Radiative transfer of 3D cloud features and the consequences for future satellite missions – a case study using McArtim

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Introduction
Motivation

TROPOMI project

- cloud fractions
- sensitivity for tropospheric trace-gases
- here also: aerosols

TROPOMI project

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- sensitivity for tropospheric trace-gases
- here also: aerosols

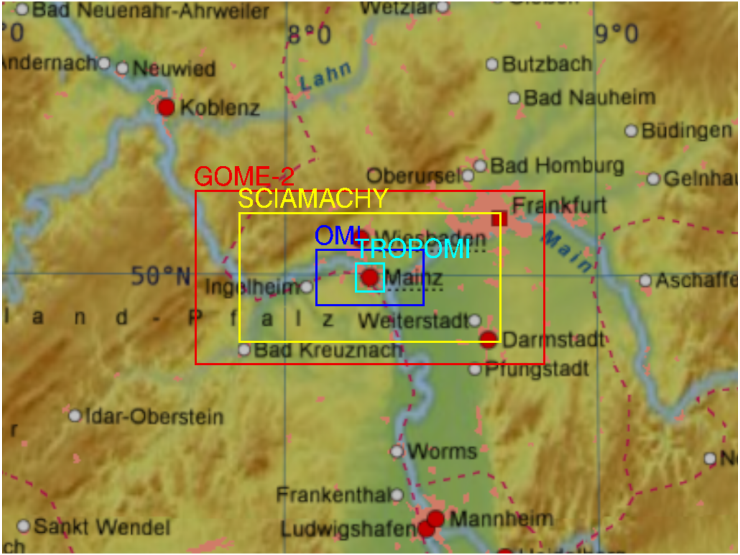
Satellite Instruments

instrument	GOME-2	TROPOMI	POLDER
first launch	2006	2015(?)	1996
resolution [km^2]	80×40	7×7	6×6
swath [km]	1950	2600	2400

horizontal resolution $\xrightarrow{\text{similar to}}$ atmosphere vertical extent

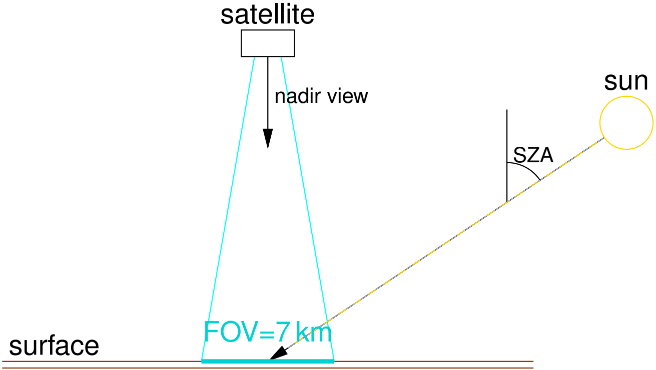
Introduction

Comparison of pixel sizes



Introduction

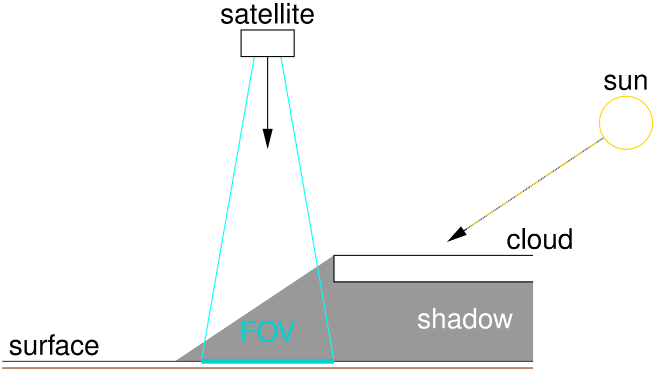
Model setup



Geometry

- SZA=50° (equinox noon in Mainz)

