IN SITU OBSERVATIONS OF A DYING SPORADIC *E*-LAYER

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ABSTRACT

One of the three rockets of the ECOMA 2008 campaign was intended to be launched into a situation without PMSE or NLC. Also the ionospheric conditions during that flight were very quiet, but unexpectedly a sporadic *E*-layer was observed during upleg, which was no longer present on downleg. The existence of the layer prior to the rocket launch was confirmed by the Tromsø ionosonde some 120 km away, but is also supported by the meteor observations with the ALWIN VHF-radar at the Andøya Rocket Range. Data from two plasma probes, a radio wave propagation experiment and the photo-electron channel of the ECOMA particle detector registered clear signatures at 109 km, whereas optical measurements do not show any discernible features. The sporadic layer is put in context with comparable observations, and its effect on the ECOMA instrument is tentatively explained.

1. INTRODUCTION

Generally electron densities of the ionosphere increase smoothly with altitude reaching a first peak near 100 km (*E*-region) and another, more pronounced one, in the *F*-region. On occasions however, there are departures from this smooth and reasonably understood behaviour, both depletions and enhancements. The former, aka as bite-outs, predominantly occur in polar summer in the 80 to 90 km region and are attributed to electrons attaching to ice crystals, whereas the latter can be observed essentially at all seasons and latitudes and are known as sporadic *E*-layers (E_s). In the ECOMA campaign conducted from the Andøya Rocket Range in Summer 2008 one rocket was intended to be flown into "normal" condition, *i.e.* in absence of noctilucent clouds (NLC) or polar mesospheric summer echoes (PMSE). This flight, coded ECOMA-5, took place on July 7th, 2008, at 21:24 UT at a solar zenith angle of 86.5°. As anticipated, the electron density profile did indeed not show pronounced signatures of either PMSE or NLC. In Fig. 1 electron densities (from all latitudes and all based on rocket-borne wave propagation data) from the solar zenith range 86.5°±5° are plotted. Of the 32 profiles extending beyond 100 km, four show a prominent layer in the *E*-region, whereof the one measured by

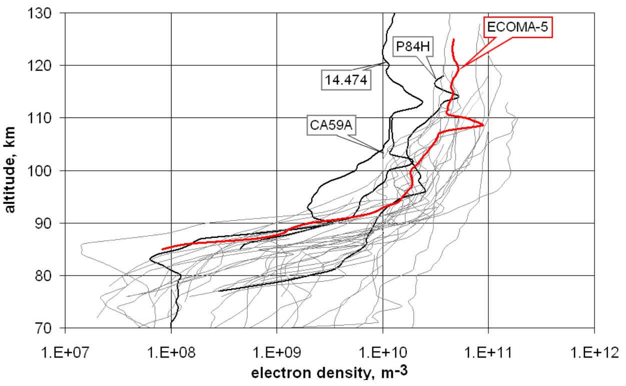

Figure 1. Electron densities measured at solar zenith angles ±5° from the 86.5° during the flight of ECOMA-5. Note the huge variability of three orders of magnitude in the D-region compared to only about one in the E-region. Profiles displaying a sporadic E-layer are highlighted

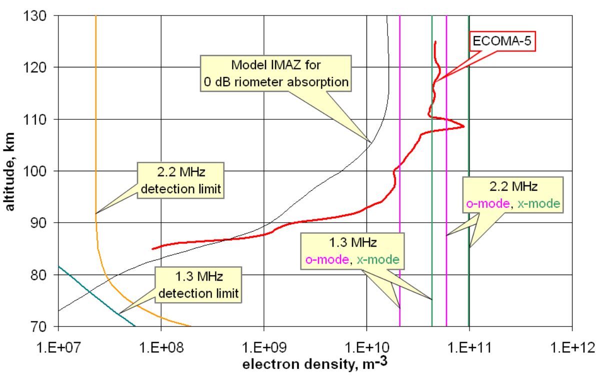

Figure 2. The ECOMA-5 electron density profile and the corresponding prediction by the empirical model IMAZ for 0 dB riometer absorption. The detection limits for the two lower sounding frequencies are indicated, as well as their total reflection densities for the respective o- and x-modes

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ECOMA-5 is the most pronounced. Given the small number of profiles reaching the *E*-region it is certainly "daring" to conclude that E_s occur an eighth of the time, but surely they are not an extremely rare phenomenon since none of the rockets was intentionally launched into an E_s. This conclusion is in general agreement with novel satellite observations of E_s on the basis of radio occultation techniques [1].

