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Density waves in Titan's upper atmosphere

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Abstract

Analysis of the Cassini Ion Neutral Mass Spectrometer data reveals the omnipresence of density waves in various constituents of Titan's neutral upper atmosphere, with quasi-periodical structures clearly visible for N_2, CH_4, $^{29}N_2$ and some of the minor constituents. These structures make an important, though not dominant, contribution to the total density variability as revealed by the data. Compositional variations are commonly seen, manifested as a mass sequence with wave-induced density variance generally increasing with molecular mass. The observed trend of compositional variation with wave activity probably suggests that waves with larger amplitudes tend to have longer periods. Especially, the observed waves with N_2 density variance above 8% are likely to be characterized by wave periods much longer than the Brunt-Väsäilä period of ~1 hr in Titan's upper atmosphere. Our analysis reveals no appreciable vertical trend in wave activity, but does show that waves tend to be more active over the southern hemisphere, at the dayside and near the anti-Saturn direction. The observed hemispheric asymmetry may also be interpreted as a seasonal trend with wave activity increasing towards the equinox. A comparison made between flybys with different plasma environments shows no evidence for the association of wave activity with magnetospheric precipitation.

1. Introduction

Waves are a ubiquitous feature of planetary atmospheres that makes significant contributions to atmospheric circulation, structure and variability (Fritts & Alexander 2003). Over the past several decades, observations of waves cover nearly every Solar System body with a permanent atmosphere, such as Mars (Fritts et al. 2006), Venus (Hinson & Jenkins 1995) and Jupiter (Young et al. 1997). This paper is dedicated to the wave structures in the atmosphere of Titan, the largest satellite of Saturn with a thick atmosphere primarily composed of N_2 and CH_4.

Rich phenomena of atmospheric waves are expected on Titan (Tokano & Neubauer 2002, Strobel 2006). Early evidences came from either the Voyager radio occultation data (Hinson & Tyler 1983, Friedson 1994) or the ground-based observations of stellar occultations (Sicardy et al. 1999, 2006). More recently, the Huygens Atmospheric Structure Instrument (HASI) data revealed wave structures extending from as low as the stratopause to the exobase region (Fulchignoni et al. 2005, Aboudan et al. 2008). Further evidences were provided by the Cassini measurements made with either the Ion Neutral Mass Spectrometer (INMS) (Müller-Wodarg et al. 2006, Cui et al. 2013, Snowden et al. 2013) or the UltraViolet Imaging Spectrograph (UVIS) (Koskinen et al. 2011).

2. Evidences for wave signatures

In this study, a detailed analysis of the density waves in Titan's upper atmosphere is presented, combining the INMS neutral data from 30 Cassini flybys with the satellite. Our analysis reveals the omnipresence of thermospheric waves on Titan, confirming the early results of Müller-Wodarg et al. (2006) and Cui et al. (2013) based on a much smaller INMS sample and including less constituents. The present study is also complementary to the recent work of Snowden et al. (2013), who identified quasi-periodical structures in the temperature profiles of Titan's upper atmosphere, also based on the INMS neutral data.

A thorough inspection of the entire dataset suggests that waves are clearly seen in the density profiles of N_2, CH_4 and $^{29}N_2$. Waves are also clearly seen in the profiles of H_2 (Cui et al. 2013) but this constituent is not investigated here due to the contamination by thruster firings (Cui et al. 2008). For minor neutrals (including various hydrocarbons, nitriles as well as Ar), waves are sometimes visible for C_2H_2 and generally invisible for the other constituents. Dividing the minor neutrals into different mass groups (G1-G4) and working on the co-added count profiles help to decrease the noise level of the data and enhance the manifestation of waves. In this way, waves are usually visible for mass groups G1 and G2, but still invisible for G3 and G4. For the latter two mass groups, it is possible that wave structures are still present but buried within the data noise since the uncertainties in fractional residual density for these mass groups tend to be significantly larger than the typical wave amplitude.

We calculate for each flyby and each constituent or mass group, i, the wave-induced density variance, σ_i, with the contribution from counting statistics removed. We compare the density variances from both inbound and outbound data with the variances from inbound data only. We find that, for mass groups G1 and G2, the former are systematically lower than the latter, which we interpret as a signature of the wall effect. The density variances derived in this paper are used to investigate two specific aspects of the density waves in Titan's upper atmosphere, which we discuss in the following.

3. Compositional variations

We first examine the compositional variations, manifested as different wave-induced density variances for different constituents (Reber et al. 1975). Our analysis reveals a mass sequence with the density variance generally increasing with molecular mass. Specifically, as compared to the N_2 density variance, the CH_4 variance is on average suppressed by ~30%, the $^{29}N_2$ and G1 variances are comparable, but the G2 variance is significantly enhanced.

The data also reveal a large variability in the ratio of density variance, σ_i / σ_{N2}. One interesting feature is that both the mean and the spread of σ_i / σ_{N2} decreases with increasing wave activity. Especially, when the N_2 density variance is above 8%, σ_i / σ_{N2} drops to a relatively low and roughly constant level. This may indicate that waves with large amplitudes tend to have longer periods. Especially, waves with σ_{N2}>8% are probably characterized by wave periods significantly longer than the Brunt-Väsäilä period of ~1 hr in Titan’s upper atmosphere (Cui et al. 2013).

