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Derivation of Wind Information from the Radar data using Signal Processing Techniques

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Abstract: **-- The Indian MST Radar (Mesosphere – Stratosphere –Troposphere Radar)-at National Atmospheric Research Laboratory, Gadanki-is a high power VHF phased array radar operating at 53MHz in coherent backscatter mode with peak power aperture product of 3x1010 Wm2.The MST radar is a pulsed Doppler radar to support the atmospheric research in the MST regions. The algorithm deals in extracting information like Power, Doppler, Doppler width, SNR (signal–to–noise ratio), Noise, oments, wind velocity & wind direction from MST radar data using signal processing techniques. This algorithm is developed using Visual Studio 2015 with C# and is tested on the MST radar data. The results were plotted graphically.**

Index Terms**—Doppler Width, Fast Fourier Transform, mesosphere-stratosphere-troposphere (MST) radar, Power Spectrum, Wind velocity.**

I. INTRODUCTION

National Atmospheric Research Laboratory (NARL) at Gadanki (13.47°N, 79.18°E) near Tirupati, India has been operating at 53 MHz atmospheric radar (Mesosphere, Stratosphere and Troposphere radar) for studying structure and dynamics of lower, middle and upper atmosphere. MST Radar provides estimates of atmospheric winds on a continuous basis with high temporal and spatial resolutions. MST Radar uses the echoes obtained over the height range of 1-100 Km to study the winds and turbulence. The Indian MST Radar is used for scientific studies of the atmosphere in the height range of 2-20 km (troposphere and lower stratosphere), 60-90 km (mesosphere), 100-150 km (E region) and 150-800 km (F region). The echoes from the atmosphere are due to neutral turbulence in the lower height regions and due to the irregularities in electron density in the higher altitudes. Weak echoes between 30-60 kms were due to less availability of 3 m scale refractive index fluctuations. The radar has a phased antenna array that has two orthogonal sets (one for east-west polarization and another one for north-south polarization) of 1024 three element Yagi-Uda antennas arranged in a 32X32 matrix over an area of 130mX130m.

The signal processing is applied on the radar data involving (1) coherent integration, (2) Normalization of the pre-processed data, (3) Windowing, (4) Fourier Analysis,(5) Power Spectrum, (6) Incoherent averaging, (7) Power Spectrum Cleaning, (8) Noise level estimation, (9) Moments Estimation, (10) Wind velocity and direction derivation.

II. SIGNAL PROCESSING

Fig 1.1 shows the functional block diagram of various processing stages involved in the extraction and estimation of atmospheric parameters.

Coherent Integration

The detected quadrature signals are coherently integrated for many pulse returns which lead to an appreciable reduction in the volume of the data to be processed and an improvement in the SNR. The coherent integration is made possible because of the over sampling of the Doppler signal resulting from the high PRF relative to the Doppler frequency.

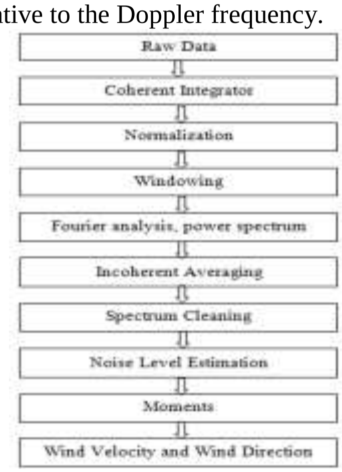

Fig 1.1 Processing steps for Extraction of parameters

Normalization of the pre-processed data

The input data is to be normalized by applying a scaling factor corresponding to the operation done on it. This will reduce the chance of data overflowing due to any other succeeding operation. The Normalization has following components.

A. sampling resolution of ADC
B. scaling due to pulse compression in decoder
C. scaling due to coherent integration
D. Scaling due to number of FFT points. if Δv - ADC bit resolution (10/16384),

w - Pulse width in microsecond, M -Number of IPP integrated = Integrated time /inter pulse period,
N - Number of FFT points, then the Normalization factor

$$s = \frac{\Delta v}{w * M * N}$$

The complex time series {Ii , Qi where i = 0, . . ,N-1} at the output of the signal processor is scaled as

$$\tilde{I}_i = s * I_i$$

$$\tilde{Q}_i = s * Q_i$$

Windowing

It is well known that the application of FFT to a finite length data gives rise to leakage and picket fence effects. Weighting the data with suitable windows can reduce these effects. However the use of the data windows other than the rectangular window affects the bias, variance and frequency resolution of the spectral estimates. In general variance of the estimate increases with the uses of a window. An estimate is said to be consistent if the bias and the variance both tend to zero as the number of observations is increased. Thus, the problem associated with the spectral estimation of a finite length data by the FFT techniques is the problem of establishing efficient data windows or data smoothing schemes.

