Satellite estimates of momentum fluxes from high-impact gravity wave events in the stratosphere and their effects on circulation
Large-amplitude GWs are important drivers of circulation and transport in the stratosphere, yet they are not treated correctly in most climate models.

GW parameterizations remain poorly constrained by observations in part because the uncertainties in observed momentum fluxes are very large.

Jewtoukoff et al., 2015 JAS
Motivation

The response of the residual circulation and transport to forcing depends strongly on the latitude of the applied force and its spatial and temporal scales.

Change in residual circulation from a strong local imposed GWD ~20-30 km

Šácha et al., 2016
Objectives

Combine observations from AIRS and HIRDLS to estimate momentum flux from high-impact gravity wave events.

Use a high-resolution global model constrained by observed large-scale (>600 km) winds and validated by observations from AIRS and HIRDLS to calculate “drag” from high-impact gravity wave events and impact on circulation and transport.
Objectives

Combine observations from AIRS and HIRDLS to estimate momentum flux from high-impact gravity wave events.

Use a high-resolution global model constrained by observed large-scale (>600 km) winds and validated by observations from AIRS and HIRDLS to calculate “drag” from high-impact gravity wave events and impact on circulation and transport.
Gravity wave hot spots in AIRS

NH winter

SH winter

Hoffmann et al., 2013
AIRS brightness T anomalies
AIRS $T_b$ and HIRDLS $T'$ anomalies
Uncertainty in momentum flux derived from observations is very large.

More than 2 orders of magnitude between AIRS and HIRDLS estimates for the same orographic area over Norway.

NH estimates are more challenging than SH because winds are more variable.
Uncertainty in momentum flux derived from observations is very large.

Momentum flux from observations:

\[ M = \frac{\rho \bar{k}}{2m} \left( \frac{g}{N^2} \right) \lambda_z \left( \frac{T}{\bar{T}} \right)^2 \]

\[ \lambda_z = 2\pi \left( \frac{N^2}{U^2} - |k|^2 \right)^{-1/2} \]

AIRS

HIRDLS

Alexander 2015
AIRS $T_b$ and HIRDLS $T'$ anomalies
Corrected momentum fluxes

Figure 2b shows the PDF of absolute momentum fluxes calculated in the ECMWF (thick lines) and derived from the Concordiasi observations (thin lines) for the peninsula and the oceanic regions depicted in Fig. 2a. The peninsula is representative of the regions with the OGW events, whereas the ocean regions devoid of (and far from) any topography are associated mainly with NOGWs. The PDFs from ECMWF and Concordiasi exhibit long tails that account for highly intermittent GWs (Hertzog et al. 2012) and are consistent with the momentum fluxes time evolution (not shown) that oscillates between weak fluxes, 10 mPa, and rare intense events where the fluxes exceed 500 mPa locally (in Concordiasi). The PDFs in the ECMWF and Concordiasi are very similar in shape, irrespective of their different means. The PDFs, over mountains and oceans, are almost indistinguishable for fluxes smaller than 10 mPa in the ECMWF and 20 mPa in Concordiasi. For larger fluxes, 40 mPa, the contrast between OGWs and NOGWs increases with a decrease in the frequency of large nonorographic events. For the larger values of momentum fluxes, occurrence frequency over mountains remains approximately one order of magnitude bigger than that over oceans. Moreover, calculations of the 90th percentiles show that 72% and 43% of the total flux are due to the 10% largest GW events over topography and smooth terrain respectively in the ECMWF. In Concordiasi, they account for 64% and 29% of the flux over mountains and oceans. In accordance, calculation of the Gini coefficient yields values of 0.6 and 0.5 for OGWs and NOGWs momentum fluxes respectively. Hence, this results in more occurrences of larger fluxes over mountains than over smooth terrain, which is consistent with the findings of Hertzog et al. (2012).

c. Time and spatial variability of the GW fluxes and their intermittency

We mentioned earlier the importance of quantifying time and spatial variations of the GW momentum fluxes to take this variability into account in the parameterizations. In the previous section we have examined the geographical distribution of the wave fluxes averaged over the Concordiasi time period, and we now focus on the time evolution of these fluxes. Figure 3 (left panel) displays the monthly averaged GW momentum fluxes calculated in the ECMWF at full resolution from September to December 2010. As for the mean fluxes, applying the balloon sampling in ECMWF analyses and multiplying the ECMWF fluxes by a factor of 5 enables us to obtain a good agreement with the balloonborne monthly averaged momentum fluxes. Still, once again, it is found that ECMWF tends to underestimate the wave fluxes over the Antarctic Plateau and Amundsen Sea. The maps notably highlight a continuous decrease in GW activity in the polar lower stratosphere throughout this 4-month period. In ECMWF and Concordiasi, the decrease of 85%–90% in momentum flux over the peninsula (see Table 1) from November to December is particularly striking, compared to the 20%–30% decrease of NOGW fluxes for...
Other estimates of orographic MF

Plougonven et al., 2013

(a)

Flux in mPa

1000
800
600
400
200
0

300
310
320
330
340
350
Day in 2005

Antarctic Peninsula

SH Islands

Heard

Kerguelen

S.Georgia

S.Sandwich

Alexander and Grimsdell, 2013

(a) Values of absolute momentum fluxes sorted in increasing order, for the Antarctic Peninsula, Kerguelen, Heard Islands, S. Georgia, and S. Sandwich Islands, showing the monthly variability of momentum fluxes.

(b) Time series for absolute momentum fluxes at (a) 70°S, 75°W, and (b) 33°S, 20°W, for the Southern Hemisphere, showing the variability of momentum fluxes over time.

(c) TKE derived from the research aircraft data over the Greenland region, showing the intermittency of momentum fluxes at different altitudes.

(c) Momentum fluxes are here revisited in this way.
Objectives

Combine observations from AIRS and HIRDLS to estimate momentum flux from high-impact gravity wave events.

Use a high-resolution global model constrained by observed large-scale (>600 km) winds and validated by observations from AIRS and HIRDLS to calculate “drag” from high-impact gravity wave events and impact on circulation and transport.
AIRS and GEOS $T_b$ anomalies

- GEOS $T_b$ wavelength and amplitude are remarkably similar to AIRS
- GEOS is smoother, probably because of smoothed topography
Summary and Conclusions

- High-impact GW events are important for circulation in the lower stratosphere
- GW mom flux and especially drag are difficult to calculate from observations
- Combining HIRDLS and AIRS can improve estimates of GW drag
- “Drag” and circulation effects can be estimated with global high-res model

Ongoing work:
- Extending methods to other orographic hotspots to get a global picture of effects on circulation and transport
- Extending methods to nonorographic hotspots
- New global, high-resolution runs with 12-, 6-, 3-, and 1.5-km horizontal resolution
Thank you!