2. DERIVING PLASMA DATA FROM THE FLIGHT ECOMA-5

For plasma measurements all ECOMA payloads carried a wave propagation experiment (Faraday rotation) using four frequencies (1.300, 2.200, 3.883 and 7.835 MHz), a fixed bias Langmuir probe and a gridded spherical probe for positive ions. In addition, the outermost grid of the ECOMA particle detector (see [2] for details) is negatively biased and hence the current it collects is also a measure of the density of positive ions. In Fig. 2 we again pre-empt the final electron density profile together with what the empirical model of the auroral zone IMAZ predicts for 0 dB riometer absorption [3]. Clearly in the height region which predominantly contributes to riometer absorption (85 to 95 km) the present profile is even below the model indicating very quiet conditions. The figure also contains important limits relevant for the wave propagation technique, the basis of our absolute values. On the left of the figure two curves indicate the practical detection limits for the two lower sounding frequencies according to [4]; obviously the present measurements do not come close to these limits. The signal of the 1.3 MHz receiver which should be the most sensitive at low altitudes was, however, always solid and far above the noise level, but the raw data (both Faraday rotation and absorption) simply do not make sense and contradict the probe results. The only explanation we can put forward for this deficiency is that due to the very pronounced E_s layer and the very low *D*-region density the waves of lower frequencies were not evanescent, as is always tacitly assumed for this type of experiment. The rocket borne receiver thus presumably observed a beat pattern between the upgoing wave and the wave reflected at the E_s layer. Contrary to normal practice we here also derive Faraday rotation from the downleg of the 1.3 MHz signal. Due to the more oblique ray from the ground transmitter to the payload such data are of poorer quality, but we here only use them to test whether in absence of the E_s at the time of the downleg the 1.3 MHz signal is usable. With all due caution, the resulting electron densities form a plausible extension of the upleg data and thus strengthen the argument made above why the upleg data of that frequency were useless. Fig. 3 shows the remaining credible results of the various sounding frequencies.

