THE FRENCH-GERMAN CLIMATE MONITORING INITIATIVE ON GLOBAL OBSERVATIONS OF ATMOSPHERIC METHANE

Gerhard Ehret[1], Pierre Flamant[2], Axel Amediek[1], Philippe Ciais[3], Fabien Gibert[2], Andreas Fix[1], Christoph Kiemle[1], Mathieu Quatrevalet[1], and Martin Wirth[1]

[1]*Institut für Physik der Atmosphäre, DLR Oberpfaffenhofen, Germany, E-mail:gerhard.ehret@dlr.de*

[2]*Institut Pierre Simon Laplace, Lab. Météorologie Dynamique, École Polytechnique, Palaiseau, France*

[3]*Institut Pierre Simon Laplace, Lab. Science du Climat et de l'Environnement, CEA CNRS, UVSQ, Gif sur Yvette France, France*

ABSTRACT

Knowledge of concentrations and fluxes of the most important long-lived greenhouse carbon dioxide (CO_2) and methane (CH_4) is a key element of climate change research. We report on the status of the French-German Climate Monitoring Initiative which aims on global observations of atmospheric methane. This mission which has recently been selected for joint Phase0/A studies at CNES and DLR is intended to improve our understanding of the Global Methane Cycle and the exploration of the nature of the processes which govern the exchange of methane between atmosphere and biosphere. As a novel feature, the observational instrument of this mission will be an Integrated Path Differential-Absorption (IPDA) lidar system embarked on the French spacecraft MYRIADE for the measurement of the column-weighted dry-air mixing ratio of CH_4. This data will be provided by the lidar technique with no bias due to particles scattering in the light path and can directly be used as input for flux inversion calculation. Other geophysical quantities which can be derived from the measurements comprise information on vegetation height, cloud layers, and surface retro-reflectance.

1. INTRODUCTION

CH_4 is a powerful greenhouse gas, which has a Greenhouse Warming Potential (GWP) of 25 relative to CO_2 on a time scale of 100 years. Human activities led to a dramatic perturbation of the natural methane cycle with the result of more than doubling of the CH_4 concentration in the atmosphere since the onset of the industrial revolution [1]. Thus, radiative forcing caused by the additional methane in the atmosphere contributes significantly to the observed global warming. Due to various feedback mechanism interacting between the biosphere and atmosphere, significant uncertainties exit in quantification of the global methane cycle [2]. About 60% of the total flux is man-made by emissions from energy production, coal mining, landfills, waste treatment, ruminants, rice agriculture and incomplete biomass burning. In addition, there are significant natural CH_4 emissions particularly from wetlands. A large fraction of the emitted CH_4 is destroyed in the atmosphere by the chemical reaction with tropospheric OH. Despite the fact that the imbalance between the sources and sinks has decreased in the early 1990's to an insignificant value [3], a significant renewal of the CH_4 growth is reported in recent years [4]. Questions arise, whether an increase of atmospheric CH_4 might be fostered through melting of permafrost soil in the Arctic region or arise from changes of the tropical wetlands which comprise the biggest natural methane source. Another reason could be the change in the agro-industrial era of predominant human influence or the very large deposits of CH_4 as gas hydrates on ocean shelves that are vulnerable to ocean warming [5].

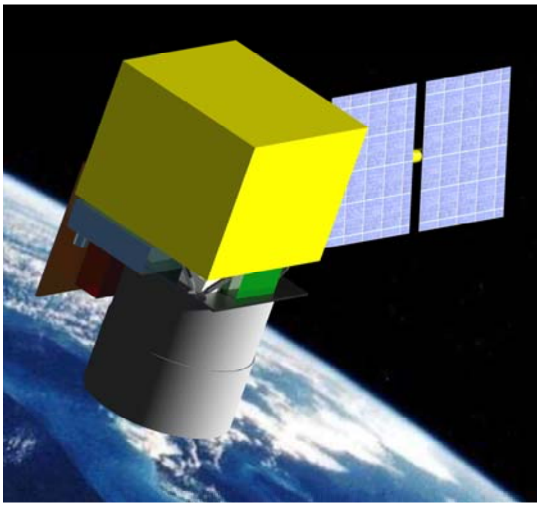

Fig.1: Artist view of the spacecraft MYRIADE from CNES carrying the CH_4 IPDA lidar instrument from DLR

High accurate satellite observations of the CH_4 concentration using Lidar instruments as proposed in this issue, is regarded an adequate tool to improve our knowledge on the methane sources, significantly [6-10].

In this presentation, we report on the status of the French-German Climate Initiative. This is a joint activity between CNES and DLR aiming on space-borne IPDA lidar measurements of the total column of atmospheric methane. Results of the measurement performance and initial instrument concept which is assumed to fit to the French platform MYRIADE are subject of our discussion.

