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7.5A CRITERIA AND ALGORITHMS FOR SPECTRUM PARAMETERIZATION OF MST RADAR SIGNALS

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INTRODUCTION

The power spectra [S(f)] of MST radar signals contain useful information about the variance of refractivity fluctuations (C_n^2), the mean radial velocity (V), and the radial velocity variance (σ_v^2) in the atmosphere. When noise and other contaminating signals are absent, these quantities can be obtained directly from the zeroth, first and second order moments of the spectra (ZRNIC, 1979; WOODMAN, 1983).

In practice the spectra contain, in addition to the atmospheric returns with a Doppler frequency shift f, undesirable components such as noise, ground clutter and interference. The effect of noise is to add a "platform" to the spectra. Ground clutter is usually manifest as a strong, symmetric smeared peak at zero Doppler shift. External interference appears as spurious peaks in the spectra. Transmitter malfunction or presence of unidentifiable rf sources in the observable range of the radar may cause persistent interference at some frequency shifts. Power line harmonics may also be present on occasion.

The power spectra S(f) are usually estimated by the time-averaged periodogram [P(f)] of the coherently integrated returned signal, at N discrete frequencies over a frequency interval (-F, F). At these frequencies, P(f) is a smoothed, weighted and aliased estimate of S(f) (FARLEY, 1983; RASTOGI, 1983). Perhaps the most serious consequence of using the periodogram method is that the ground-clutter contribution is smeared and falls off slowly as f^{-2}. For strong, fading clutter this is sufficient to mask weak signals with small Doppler shifts. This problem is encountered with UHF radars at near-vertical incidence, (SATO and WOODMAN, 1982). In most other cases, the noise, clutter, and signal components are distinctly identifiable in the periodograms.

This note outlines a step-by-step procedure that can be used effectively to reduce large amounts of MST radar data-averaged periodograms measured in range and time to a parametrized form. The next two sections respectively, outline the parameters to which a periodogram can be reduced and gives the steps in the procedure, that may be followed selectively, to arrive at the final set of reduced parameters. Examples of the performance of the procedure are given in the last section, where we also comment on its use with other radars.

BASIC PARAMETERS OF A TIME AVERAGED PERIODOGRAM

The form of the time-averaged periodogram of MST radar signals is shown schematically in Figure 1, where the noise, ground clutter, Doppler-shifted signal and spurious components are also identified.

The noise platform can be parametrized by a spectral density p_N and its variance σ_N^2. The total noise power P_N corresponds to $2p_NF$. p_N and σ_N^2 should be obtained over a suitable noise window. (The terms signal and noise window refer to an appropriate frequency interval. Beyond this interval the spectrum values are set to zero.)

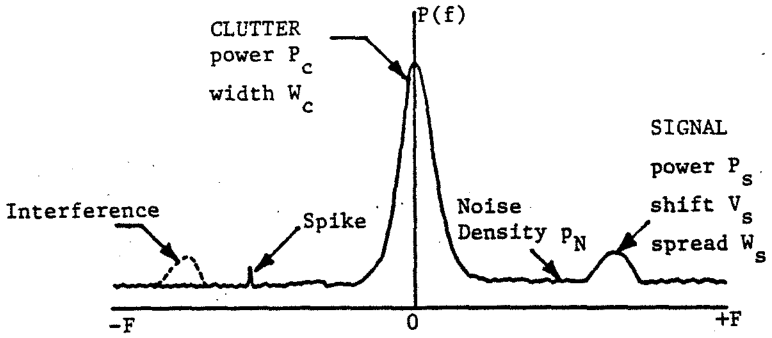

Figure 1. A typical periodogram of MST radar signals showing the clutter, noise, signal and interference component. The periodogram is measured at N discrete frequency points over an interval (-F,F).

The clutter component is symmetric about the zero frequency, and can be parametrized by the clutter power P_c and its width W_c in frequency.

To parametrize the signal component assume first that the noise and clutter contribution have been removed from the periodogram over a suitable frequency window in the vicinity of the signal peak. The signal component is then parametrized by the power P_s or the area under the signal peak, its location V_s and its frequency spread W_s. These parameters are obtained as the zeroth, first and second moment of the spectrum evaluated over the signal window.

The clutter contribution over the signal window can be removed by making use of its symmetry about the zero Doppler shift. This process also removes the noise platform. If the signal peak is well-separated from the clutter, and the clutter contribution is negligible, then the noise contribution can be removed by subtracting the noise spectral density p_n over the signal window.

The parametrization scheme outlined above requires some prior information for selecting the noise and signal windows and yields a small number of parameters: p_N, σ_N, P_N, P_c, W_c, P_s, V_s, and W_s. Originally each periodogram may contain 64-512 points. Parametrization reduces a periodogram to just 8 numbers, and thus entails a substantial data reduction.

PROCEDURE FOR PARAMETERIZATION OF PERIODOGRAMS

The outcome of an MST radar experiment is usually in the form of records, each containing periodograms averaged over a short time interval (~1/2 to 2 min) for a large number (20-200) of range cells. A typical 12-hour experiment would thus yield 10^4 to 10^5 periodograms. The step-by-step procedure discussed below is suitable for reducing the periodograms to a parametrized form using a minicomputer. It assumes the availability of two large disc storage areas, one for the unprocessed records and the other for parameters. The periodogram parameters from several experiments may be organized as a data base for subsequent analyses. The procedure has been used successfully for reducing about 600 hours of ST observations at Millstone Hill. It can be adapted with minor modifications to observations with other radars. Depending on the quality of periodograms, some steps may become redundant.