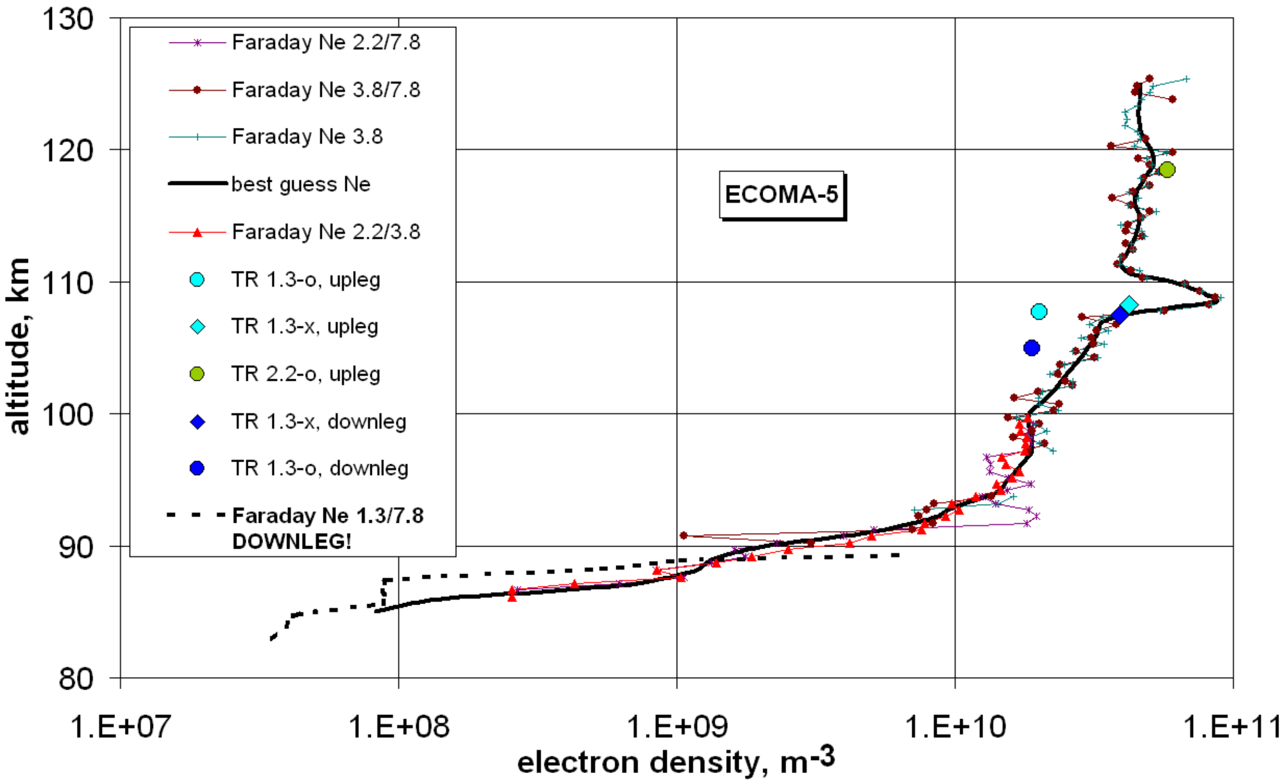

Figure 3. Electron densities from the various sounding frequencies of the upleg of ECOMA-5. Because of the interference due to the pronouncel reflection of the 1.3 MHz signal at the sporadic E-layer only its total reflection (TR) can be used. For the downleg result, see text

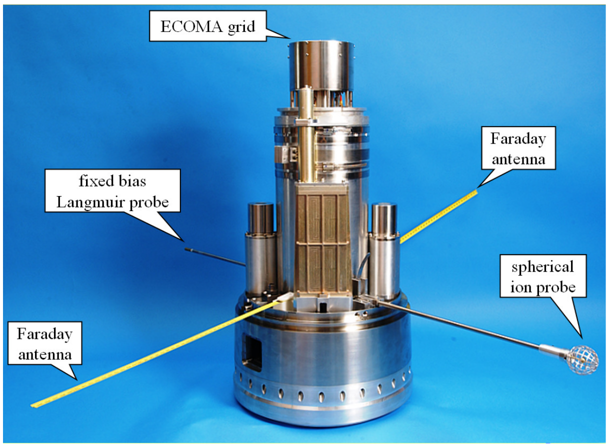

Figure 4. Physical arrangement of the various plasma sensors on the payload's forward section in flight configuration

The radio wave propagation data provide the backbone because they are unaffected by payload charging or aerodynamic effects, but only provide a height resolution of typically one or two values per kilometre.

All ECOMA payloads also carry a probe for electrons (cylindrical Langmuir type with fixed bias) and a gridded, spherical ion probe. These probes are mounted on hinged booms. In addition the ECOMA instrument, the main experiment on these payloads, has two biased grids at the entrance to keep out thermal plasma which could potentially interfere with the aerosol detection.

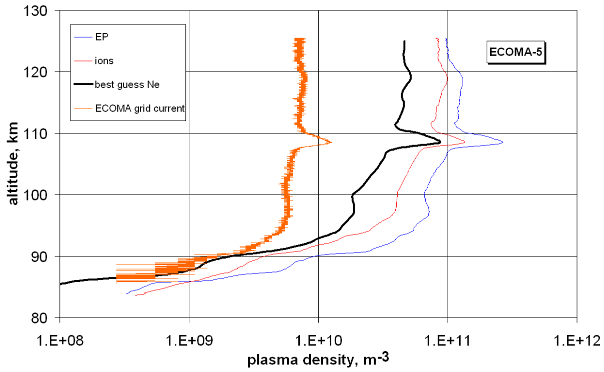

Figure 5. Nominal plasma densities due to various probes and probe proxies

These grids are biased by ±3 V whereof the outer grid is negative. Hence the current observed by this grid is due to ions and thus a measure of their number density. Fig. 4 shows the location of the hinged probes and the ECOMA instrument in the forward (ram) location. The conversion of the current to the cylindrical Langmuir probe to electron density - to a good approximation according to [5] - only depends on the probe's bias relative to the plasma. The current measured by the gridded spherical ion probe is primarily due to the probe's velocity through the plasma, whereas the contribution by the ions' thermal velocity is small and an ion mass of 32 amu and a model temperature profile suffice [6]. The current measured by the exposed,

