# THE CHARGE BALANCE IN THE PRESENCE OF METEORIC SMOKE IN THE UPPER MESOSPHERE UNDER WINTER CONDITIONS – PRELIMINARY RESULTS


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## ABSTRACT

Three winter flights of ECOMA payloads took place before, during and after the peak of the Geminid meteor shower in 2010 with the aim of studying the effect of an enhanced flux of meteors in the atmosphere. This paper will use data from all the plasma and one particle instruments (ECOMA). We present and comment the performance of the instruments on these three flights and document a clear change of payload potential in the exact height range where negatively charged smoke particles are present.


## 1. INTRODUCTION

A number of studies underline the importance of understanding the physical, photochemical and radiation processes in the upper atmosphere in order to understand what goes on in the whole atmosphere, including the long-term variations (natural and anthropogenic) that constitute climate variations. A recent study [1] states that both observations and models in the height region 50 to 80 km still are in a state of development, and while the overall agreement of models with observations is encouraging, an improvement of the situation is desirable. The thermal structure of the mesopause region (80 to 120 km) is influenced by a number of complex physical and chemical processes (e.g., radiation processes in non-local-thermodynamic equilibrium, energy exchange between $CO_2$ an O, dissipating gravity waves, turbulent transport of energy, momentum, and source constituents, energetic particle equilibrium). We need more robust observations of various atmospheric parameters from this height region in order to discriminate the influences of the different processes in a quantitative way and to indentify possible trends [1].

In 2008 and 2010, six ECOMA rocket payloads were launched from Andøya Rocket Range (69˚N) in northern Norway in the periods 30 June – 12 July and 4 – 19 December, respectively. The payloads carried different types of plasma probes to measure positive ions and electrons, as well as a set of particle detectors for measurements of charged and neutral smoke particles and NLC/PMSE particles. Additional on-board instruments measured neutral temperature and density. The summer launches took place during different geophysical situations and at different times of the day (two near noon and one near midnight), while the winter launches all took place in the morning hours and at almost the same solar zenith angle. During all three summer flights, the payloads flew through a noctilucent cloud (NLC); polar mesosphere summer echoes (PMSE) were present only during the first and third launch. All flights were accompanied by a host of active and passive ground-based observations. Many results from the launches in 2008 have been reported in [2] and by eight papers in a special issue prefaced by [3]. The charging properties of meteor smoke and implications for seasonal variation that we have learned in the ECOMA programme have been published in [4]. The processes of electron loss in the presence of meteoric smoke particles have been studied in more detail, using the same flights as this paper, and therefore perhaps in similar preliminary fashion in [5].

In this paper we will concentrate on the performance of the different plasma probes in December 2010 with and without the presence of meteor smoke particles.

## 2. INSTRUMENTS AND DATA

Of the instruments on board the ECOMA payload, this paper uses the ECOMA instrument [4], the Faraday Experiment [5], the Positive Ion Probe (PIP) and Electron Probe (EP) [6], [7], and the Multi-Needle Langmuir Probe System (m-NLP) [8].

The m-NLP sensors on ECOMA are four identical needles (see Fig. 1) held at four different, small, fixed potentials such as shown for two needles in Fig. 2. It is important that the needle diameter is much smaller than the needle length and that it is much smaller than the Debye length in the target observation height. The braid is kept at the same potential as its needle so that the observation geometry in the plasma is not perturbed from the situation with one long, thin needle (or cylindrical probe) at a given potential. The current is measured from the needles only. The largest m-NLP potential was 5.1 V so as to disturb the other plasma measurements on board as little as possible. The


