Summary of the Final Report of Research Results

1) Title of the proposed research

Study of aerosol and cloud properties using the polarization of the O_2 A-band

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

PI:

Dr. Piet Stammes

Co-I:

Dr. M.O. (Ofelia) Vieitez

Dr. A.J. (Bram) Sanders

3) PI's affiliation

Royal Netherlands Meteorological Institute (KNMI), De Bilt, The Netherlands

4) Summary of the Final Report of Research Results

The original aim of the project was to use the polarisation of the O2 A-band as measured by the GOSAT FTS to retrieve aerosol layer height. During the course of the project, this was changed to using the radiance spectrum of the O2 A-band to retrieve aerosol height. The reason was that the amount of information in the radiance spectrum itself is sufficient to get aerosol height information. The polarization is not adding much information on aerosol height, because GOSAT has only one viewing angle per pixel. The main disadvantage of using polarization measurements from GOSAT is that the instrumental corrections to get an accurate value for the degree of polarization are very cumbersome; this took quite a long time in our project. On the other hand, the (unpolarized) radiance itself can be easily found by averaging the S- and P-polarisation spectra measured by GOSAT FTS. That is why our research has been focused on using the radiance spectrum of the O2 A-band.

The GOSAT data have also been used to prepare the aerosol height retrieval algorithm for TROPOMI on the Sentinel-5P satellite, to be launched in early 2017, and for UVN on the Sentinel-4 satellite, to be launched in 2022.

The work on GOSAT aerosol retrieval research was funded by two different projects: from Feb 2010 - Feb 2012 the work was funded by NWO, the Netherlands ("GOSAT profiler" GO-project), and from May 2012 – March 2014 by ESA (AEROPRO project).

We are grateful for the help with calibration and data processing of GOSAT data from Dr. Suto and Dr. Kuze from JAXA.

Aerosol height retrieval from the GOSAT O2 A-band measurements

The aerosol profile retrieval algorithm has the following key features:

- Spectral fit of reflectance across the O_2 A band (fit window 758 – 770 nm)
- Retrieval method is Optimal Estimation
- Main fit parameters are: aerosol pressure (P), aerosol optical thickness (AOT) and surface albedo (A_s)
- Error estimates are provided to improve usability of the product (e.g. for data assimilation)
- Assumed aerosol profile: single layer with a fixed pressure thickness and a constant volume extinction coefficient within the layer.

We assume that aerosols are uniformly distributed in a single layer with a fixed pressure thickness. The retrieved aerosol pressure is the mid pressure of the layer. This parameterization is most suited for aerosol profiles that are dominated by a single, elevated, optically thick aerosol layer. Examples are free tropospheric aerosols such as desert dust, biomass burning aerosols, or volcanic ash plumes. An alternative aerosol profile assumption is that of a homogeneous aerosol-laden boundary layer, where the top pressure of the aerosol layer can be retrieved.

We used the GOSAT L1b data of TANSO Band 1 as a proxy for the UVN instrument on Sentinel-4, because of its high spectral resolution. We made use of the specially requested GOSAT FTS pointed observations over Greece and Turkey in August/September 2011. These observations were coinciding with the CarbonExp campaign of ESA in August/September 2011.

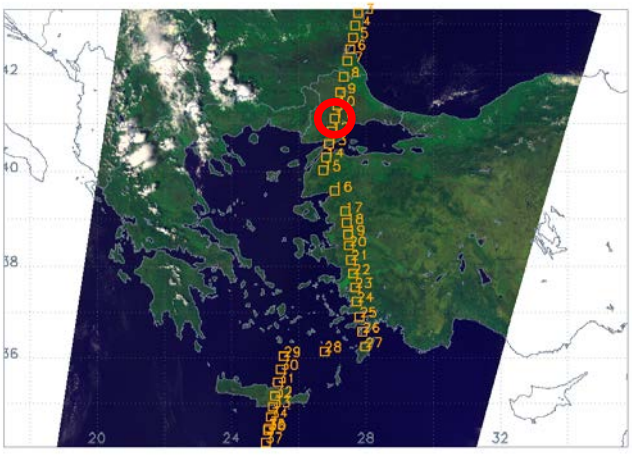

Fig. 1: GOSAT pointed observations for the CarbonExp campaign in Aug/Sept 2011 which were used for development and validation (circle) of the aerosol height retrieval algorithm.

