Radar aurora

Introduction

Strong currents, electrojets, found in both equatorial and high latitude ionosphere, lead to plasma instabilities that can be measured directly by electric field wave instruments carried by rockets, or by coherent radars as different kind of Doppler spectra (Kelley, 1989, pp. 396-419). At high latitudes, the E-region auroral electrojets and field-aligned currents produce 'radar aurora' that are somewhat more complicated than the equatorial radar echoes. In both regions, the two primary plasma instabilities are the two-stream and gradient drift instabilities, and the corresponding echoes are referred to as **type 1** and **type 2**, respectively. The two stream instability is the fundamental mechanism responsible for direct generation of short wavelength irregularities in the electrojet plasma. In addition, at auroral altitudes, there is evidence for a third mode (**type 3**), which is thought to be related to ion cyclotron waves and field-aligned currents especially at the edges of auroral arcs. Recently, however, doubts have been raised against this EIC theory, and it has been proposed that type 3 echoes might be due to type 1 waves originating in narrow sporadic Es layers located at lower electrojet altitudedes (Haldoupis et. al., 1992). **Type 4** echoes are a special type of two-stream events associated with anomalous electron heating by the auroral electrojet waves. Echoes labeled as **type 5** have been observed by Haldoupis and Nielsen (1989).

For a recent review, see Sahr and Fejer (1996).

Type 4 echoes

Type 4 echoes are relatively rare, short lived (from several seconds to several minutes) and variable, and are observed during strongly driven conditions of ion acoustic wave generation (e.g., Haldoupis et. al., 1991, where the main properties of these echoes are discussed together with the shortcomings of the present theories). They are related to **electron temperature enhancements** around an altitude of 110 km. These enhancements are not connected with auroral particle precipitation, since they are much too large (e.g., from 300 K to 1500 K), and because no correlation with electron densities can be found (Wickwar et. al., 1981). Heat conduction from above can be eliminated just from the fact that Te maximizes in the middle of the E - region, and since Ti < Te, the ion population cannot heat the electrons. The correlation with higher-altitude ion temperature indicates a relationship with Joule heating. This relationship must be indirect, since the Joule heating of electrons is negligibly small. One possibility is some kind of plasma instability driven by strong convection electric field, like vd = ve-vi dependent modified two-stream (MTSI, Farley-Buneman) instability. This instability is also confined to region around 110 km, where we find large Hall currents in combination with as low a collision frequency as possible (Schlegel and St.-Maurice, 1981). Electron heating rate due to wave heating is modeled, e.g., by Robinson (1986),

Q = Ne me n* (vd-c)^2

where n* is the anomalous or effective collision frequency (due to scattering of the electrons by the unstable waves; term electron-plasmon collision frequency is used by Jones et. al., 1991 [plasmons are pseudo-particles representing the waves]), and c is the ion acoustic velocity. Equation is analogous to the expression for the Joule (frictional) heating rate, except that the electron-neutral collision frequence is replaced by n* and the neutral gas velocity by c. In paper by Machida and Goertz (1988) this type of heating is actually called **anomalous resistive heating**. EISCAT measurements of n*(h) can be found in Igarashi and Schlegel (1987), and a method of calculating it in Jones et. al., 1991. It is most likely just this enhanced effective electron collision frequency that heats the electrons, and not the parallel wave electric fields as proposed by St.-Maurice et. al. (1981). The theory of this instability is complicated, since nonlinear kinetic theory must be used (Robinson and Honary, 1990).

Most heating events of this kind measured by incoherent scatter radars have lasted several minutes, and typically the time resolution has not been very high. Providakes et. al. (1988) present EISCAT measurements with integration time of about 10 seconds, showing very short lived (< 1 min.) heating events. An interesting findind was the very prompt anticorrelation between Ti and ne. The authors argued that they cannot be observing a temporal effect, since the heating is not able to change density in a few seconds (chemical time constant is typically about 30 s or more, and, more importantly, increasing Te should result to decreasing recombination rate; similarly the time constant for increasing plasma pressure that pushes plasma out of the heated region is measured in hours). The observed anticorrelation could thus be a result of rapid convection of depleted, hot, highly unstable regions through the radar beam.

References

- Haldoupis, C., and E. Nielsen, Very large phase velocities of non two-stream, meter scale irregularities in the high latitude E region ionosphere, *J. Geophys. Res.*, **94**, 13489, 1989.
- Haldoupis, C., K. Schlegel, and E. Nielsen, On type 3 auroral VHF coherent radar backscatter, *J. Geophys. Res.*, **97**, 4109-4120, 1992.
- Haldoupis, C., G. J. Sofko, J. A. Koehler, and D. W. Danskin, A new look at type 4 echoes of radar aurora, *J. Geophys. Res.*,**96**, 11353-11362, 1991.
- Igarashi K., and K. Schlegel, Electron temperature enhancements in the polar E-region measured with EISCAT, *J. atmos. terr. Phys.*, **49**, 273-280, 1987.
- Jones, B., P. J. S. Williams, K. Schlegel, T. Robinson, and I. Häggström, Interpretation of enhanced electron temperatures measured in the auroral E-region during the ERRRIS campaign, *Ann. Geophysicae*, **9**, 55-59, 1991.
- Kelley, M. C., *The Earth's ionosphere: Plasma physics and electrodynamics*, Academic Press, 1989.
- Machida, S., and C. K. Goertz, Computer simulation of the Farley-Buneman instability and anomalous electron heating in the auroral ionosphere, *J. Geophys. Res.*, **93**, 9993-10000, 1988.
- Providakes, J., D. T. Farley, B. G. Fejer, J. Sahr, W. E. Swartz, I. Häggström, Å. Hedberg, and J. A. Nordling, Observations of auroral E-region plasma waves and electron heating with EISCAT and a VHF radar interferometer, *J. atmos. terr. Phys*., **50**, 339-356, 1988.
- Robinson, T. R., Towards a self-consistent non-linear theory of radar auroral backscatter, *J. atmos. terr. Phys.*, **48**, 417-422, 1986.
- Robinson, T. R., and F. Honary, A resonance broadening kinetic theory of the modified two-stream instability: Implications for radar

auroral backscatter experiments, *J. Geophys. Res*., **95**, 1073-1085, 1990.

- Sahr, J. D., and B. G. Fejer, Auroral electrojet plasma irregularity theory and experiment: A critical review of present understanding and future directions, *J. Geophys. Res., 101*, 26893-26909, 1996.
- Schlegel, K., and J. P. St.-Maurice, Anomalous heating of the polar E region by unstable plasma waves 1. Observations, *J. Geophys. Res.*, **86**, 1447-1452, 1981.
- St.-Maurice, K. Schlegel, and P. M. Banks, Anomalous heating of the polar E region by unstable plasma waves 2. Theory, *J. Geophys. Res*., **86**, 1453-1462, 1981.
- Wickwar, V. B., C. Lathuillere, W. Kofman, and G. Lejeune, Elevated electron temperatures in the auroral E layer measured with the Chatanika radar, *J. Geophys. Res*., **86**, 4721-4730, 1981.