Spatio-temporal variability of snow surface albedo and grain size derived from airborne and ground-based observations in Antarctica

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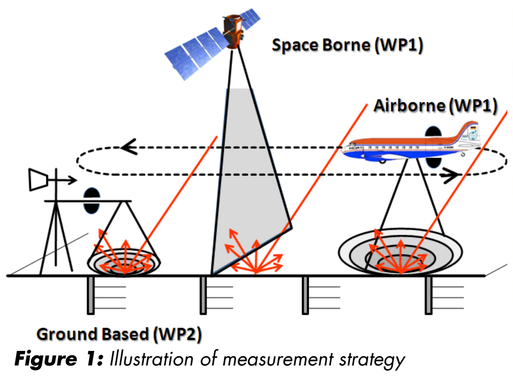
1. Motivation and Objectives



Satellite Data (WP1)	
Surface albedo	Retrieval
Airborne Data (WP1)	
Surface albedo	In situ
Surface BRDF	In situ
Surface roughness	Retrieval
Grain size	Retrieval
Ground Based Data (WP2)	
Surface albedo	In situ
Surface BRDF	In situ
Grain size profile	In situ
Surface roughness	In situ
Meteorology	In situ

Figure 1: *Illustration of measurement strategy*

MEASUREMENTS

Broadband and spectral radiation
Irradiance (↑, ↓), Radiance

+

Atmospheric properties
temperature, humidity, wind, clouds, precipitation, aerosol content

↓

Snow radiative properties
surface albedo, BRDF

↓

RETRIEVAL

Microphysical and macroscopic snow properties
specific surface area SSA (snow grain size), surface roughness

Coupling of...

- **Airborne** measurements of the **spatial variability** of surface albedo, BRDF, SSA and surface roughness
- **Ground-based** measurements of the **temporal variability** of surface albedo, BRDF and SSA

to improve prognostic snow models.

2. Campaign ANT-Land 2013/2014

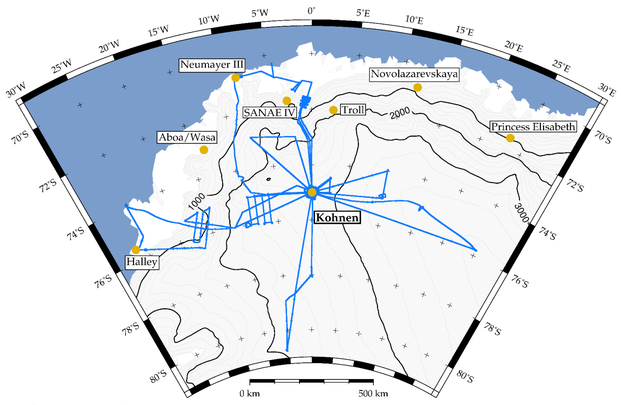


Figure 2: *Illustration of research flights with Polar6*

Key facts

10/12/2013 – 31/01/2014: Measurements
Kohnen station: 75°00'S, 0°04'E, 2892m a.s.l.
Polar6: 16 research flights, 60 flight hours

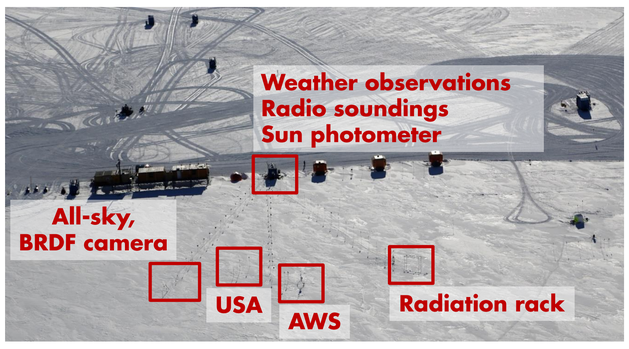


Figure 3: *Instrumentation during ANT-Land 2013/14 at Kohnen station*

3. Impact of specific surface area and clouds on surface albedo

Instrumentation

$$\text{SSA in m}^2/\text{kg} = \frac{\text{free surface area of air} - \text{snow interface}}{\text{snow mass of sample}}$$

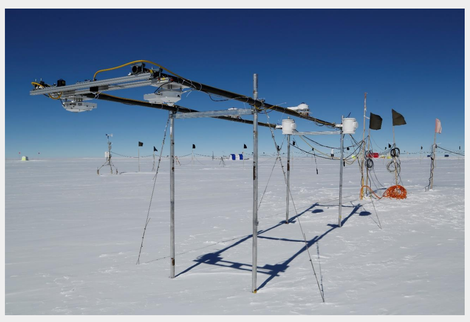
Free surface area

ICE-Cube System
(by A2 Photonic Sensors)

