EPSC Abstracts
Vol. 9, EPSC2014-688, 2014
European Planetary Science Congress 2014

Density Waves in Titan's Upper Atmosphere

J. Cui (1), R.V. Yelle (2), T. Li (3), D.S. Snowden(4) and I.C.F. Müller-Wodarg (4)

(1) National Astronomical Observatories, Chinese Academy of Sciences, Beijing, China (2) Lunar and Planetary Laboratory, University of Arizona, AZ, U.S.A., (3) School of Earth and Space Sciences, University of Science and Technology of China, Hefei, China, (4) Department of Physics, Imperial College, London, U.K. (cuij@nao.cas.cn / Fax: +86-10-64807830)

Abstract

Analysis of the Cassini Ion Neutral Mass Spectrometer data reveals the omnipresence of density waves in various constituents of Titan's upper atmosphere, with quasi-periodical structures visible for N_2, CH_4, $^{29}N_2$, and some of the minor constituents. The N_2 amplitude lies in the range of 4%-16% with a mean of 8%. Compositional variation is clearly seen as a sequence of decreasing amplitude with increasing scale height. The observed vertical variation of amplitude implies significant wave dissipation in different constituents, possibly contributed by molecular viscosity for N_2 but by both molecular viscosity and binary diffusion for the others. A wave train with near horizontally propagating wave energy and characterized by a wavelength of ~730 km and a wave period of ~10 h is found to best reproduce various aspects of the observations in a globally averaged sense. Some horizontal and seasonal trends in wave activity are identified, suggesting a connection between the mechanism driving the overall variability in the background atmosphere and the mechanism driving the waves. No clear association of wave activity with magnetospheric particle precipitation can be identified from the data.

1. Introduction

Waves are a ubiquitous feature of planetary atmospheres that makes significant contributions to atmospheric circulation, structure, and variability. Over the past several decades, waves have been detected on most solar system bodies with a permanent atmosphere. For Titan, early observational evidences came from both the Voyager radio occultation data [Friedson, 1994] and the ground-based observations of stellar occultations [Sicardy et al., 2006]. More recently, the Huygens Atmospheric Structure Instrument data revealed wave structures extending from as low as the stratopause at ~300 km to the exobase at ~1500 km [Fulchignoni et al., 2005]. Further evidences were provided by the Cassini measurements made with both the Ion Neutral Mass Spectrometer (INMS) [Müller-Wodarg et al., 2006] and the Ultraviolet Imaging Spectrograph (UVIS) [Koskinen et al., 2011].

Despite the existing observational efforts, the fundamental wave characteristics in Titan's atmosphere and their roles are not as well established as for Earth and other closer planets such as Mars and Venus. The basic wave parameters are not well constrained, the primary source mechanisms are unknown, and the contribution of wave heating to the local thermal balance remains to be pinned down with more rigorous calculations. The purpose of the present study is to systematically investigate wave structures in Titan's upper atmosphere sampled by the Cassini INMS instrument. It serves as an extension of existing works [Müller-Wodarg et al., 2006], either based on a significantly larger sample or based on the data from more constituents covering nearly the full INMS mass range.

2. Omnipresence of wave signatures in Titan's upper atmosphere

We present a detailed analysis of the density waves in Titan's upper atmosphere, 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] 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. [2013a], who identified quasi-periodical structures in the thermospheric temperature profiles for a large number of flybys. However, we caution that despite of their omnipresence, waves make only be a minor contribution to the total density variability in Titan's upper atmosphere.

A thorough inspection of the entire data set 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. 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; see Table 1 for details) 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.

3. Compositional variation

We calculate for each flyby and each constituent or mass group, *i*, the effective wave amplitude, σ_i, with the contribution from counting statistics removed. For N_2 as the most abundant constituent, the amplitude lies in the range from ~4% to ~16%, with a mean of ~8%. Our analysis also reveals that the influence of the wall effect may not be negligible for mass groups G1 and G2. In practice, the wall effect acts as an equivalent dissipative mechanism of instrument origin that reduces the G1 and G2 amplitudes by ~30% and ~20%, respectively. Such an effect is removed in the subsequent analysis.

