Irradiance sounding up to the lower stratosphere

Ralf Becker, Stefan Wacker, Lionel Doppler

What are we doing?

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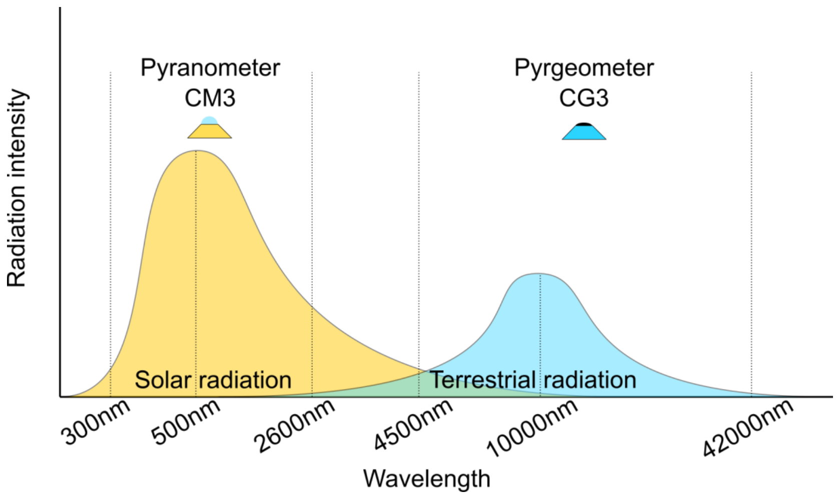
- Observation of *vertical profiles* of all four components of *net radiation* using an adapted radiosonde: solar + terrestrial, upwelling + downwelling
- Usually reached peak height about 31 km, thus the whole troposphere and lower stratosphere are subject of investigation
- Targeted probing of clouds possible
- Frequency of soundings is *about monthly*
- sonde needs to be retrieved from the landing point



- *All-season* probing but *rather fair weather* preferred (rain, storm, snowfall, strong convection excluded), up to now 64 soundings performed
- Beside weather conditions the calculated landing point is a crucial part of the decision tree to fly or not

Who has invented ?

- In 2012 Philipona et.al. introduced a balloon-carried sonde equipped with the sensors of a CNR4 to measure irradiances up to 32 km

- In 2016 Kräuchi & Philipona and 2020 Philipona et.al. this approach was extended by using a return glider the get the equipment back to predefined locations – instead of standard parachute descent

- Air traffic control: this light-weight mini-airplane is handled as a drone and thus cannot be flown in central Europe on an regular basis

- MetObs Lindenberg: long tradition of vertical sounding with different sensors and these days strongly involved in GRUAN project -> almost perfect conditions to fly a *pure balloon-based* sonde

- Sonde is manufactured by Meteolabor AG (CH)

GRUAN: global reference upper air network

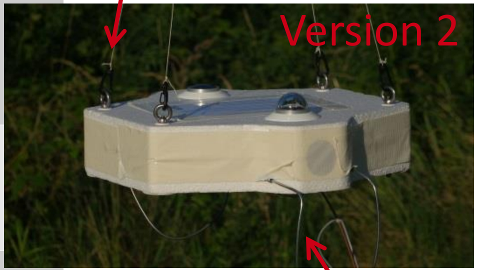
Manufacturer specifications:

	Pyrano CM3/ EKO MS80	Pyrgeo CG3
Spectral range	305 - 2800 nm 285 – 3000 nm	4.5 - 42 µm
Response time	< 18 s (95%) < 0.5 s (95%)	< 18 s (95%)
Offsets	A: < ±15 W/m2 B: < ±3 W/m2 at 5K/h A: ±1 W/m2 B: ±1 W/m2 at 5K/h	-
Tilt error	< ±1% at 1000 W/m2 ±0.2% at 1000 W/m2	< ±1 %
Uncertainty w.r.t. daily totals	< ±5% (95%) < 0.7%	< ±10% (95%)
WMO/ISO classification	Good quality/ first class ISO 9060:2018 (secondary standard)	n.a.

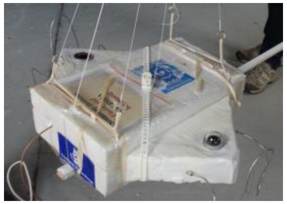
Temperatures (air, dome, body), humidity

Plus @V2.: attitude logging (yaw, roll, pitch at 1 Hz)

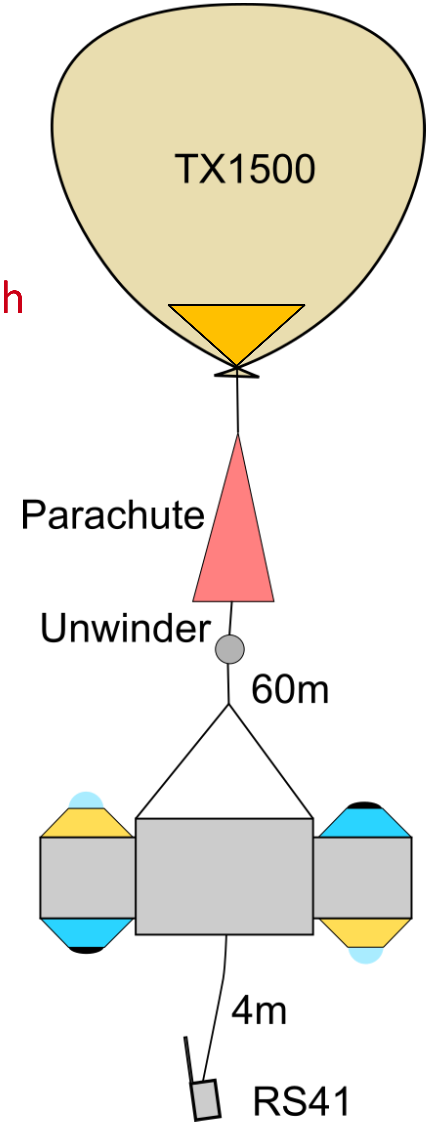
4-point fixation, levelling prior launch



bumper



Version 1



terrestrial & solar irradiance, temperature dependencies

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$$E_L = \frac{U_{\text{emf}}}{C}\left(1 + k_1\sigma {T_B}^3\right) + k_2\sigma {T_B}^4 - k_3\sigma\left({T_D}^4 - {T_B}^4\right)$$

C: calibration coefficient, updated regulary
k1: thermopile sensitivity, <<1
k2: blackbody-like emitted radiation by the instrument, =1
k3: weigthing the thermal discrepancy dome - body

$$E_{\downarrow Solar} = \frac{U_{emf}}{S_{ensitivity}} - k_3\sigma(T_D^4 - T_B^4)$$

$E_{\downarrow Solar}$	= Global radiation	[W/m^2]
U_{emf}	= Output of pyranometer	[µV]
$S_{ensitivity}$	= Sensitivity of pyranometer	[µV/W/m^2]

