Exploring Gravity Waves: Satellite Observations from Stratosphere to Lower Mesosphere

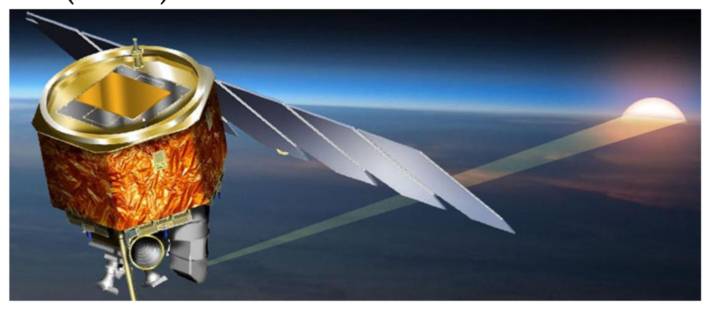
Malabika Ray, Scott England, Brentha Thurairajah, Chihoko Cullens

Abstract

This study explores Gravity Waves (GWs) in the stratosphere to lower mesosphere, using data from the Cloud Imaging and Particle Size (CIPS) experiment. The main aim is to develop a GW database for identifying patterns across different atmospheric layers, focusing on responses to seasonal cycles and Sudden Stratospheric Warmings (SSWs). Although CIPS data is limited to lower altitudes, our analysis provides significant insights into GW propagation and effects, enhancing models of GW dynamics and their impact on atmospheric behavior.

AIM – CIPS

- Figure 1. Aeronomy of Ice in the Mesosphere (AIM) is a satellite that orbits the Earth at approximately 600 kilometers and Cloud Imaging and Particle Size (CIPS) is a principal instrument on AIM, captures high-resolution images. (right) [1]



- DATA used: CIPS RAA LEVEL 2A
- Altitude ranges: 50 – 55 km
- Field of View: 80° x 120°, centered at the sub-satellite point. Image Acquisition: In each camera, initially every 43 seconds, now every 2 minutes for sunlit sides. Spatial Resolution: 56.25 km^2 per image. Data Products: Includes cloud albedo, particle radius, ice water content, and Rayleigh Albedo Anomaly (RAA) with a horizontal resolution for mapping at 0.5° x 0.5° latitude/longitude grid. [1]

