GEOPHYSICAL RESEARCH LETTERS, VOL. 28, NO. 23, PAGES 4453-4456, DECEMBER 1, 2001

Titan's Smile and Collar : HST Observations of Seasonal Change 1994-2000

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Abstract. We observed Titan with the Hubble Space Telescope in November 2000 using the Wide-Field Planetary Camera (WFPC2) and the Space Telescope Imaging Spectrograph (STIS). Considerable change is apparent between these and observations in 1994-1997 : in particular the North-South asymmetry at visible wavelengths has reversed, with the southern hemisphere brighter, as during the Voyager epoch. The asymmetry shows considerable variation with wavelength in the near-infrared : in the 889nm methane band the asymmetry (which formerly resembled a 'smile') has reversed in the last 3 years, while at 953nm the southern limb is still bright. A south polar collar, dark at ultraviolet wavelengths, is apparent some five years after equinox.

1. Introduction

The visible appearance of Saturn's moon Titan in images from the Voyager encounters in 1980 and 1981 was dominated by the interhemispheric difference in albedo, often termed the North-South Asymmetry (NSA) : the northern hemisphere was about 20% darker at blue and green wavelengths [Smith et al. 1981, 1982]. Another feature was a dark polar hood, above latitudes of about 65°N.

Imaging by the Hubble Space Telescope in 1990 observed the NSA to have reversed [Caldwell et al, 1992] and noted that the asymmetry in the near-IR (specifically at 889nm) was of the opposite sign, with the southern hemisphere brighter. The asymmetry was at its peak close to equinox in 1995 [Lorenz et al. 1997] and has since begun to decline [Lorenz et al. 1999].

Here we report new data from HST that confirms that the seasonal cycle of the asymmetry involves a rapid change after equinox : a purely symmetric sinusoidal cycle with a period of 29.5 years (equal to Saturn's orbital period) considered in early work [Sromovsky et al., 1981] would decay from a peak at equinox to zero 7.5 years later - we find it has reversed after only 5, although not at all wavelengths. The new imaging data also shows a south polar collar.

Paper number 2001GL013728.
0094-8276/01/2001GL013728$05.00

2. Observations

The year 2000 WFPC2 data were taken during 2 visits, beginning November 16 02:38 UT and November 23 16:45 UT. Both observations were taken at phase angles of 0.5°, although with opposite sign. The subsolar and subtelescope latitudes are about 23.5°S, considerably further south than the last WFPC2 observations in 1997 (10°S) [Lorenz et al. 1999]. Expressed using the climatological convention (see e.g. [Tokano et al. 1999]) the solar longitude L_s=240° for the present observations : northern winter solstice will occur at L_s=270° in October 2002.

WFPC2 images were taken with a selection of filters used previously including F255W, F336W, FQCH4N-D (889nm), F953N and F1042M. Image cubes were also taken with the Space Telescope Imaging Spectrograph (STIS) ; we substitute STIS data for images previously taken with the WFPC2 filters F547M, F673N, FQCH4N-B (619nm).

3. Disk Appearance

As has been noted before (e.g. [Lorenz et al., 1999], Titan's disk at 336nm is quite flat, with little limb darkening, and is perceptably larger in diameter than at green and red wavelengths. There is no obvious NSA (even at its peak in 1994, NSA contrast was only 5%.). The most obvious feature in the 2000 image is a darkening southward of about 60S.

At 889nm in the strong methane band, Titan's atmosphere is absorbing and the only brightness near disk center is due to haze at altitudes above about 60km. This wavelength region sounds only down to about 200km at the limb and Titan's disk is limb-brightened at this wavelength as the haze high in the atmosphere is bright against the dark methane-rich lower atmosphere. Previous observations have shown a 'smile', with Titan's southern hemisphere notably (by ∼40%) brighter than the north. The smile has now disappeared, with Titan's limb being nearly uniformly bright with perhaps a modest enhancement within ∼30° of the equator.

