

# 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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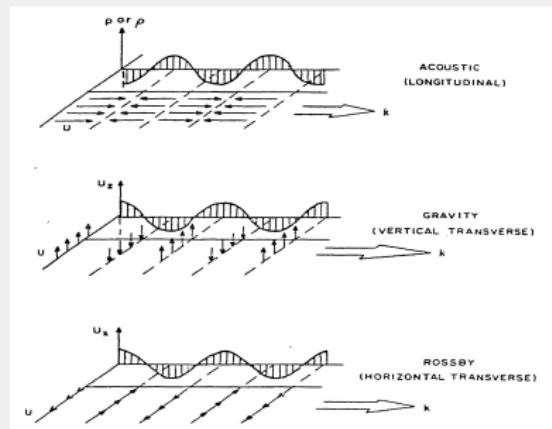
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April 5, 2021



# INTRODUCTION

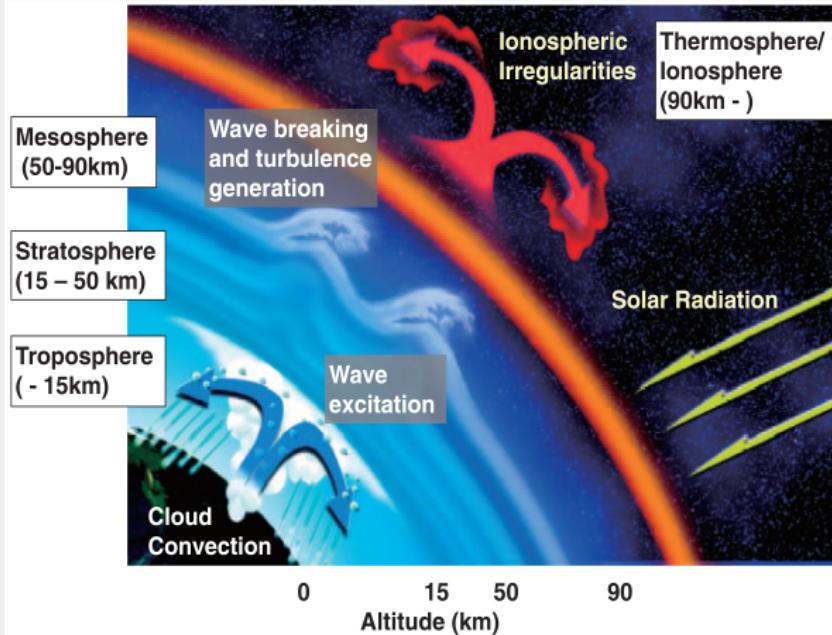
- The main forces acting in the atmosphere are:
  - ▶ **Coriolis force.**
  - ▶ **Pressure gradient force.**
  - ▶ **Force of gravity.**
- Atmospheric gravity waves (AGWs) are waves in the Earth's atmosphere as a result of the balancing between the force of gravity and buoyancy force.
- AGWs are generated 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.

