Remote sensing trace gas observations by satellite instruments over bright surfaces

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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
- over bright surfaces, trace gases below clouds may still be detected
- compensation of shielding and light path enhancement can be seen in satellite data
  - correlation of cloud cover and observed column
- $O_2 \cdot O_2$ allows analysis of this effect, having a known and suited vertical profile

Block-Airmass Factor (BAMF)

Airmass factor (AMF)

- sensitivity of satellite measurement to trace gas depends on radiative transfer
- AMF: 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: the vertical contributions to the AMF → tracer sensitivity at different altitudes
- with altitude h, the normalized vertical profile n(h) of the trace gas and the BAMF:

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

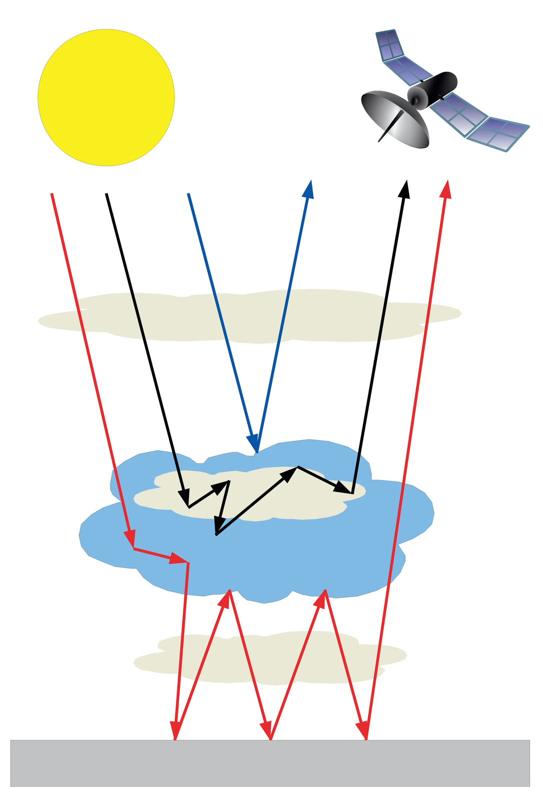
Effects of clouds on the radiative transfer

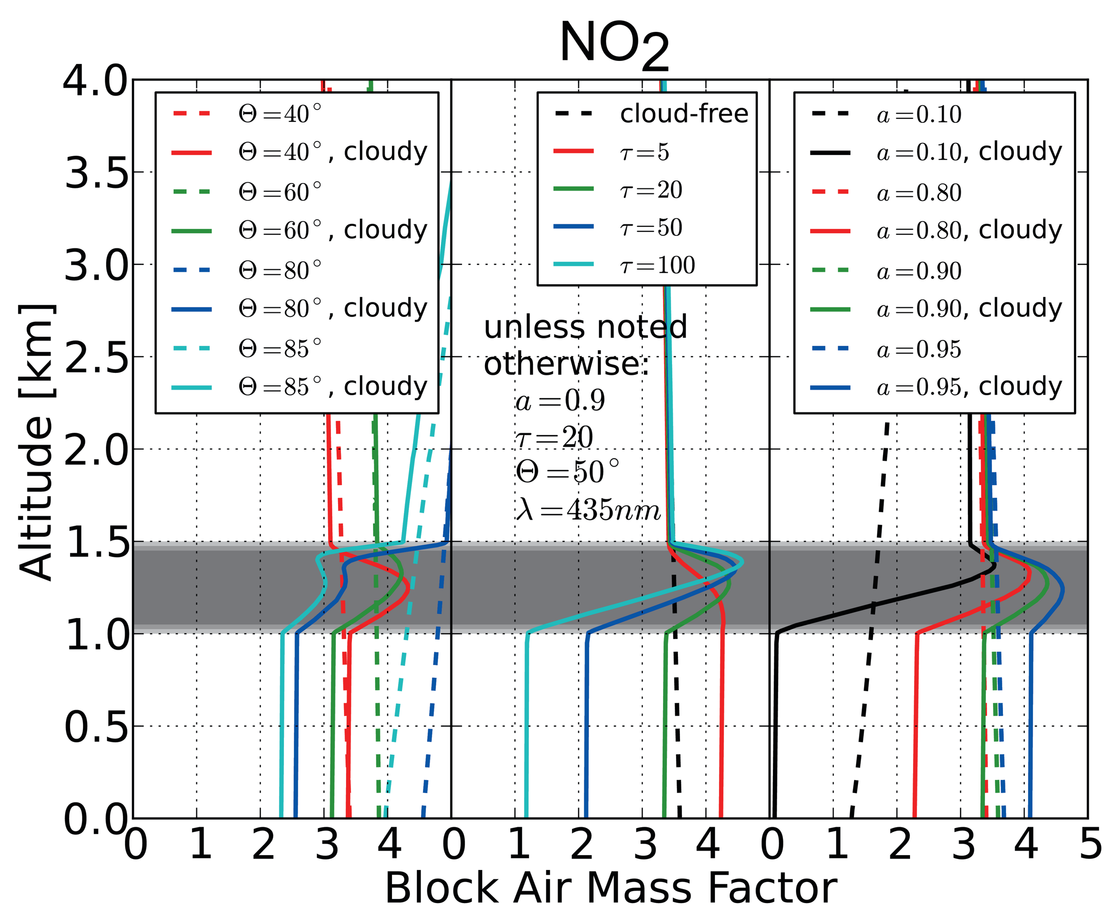
- multiple scattering inside the cloud
- high albedo on cloud top
- shielding of radiation from atmosphere below the cloud
- back-and-forth scattering between cloud and bright surface (light path enhancement)