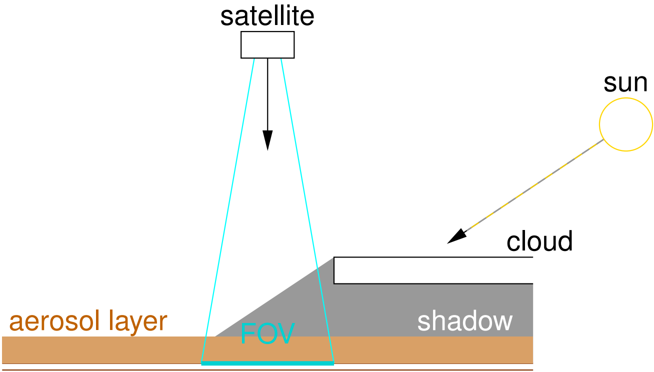
Introduction
Model setup with cloud front



Geometry

- SZA=50° (equinox noon in Mainz)
- cloud between 5 and 6 km altitude

Introduction
Model setup with cloud front and aerosol layer

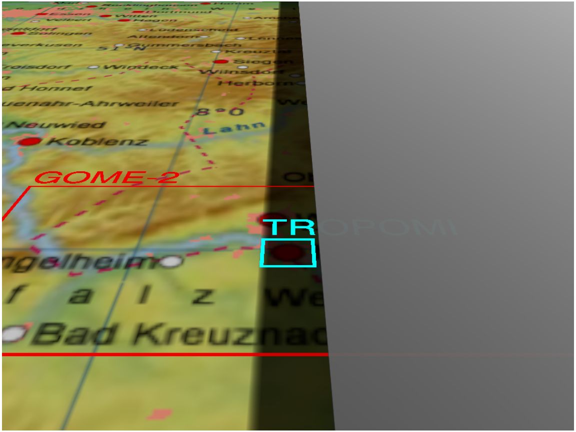


Geometry

- SZA=50° (equinox noon in Mainz)
- cloud between 5 and 6 km altitude
- aerosol layer in lowest 1 km

Example: pixel fraction in shadow

Example: pixel fraction in shadow



GOME-2 (80 km) shadow covers 9 % of pixel area

TROPOMI (7 km) pixel completely within shadow

Radiative transfer model

McArtim Monte-Carlo RT model [Deutschmann et al.,2011]

- 3D plane parallel domain reduced to 2D (y =const.)
- wavelengths: 380 nm, 440 nm, and 870 nm
- 5 % surface albedo
- Mie clouds: g=0.85, SSA=1
- Mie aerosol: g=0.68, SSA=0.9
- polarisation included

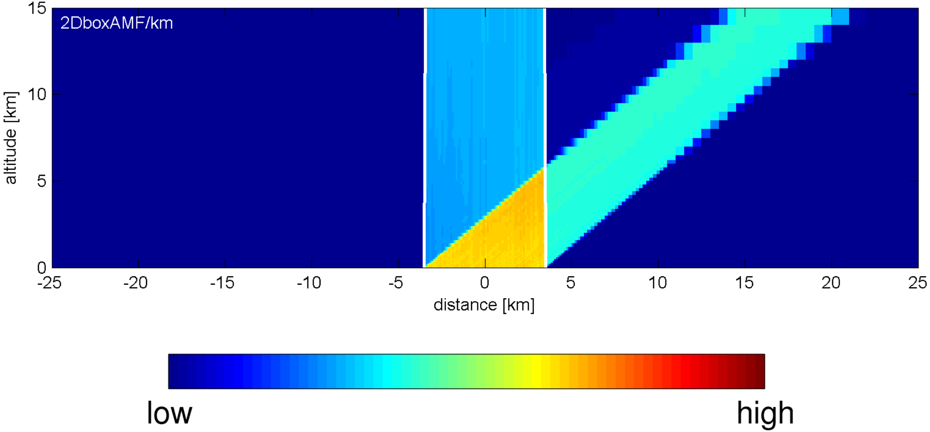
Geometry

- SZA=50° (equinox noon at Mainz)
- Nadir viewing direction (LOS=0°)

