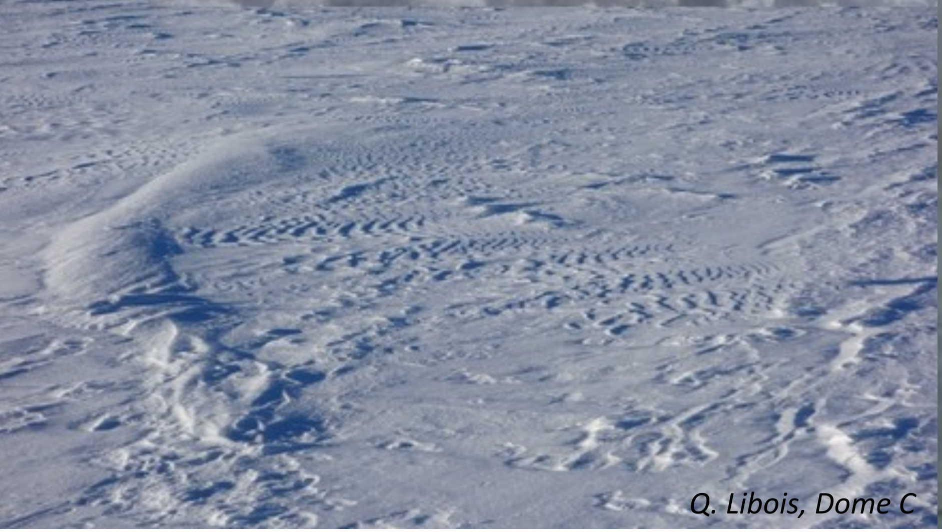

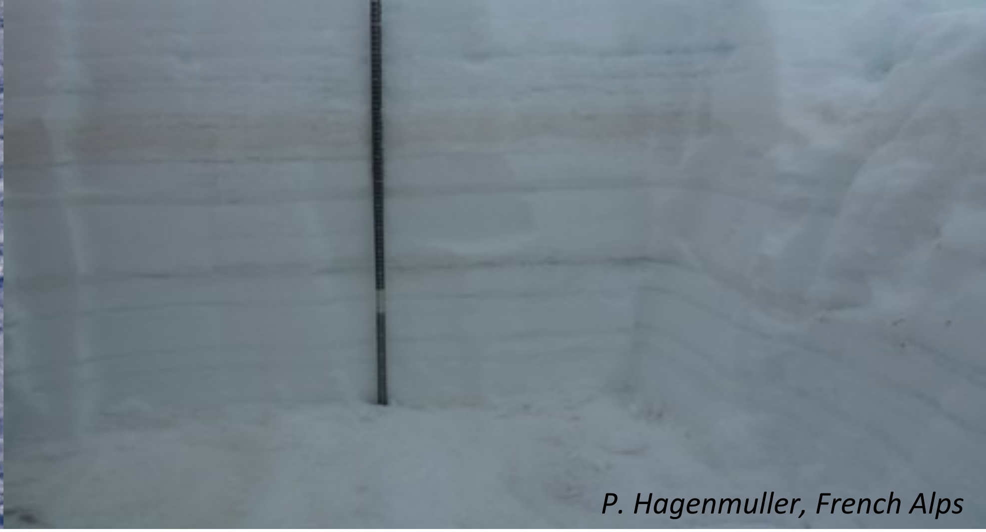

In-situ continuous spectroscopy of alpine snowpacks

M. Dumont[1],L. Arnaud[2] , G. Picard[2], Q. Libois[2,3] ,Y. Lejeune[1] and S. Morin[1]

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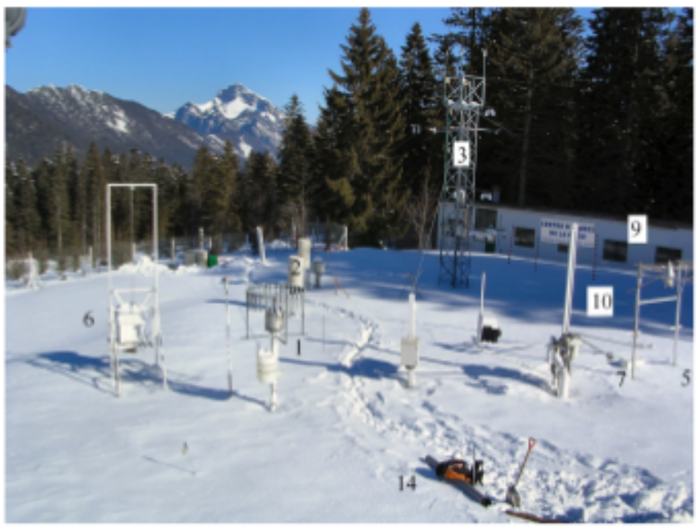
Workshop on in-situ snow albedo measurements : toward a snow albedo intercomparison experiment, Helsinki, 24-25 August 2016

Objectives

Estimation of time series of snow «surface » properties from spectral albedo and study of their evolution

Autosolexs automatic albedometer (Libois et *al*., 2015 ; Picard et *al*., 2016)
400-1050 nm with 3 nm effective resolution
12 min time step



(Morin et *al*., 2012)

Col de Porte

French Alps, 1325 m a.s.l

Operating :
January-May 2014
One albedo head
Tilted but « smooth » snow surface

Cf G. picard presentation for Dome C device

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SSA estimation at Dome C (cf G. Picard talk)

Analytical asymptotic transfer (Kokhanovsky and Zege, 2004), B=1.6, g=0.85 (Libois et al., 2014) :

$$\alpha^{\mathrm{diff}}(\lambda) = \exp\left(- \sqrt{\frac{2\pi}{3\lambda\rho_{\mathrm{ice}}\mathrm{SSA}(1-\mathrm{g})}(64\mathrm{n_i}(\lambda)\mathrm{B} + \frac{16\rho_{\mathrm{ice}}\epsilon_0\lambda_0 c_{\mathrm{imp}}}{\pi})}\right)$$

$$\alpha^{\mathrm{dir}}(\lambda,\theta) = \exp\left(- \frac{3}{7}(1+2\cos\theta)\sqrt{\frac{2\pi}{3\lambda\rho_{\mathrm{ice}}\mathrm{SSA}(1-\mathrm{g})}(64\mathrm{n_i}(\lambda)\mathrm{B} + \frac{16\rho_{\mathrm{ice}}\epsilon_0\lambda_0 c_{\mathrm{imp}}}{\pi})}\right)$$

« NO » impurity

$$\alpha(\lambda,\theta) = \mathrm{r_{diff}}(\lambda,\theta)\alpha^{\mathrm{diff}}(\lambda) + (1-\mathrm{r_{diff}}(\lambda,\theta))\alpha^{\mathrm{dir}}(\lambda,\theta)$$

Obtain from SBDART simulations (Richiazzi et al., 1999)

Scale factor 0.9-1.1

$$\alpha_{mes}(\lambda,\theta) = A\alpha_{th}(\lambda,\theta)$$

Two parameters (A, SSA) nonlinear least-square fit over 700-1050 nm

Accuracy better than 15 % if chromatic aberration lower than 2 %

(Picard et *al.*, 2016)

