Measurements of solar and terrestrial heating and cooling rate profiles in Arctic and sub-tropic stratocumulus

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1 Introduction

Motivation:

- Stratocumulus strongly influences the surface energy budget.
- Surface warming or cooling depends on the cloud and atmosphere properties.
- Evaporative and radiative cooling at the top of stratocumulus control the cloud dynamics.

Main goal:

Quantifying vertical profiles of turbulent and radiative fluxes in the cloudy boundary layer in the central Arctic and sub-tropics using slow moving platforms.

Research questions:

How do the different energy fluxes influence the cloud evolution in both areas?

Heating rates:

$\frac{\Delta T}{\Delta t} = \frac{(F_{top}^{\downarrow}+F_{bot}^{\uparrow})-(F_{top}^{\uparrow}-F_{bot}^{\downarrow})}{\rho\, c_p\,(z_t - z_b)}$ within the layer $(z_t - z_b)$

Pyrgeo-/Pyranometer:

- Solar: 0.2 -3.6 µm; terrestrial: 4.5 - 42 µm
- Slow response sensor: <18 s for 95 % response
  → correction needed

2 Tethered balloon - Arctic

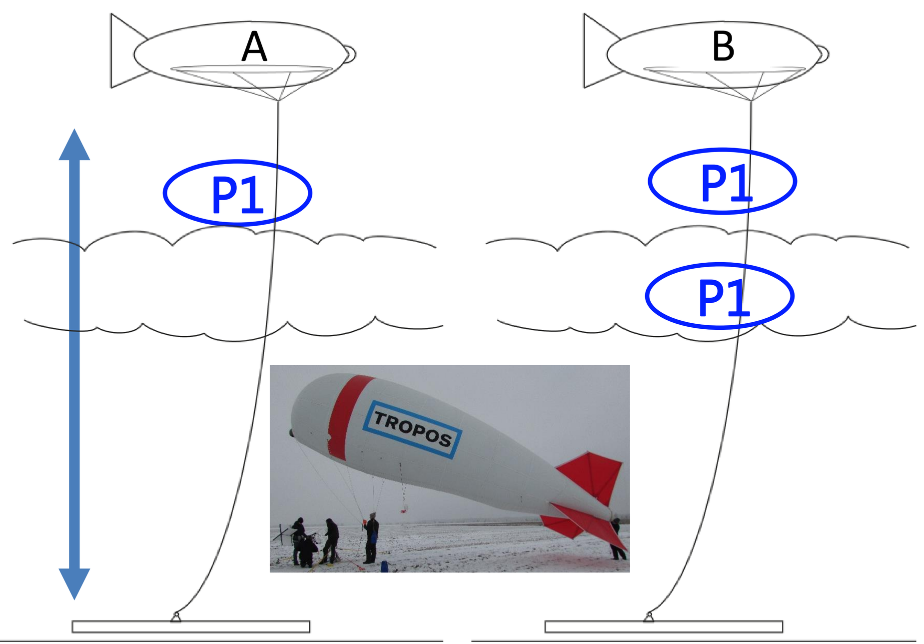

Fig 1: Measurement strategies for the balloon deployed during Arctic Balloon profiling EXperiment (ABEX) in June 2017. Photograph taken during the test phase.

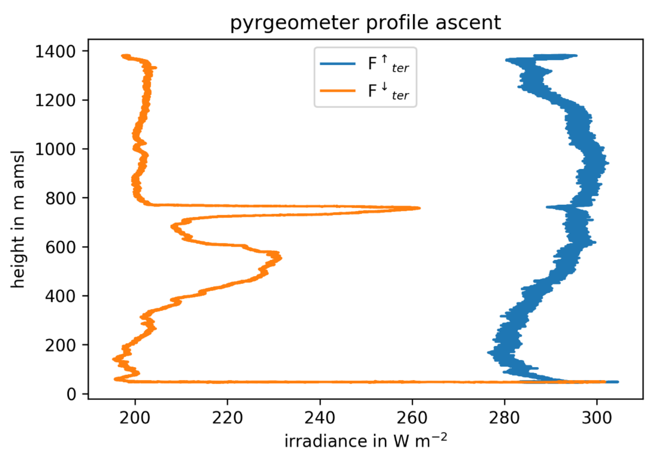

Fig 3: Profiles of terrestrial upward (blue) and downward (orange) irradiance during ascent with low level clouds on 09.03.2017.

