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Greenhouse Gas Profiles Retrieval in Cloudy Air from Combined IR-Laser and Microwave Occultation Measurements

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ACCURATE–Climate Benchmark Profiling of Greenhouse Gases and Thermodynamic Variables and Wind from Space is a new climate satellite concept, which enables simultaneous measurement of greenhouse gases (GHGs), isotopes, wind and thermodynamic variables from Low Earth Orbit (LEO) satellites. The measurement principle applied is a combination of the novel LEO-LEO infrared laser occultation (LIO) technique and the LEO-LEO microwave occultation (LMO) technique.

The LIO uses near-monochromatic signals in the short-wave infrared range (~2-2.5 μm). These signals are absorbed by various trace species in the Earth's atmosphere. Profiles of the concentration of the absorbing species can be derived from signal transmission measurements. Accurate temperature, pressure, and humidity profiles, including accurate altitude levels, are derived from simultaneously measured LMO signals and serve as essential pre-information for the retrieval of the GHG profiles. These LMO signals reside at frequencies within 13-23 GHz and, optionally, 175-195 GHz. The current mission design is arranged for the measurement of six GHGs (H_2O, CO_2, CH_4, N_2O, O_3, CO) and four isotopes ($^{13}CO_2$, $C^{18}OO$, HDO, $H_2^{18}O$, the latter two optional), with focus on the upper troposphere/lower stratosphere (UTLS, 5-35 km). The GHG retrieval can be performed in clear and cloudy air, retrieving complete GHG profiles for no and weak cloudiness (like sub-visible cirrus) and cloud-gaps-interpolated or cloud-top-limited GHG profiles for broken clouds or vertically extended clouds, respectively.

In this presentation we introduce the algorithm to retrieve GHG profiles under cloudy air conditions from quasi-realistic forward-simulated intensities of LIO signals and thermodynamic profiles and altitude retrieved in a preceding step from LMO signals. At the core of the GHG retrieval methodology is the differencing of two LIO transmission signals, one being GHG-sensitive at a target absorption line and one being a close-by reference outside of any absorption lines (reference channel). The reference signal is used to remove atmospheric "broadband" effects by the "differential transmission" approach. The key preparatory step of the GHG retrieval in cloudy air is to produce a cloud layering profile, flagging level by level the degree of cloud influence from zero (no relevant cloudiness) to unity (opaque cloudiness). For this purpose a reference channel, where transmission is essentially unity, is employed to estimate such a profile from using the channel's transmission profile to assign cloud flags from zero ($<$ 3 dB loss) to unity ($>$ 15 dB loss, cloud blocking). More than one reference channel can be used for cross-checks and robustness of this estimation. The differential transmission profiles are then interpolated over gaps of limited extend (typically $<$ 1 km) with non-zero flagged levels (broken cloudiness) and cut off at the top of vertically extended non-zero flagged levels (thick cloudiness), respectively. Subsequently the retrieval proceeds as in clear air, i.e., an Abel transform converts differential transmission profiles to absorption coefficient profiles, followed by retrieving GHG volume mixing ratios taking into account the absorption cross sections under the temperature-pressure conditions provided by the LMO profiles.

The accuracy of retrieved GHG profiles is found better than 1% to 4% for single profiles in the UTLS region outside clouds, and the profiles are essentially unbiased. The associated cloud layering profile provides information on potential gap-interpolations and on cloud-top altitude, respectively. The methodology shows promising prospects for accurate GHG monitoring based on the combined LIO and LMO technique, including through broken cloudiness.