Aerosols Measurements from Space

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with contributions from:

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- Definition and properties of aerosols
- Importance of atmospheric aerosols
- Effects of aerosols on space borne measurements
- Examples of space borne aerosol observations
- Conclusions & Outlook
Definition & Properties (1)

....By definition, aerosols are a system of liquid or solid particles uniformly distributed in a finely divided state through a gas, usually air. **Aerosol size** ranges roughly from 1 nanometer (smallest thermodynamically stable clusters) to 100 micrometers (largest dust particles not drawn to the ground by gravitation).

...What about (H2O-) clouds?

Typical cloud droplets:
Size: 5 – 20 µm, Concentration: several 100 cm⁻³

⇒ Clouds are Aerosols, but:

- because of the special role of water in the atmosphere it is often distinguished between clouds and 'other' aerosols
- especially for satellite observations clouds often complicate the measurement of 'other' aerosols
- this talk deals with both: clouds and 'other' aerosols
**Definition & Properties (2) Wavelength dependence**

**Mie extinction cross section** (r: 500 nm, refractive index: 1.5)

\( \lambda >> r \Rightarrow \sigma \sim \lambda^{-4} \quad \text{(Rayleigh scattering)} \)

\( \lambda << r \Rightarrow \sigma \sim \lambda^{-0} \quad \text{(Clouds)} \)

for typical aerosol size distributions: \( \sigma \sim \lambda^{-1} \text{ to } \lambda^{-1.5} \)
Aerosols cause absorption and scattering:

Absorption coefficient: \( K_a = \sigma_a \cdot n \)

Scattering coefficient: \( K_s = \sigma_s \cdot n \)

\( \sigma_a \): absorption cross section, \( n \): concentration

\( \sigma_s \): scattering cross section

Single scattering albedo:

\( \tilde{\omega} = \frac{K_s}{K_s + K_a} \)

Single scattering albedo for different aerosol types

(Takemura et al., J. of Climate, 2002)
Sources of Atmospheric Aerosols

**Continental Aerosols**

- **Wind Generated Aerosols**
- **Soil Derived Dust**
  - Mineral Particles
  - Desert Dust

**Biogenic Aerosols**
- Pollen, Bacteria

**Anthropogenic Aerosols**
- Combustion
- Soil Preparation
- Direct Dust Emission
- Traffic

**Marine Aerosols**

- **Sea Spray Evaporation**
- **Sea Salt Aerosol**
- **Non Sea Salt (DMS)**
- **Oceanic**

**Polar Aerosols**
- **Ice Particles**

**Cloud droplet evaporation**
**Gas to Particle Conversion**

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**Definition & Properties (5)**

- **Mixed Marine**
- **Sulfates 0.2 m**
- **Fla Ash**
- **Bacteria 1 m**
- **Seasalt 10 m**
- **Soot 0.05 μm**
- **Soot + Ammonia Sulfate 1 μm**

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**Physical state**  
- solid, liquid, mixed phase state

**Shape**  
- spherical, non-spherical

**Size range**  
- 0.005 ... 0.05 μm  
  - ultrafine – nucleation mode  
- 0.05 ... 0.5 μm  
  - submicron – accumulation mode  
- 0.5 ... 5.0 μm (>10)  
  - supermicron – coarse modes

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Importance (1) physical and chemical effects

Aerosols affect the energy balance of the earth:

Aerosols interact with the surrounding air:
- growth with humidity
- condensation nuclei, ice nuclei
- heterogenous chemistry

(C) ICCP
Importance (2) Influence on trace gas measurements

Atmospheric trace gas absorptions detected in satellite spectra:

- $O_3$ UV
- HCHO
- $OClO$
- $O_4$
- $H_2O$
- $O_2$
- $SO_2$
- BrO
- $NO_2$
- $O_3$ vis

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What do we want to know?

