Toward a global assessment of aerosol influence on cloud vertical extent

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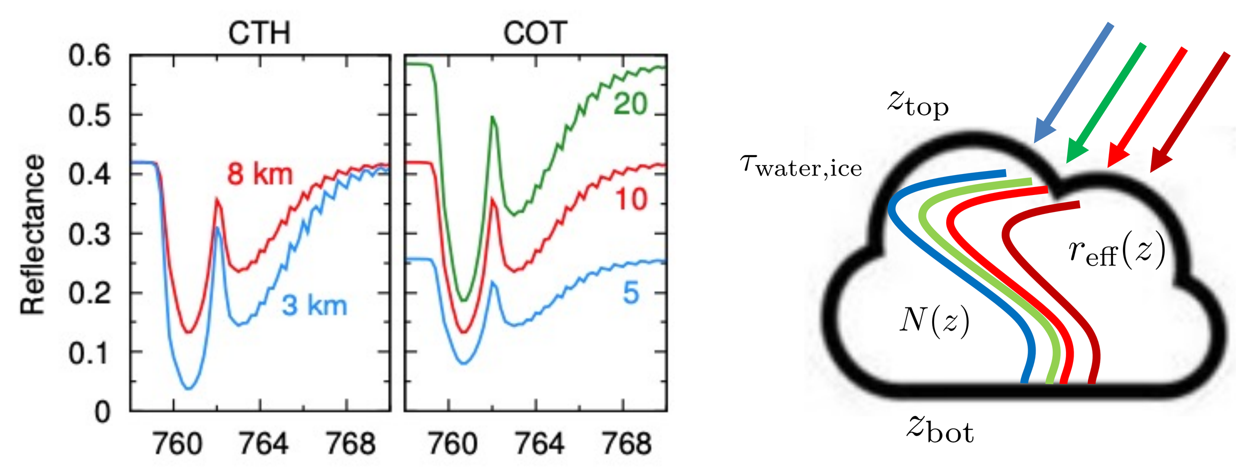
Summary

Earth's climate is a complex perturbed system, in which a wealth of chemical, physical and biological processes takes place on a wide range of spatial and temporal scales. A particularly important group of atmospheric processes is termed aerosol-cloud interactions (ACI), which describe cloud adjustments to natural and anthropogenic aerosol particles. Changes in optical and physical properties of clouds are a key factor in both reducing the uncertainty of radiative forcing estimates and in understanding the water cycle. In this work we present retrieval results of the geometrical extent of clouds based on near-infrared oxygen absorption from SCIAMACHY measurements. The retrieved bottom and top altitude of homogeneous clouds are sided by data of fine mode aerosol load and microphysical cloud properties generated within the ESA Climate Change Initiative projects. Global and regional analysis of this parameter's suite enables the identification of specific ACI regimes. Moreover, we present a technique to inherently account for aerosol perturbation of in-cloud extinction profiles based on the synergistic exploitation of oxygen absorption and multi-wavelength continuum in the solar spectral range. Preliminary results from SCIAMACHY and AATSR show that a more realistic description of in-cloud extinction is beneficial for the accuracy of the geometrical extent of homogeneous clouds. From a future perspective, this retrieval approach can be deployed with measurements of the upcoming NASA Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission, scheduled to launch in late 2023. The PACE payload suite comprises the Ocean Color Instrument (OCI), a hyperspectral scanning radiometer, and the polarimetric and multi-angular sensors HARP-2 and SPEXone. The design and the technical complementarity of the three instrument payloads make PACE measurements particularly well-suited for the advancement of our ACI knowledge, whose scientific level of confidence is still quantified as low by the Intergovernmental Panel on Climate Change.

