WALES, the Airborne Demonstrator for a Water Vapor Differential Absorption LIDAR in Space

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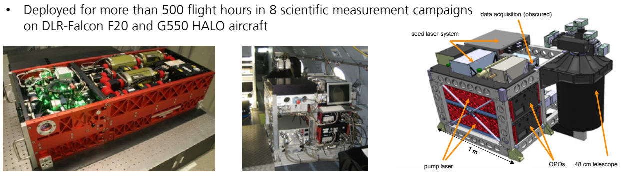
Objectives

As a contribution to the ESA Earth Explorer mission proposal WALES **[1]** the German Aerospace Center (DLR) developed an airborne demonstrator which implements all essential features of a possible space-borne instrument **[2]**. With this system a large data set has been gathered in various airborne campaigns devoted to different topics concerning the atmospheric part of the global water vapor cycle over the past years. This poster presents a selection of results from these campaigns and comparisons to other measurement techniques.

Instrument characteristics

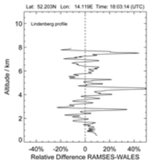
- Differential Absorption LIDAR (DIAL) operating at four wavelengths near 935 nm simultaneously
- Uses highly efficient solid-state laser and non-linear conversion technology suitable for space environment
- H_2O mixing ratio profile covering whole troposphere (typical resolution: 200 m vertical / 6 km horizontal)
- Systematic error sources (no radiometric calibration necessary): < 5 %
- Statistical error dependent on vertical/horizontal resolution, H_2O-profile and ambient light: generally in the order of 5% (1σ). Statistical error is calculated and tabulated with every profile
- Additional channels for aerosol backscatter, extinction and depolarization profile measurements at 532 nm and 1064 nm
- Deployed for more than 500 flight hours in 8 scientific measurement campaigns on DLR-Falcon F20 and G550 HALO aircraft



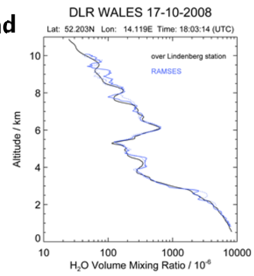
Comparison with in-situ balloon and ground based lidar instruments during LUAMI[3]

Instrument inter-comparisons show mean deviations between instruments within specified error bounds if:

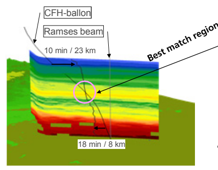
- optimal matching of measurement volume is performed
- vertical resolution is appropriately matched
- the flight path is aligned with the wind direction

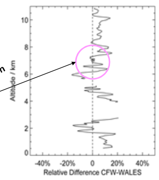


- Mean deviation (RAMSES - WALES):
  10 min profile: 3.5%
  30 min profile: 5.5%

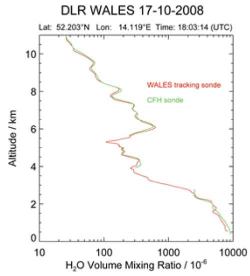


Determine best match by taking into account the wind drift



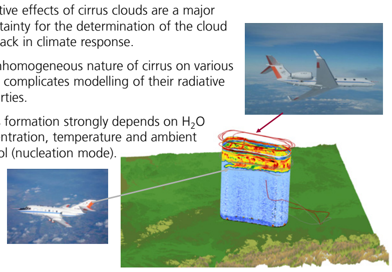


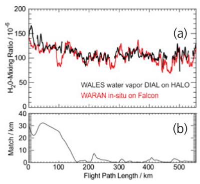
- CFH-profile smoothed with WALES averaging kernel
- Mean deviation 4,3% within the error budget of the instruments



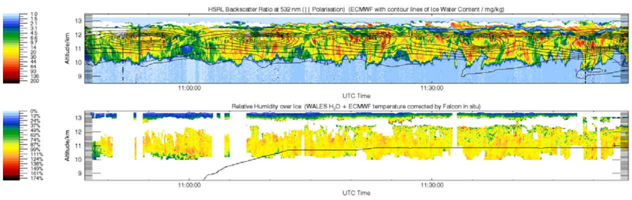
Humidity around and within cirrus[4]

- Radiative effects of cirrus clouds are a major uncertainty for the determination of the cloud feedback in climate response.
- The inhomogeneous nature of cirrus on various scales complicates modelling of their radiative properties.
- Cirrus formation strongly depends on H_2O concentration, temperature and ambient aerosol (nucleation mode).

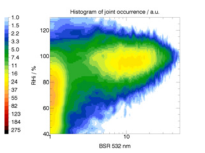




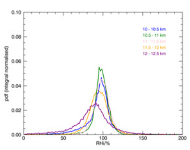
(a) Water vapour mixing ratio as retrieved by the WARAN in-situ sensor on the Falcon (red line) and the WALES instrument (black line) on HALO at the same altitude.
(b) Horizontal distance between the two aircraft as a function of time



(Upper Panel) Backscatter ratio at 532 nm (color shading) between 10:47 and 11:54 UTC on 4 November, 2010. White areas are caused by detection system overload. Black contour lines show the ECMWF cloud ice water content of 0.5 – 4.5 mg/kg.
(Lower Panel) Relative humidity over ice from combined WALES water vapour and bias corrected ECMWF temperature data. Thick black solid line indicates the altitude of the DLR Falcon.



