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Vorticity Conservation Analysis for Jupiter's Atmosphere using Juno and JOVIAL-JIVE

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Abstract

The dynamics of the Jovian atmosphere strongly relate to the energy budget, evolution, and sustainability of the polar vortices. We present an analysis of the velocity maps from the JOVIAL-JIVE project, particularly the vorticity at the higher latitudes. We make additional comparison of the velocity divergence estimates using JIRAM data from PJ4-5 (Adriani et al., 2018). We investigate the energy budget of the atmosphere by using wind map data from the polar regions (Grassi et al., 2018) and the equatorial regions, and the possibility of vortex driven acoustic oscillations. We further investigate temporal evolution of the mid-latitude vorticity via comparison with previous cloud tracking studies (Legarreta & Sánchez-Lavega, 2005).

1. Introduction

The dynamics of the gas giants are are a useful diagnostic for understanding the evolution of the solar system as they influence the overall mechanics and major interactions. The composition and global evolution of the gas giants is of immense importance for a proper characterization of planetary evolution. In as much, the atmosphere of Jupiter serves as a convenient laboratory for turbulence physics and vortex dynamics on scales inaccessible on Earth. Understanding the Jovian atmospheric dynamics allows for an estimate of the wind profile for the planet, which are required for characterizing the interior structure of Jupiter.

Structural complexities dominate the meteorological layer of Jupiter and produce a rich variety of discrete features including cyclones and anticyclones. As discussed in Grassi et al. (2018), the main polar vortices exhibit cyclonic behavior with minor anticyclonic features. They further state that the general drifts of the cyclones around the poles with respect to System-III coordinates are non-zero. These translations may relate to seismic modes in Jupiter, serving as oscillation driving mechanisms (Markham & Stevenson, 2018).

The structure, stability, and translation of vortices allows for constraints on the overall dynamics of the Jovian atmosphere. Due to the complexities inherent in turbulence physics, it is necessary to obtain empirical estimates of the vortex rotation as done in Adriani et al. (2018), the vortex wind profile as done in Grassi et al. (2018) and the vertical structure. Understanding these parameters for the vortices allows for a cohesive characterization of their thermal gradients and advective behavior.

2. Observations

Doppler imaging for Jupiter is a novel approach for velocity map generation and offers a complementary analysis to cloud and feature tracking studies. JOVIAL-JIVE (Jovian Oscillations through radial Velocity Imaging observations At several Longitudes-Jovian Interior from Velocimetry Experiment) is a multi-facility project spread over three locations: Dunn Solar Telescope at Sunspot, New Mexico (USA), Observatoire de Calern, Nice (France), and Okayama Observatory, Okayama (Japan). The project entails the use of a Doppler Spectrographic Imager using a Mach-Zehnder interferometer (Gonçalves et al., 2019). Observations have been carried out for the past two years and are being planned for the foreseeable future using all sites.

JIVE enables velocity map generation using particle flows directly. Previous studies have employed high resolution cloud tracking, which are only representative of isobaric regions and are subject to deformations. Velocity maps using feature tracking are subject to image reconstruction errors as well as contamination due to wave motion. Doppler velocimetry, however, provides sensitivity on the scale of m/s, enabling high resolution vorticity maps.

3. Methods

We generate vorticity maps at Jupiter's equatorial region using the wind maps developed in Gonçalves et al. (2019). The wind profiles are generated using preliminary observations from a prototype of the JIVE instrument during the 2018 Jupiter opposition. Using the zonal, meridional, and vertical velocity components, a 3-dimensional vorticity map is obtained for latitudes between 60°N to 60°S. We study the vorticity conservation across latitudes and compare with the values obtained in Grassi et al. (2018) for the polar regions and quantify the latitudinal vorticity gradient. We further compare our mid-latitude vorticity estimates with values determined using cloud tracking methodologies, as in Legarreta & Sánchez-Lavega (2005), to investigate potential temporal evolution. Vorticity analysis allows for a study of the energy budget of the entire system and provides a window into the possible mechanisms of excitation of Jovian oscillations.

4. Summary and Conclusions

Our work underscores the fidelity of a new methodology to obtain high resolution velocity maps as compared to previous methods involving cloud or feature tracking. The JOVIAL-JIVE project enables groundbaed measurements of Jovian velocity fields at a resolution on the scale of m/s. These fields are independent of wave deformations or image reconstruction errors, allowing a novel approach for vorticity analysis. We use the 3-dimensional maps to quantify the latitudinal vorticity gradient and explore its potential temporal evolution. The vortices may serve as excitation mechanisms for seismic modes on the planet. In that vein, we also explore the velocity divergences at the polar regions and entertain the possibility of vortex driven acoustic oscillations.

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