The GOSAT L1b data were preprocessed: spectral calibration, radiometric calibration, and convolution with the UVN slit function (0.12 nm FWHM). Also the SNR calculation was done ourselves. Aerosol height retrieval using optimal estimation from GOSAT O2 A-band spectra has been performed for about 15 selected events of cloud-free aerosol plumes over lidar sites, including the CarbonExp 2011 campaign data. Lack of convergence was often a problem. We tested various retrieval options. We found that our retrieved aerosol layer height correlates reasonably with the top of the aerosol layer as measured by the lidar. The residuals have a characteristic shape, possibly due to calibration issues or model deficiencies. Our aerosol layer height algorithm remains under development. An important recent finding was that fixing the spectral surface albedo from existing climatology gives better convergence and improved height results. This work was extended with application to GOME-2A data (Sanders et al., AMT, 2015).

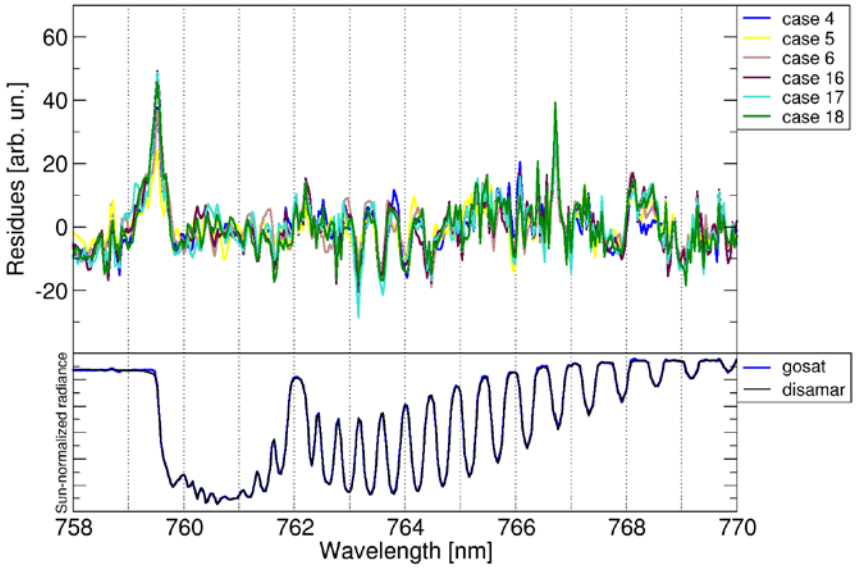

Fig. 2. Top plot: Fit residuals in the GOSAT O2 A-band for 6 different aerosol cases. The strong residual leftwards of 760 nm is due to missing line-mixing in the O2 A-band simulation used in the retrieval. Bottom plot: Measured and fitted spectra of one of the retrieval cases.