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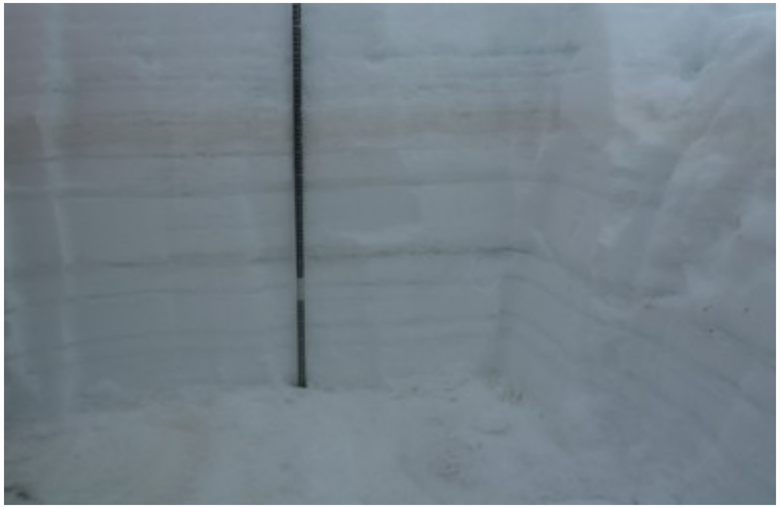
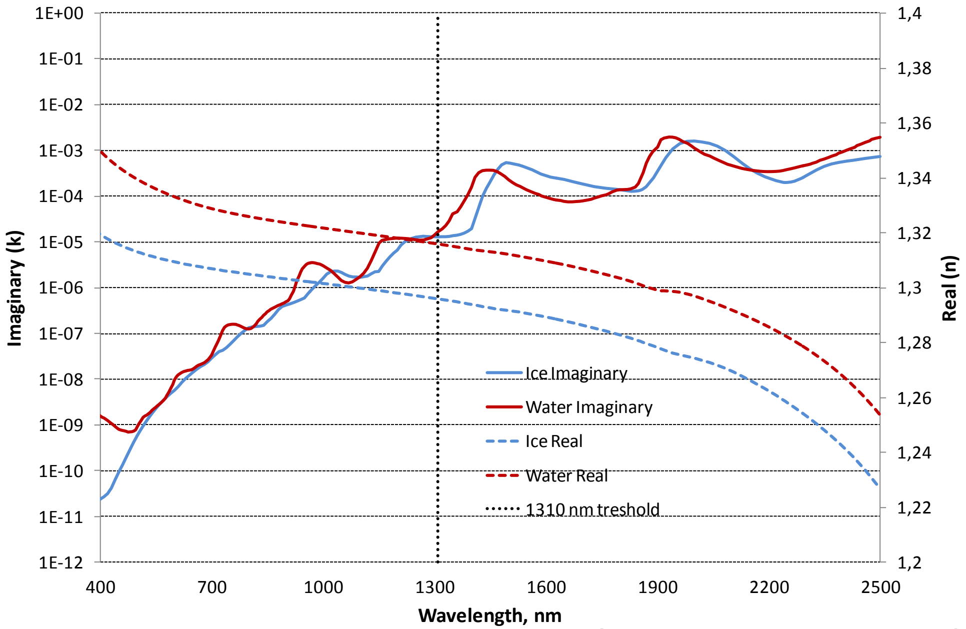
Col de Porte : a more complex case





(Gallet et *al*., 2014)

- Surface slope
- High LAI content (frequent saharian dust deposition events, e.g. Di Mauro et *al*. ,2015)
- Liquid water

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Analytical formulation of spectral albedo

Analytical asymptotic transfer (Kokhanovsky and Zege, 2004), B=1.6, g=0.85 (Libois et al., 2014) :

$$\alpha^{\mathrm{diff}}(\lambda) = \exp\left(-\sqrt{\frac{2\pi}{3\lambda\rho_{\mathrm{ice}}\mathrm{SSA}(1-\mathrm{g})}\left(64\mathrm{n_i}(\lambda)\mathrm{B} + \frac{16\rho_{\mathrm{ice}}\epsilon_0\lambda_0\mathrm{c_{imp}}}{\pi}\right)}\right)$$

$$\alpha^{\mathrm{dir}}(\lambda,\theta) = \exp\left(-\frac{3}{7}(1+2\cos\theta)\sqrt{\frac{2\pi}{3\lambda\rho_{\mathrm{ice}}\mathrm{SSA}(1-\mathrm{g})}\left(64\mathrm{n_i}(\lambda)\mathrm{B} + \frac{16\rho_{\mathrm{ice}}\epsilon_0\lambda_0\mathrm{c_{imp}}}{\pi}\right)}\right)$$

$$\alpha(\lambda,\theta) = \mathrm{r_{diff}}(\lambda,\theta)\alpha^{\mathrm{diff}}(\lambda) + (1-\mathrm{r_{diff}}(\lambda,\theta))\alpha^{\mathrm{dir}}(\lambda,\theta)$$

Scale factor
0.9-1.1

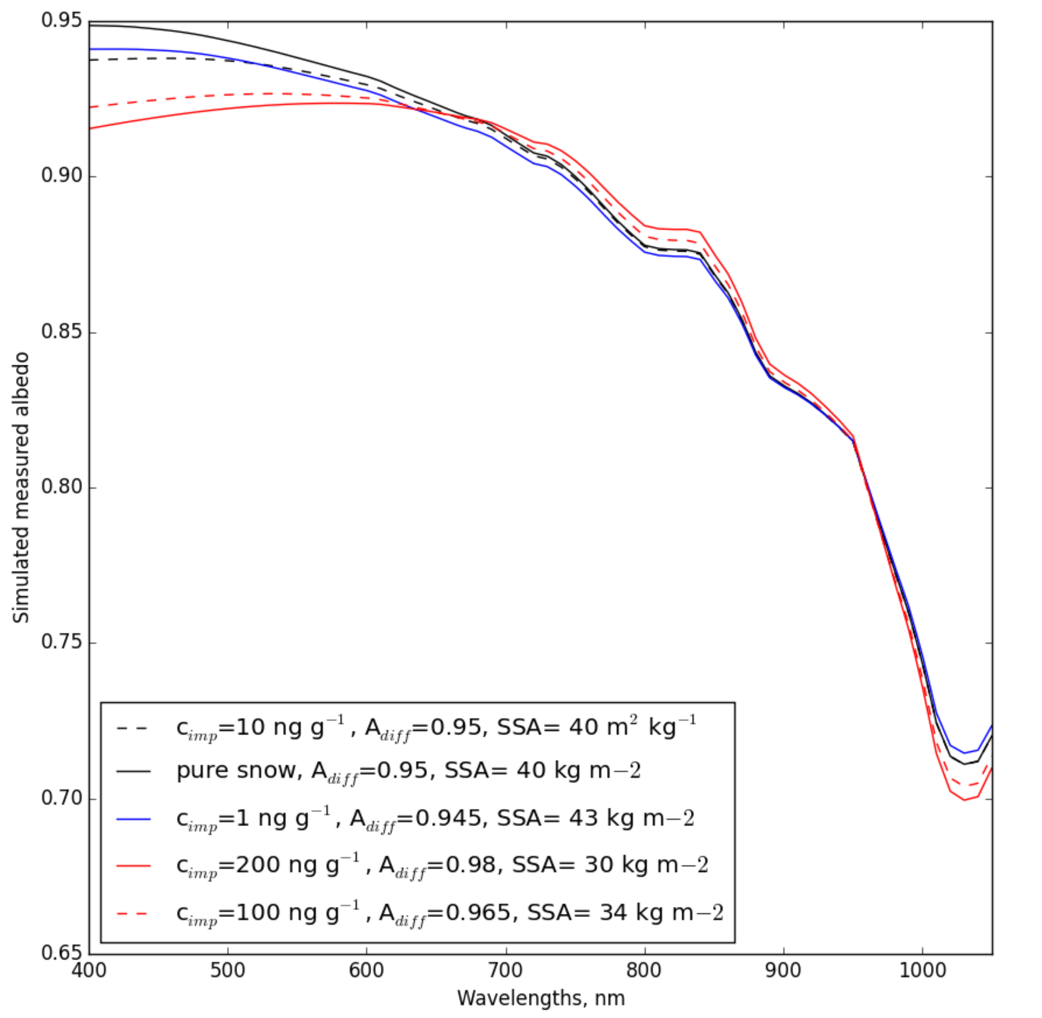
Obtain with SBDART simulations (Richiazzi et al., 1999)

$$\alpha_{mes}(\lambda,\theta) = A\alpha_{th}(\lambda,\theta)$$

(Picard et *al.*, 2016)