To be considered:

incoming irradiation

emitted radiation by the instrument

emitted radiation by the dome and the sensor's surface

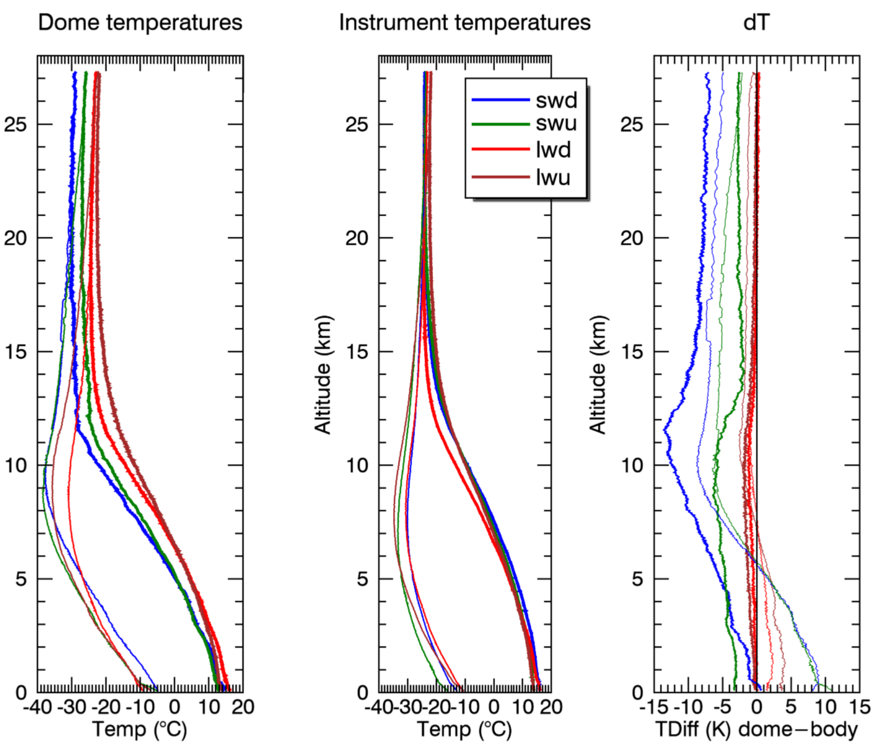
reflected radiation by the dome

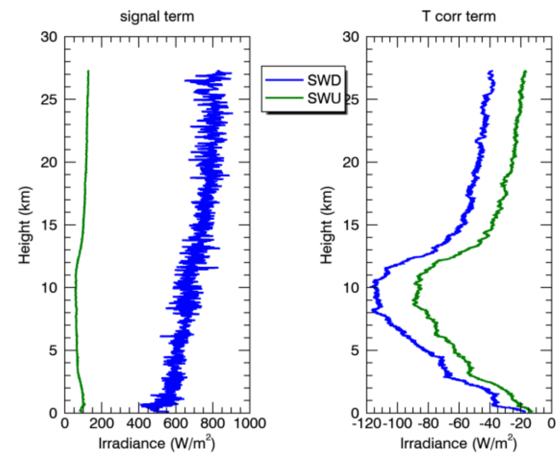
Depending on instrument:
correction of solar contribution,
no issue concerning CG3 (K&Z manual)

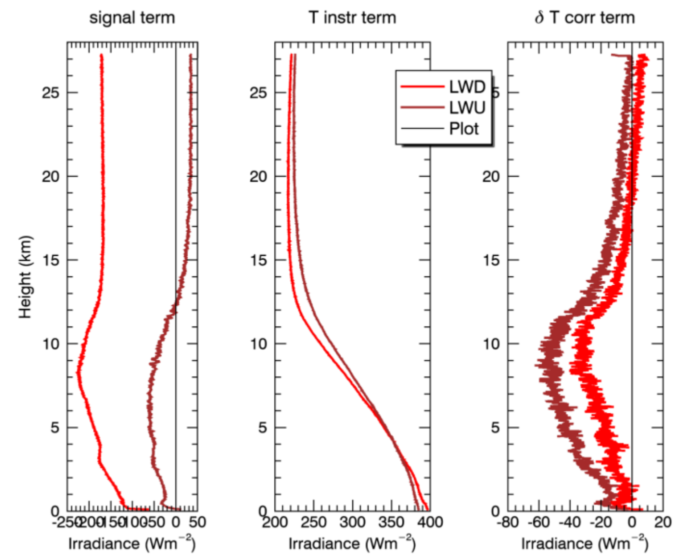
what is the impact of the dedicated terms ??

- Near surface observations: temperature difference term can be neglected in the thermal
- Profile observations: temperature difference to be regarded, except with EKO MS80

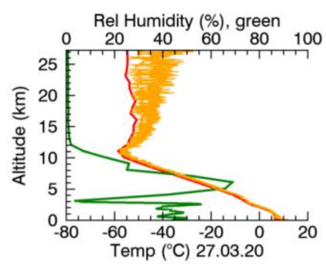
terrestrial & solar irradiance, temperature dependencies, example 20200327







At tropopause level highest impact of temperature correction term on solar and terrestrial fluxes



Radiation measurements near surface vs free atmosphere

efforts to achieve precise and reliable observations of radiative fluxes near surface …

Close to ground

- Levelling of the sensors
- At least daily cleaning of the domes plus on demand
- Ventilation using a continuous horizontal air stream (5 m/s)

Free atmosphere

- Deviations from the horizontal position are inherent but can be averaged out (V.1, mostly, combination of pendulum and rotation depends on conditions), can be tracked (ISOLDE V.2*), relevant for solar downward only*
- cleaning of the domes before start, can be subject to icing while passing water or mixed clouds. Tend to get heated away in ascent, tend to remain in descent
- Ventilation using an *almost* continuous *vertical* air stream (5 m/s) for a pair of instruments respectively, the other pair at lee side; *but dome temperatures tracked on pyranometers too*

Uncertainty budget

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Table 1 Uncertainty budget for solar and terrestrial irradiance observations, single component contributions, according to manufacturer specifications

Characteristics Instrument	CMP22	CGR4
Calibration uncertainty	2%	3%
Temperature dependence of sensitivity (−20…+50 °C)	0.5%	< 1%
Non-linearity error	0.2%	< 1%
Spectral sensitivity/selectivity	2%	< 5%
Tilt response	0.25%	1%
Directional error	5 Wm^{-2} @ 1000 Wm^{-2}, 0.5%	Not defined
Zero offset	A 3 Wm^{-2} B 1 Wm^{-2} total 4 Wm^{-2}, corresponding to 1% @ 400 Wm^{-2}	A: not defined B: < 2Wm^{-2}, plus window heating effect < 4 Wm^{-2}, total 6 Wm^{-2} @ 240 Wm^{-2} corresponding to 2.5%
Tilting angles	1.5%	1.5%
Total uncertainty irradiance	2.81% downward, 2.76% upward (directional error = 0)	6.74%

Due error propagation cumulated **uncertainties**:

Net 10,2%
Albedo 5,48%
Heating rate 14,42%

Tilting error correction
According to
Saunders et.al. 1998

-> here only applicable in slow-changing conditions


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METEOROLOGISCHES MESS

Reached altitude & landing

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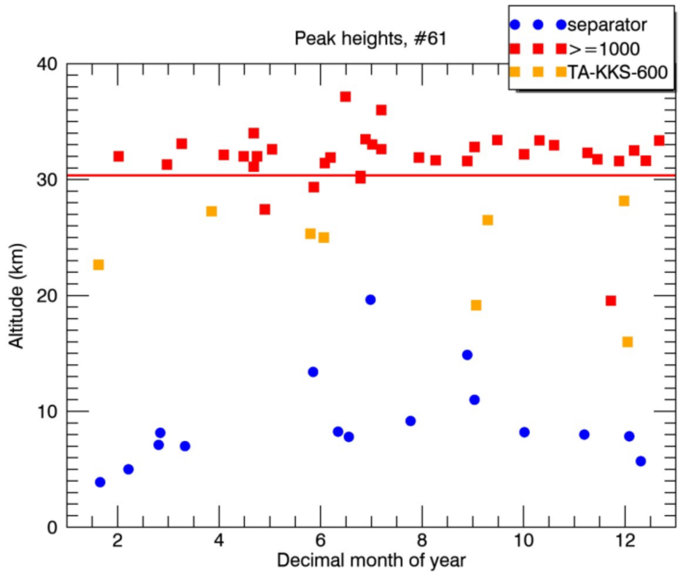

