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Estimation of Wind Speed of MST Radar Signal Using Wavelets

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ABSTRACT: The Mesosphere Stratosphere Troposphere (MST) radar is a pulsed Doppler radar to support the atmospheric research in the MST regions. Even though the radar technique is same, the extraction of the signal requires great case. In normal Radar the target will be a hard target having better reflection coefficient without many signal processing techniques the extraction of signal is possible. In the case of atmospheric radar, the target is a soft target and it is buried 40 to 50 dB below the background noise/clutter and sophisticated signal processing technique is required to extract the signal. The proposed work is based on wavelet Transformation technique gives an alternative to the existing technique.

KEYWORDS: MST Radar, Doppler radar, Noise, Clutter, Wavelet Transformation.

I.INDIAN MST RADAR SIGNAL AND DATA PROCESSING TECHNIQUES – AN OVERVIEW

1.1 Radar – General Introduction:

RADAR is the acronym for Radio Detection and Ranging. The radar invention has its roots in the pioneering research during nineteen twenties by Sir Edward Victor Appleton in UK and Breit and Tuve (1925) in USA on the detection of ionization layers in the upper atmosphere. The radar works on the principle that when a pulse of electromagnetic waves is transmitted towards a remotely located object, a fraction of the pulse energy is returned through either reflection or scattering, providing information on the object. The time delay with reference to the transmitted pulse and the received signal power provide respectively the range and the radar scattering cross-section of the target detected. These class of radars are known as pulse radar. In case the target is in motion when detected, the returned signal is Doppler shifted from the transmitted frequency and the measurement of the Doppler shift provides the line-of-sight velocity of the target. The radars having this capability are referred to as pulse Doppler radars. In addition to the above, if the location of the target is to be uniquely determined, it is necessary to know its angular position as well. The radars having this capability employ large antennas of either phased array or dish type to generate narrow beams for transmission and reception. Two major radars of this kind used for scientific research are the phased array radar of Jicamarca and dish antenna radar of Arecibo. Two important parameters that characterize the capability of radar are its sensitivity and resolution for target detection. The sensitivity is determined by the peak power-aperture product and the resolution by the pulse volume which depends on the pulse length and the radar beam width. There are several variants to the above type of pulse radars that have been developed with varying degrees of complexity to meet the demands of application in various fields, e.g. Over the Horizon (OTH) radars, Imaging radar, Synthetic Aperture Radar (SAR), Doppler Weather Radar (DWR), Precipitation radar, Atmospheric radar etc.

1.2 Atmospheric Radars:

Radar can be employed, in addition to the detection and characterization of hard targets, to probe the soft or distributed targets such as the earth's atmosphere. The atmospheric radars of interest to the current study are known as clear air radars and they operate typically in the VHF (30 –300 MHz) and UHF (300 MHz – 3GHz) bands (Rotteger and Larsen, 1990). The turbulent fluctuations in the refractive index of the atmosphere serve as a target for these radars. There is another class of radars known as weather radars which serve to observe the weather systems and they operate in the SHF band (3- 30 GHz) (Doviak and Zrnic, 1984). A major advance has been made in the radar probing of the atmosphere with the realization in early seventies, through the pioneering work of Woodman and Guillen (1974), that it is possible to explore the entire Mesosphere-Stratosphere-Troposphere (MST) domain by means of a high power VHF backscatter operating ideally around 50 MHz. It led to the concept of MST radar and this class of radars have come to dominate the atmospheric radar scene over the past few decades.

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MST radar is a high power phase coherent radar operating typically around 50 MHz with an average power-aperture product exceeding about $5x10^7$ Wm^2. Radars operating at higher frequencies or having smaller power-aperture products are termed ST (Stratosphere-Troposphere) radars. In arriving at an optimum radar frequency for MST application, the main considerations are the frequency dependence of radar reflectivity for turbulent scatter and possible interference from other sources of sporadic nature. The weak radar reflectivity of the turbulent scatter coupled with a requirement of a few tens of meters of range resolution has called for the application of pulse compression and advanced signal and data processing techniques. The efficiency of the radar system depends on how best it can identify the echoes in the presence of noise and unwanted clutter. The important parameters from the system point of view influence the radar returns are the average power of transmission and the antenna aperture size. Signal delectability is a measure of the radar performance in terms of transmission parameters.