Histogram of the joint occurrence of the relative humidity over ice (RHi) and the extinction corrected backscatter ratio (BSR) at 532 nm for the data shown above



Frequency distribution of the relative humidity over ice at different vertical layers inside the cirrus cloud shown above

- High resolution 2-d LIDAR measurements enable statistical analyses of cirrus cloud properties.
- Joint humidity and backscatter measurements allow to localize supersaturated regions and investigate the correlation with background aerosol.
- Comparisons with models are much more statistically stable than using in-situ data (lower sampling error).

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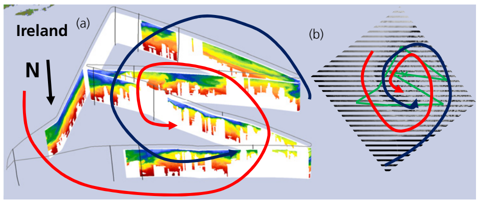
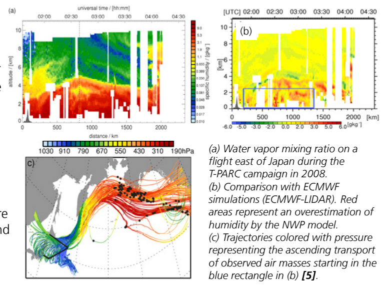
Humidity structure in extratropical weather systems



(a) 3-dimensional distribution of water vapour mixing ratio in an extratropical cyclone observed over the North Atlantic on 12 January 2014 during the NARVAL campaign.
(b) Satellite image of the cyclone and the HALO flight track (green line). Red and blue arrows in (a) and (b) represent major transport paths of moist and dry air encircling the cyclone center.

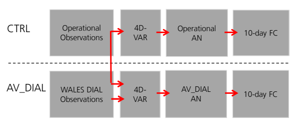
- The property of water vapor to store and release energy in the form of latent heat largely affects mid-latitude weather systems.
- Range resolved LIDAR measurements enable to study the complex transport of moisture occurring on various scales.
- Comparison of NWP fields with LIDAR observations allow to investigate the representation of water vapor.
- The boundary layer becomes especially important when the associated high moisture is transported into cyclones, forms clouds and impacts the weather evolution.



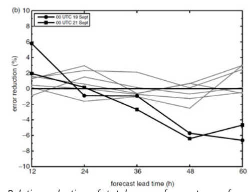
(a) Water vapor mixing ratio on a flight east of Japan during the T-PARC campaign in 2008.
(b) Comparison with ECMWF simulations (ECMWF-LIDAR). Red areas represent an overestimation of humidity by the NWP model.
(c) Trajectories colored with pressure representing the ascending transport of observed air masses starting in the blue rectangle in (b) ***[5]****.*

Data assimilation[6]

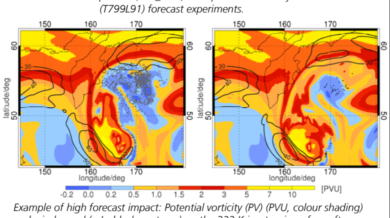
- Current observational network used for the initialization of NWP models lacks accurate, vertically resolved humidity observations.
- Investigation of the benefit of 3900 DIAL water vapor profiles collected during 25 research flights over the western Pacific.
- Assimilation in ECMWF 4-DVAR assimilation system with an effective vertical resolution of ~300 m and ~25–30 km horizontal resolution (~model resolution).



Schematic of the data assimilation procedure: operational (CTRL) and additional data assimilation of water vapour profiles (EXP_DIAL). Comparison of 10-day ECMWF IFS (T799L91) forecast experiments.



Relative reduction of total energy forecast error for AV_DIAL compared with CTRL over the western North Pacific basin (15–60N, 115E–160W). Grey lines represent the cases with small forecast impact. Negative values indicate reduced errors of AV_DIAL.



Example of high forecast impact: Potential vorticity (PV) (PVU, colour shading) and wind speed (m/s, black contours) on the 322 K isentropic surface after +36 h FC time for (a) CTRL and (b) AV_DIAL. Comparison of both panels shows a reduced isentropic PV-gradient and lower jet stream wind speeds (5 - 15 %) in the downstream ridge.

- Small forecast influence of humidity observations compared with pressure, wind or temperature when diabatic processes do not affect the model dynamics explicitly.
- In cases of strong latent heat release, high low level moisture can impact larger scale dynamics and influence the medium range predictability.
- This highlights the importance of water vapor observations to reduce humidity errors in NWP models.

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