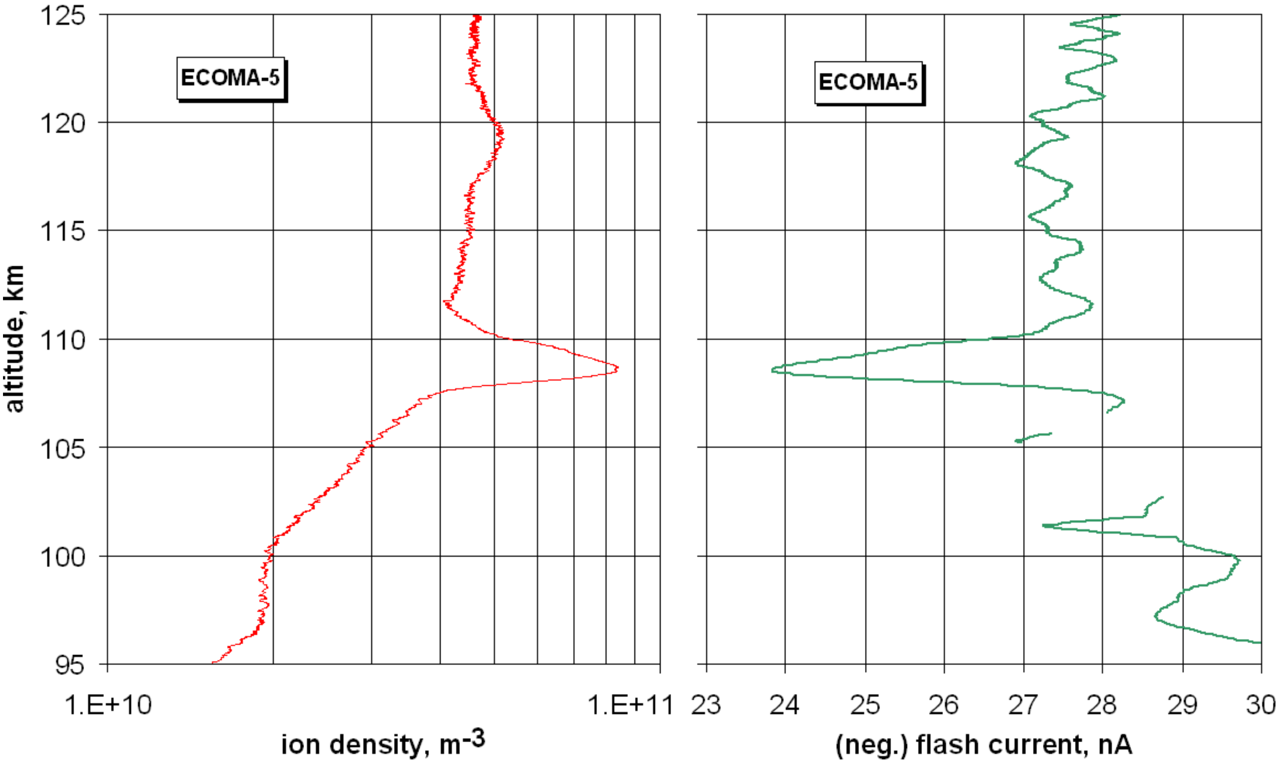

Figure 6. Blow-up of the ion density near the sporadic E-layer (left) and the current to the ECOMA detector produced by xenon flashes (right)

negatively biased ECOMA grid must be a function of the angle between rocket axis and velocity vector, but also of the effective potential *vs.* that of the plasma. Because the (proper) probes are on sideways deployed booms, it is reasonable to assume that at least once in a spin period the probes extend outside the shock cone. Hence these probes provide a basic resolution of one good value per spin period (*i.e.* 4 s^{-1}) both on up- *and* downleg. Because of its privileged location of the ECOMA instrument in the centre of the payload the grid current did not contain any variation related to the spin; one can therefore make use of the full telemetry sampling rate of 50 s^{-1} of this current, but on downleg the grid is in the wake and the measured current is related to the ion density in a more complex manner and therefore not further considered (Fig. 5). For best resolution above 100 km we use the smoothed ECOMA grid current, normalised to the once-per-spin-period data from the spherical probe, in turn normalised to the wave propagation data (Fig. 6, left).