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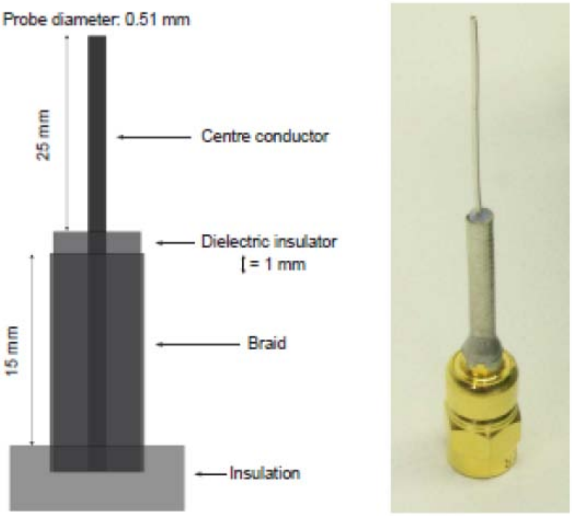
smallest potential was 2.5 V (both with respect to the payload potential), and the other two equidistant between those two values. When the square of the needle current is plotted as a function of needle potential as in Fig. 2, the slope of the regression line depends only on fundamental constants, the geometric dimensions of the needle and the local electron density [8]. Most importantly, the slope is independent of the payload potential. The intersection of the regression line with the potential axis yields the payload potential.




(a) Technical probe drawing (b) Manufactured probe

*Figure 1. The m-NLP instrument probe [8]*

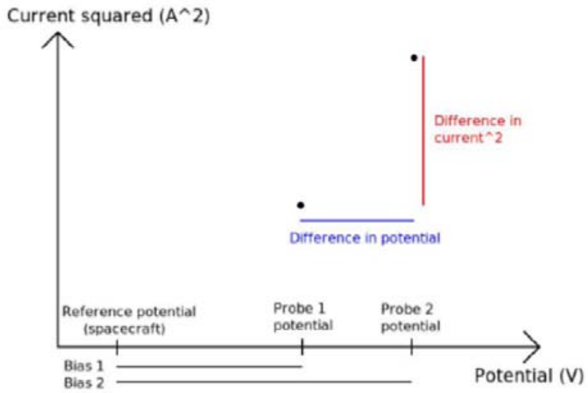



*Figure 2. The m-NLP analysis method [8]*

| Flight | Date | UT | Apogee | Conditions |
|---|---|---|---|---|
| ECOMA 7 | 04.12.2010 | 04:21 | 135 km | Before Geminids; Smallest electron density ever measured by rocket |
| ECOMA 8 | 13.12.2010 | 03:24 | 138 km | Geminids maximum; aurora near horizon |
| ECOMA 9 | 19.12.2010 | 02:36 | 136 km | After Geminids maximum; quiet ionosphere |

*Table 1. Launch times, apogees, and launch conditions of the three flights presented here. See also [5].*

Fig. 3 shows the electron density profile from ECOMA 7. The red line is from the Faraday Experiment, using all usable frequencies, Faraday rotation as well as absorption [5]. It is the profile we attach most credibility to, as it stems from Faraday rotation between the ground-based transmitter and the receivers on the payload. However, it gives only one value per spin rotation period of the payload. To our knowledge, this profile is the lowest electron density profile ever measured by this rocket-borne method at auroral latitudes. The blue and green lines give the corresponding profile measured on upleg and and downleg with the m-NLP completely independently, but on the same payload. Ideally, the red and blue lines should coincide at all heights. Below 86 km, the blue line exhibits interference from the boom deployment and should not have been drawn in this preliminary plot. Also, it would appear that the m-NLP did not perform well at electron densities below $10^8$ $m^{-3}$, a very small electron density for the D-region. Between 86 and 105 km, the values from m-NLP are nearly twice as large as the values from the Faraday experiment. The m-NLP measures the electron density independently of the payload potential, but near the payload. At this time, we attribute the discrepancy to wake effects near the payload, which do not affect the Faraday experiment. Further work is needed to confirm this explanation. The currents measured with the four m-NLP needles are digitally filtered to remove the spin frequency and a large number of higher harmonics before further processing. We will check in the near future how such filtering might 'average' the currents from ram and wake during the spin.