Fourier analysis

Spectral analysis is connected with characterizing the frequency content of a signal. A large number of spectral analysis techniques are available in the literature. This can be broadly classified in to non-parametric or Fourier analysis based method and parametric or modal based methods. Fourier proposed that any finite duration signal, even a signal with discontinuities, can be expressed as an infinite summation of harmonically related sinusoidal component; that is

$$x(t) = \sum_{k=0}^{\infty} (A_k \cos(k\Omega_0 t) + B_k \sin(k\Omega_0 t))$$

Where A_k and B_k are Fourier coefficients and $\Omega_0$is the fundamental angular frequency. Application of Fourier analysis to discrete series of data and its fastcomputation algorithm Fast Fourier transform (FFT) made this technique so popular in the spectral analysis. FFT is applied to complex time series {(Ii, Qi), i = 0,1, . . . ,N-1} to obtain complex frequency domain spectrum { (Xi, Yi), i = 0, ... , N-1}

$$X_i + Y_i = \frac{1}{N} \sum_{k=0}^{N-1} (I_k + jQ_k) \exp(-2\pi ik / N)$$
$$i = 0, \cdots N-1$$

$$P_i = X_i^2 + Y_i^2, \quad i = 0, \cdots\cdots N-1$$

Power Spectrum

Power spectrum is calculated from the complex spectrum as

Incoherent Integration

$$P_i = \frac{1}{m} \sum_{k=1}^{m} P_{ik} \qquad i = 0, \cdots\cdots\cdots N-1$$

Incoherent integration is the averaging of the power spectrum number of times where m is the number of spectra integrated.

The advantage of the incoherent integration is that it improves the detestability of the Doppler spectrum. The detestability is defined as

$$D = P_S / \sigma_{S+N}$$

Where PS is the signal power and □ S+N is the standard deviation of the power spectral density.

Power Spectrum Cleaning

Due to various reasons the radar echoes may get corrupted by ground clutter, system bias, interference, image formation etc.. The data is to be cleaned from these problems before going for analysis. Clutter/ DC removal: The presence of ground clutter presents a source of additional problem. Different techniques have been used to cancel or minimize its effect. Ground clutter signals have a spectral signature which consists essentially of a single spectral line at the origin with a strength which depends on the ground shielding of the radar. At troposphere and stratospheric heights it is at least comparable to the signal and often many orders of magnitude larger. Strictly it is very difficult to remove these signals; one way to eliminate its biasing effect is to ignore the frequencies around zero (dc) frequency. This is possible only when the spectral offset is larger than its width.

The basic operation carried out here is,

This is also can be removed in time series by taking out the bias in I and Q channel and then perform the Fourier analysis. Spikes (glitches) in the time series will generate a constant amplitude band all over the frequency bandwidth. Once Fourier analysis is done, it is difficult to identify the correct Doppler in the range bin. These points may be removed from the range bin and

$$\tilde{P}_{N/2} = \frac{(P_{\frac{N}{2}+1} + P_{\frac{N}{2}-1})}{2} \quad \text{N/2 corresponds to zero frequency.}$$

adjusted to noise floor or doing an incoherent integration of the spectrum and replace the value with good value from the second spectrum. However, this type of problem need to be corrected before doing Fourier analysis to get a better result by finding out the out-liers in data.

Constant frequency bands will form in the power spectrum by the interference generated in the system or due to extraneous signal. Due to this reason it is also possible the formation of multiple bands in spectrum. This is removed by taking a range bin, which does not have echoes but the interference. This range bin gets subtracted from all other range bins after the removal of mean noise. If the interference is not affecting the original Doppler trace then the analysis may be carried out in a window confined to the Doppler trace.

