STATISTICAL STUDIES OF LOW-FREQUENCY ELECTROSTATIC WAVES IN THE IONOSPHERIC *E* REGION

H. L. Pécseli[1], **Y. Larsen**[2], **A. Hanssen**[3], **B. Krane**[4], **J. Trulsen**[5]

[1]***Department of Physics, University of Oslo, N-0316 Oslo, Norway,*** {***hans.pecseli@fys.uio.no***}

[2]***Department of Physics, University of Tromsø, N-9037 Tromsø, Norway,*** {***yngvar.larsen@phys.uit.no***}

[3]***As (2) above but E-mail:***{***alfred.hanssen@phys.uit.no***}

[4]***Norwegian Defense Research Establishment, N-2007 Kjeller, Norway,*** {***bard.krane@ffi.no***}

[5]***Institute of Theoretical Astrophysics, University of Oslo, N-0315 Oslo, Norway,*** {***jan.trulsen@ita.uio.no***}

ABSTRACT

The spectral properties of low frequency electrostatic waves in the polar cap *E* region were studied experimentally by instrumented rockets. By comparison of the spectral index for fluctuations in the potential signal and plasma density, evidence is obtained for deviations from Boltzmann distributions in the electron dynamics. Investigations of the cross correlation between density and potential signals demonstrate that the phase between the two increases approximately linearly with frequency. The characteristics of the fluctuations were analyzed with particular attention to non-Gaussian effects and phase coherent mode couplings of the fluctuations. Short-time phase coherent effects are analyzed and quantified by means of the squared wavelet-bicoherence.

INTRODUCTION

Low frequency electrostatic waves can be spontaneously generated in the ionospheric *E*-region when a steady state electric field component $\mathbf{E}_0$ perpendicular to the geomagnetic $\mathbf{B}_0$-field exceeds a certain threshold value, so that the relative Hall-drift between the electron and ion component becomes larger than the ion-acoustic speed [1, 2]. This particular type of instability (often called the "two stream instability", although this is somewhat a misnomer) is interesting also because it gives a direct coupling between the large scale electric field imposed in the polar-cap ionosphere and the small scale dynamics. This coupling does not involve the intermediate scales. Gradients in plasma density in the direction perpendicular to the magnetic field can enhance or reduce the growth rate of the instability, depending on direction with respect to $\mathbf{E}_0$.

SUMMARY OF SOME OBSERVATIONAL RESULTS

The spectral properties of low frequency electrostatic waves in the polar cap *E* region were here studied experimentally by instrumented rockets [3], using data from the ROSE rocket experiment. The ionospheric conditions and details of the instrumentation relevant for the present data set were discussed in a special issue of *Journal of Atmospheric and Terrestrial Physics* (*54*, 655-818, 1992). Fluctuations in plasma density were detected, as well as potential differences between boom-mounted probes. The rocket was equipped with two sets of probes, giving all together six simultaneous data series for the potential differences, $U_1 - U_6$. The redundancy in the dataset can be used for verifying the consistency of the data, for instance. DC electric field values of approximately 40 and 70 mV/m were measured on upleg and downleg passages of the *E*-region, respectively. The corresponding $\mathbf{E}_0 \times \mathbf{B}_0/B_0^2$ velocities are approximately 800 and 1400 m/s. These are of a sufficient magnitude to excite the Farley-Buneman instability. Electrostatic fluctuations with typical rms amplitudes of 4–8 mV/m were observed in the altitude range 90–110 km for the flights. The intensity of the fluctuations decayed slowly for increasing altitudes, eventually to disappear at around 115 km. A difference in the density and potential root-mean-square fluctuation levels for upleg and downleg conditions was noted, consistent with the increased linear growth rate as the DC-electric field increased [3]. However, the magnitude and altitude variations of the detected phase velocities were practically identical for the upleg and downleg conditions, irrespective of the significant difference in the DC electric fields, $\mathbf{E}_0$.

