FINNISH METEOROLOGICAL INSTITUTE

COST-SNOW Helsinki Workshop 24.8. on in situ snow albedo measurements: Toward a snow albedo intercomparison experiment

ALBEDO OF SODANKYLÄ SNOW:

Observation experiences, results and error sources

Outi Meinander
Finnish Meteorological Institute (FMI)

Acknowledgements to all my co-workers

A European network for a harmonised monitoring of snow for the benefit of climate change scenarios, hydrology and numerical weather prediction

ESSEM COST Action ES1404

cost

CONTENTS

1 Irradiance ($E\downarrow$) measurements

- **Example 1.** Intercomparison

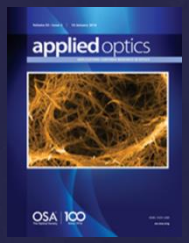
(filterradiometer participation, and data analysis)

[WMO TD No. 1454, Johnsen et al. JGR 2008]

- **Example 2.** Remarks to cosine response

(spectral irradiance intercomparison data)

[Meinander et al. Applied Optics 2006]



- **Example 3.** Rapid temporal changes in irradiance

(investigating spectral data)

[Meinander et al. Optical Engineering 2003]

CONTENTS

2 MEASURING SNOW ALBEDO ($E\uparrow/E\downarrow$)

Experiences on

- Broadband
- Multiband, and
- Spectral instruments
- Operational and experimental use

[based on multiple literature references]

CONTENTS

3 DISCUSSION (RESULTS, EXPERIENCES ON ALBEDO MEASUREMENTS, ERRORS ETC.)

- **Example 4.** Understanding and identifying needs:

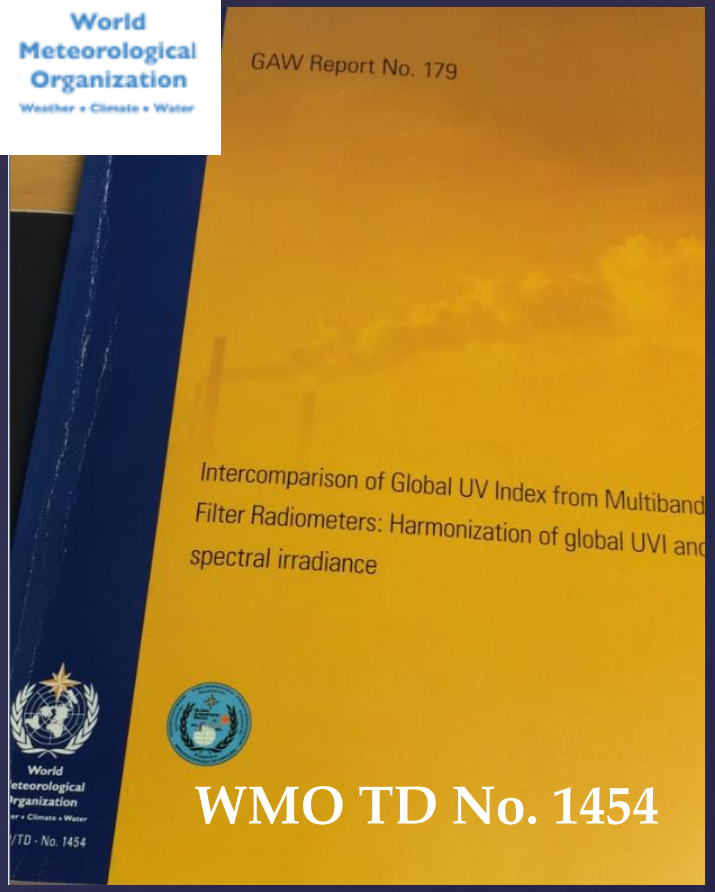
  Albedo of Sodankylä snow: Impurities in snow and albedo at UV wavelengths vs SNICAR [Meinander et al. ACP 2013]

4 CONCLUSIONS

- Conclusions based on experiences
- Some remarks related to using snow albedo modeling or satellite data

EXAMPLE 1.

WMO/COST-726 Irradiance measurement intercomparison (in NRPA, Norway)



Johnsen, B., et al. (2008), Intercomparison and harmonization of UV Index measurements from multiband filter radiometers, *J. Geophys. Res., 113, D15206, doi:10.1029/2007JD009731*.

EXAMPLE 1. Harmonization of global UVI and spectral irradiance

Q1: WHAT WAS COMPARED?

- Retrieval of Global Solar Ultraviolet Index (UVI) [WHO 2002]

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Q2: FOR WHAT?

- To harmonize the worldwide UVI measurements for alerting people about harmful UV exposure

EXAMPLE 1. Harmonization of global UVI and spectral irradiance

Q3: HOW WAS THE INTERCOMPARISON ARRANGED?

- In one place side by side irradiance measurements
- Using same type of Multiband Radiometers **(MBFR)**
- Compared to a group of reference spectrometers
- Spectrometers' spectral calibration scale agreement was investigated, and reference spectra for comparison established

EXAMPLE 1. Harmonization of global UVI and spectral irradiance

Q4: WHAT WERE THE MAIN TASKS?

1. **Characterize the instruments' spectral and angular responses (*by the organizer*).**

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3. **Harmonized results calculated by the intercomparison organizer.**

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3. Harmonized results calculated by the intercomparison organizer.
4. **Comparison of harmonized results with data provided by the operators.**

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3. Harmonized results calculated by the intercomparison organizer.
4. Comparison of harmonized results with data provided by the operators.
5. SZA dependent correction function outcome : All results within ±4.6% (2**σ**) for SZA<80º

The biggest challenges in the intercomparison

- **Changing weather conditions:** rain, fog, clouds…

- but also clear sky -> -> -> **how many weeks are needed to perform a good intercomparison?**

-> here the originally planned 6 weeks were enough (here: only *E*↓, no problem of changing snow properties and conditions; just to gain cloudless and fully coudy Irradiance data for various SZA!)

The biggest challenges in the intercomparison

- **4 highest quality reference spectrometers** were operated "as usual" and their data were compared

-> **how to select the reference spectra?**
Possibilities: One instrument selected? Median spectra? Or other calculated spectra, what?

- > spectra compared with each other and with RT modeled and two MBFR -> outcome was to choose one intrument as a Reference

Challenges… (continued)

SZA differences in data

How good is the cosine correction?

Temporal differences in data:

- How rapid is the sampling of each instrument?
- How rapid are the changes in cloudiness?

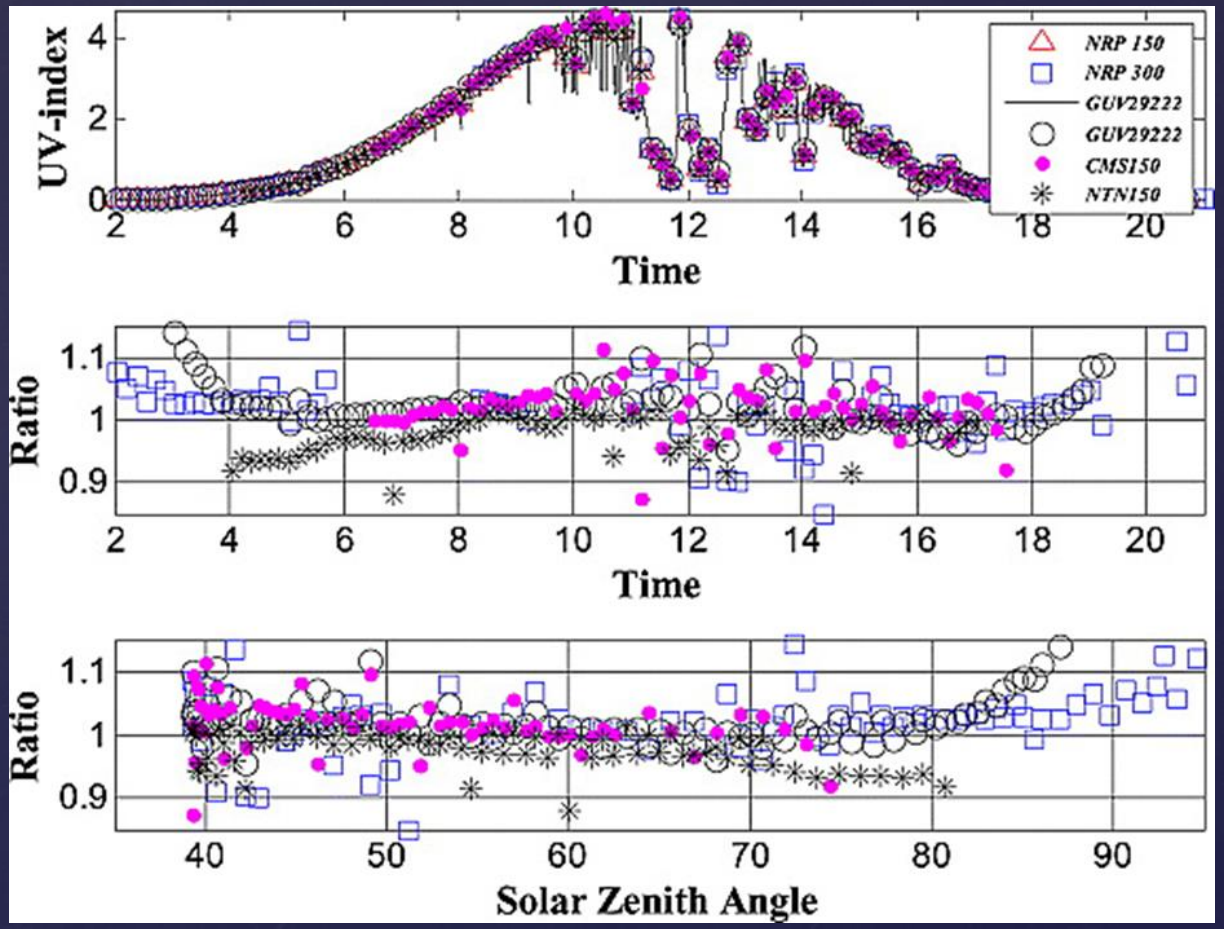


Fig. 1 of Johnsen et al. (2008)

EXAMPLE 2.
Azimuthal error in the diffuser

Meinander et al. 2006. Applied Optics, ISSN 1559-128X, E-ISSN 2155-3165, Vol. 45, no 21, 5346-5357 . Doi 10.1364/AO.45.005346

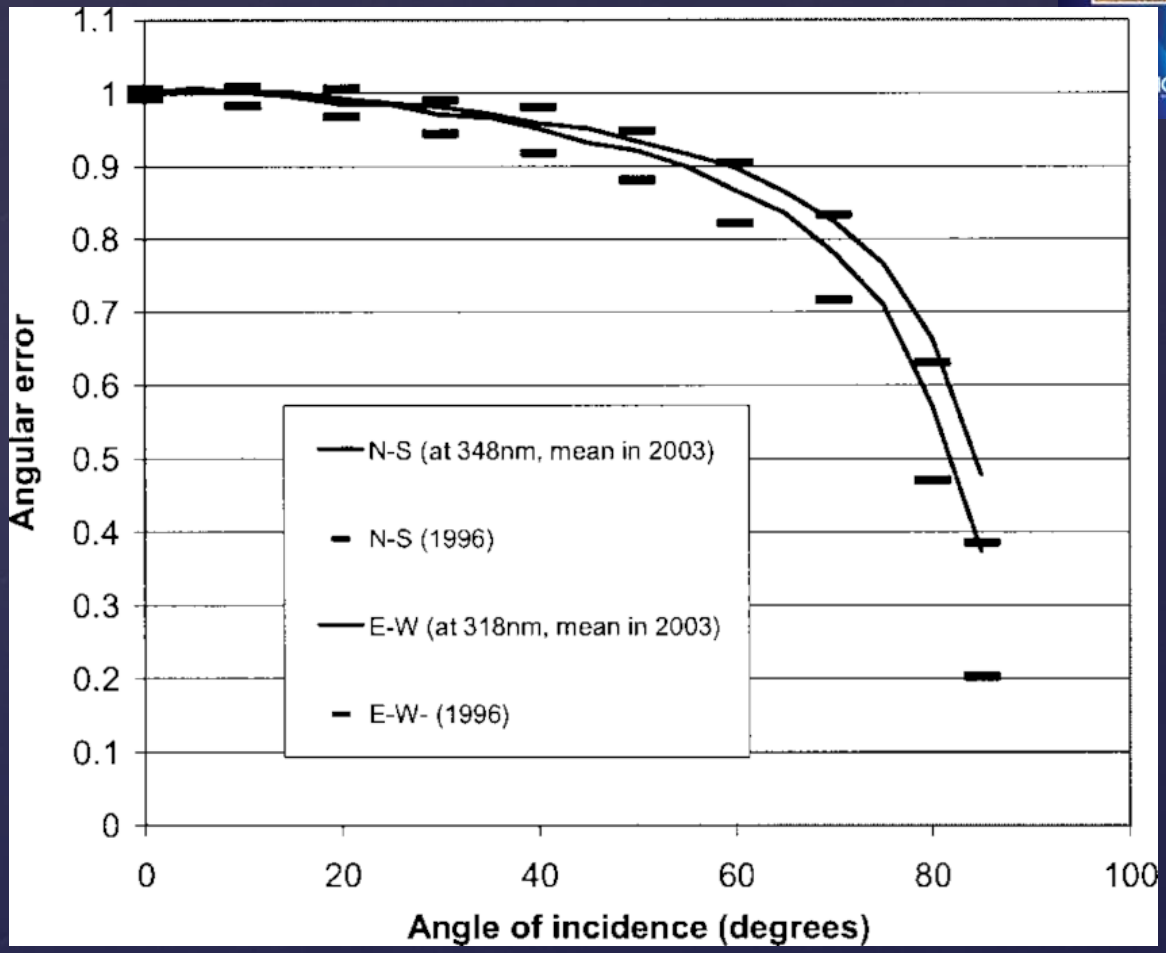
- A diurnal variation of approximately 2-9% was detected in one spectrometer irradiance spectra.
- This cannot be explained by the non-ideal angular response of the instruments' input optics in one plane (cosine effect).
- Instead, by using a radiative transfer model, we show that differences in the angular response in four azimuth planes have the potential to bias the measured data by up to 4.4% (azimuth effect).

