Observing the upper troposphere and lower stratosphere with GPS radio occultation data: Results from CHAMP, GRACE, and COSMIC

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The CHAMP and GRACE team (GFZ)
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Overview

• GPS RO data base

Applications

• Variability of the UTLS: tropopause, temperatures and bending angles
• Gravity wave activity in the UTLS
• Tropopause inversion layer
• Summary
Data base

CHAMP: 2001.05-2008.09
GRACE: since 2006.01

COSMIC: since 2006.04 (6 satellites)

\[ \Delta \phi = 10° \]
about 150/300 profiles/day

\[ \Delta \phi = 5° \]
about 2,500 profiles/day

COSMIC workshop, Boulder, Oct. 27-29, 2009
Applications

Climate
Are the ROs benchmark data for climate monitoring/change?

Link between tropospheric/LS warming/cooling and tropopause height

Recent trend studies with GPS RO data

**Schmidt et al., GRL, 2008:**
Global LRT height increase of ~7m/yr from CHAMP temperatures (2001-2007)

**Ho et al., JGR, 2009:**
Trend study of CHAMP refractivity (2002-2006) from different centers

**Steiner et al., GRL, 2009:**
Temperature trend study for February/November months with GPS/MET (1995, 1997) and CHAMP (2002-2008)

Is this visible in the RO data?
Climate monitoring based on T, N or $\alpha$?

**Advantages of bending angles:**

- less sensitive to uncertainties related to data processing than refractivity or dry temperature
- avoid inclusion of *a priori* information in the Abel transform, hydrostatic equilibrium and *a priori* pressure or temperature in the hydrostatic integration to derive the dry temperature

**Demonstrations:**

Healy and Thepaut, QJRMS, 2006 (weather)

Ringer and Healy, GRL, 2008 (climate)

Lewis (GRL, 2009) introduced a new method for the tropopause identification using $\text{ln}(\alpha)$ profiles
Tropopause height and bending angles

LRT algorithm
(Reichler et al., 2003)

α (BA) based algorithm
(Lewis, 2009)

Basis: CHAMP/GRACE May 2001-August 2009

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Tropopause height variability

\[ y(t) = \text{const} + \alpha \cdot t + \beta \cdot QBO(t) + \gamma \cdot ENSO(t) \]
Tropopause height variability

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Bending angles and temperature trends

Basis: CHAMP/GRACE May 2001-August 2009

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Gravity waves
Gravity wave analysis

\[ T'(z) = T(z) - \overline{T}(z) \]

\[ \overline{T'}^2(z) = \frac{1}{z_2 - z_1} \int_{z_1}^{z_2} T'^2(z) \, dz \]

\[ N^2(z) = \frac{g}{\overline{T}} \left( \frac{\partial \overline{T}}{\partial z} + \frac{g}{c_p} \right) \]

\[ E_p(z) = \frac{1}{2} \cdot \frac{g^2}{N^2} \cdot \left( \frac{T'}{\overline{T}} \right)^2 \]
Lower stratospheric GW climatologies

CHAMP/GRACE
May 2001-Aug. 2009
$\Delta \phi = 5^\circ$
on-overlapping bins

COSMIC
$\Delta \phi = 5^\circ$
non-overlapping bins
Lower stratospheric GW climatologies

CHAMP/GRACE
May 2001-Aug. 2009
$\Delta \phi = 5^\circ$

COSMIC workshop, Boulder, Oct. 27-29, 2009
GW analysis in the tropopause region

(from Schmidt et al., GRL, 2008)
GW analysis in the tropopause region

Basis: CHAMP/GRACE May 2001-August 2009

(update from Schmidt et al., GRL, 2008)
Tropopause inversion layer
Tropopause inversion layer (1)
Tropopause inversion layer (2)

CHAMP/GRACE 2001.05-2009.08
\( \Delta \phi = 5^\circ \)
overlapping bins
Summary

- RO technique is a suitable tool for monitoring the UTLS
- TPHs directly from bending angles (Lewis, 2009)
- Tropopause height trends with different data sets and methods
  - increase of about 5-9 m/year
  - good agreement with radiosonde data (25 years)
- Variability of the UTLS with BAs
  - advantages
- Improving of methods for gravity wave analysis with RO (detailed error characteristics is very important)
- TIL as a feature of the extratropics