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Imaging Radiance Measurements to Derive Cirrus Optical Thickness and Ice Crystal Shape

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1. Introduction

- cirrus radiative forcing strongly depends on spatial inhomogeneities and ice crystal shape [1]

→ development of methods to derive
1. spatial distribution of cirrus optical thickness τ
2. cirrus ice crystal shape

→ imaging radiance measurements with AisaEAGLE, CARRIBA 2011

2. CARRIBA 2011 (Clouds, Aerosol, Radiation and tuRbulence in the tRade wInd regime over BArbados)

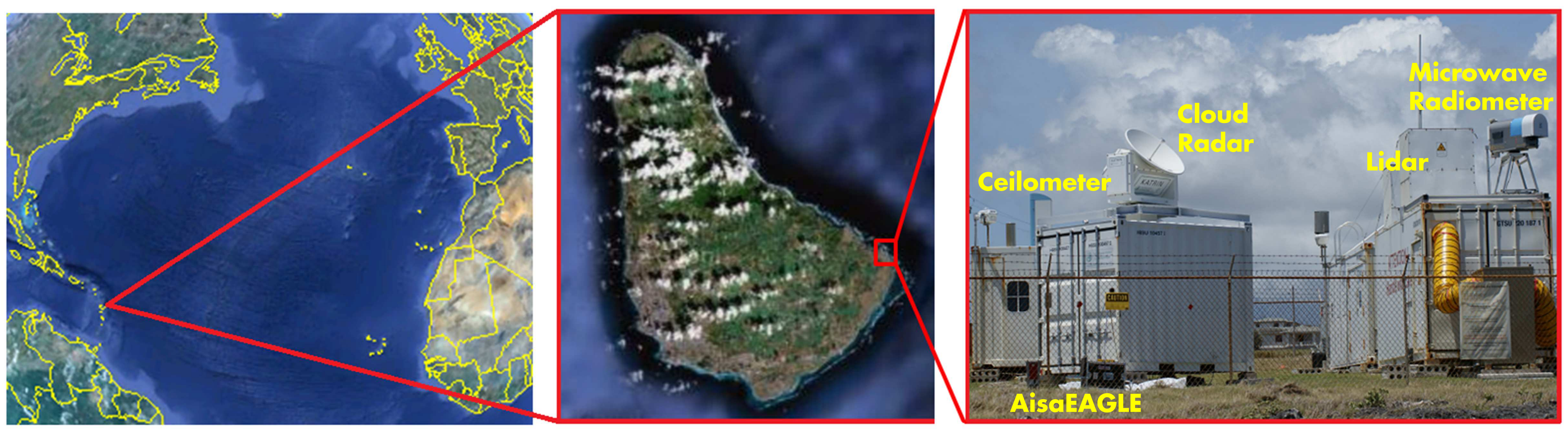

Fig. 1: Site of the AisaEAGLE radiance measurements at Deebles Point on the east coast of Barbados, Google Maps, Photo: E. Bierwirth

- Collaboration project:
  - Leibnitz Institute for Tropospheric Research, Leipzig
  - Leipzig Institute for Meteorology
  - Max Planck Institute Hamburg
  - University of Miami
- Aim:
  - airborne and ground based investigations of trade wind cumulus
- Measurement Sites:
  - Helicopter
    - ACTOS
    - SMART-HELIOS
  - Deebles Point
  - Ragged Point
    - Aerosol
- Instrumentation at Deebles Point:
  - AisaEAGLE (LIM)
  - All-Sky Camera (LIM)
  - Lidar (MPI)
  - Cloud Radar (MPI)
  - Microwave Radiometer (MPI)
  - Ceilometer (MPI)
- Measurements:
  - 6 April 2011 – 25 April 2011
  - measurements on 14 different days
  - two hours dataset per measurement day

