Intercomparison of Airborne Water Vapour DIAL Measurements with Ground Based Remote Sensing and Radiosondes within the Framework of LUAMI 2008

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ABSTRACT

Within the framework of the 'Lindenberg campaign regarding an Upper-Air Methods Intercomparison' (LUAMI), an intercomparison of water vapor profile measurements between ground based lidars and radiosondes with an airborne differential absorption lidar (DIAL) were performed. On 17. October 2008 the DLR Falcon aircraft carried out a flight over middle Europe with overpasses of the ground based observatories located at Payerne (MeteoSwiss, Switzerland), Bilthoven (RIVM, Netherlands), Lindenberg (DWD, Germany) and Zugspitze (IMK, Germany). The aircraft was equipped with DLR's new four-wavelength water-vapor DIAL WALES and a coherent wind lidar operating at 2-µm wavelength. On this day, the water vapor field over the probed region showed a highly non-standard vertical distribution with a very dry layer at about 3 km altitude, most probably originating from a stratospheric intrusion. This gave an excellent opportunity to compare RAMAN lidar, DIAL and radiosonde measurements under conditions far from the standard profile. The results of this effort will be shown together with a critical analysis of the relative benefits and deficits of the different probing methods which were applied.

1. OBJECTIVES

Within the WMO program CIMO (*Commission for Instruments and Methods of Observation)* the *Lindenberg campaign regarding an Upper-Air Methods Intercomparison* (*LUAMI*) was conducted to make a contribution to the improvement and correction of water vapor soundings from surface up to the middle stratosphere.

Besides this main goal, the campaign should contribute in the following issues (among several others):

To assess and inter-compare both up-to-date active and passive ground-based remote sensing systems for meteorological parameters in view of their potential in operational networks as well as for high-quality reference or ground-truth e.g. for satellite sensors.

To improve the quality of worldwide standard radiosoundings for further reduction of systematic measuring errors (bias), and to check existing correction methods for known systematic errors, primarily for the parameter water vapor/humidity.

One special activity within LUAMI was an instrument intercomparison between an airborne water vapor DIAL instrument and three ground-based Raman lidars and one ground-based DIAL as well as a balloon-borne high precision frost point hygrometer. For this purpose a measurement flight over central Europe was carried out on 17. October 2008. This paper describes the instrumentation and the measurement strategy and shows first results from the airborne measurements. A detailed quantitative comparison with the ground based measurements is still in progress. First results will be shown on the conference poster presentation.

2. INSTRUMENTATION

For the validation flight the DLR Falcon F20 aircraft was equipped with WALES a new four-wavelength water vapor differential absorption lidar (DIAL), in analogy to the core instrument proposed by DLR for a satellite mission [1]. The new instrument design which is described in more technical detail in [2] enables the realization of a robust, highly compact and efficient transmitter system which fulfils all spectral requirements for a water vapor DIAL. The power aperture area product has been increased by more than a factor of 12 compared to our former system [3][4] by only a small increase of volume, weight, and electrical power consumption. Most importantly, the instrument is capable of simultaneously generating three on-line and one off-line wavelength which can arbitrarily be chosen from a spectral interval between 935 nm to 936 nm where several appropriate water vapor absorption lines exist. Using this set of wavelengths enables to deal with the large dynamic range of water vapor from the planetary boundary layer to the lower stratosphere. Additionally, DLR's 2 µm wind lidar was installed on the aircraft for simultaneous wind profiling.

The ground stations at Payerne (MeteoSwiss, Switzerland), Bilthoven (RIVM, Netherlands) and Lindenberg (DWD, Germany) were equipped with water vapor Raman Lidars and the Zugspitze (IMK, Germany) with a near infrared water vapor DIAL. Besides standard radio-sondes, a special high precision balloon borne frost point hygrometer (CFH) was launched at Lindenberg in close temporal vicinity to the aircraft overpass.