Parameter Estimation

MST radar echoes are produced by fluctuations in the index of refraction of the atmosphere. In most cases, these are turbulence-induced fluctuations. Because of the random nature of the turbulence, radar returns from turbulence-induced fluctuations represent stochastic processes and have to be characterized statistically. The returns from any one height form a random time series and can be considered stationary within an integration time and Gaussian in nature (Woodman 1985; Zrnic 1979). A Gaussian and stationary process is fully characterized by its autocorrelation function or equivalently by its Fourier transform, the frequency power spectrum. To characterize the process, it is essential to know the turbulence intensity, mean radial velocity and velocity dispersion, which are a measure of physical properties of the medium. If the spectrum is Gaussian, these three parameters contain all the information which we can obtain from the radar echoes. Following section will give the parameter extraction procedure.

$$\frac{Variance(S)}{mean(S)^2} \leq 1$$

$$over\ number\ of\ spectra\ averaaged$$

Noise Level Estimation

There are many methods adapted to find out the noise level estimation. Basically all methods are statistical approximation to the near values. The method implemented here is based on the variance decided by a

$$P_n = \sum_{i=0}^{n} \frac{A_i}{(n+i)}$$

$$Q_n = \sum_{i=0}^{n} \frac{A_i^2}{n+1} - P_n^2$$

$$and \quad if \quad Q_n > 0, \quad R_n = \frac{P_n^2}{(Q_n * M)},$$

$$for \quad n = 1, \cdots\cdots, N$$

Threshold criterion,

Hildebrand and Sekhon (1974). This method makes use of the observed Doppler spectrum and of the physical properties of white noise; it does not involve knowledge of the noise level of the radar instrument system. This method is now widely used in atmospheric radar noise threshold estimation and removal.

The noise level threshold shall be estimated to the maximum level L, such that the set of Spectral points below the level S, nearly satisfies the criterion,

Step 1:

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Reorder the spectrum { Pi, i = 0, . . . N-1} in ascending order to form. Let this sequence be written as{ Ai, i = 0, . . . N-1} and Ai <Aj for i< j

Step 2: compute

where M is the number of spectra that were averaged for obtaining the data.

Step 3:

Moments Estimation

The extraction of zeroth, first and second moments is the key reason for on doing all the signal processing and there by finding out the various atmospheric and turbulence parameters in the region of radar sounding. The basic steps involved in the estimation of moments, Woodman (1985) are given below.

$$Noise \quad level\,(L) \;=\; P_k$$

$$where \quad k = \min \Big|_{1.\ \ if\ no\ n\ meets\ the\ above\ criterion}^{n\ \ such\ that\ R_n > 1}$$

Step 1

Reorder the spectrum to its correct index of frequency (ie. -fmaximum to +fmaximum) in the following manner.

Step 2:

Subtract noise level L from spectrum

Step 3:

i) Find the index l of the peak value in the spectrum,

$$ie \quad \tilde{P}_1 \geq \tilde{P}_i \quad for\ all\ i = 0,\cdots\cdots N-1$$

ii) Find m, the lower Doppler point of index from the peak point.

$$ie \quad \tilde{p}_i \geq 0 \quad for\ all\ m \leq i \leq l$$

iii) Find n the upper Doppler point of index from the peak point

Step 4:

The moments are computed as

represents zeroth moment or Total Power in the Doppler spectrum.

represents the first moment or mean Doppler in Hz

$$iii) \quad M_2 = \frac{1}{M_0}\sum_{i=m}^{n}\tilde{P}_i\,(f_i - M_1)^2$$

represents the second moment or variance, a measure of dispersion from central frequency.

$$iv) \quad Doppler\ width\ (full) = 2\sqrt{M_2} \quad Hz$$

$$v) \quad SNR = 10\log\left[\frac{M_0}{(N*L)}\right]dB$$

where

IPP - is interpulse period in microsec.

N - is the number of FFT points.

Calculation of spectral moments of spectrum with composite structure is done in a slightly different way from the procedure explained above. This type of spectrum normally comes in the upper atmospheric region (Ionosphere). Here the spectra shows multiple spikes and wide, so after the removal of mean noise level the spectra may be crossing from positive values to negative many times. Thus, the peak and valley detection described above can not give the correct result. To overcome this problem, a running template is taken with seven Doppler points (Patra et.al., 1995). The Doppler point to be checked is the central point of the template. This template will move from the peak to the either side of the spectrum to find the lower and upper point of Doppler index from the maximum peak. The running average of seven points is checked against a threshold. The threshold is kept 3dB above the mean noise level. The Doppler point is considered till the template average is above the threshold. Remaining part of the moments calculation is same as that of the calculation for the single peak Doppler spectrum.