EXAMPLE 2.

Azimuthal error in the diffuser

- Nordic NOG spectrometer Intercomparison (Tylosand, SWE)

- Cosine characterized Instruments



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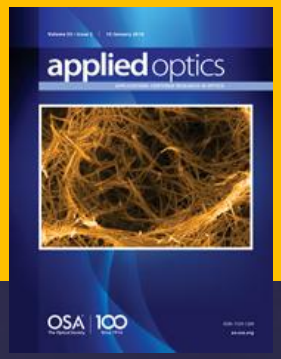

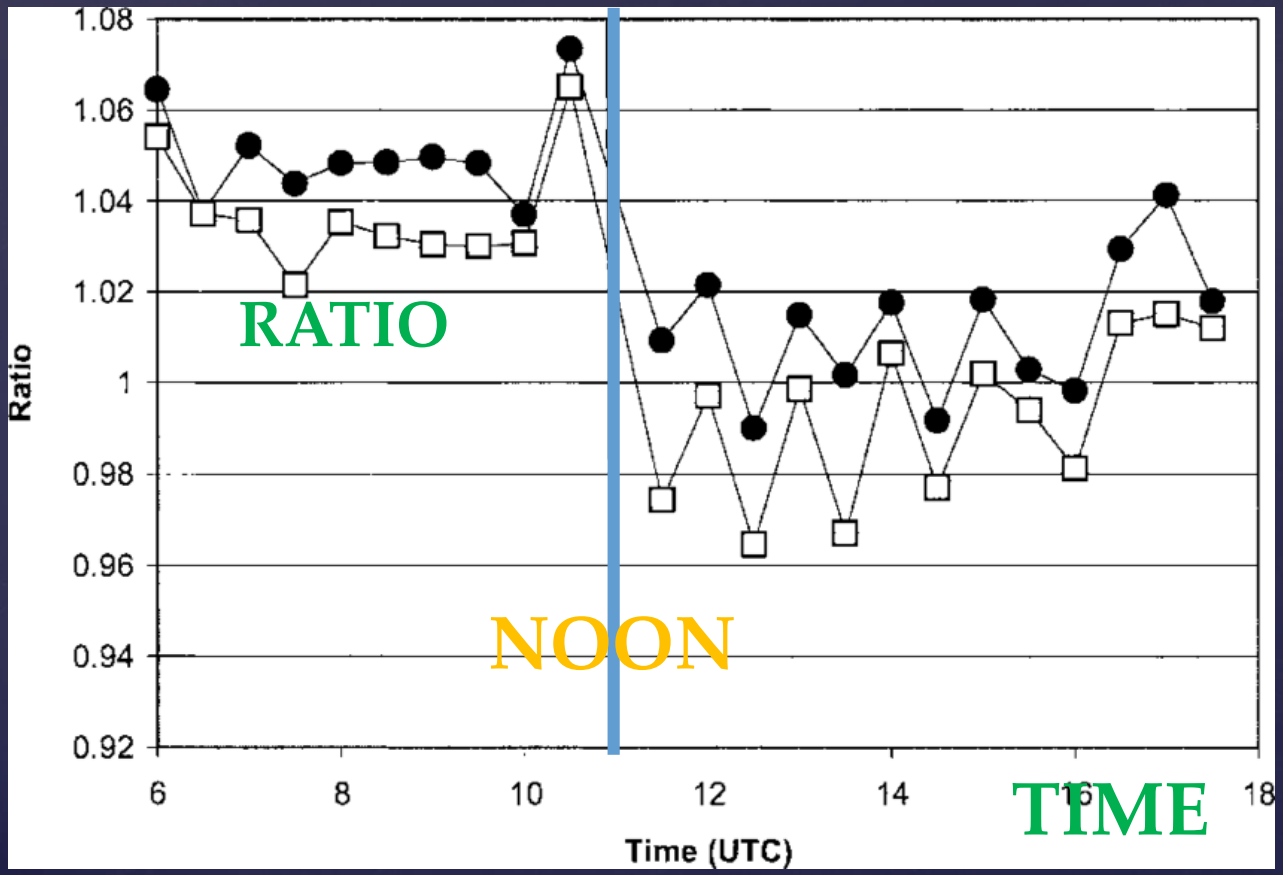

SZA dependent difference in irradiance ratios against One of the spectrometers (all ratio values should be ~1)

Meinander et al. 2006. Applied Optics, ISSN 1559-128X, E-ISSN 2155-3165, Vol. 45, no 21, 5346-5357 . Doi 10.1364/AO.45.005346

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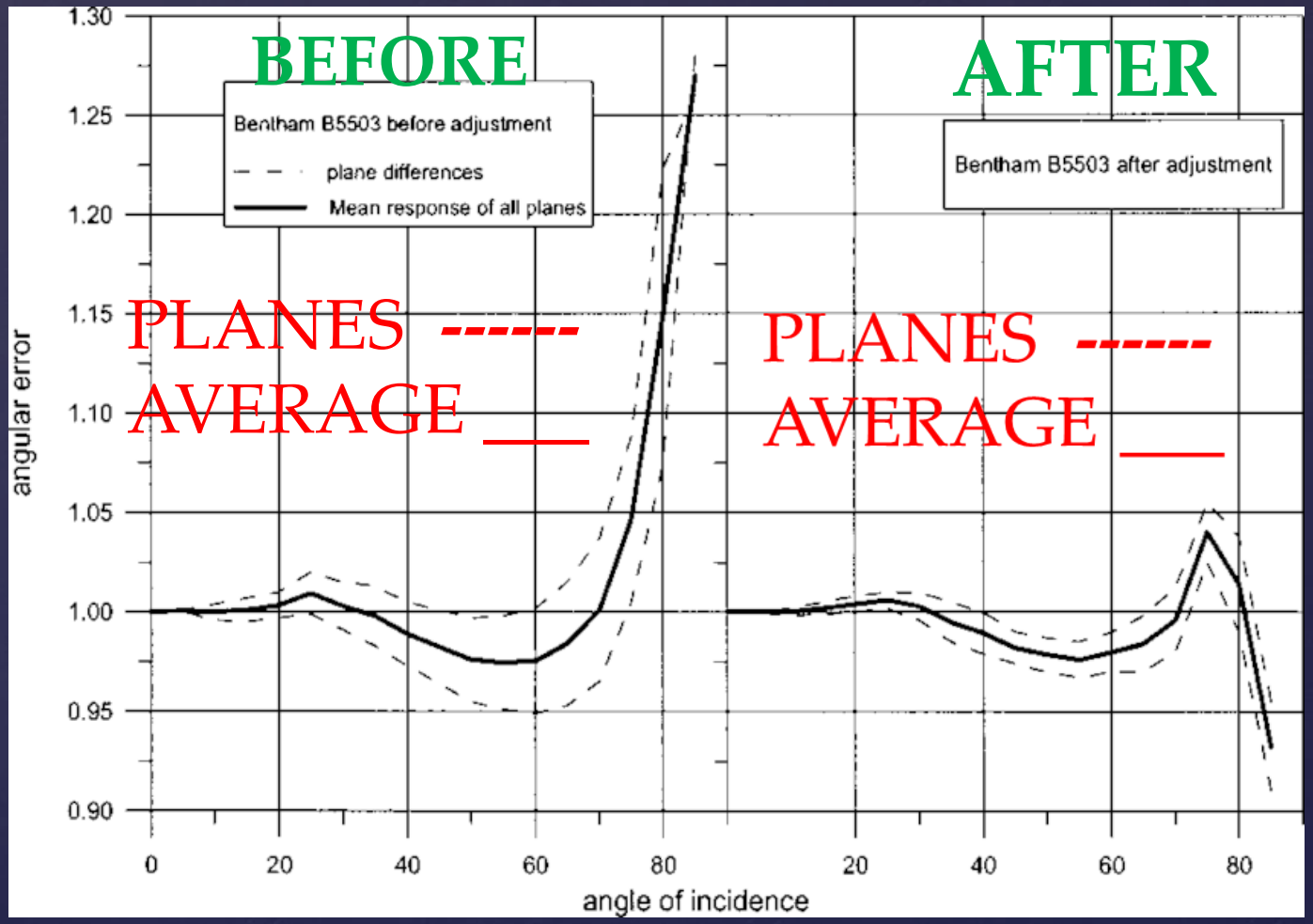

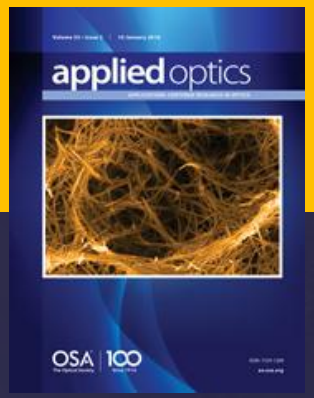

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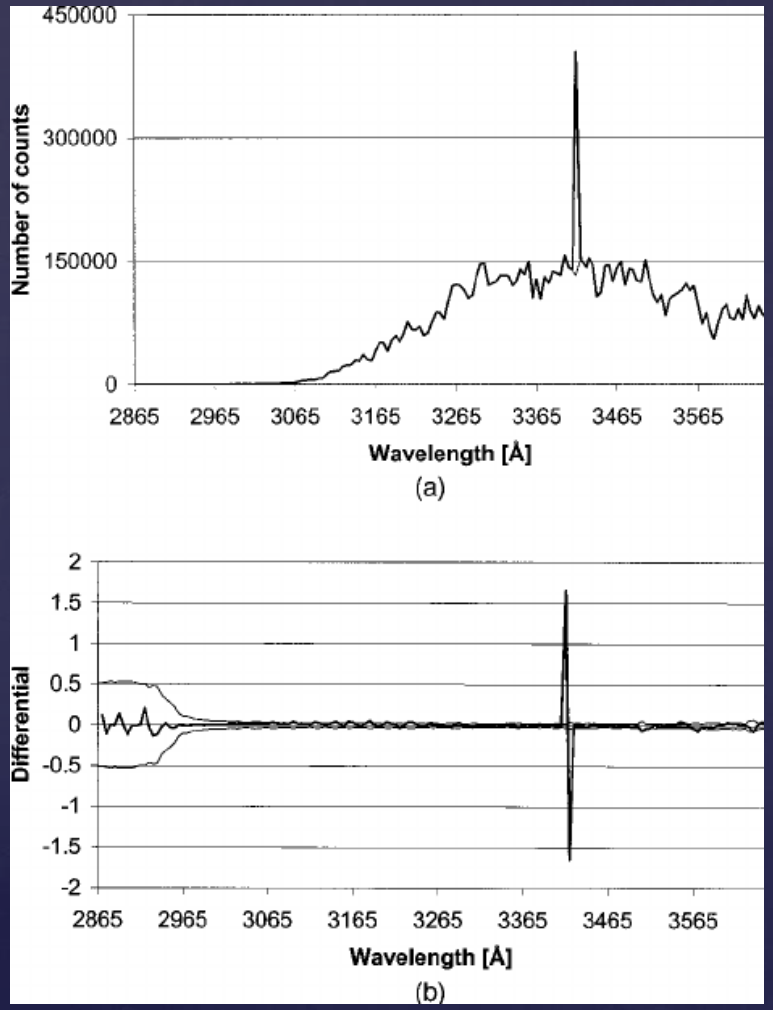
EXAMPLE 3.

