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A planetary-scale disturbance in a long living three vortex coupled system in Saturn's atmosphere

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ABSTRACT

The zonal wind profile of Saturn has a unique structure at 60°N with a double-peaked jet that reaches maximum zonal velocities close to 100 ms^{-1}. In this region, a singular group of vortices consisting of a cyclone surrounded by two anticyclones was active since 2012 until the time of this report. Our observation demonstrates that vortices in Saturn can be long-lived. The three-vortex system drifts at $u = 69.0 \pm 1.6$ ms^{-1}, similar to the speed of the local wind. Local motions reveal that the relative vorticity of the vortices comprising the system is ~2–3 times the ambient zonal vorticity. In May 2015, a disturbance developed at the location of the triple vortex system, and expanded eastwards covering in two months a third of the latitudinal circle, but leaving the vortices essentially unchanged. At the time of the onset of the disturbance, a fourth vortex was present at 55°N, south of the three vortices and the evolution of the disturbance proved to be linked to the motion of this vortex. Measurements of local motions of the disturbed region show that cloud features moved essentially at the local wind speeds, suggesting that the disturbance consisted of passively advecting clouds generated by the interaction of the triple vortex system with the fourth vortex to the south. Nonlinear simulations are able to reproduce the stability and longevity of the triple vortex system under low vertical wind shear and high static stability in the upper troposphere of Saturn.

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1. Introduction

Vortices in Saturn are difficult to see from ground-based telescopic imaging because of their relatively small size and low albedo contrast. Prior to Cassini spacecraft's arrival to the planet in 2004, most Saturnian vortices were detected either during the Voyager flybys in 1980–81 (Smith et al., 1980, 1981; Ingersoll et al., 1984; Sánchez-Lavega et al., 1993; Sanchez-Lavega et al., 1997; García-Melendo and Sánchez-Lavega, 2001), or in observations taken by the Hubble Space Telescope (HST) (Sánchez-Lavega et al., 2003, 2004). Since 2004, Cassini has provided a more continuous coverage of the atmospheric features of the planet. Several studies have analyzed the size, morphology, lifetime and latitudinal distribution of different vortices observed by the Imaging Science Subsystem (ISS) (Vasavada et al., 2006; Del Genio et al., 2009; del Río-Gaztelurrutia et al., 2010; Sayanagi et al., 2013, 2014; Trammell et al., 2014) and by the Visual and Infrared Mapping Spectrometer (VIMS) instrument (Baines et al., 2009; Dyudina et al., 2007). These analyses provide important clues on the large-scale dynamics of Saturn's atmosphere (Trammell et al., 2014; Trammell et al., 2016). In particular, numerical modeling of these systems shows the atmospheric conditions at deep levels of the weather layer under which the Saturn vortices are stable (García-Melendo et al., 2007; del Río-Gaztelurrutia et al., 2010). Thus, the existence and evolution of long-lived vortices are key to understanding the atmospheric conditions beneath the observable upper clouds.

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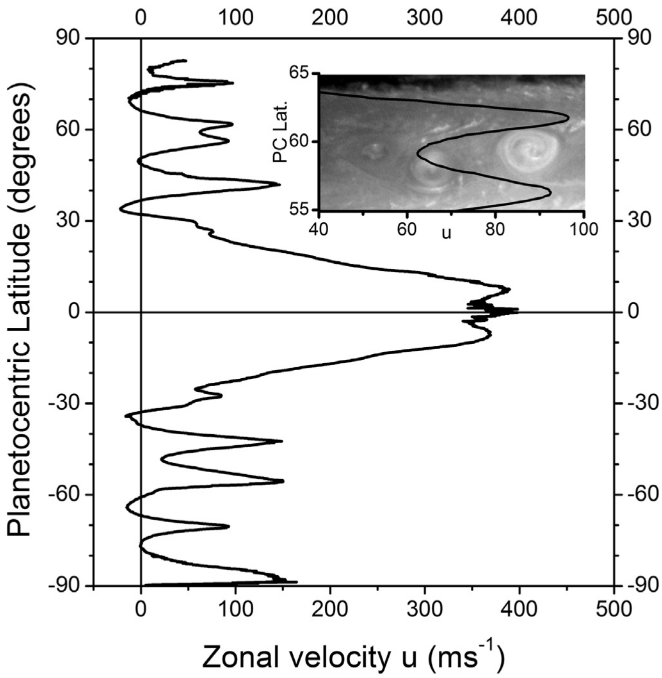

Fig. 1. Zonal wind velocity profile of Saturn. Inset shows the double peak jet between 55° and 65°N, together with a cylindrical projection of the triple vortex system.

The zonal wind profile of Saturn, like that of Jupiter, is approximately symmetric in latitude, with a strong prograde (eastward) equatorial jet and four other eastward jets in the North and South hemispheres. The jet around + 60° planetocentric latitude has a distinct double-peak structure and reaches maximum zonal velocities close to 100 ms^{-1} (Fig. 1). This feature of the jet is stable in time: It was present in 1981, when the Voyagers' flybys allowed measurements of zonal wind with sufficient latitudinal resolution (Sánchez-Lavega et al., 2000) and it was also observed by Cassini (Vasavada et al., 2006; García-Melendo et al., 2011). However, this double-peak structure is not present in any other wind jet either in Saturn or in Jupiter (García-Melendo and Sánchez-Lavega, 2001; Porco et al., 2003).

