Airborne Measurement of the Areal Spectral Surface Albedo

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1. Introduction

- **Goal:** Airborne measurement of the area-averaged *(areal)*, spectral surface albedo.
- **Problem:** Atmospheric scattering and absorption beneath the flight level. In case of high aerosol optical thickness and inhomogeneous vertical distribution of the aerosol optical properties, this atmospheric masking is non-linear with height, as shown in Fig. 1.
- **Solution:** A non-linear extrapolation algorithm has been developed in order to derive the areal spectral surface albedo from airborne measurements of upwelling and downwelling irradiances. [1]

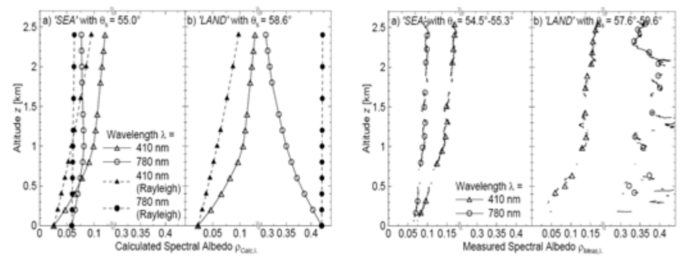

Fig. 1: *Calculated and measured albedo at 410 and 780 nm at different heights above sea and land surface. Linear extrapolation to the ground is not applicable in the presence of significant aerosol amounts. [1]*

2. Instrumentation

- The spectral irradiance measurements are accomplished with the Albedometer, developed at the IfT, mounted on a Partenavia P68B aircraft (see Fig. 2), and with the NASA Solar Spectral Flux Radiometer (SSFR), mounted on ER2 and Twin Otter UV-18A aircraft.
- The Albedometer consists of cosine and isotropic optical inlets connected to spectrometer systems for the visible (λ = 290–1000 nm) and near-infrared (λ = 1000–2200 nm) wavelength ranges. A set of inlets and spectrometers is applied for upwelling and downwelling radiation each; see Fig. 3.
- During flight, the optical inlets are stabilised into the horizontal plane by a real-time GPS-controlled stabilisation system. The resulting overall uncertainty for the spectral irradiance measurements is estimated at ± 4% for λ = 400–770 nm, and ± 6% for λ ≤ 400 nm and λ ≥ 770 nm [2].

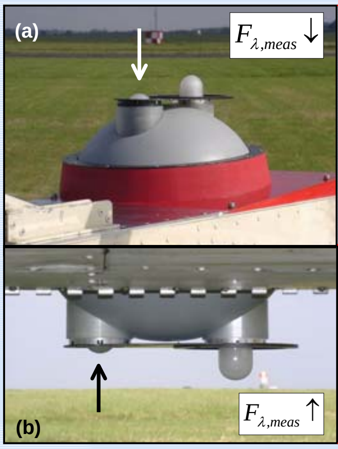

Fig. 2: *The Partenavia aircraft returns from a mission. The optical inlets on the top and bottom are marked (close-up in Fig. 3).*

Fig. 3: *Irradiance cosine optical inlets (marked by arrows) of the IfT Albedometer mounted on top (a) and on the bottom (b) of the aircraft. – The bigger inlets to the right are used for measuring actinic irradiance (isotropic inlets). – The grey cupola holding the inlets is driven by GPS-controlled servo motors which provide accurate horizontal stabilisation during flight.*

3. Methodology

i=0: Initial guess for the surface albedo $\rho_\lambda^{(i=0)}$ (λ denotes wavelength dependence)