Rapid changes in irradiance or spikes?



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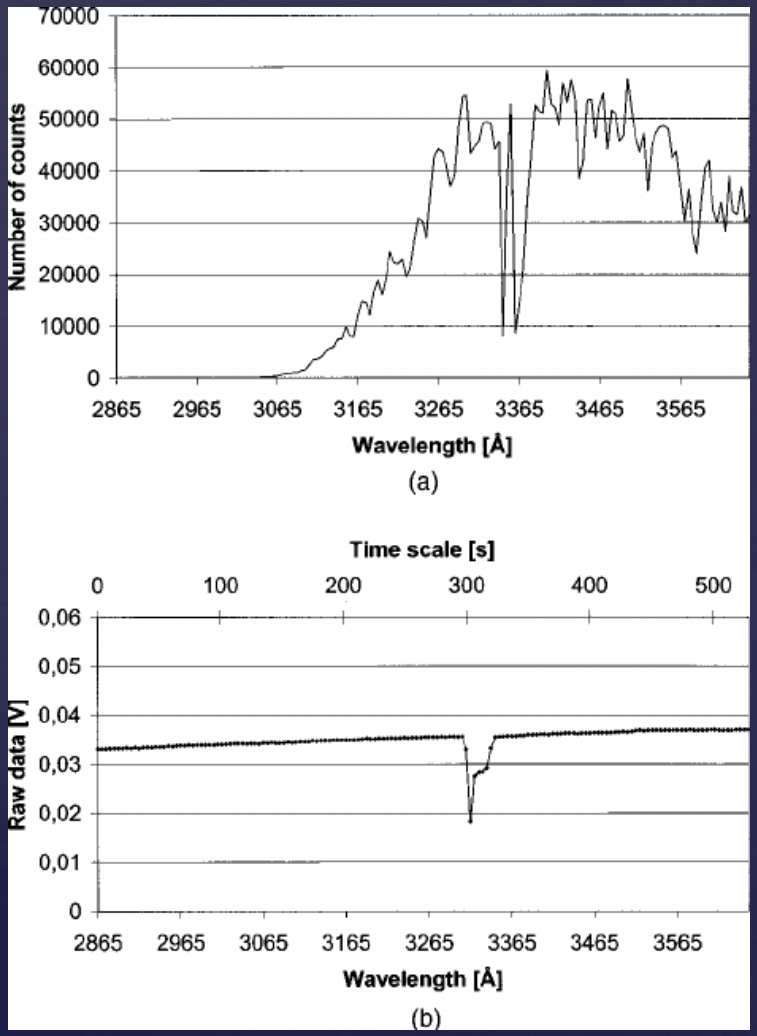

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2Reflectance & Albedo Instruments

ASD FieldSpec 350-2500 nm

ASD HH 325-1075 nm

SL501 erythema weighted UV (< 390 nm)

Bentham DM-150 290-550 nm

Kipp & Zonen CM-14 albedometer, non-Weighted broadband 310-2800 nm

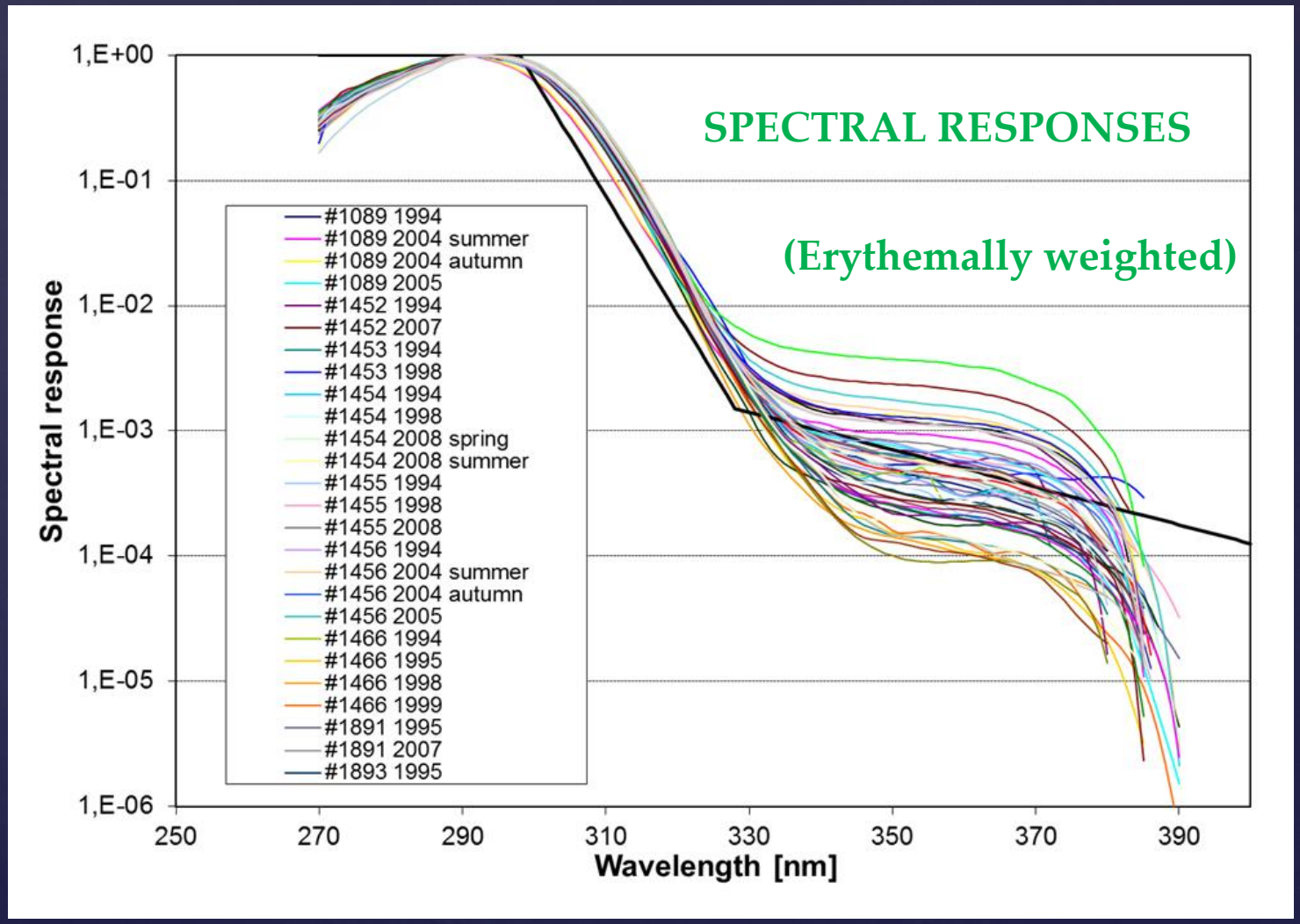
NILU-UV 305, 308, 320, 340 and 380 nm multichannel, bandwidth~10 nm
+ PAR 400-700nm

2. MEASURING ALBEDO

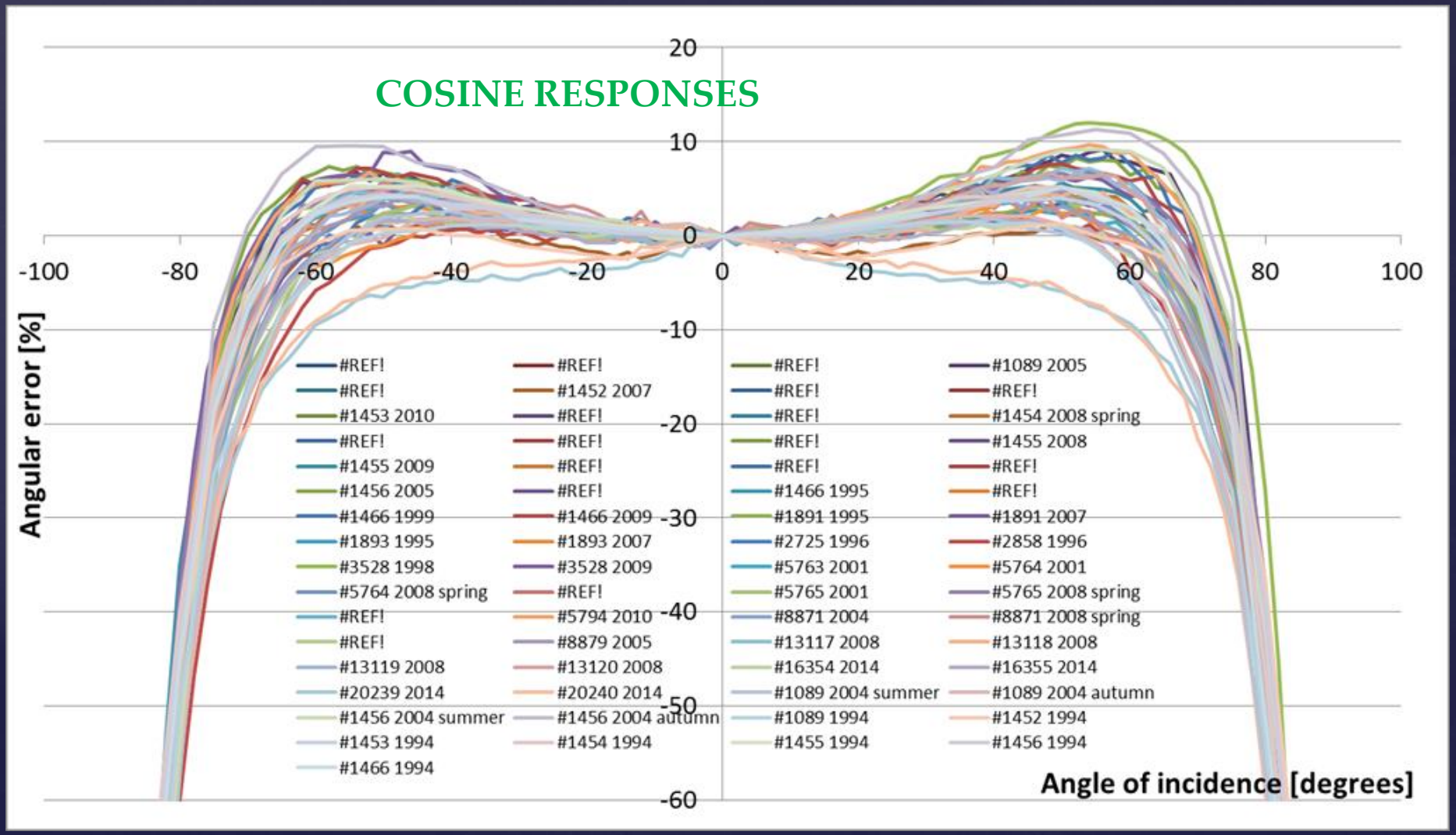
HOW MEASURED/ HOW EFFECTS ERRORS (X)	Sensor	Cosine difference (sensor optics)	Spectral difference (detector)	Temporal difference
2 independent sensors	SL501	X	X	_
1 sensor turned up and down	NILU-UV, ASD* (spectral)	_	_	X
2 sensors , 1 detector	Bentham (spectral)	X	_	X

