Summary of short visit to IAA-CSIC, Granada, Spain

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1 Purpose of the visit

Transient Luminous Events (TLE) are speculated to exist on other planets of the Solar System with electrically active atmospheres, such as Venus, Saturn and Jupiter. Recently, a series of theoretical and experimental studies have been dedicated to clarify the hypothetical signatures of extra-terrestrial TLEs. However, no self-consistent, electrodynamic model has yet been developed for these phenomena.

During this short visit we established a collaboration in an attempt to extend and modify the present models for the electrodynamic response to lightning discharges of Earth's atmosphere to the atmospheres of other planets, in particular Saturn. That entailed (a) obtaining realistic estimation of the electron density profile of the lower ionosphere on Saturn (b) estimating realistic parameters of the lightning discharges in Saturn, and (c) obtaining a proper set of reaction rates and transport parameters for the gas composition of Saturn's atmosphere.

2 Visit summary

During the visit we approached each of the points listed above:

2.1 Electron density profile on Saturn

There is significant uncertainty regarding the electron density in Saturn's ionosphere, in particular at altitudes below 1000 km above the 1 bar level, which are of most interest in the context of our work. Current reliable measurements are available but they don't reach deeper than 1000 km above the 1 bar level (A.Nagy, personal communication). According to Kliore et al. [2009] mid-latitude, dawn electron density at this altitude are $\sim 10^3\,cm^{-3}$. However this value is based on just two radio occultation profiles. Numerous dusk profiles, as well as measurements at high- and low-latitudes show significant variability in the electron density. It is not clear how the electron density changes as one descends deeper into the atmosphere.

Moore et al. [2004] predict night-time mid-latitude electron density of $\sim 10^2\,\mathrm{cm}^{-3}$, followed by a steep decrease at lower altitudes with the scale height of $\sim$ 30 km. Galand et al. [2009], Moses and Bass [2000] locate the base of the ionosphere at a lower altitude of 600 km, predicting $N_e \sim 10^2\,\mathrm{cm}^{-3}$ in the altitude range of 600 to 1000 km. Zarka [1985] provides an altitude dependent upper limit for the electron density based on Saturn Electrostatic Discharges (SED) cutoff frequency. At altitude 600 km he predicts nigh-time maximum of $10\,\mathrm{cm}^{-3}$. None of these predictions can be compared with observations.

Due to this uncertainty we decided to perform tests on two case studies, one using the modeled profile by Moore et al. [2004] and the other using the modeled profile by Galand et al. [2009], Moses and Bass [2000].

2.2 Realistic parameters for lightning discharges

In terms of TLE models two parameters of the lightning discharge are important: the charge moment change (CMC) determines the maximum electric field that would be reached at any given altitude, and the duration of the flash, which determines how fast this field grows. The second parameter must be shorter than the local field relaxation time in order for electric breakdown conditions to occur. The relaxation time is determined by $\tau_{rel} \sim \sigma/\varepsilon_0$, where ε_0 is the vacuum permittivity coefficient and $\sigma = eN_e\mu(E/N)$ is the conductivity, calculated using the local electron density and the electron mobility.

Not much is known about the characteristics of lightning on Saturn. Based on SED intensities and optical observations it is estimated that the average total energy dissipated by lightning is $\sim 10^{12}$ J [Dyudina et al., 2010, Fischer et al., 2007]. The duration of the lightning discharge is generally assumed to be similar to earth's super-bolts $\sim 1\,\mathrm{ms}$. Farrell et al. [2007] suggested that a faster discharge would fit the observed SED frequency spectrum better than the assumed longer discharge, implying significantly lower energies ($\sim 10^9$ J). The optical observations by Dyudina et al. [2010] provide an independent confirmation of the super-bolt like scenario (G.Fischer, personal communication).

We therefore assume that the energy dissipated by lightning is 10^{12} J, and try to test the response of the atmosphere for several discharge durations, using the following function to describe the current evolution, $i = i_0(\exp(-t/\tau) - \exp(-t/2\tau))$. The value of τ is usually $1\,ms$.

The energy provides a clue for the estimation of CMC as well. Lightning discharges are assumed to take place in the water-ice clouds deep in the atmosphere. The base of these clouds is located at $\sim$ 10 bar, $\sim$ 160 km below the 1 bar level. During lightning storms the cloud undergoes significant upward development, which may reach as high as the 1 bar level [Fischer et al., 2008].

However it is generally assumed that the discharges are taking place at 8-10 bar depth [Dyudina et al., 2010]. Therefore we are assuming the charge cells are vertically separated by a few 10-s of kilometers. We also try scenarios where the charge separation reaches 100 km. Assuming the charge removed by the discharge is concentrated within a radius of a few 10-s kilometers at most, we can estimate the CMC. It is $\sim 10^4$ C km for small scale dipoles with 30 km separation, and can reach 10^5 C km with the larger separation of 100 km. The most extreme estimation is 10^6 C km.

We find that if base of the ionosphere is located at 1000 km, CMC$\sim 10^4$ C km generates an electric field exceeding breakdown, making TLEs a real possibility. However, if the base of the ionosphere is located at 600 km, a significantly stronger CMC is required, $> 10^5$ C km. Since the profile of the electron density at the lower ionosphere is not known with certainty, we can not conclude whether TLEs are indeed possible on Saturn. However, if TLEs are observed, it would be an indication that the base of the ionosphere is located higher in the atmosphere than recent models predict.

2.3 Set of reactions in the $H_2 - He$ mixture representing the atmosphere of Saturn.

We calculate swarm parameters using BOLSIG+ based using cross-sections from the SIGLO database, for only the most basic reactions in the gas - electron impact ionization of molecular hydrogen and mobility. A more detailed model was developed by F. J. Gordillo-Vazquez. This model can be used to estimate chemical residuals due to TLEs and their emission spectrum. However, since we are not sure that TLEs may exist, this model was not developed further.

2.4 Future plans

We believe that the results outlined here will shed a new light on the standing question whether TLEs can exist on Saturn. Moreover, if TLE's where discovered on Saturn, this would serve as a probe of the lower ionosphere, providing an upper limit to the low altitude electron density of the night-time mid-latitude ionosphere. We plan to publish our results in the near future. A further reevaluation of conditions of TLE generation on Jupiter is planned.

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