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Interactive Comment

Interactive comment on "On the efficiency of rocket-borne particle detection in the mesosphere" *by* J. Hedin et al.

J. Hedin et al.

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Dear Editor and Referees,

We would like to thank the reviewers for their very helpful comments and suggestions. We are particularly grateful to the reviewers for pointing out problems in our simulation results. Because of a numerical problem there were instances where too many particle-molecule collisions occurred within one time step. This problem has now been solved and the model has been re-run. Also the procedure to select the colliding molecule has been improved. We here reply to the comments. The referee comments are included and the replies are included after each comment.

Best regards,

Jonas Hedin

Answers to Anonymous Referee #2 This paper presents a much-needed update to the calculation of smoke detector efficiencies first discussed by Horanyi (1999). The inclusion of Brownian motion in the trajectory calculations serves to illustrate the fate of smoke particles that reach a stagnation point inside the detector. Most interesting is the effect of Brownian motion on the particle collection efficiency; Figure 6 shows that the inclusion of Brownian motion in the trajectory calculations severely inhibits particle collection in an unventilated detector. A few observations concerning the paper content follow:

- The trajectories presented in Figure 3 are slightly confusing. If it is assumed that the front grid is at -6.2V and the second grid at +6.2 V, then postitively charged particles entering the detector would naturally be slowed down at the second grid; this is particularly true for smaller particles, and would tend to exacerbate the effects of Brownian motion, as seen in the top panel of Figure 3. However, the usual "picture" of Brownian motion for heavy particles with a large kinetic energy (compared to the ambient molecules) is a gradual spreading of the particle beam in position and velocity space, as is commonly presented in statistical mechanics texts. However, the trajectories presented in the lower two panels in Figure 3 show sharp trajectory changes, presumably from single-molecule collisions in the detector, that I would not have expected in the large-particle limit of Equation 6. A more detailed sample trajectory with collision points clearly marked might resolve this apparent inconsistency.

A: This inconsistency was due to the above mentioned bug in our numerical code. In the corrected code there are no longer sharp trajectory changes.

- To continue with the above point, although Brownian motion may dominate particle motion at stagnation points in the detector, an applied electric field would tend to decrease this influence; the continuum limit would be some "terminal velocity". Presumably, the weak electric field inside the detector that results in the positive/negative assymetry evident in the top panel of Figure 8 is due to the effective terminal velocity in the detector. This might mean that the electric field configuration can play a greater

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role in detector efficiency than implied here. More emphasis on the neutral-particle trajectory would result in a clearer picture of the effects of Brownian motion.

A: With the corrected code no more significant differences between simulations with different particle charges. The kinetic energy of a 1 nm particle at 1000 m/s is ~39 eV, thus hardly influenced by a potential difference of 6 V.

- Different assumptions about unknown smoke particle properties (particle density, shape, etc.) can also significantly change the effective cross sections calculated in the text. If particles are less dense and aerodynamic effects are larger, mass losses due to heating and sublimation may need to be considered, even for smoke particles. It would be interested to see dependencies on particle properties explored in future work.

A: The need for such simulations has now been pointed out in the conclusions.

In summary, the paper presents results that build upon, but differ significantly from, previous work (Hornayi, 1999). The differences between the continuum and Brownian motion simulations deserve further comment, particularly given the large mass difference between smoke particles and ambient molecules. It should also be noted that the effective cross sections calculated here only partially describe quantities that influence the efficiency of smoke particle collection; the results are presented as a generalization of smoke particle detectors currently in existence, and should not be taken as an absolute efficiency for smoke particle detection in general.

A: Our simulations have been performed for a “typical” geometry of Faraday Cup detectors that are widely in use. The purpose of our paper is to show the basic aerodynamic problems of smoke particle detection for some representative cases. Of course, a major conclusion of the paper is that detailed simulations should be performed for any particular rocket flight, instrument geometry and flow conditions of interest. This should be an integral part of any smoke data analysis.

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Answers to Anonymous Referee #3 General Comments Faraday-cups and other types of instruments have been used on sounding rockets to study the mesosphere for about a decade. These instruments can detect smoke particles of cosmic origin or icy aerosol particles in the summertime. These particles are generally too small to be visible and thus observable by optical methods. It has been realized that the shock wave developing in front of the instrument has a strong influence on the collection efficiency of the nm sized particles. Hedin and his coauthors point out in their work that the continuous air drag model, often used to simulate the effect of the shock wave, is inadequate for particles smaller than about 10 nm. The manuscript is well-written and organized, however I have reservations about some of their results, and would like to ask for further clarifications before recommending the publication of this manuscript. Specific comments The authors apply the Monte Carlo method for tracing nanometer sized particles toward the detector through the shock wave that develops due to the supersonic motion of the sounding rocket. This method is the right choice to solve the problem. However, several of the presented results seem to go against common sense. The conclusion of this referee is that most likely there is a bug in the simulation code. These indications are summarized below.

