

Gravity Wave Analyses from Temperature, Wind, and Ascent Rates in US High Vertical Resolution Radiosonde Data

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ABSTRACT

In the presence of a spectrum of gravity waves, different waves are preferentially measured by the different variables obtained from high vertical-resolution radiosonde soundings. This is demonstrated in two different ways. One is by the relatively low correlations between pairs of the kinetic energy (KE), potential energy (PE), and the energy in the ascent rate fluctuations (VE) in both observations and in a simple model involving random superpositions of waves. Another is to derive the characteristic frequencies observed from KE/PE and VE/PE. The VE/PE indicates much higher wave frequencies. In fact, the frequencies suggest that we are seeing non-hydrostatic waves in VE. Latitude-time sections of KE and PE in the troposphere and lower stratosphere show maxima during winter, while clear summer maxima are seen in tropospheric VE, with the situation in the lower stratosphere being less clear. Evidence is shown that moist convection is likely the main forcing of the waves being seen in VE while spontaneous wave emission from jet structures is likely a principal forcing of the waves seen in KE.

Gravity Wave Energies

Hydrostatic:

$$\left. \begin{aligned} \overline{KE} &= \frac{1}{2}(u^2 + v^2) = \frac{1 + \left(\frac{f}{\omega}\right)^2}{1 - \left(\frac{f}{\omega}\right)^2} \frac{m^2}{N^2} g^2 H^2 \frac{\hat{p}^2}{4} \\ \overline{PE} &= \frac{1}{2} \frac{g^2}{N^2} \left(\frac{T}{T_0}\right)^2 = \frac{m^2}{N^2} g^2 H^2 \frac{\hat{p}^2}{4} \\ \overline{VE} &= \frac{1}{2} \frac{1}{w^2} = \frac{\hat{\omega}^2 m^2}{N^4} g^2 H^2 \frac{\hat{p}^2}{4} \end{aligned} \right\} \begin{aligned} \frac{\overline{KE}}{\overline{PE}} &= \frac{1 + \left(\frac{f}{\omega}\right)^2}{1 - \left(\frac{f}{\omega}\right)^2} \\ \frac{\overline{VE}}{\overline{PE}} &= \frac{\hat{\omega}^2}{N^2} \end{aligned}$$

- VE responds more to higher frequency waves than do KE and PE (previously shown by Lane et al., 2003).
- The ratios give a new way to estimate wave frequencies.
- Nonhydrostatic equations do behave similarly to the hydrostatic ones in the limits $\hat{\omega} \rightarrow f$ and $\hat{\omega} \rightarrow N$ (not shown here).

Correlation Simulations

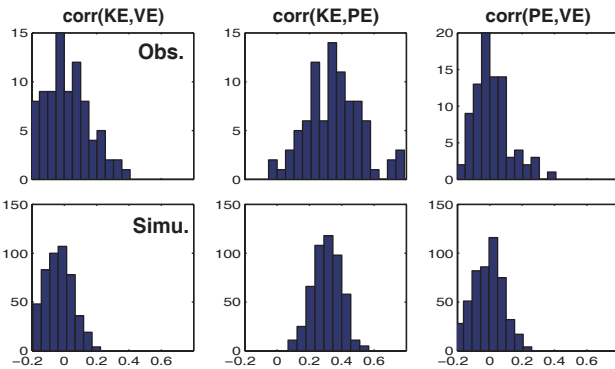
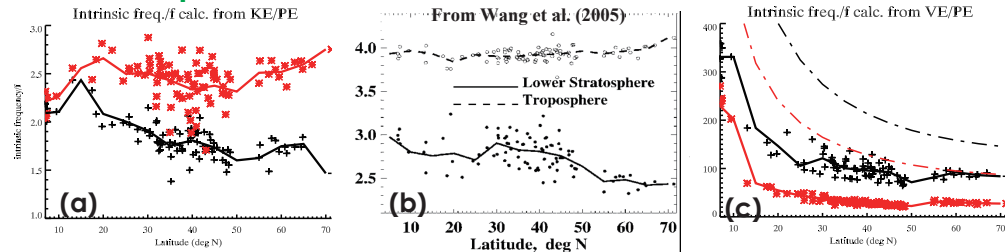


Figure 1. Histograms for correlation coefficients calculated from the nine-year time series of observations (top, annual cycle removed), and 500 simulations of 60 superposed gravity waves where the frequencies are randomly chosen between f and $20f$, with the wave amplitude scaled by $\hat{\omega}^{-1}$ if $\hat{\omega} > 8f$; vertical wavenumber m selected from the observed PDF, and horizontal wavelengths bounded by 10 - 2000 km (bottom).