1.3 MST Radar Signal Characteristics:

MST Radar returns from the atmosphere arise either through turbulent scatter (Bragg Scatter) or partial reflection (Fresnel reflection or more generally Fresnel Scatter) or the combination of two. The turbulent scatter is due to the irregularities in refractive index scale size of half the radar wavelength and Fresnel reflection is due to steep gradients of refractive index associated with the stratified layers. The fluctuations are random and so are the signals received by the radar. Both have to be characterized statistically. In order to interpret the signal received, the statistical nature of these fluctuations is to be understood. The signal characteristics would be Gaussian if it arises from turbulent scatter and non-Gaussian if it is due to Fresnel reflection. The scatter characteristics are expected to be predominantly Gaussian when the radar beam is pointed significantly away from zenith, since the signal arises mainly from the turbulent scatter. For Zenith beam, however the signal could be significantly non-Gaussian because of the possibility of Fresnel reflection to an appreciable extent along with turbulent scatter.

1.4 Indian MST Radar System:

The MST radar facility at Gadanki (13.5° N, 79.2° E, 6.3° N mag.lat) is an excellent system used for atmospheric probing in the regions of Mesosphere, Stratosphere and Troposphere (MST) covering up to a height of about 100 km. It is also used for coherent backscatter study of the ionospheric irregularities above 100 Km. MST radar is a state-of-the-art instrument capable of providing estimates of atmospheric parameters with very high resolution on a continuous basis which contribute to study different dynamic process in the atmosphere. It is an important research tool in the investigation of prevailing winds, waves, turbulence and atmospheric stability and other phenomenon.

The Indian MST radar has been established as a major national facility for atmospheric research in India. The facility, named as National MST Radar Facility (NMRF), is unique of its kind in India. The MST radar was commissioned for scientific utilization in 1993 and it has since been operating on regular basis. The Indian MST radar is highly sensitive, pulse-coded, coherent VHF phased array radar operating at 53 MHz with a peak power-aperture product of $3x10^{10}$ Wm^2. Important specifications of the MST radar at Gadanki are given in Summary form in the following Table – 1:

Parameter	Specifications
Location	Gadanki (13.4° N, 79.18° E)
Frequency	53 MHz
Peak Power – Aperture Product	$3x10^{10}$ Wm^2
Receiver bandwidth	1.7 MHz
Receiver Dynamic Range	70 dB
Peak Power	2.5 MW
Maximum Duty Ratio	2.5 %
Number of Yagi Antennas	1024
Beam Width	3°
Number of beams for automatic scan	18 out of 82 beams in auto mode
Pulse Width	16 & 32 µs coded and 1 to 32 µs uncoded (in binary steps)
Pulse Repetition Frequency	62.5 Hz – 8 kHz (in binary steps)

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Maximum number of range bins	256
Number of coherent integrations	4 – 512 (in binary steps)
Maximum number of FFT points	512
Radar Controller	PC/AT featuring programmable experiment specifications file
Computer System	32 – bit super mini with vector accelerator (Masscomp – MC5600)

Table 1: Main Specifications of the Indian MST radar

1.5 Signal Processing System:

The quadrature (I and Q) outputs of the receiver are limited to $\pm$5V and given to a signal processor unit consisting of two identical channels of A/D converter (ADC), decoder and coherent integrator and a common interface. The functional block diagram of the signal processing subsystem is shown in following figure:

