Tropospheric water vapour observations by ground-based lidar

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Abstract: Ground-based lidars can provide continuous observations of tropospheric humidity profiles using the Raman-scattering of light by water vapour and nitrogen molecules. Profiles obtained since the beginning of year 2000 at the Koldewey Station (Ny-Ålesund, Spitsbergen) will be presented. Under nighttime conditions the observations cover a range from about 200 m altitude up to the upper troposphere, while daylight limits the observations to the lower troposphere, depending on water vapour content of the atmosphere. Lidar soundings are limited to clear-sky and high-cloud conditions. The usage of additional, weather-independent methods like radiosonde or GPS-based observations will be discussed. Simultaneous observations of humidity and aerosol extinction during the advection of aerosol rich air masses from the Kara Sea show some delay of the extinction increase compared with humidity increase. By another case study, the influence of the mean wind direction and the orography on the water vapour concentration near the ground and in the free troposphere will be discussed. E.g. during wintertime often a humidity inversion up to about 1.5 km altitude with drier air near the ground has been found, if wind comes from the south-east. Such local effects and small-scale structures observed by stationary lidar mostly cannot be resolved by satellite soundings or atmospheric models used e.g. for meteorological analyses or regional climate investigations.

Introduction

Water vapour causes about two third of the natural greenhouse effect of the Earth's atmosphere and is for this reason the most important greenhouse gas. Several climate models show that an increase in atmospheric humidity by 12-25 % will have the same global mean radiative effect than doubling the CO_2 concentration (Harries 1997). But in contrast to the homogenous distribution of the long-lived carbon dioxide is the water vapour distribution highly variable in space and time. Additionally, beside its (direct) radiative effect water vapour acts indirectly by interaction with aerosols, clouds, and precipitation (Hegg et al. 1996; Ramanathan et al. 2001). This indirect effect of surface cooling provides one of the largest uncertainties in the understanding of the radiative balance of the Earth's atmosphere (IPCC 2001).

To improve the understanding of the role of water vapour in the atmosphere, extensive water vapour soundings with high spatiotemporal resolution are necessary. Up to know, radiosondes provide the most valuable humidity data set, e.g. for numerical weather prediction (NWP) models. But today's standard radiosondes are of limited accuracy under the dry and cold conditions (Elliot & Gaffen 1991; Miloshevich et al. 2001) typical for the Arctic. Process studies of the hydrological cycle and aerosol-water vapour interaction require time series of humidity profiles, typically not performed by free ascending radiosondes. But this continuous water vapour soundings can be provided by optical lidar.

Water vapour observations by detection of the Raman-scattering of laser light have been described first by Melfi et al. (1969). A short laser pulse is emitted into the atmosphere. Besides elastic Rayleigh scattering with the air molecules, inelastic Raman scattering occurs, producing light with a wavelength shift characteristic for the scattering molecule. Water vapour Raman lidars detect the light backscattered by nitrogen and water vapour molecules. The ratio of the photons scattered by water vapour and nitrogen is proportional to the water vapour mass mixing

ratio. Water vapour lidars dispread past the end of the 80ies, when more powerful laser system elude the problems of small Raman backscatter cross sections (e.g. Whiteman et al. 1992).
The Koldewey Aerosol Raman Lidar (KARL) at Ny-Ålesund (78.9°N, 11.9°E) was build up in the end of the 90ies (Schumacher et al. 2001) and started regular water vapour sounding in the beginning of year 2000. It emits light at three different wavelengths (UV, vis, IR), and detects the backscattered light at seven different wavelengths from different height regimes in the troposphere and lower stratosphere. Table 1 summarises the system parameters. The KARL water vapour channels cover an altitude range between about 200 m and 6 km at nighttime conditions, while daylight limits the range to the lower troposphere, depending on water vapour content and skylight conditions. Typically, integration times of 30-60 minutes, altitude resolutions of 60 m and additional running averages of 180 m to 300 m are applied for water vapour profiles. The resolution in time can be increased for time series.