Problem setting and retrieval approach

1. Bias in geometrical properties and understanding their uncertainties
2. Role of LWC/LWP and droplet effective radius in biases
3. How does aerosols influence cloud geometrical extent



1. O_2 A-band at moderate spectral resolution delivers best geometrical properties
2. Multispectral sensors appropriate to derive profile of in-cloud properties

Homogeneous clouds → **Inhomogeneous clouds** ← aerosol influence

Forward problem

1) Homogeneous cloud $\tau = Q_{ext}(r_{eff})\,N\,\Delta z \qquad N = \dfrac{\tau}{Q_{ext}(r_{eff})\,\Delta z}$

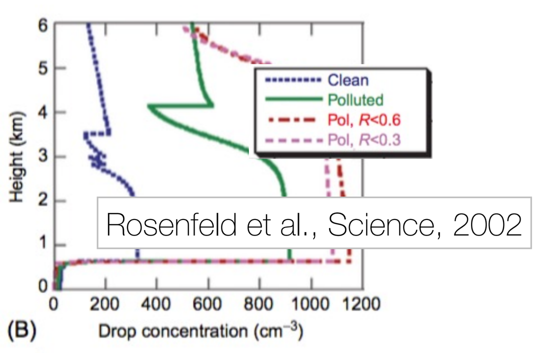
2) Inhomogeneous cloud, assume $r_{eff}(z)$ is known

$$\tau = \int_{z_{bot}}^{z_{top}} Q_{ext}(r_{eff}(z))\,N(z)\,dz \qquad N(z) = C\,\overline{N(z)}, \qquad C > 0$$

$$\tau = \int_{z_{bot}}^{z_{top}} Q_{ext}(r_{eff}(z))\,C\,\overline{N(z)}\,dz$$

$$C = \frac{\tau}{\int_{z_{bot}}^{z_{top}} Q_{ext}(r_{eff}(z))\,\overline{N(z)}\,dz}$$

Aerosol modulation



Rosenfeld et al., Science, 2002

Inverse problem

(1) SCIAMACHY 758 (0.2) 772 nm (homogeneous cloud)

$$\tau = \int_{z_{bot}}^{z_{top}} Q_{ext}(r_{eff} = 6\,\mu m)\,1\,dz \rightarrow \tau,\ \overline{z_{bot}},\ \overline{z_{top}} \rightarrow \tau = \int_{z_{bot}}^{z_{top}} Q_{ext}(r_{eff}(z))\,N'(z)\,dz$$

(2) AATSR (0.66, 0.87, 1.6, 3.7 µm) (inhomogeneous cloud)

$$W_r(z,\lambda) = \frac{\delta R(\lambda)}{\delta \ln r_{eff}(z)} \rightarrow r_{eff}(z)$$

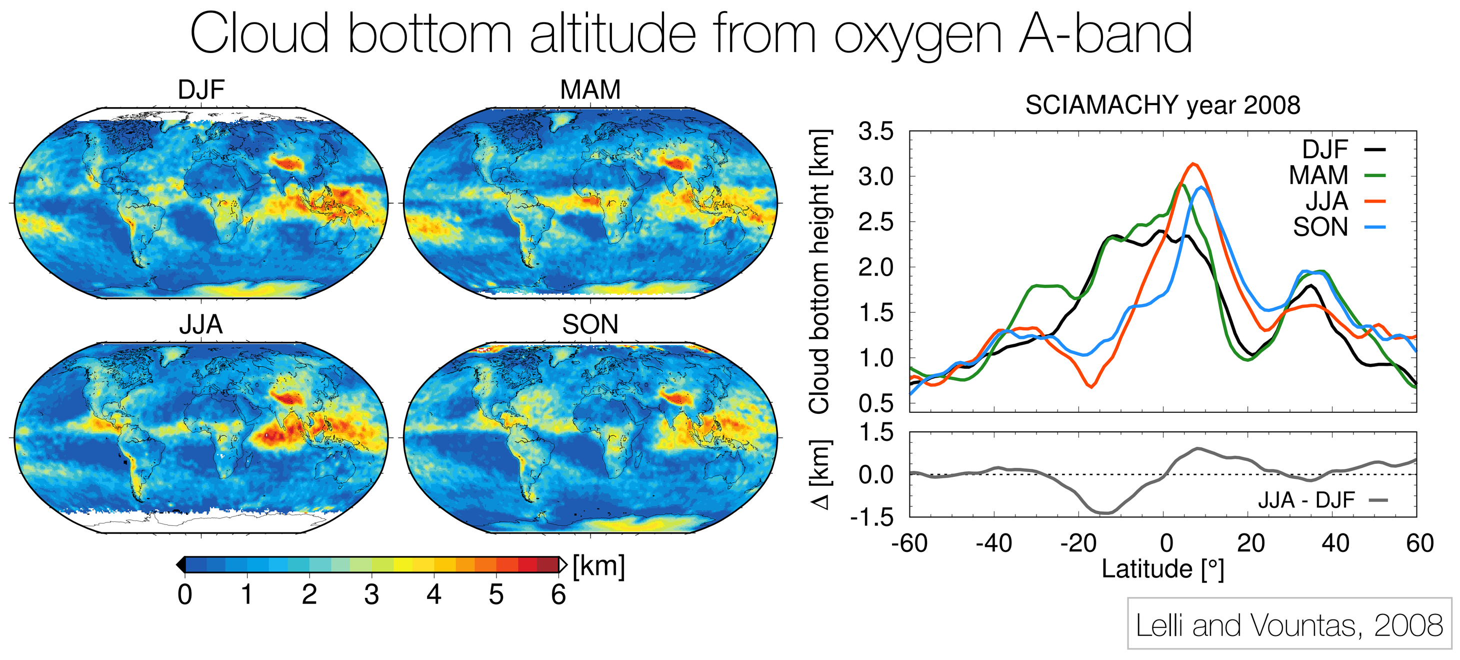
$$\tau = C \int_{z_{bot}}^{z_{top}} Q_{ext}(r_{eff}(z))\,\overline{N(z)}\,dz \rightarrow N'(z) = C\,\overline{N(z)}$$