# ATMOSPHERIC COUPLING

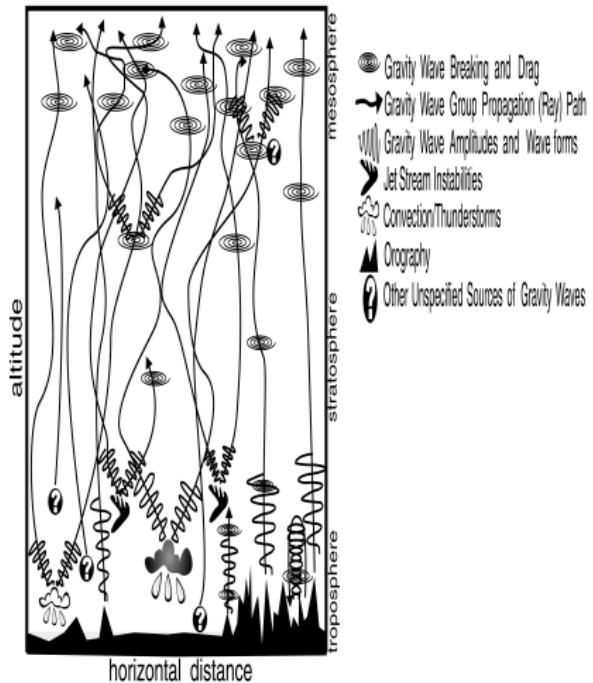


**Figure 2:** Atmospheric coupling processes in the equatorial atmosphere [Tsuda, 2014].

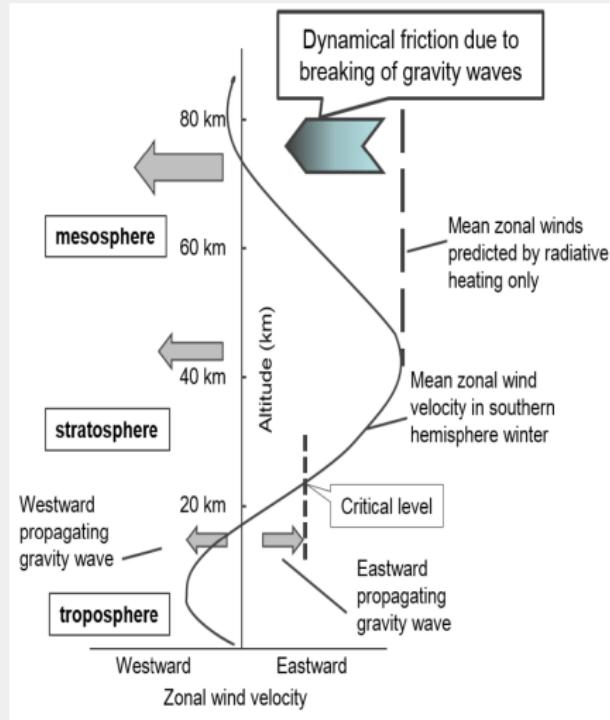
## Why Do We Care About GW?

- Vertical momentum and energy transport;
- Meridional circulation and heat transport;
- Transport of chemical species;
- Atmospheric mixing and 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].



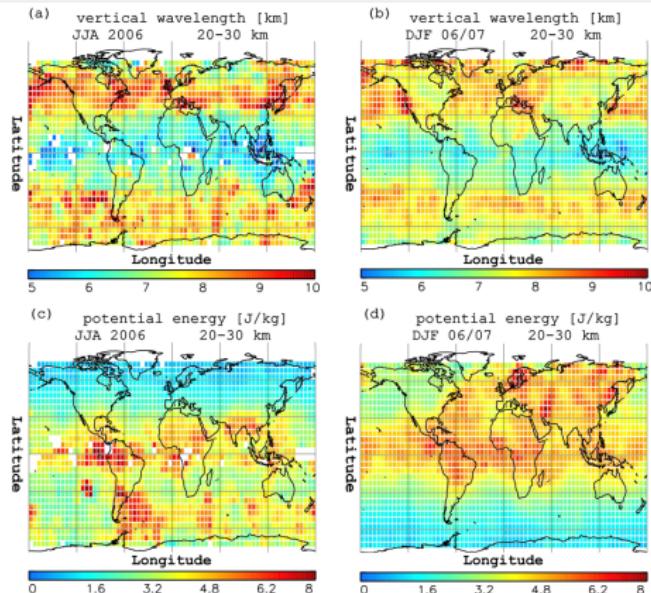
**Figure 4:** A schematic diagram depicting the fundamental concepts of interaction between mean winds and gravity waves [Tsuda, 2014].

# ATMOSPHERIC SOUNDING

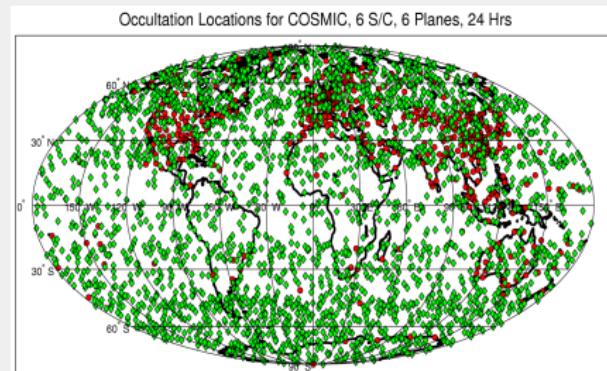
There are many ways to observe AGWs in the atmosphere using different types of sounding techniques.

