



On the ability of Multi-Axis-DOAS to detect clouds

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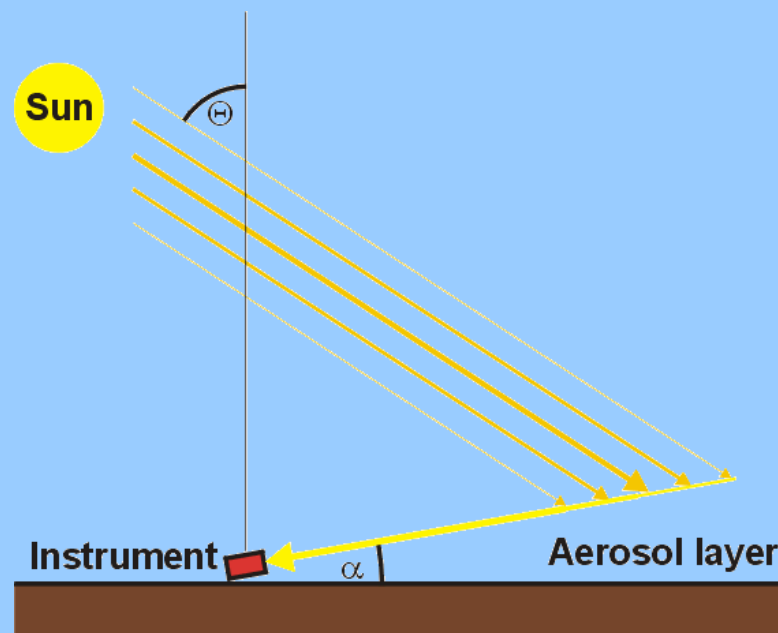
MAX-DOAS measurements under cloudy conditions

- Clouds have a strong impact on the atmospheric light path and thus significantly influence scattered light DOAS measurements.
- Advanced cloud flagging methods for MAX-DOAS measurements were developed within NORS WP4:
 - Thomas Wagner et al., *Cloud detection and classification based on MAX-DOAS observations*, AMT, 2014
 - Clio Gielen et al., *A simple and versatile cloud-screening method for MAX-DOAS retrievals*, AMT, 2014
- These are based on several indicators (intensity, O₄ absorption, temporal variability).
- But how are MAX-DOAS measurements and retrieval algorithms actually performing under cloudy conditions?



MAX-DOAS observations under clear-sky conditions

- Visibility is and thus atmospheric path length determined by aerosol content.
- Higher extinction leads to shortening of light paths
- At high aerosol load, multiple scattering becomes important.





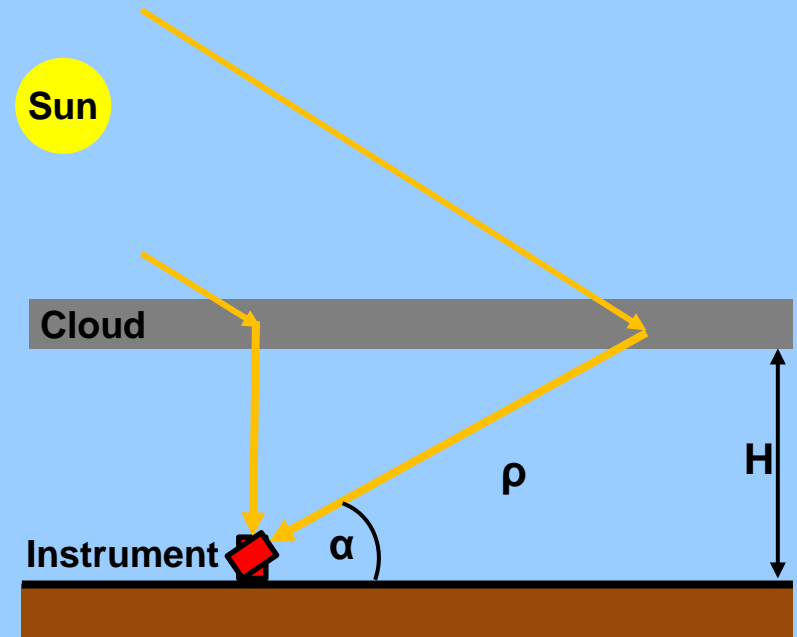
MAX-DOAS observations under cloudy conditions