3. AisaEAGLE

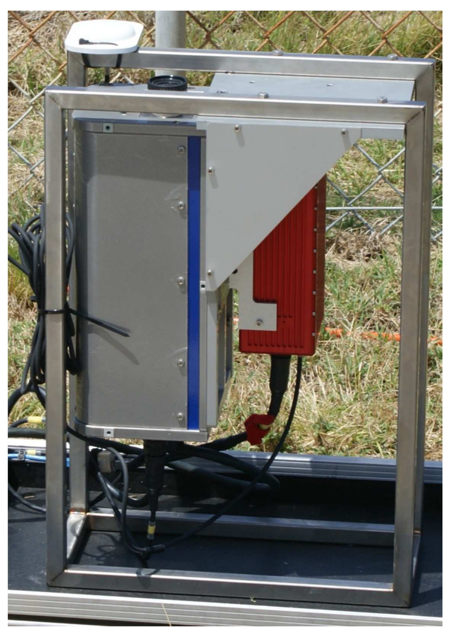

Fig. 2: AisaEAGLE sensor during CARRIBA 2011 at Deebles Point, Photo: E. Bierwirth

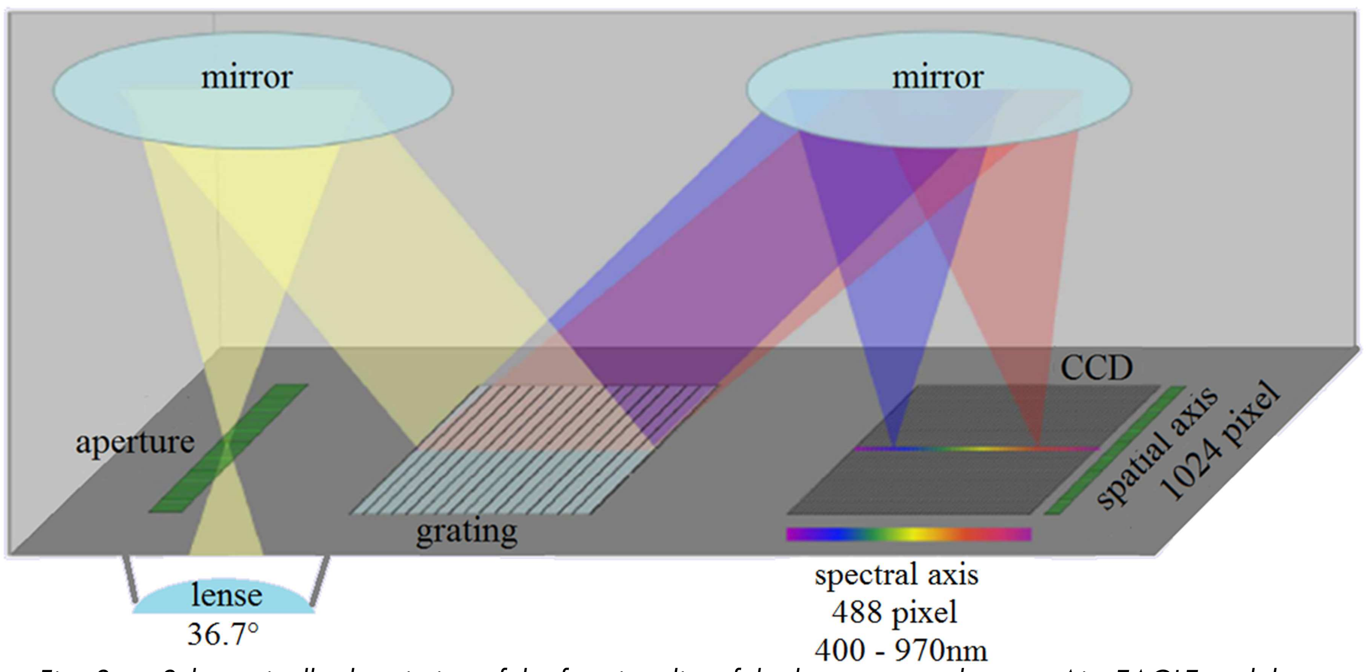

Fig. 3: Schematically description of the functionality of the hyper-spectral sensor AisaEAGLE and the producing of spatial and spectral pixel [2]

