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Modelling the ion chemical impact of sprites at night and during daytime

Holger Winkler and Justus Notholt, Institute of Environmental Physics, University of Bremen, Germany.

Introduction

Ion chemical impacts of sprites

- Ionisation, dissociation, excitation, and electron attachment.
- Complex ion/neutral chemistry in the afterglow [1,2].

→ *Production of reactive* $NO_x = (N, NO, NO_2)$.
→ *Formation of reactive* $HO_x = (H, OH, HO_2)$.
→ *Release of atomic oxygen, ozone perturbations, ...*

Night and day

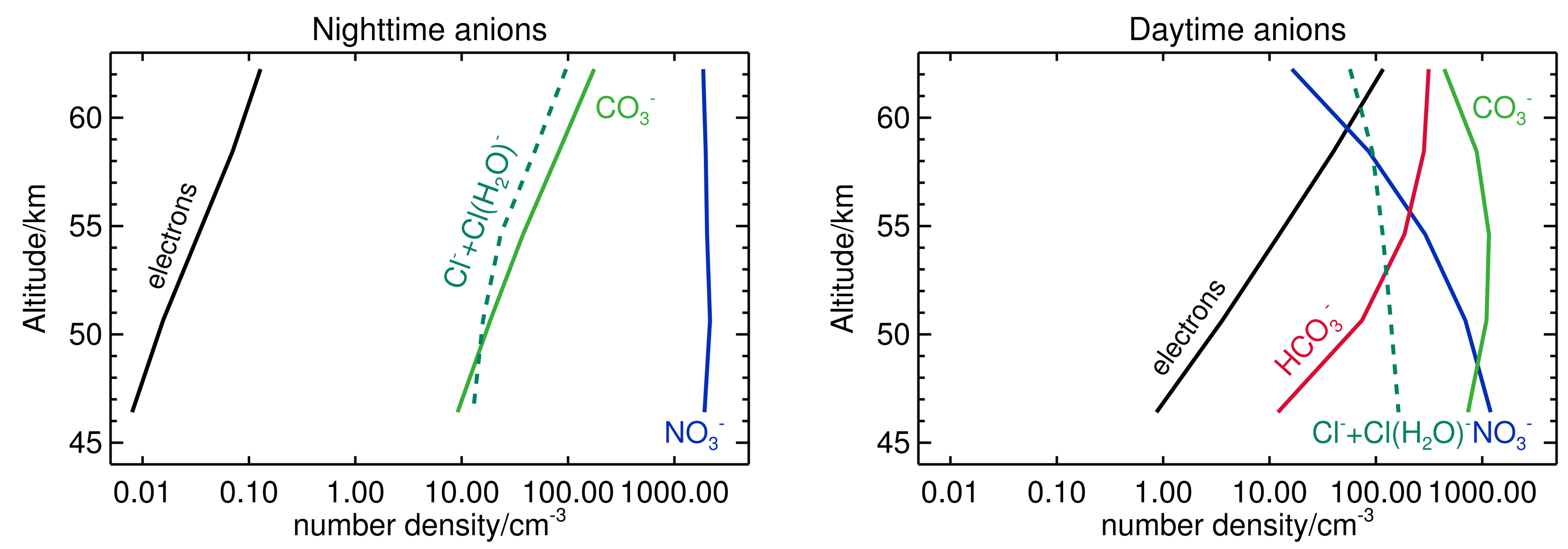
- Sprites are mainly nighttime phenomena, and their impacts have commonly been studied for nighttime conditions [1-4].
- However, daytime sprites have been detected after exceptionally large positive cloud-to-ground strokes [5].

Effects of sunlight

☼ Diurnal variation of the atmospheric chemistry due to photolysis.
☼ Photoelectron detachment (and photoionisation).
☼ Daytime conductivity of the mesosphere is higher than at night.
☼ Daytime breakdown at lower altitudes (~54 km [5]) than at night.

Background anions

In the lower and middle mesosphere, most of the negative charges are molecular ions such as NO_3^- and CO_3^-. Free electrons are only a minor fraction of the total charge density because of electron attachment. Due to photoelectron detachment, the electron density is two to three orders of magnitude larger for daytime conditions than at night.



