Sensitivity of satellite observations over bright and cloudy scenes

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Introduction

- clouds affect the remote sensing of trace gases in the atmosphere
- three competing effects occur in the radiative transfer
  - albedo effect above the cloud
  - shielding of trace gas within and below the cloud
  - light path enhancement by multiple scattering within and below the cloud
- excluding cloudy data leads to significantly smaller data set and may introduce biases
- some phenomena, such as transport events, are typically associated with clouds and need a proper treatment of cloudy data
- $O_2 \cdot O_2$ allows analysis of this effect, having a known and suited vertical profile

Block-Airmass Factor (BAMF)

Airmass factor (AMF)

- sensitivity of satellite measurement to a trace gas depends on radiative transfer
  → can be characterized by AMF
- AMF describes enhancement of the light path relative to a single vertical path through the atmosphere
- relates slant (observed) column density (SCD) and vertical column density (VCD):

$$\mathrm{AMF} \equiv \frac{\mathrm{SCD}}{\mathrm{VCD}}$$

Block-airmass factor (BAMF)

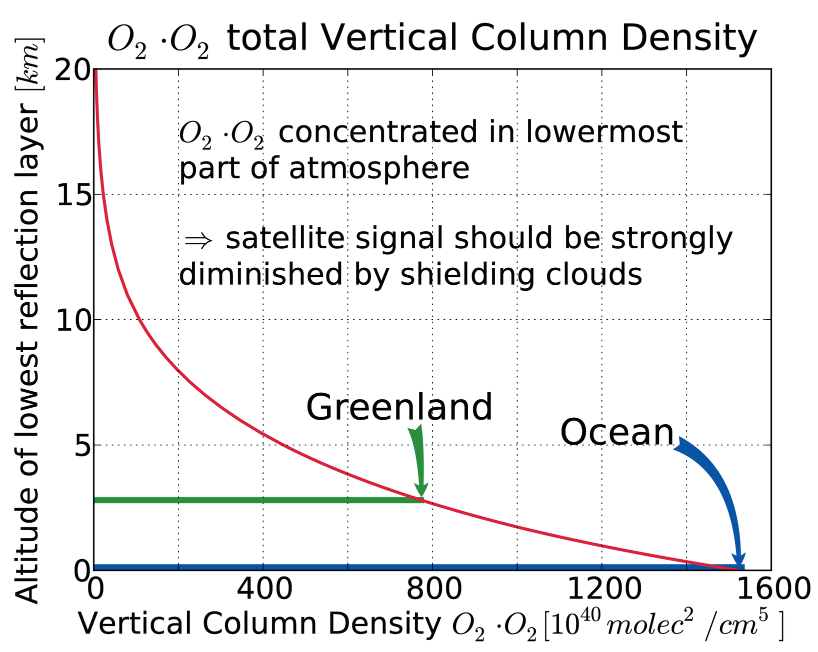
- BAMF describes the vertical contributions to the AMF
  → sensitivity to trace gases at different altitudes
- integral over altitude h of the product of the normalized vertical profile *n(h)* of the trace gas and the BAMF yield the AMF
  → linear approximation