The 953nm image in a methane window sounds much deeper in Titan's atmosphere and is sensitive to surface albedo [Smith et al, 1996]. Figure 1 shows the 889nm and 953nm images, with 1995 images for comparison. It is notable in both 953nm images (and in 950nm image in 1997 in [Meier et al. 2000]) that the southern limb is bright,

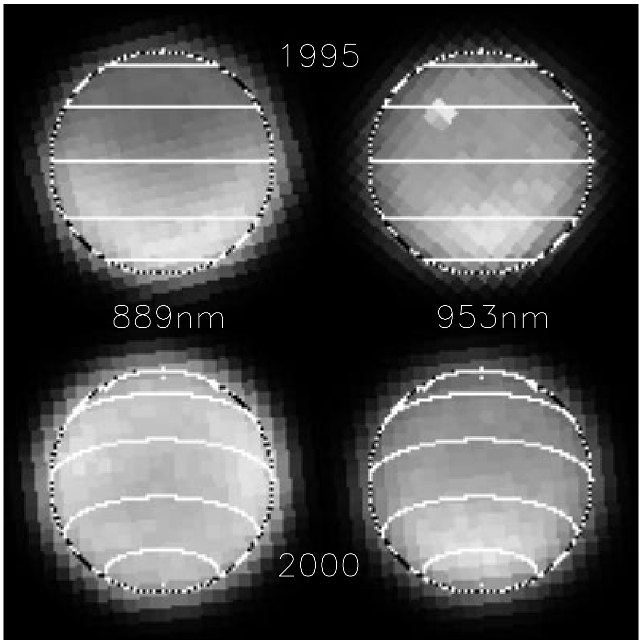

Figure 1. Narrowband WFPC2 images in methane band at 889nm and window at 953nm in 1995 and 2000 : the asymmetry has reversed at 889nm, while the south remains far brighter than the north at 953nm. Lines of latitude at 30° intervals are superimposed. The bright spot in the 1995 953nm image is a cosmic ray hit.

suggesting that while the haze opacity at high altitudes (as shown by the 336nm and 889nm images) does not have a dramatic variation with latitude, the opacity deeper in the atmosphere is much higher in the south (poleward of about 40°) than the north. The brightness contrast of ∼20% is probably too high to be indicative of a surface albedo difference, while the fact that the same enhancement is not seen at 889nm suggests the opacity is in the troposphere. This may be related to preferential 'spring pole' condensation of ethane and methane [Samuelson and Mayo 1997] triggered by higher, earlier C_4N_2 sedimentation (see section 5).

East-West cuts of our 889 and 953nm images indicate that both limbs are equally bright at 889nm at LCM 90, to within ∼1%. At LCM 270, when the subsolar point was about 0.5° degree to the west of the subtelescope point, the W (evening) limb appears to be about 3% brighter. Thus we find no evidence for a a 'dawn brightening' reported by [Coustenis et al. 2001. in press], although it may be noted that we are observing at rather shorter wavelengths where the effect may be muted. Our observation is consistent with phase angle being responsible for the effect, as suggested by [Meier et al. 2000].

At 255nm wavelength (not shown) there are no obvious features. It should be noted however that the signal to noise at this very short wavelength is quite low, and this observation uses the WF4 camera on WFPC2, so has a pixel scale 2x coarser than the planetary camera's 0.0454 arcsec/pixel. However, gross features such as a strong north-south asymmetry can be excluded by the data.

4. North-South Asymmetry

The NSA changes are obvious by eye in figure 1, but can be quantitatively determined by fitting a Minnaert disk to each hemisphere (i.e. brightness $I=I_0\mu^k\mu_0^{k-1}$ where μ,μ_0 are the cosines of the emission and solar zenith angles, and k a limb-darkening exponent. I_0 is the normalized center brightness, and the North:South albedo ratio is the ratio of I_0 values for the two hemispheres. The results of this fitting procedure (See e.g. [Lorenz et al., 1999]) are shown in figure 2. STIS images (i.e. co-added slices of the image cubes) were fit in the same way. The STIS data at 889nm and 953nm are in excellent agreement with the WFPC2 images.