A: Single platform approach → profiles

B: Collocated approach → temporal variability

Technical information:

max. altitude = 1500 m
maximal payload = 7 kg
ascend velocity ≤ 1 m s^{-1}
flight time ≈ 3 - 4 h

Additional probes:

- Fast temperature, humidity and wind probes for turbulence
- Spectral radiance to retrieve cloud optical thickness and effective radius

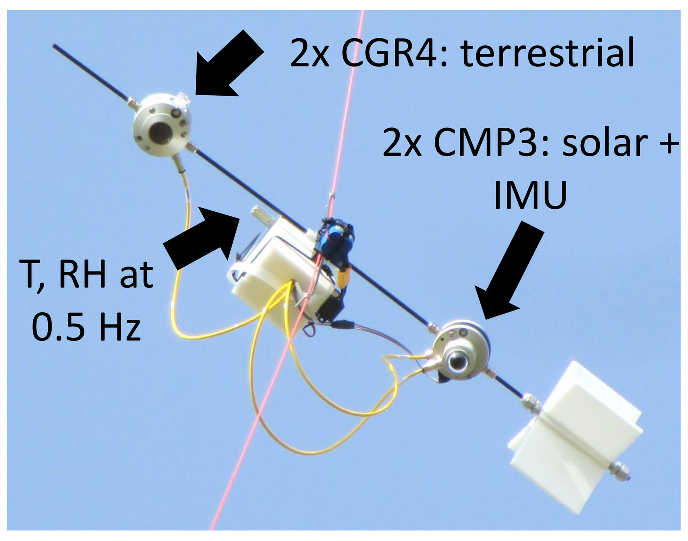

Fig 2: Broadband radiation package (P1) for tethered balloon.

3 Helicopter – subtropics

- SMART-HELIOS (A):
  - broadband radiative energy flux density (Pyranometer/Pyrgeometer)
  - spectral upward solar radiance 300-2200 nm
- ACTOS (B): turbulence and cloud microphysics measurements

Technical information:

max. altitude = 3000 m
horizontal velocity = 20 m s^{-1}
flight time ≈ 2 - 3 h

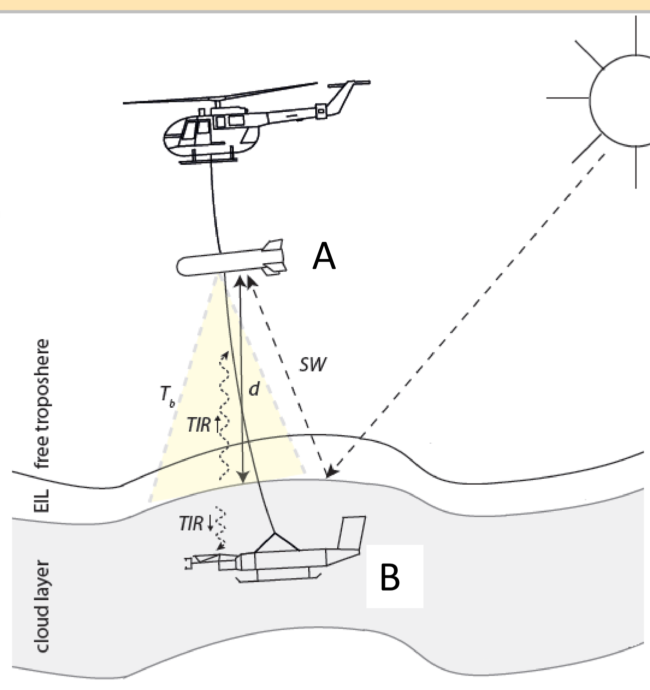

Fig 4: Measurement strategy.

Fig 5: Photograph of SMART-HELIOS (A) and ACTOS (B) on ground.

