ACFs and Turbulence Characteristics from Artificial Field-Aligned Irregularities

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The plasma in the auroral ionosphere may be considered as a flowing turbulent fluid, where turbulence occurs in both the E-region and the F-region. In this study, the auto-correlation function (ACF) is used to derive turbulence characteristics, such as diffusion coefficients and correlation times, from artificially produced backscatter as detected by the CUTLASS radar system. This is accomplished by utilising standard turbulence theory and applying it to the ACFs obtained, as was done in the study by Villain et al. [1], where backscatter from naturally occurring irregularities was examined. It was found that the distribution of diffusion coefficients, for artificially generated backscatter, centred around a value that was about half that corresponding to the return from naturally occurring irregularities. Similarly, the correlation lengths were about twice those corresponding to the natural case. This concurs with a fairly static irregularity distribution for the artificially generated return.

1. INTRODUCTION

SuperDARN data is usually considered in terms of the fitted parameters, e.g. backscatter power and Doppler velocity. This is entirely adequate for most purposes, e.g. the construction of convection maps relating to magnetospheric plasma flow. These parameters are obtained from the ACF, by the FITACF software that uses appropriate signal processing techniques [2], and may be used without any further consideration of the ACF itself. However, a more in-depth study of the properties of the autocorrelation function allows further characteristics to be determined. The CUTLASS radar system, together with other SuperDARN radar systems, uses a pulse scheme consisting of 7 pulses. Each pulse is transmitted and then received, together with associated phase and amplitude information. The lags are obtained by combining information from different pairs of pulses. After this is done for all possible pairs, an 18-lag ACF is obtained. The lags are numbered from 0 to 18 and lag 16 is missing. The ACF is the Fourier transform of the power spectrum. The fitted parameters are calculated by performing a fit to the ACF. The power is taken as the lag-0 power, the spectral width comes from the decorrelation rate, the decay profile, of the ACF and the Doppler velocity comes from a linear fit to the residual phase calculated from the pulse pairs.

2. EXPERIMENTAL ARRANGEMENT

The EISCAT Heating Facility [3], situated at Ramfjordmoen, near Tromsø, Norway, has been operational for around 20 years, during which time many types of ionospheric modification experiment have been conducted. The heater operates by transmitting high-power radio waves into the ionosphere, where they produce FAIs. These FAIs then act as backscatter targets for the CUTLASS radar system. The EISCAT site lies in the field of view of beam 5 of CUTLASS Finland (at Hankasalmi) and beam 15 of CUTLASS Iceland (at Pykkvibær), the distance to the Iceland radar being about twice that to the Finland radar. The data examined in this study came from the Finland radar.

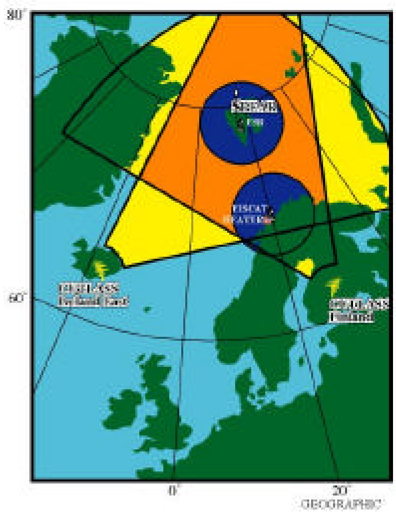

Figure 1: The location of the heater in the CUTLASS field of view.

3. HEATING

The EISCAT Heating Facility consists of a set of cross-dipole antennae that transmit O-mode polarised or X-mode polarised radiation with a frequency of around 4-8MHz. The X-mode radiation is reflected below the height at which interactions occur, thus not usually contributing to heating effects. The upper-hybrid height lies about 6km below the O-mode reflection height and so O-mode radiation may excite plasma instabilities in the auroral F-region. This happens by a coupling to electrostatic waves, leading to an instability called the Parametric Decay Instability (PDI). This process results in the generation of field-aligned irregularities. Experiments carried out using the heater usually consist of power-stepping, spatial sweeping and alternate intervals of heater on and heater off, usually for time periods of 3 or 4 minutes. The data presented in this study were taken during times when the on/off experiment was running, with the ACFs being studied when the heater was transmitting.

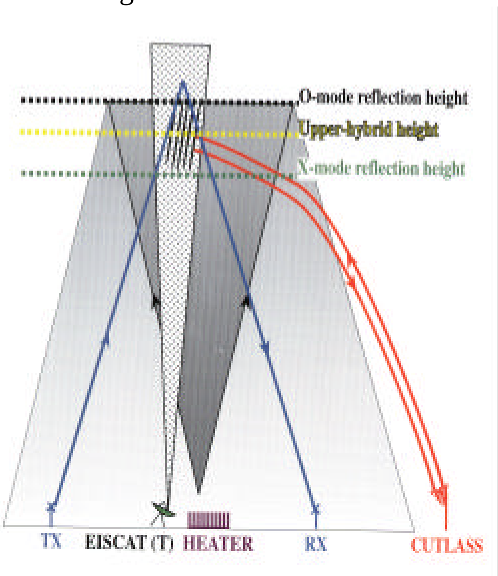

Figure 2: The generation of artificial field-aligned irregularities by ionospheric modification.

