Impact of mesospheric ion conductivity variations on the initiation of long-delayed sprites

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Important parameters in the sprite-halo events

- Sprites [*Sentman et al.,* 1995] are transient luminous events usually produced by positive cloud-to-ground lightning discharges.
- For short-delayed sprites, the establishment of a streamer initiation region (SIR) depends on two parameters:

  (1) The charge moment change produced by the lightning discharge [*e.g., Cummer and Lyons,* JGR, 110, A04304, 2005; *Qin et al.,* JGR, 116, A06305, 2011].

  (2) The ambient electron density at the sprite initiation altitudes (∼65–85 km) [*Qin et al.,* 2011].
- In [*Qin et al.,* 2011], ambient ion conductivity was not included.
- For long-delayed sprites, relaxation effects related to ion conductivity may become significant.

Plasma fluid model

- A high-resolution one-dimensional (1D) plasma fluid model is used to simulate the sprite-halo dynamics.

$$\frac{\partial n_{\mathrm{e}}}{\partial t} + \nabla \cdot (n_{\mathrm{e}} \vec{v}_{\mathrm{e}} - D_{\mathrm{e}} \nabla n_{\mathrm{e}}) = (\nu_{\mathrm{i}} - \nu_{\mathrm{a2}} - \nu_{\mathrm{a3}}) n_e + S_{\mathrm{ph}}$$

$$\frac{\partial n_{\mathrm{p}}}{\partial t} + \nabla \cdot n_{\mathrm{p}} \vec{v}_{\mathrm{p}} = \nu_{\mathrm{i}} n_{\mathrm{e}} + S_{\mathrm{ph}}$$

$$\frac{\partial n_{\mathrm{n}}}{\partial t} + \nabla \cdot n_{\mathrm{n}} \vec{v}_{\mathrm{n}} = (\nu_{\mathrm{a2}} + \nu_{\mathrm{a3}}) n_{\mathrm{e}}$$

$$\nabla^2 \phi = -\frac{q_{\mathrm{e}}}{\varepsilon_0} (n_{\mathrm{p}} - n_{\mathrm{n}} - n_{\mathrm{e}})$$

- The advantage of 1D modeling is that it avoids small 2D scale instabilities and it is capable of resolving the halo features during long temporal development with a high spatial resolution.

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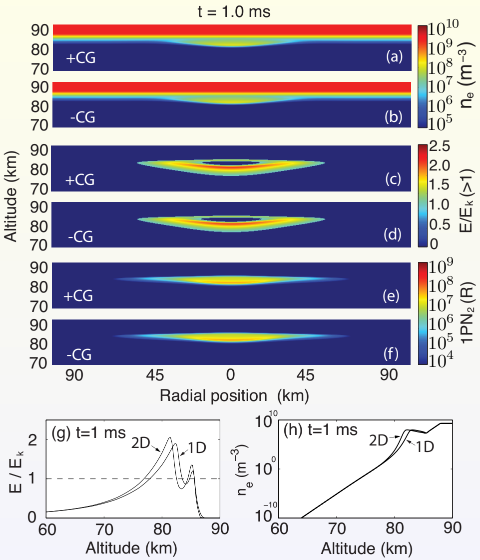
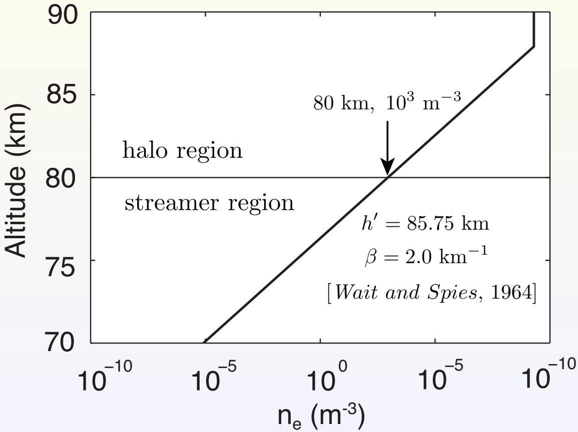


- Comparison between 1D and 2D modeling of the halo dynamics.

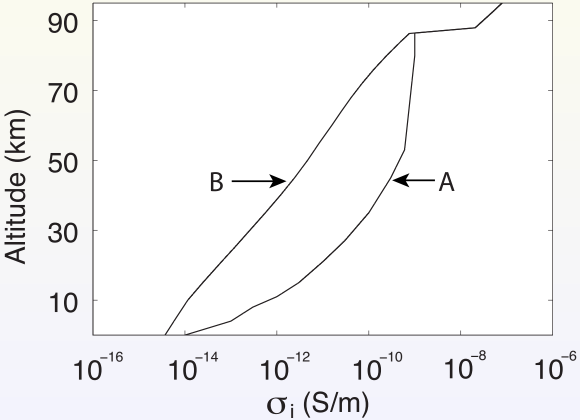
Ambient electron density profile

- The electron density profile used in the present study is the same as the one utilized in [*Qin et al.*, 2011, Figures 3, 4 and 5] in order to focus on the effect of ion conductivity.

