Recent results on RO climate data analysis

Chi Ao

Jet Propulsion Laboratory
California Institute of Technology, Pasadena, CA, USA

January 8, 2014
CLARREO SDT Meeting, Greenbelt, MD, USA

Overview

• UTLS studies [updates from Apr 2013 meeting]

  I. Tropical width trends
  II. Evaluation of CMIP5 geopotential height

• Uncertainty analysis beyond UTLS

  III. Progress on stratospheric retrieval
I. Width of tropical belt

C. O. Ao and A. J. Hajj, Monitoring the width of the tropical belt with GPS radio occultation measurements, GRL, 2013.

• Use a decade of RO data from CHAMP and COSMIC to infer the trend of the tropical belt width as defined by characteristics of the lapse-rate tropopause heights (ZLRT).

• Compare with ECMWF Reanalysis interim
  o “ERA”: full gridded 6 hourly profiles
  o “ERAs”: ERA interim subsampled at RO locations and times.
Defining the width of tropical belt

Employed two definitions from Davis and Rosenlof (2012) for the tropical edge latitude (TEL) in each hemisphere:

1. “Subjective criterion”: TEL is defined as the lat where ZLRT drops to 1.5 km below the tropical average (15S–15N).

2. “Objective criterion”: TEL is the mean latitude weighted by the meridional gradient of ZLRT.

\[
\phi_{TEL} = \left[ \sum_{\phi=15^\circ}^{60^\circ} \phi \frac{\partial Z_{LRT}}{\partial \phi} \cos \phi \right] / \left[ \sum_{\phi=15^\circ}^{60^\circ} \frac{\partial Z_{LRT}}{\partial \phi} \cos \phi \right]
\]
(a) Northern Hemisphere

(b) Southern Hemisphere

(c) Northern Hemisphere

(d) Southern Hemisphere

Subjective Criterion
Seasonal Trends

Subjective (1.5 km relative height threshold)

Objective (mean tropopause gradient)
Conclusions (Part I)

• Statistically significant expansion of the tropical width was found in the NH (~ 0.5 deg over the last decade) but not in SH.
• RO and ERA-int are in good agreement but significant differences can be found in SH.
• Results suggest that NH and SH exhibit distinctly different seasonal trends. NH is expanding in all seasons, while SH expansion in summer (DJF) is countered by contraction in spring (SON).
II. Evaluation of CMIP5 GPH


• Optimal fingerprinting studies based on simulated [Leroy et al. 2006] and observed [Lackner et al., 2011] RO data show that GPH in the UTLS is a sensitive indicator of climate change.

• We performed a detailed comparison of UTLS GPH between RO and CMIP5 models.

• We focus on the annual mean, seasonal cycle, and interannual variability of 200 mb GPH (proxy for the layer-averaged temperature of the tropospheric column.)
Data

• GPS RO:
  – CHAMP (Jan 2002 – May 2006) ~ 150 profiles/day
  – COSMIC (June 2006 – Present) ~ 1500 profiles/day
  – Monthly gridded averages obtained via Bayesian mapping [Leroy et al. 2012]

• 11 CMIP5 Models (AMIP, mostly up to 2008):

<table>
<thead>
<tr>
<th>Model</th>
<th>2002–2008</th>
<th>ERA interim &amp; MERRA</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCCMA AM4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CNRM CM5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CSIRO mk3.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GFDL AM3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UKMO HadGEM2-A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>INM CM4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPSL CM5A-LR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIROC5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MPI ESM-LR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MRI CGCM3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NCC NORESM1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


• Reanalyses: ERA interim & MERRA, which did & didn’t assimilate RO, respectively.
Seasonal Variability (Zonal)

Enhanced Seasonal amplitude in S. High Lat

More different in N. High Lat
Correlation of Monthly Anomalies (interannual variabilities)

- Poor corr. in extratropics
- Good corr. in tropics
- Drop due to CHAMP under-resolves diurnal cycle

Corr(model,gpsro)
Monthly Anomalies (Mid-Lat)

40N–50N at 200 mb

GPH monthly anomalies [m]

Year

Model

− GPSRO [m]

Model Mean
Tropospheric Temp. (Global)

Global (90S-90N) average at 200 mb

Temperature monthly anomalies [K]

Year

Tropospheric and surface temp gap

Model
GPSRO
MSU
HadCRU4
Conclusions (Part II)

• GPH observations from GPS RO were compared with selected atmosphere-only model runs (AMIP) from the CMIP5 archive over 2002–2008.

