Cloud effects on tropospheric NO_2 measurements from satellite

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Introduction

- clouds affect the observation of trace gases in the atmosphere by satellite
- two competing effects occur in the radiative transfer
  - shielding of trace gas below and within the cloud
  - light path enhancement within and below the cloud
- large fraction of satellite data is excluded from analysis due to clouds
  - leads to significantly smaller data set
  - may introduce biases & artificial structures
- some phenomena, such as transport events, are typically associated with clouds and need a proper treatment of cloudy data

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):

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

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:

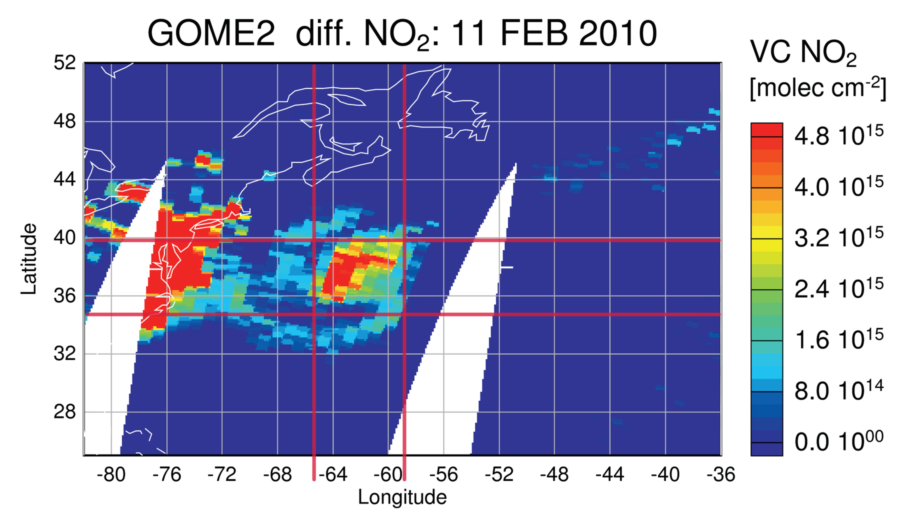
$$\mathrm{AMF} = \int_0^{\mathrm{TOA}} n(h)\,\mathrm{BAMF}(h)\,\mathrm{d}h$$

→ linear approximation

Observed Tracer Distributions

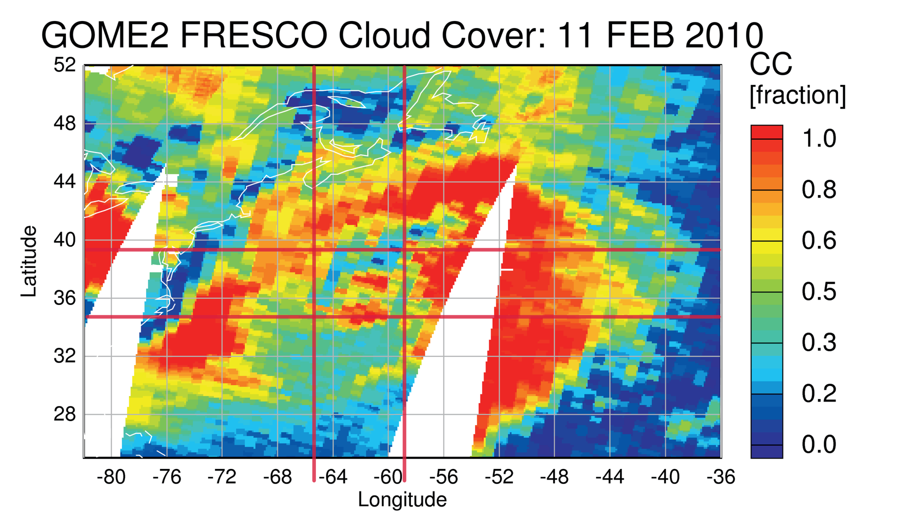
Long-range transports

- frontal systems lift plumes of pollution into higher layers
- concentrated plumes get transported by winds
- typically associated with clouds
→ cannot be detected in cloud-screened data
→ cannot be analyzed without proper cloud treatment



Cloud influence on observed distributions over dark surfaces

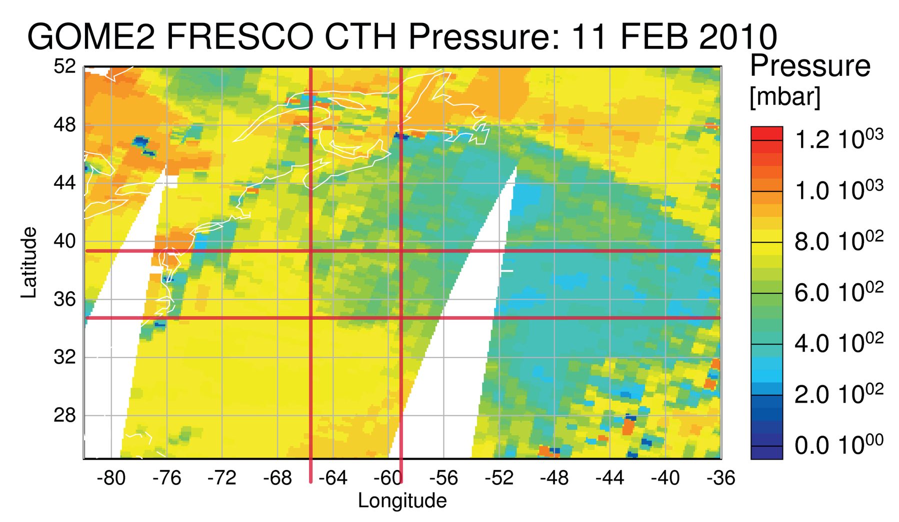
- high and thick clouds may shield parts of the plume
- low clouds provide a strong signal
  → trace gas resides above or inside top of cloud
→ observed plume shows structures of the cloud system



