Study on Atmospheric gravity wave propagations from the Troposphere to Mesosphere using GNSS Satellite Radio Occultation measurements

Stratospheric Gravity Waves Potential Energy Characteristics Over South America Using COSMIC-2 Satellite

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April 5, 2021

- The main forces acting in the atmosphere are:
  - **Coriolis force**.
  - **Pressure gradient force**.
  - **Force of gravity**.

- Atmospheric gravity waves (AGWs) are waves in the Earth's atmosphere as a result of the balancing between the force of gravity and buoyancy force.

- AGWs are generated by different mechanisms that causes vertical displacements of air parcels.

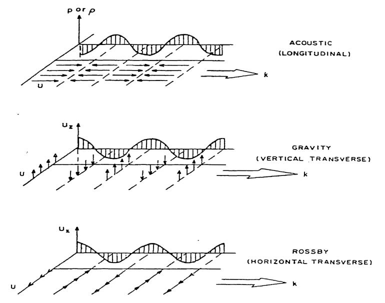

Figure 1: Three principal types of Atmospheric waves [Beer, 1974].

- AGWs propagate vertically and transports momentum and energy upward.

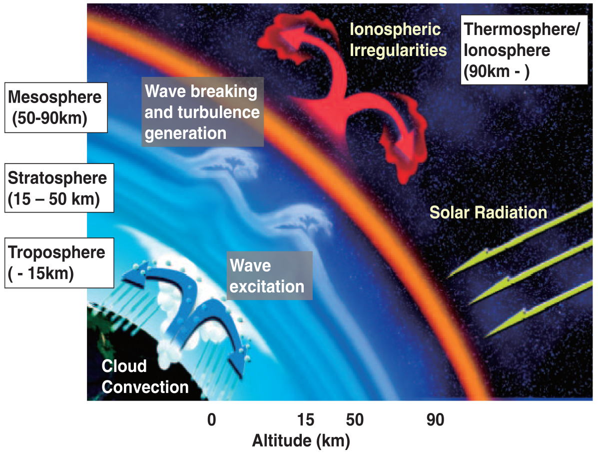

Figure 2: Atmospheric coupling processes in the equatorial atmosphere [Tsuda, 2014].

Why Do We Care About GW?

- Vertical momentum and energy transport;
- Meridional circulation and heat transport;
- Transport of chemical species;
- Atmospheric mixing end eddy diffusion;
- Quasi-biennial oscillations;
- Traveling ionospheric disturbances (TID);
- ionospheric instabilities: communications;

AGWs Coupling

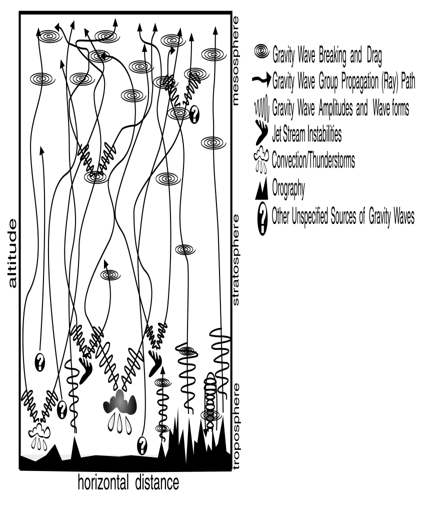

Figure 3: Schematic of various gravity wave production, propagation and dissipation processes that parametrizations seek to capture, along with associated processes [Kim et al., 2003].

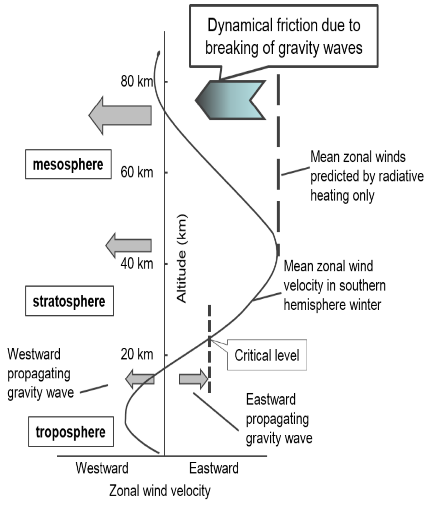

Figure 4: A schematic diagram depicting the fundamental concepts of interaction between mean winds and gravity waves [Tsuda, 2014].

Atmospheric Sounding

There are many ways to observe AGWs in the atmosphere using different types of sounding techniques.