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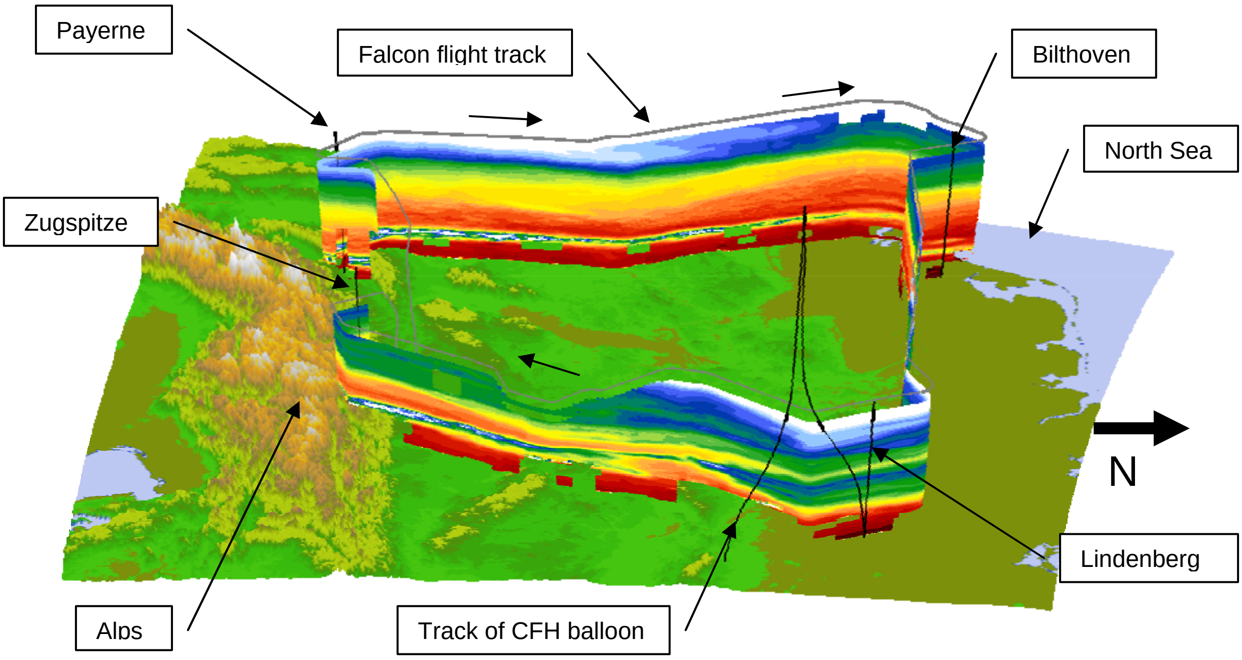

Figure 1: *Pattern of the validation flight made on 17. October 2008 over central Europe. The color coded 2-d curtain shows the water vapor mixing ratio as measured by the WALES instrument (color scale is the same as in Figure 2). The positions of the overflown ground stations are marked by vertically pointing lines (lidar beams). Additionally the flight track of the balloon carrying the CFH sonde ist shown.*

3. MEASUREMENTS

The validation flight started at DLR Oberpfaffenhofen on 17. October 2008 at 15:42 UTC. The aircraft turned to the West and climbed to about 11 km altitude. Then it overpassed Payerne at 16:18 UTC, Bilthoven at 17:15 UTC, Lindenberg at 18:03 UTC and the Zugspitze at 18:52 UTC. Figure 1 shows the flight track and the water vapor measurements along with the locations of the ground based lidar systems. Near the overpasses the flight track was aligned parallel to the wind direction in the mid troposphere to minimize the sampling error caused by the different averaging times of the instruments. Close to the Lindenberg overpass a balloon was launched which carried a frost point hygrometer.

4. RESULTS

The results of the airborne H_2O-DIAL measurements are shown in the uppermost panel of Figure 2. The vertical resolution of the data is 250 m and the temporal resolution 60 s, which corresponds to 12 km in distance. The mixing ration was calculated using temperature and pressure data from ECMWF analyses (T799L91 data at 6 hours output) interpolated in space and time to the location of the measurement. The white (blanked) regions with no data were covered by clouds, but most of the atmosphere along the flight was cloud-free on this day.

The most apparent feature in the data is a very dry layer at about 3 km of altitude, which is stretched out all over the measurement region. The water vapor mixing ratios below 30 ppm within this layer are typical for the uppermost troposphere or lowermost stratosphere. The exact minimum values could not be determined by the DIAL measurements because we had to use the weakest of all three absorption lines to evaluate the data. The in principle much more suited stronger absorption lines could not be used because the laser beam was not able to penetrate the moist layers above the dry region on the central wavelength of these lines. This dry layer touched the surface within the Alps, where ground based ozone measurements indicate that it really resulted from a stratospheric intrusion (T. Trickl private communication). More to the north the dry layer dissolves and is stretched out vertically, especially near the Lindenberg overpass at about 18:00 UTC. To resolve this dry layer is an extreme benchmark for all water vapor profiling instruments and thus an excellent test case for the objectives of LUAMI.

The middle panel of Figure 2 shows the water vapor mixing ratio from the ECMWF analyses interpolated to the same time and location as the airborne measurements and the lowermost panel the relative difference between the WALES measurements and the ECMWF-analysis. The analysis shows roughly the same H_2O distribution as the measurements but it is apparent from its much smoother structure that the model is not able to resolve the fine structure of the dry layer. This leads to peak deviations of up to $\pm$50% near the boundary of the dry layer and other sharp gradients. The mean deviation between the WALES measurements and the ECMWF analyses is -13% (i.e. WALES is dryer). If the altitude region of the dry layer is excluded, the mean difference is about -8%. Since the bias of the WALES instrument is estimated to below 5% this is a significant deviation which indicates that the ECMWF model is to moist over all, at least for this special event and region.