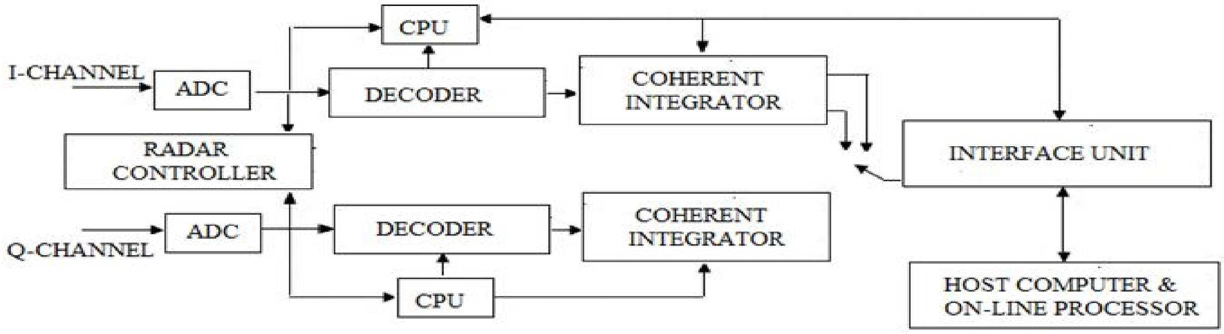

Figure 1.1: Block Diagram of the Signal Processor Unit

The ADC is of 12-bit resolution to match the dynamic range of the receiver and has 500 ns conversion time to meet adequately the requirement of 1 MHz sampling rate. The decoding operation essentially involves cross correlating the incoming data from the ADC with the replica of the transmit code. It is implemented by means of 16 bit, 32-tap correlator transversal filter chip (IMS A100). Since A100 is fast enough to decode the signal pulse by pulse, it could precede the coherent integrator with some advantage. The coherent integration is a processing step introduced to affect a significant reduction in the volume of the data without compromising in any way the information derived from the signal. Since the noise bandwidth is reduced by a factor of number of integrations, this will essentially improve the process gain by a factor of number of integrations. A 16 bit parallel interface multiplexes the integrated outputs from I and Q channels and transfers the data into the host computer for further processing. The system has a maximum data acquisition rate of 0.5 Mbps and a maximum speed of 5 MFLOPS which enable on-line processing to the extent of 512 point Fast Fourier Transform (FFT) of 256 range bins. For on-line monitoring, the integrated spectra can be displayed on the graphics console of the host computer in a selected format. the method adopted for off-line data processing, involving computation of spectral moments and vector winds also support the computation of spectrum, editing power spectrum for any interference or clutter removal etc.

1.6 Data processing and Parameter extraction:

Figure 1.2 shows the functional block diagram of various processing stages involved in the extraction and estimation of atmospheric parameters. The complex time series of the decoded and integrated signal samples are subjected to the process of FFT for the on-line computation of the Doppler Power Spectra for each range bin of the selected range window. The off-line data processing for parameterization of the Doppler Spectrum follows closely the procedure adopted at the poker flat radar. The computation involved in the various stages of operation and its advantages are given below:

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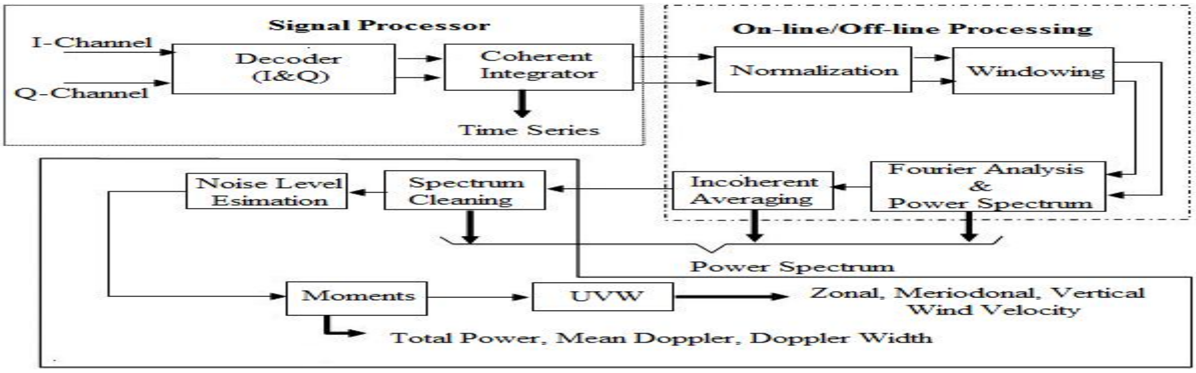

Figure 1.2: Processing Steps for Extraction of Parameters

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.