In Jupiter, cyclonic and anticyclonic vortices tend to form between jet peaks, in regions with low wind velocity and weak meridional vorticity gradient. These Jovian vortices drift at velocities not identical to the local winds (Simon and Beebe 1996; Li et al., 2004; Del Genio et al., 2009; Ingersoll et al., 2004). In Saturn, vortices have been observed drifting zonally at high velocities, and in regions with weak vorticity gradient, suggesting that cyclones and anticyclones tend to form close to the inflection point of the jet curvature ($d^2u/dy^2 = 0$) In the case of Saturn, the precise rotation rate of the planet has not been yet determined (Del Genio et al., 2009) but, as is standard, we adopt System III West longitudes (Archinal et al., 2011) to compute zonal winds. Although a change in the rotation period within the values proposed so far would change the values of zonal velocities, it would not change the meridionally alternating shape of the zonal wind profile (Sánchez-Lavega, 2005) and the values of vorticity. The twin peaks of the 60°N jet mark two distinct dynamical regions, very close in latitude, with similar rather high eastward velocity but with opposite ambient vorticity. Thus, the jet structure in this region of Saturn facilitates the coupling of ovals of opposite vorticity North and South of the local minimum of velocity in the region of the double peak jet.

Trammel et al. (2016) analyzed Saturn's northern hemisphere from 2009 to 2015 and found that, with the exception of the large anticyclone that developed after the Great White Storm of 2010 (Sánchez-Lavega et al., 2012; Sayanagi et al., 2013), vortices had a lifetime of less than a year, and that the number of vortices varied in a significant way in the period of study. In their work, they did not concentrate in a particular region of the hemisphere, and their estimate of the lifetime of the vortices was based on temporal changes in vortex statistics rather than tracking individual vortices.

This work focuses on the region between 55°N and 65°N around the double peaked jet. We briefly describe the temporal evolution of the vortices in that region between 2007 and 2016 and then we focus our analysis on a long-lived system of one cyclone and two anticyclones that started interacting around 2012. This coupled system is still visible in images of Saturn at the end of 2016 and thus has survived for at least four years. In what follows, we shall refer to the triple vortex system as Anticyclone-Cyclone-Anticyclone abbreviated as ACA system (Fig. 1, inset). In May 2015, a large disturbance developed at the location of ACA system, prominent enough to be observable in ground-based images captured with small telescopes. This disturbance expanded quickly in longitude following the zonal winds and covered approximately a third of the longitudinal circle. The disturbance faded by July 2015 but the ACA system survived and remained essentially unchanged, illustrating the remarkable stability of the system.

Other well-known cases of anticyclone-cyclone-anticyclone systems occurred on Jupiter during the mergers of White Ovals at 33°S latitude that eventually became the present-day Oval BA (Sánchez-Lavega et al., 2001; Hueso et al., 2009). These ovals, nicknamed BC, DE and FA, formed around 1940 as long elongated white sectors in a Jovian band and then shrunk progressively until they reached about 10,000 km in the east-west direction (see e.g. Rogers, 1995). During their lifetime, these ovals wandered in longitude, approaching and separating as if they repelled each other. In 1998, BC and DE approached very closely; initially, a cyclonic cell between them impeded their approach, forming a compact anticyclone-cyclone-anticyclone system. However, subsequent interaction of the northern edge of the three vortex system with the southern edge of Jupiter's Great Red Spot (GRS) displaced the cyclone meridionally and led to the merger of BC and DE, forming BE (Sánchez-Lavega et al., 1999). One year later, a merger between BE and FA followed a similar sequence of events and formed the anticyclone BA (Sánchez-Lavega et al., 2001), still present in the atmosphere of Jupiter (Simon et al., 2015). The longevity of the vortices and their sudden merger was explained by Youssef and Marcus (2003), while the cause of an intriguing and lasting change in color from white to red has been addressed by, e.g., de Pater et al., 2010; Wong et al., 2011; Marcus et al., 2013.

The objective of the research presented in this paper is to conduct a detailed study of Saturn's ACA system and the disturbance that developed at the location of the system in May 2015, in an attempt to establish its origin. In Section 2, we describe our data and methods of analysis. In Section 3, we establish the lifetime and long time evolution of the ACA system and in Section 4, we present its morphology and local motions. Section 5 is dedicated to an analysis of the perturbation that developed in May 2015. In Section 6, we include some numerical analyses of the stability of vortices in the double peaked jet. In Section 7, we summarize our conclusions.

2. Data and methods

The images we analyze in this work can be classified in three sets. A first set comprises images taken by the ISS instrument onboard Cassini (Porco et al., 2004) using both the Wide Angle Camera (WAC) and the Narrow Angle Camera (NAC). Those images have a wide range of spatial resolutions and are mostly captured at filters covering methane absorption bands MT2, MT3 and their

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