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Enabling Technologies for Cross-Cutting Airborne and Spaceborne Water Vapor and Methane DIAL

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Abstract: NASA Langley Research Center has developed the High-Altitude Lidar Observatory (HALO), a water vapor and methane Differential Absorption Lidar (DIAL) and High Spectral Resolution Lidar (HSRL) system to address the observational needs of weather, climate, carbon cycle, and atmospheric composition communities, but also serve as a technology testbed to mature and demonstrate requisite technologies need to enable future space-based water vapor and methane DIAL missions. We will present on the HALO airborne architecture, enabling technologies, and representative water vapor and methane measurements. We will also present on technologies adapted from HALO to enable a cross-cutting water vapor and methane DIAL space-based mission being advanced through the Atmospheric Boundary Layer Lidar Pathfinder (ABLE) project.

1. Introduction

Water vapor and methane are two of the most relevant greenhouse gases from a weather and climate perspective. Water vapor is the most dominant of the short-lived greenhouse gases and plays a key role in many atmospheric processes critical to driving Earth's weather, air-quality, and climate systems.

Characterizing the complex three-dimensional water vapor structure of the troposphere from process (e.g., clouds, land atmosphere feedback) to global scales (convective organization and synoptic flow) with high vertical resolution and high accuracy remains unmet grand challenge and called for by many communities and consensus reports. Similarly, rising atmospheric concentrations of methane with it's much shorter atmospheric lifetime and much stronger warming potential make its radiative forcing equivalent to that for CO_2 over a 20-year time horizon and makes it another greenhouse gas (albeit long-lived) particularly attractive for climate mitigation strategies. Changes in land-atmosphere carbon exchange happen across a range of space and time scales, from individual oil and gas extraction wells to urban areas to large ecosystems (e.g., boreal and tropical wetlands).

The space-borne program of record for water vapor and methane is insufficient to constrain key processes across these vastly different scales, across diurnal and seasonal cycles, and across different latitudes. Airborne and space-based DIAL fill a unique gap and compliment the current passive program of record by providing accurate, dense coverages, and high-resolution observations in scenes that have historically challenged passive sensors (e.g., high aerosol loading, in between and through broken cloud fields, high latitudes, and low sunlit conditions).

2. Airborne Methods and Technologies

The High-Altitude Lidar Observatory (HALO) was developed at NASA Langley Research Center as a modular system based off of the High Spectral Resolution Lidar – 2 (HSRL-2) instrument architecture to enable measurements in three discrete instrument configurations (Figure 1); 1) water vapor DIAL+HSRL, 2) methane DIAL/Integrated Path DIAL (IPDA)+HSRL, 3) water vapor DIAL+Methane DIAL/IPDA+coherent winds.

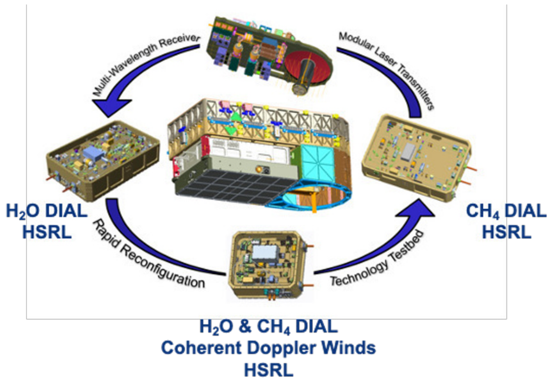

Figure 1: HALO instrument with multi-channel receiver and laser transmitters that support the three different measurement configurations.

The first two HALO configurations employ Nd:YAG pumped optical parametric oscillators (OPO) to access the water vapor (935 nm, [1]) and methane (1645 nm, [2]) absorption lines, respectively. Residual 532 or 1064 nm pump energy is transmitted for contemporaneous HSRL/elastic backscatter measurements at 532/1064 nm, respectively. Coupled with compact optomechanical design of the transmitter and receiver subsystems (including compact seed lasers), the end-pumped high-power lasers enable unique science from a wide range of aircraft that allow for deployment with other synergistic active and passive instruments.