3 unknows A, c_{imp} and SSA

A and c_{imp} coupling



Multiple (A, SSA, c_{imp}) solutions give the same spectra

-> need to set A to only one value for the whole season

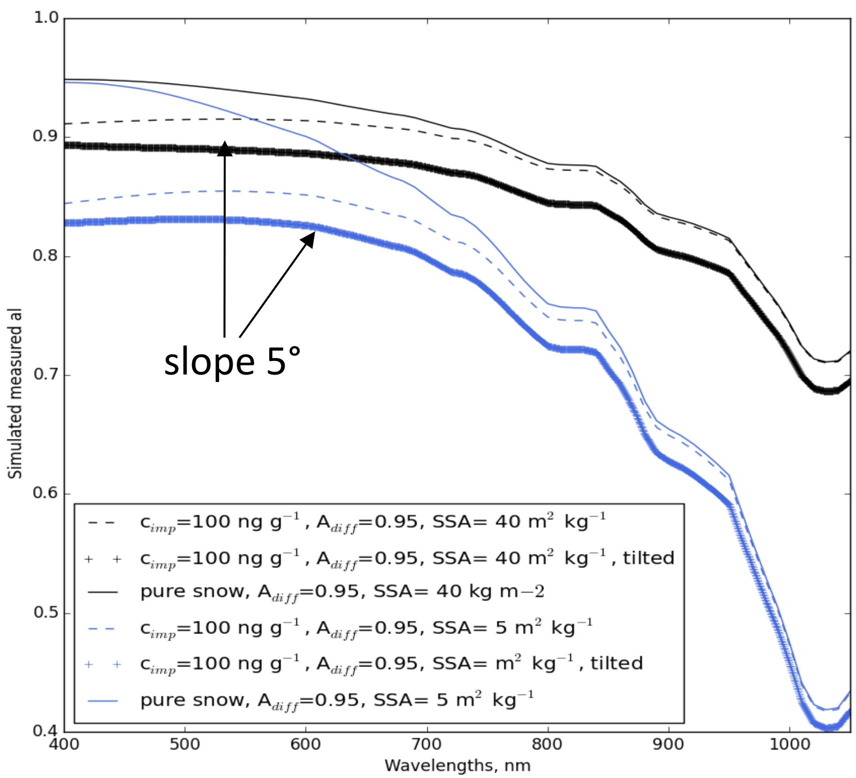
Effect of surface slope on measured albedo

$$\alpha_{mes}(\lambda,\theta) = A\alpha_{th}(\lambda,\theta)$$

$$\alpha_{mes}(\lambda,\theta_s) = \frac{A_{diff}}{r_{diff}(\lambda,\theta_s) + (1 - r_{diff}(\lambda,\theta_s))K}\alpha_{th}(\lambda,\theta_s)$$

$$K = \cos\theta_{\mathrm{n}} + \tan\theta_{\mathrm{s}}\sin\theta_{\mathrm{n}}\cos(\phi_{\mathrm{n}} - \phi_{\mathrm{s}})$$

Impact of surface slope varies with wavelength



Retrieval method

Dome C

Measured spectra

↓

2-parameters Least square optimization (700, 1050) nm

↓

Optimal A, SSA

Retrieval method

Dome C

Measured spectra

↓

2-parameters Least square optimization (700, 1050) nm

↓

Optimal A, SSA

Col de Porte

Estimation of A_{diff} for fully cloudy days

↓

Measured spectra (clear days)

↓

3-parameters Least square optimization (400, 1050) nm

↓

Optimal K, SSA, c_{imp}

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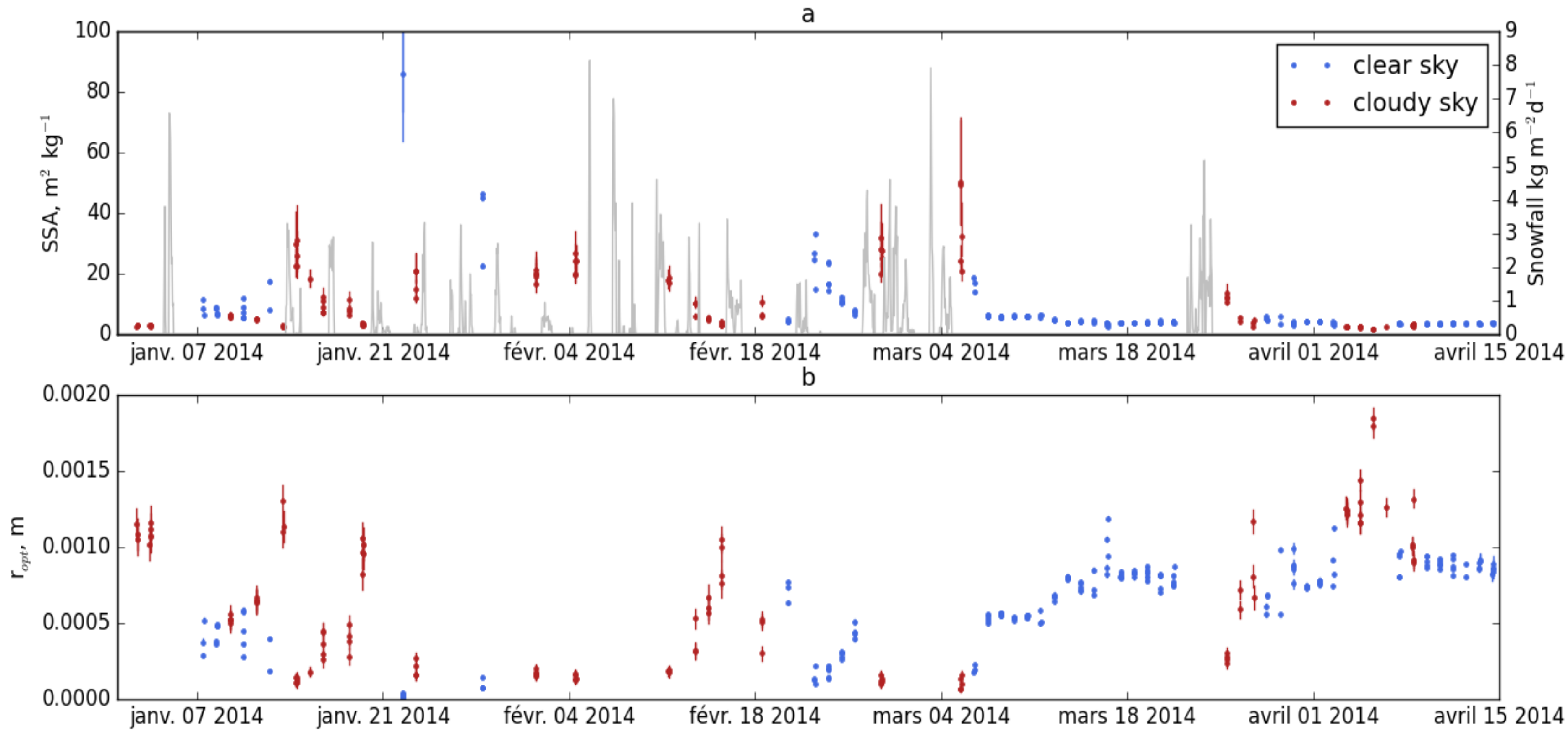
SSA time series



- Large uncertainties for cloudy days due to the retrieval method
- Exponentiel SSA decay
- ASSSAP surface value 44+-4 vs spectral albedo [31, 36, 41] $m^2\ kg^{-1}$