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

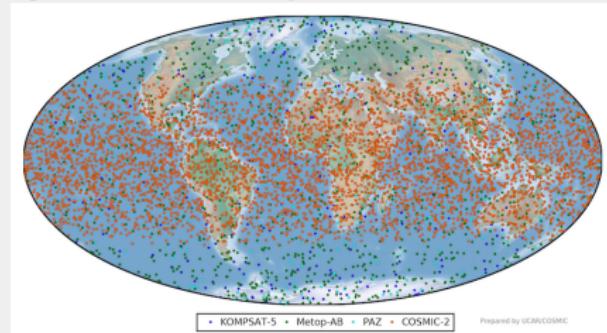
# MOTIVATION



**Figure 5:** Vertical wavelength derived from COSMIC for the available 3-point groupings JJA 2006 and DJF 06/07, 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.

## STUDY OF AGW ENERGY

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

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

$E_k$  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  $E_o$  from temperature observations only.

## STUDY OF AGW ENERGY: POTENTIAL ENERGY

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

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

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

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

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

- 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.

## RESULTS AND DISCUSSION: OCCULTATION POINTS

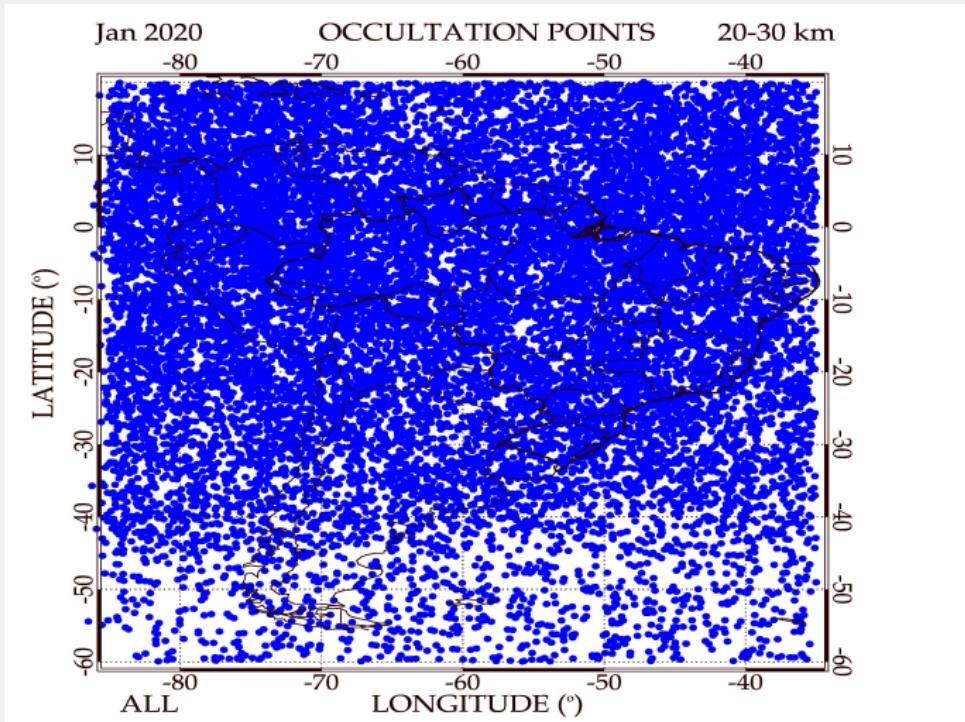


Figure 8: The occultation points for January 2020.