4. Geophysical trends of wave activity

We further examine the geophysical trends of density waves in Titan's upper atmosphere. In general, the overall wave activity shows no vertical trend, implying strong damping that offsets the exponential increase in wave amplitude with decreasing density (Müller-Wodarg et al. 2006). However, the data do reveal some horizontal trends, which we address as follows.

(1) Waves in Titan's upper atmosphere appear to be more active over the southern hemisphere, being maximized as approaching the equator, but decrease drastically into the northern hemisphere. The above feature could be compared to the observations of Titan's thermospheric temperature, also revealing a hemispheric asymmetry with a considerably larger temperature scattering at southern latitudes (Snowden et al. 2013), but the nature of the asymmetry is not well understood.

(2) The data reveal a remarkable zonal trend, in terms of an enhanced level of wave activities as approaching the anti-Saturn direction. Specifically, σ_{N2} at the anti-Saturn side roughly doubles the value at the sub-Saturn side, and the values of σ_{N2} at both the magnetospheric ramside and wakeside lie just between the above two cases.

(3) Waves tend to be more active at the dayside than the nightside. Especially, nearly all of the flybys with σ_{N2} below the mean variance sample Titan's nightside or near-terminator regions at closest approach.

(4) The hemispheric asymmetry described in (1) may also reflect a seasonal trend since earlier Titan flybys preferentially sample the northern hemisphere and later ones preferentially sample the southern hemisphere instead. This implies that the wave activity may tend to increase with time towards the equinox.

Finally, we also compare the N_2 density variances obtained for different conditions of the ambient plasma based on the classification schemes of Rymer et al. (2009), Németh et al. (2011) and Garnier et al. (2010). However, we do not find any evidences for the association of wave activity with magnetospheric charged particle precipitation.

5. Discussions

Considerable variability in Titan's upper atmosphere has been clearly revealed by recent studies based on the INMS neutral data, in terms of density and mixing ratio (Müller-Wodarg et al. 2008, Cui et al. 2009, 2011), temperature (Westlake et al. 2011, Snowden et al. 2013) and CH_4 escape rate (Cui et al. 2012). The same regions of Titan's atmosphere are also seen with a large variability in ionospheric structure (Ågren et al. 2009, Kliore et al. 2012), charged particle precipitation (Rymer et al. 2009, Németh et al. 2011, Garnier et al. 2010), as well as ambient magnetic field configuration (Bertucci et al. 2009). The present study further shows that waves are an important aspect of the observed variability in Titan's upper atmosphere, as already noted by Snowden et al. (2013).

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References

[1] Aboudan, A., et al., 2008, Planet. Space Sci., 56, 573-585. [2] Ågren, K., et al., 2009, Planet. Space Sci., 57, 1821-1827. [3] Bertucci, C., et al., 2009, J. Geophys. Res., 116, E11002. [4] Cui, J., et al., 2008, J. Geophys. Res., 113, E10004. [5] Cui, J., et al., 2009, Icarus, 200, 581-615. [6] Cui, J., et al., 2011, J. Geophys. Res., 116, A11324. [7] Cui, J., et al., 2012, J. Geophys. Res., 117, E11006. [8] Cui, J., et al., 2013, Geophys. Res. Lett., 40, 43-47. [9] Friedson, A.J., 1994, Icarus, 109, 40-57. [10] Fritts, D.C., & Alexander, 2003, Rev. Geophys., 41, 1003. [11] Fritts, D.C., et al., 2006, J. Geophys. Res., 111, A12304. [12] Fulchignoni, M., et al., 2005, Nature, 438, 785-791. [13] Garnier, P., et al., 2010, Planet. Space Sci., 58, 1811-1822. [14] Hinson, D.P., & Jenkins, J.M., 1995, Icarus, 114, 310-327. [15] Kliore, A.J., et al., 2012, J. Geophys. Res., 116, A11318. [16] Koskinen, T.T., et al., 2011, Icarus, 216, 507-534. [17] Müller-Wodarg, I.C.F., et al., 2006, J. Geophys. Res., 111, A12315. [18] Müller-Wodarg, I.C.F., et al., 2008, J. Geophys. Res., 113, E10005. [19] Németh, Z., et al., 2011, J. Geophys. Res., 116, A09212. [20] Reber, C.A., et al., 1975, J. Geophys. Res., 80, 4576-4580. [21] Rymer, A.M., et al., 2009, Geophys. Res. Lett., 36, L15109. [22] Sicardy, B., et al., 1999, Icarus, 142, 357-390. [23] Sicardy, B., et al., 2006, J. Geophys. Res., 111, E11S91. [24] Snowden, D.S., et al., 2013, J. Geophys. Res., in press. [25] Strobel, D.F., 2006, Icarus, 182, 251-258. [26] Tokano, T., & Neubauer, F.M., 2002, Icarus, 158, 499-515. [27] Westlake, J.H., et al., 2011, J. Geophys. Res., 116, A03318. [28] Young, L.A., et al., 1997, Science, 276, 108-111.