Correction of broadband albedo measurements affected by unknown slope and sensor tilts

in-situ snow albedo measurements

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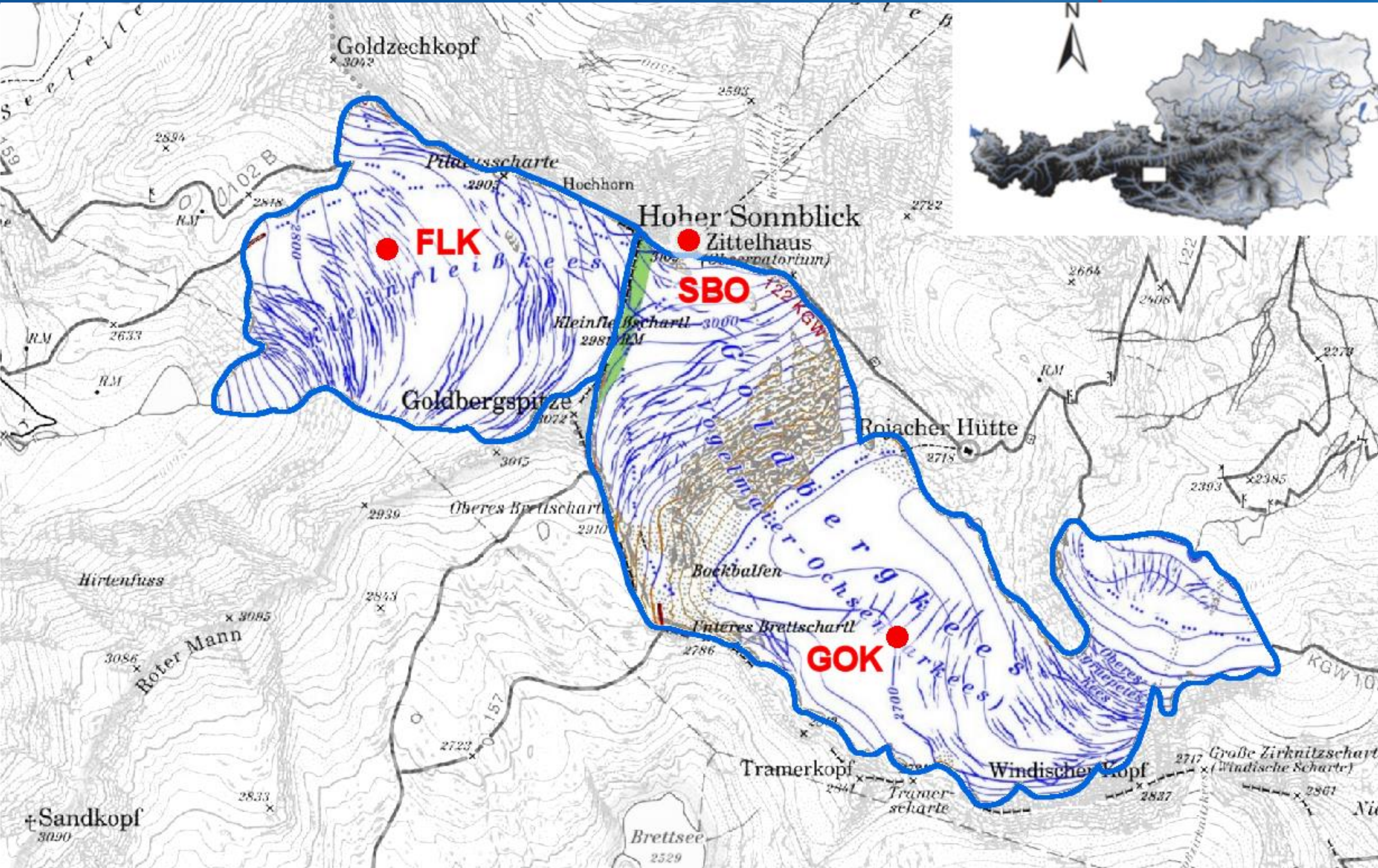
locations


FLK
SBO
GOK
Goldzechkopf
Hoher Sonnblick
Zittelhaus
Goldbergspitze
Rojacher Hütte
Tramerkopf
Windischer Kopf
Sandkopf
Roter Mann
Hirtenfuss
Bockbalfen
Brettsee
Hochhorn
N

- albedo: α = diffuse reflectivity of a surface

$$\alpha = \frac{F^{\uparrow}}{F^{\downarrow}}$$

	albedo values
fresh snow	$0.7 < \alpha < 1.0$
old snow, firn	$0.4 < \alpha < 0.8$
glacier ice	$0.2 < \alpha < 0.5$

methods

- expectations:
  - without snowfall small decrease of α
  - α -ranges of snow/glacier ice:

$$0.2 < \alpha < 1.0$$

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methods

- expectations:
  - without snowfall small decrease of α
  - α -ranges of snow/glacier ice:

    $0.2 < \alpha < 1.0$

- measurements:
  - large diurnal variation of α on clear sky days
  - measured α-ranges:

    $0 < \alpha < 1+$

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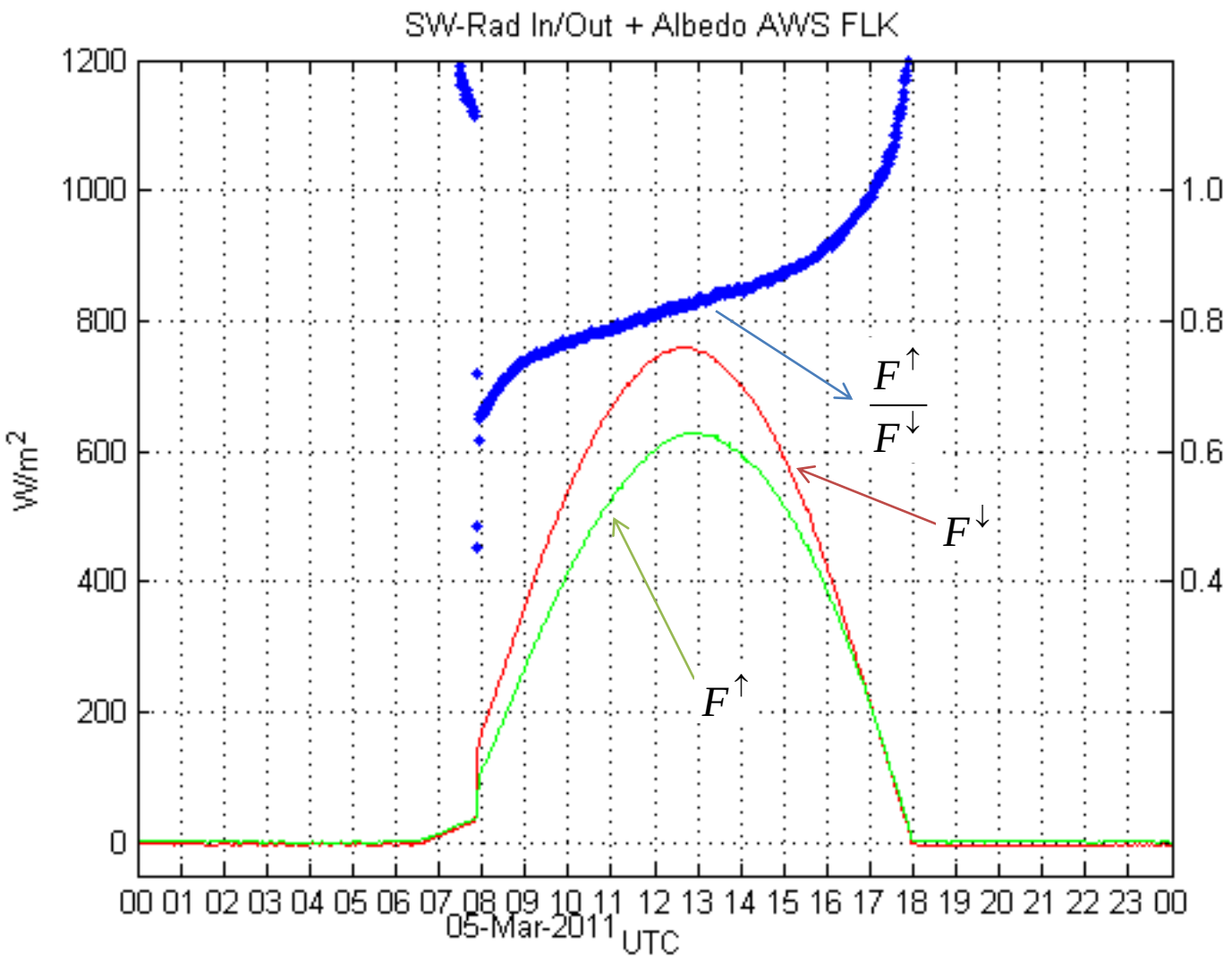
methods



