Spaceborne Water Vapor DIAL: Has the time come now?

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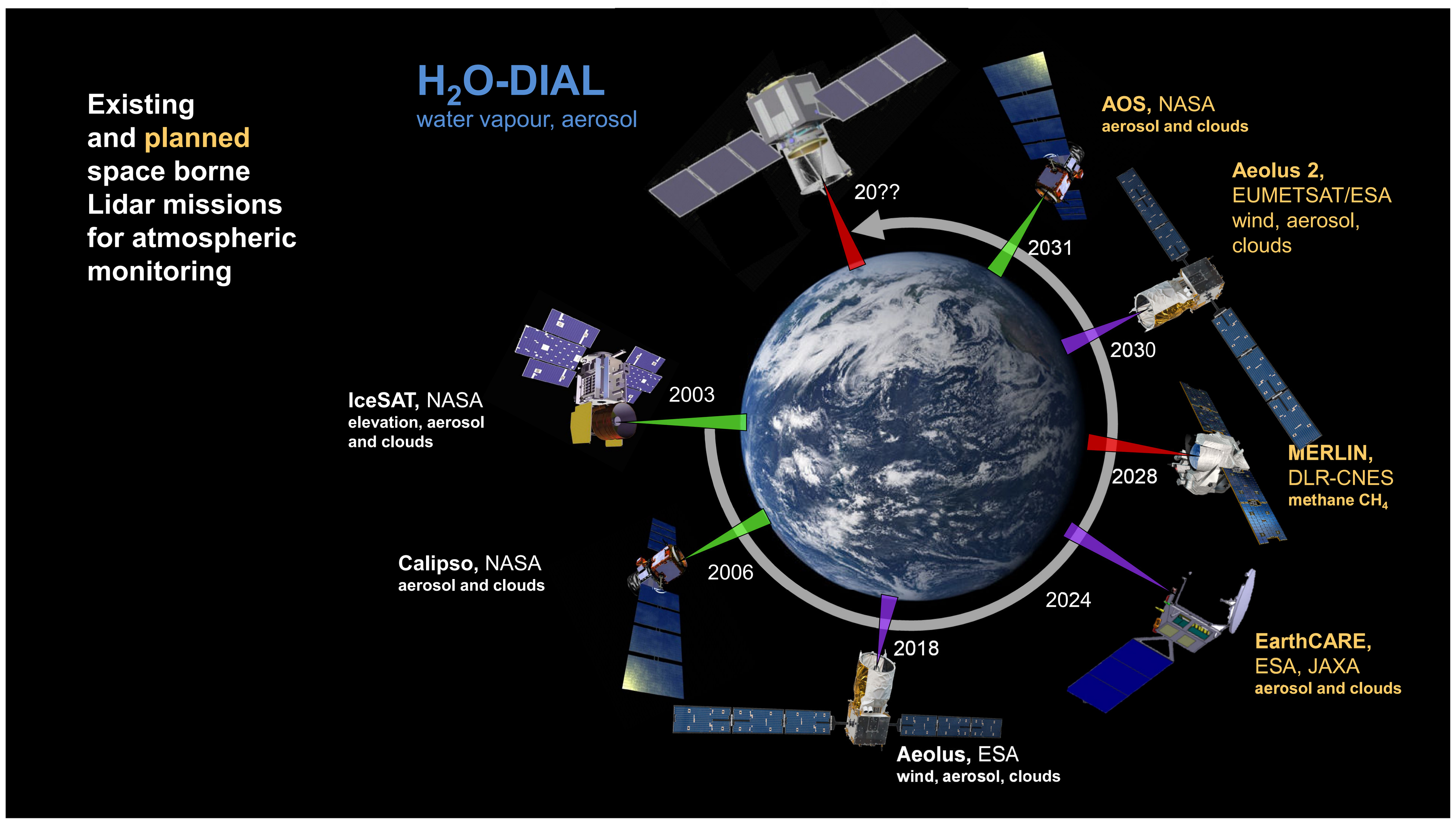
Abstract

Water vapor is the key trace gas component of the air and involved in virtually all relevant atmospheric processes. To know the vertical profile with decent resolution is crucial in all cases. For example, there are several regions of the atmosphere where numerical weather prediction models show biases which are not understood. So, after aerosol/cloud and wind lidars have been very successfully applied within space missions, the natural next step would be the profiling of water vapor by a Differential Absorption Lidar (DIAL) from a satellite in a low Earth orbit. About 20 years ago the ESA Earth-Explorer Proposal WALES went through phase A, but was not further selected due to the identified technological risks and the corresponding financial efforts. Thanks to the European spaceborne lidar missions Aeolus/2, EarthCare, and MERLIN now the major building blocks for a such water vapor DIAL have reached the necessary technological readiness to realize such a program within the financial limits of a typical Earth observation mission.



