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An analysis of the stability of Saturn's Hexagon jet and its counterpart in the South

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Abstract

In this study we use the wind and vorticity gradient profiles from A. Antuñano et al. [1] to study the stability of Saturn's Hexagon jet and its counterpart in the south by analyzing the barotropic instability of quasi-geostrophic jets. We also present the growth rates of the barotropic instabilities for both jets.

1. Introduction

Images obtained by the Voyager I and II flybys in 1980-1981 showed a hexagonal feature at 75ºN planetocentric latitude with an embedded fast eastward jet reaching a peak velocity of 120 ms^{-1} [4]. This same feature was again re-observed by ground based telescopes and by the Hubble Space Telescope (HST) in 1990-1995 [5-6]. After the arrival of the Cassini Mission to Saturn in 2004, the hexagon was again observed, first in the infrared with VIMS [2] and then, with the ISS after the equinox in 2009. The hexagon has remained stationary in System III for the last 30 years [5-7]. During 1997 and 2002 the South of Saturn's was captured by the HST showing a strong eastward jet at similar latitudes [6]. However, these images did not show any hexagonal feature in the south.

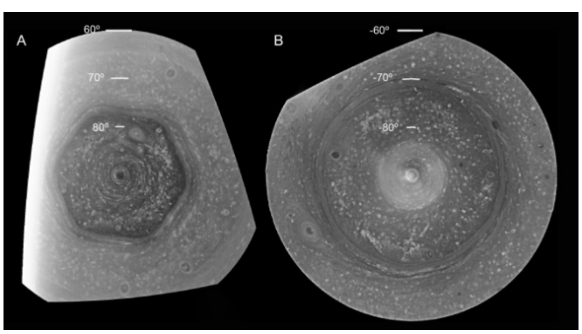

Figure 1 Cassini ISS CB2 images of Saturn's poles: A) North polar region on 14 June 2013. B) South polar region on December 2008. [1]

Antuñano et al. [1] compared the dynamics of both polar regions, showing that the wind and vorticity profiles of both jets (hexagon and its counterpart) are similar, except for the 5º difference in latitude of the jets, and that the Rayleigh-Kuo instability is satisfied in both jets.

As the violation of Rayleigh-Kuo stability criterion does not guarantee the growth of an instability, we analyze the linear barotropic stability of the Hexagon jet and its equivalent using the data from Antuñano et al. [1]. We also compute the growth rates of the barotropic instability for different Rossby deformation radius L_D and wave numbers m.

2. Analysis

The vorticity equation for a barotropic and inviscid flow is

$$\frac{D(q'+f)}{Dt} = 0 \qquad (1)$$

Where $q' = \nabla^2\psi' - \frac{\pi^2}{L_D^2}\psi'$ is the shallow water quasi-geostrophic potential vorticity, ψ' is the eddy stream function, L_D is the Rossby deformation radius and f is the Coriolis parameter. We seek for a solution of the type

$$\psi' = \Psi'(y)e^{ik(x-ct)} \qquad (2)$$

where $k = m / r\cos(\varphi)$ is the wave number, r is Saturn's radius at that latitude, φ is the mean latitude [3] and c is the phase velocity and may be complex. Substituting this solution in (1) and after derivation we obtain the vorticity equation.

$$u(y)\left[\partial_{yy} - k^2 - \frac{\pi^2}{L_D^2}\right]\Psi + \left[\beta - u_{yy}\right]\Psi = c\left[\partial_{yy} - k^2 - \frac{\pi^2}{L_D^2}\right]\Psi \qquad (3)$$

We have solved this eigenvalue equation for different values of L_D and k, with the zonal velocity and vorticity gradient profiles from Antuñano et al. [1], using the finite difference method and $\partial\Psi'/\partial y = 0$ at 5000km north and south from the peak as boundary conditions. The aim of this study is to obtain the growth rates (kc_i) of a barotropic disturbance, thus, we seek for the eigenvalue (phase speed) with the largest imaginary part for each L_D and k, which corresponds to the most rapidly growing mode.

3. Results

Our barotropic instability analysis shows that the faster growing mode for a Rossby deformation radius of L_D=3000km, is m=5-6 for both the northern and southern hemisphere. One could be tempted to assume that the hexagon in the north, mode 6, is related to this instability maximum. However, no hexagonal feature is observed in the south and thus, this analysis does not shed light on the hexagon absence in the South.

The growth rates of the instability for different values of L_D are shown in Figure 1 and Figure 2 for the North and South respectively. As mentioned before, in both cases we find that the maximum growth rate (kc_i) peaks at values of m that decrease with decreasing Rossby deformation radius.

Future work includes 3D numerical models of the jets instabilities in both North and South hemispheres.

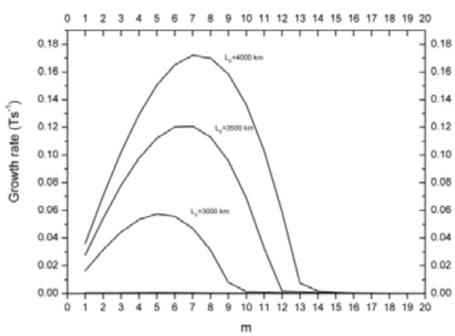

Figure 2 Growth rates of the barotropic instability for different L_D and m for the north.

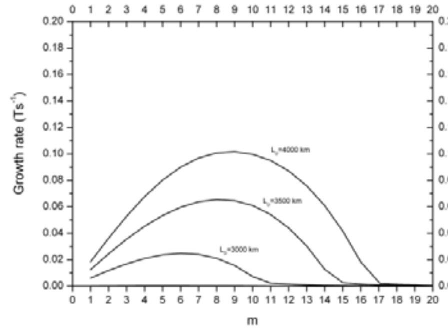

Figure 3 Growth rates of the barotropic instability for different L_D and m for the south.

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