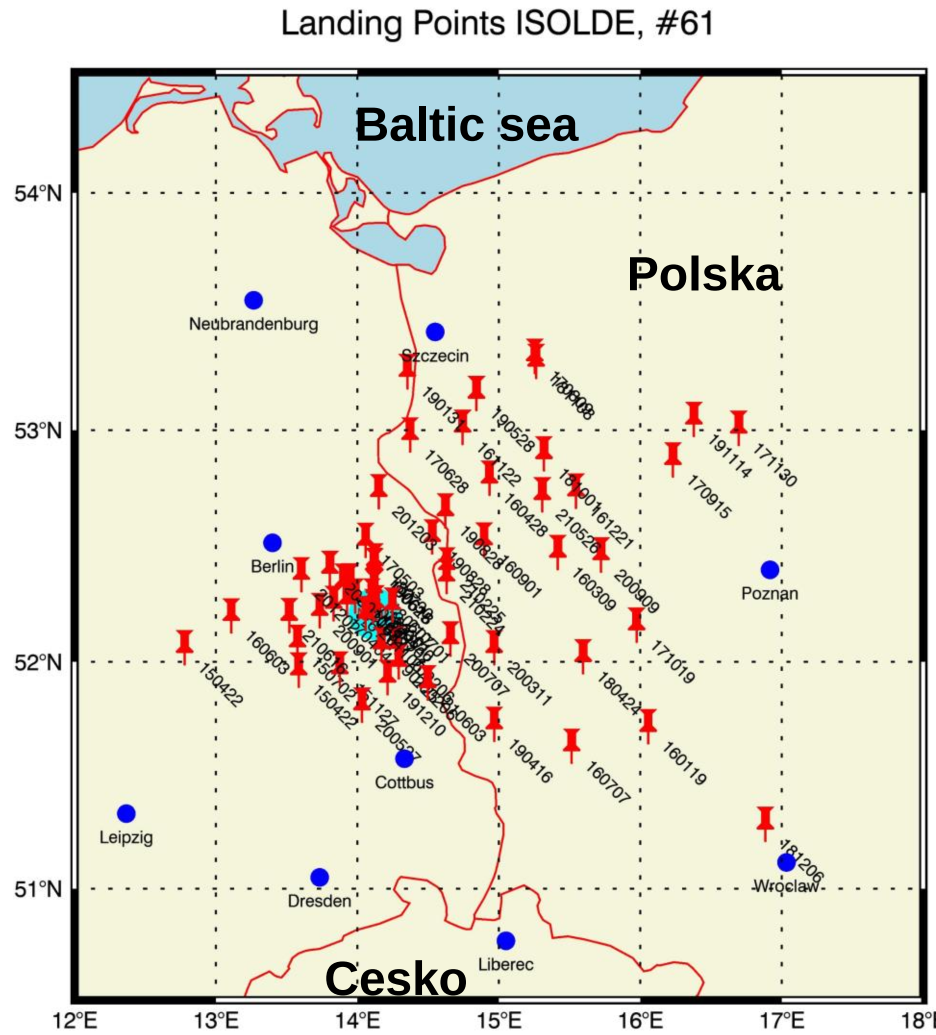

Mean burst height without separator: 30.3 km

Predominantly westerly winds only partly provide invited sounding scenarios (horizontal drifting), otherwise region east of Berlin and western Poland sparsely populated

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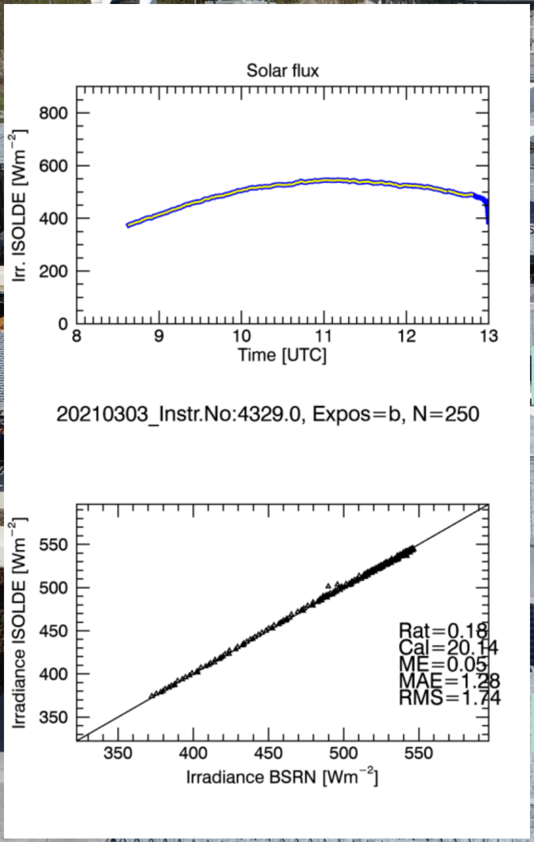
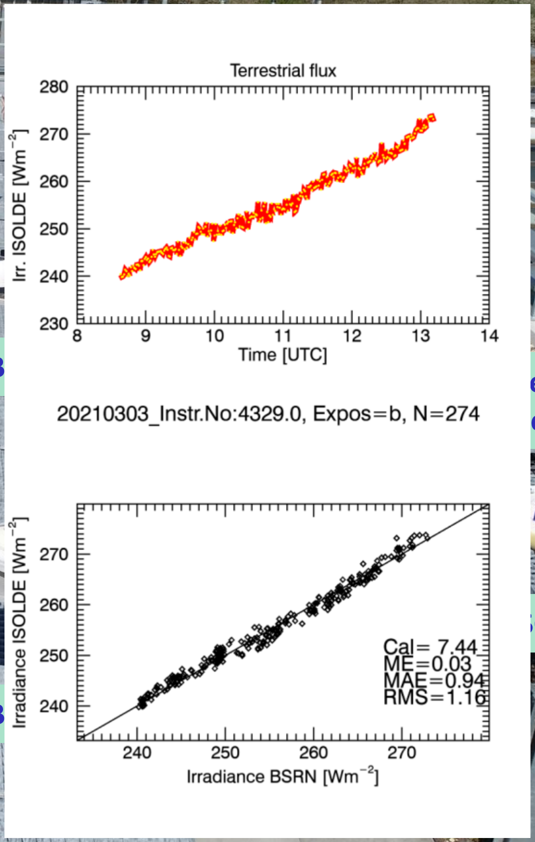
Calibration by iteratively minimising the mean error and mean absolute error w.r.t to BSRN readings

-> selection of clear sky days/hours, further filtering using ratio diffuse/direct
-> top and bottom side sky viewing