- Optically thick homogeneous clouds act like a diffusor.
- Differential slant column density relative to zenith sky:

$$\Delta S(\alpha) = \varrho \cdot H \cdot \left(\frac{1}{\sin(\alpha)} - 1 \right)$$

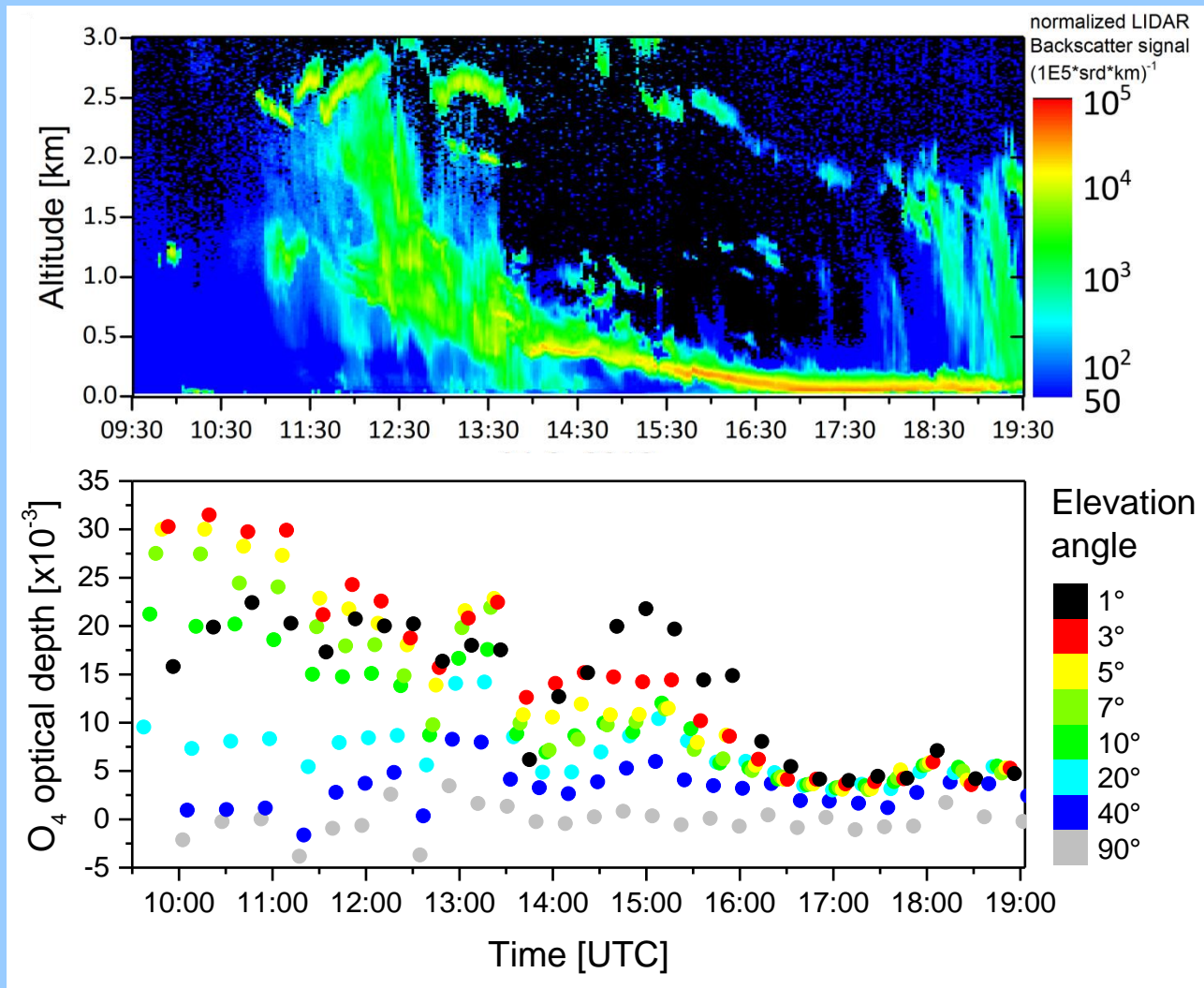
- Thus, if the trace gas concentration ϱ (e.g., O_4) is known, the cloud bottom height can be readily determined:

$$H = \frac{\Delta S(\alpha)}{\varrho \cdot \left(\frac{1}{\sin(\alpha)} - 1 \right)}$$