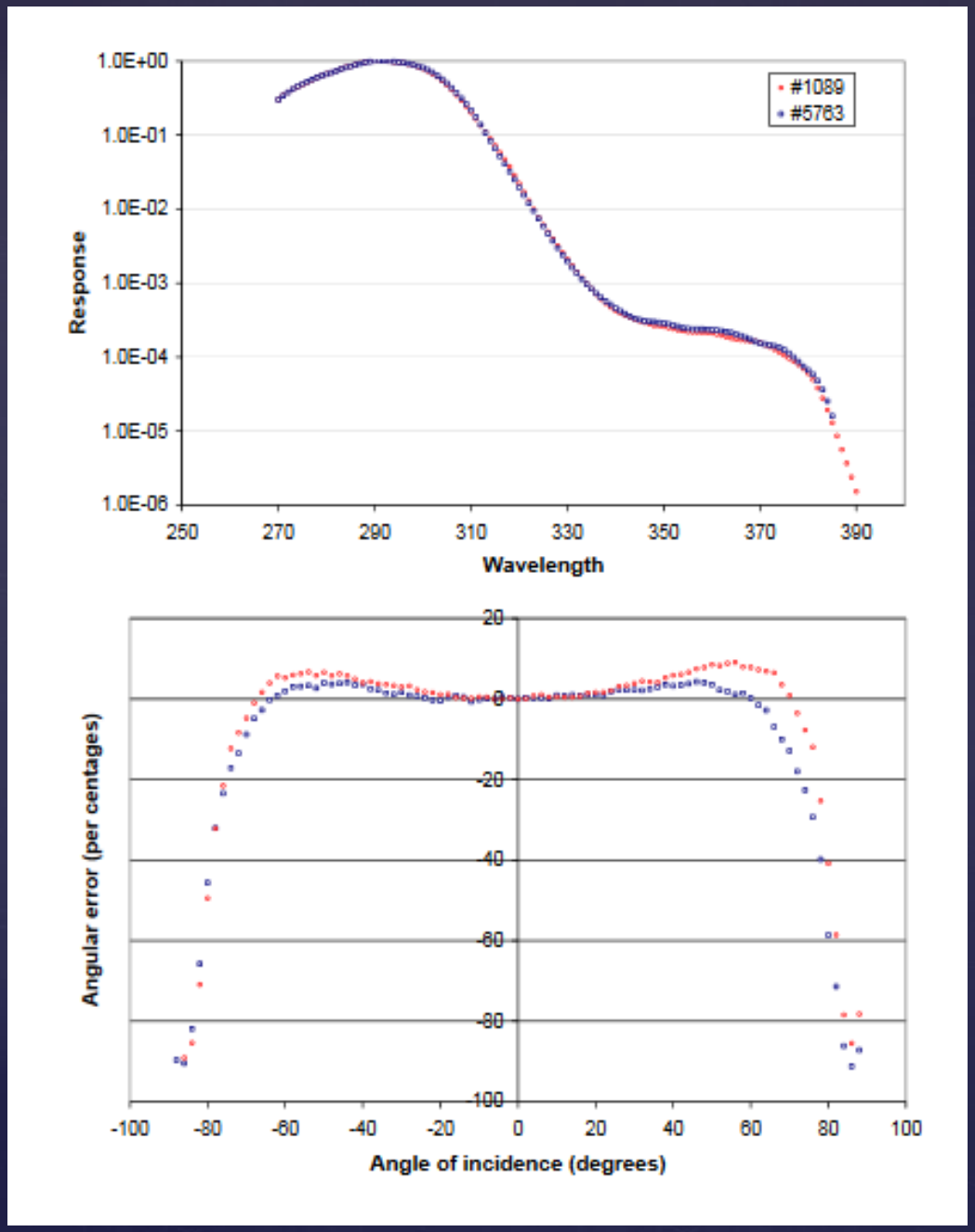
*ASD for albedo with a cosine receptor (ASD reflectance using a Reflectance standard)

Difference from sensor to sensor: Sensors #1089 ja #1456 were observed to change for their **spectral responses and calibration coefficients** in 2004, and therefore the responses for these sensors have been measured more often than other sensors and also with quick checks (calibration at STUK by Lasse Ylianttila) **(TEMPORALLY CHANGING PROPERTY)**



Differences from sensor to sensor: the two curves, which clearly separate from the group of all the other measurement data in Figure 6, are for SL501 sensors #20239 and #20240, which are the newest FMI sensors. **(SENSOR PROPERTY)**





Measurement uncertainty with SL501

- the typical total uncertainty for SL501 is 1.7 - 4.3 % [Hulsen and Grobner 2007]
- When 2 similar sensors for albedo, error < 1% [WMO 1996]

For albedo, always 2 sensors with similar cosine and spectral responses

[Meinander et al. 2008, ACP)]

Bipolar BB Snow UV Albedo

S = Sodankylä Arctic Research Center of FMI, Finland (67°22'N, 26°39'E, 179 m a.s.l.) Continuous *A(UV)* since 2009.
Also: BC on snow, weekly sampling during snow time.

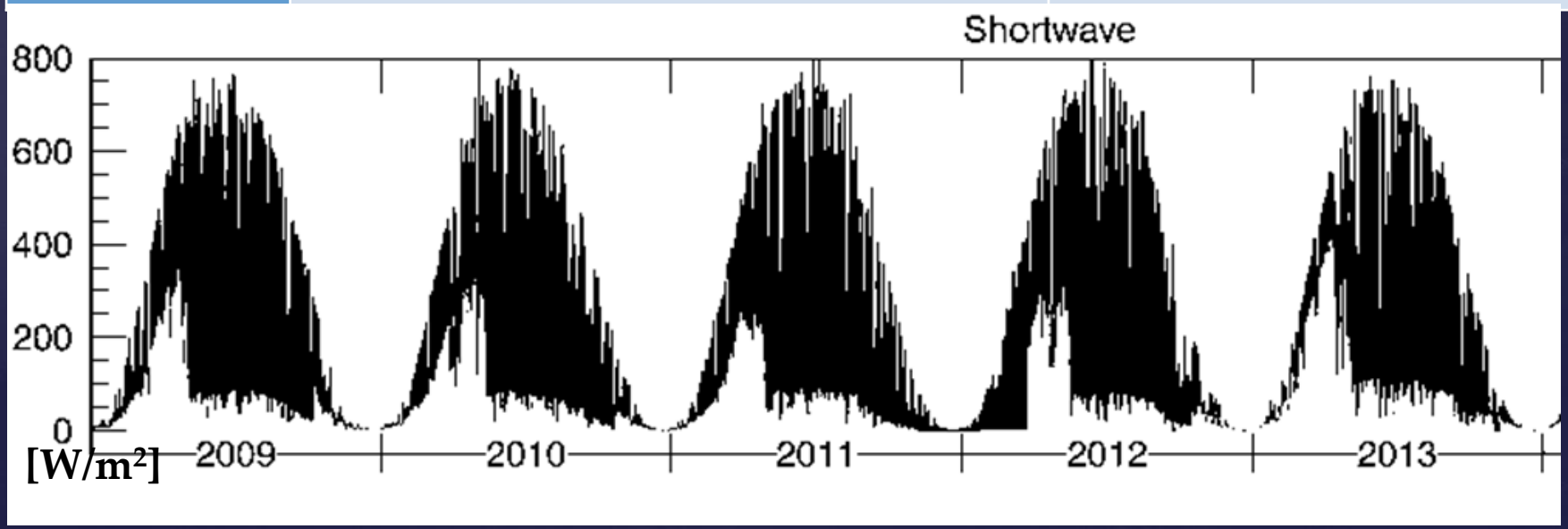
M = Marambio base of Argentina, Continuous *A* (UV) since 2013.

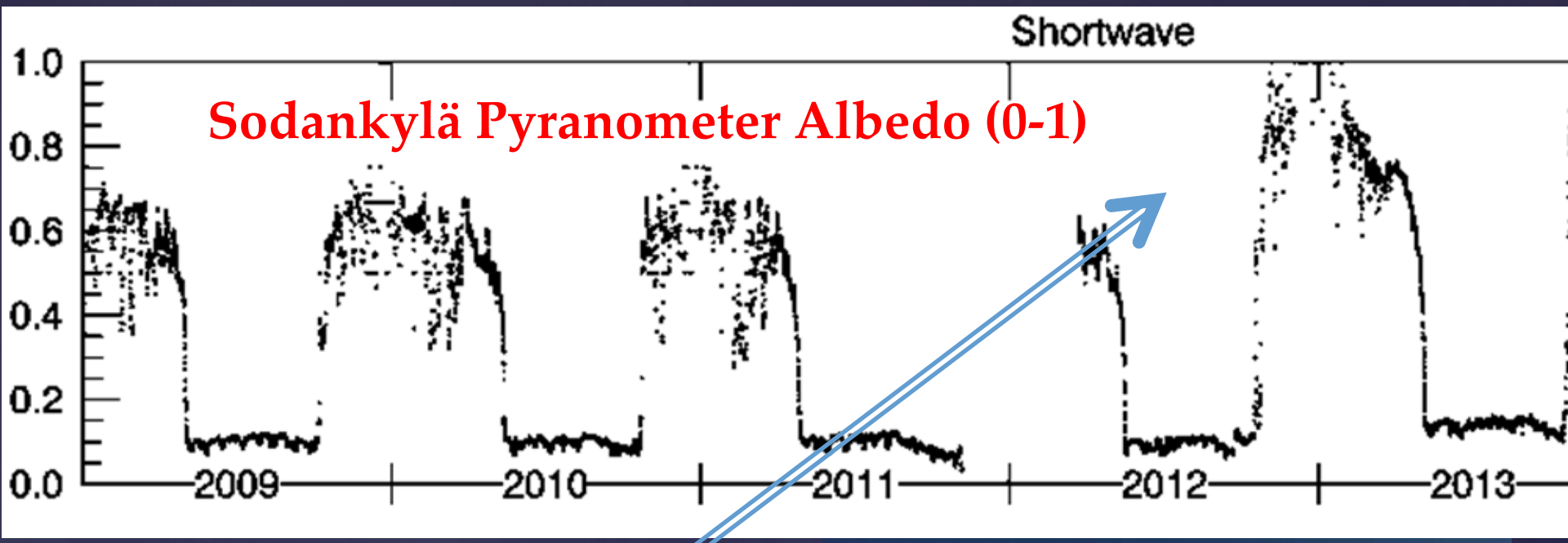
Also: a new weather station and instruments to measure the optical properties, number size distribution and chemical composition of aerosol particles, as well as the concentrations of carbon dioxide and methane.

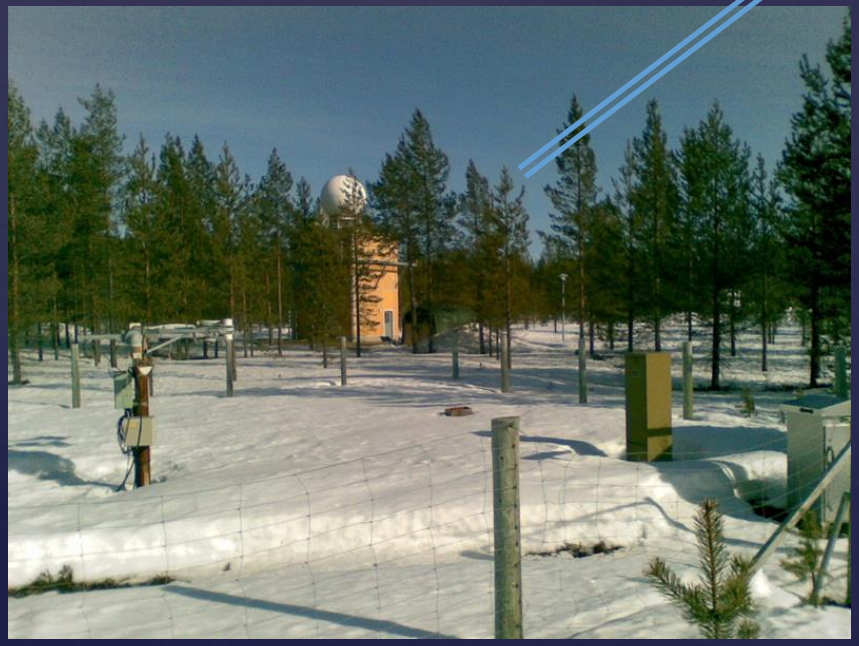
CHALLENGE / POTENTIAL ERROR SOURCE	SODANKYLÄ OPERATIONAL ALBEDO FIELD	MARAMBIO CONTAINOR
Temperature	The temperature of the sensor needs to be stabilized and the recorded sensor temperature to be used in the QA/QC of the data.	The same as in Sodankylä.
Low solar elevation	Cosine error of the sensor may cause a need to exclude low elevation data from the analysis	The same as in Sodankylä.
Wind	Due to the lack of wind, snow accumulates on the sensors; some frost can be formed.	High winds can break the connector or produce radial shake, which may affect the levelling among other things.