The third HALO configuration employs the use of a frequency doubled Er:YAG laser that enables simultaneous WV and CH_4 DIAL measurements through novel implementation of spectroscopy in the 823 nm, WV, and 1645 nm, CH_4, spectral bands (Figure 2). Figure 3 shows a solid model drawing of the Er:YAG laser transmitter depicted in Figure 2. Due to the significant reduction in size of the Er:YAG laser compared to the traditional OPOs (HALO configuration 1 and 2), an additional Nd:YAG laser can be integrated into the same volume to enable simultaneous HSRL measurements as well as a coherent refractive transceiver (enabled from longer laser pulse widths resulting from low gain from the Er:YAG material). We are currently in the process of integrating this new transmitter and successful demonstration will enable for the first-time simultaneous water vapor DIAL, methane DIAL/IPDA, coherent winds, and HSRL for detailed airborne process studies.

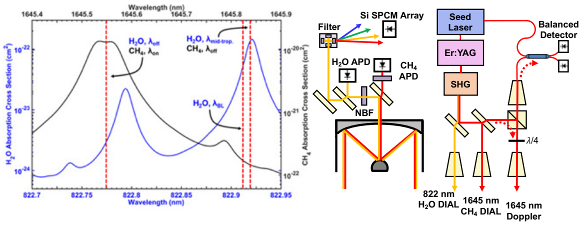

Figure 2: Left) Simulated spectra of surface level methane (black) and water vapor (blue) absorption-cross-sections corresponding to the fundamental and doubled output of the Er:YAG laser. The water vapor DIAL and methane IPDA wavelengths are indicated by the dashed lines. Right) Functional system block diagram for the implimentation of the Er:YAG laser within the HALO system.

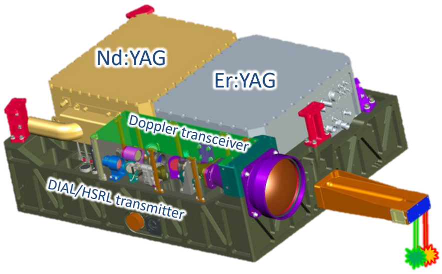

Figure 3: Solid model drawing of Er:YAG DIAL, HSRL, winds transmitter/transceiver.

3. Space-Based Methods and Technologies

The complimenting technologies that enable the efficient use of the new Er:YAG laser (Figure 2) for simultaneous water vapor, methane, and wind measurements include 1) dynamically tunable photonic integrated seed laser, 2) high efficiency pump diode lasers (enabling of future space-missions), 3) high spectral resolution optical filtering at 823 nm employing polarization multi-plexing to spatially spearate the on and off wavelengths for suppression of solar background, 4) single photon counting detectors at 823 nm with increased dynamic range (enabling of future DIAL mission), and 5) high efficiency and high gain HgCdTe detectors for CH4 IPDA (space) and water vapor DIAL (airborne) measurements.

These technologies are being advanced and integrated into the HALO system as a stepping stone towards enabling space-based water vapor DIAL measurements throughout the mid-to-lower troposphere with cross-cutting capabilities to measure attenuated backscatter profiles, distributions of PBL height, precipitable water vapor, and surface weighted water vapor (XH_2O), as well as methane columns (XCH_4) [3]. These advances for a future space-based water vapor and methane DIAL system are being pursued under the Atmospheric Boundary layer Lidar Pathfinder (ABLE) project. Figure 4 shows the ABLE concept on a small satellite platform with some of the critical technologies/subsystems being advanced directly depicted.

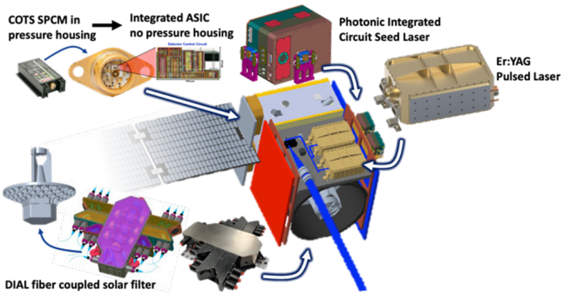

Figure 4: Solid model drawing of the ABLE space-concept on a small satellite platform along with critical transmitter and receiver subystems.

4. Summary

New transmitter and receiver technologies have enabled more compact and capable airborne DIAL measurements of water vapor and methane. High power Er:YAG lasers and novel implementation of spectroscopy allows for new capabilities to simultaneously measure water vapor and methane and also enables efficient space-concepts that addresses the observational needs of disparate science communities. System architecture, enabling technologies, and representative data sets from HALO will be presented to demonstrate the utility of airborne lidar observations and how they serve as an incubator to enable future space-mission concepts. Similarly, technologies being advanced under ABLE and future measurement capabilities will be presented.

5. References

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