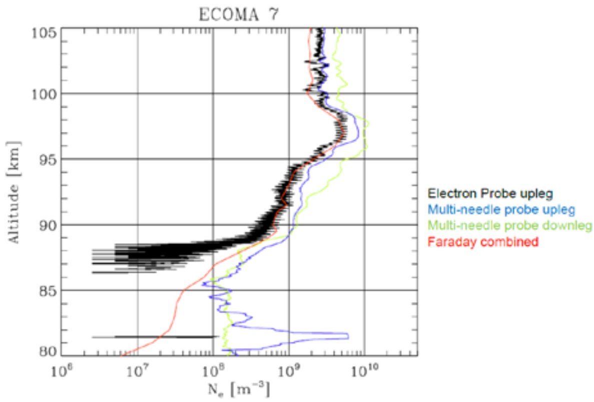



*Figure 3. Electron density profiles from ECOMA 7 using three independent instruments, two on upleg and m-NLP both from upleg and downleg. The blue and green lines are unreliable below 86 km.*

The green line is the electron density profile from the m-NLP from downleg. It is included to show how much the electron density changes over a horizontal distance of several tens of km. The black line is the electron density profile from the electron probe (EP), which gives a relative value and must be normalised at one altitude. Here, we have normalised the profile to the Faraday profile at 95 km. This profile still exhibits a strong spin modulation which we did not have time to remove before the ESA Symposium. Below 90 km and above 98 km, the EP profile deviates somewhat from the Faraday profile, presumably due to changes in the instrument's equivalent area in different flow regimes. Experience from earlier flights encourages us that these deviations can be explained by physical processes after further work. Also the EP does not appear to be reliable at electron density values smaller than $10^8$ $m^{-3}$. Note that all three instruments independently detect a small increase between 91 and 92 km, where a sporadic E layer was observed at the same time with the EISCAT radar some 125 km away.

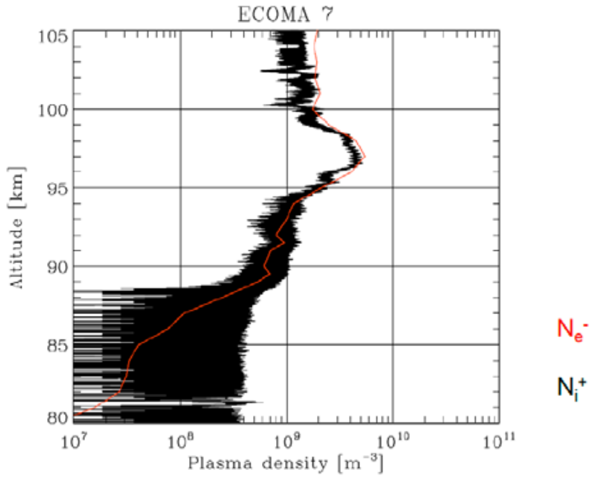



*Figure 4. Electron density from the Faraday experiment and positive ion density from PIP on upleg (ECOMA 7)*

Fig. 4 compares the red line from Fig. 3 with the positive ion density profile measured with PIP, also on upleg. This profile also needs spin removal before further processing. As EP, PIP gives a relative profile, and we have normalised it to the Faraday profile at 95 km. Also PIP exhibits the small maximum near 97 km. There may be flow and sensitivity issues yet to be studied above 98 km, and the instrument appears to perform unreliably at plasma densities below $10^8$ $m^{-3}$. To the degree of detail visible here, we observe charge neutrality, but see [5].

Fig. 5 is analogous to Fig. 3, but for ECOMA 8. The feature in the m-NLP profile near 82-83 km is an artefact of boom deployment. The m-NLP system shows up to twice as many electrons $m^{-3}$ than the Faraday experiment, presumably due to wake effects. Spin modulation has unfortunately not yey been removed from the EP profile, which was normalised to Faraday at 97 km. In Fig. 6, the spin modulation has not yet been removed from the PIP profile, and it has been normalised to the Faraday Profile at 100 km. We obviously have more work to do concerning the sensitivity of PIP at flows of different velocities.