Visualisation of RT

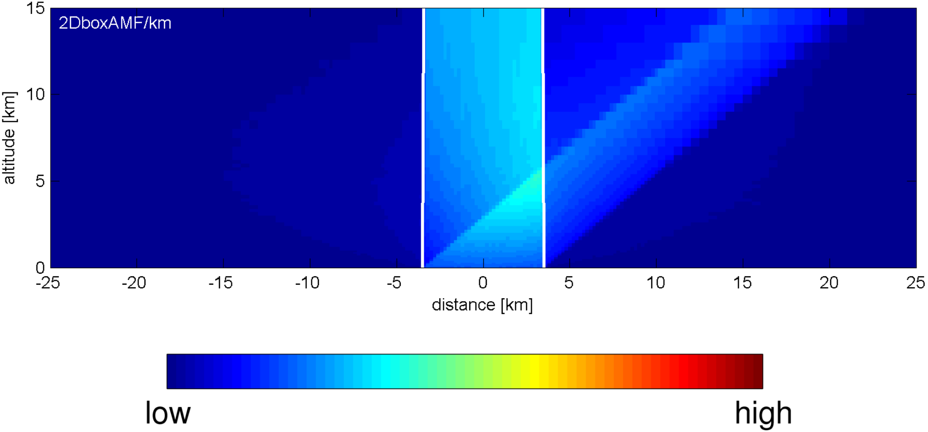
sensitivity → photon path density (2D boxAMF)

Photon path density at 870 nm



almost geometric photon paths

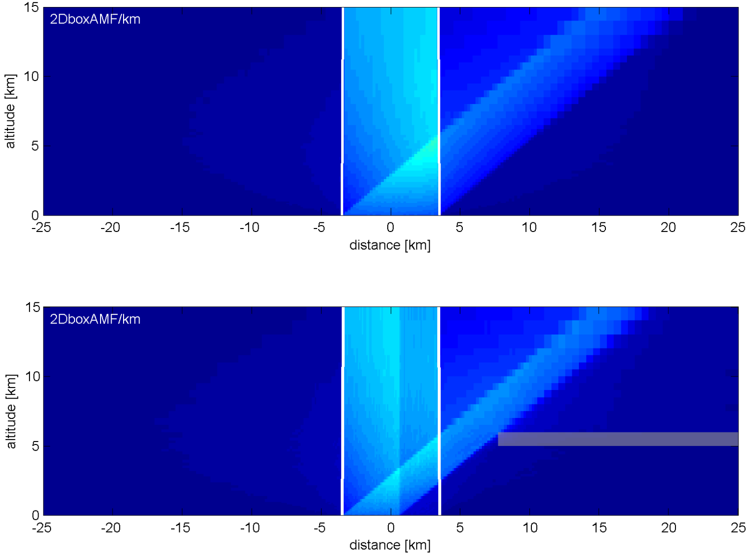
Photon path density at 440 nm



considerable Rayleigh contribution at shorter wavelength

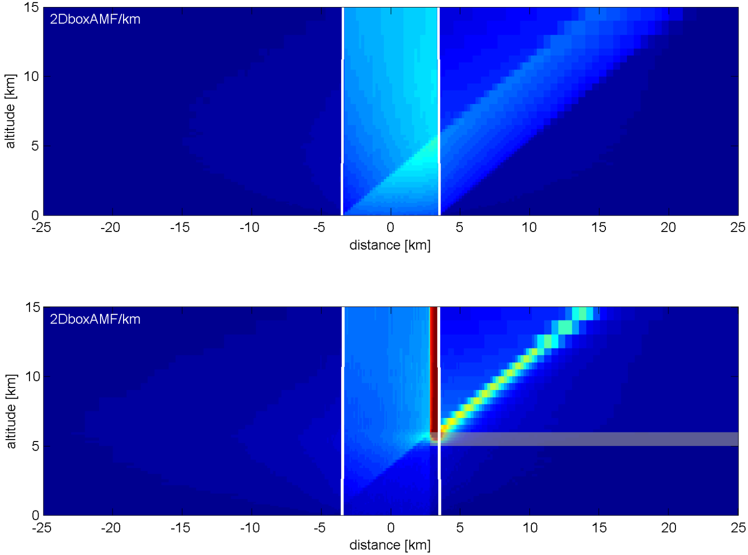
Cloud fraction

RT in shadow (440 nm)



Cloud fraction

cloud compensates shadow (440 nm)



Definition of cloud fraction

assumptions

- pixel are divided into cloud-free and cloudy part
- based on top-of-atmosphere (TOA) radiance measurements