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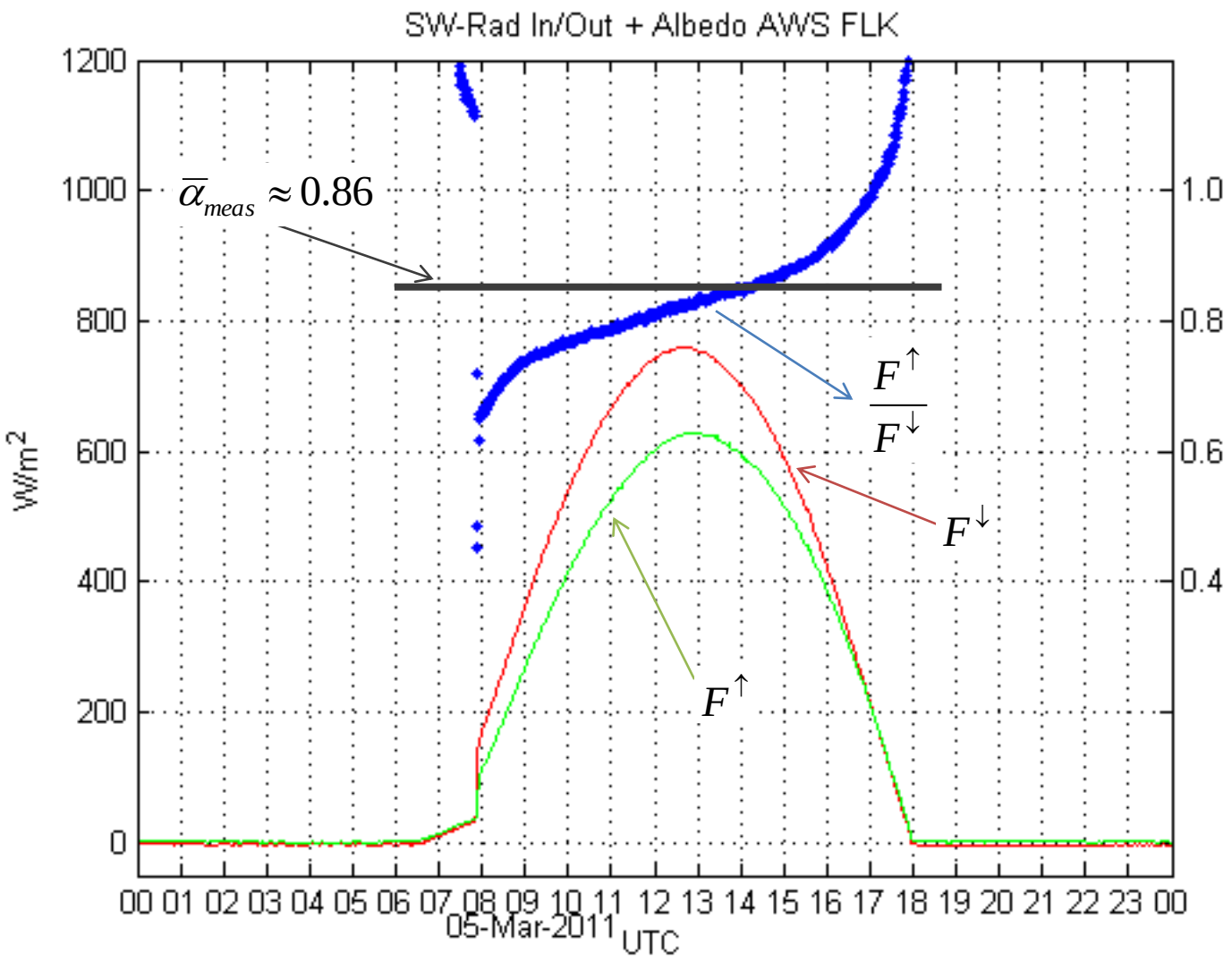
methods



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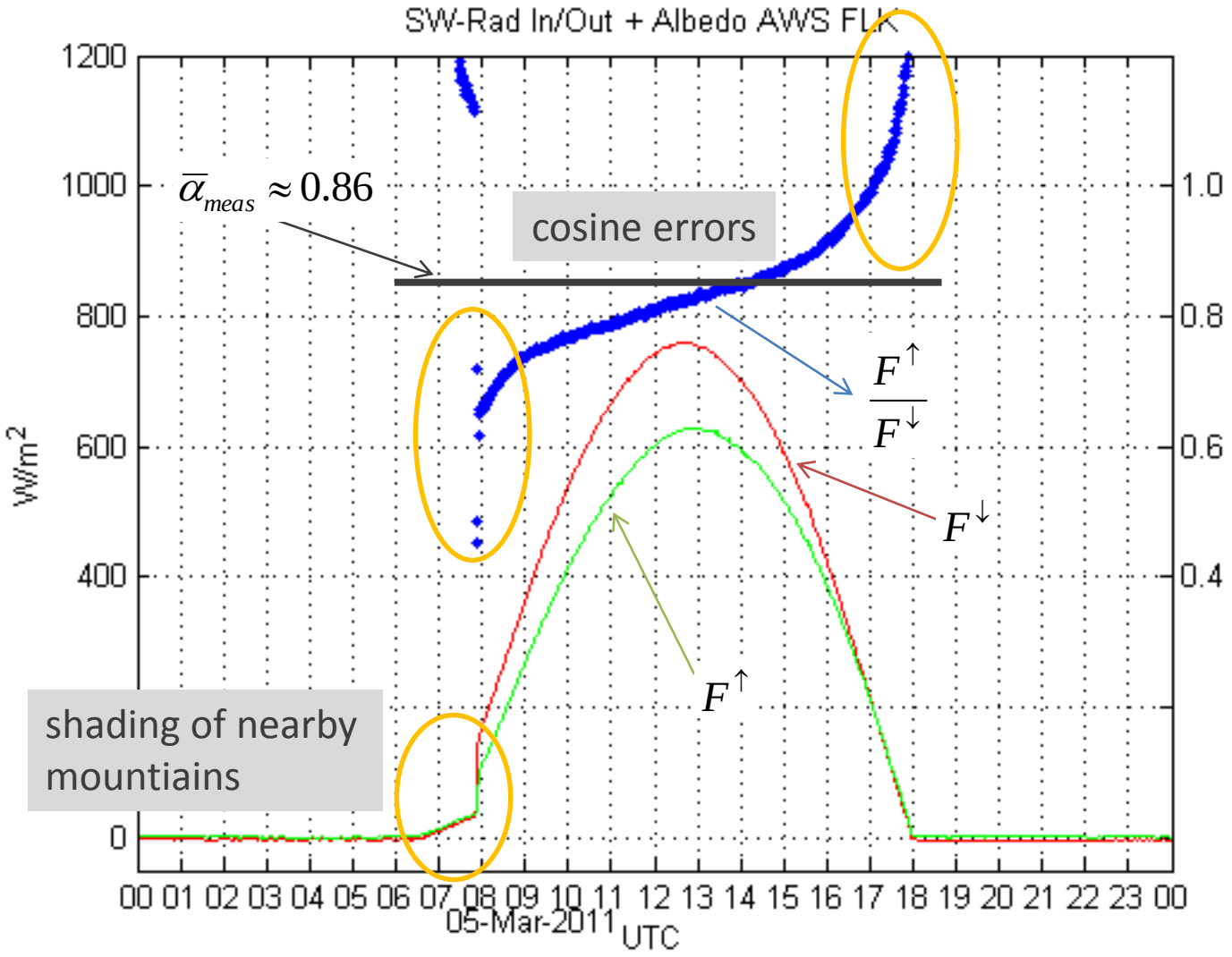
methods



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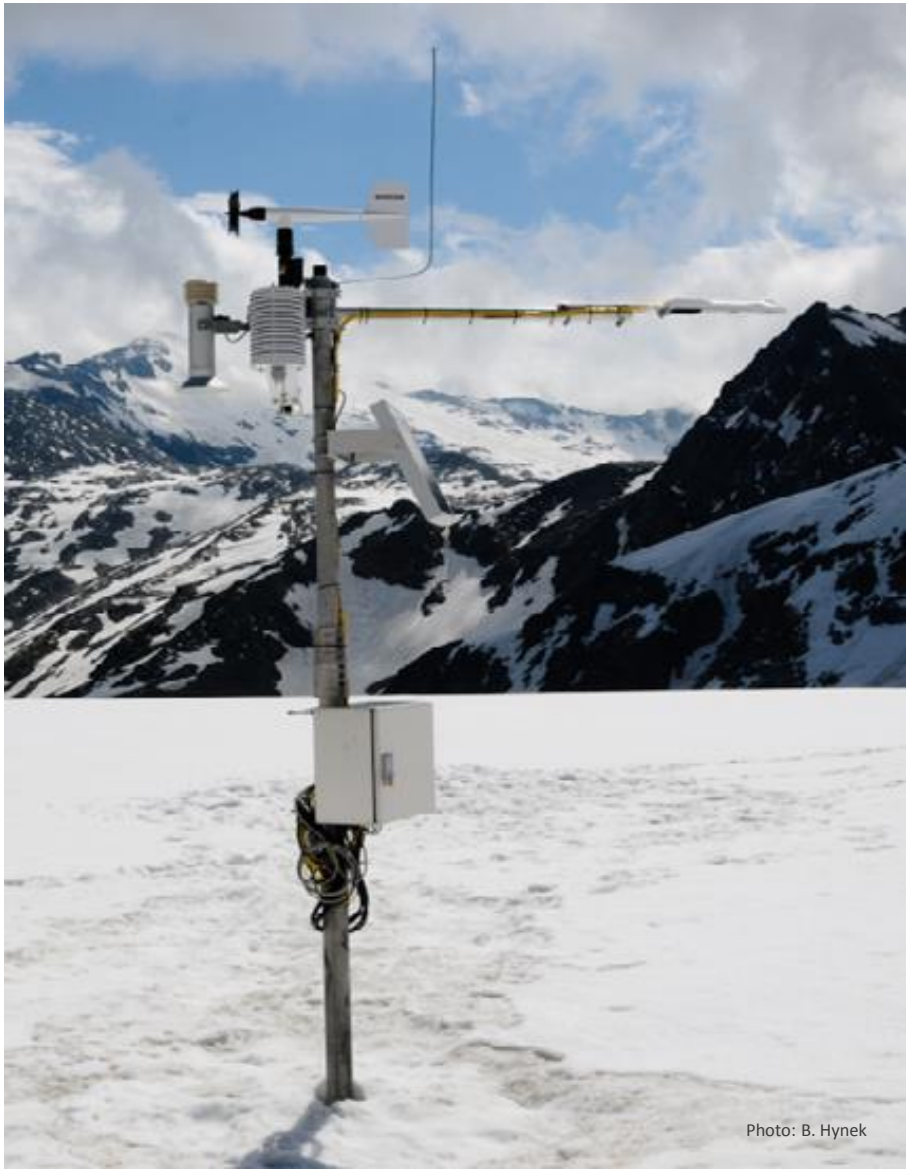
methods