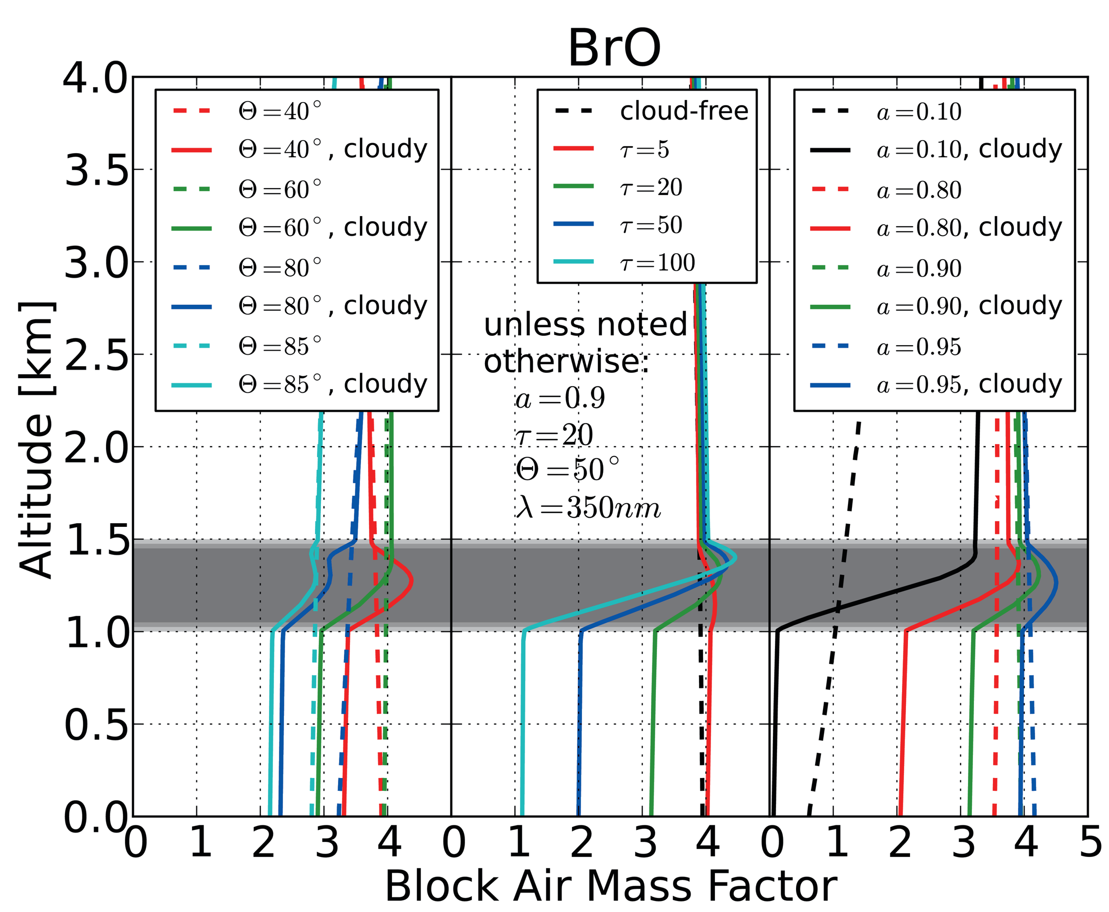
Effects of clouds on the BAMF

- shape depends strongly on cloud and surface properties
- below cloud little variance under different viewing geometries over bright surfaces
- trace gases between bright surface and cloud can still be detected → compensation of effects
- influence strongest in visible spectrum, but still valid for UV

→ the vertical distribution of the trace gas has a significant effect on the sensitivity of the measurement







Comparison of BAMFs for varying solar zenith angle, optical thickness and surface albedo at a wavelength of λ = 435 nm for NO_2 and λ = 350 nm for BrO.