$$\mathrm{AMF} = \int_0^{\mathrm{TOA}} n(h)\,\mathrm{BAMF}(h)\,\mathrm{d}h$$

Observed $O_2 \cdot O_2$ Columns

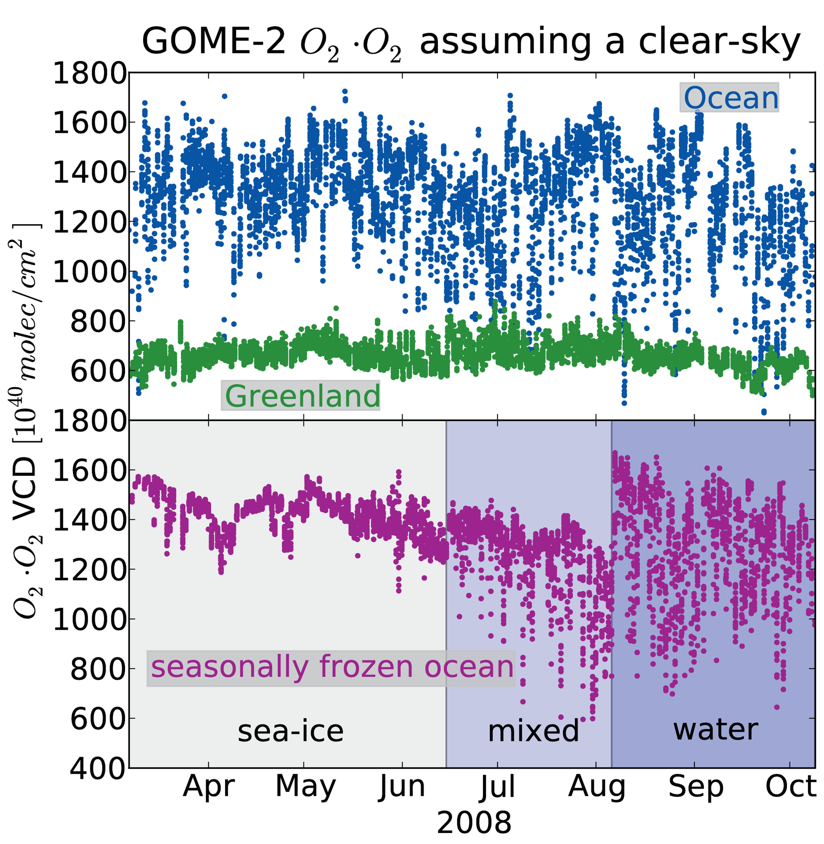
Oxygen dimer ($O_2 \cdot O_2$) vertical profile

- known and almost invariant profile
  → precise analysis possible
- very steep profile
  → little trace gas above cloud
  → cloud effects strongly visible



Satellite data

- examine $O_2 \cdot O_2$ observations over dark and bright areas
- calculate VCD assuming a cloudless sky
  → cloud effects should be visible in data
  → different behaviour over bright and dark scenes expected
- albedos: ocean 0.15, Greenland 0.90
- aerosols:
  - ocean: sea salt, water soluble
  - Greenland: sea salt, water soluble, sulfate, soot



O_2-O_2 Vertical Column Densities as measured from the GOME-2 satellite DOAS instrument. Clear-sky AMFs have been applied to obtain the vertical columns using an albedo of 0.15 over water, 0.9 over ice and 0.5 over mixed surfaces. Cloud influence is not corrected for.

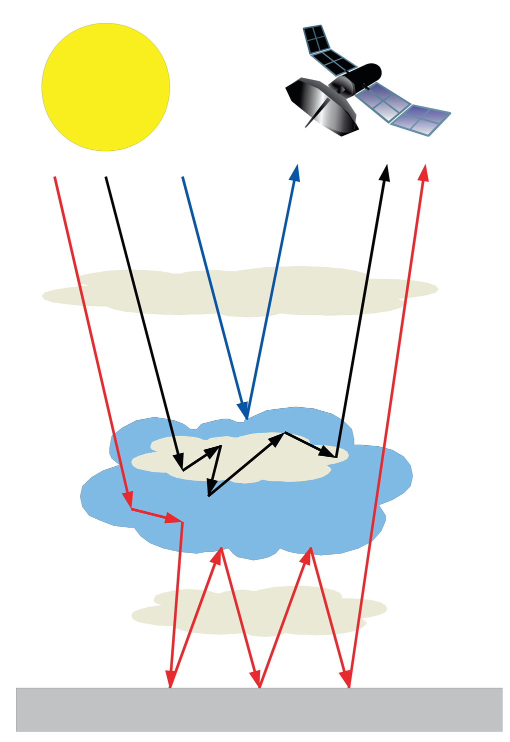
Results

- ocean shows strong cloud shielding
- Greenland and sea-ice show little variance
  → shielding compensated by light path enhancement
- clouds may amplify signal

→ presence of clouds may diminish or enhance the signal or the two effects may counter-balance and leave the signal indifferent

