Cloud effects on tropospheric NO\textsubscript{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):
  \[ \text{VCD} = \frac{\text{SCD}}{\text{AMF}} \]

Block-airmass factor (BAMF)

- BAMF describes the vertical contributions to the AMF
  → sensitivity to trace gases at different altitudes
- integral over altitude of the product of the normalized vertical profile \( n(h) \) of the trace gas and the BAMF yield the AMF:
  \[ \text{AMF} = \int_0^\text{TOA} n(h) \text{BAMF}(h) \, dh \]

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.

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.

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

Koshakwsky, A. A., Rizov, V. V., Retrieval of NO\textsubscript{2} vertical column under cloudy conditions: A sensitivity study based on SCIAMACHY calculations, Atmospheric Research, 93, 1, 608-608, 2009.

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