→ i=i+1 →

Model calculation (using $\rho_\lambda^{(i-1)}$) of upward (↑) and downward (↓) irradiances $F^{(i)}_{\lambda,calc}$ at the ground z_0 and the flight level z_{flight}; compare with measured irradiances $F_{\lambda,meas}\downarrow$

$$F^{(i)}_{\lambda,calc}\downarrow(z_{flight}) \cong F_{\lambda,meas}\downarrow(z_{flight})$$

no → Reject case

yes ↓

Calculate transmittance $\tau^{(i)}_{\lambda,calc}$ of the layer between flight level z_{flight} and ground z_0

$$\tau^{(i)}_{\lambda,calc} = \frac{F^{(i)}_{\lambda,calc}\downarrow(z_0)}{F^{(i)}_{\lambda,calc}\downarrow(z_{flight})}$$

Extrapolate downward irradiance $F_{\lambda,meas}\downarrow$ (measured in flight) to the ground

$$F^{(i)}_{\lambda,ext}\downarrow(z_0) = F_{\lambda,meas}\downarrow(z_{flight})\cdot\tau^{(i)}_{\lambda,calc}$$

Derive the (extrapolated) upward irradiance $F^{(i)}_{\lambda,ext}\uparrow$ at the ground from the assumption that the ratio of upward irradiances at ground and flight level, respectively, is the same for both measurement and model calculation

$$\frac{F^{(i)}_{\lambda,ext}\uparrow(z_0)}{F_{\lambda,meas}\uparrow(z_{flight})} = \frac{F^{(i)}_{\lambda,calc}\uparrow(z_0)}{F^{(i)}_{\lambda,calc}\uparrow(z_{flight})}$$

Calculate the areal spectral surface albedo $\rho_\lambda^{(i)}$

$$\rho^{(i)}_\lambda(z_0) = \frac{F^{(i)}_{\lambda,ext}\uparrow(z_0)}{F^{(i)}_{\lambda,ext}\downarrow(z_0)} = \rho^{(i-1)}_\lambda(z_0)\cdot\frac{\rho_{\lambda,meas}(z_{flight})}{\rho^{(i)}_{\lambda,calc}(z_{flight})}$$

$$\rho^{(i)}_\lambda \cong \rho^{(i-1)}_\lambda$$

no → i=i+1

yes ↓

Final surface albedo

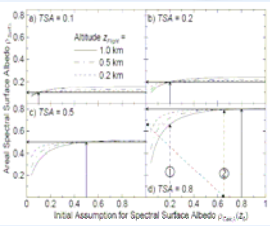

Fig. 4: *The principle of the algorithm for various true surface albedos (TSA; indicated by arrows). λ = 410 nm, SZA = 32°. [1]*

4. Examples

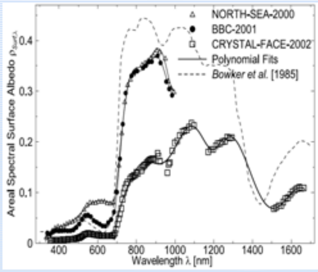

Fig. 5: *Areal spectral surface albedo, derived from irradiance measurements over different land surfaces during the campaigns NORTH-SEA† (N Germany), BBC† (Holland), CRYSTAL-FACE‡ (Florida). Also albedo data from [3] for surface type 'grass' are shown as a dashed line. Figure taken from [1].*

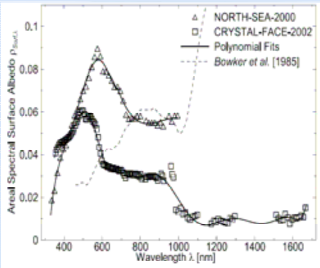

Fig. 6: *Same as Fig. 5, but over different sea surfaces (North Sea†, triangles; Gulf of Mexico‡, squares). The dashed line stands for the surface albedo data for surface type 'water' from [3]. Figure taken from [1].*

† using IfT Albedometer; ‡ using NASA SSFR

5. Problems

- Artefacts (spikes) due to high albedo gradients in absorption bands
- Surface albedo depends on solar zenith angle (usually, lowest at noon)
- Significant influence of small-scale surface variability
- Uncertainty of obtained albedo grows with increasing flight level
- Parallel measurement of vertical profile of aerosol and meteorological data needed for model calculations

Physics Department

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