Observations over snow & ice

Effects of high albedo below clouds

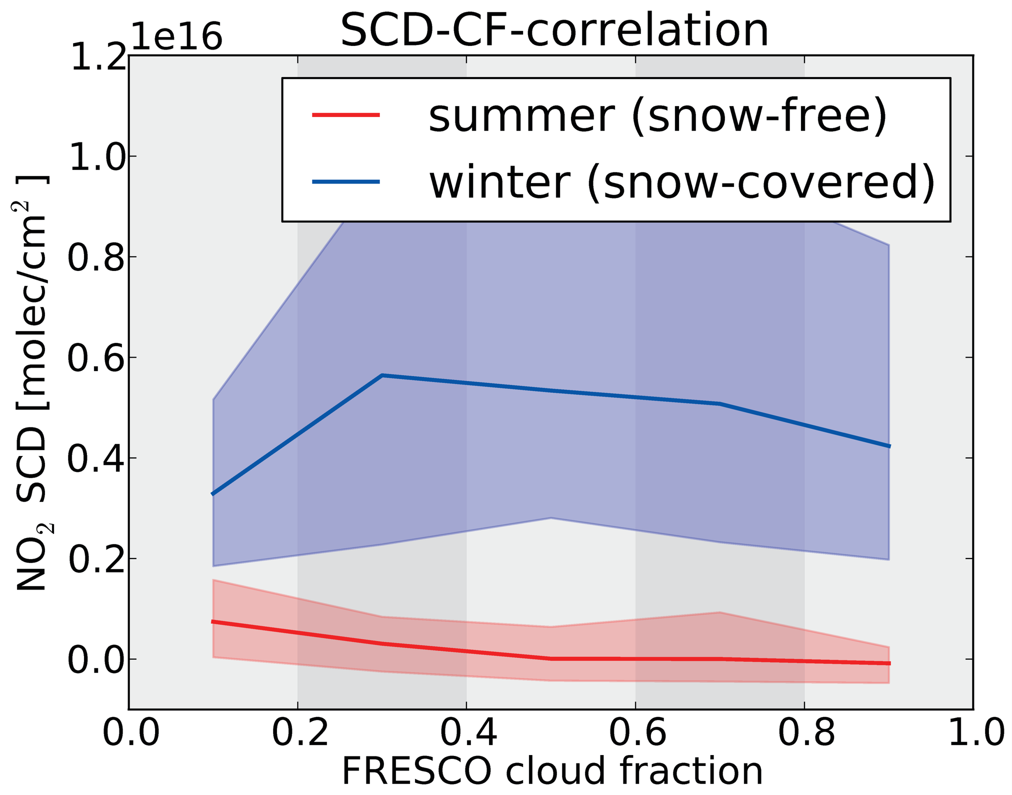
- light path enhancement should be visible in observation time series over scene with variable albedo
- over bright surfaces, trace gases below clouds can still be detected by satellite
  → explains e.g. observation of BrO over the Arctic regardless of clouds
- observations of trace gases mixed with clouds may be enhanced
  → challenge and opportunity for analysis of scenes influenced by convection
  - e.g. long range transport of pollution which is linked to frontal systems
- compensating effect has been confirmed in $O_2 \cdot O_2$ observations at high latitudes
  - $O_2 \cdot O_2$ has a known profile, strongly peaking in the troposphere
    → showcase gas for light path enhancement
  → see poster: http://www.doas-bremen.de/posters/cospar_2010_zien.pdf

Edmonton, Canada (53°N, 113°W)

- center for the oil and gas industry
  → strong NO_x emissions
- continuous snow cover in winter
- higher emissions in winter

Observation of NO_2

- area of continuously high NO_2 values with SCIAMACHY
  - 52° ≤ latitude ≤ 54°
  - -114° ≤ longitude ≤ -112°
- tropospheric NO_2 SCD
- FRESCO cloud fraction (CF)
- periods of full and zero snow cover have been selected



Median (line) and first and thrid quartile (shaded) of the Edmonton summer (1082 datasets) and winter (1241 datasets) NO_2 SCD data from SCIAMACHY in 2007 and 2008.

Correlation of SCD and CF

- snow-free: correlation coefficient r = -0.289
  → significant correlation between observed column and cloud fraction
  → decrease of SCD with cloud cover, as expected
- snow-covered: correlation coefficient r = -0.003
  → compatible with random distribution
  → only weak dependence on cloud cover
- cloud retrieval may have an effect on the result

→ compensating effect of llight path enhancement for cloudy scenes with bright surface

Results

- Presence of clouds strongly perturbs the radiative transfer
- Effects of albedo, shielding and light path enhancement compete to either enhance or diminish the remote sensing sensitivity
- Precise vertical profile of trace gas and cloud needed for detailed analysis
- Effects of clouds over bright surfaces can be seen in satellite data
  - showcase gas $O_2 \cdot O_2$: strong sensitivity to albedo
  - NO_2: weak correlation between observed column and cloud cover
- over bright surfaces, trace gases may be detected below clouds
- challenge and opportunity for remote sensing under cloudy conditions

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