- The Zenith Sounding,
  - All-sky Imager, Fabry-Perot Interferometer, Photometer, Radiosonde, e.t.c.
- The Nadir Sounding,
  - Satellite.
- The Limb Sounding,
  - Radio Occultation (RO).

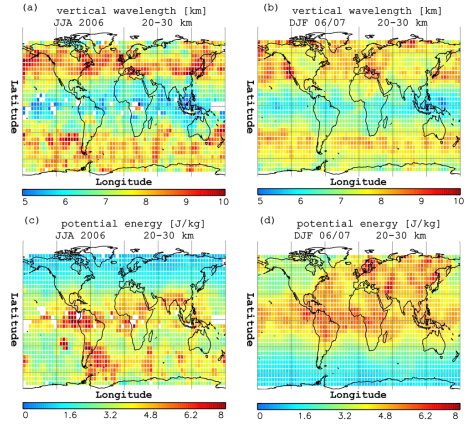

Figure 5: Vertical wavelength derived from COSMIC for the available 3-point groupings JJA 2006 and DJF 2006/07, and the mean potential energy distribution for each season for the altitude range of 20 — 30 km [Faber et al., 2013].

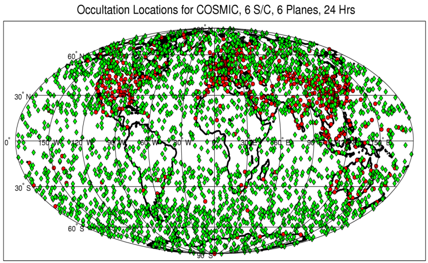

Figure 6: COSMIC 1 Soundings.

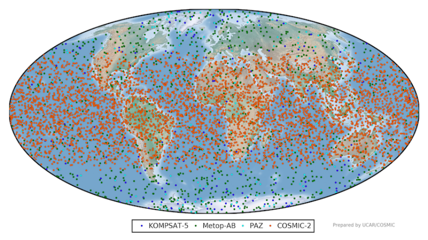

Figure 7: COSMIC 2 Soundings.

Objectives

1. To investigate spatial and temporal variation of the AGWs activity over South America.
   (i) Latitudinal and longitudinal variations
   (ii) Day-to-day variations
   (iii) Seasonal variations
   (iv) Annual variations
2. To compare the result of potential energy, momentum flux, and vertical wavenumbers (wavelengths) obtained from the RO and TIMED/SABER with the previous results from All-sky Imager observations over some Brazilian stations.
3. To understand the coupling dynamics of AGWs in the troposphere, stratosphere, and mesosphere.

The gravity wave energy (E_0) is usually defined as the measure of gravity wave activity which is given by [Tsuda et al., 2000],

$$E_0 = \frac{1}{2}\left[\overline{\mu'^2} + \overline{v'^2} + \overline{\omega'^2} + \left(\frac{g}{N}\right)^2 \left(\frac{\overline{T'}}{\overline{T}}\right)^2\right] = E_k + E_p$$

E_k and E_p is the Kinetic energy and the potential energy respectively.

$$E_k = \frac{1}{2}\left[\overline{\mu'^2} + \overline{v'^2} + \overline{\omega'^2}\right]$$

$$E_p = \frac{1}{2}\left[\left(\frac{g}{N}\right)^2 \left(\frac{\overline{T'}}{\overline{T}}\right)^2\right]$$

- A linear theory of AGWs predicts that the E_k/E_p is a constant [VanZandt, 1985].
- Therefore, under the linear theory it is possible to estimate E_0 from temperature observations only.

The E_p is a parameter for the characterization of AGW activity given by,

$$E_p(z) = \frac{1}{2}\left(\frac{g}{N(z)}\right)^2\left(\frac{\overline{T'}}{\overline{T}}\right)^2$$

$$T' = T - \overline{T}$$

$$\overline{T}'^2 = \frac{1}{z_{max} - z_{min}}\int_{z_{min}}^{z_{max}} T'^2 dz$$

$$N_z^2 = \frac{g}{T}\left(\frac{d\overline{T}}{dz} + \frac{g}{c_p}\right)$$

- Temperature perturbations are associated with the vertical displacement of an air parcel.
- This can be used as a measure of the E_p of the waves giving rise to such perturbations.