1) In Fig. 4 the probability of detection decreases close to R = 0 for all particle sizes. Is there a reason why smoke particles entering the detector at R = 0 would have a smaller probability being detected than those entering for example at R = 20 mm?

A: No, there is no reason for smoke particles entering the detector at R = 0 to have a smaller detection probability than those entering for example at R = 20 mm. This was due to a bug in the simulation code and has now been corrected.

2) Figure 4 shows the probability of detection of particles with 20 nm radius being approx 70 % at its maximum. This is about the same as for particles with 5 nm radius. One would expect that in the large particle limit the continuous and Brownian models would give the same answer. The authors put this threshold around 10 nm. Clearly the continuous model would give close to 100% detection (compare to Fig. 2).

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A: Yes, in the large particle limit the continuous and Brownian models give the same answer. Also this was an effect of a bug in the simulation code that has now been corrected.

3) Figure 3 shows the Brownian motion of smoke particles with 5 nm radii. There are very abrupt changes in the particles trajectory. Often the deflection is 90 degrees or more and these occur even outside the shock region. How do these collisions happen? The 5 nm radius corresponds to about 1.5 x 10Ĺ-21 kg in mass, that is over 33,000 times heavier than the N2 molecule. It is very hard to imagine a series of collisional events that would change the trajectory by as much as shown in the picture. Rather, one would expect very smooth trajectories for these smoke particles.

A: These abrupt changes in the particle trajectories were an effect of a bug in the simulation code. There were instances where too many collisions occurred within one time step. This has now been corrected in the updated numerical code.

These discrepancies in the presented results suggest the need for checking the numerical procedures and, most likely, to re-run the calculations. The same error might have affected other results presented in the work.

A: Yes.

The effect of dust charge has been omitted from the model description (section 2).

A: Yes. A short section about this has been added.

Figure 7: It is hard to judge from this figure if venting the detectors helps or not to enhance performance. In the figure the 50 % transmissive detector has maximum detection efficiency only 50% and cannot be directly compared to the detector without a vent. Perhaps would be better to normalize to the actual area of the collector surface. This also applies to the conclusions presented on p. 1196, lines 9-24.

A: After re-running the calculations the figure is clearer and the conclusions in the text has been re-formulated.

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Technical corrections 1) The method the authors apply in tracing the motion of the smoke particles is widely known as Monte Carlo. This should be noted.

A: Yes, this is now noted in the text.

2) Page 1186 reviews the instrument used for the in-situ detection of mesospheric aerosols. The referee is aware of three flights using magnetically shielded detectors. These should also be mentioned as they work on a similar principle. See for example Smiley et al, J. Atmos. Solar-Terr. Phys. 68, 114, 2006 or Robertson et al. IEEE Trans. Plasma Sci. 32, 716, 2004.

A: Yes, the magnetically shielded detectors are now also mentioned and the two papers by Smiley et al. and Robertson et al. are now referenced to.

3) P. 1191, line 12. Change to: "Second, the..."

A: Yes, this has been changed.

4) P. 1193, line 1. It is stated that the time step is dt. What is the relation of this to the mean collision time?

A: The model time step dt is generally smaller than the mean collision time in the unperturbed atmosphere. This is now clarified.

5) P. 1193, lines 15 - 17. A table should be presented listing the number densities and temperatures for the given altitudes in case one would like to reproduce the DSMC calculations.

A: A table has been added listing the temperatures and number densities for the given altitudes.

6) P. 1194, line 1. Change "...should be..." to "is".

A: This has been changed.

7) P. 1194, line 20. The "...certain distance..." is not informative enough. Better to use

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something like: in the undisturbed region in front of the detector.

A: Yes, we have now used “in the undisturbed region in front of the detector” as suggested.

8) P. 1195, line 11. It is stated that “Essentially all modeled particle sizes will be detected at and above 95 km.” Without looking at the figure this sounds like everything is detected. Are the authors trying to say that all particles sizes are sampled, although with a different probability?

A: This part has been reformulated after re-running the model

9) P. 1203, eq. A15. Isn’t Vg supposed to be Vg0?

A: Yes.

Interactive comment on Atmos. Chem. Phys. Discuss., 7, 1183, 2007.

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