OVERVIEW and STATUS of the METHANE REMOTE SENSING LIDAR MISSION: MERLIN

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Abstract. The Methane Remote Sensing Lidar Mission (MERLIN) aims at global observations of spatial and temporal gradients of atmospheric methane (CH_4) using spaceborne active measurements based on an Integrated Path Differential Absorption (IPDA) nadir-viewing Lidar instrument. It is a joint French and German space mission which is currently in its phase D with a planned launch date in 2027. The main scientific goal of the mission is to provide the column-integrated dry-air mixing ratio of CH_4 (XCH_4) for all latitudes and for all seasons of the year with very small systematic errors. These accurate spaceborne data will enable to significantly improve our knowledge of CH_4 sources especially in regions like the tropics and high latitudes where data is still sparse compared to other regions of the world.

Keywords: Methane, Active Remote Sensing, Space Mission

1 Introduction

Methane (CH_4) is known to be the second most important greenhouse gas after Carbon dioxide (CO_2). On a 20-year timescale, the warming potential of CH_4 is even 84 times higher than that of CO_2. Therefore, reducing CH_4 emissions to slow down man-made climate change is of great urgency. Detailed observations of CH_4 also from space are critical to monitor and control the progress of these efforts.

The Methane Remote Sensing Lidar Mission (MERLIN) is a joint cooperation between Germany and France on developing and operating a satellite dedicated to monitor atmospheric CH4 from space ([1], [2]). It will be the first space mission using active remote sensing for measuring atmospheric CH4. The French space agency (CNES) is responsible for the satellite platform whereas the Germany space agency (DLR) is responsible for the payload. The satellite will be jointly operated and the quality of the processed scientific mission data will be controlled by a French-German science expert group.

As an active mission MERLIN has several advantages: Firstly, it is independent of sunlight which means MERLIN will deliver CH_4 column data with global coverage during all seasons with a relatively low bias. This is extremely important especially for the Arctic region which is likely to be especially affected by global warming due to climate change, and where positive feedbacks such as melting permafrost occur. Furthermore, the light path is well-known which minimizes the effects due to aerosol and thin cirrus scattering. The high spatial resolution with a small footprint of only about 150 m allows measurements in cloud holes. Analyzing signals backscattered from the cloud top instead of the ground, so-called cloud slicing, can deliver profile information. Another key advantage is the small systematic error which allows detection of the small large scale gradients of atmospheric CH_4.

The MERLIN mission benefits from planned and realized other active space mission. Important heritage is provided in connection to the Earth Explorer missions Aeolus (ALADIN) and EarthCARE (ATLID) as well as by A-SCOPE (ESA mission for CO_2) and ASCENDS (NASA mission for CO_2). The technology of the MERLIN laser is a new development jointly performed by Fraunhofer Institute for Laser Technology ILT and Airbus GmbH with technological support from DLR.

2 Methodology

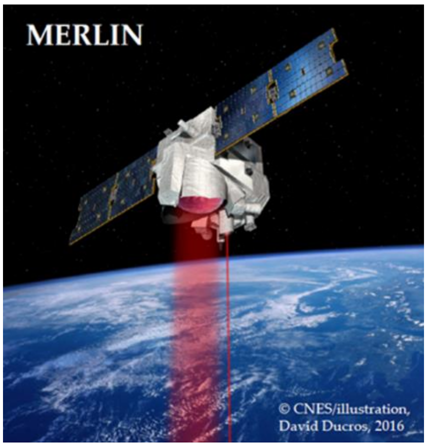

Fig. 1. Shown here is an artistic representation of the MERLIN satellite.

The MERLIN payload consists of an Integrated Path Differential Absorption (IPDA) nadir-viewing Lidar instrument. This method uses two laser pulses which have slightly different wavelengths (λ_{on} and λ_{off}). Those pulses are sent out by the instrument and scattered and reflected from the Earth's surface and cloud tops (see Fig. 1). The wavelength λ_{on} corresponds to the a CH_4 absorption line manifold in the 1.64 µm near-infrared spectral region whereas only negligible absorption by CH_4 happens at the wavelength λ_{off}. Hence, the measurement at λ_{off} serves as a reference.