- commercial available by Specim, Spectral Imaging Ltd., Finland
- downward radiance measurements with high spatial, spectral and temporal resolution [3]

→ 1024 spatial pixels
→ 7 m pixel size and 7 km swath for a target in 10 km distance
→ 400 – 970 nm wavelength range, 1.25 nm FWHM
→ 4 ms integration time

- Measurement example 9 April 2011:

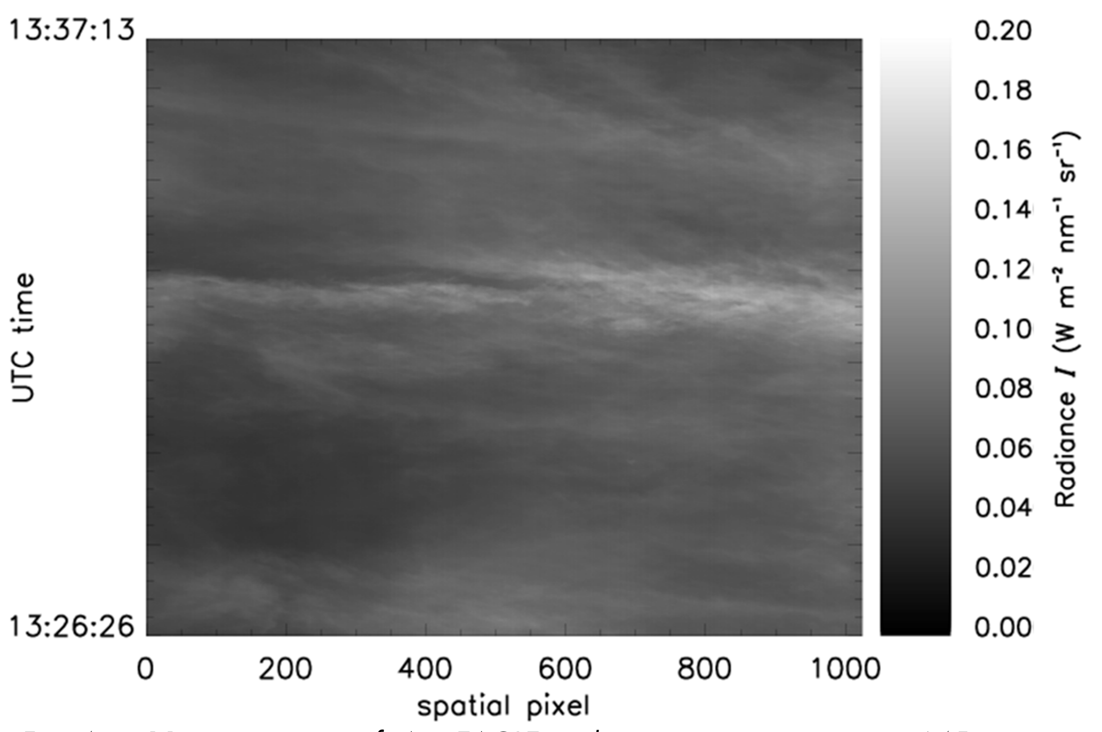

Fig. 4: 11 min extract of AisaEAGLE radiance measurements at 645 nm wavelength, recorded on 9 April 2011