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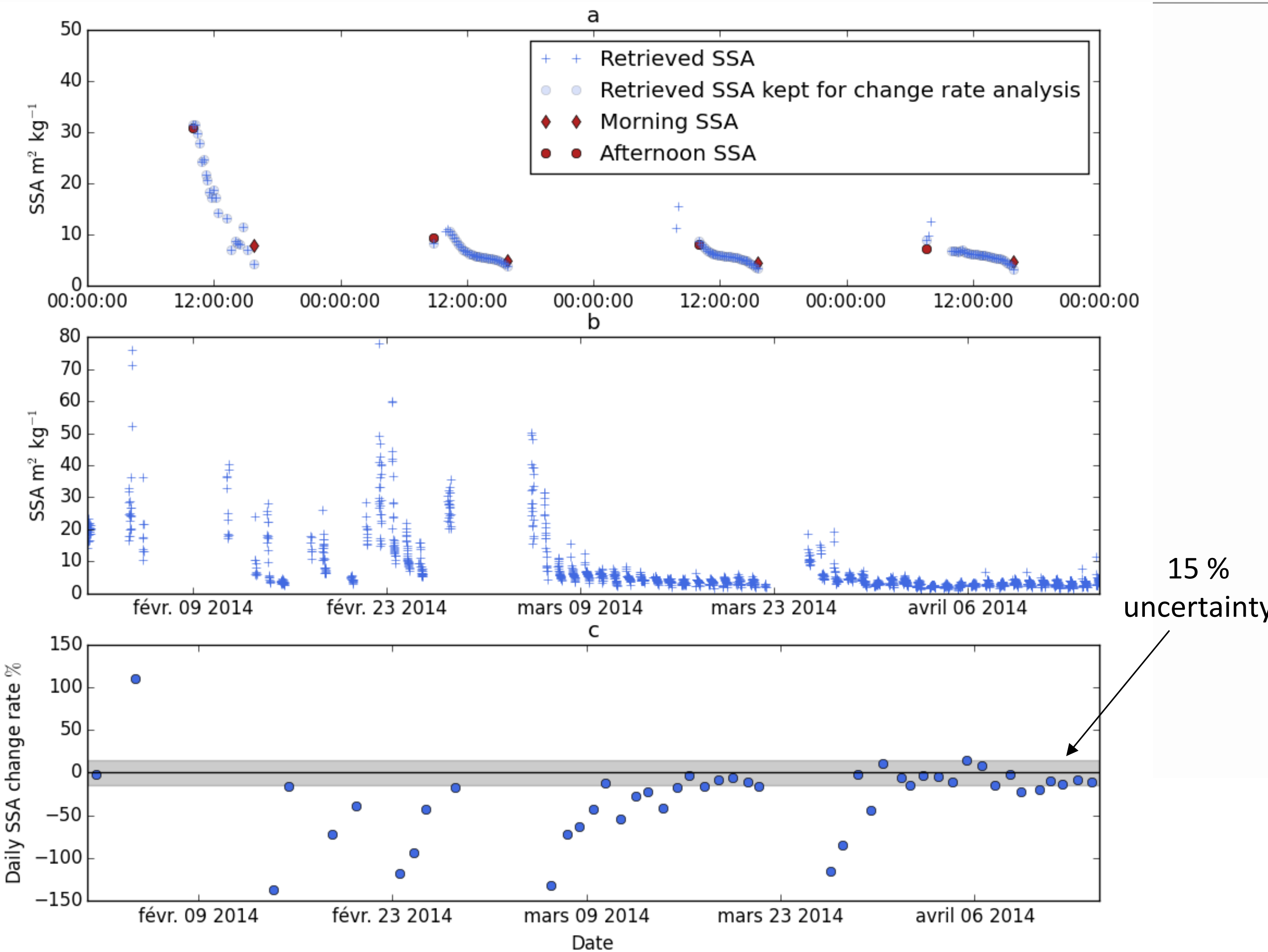
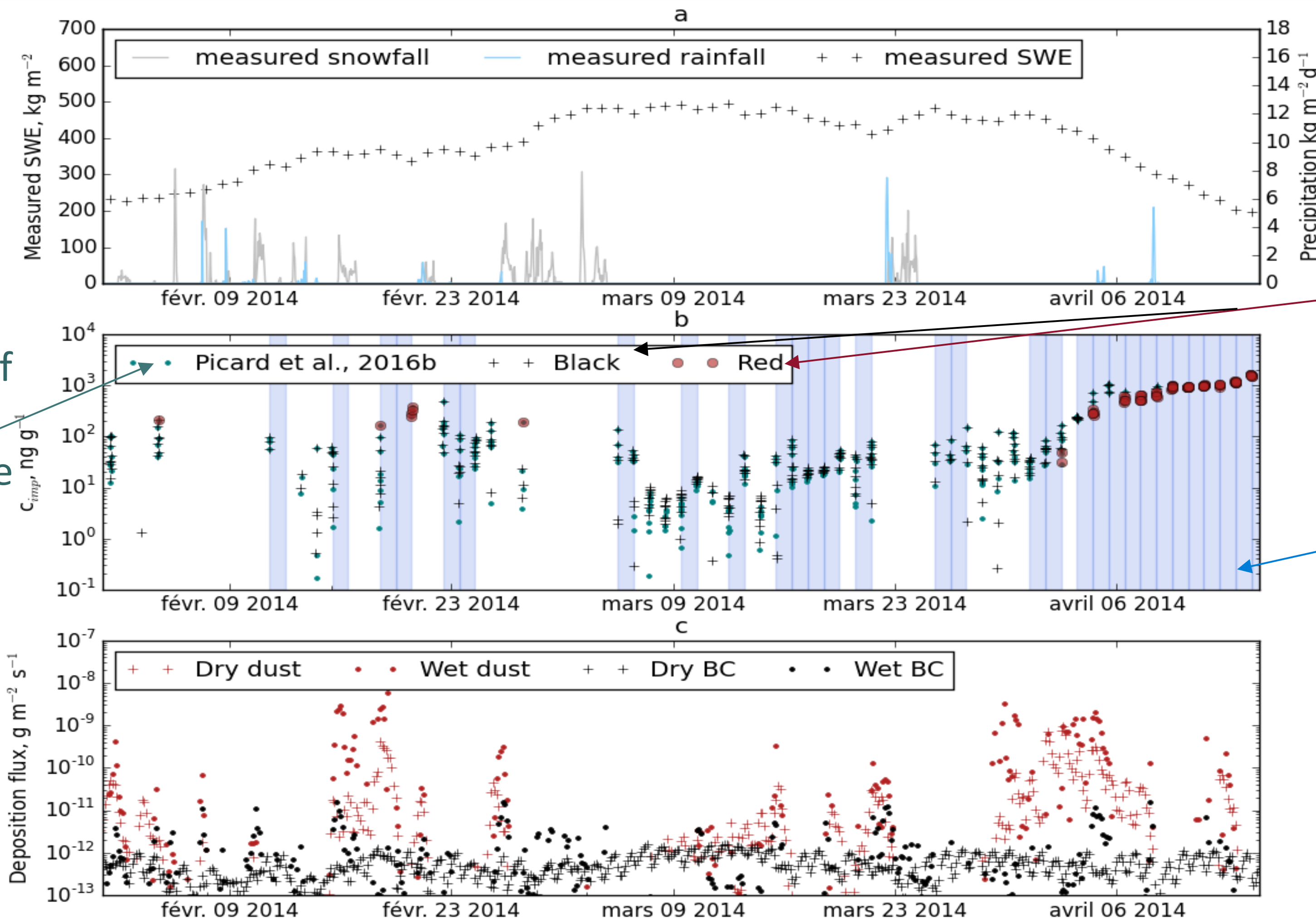
SSA diurnal evolution



LAI content (soot equivalent)