Wind speed Computation

The prime objective of atmospheric radar is to obtain the vector wind velocity. Velocity measured by a radar with the Doppler technique is a line of sight velocity, which is the projection of velocity vector in the radial direction. There are two different techniques of determining the three components of the velocity vector: the Doppler Beam Swinging (DBS) method and Spaced Antenna (SA) method. The DBS method uses a minimum of three radar beam orientations (Vertical, East-West, and North-South) to derive the three components of the wind vector (Vertical, Zonal and Meriodional), Sato (1988). In the spaced antenna

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method, the backscattered signal is received by three non-coplanar antennas, located usually at the corners of a right angle triangle. The horizontal velocity and the characteristics of the ground diffraction pattern and thereby that of the scattering irregularities can be obtained through the full correlation analysis of Briggs (1984).

Calculation of radial velocity and height:

For representing the observation results in physical parameters, the Doppler frequency and range bin have to be expressed in terms of corresponding radial velocity and vertical height.

$$Height,\quad H = \frac{(c * t_R * \cos\theta)}{2} \quad meters$$

$$Velocity,\quad V = \frac{(c * f_D)}{(2 * f_C)} \quad or \quad \frac{f_D * \lambda}{2} \quad m/\sec$$

Where c – velocity of light in free space, f_D– Doppler frequency, f_C– Carrier frequency, λ - Carrier wavelength (here 5.86 m), θ- Beam tilt angle, t_R - Range time delay.

Computation of absolute Wind velocity vectors (UVW):
After computing the radial velocity for different beam positions, the absolute velocity (UVW) can be calculated. To compute the UVW, at least three non-coplanar beam radial velocity data is required. If higher number of different beam data are available, then the computation will give an optimum result in the least square method.
Line of sight component of the wind vector V (Vx, V_Y, Vz) is

$$V_D = \mathbf{V} \cdot \mathbf{i} = V_x \cos\theta_x + V_y \cos\theta_y + V_z \cos\theta_z$$

where X, Y, and Z directions are aligned to East-West, North-South and Zenith respectively. Applying least square method, residual

$$\varepsilon^2 = (V_x \cos\theta_x + V_y \cos\theta_y + V_z \cos\theta_z - V_{D\,i})^2$$

where $V_{Di} = f_{Di} * \lambda/2$ and i represents the beam number

To satisfy the minimum residual

$\partial\varepsilon^2 / \delta V_k = 0$ k corresponding to X,Y, and Z

leads to

$$\begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix} = \begin{bmatrix} \sum_i \cos^2\theta_{Xi} & \sum_i \cos\theta_{Xi}\cos\theta_{Yi} & \sum_i \cos\theta_{Xi}\cos\theta_{Zi} \\ \sum_i \cos\theta_{Xi}\cos\theta_{Yi} & \sum_i \cos^2\theta_{Yi} & \sum_i \cos\theta_{Yi}\cos\theta_{Zi} \\ \sum_i \cos\theta_{Xi}\cos\theta_{Zi} & \sum_i \cos\theta_{Yi}\cos\theta_{Zi} & \sum_i \cos^2\theta_{Zi} \end{bmatrix}^{-1} * \begin{bmatrix} V_{Di}\cos\theta_{Xi} \\ V_{Di}\cos\theta_{Yi} \\ V_{Di}\cos\theta_{Zi} \end{bmatrix}$$

THUS, ON SOLVING EQUATION WE CAN DERIVE V_X, V_Y, AND V_Z, WHICH CORRESPONDS TO U (ZONAL), V (MERIDONAL) AND W (VERTICAL) COMPONENTS OF VELOCITY.

Estimation of wind-speed

The winds speed can be calculated by using theformula:
Wind-speed $W = \sqrt{(U^2 + V^2)}$

The horizontal component of the wind velocity iscalculated from the UV components which are estimatedfrom the Doppler frequencies.

