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Determination of Stratospheric Temperature and Density by GOMOS: Verification with Respect to High Latitude LIDAR Profiles from Thule, Greenland

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Abstract. High resolution temperature profiles (HRTP) have been derived from measurements performed by Global Ozone Monitoring by Occultation of Stars (GOMOS) onboard ENVISAT. HRTP are derived from measurements with two fast photometers whose signal is sampled at 1 kHz, and allows investigating the role of irregularities in the density and temperature profiles, such as those associated with gravity waves. In this study high resolution temperature and density profiles measured at high latitude by GOMOS are compared with observations made with the ground-based aerosol/temperature LIDAR at Thule, Greenland. The LIDAR at Thule contributes to the Network for the Detection of Atmospheric Composition Change. The LIDAR profiles are analyzed in the height interval overlapping with GOMOS data (22-35 km), and the density and temperature profiles are obtained with 250 m vertical resolution. The comparison is focused on data collected during the 2008-2009 and 2009-2010 Arctic winters. Profiles measured within 6 hours and 500 km are selected. The profiles are classified based on spatial and temporal variability of dynamical indicators over Thule and at the GOMOS tangent height position. Several corresponding features can be identified in the GOMOS and LIDAR profiles, suggesting that the GOMOS HRTP could be used to investigate the global distribution of small scale fluctuations. As an example, two cases corresponding to inner and outer vortex conditions during the 2008-2009 winter are discussed, also in relation with the very intense sudden stratospheric warming occurred in this season.

INTRODUCTION

Gravity and other type of waves play an important role in determining the dynamical and thermal structure of the stratosphere. As an example, they play a crucial role in the determination of the Quasi Biennial Oscillation characteristics [1]. The occurrence of waves, especially with relatively small wavelength, also affects the comparison between different measurements of stratospheric temperature or density, especially when an exact co-location is not possible. In addition, the occurrence of waves may produce biases in the determination of climatological profiles. Thus, it is essential to develop a method that enables to compare density/temperature profiles obtained with different sensors in the stratosphere. In this study vertical profiles obtained by GOMOS are compared with measurements of the stratospheric density and temperature carried out using the Rayleigh LIDAR operating at Thule (76.5°N, 68.8°W; Greenland). LIDAR observations are performed in winter and early spring, when the stratosphere is characterized by a very large variability. Thus, a specific comparison strategy, based on the occurring stratospheric conditions in the observation region, and on an improved method to extract wave signals from the profiles, was developed. This study shows some specific cases, corresponding to different polar vortex conditions.

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OBSERVATIONS

The GOMOS instrument is a spectrometer that exploits the stellar occultation technique. GOMOS comprises one UV-Visible channel (250-675 nm) and two near infrared channels (756-773 nm and 926-952 nm). These wavelength regions allow retrieving atmospheric vertical profiles of O_3, NO_2, NO_3, O_2, H_2O, and aerosols.

In addition, two fast photometers operate at 1 kHz sampling frequency in the blue (470-520 nm) and in the red (650-700 nm) spectral regions.

High Resolution Temperature Profiles (HRTP) are obtained from the synchronous scintillation measurements performed with the two fast photometers. Density and temperature are derived from the delay between scintillations induced by density fluctuations at the two wavelengths. The delay is related to the refraction angle, which depends on refractive index, thus density. The temperature profile is derived by applying the hydrostatic equation and the perfect gas law. HRTP are retrieved between <10 and 35 km altitude, with a vertical resolution that is about 200-250 m. The GOMOS HRTP data used in this study were generated with the Instrument Processor Facility (IPF) version 6.01, and have been publicly available since December 2012 (https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/gomos/products-and-algorithms/products-information). GOMOS was flown onboard the ENVISAT satellite, which operated over the period 2002-2012.

As part of the Network for Detection of Atmospheric Composition Changes (NDACC), a temperature/aerosol LIDAR has been operational at Thule since 1990. Additional instruments to investigate the atmospheric structure and chemical composition are operational at Thule. They include solar and infrared radiometers, a FTIR instruments, a radio/ozonesonde system, a sun-photometer, a high resolution mm-wave spectrometer for measurements of the stratospheric chemical composition, etc. The instruments are operated by different institutes (DMI, NCAR, ENEA, INGV, and University of Rome).

The LIDAR uses a Nd:YAG laser, three telescopes, and four receiving channels to measure the aerosol backscatter ratio and depolarization in the troposphere and lower stratosphere, and the atmospheric temperature (T) profile from 25 up to 70 km altitude. The LIDAR temperature profiles used in this study have a vertical resolution of 150 m and a time resolution varying between 15 and 30 minutes.