4. HEATING DATA

Figure 3 shows a 25-minute duration on 20th October 1999, from 1505UT to 1530UT. There are 3 4-minute-on intervals, separated by periods of 4-minute-off, during this interval. About 30 seconds after 1516UT, CUTLASS changes mode to a new longer-lag mode, described below. The most noticeable aspect of this mode change is the disappearance of the cross-range noise. However, from a scientific point of view, it is the increase in spectral width values that is of most interest. The values of backscatter power and Doppler velocity remain more or less unchanged after the mode change.

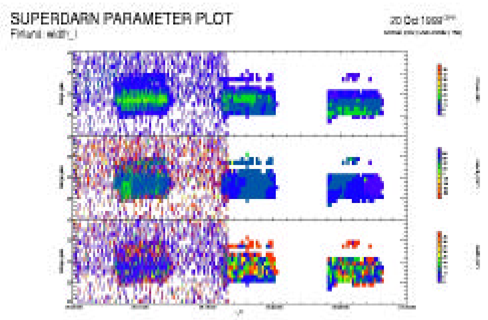

Figure 3: The normal-longer and longer-lag CUTLASS modes in operation.

5. SPECTRAL WIDTHS

A well-known characteristic of heater scatter is the low spectral width values of the backscatter return corresponding to the scatter. Naturally occurring ionospheric backscatter, associated with, say, magnetospheric convection, has spectral width values of the order of a few hundred metres per second, in velocity space. The backscatter corresponding to artificially generated FAIs mostly has spectral width values of the order of one, although sometimes increasing to a few tens. These spectral width values, as mentioned above, are derived from the decorrelation rate of the ACF, a higher spectral width value corresponding to a higher value of the ACF decorrelation rate. Conversely, a lower value for the spectral width is associated with an ACF that does not decorrelate as much. From this, it is seen that for naturally occurring radar backscatter, the ACF decorrelates quickly whereas it stays fairly constant for artificially generated irregularities. This in turn indicates that the irregularity distribution, sampled by the radar, remains fairly static for the period during which the sampling occurs. On the other hand, the irregularity distribution corresponding to naturally occurring irregularities, usually generated by the gradient-drift instability, changes sufficiently quickly during the sampling interval to allow the ACF to decorrelate.

6. LONGER-LAG MODES

The most recently conducted experimental campaign, October 1999, was the first where a longer-lag mode was used. This mode was utilised in order to determine if the ACF decorrelated for time scales longer than those used in ordinary operation of CUTLASS. Figure 4 shows the ACF corresponding to a backscatter return scan taken when the ordinary lag mode was running. Concentrating on the ACF magnitude, denoted by the asterisks, it is seen that the power remains more or less constant. The ordinary lag separation is 2400μs.

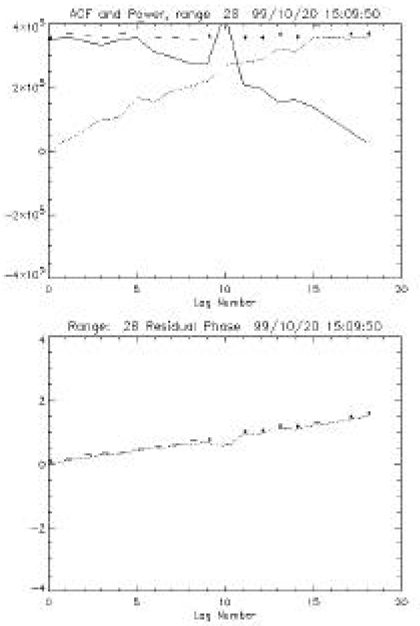

Figure 4: Normal-lag ACF power and phase.

During the October 1999 campaign, lag separations of 12000μs and 24000μs were used. Figure 5 shows an ACF taken when the new longer-lag mode, with a basic lag separation of 24000μs, was running. For these longer-lag modes, it was found that the ACF did decorrelate, thus indicating that the irregularity distribution was not static for the new time scales being considered. Now, it is clear that the reason for the very low spectral width values was the effective constancy of the ACF. The FITACF software had difficulty fitting a decay profile to the ACF since it remained fairly constant in value. Use of the new longer-lag mode resulted in a more reasonable decay profile, thus allowing the software to obtain more sensible values.