Analysis Method

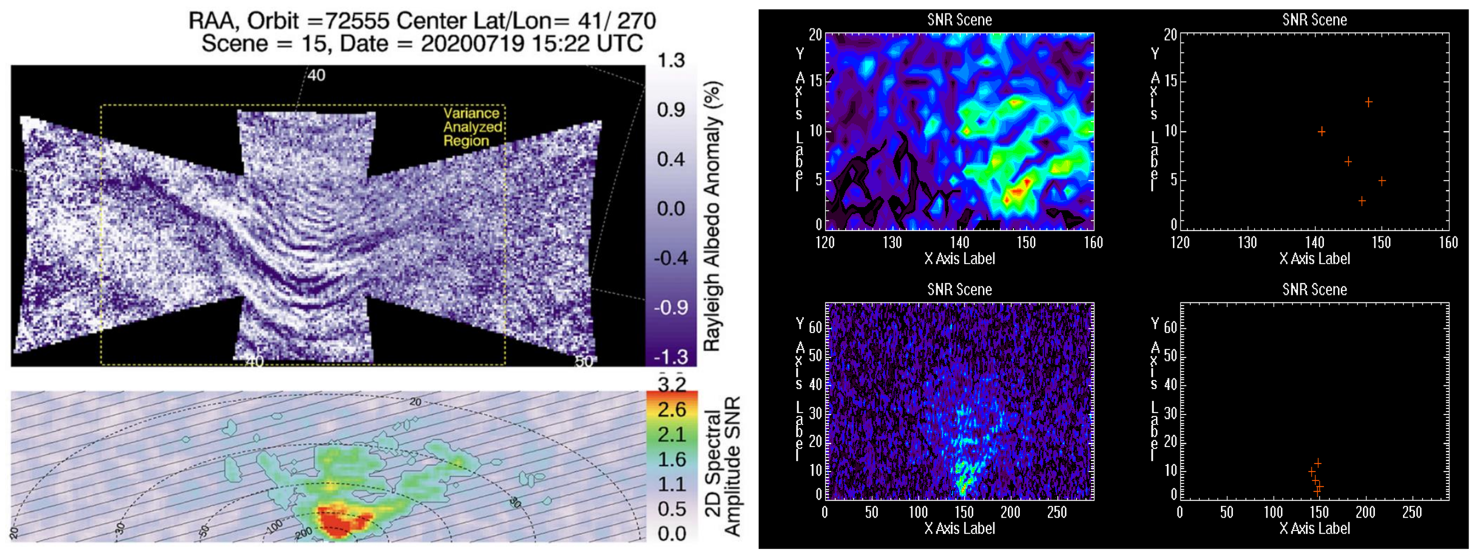