Step I: Record organization and graphical preview. The records to be processed must be organized sequentially in time without large time gaps. All the records in this sequence must correspond to the same radar pointing direction. The range cells in a record must be contiguous.

It is desirable to obtain crude prior estimates of Doppler Shifts at key ranges for selected records. Graphical displays of periodogram records are of considerable help in obtaining these estimates.

Step II: Periodogram editing, smoothing and folding. Periodogram editing involves removal of undesirable spikes using a simple despiking algorithm, based e.g. on a 3 or 5 point median filter.

Smoothing involves a circular discrete convolution with a 3-point window, e.g. a Hanning window with weights (0.25, 0.50, 0.25). If the periodogram are too noisy, a two (or even three) pass smoothing is desirable.

Folding involves the removal of ground clutter by removing that part of the periodogram that is symmetric about the center frequency. Folding also removes the noise platform.

Step III: Peak detection and tracking in range. Simple peak detection and tracking algorithms can be used to extract an initial Doppler profile from the edited periodogram records. Peak detection requires a threshold level and limiting values for the first and second difference at the peak frequency.

Once a signal peak has been unambiguously detected, it can be tracked in range by setting an ambient frequency window. The extent to which this frequency window should move between adjacent range cells can be specified on the basis of prevailing wind shear. Peak tracking in range, through a frequency window, is also effective in rejecting sporadic external interference.

Step IV: Estimating parameters. Once an initial Doppler profile has been obtained, the signal parameters discussed earlier can be obtained by computing the zeroth, first and second order periodogram moments over a signal window. To reduce the effect of smoothing, the signal parameters should be inferred from the despiked and folded periodograms. The clutter parameters are obtained from the part of the periodogram that is symmetric about the center frequency.

The noise parameters are obtained either through a noise window far removed from the Doppler profile and clutter, or from the periodogram for a distant range.

Step V: Improved estimates. The signal parameter estimates in the previous step can be improved by using the Doppler-shift information recursively. When the magnitude of Doppler shift is large and relatively steady, the signal parameters can be estimated by setting windows about the median Doppler profile. This provides a very effective means of discriminating against external interference.

EXAMPLES AND SOME COMMENTS

Figure 2 shows an example of Doppler tracking of signal peaks for two sets of periodograms observed at Millstone Hill. Figure 3 shows the development of horizontal wind field, synthesized from observations along twelve equispaced azimuths, over a ten-hour period, and illustrates the usefulness of setting up a data base.

The procedure outlined here should be useful for other VHF and UHF experiments as well. When the Doppler-shifter signal peaks are not sufficiently

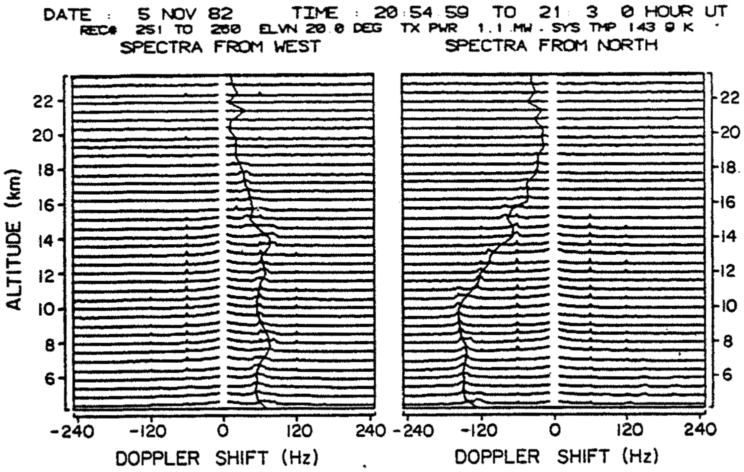

Figure 2. An example of Doppler tracking in ST radar spectra observed at Millstone Hill using the algorithms outlined in the text.

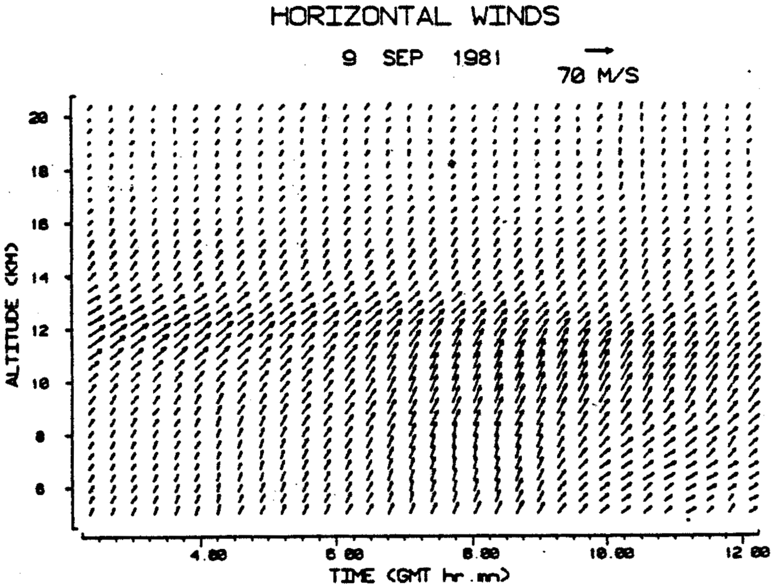

Figure 3. An example of the horizontal wind field obtained from a 12-position azimuth scan during the passage of a thunderstorm at Millstone Hill. The periodograms for each position were reduced by the method described in the text. The reduced parameters were organized as a data base and were used later to synthesize the horizontal wind field.

separated from the ground clutter, the estimates obtained by this method may be used as initial guesses for the least-squares algorithms described by SATO and WOODMAN (1982).

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