@1310nm

daily, along 100m profile

Figure 4: *Snow sampling for SSA measurement, by Katharina Klein (AWI)*



Broadband radiation

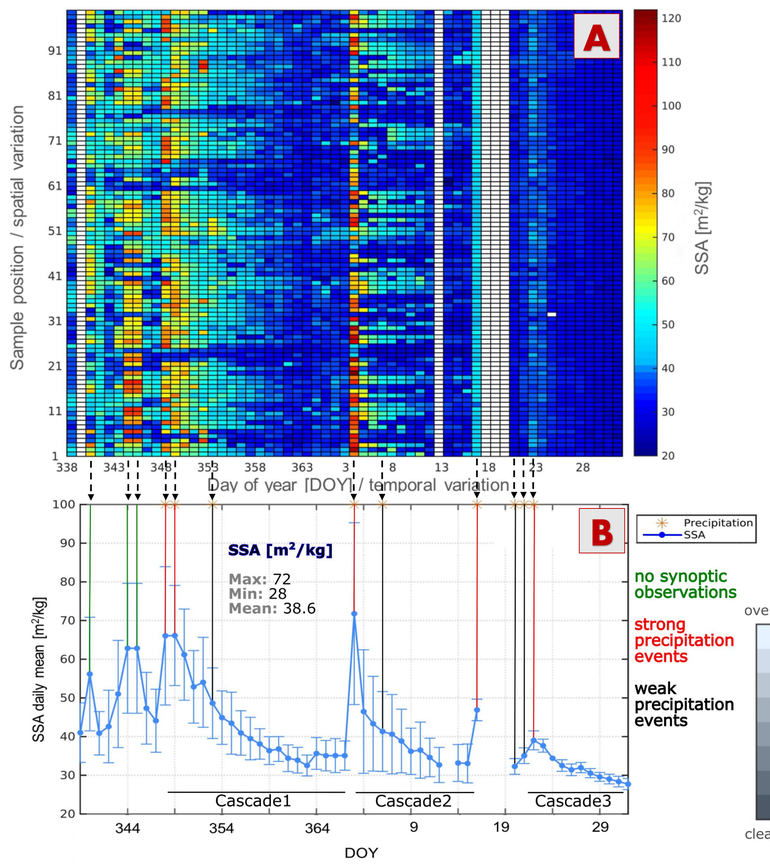
two CM22 pyranometers (Kipp&Zonen)

spectral range: 300-3600nm

1-min-mean values

albedo uncertainty: ±1.6%

Figure 5: *Radiation rack with broadband radiation sensors and two spectral irradiance sensors from the **CO**mpact **RA**dation measurement **S**ystem (**CORAS**)*