Impact of ice refractive index

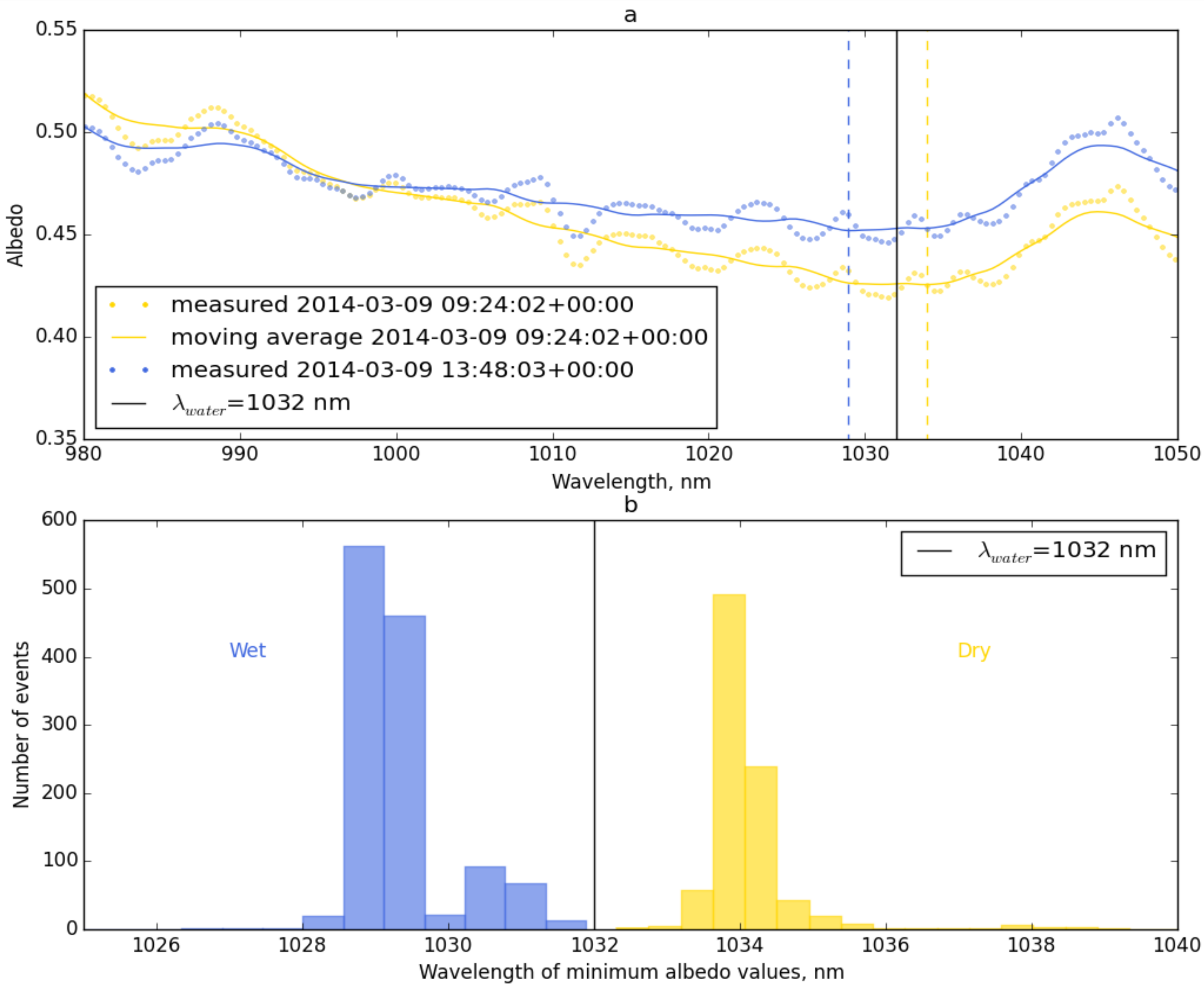
Prevailing impurities colour

Melt events

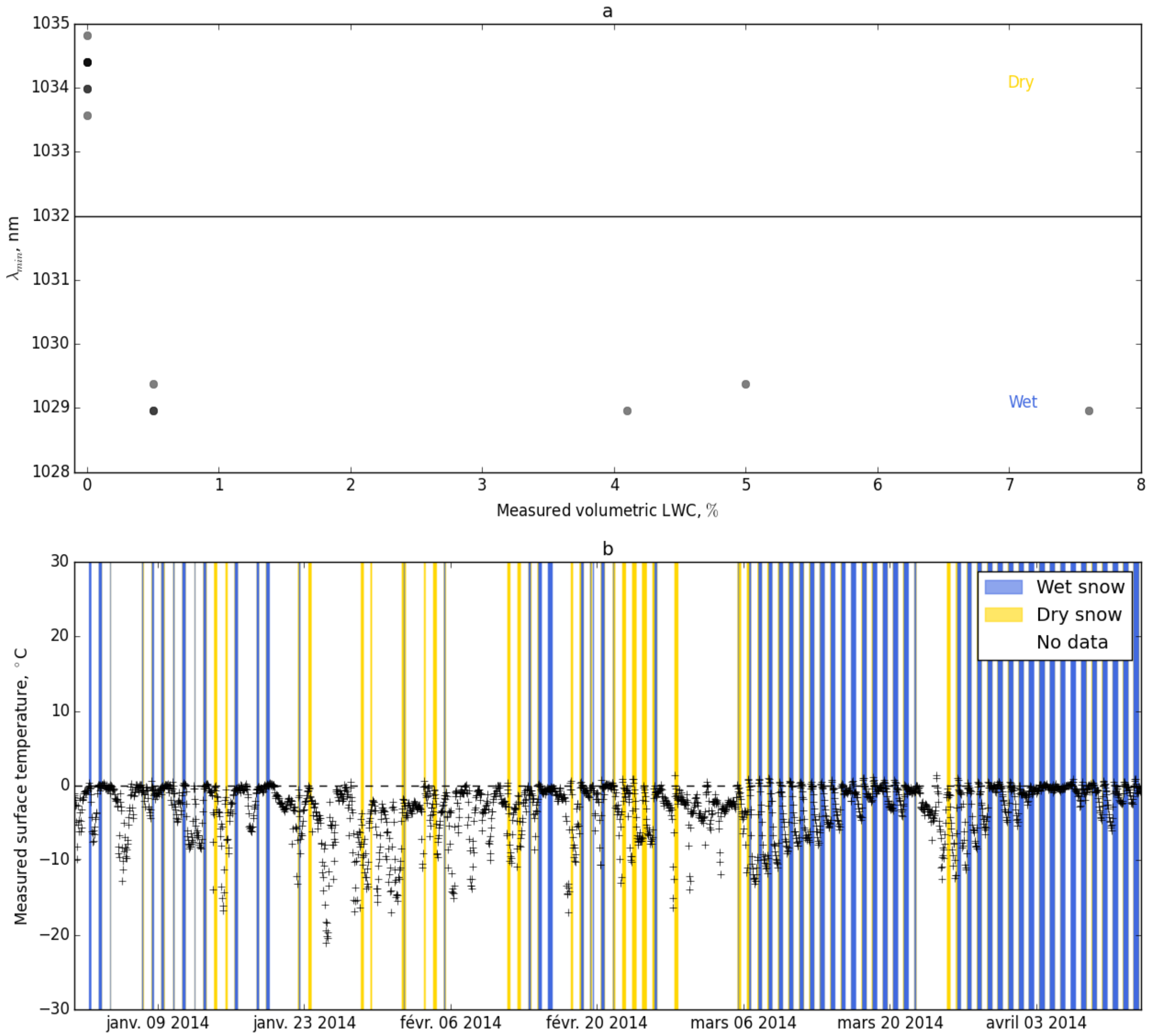
ALADIN-climate (Nabat et *al.*, 2015)

- Measured averaged 2cm values 15+-3 ng g^{-1} vs spectral albedo values [0,2,38] ng g^{-1}.

Presence of liquid water



Presence of liquid water



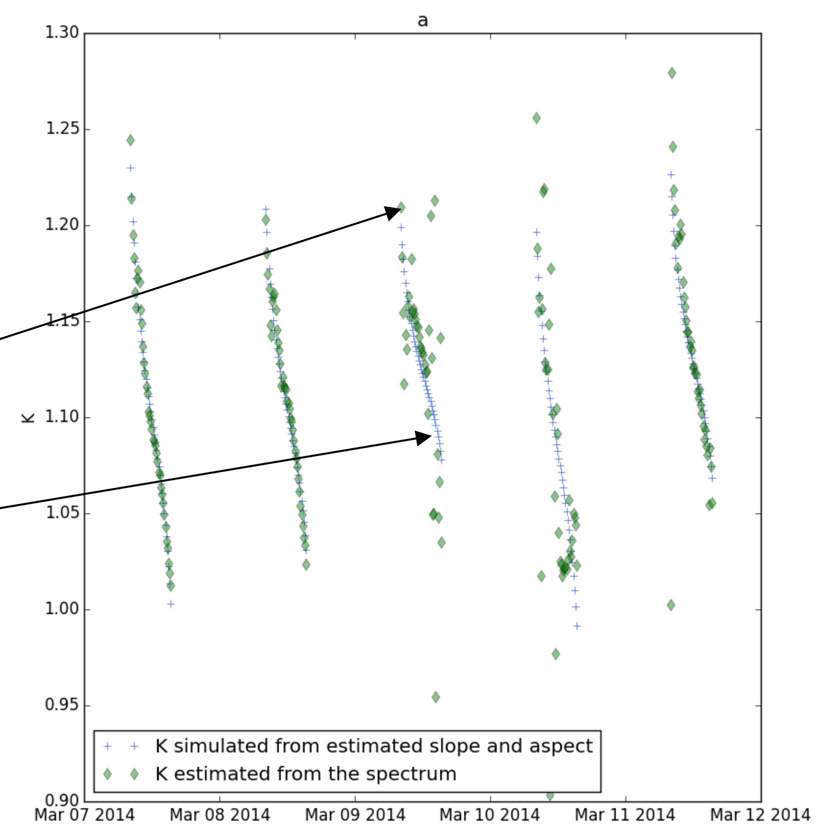
- Perfect agreement with measured LWC (only 8 dates …)
- Occurence of false detection cases from measured Ts : 3.5 %

Conclusions

- The evolution of near surface properties (SSA, LAI content, presence of liquid water) can be monitored using time series of spectral albedo.
- SSA and presence of liquid water estimation from the spectra are more robust than LAI content estimation since they are based on spectrum shape and not on spectrum level.
- SSA retrieval uncertainties are larger in presence of a tilted snow surface and medium to large amount of LAI. Need to be further investigated using microCT SSA measurements and LAI content « direct » measurements.
- Continuous spectral albedo measurements offer a new insight into the evolution of snow near surface properties, they can be used to evaluated detailed snow model but they can also be assimilated into such model in order to obtain accurate snowpack simulations (e.g. Charrois et *al*., 2016)
- Surface roughness and anisotropy of reflected and incident diffuse radiations are not accounted for in our methodology and this effect must be further investigated.