- Sampling resolution of ADC
- Scaling due to pulse compression in decoder
- Scaling due to coherent integration
- Scaling due to number of FFT points.

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 the variance of estimate increases with the use 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. The selection of rectangular window is done before FFT computation.

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.

Incoherent Integration (Spectral averaging)

Incoherent integration is the averaging of the power spectrum number of times.

$$P_i = \frac{1}{m}\sum_{k=1}^{m} P_{ik} \qquad \text{(i= 0,……….N-1 and m is the number of spectra integrated)}$$

The advantage of the incoherent integration is that it improves the detectability of the Doppler spectrum. The detectability is defined as $\mathbf{D} = \frac{\mathbf{PS}}{\mathbf{\sigma S+N}}$ Where P_S is the signal power and σ_{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.

A strong DC value or zero mean velocities may be present in the spectrum after the FFT. This is removed by replacing the zero Doppler points by the average of adjacent Doppler points on either side.

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 adjusted to noise floor or doing an incoherent integration of the spectrum and replace the value with good value from the second spectrum.

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Noise level estimation:

All methods adapted to find out the noise level estimation are statistical approximation to the near values. The method implemented here is based on the variance decided by a threshold criterion, Hildebrand and sekhon. 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.

$$\frac{\text{Variances(s)}}{\text{mean(s) 2}} \leq 1 \text{ over number of spectra averaged.}$$

Moments:

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 probing.

II.IMPROVING SNR OF RADAR SIGNAL USING WAVELET DE-NOISING SCHEME

2.1 General Introduction:

Noise is one of the major factors of signal distortion and is prime reason for careful design of signal processing units. The main problem with noise is that it tends to interface with the signal and distort it. Noise is present everywhere, in every medium and cannot be avoided. Noise is random in nature and so cannot even be modelled except statistically. For a particular application noise can be modelled for and estimated statistically. Noise can be modelled as White noise or Gaussian noise. It has its spectrum throughout the frequency spectrum. So it is quite useless trying to eliminate the noise using filters with some particular cut-off frequency.

Signal-to-Noise Ratio:

The calculation of the equivalent noise of an amplifier, receiver or device may have one of two purposes or sometimes both. The first purpose is comparison of two kinds of equipment in evaluating their performance. The second is comparison of noise and signal at the same point to ensure that the noise is not excessive. In the second instance, and also when equivalent noise is difficult to obtain, the signal-to-noise ratio (S/N) is very often used. It is defined as the ratio of signal power to noise power at the same point. Signal-to-Noise Ratio gives the fidelity of the desired signal. It is usually measured in dB.

$$\text{SNR} = \frac{\text{Average power of message signal at the receiver output}}{\text{Average power of noise at the receiver output}}$$

De-Noising:

De-Noising is the process by which noise is eliminated by processing the signal. In general De-Noising is done by transforming the signal at hand into other domains, process the signal, and then finally reconstruct it back into the time domain. The De-Noising process improves the Signal-to-Noise Ratio of the signal.

2.2 Wavelet De-Noising Scheme:

In the recent wavelet literature one often encounters the term 'De-Noising', describing in an informal way various schemes which attempt to reject noise by damping or thresholding in the wavelet domain. The Thresholding of wavelet coefficient has near optimal noise reduction for many classes of signals. De-Noising differs from filtering schemes in the following aspects:

a) De-Noising does nonlinear filtering i.e., filtering is made as function of some Threshold function.

b) De-Noising tends to optimize the Mean Square Error i.e., $\frac{1}{N}\sum E\ [f\ (x_n) - f\ (...)]^2$

Wavelets are used as it provides a whole lot of advantages over Fast Fourier Transform (FFT). Fourier analysis has a serious drawback. In transforming to the frequency domain, time information is lost. When looking at a Fourier transform of a signal, it is impossible to tell when a particular event took place. Wavelet analysis is capable of revealing aspects of data that other signal analysis techniques miss, aspects like trnds, breakdown points, discontinuities in higher derivatives and self-similarity. Furthermore, because it affords a different view of data than those presented by traditional techniques, Wavelet analysis can often compress or De-Noise a signal without appreciable degradation. The underlying model for the noisy signal is basically of the following form: $s(n)=f(n) + \sigma\ e(n)$ Where time 'n' is equally spaced.