Calibration vs BSRN Lindenberg

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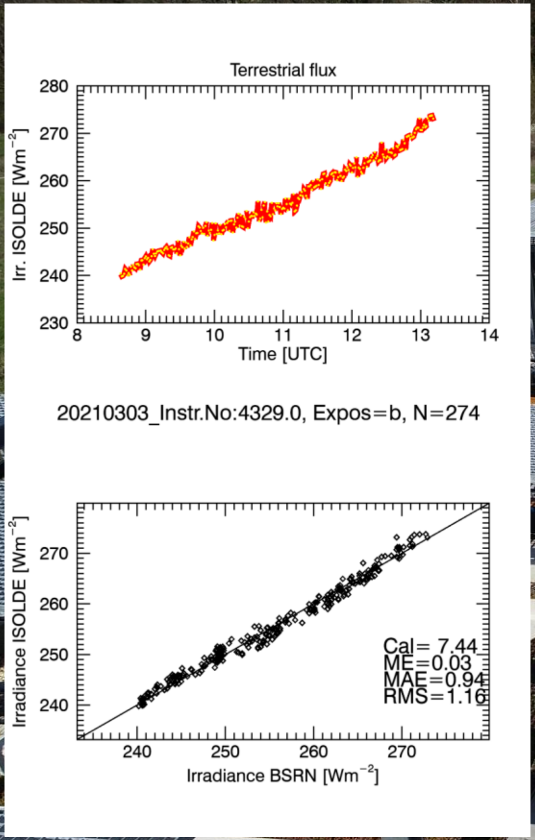
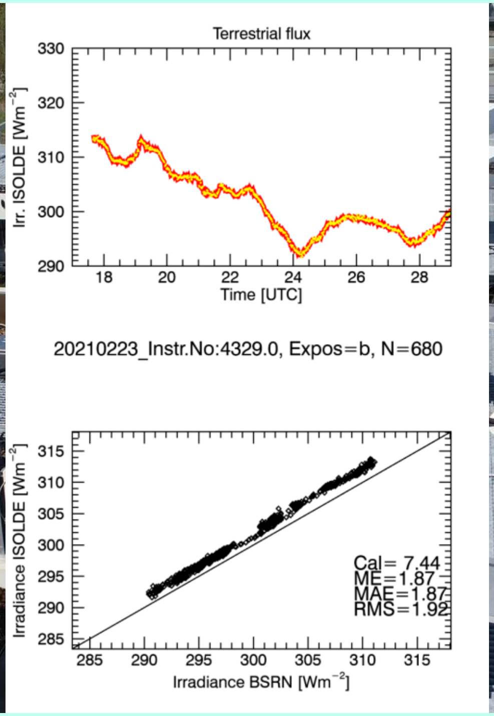
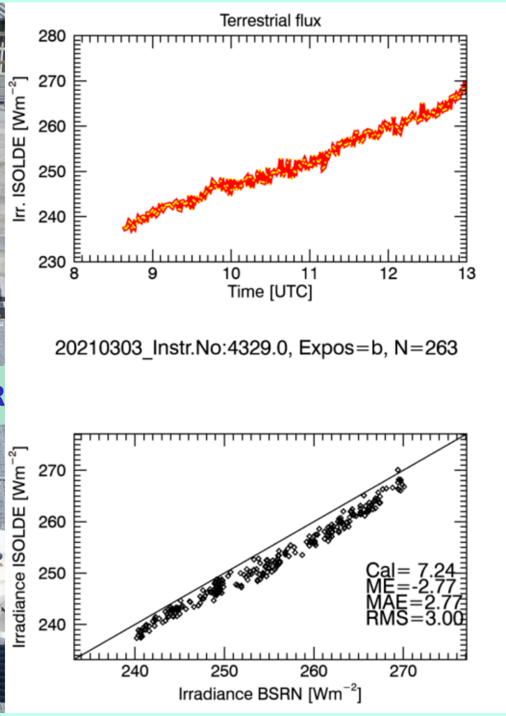
Why pyrgeometer calibration during day ?







Applying daytime calib to nighttime data (center),
Nighttime calib to daytime data (right)
-> almost all sounding performed at daylight conditions
-> reference CGR4 shaded, CG3 unshaded

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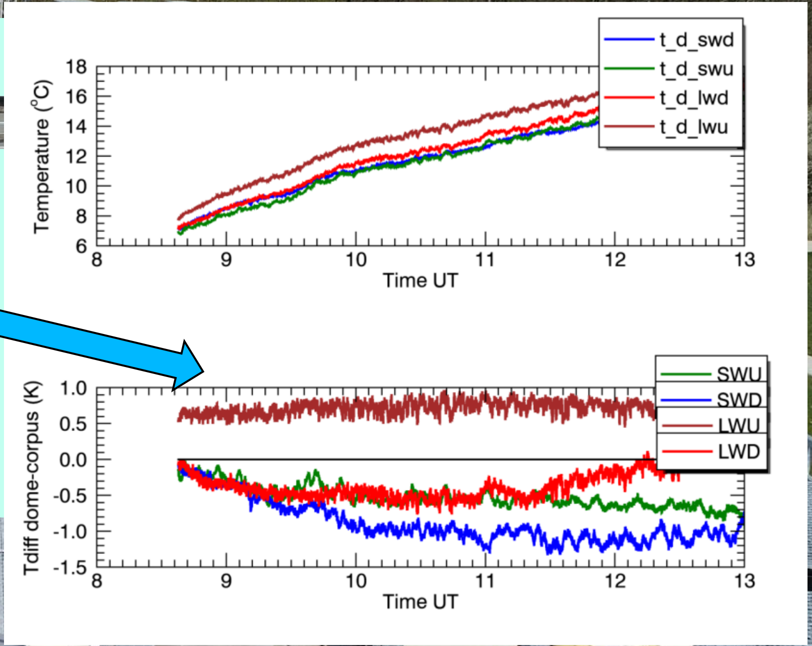
Why pyrgeometer calibration during day ?

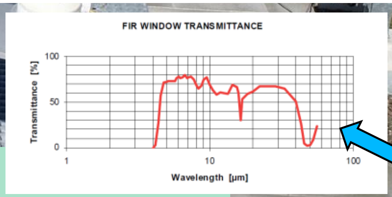
Temperature difference Dome/Body given (and corrected for)

On the other hand, spectral behaviour of both CG3 and CG4 domes concerning solar contribution in 3-4 µm should be the same, i.e. sun blind (Kipp&Zonen)



IWC at 20210223 about factor of 3 compared to 20210303 (1.77 vs 0.58 cm)

Solution: keep dry measurements out or (better) find a way to parameterize the wv-contribution