METHOD

Lower and middle stratospheric measurements carried out by LIDAR and by GOMOS within 6 hours and about 500 km difference in the period 2007-2012 are selected for the analysis. A total of 58 pairs of co-located and quasi-simultaneous profiles are included in the dataset; all profiles are obtained in January and February. The mean time difference between LIDAR and GOMOS profiles is about 2.5 hours; the mean spatial difference in the dataset is about 410 km. The number of pairs naturally increases with distance. There are 9 profiles acquired within 300 km. The profiles are further classified based on information on the stratospheric dynamics (maps of stratospheric temperature, T, potential vorticity, PV, and geopotential height, GPH) to exclude cases in which large temperature or geopotential gradients are present above Thule; these cases generally correspond with the edge of the polar vortex close to Thule.

Since GOMOS HRTP and LIDAR temperature profiles have different vertical resolution, we adopted a common vertical grid by applying a linear interpolation to both GOMOS and LIDAR data, for direct comparison. Subsequently, the LIDAR and GOMOS density and temperature profiles were independently analysed by using the continuous wavelet transform (CWT), which provides a decomposition of the signal in both space and frequency domains. This space-frequency representation of the signal offers a very good space and frequency localization, so wavelet transforms can analyse localized intermittent periodicities. The Morlet mother function, which has proven to give a good resolution in space as well as in frequency, has been selected [2].

The wavelet analysis was carried out separately on the LIDAR and GOMOS temperature/density profiles. In this way, the wave signal is estimated for the two profiles, allowing to investigate the occurrence of wave structures, and to check the consistency of the oscillatory signals on the two sensors. The wave signal is also subtracted from the original temperature or air density profile, thus providing wave-free profiles, which may be used for an extended comparison and validation of the satellite retrievals.

It must be pointed out that the frequency domain of the identified waves depends on height, as well as on the vertical extension and resolution of the original data. By considering the characteristics of the LIDAR and GOMOS sensors, the implemented algorithms permit to identify structures with periods between 0.3 and 4 km between 24 and 32 km altitude.

SELECTED CASE STUDIES

Meteorological analyses from NCEP (available at http://mls.jpl.nasa.gov/plots/met/) were used to characterize the conditions and spatial homogeneity around Thule during the coincidences in the lower stratosphere during years 2007, 2009, and 2010. GPH, T, and PV fields at 10 mb and at 5 mb were considered. We have selected two representative cases with different conditions to display the main results of the analysis. Figure 1 shows an example of dynamical parameters for the period January - February 2009. In the three panels the solid lines represents the geopotential height, the temperature, and the potential vorticity, respectively, above Thule. The full circles represent the values of the three parameters at the GOMOS tangent altitude position.

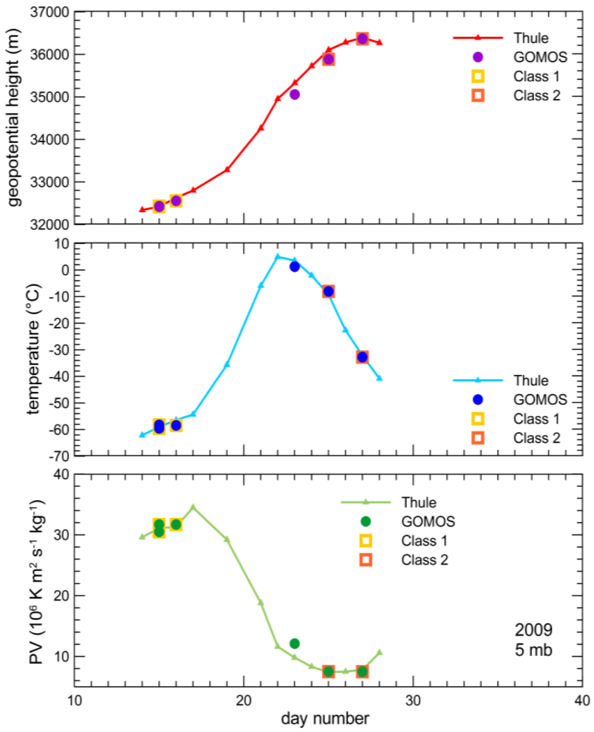

Figure 1: Time series of (top) geopotential height, (middle) temperature, and (bottom) potential vorticity at 5 mb above Thule in January-February 2009. The full dots are relative to the GOMOS tangent height position. Class 1 and Class 2 data are relative to cases with low variability respectively inside and outside of the polar vortex.

Potential vorticity values were used to identify cases corresponding to inner vortex, outside the vortex, and vortex edge. In particular, we distinguished a Class 1 (yellow square) representing profiles with low variability and inner vortex conditions, and a Class 2 (orange square) with profiles with low variability and conditions outside the vortex. The full circles without squares are the cases that are characterized by high variability.

It is worth noting how the potential vorticity follows an inverse pattern with respect to the temperature, and large changes of these parameters occur in the period. Temperature reached a maximum value > 0 °C between 22 and 28 January 2009. This rapid increase in temperature is due to the very intense Arctic Sudden Stratospheric Warmings (SSW), which affected the dynamics and thermal structure of the winter stratosphere. The 2009 Arctic SSW was the most significant event of this kind ever observed [3].

