

Interactive comment on “A chemical model of meteoric ablation” by T. Vondrak et al.

T. Vondrak et al.

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Response to referee #1

The authors thank this referee for very constructive suggestions regarding sputtering from meteoroids. We have tried to incorporate these into the revised manuscript for ACP, and included most of the references that the referee provided.

In response to the numbered points laid out in the report:

(1). We have included the following discussion in Section 2.2 to address this point:

The sputtering yields calculated in this treatment apply to interstellar ions such as H⁺, He⁺ and D⁺, rather than the neutral constituents of interest in the MLT such as N₂, O₂ and O. Although there are few experimental studies of sputtering from neutral bombardment, one study of low-energy neutral and ionised neon impacting on Cu, Si and SiO₂ surfaces found the sputtering yields to be similar for both the neutral and ion beams,

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with the neutral yield / ion yield ratio ranging from 1 for Cu to 0.7 for SiO₂ (Mizutani and Nishimatsu, 1988). Therefore, it seems reasonable to use this method in the CAMOD model.

(2). We have added the following discussion in Section 3.3, which now refers to other recent work on sputtering, acknowledges that hyperthermal collisions with molecules can lead to other processes than sputtering, and makes clear that the sputtering treatment that we have used provides the useful result that sputtering is not likely to be an important contributor to the bulk vaporized meteoroid input into the atmosphere:

Sputtering has been proposed as an explanation for the luminosity of high-altitude meteors above 130 km, which cannot be explained by classical ablation theory (Hill et al, 2004; Popova et al, 2007; Vinkovic, 2007). Several other processes have been observed to occur during collisions between high-energy beams and various surfaces in laboratory experiments (Behrisch and Eckstein, 2007), such as neutralisation of ionic projectiles followed by their reflection (Kleyn, 1992), negative ion formation (Greber, 1997), and compaction of the impacted surface (Mizutani, 1995). However, only sputtering is considered in the present study since we are primarily concerned with mass loss from the meteoroid. In 2002, a simple sputtering mechanism was incorporated into a meteor model (Coulson, 2002; Coulson and Wickramasinghe, 2003), followed by a more detailed sputtering model which included the variation of atmosphere composition along the meteoroid trajectory (Rogers et al., 2005). This later model used the treatment developed for ion impact on surfaces by Tielens et al. (1994), which we have also incorporated into CAMOD. Notwithstanding the fact that this treatment was developed for ionic projectiles rather than the neutral projectiles that predominate in the thermosphere (Section 2.2), the results discussed below should provide a useful indication of the relative importance of sputtering.

(3) We actually corresponded with Hill et al. over this point - there is an error in the atmospheric densities shown in figure 3 of their paper.

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(4) We have now referred to these papers in the paper for ACP.

(5) We prefer to continue using the term sputtering as it is widely used in the meteor community.

(6) Not referencing the work of Alexander was a significant omission, since this study showed that the approach used in CAMOD gives good agreement with experimental data. We have now added the following sentences at the end of Section 2.5:

This approach is similar to the Equilibrium Reference Model for evaporation into a vacuum from a silicate melt that was developed by Alexander (2001). It is important to note that this model reproduced the measured elemental evaporation rates from chondritic-type melts over a temperature range of 1900 - 2300 K, for up to 95% of mass loss.

Response to referee #2

Specific comment 1.

We agree with this comment and have inserted the following discussion of this point in Section 1:

The mean entry velocity is around 40 - 50 km s⁻¹ (Mathews et al., 2001), significantly higher than distributions measured by meteor radars which detect the reflection from a semi-stationary ionized trail left behind the meteoroid path (see, for example, Galligan and Baggaley (2004), Fig. 27a). The difference in the velocity distributions measured by the two techniques is due to the echo ceiling effect inherently present in the meteor radar observations. That is, these radars do not efficiently detect meteors which occur at higher altitudes (> 100 km), because of the rapid diffusion of the ionized trails (Chau et al., 2007). Since faster meteors generally occur at higher altitudes, distributions measured by meteor radars are biased towards the lower speeds. In fact, Janches et al. (2008) showed that HPLA radars observe the same population of meteors as observed by meteor radars, and in addition detect a population of faster meteors that ablate at

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altitudes where specular trails are not efficiently detected. However, the magnitude of the head echo still depends on the meteoroid mass and velocity, and each HPLA radar is sensitive to a particular mass range (Janches et al., 2008). This implies that the velocity distribution of the smallest particles measured by an HPLA radar will be biased towards faster speeds. In particular, for the case of the Arecibo HPLA radar this effect is determined by the ablation limit (Fentzke and Janches, 2008), where small and slow particles will not have sufficient kinetic energy to ablate, and hence will not produce sufficient electrons to be detected.

Specific comment 2.

We have clarified this point by adding the following clause (*italicised*) in Section 2.6:

The resulting masses, ablation rates and temperature, which are calculated with a variable height resolution (maximum 22 m), are then interpolated onto a regularly spaced 100 m step altitude grid.

New references in the revised paper:

Alexander, C. M. O. D.: Exploration of the quantitative kinetic models for the evaporation of silicate melts in vacuum and in hydrogen, *Meteoritics Planet. Sci.*, 36, 255-283, 2001.

Behrisch, R., and Eckstein: Sputtering by Particle Bombardment - Experiments and Computer Calculations from Threshold to MeV energies, *Topics in Applied Physics*, Springer, Heidelberg, 2007.

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Galligan, D.P., and Baggaley, W.J., The orbital distribution of radar-detected meteoroids of the Solar System dust cloud. *Mon. Not. R. Astron. Soc.* 353, 422-446, 2004.

Kleyn, A. W.: Dissociation in molecule-surface collisions, *J. Phys. Cond. Matter*, 4,

8375-8394, 1992.

Mizutani, T.: Compositional and structural modifications of amorphous SiO₂ by low-energy ion and neutral beam irradiation, *J. Non-Cryst. Solids*, 181, 123-134, 1995.

Mizutani, T., and Nishimatsu, S.: Sputtering Yield and Radiation-Damage by Neutral Beam Bombardment, *J. Vacuum Sci. Tech.*, 6, 1417-1420, 1988.

Popova, O. P., Strelkov, A. S., and Sidneva, S. N.: Sputtering of fast meteoroids' surface, *Adv. Space Res.*, 39, 567-573, 2007.

Vinkovic, D.: Thermalization of sputtered particles as the source of diffuse radiation from high altitude meteors, *Adv. Space Res.*, 39, 574-582, 2007.

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