• Most models matched well with the observations and reanalyses in the tropics in both the means and variabilities. However, the agreement was poor in the extratropics.

• Models have a consistently negative bias in the Southern high latitudes, while the inter-model spread is largest in the Northern high latitudes.

• Qualitatively similar results for 100 & 300 mb levels.
III. Stratospheric Retrieval


• Further previous work, which improves stratospheric refractivity by extending the upper altitude of the bending angle obs by computing the average refractivity from the average bending angles (average bending inversion or ABI).

• Multi-center collaboration in characterizing the structural uncertainty of RO retrievals [Ho et al. 2012; Steiner et al. 2013]. JPL will lead new effort towards better understanding of differences in stratosphere.
Bending Angle Noise Reduction

![Graph showing bending angle noise reduction with latitude. The graph compares CO Single, CH Single, CO Avg, and CH Avg for different latitudes.](image-url)
Sensitivity to Top Height

Exponential, $H_{sc}=7.5 \text{ km}$

0.03% CLARREO requirement

Altitude [km]

Refractivity from $h > h_m$ [%]

- Blue line: $h_m=80\text{ km}$
- Green line: $h_m=70\text{ km}$
- Red line: $h_m=60\text{ km}$
- Cyan line: $h_m=50\text{ km}$

CLARREO SDT Meeting, Greenbelt, MD, Jan 7–9, 2014
<N> from Individual Profiles

2008-01 N[COSMIC AN60]–N[MERRA] [%]

2008-01 N[CHAMP AN50]–N[MERRA] [%]

COSMIC - MERRA

CHAMP - MERRA
Cons of ABI

• ABI approach has two down sides:
  – Nonlinearity leads to systematic $<N>$ errors in the troposphere.
  – Additional nonlinearity between $T$ and $N$ in the hydrostatic equation means that $<T>$ cannot be derived from $<N>$ directly.

\[
T(z) = T(z_m) \frac{N(z_m)}{N(z)} + \frac{m_d}{a_1 R} \int_{z}^{z_m} d z' g(z') \frac{N(z')}{N(z)}
\]
A Hybrid Approach

- Use $<BA>$ to extend individual BA profile above a certain height.
- Perform Abel inversion for each hybrid BA profile.
- Perform hydrostatic integration on each N profile.
- Average over individual N, T to obtain $<N>$, $<T>$. 
<N> from Hybrid Approach

**2008–01 COSMIC N[AB70]–N[AN60] [%]**

**2008–01 COSMIC N[AB70]–N[AN50H] [%]**

Latitudes range from -90 to 90 degrees, altitudes range from 0 to 60 km.

**ABI - AN**

**ABI - Hybrid**
Conclusions (Part III)

• ABI applied to CHAMP and COSMIC data showed clear improvement in the upper stratosphere, especially for the noisier CHAMP data.

• A hybrid approach that offers the advantage of ABI in the stratosphere and reduces the nonlinearity errors in the troposphere is promising.
RO Missions Current & Pending

- COSMIC-1 (5 s/c) – IGOR
- GRACE-A – BlackJack
- TerraSAR-X – IGOR
- Tandem-X – IGOR
- Metop A/B – GRAS
- KOMPSAT-5 – IGOR
- OceanSat-II – ROSA
- Aquarius/SAC-D – ROSA
- Megha-Tropiques – ROSA
- FY3-C – GNOS
- PAZ (2014) – IGOR
- COSMIC-2 Eq 6 s/c (2016) – TriG
- Metop C (2018) – GRAS
- COSMIC-2 Pol (?)
- GRACE Follow-on (?)
- JASON-CS (?)