APPLICATION OF MEM SPECTRAL ESTIMATION TO MU RADAR OBSERVATION

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ABSTRACT

Preliminary results of the wind velocity estimation using the Maximum Entropy Method (MEM) to MU radar observation data sets are presented. The comparison of the results from the periodogram method and the MEM shows that the MEM estimation is reliable, and has higher accuracy, resolution and detectability than the estimation from periodogram method. The high accuracy power spectrum obtained by the MEM is very useful to studying the atmospheric turbulence structure. However. the MEM needs the longer computing time for obtaining the high accuracy spectrum. Particularly, the estimation of MEM will bring serious deviation at lower signal-to-noise ratio.

Key words: the Maximum Entropy Method (MEM), the periodogram method, MST radar, the wind velocity estimation

I. INTRODUCTION

In recent years there has been considerable interest in the technique of spectrum analysis called the Maximum-Entropy Method (MEM), developed by Burg (1967). This method appears to offer results which have higher accuracy and smoother spectra than the traditional methods. A reliable method of spectrum analysis is very important in real-time processing of Mesosphere-Stratosphere-Troposphere (MST) radar signals. In conventional case, the FFT periodogram method is used in MST radar data processing. This method is a high efficient method for calculation, both simple and direct. But the major shortcoming of this method is that the frequency resolution is limited by the period of sampling process. In other words, we must spend enough long sampling process for getting the high resolution. Owing to the limitation of the coherent time scale of the measured physical process (in general, several seconds), we can not increase the sampling time arbitrarily. In order to solve this problem, it is obvious that the method other than periodogram should be tested. Recently Klostermeyer (1986) reported the results of applying MEM and MLM (Maximum Likelihood Method) to the estimation of simulated signals of VHF radar, and compared the accuracy of those methods with the conventional periodogram method.He found that at large signal-to-noise ratio the differences between their Doppler shift estimates are very small; at moderate signal-to-noise ratio, the MEM estimates have significantly higher accuracy than the periodogram estimates; but at small signal-to-noise ratio, the MEM clearly indicates a limitation, and its estimates are controlled by noise and its accuracy compared to the periodogram method is worse. In this paper, in order to further study the effect of MEM for estimating the MST radar signals, we calculate the real MU radar observation data sets, and realize the applicable conditions of MEM to MST radar data processing.

II. DATA AND METHOD

The MU radar, located at Shigaraki Observatory of the Kyoto University, Japan, is an MST radar with the operating frequency at 46.5 MHz. The troposphere-stratosphere data sets used here were taken at 1241—1308 JST 18 Dec. 1987 (JST: Japan Standard Time). The antenna beam was steered at every inter- pluse period (IPP) for two directions, i.e., 10° off-zenith toward the east and vertical. IPP was 400μs. In each direction, 64 heights in the range 1.95—20.85km were sampled with an interval of 300m. In order to improve the signal-to-noise ratio, the number of coherent integration was up to 80. One observation consisted of 512 point time series data at each height and each beam direction. One observation time was about 33 seconds. The data sets we used here covered up to 27 minutes. Based on the data sets we performed the spectral estimates of the conventional periodogram method and the MEM. In the periodogram method, the power spectra were calculated with FFT algorithm, the power spectral parameters (i.e., echo power, radial wind velocity and spectral width) were derived by a nonlinear least square Gaussian fitting method. In the MEM, we selected 10 as the greatest filter order, in many cases, automatically selected 6—8 as the optimum filter order on the basis of the Final Prediction Error criterion. The power spectral accurary of MEM depends on filter length, signal-to-niose ratio, and other factors. Therefore, the MEM has a unique advantage in the radar signal of short time interval to the periodogram method.