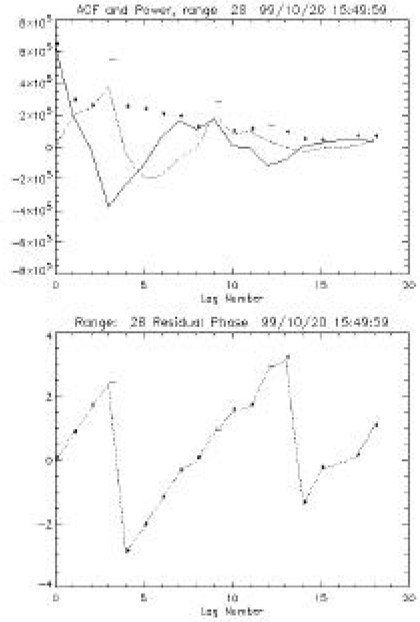

Figure 5: Longer-lag ACF power and phase.

7. TURBULENCE CHARACTERISTICS

Proceeding from the ACF, it is possible to obtain turbulence characteristics, using well-known turbulence theory, [4] and [5]. Three types of ACF are usually seen [1]: those with an exponential decay profile, those with a Gaussian decay profile and a mixture of the two. The exponential type corresponds to the case where the observation wavelength of the radar is much larger than the correlation length of the turbulent motion. This is similar to a random walk distribution. The Gaussian type corresponds to the wavelength being very small compared to the correlation length. In this case the velocity distribution of the plasma is being sampled. The third, and most useful, case corresponds to the situation where the observation wavelength is of the order of the correlation length [6].

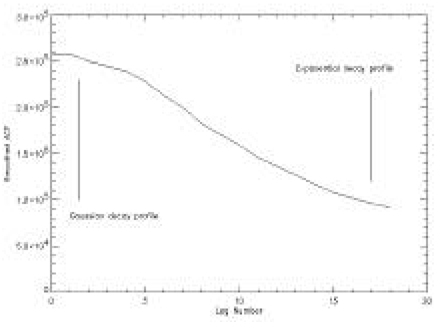

Figure 6: An example of the third type of ACF, containing both Gaussian and exponential decay profiles.

Figure 6 shows such an ACF: at first with a Gaussian decay profile, passing through a transition time and then having an exponential profile. Fitting a Lagrangian ACF to the decay profile allows the immediate derivation of a diffusion co-efficient and correlation time. From these a correlation length and fluctuation velocity may be obtained. It should be noted that the ACF for each case was obtained by averaging the individual ACFs for the 4-minute-on period, and then smoothing to remove the effects of known bad lags. The averaging may be justified by assuming that the same conditions should hold in the ionosphere for the 4-minute-on period. The values of the diffusion co-efficient may be calculated from the exponential and Lagrangian decay profiles. The purely Gaussian case is ambiguous, since it is only possible to obtain a value for the ratio of diffusion co-efficient to correlation time. Figures 7, 8 and 9 show the results of the analysis as performed.

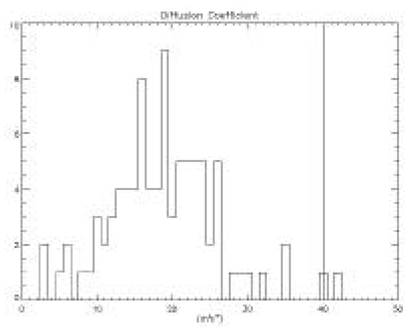

Figure 7: The diffusion coefficient as obtained from the analysis. The vertical line refers to the modal value obtained by Villain et al.

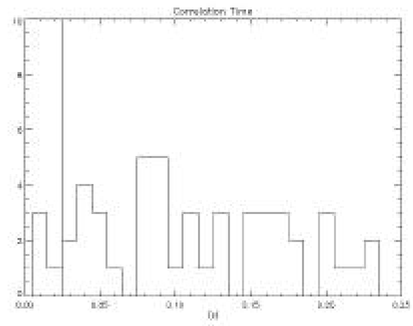

Figure 8: The correlation time. The vertical line refers to the limiting correlation time used by Villain et al, since they consider the normal-lag mode.

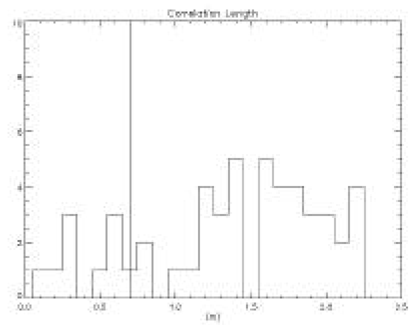

Figure 9: The correlation length. The vertical line again refers to the study by Villain et al.

8. CONCLUSIONS

It was found that the values for the turbulence characteristics so obtained were distinctively different from those corresponding to naturally occurring backscatter. The diffusion co-efficient was smaller and the correlation length was longer. This results concurs with the assumption that the artificial irregularity distribution that is being sampled is fairly static. Also, the correlation time spanned a greater range for the longer lag mode. It should also be noted that the study by Villain et al took into account a wide variety of ACFs in both the E-region and the F-region. This is in contrast to this study, which only took into account F-region spectra corresponding to artificially produced backscatter. Andre et al [7] have, recently, obtained many new results relating to the factors that can affect the spectral width, via the ACF.

9. REFERENCES

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