# Dynamics of Saturn's South Polar Vortex

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Most planets with an atmosphere have large vortices. Here, we present observations of Saturn's south polar vortex (SPV) showing that it has a unique combination of properties, resembling some vortices in some respects but not any other vortex in all respects.

Our data are from observations over 3 hours by Cassini on 11 October 2006. A false-color image of cloud heights (Fig. 1A) shows a dark, red, central eye, indicating a nearly cloud-free upper atmosphere above lower, tropospheric clouds. The blue-green ring outside the eye indicates high clouds and haze, which is consistent with uplifted air. The eye has two concentric boundaries.

The eye wall clouds cast shadows that followed the sun in a counterclockwise direction as the planet turned (Fig. 1, B to D). From the shadow lengths, we estimate that the outer wall is 40 ± 20 km high and that the inner wall is 70 ± 30 km high, about twice the pressure scale height of Saturn's atmosphere. The eye wall clouds seem to extend up to the tropopause, which is at the ~100 mbar level (*1*).

We tracked the motion of individual cloud features (*2*). The peak zonal velocity, $\overline{u}$, was $150 \pm 20$ m s$^{-1}$ near the outer eye wall. Absolute vorticity consists of two parts: a part ζ due to motion relative to the planet and a part *f* due to the planet's rotation (*3*). Up to latitude –85°, the measured $\overline{u}$ increased slightly faster than a constant absolute vorticity profile. Poleward of –85°, $\overline{u}$ increased more slowly. Constant absolute vorticity is consistent with horizontal stirring by eddies. The angular momentum in Saturn's SPV decreased toward its center. We observed no poleward or equatorward mean motion.

The relative vorticity, ζ, estimated from the measured $\overline{u}$ is close to zero outside the outer eye wall. The puffy red clouds in Fig. 1A are anticyclones (*2*), with a vorticity of $-1 \times 10^{-4} \pm 1 \times 10^{-4}$ s$^{-1}$, which is ~1/3 the magnitude of the planetary vorticity, *f*, but of opposite sign. This result is consistent with a convective origin because parcels rising from the convective interior should have $\zeta + f = 0$ when they spread out in the upper troposphere (*3*).

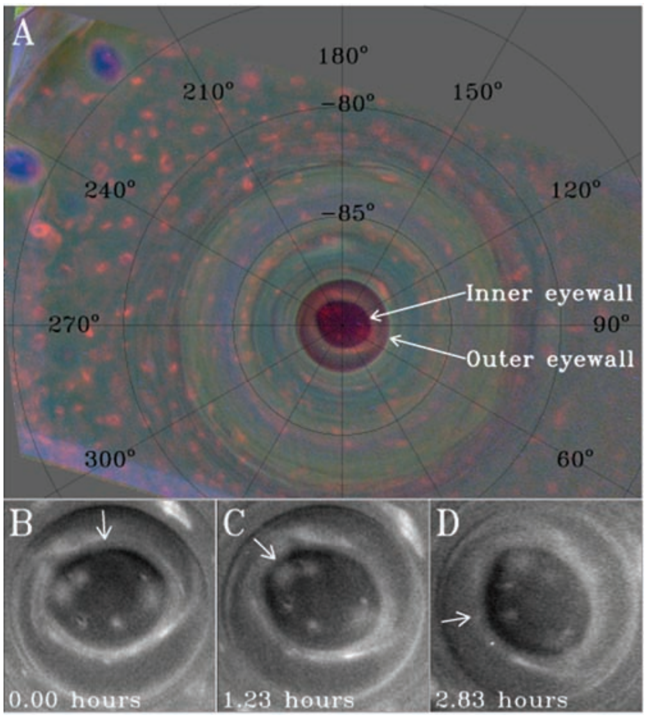


**Fig. 1.** Images of Saturn's south polar clouds taken by the Cassini imaging science subsystem (ISS). The images have been map-projected with use of polar stereographic projection. Latitudes are planetocentric. (**A**) False-color image from light at 889 nm, 727 nm, and 750 nm projected as blue, green, and red, respectively. In the original images, sunlight was attenuated by a factor of *e* (2.71...) at the 80-mbar and 300-mbar levels for light at 889 and 727 nm, respectively. Sunlight passes through to deeper levels for light at 750 nm. Thus clouds below 300 mbar appear red, and high thin clouds appear blue or green (*2*). The eye walls can be seen in all three color planes and thus extend above the 80-mbar surface. (**B** to **D**) Time sequence showing shadows (the dark crescent-shaped areas inside the walls). The first map was taken on 11 October 2006 at 19 hours 42 min. The maps are labeled by the time lapsed since the first map. The white arrow shows the direction of propagation of the incident sunlight.

Cassini Composite Infrared Spectrometer (CIRS) data show that the vortex is anomalously warm, particularly just beneath the tropopause (by 5 K) but also in the stratosphere (by 3 to 4 K) (*1*). The warm central core means that the central low pressure, and with it the cyclonic circulation, should weaken with altitude if the flow is balanced. However, a movie of images like Fig. 1A shows no weakening (*2*).

The failure of the wind to weaken means that the centrifugal force at high altitudes is not completely balanced by the inward pressure force. This unbalanced force could drive an outward flow.

The SPV is a warm-core feature with cyclonic (clockwise) relative vorticity. Like a terrestrial hurricane, it has an eye, eye wall clouds, and multiple convective clouds outside the eye. However, hurricanes exist in the tropics, are not stationary, and derive their energy from interaction with the underlying ocean. The SPV is different from Jupiter's Great Red Spot and white ovals, which are anticyclones with uniformly high clouds at their centers (*4*). Observations do not cover the poles of Jupiter well enough to detect a possible vortex there.

In some respects, the SPV resembles the polar vortices on Venus, which are cyclonic and have warm features at the poles, although the Venus features are dipole-shaped, have cold collars, and are not surrounded by convective clouds (*5*). Similar to Saturn's atmosphere, Neptune's atmosphere is warm poleward of 70° at altitudes near 100 mbar (*6*). The SPV is different from Earth's Arctic and Antarctic polar vortices, which are cold-core features that are not associated with clouds and/or convection.

### References and Notes

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### Supporting Online Material

www.sciencemag.org/cgi/content/full/319/5871/1801/DC1
Materials and Methods
Fig. S1
References
Movie S1

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