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Jupiter's Atmospheric Variability from Long-Term Ground-Based Observations at 5 microns

Arrate Antuñano (1), Leigh N. Fletcher (1), Glenn S. Orton (2), Henrik Melin (1), Steve Milan (1), John Rogers (3), Thomas Greathouse (4), Joseph Harrington (5), Rohini Giles (4) and Padraig Donnelly (1).
(1) University of Leicester, Leicester, UK, (2) Jet Propulsion Laboratory, Pasadena, CA, USA, (3) British Astronomical Association, London, UK, (4) Southwest Research Institute, San Antonio, TX, USA, (5) University of Central Florida, Orlando, FL 32816-2385, USA.

Abstract

We use ground-based 5-µm data captured between 1984 and 2018 by 8 different instruments to study the long-term temporal variability of Jupiter's belts and zones at the 1-4 bar pressure level. The data show a large temporal variability mainly at the equatorial and tropical latitudes, with a smaller temporal variability at mid-latitudes. A comparison of the location of the 5-µm-dark and -bright regions and the belts and zones at visible wavelengths show that these regions are not always co-located, especially in the southern hemisphere. Lomb-Scargle and Wavelet Transform analyses show that some of the variations of the banded structure occur periodically in time intervals of 4-8 years. Finally, a Principal Component Analysis reveals a clear anticorrelation on the 5-µm brightness changes between the North Equatorial Belt and the South Equatorial Belt.

1. Introduction

At visible wavelengths, Jupiter displays a characteristic banded structure with low-albedo brownish belts and high-albedo whitish zones alternating in latitude, which seem to be bounded by the eastward and westward zonal tropospheric jets in Jupiter. At 5 µm, sensitive to the thermal emission from Jupiter's cloud-forming region at 1-4 bar level, a similar banded structure is observed, with 5-µm-dark zones (due to the presence of ammonia ice and deeper clouds) and bright belts. This banded structure undergoes dramatic planetary-scale changes both at visible wavelengths and 5 µm in a very complex way [1], with some variations repeating periodically [2-4] and some others occurring randomly [e.g. 5]. So far, the origin and nature of these changes, as well as their relationship to the three-dimensional atmospheric dynamics, are not well understood. Here we seek to analyse these changes in a systematic fashion, testing the robustness of the periodicities cited in the literature.

2. Observations and Methodology

Images captured between June 1984 and July 2018 at wavelengths between 4.76 and 5.18 µm are used to analyze the latitudinal brightness variability of Jupiter. These data are longitudinally averaged by binning the 5-µm brightness in latitudinal bins of 1° between ±70° latitude. Due to the very different atmospheric conditions at which the data were acquired, we do not calibrate the data before computing the average brightness. Instead, we scale the averaged brightness to the three most quiescent latitudinal regions in Jupiter: (i) the South South South Temperate Zone (S3TZ) between 46 and 48° S, (ii) the South Temperate Belt (STB) at 24-28° S and (iii) the EZ between ±5° of the equator (for the dates with no EZ disturbance events [3]), and perform the same analysis using these three scaling regions independently to analyze the robustness of our results.

3. Temporal Mean brightness

A comparison of the locations of the 5-µm-bright and -dark regions with the location of the visible belts and zones defined by [6] is performed. A clear asymmetry of the temporal mean 5-µm brightness between the northern and southern hemispheres is observed, where the northern latitudes display a large meridional variability compared to the south. The picture of bright, cloud-free belts and dark, cloudy zones only seems to hold at the tropical and equatorial latitudes. At mid- to high-latitudes the correspondence between the albedo, zonal jets, and 5-µm brightness breaks down, as stated in [1].

4. Periodogram Analysis

Lomb-Scargle and Wavelet-Transform analyses are performed in order to identify potential periodicities on the 5-µm brightness variability that could hint to some physical processes. Our results show 4-8-year periods for the brightness changes, which could hint at some moist convective process and are comparable to the radiative time constant [7], suggesting that these changes could be related to moist convection. In particular, an 8.5±0.5-year periodicity at 30-33°N is found, where a brightening of the usually dark North Temperate Zone forms a belt between 28° and 35°N. This is unrelated to the 5-year periodicity of NTB outbreaks at visible wavelengths, which is not observed in our study. Additionally, 4.4±0.4 and 4.5±0.8-year periodicities are found at the NEB and SEB, respectively. These periodicities coincide with the ~4.5-year variability of the equatorial stratospheric temperatures (Quasi Quadrennial Oscillation, QQO, [8]). The relationship between the QQO and the NEB and SEB variations is not yet understood and new observations and numerical simulations will be essential to understand it. Finally, a peak of 6.6±0.5 years is found south of the equator corresponding to EZ disturbance events, in agreement with [3], and a peak at 7.4±1 years is observed at the southern edge of the NEB, at 7-9° N, in agreement with the ~7-year periodicity observed on the changes of the equatorial wind profile at cloud level [e.g. 6].

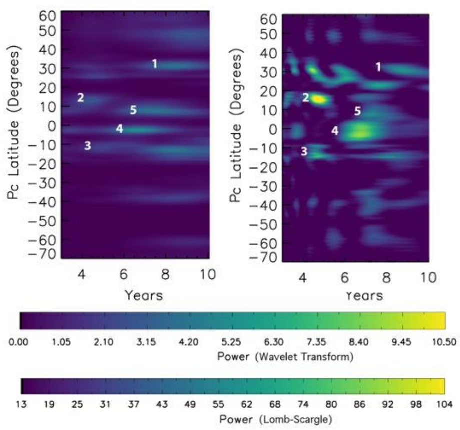

Figure 1: Wavelet Transform periodogram (left) and Lomb-Scargle periodogram (right) of the 5-µm emission variability, scaled at the S3tZ. The numbers represent the periodicities that do not depend on the scaling region and therefore are trusted here.

5. Principal Component Analysis

A Principal Component Analysis is performed in order to analyse whether a correlation/anticorrelation exists in the brightness variations of different belts and zones. We find a clear anticorrelation in the brightness of the NEB and SEB at all studied epochs, suggesting that brightness variability at these belts could be related (Fig 2). So far, the physical processes underlying this anticorrelation is unknown and the development of new General Circulation Models will be essential to understand it.

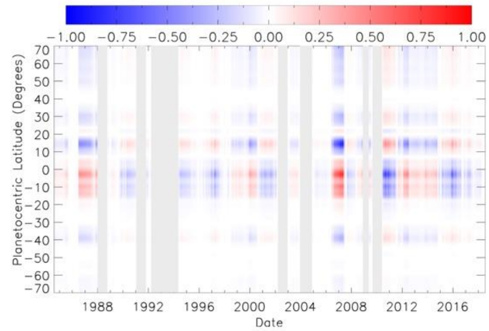

Figure 2. Principal Component Analysis results, showing the third eigenvector, showing the anticorrelation between the NEB and SEB. Red indicates brightness increases respect to the temporal mean and blue represents the contrary.

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