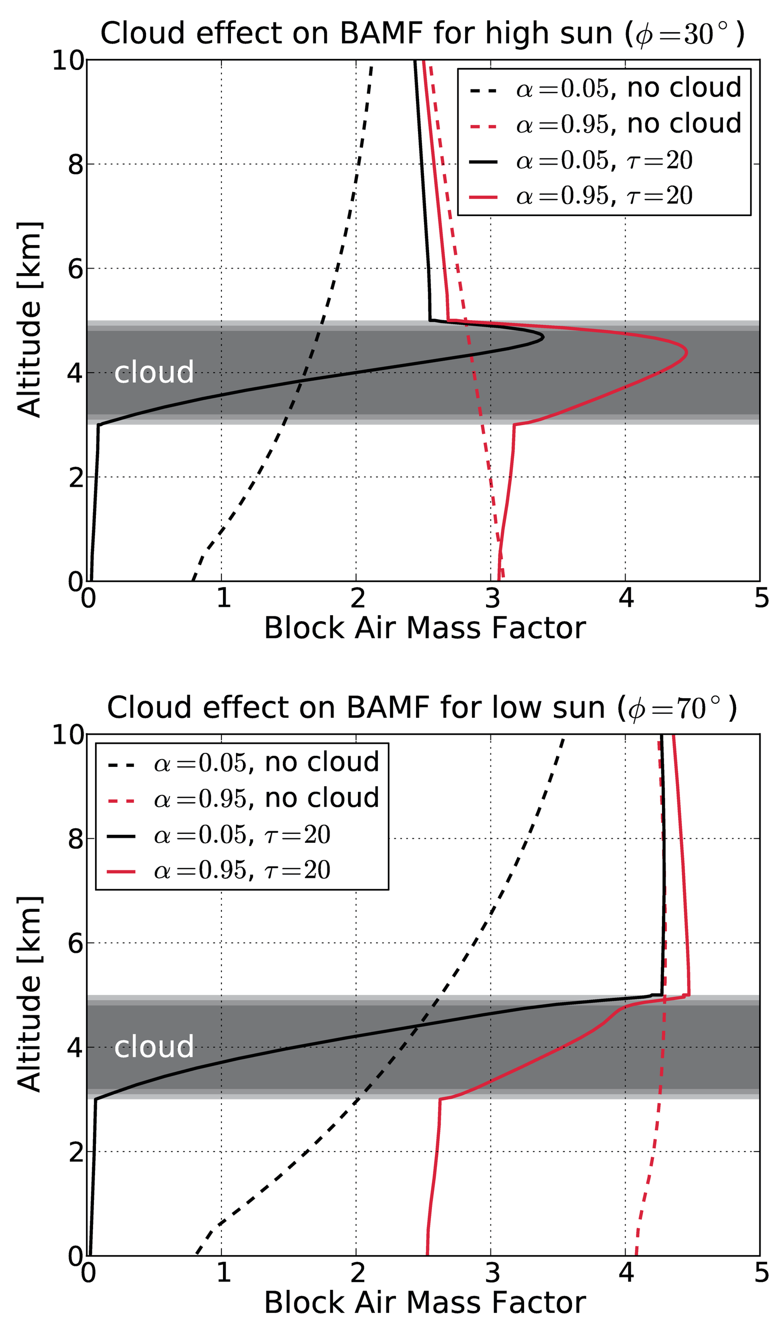
Cloud Effects on the BAMF

Effects of clouds on the radiative transfer



- high albedo at cloud top
  → increased BAMF directly above the cloud
- strong multiple scattering inside cloud
  → light path enhancement leads to high BAMF
- loss of photons inside and below the cloud
  → reducing BAMF due to shielding
- high albedo cover above ground
  → photons cannot easily reach the detector
  → light path enhancement and shielding compete depending on cloud and surface parameters

This may allow detection of small amounts of trace gases under cloudy conditions.



Comparison of BAMFs for different surface albedo and solar zenith angle scenarios at a wavelength of λ = 435 nm.

Influence of albedo

- shape of BAMF strongly dependent on albedo
  → higher photon flux boosts light path enhancement
- high surface albedo leads to strong peak inside the cloud
- multiple back-and-forth scattering counteracts shielding below the cloud

Influence of vertical profile

- strong vertical variance of BAMF
  → little variance above & below cloud
  → strong local variance within cloud
- demands precise knowledge of the vertical profile of the trace gas

Influence of viewing geometry

- high solar zenith or viewing angles lead to high BAMF by geometry
- radiative transfer below top of cloud only weakly dependent on geometry
- BAMF below cloud is small compared to BAMF above cloud
  → still, the trace gas can be detected

Results

- Presence of clouds strongly perturbs the radiative transfer
- Bright surfaces below clouds significantly alter the radiative transfer
- Multiple scattering may compensate the photon-loss below and inside the cloud
- Effects of albedo, shielding and light path enhancement compete to either attenuate or amplify the signal
- Precise vertical profile of trace gas needed for analysis of cloudy scenes
- Effects of clouds over bright surfaces can be seen in $O_2 \cdot O_2$ observations

Selected References

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