Spectral Modular Airborne Radiation measurement sysTem - HELicopter-bOrne ObvervationS(SMART-HELIOS)

Airborne Cloud Turbulence Observation System (ACTOS)

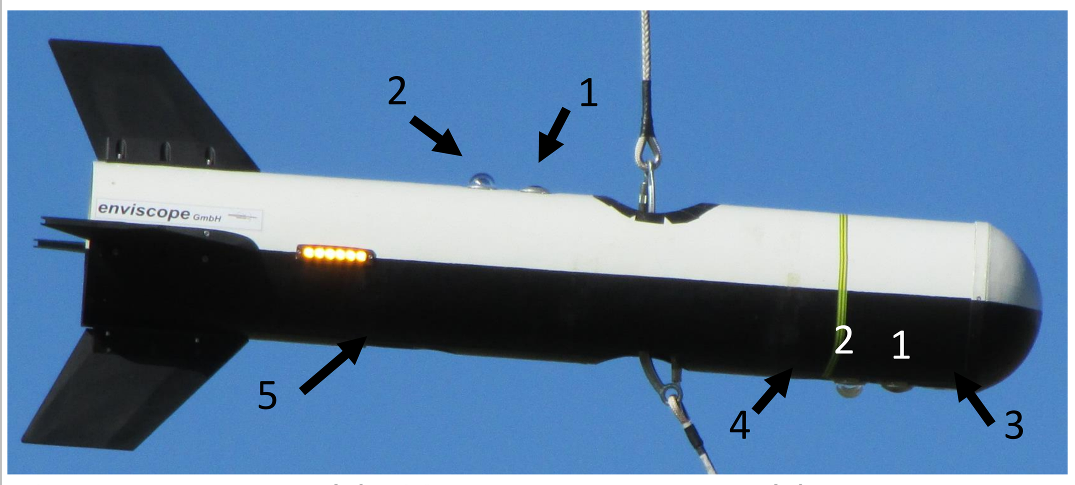

Fig 6: SMART-HELIOS (C) with 2x pyrgeometer CGR4 (1), 2x pyranometer CMP22 (2), spectral solar radiance (3), infrared camera (4) and altimeter (5).

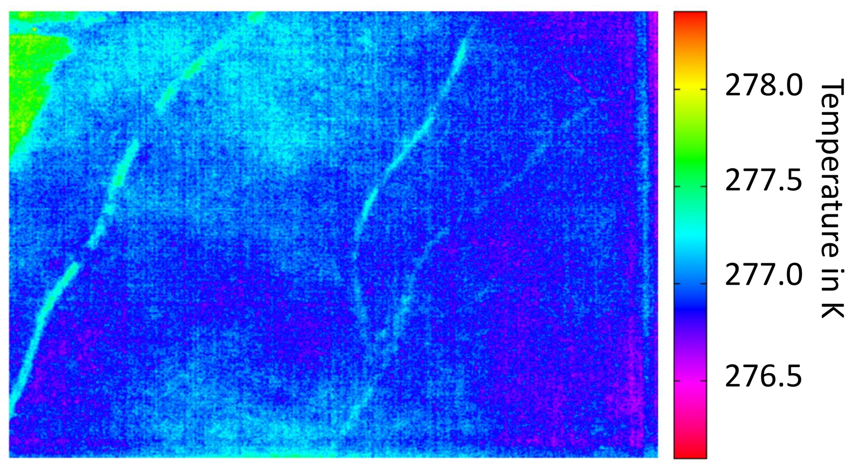

Fig 7: Temperature map measured by the infrared camera (4) from test flights in Winningen, Germany (10.2016).

