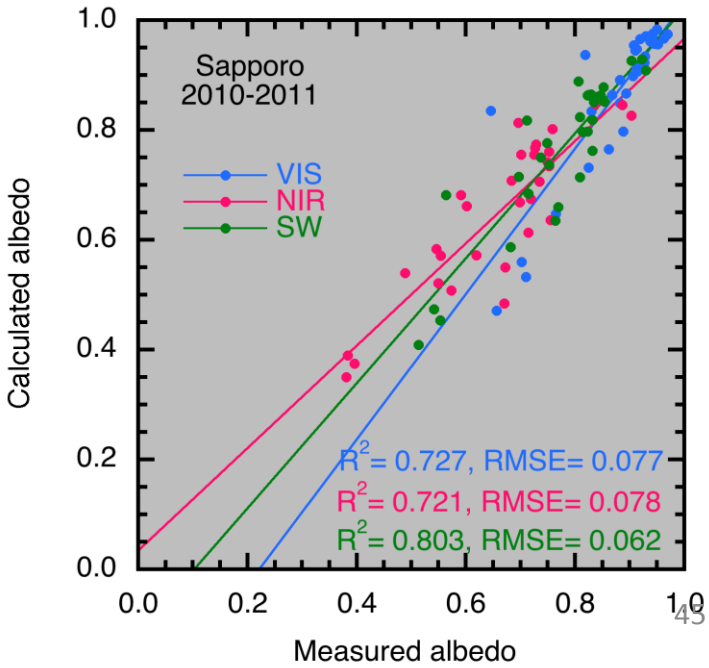
- ✓ Effects of snow impurities (e. g., BC and dust) on climate.
- ✓ Interaction between climate and snow properties (snow grain size, snow grain shape, snow water content, etc.) by using it with snow metamorphism model (e. g., SMAP, Niwano et al., 2012).

Snow parameters and albedo at Sapporo

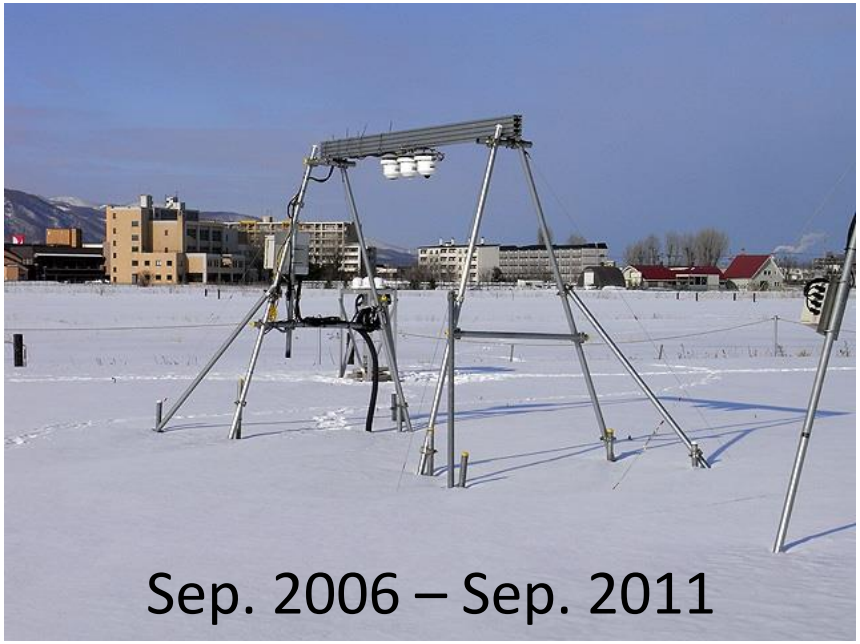
(Aoki et al., 2011, JGR)







Broadband albedo observation in Sapporo (ILTS)



