Turbulence in Jupiter's Clouds

N. Barrado-Izagirre, S. Pérez-Hoyos, and A. Sánchez-Lavega

Abstract We have studied the spatial distribution of Jupiter's higher clouds in order to characterize the turbulent regime and the presence of waves in this planet's atmosphere. We have used images from the Hubble Space Telescope (HST) 1995's archive and from Cassini's ISS camera during its Jupiter fly-by in its way to Saturn in 2000 in three wavelengths: near infrared ($\sim$ 940 nm), blue ($\sim$ 430 nm) and ultraviolet ($\sim$ 260 nm). These images were cylindrically projected and composed to obtain complete planispheres of Jupiter that cover the latitudinal range from 60°N to 60°S. When applying the Fast Fourier Transform (FFT) to each latitude reflectivity scan, we obtain brightness power spectra and periodograms that show the presence of wavy phenomena. From the spectra we study the decay of the slopes and their possible correlation with the underlying turbulent regime. We compare the turbulent structure of Jupiter's clouds with the dynamic structure characterized by the latitudinally alternating zonal wind regime (East-West) and with the meridional wind shear.

1 Wave Search

Jupiter's atmosphere shows plenty of wavy and periodic features. Using a Lomb-Scargle technique we obtain a periodogram for each latitude's brightness scan that allows us to construct periodogram maps as those shown Fig. 1. Looking through the maps we found some periodic phenomena at different latitudes. We retrieve the latitudinal location and dominant wavenumber for the most strongly contributing periodic phenomena. Contrasting them in the planispheres we verify their existence avoiding possible artifacts on the image. Although there are waves in many latitudes, the strongest ones are located in the equatorial zone.

N. Barrado-Izagirre, S. Pérez-Hoyos and A. Sánchez-Lavega
Universidad del Pais Vasco, Alda. Urkijo s/n, 48013 Bilbao, e-mail: naiara.barrado@ehu.es

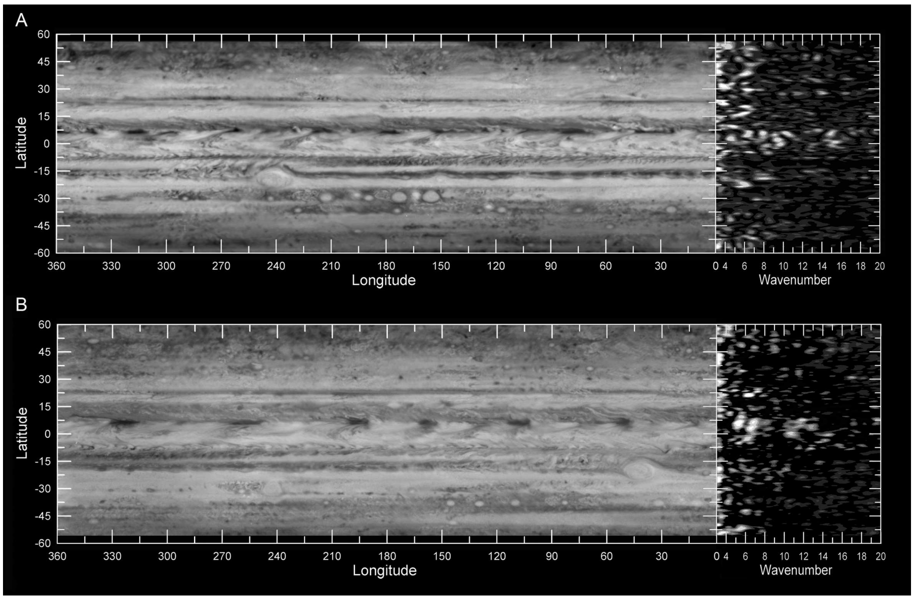

Fig. 1 Reflectivity NIR maps or planispheres in the left and periodogram maps on the right. Top figure constructed with HST images and bottom with Cassini ones.

2 Power Spectra Analysis

The Fast Fourier Transform applied to a given brightness scan allows a one dimensional study of the power spectra. This can be performed either in the meridional and in the zonal directions.

Meridional Analysis

For the meridional analysis we take the zonal wind profile and the averaged North-South reflectivity profile and apply the FFT but from North to South. We compare the spectral decay obtained from both profiles in each wavelength. Obtained slopes are very similar in the near infrared and in the blue, but not in the case of the ultraviolet as shown in the Fig. 2. This figure uses Cassini's data it was also done for HST. All the results are summarized on Table 1.

This analysis is in good agreement with previous theoretical models for terrestrial oceans and the atmospheres of the giant planets, as previously reported by [1], [2] and [3].