- AWS

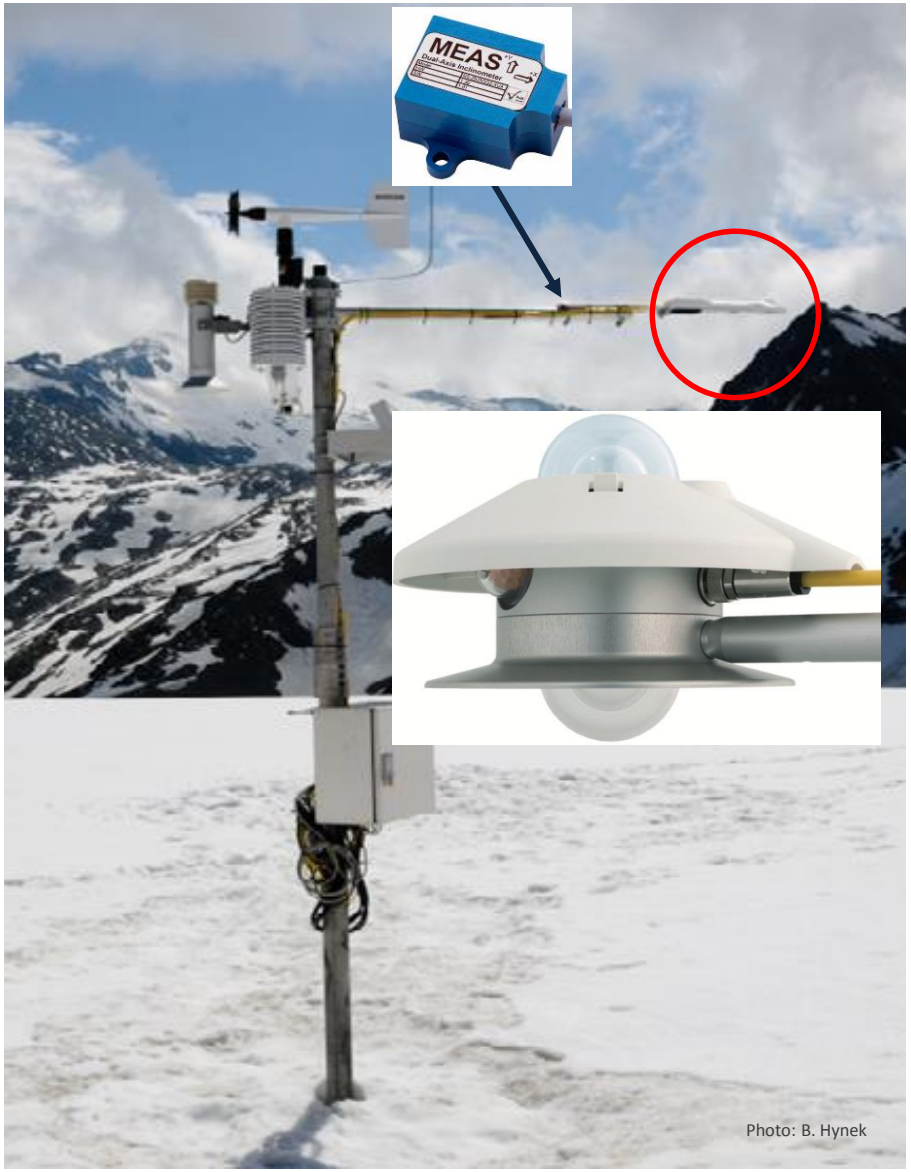


methods

- AWS
- albedo measurement
  - 2 opposing pyranometers (=albedometer)

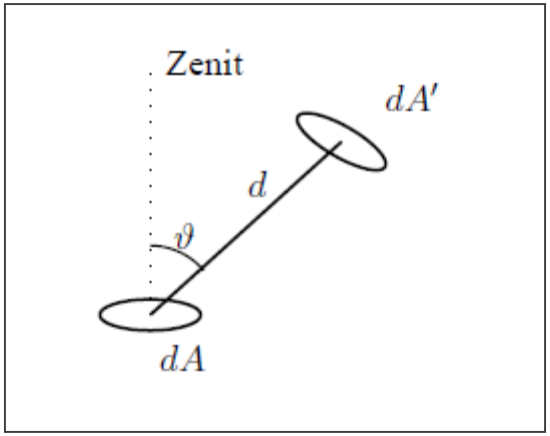
methods

- AWS
- albedo measurement
  - ➢2 opposing pyranometers (=albedometer)
- inclinometer



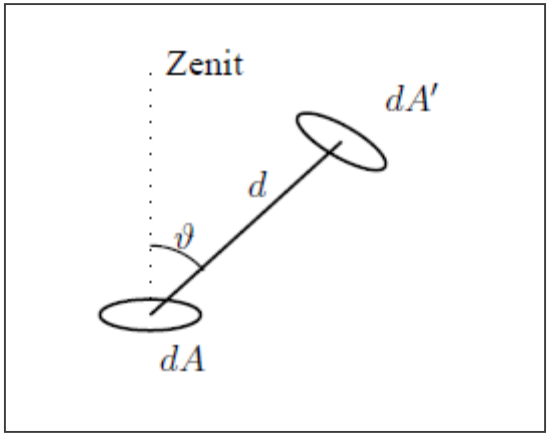
correction

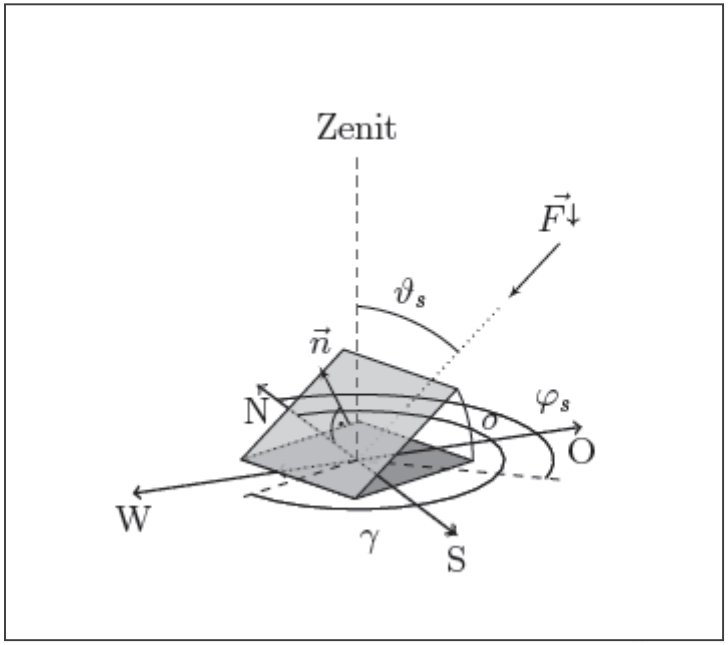
- radiation on a horizontal plane



correction

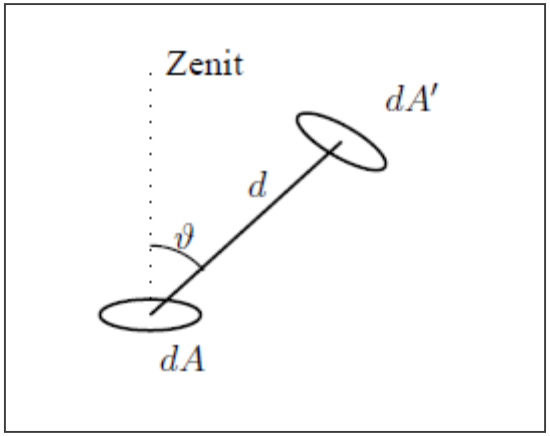
- radiation on a horizontal plane
- radiation on a tilted plane