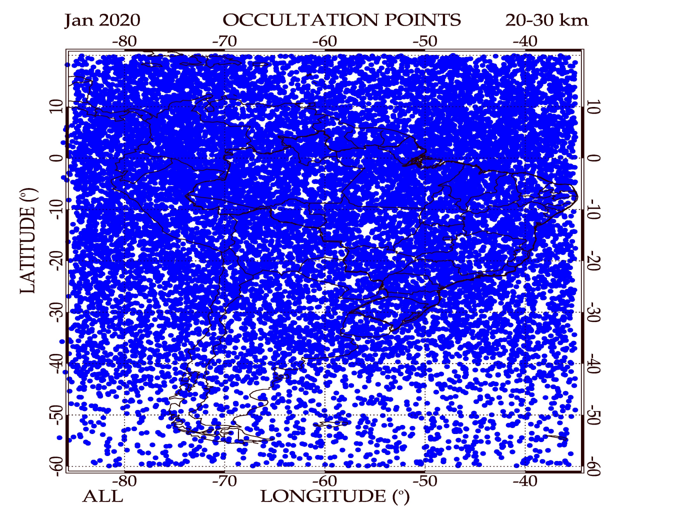

Figure 8: The occultation points for January 2020.

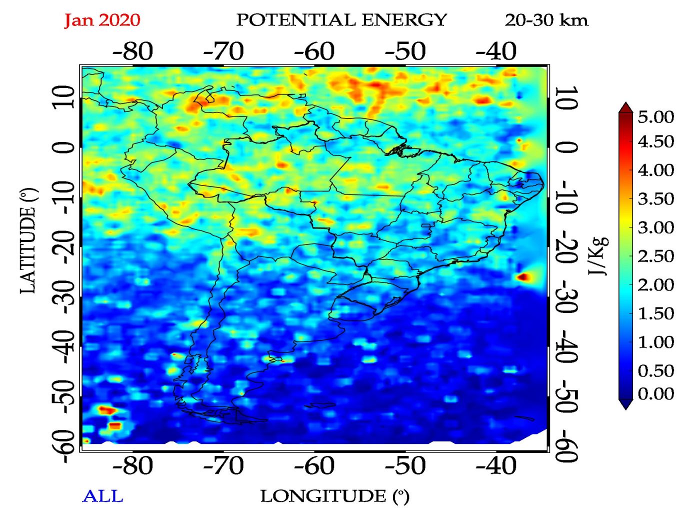

Figure 8: Mean *Ep* distribution for January 2020 for the altitude range of 20 - 30 km.

Results and Discussion: Monthly *Ep* Variability and Zonal Mean Winds

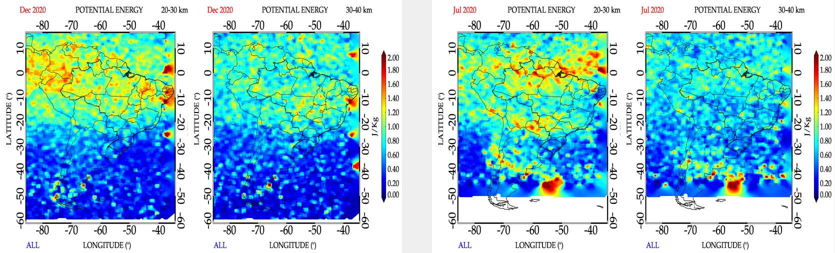

Figure 10: The monthly mean *Ep* for December and July 2020 the altitude range of 20-30 km and 30-40 km.

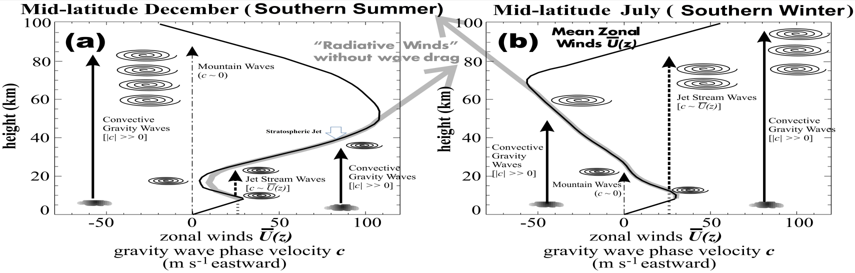

Figure 9: Typical mid-latitude zonal winds $\overline{U}_{(z)}$ during northern **(a)** winter and **(b)** summer [Kim et al., 2003].