III. RESULTS

1. *Reliability of MEM Doppler Shift Estimate F_e*

If we regard that the frequency estimate F_p of the conventional periodogram method is reliable, the confidence level of MEM Doppler shift estimate F_e could be determined by comparing the estimation of the periodogram method with the estimation of the MEM. A typical set of these comparisons is shown in Fig. 1 for power spectra and in Fig. 2 for the 6 min. average radial velocity profiles. Fig. 1 shows the calculated results for one observation sampling

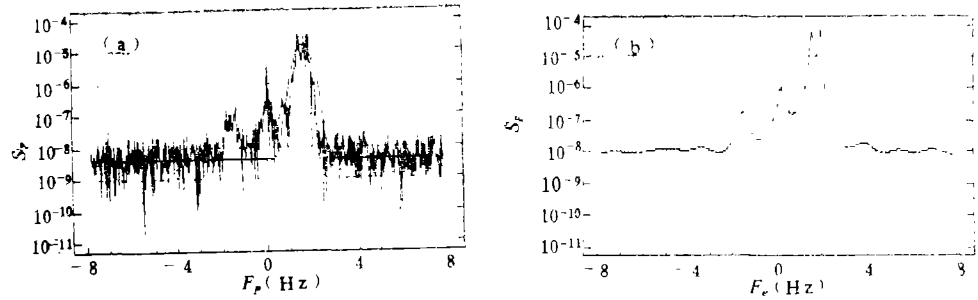

Fig. 1. The power spectrum (S_p) at 5.55km, in 10° off-zenith toward the east direction for the periodogram method (a) and for MEM (b).

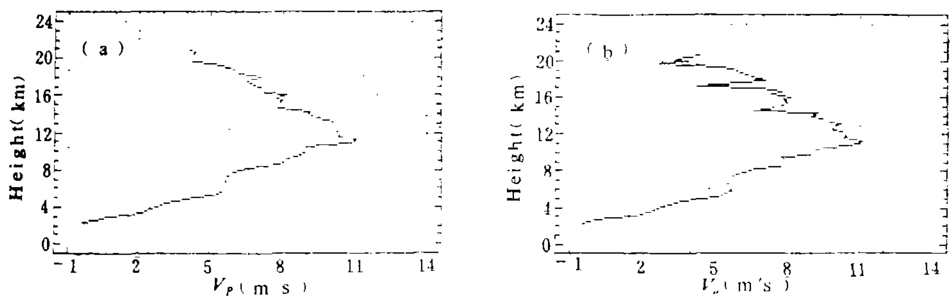

Fig. 2. The profile of the averaged radial velocity, in the 10° off-zenith toward the east direction for the periodogram method (a) and for MEM (b).

in the 10° off-zenith toward the east direction at the altitude of 5.55 km. There are two curves in Fig. 1a, one is the power spectrum of FFT method, and the other, smoother one, is the nonlinear least square Gaussian fitting curve. Fig. 1b shows the corresponding power spectrum with MEM. From Fig. 1 we can see that the power spectra of the two methods are very identical in the main peak, the ground clutter, and the secondary peak. It is obvious from Fig. 1 that the MEM produces a smoother and clearer spectrum with higher resolution. The profiles in Fig. 2 show a good coincidence between the results of the FFT and MEM, but the profile of MEM gives out the detailed velocity structure. From Fig. 1 and Fig. 2, we can realize that the spectral estimation obtained by these two methods are coincident, thus the spectral estimation of the MEM is reliable.