Zonal Analysis

Most of the retrieved power spectra in the zonal analysis have two slope regimes, n_1 and n_2, separated at a turning point k_I. We have selected three integration criteria

Table 1 Power spectra slopes for meridional scans

Profile	Observations	Near Infrared	Blue	Ultraviolet
Zonal Wind	HST	-4.1±0.5	–	–
	Cassini	-4.6±0.5	–	-2.5±0.4
Meridional Wind Shear	HST	-3.7±0.4	–	–
	Cassini	-4.2±0.4	–	-2.0±0.5
Albedo	HST	-3.9±0.3	-4.0±0.5	-2.8±0.3
	Cassini	-4.1±0.3	-4.5±0.4	-2.5±0.2

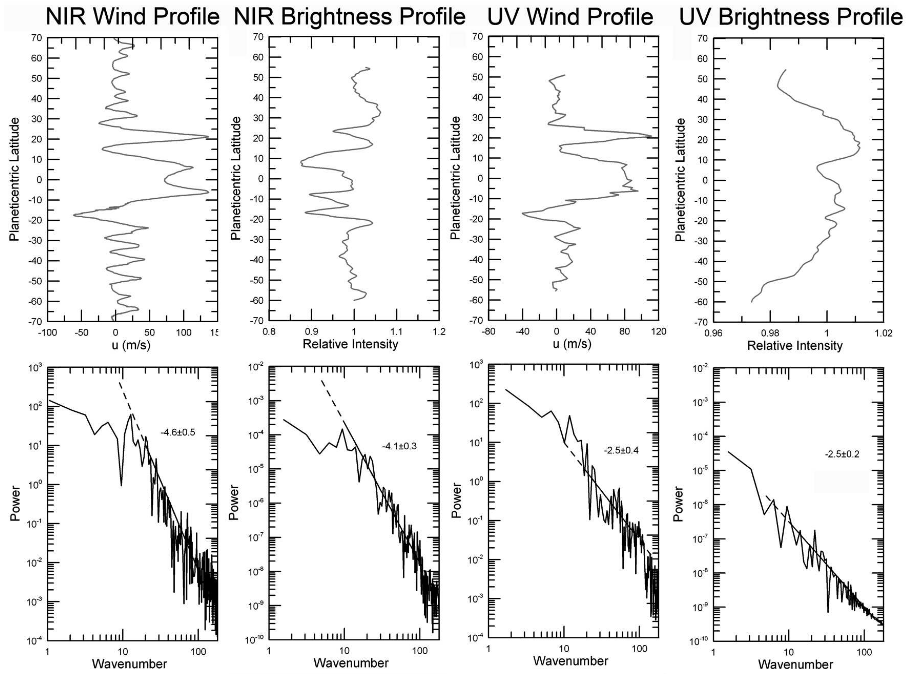

Fig. 2 Top panels show the wind profiles and the averaged brightness profiles for the near infrared (NIR) and the ultraviolet (UV). Bottom ones show the power spectrum of each profile and the slope value.

depending on wind direction (eastward or westward), local vorticity (cyclonic or anticyclonic) and brightness (dark belts or bright zones) to study the possible correlation of the spectral slopes with these physical factors as shown in Fig. 3 for the wind direction case. We obtain two slopes (n_1 and n_2) for each grey or white zone. This figure show results from NIR images but we have developed the same analysis for blue and ultraviolet wavelength images. It is noticeable that the value of the slopes is not correlated with these physical parameters; mean values of n_1 and n_2 are very similar following any criteria (n_1 = -1.3 ± 0.4 for wavenumbers between 10 and 80 and n_2 = -2.5 ± 0.7 between 80 and 150 for near infrared and blue and n_1 = 1.9 ± 0.4 and n_2 = -0.7 ± 0.4 for ultraviolet) but they seem to be latitude dependent.

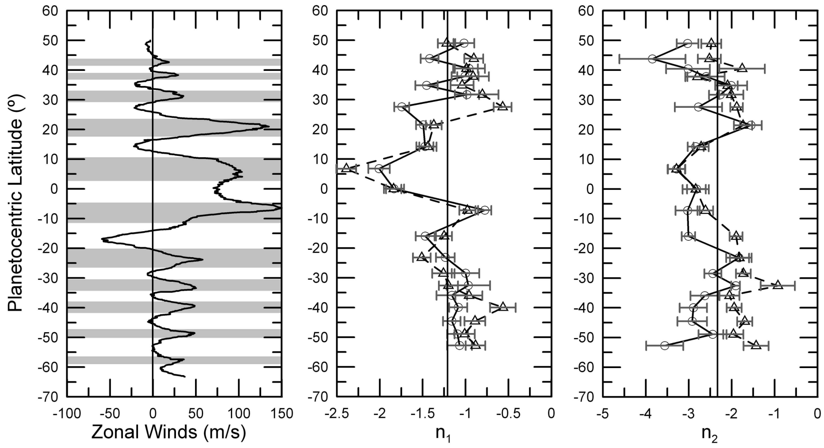

Fig. 3 Left panel represents Jupiter's wind profile with the integration zones in grey and white. Center and right panel show the derived values of n_1 and n_2 for each zone.