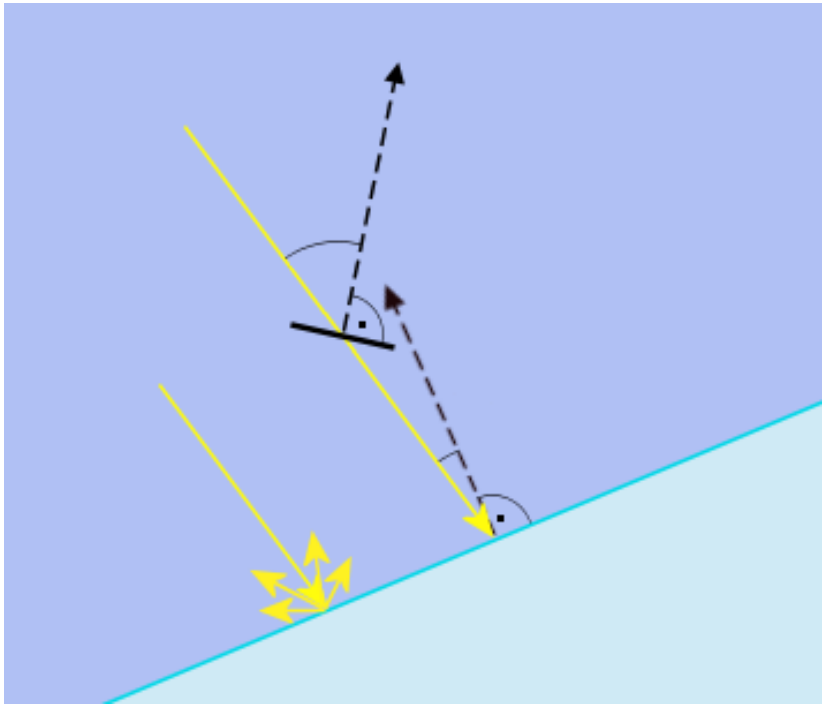


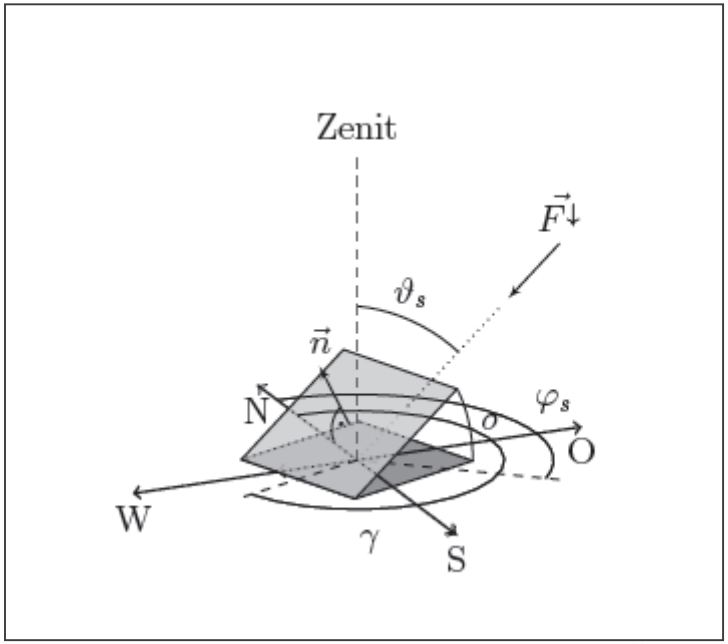


correction

- radiation on a horizontal plane
- radiation on a tilted plane
- radiation on two different tilted planes

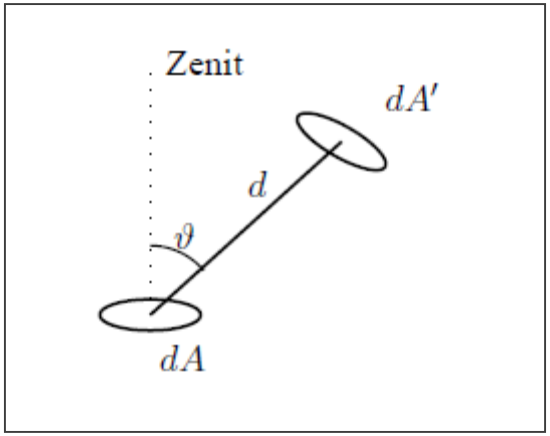


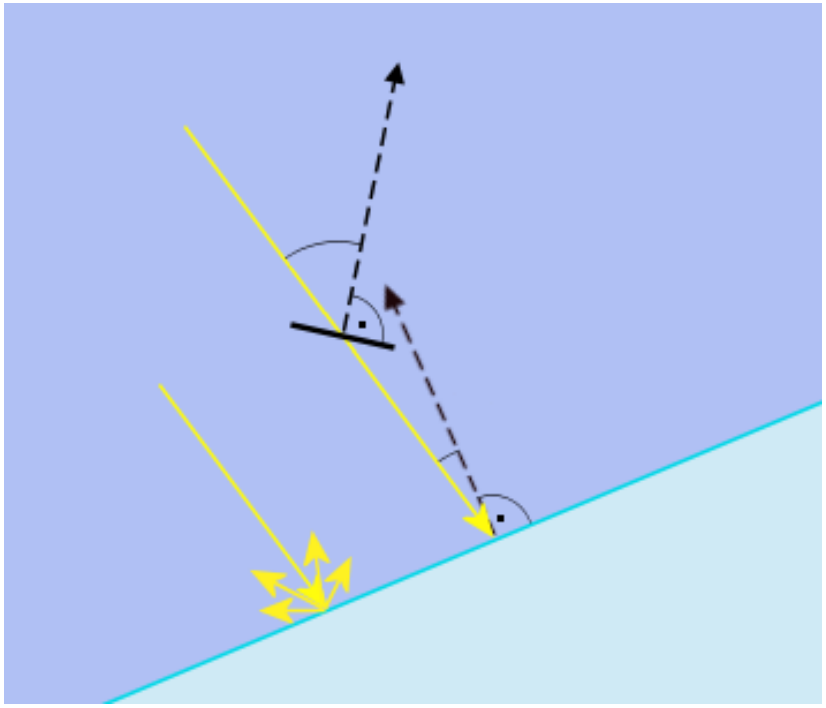


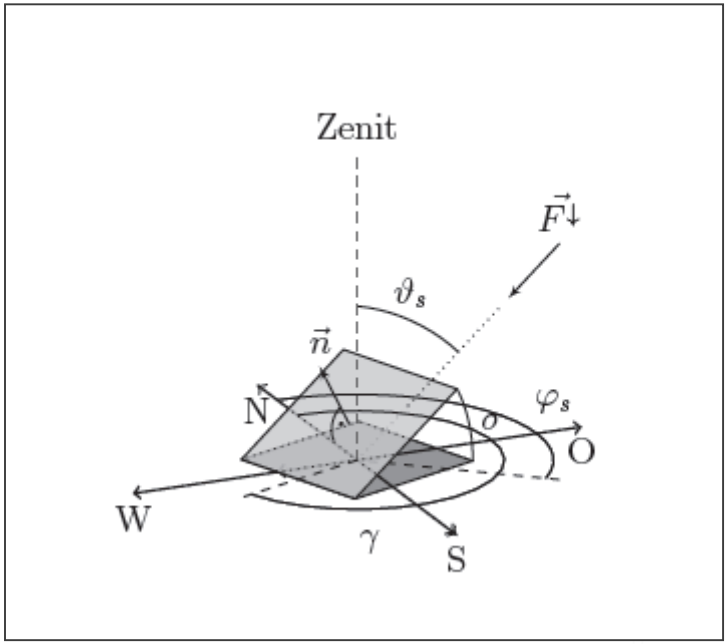


correction

- radiation on a horizontal plane
- radiation on a tilted plane
- radiation on two different tilted planes
- aim = measured α → true α

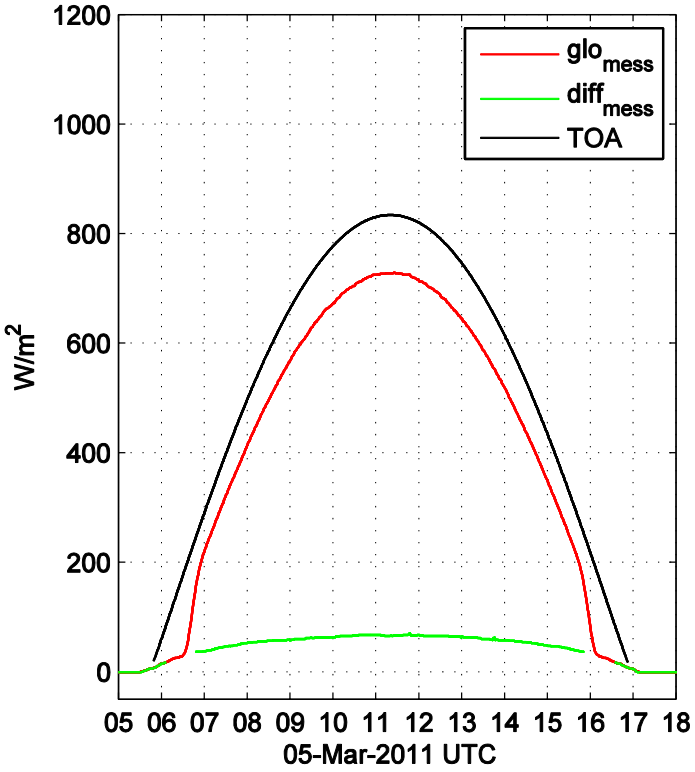






correction

- fitting of atmospheric parameters with horizontally levelled reference measurement
  - ➢ Suntracker (BSRN)