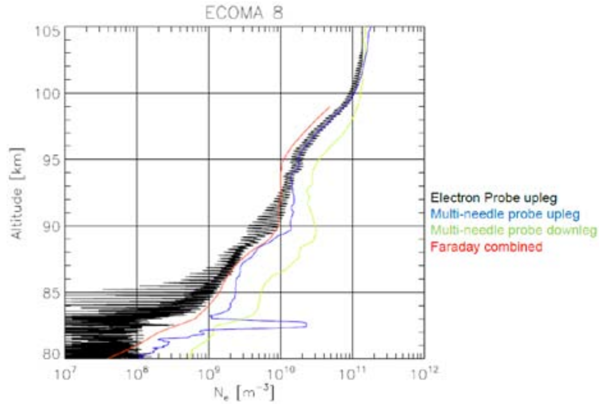



*Figure 5. As Fig. 3, but for ECOMA 8*

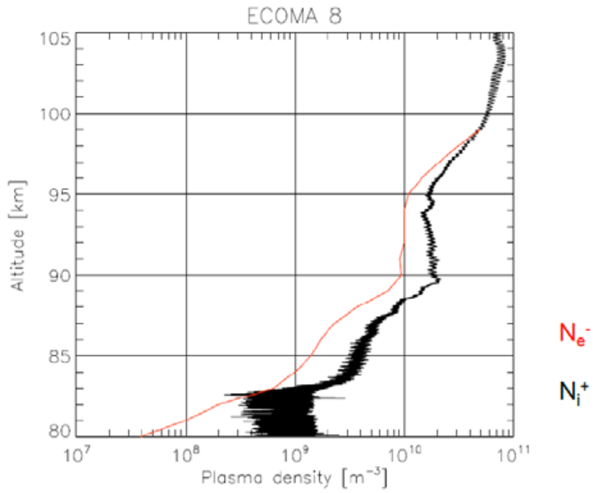



*Figure 6. As Fig. 4, but for ECOMA 8*

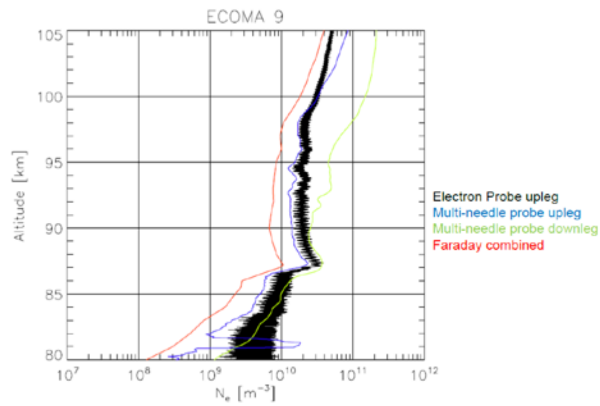



*Figure 7. As Fig. 3, but for ECOMA 9*

Fig. 7 displays the same kind of data as Fig. 3, but for ECOMA 9. This time, the EP profile has been normalised to the m-NLP profile from upleg at 99 km. The m-NLP profile shows the artefact from boom deployment at 81 km, and perhaps we ought to not have plotted the profile below 82 km. Fig. 8 is analogous to Fig. 4, but for ECOMA 9. The same general comments apply to Figs. 7 and 8 as to the other pairs.