RESULTS

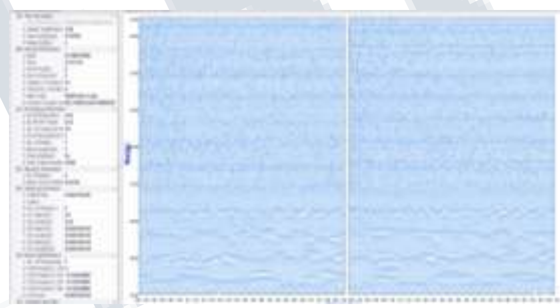

Fig 1.2Raw data (I, Q)of MST Radar

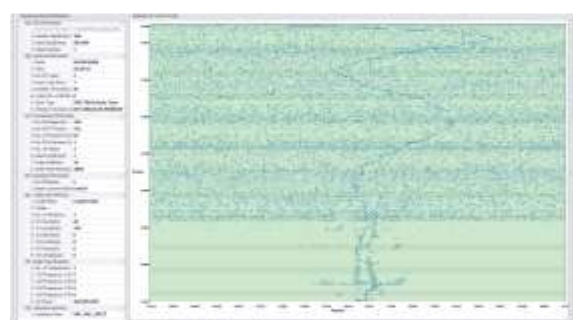

Fig 1.3Conversion of Raw data to Spectrum using FFT

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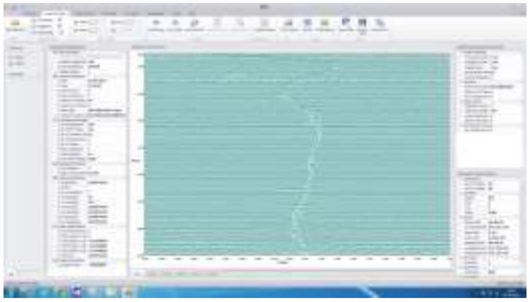

Fig 1.4Conversion of Raw data to Spectrum using FFT, Gaussian fitting

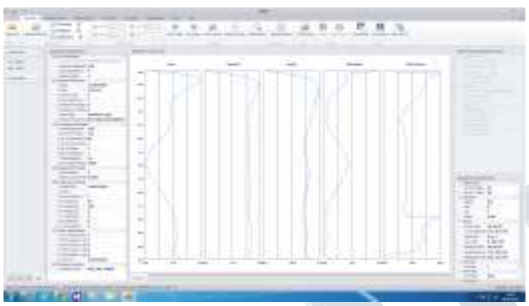

Fig 1.5Moments plotting (SNR, POWER, DOPPLER, DOPPLER WIDTH, NOISE)

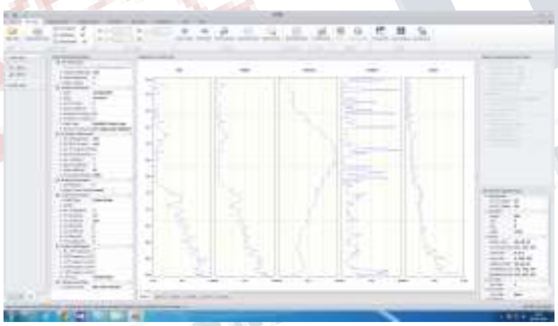

Fig 1.6 Wind velocity and Wind direction plotting

REFERENCES

1) Farley, D.T., "On-line data processing techniques for MST radars," Vol 20, No.6, Pp 1177-1184, 1985

2) Hildebrand, P.H., and R.S Sekhon, "Objective determination of the noise level in Doppler spectra,"J.Appl.Meterol., 13, 808-811, 1974.

3) **P**atra, A.K., V.K.Anandan, P.B.Rao, and A.R.Jain"First observations of equatorial spread –F from Indian MST radar," Radio Sci., 30, 1159-1165, 1995

4) **R**abiner, L.R., and B.Gold, "Theory and application of Digital signal Processing," Prentice Hall, Englewood Cliffs, N.J, 1975

5) **R**ao, P.B., A.R Jain, P.Kishore, P.Balamuralidhar, S.H.Damle and G.Viswanathan.,"Indian MST radar1. System description and sample vector wind measurements in ST mode.," Radio sci., vol 30, No.4 pp 1125-1138 1995

6) **R**iddle, A.C., "Parameterization of spectrum, in Handbook for MAP," edited by S.A. Bowhill and B.Edwards, 9. pp 546-547, SCSTEP Secr., Urbana, Ill., 1983

7) **R**ötteger, .J., and M.F. Larsen, "UHF/VHF Radar techniques for atmospheric research and wind profiler applications, in Radar in Meteorology," edited by D. Atlas, chap. 21a, pp 235-281, American Meteorological Society, Boston, Mass., 1990

8) **S**chmidt, R., "Multiple Emitter Location and Signal Parameter Estimation, Proc. Of the RADC spectrum Estimation Workshop," RADC-TR-79-63, Rome Air Development Center, Rome, NY, , PP243, Oct 1979