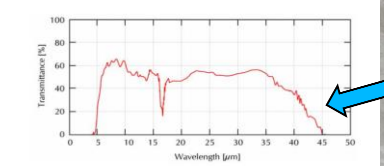


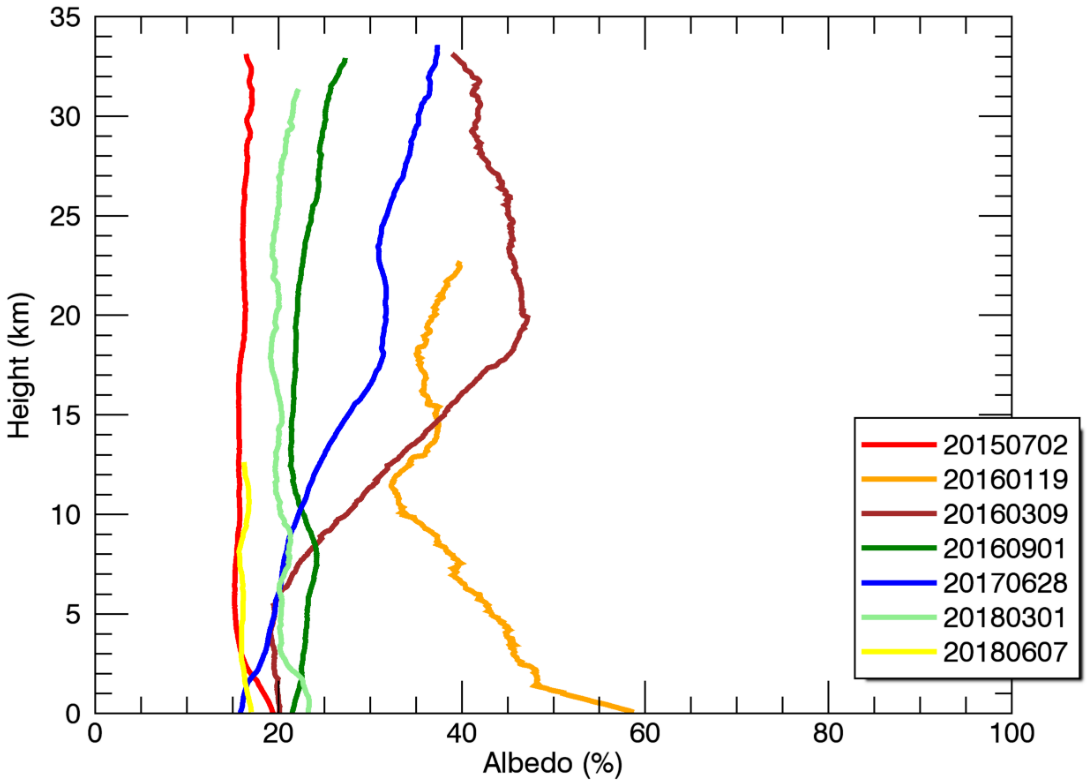
Figure 1.2 Typical transmittance of the CG 3 window.

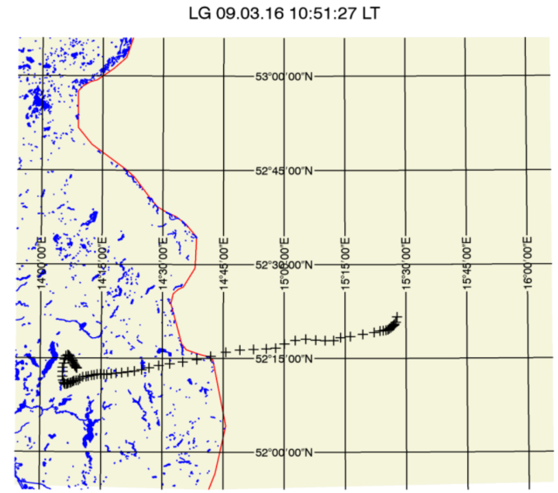
Spectral trans-mittance of CG4 and CG3

Expectations: how irradiances change when lifting the sensor

Solar downwelling	**-> $I_0 * \cos(\Theta)$**
Solar upwelling	**-> strong dependence on surface characteristics , solar zenith angle and atmospheric composition… (planetary albedo: .306)**
Terrestrial downwelling	**-> a few Wm^{-2}**
Terrestrial upwelling	**-> global mean 239 Wm^{-2} (Trenberth et.al. 2011, Wild et. al. 2015)**