3. OTHER OBSERVATIONS

The data discussed so far are all from instruments dedicated to measure plasma parameters (Langmuir and ion probe, wave propagation) or could reasonably be expected to "see" plasma density variations (the ECOMA shielding grid). Interestingly, however, also the actual data channel of the ECOMA aerosol detector recorded a signature of the E_s layer whenever the volume in front was ionised by its xenon lamp and corresponding photoelectron pulses were detected at the ECOMA electrode. Maxima of these photoelectron pulses are shown in the right of Fig. 6 and denoted 'flash current'. Strangely, the observed current *decreased* suggesting that whatever ionisable matter exists at that height - arguably NO - is reduced within the E_s. This hypothesis is supported by the mass spectrometer measurements by [7] who found that in the ion composition in an E_s NO^+ was not only relatively reduced (2.5%), but also its absolute density was only a quarter compared to the region above and below, which suggests that neutral NO was similarly lowered.

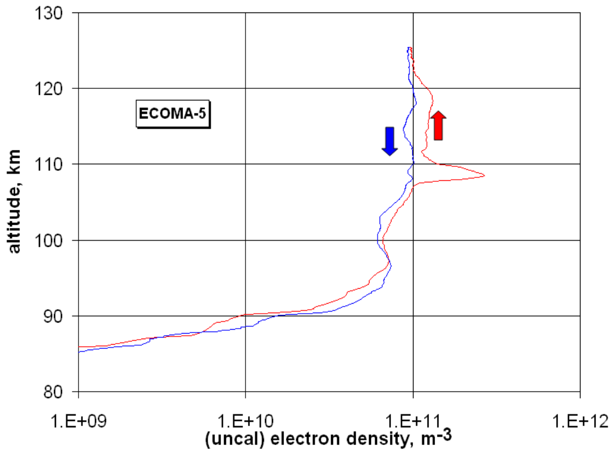

Figure 7. Up- and downleg of the (un-normalised) electron densities according to the Langmuir probe. The essential agreement below 105 km is evidence of a stable ionosphere (red = upleg, blue = downleg)

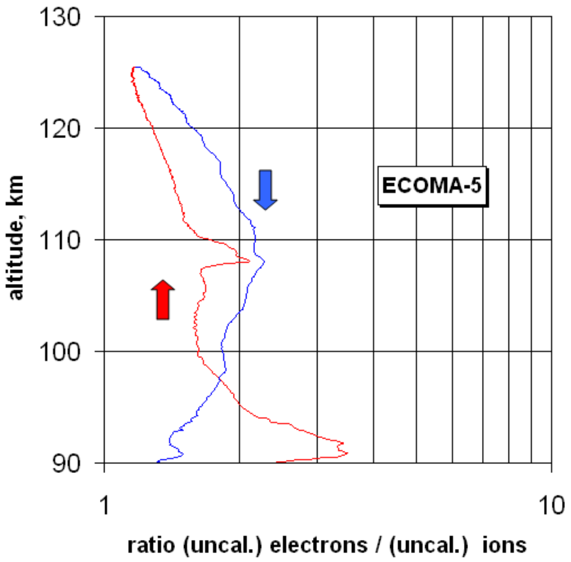

Figure 8. Ratio of the (un-normalised) electron densities to the (un-normalised) ion density on up- and downleg

As already indicated in the title, the sporadic *E*-layer had completely disappeared when the payload passed the same height on downleg (2 minutes later and 34 km away). Fig. 7 shows the (non-normalised) electron densities obtained from the Langmuir probe from up- and downleg. Apart from the sporadic *E*-layer, the agreement between up- and downleg means that (1) using the highest value in a spin period indeed represents the undisturbed plasma density, and (2) that the ionosphere was otherwise quiet and stable.