The compositional variation is clearly seen in the data, manifested as a sequence in that the amplitude increases with decreasing scale height in the background atmosphere. As compared to the mean N_2 amplitude, the mean CH_4 amplitude is suppressed by ~30%, the mean $^{29}N_2$ amplitude is roughly identical, but the mean G1 and G2 amplitudes are enhanced by ~30% and ~90%, respectively. The data also reveal a large variability in the amplitude ratio, σ/σ_{N2}, with both the mean and the spread of σ/σ_{N2} decreasing with increasing wave activity. We interpret this as suppressed wave activity in Titan's upper atmosphere with shorter wave period or higher wave frequency.

4. Wave dissipation

We further examine the pattern of wave dissipation for different constituents by observing the vertical variations of their amplitudes. We obtain a best-fit damping scale of ~126 km for N_2, ~215 km for CH_4 , ~144 km for $^{29}N_2$, respectively. The vertical variations of σ_{G1} andσ_{G2} are well described by the ideal non-dissipative model with infinite damping scales, but we argue that this is more likely an unphysical result caused by the variation of the wall effect along the spacecraft trajectory. Based on a quantitative evaluation made at a representative altitude of 1300 km, we are able to explain the relative magnitudes of the damping scales for N_2, CH_4, and $^{29}N_2$. We argue that the wave dissipation for N_2 is dominated by molecular viscosity, but for the other constituents, both molecular viscosity and binary diffusion are in function.

5. Derivation of wave parameters

A combined analysis of compositional variation and wave dissipation helps to reveal the nature of the observed density waves in Titan's upper atmosphere, summarized as follows: (1) The observed waves are upward propagating gravity waves; (2) Wave trains with characteristic wavelength of ~400-800 km and characteristic wave period of ~2.4-11 h are consistent with all aspects of the INMS observations reported in this study within 25%; (3) The best solution is given by a wave train with near horizontally propagating wave energy and characterized by a wavelength of ~730 km and a wave period of ~10 h. The interpretation of the data as Rossby waves can be rejected by the observation of wave dissipation, and the interpretation as acoustic waves rejected by the observation of compositional variation.

6. Trends of wave activity

Finally, we examine the horizontal and seasonal trends of wave activity in Titan's upper atmosphere, using the N_2 amplitude as a proxy. The most prominent trend revealed by the data is that waves are more active at the southern hemisphere than at the northern hemisphere, but this may also be interpreted as increasing wave activity with time toward the equinox. Also seen in the data is a remarkable zonal trend, with enhanced wave activity near the anti-Saturn side as compared to the other zonal regions, but the diurnal difference appears to be weak. We compare the average wave activity among categories of flybys with different ambient plasma conditions, and the comparison does not support any association of wave activity with magnetospheric precipitation. It is interesting to note that the wave activity increases with the variability in Titan's background upper atmosphere. We speculate that waves likely make an important contribution to the overall thermospheric variability.

7. Tables

Table 1: The definition of mass groups for minor neutrals considered in this study.

Notation	ΔM_i (Da)	Constituents involved
G1	24-26	C_2H_2, C_2H_4, C2H6
G2	37-41	CH_3C_2H, Ar
G3	48-52	C_4H_2, HC_3N, C_2N_2
G4	77-79	C_6H_6

Acknowledgements

This work is supported by the National Science Foundation of China through grants NSFC-41174146, NSFC-41225017, and NSFC-41374178.

References

[1] Friedson, A. J. (1994), Gravity waves in Titan's atmosphere, Icarus, 109, 40–57.

[2] Fulchignoni, M., et al. (2005), In-situ measurements of the physical characteristics of Titan's environment, Nature, 438, 785–791.

[3] Koskinen, T. T., et al. (2011), The mesosphere and thermosphere of Titan revealed by Cassini/UVIS stellar occultations, Icarus, 216, 507–534.

[4] Müller-Wodarg, I. C. F., et al. (2006), Waves and horizontal structures in Titan's thermosphere, JGR, 111, A12315.

[5] Sicardy, B., et al. (2006), The two Titan stellar occultations of 14 November 2003, JGR, 111, E11S91.