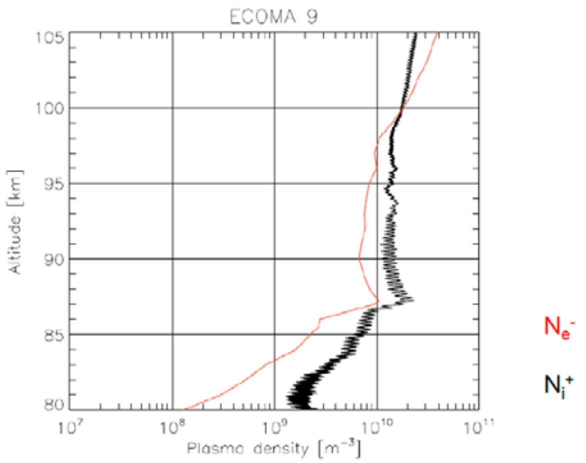



*Figure 8. As Fig. 4, but for ECOMA 9. Normalisation altitude 100 km.*

Fig. 9 shows in the right panel how the payload potential varied during the ECOMA 8 flight according to the m-NLP. While the payload potential was nearly constant near -2.5 V to -2.6 V, it became much less negative in the height region 85 to 100 km on upleg. We have never had the instrumentation to measure a profile of payload potential at several times during a flight. The left panel of Fig. 9 shows the number density of charged (meteoric) smoke particles from the ECOMA instrument [4]. Obviously, the payload potential excursion happens at the same height where we observe a layer of negatively charged smoke particles, and the two profiles are very similar, even if not exactly mirror images of each other. We observe similar effects on ECOMA 7 and ECOMA 9. Our tentative explanation is that about $8 \cdot 10^7$ m$^{-3}$ of the approximately $2 \cdot 10^9$ m$^{-3}$ negative charges have become attached to smoke particles. Therefore, there are fewer free electrons, which have much larger mobility than smoke particles, and there is correspondingly less negative charging of the payload due to electrons impinging on the payload from all sides. The charged smoke particles collide only with the payload's front deck, a much smaller surface area. Assuming that most of the (meteoric) smoke particles were negatively charged, which we will know after further analysis of the ECOMA data, our observation would also agree with another possible physical process: Glancing collisions of smoke particles on the payload skin could knock out electrons from the payload, thus leading to a smaller negative potential.

## 3. CONCLUSIONS AND OUTLOOK

As expected, we observed no strong electron bite-outs in December. The payload potential becomes less negative in the presence of meteor smoke particles, either because some of the otherwise free electrons become attached to smoke particles and lose their mobility, or because the slanting impact of smoke particles on the payload skin removes electrons from the payload. The multi-needle probe measures a high-resolution electron density profile in the immediate vicinity of the payload, independent of the payload potential, but presumably these measurements include wake effects. The Faraday experiments measures the electron density profile as the derivative of the total electron density between the transmitter on the ground and the receiver on the moving payload – without wake effects but with coarser height resolution. For future sounding rocket launches, we recommend combining the Faraday experiment, the Multi-Needle Probe and the Positive Ion Probe as a plasma diagnosis package.

This paper shows early, preliminary results from the data analysis after less than six months. Additional work will refine the details of the profiles, hopefully remove spin modulation and yield much more information by combining information with other on-board and ground-based results.

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## 4. REFERENCES

1. von Zahn, U. & Berger, U. (2011). *Langfristige Änderungen in Eigenschaften der oberen Atmosphäre.* Nordrhein-Westfälische Akademie der Wissenschaften und der Künste, NM478, ISBN 978-3-506-77348-7, Verlag Ferdinand Schöningh, Paderborn, München, Wien, Zürich.

2. Rapp, M. Strelnikova, I., Strelnikov, B., Friedrich, M., Gumbel, J., Hoppe, U.-P., Blix, T. A., Havnes, O., Bracikowski, P., Lynch, K., Knappmiller, S. (2011). Microphysical properties of mesospheric aerosols: An overview of in-situ results from the ECOMA project, in: IAGA Special Sopron Book Series, Vol. 2, *Aeronomy of the Earth's Atmosphere and Ionosphere*, edited by M.A. Abdu, D. Pancheva & A. Bhattacharyya, Springer, ISBN: 978-94-007-0325-4.

3. Rapp, M. & Robertson, S. (2009). ECOMA/MASS: aerosol particles near the polar summer mesopause. *Ann. Geophys.* 27, 823-1456.

4. Rapp, M., Strelnikova, I., Strelnikov, B., Hoffmann, P., Friedrich, M., Gumbel, J., Megner, L., Hoppe, U.-P., Robertson, S., Knappmiller, S., Wolff, M., Marsh, D. R. (2010). Rocket-borne in-situ measurements of meteor smoke: Charging properties and implications for seasonal variation, *J.Geophys.Res.-Atmospheres* 115, D00I16.