With the light power $P_{on/off}$ and the emitted laser pulse energy $E_{on/off}$ at both frequencies, the differential atmospheric optical depth (DAOD) can be calculated [3]:

$$\mathrm{DAOD} \equiv \frac{1}{2}\ln\frac{P_{off} \cdot E_{on}}{P_{on} \cdot E_{off}}$$

The DAOD can be converted into the column-integrated dry-air mixing ratio of methane, XCH4, which is the quantity of scientific interest:

$$XCH_4 = \frac{\mathrm{DAOD}}{\int_0^{p_{surf}} WF(p)dp}$$

with

$$WF(p) = \frac{\sigma_{on}(p,T) - \sigma_{off}(p,T)}{g \cdot \left(m_{dry-air} + m_{H_2O} \cdot q_{H_2O}\right)}$$

as the weighting function. This function contains the methane absorption cross-sections for the online wavelength (σ_{on}) and for the offline wavelength (σ_{off}), dependent on pressure p and temperature T, g is the acceleration of gravity, $m_{dry-air}$ is the average mass of a dry-air molecule, m_{H2O} is the mass of a water molecule, and q_{H2O} is the dry-air volume mixing ratio of water vapor.

The derived quantity XCH4 can be used in inverse modelling to calculate CH4 surface fluxes globally and down to a sub-continental scale.

Apart from the XCH4 values which are also called the Level 2 product, the mission will also provide lower Level data, e. g. the DAODs (Level 1b). Furthermore, secondary products or so-called spin-off data could be derived from MERLIN observations. Those products are cloud tops and vertical distribution, canopy height, and surface retro-reflectance.

Once launched, MERLIN will be in a sun synchronous polar low Earth orbit (LEO) with a height of approx. 500 km. The local time ascending node (LTAN) will be either 06:00 h or 18:00 h and MERLIN will have a repeat cycle of 28 days. With these orbit parameters MERLIN will perform measurements around the whole globe with very good quality.

3 Status of the mission

By now, the system definition is fully completed and measurements on critical subsystems of the payload have been performed indicating that the mission will meet the defined requirements. Figure 2 shows the final version of the MERLIN satellite with all its technical components. Some details regarding the status of the mission are given in the next sections.

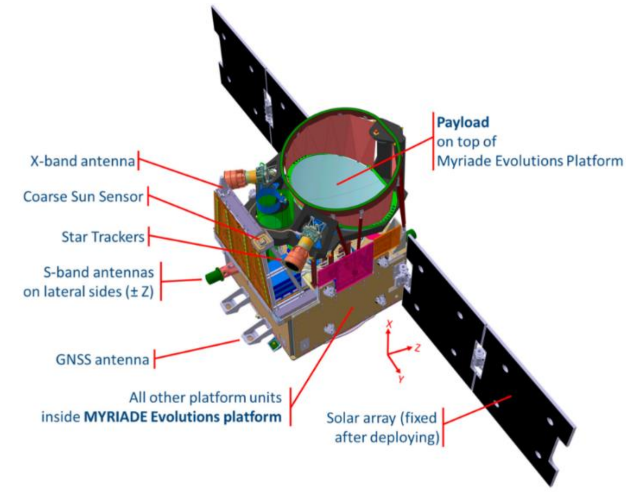

Fig. 2. MERLIN satellite with the IPDA lidar instrument from DLR attached on the MYRIADE evolution platform from CNES (Copyright Airbus Defence and Space).

3.1 Schedule

After successfully completing the payload and the satellite critical design reviews, MERLIN is in phase D of its mission life cycle since mid-2021. Major upcoming milestones are the finalization of all receiver optics flight models (1^{st} quarter of 2023), the finalization of the laser flight model (2^{nd} quarter of 2024) and the finalization of the IPDA payload (2^{nd} quarter of 2026). The launch of MERLIN is anticipated to take place in 2027.

