Internal Gravity Wave Activity Hotspot and Implications for the Middle Atmospheric Dynamics

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Abstract: The internal gravity waves are widely recognized to contribute significantly to the energy and angular momentum transport. They play significant role in affecting many of the middle atmospheric phenomena (like QBO or Brewer-Dobson circulation). Using the GPS RO density profiles, we have discovered a localized area of increased GW activity and breaking in the lower stratosphere of Eastern Asia and Northern Pacific region. With a theoretical model of the middle atmosphere we studied the effects of such a localized breaking region on a large scale dynamics and transport. Possible formation and propagation directions of planetary waves caused by such a localized forcing were investigated and compared with the observed planetary wave activity in the Northern Hemisphere. Results showed that waves originating in the breaking region of GWs can propagate to the middle and upper atmospheric layers. The comparison of the GW activity with the observed planetary wave activity confirms the importance of the Eastern Asia-Northern Pacific region for middle atmospheric dynamics.

Methodology

1. L2 level FORMOSAT-2/COSMIC GPS RO density profiles (Sacha et al., 2016) on 3° x 3° grid ranging from tropopause up to 35 km and from 2007 to 2015
2. The potential energy density of disturbances per unit mass (Ep) as a proxy for IGW activity was computed using the formula provided by Wilburn et al. (1991).
   \[ Ep = \frac{1}{2} (\frac{\partial^2 u}{\partial z^2} + \frac{\partial^2 v}{\partial z^2}) \]

3. To access the stability of the wave field:
   - Dynamic stability - gradient Richardson number estimated by Senft and Gardner (1993)
   - Rayleigh–Taylor convective instability - Sutherland (1958)
   - Richardson number and convective instability growth rate values and distributions are further accentuating the importance of our area making a dominant feature of the maps across all the levels even in spring and winter months and being suggestive of vertically robust and long lasting breaking of GWs (See Figures 2 and 3).

4. Results I
   - Analysis of geographical and seasonal distribution of IGW activity and effects
   - Distribution of potential energy of disturbances: in average, a distinguished region of high GW activity and of maximal values in the Northern Hemisphere in October and November (see Figure 1). This area is significant starting from the 70 hPa level up to the 600 hPa level.
   - Wave breaking indication: Richardson number and convective instability growth rate values and distributions are further accentuating the importance of our area making a dominant feature of the maps across all the levels even in spring and winter months and being suggestive of vertically robust and long lasting breaking of GWs (See Figures 2 and 3).
   - Possible wave sources:
     - Convective activity connected with the Kuroshio current in autumn.
     - Low values of cumulative wind rotation above our region are favorable for vertical propagation of oceanic waves (Pc 40).
     - Surface winds suggestive of orographic creation of IGW due to the topography of Japan, Sakhalin, Korean Peninsula and eastern Asia coastline.
     - In situ wave generation in the upper troposphere/lower stratosphere (Achim (1953) – subtropical and polar jet stream merging).

Results II

Longitudinal variability of BOC and planetary wave sources

1. MUMIA 3D mesospheric circulation model (Koch et al., 2007) runs with IGW parameterization input based on geographical distribution of wave activity from GPS RO
   - In comparison with the reference run for January - 2D Bismann-Palm flux analysis reveals in the US the strongest planetary wave propagation from midlatitude equatorward and at the edge of pole vortex (Fig. 4).
   - 3D analysis reveals enhanced downwelling above NPIFA region penetrating to lower levels than elsewhere.
   - Robustness of the enhanced BOC branch occurrence above NPIFA region and modeled vertical residual circulation distribution is confirmed by the 30 year average of total ozone column in January (Fig. 6), where the maximum is located in this region.

Results III

1. Comparison of MUMIA residual vertical velocity and trace gases distributions confirms realistic behavior of model atmosphere
   - From roughly 25N we can see existence (Max) of GW activity characteristics of the enhanced branch of BOC in the middle layer around 140°E (compare with location of IGW activity hotspot).

Fig. 7. Zonal cross sections at latitudes around 35N of MUMIA residual vertical velocity in November; CO mole content in atmospheric layer and volume mixing ratios of N2O, H2O and CO for November 2009.

Fig. 8. Mean total ozone column distribution in January (ENRAF 2006-2008).

Fig. 9. Geographical distribution of the residual vertical velocity (Sachta and Sacha, 2013) on three consecutive model levels in the US region.

Summary and conclusions

- Using GPS RO data high GW potential energy values were found. Static and dynamic stability indices suggestive of massive wave breaking in this region (Submitted to ACP).
- 3D P-flux diagnostics of MUMIA runs reveals enhanced equatorward and poleward propagation of planetary waves, if the GW hotspot area is included - possible consequences for the IMF and solar cycles.
- Distributions of geos and 3D analysis of MUMIA runs are pointing to robust downwelling of equatorial air masses (enhanced branch of Brewer-Dobson circulation) reaching deeper in the NPIFA region stratosphere than elsewhere. The causality is unclear - product of wave mean flow interactions and induced residual circulation in 3D.