- aerosol concentration
- aerosol composition
- vertical distribution
- global distribution
- high spatial resolution

....how can we get this (from Space)?
...utilise the **scattering** and **absorbing** effects of aerosols:

**Aerosol absorption and scattering influences:**
- intensity of the observed radiation
- wavelength dependence of the observed radiation
- angular dependence of the observed radiation
- polarisation of the observed radiation

=> **broad band intensity measurements**

**Aerosol scattering influences:**
- atmospheric photon paths
- atmospheric trace gas absorptions
- Raman scattering (Ring effect)

=> **high and moderate spectral resolution**
Influence of changed Photon Paths:

A)  
- **Intensity:** Low  
- **Absorption:** High  
- **Concentration profile:** e.g. O₂  
- **Low surface albedo**

B)  
- **Intensity:** High  
- **Absorption:** Low  
- **Concentration profile:** e.g. O₂  
- **Low surface albedo**

C)  
- **Intensity:** High  
- **Absorption:** High  
- **Concentration profile:** e.g. O₂  
- **High surface albedo (Snow, Ice)**

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Different viewing geometries and wavelength ranges:

**Processes:**
- Extinction
- Emission
- Extinction
- Scattering
- Emission
- Reflection

**Instruments:**
- SAGE, ILAS, HALOE, GOMOS, SCIAMACHY, ...
- LIMS, MLS, CLAES, MIPAS, SCIAMACHY, ...
- SBUV, TOMS, GOME, SCIA, OMI, (A)ATSR, MISR, POLDER, SeaWiFS, MERIS, MOPITT, ...
- ...weather satellites...

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Limitations (1)

Compromise between spectral and spatial resolution

Spatial Resolution of instruments with 'high' spectral resolution

- GOME
  40x80km²
- SCIA
  15x26km²
- OMI
  13x13km²

Spatial Resolution of instruments with 'low' spectral resolution (e.g. MERIS: 0.3x0.3 km²)

MERIS image, Mt Etna, Sicily
28 March 2002
(c) ESA
**Limitations (2)**

**Influence of clouds**
- many measurements are covered by clouds (e.g. nearly all GOME ground pixel)
- clouds are bright (even small clouds can mask aerosol effects)
- clouds are white ($\lambda^{-0}$)

![GOME ground pixel size](image)
Limitations (3)

Effects of surface reflectivity and trace gas absorptions

-especially snow, ice

⇒ one solution: multi viewing angles

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Composite map of the mean AOT at 0.659 µm retrieved using ATSR-2 data for February and March, 1999 over the INDOEX area. Over white areas no data is present (G. de Leeuw)

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High Spatial Resolution:

Aerosol over Central Europe

Large cities as source regions
Regional distribution of AOT and thin cloud coverage

(SeaWiFS)

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High Spatial Resolution:

MODIS color image using 0.47, 0.55 & 0.66 for blue green and red

MODIS aerosol optical thickness of coarse dust and fine pollution

March 20, 2001

China

Korea
High Spatial Resolution:

MODIS and models for September 2000

- Model Chin et al., 2002

MODIS aerosol optical thickness

Fine aerosol

- Natural fine aerosol
- Fine anthropogenic

Coarse aerosol
Both CO and fine mode aerosol are produced by urban pollution, industrial combustion, and biomass burning.
High Spectral Resolution:

Absorbing aerosol index (aai) retrieval from Sciamachy and GOME
Martin de Graaf and Piet Stammes, KNMI

\[
\text{AAI} = -100(\log(R_{335}/R_{380})_{\text{meas}} - \log(R_{335}/R_{380})_{\text{Ray}})
\]

See also poster at session AS14:
'Global observation of UV-absorbing aerosols from ERS2/GOME data'.

- dust aerosols over the Sahara
- biomass burning aerosols over Borneo
- probably anthropogenic aerosol
Aerosol climatology of Sahara desert dust from GOME data. Here the average value of desert dust is reported for June 1997. The yellow-red range indicates the presence of desert dust events embedded into a maritime aerosol and residual clouds (light blue). (R. Guzzi)
**Combination of instruments:** Aerosol OT and component maps from GOME/ATSR-2 (SCIA/AATSR)

T. Holzer-Popp and M. Schroedter, DLR-DFD
Method and case study validation published in: JGR 107 (2002), D21 and D24

Europe 1-3 September 1995
full resolution OT map (right)
component map (below)

Case study validation against AERONET sun photometers from 340 to 870 nm indicates to selecting the right aerosol OT and mixture

IN=insoluble, WA=watersoluble, SO=soot, SA=sea salt accumulation mode, SC=sea salt coarse mode, MT=mineral transported
Validation:

AOT over Central Europe, Aug. 1998

Pollution outbreak from US East coast, Aug. 2001

Australian forest fires, Dec. 2001

Some SeaWiFS Examples

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Validation:

Satellite retrieved vs. measured AOT at three sites

Venice

Ispra

Toulouse

with VGT blue band

with SeaWiFS band at 412 nm

The retrieval algorithm requires calibration with a limited amount of ground measurements. We think that this method potentially allows to monitor the AOT at particular sites (e.g. industrial), without permanent ground instrumentation and also retro-actively by using archived satellite data.