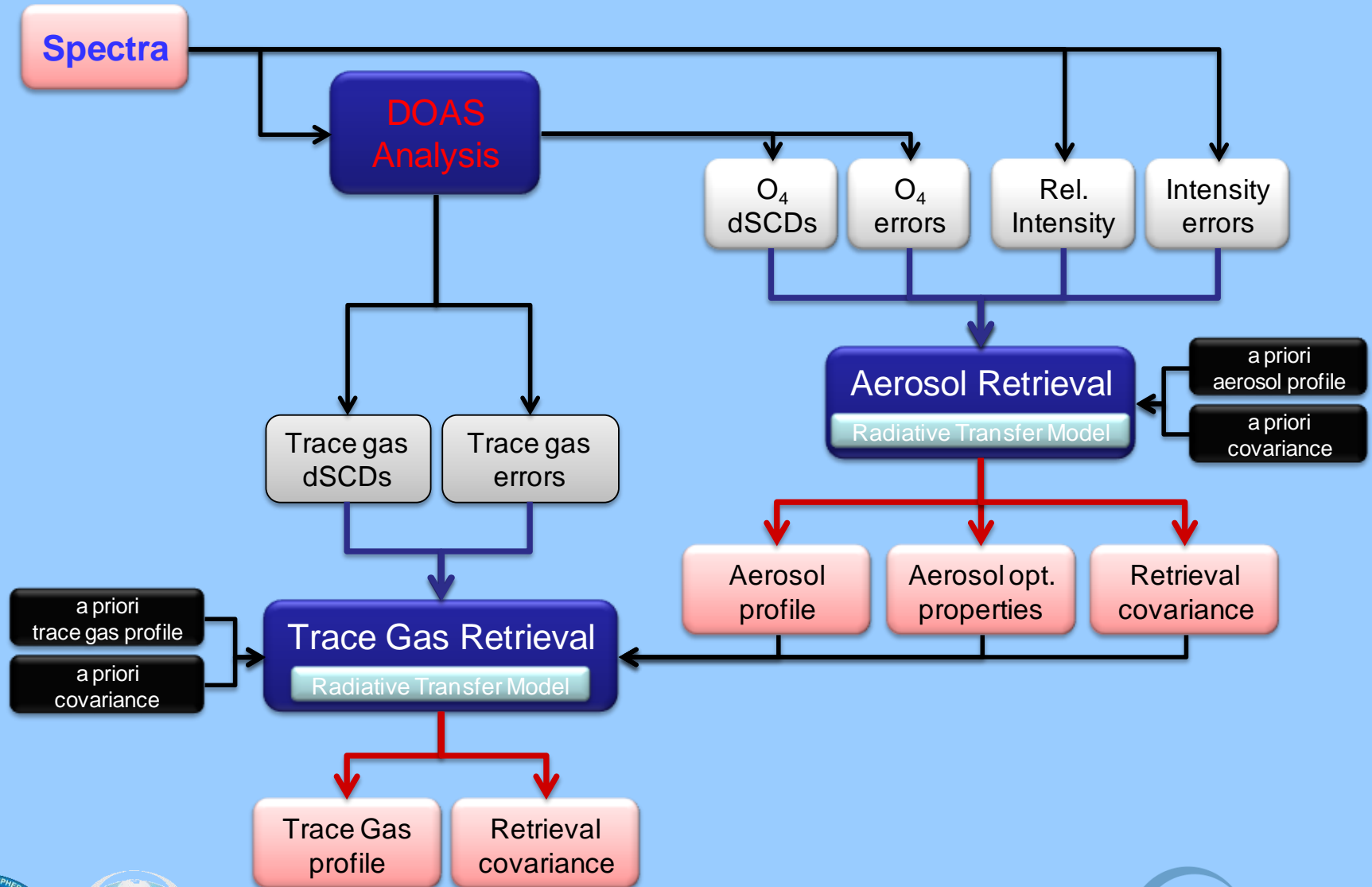


Variation of O_4 with cloud cover





Retrieval of Trace Gas and Aerosol Profiles from MAX-DOAS measurements





Polarstern cruise ANT XXIX-7

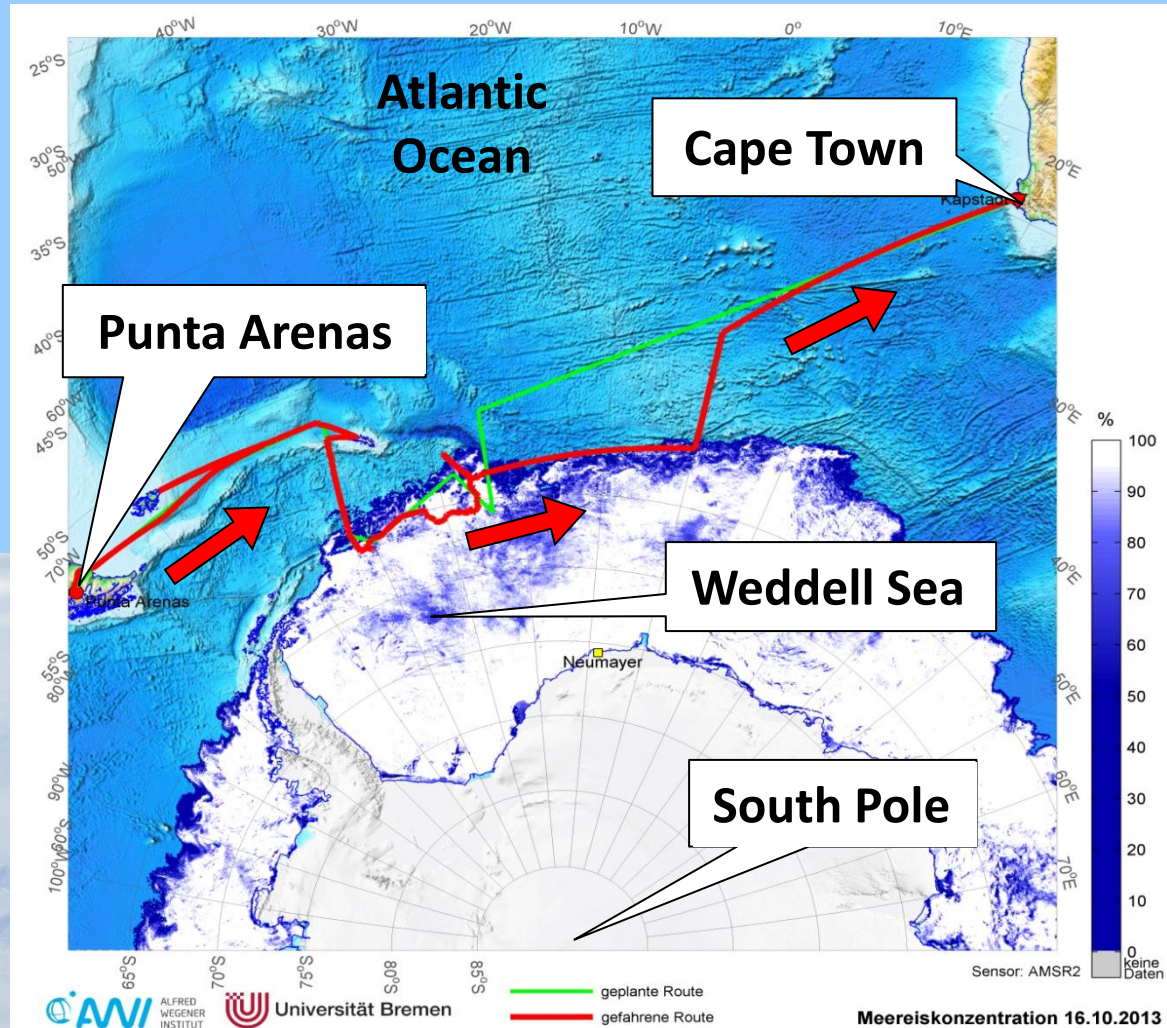
Punta Arenas – Cape Town

14. 8. 2013 – 16. 10. 2013

Continuous MAX-DOAS
measurements

33 helicopter DOAS
measurement flights

12 profile flights on 11 days



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NORS/NDACC/GAW Workshop, 7.11.2014