Retrieval Method

- Step 0 : estimate A_{diff} using only cloudy days (limited tilt effect)
- Step 1a : estimate K diurnal cycle from the spectra
- Step 1b : estimate daily slope and aspect from K diurnal cycle
- Step 2 : estimate SSA, cimp using daily slope and aspect



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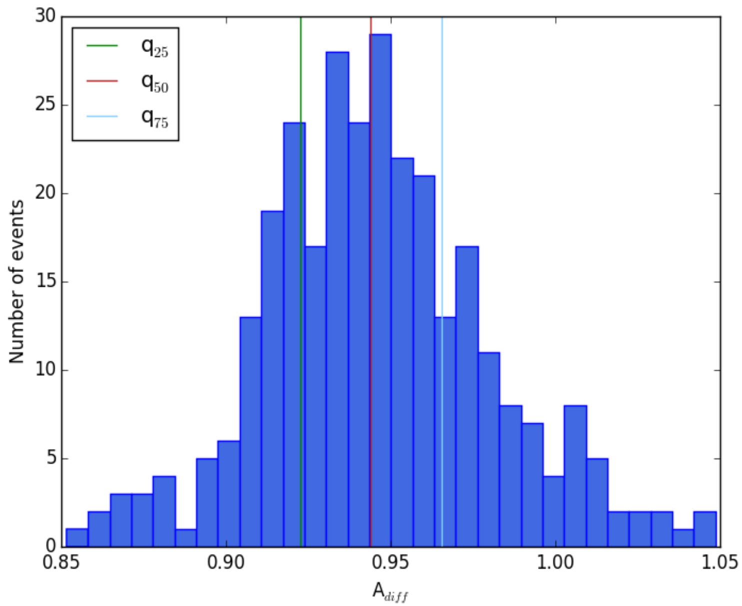
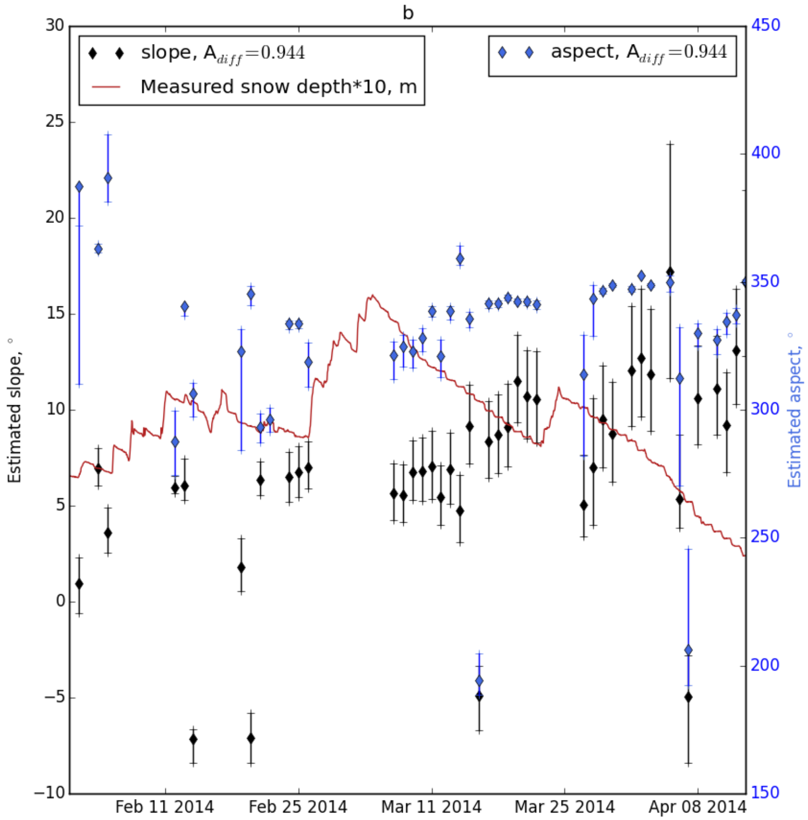
A_{diff}, slope and aspect



A_{diff} spread : precipitations, remaining direct radiation, optical switch, ...

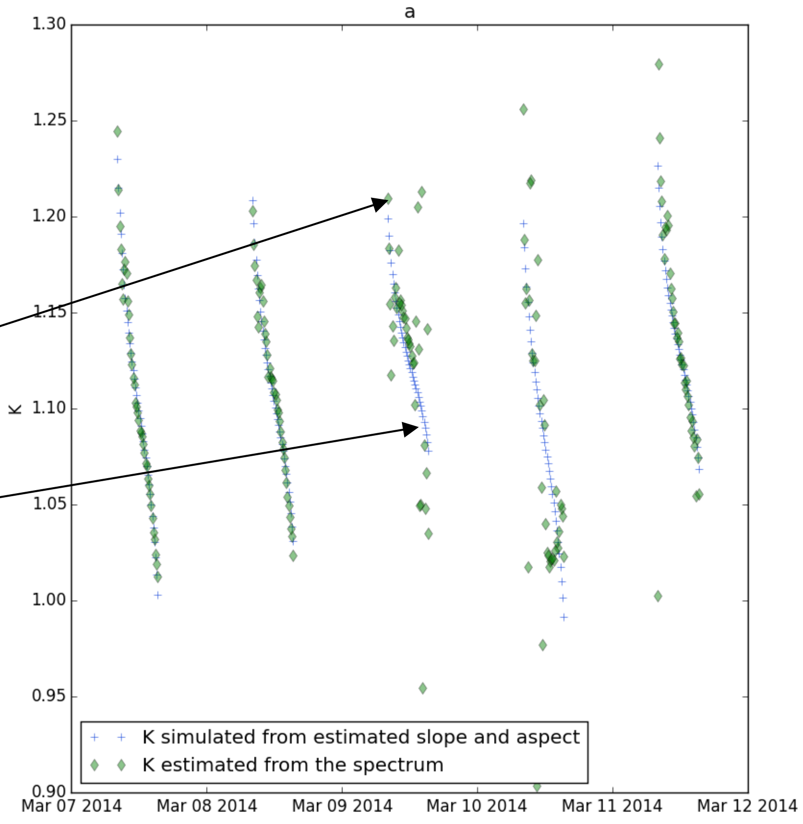


Slope smaller after snowfall, increases with melt

Dome C estimated slope angle +-2°

Daily slope and aspect estimation

- Step 1a : estimate K diurnal cycle from the spectra
- Step 1b : estimate daily slope and aspect from K diurnal cycle