2. *Bimodal Structure of MEM-Deduced Spectra*

In some power spectra of MEM, we clearly found the bimodal spectral structure, and roughly identified the relevant peak in the corresponding spectrum of FFT method (Fig. 1). Because of the lower frequency resolution and the white noise added in FFT-deduced spectra, in most cases we can not confirm the bimodal structure from them. In fact, the bimodal spectral structure is worth studying further.As early in the 1980s, Wand and Rostogi (1983) reported the bimodal structure. They considered that two main mechanisms would contribute to the multi-peak structure, i.e. (1) random velocity fluctuations due to turbulence within the layer and (2) the " shear broadening " effect associated with the difference in Doppler shift between the upper and lower boundary of a turbulent layer moving horizontally with the vertically sheared background flow. We should clarify whatever this bimodal spectral structure is the real effect of the atmospheric process raised by Wand and Rostogi or the spontaneous line splitting of Burg's technique at high signal-to-noise ratio case (see Fougere, 1976; 1977). We made the statistics of the signal-to-noise ratio range and the height range in which there exist the bimodal structure during this period of observation time (Fig. 3). The result shown in Fig. 3 indicates that the bimodal structures are distributed very centrally around 5 and 11 km height. From the averaged vertical profile of signal-to-noise ratio (Fig. 4), we can see that the heights of 5 km and 11 km are not the heights with the highest signal-to-noise ratio. The region below 5 km has even higher signal-to-noise ratio. Therefore, appearance of the bimodal structure is not inevitably related to S/N ratio. Moreover, the identity of the bimodal structure of MEM and FFT shows that the bimodal structure is not caused by the spontaneous line splitting. At 5 km altitude, the velocity profile is on an inflexion point

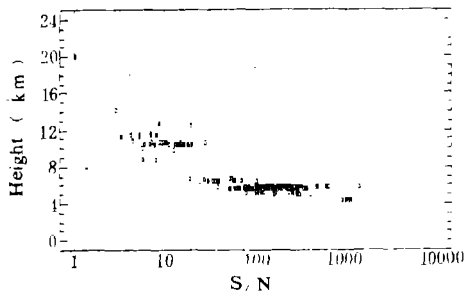

Fig. 3. The distribution diagram of the bimodal structure in MEM for the height and signal-to-noise ratio.

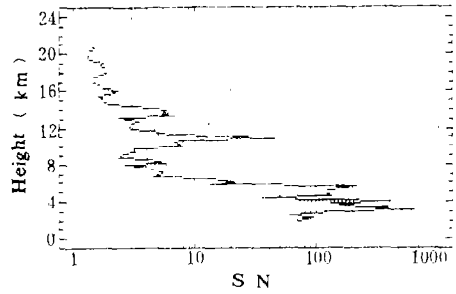

Fig. 4. The profile of the averaged signal-to-noise ratio.

(see Fig. 2). The 11 km height maybe is near the tropopause. At these heights, the echo power has maximum (see Fig. 4). And this is probably caused by the strong turbulence layer or the vertical shear of the horizontal wind. Sato and Woodman (1982) found a correlation between the power, the vertical shear of horizontal velocity and the spectral width of the return. They suggested that the wind shear leads to turbulence, thus increases the power and the spectral width of the radar returns. This bimodal may result from the two most probable velocity values in turbulence layer. In the above analysis, we can say that the MEM could generate a high resolution spectrum. It provides us a useful method for investigating the detailed structure of atmospheric motion. Due to the lower resolution of the periodogram method, it gives us only the average velocity in turbulence layer, but not the velocity distribution there. Therefore, using the high resolution spectral estimation method, together with the echo power, spectral width, signal-to-noise ratio, wind profile, temperature profile and so on, we can further study atmospheric turbulence, wind shear, stratification and other physical phenomena.

3. *Reliability of MEM-Deduced Spectra in Different S/N Ratio Ranges*

For the sake of discussing the relationship between the MEM and the signal-to-noise ratio, we give out the distribution of the height and the signal-to-noise ratio of the error points (Fig. 5). The error point means the abnormal point of Doppler shift estimation in the spectral

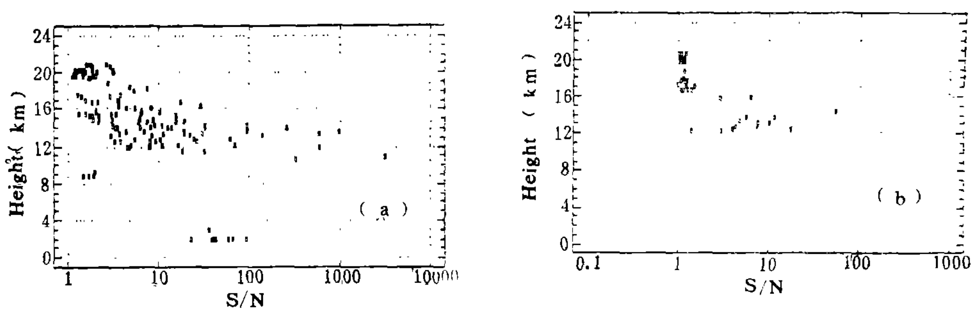

Fig. 5. The distribution of the height and the signal-to-noise ratio of the error velocity estimation point for the periodogram method (a) and for MEM (b).

