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Dynamics of Jupiter's equatorial region at cloud top level from Cassini and HST images

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ABSTRACT

We present a study of the equatorial region of Jupiter, between latitudes ~15°S and ~15°N, based on Cassini ISS images obtained during the Jupiter flyby at the end of 2000, and HST images acquired in May and July 2008. We examine the structure of the zonal wind profile and report the detection of significant longitudinal variations in the intensity of the 6°N eastward jet, up to 60 m s^{-1} in Cassini and HST observations. These longitudinal variations are, in the HST case, associated with different cloud morphology. Photometric and radiative transfer analysis of the cloud features used as tracers in HST images show that at most there is only a small height difference, no larger than ~0.5–1 scale heights, between the slow (~100 m s^{-1}) and fast (~150 m s^{-1}) moving features. This suggests that speed variability at 6°N is not dominated by vertical wind shears but instead we propose that Rossby wave activity is the responsible for the zonal variability. Removing this variability, we find that Jupiter's equatorial jet is actually symmetric relative to equator with two peaks of ~140–150 m s^{-1} located at latitudes 6°N and 6°S and at a similar pressure level. We also study the local dynamics of particular equatorial features such as several dark projections associated with 5 μm hot spots and a large, long-lived feature called the White Spot (WS) located at 6°S. Convergent flow at the dark projections appears to be a characteristic which depends on the particular morphology and has only been detected in some cases. The internal flow field in the White Spot indicates that it is a weakly rotating quasi-equatorial anticyclone relative to the ambient meridionally sheared flow.

1. Introduction

Understanding the formation of the jet stream system which dominates the global circulation of gas giants Jupiter and Saturn represents a challenge for the geophysical sciences. In particular, the equatorial circulation is dominated by a broad and intense eastward equatorial jet, about 30° wide and 140 m s^{-1} in Jupiter, and ~60° wide and 400 m s^{-1} in Saturn whose formation mechanism is a subject of debate (Ingersoll et al., 2004; Vasavada and Showman, 2005; del Genio et al., 2009). In Jupiter, the equatorial zonal winds measured in a variety of high-resolution datasets show an asymmetric equatorial jet with a strong peak at 6°S ranging from 140 to 150 m s^{-1}, and a slower jet (~100–110 m s^{-1}) at 6°N (Limaye, 1986; Simon-Miller, 1999; García-Melendo and Sánchez-Lavega, 2001; Porco et al., 2003). This asymmetry poses an additional difficulty to numerical models either based in deep convection or in a shallow layer fed by solar radiation. For instance, when deep convective activity in fast rotating giant planets is simulated, state of the art models (Jones and Kuzanyan, 2009; Kaspi et al., 2009) are able to reproduce strong symmetric equatorial jets, some of them resembling Jupiter's and Saturn's equatorial circulations.

Centering on the Jupiter's case, several researchers have found signs of variability in the northern branch of the equatorial jet. A few, rapidly moving features at 6°N were found by Beebe et al. (1996) on HST observations. In 2006, Li et al. reported the detection of fast individual tracers in ISS Cassini images with velocities up to 170 m s^{-1}. In this latter case the authors interpreted them as small cloud formations at deep levels, probably at a depth of ~3 bars, moving at a faster speed due to the effect of increasing winds in depth produced by a vertical shear, in accordance with the Galileo Doppler Wind Experiment (Galileo DWE; Atkinson et al., 1998).

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More recently, Asay-Davis et al. (2010) reported that the 6°N peak had increased its intensity to $\sim$140 m s^{-1} in HST images. Fig. 1 summarizes the measured profiles as published in the literature which made use of different spacecraft data, navigation and analysis techniques chosen as a representative sample of different epochs (e.g. Limaye, 1986; García-Melendo and Sánchez-Lavega, 2001; Porco et al., 2004), including the fast measurements made by Beebe et al. (1996), Li et al. (2006a), and Asay-Davis et al. (2010). Such precedents motivated us to revisit high spatial resolution Cassini data to study the equatorial zonal wind profile and compare it with more recent wind measurements obtained from HST images. For the sake of consistency it is important to study Jupiter's equatorial jet dynamics using the same analysis tools on different data sets spanning a long time interval. This can be done combining Cassini 2000 flyby data with the long-term coverage available at the HST imaging archive.

