The Diurnal Cycle of Gravity Waves in GNSS-RO Data

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1. Summary

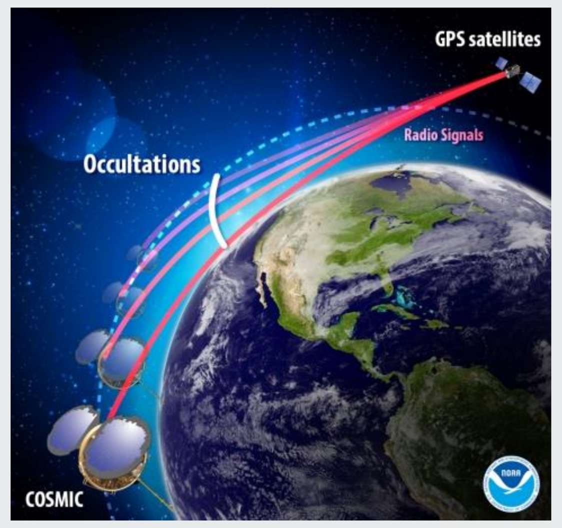
- The diurnal cycle of gravity waves in the stratosphere is investigated using GNSS-RO satellite data.
- Gravity wave amplitudes are found using the 1D S-Transform.
- The results show a diurnal cycle in gravity wave activity can be seen in the data that varies with season.

2. Background

- Gravity wave sources, including convection, follow a diurnal cycle,. Thus, it is expected that these waves should also follow a diurnal cycle.
- However, this cycle is difficult to observe using satellite data, because of the sun-synchronous orbits of most gravity wave-resolving instruments.
- The diurnal cycle of convection is affected by solar heating and is strongest over tropical land, with a weaker signal over the oceans.

2. Data

- GNSS Radio Occultation (GNSS-RO) dry temperature data is used from a merged data product stored in the Amazon Web Services Registry of Open Data [1]. This includes data from satellite missions such as COSMIC 1, Metop-A, -B and -C, and GRACE.
- Unlike most gravity wave-resolving instruments, these data are pseudorandom in local solar time.
- Radio occultation uses GNSS signals which are received by a satellite that measures the bending angles and phase delay due to these signals passing through the atmosphere. Temperature can then be derived from these measurements.
- Integrated Multi-satellitE Retrievals for GPM (IMERG) precipitation rate data is also used [2] for comparison. This is a global NASA product, which estimates half hourly precipitation rates.



(National Oceanic and Atmospheric Administration (NOAA) [3])

3. Methods

- The background is removed from the GNSS RO profiles using a planetary wave filter to remove waves with modes ≤ 9.
- The 1D S-Transform, which is a spectral analysis method, is used to find wave amplitudes [4].
- GNSS-RO data is used from 2007 – 2018 and an altitude range of 20 – 40 km is used for the input of the 1D S-Transform. All results are presented at 27 km altitude.

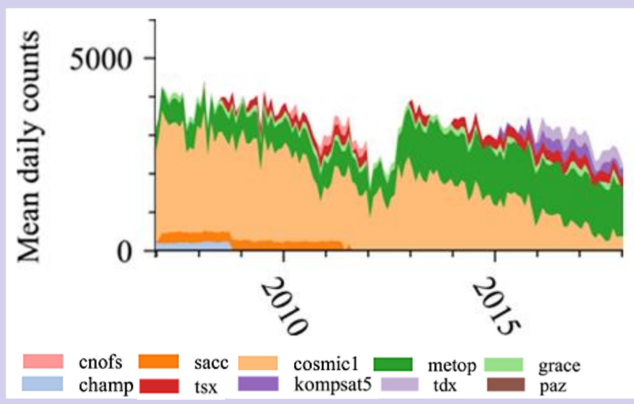


Figure 1: Stack-plot of daily average occultations in a month for the GNSS-RO data used (section of Figure 2. in Leroy et al. (2024)) from 2007 – 2018.