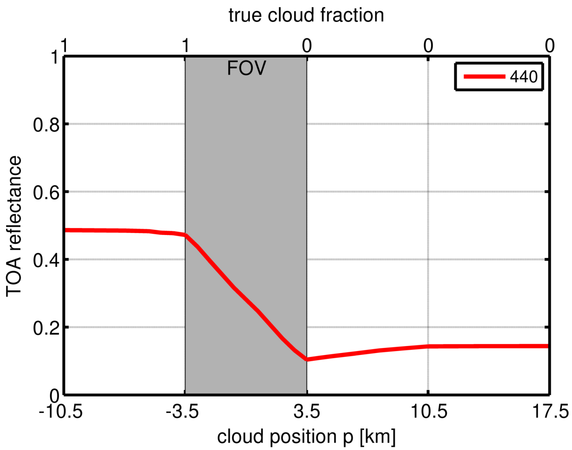
definition of cloud fraction (CF)

$$CF = \frac{I - I_{cloudfree}}{I_{cloudy} - I_{cloudfree}} = 0 \ldots 1$$

- $I_{cloudfree} \rightarrow$ no clouds, no aerosol
- $I_{cloudy} \rightarrow$ here: constant cloud OD=50

Cloud fraction

OD10 cloud front relative to definition using OD50 (440 nm)



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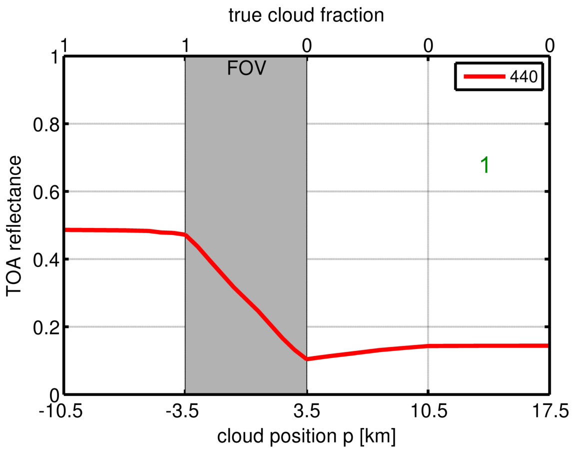

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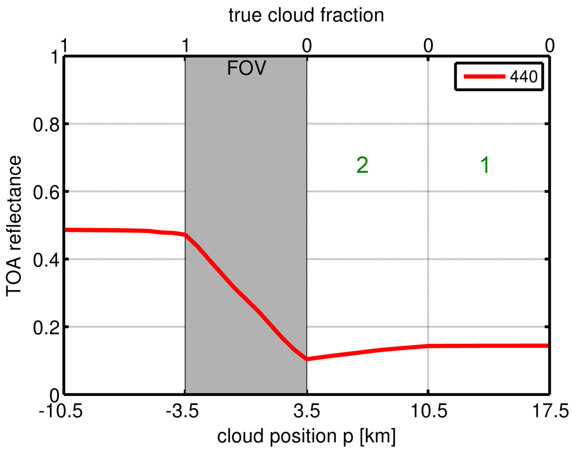

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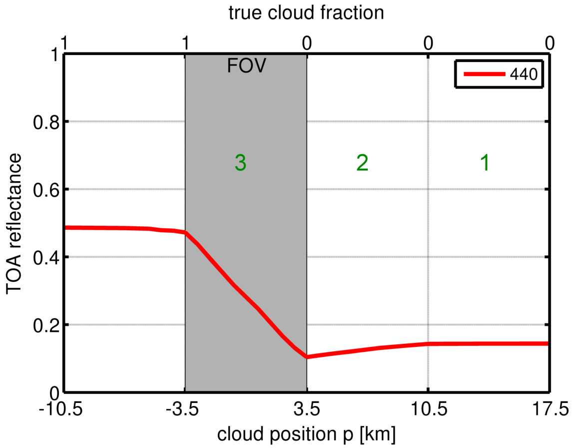