Another interesting feature observed in the E_s layer is the ratio between the electron density obtained from the Langmuir probe to the ion density of the gridded sphere (Fig. 8). Whereas on downleg (no E_s) this ratio varies smoothly with altitude, there is a distinct signature of the E_s on upleg. If we assume charge neutrality, the ratio implies that inside the E_s the sensitivity of the electron probe increases, or that of the ion probe decreased. Three explanations for that behaviour spring to mind:

(1) the payload potential became less negative and thus the effective positive bias of the Langmuir probe increased and with it the collection efficiency, whereas the ion probe's sensitivity is at the same time somewhat reduced,

(2) the electron temperature was enhanced inside the E_s, or,

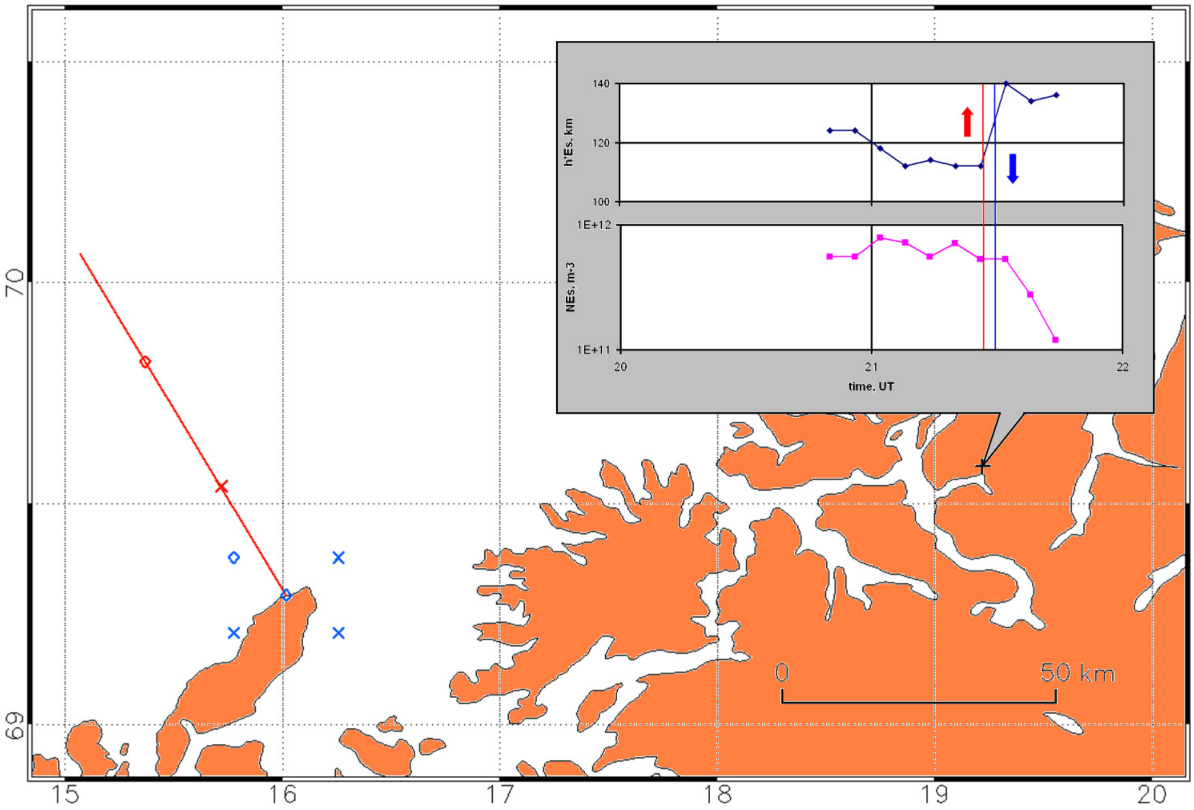

Figure 9. Geography of the rocket trajectory, the intersects of the ALWIN radar with the 109 km layer and the location of the Tromsø ionosonde. An X indicates a layer at 109 km, an O its absence. The insert shows the temporal development of the altitude and peak density of the sporadic E-layer over Tromsø. The times of the up- and downleg of the rocket passing 109 km are indicated

(3) the ions were rather large and thus not fully collected by the ion probe.

We have no indication that explanations (1) or (2) apply, but we have reasonable arguments for explanation (3). [8] measured the ion composition by a rocket borne mass spectrometer in a comparable E_s situation and found Fe^+ to be the dominant ion (77%). Its mass of 57 amu, *i.e.* almost twice that of O_2^+ or NO^+, could conceivably explain the reduced collection efficiency of the ion probe by mass discrimination due to the small bias on the inner collector sphere (-2.5 V). The changing behaviour of the ratio below 100 km is likely caused by the quite different aerodynamics on downleg which has significantly more impact on the ion than on the electron probe measurement.