Figure 2 shows the GOMOS and LIDAR profiles obtained on 15 January, when the polar vortex was strong and Thule was located well inside it. From left to right, the first panel of Figure 2 depicts the raw profiles interpolated at 200 m vertical resolution. The second panel shows the wave-free temperature profiles after applying the wavelet method. The dynamical features present in the GOMOS and LIDAR temperature profiles are removed after performing the wavelet analysis. The third and fourth graphs show the temperature and density perturbation profiles, obtained as the difference between the original and the wave-free profiles.

The wavelet analysis allows the subtraction of a background from the temperature/air density profiles. The remaining perturbations are assumed to be small-scale fluctuations.

The profiles for 25 January 2009 are shown in Figure 3. On 25 January the SSW reached its peak, and the polar vortex was severely weakened and distorted. Thule was clearly outside of the vortex region. Temperatures were significantly higher than on 15 January.

A good agreement is observed between collocated HRTP and LIDAR profiles. A similarity of small scale fluctuations is also visible. It is noteworthy, however, that a phase difference between the GOMOS and LIDAR perturbation profiles is clearly visible in the third and fourth panels of Figure 2 and 3. This phase difference is attributed to the time and distance separation between the measurements [4]. Finally, as expected it is possible to see that GOMOS temperature fluctuations (expressed in K) and air density fluctuations (expressed in percentages) are perfectly anti-correlated. A clear anti-correlation is also observed between LIDAR temperature and air density percentage fluctuations.

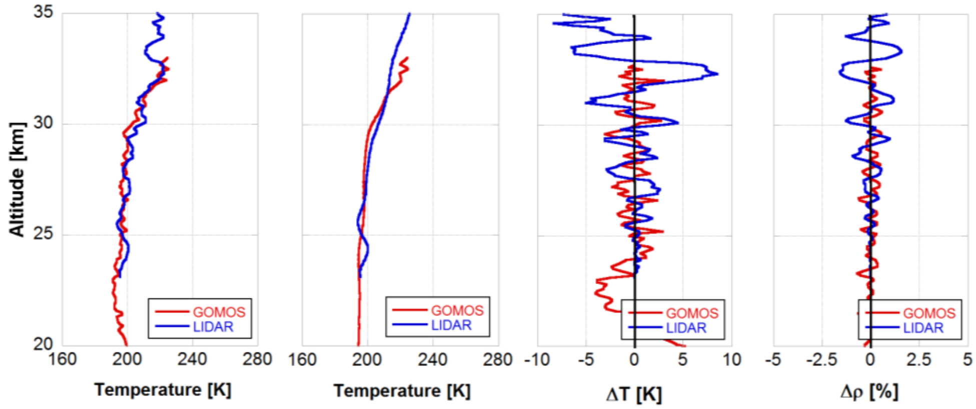

Figure 2: from left to right: raw GOMOS and LIDAR temperature profiles; wave-free temperature profiles; temperature perturbations; density perturbations for the profiles of 15 January, 2009.

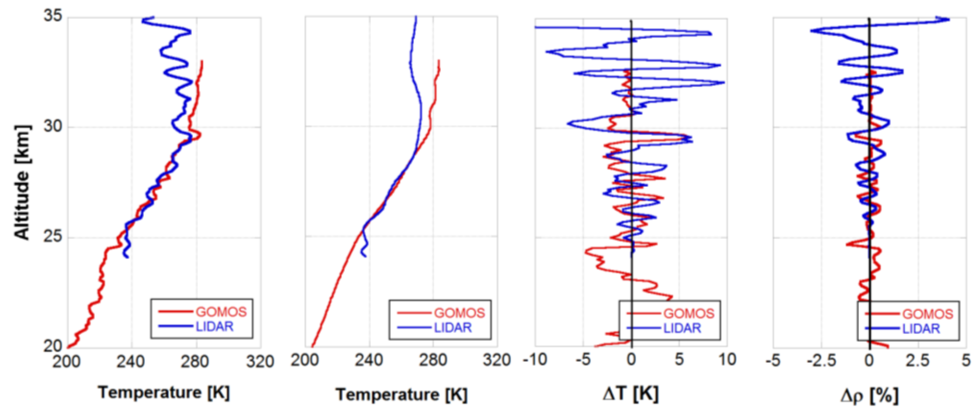

Figure 3: same as Figure 2, but for 25 January, 2009.

The analysis is being extended to the relatively large dataset at Thule, over the years 2003-2012. These first results suggest that CWT enables the detection and the removal of small-scale vertical fluctuations, producing wave-free profiles of atmospheric temperature and density. This method can be used to study the characteristics of the fluctuations, as well as to minimise the impact of the atmospheric fluctuations in the validation of profile data, reducing the uncertainty on bias estimates [4]. In addition, the determination of wave-free profiles may positively impact the estimates of stratospheric temperature trends.

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