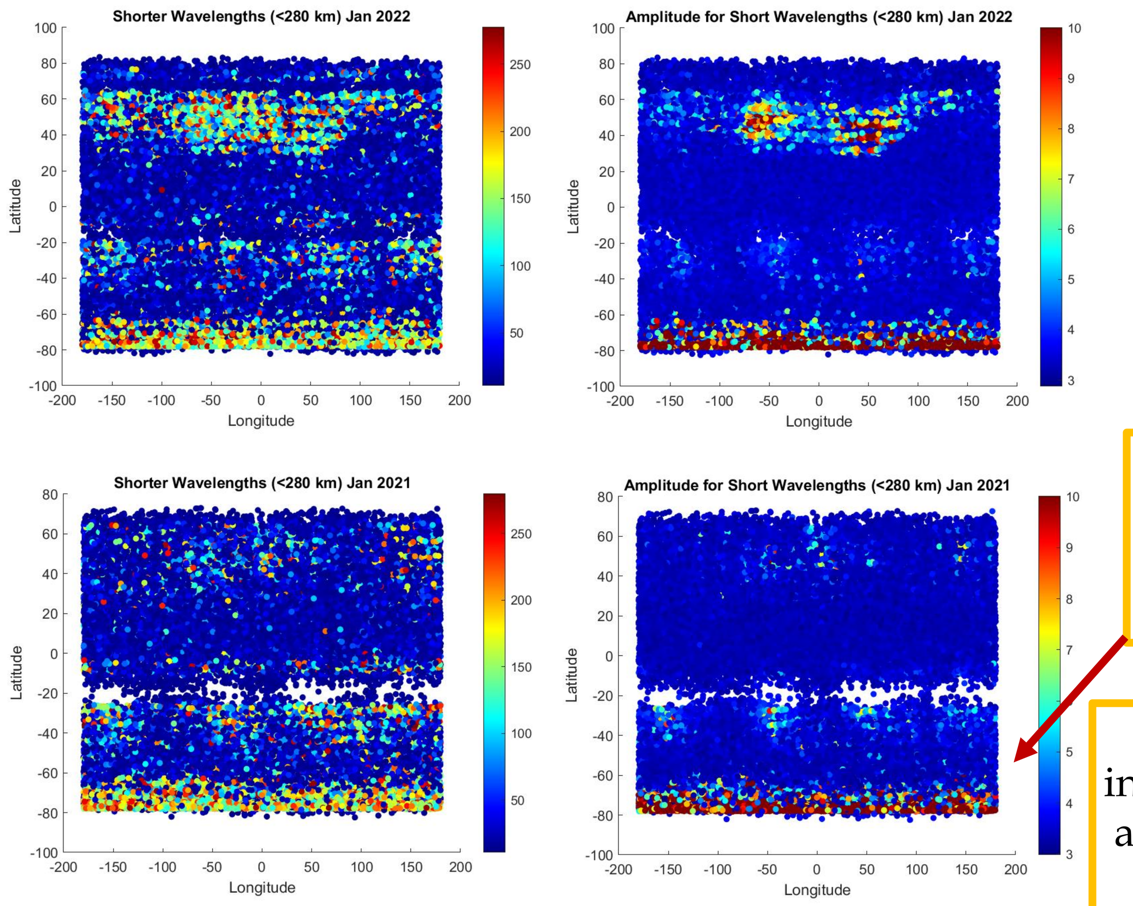