In the simplest model, suppose that e (n) is a Gaussian White Noise N (0, 1) then the noise level is supposed to be equal to 1. The De-Noising objective is to suppress the noise part of the signal s and to recover f.

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So the main problem lies in modelling the noise and the noise level. In practical case an exhaustive study is to be done in modelling these and then try to eliminate the noise.

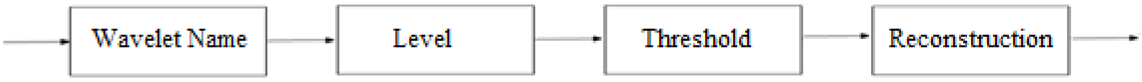

Figure 2.1: Block Diagram for Wavelet De-Noising Scheme

The wavelet transform provides the time-frequency representation of the signal. (There are other transforms which give this information too, such as STFT, Wigner distribution etc.). This property is used for de-noising which can be achieved in four steps:

Step 1: Selection of Wavelet

There are many types of wavelets available (Haar, Daubechies, Symlets etc....) with different properties among which select one according to the requirement.

Step 2: Obtaining Wavelet Transform Coefficient

Compute the wavelet decomposition of the signal at the selected level N.

Step 3: Selection of Threshold

For each level from 1 to N, select hard or soft Thresholding to the detail coefficients. In addition to these , there are minimaxi, rigrsure, heursure Threshold techniques present. Each of these techniques has a unique behaviour suitable for de-noising a particular type or class of signals.

Step 4: Reconstruction:

Reconstruct the signal using the approximation coefficients of level N and the modified detail coefficients of levels from 1 to N.

2.3 Hard or Soft Thresholding:

Hard Thresholding is the simplest method. Hard Thresholding can be described as the usual process of setting to zero the elements whose absolute values are lower than the Threshold. Soft Thresholding is an extension of Hard Thresholding, first setting to zero the elements whose absolute values are lower than the Threshold and then shrinking the non zero coefficients towards o.

2.4 Threshold selection rules:

Option	Threshold Selection Rule	Threshold Return
'rgrsure'	Selection using principle of Stein's Unbiased Risk Estimate (SURE)	2.0735
'sqtwolog'	Fixed form Threshold equal to sqrt(2*log(length(s)))	3.7169
'heursure'	Selection using a mixture of the First two points	3.7169
'Minimaxi'	Selection using minimax principle	2.2163

2.5 Threshold Rescaling:

To deal with unscaled and non-white noise Threshold's rescaling parameter is used

Option	Corresponding Model
one	Basic Model
sin	Basic Model with Unscaled Noise
min	Basic Model with Non-White Noise

2.6 Algorithm for the calculation of SNR:

Generally, as height increases the signal power decreases whereas the noise power increases. Hence it is assumed that the signal-to-noise ratio is a linear function of height. But this need not always be true in the case of

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atmospheric signals as it depends upon the atmospheric conditions at that particular height. The SNR may vary from maximum to minimum values in a random way but maximum at lower bins when compared to higher bins. The following algorithm can be used for the computation of SNR:

Step 1:

Recorder the spectrum $\{P_i, i=0, 1......N-1\}$ in ascending order to form
$\{A_i, i=0, 1.......N-1\}$ where $A_i<A_j$ for $i<j$

Step 2: Compute

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

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

and if $Q_n > 0$, $R_n = \dfrac{P_n^2}{(Q_n * M)}$, for n = 1,........N

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

Step 3:

Noise level (L) = P_k Where k= min $\begin{bmatrix} n \text{ such that } Rn > 1 \\ 1.\ no\ n\ meets\ the\ above\ criterion \end{bmatrix}$

Step 4:

Record the spectrum to its correct index of frequency (i.e. – $f_{maximum}$ to + $f_{maximum}$) and subtract noise level L from spectrum

Step 5:

i. Find the index 1 of the peak value in the spectrum i.e. $\tilde{P}_1 \geq \tilde{P}_i$ for all i=0 ....N-1

ii. Find m, the lower Doppler point of index from the peak point i.e. $\tilde{p}_i \geq 0$ for all $m \leq i \leq 1$

iii. Find n, the upper Doppler point of index from the peak point i.e. $\tilde{p}_i \geq 0$ for all $1 \leq i \leq n$

Step 6:

i. The zeroth moment is computed, $M_0 = \sum_{i=m}^{n} \tilde{P}_i$

Represents Total power in the Doppler spectrum.

ii. Signal to Noise Ratio (SNR) = 10 $\log\left[\dfrac{M_0}{(N * L)}\right]$ dB

III.COMPUTATION OF WIND SPEED

3.1 Introduction:

The purpose of radar signal processing is to extract the desired data from radar signals. The desired data usually concerns the detection of target of interest, the location of the target in space. About the radar the true rate of change of the target's location in space and in some cases the identification of a target as being a particular one of a number of class of targets.

The accuracy of the data available from radar is limited by thermal noise introduced by the radar receiver, echoes from targets of no interest (known as clutter) and externally generated interference. As a result radar signal processing is also used to enhance signals and to suppress clutter and externally generated signals.

The Mesosphere Stratosphere Troposphere (MST) radar is a pulsed Doppler radar to support the atmospheric research in the MST region. Even though the radar technique is same the extraction of signal requires great care. In

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normal radar the target will be a hard target having better reflection coefficient. Without many signals processing technique the extraction of signal is possible. In the case atmospheric radar the target are soft target and it is buried 40 to 50 dB below the background noise/clutter and sophisticated signal processing technique is required to extract the signal.

Due to various reasons the radar echoes may be corrupted by ground clutters, system bias, interference, image formation etc. The data is to be cleaned from these problems before going to analysis. The below block diagrams shows the process of the calculating the wind speed.

