Validation of GOMOS High Resolution Temperature Profiles using Wavelet Analysis - Comparison with Thule Lidar Observations

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Introduction: Motivation

The validation of high resolution atmospheric temperature and density profiles is impacted by the presence of gravity waves.

Gravity waves influence the large-scale circulation in the stratosphere by transporting the momentum and the energy flux from the troposphere. Gravity waves have been observed by a variety of techniques including radar, lidars and satellite measurements. These wavelike motions appear as periodic oscillations in temperature, pressure, and density of the air, as waves propagate both vertically and horizontally.

Below 35 km, the peak-to-peak amplitude of the wavy structures can be of the order of 10 K. As a consequence, two waves out of phase by half wavelength will produce a difference in temperature of same order.

The aim of the proposed method is

Analyse temperature perturbations with Morlet wavelet to isolate wave packets in altitude, and then to remove as much as possible the gravity wave signals from the GOMOS and correlative temperature profiles.
**Introduction: GOMOS instrument**

The GOMOS (Global Ozone Monitoring by Occultation of Stars) instrument is a spectrometer that exploits the stellar occultation technique.

GOMOS comprises:

- **2 UV-Visible channels:**
  - A1: (250-389 nm)
  - A2: (389-690 nm)

- **2 near infrared channels:**
  - B1: (756-773 nm)
  - B2: (926-952 nm)

These wavelength regions allow retrieving atmospheric vertical profiles of O$_3$, NO$_2$, NO$_3$, O$_2$, H$_2$O.

High Resolution Temperature Profiles (HRTP) are obtained from the synchronous scintillation measurements performed with the two fast photometers. The two fast-photometers operate at 1 kHz sampling frequency in the blue (470-520 nm) and in the red (650-700 nm) spectral regions, respectively.
Introduction: Lidar instrument

As part of the Network for Detection of Atmospheric Composition Changes (NDACC), a temperature/aerosol lidar is operational at Thule (76.5°N, 68.8°W) since a long time (first installation in 1990; activation of temperature measurements in 1994).

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 24 up to 70 km altitude.

The density profile is derived from the lidar Rayleigh signal as described in Marengo et al. (1997); the temperature profile is derived by applying the hydrostatic equation and the perfect gas law. Profiles with a vertical resolution of 150 m, and a time resolution varying between 15 and 30 minutes are used in this study.
Methodology

1) HRTP/LIDAR co-location criteria: distance < ~500 km;
2) Classification based on stratospheric dynamics (potential vorticity, PV, and maps of stratospheric temperature, and geopotential height);
3) Interpolation of HRTP/LIDAR profiles to a common grid;
4) Wavelet analysis of HRTP/LIDAR interpolated profiles;
5) HRTP/LIDAR comparison of wave-free T and ρ profiles
Methodology: Temperature and Density co-located profiles 2003-2012

Selected Lidar-GOMOS data pairs

2003: 13 coincidences – 9 days
2007: 30 coincidences – 13 days
2009: 6 coincidences – 5 days
2010: 9 coincidences – 6 days
2012: 1 coincidence – 1 day
Methodology: NCEP/CPC analyses

In winter the stratosphere above Thule is affected by the polar vortex and characterized by a high variability.

NCEP/CPC analyses, NASA Atmospheric Chemistry and Dynamics Laboratory

Pressure; Geopotential height; Temperature; Potential vorticity

Calculated over Thule on the day of the LIDAR sounding and calculated at the same time at the GOMOS tangent altitude position.

White dot: position of Thule; Black dot: location of the GOMOS profile

NASA GMAO (Global Monitoring and Assimilation Office) maps available at http://mls.jpl.nasa.gov/plots/met
Methodology: NCEP/CPC analyses

2007
10 mbar $\approx 29$ km ; PV$>$30 PVU Inner vortex

- Class 0
  Variable conditions
- Class 1
  Inside the polar vortex
- Class 2
  Outside the polar vortex

The profiles are further classified based on information on the stratospheric dynamics (potential vorticity, PV, and maps of stratospheric temperature, PV, and geopotential height) 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.
Methodology: Wavelet analysis

Wavelet analysis of GOMOS and LIDAR temperature and density based on Torrence and Compo (Torrence and Compo, 1998).

Analyse temperature and density profiles with Morlet wavelet to isolate wave packets in altitude.

The continuous wavelet transform possesses the ability to construct a space-frequency representation of a signal that offers very good space and frequency localization, so wavelet transforms can analyse localized non stationary structures of potentially great interest in the temperature signals.

- Remove background from temperature and density profiles
- Create wavelet spectrum and isolate local maxima within the Cone of Influence (region not effected by upper and lower altitude limits)
- Significance levels
GOMOS $T$ and $\rho$ fluctuations are “perfectly” anti-correlated by construction, as the $T$ profile is derived from the $\rho$ profile.
Methodology: Wavelet analysis

Distance: 340km; Time difference: 2 h

T [K]  ΔT [K]  Δρ [%]  T [K]

GOMOS  LIDAR  ECMWF

Tangent Height [km]

20  225  240  255
25  30  35

195  210  225  240  255
Methodology: Wavelet analysis

Distance: 490 km; Time Difference: 0 h
Results: Case studies 2009

2009
5 mbar
≈33 km

PV>25 PVU
Inner vortex

Class 1
Inside the polar vortex

Class 2
Outside the polar vortex
Results: Case study 2009

Potential Vorticity

Temperature

15/1/2009

~30 km

25/1/2009
Results: Case study 2009

Distance: 516 km; Time Difference: 1h

Distance: 470 km; Time Difference: -4 h
Results: Case studies 2009

Di Biagio et al., 2010: Evolution of temperature, O3, CO, and N2O profiles during the exceptional 2009 Arctic major stratospheric warming as observed by lidar and mm-wave spectroscopy at Thule (76.5°N, 68.8°W), Greenland. JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, D24315.
Results: Validation of small-scale structures

![Histograms showing relative frequency of temperature and density variations for GOMOS and Lidar data.](image-url)
Results: analysis of the temperature differences

Class 0,1&2

Class 1&2
Conclusion

A new method for the comparisons of temperature and density profile data from high vertical resolution measurements is described;

The temperature profiles might be more or less affected by geophysical variability due to the presence of the gravity waves and the magnitude of uncertainty of the bias is based also on the different conditions in the validation exercises, such as location and season;

The method is thus very useful to estimate the contribution due to the presence of small-scale fluctuations from the temperature and density profiles, and is the basis for comparing the oscillation-free profiles.