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Energy deposition in Titan's neutral upper atmosphere through charged particle precipitation from Saturn's magnetosphere

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Abstract

We investigate various aspects of Titan's upper atmosphere and lower exosphere based on the Ion Neutral Mass Spectrometer (INMS) data of the two strongly escaping species (CH_4 and H_2) acquired during close Titan flybys of Cassini from T5 to T71. We are specifically aimed at identifying possible evidences of energy deposition by charged particle precipitation from Saturn's magnetosphere. Both the investigations in a global average sense and the comparisons made between cases with distinct levels of particle precipitation have revealed the signatures of such a non-solar source in Titan's neutral upper atmosphere and lower exosphere. Our findings are two-fold. First, the considerable H_2 variability in Titan's exosphere is difficult to interpret by solar inputs only. Second, to support the CH_4 outflow on Titan as implied by the INMS data, a significant non-solar source is required.

1. Introduction

The energy deposition in Titan's upper atmosphere can take a variety of forms, of which both solar radiation and magnetospheric particle precipitation have been studied extensively. The relative importance of the two sources depends not only on the depth in Titan's atmosphere, but also on the location of Titan within Saturn's magnetosphere as well as the ambient magnetic field configuration.

The direct observational evidences for the response of Titan's neutral upper atmosphere to charged particle precipitation are scarce. Recently, Westlake et al. [4] have reported an apparent correlation of Titan's mean thermospheric temperature with the broad categories of its plasma environments ([1]). In another study, Strobel ([3]) proposed that the interpretation of the H_2 density profile throughout Titan's upper and lower atmospheres requires an additional production source of non-solar nature. In this report, further evidences will be presented, based on the Ion Neutral Mass Spectrometer (INMS) data in the Closed Source Neutral (CSN) mode acquired during 24 flybys of Cassini with Titan.

2. What causes the variability of Titan's H_2 exosphere?

We investigate the distribution of H_2 in Titan's exosphere, which shows significant variance from flyby to flyby. Our analysis suggests that at any given time, the physical conditions near or above Titan's exobase tend to be globally uniform, but evolve with time. The observations can be interpreted as a result of exobase perturbations on timescales in the range of $\sim 10^3$-10^6 s. Such a time-varying H_2 exosphere on Titan is ultimately driven by the variations in either the solar EUV/UV irradiance or the level of charged particle precipitation from the ambient plasma. However, we do not expect the considerable variability observed in Titan's H_2 exosphere, which is ~100% in terms of the total energy content, to be induced by the varying solar inputs into Titan's atmosphere. Instead, we postulate that such variability is more likely to be associated with Titan's varying plasma environment ([1]). Comparisons are made for different levels of electron precipitation on Titan, which show that the H_2 exosphere tends to be more energetic and more extended, and H_2 molecules tend to escape more rapidly, for the plasma-sheet and magnetosheath cases as compared to the lobe-like cases.

3. What powers the CH_4 outflow on Titan?

We investigate the local energy balance of CH_4 in Titan's upper atmosphere. By comparing the mean atmospheric and exobase temperatures, we identify for 15 flybys clear evidences of temperature excursion near Titan's exobase, both positive and negative. Such a temperature excursion, at a typical level of ~20 K, could be used to estimate the CH_4 conductive heat flux in Titan's upper atmosphere. Through an analysis of the divergence of the total CH_4 energy flux, we find that the maintenance of the local energy balance requires an external source with an average heating rate of $\sim 4\times10^{-12}$ erg $cm^{-2}s^{-1}$ or 2.5 eV $cm^{-2}s^{-1}$ at the exobase. This is a factor of ~4 larger than the net solar heating rate at the same altitude (e.g., [5], [2]), thus calling for non-solar processes at work. We expect the non-solar source to be associated with energetic particle precipitation from Titan's plasma environment, and the data reveal that the energy deposition rates for the plasma-sheet cases appear to be systematically higher than those for the lobe-like cases by a factor of ~3.

4. Summary and Conclusions

In this report, we present our investigations of the energy deposition in Titan's upper atmosphere and lower exosphere, through an analysis of the INMS neutral data of CH_4 and H_2. The large solar distance of Titan, as well as the relatively long response timescale of its neutral atmosphere to varying levels of energy input as compared to the ionosphere, imply that charge particle precipitation from the ambient plasma may leave detectable signatures in the density and thermal structures of Titan's neutral upper atmosphere as probed in-situ by Cassini.

For H_2, we focus specifically on its density variability in Titan's exosphere. To interpret the data, we propose a scenario in which the H_2 density structure remains uniform near or above the exobase but evolves considerably with time in response to the time-varying levels of magnetospheric particle precipitation. The variation in solar EUV/UV irradiance is not large enough to account for the observations. For CH_4, we investigate what drives its large escape rate based on the consideration of energy support. Our analysis suggests that a net energy deposition rate of ~ 2.5 $eVcm^{-3}s^{-1}$ is required to power the CH_4 outflow, which is a factor of ~4 larger than the amount available from solar inputs only. Both facts suggest strongly that charged particle precipitation from the ambient plasma plays an important role in shaping the structure of Titan's upper atmosphere and lower exosphere.

The above conclusion gains further supports from a comparison of various parameters obtained for two categories of flybys with remarkably different plasma environments ([1]). On the one hand, the plasma-sheet cases present H_2 exospheres that tend to be more energetic and extended as compared to the lobe-like cases. One the other hand, the net energy deposition rate required to power the CH_4 outflow for the former category is also higher than that for the latter by a factor of ~3. Follow-up studies are currently underway to search for signatures of magnetospheric particle precipitation directly in Titan's thermal structure derived from the INMS N_2 data.

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