DUST	**Not a problem in Sodankylä.**	**The dome may get scratches due to the ice and sand and dust; surfaces of the quartz domes are not easy to maintain cleanest and free of dust. Snow can sometimes be dirty.**
SNOW SURFACE	Seasonal snow cover, snow height varies. **According to the WMO, the operational meteorological local 210 albedo is defined to be measured at a standard height of 1–2 m (WMO, 2008, I. 7)**	Snow is sometimes blown away revealing the bare ground under the down-looking sensor in Marambio.

Maintanence	**Snow surface is not totally untouched during the installation; may cause error in the data until new snow.**	**The surface of the quartz domes are not easy to maintain cleanest and free of dust, as the shelter is visited once a week.**
Measurement horizon	Trees surround the area. As Sun is low during snow time, the tree shadows can be long. Surrounding trees were cut 19 Oct 2012.	Not a problem, the horizon is open.




Shortwave
Sodankylä Pyranometer Albedo (0-1)
1.0
0.8
0.6
0.4
0.2
0.0
2009
2010
2011
2012
2013



Sodankylä:
Flat surface and open horizon
SoS-2013 at Sodankylä airport
Outi Meinander, FMI

SZA dependency of Snow albedo (U-shape)

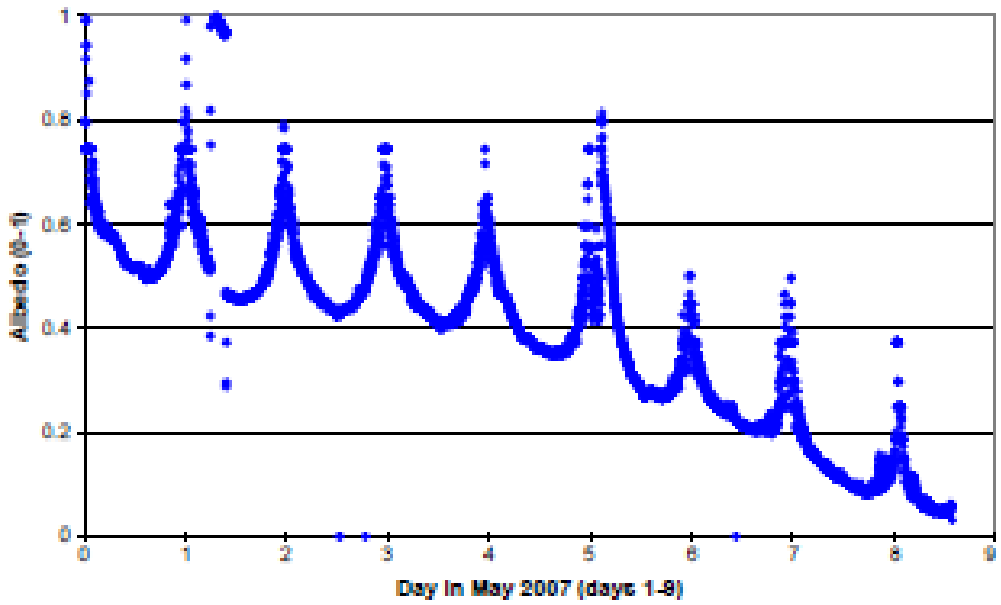


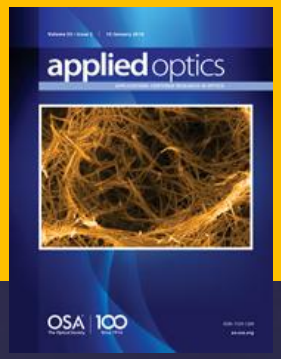
Fig. 10. May albedo data with the U-shape appearing each day. Only cases SZA<85° for each day from 1 to 9 May (days 121–129) shown here.

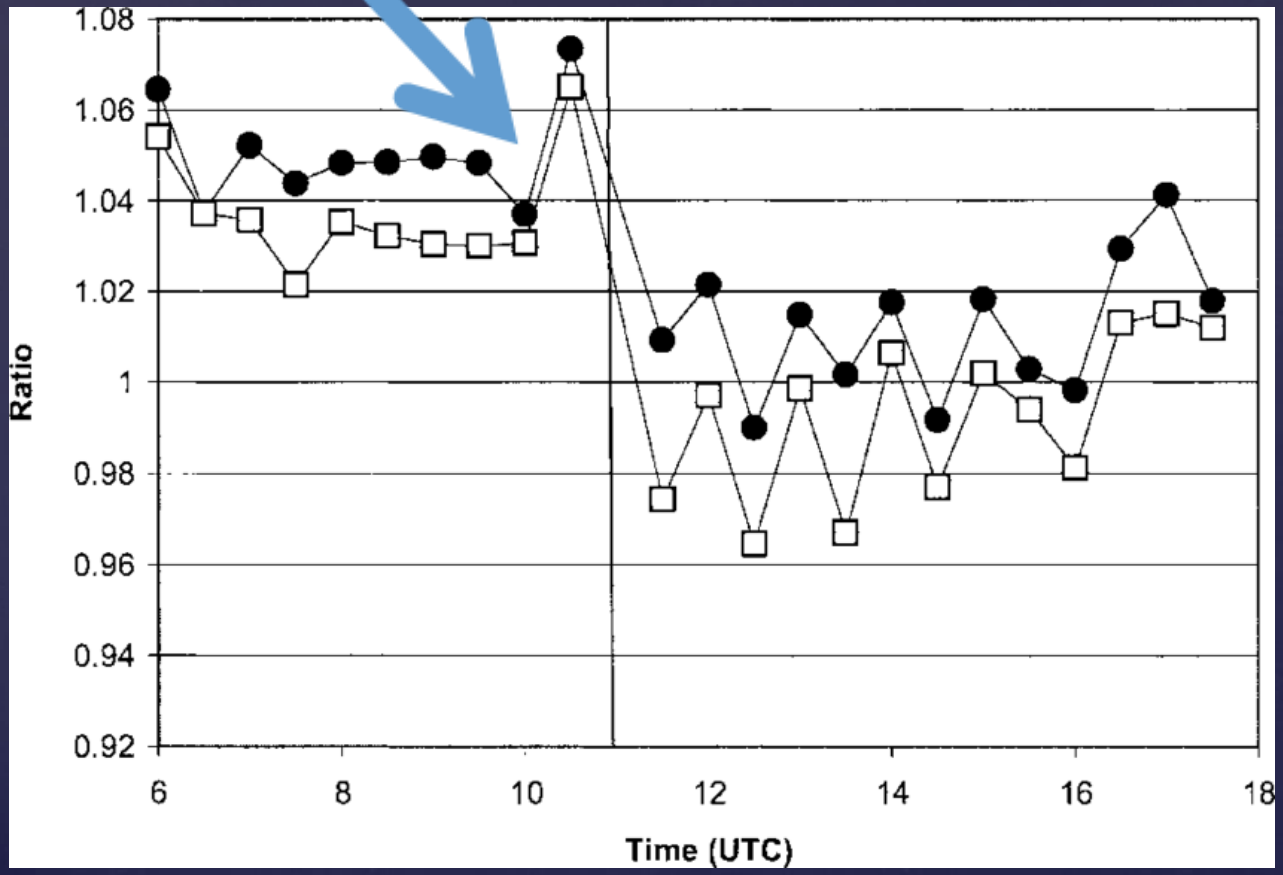
$$R(\mu) = R0 \frac{(1+d)}{1+2d\mu}$$

Where μ is the cosine of SZA and R0 is the reflectivity for μ = 0.5, and d is empirical parameter according to Briegleb et al. (1986)

[Meinander et al. ACP 2008]

Azimuthal error in the diffuser vs azimuthal error in albedo?





Other possible reasons for
Observed asymmetry:

- Sensor levelling?
- Changes in sky
- conditions
due to aerosols
- Etc.

Meinander et al. 2006. Applied Optics, ISSN 1559-128X, E-ISSN 2155-3165, Vol. 45, no 21, 5346-5357 . Doi [10.1364/AO.45.005346]

EXAMPLE X. Azimuthal error in the diffuser vs azimuthal error in albedo?

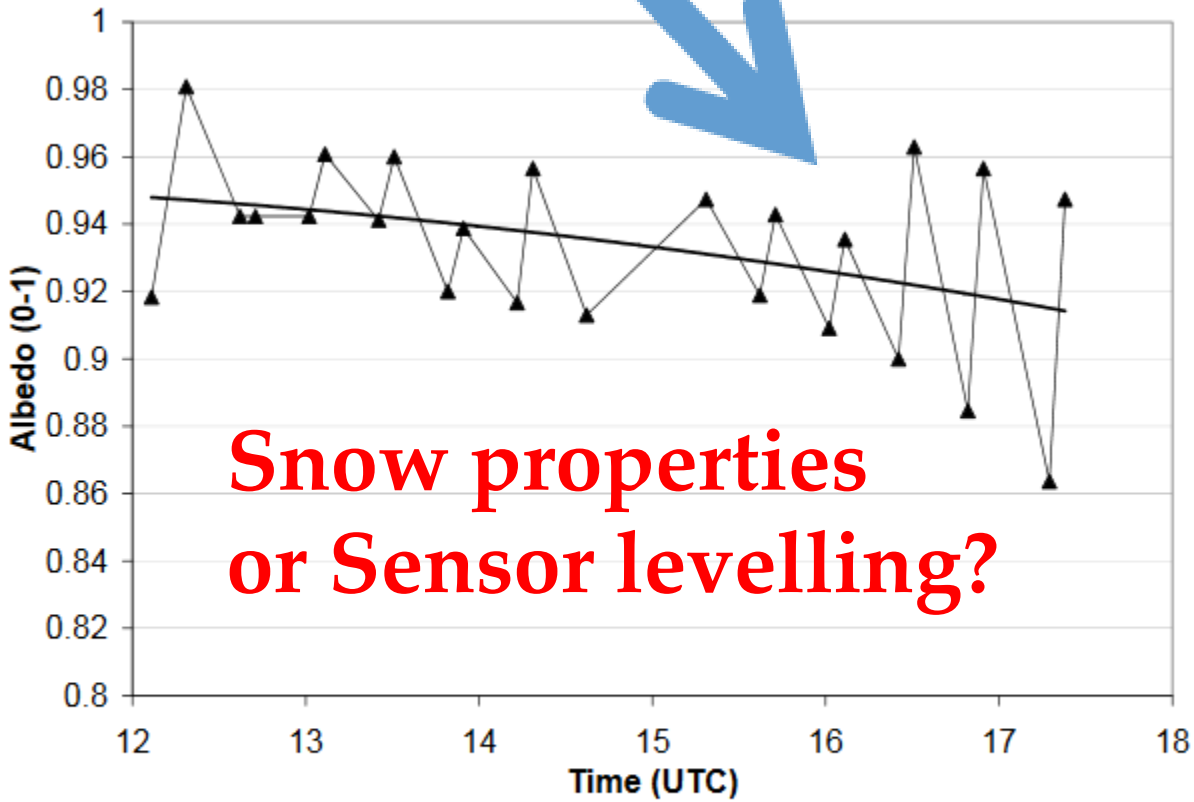


Fig. 5. The re-calculated 1-min albedo data of the Antarctic SZA asymmetry case on 4 January 2004 at Neumayer, with a linear fit calculated by the least squares method.