$z'_{bot},\ z'_{top}$

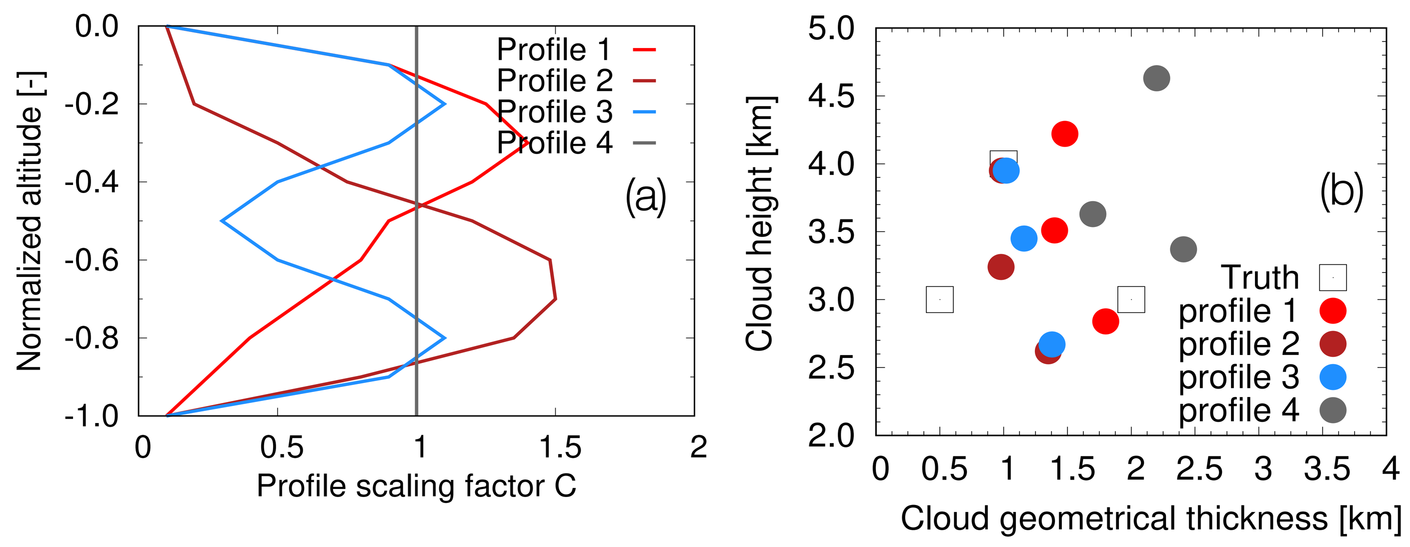
- Updated geometrical cloud boundaries
- accounting for in-cloud extinction
- which is inherently aerosol-modulated

