Atmos. Chem. Phys. Discuss., 8, S759–S762, 2008
www.atmos-chem-phys-discuss.net/8/S759/2008/

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Chemistry of sprite discharges through ion-neutral reactions" *by* Y. Hiraki et al.

Y. Hiraki et al.

Received and published: 14 March 2008

We appreciated the reviewer's comprehensive and valuable suggestions. We carefully read the kind criticisms of the reviewer along with Editor's comments, and could modify our manuscript according to the all reviewer's comments.

The main revision points are to add "comparison with recent observational and laboratory studies" in Sections 1 and 4 (Specific comment 7). Our response to the reviewer's comments are described in order as follows.

Specific comments:

1. According to the reviewer's comment, we add the sentence about the timescale of sprites along with referring several papers in the 1st paragraph of Section 1.

2. As the reviewer pointed, we have known that the lightning-induced electric field (and

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the propagation of streamers) is not directed vertically. According to the comment we add the corresponding sentence in Section 2.1; "note that this is really an assumption as it tends to curve and converge to the thundercloud charge center at the lower parts of 40–50 km (Neubert et al., 2005)". Not mentioned but, the authors consider that this modification (if done) will result in a slight enhancement of sprite impacts due to the increase in the transition time of streamers at a certain point.

3. We modify the inadequateness of the corresponding sentence in Section 2.1; "For simplicity and maximum estimation, we set these values as $E_\mathrm{s} = 150$ kV/cm, $n_\mathrm{es} = 10^{14}$ cm^{-3}, $r_\mathrm{s} = 10^{-1}$ cm, and $v_\mathrm{s} = 10^7$ cm/s within the realistic range based on the numerical study in Kulikovsky (1997)". We only mentioned that the values of streamer parameters are chosen in the realistic range for our maximum estimation.

4. We tried to point out that the effects of sprite streamers initiated at different altitudes at different period should be treated separately. The corresponding sentence is modified in the 2nd paragraph in Section 2.2;

"Here we disregard the vertical diffusion term in order to focus the streamer effect on each-altitude local chemistry. This assumption is still valid because the initiations of actual streamers at different altitudes do not coincide at t_0 with millisecond orders of delay and the effects should be treated separately".

5. We tried to mention that a rough estimation of secondary sprites can be made by multiplying the density enhancements of the single case. However, as this kind of estimation has a limitation due to overlapping and mixing processes of the streamer effects, we notice it and a future problem of the sophisticated chemical simulations in Section 2.2;

"If one tries to estimate roughly the secondary sprite impact occurring with a certain delay (e.g. ≈ 100 s), it is easily to multiply the values of our calculation, e.g. 2 orders of magnitude $\times 2$, as discussed in the discussion section. We can suppose that the primary effect seems to be advected far away (≈ 1 km) by the horizontal wind, ≈ 10 m/s.

It is, however, noted that the local overlapping and mixing effects make the problem complicated since the advection scale is apparently less than the overall scale (tens of kilometer) of sprites".

6. We only mentioned that the impact of sprite streamer on local NO concentration is the largest among all species. The corresponding sentence is modified in the 1st paragraph of Section 4 as

"It is shown that the density variation of NO by a streamer is over 6 orders of magnitude at 60 km, largest in all target species, so that the impact on its local area chemistry is estimated below".

7. We modify the entire part of Section 4 stimulated by the reviewer's comment. We firstly add the discussion on comparison with laboratory discharges referring Pasko (2007) as the 3rd paragraph; one of our future targets (NO-γ emission in sprites) is suggested. Besides, we discuss on the comparison of our results with those of very recent observations by Arnone et al. (2008) in the 2nd paragraph, with referring the outline of their results in Section 1. As Enell et al. (2008) also presented their updated results, we modify the sentences on comparison with them in the final paragraph.

The latter part of 2nd paragraph and all of 3rd paragraph are described as follows:

As one of these trials, the results of Arnone et al. (2008) as 10 $\%$ density increase of NO_2 are comparable with those of ours as 1 order of increase (Figures 2 and 3). We can make a similar estimation as above using the field-of-view (1.5×10^4 km^2) of the sensor they showed. As the reduction factor is 10^{-2} for assumed scale of streamers 100 km^2, our NO_2 density enhancement is consistent with their values if tens of sprites can be produced in a couple of hours. It could be sufficiently expected for the case of active thunderstorm. More reliable consistency will be obtained by future cooperative assessment between theory and observation.

Other possible method to demonstrate the density increase of NOx is the spectroscopic

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observations of direct sprite emissions as previously done by Morrill et al. (2002). Pasko (2007) suggested a possibility of NO-γ band emission in sprites on the basis of analogy with laboratory steady-state corona discharge processes. For its mechanism they showed that the interaction of O and N(^{2}D) with N_2(A), all of which are the first products of electron impact processes, leads to the formation of NO($X^2\Pi_r$); it interacts again with N_2(A) to form NO($A^2\Sigma^+$) state, which is the source of γ band emission. In the streamer-type transient discharge of our interest, such a dominant production of NO($A^2\Sigma^+$) state and γ emission as the steady-state case are not expected. This is due to the small propagation timescale of streamer and the small amounts of the above secondary and ternary products. However, it can contribute certainly to the sprite emission in the wavelength range of 150–280 nm of ISUAL spectrophotometer onboard FORMOSAT-2 as they pointed. We emphasize that this photometric observation aims at the estimation of enhancement of NO ground state by sprites. We also encourage the ground-based spectroscopic observations with a fine spatial and wavelength resolutions to identify its γ emission.

8. According to the reviewer's comment, we modify the entire part of Section 5 along with future improvements and problems of this kind of chemical simulations.

Technical comments:

We carefully read the reviewer's comments and our manuscript again, and tried to improve the level of English and syntax errors in the entire part of the manuscript (comment 1), to modify several descriptions of the terms pointed as comments 2-7.

Interactive comment on Atmos. Chem. Phys. Discuss., 8, 2311, 2008.