New estimates of gravity wave contributions to the momentum budget using GPS and HIRDLS

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“Emerging evidence that NAO is highly predictable a month ahead” – D. Smith

Results from Scaife et al. [2014] shows correlation = 0.62 “highly predictable”

This skill requires deep atmosphere coupling with the ocean and sea ice.

High sensitivity to the stratospheric quasibiennial oscillation (QBO).

Scaife et al. [2014]
The quasi-biennial oscillation in a warmer climate: sensitivity to different gravity wave parameterizations

Schirber et al [2014]

Effects of changes to the model’s gravity wave scheme on the simulated QBO.

- Subtle changes in the gravity wave parameterization details gave different predictions for changes in the QBO in a warmer climate.
- A previous study reported lengthened future QBO period, but here many experiments gave a shorter period.
**Stratospheric Circulation and Climate**

*Butchart et al. [2011]*: Chemistry-Climate Model wind and temperature biases in SH

Large errors in SH circulation are common in CCMs

Large temperature biases are common in springtime
McLandress et al. [2012]—Gravity wave drag effects on SH circulation & \( O_3 \)

Addition of gravity wave drag in Southern Hemisphere reduces winter wind bias.

Improves the timing of the seasonal transition to easterlies.

Associated changes in temperature and residual circulation weaken the ozone hole.
High Resolution Dynamics Limb Sounder

HIRDLS Sampling:
- Single azimuth
- ~100 km spacing
- 64°S – 80°N
- ~1 km Δz

- Typically > 5500 profiles per day
- Coverage 63.5°S – 80°N
- Close spacing of temperature profiles permits global studies of gravity wave properties.
Closely spaced profiles permit estimates of gravity wave momentum flux

[Alexander et al. 2008]

- Wavelet analysis of temperature profiles \( \rightarrow \) vertical wavelength \( \lambda_Z(z) \)
- Covariance in adjacent profiles \( \rightarrow \) finds coherent signals
- Phase shift \( \Delta \phi \rightarrow \) horizontal wavenumber \( k_H \)
- \( \Delta r \) is separation between profiles

\[
k_H = \frac{\Delta \phi_{i,i+1}}{\Delta r_{i,i+1}}
\]

- Estimate momentum flux \( M \):

\[
M_{i,i+1} = \frac{\rho}{2} \frac{\lambda_z}{2\pi} \frac{k_H}{N} \left( \frac{g}{N} \right)^2 \left( \frac{\hat{T}_{i,i+1}}{T} \right)^2
\]

HIRDLS remain the best global data available for estimating gravity wave momentum flux
Limitations of two-dimensional (along track only) information provide by HIRDLS

- Always overestimate horizontal wavelength (factor of 3 or more?)
- Always underestimate momentum flux (by same factor)
- Don’t know direction of the flux or the force on the mean flow
Gravity Waves and General Circulation

Global maps of gravity wave momentum fluxes [Geller et al. 2013]

- January map at 20 km shows high resolution models (Kanto, CAM5) have similar distributions in gravity wave fluxes
- Peak fluxes over summer subtropical continents are missing in parameterized wave fluxes (GISS, MAECHAM5, HadGEM3)
- Indication that HIRDLS fluxes are weak due to 2-D nature of the sampling.
GPS Radio Occultation

- COSMIC + Champ good overlap with HIRDLS measurement period
- Roughly 2000 profiles/day
- Coverage ~80°S – 80°N
- Sampling mixes time and space variations for gravity waves

**Wang and Alexander [2010]**

DJF results with *4-hr sampling period* indicates poor sampling for gravity waves
Combining GPS and HIRDLS

Map of daily coverage color-coded by UT

GPS Close Coincidences
\( \Delta t < 30\text{min}; \Delta r < 400\text{km} \)

- This restriction on sampling gives 101 close coincidences on this day
- Example profile trio shows same vertical structure with varying phase at different locations
- \( \Delta \) Phase provides horizontal wavelength and direction.
Combining GPS and HIRDLS

Using 3 neighboring profiles solve for the true direction of propagation $\delta$:

$$\delta = \arctan\left(\frac{\lambda_2 \cos \theta_2 - \lambda_1 \cos \theta_1}{\lambda_1 \sin \theta_1 - \lambda_2 \sin \theta_2}\right)$$

- Early results suggest HIRDLS $\lambda$ too long on average by a factor $\sim 2$.
- Implies momentum fluxes too low by a factor $\sim 2$. (30% > factor of 5!)

Ongoing work collecting statistics for geographic & seasonal variations to improve constraints for climate models.
Conclusions

- **Combining GPS and HIRDLS data to evaluate biases in stratospheric gravity wave analyses for climate applications**
  - Horizontal wavelengths
  - Propagation directions
  - Momentum flux and direction of force on the circulation

- **Climatology of biases can provide “correction factors” for HIRDLS analyses to provide constraints for gravity wave drag parameterizations in climate models.**

- **Higher density COSMIC-2 dataset will greatly benefit analysis of gravity wave properties.**
Combining GPS and HIRDLS

- Previous analysis compared amplitudes of largest wave components of co-located profiles, suggested HIRDLS & COSMIC RO temperatures had same vertical resolution to 1km.
- Wright et al. (2011) did S-Transform, looked at max amplitude wave. Conclusion: HIRDLS resolution = 1 km, COSMIC slightly better.

Gille et al., 2008 JGR
Barnett et al, 2008, SPIE

Wright et al., 2011
GPS Radio Occultation

- Daily coverage is not a good indicator of sampling for gravity wave analyses. (e.g. Wang & Alexander [2010] used 4-hr sampling.)
- Gravity wave periods > 10 min & horizontal wavelengths > 10km are likely important.

New work using close coincidences of GPS RO profiles with HIRDLS to:
- Provide the third dimension
- Evaluate biases in horizontal wavelength & momentum flux
- Provide a “correction” for the HIRDLS record and prepare for future higher-density GPS RO data