Results and Discussion: **Seasonal *Ep* Variability**

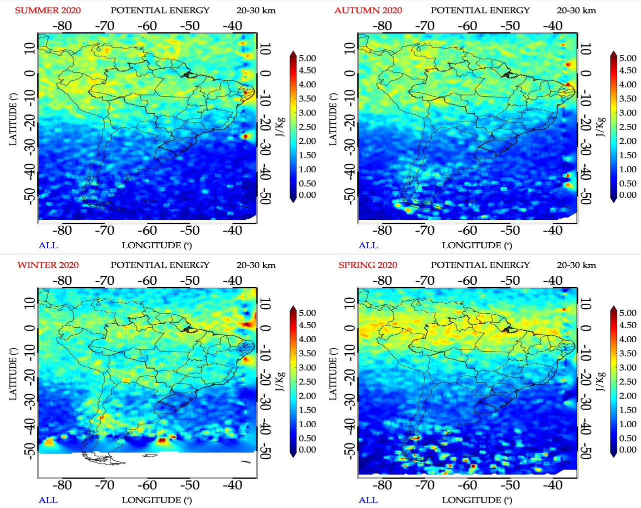

Figure 11: The Seasonal mean *Ep* distribution for all the altitude ranges.

- At the low latitude (20° N-30° S) has the highest *Ep* in the Summer and Spring and lowest in the Winter and Autumn
- At the mid latitude (30° S-60° S) has the lowest *Ep* in the Summer and Spring and highest in the Winter
- There is an evidence of jet stream activities in the winter of mid latitude of Atlantic oceans.

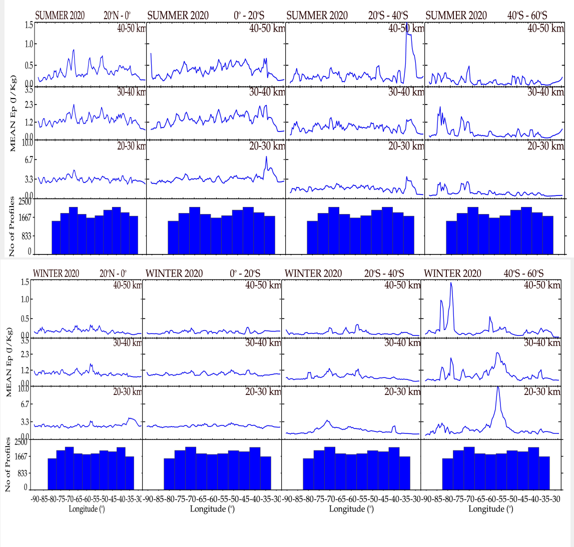

Figure 13: The Seasonal mean *Ep* latitudinal distributions for all the altitude ranges in 2020.

- The Winter shows the lowest mean *Ep* variability across the latitudinal distributions.
- The Summer and Spring shows the highest mean *Ep* variability across the latitudinal distributions.
- At 40°S -60° S, there is clear evidence of Andes and the Patagonia mountain waves for all the altitudes ranges

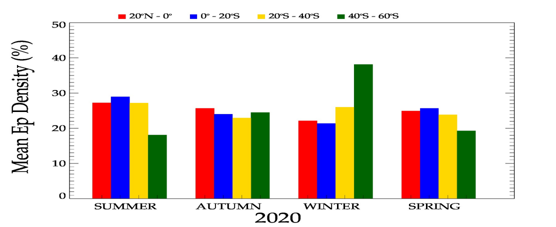

Figure 16: The Seasonal Mean *Ep* latitudinal distributions in percentage for 2020.

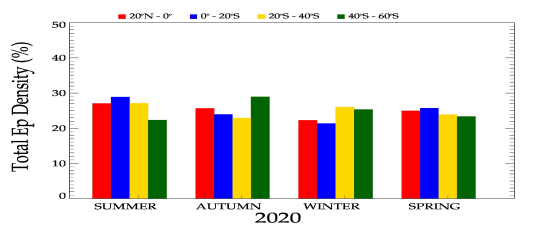

Figure 17: The Seasonal total *Ep* latitudinal distributions in percentage for 2020.

- The low latitude has the lowest *Ep* density and the mid latitude has the highest *Ep* density.
- The *Ep* density in the Summer and Spring followed the same trend and Autumn and Winter with the same trend.
- At 40°S - 60° S the mean *Ep* density is highest in the Winter and total *Ep* density is highest in the Autumn.

Conclusions

- The *Ep* variation shows waves activities due to convective activities, jet streams, and mountain sources.
- The *Ep* variation shows the effect of wind activities.
- The Summer and Spring revealed the highest mean and total *Ep* variability and lowest in the Winter across the latitudinal distributions.
- There is clear evidence of mountain waves of the Andes and the Patagonia mountains

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Thanks for listening!

Backup Slide

This is a backup slide, useful to include additional materials to answer questions from the audience.

The package `appendixnumberbeamer` is used to refrain from numbering appendix slides.