2. MISSION OBJECTIVE

By the joint climate mission, it is intended to perform space-borne measurements of the spatial and temporal variability of atmospheric CH_4 with an accuracy which is significantly better than 1%. The gradients resulting from the lidar observations will permit quantification of the regional methane sources by the use of models that describes transport and mixing. Further objectives include information on high latitudes for marshes and permafrost melting or the Amazon basin, flooded areas, and the tropical forest. Also coastal waters, methane hydrates, and CH_4 production from biomass burning are in the focus of this mission. The measured data are also expected to serve as an estimate of the anthropogenic methane emissions for control of emission inventories and international agreements (Kyoto protocol and follow-up). In addition, this mission yields information on vegetation height and its temporal change for an estimation of biomass dynamics.

The payload discussed and selected in our analysis consists of an Integrated Path Differential-Absorption (IPDA) lidar with altimeter capability. The observational principle of the instrument is shown in Figure 2. The lidar measures the light scattered and reflected from the Earth's surface and cloud tops which are illuminated by two laser pulses having slightly different wavelengths denoted as λ_{on} and λ_{off} . The online wavelength λ_{on} is accurately positioned to the trough of one of the CH_4 absorption line multiplets in the 1.64-1.67 µm region. The measurement at λ_{off} serves as the reference measurement with negligible CH_4 absorption. From the ratio of the lidar echoes of both signals, the differential optical depth and with that the column-averaged CH_4 volume mixing ratio can be calculated [8]. From analysing the waveform of the backscattered pulses, information on the vegetation height with respect to the ground, cloud boundaries, and strong aerosol layers can be derived with high vertical resolution.

A near-polar, sun-synchronous orbit to observe all latitude zones and providing good samples of all climate zones is envisaged. The IPDA lidar instrument which will be provided by DLR is expected to accommodate with the French spacecraft MYRIADE. The latter will be delivered by CNES. Power supply, onboard data storage, processing, and downlink capacity shall account for continuous operation of the instrument at day and night time conditions. The costs of this mission are equally shared between France and Germany.

3. INSTRUMENT REQUIREMENTS

The IPDA Lidar instrument foreseen in this mission transmits alternatively two light pulses which have slightly different wavelengths. As this measurement technique is sensitive to the number of CH_4 molecules

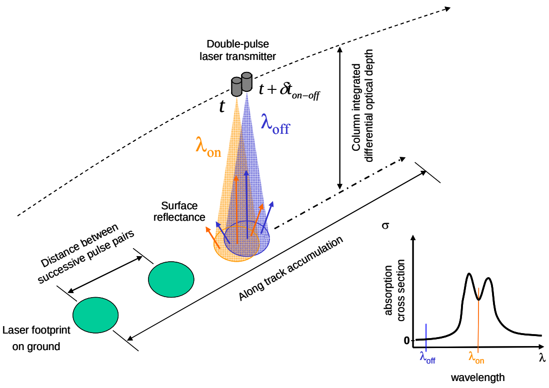

Fig. 2: Measurement principle of space-borne CH_4 IPDA lidar instrument.

in the light path, it measures the Differential Atmospheric Optical Depth (DAOD) of methane between the top of the atmosphere and the scattering surface layer on ground or cloud top. A small temporal separation between the on- and off-line pulses is needed to avoid signal ambiguity of lidar echoes originating from ground and those from high level clouds. The size of the footprint at the target on ground is about 100 m in diameter whereas the distance between successive pulse pairs in Figure 2 is about 140 m. The latter depends on the shot-pair repetition rate of the envisaged laser transmitter. A further data product is the local Scattering Surface Elevation (SSE) and its difference to the elevation from NWP orography. This data is required to correct for local surface pressure changes relative to the NWP grid. For this, a ranging accuracy of better than 10 m would be required. The measured DAOD and SSE data products are converted to the column-averaged mixing ratio, commonly referred to XCH_4, by dividing the measured DAOD through the Integrated Weighting Function (IWF). Determination of the latter requires input from NWP analysis on surface pressure, temperature and humidity profiles. In our analysis it could be shown that a surface pressure uncertainty of 2 hPa (rms) would be acceptable. In addition accurate date on line parameters for the calculation of the differential-absorption cross section are required. Selection of appropriate sounding wavelengths needs careful analysis. Several lines around 1.64 µm have been studied in order to find a good compromise between a small temperature and water vapour sensitivity on one hand and appropriate weighting function and optical depth on the other hand. The latter enables high measurement sensitivity near the ground. Close spacing between on- and off-line is always desirable to minimise any spectral dependence of the surface reflectance and/or atmospheric extinction. Sounding in the trough region of the CH_4 line multiplet as shown in Figure 2 would lead to a dramatic relaxation of the required laser frequency stability/knowledge and pointing requirement compared to sounding at the edge of an absorption line.