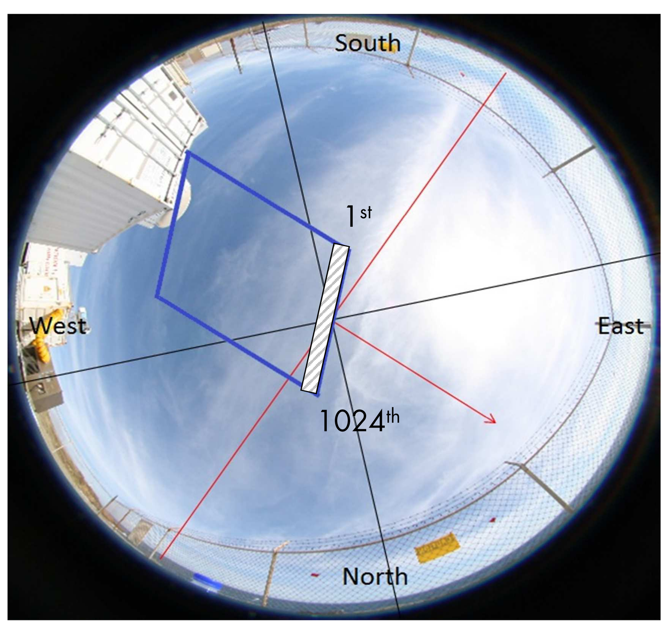

Fig. 5: All-sky image at the beginning of the AisaEAGLE radiance measurement shown in Fig. 4, direction of cloud motion (red), sensor position (grey bar), schematically detected area (blue)

4. Retrieval of Cirrus Optical Thickness τ

- forward simulations of radiance $I_{\downarrow}$ in dependence of $\tau < 2$
- libRadtran, DISORT 2, 1-dimensional, plane-parallel
- no measurements within infrared absorption band
  → r_{eff} is fixed in the retrieval (r_{eff} = 20 µm)

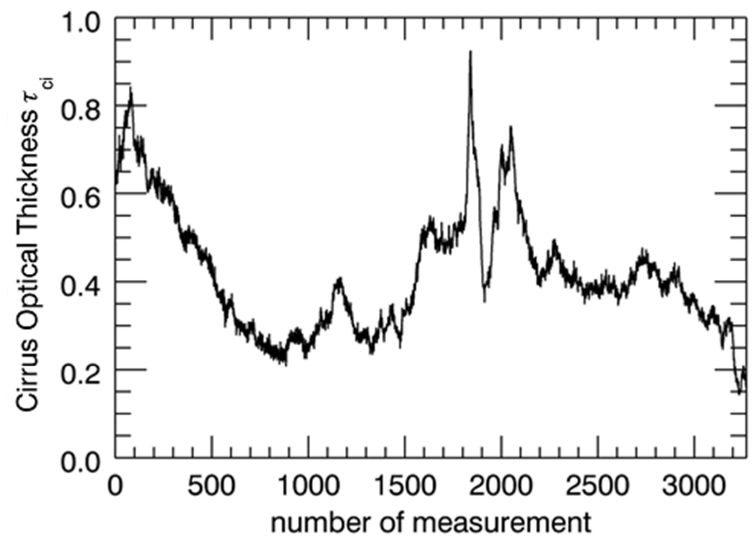

Fig. 6: Time series of cirrus optical thickness τ at pixel 512 (zenith) retrieved from the radiance measurement example shown in Fig.4

- Example: 9 April 2011

parameter	value
parameterization	Hey
effective radius	20 µm
surface albedo	water
wavelength	530 nm
cloud base	11 km
aerosol	marine, summer
ice crystal shape	solid columns

Tab. 1: Chosen parameters for the forward calculations to retrieve τ

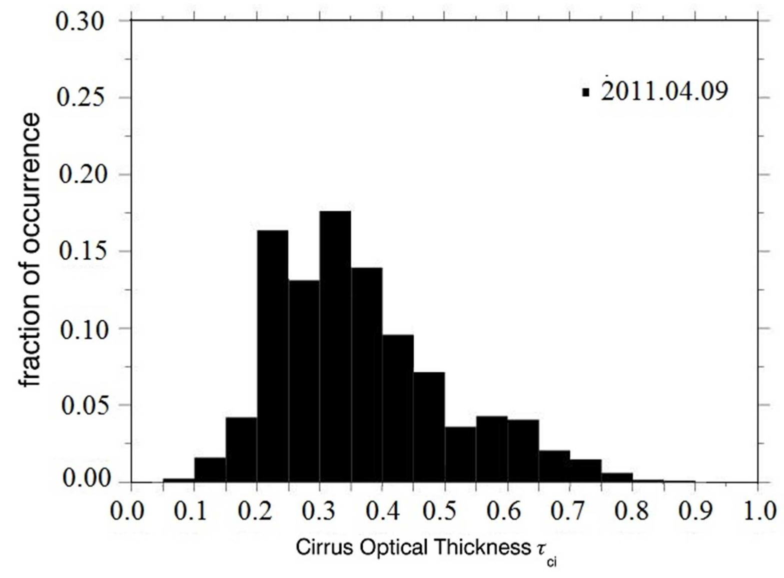

Fig. 7: Normalized histogram of the cirrus optical thickness τ, retrieved from the radiance measurement example shown in Fig. 4