- The wave amplitudes are binned onto longitude-latitude grids with 10° grid spacing averaged for each month in the years from 2007 – 2018. Data is binned for 3 hour time windows centered at every 20 minutes in a day in UTC and Local Solar Time (LST).
- IMERG precipitation rate data is binned with the same grid spacing and compared to the gravity wave amplitudes.

4. Results

4.1 The Diurnal Cycle of Gravity Waves

- Figure 2 shows how the gravity wave amplitude at each time changes with longitude, averaged over -25° – 25° latitude at 27 km altitude.
- Areas of higher amplitude move westwards with time. The 3 diagonal lines, (indicated by dashed lines on the plots) of higher amplitude are seen for all months (not all months are shown). Two peaks in amplitude can be seen at all times.
- Amplitudes are higher in January than in May and September and are highest near 0° longitude in January and September.

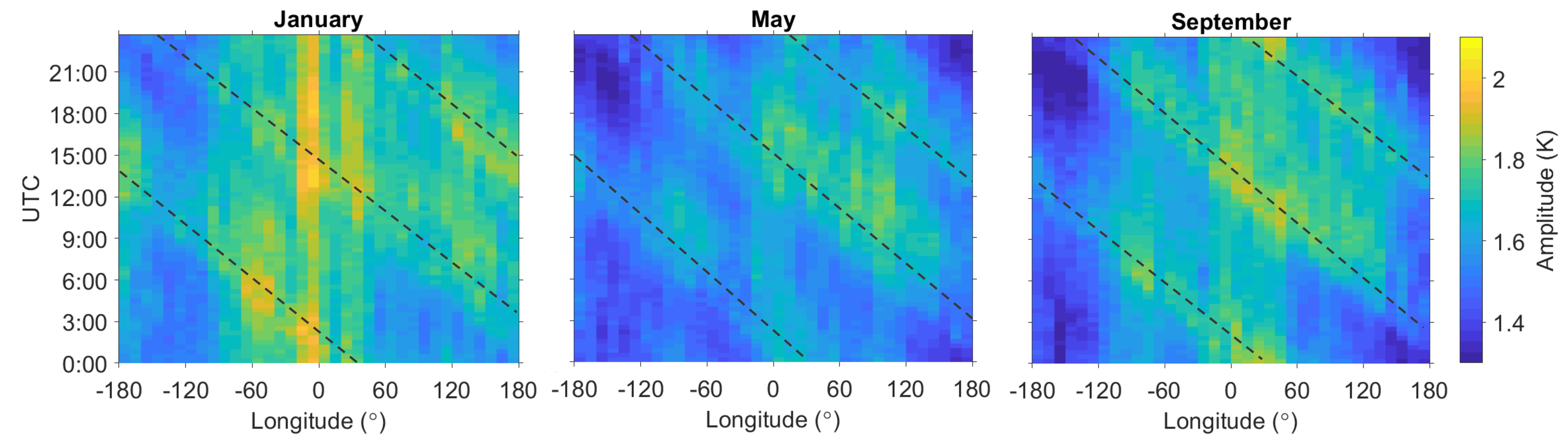


Figure 2. Hovmöller plots for January, May and September averaged over the tropics.