Results

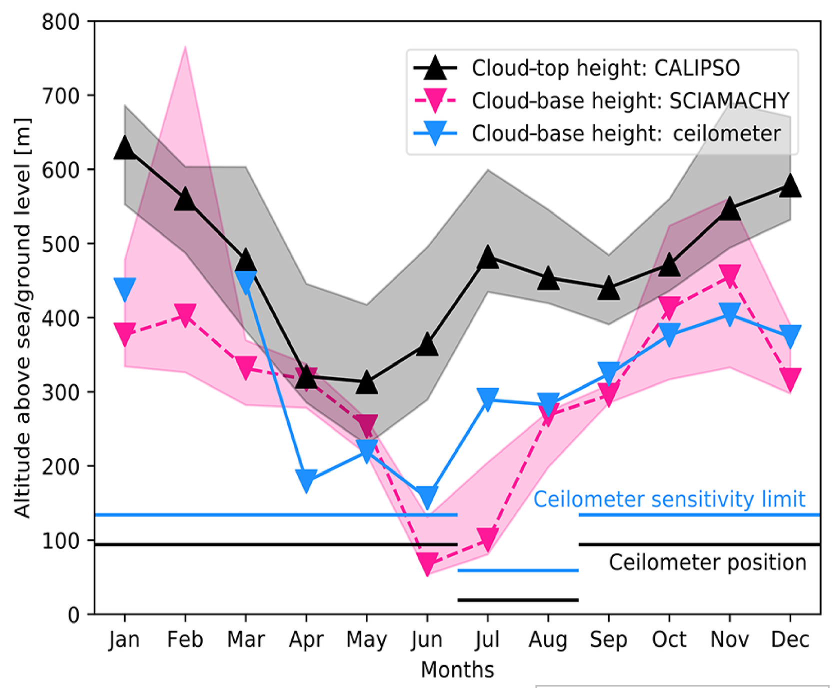
Cloud bottom altitude from oxygen A-band



Lelli and Vountas, 2008

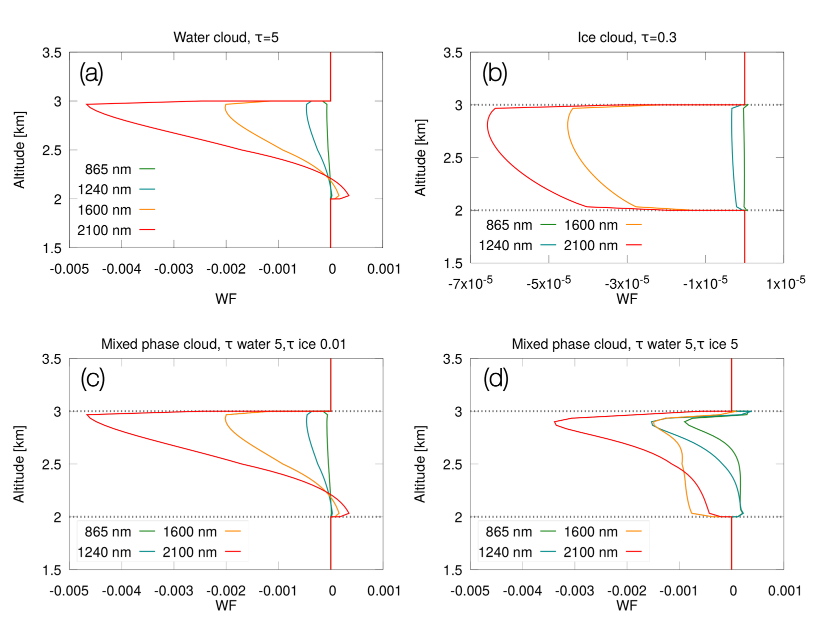


Walvis Bay [22.5-24.0° S,14.0-15.5° E]