Instrumentation on-board Polarstern

MAX-DOAS



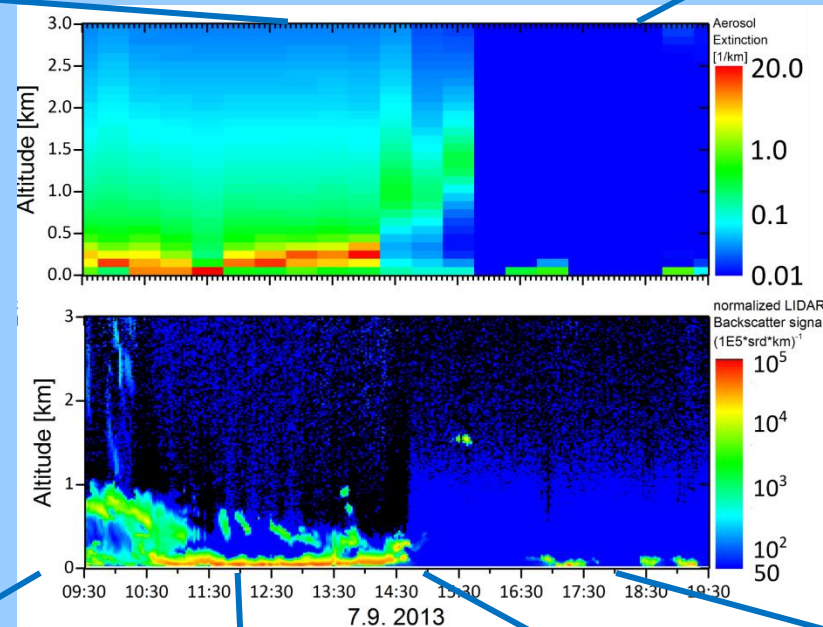
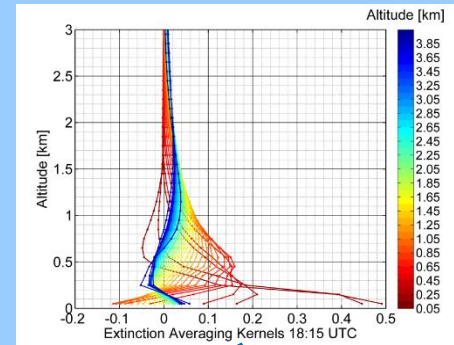
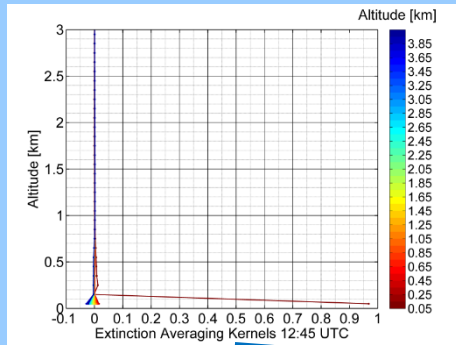
spectrometers	2 OMT
spectral range	277-617 nm (UV+VIS)
resolution	0,9 (VIS)/0,7 (UV)
measurement direction	perpendicular to heading
Elevation correction	yes
Elevation angles	1°, 3°, 5°, 10°, 20°, 40°, 90°