Solar fluxes – clear sky and minor cloudiness

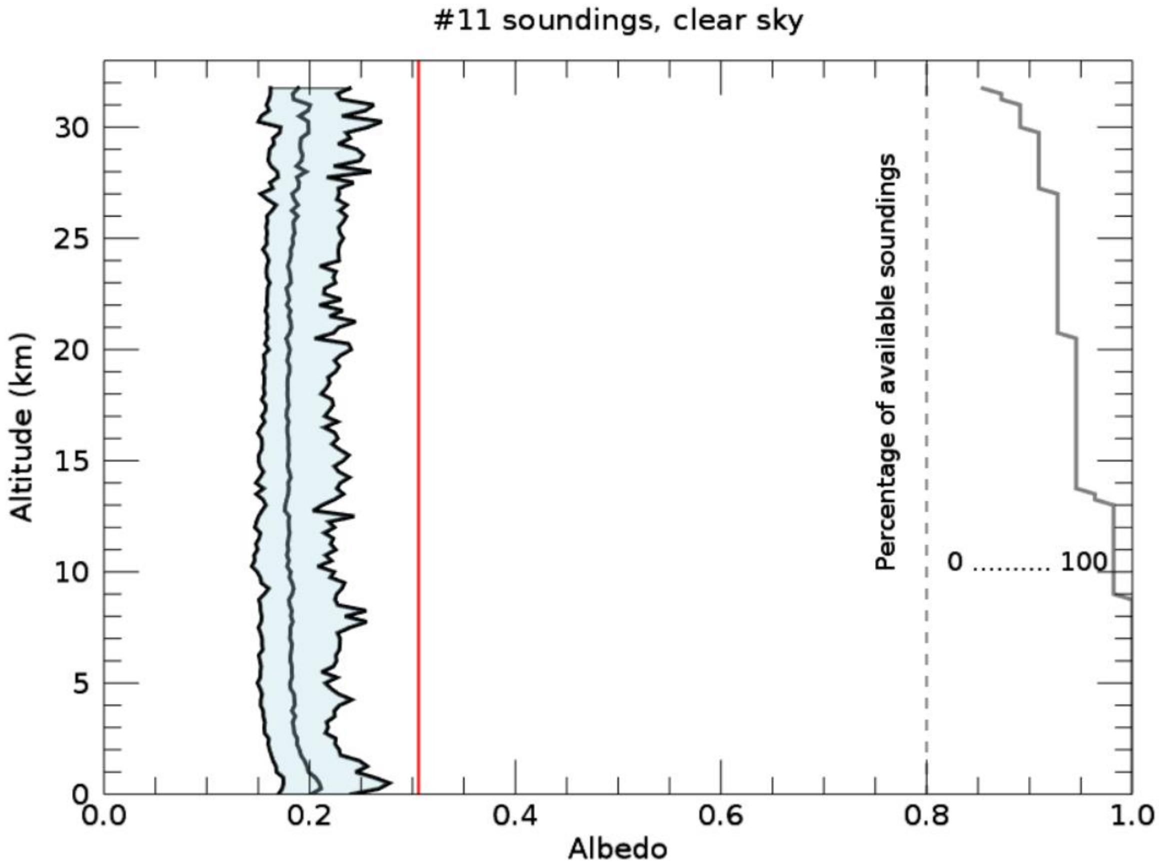




Solar fluxes – clear sky and minor cloudiness

Albedo
of all soundings with
peak heights >10 km

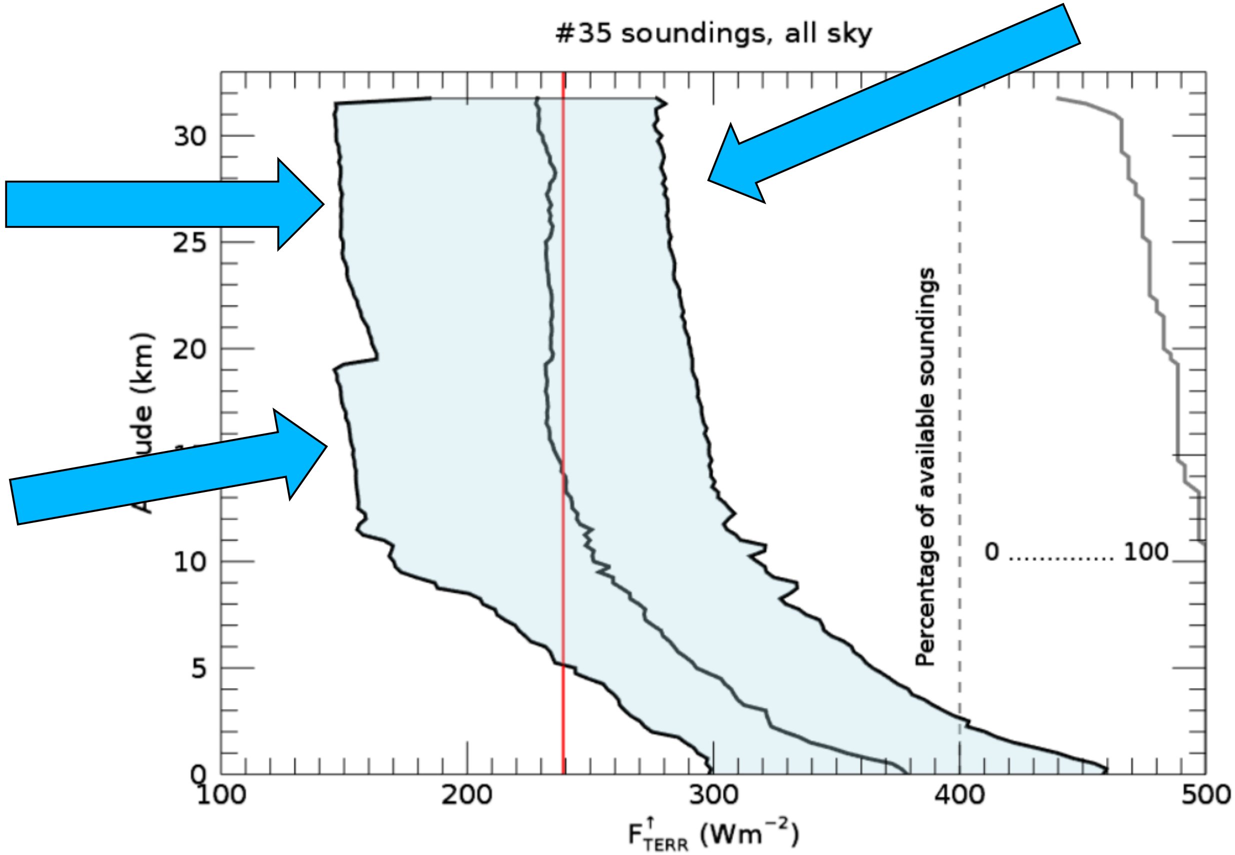
-> only few cases up to now



Terrestrial upwelling of all soundings with peak heights >10 km

Minima:
20161122, Ci at 9 km ended at 19 km
20180424, Cs at 7 km

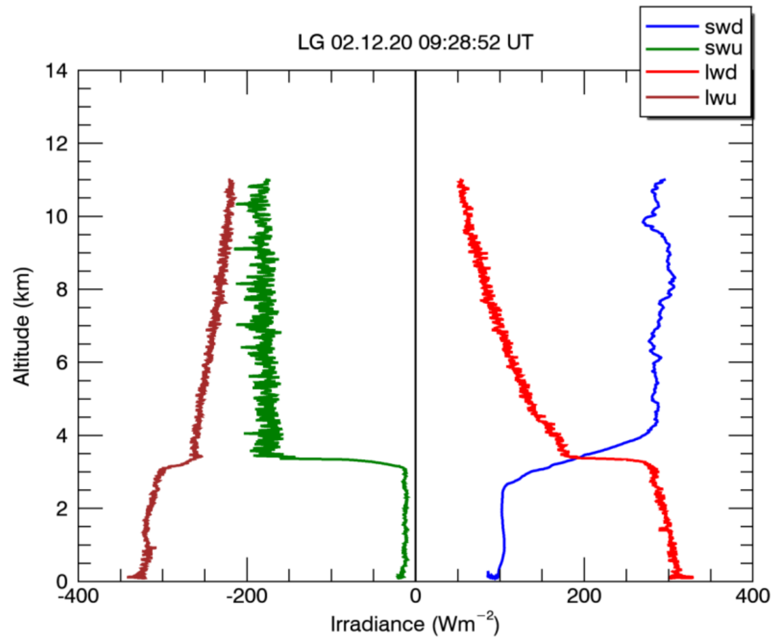
Maximum:
20160901, almost Clear summer day