## RESULTS AND DISCUSSION: MONTHLY $Ep$ VARIABILITY

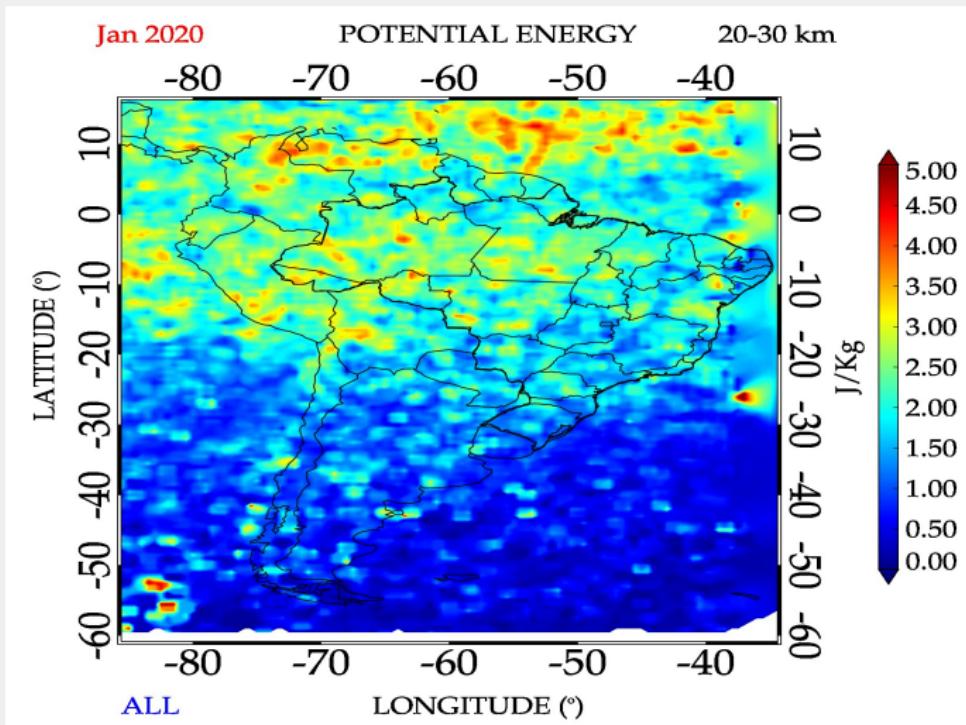


Figure 8: Mean  $Ep$  distribution for January 2020 for the altitude range of 20 - 30 km.

## RESULTS AND DISCUSSION: MONTHLY $Ep$ VARIABILITY AND ZONAL MEAN WINDS

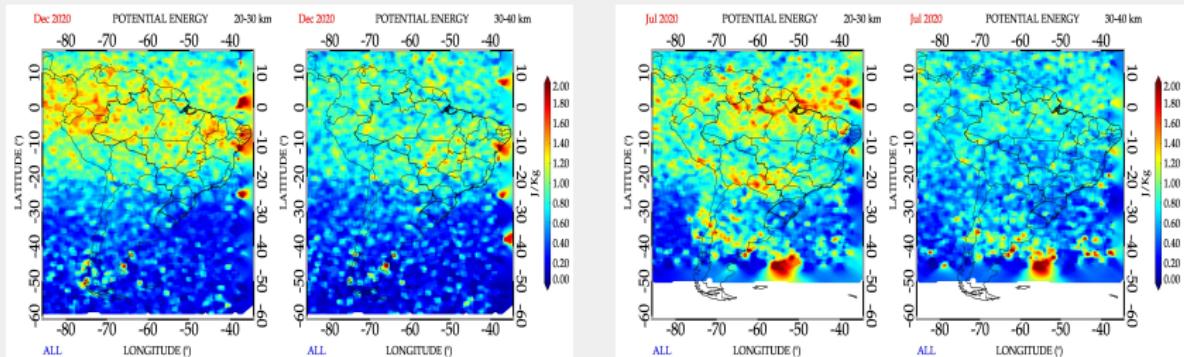


Figure 10: The monthly mean  $Ep$  for December and July 2020 the altitude range of 20-30 km and 30-40 km.