Laser			
emitted wavelength [nm]	1064.2	532.1	354.7
pulse energy [mJ]	180	80	70
pulse length [ns]	6-8	5-7	5-6
repetition rate [s^{-1}]	30	30	30

Detection/ Telescope	***small***	***large***
diameter [mm]	110	300
focal length	445	1200
aperture diameter [mm]	1	1
field of view [mrad]	2.2	0.8
detected wavelength [nm]	660.5, 607.3, 532.1	1064.2, 607.3, 532.1, 407.5, 386.7, 354.7

Table 1: System parameters of the Koldewey Aerosol Raman Lidar (KARL)

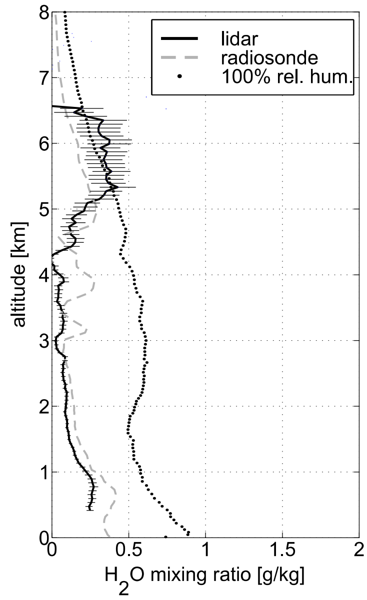

Figure 1: Water vapour profile from January 17, 2002

Figure 1 gives an example for a water vapour profile observed by lidar compared with the regular radiosonde. It was observed on January 17, 2002 between 14:04 and 15:01 UT. The water vapour mixing ratio was found below 0.5 g/kg in all altitudes, even in the lower and middle troposphere. In the upper troposphere the mixing ratio increased, providing small supersaturation between 5.3 and 6.5 km altitude. The regular radiosonde launched at 11 UT measured a smaller, but probably underestimated humidity. Simultaneous to the lidar sounding a balloon-borne SnowWhite frostpoint hygrometer was launched, observing also a supersaturated layer in about 6 km altitude (M. Fujiwara, private communication).

Observations on November 11, 2001

On November 11, 2001 the KARL has been operational during the whole day for aerosol and humidity soundings, with only minor gaps for system maintenance. The time evolution of observed parameters is displayed in Figure 2 (left and right, respectively). The left part of Figure 2 shows a maximum in water vapour mixing ratio slightly above 1 km altitude. The maximum humidity changes during the day between about 0.5 and 0.75 g/kg. The vertical extension of the humid layer as well as the gradient at the top vary strongly. After about 12 UT the water vapour concentration between 1.5 and 3 km altitude increased. The right part of Figure 2 displays the aerosol extinction coefficient for 532 nm wavelength (see Ritter et al., this issue). A nearly aerosol free troposphere until about 12 UT is obvious from the figure. Between 15 UT and 17 UT a small but vertical expanding cloud appears above the station, affecting also the water vapour soundings. The aerosol extinction coefficient rises past 17 UT in the same altitude range as the expanded humid layer. While the humidity decreases again in the late evening of November 11, this can not be stated from the aerosol soundings.

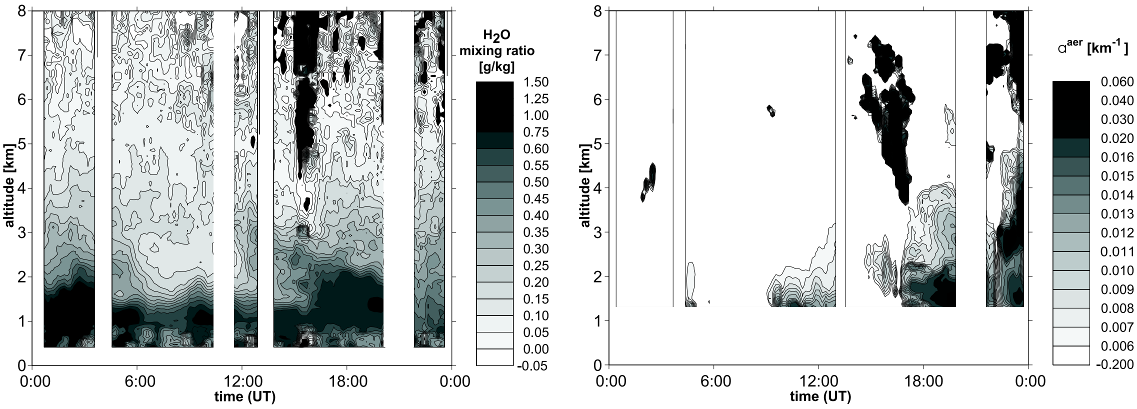

Figure 2: Water vapour mixing ratio (left) and aerosol extinction at 532 nm (right) on November 11, 2001 as observed by KARL.