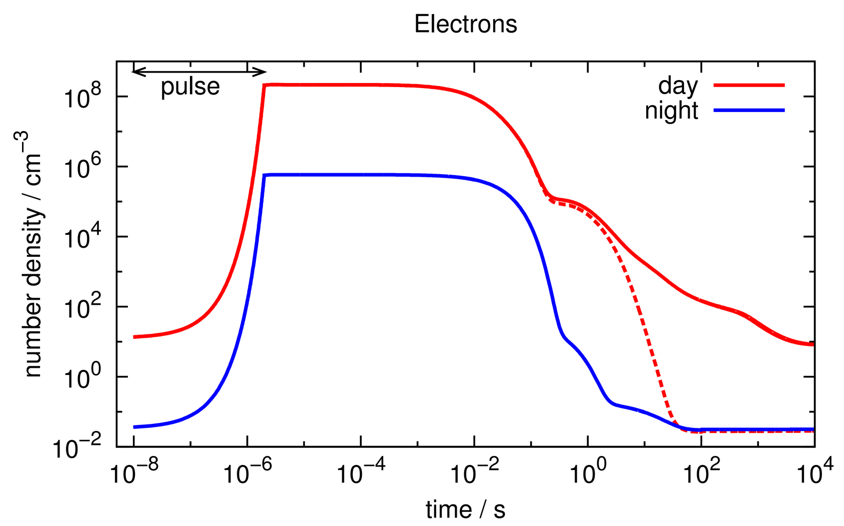
Some selected important anions at 27.5°N on August 14th, for (top) midnight, and for (bottom) daytime conditions (solar zenith angle 65°). Time and location have been chosen to match with the daytime sprite detection [5].

Sprite impact: Ions

To a good approximation, the number of electrons released during an electric pulse is proportional to the initial electron density. Therefore, the electron density increases to much higher values for daytime conditions than at midnight, see the figure on the right. →

The four figures below show the relative abundance of the most important ions under the influence of the electric pulse at 54 km.

- Free electrons rapidly attach to molecules, and ~10 ms after the pulse, molecular anions dominate.
- A few minutes after the pulse, NO_3^- has become the most abundant negative species. Note, that this also applies to the daytime event, although under quiet conditions CO_3^- is the principle anion. The reason for this are reactions of CO_3^- with increased NO_x.
- N_2^+ and O_2^+ are the most abundant cations just after the pulse, followed by heavier cluster ions ~10 ms later.



Time profiles of the electron densities for daytime (red) and nighttime (blue) conditions at 54 km altitude for an electric field pulse of 450 Td lasting for 2 μs. The dashed red line shows the result of a model run with deactivated photodetachment after the pulse.

The Model

- Ion chemistry box model, no transport.
- 36 positive, 19 negative, and 31 uncharged species.
- >1000 reactions.
- Background ionisation due to galactic cosmic rays [6].
- Streamer parameterised after [7] (*450 Td for 2 μs at 54 km*).

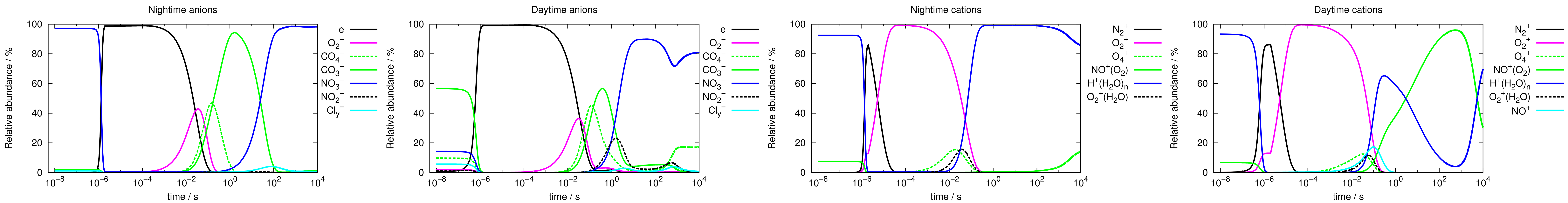
↯ Electric field driven processes:

$O_2 + e \rightarrow O_2^+ + 2e$
$O_2 + e \rightarrow O^+ + O + 2e$
$O_2 + e \rightarrow 2O(^3P, ^1D) + e$
$O_2 + e \rightarrow O_2(a, b) + e$
$O_2 + e \rightarrow O^- + O$
$N_2 + e \rightarrow N_2^+ + 2e$
$N_2 + e \rightarrow N^+ + N(^4S, ^2D) + 2e$
$N_2 + e \rightarrow 2N(^4S, ^2D, ^2P) + e$
$N_2 + e \rightarrow N_2(A, B, C, a, a') + e$

☼ Photo-ion processes:

- Photodetachment
  $X^- + h\nu \rightarrow e + X$ ($X = O, O_2, O_3, OH, NO, NO_2, NO_3, Cl, ClO$)
  $O_4^- + h\nu \rightarrow e + O_2 + O_2$
  $CO_4^- + h\nu \rightarrow e + CO_2 + O_2$
  $O_2^-(H_2O) + h\nu \rightarrow e + H_2O + O_2$
- Photodissociation
  $O_3^- + h\nu \rightarrow O^- + O_2$
  $CO_3^- + h\nu \rightarrow O^- + CO_2$
  $O^-(H_2O) + h\nu \rightarrow O^- + H_2O$
  $O_3^-(H_2O) + h\nu \rightarrow O_3^- + H_2O$
  $ClO^- + h\nu \rightarrow Cl^- + O$