Ceilometer

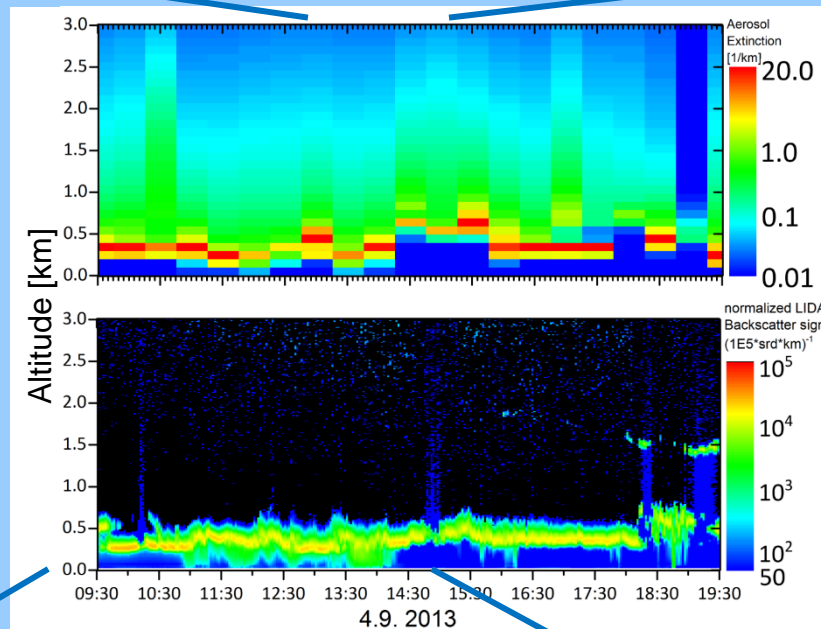
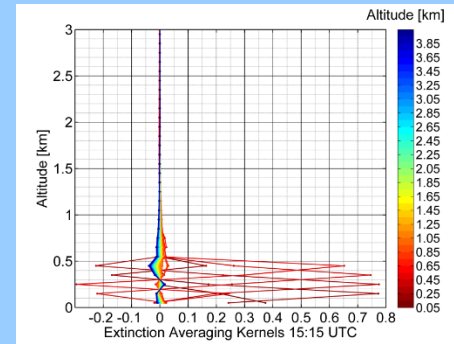
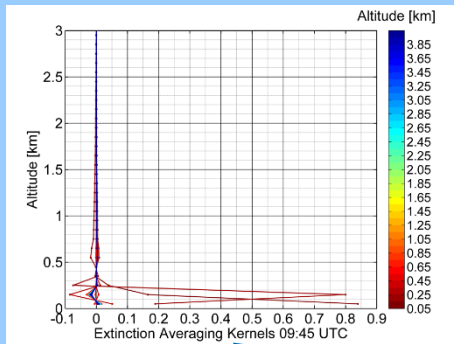


instrument	Vaisala CL51
measurement principle	LIDAR
vertical range	15000 m
vertical resolution	10 m
wavelength	910 nm

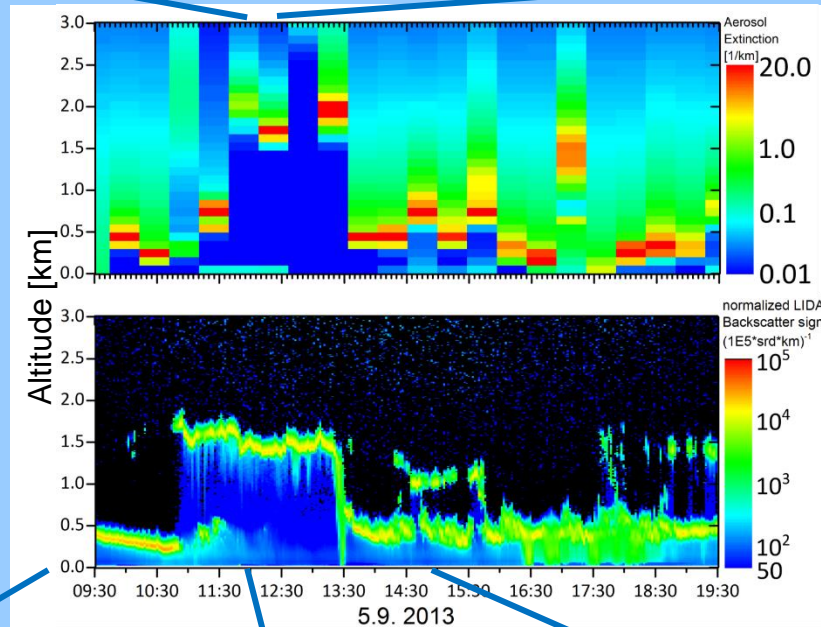
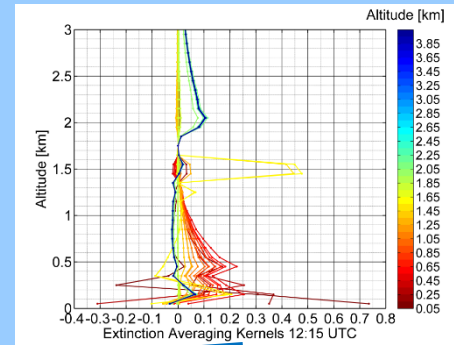
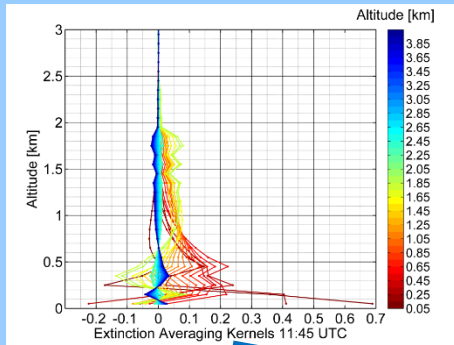
Polarstern Aerosol Extinction Profiles