Continuous records of meteorological parameters at 2 m and 10 m exhibit a decrease in temperature by about 5 K simultaneous with the water vapour increase below 3 km altitude after 12 UT (not shown here). During the whole day the pressure was rising by about 16 hPa. Despite there may be some different evolution between the temperature at ground and in the free troposphere, it seems likely that the relative humidity between 1 and 3 km rises past noon. Stationary lidar observations do not allow to separate between changes in the sounded air and advection of air masses with different properties. But the phase differences between the changes in humidity and aerosol extinction give reason for the assumption of growing aerosol particles during the increasing humidity. Of course, further analyses e.g. of the backscattered UV and IR light is necessary to prove this scenario. Trajectory calculations from European Centre for Medium Range Weather Forecast (ECMWF) analyses reveal a change in air mass origin from the Arctic Ocean to the Kara Sea during the day (not shown here).

Observations on February 28, 2002

During February 28, 2002 lidar soundings with the KARL have been performed throughout the whole day. But the humidity profiles between about 6 UT and 16 UT have been omitted in Figure 3 (left), because they are strongly affected by daylight. Figure 3 (left) shows a nearly homogenous humid layer up to 2 km altitude above the station. The mixing ratio amounts up to about 1.5 g/kg. Above 2.3 km the humidity decrease strongly, reaching less than 0.1 g/kg at 4 km altitude. The layer remains about unchanged during the first six hours of the day. Also past 16 UT the maximum of water vapour mixing ratio was about 1.5 g/kg around 1.5 km, with the upper ledge of the humid layer still near 2.5 km altitude. But now also a distinct lower ledge has been formed, with a dry boundary layer below 1 km altitude.
Meteorological ground data reveal a fast change in wind direction at 12:30 UT, succeeded by a decrease in 2 m relative humidity (Figure 3, right). The westerly wind past 4 UT comes from the direction of the Arctic Ocean, while the south-easterly wind of the afternoon has passed the mountain- and glacier-covered Spitsbergen inland. Before 4 UT the wind velocity was found very small (below 2 m/s), increasing later (not shown here).
Global weather analyses show no significant mesoscale change in wind direction because of transient weather systems. Trajectories reveal about the same path of air parcels throughout the day. The regular pressure data from Koldewey Station confirm only small changes of the air

pressure. Therefore, the wind field seem to be affected by local phenomena like e.g. air-sea interaction and orography. In turn, the lidar data show that the regional orography and the different surface conditions above the ocean and the inland are able to affect the humidity profile in the boundary layer above Ny-Ålesund. Local wind speed influences the contribution of the surface parameters to the boundary layer humidity (cp. before 3 UT).

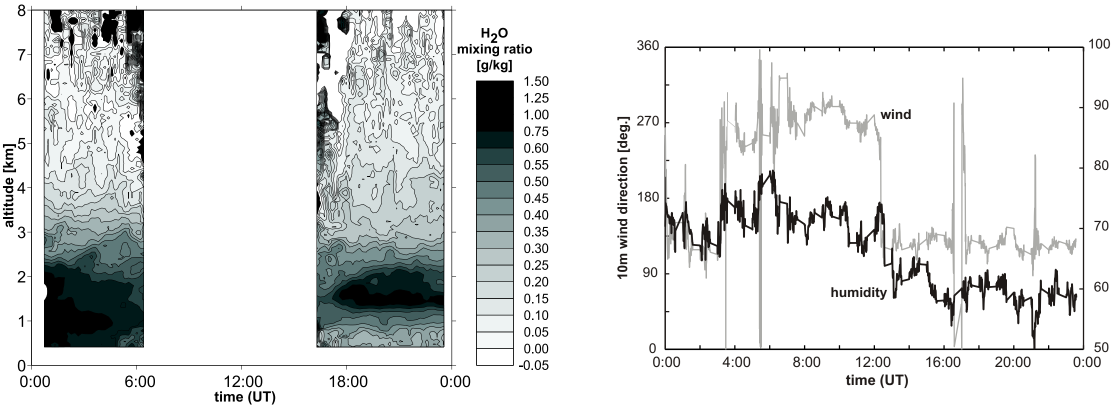

Figure 3: Water vapour mixing ratio observed by KARL (left) and wind and relative humidity from the meteorological station on February 28, 2002.

Summary

The Koldewey Aerosol Raman Lidar KARL provides atmospheric humidity data since the beginning of year 2000 in a combination of regular and intense campaign soundings. During dark conditions the profiles cover large parts of the troposphere nearly from the ground up to about 6 km altitude. The multi-wavelength detection system allows the retrieval of aerosol parameters in the UV-vis-IR range simultaneous and in a common volume with the water vapour soundings. This enables the investigation of aerosol-humidity interaction as an important parameter in the radiative budget of the Earth's atmosphere. The possible influx of local orography and surface conditions on the boundary layer humidity has been demonstrated.

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