スポラディック金属層の生成に寄与する沿磁力線電流系モデル

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Field-Aligned Current Loop Model on Formation of Sporadic Metal Layers

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A fascinating and puzzling phenomenon linked with the sporadic-E (Es) layer is a sporadic thin layer of metal atoms which has typical thickness of a few km or less and appears in the height range mainly between 90 and 110 km. The remarkable features of the sporadic metal atom layers are the time of occurrence mainly during nighttime, the horizontal structure extending up to 1,000 km, and the latitude dependent occurrence. The sporadic sodium layers have been observed frequently at low and high latitudes, but rarely observed at mid-latitudes and equatorial regions.

The metal ions and atoms in the upper atmosphere originate without doubt from the meteoroids impinging the Earth's atmosphere. Several mechanisms have been proposed to explain the formation of the sporadic metal atom layers. Sporadic extra sources of metal ions and atoms have been proposed such as the ablation of a large impinging meteor with sufficient mass and the bombardment of energetic auroral particles upon dust and smoke particles. These mechanisms will have difficulty in explanation of the horizontal extent of the sporadic layers up to 1,000 km and difficulty in evidence for such a large meteor and the smoke particles. The most promising mechanism proposed hitherto is that the metal ions are gathered to the thin Es layer by vertical redistribution arising from the effects of winds and electric fields and that the metal ions of the thin Es layer are neutralized to the metal atoms by chemical reactions. The difficulty for this mechanism is that the observed column content of the background sodium ions is usually insufficient as the reservoir to form the sporadic sodium layer by the vertical redistribution.

In the present paper, the horizontal redistribution of the background metal ions capable to supply a rich reservoir is proposed as a new mechanism for formation of the thin Es layers and the following formation of the thin metal atom layers by neutralization of the metal ions. The essential point of the present mechanism is the occurrence of three dimensional field-aligned current (FAC) loop, which consists of the horizontal electric field converging (diverging) at the foot of upward (downward) FAC. In the ionosphere, field-aligned mobility for electrons is larger than that for ions by order of about three and the Pedersen mobility for ions is larger than that for electrons. Therefore, divergence free condition for the electric currents of the FAC loop results the convergence (divergence) of the positive ions by the horizontal Pedersen flow and an equal amount of convergence (divergence) of electrons by the field-aligned flow within the volume at the foot of upward (downward) FAC. Efficiency for the accumulation of the metal ions is governed by the intensity and duration of the horizontal electric field, the Pedersen mobility and the height distribution of the background metal ions. The time constant for the rate of ion convergence within the unit volume at the foot of FAC is given as $\tau_A(z) = (BL/\alpha E)$, where E, B, L, $\alpha(z)$ and z denote respectively, horizontal electric field, earth's magnetic field, horizontal scale of the volume at the foot of FAC, coefficient of the Pedersen mobility and the altitude.

The accumulated metal ions are reacted with atmospheric constituents into the clustered metal ions which are transferred to the metal atoms through recombination. The chemical lifetimes, $\tau_C(z)$, for the metal ions Na^+, $Fe^+$and Ca^+ are evaluated by Collins et al. (2002) and Raizada et al. (2012). The equation of continuity with respect to the number density n (z,t) of the metal ions within the unit volume at the foot of FAC is represented by,

$$\partial n / \partial t = (n_b / \tau_C) + (n_b / \tau_A) - (n / \tau_C), \quad (1)$$

where three terms on the right hand side of Eq.(1) are respectively, the rate of background source (which is balanced with the chemical loss for the background ions of the number density $n_b(z)$) , the rate of accumulation by the FAC loop effect and the rate of chemical loss. Here, it is assumed for simplicity that the chemical lifetime τ_C is explicitly independent of n (z,t) and the effects of advection, gravitation and diffusion are neglected. The number density of the metal ions n (z,t) is obtained by solving Eq. (1), and the number density of the metal atoms N(z,t) is determined under the assumption that 100 % of the loss of metal ions is converted to the metal atoms through chemical reactions.