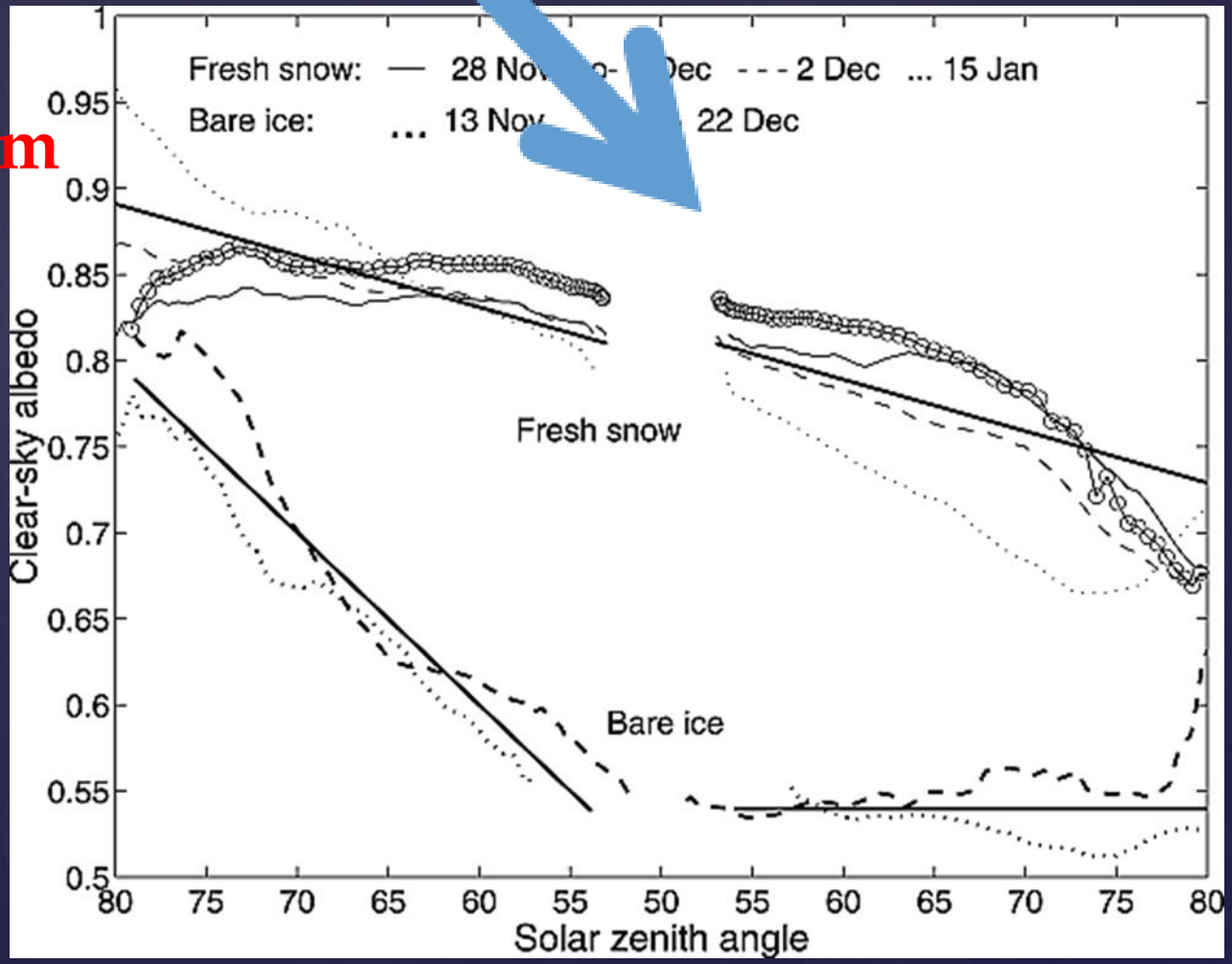
EXAMPLE X. Azimuthal error in the diffuser vs azimuthal errot in **albedo** [Pirazzini JGR 2004]

Snow metamorphism

Sastruga

Sloping

Non-homogenous snow surface



SZA asymmetry

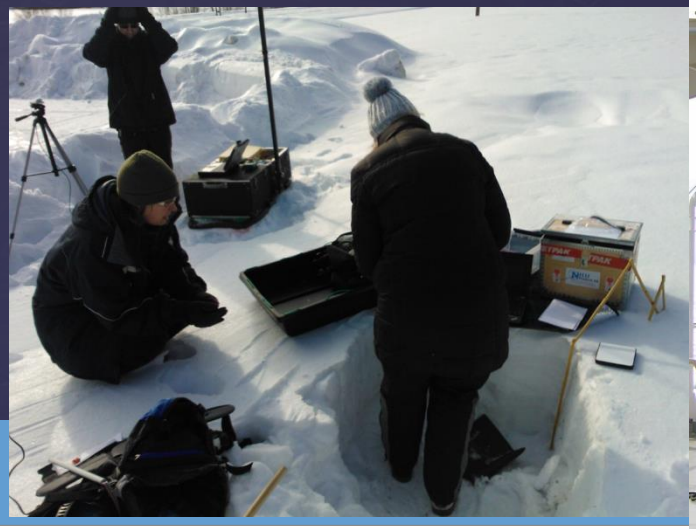
Due to temporal changes of snow properties that Dominate over the SZA dependent albedo shape, e.g.,

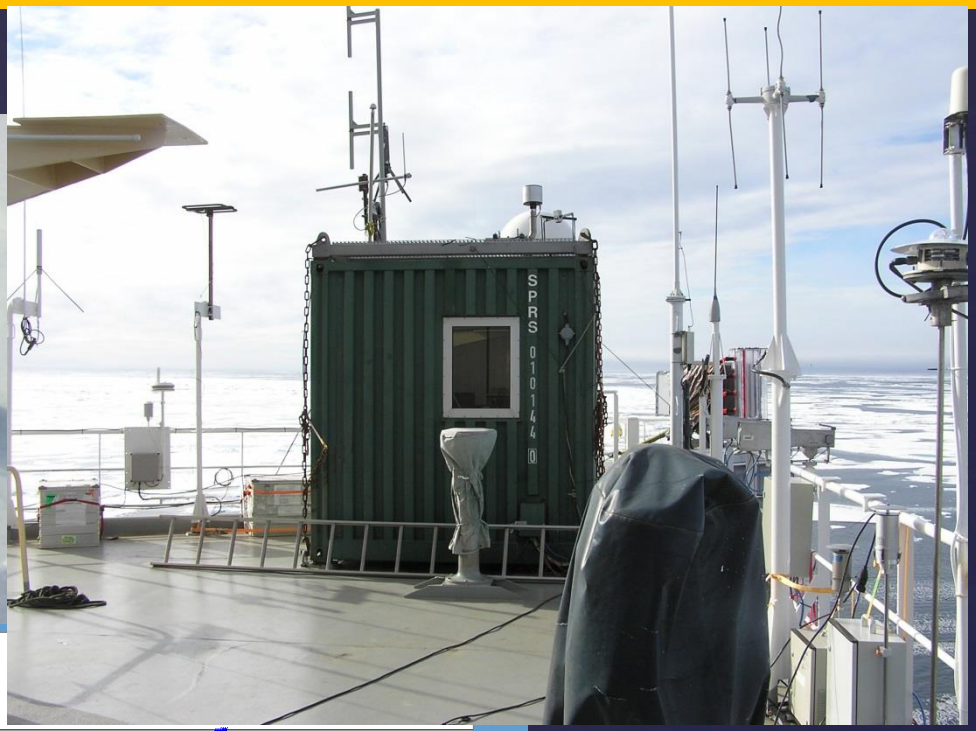
1. Snow surface is below freezing during night. Moisture in the air makes frost on the snow surface during evening and night, and higher albedo is observed in the following morning. The effect of frost disappears towards afternoon as the frost melts (or evaporates) from the surface. The physical process on the surface may be quite complex, as we are dealing with a transition between solid and gas state here. But, as a result, the albedo declines within the day.

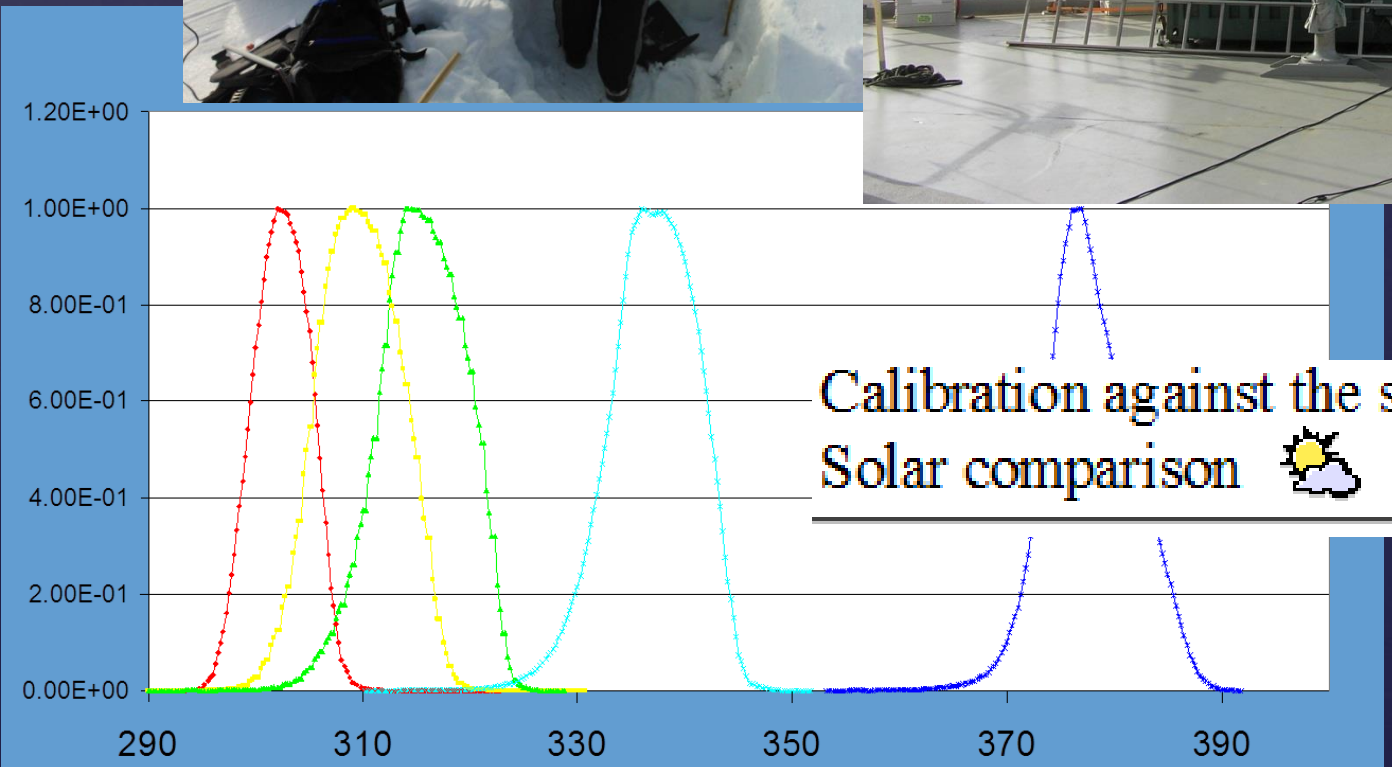
2. In case of no frost, the melting of the snow surface during day leads to a decrease in the albedo, as the effective grain size increases. Re-freezing during night contributes to the higher albedo of snow in the morning, as the effective grain sizes decreases again.

3. New snow during the previous evening and night, or in the morning of the albedo asymmetry day, can result in a higher albedo for the morning hours. This albedo may decrease as a function of time due to changes of the snow properties.

NILU-UV ALBEDO (UV+PAR 400-700 nm)







Calibration against the spectroradiometer

Solar comparison +

NILU-UV albedo measured during SOS-2012 campaign (data unpublished)

Albedo / BC	Reference spot Average (std)	Spot1('DC') Average (std)
UV	**0.70** (0.08)	**0.28** (0.10)
VIS	**0.92** (0.03)	**0.29** (0.01)
EC (surf)	-	**50** (14)
EC(all)	**160** (113)	-
EC (top)	**87** (-)	**4916** (1909)

Table 4. Albedo of snow at 305, 313, 320, 340, 380 nm, and of PAR (400–700 nm), calculated from the raw values of one radiometer turned up and down.

Date Time, UTC	LAT	LON	SZA	305	313	320	340	380	PAR
27.8. 13	87.352	-8.638	76.97	0.94	0.92	0.92	0.92	0.92	0.92
28.8. 13.30	87.295	-9.433	77.27	0.92	0.91	0.91	0.91	0.92	0.93
29.8. 13	87.248	-9.475	77.57	0.95	0.92	0.92	0.92	0.92	0.91
29.8. 14	87.247	-9.445	77.73	0.97	0.96	0.95	0.95	0.96	0.92
30.8. 16	87.206	-9.501	78.89	0.97	0.91	0.91	0.91	0.92	0.93

NILU-UV albedo during ASCOS study, Arctic Ocean

ASD spectrometer

Perovich method for albedo

Measurements

ASD HH (325 – 1075 nm)

ASD4 (350-2500 nm)

EXAMPLE 4.