5. Friedrich, M., Rapp, M., Blix, T. A., Hoppe, U.-P., Torkar, K. (2011). Electron loss and meteoric dust in the mesosphere. *Proceedings of the 20th ESA Symposium on Rocket and Balloon Programmes and Related Research, Hyères, France, May 2011, Editor Leny Ouwehand, ESA* **SP-700** *(this issue).*

6. Brattli, A., Lie-Svendsen, Ø., Svenes, K., Hoppe, U.-P., Strelnikova, I., Rapp, M., Latteck, R. & Friedrich, M. (2009). The ECOMA 2007 campaign: rocket observations and numerical modeling of aerosol particle charging and plasma depletion in a PMSE/NLC layer. *Ann. Geophys.* 27, 781-796, www.ann-geophys.net/27/781/2009/

7. Brattli, A., Blix, T. A., Lie-Svendsen, Ø., Hoppe, U.-P., Lübken, F.-J., Rapp, M., Singer, W., Latteck, R. & Friedrich, M. (2006). Rocket measurements of positive ions during polar mesosphere winter echo conditions, *Atmos. Chem. Phys.*, 6, 5515–5524, www.atmos-chem-phys.net/6/5515/2006/

8. Bekkeng, T. A. (2009). *Prototype Development of a Multi-Needle Langmuir Probe System.* Master Thesis, University of Oslo, Department of Physics.


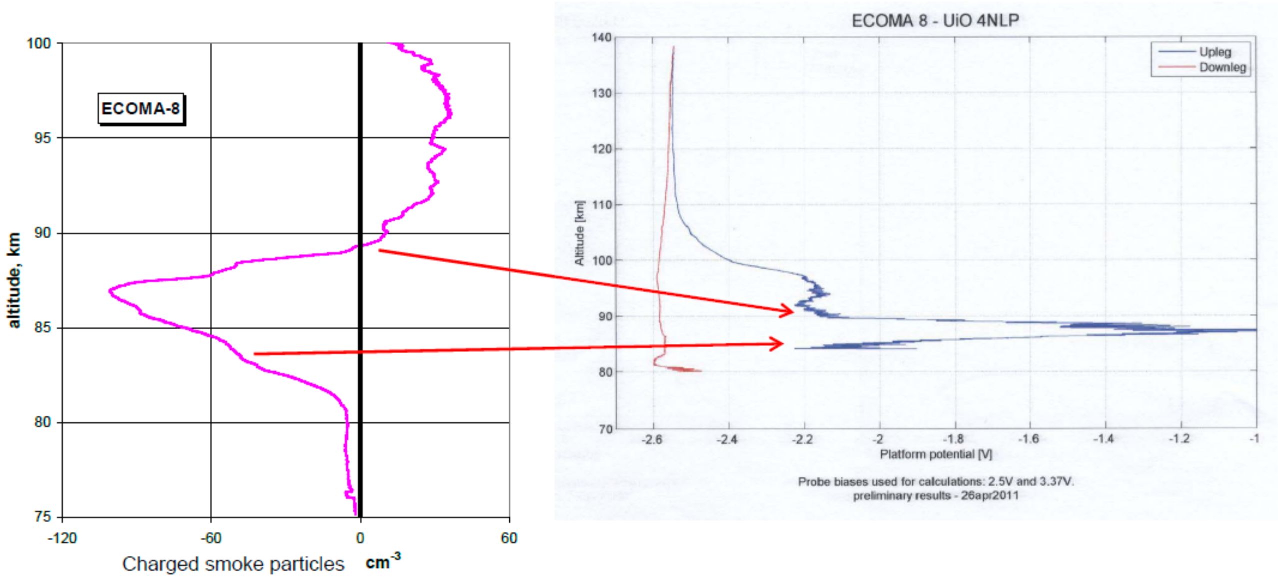


*Figure 9. The payload potential becomes less negative in exactly the height region where we observe negatively charged (meteoric) smoke particles with the ECOMA instrument. The red arrows mark the same altitudes in the two panels, which have different altitude scales.*