- Retrieval Sensitivity:
  - Variation of:
    1. albedo
    2. effective radius
    3. cloud base
    4. ice crystal shape
  - Results:
    - albedo → significant, precise to determine
    - effective radius → within measurement uncertainties
    - cloud height → negligible
    - ice crystal shape → significant, hard to determine

parameter	value	difference
albedo	0.073 (grass)	2.6 %
	0.314 (sand)	27.8 %
r_{eff}	15 µm	0.5 %
	40 µm	- 4.9 %
cloud base	lower (4 km)	- 0.45 %
	higher (4 km)	0.31 %
crystal shape	plates	14.8 %
	rough aggregates	23.3 %

Tab. 2: Parameter varied for the sensitivity study and resulting difference in τ.

➔ **ice crystals shape determination necessary to improve retrieval**

5. Deriving Ice Crystal Shape with AisaEAGLE

→ *multi-directional measurements*

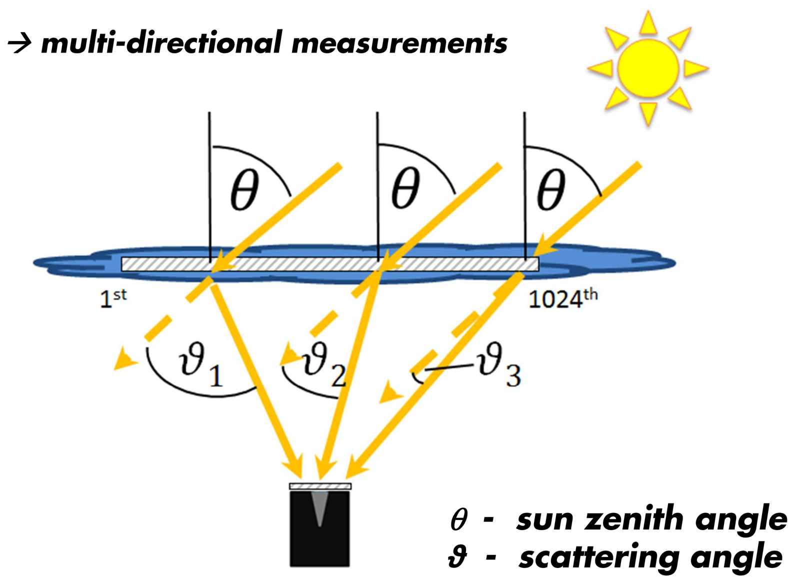

Fig. 8: Illustration of the retrieval method for ice crystal shape. Each spatial pixel measures radiance with different scattering angle.