4.2 Gravity Wave Amplitudes

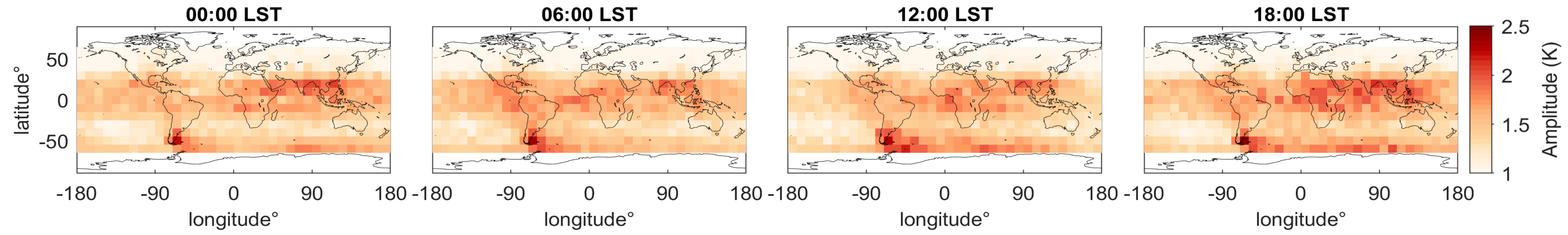


Figure 3. Gravity wave amplitudes in June using all data from 2007-2018 at 27 km altitude.

- Figure 3 shows the variation in gravity wave amplitudes at 4 times in a day (in LST), using all the data in June from 2007-2018.
- Peaks in amplitude can be seen over the Andes, and near Mexico and northern South America. The areas with higher amplitude over Africa, and India and southeast Asia are greatest at 18:00 LST, compared to the other times shown.

4.3 Case Studies

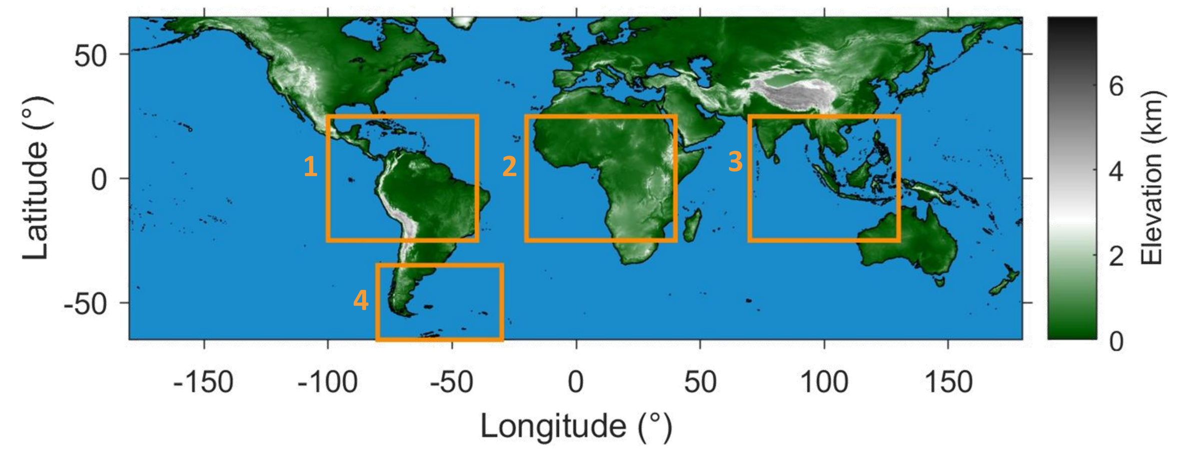


Figure 4: Regions selected for case studies in orange boxes.

- Time series of the mean gravity wave amplitudes and IMERG precipitation rate in regions 1 to 4 (labeled in Figure 4), in May and October are presented in Figure 5.
- The signal is divided by the mean of each time series.
- A diurnal cycle with two peaks in gravity wave amplitude and precipitation rate can be seen in regions 1 – 3, in the tropics.
- The amplitude of the gravity wave amplitude signal is greatest for region 3 for both months, which varies by around 17% of the time series mean.
- Regions 1 and 2 vary by around 10% and 12% respectively in the months shown.
- Peaks in gravity wave amplitudes are at around the same local solar time in May and October for each region.
- There is significantly less variation in precipitation in region 4 , over the Andes, for both months. Gravity waves in this region are expected to have mostly orographic sources.
- The mean gravity wave amplitudes in region 4 vary by around 12% of the time series mean.

