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Preliminary modelling of the chemical impact of possible TLEs on the lower ionosphere of Saturn

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Abstract

Lightning on Saturn has been confirmed by radio [1] and optical signal observations [2]. On Earth, lightning activity is accompanied by a diversity of Transient Luminous Events (TLEs) above the thunder clouds in the stratosphere, where crawlers and blue jets take place, and in the mesosphere where elves, sprites, halos and giant blue jets occur. Optical emissions from TLEs are produced by electric breakdown in the mesosphere (50 - 90 km) due to the field generated by the electric charges accumulated in the trophospheric thunder clouds.

The existence of powerful lightning on Saturn might produce, as on Earth, elves and other TLE phenomena in the lower ionosphere of Saturn [3]. We have developed a preliminar time-dependent kinetic model to account for the possible chemical disturbances of halo-like TLEs in the night-time mid-latitude H_2/He atmosphere of Saturn. In particular, we have quantified the variation of electron and ion densities at different altitudes (650 - 1000 km) above the 1 bar level together with an estimation of the photon emissions associated to the radiative decays of some excited electronic levels of H_2 like $H_2(d^3\Pi_u)$ responsible for the Fulcher bands in the blue optical range and $H_2(a^3\Sigma^+{}_g)$ that radiatively decays producing ultraviolet blue continuum emission.

1. Introduction

The electric breakdown in the mesosphere of the Earth occurs when the electric field (E) created by the charges accumulated in the thunder-clouds is above the air conventional breakdown field, that is, around E_k/N = 120 Td (1 Td = 10^{-17} V cm^2) with N being the air density. This means that, for fields greater than 120 Td, ionization processes (generating electrons) is larger than attachment (eliminating electrons) and, eventualy, an electron avanlanche is produced resulting in an electric dischage in the mesosphere. The intensity of the eletric field originated by the charged thunder-clouds depends on the total charge in the clouds. The charge moment change (CMC) for Saturn intracloud lightning is defined, following the convention of CG lightning on Earth, as charge × distance between clouds/2 and is a usual form to clasify the lightning strengths. For Saturn, E_k/N = 32 Td. However, recents results [4] indicate that, if they occur, lightning-induced TLEs on Saturn require that the atmospheric conductivity (σ) must be small to allow significant electric fields. The latter means that the Maxwell relaxation time $\tau_m = \varepsilon_0/\sigma \geq \tau_d$ (typical discharge times) where τ_d stands for the inverse of the ionization rate. The relaxation critical electric field (E_c) is obtained from $\tau_m = \varepsilon_0/\sigma = \tau_d$ assuming some neutral (N) and electron density (N_e) profiles in the atmosphere of Saturn. Breakdown can take place if the induced electric field is larger than both the relaxation critical field and the conventional breakdown field, provided the lightning stroke duration is comparable with the relaxation time at the corresponding altitude.

2. Kinetic model of Saturnian TLEs

The basic kinetic model equations controlling the non-equilibrium H_2/He plasma chemistry induced by possible TLEs in Saturn are a set of time-dependent continuity equations self-consistenly solved with the time-dependent and spatially-uniform Boltzmann equation controlling the energy distribution function of the free H_2/He plasma electrons.

The kinetic model requires as an input a previously calculated altitude-time dependent electric field induced by water/ice thunder clouds in Saturn located around 130 below the 1 bar level. This field is calcuted by a self-consistent 0d model of electric fields considering planar geometry + conservation of total current [4], [5]. For Saturn, the electric field model considers a CMC of 10^5 Ckm related to lightning occuring between clouds with the current flowing through the lightning channels following a bi-exponential function with $\tau_{decay} = 10\tau_{rise} = 1$ ms.

Our kinetic model considers 34 species and more than 160 kinetic processes including, among others, heavy-heavy reactions and electron attachment, electron impact excitation and ionization of atomic and molecular species, electron impact excitation of vibrational and electronic levels of H_2, electron impact attachment of H_2, Penning ionization producing He^+ and charge transfer processes. At the present stage, our kinetic model does not include photochemical processes. The model covers the altitude range between 650 km and 1000 km above the 1 bar level. We have used the night-time mid-latitude electron density profile of Saturn proposed by Moore *et al.* [6] continued exponentially below 900 km to 600 km. The neutral density in the Saturn mesosphere is obtained from an interpolation between two date sets [7]. The Saturnian TLE kinetic model is inspired in a previous model we have developed for TLEs on Earth [8]-[9].

3. Results

Our preliminary results in Fig. 1 show how Saturnian TLE discharges could influence the concentration of ions and electrons at 850 km above the 1 bar level.

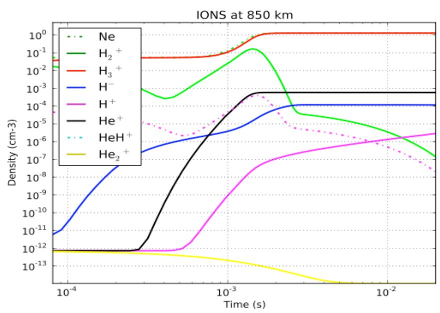

Figure 1: Kinetic model simulations of main ion concentrations caused by a TLE discharge at 850 km above the 1 bar level of Saturn atmosphere caused by a lightning stroke with CMC = 10^5 Ckm.

The dominant source of electrons is electron impact ionization of H_2 producing H_2^+ ions that are quickly converted to H_3^+ ions through the reaction $H_2^+ + H_2 \rightarrow H_3^+ + H$ so that H_3^+ becomes the dominant ion.

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