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correction

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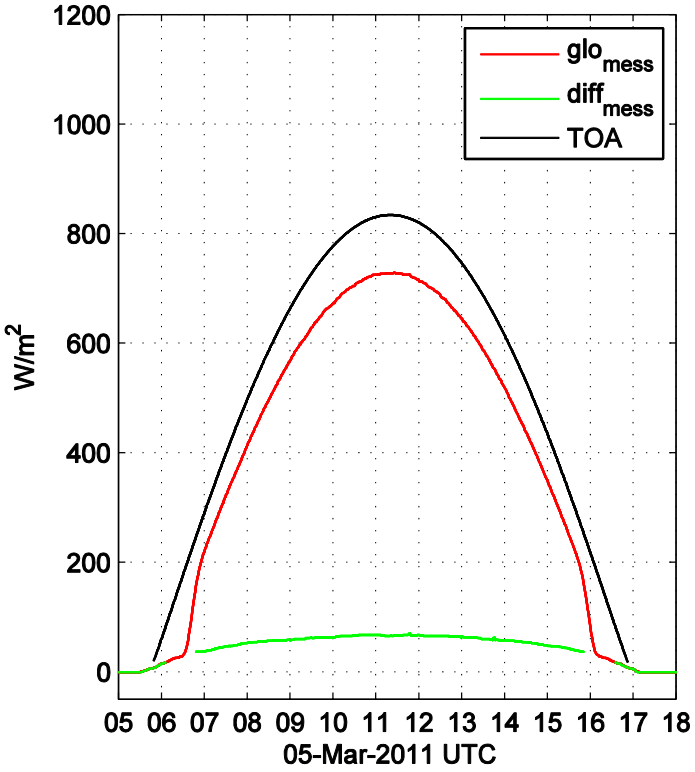
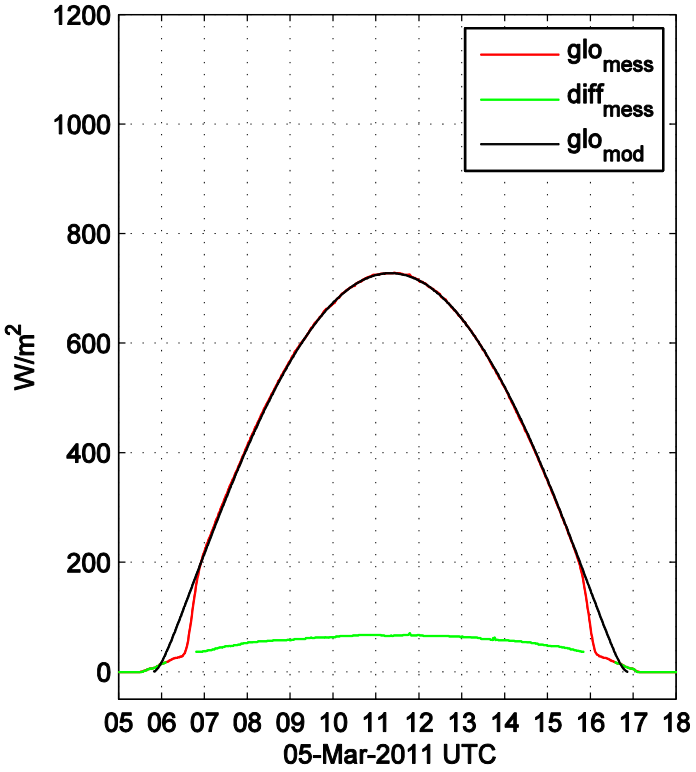
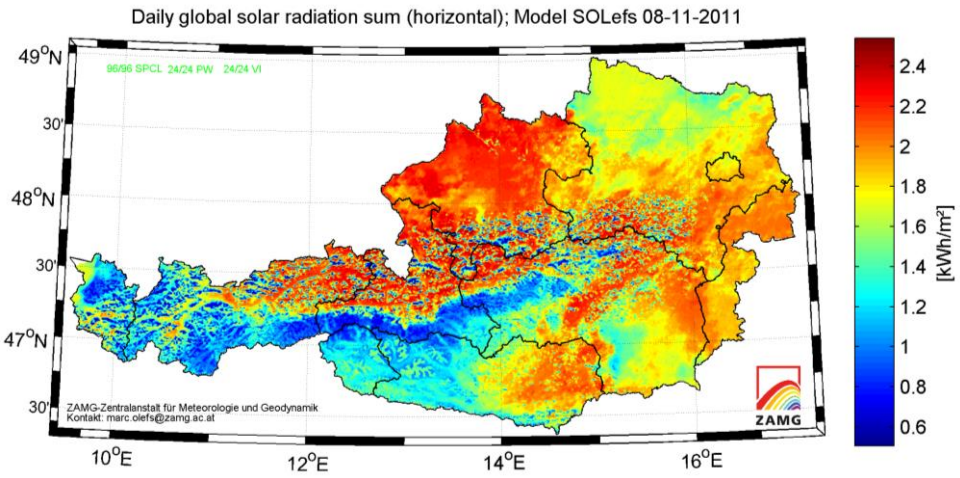
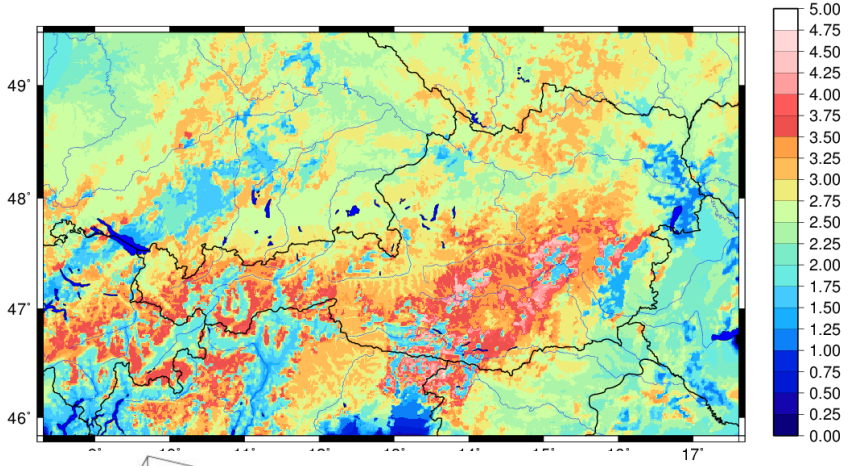


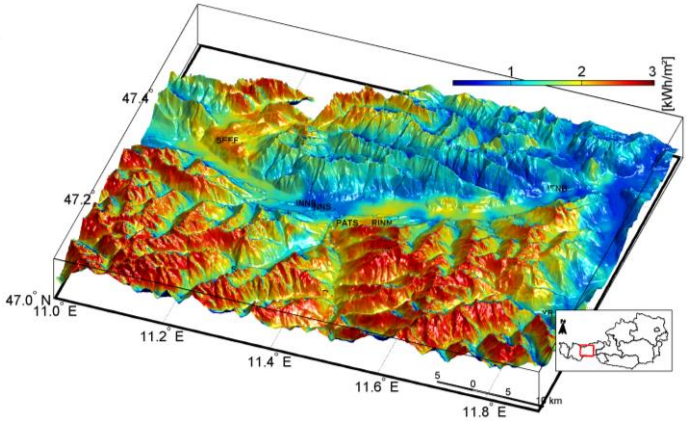


correction

- fitting of atmospheric parameters with solar radiation model
  - ➢ solar radiation model STRAHLGRID
    - ⇨ 100 m x 100 m, 15 min







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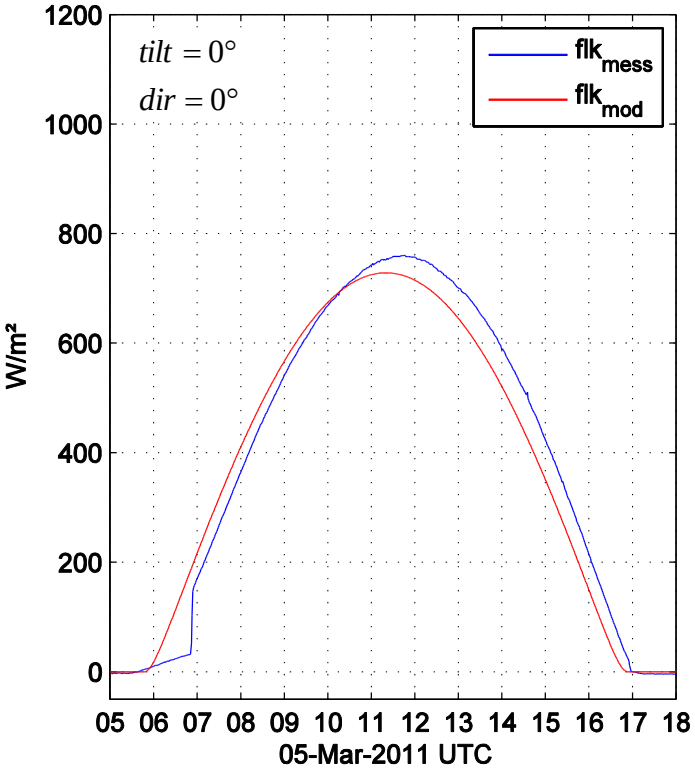
correction