Retrieval Method

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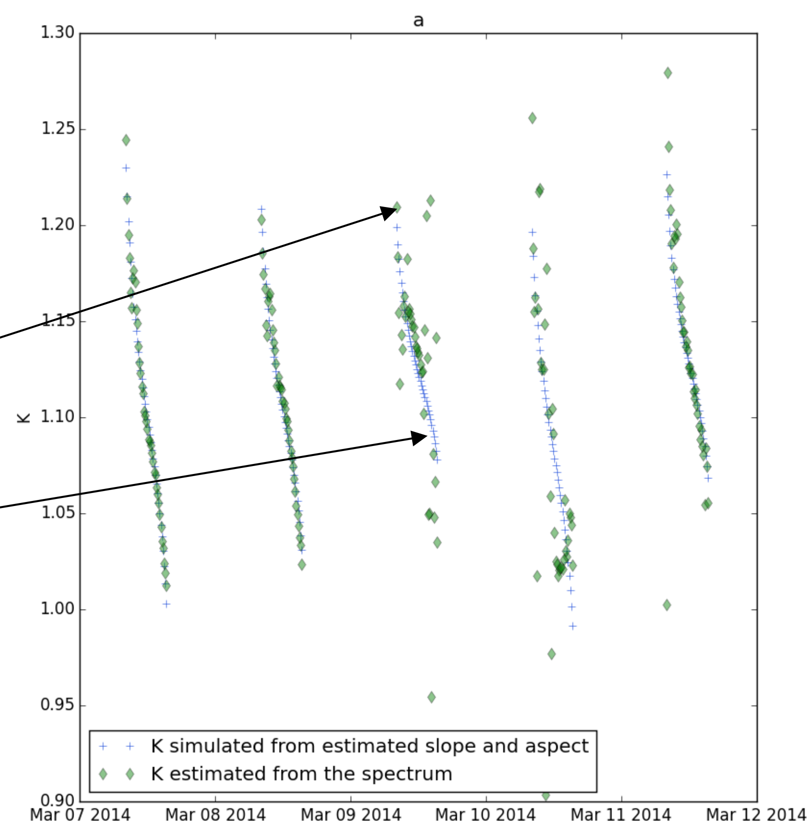
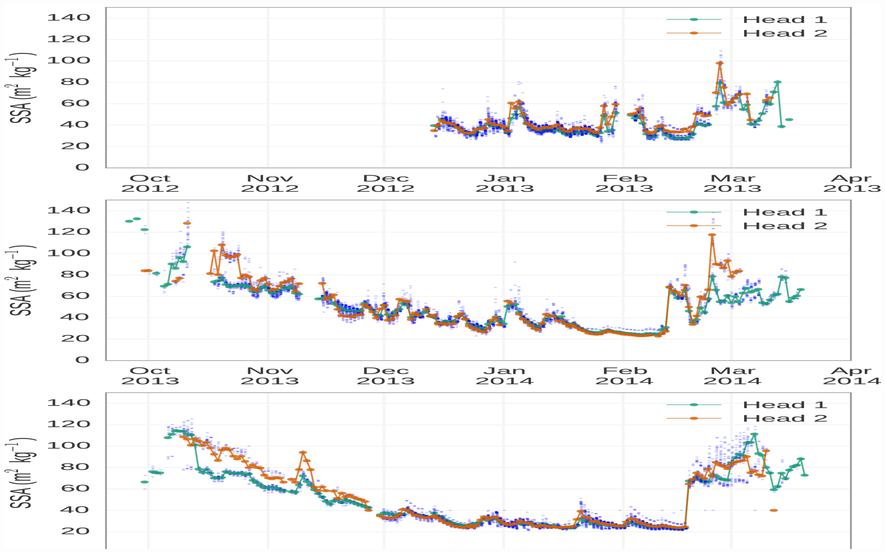
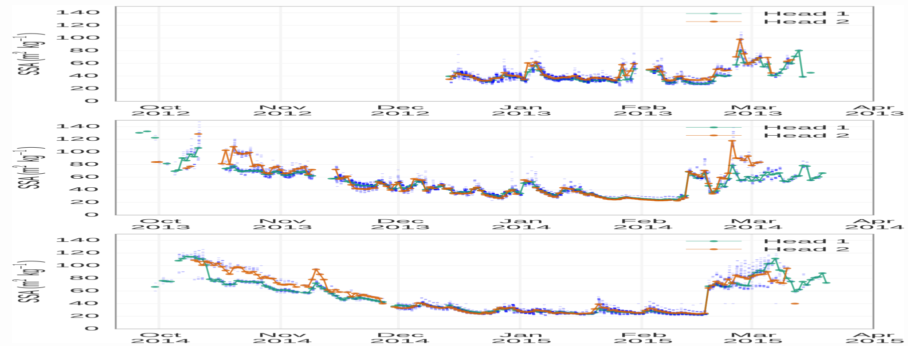
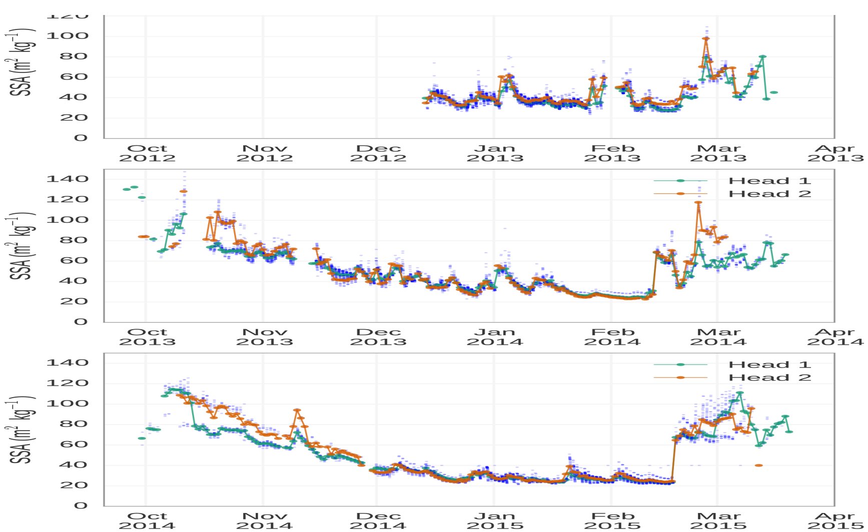


SSA time-series



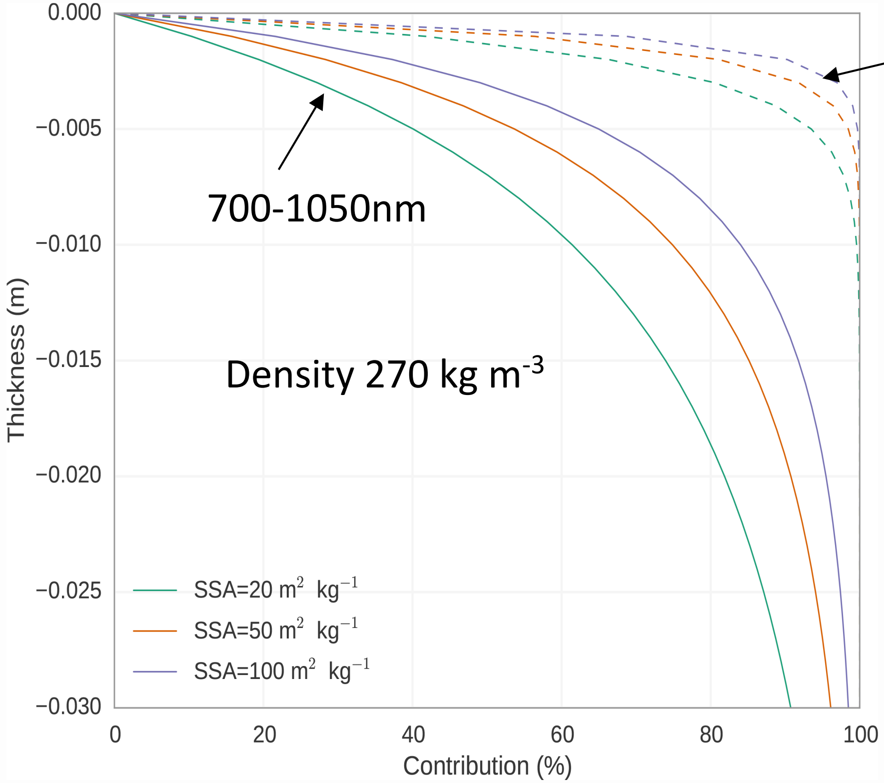




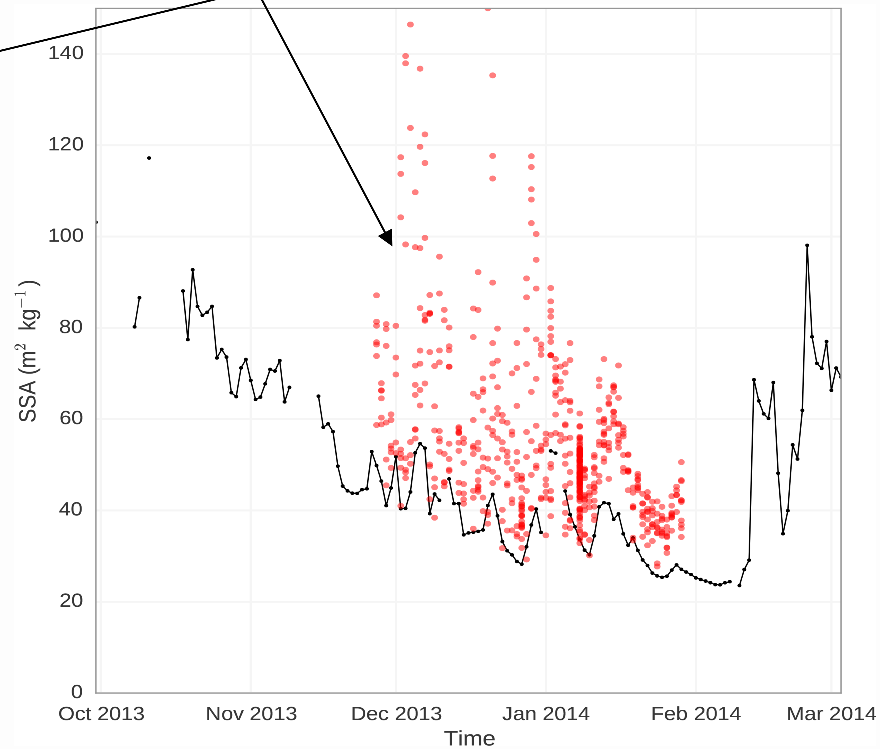
- 2 to 3 fold decrease in SSA during boreal summer
- Significant temporal variability due to precipitation events and snow drift
- Spatial variability between the two heads