Spectral albedo of seasonal snow during intensive melt period at Sodankylä, beyond the Artic circle

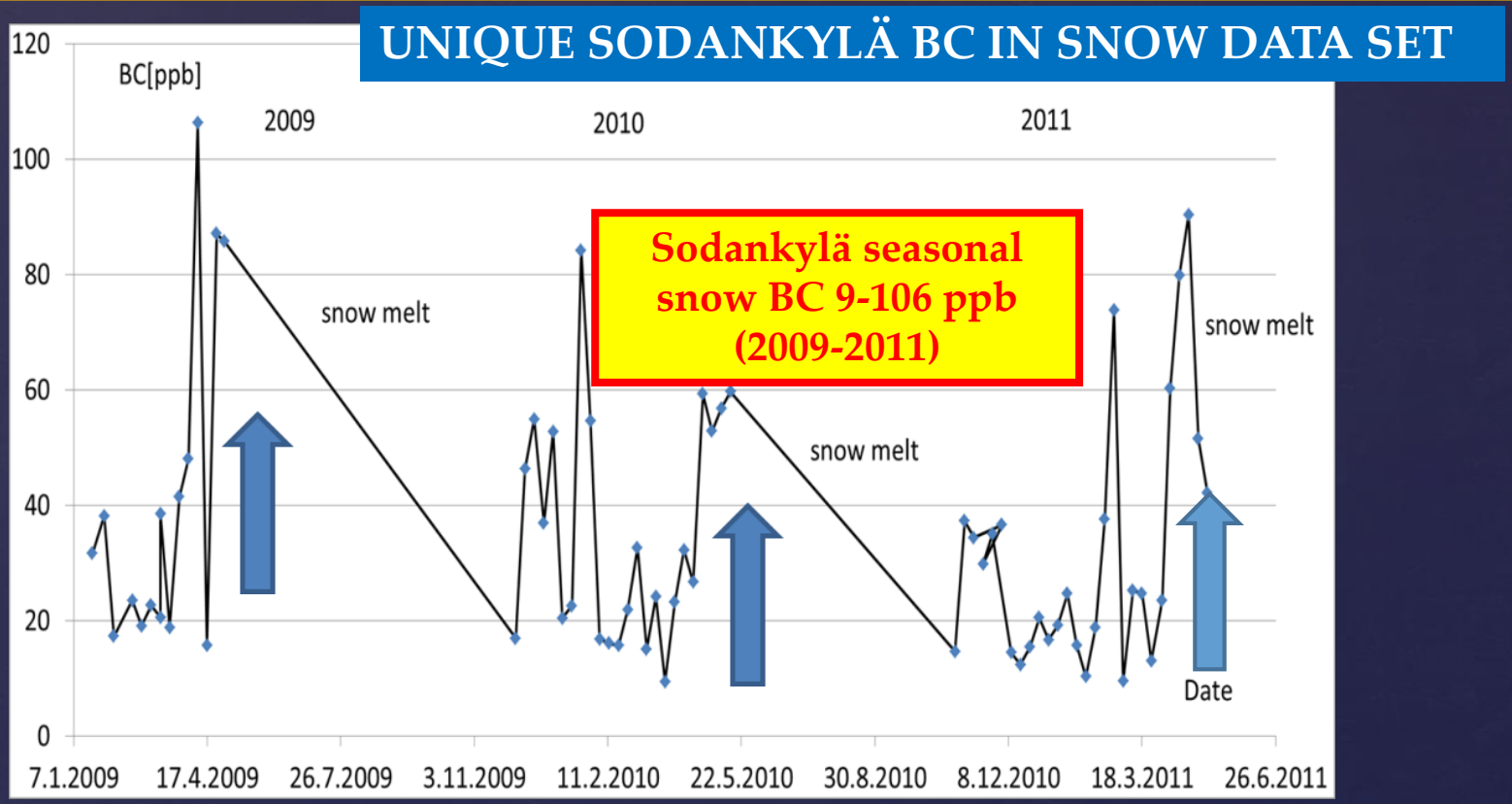
(Meinander et al. 2013 ACP 2013)

BLACK CARBON

Motivation for the paper (Scientific questions):

1. How much BC is there in snow in Arctic Finland?
2. Why these BC concentrations?
3. How is snow BC connected to spectral albedo?

BC and OC in Sodankylä snow can be high (BC up to 106 ppb)

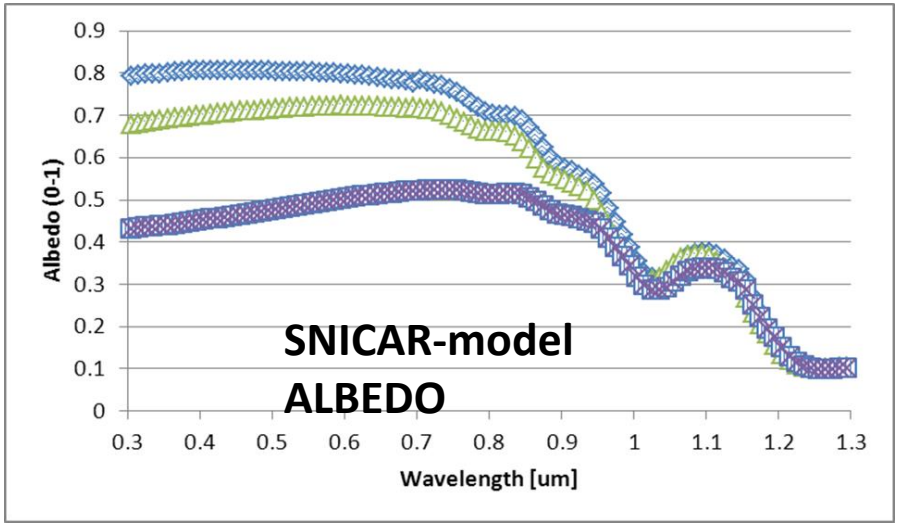


WHY HIGH CONCENTRATIONS OF BC IN SODANKYLÄ SURFACE SNOW?

1. **Hydrophobic particles-**> Accumulation of BC in surface snow during snow melt
2. Anthropogenic emissions **? -> Kola Peninsula**

Spectral albedo of seasonal snow during intensive melt period at Sodankylä, beyond the Artic circle

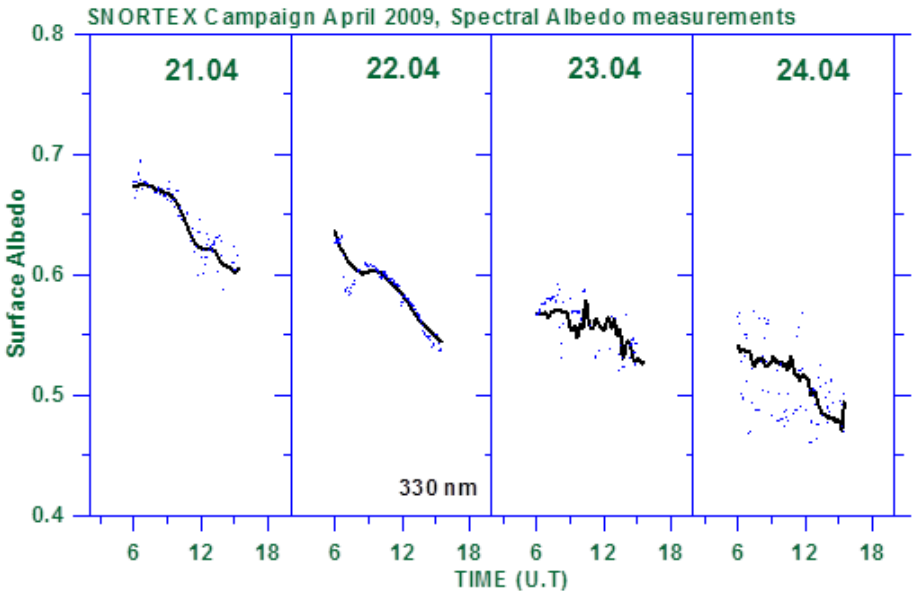
Absorption caused by BC in snow is the bigger the shorter the wavelength (model+OBS)



SNICAR (Flanner et al. 2007) simulated clear sky snow albedo spectra: **for clean snow (blue, 0 ppb)**, **realistic snow (green,200ppb, and to match the measured with the modeled, we need MAC multiplying factor =10, purple).**

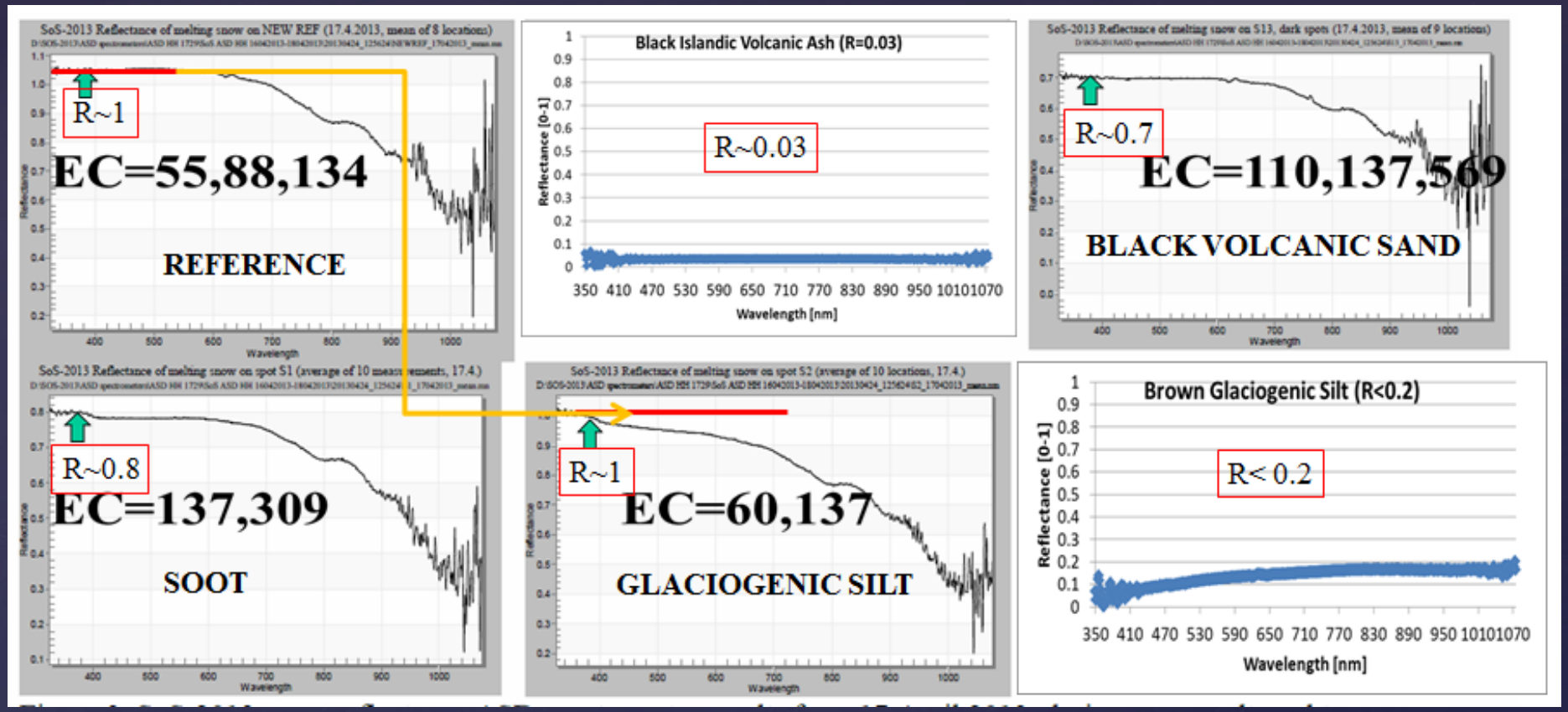
SZA=55 deg, grain radius 1.5 mm, snow depth 10 cm
snow density 350 kg/m3
MAC Fresh snow ~7.5 (Bond et al. 2013) Atm.aged BC MAC ~ 15 (Hadley & Kirchtetter, 2012)

Diurnal 10 % SZA asymmetry -> RT calculations show an 2-4 % daily error for satellite snow albedo estimates



Diurnal change in measured albedo (during snow melt)

LAI in Iceland: volcanic particles



- ASD *in situ* reflectance challenging to measure
- Albedo with the Cosine receptor

(the Perovich method: 25 FOV attached to a small Spectralon plate, turn up and down)

- Contact probe applications

BC in snow can change in metre scale

- side-by-side ratios between **clean site** neighbour samples (5 m apart), a **ratio of ~2** was observed.
- The median for the **polluted site** had a **ratio of 1.2** between neighbouring samples.
- **-> regions exposed to snowdrift may be more sensitive to horizontal variability in BC concentration**.