The NSA at 550nm (green) has reversed since 1997 - indeed the rate of change has slightly accelerated, as at 889nm. Both of these wavelengths probe only high altitudes, and thus the high-altitude haze (dark at visible wavelengths, bright in the near-IR, compared to the deeper atmosphere below) now has a higher number density in the north. This is consistent with the model in [Lorenz et al, 1999] where meridional circulation (similar in flow, if not in cause, to thermally-direct winds) causes haze to flee to the winter hemisphere. However, the fact that the asymmetry has not reversed at wavelengths that probe deeper in the atmosphere (e.g. 600-700nm, and windows at 820nm and 940nm) suggests that the seasonal cycle has an altitude-dependent phase lag : the behaviour of the atmosphere is

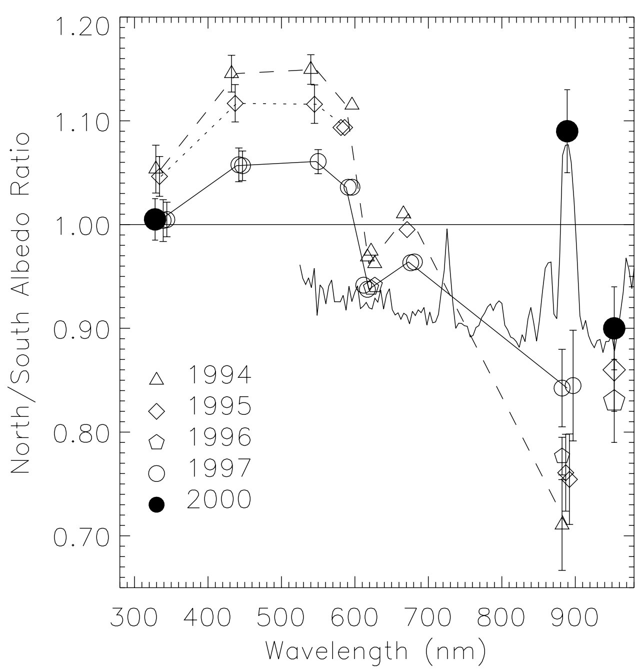

Figure 2. North:South Albedo ratio in November 2000 from WFPC2 images at 336, 889 and 953nm (filled symbols) and STIS image cubes binned into 128 wavelengths (line). The North:South albedo ratio shows a generally linear trend with wavelength, from about 0.95 at 500nm to 0.87 at 1000nm. However, sharp spikes are evident in the 730nm and 889nm methane bands. Results from WFPC2 and STIS agree well at 889nm and 953nm. The data are compared with ratios (open symbols) measured from WFPC2 images in 1994-1997 by Lorenz et al. (1999), supplemented by additional images at 953nm which were not previously analyzed. Striking changes are apparent - the asymmetry at green and yellow wavelengths has reversed in the last 3 years, roughly in line with expectations. The asymmetry (in the opposite sense) at 953nm has decreased slightly, yet has made a dramatic reversal at 889nm.

complex and requires simulation with sophisticated models (e.g. [Tokano et al, 1999]).

STIS data obtained in 1997 covers a wider wavelength range but did not include full image cubes, only a north-south cut. A crude wavelength-resolved measure of the NSA can be derived by comparing the brightness ratio of points a fixed fraction of the disk north and south of center. This is shown in figure 3 : this is not the same measure as the 'classic' NSA, in the sense that different limb-darkening at different wavelengths influences the result, as does the changing geometry from year-to-year. An intensive study with a radiative transfer model (beyond the scope of this paper) will be required to fully exploit these data.

5. Polar Hood

Titan's obliquity of some 27° leads to a long polar night. A number of compounds such as C_4N_2 which are readily destroyed by photolysis may therefore build up [Yung, 1987]; in the low temperatures they may condense in that shadowed region poleward of 63° latitude (the situation is somewhat analogous to the 'ozone hole' phenomenon on Earth.) [Samuelson et al. 1997] have observed C_4N_2 ice in this region, consistent with this idea. This is the likely cause for the polar hood seen by Voyager 1, which resembled a ring or band when viewed 9 months later by Voyager 2 : the feature, most apparent in blue and violet images, is invisible at red wavelengths.

Some hints of the southern equivalent of the feature were noted in [Lorenz et al. 1999], although since the sub-telescope latitude was only 10°S, the darkening was within a pixel or two of the limb and so was hard to see except as a 'flat bottom' to 336nm and 439nm images in 1995 and 1997 (a hood could not be discriminated from a ring, although analogy with two seasons previously suggests that in 1995 the feature may have resembled a hood.)