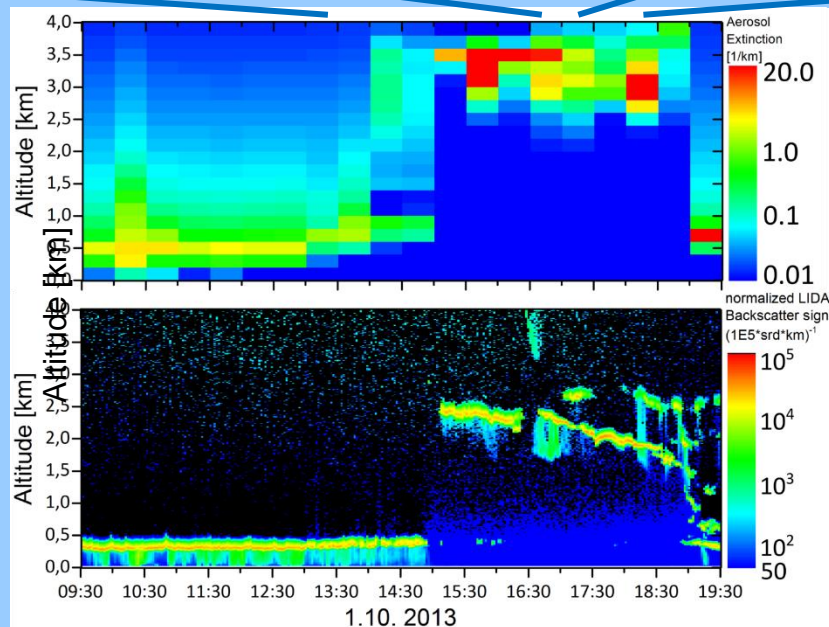
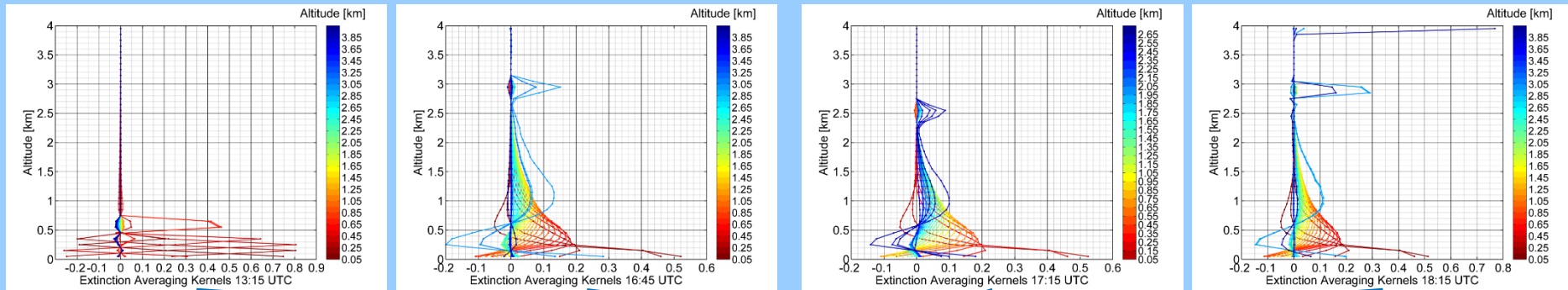
Polarstern Aerosol Extinction Profiles



Polarstern Aerosol Extinction Profiles



Polarstern Aerosol Extinction Profiles





MAX-DOAS Measurements of BrO and Aerosols in Barrow, Alaska during the OASIS field Campaign, February-April 2009