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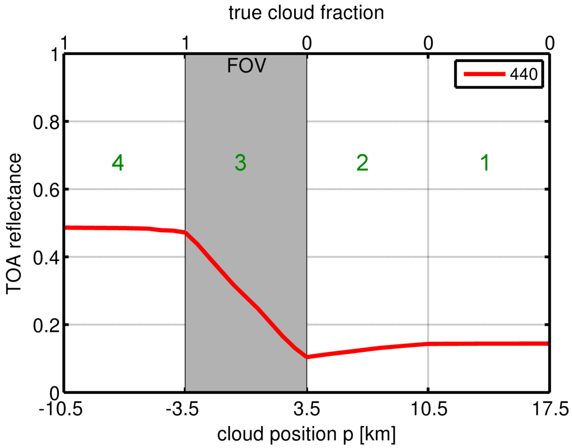

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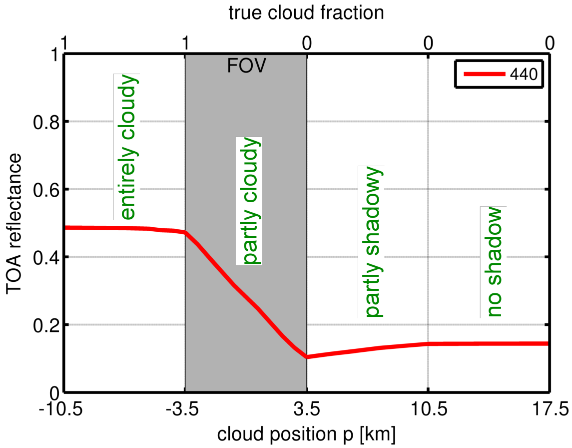

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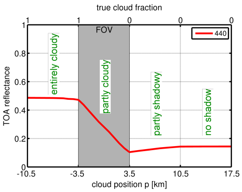

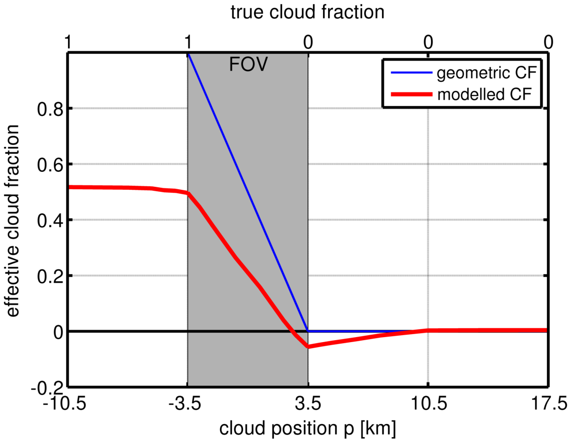

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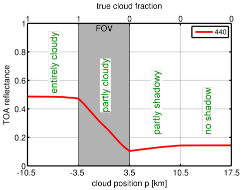

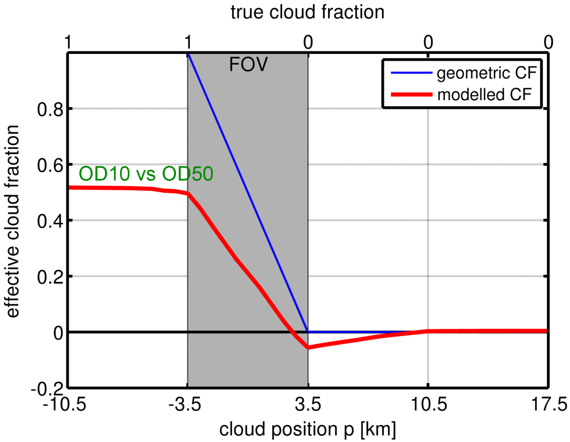

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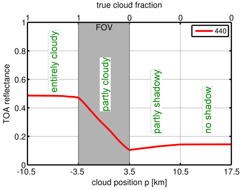