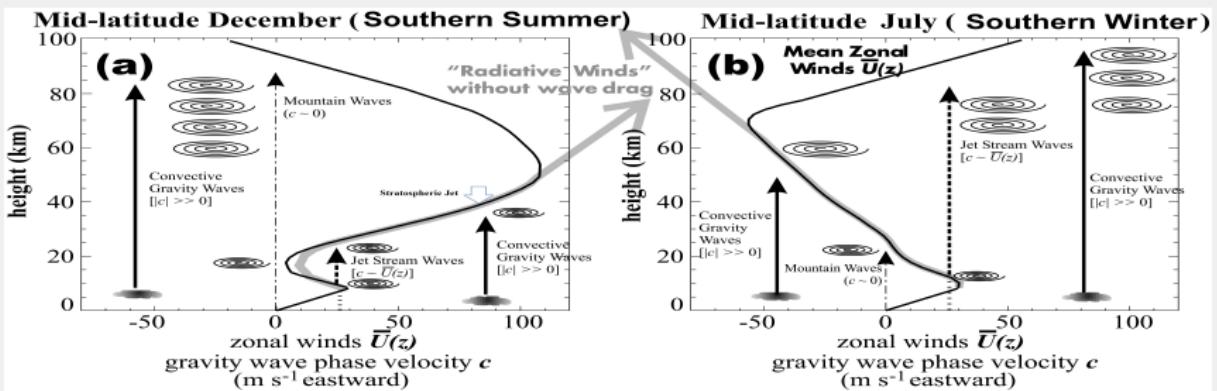


Figure 9: Typical mid-latitude zonal winds  $\bar{U}_z$  during northern (a) winter and (b) summer [Kim et al., 2003].

## RESULTS AND DISCUSSION: SEASONAL *Ep* VARIABILITY

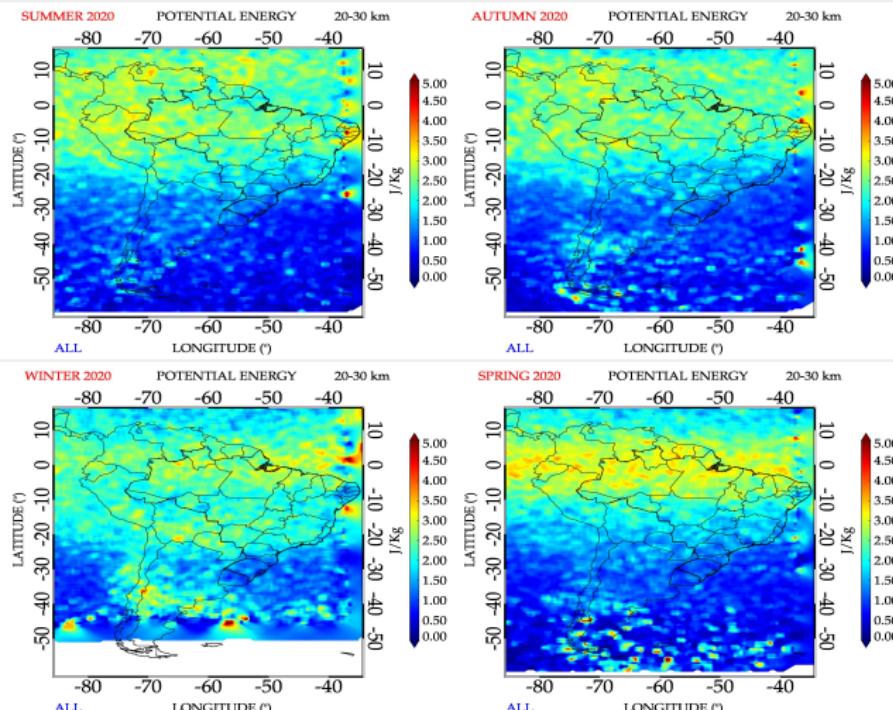
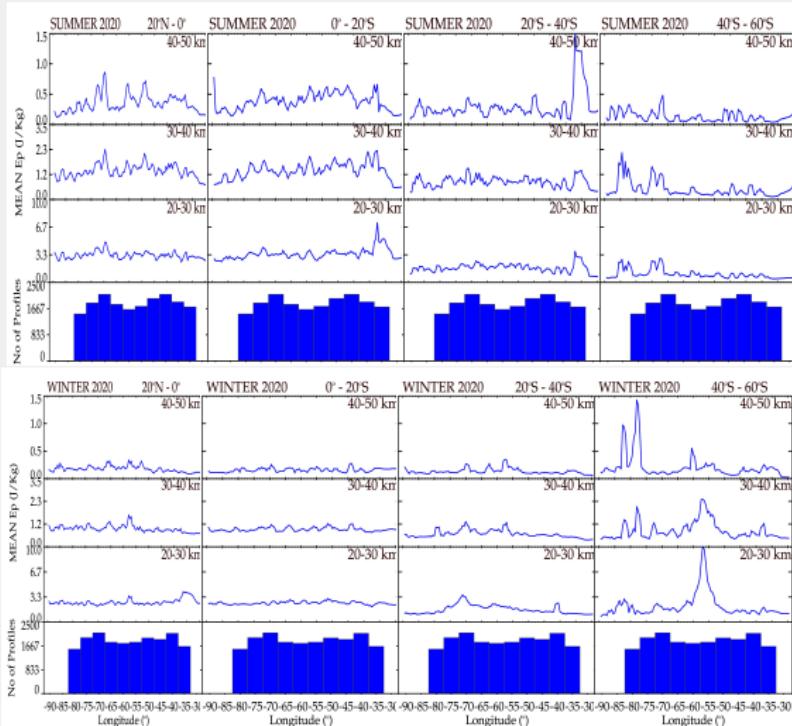