- fitting of tilts and directions of pyranometer
  - ➢ incoming SW radiation



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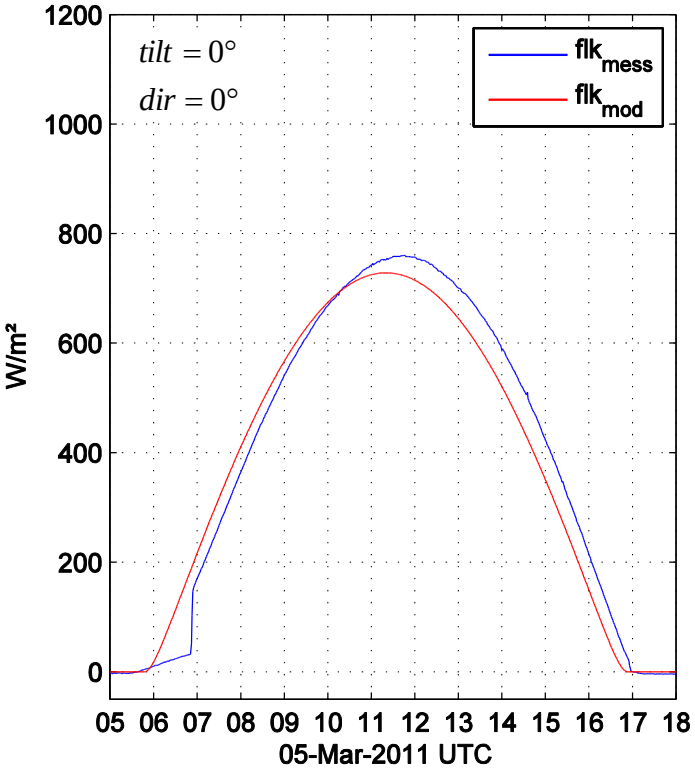
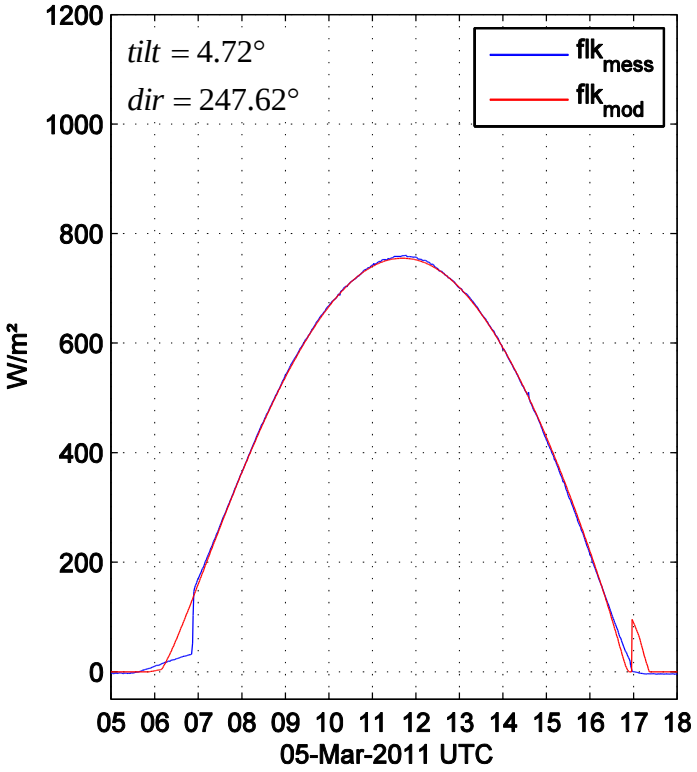
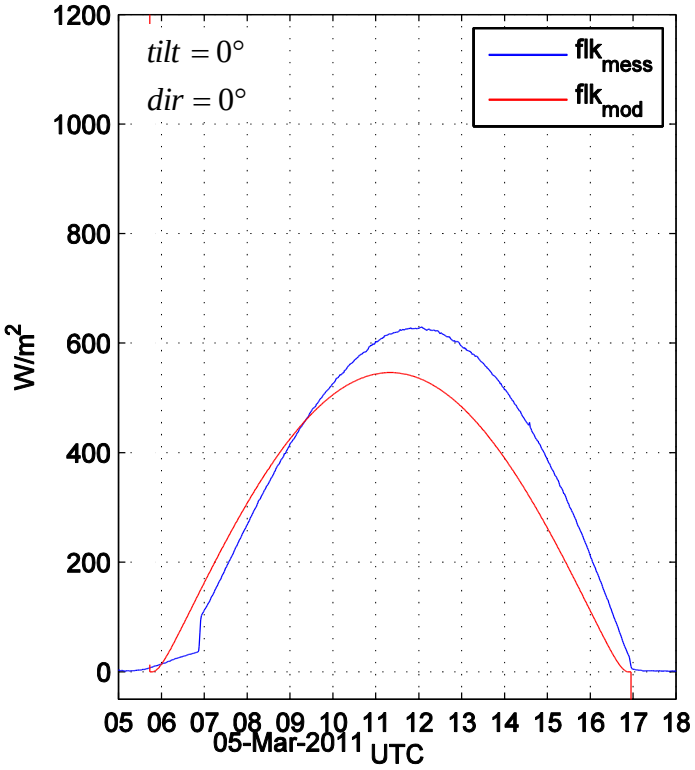




correction

- fitting of tilts and directions of glacier surface
  - ➢ reflected SW radiation



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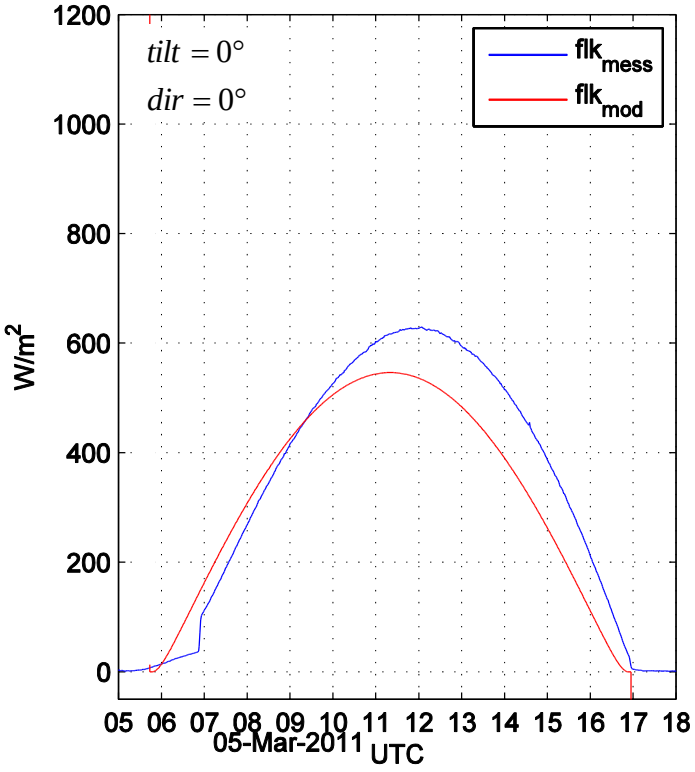
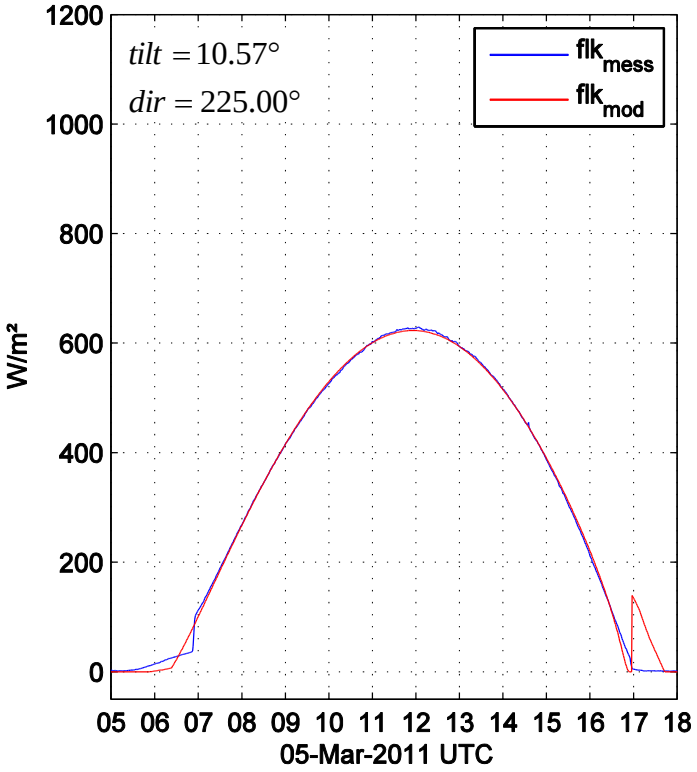
correction

- fitting of tilts and directions of glacier surface
  - ➢ reflected SW radiation





correction

Step A: calibrate atmospheric parameters with data of BSRN or STRAHLGRID

↓

Step B: compare model to measured data of up-facing pyranometer at AWS to find inclination and orientation of the sensors

↓

Step C: determine tilt and direction of the terrain slope

↓

Step D: derive true albedo

↓

Step E: derive corrected shortwave radiative balance

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correction

Step A: calibrate atmospheric parameters with data of BSRN or STRAHLGRID

Step B: compare model to measured data of up-facing pyranometer at AWS to find inclination and orientation of the sensors

Step C: determine tilt and direction of the terrain slope

Step D: derive true albedo

$$\alpha_{true} = \alpha_{meas} \left(\frac{p_{diff} \cdot \cos \vartheta_s + (1 - p_{diff}) \cdot \cos \vartheta_p}{p_{diff} \cdot \cos \vartheta_s + (1 - p_{diff}) \cdot \cos \vartheta_t} \right)$$

Step E: derive corrected shortwave radiative balance

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correction

Step A: calibrate atmospheric parameters with data of BSRN or STRAHLGRID

$$F_{hor} = \frac{S}{\tilde{r}^2} \cdot V \cdot e^{-\varepsilon \frac{1}{\cos \vartheta_s}} \cdot \cos \vartheta_s$$

Step B: compare model to measured data of up-facing pyranometer at AWS to find inclination and orientation of the sensors

$$F_{tilt} = p_{dir} F_{tilt}^{dir} + p_{diff} F_{hor}$$

$$\cos \vartheta_p = \overrightarrow{F^{\downarrow}} \cdot \vec{n} = \sin \vartheta_s \cos \varphi_s \sin \sigma_p \cos \gamma_p + \sin \vartheta_s \cos \varphi_s \sin \sigma_p \cos \gamma_p + \cos \vartheta_s \cos \sigma_p$$

Step C: determine tilt and direction of the terrain slope

$$F^{\uparrow} = \alpha_{true} \cdot \cos \vartheta_t$$

$$\cos \vartheta_t = \overrightarrow{F^{\downarrow}} \cdot \vec{n} = \sin \vartheta_s \cos \varphi_s \sin \sigma_t \cos \gamma_t + \sin \vartheta_s \cos \varphi_s \sin \sigma_t \cos \gamma_t + \cos \vartheta_s \cos \sigma_t$$

$$C = \left\langle \left(\frac{F^{\uparrow}}{\cos \vartheta_t} \right) \right\rangle \Rightarrow \left(C \cdot \cos \vartheta_t - F^{\uparrow} \right)^2 \rightarrow \min$$

Step D: derive true albedo

$$\alpha_{true} = \alpha_{meas} \left(\frac{p_{diff} \cdot \cos \vartheta_s + (1 - p_{diff}) \cdot \cos \vartheta_p}{p_{diff} \cdot \cos \vartheta_s + (1 - p_{diff}) \cdot \cos \vartheta_t} \right)$$