Bright surfaces (not shown)

- less absorption on the ground
- higher radiation field below and inside the cloud
→ compensates shielding below cloud
→ further enhancement of signal inside cloud

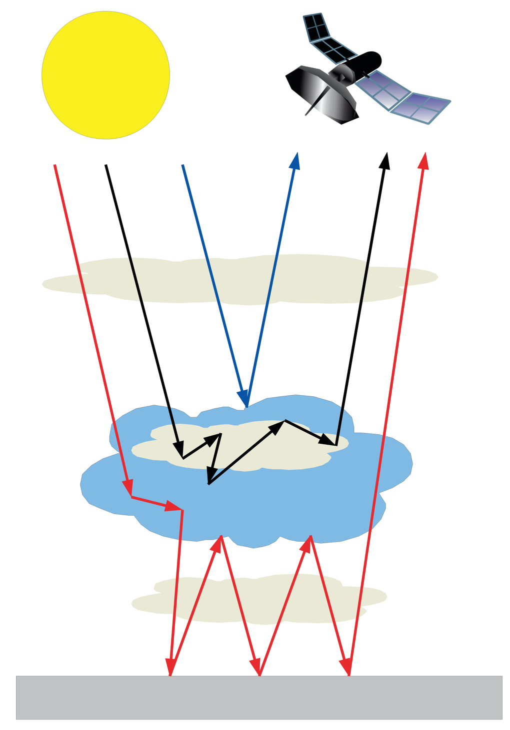
This may help the detection of transport events in polar regions.
→ reliable detection of clouds over bright surfaces necessary



Measured NO_2, cloud cover and cloud top height pressure for a transport event over the Atlantic Ocean

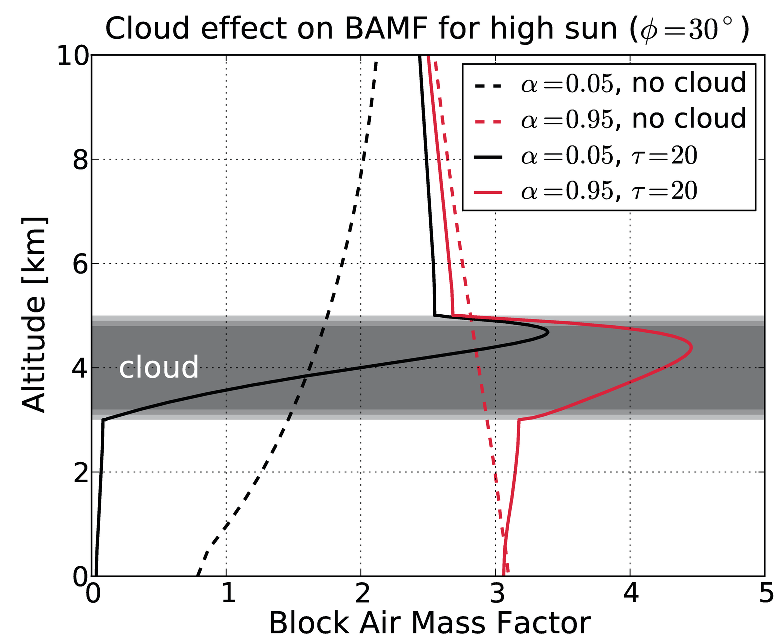
Cloud Effects on the BAMF

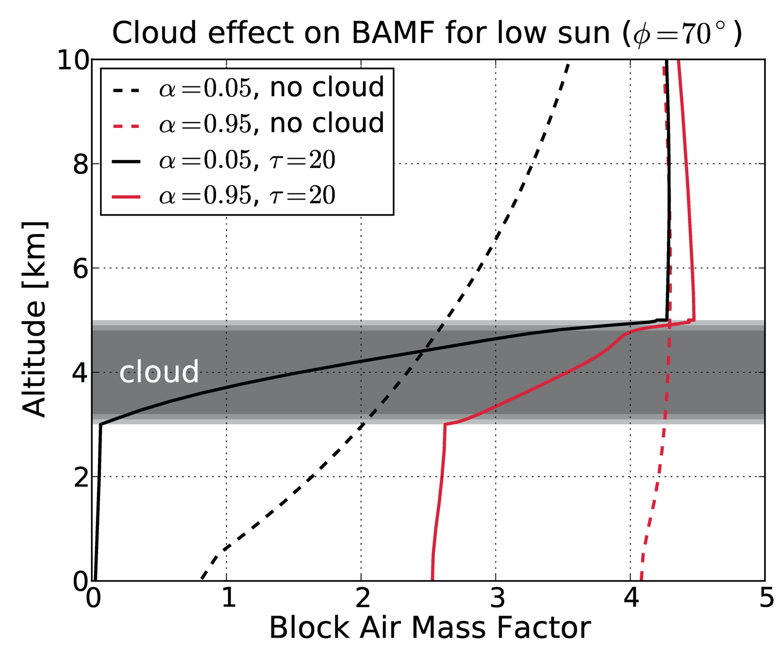
Effects of clouds on the radiative transfer



- 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 be used to detect small amounts of trace gases under cloudy conditions.





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

Albedo influence

- 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 compensates shielding below the cloud

Geometrical influence

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

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

Results

- Presence of clouds strongly perturbs the radiative transfer
- Effects of shielding and light path enhancement compete to either attenuate or amplify the signal
- Light path enhancement by clouds may lead to signal amplification
- Bright surfaces below clouds significantly alter the radiative transfer
- Multiple scattering may compensate the photon-loss below and inside the cloud
- Precise vertical profile of trace gas needed for analysis of cloudy scenes

Selected References

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