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Retrieving Spectral Behavior of Aerosol Optical Thickness

Spectral Behavior

Spectral ranges:
- over land: 6 channels 0.412 - 0.670 µm
- over ocean: 8 channels 0.412 - 0.865 µm

Investigation of different aerosol types

Spectral Aerosol Optical Thickness

Australian Forest Fire Haze

near the fires

far the fires

unaffected

CIMEL, Coleambally
34.80S, 146.05E

43N, 12W (W of Spain), continental outflow

C. Verde I.

**Limb IR:**

Simulated MIPAS spectra for a partly opaque cirrus cloud in 16.5 km.

Black: without cloud

Blue: including absorption, emission of the cloud as well as single scattering out of the line of sight

Red: including also single scattering into the line of sight

(G. Stiller, FZ Karlsruhe)
**Limb IR:**

Mikrophysical aerosol parameters from MIPAS-Envisat measurements

Michael Höpfner, Institut für Meteorologie und Klimaforschung, Forschungszentrum Karlsruhe in der Helmholtz-Gemeinschaft

MIPAS-Envisat cloud-top height:
PSCs and tropical cirrus

- High-resolution, mid-IR limb-emission spectra contain information about aerosols and thin clouds
- Mean size, volume density and composition were derived from MIPAS-Balloon measurements of PSCs in the Artic winter stratosphere (Höpfner et al., GRL, 2002)
- With MIPAS-Envisat it is possible to derive information on PSCs and sub-visible cirrus clouds on a global scale
### Aerosol sensitive parameters measured by GOME

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Depending on</th>
</tr>
</thead>
<tbody>
<tr>
<td>$O_4$-absorption 630 nm</td>
<td>Clear view down to the ground</td>
</tr>
<tr>
<td>$O_4$-absorption 360 nm</td>
<td>Clear view down to the ground, ground albedo</td>
</tr>
<tr>
<td>$O_2$-absorption 630 &amp; 760 nm</td>
<td>Clear view down to the ground, ground albedo</td>
</tr>
<tr>
<td>Polarisation</td>
<td>Ratio of single Rayleigh scattered light to total intensity</td>
</tr>
<tr>
<td>Ring effect</td>
<td>Ratio of Raman scattered light to total intensity</td>
</tr>
</tbody>
</table>
Special use of high spectral resolution:

Absorption spectrum of the oxygen dimer O₄ (Greenblatt et al., 1990).

O₄ absorption bands analysed in GOME spectra

O₄-Absorptionen (Greenblatt et al., 1990)
Test of different parameters over extended clouds:

04.09.1996: Hurricane Fran

NOAA GOES-8 Satellite, 16:02 UTC
Sensitivity to snow / ice

Dundee Satellite Receiving Station, Dundee University, Scotland (http://www.sat.dundee.ac.uk/).

Change from snow to open ocean

GOME flight track

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Direct Aerosol (and cloud and albedo) correction for GOME H$_2$O measurements using O$_4$ absorption measurements

(Wagner et al., ACPD, 2003)

Comparison of the GOME H$_2$O with modelled H$_2$O VCDs (ECMWF)
Conclusions & Outlook

• Many satellite instruments are sensitive to atmospheric aerosols, they can measure the spectral dependent effects of aerosol scattering and absorption.

• Aerosol products include optical thickness and composition.

• Also molecular absorption and Raman scattering can be used to derive aerosol information (‘high’ spectral resolution).

  => Profile information?

• More detailed aerosol products should be derived from a combination of different satellite sensors, ground based instruments and atmospheric models.
Aerosol influence on ground based O₄ DOAS measurements

(Wagner et al., JGR, 2002)

O₄ Measurements clear sky Kiruna, 22.03.1994

Model results including aerosols
Aerosol extinction [km⁻¹]

<table>
<thead>
<tr>
<th>Altitude [km]</th>
<th>0.025</th>
<th>0.05</th>
<th>0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 1</td>
<td>![Graph 1]</td>
<td>![Graph 2]</td>
<td>![Graph 3]</td>
</tr>
<tr>
<td>5 – 6</td>
<td>![Graph 4]</td>
<td>![Graph 5]</td>
<td>![Graph 6]</td>
</tr>
<tr>
<td>11 – 12</td>
<td>![Graph 7]</td>
<td>![Graph 8]</td>
<td>![Graph 9]</td>
</tr>
</tbody>
</table>

Model results without aerosols

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