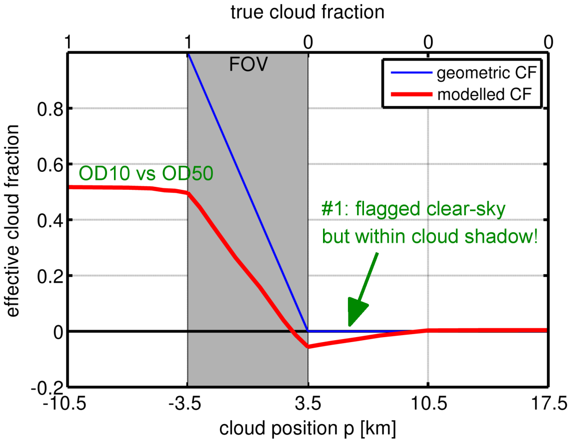

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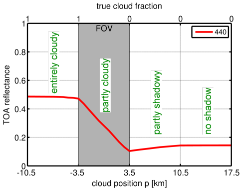
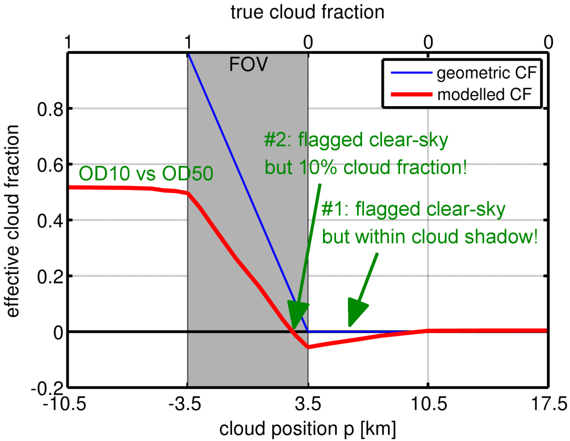
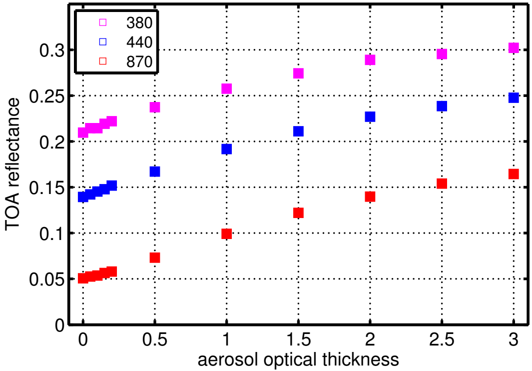




TOA reflectance depending on AOT

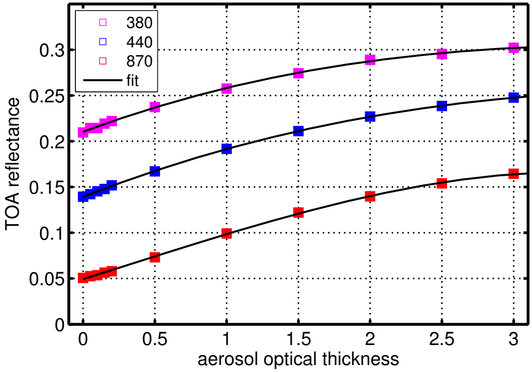
clear-sky:



Aerosol settings

- between surface and 1 km altitude
- HG = 0.68; SSA = 0.9

TOA reflectance depending on AOT



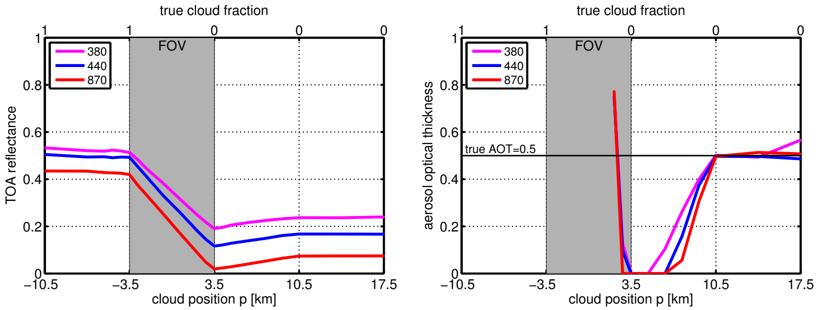
clear-sky:

Aerosol settings

- between surface and 1 km altitude
- HG = 0.68; SSA = 0.9
- fit 3rd order polynomial