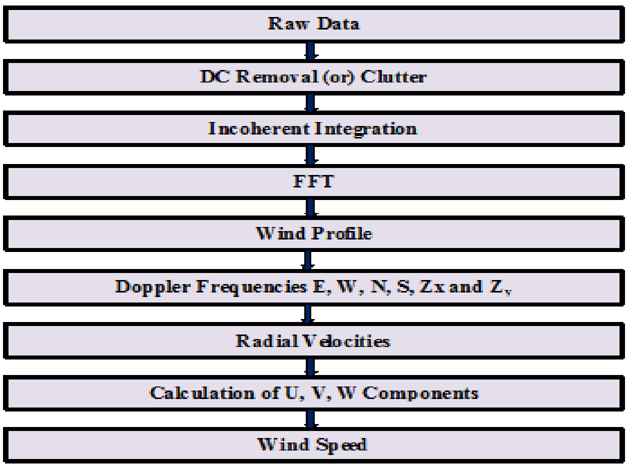

Figure 3.1: Existing Method

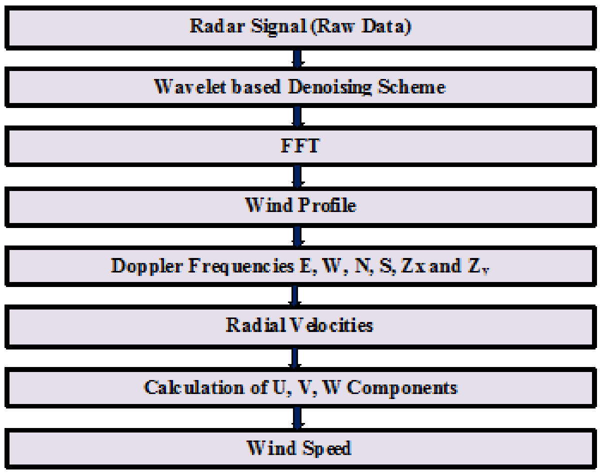

Figure 3.2: Proposed Method

3.2 Clutter/DC removal:

A strong DC value or zero mean velocities may present in the spectrum after doing FFT. This is removed by replacing the zero Doppler bins by the average of adjacent Doppler on either side. This also can be removed in time series by taking out the bias in I and Q channel and do the Fourier analysis. The basic operation carried out here is,

$P_{N/2}= (P_{N/2+1} + P_{N/2-1})/2,$ (N/2 Corresponds to zero frequency).

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 adjusted to noise floor or doing an incoherent integration of the spectrum and replace the value with good value from the 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 affected the original Doppler trace then the analysis may be carried out in a window confined to the Doppler trace.

3.3 In-coherent Integration:

The type of averaging used in wind profiling is the averaging of consecutive power spectra, point for point in the frequency domain. This is referred to as spectral averaging or In–Coherent averaging. This improves the delectability of the spectral peak by smoothing out the noise "floor" and making the peak better defined the maximum height of useful data is there by increased. The disadvantage of In-Coherent averaging is the loss of time resolution. For many applications this is no problem since one wind profile every few minutes is adequate. Without spectral averaging it is possible to get a profile every few seconds.

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3.4 Fast Fourier Transform:

The transformation of a wave –form from the time to the frequency domain is known as Fourier transformation. In particular, if the wave-form is discrete (that is sampled at regular intervals) the process is known as the Discrete Fourier Transform (DFT). There are several numerical schemes or algorithms for computing the DFT. One rapid method commonly used is digital computer is known as the Fast Fourier Transform (FFT). This is the method often used in wind profiling. Some of the basic relationships relating to it will be given.

If the input to a DFT is a single discrete waveform, the output will be a frequency spectrum showing the Doppler shift, but it will not be possible to know if the Doppler shift is positive or negative. To remove this ambiguity, the echoes from each pulse transmitted are sampled twice for each range gates. One sample is taken from the direct input signal and the other is taken from the input signal that has been delayed one-greater wavelength (900 phase difference). These signals are known as the in-phase and quadrature components. If these phase differences that determines whether Doppler shift is positive or negative.

For each range gate, the discrete samples are spaced apart in time at the Pulse Repetition Period (PRP). The inverse of this is the Pulse Repetition Frequency (PRF), the rate at which the samples are taken. The resulting discrete waveform is the sum of many sine curves of various amplitudes and frequencies. In order to be able to determine any one of these sine curves, it must be sampled at least twice per wavelength. Thus, the highest possible Doppler frequency that can be detected is half the PRF. As discussed in the following section, several consecutive samples are normally averaged together before the FFT is calculated. Thus the effective sampling rate is lower. If NCOH is the number of samples averaged, then the maximum frequency detectable is f_N = PRF/2 (NCOH) = 1/2 (NCOH) (PRP)

This maximum frequency is sometimes called Nyquist frequency.
A fixed number (NFFT) of these averaged values actual pairs of values, as both the in-phase and quadrature components must be averaged separately- are then used as the input to the FFT. This number should be large enough to allow the spectrum to be defined adequately but small enough to keep the number of computations manageable for the computer that is to be used NFFT is usually 2n, where n is an integer, as this greatly speeds the computations. The output of the FFT computation is a pair of number sets (called real and imaginary components), each having NFFT points. These are then squared and summed point to point to yield the power spectrum, which also has NFFT points.
The total time required to gather the data for the FFT calculation is thus (NFFT) (NCOH) (PRP). The inverse of this is the frequency resolution of the power spectrum of:
Δf = 1/ (NFFT) (NCOH) (PRP)
The efficiency of the radar system depends on how best it can identify the echoes in the presence of noise and unwanted clutter.
Atmospheric radars are primarily designed to study the varying properties of the density distribution of the various layers of the atmosphere. Since there is no specific target and the whole of the atmosphere is to be studied the received signal had to be monitored, for reflections or scatterings from each of the layers. The variations of the Doppler shift from each of the layers gives the wind profile of the atmosphere at that particular instant. From the wind profile we obtain the Doppler frequency for further processing.