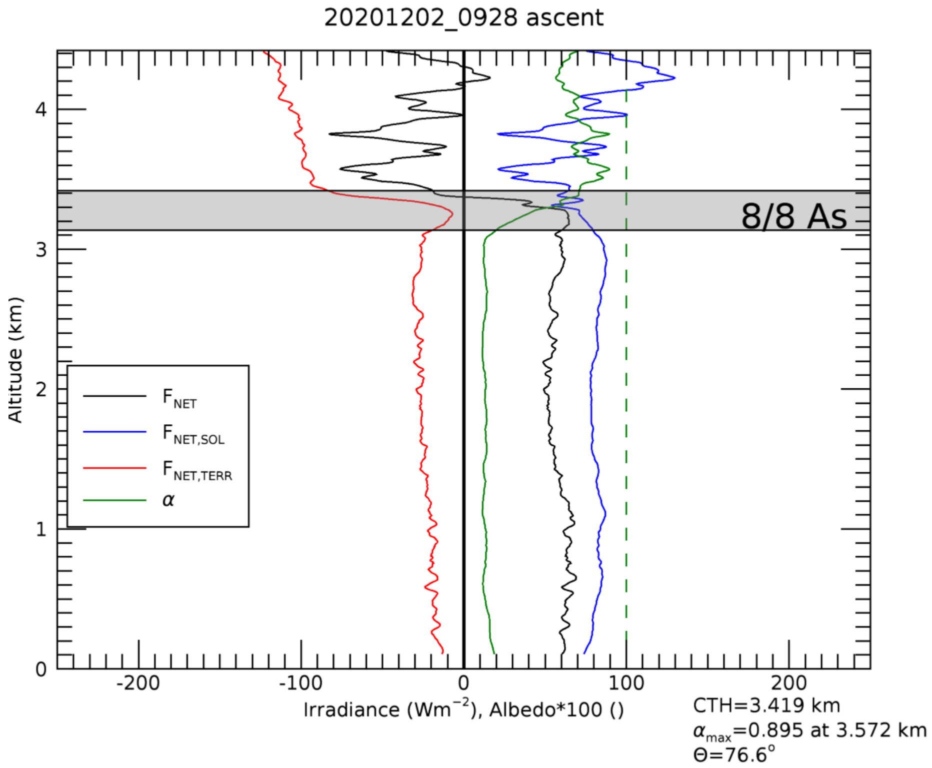


Example cloud flight
Dec 02, 2020

Single layer mid-level cloud

Ascent only





Example cloud flight
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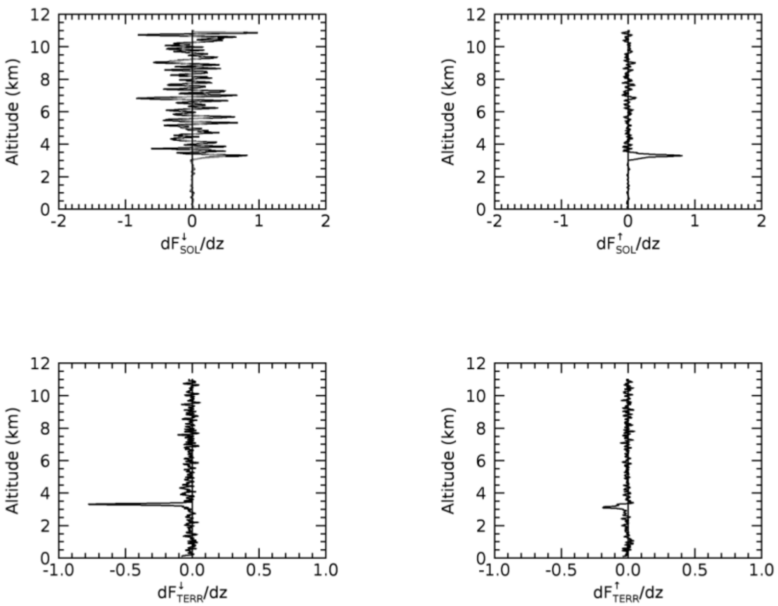
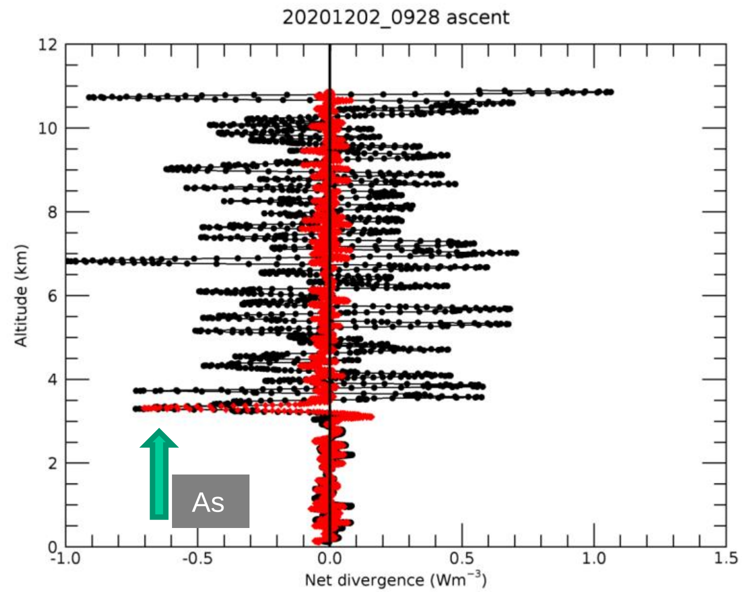
Vertical gradients of single fluxes



Flux divergence: terrestrial (red) and total



Clouds:

Altostratus, overcast, opaque, from 3136 to 3419 m

Distinct peak in vertical gradient close to cth in solar upward and terrestrial downward, but close to cloud base in terrestrial upward

Example cloud flight
Dec 02, 2020

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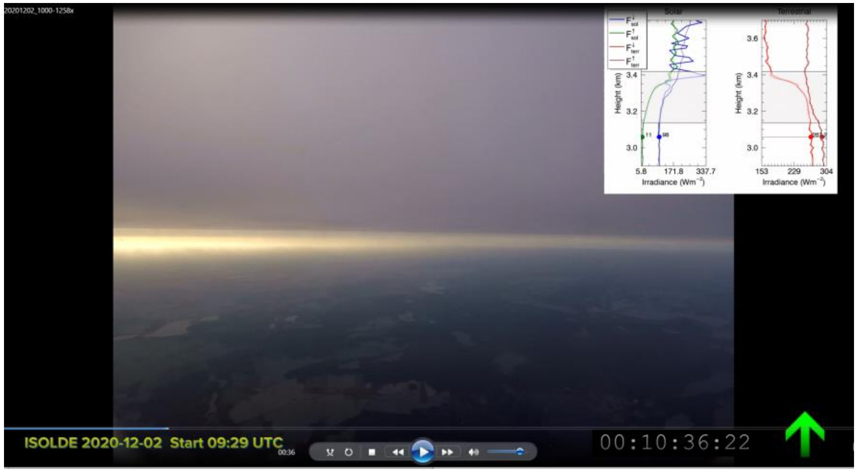

