TOWARDS MORE ACCURATE WATER VAPOUR OBSERVATIONS: AIRBORNE LIDAR MEASUREMENT EXAMPLES AND CHARACTERISTICS

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Abstract: Airborne differential absorption lidar measurements of mid-latitude, subtropical and tropical water vapour were performed during several recent campaigns over North and South America, and Australia, as well as on the corresponding long-range transfer flights from and to Germany with the DLR "Falcon" research aircraft. These include tropospheric as well as lower stratospheric observations. Complex advection and rapid vertical transport associated with meso- and synoptic scale dynamical processes reflect in inhomogeneous water vapour distributions along the flight paths, as observed by the lidar. The tropical (Hadley) circulation, stratospheric intrusions and humidity transitions between different air masses are clearly detected. The measurements are compared to operational ECMWF analyses interpolated in space and time to the flight path. The relevant transport processes are adequately represented in the analyses as long as vertical and horizontal scales exceed roughly 0.5-1 km in the vertical and 50 km horizontally, while smaller structures and larger gradients are smoothed out. On the longer term, space-borne lidar instruments may provide unprecedented high-resolution (especially in the vertical) and high-precision, low-bias observations of water vapour throughout the troposphere with high added value to next generation observing systems for assimilation into NWP models.

Keywords – *Airborne Lidar, Water Vapour Observations, Stratospheric Intrusions.*

1. INTRODUCTION

Water vapour, the most important greenhouse gas, controls cloud formation and the evolution of weather systems. As its tropospheric concentration may rapidly vary over four orders of magnitude, accurate monitoring especially in the upper troposphere and lower stratosphere (UT/LS) and in remote areas remain important scientific and logistical issues. Water vapour assimilation is still limiting the accuracy of numerical weather prediction (NWP) models, most of which are based on lower and middle tropospheric humidity from regular radiosonde soundings that do not provide reliable humidity profiles at altitudes > 300 hPa or in dry regions < 0.1 g/kg. Moreover, major "birth" regions of severe continental weather to which short-term forecast errors are most sensitive are often only covered by few radiosonde stations. It is therefore obvious to question the accuracy of water vapour distributions in weather services' analyses, particularly with respect to the scales, lifetime and geographical location of investigated structures.

2. OBSERVATIONS

Between 2002 and 2005 the DLR Falcon research aircraft performed long-range transfer flights to various remote campaign destinations in Oklahoma, Brazil and Australia, carrying the water vapour Differential Absorption Lidar (DIAL) in nadir looking arrangement. The DIAL transmitter is based on a Nd:YAG pumped, injection seeded KTP-OPO (Optical Parametric Oscillator) which produces 18 mJ per pulse at 925 nm at 100 Hz. Atmospheric backscatter is measured simultaneously. Using the 925 nm spectral region allows to cover typical water vapour concentrations from the PBL to the upper troposphere with vertical and horizontal resolutions of some 100 m to 1 km and few km to about 10 km, respectively. Main sources of systematic errors are the uncertainty in the determination of the water vapour absorption line cross section (5% estimated uncertainty), laser spectral impurity (1-2%), atmospheric temperature uncertainty (<1%), and the Rayleigh-Doppler absorption line broadening (<1.5%), about 5% in geometric total (Poberaj et al., 2002). The statistical error, controlled by horizontal and vertical averaging, mostly remains below 10%.

Water vapour and aerosol/cloud distributions have been measured with the DLR airborne DIAL in May 2002 during the transfer flights to the International H2O Project (IHOP_2002) across the Northern Atlantic Ocean (Figure 1). The flights went from Germany via Iceland, Greenland and Canada to Oklahoma. Owing to intense dynamical activity over the Atlantic a variety of complex atmospheric structures was observed during the transects such as stratospheric intrusions, PV streamers, frontal zones, gravity waves, convection and patches of vertical turbulence. Stratospheric intrusions and extended extremely dry layers even in the lower troposphere turn out to be the normal case rather than the exception in this part of the globe. The large dynamical range of tropospheric water vapour is impressively demonstrated. Large gradients in the H_2O and backscatter fields dominate the scene and in general can *qualitatively* be reproduced by mesoscale simulations and even to a large extent by ECMWF analyses. However, the gradients and the minimum mixing ratios can not yet be satisfactorily reproduced in a quantitative sense (Flentje et al., 2005).

Figure 2 shows water vapour lidar results of another long-range flight of the DLR Falcon between Dubai and Hyderabad (India) on its way back from a campaign in Australia in late 2005. T799/L91 operational analyses of the European Centre for Medium Range Weather Forecast (ECMWF), interpolated linearly in space and time to the transfer flight path are used for the comparison to the lidar observations. The large-scale circulation is reproduced by the ECMWF analyses but differences are found at smaller scales where strong gradients occur and rapid temporal development takes place due to advection perpendicular to the measurement plane.