4. CONCLUSIONS

A sporadic *E*-layer was detected and resolved in detail by a number of independent instruments aboard the rocket payload ECOMA-5. On downleg there was no signature of the layer. The Tromsø ionosonde some 120 km away recorded the same "dying" feature at a somewhat higher altitude and with a more pronounced peak density (Fig. 9). The meteors detected by the 53.5 MHz radar ALWIN at the rocket range at exactly

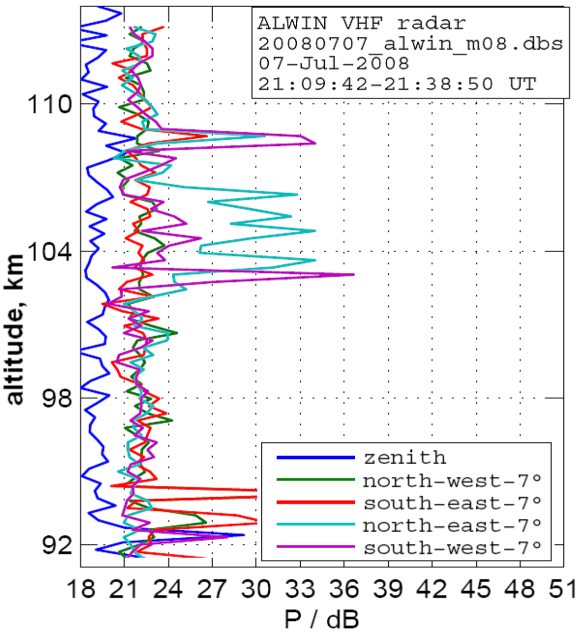

Figure 10. Echo power from the ALWIN VHF radar averaged over 30 minutes. Three of the five beams detected typical meteor signatures at 109 km, presumably the precursors of the sporadic E-layer

the same height as the E_s presumably were the source of the metal ions which E_s are generally believed to consist of (Fig. 10).

Only speculatively explained features are the depletion of the flash current of ECOMA detector and the discontinuity of the electron-to-ion ratio of the probe currents in the layer.

The low density in the *D*-region and the pronounced E_s led to a situation where the generally very robust and reliable radio wave propagation method to measure electron densities had a problem. The two lower sounding frequencies were not evanescent, but were reflected by the E_s and led to a beat pattern between the upgoing and reflected wave, superimposed on the regular signal.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

1. Arras, C., Wickert, J., Beyerle, G., Heise, S., Schmidt, T. & Jacobi, C. (2008). A Global Climatology of Ionospheric Irregularities Derived from GPS Radio Occultation. *Geophys. Res. Lett.* **35**, L14809, doi:10.1029/2008GL034158.

2. Rapp, M. & Strelnikova, I. (2009). Measurements of Meteor Smoke Particles During the ECOMA-2006 Campaign. *J. atmos. solar terr. Phys.* **71**, 477-485.

3. McKinnell, L.-A., & Friedrich, M. (2007). A Neural Network-Based Ionospheric Model for the Auroral Zone. *J. atmos. solar terr. Phys.* **69**, 1459-1470.

4. Jacobsen, T.A. & Friedrich, M. (1979). Electron Density Measurements in the Lower *D*-Region. *J. atmos. terr. Phys.* **41 (12)**, 1195-1200.

5. Smith, L.G. (1969). Langmuir Probes in the Ionosphere, in: "Small Rocket Techniques", North Holland, 1-15.

6. Folkestad, K. (1970). Ionospheric Studies by *in situ* Measurements in Sounding Rockets. Internal NDRE Report **59** (and PhD Thesis).

7. Roddy, P.A., Earle, G.D., Swenson, C.M., Carlson, C.G. & Bullet, T.W. (2007). The Composition and Horizontal Homogeneity of *E* Region Plasma Layers. *J. geophys. Res.* **112 (A06312***),* doi:10.1029/2006JA011713.

8. Roddy, P.A., Earle, G.D., Carlson, C.G. & Bullet, T.W. (2004). Relative Concentration of Molecular and Metallic Ions in Midlatitude Intermediate and Sporadic *E* Layers. *Geophys. Res. Lett.* **31**, L19807, doi:10.1029/2004GL020604.