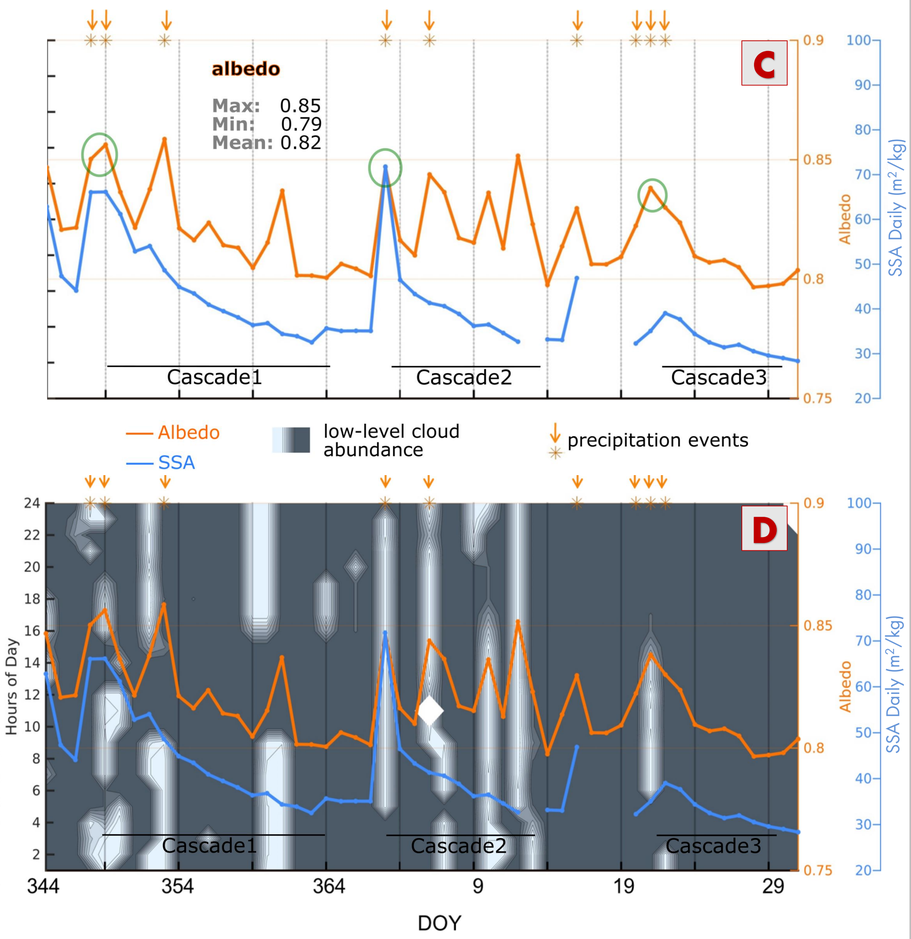


Figure 6: ***Part A:*** *Spatial and temporal grid for measured SSA, each square corresponds to one sample, x-axis: each step = one day, y-axis: 100 samples along 100m profile*
Part B: *Daily mean of SSA values (100 samples);* ***Part C:*** *Correlation of seasonal broadband surface albedo (orange) with SSA (blue), peaks in SSA mirrored by albedo (○)*
Part D: *Cloud influence on broadband albedo (SSA – blue, surface albedo – orange, low-level cloud cover – grey color table)*

4. Temporal variability of SSA observed by different in situ and remote sensing methods

Satellite: MODIS SGSP retrieval

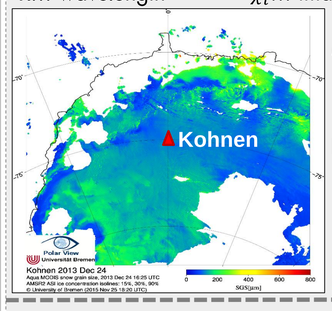
Snow **G**rain **S**ize and **P**ollution amount retrieval, after Zege et al. (2011)

Plane albedo:

$$r(\theta_0) = exp(-y g(\theta_0))$$

$$g(\theta_0) = \frac{3}{7}(1 + 2\cos\theta_0) \qquad y = A\sqrt{\frac{4\pi\chi}{\lambda} a_{eff}}$$

θ_0... solar zenith angle
λ... wavelength
A... shape factor (fractals: 5.1, spheres: 6.5, average: 5.8)
χ_i... imaginary part of complex refraction index of ice @ λ_i



MODIS channels:
$R_3 = 469\text{nm}$
$R_2 = 858.5\text{nm}$
$R_5 = 1240\text{nm}$

Effective grain size:

$$a_{eff} = \left(\frac{\ln r_i}{A g(\theta_0) \left[\sqrt{\frac{4\pi\chi_i}{\lambda_i}} \right]} \right)^2$$

Figure 7: *Map of MODIS retrieved snow grain size, spatial resolution: 1km x 1km*

Ground-based: CORAS retrieval

Instrument: (see Fig. 5)
Spectral irradiance (F↑, F↓)
Temporal resolution: 15 s
Spectral range: 0.3-2.2 µm

Difference to Zege-Formula:
New I: Using RATIO
New II: Overcast conditions

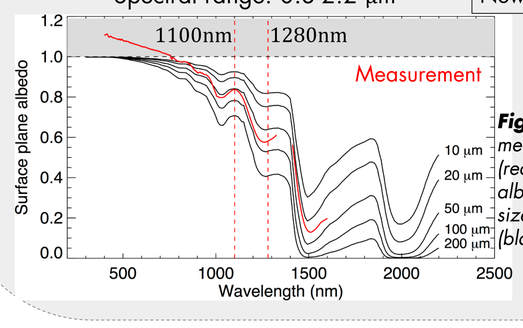


Figure 8: *Exemplary CORAS measurement of spectral albedo (red) and computed spectral albedo for different snow grain sizes after Zege et al. (2011) (black)*