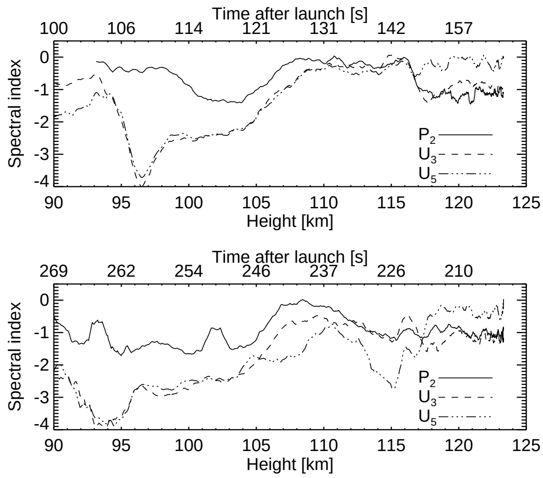

Figure 1: Altitude variation of the spectral index for the probe potential difference (U_1 and U_6) and density fluctuations (P_2) on the upleg and downleg parts of the flight. The two electric field signals originate from two sets of probes on the rocket.

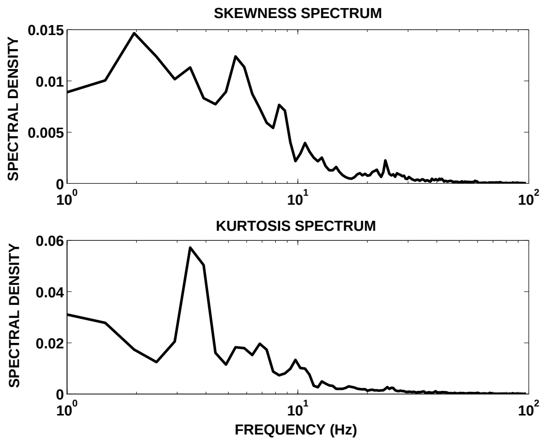

Figure 2: Spectral analysis of the variation of the local skewness and kurtosis of the probability densities associated with the signals for the probe potential difference, U_6. The figure is based on all together 20 overlapping segments, each of duration 2 s [4].

By comparison of the spectral index for fluctuations in the potential signal and plasma density in the high frequency part of the spectrum ($f > 100$ Hz), evidence is obtained for deviations from Boltzmann distributions in the electron dynamics, which would predict fluctuations in density and potential to be proportional, with the same constant of proportionality at all frequencies. Figure 1 shows examples of the altitude variation of the spectral indexes [3]. Investigations of the cross correlation between density and potential signals demonstrate that the phase between the two increases approximately linearly with frequency. Empirical relations were obtained for the frequency dependence of the amplitude and phase relations between fluctuations in density and potential.

The time-resolved statistical properties of the fluctuations can deviate significantly from those associated with a Gaussian process [4]. For short time records as these, it can be difficult to assert that observed deviations from a Gaussian process are significant characteristics of the physical phenomena or merely due to the limited data sets. Here we found that the observed skewness and kurtosis of the amplitude distributions vary systematically with the rocket spin, and argue that the estimators obtained are representative for the ionospheric fluctuations. Simple geometrical arguments demonstrate that the skewness will vary with the rocket spin frequency, while the kurtosis varies with *twice* the rocket spin frequency of approximately 1.7 Hz. This is seen in Fig. 2. The skewness is rather small ($|S| \approx 0.5$) for the present case, and and the peak at the rocket spin frequency is therefore not pronounced. The kurtosis peak is on the other hand clearly visible. We have $K \approx -1$, for the present platycurtic signals, having an excess *below* that for a Gaussian random signal.

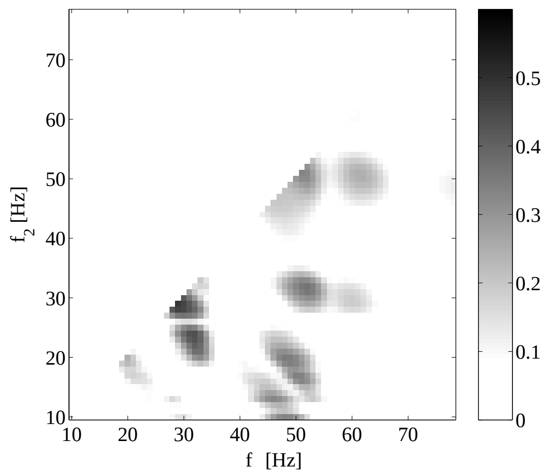

Figure 3: Sample of the squared wavelet bicoherence for the U_6-signal obtained at an altitude of approximately 98.6 km altitude on the downleg part of the flight.

