NITRIC OXIDE PRODUCTION BY CENTIMETER-SIZED METEOROIDS IMPACTING THE EARTH'S ATMOSPHERE.

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Introduction: All optically detectable meteors, as well as many of the stronger radio-detectable meteors, produce shockwaves during the lower transitional flow regimes in the MLT (Mesosphere-Lower Thermosphere) region of the atmosphere, at altitudes between 75 km and 100 km [1]. Meteor generated shock waves can modify the surrounding atmosphere and produce a range of physico-chemical effects [1]. Some of the thermally driven chemical and physical processes induced by meteor shock waves, such as nitric oxide (NO) production, are less understood. Any estimates of meteoric NO production depend not only on a quantifiable meteoroid population with a size capable of producing high temperature flows, but also on understanding the physical properties of the meteor flows along with their thermal history. These combined factors were the sources of significant uncertainties in assessing meteoric NO production in the MLT region in early studies (e.g. [2]). Nitric oxide, a trace species in the upper atmosphere, plays an important role in the energetics of the MLT, especially in the lower thermosphere where it exhibits the highest concentration [3]. Nitric oxide also emits efficiently in infrared at 5.3 µm, and as such, it is also an important source of radiative cooling in the upper atmosphere (e.g. [4]). However, the mechanisms responsible for N_2 dissociation (e.g., soft X-rays, UV radiation and high energy auroral electrons) are typically less efficient in the MLT below 95 km, and other sources of NO at those altitudes, such as meteoroid high temperature flow fields, require better quantification. We examined the capacity of centimeter-sized meteoroid hypersonic flow fields to produce NO via the Zel'dovich mechanism, at altitudes of 80-95 km and sought to establish the upper mass boundary of meteoric NO deposited in that region of atmosphere.

Analytical Approach: The two main reactions, collectively known as the Zel'dovich mechanism, that are primarily responsible for the NO production in the incipient high temperature hypersonic flows, in the range of approximately 2,000 – 10,000 K, can be written as:

$$N_2 + O \rightarrow NO + N \qquad (1)$$

$$N + O_2 \rightarrow NO + O \qquad (2).$$

In our study, we assume the following: (i) the value of mole fraction of the NO production remains constant for both endothermic Reaction (1) and temperature independent Reaction (2); (ii) the NO production is bound within the volume of bright meteor plasma train with an initial radius r_0 [5]. Consequently, the mass of produced NO is computed from 80 to 95 km altitude within the plasma volume with the height dependent the initial radius of a bright meteor train (e.g. [6]). The full treatment, the assumptions implemented in the analytical approach and the methodology are presented in [7]. We then use the most recently published flux rates to obtain the estimate for the annual NO production by cm-sized meteoroids [8]. In order to validate our assumption regarding the centimeter-sized meteoroid NO production boundary governed by r_0 of bright meteors, we take advantage of the characteristic or blast radius (R_0), which represents the region of maximum energy deposition per unit path length and is written as $R_0 = (E_0/p_0)^{0.5}$ (e.g. see [1]). In this expression, E_0 is the energy deposited by the meteoroid per unit path length and p_0 is the ambient pressure [1]. We subsequently investigated the effect of impact velocity and size of ablating meteoroids.

Conclusions: Our study suggests that the upper mass limit for NO produced by centimeter-sized meteoroids is in the range of 100 tons/year. This value is significantly smaller than the mass estimated in the early studies [2,9]. Further interpretation of our results demonstrates that the maximum cumulative annual production of NO by meteoroids with sizes capable of sustaining high temperature flows cannot exceed 1,000 tons annually. This is primarily due to a drastically revised meteoroid annual mass influx [1]. We also discuss the reasons why cm-sized meteoroids are the most efficient producers of NO.

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