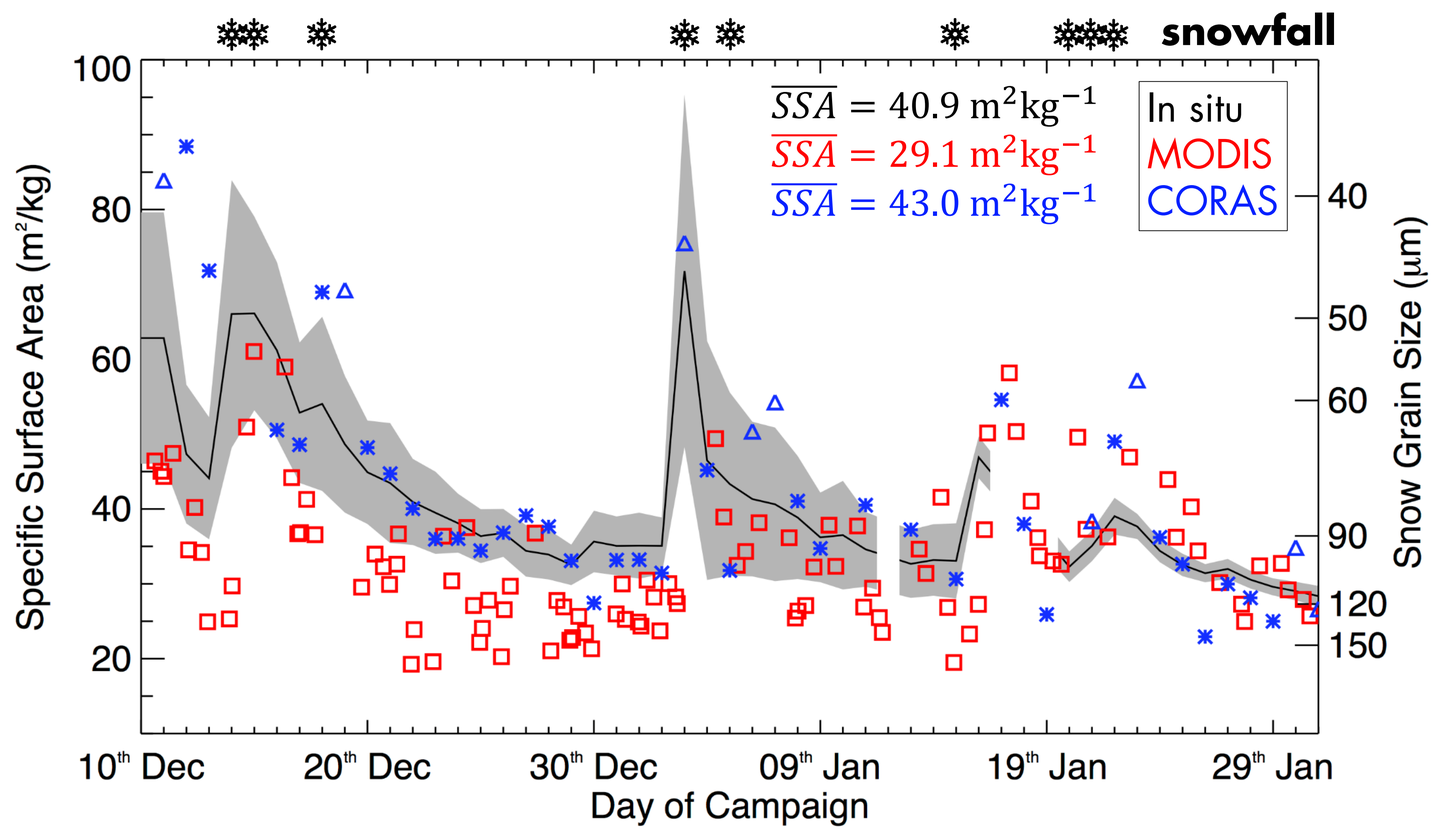


Figure 9: *Temporal variability of SSA during ANT-Land 2013/14 and comparison of in situ SSA with retrieved SSA by different remote sensing methods*
In situ: *Daily mean SSA value for 100m profile (solid black line) and standard deviation along 100m profile (shaded grey area)*
MODIS: *Running mean over 3 consecutive timesteps for mean of 4 pixels which surround Kohnen station (red rectangles), ~4-times per day when clear-sky*
CORAS: *Daily SSA values for clear-sky (blue stars) and overcast (blue triangles) days*
Top: snowfall events are illustrated by black symbols (❄)

5. Summary and conclusion

- **cloud abundance** in the lowest cloud layer increases albedo by 3%
- albedo increase by 3% is also provoked by **SSA increase** of 18 m^2kg^{-1}
- average **precipitation** induced increase in SSA is 20 m^2kg^{-1}
- **SSA** varies between 20 m^2kg^{-1} and 95 m^2kg^{-1}, 4 maxima due to precipitation events
- **MODIS:** systematic underestimation, **CORAS:** mostly within standard deviation of in situ data

6. Outlook

I. **Further development** of **grain size retrieval**, e.g. using different albedo model
II. **Apply** retrieval to **airborne measurements** (Polar6 overflights)
III. **Simulation** and **validation** of temporal variability of snow grain size with microphysical snow model **SNOWPACK**

Reference: E.P. Zege, I.L. Katsev, A.V. Malinka, A.S. Prikhach, G. Heygster, H. Wiebe, Algorithm for retrieval of the effective snow grain size and pollution amount from satellite measurements, Remote Sensing of Environment, 2011