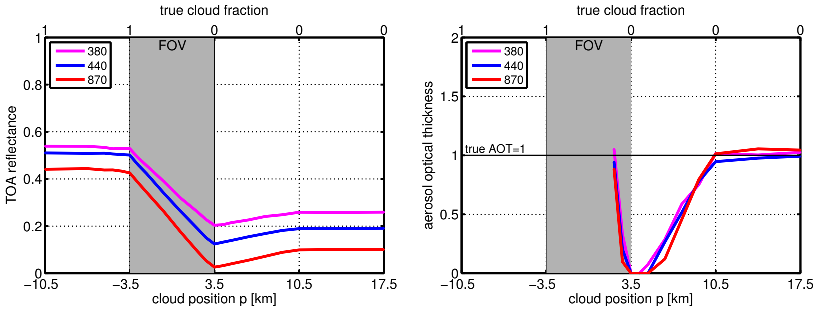
Aerosol optical thickness

AOT = 0.5



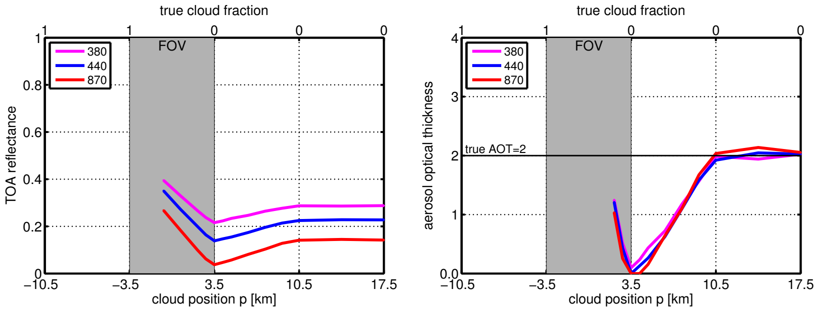
Aerosol optical thickness

AOT = 1



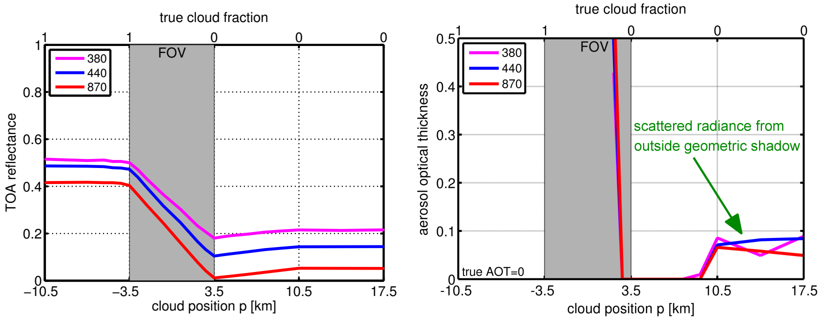
Aerosol optical thickness

AOT = 2

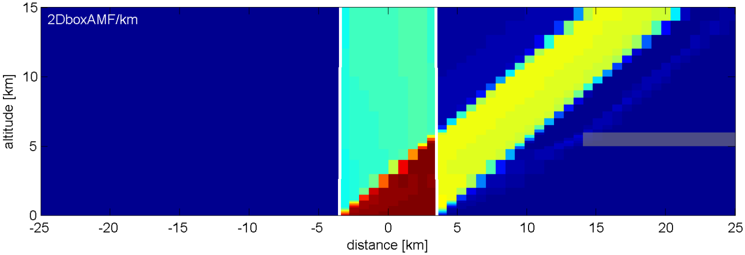


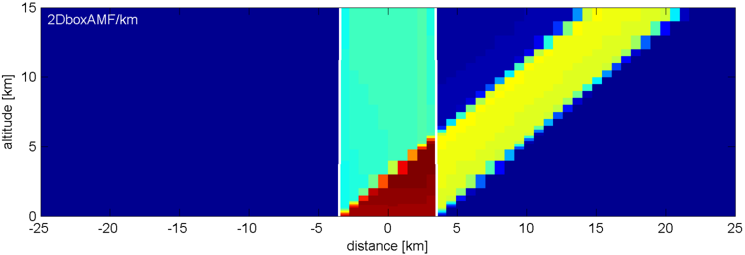
Aerosol optical thickness

no aerosol

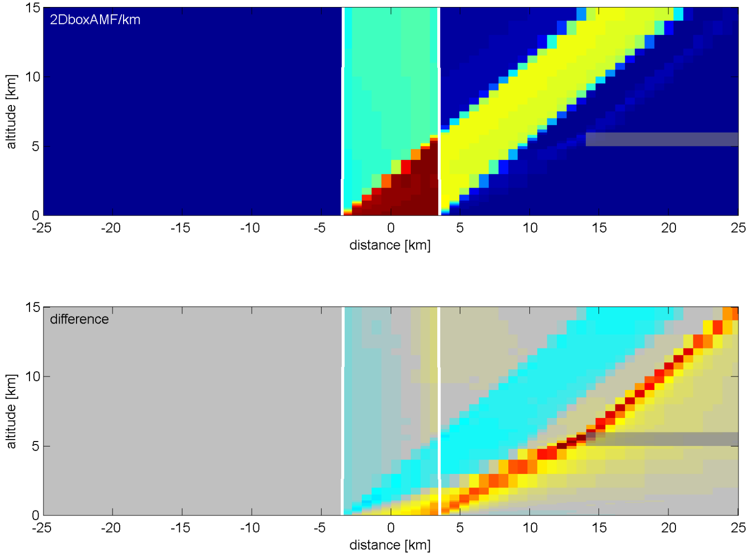


Aerosol optical thickness
no aerosol (870 nm)





Aerosol optical thickness
no aerosol (870 nm)



Conclusions

cloud shadows

- are a frequent phenomenon
- interfere with cloud and aerosol retrievals
- manipulate polarisation measurements

cloud fractions