Sep. 2006 – Sep. 2011

Sep. 2011 – present

- ✓ PBSAM accuracy validated with 5-year data at Sapporo: RMSE=0.056
- ✓ Possible causes of error in albedo measurement and simulation
  - ➢ Effect of a mount for upward radiation
  - ➢ Effect of snow surface condition disturbed by a mo
  - ➢ Error in snow parameters measured by snow pit ob

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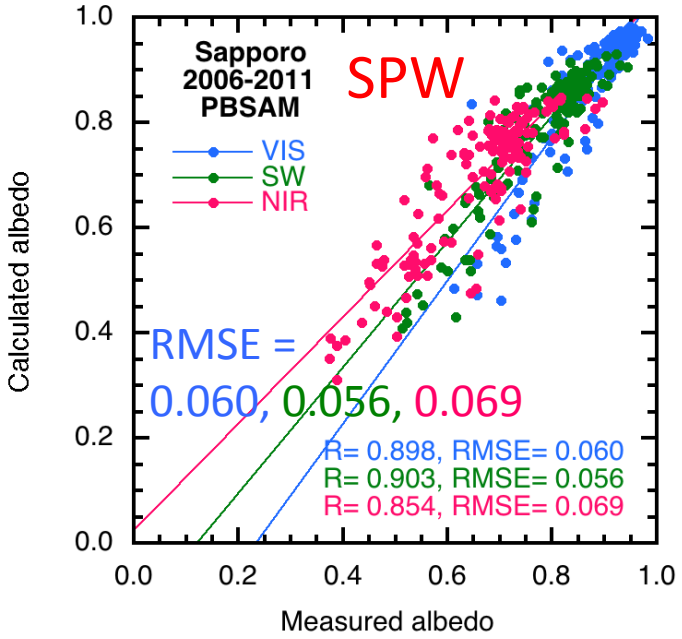
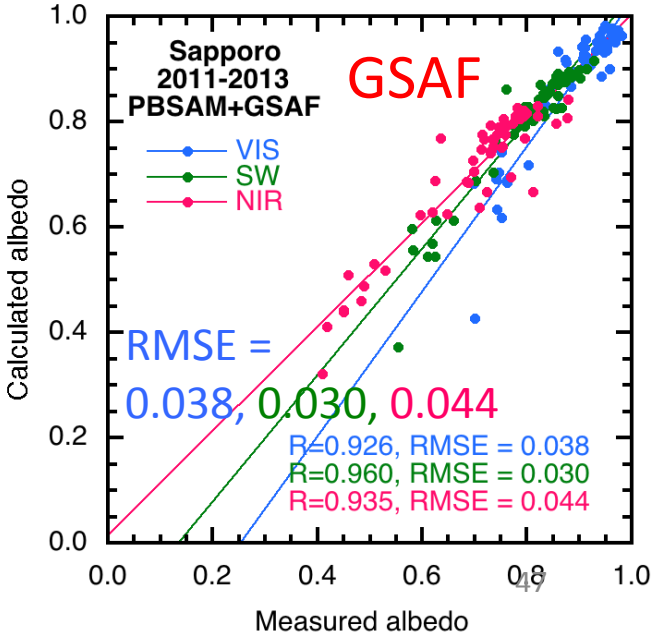
- ➢ Improved mount installed in September 2011
- ➢ GSAF-derived snow parameters employed

Effect of albedo mount and input data





Broadband albedo

- ✓ Broadband albedo is a fundamentally importance parameter in climate studies, radiation budget and snow microphysics.
- ✓ By employing the long horizontal pipe and a roof of the pyranometers, issues of disturbed snow surface and dirt on glass dome of the pyranometers can be improved.

Summary

- ✓ Optical devices to measure spectral albedo, spectral BRDF, narrowband and broadband albedos of snow surface have been developed.
- ✓ High accuracy measurement using the optical devices and systems could contribute the studies of snow microphysics, optical properties of snow, monitoring of snow parameters, and satellite remote sensing.