The sodium atom density profiles observed at the EISCAT radar site in Tromsø, Norway before and during the sporadic sodium layer event on 11 January 2011 are shown in **Figure 1a** (Tusda et al., 2011). Model density profiles of sodium atoms calculated from the solution mentioned above are shown in **Figure 1b** (Matuura et al., 2012), where the electric field is defined with intensity of 50 mV/m and duration of 1 hour and the background distribution of the sodium density is defined by the profiles observed at 17.5 hrs UT, three hours before the beginning of the event.

It is well known that the large scale FAC loops exist in the high latitudes and they are generated by electro-dynamics in the magnetosphere. The FAC loops in the equatorial and low latitude ionosphere are generated by two factors, one is the wind-driven currents and the other is the gravity-driven currents in the (practically) collision-less F-region. The longitudinal non-uniformity in the gravity-driven currents generates the FAC and the Pedersen current driven by the longitudinal electric fields. The longitudinal electric fields evaluated based on the IRI model are shown in **Figure 2** (Matuura et al., 2012). The electric fields reveal the field convergences in the late evening and early morning, which coincide well with the time of frequent appearance of the sporadic sodium layers reported from observations at the low latitudes. The FAC loops in the high and low latitudes may give support to interpret the latitude dependent features of the sporadic sodium layers.

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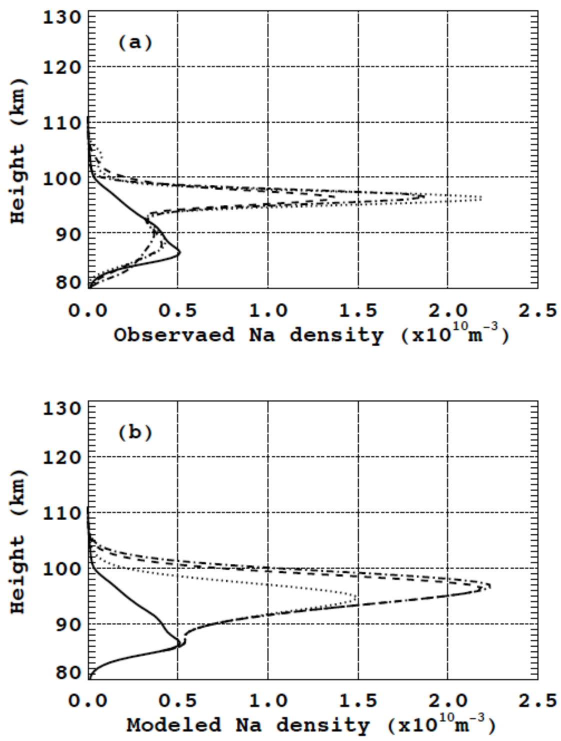

Figure 1. (a) Na density profiles observed before the event at 17.5 hrs UT (solid) and during the event at 20.5 hrs (dotted), 21.5 hrs UT (dashed) and 22.5 hrs UT (dot-dashed) on 11 Jan. 2011. (b) Model Na profiles at t = 0 (solid), 1 hr (dotted), 3 hrs (dashed) and 5 hrs (dot-dashed).

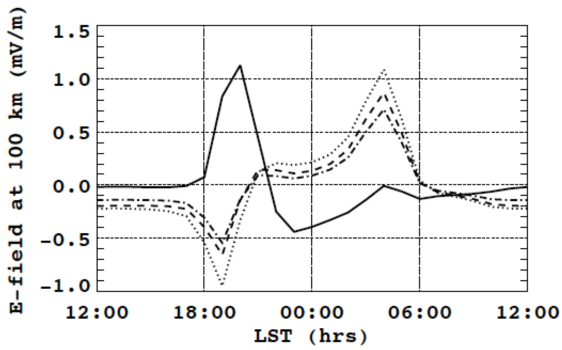

Figure 2. Longitudinal electric fields (positive eastward) in the low-latitude ionosphere at magnetic latitudes 12.6º (solid), 17.6º (dotted), 20.6º (dashed) and 26.0º (dot-dashed) on the height level of 100km.