The instrument will employ the direct detection principle, where the received optical signal is directly converted to the photon current. The measured number of photoelectrons from target reflection contains all information on the total number of CH_4 molecules within the atmospheric column. The main error source of the measurement is the statistical noise from the relatively small number of received photons from far distant targets and the noise generated by the detection process of the detector-amplifier system. The latter can be quite large compared to the useful signal from lidar returns. Many lidar shots need to be averaged in order to fulfil the envisaged measurement precision of about 1% over a certain averaging scene. In fact, the size of the receiving telescope and the transmitter average power largely determines the radiometric resolution of the measurement.

A key issue of the activity in Phase0/A will be the selection of the optimum instrument size that fits technically to the MYRIADE platform. Also the mission has to meet the user requirements in terms of measurement precision and bias. For this, a science team will be established consisting of experts in the field of greenhouse gas fluxes. The orbit height needs also particular attention. Selection of a 450 km orbit instead in 650 km, for example, would lead to a relaxation of the laser power by a factor of two. Or, if one keeps the size of the instrument is it, the lower orbit would allow for a relaxation of the integration length by a factor four.

4. INITIAL SYSTEM CONCEPTS

The key element of the payload will be the transmitter subsystem. It has to generate a pair of pulses at a repetition rate of about 50Hz and a pulse energy around 3-5 mJ is envisaged. Further characteristics are a narrow bandwidth and sufficient spectral stability in order to fulfill the measurement requirements. Based on significant heritage at DLR with similar systems for water vapour and CO_2 [11, 12] a pulsed single-frequency Nd:YAG laser at 1.064 µm followed by an OPO-based frequency converter is proposed as the baseline transmitter concept. Narrow-band and frequency-stable operation of the OPO will be achieved by means of injection seeding using a cw single-frequency DFB diode laser system which is locked to a multi-pass absorption cell, filled with CH_4 gas. For optimum spectral purity, the OPO cavity modes are matched to a multiple of the wavelength of the seed laser radiation by using a novel feedback loop which aims on suppression of the OPO side modes [13]. To guarantee a high data quality, each transmitted laser pulse will be controlled by the beat signal of the OPO output with the frequency of the cw seed-laser system which itself is locked to the multi-pass cell.

The main parts of the receiver subsystems will comprise a lightweight telescope of the half-meter class in size to fit to the size of the MYRIADE platform and a low-noise avalanche photodiode/ amplifier hybrid receiver at. 1.64 µm. Use of a 1 nm bandpass filter is regarded to be sufficient to suppress the solar background radiation even for a "worst case" orbit with LTN around noon. For the measurement of the laser pulse energy, the output of an integrating sphere will be fiber-coupled to the same detector assembly which is used for the lidar echoes.

The proposed satellite platform MYRIADE has significant heritage from prior applications. It constitutes of a set of functional items which can evolve to fit to a specific payload. The platform was used for the first microsatellite of the series DEMETER, as well as for PARASOL. The platform is designed for low orbit operation and a typical 2-year mission. The orbit inclination covers the range 20° to 98°. As analysed in detail, pointing accuracy and data handling capacity provided by MYRIADE fits very well to the needs of the envisaged payload.

5. PROOF-OF-CONCEPT

The methodology of differential-absorption lidar (DIAL) for remote sensing of atmospheric trace gases such as ozone or water vapour is mature as it has been developed and evaluated by many groups around the world. Regarding DIAL measurements of the long-lived greenhouse gases CO_2 with a similar technique, France and Germany have developed and applied different instruments that consider either the 1.6 µm

[12] or the 2.0 µm spectral domain [14,15]. Helicopter-borne IPDA lidar measurements of methane are routinely performed in Germany with the aim to detect gas pipeline leaks. The lidar instrument which uses a similar OPO technology as described above was developed with substantial contribution of DLR [16]. At DLR a new airborne IPDA lidar system, called CHARM-F, is under construction for the measurement of CO_2 and CH_4 columns, simultaneously using the German high flying research aircraft HALO.

6. SUMMARY

Results from a Pre-Phase0 study for preparation of the French-German Climate Monitoring Initiative are presented. Preliminary requirements for a CH_4 IPDA lidar instrument embarked on the platform MYRIADE are derived. The analysis was based on i) the needs for flux inversion calculations using the satellite measurements as input and ii) the platform resources provided by the envisaged spacecraft. Technical concepts and the availability of significant subsystems are discussed. The encouraging results led to selection of the mission proposal for joint Phase0/A studies at CNES and DLR.

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