Analyzing the Relationship Between Periodic Expansion Events in Jupiter's North Equatorial Belt and Thermal Waves in its Upper Troposphere Using Near-Infrared Imaging

Joheen Chakraborty
Columbia University
jc5110@columbia.edu
Mentor: Dr. Glenn S. Orton

June 16, 2020

1 Introduction/Background

My project will focus on using near-infrared imaging of Jupiter to examine and characterize upper-tropospheric waves in Jupiter's North Equatorial Belt (NEB). The presence of both upper-tropospheric and stratospheric thermal waves during and after the periodic NEB expansion events is a well-documented phenomenon[1] across ∼20 years (from 1995 onward) of near-infrared imaging of Jupiter's atmosphere by NSFCam, NSFCam2, and SpeX. Observations of the NEB reveal an expansion cycle with a period of 3-5 years, and the expansion events were all observed to coincide with zonal waves in the haze layer. I will expand upon a number of previous quantitative approaches[2,3] devised to evaluate cylindrical maps of Jupiter to obtain information about the classification and intensity of the waves.

Previous student work in 2018 sought to answer the notable unanswered question of whether thermal waves appeared solely during the expansion events, which would have indicated a related source for both phenomena.[3] This work used two approaches: (1) using variance of wave intensity to track their temporal evolution, and (2) a visual approach to wave classification (into "intensity", "width", and "combination" categories) to verify the variance analysis and obtain further results. The work concluded that waves are present *outside* just the NEB expansion events, potentially disproving a correlation between the two.

Further work in 2019 expanded temporal and longitudinal coverage of the analysis, as well as explored other analytical approaches including neural network-based classification of waves, a relative wave power approach, and Fourier analysis.[2] The analyses provide robust alternatives to the earlier "variance" approach, and found that variations in brightness and latitudinal width are strongly correlated.

One immediate continuation of previous efforts in this domain would be experimenting with stitching together cylindrical maps to improve spectral resolution, allowing for more refined and accurate analytical approaches. I will also look into dynamical modeling of the NEB, machine learning-based classification of haze-layer waves, and Fourier analysis of the waves to see if these approaches will yield any further information that could be helpful in characterizing the NEB expansion-wave propagation relationship. The ultimate goal would be to obtain insights on the nature of the relationship between upper-tropospheric waves and the NEB expansion cycle, as well as general dynamical information on the waves and the NEB.

2 Objectives

My research goals, which are direct continuations from the previous work done on this project, include:

- Expand the temporal coverage of near-IR imaging data reduction by filling any gaps present and adding upcoming data (April, early June, and late July) from the NIRI instrument on the Gemini North observatory.

- Stitch together cylindrical maps from dates relatively close together to increase spectral resolution and reduce variations in the scatterplots of the previous "relative wave power" approach. This stitching procedure should also allow for improvements in other analytical approaches (e.g. Fourier analysis, machine learning) that were previously bottle-necked by the low spectral resolution of the data.
- Explore methods for understanding the NEB expansion-wave propagation relationship dynamically. One such method could be dynamical/numerical modeling of the NEB, which would require extensive literature review of work already done on the problem.
- Investigate the relationship (if any) between relative wave power and intensity/width coefficients of the waves. This would begin by measuring each independently to look for a correlation.
- Time permitting: Fourier analysis of haze-layer waves, which exhibit wavenumbers of 16-17. Previous work conducted Fourier analysis on 160px-wide observations and scaled the data to obtain wavenumbers relative to Jupiter's entire surface. However, stitched data at a higher spectral resolution would allow for a more accurate analysis (potentially without any need for scaling the data).
- Time permitting: expand upon the neural network-based classification of haze-layer waves. The previously created model is able to distinguish between images containing waves, no waves, and anomalies with 82% accuracy; however, limitations of the data (e.g. low spectral resolution) make differentiating between wave types difficult. A worthwhile effort would be trying different machine learning models or neural network architectures, as well as augmenting the data (e.g. through the aforementioned stitching procedure) to achieve more refined and accurate classifications.

3 Approach

I will analyze images of Jupiter's atmosphere obtained by ground- and space-based observatories in the near infrared by first reducing them (to smoothen blemishes and clean bad data) and splicing them into CMAP files. I will then expand upon previously written algorithms, as well as write new algorithms of my own, to automate analysis of the data files (these algorithms are/will be written primarily in IDL). The results of these algorithms will then be plotted to search for potential correlations of scientific interest, which would then be further investigated manually or with numerical modeling.

4 Work Plan

Weeks 1-2: Assess the current state of available data and data reduction. Learn how to use IDL and Data Reduction Manager (DRM). Learn how to splice cylindrical maps (CMAP files) of Jupiter.

Weeks 3-4: Reduce and analyze available data to fully expand temporal coverage of the project. Determine how the results from the new data compare to results obtained from previous work. Apply the aforementioned stitching procedure to combine CMAPs from similar times to increase spectral resolution for further analysis.

Weeks 5-6: Do a thorough literature review to learn about dynamical and numerical modeling of Jupiter's atmosphere, with a particular emphasis on the NEB region. Apply modeling techniques to the NEB during periods of interest and adjust the model to account for observed wave patterns.

Weeks 7-8: Conduct measurements of wave coefficients and power to search for a correlation between the two. Experiment with other analytical approaches, such as Fourier analysis and neural networks.

Weeks 9-10: Write up a formal written report. Potentially complete a peer-reviewed article. Create and present a final oral report. Finish up documentation for future continuation of the project.

References

[1] L. N. Fletcher, G. S. Orton, J. A. Sinclair, P. Donnelly, H. Melin, J. H. Rogers, T. K. Greathouse, Y. Kasaba, T. Fujiyoshi, T. M. Sato, J. Fernandes, P. G. J. Irwin, R. S. Giles, A. A. Simon, M. H. Wong, and M. Vedovato. Jupiter's north equatorial belt expansion and thermal wave activity ahead of juno's arrival. *Geophysical Research Letters*, 44:7140–7148, 2017.

[2] T. Hackett and G. S. Orton. Investigating a relationship between quasi-periodic meridional clearing of deep clouds in jupiter's north equatorial belt and the propagation of zonal waves in its upper tropospheric haze: A study of near-infrared images. *Final SURF Report*, 2019.

[3] S. Wells and G. S. Orton. Infrared detection of waves in jupiter's north equatorial belt. *Final SURF Report*, 2018.