Sprite impact: Ions



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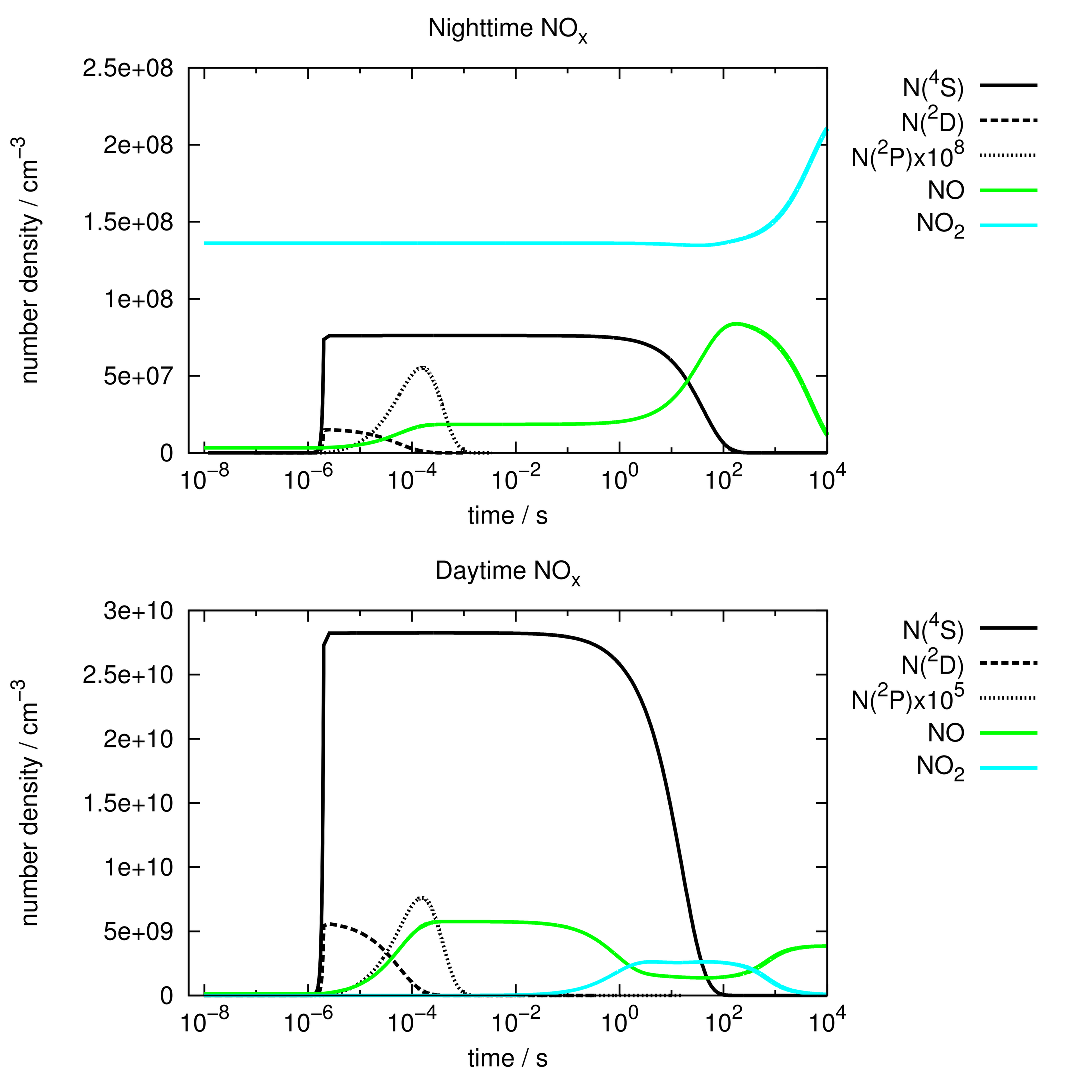
Sprite impact: NO_x and O_x



The figures show the evolution of NO_x and O_x species under the influence of the electric pulse at 54 km.

- During night, NO_x is mostly NO_2, and the excess nitrogen is eventually converted to NO_2.
- During day, the initial NO_x production is more than two orders of magnitude larger, but there is significant chemical loss a few seconds after the pulse.
- During night, O_x is mostly ozone, and it is basically not affected.
- During day, O_3 decreases after ~100 s due to $O_3 + NO \rightarrow O_2 + NO_2$.
- The daytime event causes significantly larger impact than the event at midnight.

⋆ The nighttime NO production is smaller than in [1] and [2]. A $N(^2D)$ issue?
⋆ In order to properly model the long-term effects, the *changing* solar zenith angle has to be taken into account.