Figure 2. The referenced paper by Xu et al. (2023) [2] utilizes CIPS data to detail the seasonal distribution of gravity waves near the stratopause, highlighting significant spatial and temporal patterns (left). Our image contrasts these findings by applying an analysis method to identify and visualize the top amplitude gravity waves from distinct 5 by 5 bins. Out of all the collected data, the top 5 are displayed in the plot which correspond to their high SNR variances demonstrating our method's capability to detect and analyze significant atmospheric phenomena (right).

Year wise comparison among amplitudes and wavelengths

Year 2022 and 2021 – January



The significant difference in short ranges may be from increased Solar activity, or climatic variations.

Around latitudes 60-80S, are likely to be PMCs as their formation needs colder temperatures.

This could be due to instrumental anomalies, adjustments in satellite coverage, or unique atmospheric conditions

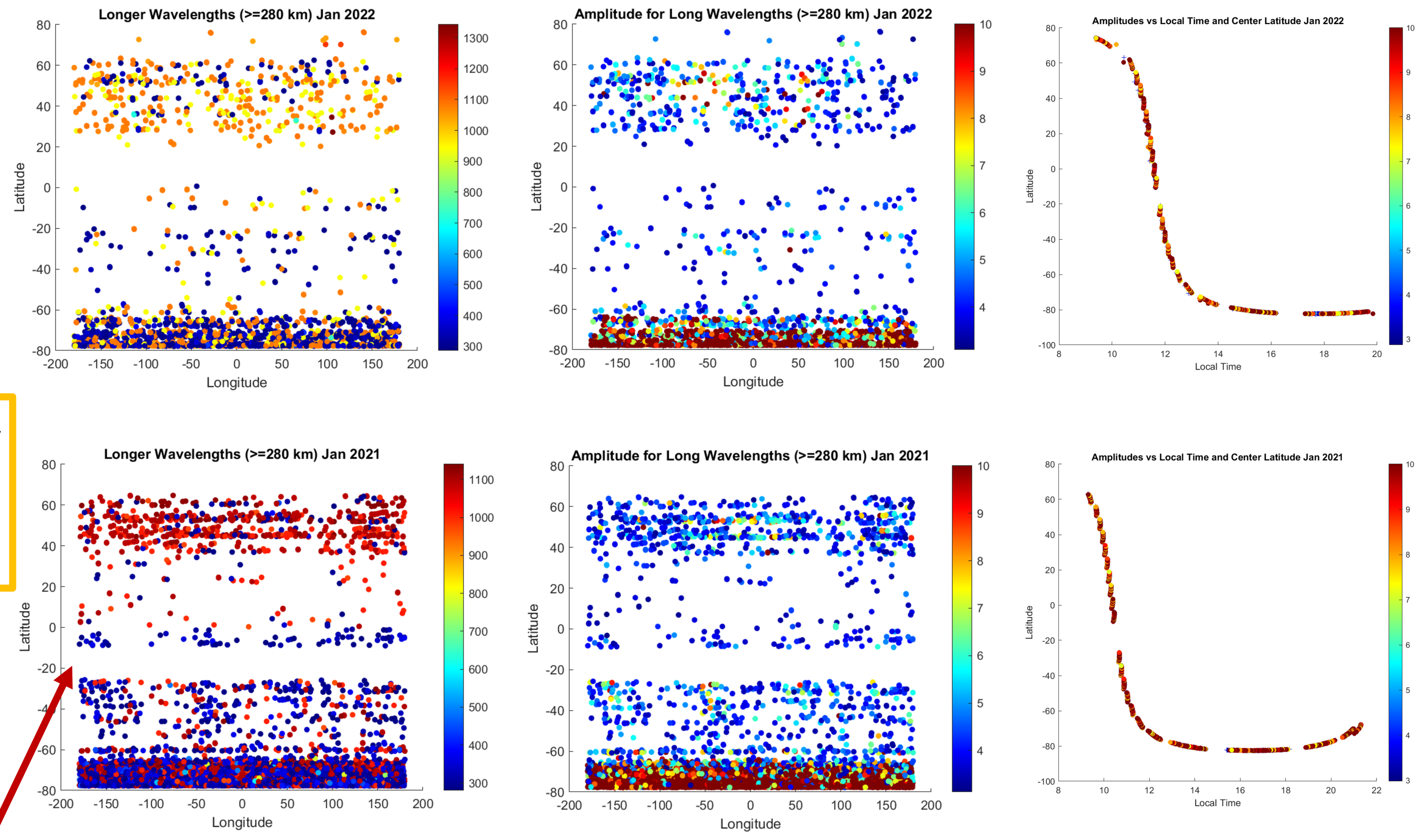
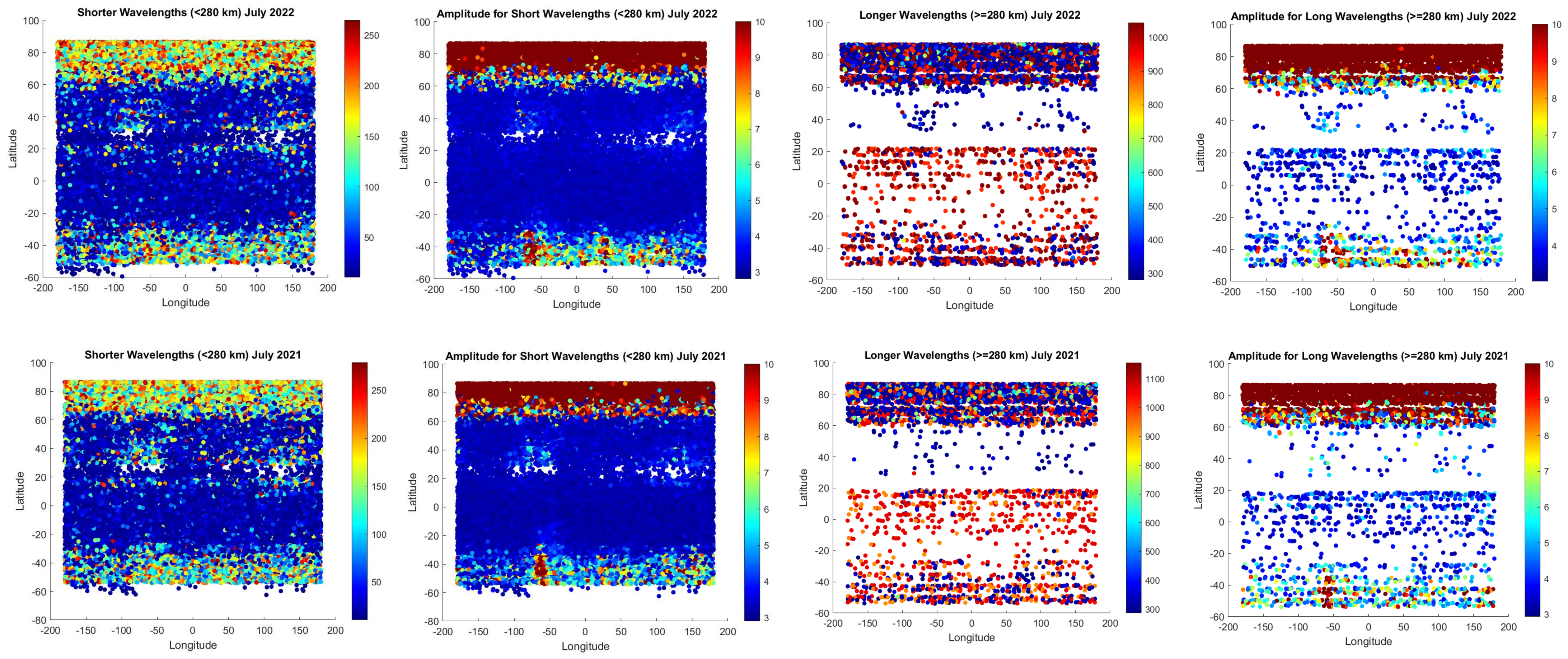
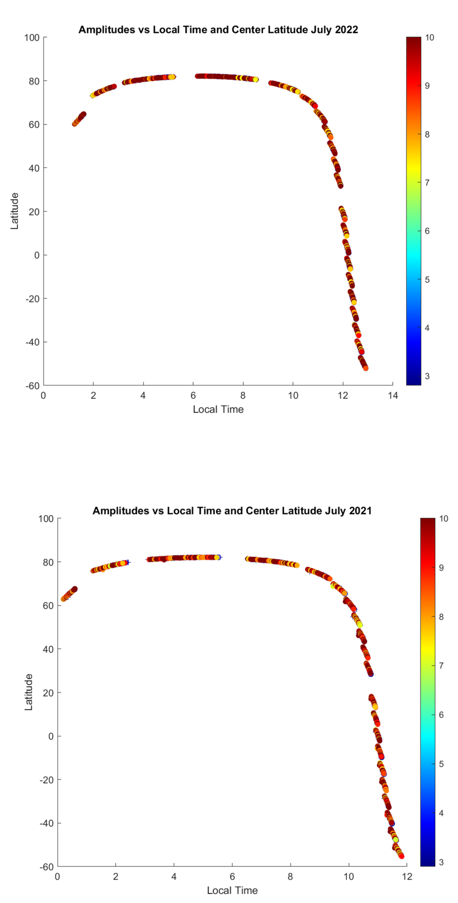