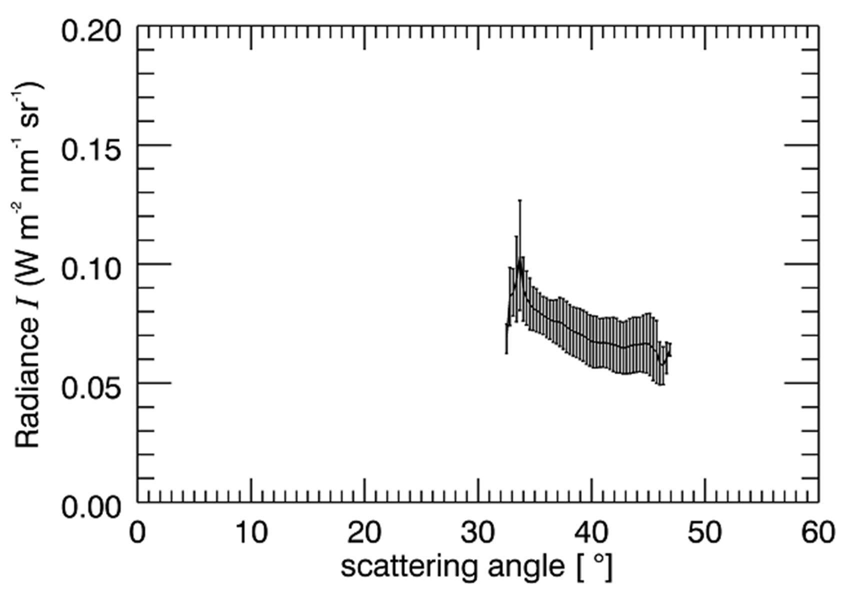

Fig. 9: Measured radiance in dependence of scattering angles for the AisaEAGLE radiance measurement shown in Fig. 4

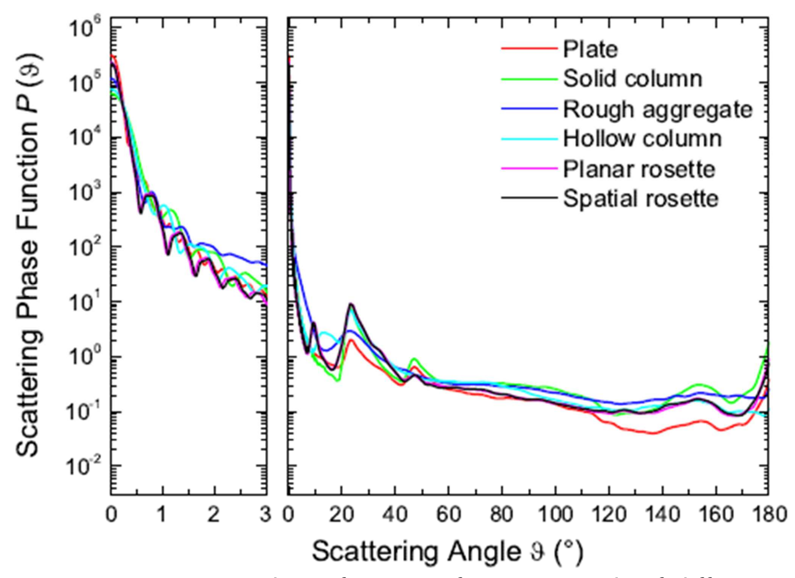

Fig. 10: Scattering phase functions for ice crystals of different shapes, [1]

- scan of characteristic regions (22° Halo and 46° Halo region)
- determine scattering phase function
- identify ice crystal shape
- tilting AisaEAGLE to expand range of scattering angles

6. Outlook

- apply shape retrieval to CARRIBA measurements
- further measurements and forward simulations of downward radiance $I_{\downarrow}$
  - retrieve cirrus optical thickness τ for several cirrus cases
- statistical evaluations on this cirrus optical thickness τ and heterogeneity
- 3d-simulations to quantify 3d-radiative effects
  - parameterization of this 3d-radiative effects in dependence of cirrus inhomogeneities

[1] Eichler, H., A. Ehrlich, M. Wendisch, G. Mioche, J.-F. Gayet, M. Wirth, C. Emde, and A. Minikin (2009), Influence of ice crystal shape on retrieval of cirrus optical thickness and effective radius: A case study, J. Geophys. Res., 114, D19203, doi:10.1029/2009JD012215

[2] Bernhardt, F.: Optimierung und Anwendung eines abbildenden Spektrometers zur räumlich aufgelösten Messung atmosphärischer Spurengase vom Flugzeug, Diplomarbeit, Universität Bremen, Institut für Umweltphysik (IUP), 2010

[3] Hanus, J., Z. Malenovsky, L. Homolova, K. Veroslav, L. Petr, and C. Pavel (2008). Potentials of the VNIR airborne hyperspectral system AISA Eagle. In GIS Ostrava.