- **Comparisons between observations and this simple model are consistent with the different variables observed in radiosonde data preferentially selecting different wavelengths and frequencies of GWs.**
- **Simulations using non-hydrostatic polarization relations give very similar results (not shown here).**
- **Matching observations with simulations implies constraints on the frequency spectrum.**

Wave Frequencies



- (a) is quantitatively similar to (b) in figure 2, albeit the frequencies are about 2/3 of those in Wang et al. (2005). We can account for this by comparing the average of the ratio of KE/PE with the ratio calculated using the average frequencies in our simulations.
- The frequencies calculated using VE/PE are much higher than those implied by KE/PE. VE seems to be responding to both hydrostatic and non-hydrostatic waves.

Figure 2. Intrinsic frequency/f derived from KE/PE (a), VE/PE (c) and from Wang et al., 2005 (b). Red (dashed) for troposphere, and black (solid) for lower stratosphere. The two dot-dashed lines in (c) give N/f in the troposphere and lower stratosphere.

Energy Climatologies

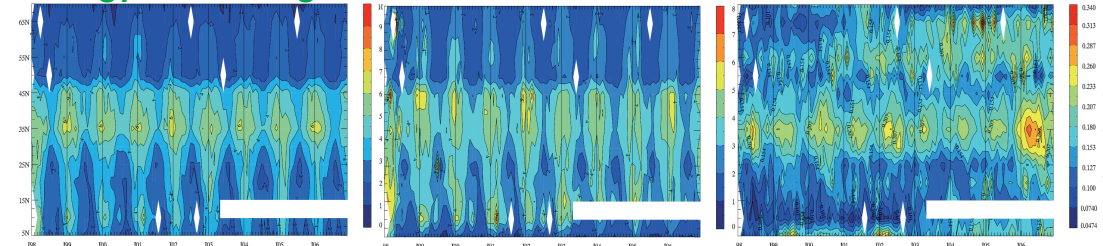
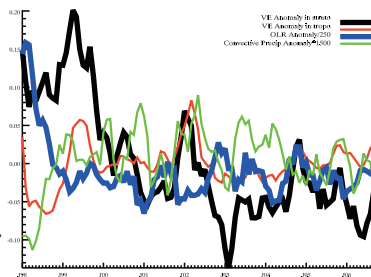


Figure 3. From left to right: nine-year monthly mean values of KE, PE and VE in the troposphere. Averaged with 5-degree latitudinal bins. Unit is J/kg. "J" on the horizontal axis means January.

Convective Sources Tropics

Figure 4. Three-month running averages of VE in the lower stratosphere (black), the troposphere (red), convective precip at the surface (green, multiplied by 1500) and OLR (blue, divided by 250) at the western Pacific island stations.



- VE shows signatures of convection in the tropics (Figure 4) and in the diurnal variations (not shown) in the extratropics.
- Spontaneous emissions of inertia-gravity waves from jet structures have been indicated in case studies (e.g., Plougonven and Teitelbaum, 2003). These imbalances are largest in winter, which correspond to maxima of KE and PE in winter (Figure 3).

CONCLUSIONS

1. KE (VE) is a good climatological measure for low (high) frequency gravity waves.
2. It is likely that the high frequency gravity waves in the troposphere have moist convection as the principal source.
3. It is likely that spontaneous emission from jet structures is a very important source for low-frequency inertia-gravity waves.

MAJOR REFERENCES

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ACKNOWLEDGMENTS

This work is funded by NSF grant ATM0413747.