(Libois et *al*., 2015 ; Picard et *al*., 2016)

SSA vertical representativeness



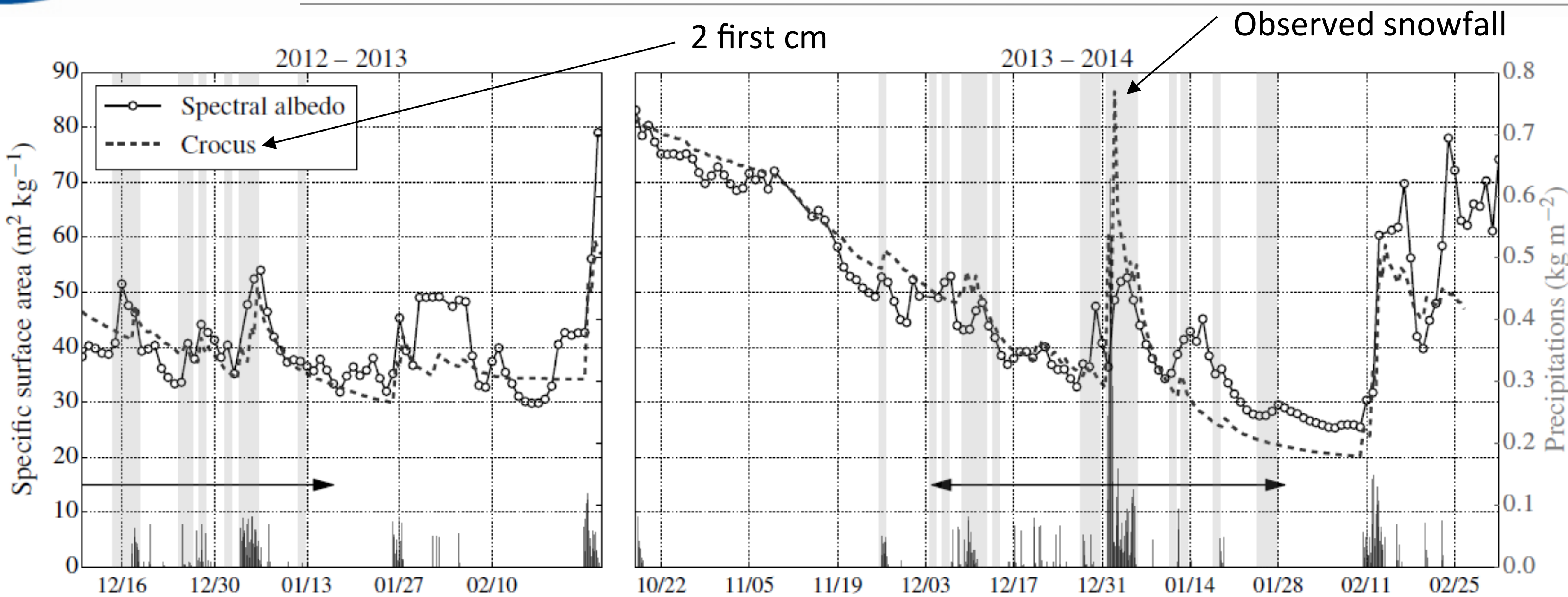
ASSSAP, 1310 nm, Arnaud et *al*., 2011



- Near surface SSA estimated from the spectra come from the uppermost 1-2 cm
- A sharp SSA gradient exists near in the first cm (e.g. Grenfell et *al*., 1994)

(Picard et *al*., 2016)

SSA time-series measured vs simulated



- Crocus simulations (Vionnet et *al*., 2012) driven by ERA-interim reanalysis agree well with observed near surface SSA evolution (intensity and timing of summer metamorphism)

(Libois et *al*., 2015)

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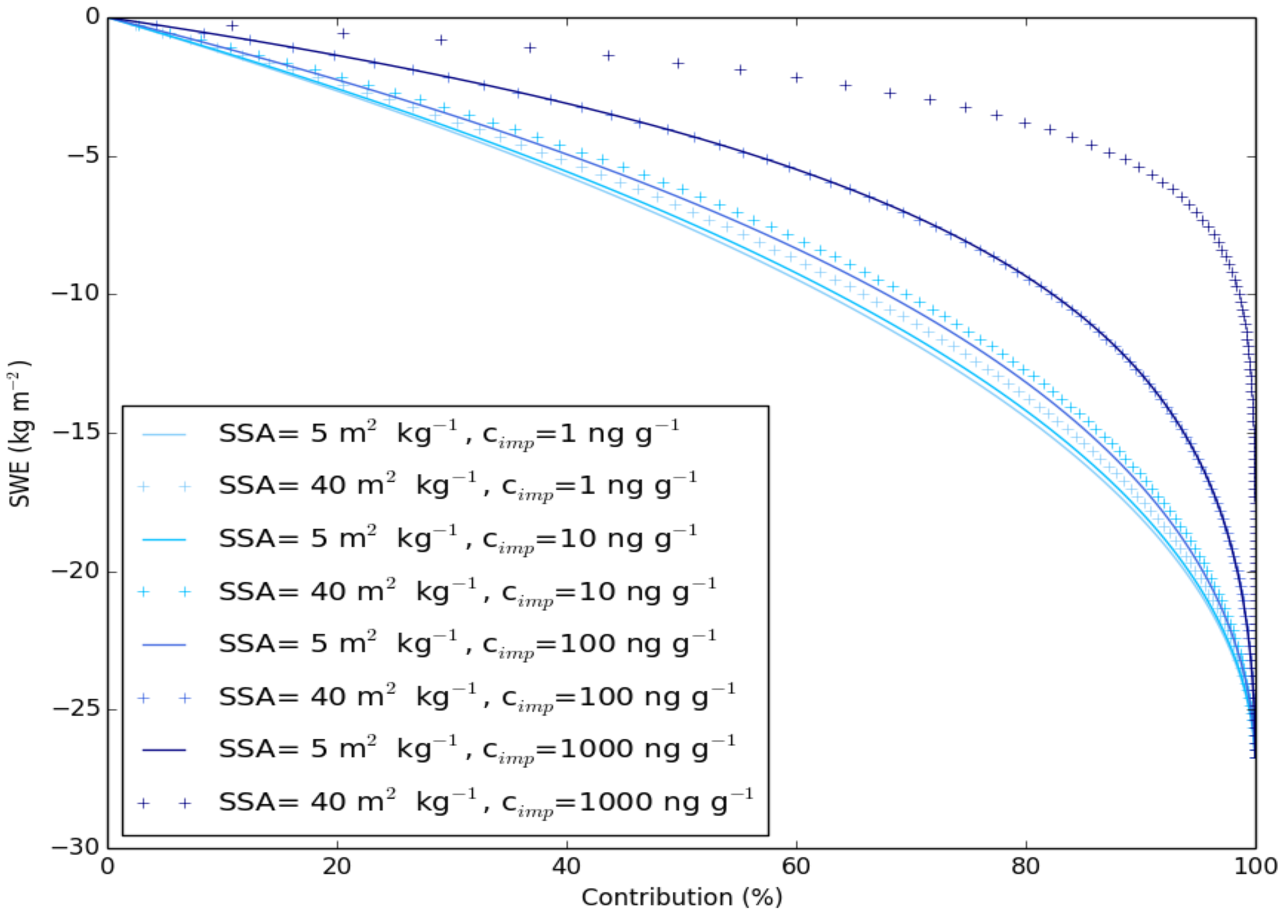
c_imp vertical representativeness



Melt freeze cycle