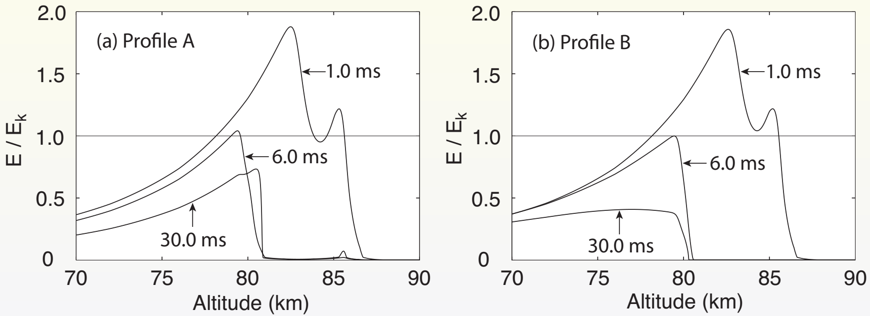


Positive ion conductivity profiles

- Profile 'A' is identical to the profile 'A' in [*Pasko and Stenbaek-Nielsen,* GRL, 29, 1440, 2002, Figure 4(a)]. Profile 'B' corresponds to constant ion density that has a value 10^8 m^{-3} (midnight).



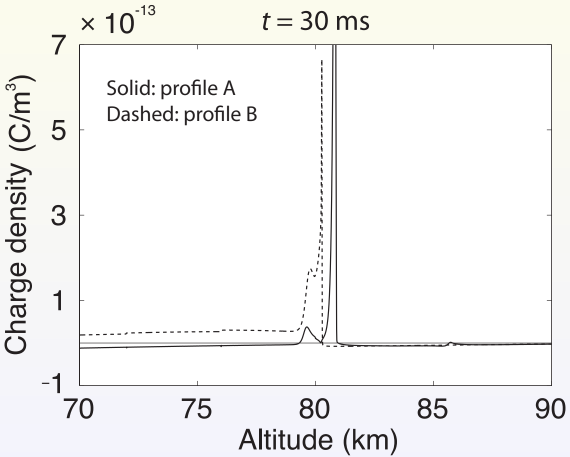
Persistence of the electric field



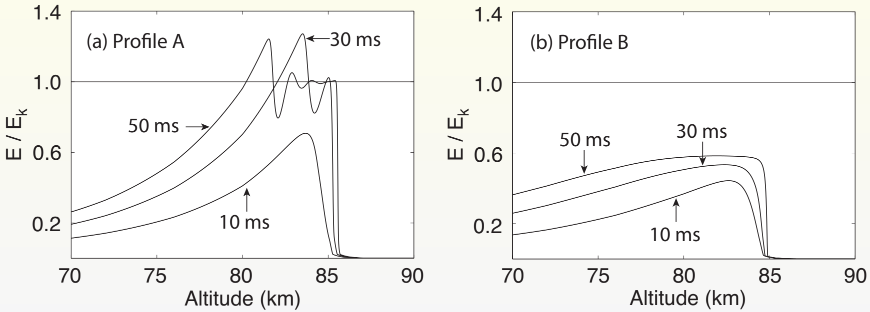
- Results for charge moment change of 500 C km produced by a +CG during 1 ms.

Space charge distributions

Charge conservation equation: $\frac{\partial \rho}{\partial t} = -\nabla \cdot \vec{J} = \sigma \nabla \cdot \vec{E} - \vec{E} \cdot \nabla \sigma$



Formation of a high field region / continuing current



- Results for a halo event driven by continuing current with a current moment magnitude of 10 kA km after the return stroke of a +CG that initially produced a charge moment change of 100 C km.
- High electric field is favored by low conductivity gradients.

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Conclusions

- The gradient of the ion conductivity profile is an important parameter that influences the reduced electric field in halos over long durations. Lower gradient of the ion conductivity, such as that in constant ion conductivity profile, is favorable to the initiation of long-delayed sprites.
- Based on the present work and that in [*Qin et al.,* 2011], we suggest that the variation of conductivity in the upper atmosphere due to long-term effects may lead to the differences of sprite production observed in different years, for example, due to variation in the galactic cosmic ray flux.
- This long-term change and the geographical variation of conductivity might partly answer the question raised in [*Stenbaek-Nielsen et al.,* JGR, 115, A00E12, 2010], as to factors responsible for variations in sprite production rates and other sprite characteristics from one campaign to another.

Acknowledgements

THANK YOU FOR YOUR ATTENTION!
QUESTIONS?

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