3 Power Spectra Interpretation and Conclusions

In the meridional direction resulting slopes are almost the same for both the zonal wind speeds and mean albedo and they are similar to those predicted by some previous theoretical models of turbulence.

In the zonal direction, when comparing our results with previous works for kinetic energy [5] and for cloud opacity [6], [7] and with 2D and 3D turbulence theories (see Fig. 4) we find consistent results. We notice that our results are in good agreement with 2D turbulence in the longer wavelengths (NIR and BL), but not in the ultraviolet, where we observe that the results fit better with a passive tracers turbulence model.

A first conclusion that immediately follows from this work is the anisotropy of the turbulent field in the zonal and meridional directions, being the spectral decay in stronger in the later than in the former. The link between the brightness power spectra and the kinetic energy spectrum remains unclear, although in this work we show new evidences that such a link may exist.

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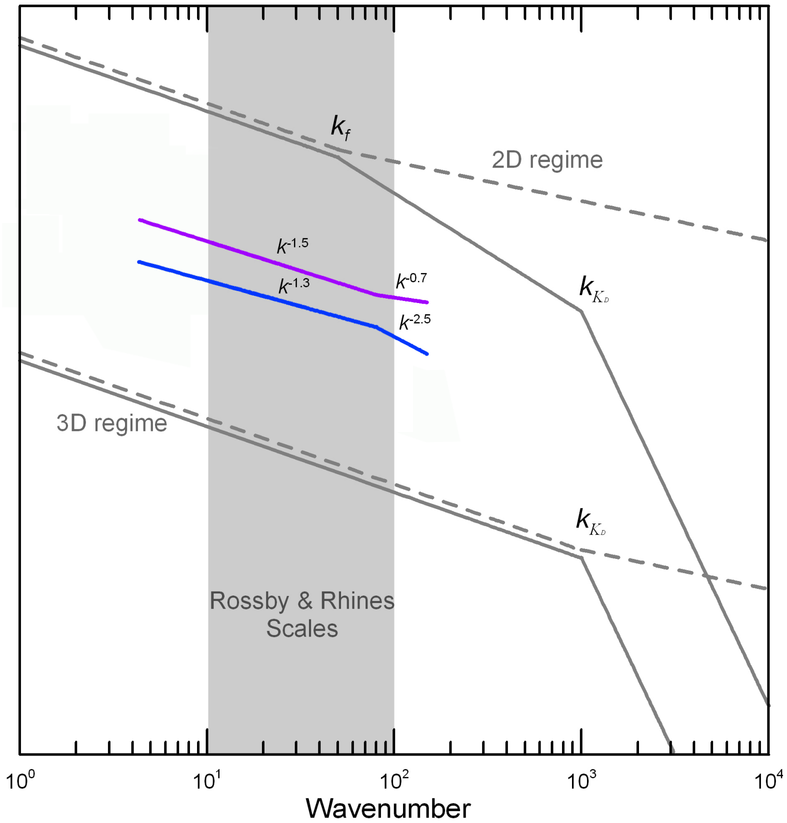

Fig. 4 Schematic comparison between turbulence theories and this work experimental results. Upper grey lines show the 2D-turbulent regime: continuous line for the kinetic energy spectrum and dashed line for a passive tracer spectrum. Bottom grey line is the same but for the 3D-turbulent regime. The intermediate curves show our results for ultraviolet slopes (purple) and blue and near-infrared slopes (blue). The shaded area depicts expected range of values for the Rhines and Rossby scales.

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References

1. Galperin, B., Nakano, H.,Huang, H.P., Sukoriansky, S.: The ubiquitous zonal jets in the atmosperes of giant planets and Earth' oceans. Geophys. Res. Lett. **31**, L13303 (2004)
2. Galperin, B., Sukoriansky, S., Huang, H.P.: Universal n-5 spectrum of zonal flows on giant planets. Phys. Fluids **13**, 1545–1548 (2001)

3. Sukoriansky, S., Galpering, B., Dikovskaya, N.: Universal Spectrum of Two-Dimensional Turbulence on a Rotating Sphere and Some Basic Features of Atmospheric Circulation On Giant Planets. Phis. Rev. Lett. **89**, 124501 (2002)
4. Mitchell, J.L.: The nature of large-scale turbulence in the jovian atmosphere. Ph.D. Thesis. Jet Propulsion Laboratory, California Institute of Technology (1982)
5. Mitchell, J.L., Maxworthy, T.: Large-scale turbulence in the jovian atmosphere. In Turbulence Predictability in Geophisical Fluid Dynamics, pp. 226-240. Tipografia Compositori, Bologna, Italy (1985)
6. Harrington, J., Dowling, T.E., Baron, R.L.: Jupiter's Tropospheric Thermal Emission: I. Observations and Techniques, Icarus **124**, 22 - 31 (1996a)
7. Harrington, J., Dowling, T.E., Baron, R.L.: Jupiter's Tropospheric Thermal Emission: II. Power Analysis and Wave Search, Icarus **124**, 32 - 44 (1996b)