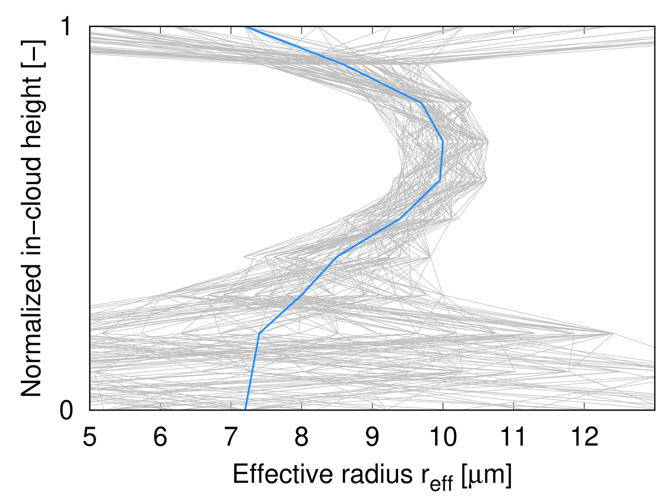
Andersen et al, 2019

Weighting functions of effective radius profile

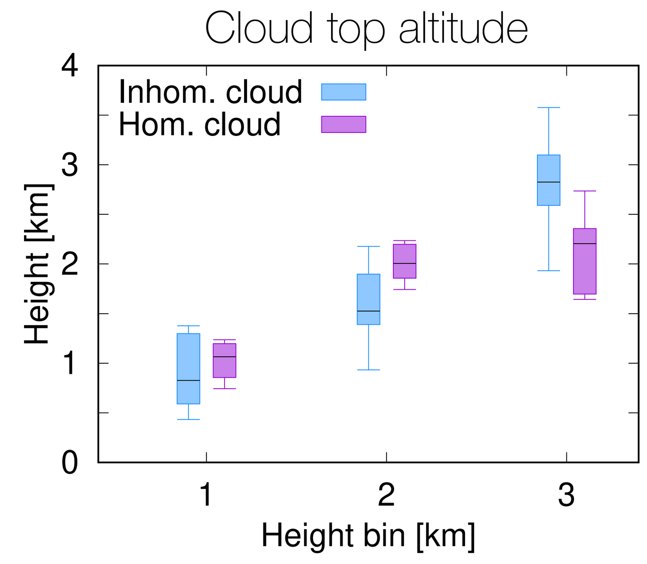


Walvis Bay May-June 2008

CF ≥ 0.8 COT 18.72±5.02



Cloud top altitude



Open development issues

1. Influence of LWC and IWC : empirical relationships needed for effective radius – LWC and effective diameter – IWC
2. Prior information on N(z) : CloudSat (or CPR alike) reflectivity profile (dBz) is proportional to particle number density
3. Even knowing the cloud top phase : calculation of local profiles of optical extinction by water and ice mixtures
4. Aerosol typing (scattering vs. absorbing) and clouds' horizontal inhomogeneity
5. Uncertainty propagation
6. New metric incorporating profile of effective radius

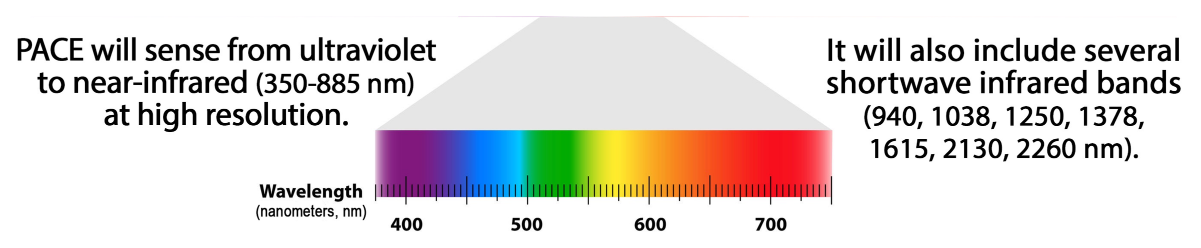
NASA Plankton, Aerosol, Cloud, ocean Ecosystem (PACE)

Primary hyperspectral imaging radiometer

Ocean Color Instrument (OCI) (GSFC) 1 km footprint
Continuous spectral coverage: 340 to 890 nm (resolution 5 nm, 2.5 nm) (UV-Vis-NIR)
7 discrete bands from 940 nm to 2260 nm (SWIR)

Two contributed multi-angle polarimeters

(1) **SPEXone** (SRON/Airbus) 5 km footprint
Continuous spectral coverage: 385 to 770 nm (Resolution 2-5 nm, 10-40 nm for polarization), 5 viewing angles (0°, ±20° and ±58° on ground)
(2) **HARP2** (UMBC) 2,6 km footprint, 60 along track viewing angles for 669 nm, 10 along track viewing angles for 441, 549, and 873 nm



TROPOMI on Sentinel 5P - or - MetOp SG