Figure 3. Distribution of the top wavelengths and their corresponding amplitudes from 5 by 5 grids of each scene from all orbits covered every day for the whole month of January in 2022 and 2021 (up) and of July 2022 and 2021 (down). Relatively increased spatial distribution is seen in January 2022 from 2021 between latitudes 40 – 60 N latitudes and a sudden gap for measurements are noted around 20 S latitude in January 2021. Overall same pattern is seen for July and a concentration of distribution in higher latitudes.

Year 2022 and 2021 – July



The opposite trends observed in GWs characteristic between July and January can be attributed to the seasonal reversal of atmospheric conditions, including variations in temperature gradients, jet stream positions, and solar radiation effects. These factors significantly alter wave propagation patterns between the Northern Hemisphere's summer and the Southern Hemisphere's winter, and vice versa.



Data density of Amplitudes vs Wavelengths +/- 60 degrees

Year 2022 and 2021 - January

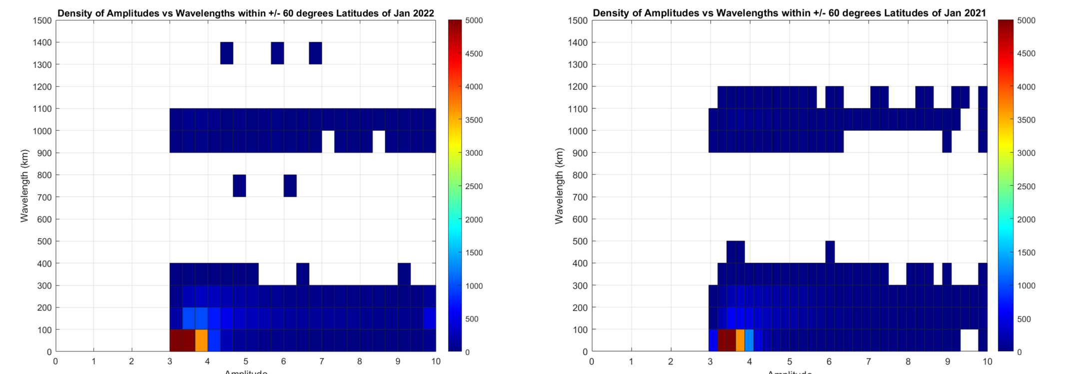
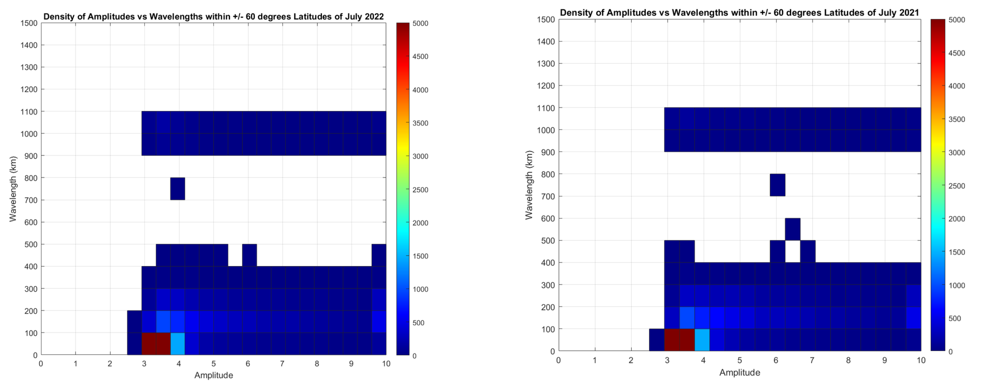


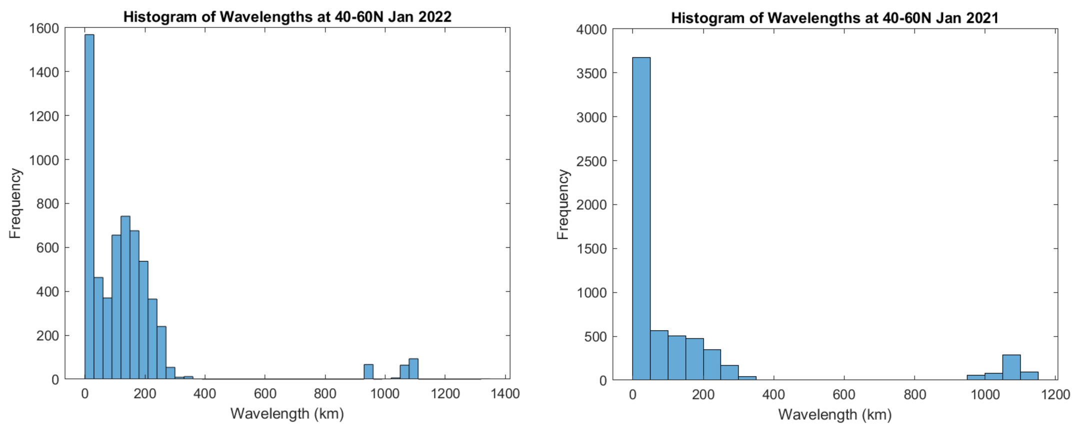
Figure 4. This series of plots illustrates the distribution of gravity wave characteristics across different latitudes and longitudes for the years 2021 and 2022. Each plot highlights variations in wave amplitude and wavelength providing insights into seasonal and annual changes in atmospheric wave dynamics.

