Summary of the Final Report of Research Results

1) Title of the proposed research

Space-based analysis of the relationship between vegetation functioning and atmospheric CO_2 and CH_4 greenhouse gases

2) Principal Investigator (PI) and Co-Investigators (Co-Is)

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4) Summary of the Final Report of Research Results

The terrestrial sun-induced chlorophyll fluorescence signal (Fs) is emitted by the photosystem II of the chlorophyll molecules of assimilating leaves: part of the energy absorbed by chlorophyll is not used for carbon fixation, but re-emitted at longer wavelengths in the 650–800 nm spectral region (Papageorgiou,1975; Baker, 2008). The Fs signal originates at the cores of the photosynthetic machinery and responds instantaneously to perturbations in the environmental conditions such as light and water stress. This makes it a more direct proxy to the plant photosynthetic activity than the reflectance-based vegetation indices traditionally used in vegetation remote sensing applications (Coops et al., 2010). The very recent publication of the first global maps of chlorophyll fluorescence (Joiner et al., 2011; Frankenberg et al., 2011b) opens the door to a new, unexplored field of research that couples remote sensing with vegetation and atmospheric sciences.

The Fs retrieval methods developed by Joiner et al. (2011) and Frankenberg et al. (2011a,b) share a common fundamental basis: the fractional depth of solar Fraunhofer lines decreases due to in-filling by Fs. The feasibility of Fs retrieval using individual Fraunhofer lines had been proposed some years ago (Sioris et al., 2003). However, it has not been until the advent of the Greenhouse gases Observing SATellite "IBUKI" (GOSAT), carrying the Thermal And Near infrared Sensor for carbon Observation (TANSO) (Kuze et al., 2009), that the first global Fs maps have been produced. TANSO includes a Fourier Transform Spectrometer (FTS) measuring with high spectral resolution in the 755–775 nm range, which allows to resolve individual Fraunhofer lines overlapping the Fs emission.

This report corresponds to the research activity performed during the time period September 2011 to August 2015 for the GOSAT 2nd Research Announcement project entitled Space-based analysis of the relationship between vegetation functioning and atmospheric CO2 and CH4 greenhouse gases. As it is described in the document, this research has mostly dealt with the development of methods for the retrieval of terrestrial chlorophyll fluorescence from TANSO-FTS measurements. On the one hand, a data-driven method based on singular vector decomposition (SVD) has been developed (Guanter et al., 2012). This method is based on a statistical approach as opposed to the physically-based approaches previously developed by Frankenberg et al. (2011a) and Joiner et al. (2011). The main advantage of this method is that it has a linear forward model which can be inverted by non-weighted linear regression and that it does not require the modeling of the instrument line shape function and external solar irradiance data sets. On the other hand, a new SIF retrieval approach (GARLIC, for GOSAT Retrieval of chlorophyll fluorescence) is presented (Köhler et al., 2015). This method is intended to simplify some of the assumptions of existing retrieval approaches without a loss of accuracy. In addition, we have used existing GOSAT-based SIF data derived with the approach described in Guanter et al (Guanter et al., 2012) as a reference for an initial quality check of the recent SIF retrievals performed from MetOp-A GOME-2 data by Joiner et al (Joiner et al., 2013).

The SVD-based retrieval method makes use of the Fraunhofer lines located in two spectral windows of 2–3 nm centered in 755 and 770 nm to disentangle Fs from the solar radiation reflected by the surface-atmosphere system. The inversion of TOA radiances is achieved by means of a linear forward model consisting of a basis of orthogonal vectors to reproduce Fs-free spectral patterns plus the fluorescence contribution. The basis of singular vectors has been derived with the singular vector decomposition of a training set of vegetation-free spectra for the two spectral micro-windows. Whereas this SVD-based method has some fundamental similarities with the state-of-the-art approach described in Frankenberg et al. (2011a,b) (same two spectral micro-windows, two polarizations processed separately, empirical correction of radiometric offsets), this method may have some advantageous features such as a simple implementation and a higher efficiency.

Concerning the GARLiC full-physics retrieval method also developed in this project, it demonstrates that simplifying some assumptions of the existing state-of-the-art algorithm by Frankenberg et al. Frankenberg et al. (2011a) is not leading to a loss of accuracy in the retrieval. The simplifications consist in neglecting the spectral stretch and decoupling the spectral shift estimation from the forward operator. Thus the GARLiC forward model is linear and easy to invert with the ordinary least squares method.

In addition, we have demonstrated that SIF composites have a lower precision in presence of clouds because of the lower number of available soundings, but the changes in accuracy for a wide range of cloud coverage is only marginal. For this reason, it can be stated that the SIF retrieval is less affected by clouds than reflectance-based vegetation indices. These finding impact future developments on SIF retrieval for the upcoming OCO-2 system (Frankenberg et al. (2014)), which will have spectral characteristics similar to those of the GOSAT-FTS and will provide about 100 times more measurements than GOSAT.

This document provides a summary of the fundamentals of the retrieval methods by Guanter et al. and Köhler et al. developed in this project as well as of the results found after the comparison with equivalent retrievals with other methods and with state-of-art vegetation products based on remote sensing data, including fluorescence retrievals from GOME-2 by Joiner et al.

5) List of publications relating to the proposed research

1. Guanter, L., C. Frankenberg, A. Dudhia, P. E. Lewis, J. Gómez-Dans, A. Kuze, H. Suto, and R. G. Grainger (2012), Retrieval and global assessment of terrestrial chlorophyll fluorescence from GOSAT space measurements, Remote Sensing of Environment, 121, 236–251.

2. Joiner, J., L. Guanter, R. Lindstrot, M. Voigt, A. P. Vasilkov, E. M. Middleton, K. F. Huemmrich, Y. Yoshida, and C. Frankenberg (2013), Global monitoring of terrestrial chlorophyll fluorescence from moderate-spectral-resolution near-infrared satellite measurements: methodology, simulations, and application to GOME-2, Atmospheric Measurement Techniques, 6(10), 2803–2823.

3. Guanter, L., et al. (2014), Global and time-resolved monitoring of crop photosynthesis with chlorophyll fluorescence, Proceedings of the National Academy of Sciences, 111(14), E1327–E1333.

4. Köhler, P., L. Guanter, and C. Frankenberg (2015a), Simplified physically based retrieval of sun-induced chlorophyll fluorescence from GOSAT data, Geoscience and Remote Sensing Letters, IEEE, 12(7), 1446–1450.

5. Köhler, P., L. Guanter, and J. Joiner (2015b), A linear method for the retrieval of sun-induced chlorophyll fluorescence from GOME-2 and SCIAMACHY data, Atmospheric Measurement Techniques, 8(6), 2589–2608.