The characteristics of the fluctuations were analyzed with particular attention to non-Gaussian effects and phase coherent mode couplings of the fluctuations. Short-time phase coherent effects in the low frequency part of the spectrum ($f < 100$ Hz) are analyzed and quantified by means of the squared wavelet-bicoherence, as illustrated by a sample in Fig. 3. A peak at the diagonal can indicate second harmonic generation, while off-diagonal signatures are indicative of a phase coherent coupling between frequencies f_1, f_2 and $f_1 + f_2$. Figure 4 illustrates the altitude variation of the bicoherence on the downleg part of the flight. It was found that the bicoherence was largest in altitude regions with the largest fluctuation levels (i.e. the upper part of Fig. 4), which in turn corresponded to regions with the largest growth rates, as obtained from a linear stability analysis, using as input electric fields $\mathbf{E}_0$ and other plasma parameters measured on the rocket. For the upleg part of the flight, the DC electric field, E_0, was smaller than for downleg, and the overall fluctuation level somewhat smaller. For this part of the flight we found a significantly lower bicoherence level, consistent with expectations for a bicoherence caused by nonlinear wave interactions.

Results from data obtained over Søndre Strømfjord in Greenland in 1974 [5, 6, 7], and the present data from the ROSE campaign over northern Scandinavia are compared. The bicoherence results [4, 7] show a remarkable similarity, although these two datasets were analyzed by somewhat different methods. This indicates that the observed phase coherence is a robust feature of the saturated stage of the *E*-region instabilities. This observation can indicate that couplings within the turbulent spectral components is important for the saturation of the linear plasma instability. It might thus be anticipated that energy can couple to linearly damped modes, which thereby constitute a “sink” of wave energy. It is evident, though, that this need not be the *only* saturation mechanism operating.

An interesting discrepancy between phase velocities associated with the fluctuations as observed in laboratory experiments and in space can be noted: in the ionospheric *E*-region we usually find characteristic propagation speeds to be of the same order of magnitude as the ion acoustic sound speed (sometimes even less), while laboratory experiments give velocities closer to the $\mathbf{E}_0 \times \mathbf{B}_0/B_0^2$ velocity [8, 9, 10]. It is for the time being not clear to what extent the laboratory results can be influenced by finite geometry, or the cylindrical symmetry imposed by most of the relevant experiments. Even if these effects play a role, it is by no means obvious that they should give rise to an *increase* in the propagation velocities.

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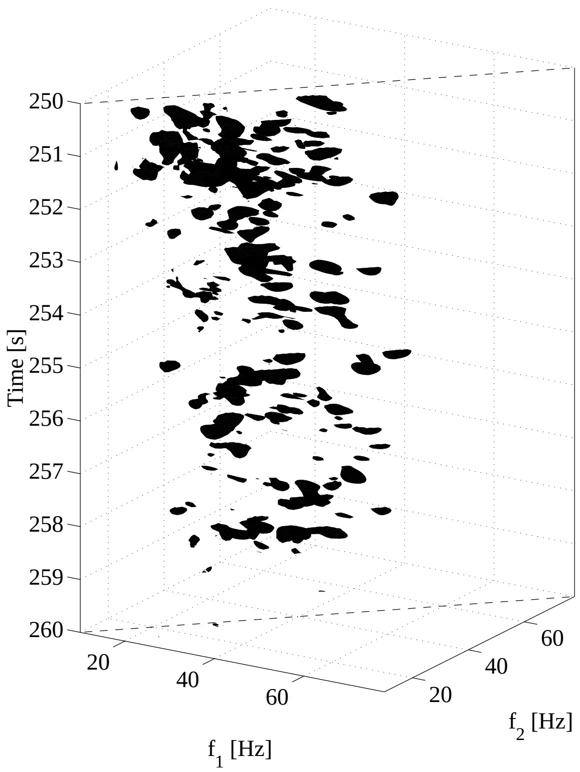

Figure 4: Estimate of the time-resolved squared wavelet bicoherence for the U_6-signal shown at an isosurface level 0.55. The time window corresponds to an altitude interval 103-106 km, on the downleg part of the flight.

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