Development of a differential absorption lidar for remote sensing of water vapor and the isotopologue HDO

Soutenance de thèse – Jonas HAMPERL (DPHY/SLM)

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Résumé

Observations of stable water isotopologues in the lower troposphere provide valuable insights into the condensation and evaporation history of water vapor. The provision of such data with sufficient vertical resolution in the lower troposphere (0–3 km) helps to improve our understanding of basic processes like cloud formation, moist convection and mixing and it offers the potential to increase the accuracy in the predictions made by atmospheric general circulation models. Despite the progress in remote sensing from the ground and from space, retrievals from passive sensors are prone to biases and lack the vertical resolution required for water cycle studies in the lower troposphere.
The aim of this thesis is to investigate an active remote sensing approach based on the differential absorption lidar (DIAL) method to measure both the water vapor main isotopologue $H_2^{16}O$ and the semi-heavy water isotopologue $HD^{16}O$. The expected performance of such an instrument in terms of random and systematic errors was first analyzed using simulations accounting for instrumental and atmospheric parameters. The theoretical analysis showed that the spectral range around 1.98 µm is suitable for DIAL profiling of $H_2^{16}O$ and $HD^{16}O$ and that range-resolved measurements require a tunable laser in that wavelength range with pulse energies of tens of mJ. To fulfill this requirement, a parametric laser source based on a nested-cavity optical parametric oscillator and an optical parametric amplification stage using state-of-the-art high-aperture periodically poled potassium titanyl phosphate (PPKTP) crystals was implemented. It delivers widely tunable (1.95–2.30 µm) single-frequency radiation with energies up to 9 mJ for 12 ns pulses at a repetition rate of 150 Hz. Using the developed laser source, DIAL measurements of $H_2^{16}O$ and $HD^{16}O$ in the atmospheric boundary layer were conducted in direct-detection mode in the frame of several measurement campaigns. It was shown that with the developed lidar setup, isotopologue measurements with meaningful precision are limited to the first few hundred meters above the ground. To achieve measurements with range resolution and precision suitable for water cycle studies within the entire boundary layer, further instrumental improvements in terms of laser energy and reduced detection noise are necessary. For this purpose, a further step is proposed for the design and pre-development of a lidar setup capable of achieving a higher sensitivity thanks to an optimized double-stage amplification scheme for the laser transmitter that should allow to reach output energies >40 mJ.

Mots clés

Stable water isotopologues, remote sensing, differential absorption lidar, parametric laser, nonlinear materials