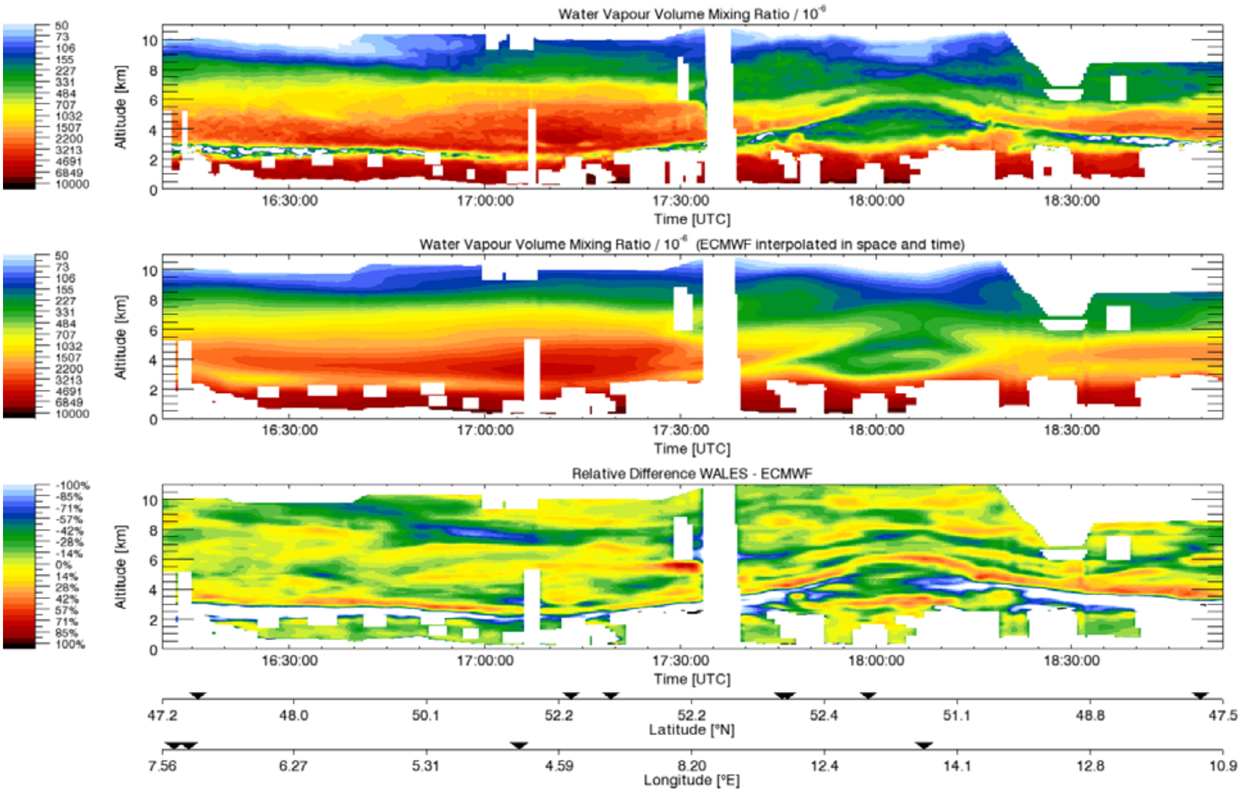

Figure 2: *Water vapor mixing ratio along the flight tack. Values measured by the WALES instrument are shown in the uppermost panel. The mid panel shows the mixing ratio from the ECMWF analyses interpolated in space and time to the locations/times of the airborne measurements. The lowermost panel shows the relative differences between the WALES and the Model data.*

5. OUTLOOK

A detailed quantitative comparison of the airborne measurements with the ground-based profiling is still pending. Besides calibration issues the main problem is to ensure an optimal matching of the probed air-masses. This is not trivial, as the averaging times is on the order of 30 s to 60 s for the airborne instrument but typically 10 min to 60 min for the ground based systems. As can be estimated from a typical wind speed in the mid troposphere and the horizontal gradient in the water vapor distribution (cmp. Fig. 2) averaging over 30 min as compared to 30 s may easily lead to a difference of 10% to 20% in the compared profiles which are not due to measurement errors but only different spatial sampling. A similar problem occurs when one tries to compare the airborne measurements with the balloon sounding. Here the in situ instrument performs a point measurement which is stretched out in time for 30 min between ground and the flight altitude of the aircraft and at the same time has a continuously changing geo-location. These problems will be approached by carefully aligned spatial averaging and selection of the data from the 2d mixing ratio fields of the airborne measurements taking into account the 3d wind field. First results will be presented on the poster shown on the conference.

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