Global measurements of H_2O profiles with high vertical resolution and low bias are key to:

- Understand the role of water vapour in the tropics:
  - low, non-precipitating clouds and their radiative effects
  - deep convection and precipitation
  - interactions with the land surface
  - understand and predict the formation of extreme weather events
  - thunderstorms, flash floods etc. - in the Extratropics, linked to strong vertical transport of water vapour
- Better quantify the transport of water vapour across the boundary layer into the lower troposphere to estimate and resolve biases in NWP and climate models
- Understand the origin of the longstanding wet-bias of numerical models in the UTLS

Shortcomings of current H_2O profiling systems:

- Radio sondes are still the only operational true high resolution profiling instruments, but very sparse in space and time and of limited accuracy in the upper troposphere
- Passive space-borne humidity sounders have a poor vertical resolution (4-5 km) in the lower troposphere and high biases over land
- The vertical weighting functions of passive instruments have extended side-lobes
- Performance of passive retrieval only decent with good first guess
- Other emerging profile sources (networks of Raman lidars, Infrared/Microwave Scanners etc.) and measurements on commercial airplanes will not change the sparse coverage

Features

- Applicable throughout the whole troposphere, day and night, all seasons and latitudes
- Simple, calibration-free technique with direct retrieval, free of ambiguities, no a priori information needed
- Well defined vertical and horizontal weighting function, that is exactly zero outside the estimation interval
- Accurate estimation of the random error for each profile
- Small footprint below 100 m enables sounding through gaps in broken cloud decks
- Detection of ground return allows high temporal resolution of mean boundary layer humidity

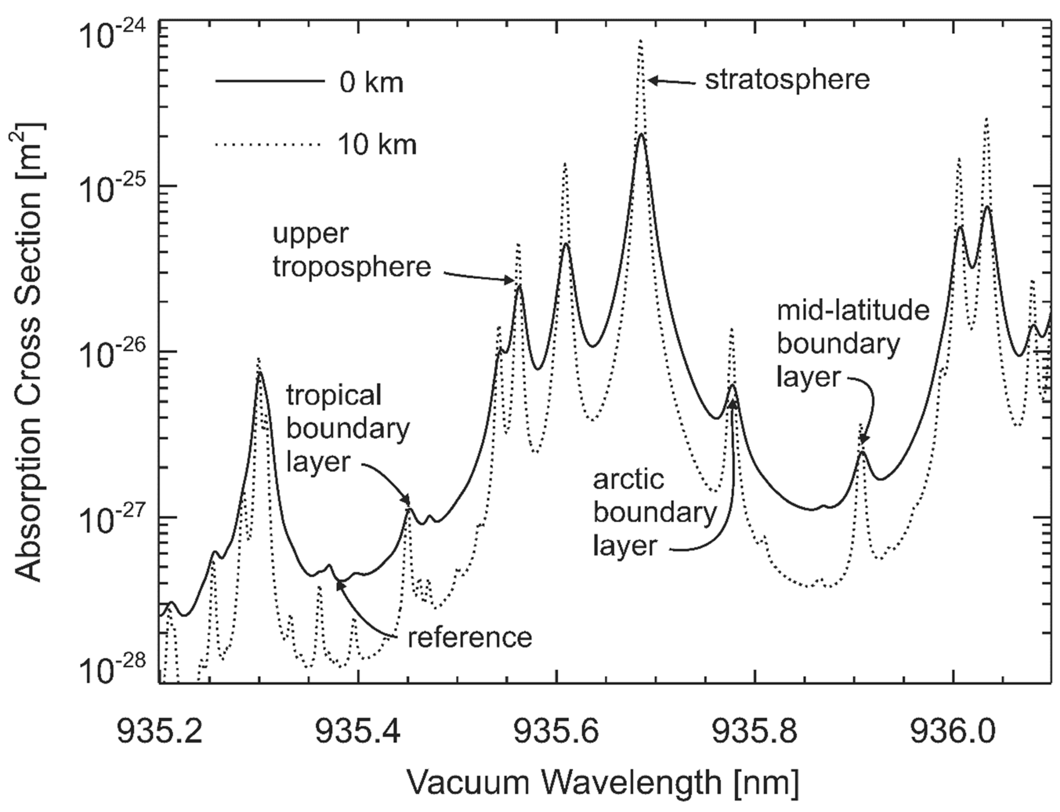
Technological readiness of main building blocks

Subsystem	Reference Instruments	TRL of the reference Unit
OPO/OPA for 935 nm	(WALES demonstrator)	4
Pump laser opto-mechanical Assembly	FULAS / MERLIN / Aeolus-2	6
Laser Housing and Thermal Control System	FULAS / MERLIN / Aeolus-2	6
Laser Electronics Unit	MERLIN / Aeolus-2	6
Frequency Reference Unit	MERLIN	6
Transmitter Telescope Assembly	MERLIN /ATLID	6
Receiver Telescope Assembly	Aeolus/Aeolus-2	9
Etalons / Background filters	Aeolus / ATLID	6
Detectors / Electronics	MERLIN	6