Step E: derive corrected shortwave radiative balance

$$SW_{net} = SW_{in} + SW_{out} = SW_{in}(1 - \alpha)$$

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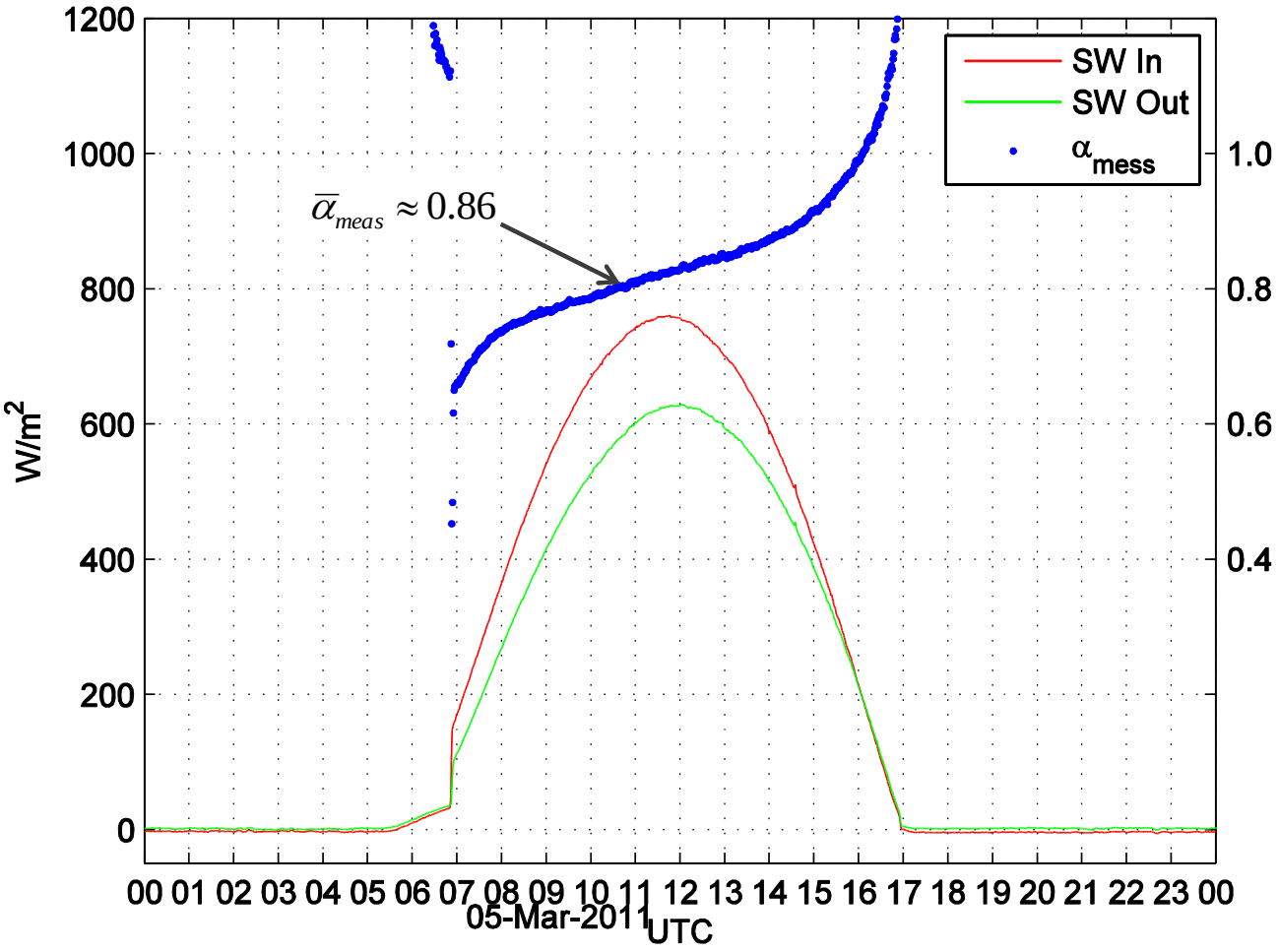
corrected daily mean α on Kleinfleißkees



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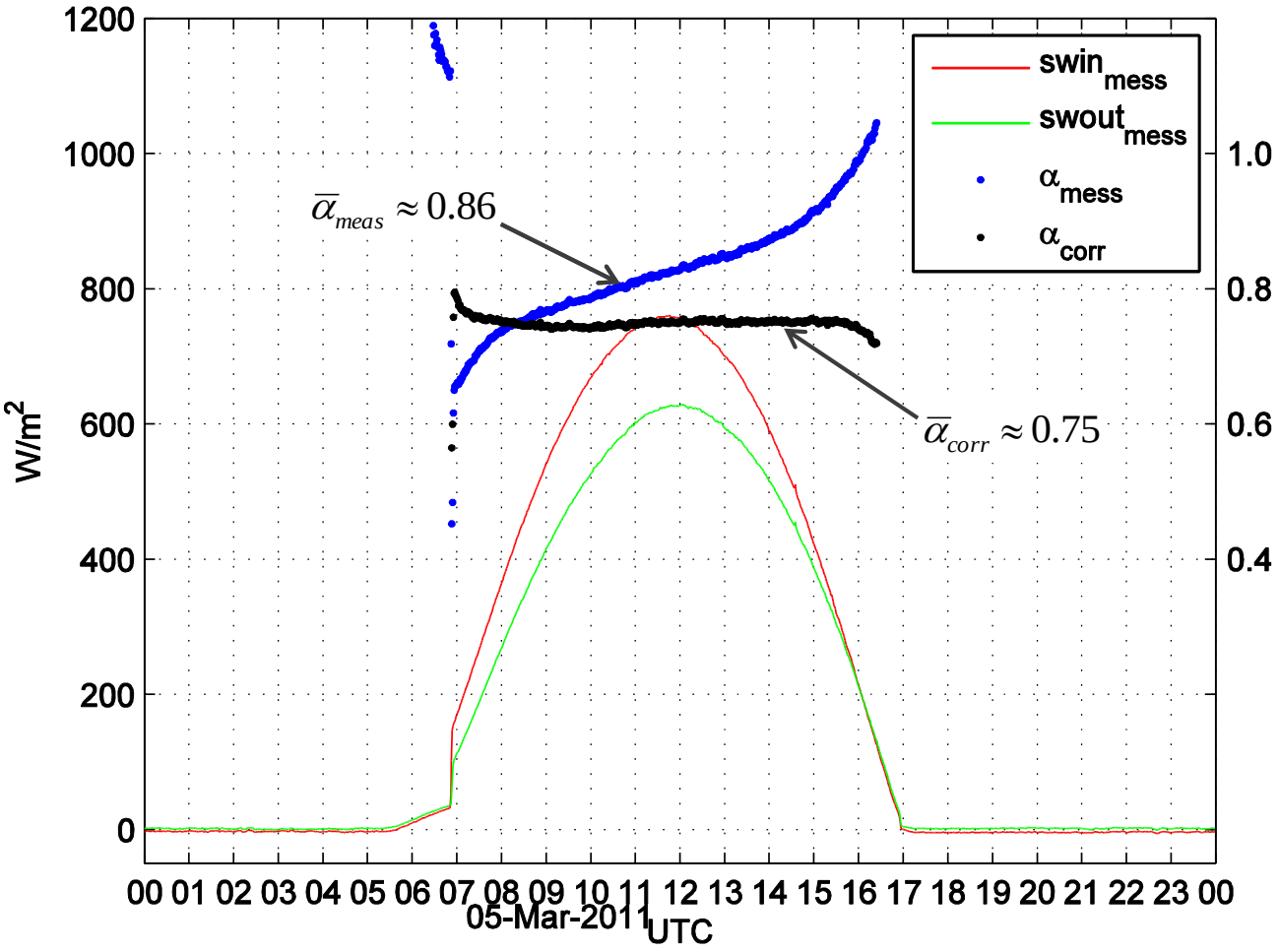
corrected daily mean α on Kleinfleißkees



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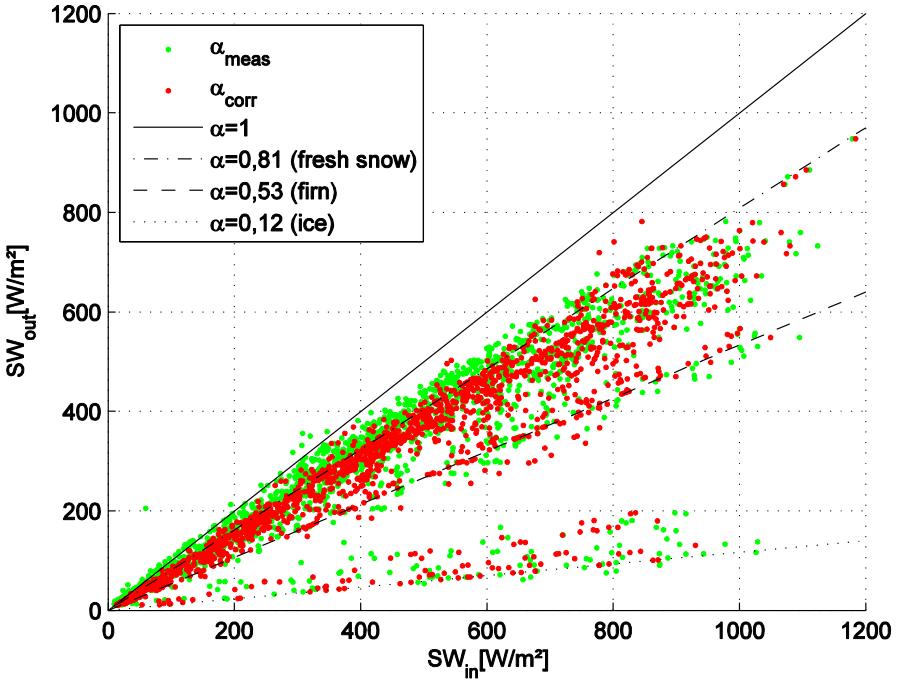
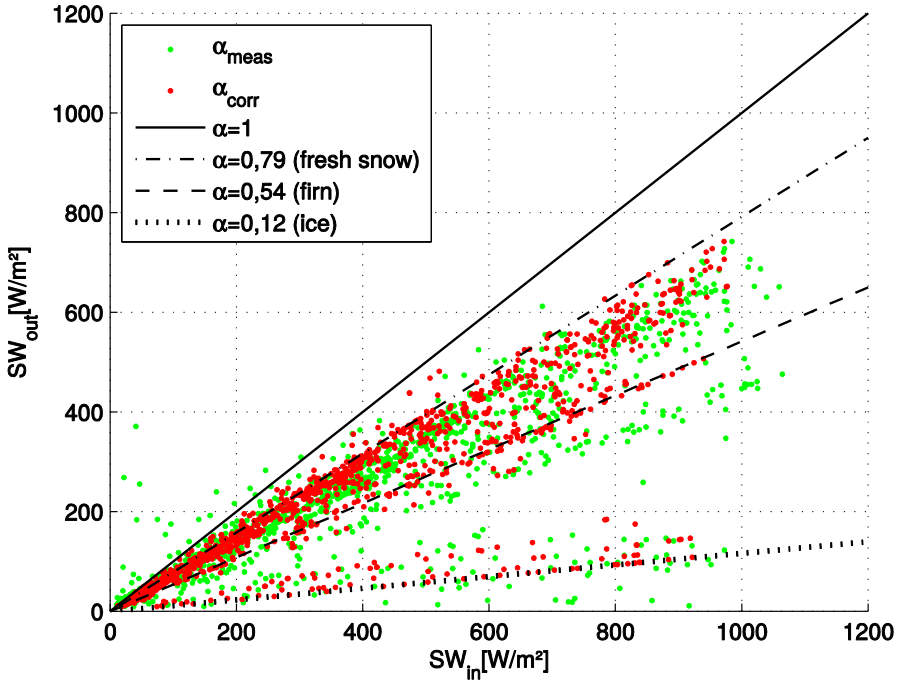
results