3.2 Expected Performance

Different user requirements concerning the random and the systematic error have been defined for classifying the usefulness of MERLIN products when used in inverse modeling for retrieving CH4 fluxes. The “threshold” requirement is the minimum requirement with values of 36 ppb for the random error and 3 ppb for the systematic error, respectively. Meeting the “breakthrough” requirement with values of 18 ppb for the random error and 2 ppb for the systematic error, respectively, results in a significant improvement to the current satellite observation system. This requirement is also regarded as the optimum from a cost-benefit point of view. Current performance estimations calculate a systematic error of 1.8 ppb which is even less than the breakthrough requirement of 2.0 ppb.

It is shown that future MERLIN data will reduce the uncertainties regarding the CH4 fluxes especially in the high latitudes [2]. In the boreal area, the expected uncertainty reduction when using MERLIN observations in inverse modelling instead of observations from the Greenhouse Gases Observing Satellite (GOSAT) is about 50 % which is significant for this climate sensitive region (see Fig. 3).

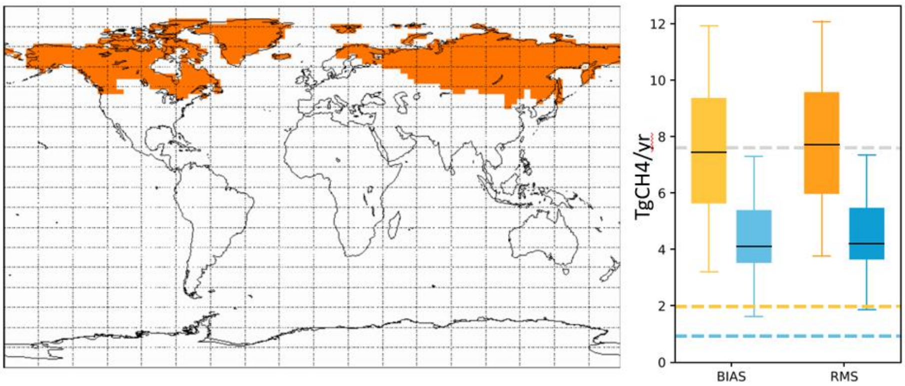

Fig. 3. Shown here is the uncertainty reduction for the boreal regions. In the left panel the orange shaded areas indicate the boreal regions. In the right panel the light and dark blue colors indicate the results for MERLIN whereas yellow and orange show the results for GOSAT. The dashed grey line indicates the prior, the dashed blue line is the mean MERLIN root means square (RMS) and the dashed yellow line denotes the mean GOSAT RMS.

In order to improve the overall performance of MERLIN strong efforts have been made to enhance the spectroscopic parameters in the spectral region of interest. A significant improvement could be achieved regarding the spectroscopic modeling of methane absorption in the band of the MERLIN on-line wavelength centered at 1645.552 nm [4]. The absorption spectroscopy of water vapor in this region around 1.64 µm could also be determined more precise [5]. In summary, this results in a more accurate determination of the weighting function.

4 Validation efforts

Having a sophisticated validation strategy for the MERLIN observations is very important for achieving the goals of the mission. Ground-based networks, aircraft and balloon data and other satellite data could be used for validating MERLIN data. Especially important are data from airborne campaigns because they provide CH4 profiles which are very useful for validation efforts.

In order to prepare the validation of MERLIN various campaigns such as the MAGIC campaigns (a French initiative) and the CoMet campaigns led by the DLR Institute for Atmospheric Physics have taken or will take place. CHARM-F, an airborne demonstrator of MERLIN, has already measured weighted vertical columns of CH_4

(and CO_2) during CoMet 1.0 in 2018 on board the German HALO aircraft and during the MAGIC campaign in 2021 on board the French research aircraft ATR-42, respectively. This instrument will also be on board the HALO aircraft during the CoMet 2.0 campaign in August and September 2022, focusing on the Canadian Arctic region. Together with complementary data from various other CH_4 sensors, the collected airborne lidar data during these campaigns are important not only for preparing the MERLIN validation. They also allow for mission support such as for e. g. algorithm development and improvement.

5 Summary and outlook

The MERLIN mission aims to reduce uncertainties regarding the global methane budget. It will provide the first low-bias, global, spaceborne IPDA Lidar data for atmospheric CH_4. Furthermore, the mission paves the way for future active remote sensing missions dedicated to monitoring greenhouse gases from space.

Acknowledgements

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