The long-range water vapour lidar data will be used for assimilation experiments with the ECMWF global model. First test experiments indicate a reduction of the model's first-guess errors of the water vapour column in the vicinity of the observations. However, this has to be consolidated with further experiments.

3. CONCLUSIONS AND OUTLOOK

Airborne lidar provides unprecedented high-resolution (especially in the vertical) and high-precision, low-bias observations of water vapour throughout the troposphere. Future space-borne lidar instruments could be of high added value to next generation observing systems for NWP because, unlike passive remote sensors, lidar measurements are basically calibration-free, do not depend on a-priori information and are not biased by surface albedo variations, aerosols or clouds. The potential benefit of such new-quality water vapour observations to NWP models could be threefold: First, the exact 4-D location of intrusions of stratospheric dry air into the upper and middle troposphere will help constrain the model dynamics when using variational assimilation techniques. Similar to the construction of motion vectors from cloud tracking, the tracking of stratospheric intrusions in lidar water vapour observations will provide motion vectors in cloud-free regions and in typically highly-sensitive regions like the North Atlantic storm track area where intrusions often occur. Second, latent heat release from the evolution of convective systems influences the local and mesoscale dynamics; here, more accurate water vapour observations prior to the initiation of strong convection would directly improve the model performance when appropriately assimilated. Last not least, the model physics would be improved through better subgrid scale parameterisations from process studies based on the high resolution observations.

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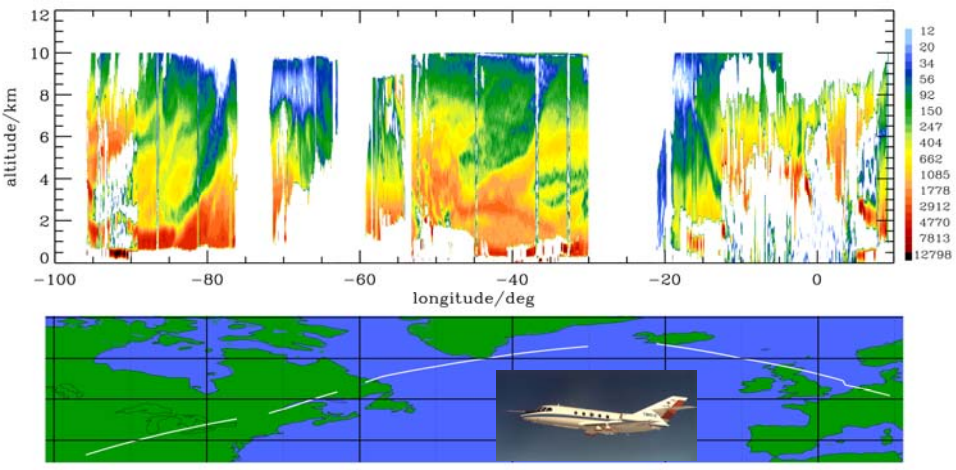

Figure 1. Vertical tropospheric cross section of water vapour mixing ratio (mg/kg) over the North Atlantic. The vertical lidar resolution is 0.5 km. The observed intrusions of dry stratospheric air into the troposphere are associated to the complex dynamics of subsequent synoptic systems. See Flentje et al., 2005.

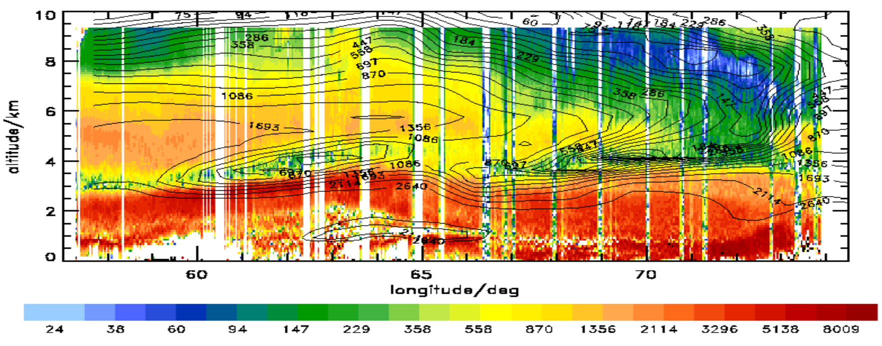

Figure 2. Lidar cross section of water vapour volume mixing ratio (µmol/mol; colours) with ECMWF analysis (T799/L91; lines) interpolated to the flight path. The stratospheric intrusion is well captured by the model; smaller scale and boundary layer humidity variations are smeared or not represented.