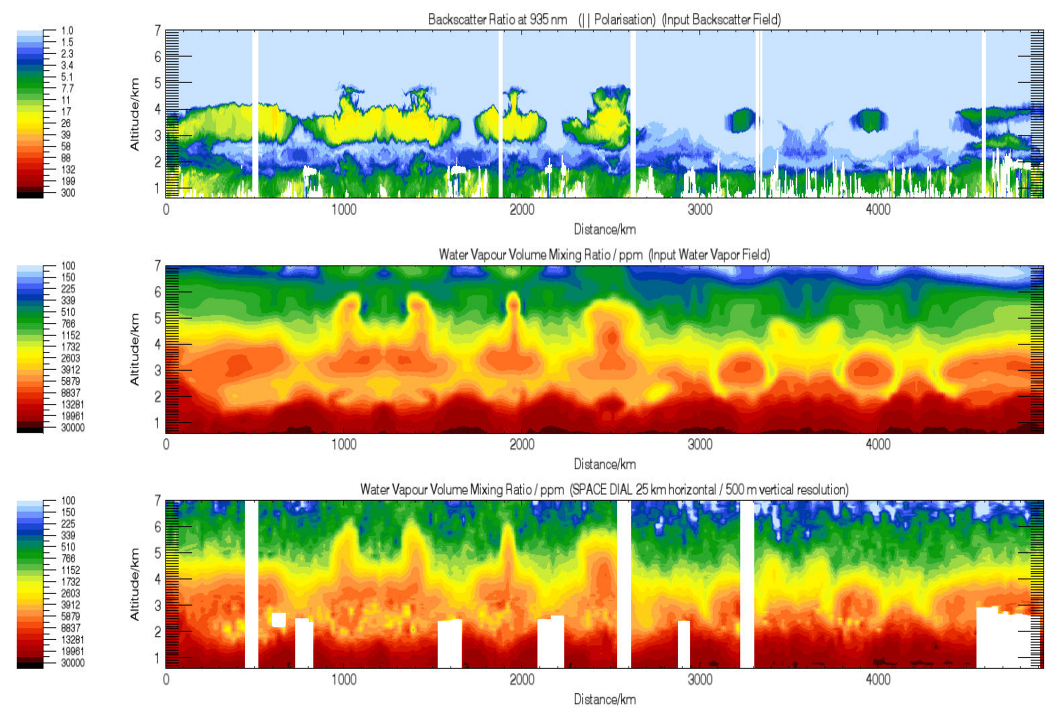
All subsystems except the frequency converters (OPO/OPA for 935 nm) are simple modifications of existing spaceborne subsystems

Spaceborne H_2O-DIAL: Baseline concept

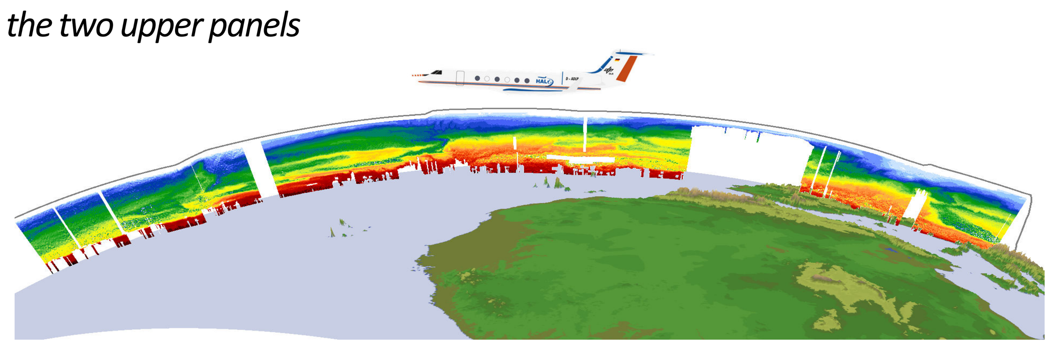
Parameter	H_2O-DIAL baseline
Number of Wavelength	4
Laser pulse energy	70 mJ
Pulse repetition frequency	25 Hz (100 Hz)
Wavelength range	935 nm to 936 nm
Laser frequency accuracy and stability	< 60 MHz
Laser linewidth (fwhm)	< 160 MHz
Laser spectral purity	> 99.9%
Telescope diameter	1.5 m
Telescope field of view	100 µrad
Receiver bandpass filter-width (fwhm)	40 pm
Detector type	APD
Quantum efficiency	80%
Total optical efficiency	40%



H_2O absorption cross sections in the 935 nm wavelength region. Data calculated from HITRAN 2012 line parameter data-base.



End-to-end simulation result (lowermost panel) using the input data from the two upper panels



Example cross section form the WALES airborne demonstrator operated on the German research aircraft HALO. Flight from Germany to Barbados in Feb. 2020

Conclusions

- Global high accuracy water vapor profiling is urgently needed for various atmospheric research areas
- Multi-wavelength DIAL technology is able to provide measurements going beyond all what will ever be possible by passive instruments
- The scientific impact has been shown in numerous case studies using data from airborne demonstrators
- Space hardware is now available for nearly all critical components now, thanks to previous or current space lidar missions
- To lift the readiness level of the remaining parts (mostly OPO/OPA) usual phase 0/A studies are sufficient

➡ It's high time to unleash the power of space borne H_2O DIAL now!

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