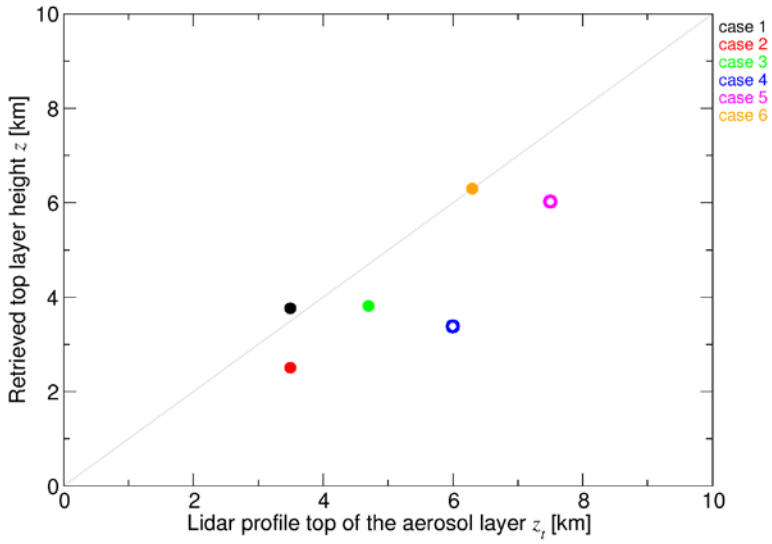

Fig. 3. Comparison of the GOSAT retrieved aerosol layer top height with the lidar profile aerosol top height, for cases 1 to 6, using line-mixing in the O2 A-band. Each case is separated by color. The full symbols indicate that the boundary layer model was used. The open symbols indicate that the elevated layer model was used.

Alternative method for aerosol height retrieval

We have also been working on an alternative method of aerosol height retrieval, namely to use the shape of the k-distribution of the lines in the O2 A-band. From simulations of reflectance as a function of absorption optical thickness for varying aerosol optical parameters, we found that the shape of the k-distribution gives a strong dependence on aerosol layer height. This was also demonstrated with a few GOSAT scenes. This line of research was presented by Parikh et al. at the workshop "Remote sensing in the O2 A-band", which was organised at KNMI in July 2016. The proceedings from this workshop will be published in a special issue of AMT.

5) List of publications relating to the proposed research

Presentations and posters:

- Presentation "Vertical Distribution of Aerosols from GOSAT Measurements of the Polarized O2 A-band", by P. Stammes at the GOSAT 2-nd PI Meeting held in Kyoto, Japan, 28-29 January 2010.
- Poster "Towards an accurate Light path correction of greenhouse gases: Altitude of aerosols

from GOSAT observations of the polarized oxygen A-band" presented by O. Vieitez at the EGU conference held in Vienna, Austria, May 2010

- Poster "Development of aerosol altitude retrieval from GOSAT observations of the oxygen A-band", at the EGU conference in Vienna, Austria, April 2011.
- Presentation by P. Stammes at the 3rd GOSAT RA PI meeting, held in Edinburgh, Scotland, 19-20 May 2011
- Presentation by M.O. Vieitez at the GOSAT workshop "Towards the GOSAT-2 mission", Feb/March, 2012
- Presentation by P. Stammes et al., "Analysis of GOSAT high spectral resolution O2 A-band measurements", ESA Atmospheric Science Conference, Bruges, June 2012
- Presentation by P. Stammes et al. at the 5-th GOSAT RA PI meeting, Yokohama, May 2013
- Presentation by P. Stammes et al. at ESA Living Planet Symposium, Edinburgh, September 2013
- Presentation by A. Sanders et al. at the 6-th GOSAT RA PI meeting, Tsukuba, May 2014

Publications:

- Sanders, A. F. J., de Haan, J. F., Sneep, M., Apituley, A., Stammes, P., Vieitez, M. O., Tilstra, L. G., Tuinder, O. N. E., Koning, C. E., and Veefkind, J. P.: "Evaluation of the operational Aerosol Layer Height retrieval algorithm for Sentinel-5 Precursor: application to O_2 A band observations from GOME-2A", Atmos. Meas. Tech., 8, 4947-4977, doi:10.5194/amt-8-4947-2015, 2015.

- Parikh, A., Stammes, et al., "An alternative method for aerosol height retrieval from the O2 A-band", to be submitted to AMT (special issue of O2 A-band remote sensing).

- P. Stammes, A. Apituley, A.F.J. Sanders, O.M. Vieitez, J.F. de Haan (KNMI), AEROPRO study - Final Report, 01-August-2014, "Aerosol Profile Retrieval Concept Development and Validation for Sentinel-4", ESA ITT AO/1-7017/11/NL/MP, Contract: 4000105882/12/NL/MP

- Appendix to AEROPRO Technote 2B: "GOSAT data calibration and treatment", M.O. Vieitez, March 26, 2013