The year 2000 image at 336nm (figure 4) with a better aspect of the southern polar regions does show a weak dark feature : further enhancement shows this to be a ring at around 60° latitude, rather like the ring seen by Voyager 2. Models (see [Lorenz et al. 1999] show that at least some of the material responsible for this feature must be at altitudes of above 150km. It is striking that this feature persists some six or so years after these latitudes have been exposed to sunlight.

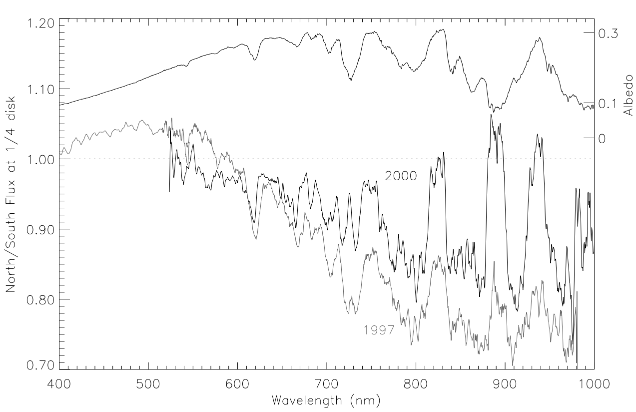

Figure 3. Comparison of a North/South brightness measure (flux from pixel 0.22 arcsec north of the center of the disk divided by that 0.22 arcsec south of center) recorded by STIS in 1997 with that in 2000 - lower and upper curves respectively. Note the considerable wavelength structure: in this crude measure the North/South ratio is greater than one at both 889 and 953nm - in window and band. Disk-integrated albedo spectrum from Karkoschka (1995) is shown at top to aid in identification of methane bands and windows.

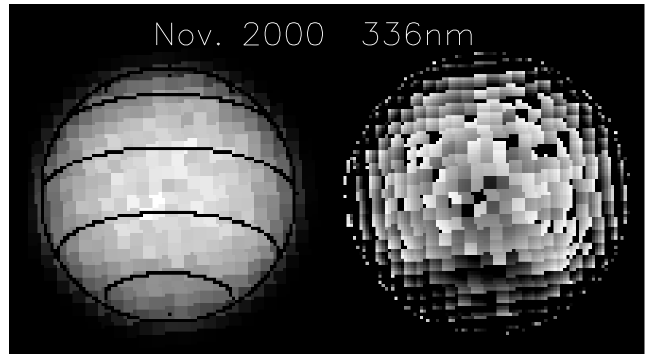

Figure 4. 336nm image (left) shown with intensity cubed to increase contrast, with latitude lines superimposed. A faint darkening can be seen at the south limb. Extreme contrast enhancement (right) by subtracting a model image shows the southern polar feature to be a ring.

6. Conclusions

Our data show two processes at work - the northward migration of high altitude haze, and processes related to high-latitude condensation around the south pole. A surprising result is the observation of the dark UV polar hood, some 5 years after equinox. Although it apparently builds up during the polar night, it is not immediately destroyed in spring.

The NSA has evolved rapidly between 1997 and 2000 in a manner consistent with the change from 1995 to 1997, also consistent with a model wherein meridional motions akin to a thermally-direct pole-to-pole Hadley cell (but probably involving a rather more complicated arrangement of meridional flows) transport high-altitude haze from the spring/summer hemisphere to the autumn/winter one. The phase of the NSA cycle, however, is strongly wavelength-dependent, since deeper altitudes respond more slowly. The asymmetry at high altitudes probed by blue and methane-absorbed light has already reversed.

The enhanced tropospheric haze opacity southward of 45°S may well be connected with the formation and more particularly, decay, of the polar hood. As the condensed species making the dark haze sediment out of the atmosphere, they act as condensation nuclei for ethane and methane at deeper levels. If this material sediments out in the next 3 years, Cassini (and earth-based observers) should have a more clear view of the southern hemisphere of Titan.

Acknowledgments. Support for Proposal numbers 7321 and 8580 were provided by NASA through a grant from the Space Telescope Science Institute, which is operated by the Association of Universities for research in Astronomy, Inc., under NASA contract NAS5-26555. We thank the reviewers for helpful comments.

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(Received July 3, 2001; revised September 10, 2001; accepted September 19, 2001.)