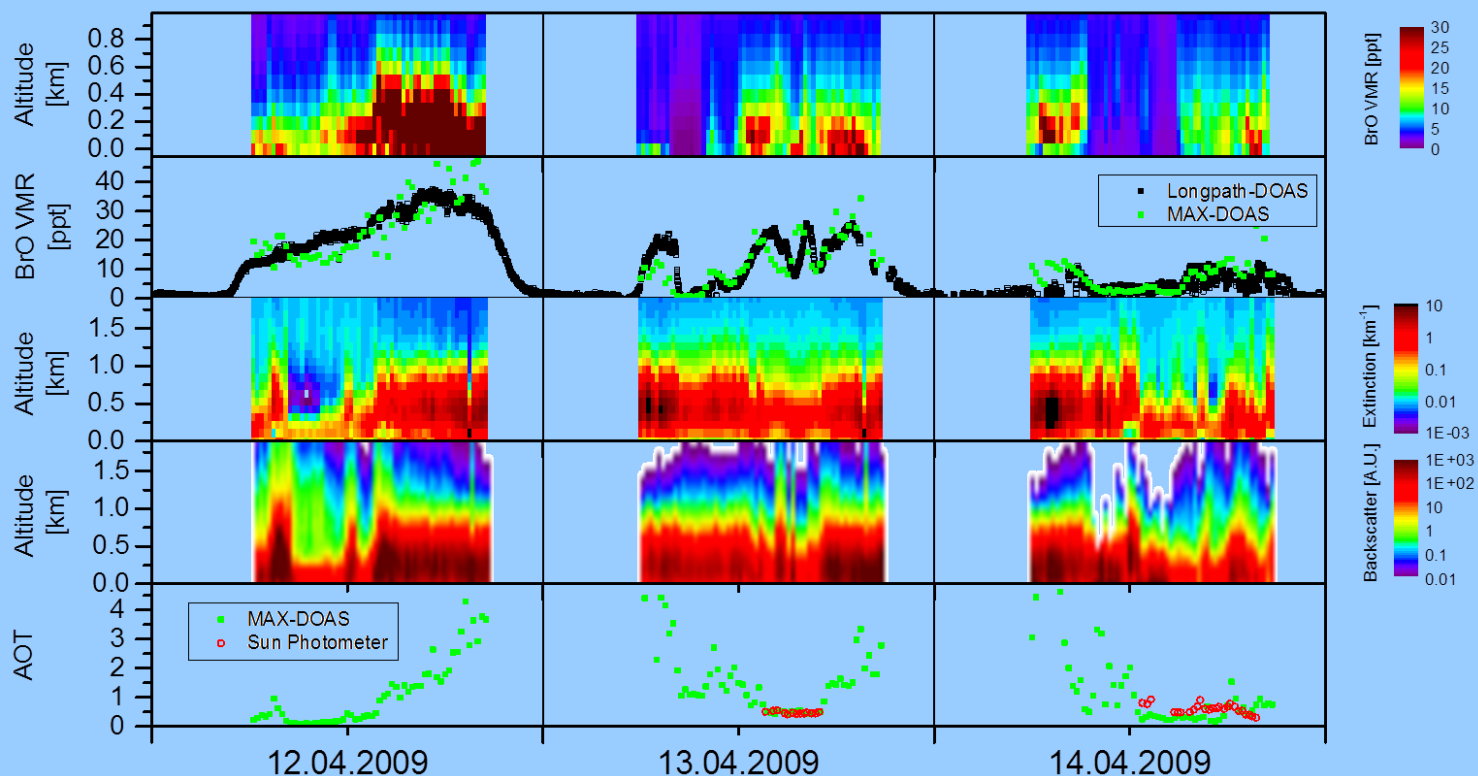
MAX-DOAS BrO profiles

BrO surface mixing ratio

MAX-DOAS extinction profiles

Ceilmeter backscatter profiles (AV Kernel applied)

Aerosol optical thickness



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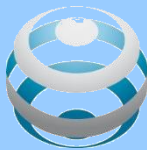
NORS/NDACC/GAW Workshop, 7.11.2014 [Frieß et al., JGR, 2011]





Summary

- Clouds strongly affect MAX-DOAS measurements. A cloud flagging of MAX-DOAS data is therefore important, but...
- Cloud-contaminated MAX-DOAS data should not be discarded since it may contain useful information on clouds, aerosols and trace gases.
- Due to the non-linear nature of MAX-DOAS measurements, cloud bottom height and to a certain extent also cloud vertical extent can be determined accurately in the presence of a homogeneous cloud cover.
- Compared to clear-sky conditions, the vertical resolution of trace gases and aerosols can even increase below a cloud.
- Useful information on trace gases can be gained even at very low visibility (fog, blowing snow).
- However, MAX-DOAS measurements in the presence of broken clouds still pose a serious problem.



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