Polar Mesospheric Cloud Particle Size Retrieval from GOMOS / ENVISAT Observations

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Polar Mesospheric Clouds (PMCs), or Noctilucent clouds (NLCs)

- **Location:**
  High latitude summertime mesopause region (HLSM)
  (80 < altitude < 86 km, latitude > 55°)

- **Composition:**
  Water ice – meteoric smoke mixture (H₂O > 97% by volume, Hervig et al., 2012)

- **Why do we care?**
  - Very sensitive to changes in their environment → Important tracers for the complex processes that control the mesosphere
  (wave activity, dynamical coupling mechanisms)
  - Possible indicators of long-term climate change in the Mesosphere
GOMOS: Global Ozone Monitoring by Occultation of Stars

Part of the ENVISAT mission, developed by the European Space Agency. Launched in 2002 by Ariane 5 in Kourou (French Guyana).

Sun-synchronous orbit:
- Average altitude ≈ 800km, inclination = 98.6°, orbital period = 100.6min,
- Equator descending crossing-time = 10:00 local time

Stellar occultation technique:
- Very accurate altitude retrieval
- Very good geographical and temporal coverage
- Observations at various local times
- Self-calibrated data

Pointing system
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4 spectrometers UV-vis-NIR:
- **Spectral region:** 248-955 nm (UV – vis – NIR)
- **Spectral resolution:** 0.8 nm (A) and 0.13 nm (B)
- **Vertical resolution:** 1 to 1.7 km

(ESA)
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2 fast photometers

(ESA)
**PMC detection from GOMOS observations**

**Daytime**

2 fast photometers:

- Spectral bands:
  - FP1: ~470 – 520 nm
  - FP2: ~650 – 700 nm

- Sampling frequency = 1 kHz
- Vertical resolution < 1 km

Dark limb:

\[ F(z_t) = F_{\text{star}}(z_t) \]
Daytime PMC detection from GOMOS observations

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Bright limb without PMC along the line of sight:

\[
F(z_t) = F_{\text{star}}(z_t) + F_{\text{Ray}}(z_t) + F_{\text{straylight}}(z_t)
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Bright limb with PMC along the line of sight:

\[
F(z_t) = F_{PMC}(z_t) + F_{star}(z_t) + F_{Ray}(z_t) + F_{straylight}(z_t)
\]

→ PMC detection algorithm, and retrieval of their main properties (peak altitude, radiance)
GOMOS PMC data set

Detection algorithm applied to all GOMOS measurements from August 2002 to July 2010:

- > 300,000 profiles analysed
- > 21,000 PMCs detected

Extension of this data set until the end of GOMOS operational life (April 2012):
in progress at LATMOS in the framework of the ESA project mesosphEO (exploitation of the mesosphere).
**PMC particle size retrieval:**

**Determination of the Ångström exponent**

Knowledge of the size distribution of PMC ice particles:

**Essential for a correct modeling**

Ångström exponent \( \alpha \): characteristic parameter of the spectral dependence of light scattering by small particles.

- **Background bands** of GOMOS spectrometers CCD
- **Spectral range**: [350-600] nm
- **For each detected PMC**:
  1. External stray light correction
  2. Rayleigh radiance spectrum (reference):
     \[ L_{\text{Ray}} \propto \lambda^{-4} \]
  3. PMC radiance spectrum:
     \[ L_{\text{PMC}} \propto \lambda^\alpha \]
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- **For each detected PMC:**

4. **Ratio:**

$$R_{PMC} = \frac{L_{PMC}}{L_{Ray}} \propto \frac{\lambda^\alpha}{\lambda^{-4}} = \lambda^\alpha$$

logarithmic form:

$$\ln(R_{PMC}) = x \cdot \ln(\lambda) + C$$

with:

$$\alpha = x - 4$$
PMC particle size retrieval:
From Ångström exponent to particle size

- Assumptions:
  - Spheroids (AR = 2)
  - Normal distribution:
    \[ \sigma = \begin{cases} 
    10 \text{nm} & \text{if } r \leq 20 \text{nm} \\
    \frac{r}{2} & \text{if } 20 \text{nm} < r < 60 \text{nm} \\
    30 \text{nm} & \text{if } r \geq 60 \text{nm} 
    \end{cases} \]
  - Pure ice particles

- Modelling: T-matrix method
  (calculations by Gerd Baumgarten, IAP Kühlungsborn)

Note: median radius of a Gaussian distribution
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- Example:
  $\alpha = -2.58$ and $\theta = 138.2^\circ$

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  \[ r = 40.01\text{ nm} \]

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Example:
- $\alpha = -2.58$ and $\theta = 138.2^\circ$
  $\Rightarrow r = 40.01\text{ nm}$

More uncertain retrieval for the Southern hemisphere

Note: median radius of a Gaussian distribution
PMC particle size retrieval:
Results for the northern hemisphere

- Algorithm applied to all clouds detected between 2002 and 2010:
  ~14 000 PMCs in the northern hemisphere

- Output values:
  \[ 20 \text{ nm} < r < 45 \text{ nm} \]
  Mean radius = 30.3 nm
  Standard deviation = 5.2 nm
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*Results for the northern hemisphere*

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- **Good consistency** with other instruments:

  For example, SOFIE and SBUV:
  Observations in the Northern Hemisphere, between 2007 and 2013,
  Similar assumptions on the shape of the particles and on the particle size distribution:
  **SOFIE mean radius** = 30 nm, **SBUV mean radius** = 37 nm.
Seasonal features:
correlated with peak radiance

Consistent with seasonal evolution of the mesopause region:
*Saturation level higher in mid-season*

From Hervig and Stevens (2014)
Vertical and latitudinal variations

Anticorrelation between altitude and particle size:
1. PMC particles form near the mesopause where saturation ratios are largest.
2. Particles fall within the saturated layer and keep growing.
3. The deepest the layer, the larger the particles.

Clear linear increase towards the poles:

The vertical extent of the saturated region increases with latitude

→ Particle growth favored
Summary

PMCs:
Tracers for the **physical processes** that control the **mesosphere**.

Particle size:
Important parameter to look at, **essential for a correct modelling** of their formation, their growth and their lifetime.

GOMOS:
**8-year data set** (extension to 10 years in the framework of the ESA mesosphEO project)

Thank you for listening!