- cloud fraction within shadow underestimated
- extreme case: true CF$>$0 but measured CF=0

aerosol optical thickness

- is underestimated in cloud shadows
- influence also outside geometrical shadow

Thank you for your attention!

Very Special Thanks to

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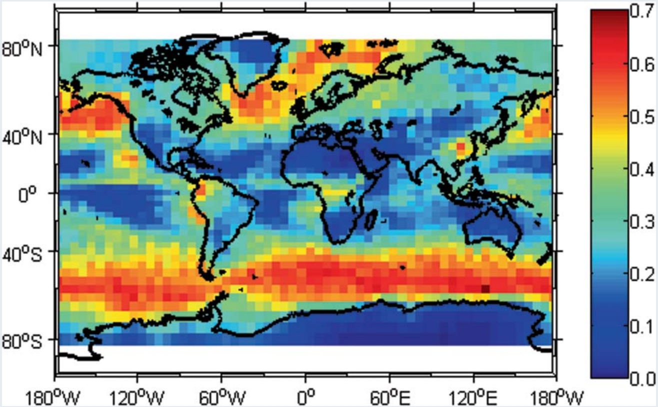
Satellite Group at MPI Mainz, Germany
Atmospheric Chemistry Group, University of Heidelberg, Germany

Cloud-top height statistics

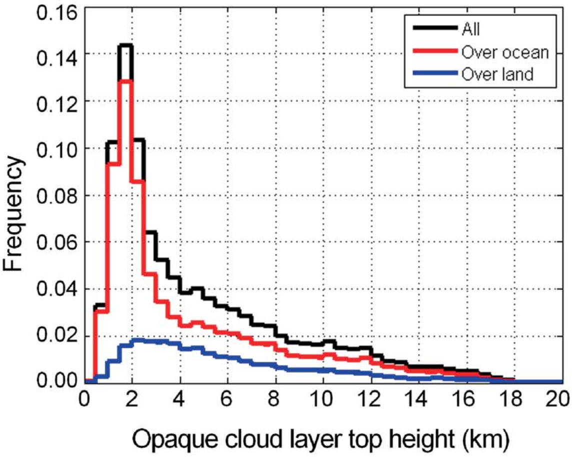
Frequency of opaque cloud-layer occurrence



[Wu et al., 2011]

Cloud-top height statistics

Cloud-top height of all opaque clouds



[Wu et al., 2011]