measured and corrected albedo values on

Kleinfleißkees (SW)



Goldbergkees (NE)

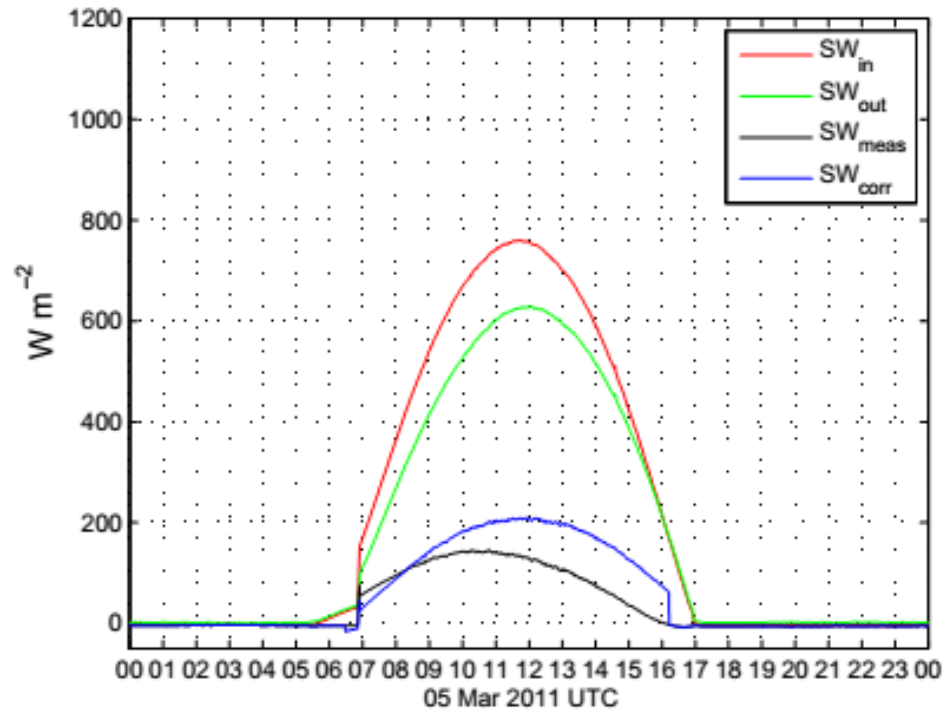


results

corrected daily radiative balance on

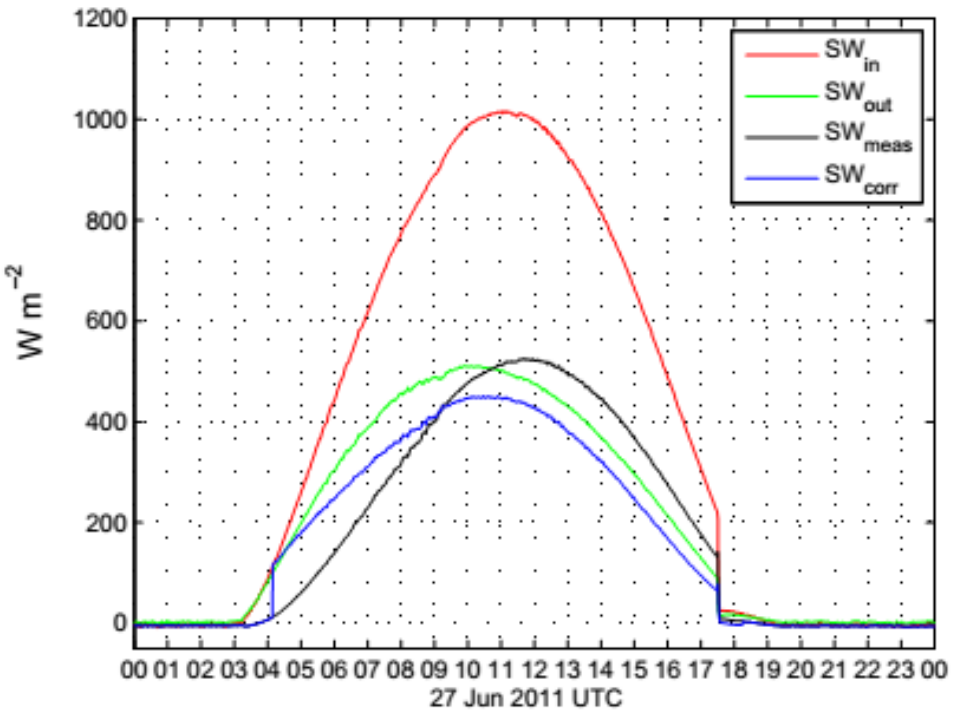
Kleinfleißkees (SW)

≈ 55% higher



Goldbergkees (NE)

≈ 7% smaller



results

Results of measured and corrected inclinations and directions and daily average albedo, including all tandard deviations, at the AWS sites Kleinfleißkees on 5 March 2011 and Goldbergkees on 27 June 2011.

	FLK, 5 Mar 2011	GOK, 27 Jun 2011
ε	0.051 ± 0.001	0.071 ± 0.002
ε_{mod}	0.071 ± 0.001	0.081 ± 0.002
V	0.95 ± 0.03	0.93 ± 0.04
V_{mod}	0.91 ± 0.03	0.90 ± 0.04
σ_t	$10.57° \pm 0.05°$	$13.51° \pm 0.11°$
γ_t	$225.00° \pm 5.60°$	$41.43° \pm 4.93°$
σ_p	$4.72° \pm 0.11°$	$3.93° \pm 0.08°$
γ_p	$247.62° \pm 3.37°$	$9.68° \pm 0.68°$
$\sigma_{p(meas)}$	$4.29° \pm 0.02°$	$7.77° \pm 0.39°$
$\gamma_{p(meas)}$	$305.43° \pm 1.53°$	$52.54° \pm 0.26°$
α_{meas}	0.86 ± 0.07	0.51 ± 0.06
α_{corr}	0.75 ± 0.01	0.54 ± 0.01

Measured and retrieved sensor inclinations and directions and daily average albedo, including all standard deviations, in Vienna (WHW) on 4 and 19 July 2014 on a horizontal concrete surface.

	4 Jul 2014	19 Jul 2014
ε	0.102 ± 0.001	0.111 ± 0.002
ε_{mod}	0.129 ± 0.001	0.118 ± 0.002
V	0.86 ± 0.03	0.84 ± 0.04
V_{mod}	0.81 ± 0.03	0.80 ± 0.04
σ_p	$0.3° \pm 0.0003°$	$24.0° \pm 0.024°$
γ_p	$5.0° \pm 0.025°$	$265.0° \pm 1.325°$
$\sigma_{p(meas)}$	$1.27° \pm 0.01°$	$23.33° \pm 0.12°$
$\gamma_{p(meas)}$	$170.44° \pm 0.85°$	$264.32° \pm 1.32°$
α_{meas}	0.1791 ± 0.0063	0.2083 ± 0.0696
α_{corr}	0.1789 ± 0.0064	0.1773 ± 0.0082

Mean bias error (MBE) and mean absolute error (MAE) for corrected albedo values between modelled and measured data determined with reference measurement (Suntracker) and solar radiation model (STRAHLGRID).

		Suntracker		STRAHLGRID	
		MBE	MAE	MBE	MAE
5 Mar 2011	FLK	-0.08	2.44	-3.30	3.55
27 Jun 2011	GOK	0.25	1.86	-1.87	2.50
4 Jul 2014	WHW	1.51	3.55	4.07	6.52
19 Jul 2014	WHW	2.88	6.29	3.64	6.32

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conclusion

- albedo α has to be corrected on clear sky days
- atmospheric parameters
  - reference measurement
  - solar radiation model
- tilts and direction of pyranometer
- tilts and direction of glacier surface

→ model is fitted to the measured data

- true albedo α over- or underestimated
- corrected α values → realistic ranges
  → diurnal variation

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Thank you very much for your attention!

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Weiser, U., Olefs, M., Schöner, W., Weyss, G., Hynek, B.: Correction of broadband snow albedo measurements affected by unknown slope and sensor tilts, The Cryosphere, 10, 775-790, 2016

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