Figure 11: The Seasonal mean *Ep* distribution for all the altitude ranges.

- At the low latitude ( $20^{\circ}$  N- $30^{\circ}$  S) has the highest *Ep* in the Summer and Spring and lowest in the Winter and Autumn
- At the mid latitude ( $30^{\circ}$  S- $60^{\circ}$  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.

## RESULTS AND DISCUSSION: SEASONAL *Ep* LATITUDINAL DISTRIBUTION



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

## RESULTS AND DISCUSSION: SEASONAL *Ep* DENSITY IN PERCENTAGE

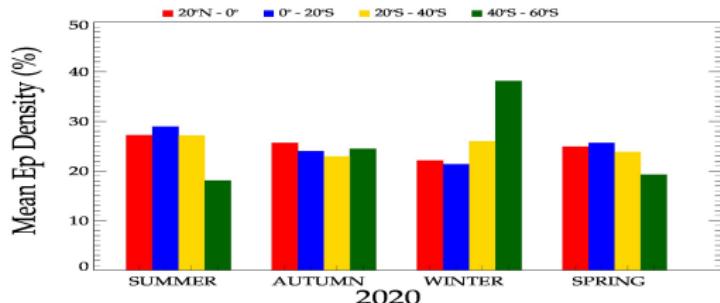


Figure 16: The Seasonal Mean *Ep* latitudinal distributions in percentage for 2020.

- 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  $40^{\circ}\text{S} - 60^{\circ}\text{S}$  the mean *Ep* density is highest in the Winter and total *Ep* density is highest in the Autumn.

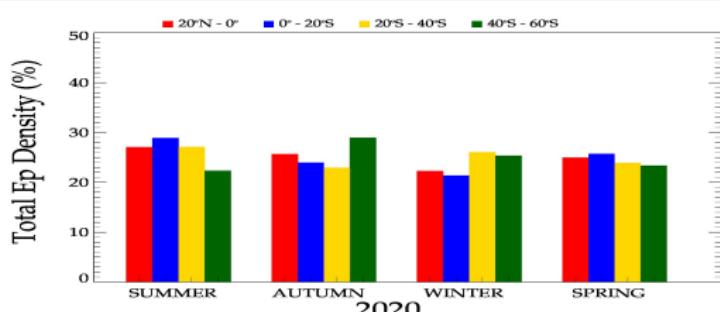


Figure 17: The Seasonal total *Ep* latitudinal distributions in percentage for 2020.

# 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.