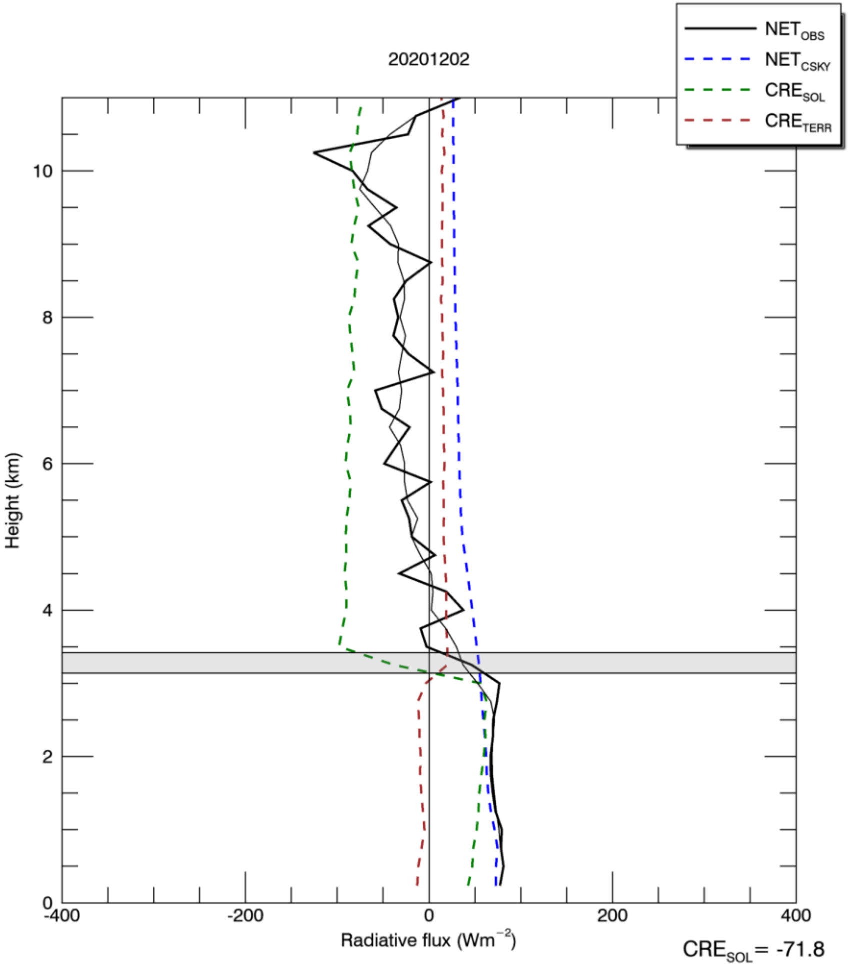

CRE_{SOL} = -71.8
CRE_{TERR} = 13.5
CRE_{TOT} = -58.3

Cooling at CT: -2.8 K/h

Example cloud flight
Dec 02, 2020: Obs vs Model

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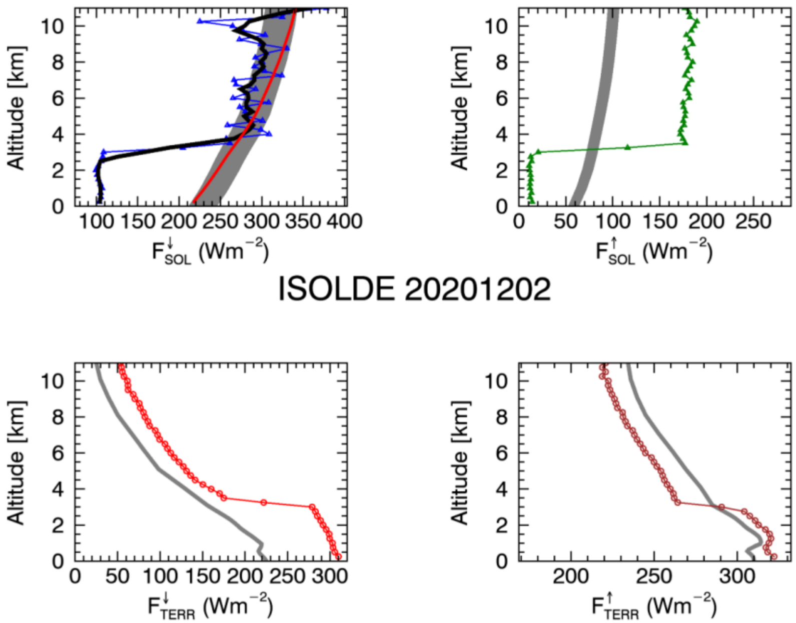
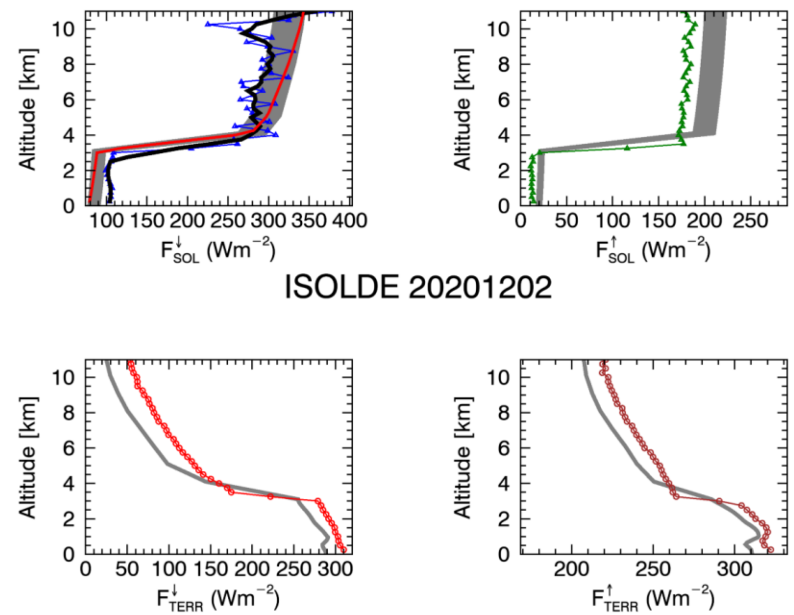
Clear-sky



Cloud

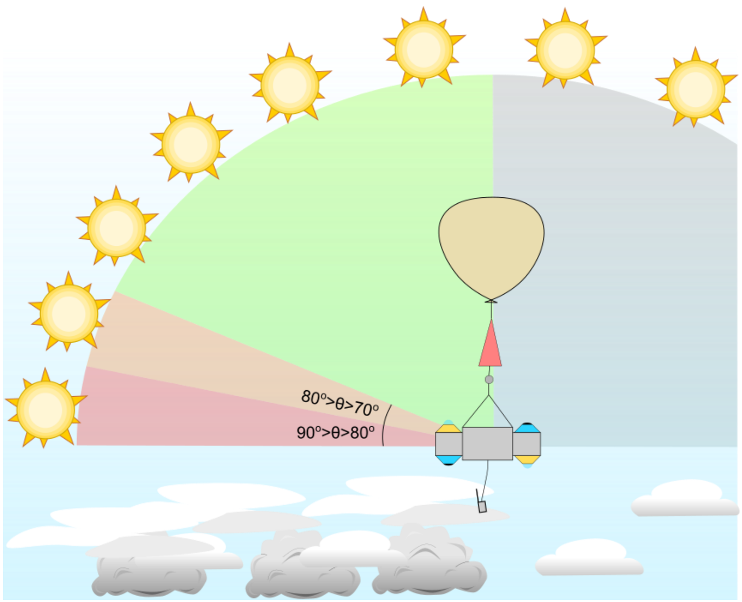


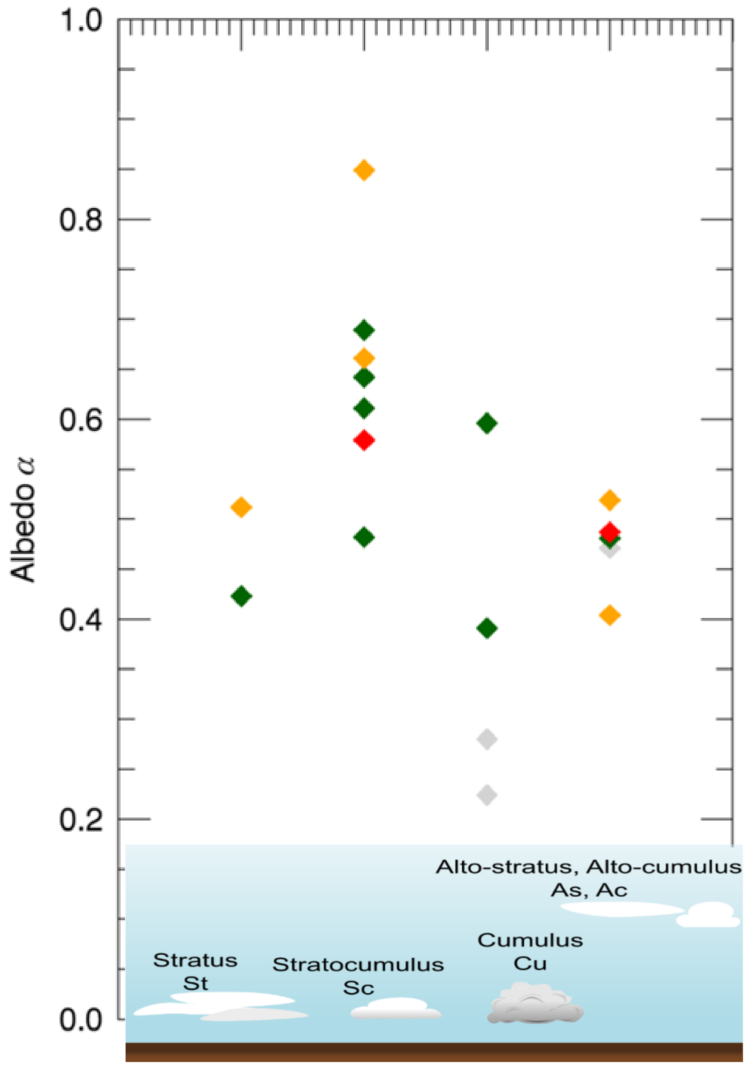
ice cloud at the observed level with OD=5 & Reff=10 µm, T@CBH: -12°C

Simulations made with *Streamer* (Key & Schweiger 1998: Tools for atmospheric radiative transfer)

Solar fluxes – overcast, cloud top albedo

Stratocumulus (7x): 0.482 -0.849
Altocumulus/Altostratus (5x) 0.404 - 0.519.
If cloud cover N<6/8 (mixed scene): gray





More to come ...

Summary & Outlook

- Profiles of net radiation components can be measured using a balloon-carried 4-sensor system
- Free flying sondes and tethered ballooning (V.1) too …
- In-situ observation of net radiation divergence, cooling and heating effects related to clouds -> assign that to cloud categories
- Link the results to collocated observations of microphysical properties
- Above 20 km: careful selection of valid data points to get the direct solar component, i.e. TSI (seems to work)


Thank you for your attention !
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