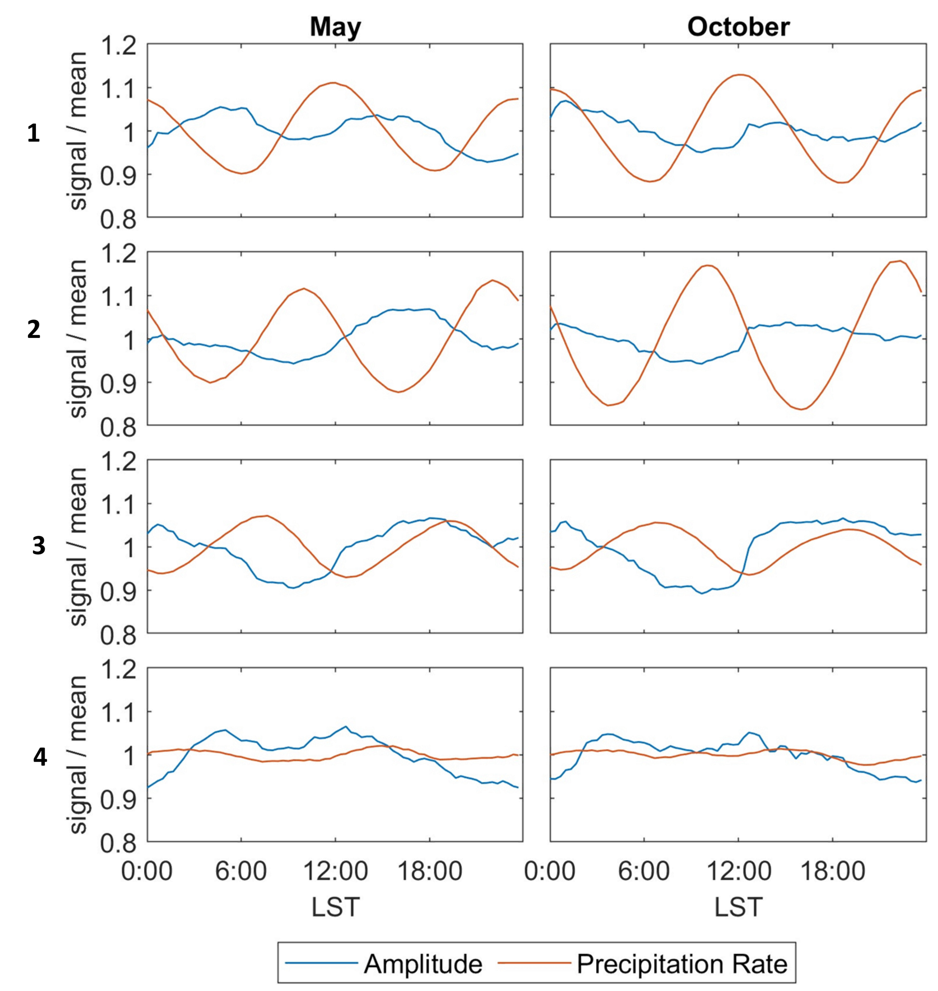


Figure 5: Time series of the gravity wave amplitude at 27 km altitude and surface precipitation rate.

5. Conclusions

- A clear diurnal cycle in gravity wave activity, with two peaks, can be seen using GNSS-RO data from multiple satellite missions, which varies with season and latitude.
- The results indicate there may be significant regional differences in the diurnal cycle, but this would require further investigation. A variation of around 10% – 17% of the mean can be seen in the regions selected in the tropics in May and October over a day.
- Both diurnal and non-diurnal gravity wave features can be identified in the data.

6. Future Work:

- Increase the time range of data used to include GNSS-RO data from COSMIC 2.
- Compare wave amplitudes to ERA5 wind data.
- Compare to Outgoing Longwave radiation data or brightness temperature data.
- Use continuous wavelet transform to identify individual waves in the GNSS-RO data, following the method described in Hindley et al. 2015 [5], to investigate how the number and distribution of gravity waves varies over a day.

Online presentation page

References

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