time series or height series, with its estimation unreasonable. In conventional observations, we cancel these points as the bad data. In Fig. 5, we found that the error points in the FFT method are about three times more than in the MEM, and distributed in a wide region. The error points in the MEM are less and centered in the region of signal-to-noise ratio of about one. It proves that the MEM has the higher detectability than the FFT method.

The relations of DV, the difference of radial velocity determined by the MEM and the FFT method, with the height and the signal-to-noise ratio are shown in Fig, 6 and Fig. 7, respectively.

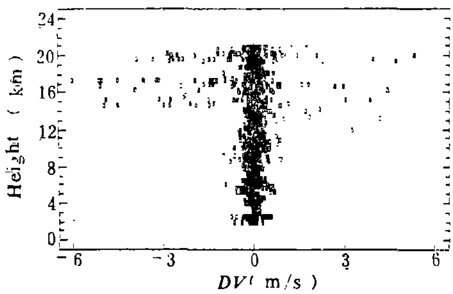

Fig. 6. The height distribution of the difference (DV) between radial velocities estimated by the periodogram method and the MEM.

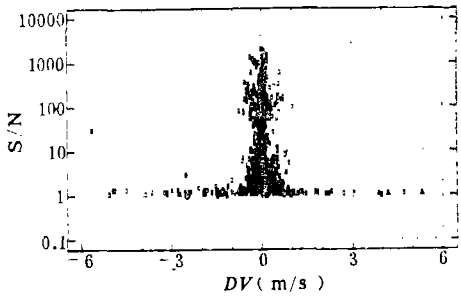

Fig. 7. As in Fig,6,but for signal-to-noise ratio distribution.

It can be seen from the height distribution of DV (Fig. 6) that in the region above 15 km, the values of DV are larger and disperse. This results from the lower signal-to-noise ratio in the region above 15 km (see Fig. 4). The distribution of the DV versus signal-to-noise ratio in Fig. 7 tells us that when signal-to-noise ratio approximates one, the DV increases rapidly. In other words, at lower signal-to-noise ratio, the velocity estimates of the MEM have larger deviation from those of the periodogram method. If we consider the estimation of the periodogram method reliable, then the estimate of the MEM has a larger deviation at lower signal-to-noise ratio.

IV. CONCLUSIONS

In the previous section, we have investigated the power spectra of MU radar observation data sets calculated by both the periodogram and the MEM. The results lead us to conclude:

(1) There is an excellent agreement between the radial velocity estimates calculated by both methods. Therefore, the MEM is suitable to MST radar power spectral estimation, and the estimate is reliable.

(2) Because of the high frequency resolution, the MEM can give us the multi-peak fine structure of the power spectrum. It is very useful to understanding the atmospheric turbulence, shear and other physical processes with this kind of fine structure.

(3) The MEM has higher detectability than the FFT method. But at lower signal-to-noise ratio, the velocity estimated by MEM will have serious deviation.

In the present study case, the computer CPU time for MEM is about four times longer than that for the periodogram method. This is a disadvantage for routine real-time observations. In real-time processing, the FFT calculation is often finished by hardware, so the calculation speed of the periodogram method is obviously faster. In fact, in the height region of high signal-to-noise ratio, we can decrease the filter order to shorten computer CPU time for MEM. We may expect to operate the MEM estimation by use of hardware in near future. The high resolution spectrum of MEM is a new method for us to observe the turbulence morphology in the troposphere and stratosphere. If increasing the height resolution, we can get more comprehensive observations of turbulence structure.

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