-> CHOOSE SAMPLING SITES, TIMING, MULTIPLE SAMPLES FROM ONE SITE

4 CONCLUSIONS

1. **WMO intercomparison** reports: useful for the benefit of planning an albedo intercomparison?

Table 1. The midday SZA values [degrees] (at accuracy of one degree) at Sodankylä (67°22′N, 26°39′E) in 2007, and the time for solar noon [UTC] (at accuracy of ten minutes).

Month	February		March		April		May
Date	1	15	1	15	1	15	1
Solar noon	10.30	10.30	10.30	10.20	10.20	10.20	10.10
SZA	85	80	75	70	63	58	53

2. Location (where, when, how long?
High latitude snow, low Sun? vs
High altitude snow, big slopes?
Cold snow/melting snow?
Cloudfree cases for all SZA? Cloudy sky cases for all SZA?

3. Absolute irradiance scale and trace?
4. Radiometric calibration protocol? Solar or small lamps?
5. Sensor characteristics? Cosine and spectral responses. **-> what should be determined as part of intercomparison campaign?**

6. Albedo Measurement protocol and QA/QC?
The data quality demand to fit the research question!

4 CONCLUSIONS

7. Error sources and uncertainties due to

7.1 **Sensor properties** (cosine and azimuthal response errors, response time, slit function, etc.) and data correction procedures

7.2 **Environment** (rapid changes in cloudiness, shadows, SZA, humidity, slopes, BC & OC & dust, etc.) ,

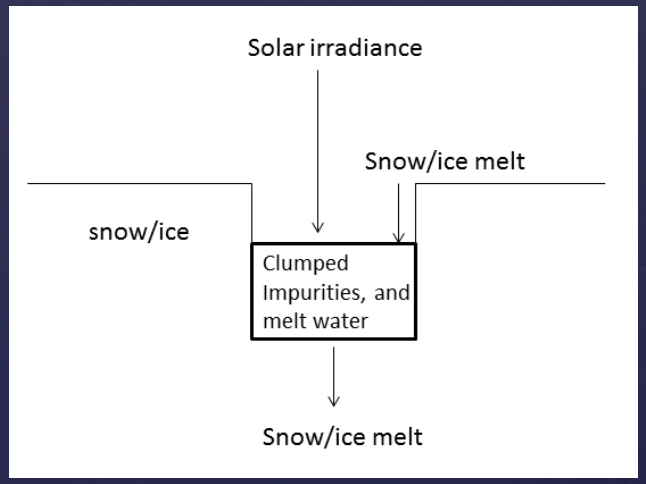
IF **IN SITU DATA COMPARED AGAINST MODEL SIMULATED ALBEDO**, WHAT ARE THE ERROR SOURCES AND UNCERTAINTIES IN THE MODEL,

E.G. IN CASE OF SNICAR ALBEDO MODEL THE **MAC** VALUES FOR LIGHT ABSORBING PARTICLES AND ORGANIC MATTER?

4 CONCLUSIONS

7.3 Target (Spatial variablity of snow properties and snow albedo **directional reflectance properties** of the target?? With soot affecting satellite detection? **[Peltoniemi et al. TC (figifigo)].**

-> How much do these influence the intercomparison results? i.e., **How important it is in one meter scale where my sensor is??**



7.4 Intercomparison **itself**: Holders (shadowing my sensor); sensor tilt, sensors & holders shadowing each other

UNEXPECTED! Dust vs BC vs OC in Icelandic snow?

Table 7.5. Characteristics of operational pyranometers

Characteristic	*High quality*[a]	*Good quality*[b]	*Moderate quality*[c]
Response time (95 per cent response)	< 15 s	< 30 s	< 60 s
Zero offset:			
(a) Response to 200 W m^{-2} net thermal radiation (ventilated)	7 W m^{-2}	15 W m^{-2}	30 W m^{-2}
(b) Response to 5 K h^{-1} change in ambient temperature	2 W m^{-2}	4 W m^{-2}	8 W m^{-2}
Resolution (smallest detectable change)	1 W m^{-2}	5 W m^{-2}	10 W m^{-2}
Stability (change per year, percentage of full scale)	0.8	1.5	3.0
Directional response for beam radiation (the range of errors caused by assuming that the normal incidence responsivity is valid for all directions when measuring, from any direction, a beam radiation whose normal incidence irradiance is 1 000 W m^{-2})	10 W m^{-2}	20 W m^{-2}	30 W m^{-2}
Temperature response (percentage maximum error due to any change of ambient temperature within an interval of 50 K)	2	4	8
Non-linearity (percentage deviation from the responsivity at 500 W m^{-2} due to any change of irradiance within the range 100 to 1 000 W m^{-2})	0.5	1	3
Spectral sensitivity (percentage deviation of the product of spectral absorptance and spectral transmittance from the corresponding mean within the range 300 to 3 000 nm)	2	5	10
Tilt response (percentage deviation from the responsivity at 0° tilt (horizontal) due to change in tilt from 0° to 90° at 1 000 W m^{-2})	0.5	2	5
Achievable uncertainty (95 per cent confidence level):			
Hourly totals	3%	8%	20%
Daily totals	2%	5%	10%

References… e.g,

Johnsen, B., et al. (2008), Intercomparison and harmonization of UV Index measurements from multiband filter radiometers, J. Geophys. Res., 113, D15206, doi:10.1029/2007JD009731.

WMO, TD No. 1454, GAW Report No. 179, 2008.

WMO: WMO GAW report 120. WMO-UMAP Workshop on Broad-Band UV Radiometers, Garmisch-Partenkirchen, Ger many, 22–23 April 1996, WMO TD No. 894, 1996.

Sodankylä snow conditions

Grain sizes, and snow depth during One winter (2007)

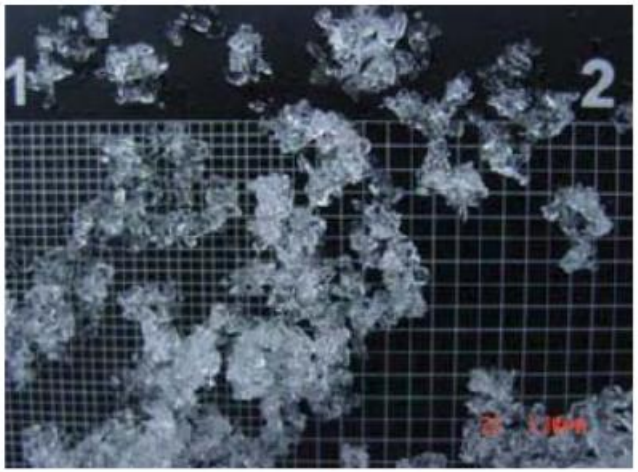


Fig. 4. The grids used for the snow grain size measurements. Numbers 1 and 2 in the figure indicate the corresponding grid sizes of 1 mm and 2 mm.

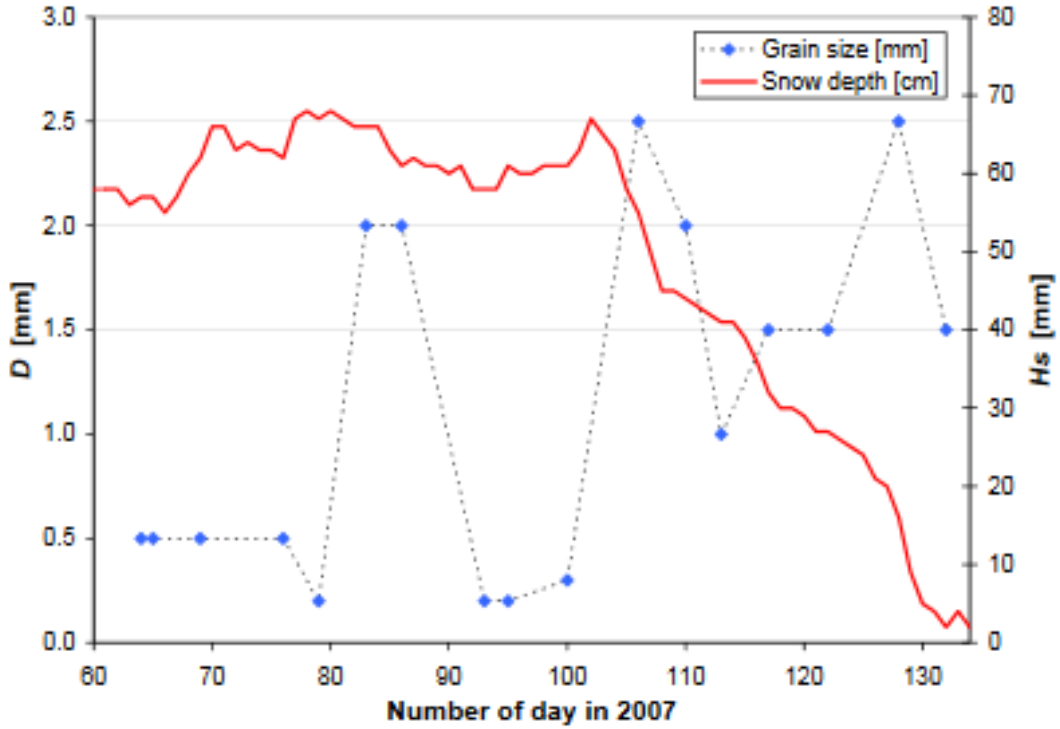


Fig. 6. Snow grain size D [mm] (dashed line with blue squares) and snow depth h_s [cm] (red solid line) in spring 2007.

[Meinander et al. ACP 2008]

The Bentham spectroradiometer

consists of a commercially available Bentham DM-150 double monochromator with a focal length of 150 mm, and with gratings of 2400 lines mm−1. The entrance and exit slit widths were chosen to yield a nearly **triangular slit function, with a full width at half maximum (FWHM) resolution of 0.74 nm**. The solar irradiance is sampled through a specially designed entrance optics (CMS Schreder, Model UV-J1002), connected to the port of the spectroradiometer through a quartz fiber. The fiber optic splits and leads to two identical entrance optics receivers (diffusers) that can be distinguished through an

internal switch. The angular response of the two diffusers is better than 2 % for incident angles less than 70 degrees. As the instrument is designed for outdoor solar measurements, the whole spectroradiometer system, including the data-acquisition electronics, is contained in a **temperature-controlled box that is stabilized** to a predetermined temperature with a precision of 0.5 K. **Absolute irradiance scale calibration is performed using measurements of calibrated 1000 W quartz halogen lamps.** To measure at locations far from its laboratory, a portable irradiance scale was devised. It is composed of a **portable lamp enclosure (calibrator), a set of 100 and 250 W tungsten halogen lamps**, and a feed-

back system. For this particular campaign, the two entrance optics were used for measurements of the down-welling and the up-welling global solar irradiance. The calibration of the instrument was performed at the beginning and at the end of the campaign, showing deviations of less than ±1 % for the entire spectral range based on measurements of the **three lamps** used for the calibration procedure.

NILU-UV

The NILU-UV 6T radiometer is a filter instrument with five UV channels, with central wavelengths at around 305, 312, 320, 340 and 380nm, and bandwidths of around **10 nm at full-width half-maximum (FWHM**). A sixth channel measures the photosynthetic active radiation (PAR) in the 400–700nm wavelength region.

The radiometer has a Teflon diffuser, silicon detectors, high-quality bandpass filters and is **temperature-stabilized to 40◦C**. One-min averages of measured irradiances and detector temperaures are recorded.

The measurements can be used to retrieve UV-B, UV-A, erythemally - weighted UV radiation and the total ozone column, as well as to provide cloudiness information, using the method described by Dahlback (1996). The characteristics of the instrument are described in more detail in Hoiskar et al. (2003).