4 Post processing and limitations

Single platform approach

Influence of ascent rate:

Typical ascent/descent rates:	
aircraft:	< 4 m s^{-1}
balloon:	< 1 m s^{-1}

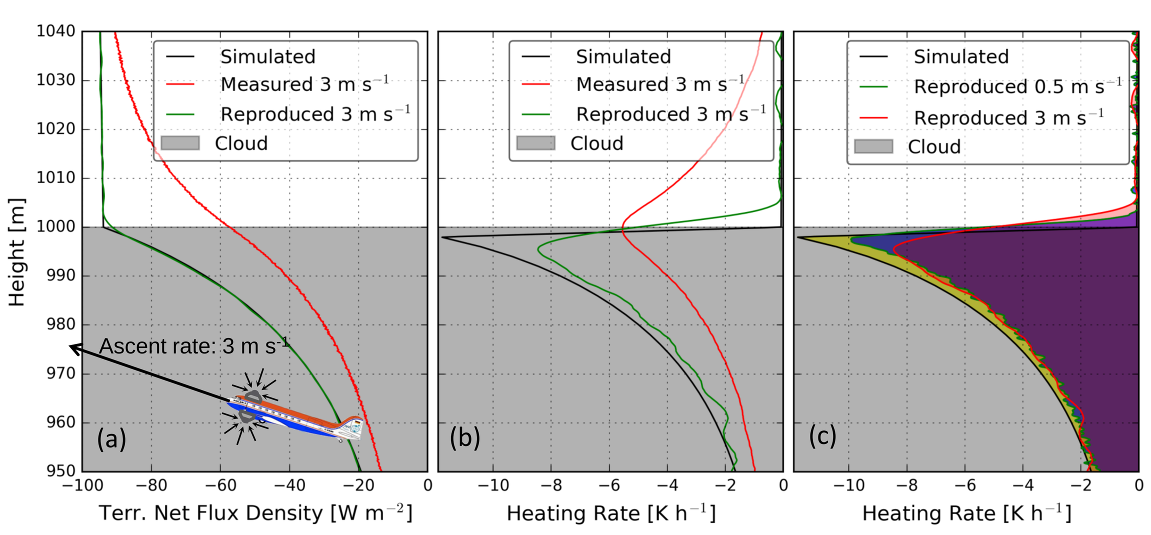

Fig. 8: (a) Simulated (black), synthetically measured (red), reproduced (green) terrestrial flux density profiles for 3 m s^{-1} ascent rate. (b) Derived heating rate profiles from (a). (c) Heating rate profiles derived from synthetic measurements of different ascent rates.

- Correction of slow response measurements with deconvolution after [1]
- Strong dependence on:
  1. Ascent/ descent rate of the instrument
  2. Fitting/ smoothing of the data within the deconvolution routine
- Systematic error induced

Collocated approach

Vertical resolution:

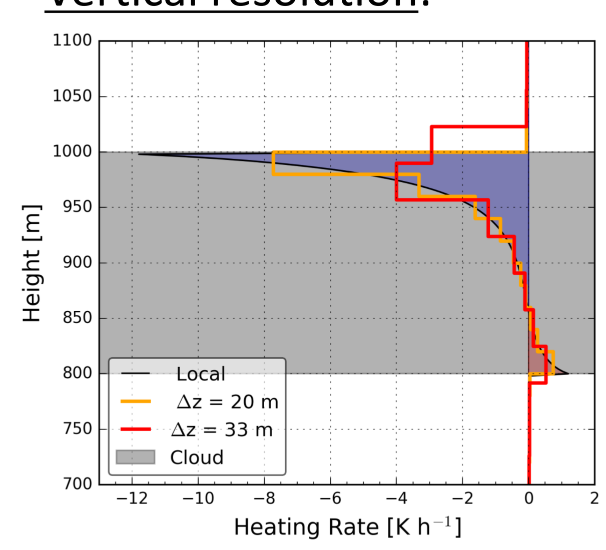

Fig. 9: Simulated heating rates for collocated approach with different platform distances in comparison with the actual heating rate profile.