The dominant morphology around 6°N shows chains of bluish large dark spots (projections) sometimes coupled with bright plumes which move at an average velocity of 100 m s^{-1} (Rogers, 1995). These dark spots correspond to the "hot spots" or high thermal emission regions appearing bright in the thermal infrared at 5 μm (Westphal, 1969; Orton et al., 1996). Results from the Galileo Probe and Orbiter show that dark spots in visible images are depleted of clouds and condensable species (Niemann et al., 1998; Wong et al., 2004; Ross-Serote et al., 1998), forming a transparent window to the thermal radiation coming from the 4 bar altitude level. Several authors interpret dark spots as downdraft regions (Vasavada et al., 1998; Showman and Ingersoll, 1998; Baker and Schubert, 1998; Hueso et al., 1999) coupled to a planetary scale Rossby wave (Allison, 1990; Ortiz et al., 1998; Friedson, 2005). The proposed Rossby wave is trapped around 6°N and may propagate between 40 m s^{-1} and 70 m s^{-1} towards the west, according to non-linear simulations (Showman and Dowling, 2000), hiding the real speed of the jet where it sits. Wave phenomena may also have been detected in Jupiter's stratosphere near the equator (Li et al., 2006b; Simon-Miller et al., 2006, 2007), but it is still unclear if morphology at the North Equatorial Belt (NEB) is the result of wave activity at the visible cloud top level. During the 2000–2008 period, Jupiter's equatorial region presented important morphological changes at cloud level which include, in some occasions for example, a decreasing number of dark spot-plume pairs (Arregi et al., 2006). This represents a good opportunity to study whether zonal wind structure is correlated to morphological changes and wave activity. In this work we explore in detail the longitudinal dependence of the equatorial zonal winds and the cloud top altitude to assess the possible contribution of vertical wind shear to the possible variability. Morphological differences, apparent when comparing Cassini and HST images in different epochs at similar wavelengths, have also motivated us to revisit the dynamics of the dark spots and projections by using a 2D correlation tool to capture motions in image pairs and compare them with those reported in previous works of these regions (Showman and Ingersoll, 1998; Baker and Schubert, 1998; Vasavada et al., 1998; Hueso et al., 1999). Furthermore, we have extended our analysis to the less studied region at the Southern branch of the equatorial jet at 6°S, including a feature known as the "White Spot" (WS), in order to compare it to a similar feature observed in the Voyager era (Smith et al., 1979; Maxworthy, 1985; Sánchez-Lavega and Rodrigo, 1985). All this gives us a long term, unified vision of the dynamics of Jupiter's equatorial region.

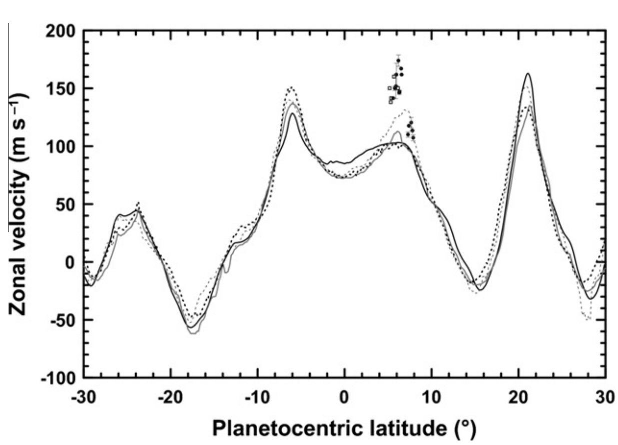

Fig. 1. Nominal wind profiles retrieved by several authors: solid black line, Limaye (1986); solid grey line, Porco et al. (2003); dotted line García-Melendo and Sánchez-Lavega (2001). Open squares are sightings of fast tracers peaking around 150 m s^{-1} by Beebe et al. (1996), and solid dots up to 170 m s−1 were reported by Li et al. (2006a). The grey dashed line is the HST 9–10 May 2008 zonal profile reported by Asay-Davis et al. (2010).

2. Observations

2.1. Image datasets

We used three different sets of images covering an 8-year time span. Our first collection is composed of images taken by the Cassini mission during its Jupiter flyby between the end of 2000 and the first month of 2001. Cassini images were obtained by the Cassini Imaging Science Subsystem (ISS) Narrow Angle Camera. We analysed observations acquired at the weak (MT1, centred at 603 nm), intermediate (MT2, 727 nm) and strong (MT3, 890 nm) methane absorption band filters, their adjacent continuum wavelengths (CB1 – 603 nm; CB2 – 750 nm; CB3 – 938 nm), and the broadband BL1 filter centred at 451 nm (Porco et al., 2004). The selected set of Cassini data is listed in Table 1 and can be divided in different subsets. Zonal winds were measured in images obtained from December 11 to December 13, 2000, about 20 days before the Cassini spacecraft reached its perijove, resulting in an almost constant $\sim$120 km pixel^{-1} resolution. A second subset at higher resolution of $\sim$60 km pixel^{-1} was selected from December 29, 2000 to January 5, 2001 to study the dynamics of dark spots-projections. The global evolution of the White Spot, hereafter denominated WS1 to distinguish it from a similar White Spot observed in 2007, and the dynamics of the 6°S jet were studied on Cassini ISS images spanning from October 31, 2000 to December 13, 2000.

The second image set, used to study the long-term behaviour of the WS1, includes a group of images taken with the 1 m planetary dedicated telescope at Pic du Midi (Paris-Meudon Observatory) in April, May 1999, and December 2001, and images from the International Outer Planets Watch (IOPW) database (Hueso et al., 2010a) from June 1999 to December 2001. The IOPW is a network of amateur observers who monitor Jupiter at low resolution ($\sim$1000 km pixel^{-1}) but good enough to study the long term evolution of the planet's morphology. Hubble Space Telescope (HST) images acquired in August and October 1999 with the F953N filter were also used to study WS1 morphology.

Jupiter's equatorial zonal winds were measured again from a third set composed by HST archive images obtained in 2008 between the 9th and 10th of May (P.I.I. de Pater), and during the 8th of July (P.I.A. Simon-Miller). These images are listed in Table 2. We retrieved zonal winds at four different System III longitudes of the central meridian from the 9–10 May HST subset in the F673N (673 nm) and F410M (409 nm) filters. 8th of July HST images acquired with filters F390N (390 nm), F410M (409 nm), F437N (437 nm), F469N (469 nm), and F673N (673 nm), covered only a limited longitudinal section of the planet (System III central meridian longitudes from 110° to 130°).