Year 2022 and 2021 - July

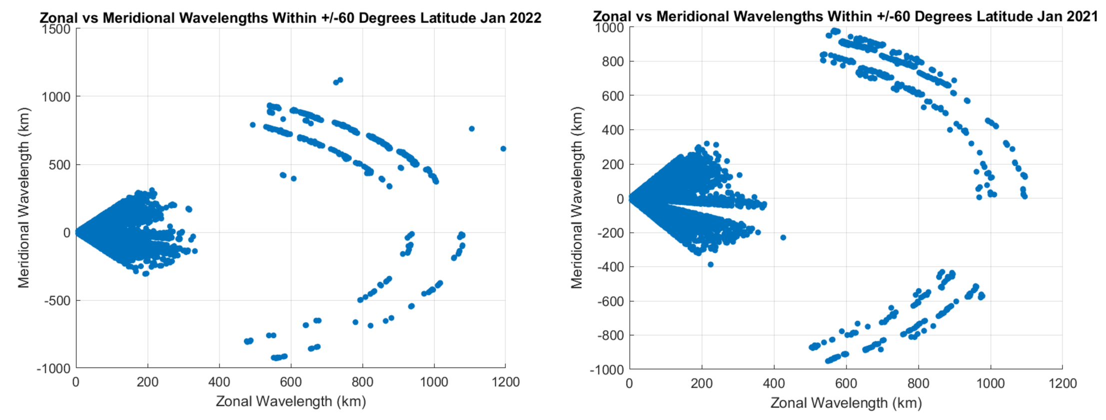


Frequency of GW Wavelengths

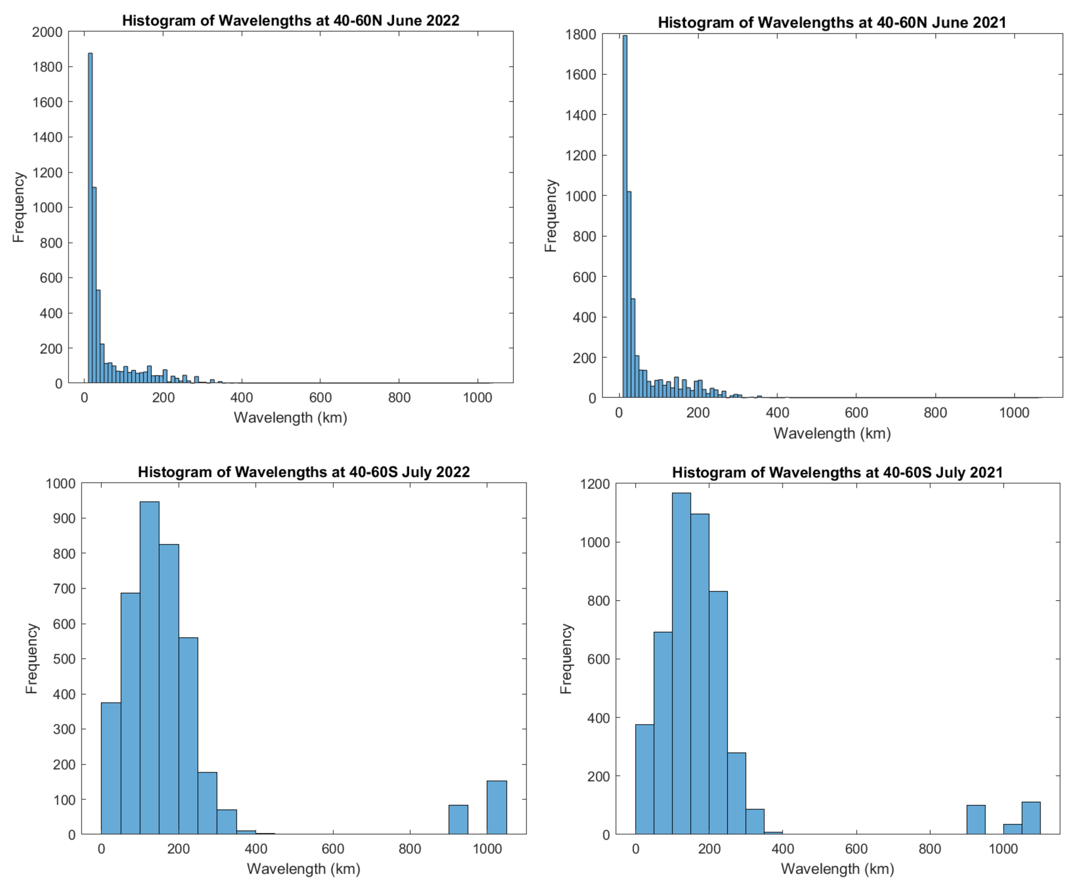
Year 2022 and 2021 - January



In winter, the atmosphere tends to have stronger zonal winds and a more stable polar vortex, which can enhance the north-south propagation of gravity waves.



Year 2022 and 2021 - July



Conversely, in summer, the polar vortex is weaker or absent, and the wind patterns are generally less supportive of wave propagation over long distances.

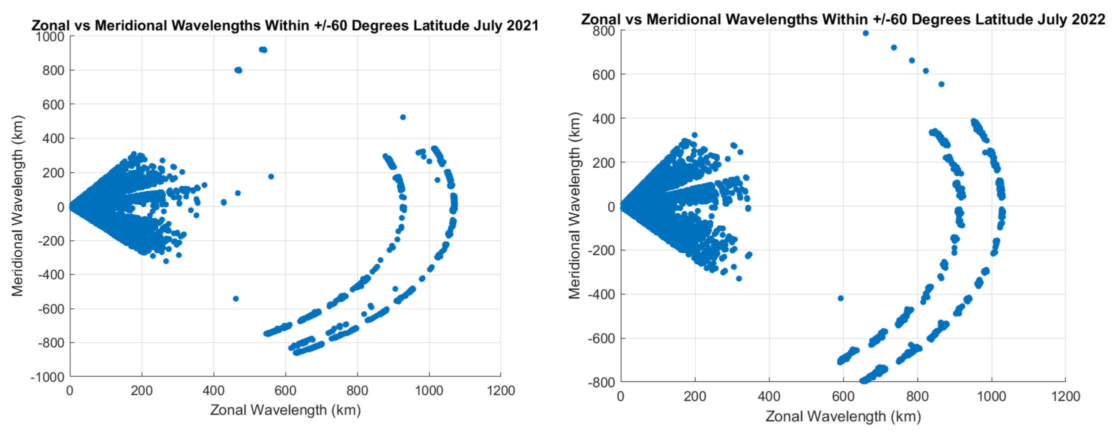


Figure 4. Frequency of wavelengths across the years 2022 and 2021 and their Zonal-Meridional distribution of the wavelengths are displayed.

Conclusion and Future Work

Our analysis identifies and characterizes GW patterns near the stratopause. The observed seasonal differences, particularly between January and July, highlight the complex interplay of atmospheric dynamics influenced by solar activity, temperature gradients, and hemispheric weather patterns. These findings not only validate the capability of the CIPS instrument.

We plan to extend our multi-year analysis, integrate ERA5, SOFIE, and AIRS data for comprehensive validation, focus on specific atmospheric events, and prepare our research for publication and future scholarly work.

Citations

- Laboratory for Atmospheric and Space Physics. (2024). Aeronomy of Ice in the Mesosphere (AIM). University of Colorado Boulder. Available at: https://lasp.colorado.edu/aim/ [Accessed date].
- Xu, S., Carstens, J. N., France, J. A., Randall, C. E., Yue, J., Harvey, V. L., et al. (2023). Seasonal distribution of gravity waves near the stratopause in 2019–2022. Earth and Space Science, 11, e2023EA003076. https://doi.org/10.1029/2023EA003076