- Underestimation of cloud top cooling
- Vertical displacement and reduced localisation in heating rate distribution
- Possible misinterpretation in estimation of induced turbulence and cloud top cooling characteristics

Cloud inhomogeneities:

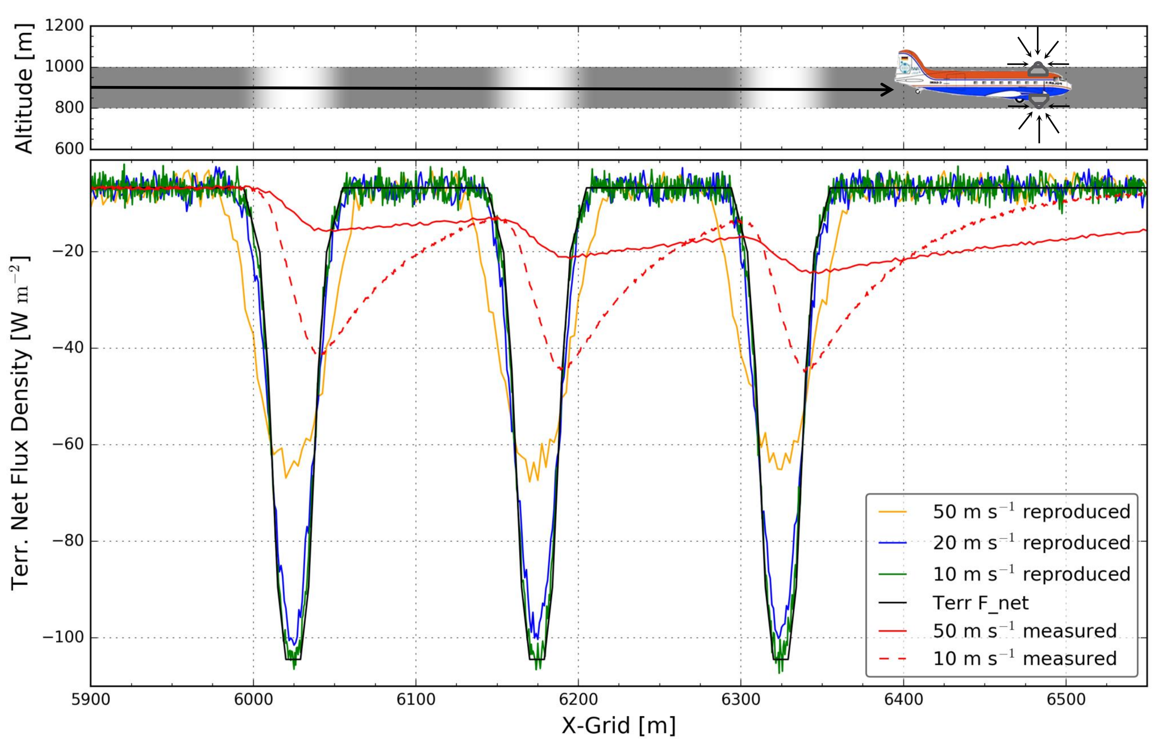

Fig. 10: Upper panel: Simulated cloud optical thickness field with cloud patches of 100 m size (τ = 10). Flight altitude 900 m. Lower panel: Corresponding simulated terrestrial net flux density (black), synthetically measured by sensor with 10, 20 and 50 m s^{-1} flight speed (red) and the corresponding constructed series (green, blue, yellow).

- Reproducibility of inhomogeneities strongly depends on flight speed:
  - Balloon (< 10 m s^{-1}) & helicopter (20 m s^{-1}) → reproduction of real signal possible
  - Aircraft (> 50 m s^{-1}) → restricted possibility to resolve inhomogeneities
- For perturbation frequencies < 0.5 Hz deconvolution works fine [1]

4 Conclusion and outlook

- Systematic error is induced by slow response measurements in high dynamic observations.
- Derivation of heating rates requires deconvolution.
- Slowly moving platforms (balloon and helicopter) are needed to study the cloud top processes.

- Vertical profile of heating rate:
  → single platform approach
- Cloud inhomogeneities:
  → collocated approach

Upcoming campaigns:

- Arctic Balloon profiling EXperiment (ABEX), June 2017 → tethered balloon
- Arctic CLoud Observation Using airborne measurements during polar Day (ACLOUD), June 2017 → two aircraft
- July 2017 on Graciosa, Azores → helicopter

References

[1] Ehrlich, A. and Wendisch, M., 2015: Reconstruction of high-resolution time series from slow-response broadband terrestrial irradiance measurements by deconvolution, *Atmos. Meas. Tech*., **8,** 3671-3684, (2015), doi:10.5194/amt-8-3671-2015.

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