3.5 Doppler Frequency:

If there is a relative motion between the source of the waves and an object encountering the waves, the frequency is measured at the object will be different from that at the source. This is called the Doppler Effect. If the object is approaching the source, the frequency will be higher, if it is receding, the frequency will be lower. The amount of frequency change-called the Doppler Shift-is directly proportional to the relative radial velocity between the source and the object and inversely proportional to the wavelength. In the case of wind profiling the source is the wind profiler and the object is the refractive irregularity that scatters the waves. A double Doppler shift is encountered here: one shift as the pulse impinges upon the scattering volume and other as the pulse is scattered back towards the wind profiler. The Doppler Shift is therefore:$f_D = (-2Vr/\lambda) \sin\theta$
Where Vr = Radial velocity of the scatters along the beam
θ = Angle deviated from the vertical direction.
The –ve sign arises from the fact that positive radial velocities refer to motion away from the radar, which causes the frequency to be lower.

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From Doppler shift, the radial velocity is given as: $V_r = -f_D\lambda/2\sin\theta$
For the directions of Zenith-X and Zenith-Y the radar is operated in vertical direction. So the related equation for Doppler frequency is $f_D = -2V_r/\lambda$

3.6 Computation of absolute Wind velocity Vectors(UVW):

After computing the radial velocity for different beam positions, the absolute velocity can be calculated. To compute U, V & W, at least the 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 (V_x,V_y,V_z) is
$V_D = V_i = V_x \cos\theta_x + V_y \cos\theta_y + V_z \cos\theta_z$
Where X, Y and Z directions which are aligned to East-West, North-South and Zenith respectively. Applying least square method residual, $\varepsilon^2 = (V_x \cos\theta_x + V_y \cos\theta_y + V_z \cos\theta_z)^2$ 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 corresponds to X, Y, and Z

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

Thus, on solving equations we can derive V_X, V_Y, and V_Z, which corresponds to U (Zonal), V (Meridonal) and W (Vertical) Components of velocity.

Zonal velocity (U):
Zonal velocity = (Radial velocity in East Direction + Radial velocity in west direction)/2
i.e. $U= (V_rE+V_{rw})/2$

Meridional velocity (V):
Meridional velocity = (Radial velocity in North direction + Radial velocity in south direction)/2
i.e. $V= (N_rN+V_rS)/2$

Vertical velocity (W):
Vertical velocity = (Radial velocity in Zenith X direction + Radial velocity in Zenith Y direction)/2
i.e. $W = (V_rZ\text{-}x+V_rZ\text{-}y)/2$
Using the Zonal velocity and Meridonal velocity the Wind Speed can be computed using the formula:
The Magnitude of Wind speed $(W_s) =\sqrt{(U^2+V^2)}$

IV. RESULTS AND CONCLUSIONS

MST Radar returns from the atmosphere arise either through turbulent scatter or partial reflection or the combination of the two. The adaptive algorithm designed is carried out on the data obtained by operating radar in three different conditions with specifications as given below:

1. Lower Stratosphere (Up to 30 Km)

No. of Range Bins	: 150
No. of FFT Points	: 512
No. of Coherent integrations	: 64
No. of In-Coherent Integrations	: 1
Interpulse Period	: 1000 μ Sec
Pulse Width	: 16 μ Sec
Beam	: 10°
One Range bin Corresponds to	: 0.15 Km

2. Lower Stratosphere with predominant Clutters (Up to 30 Km)

No. of Range Bins	: 91
No. of FFT Points	: 512
No. of Coherent integrations	: 256
No. of In-Coherent Integrations	: 1
Interpulse Period	: 250 μ Sec
Pulse Width	: 2 μ Sec
Beam	: 10°
One Range bin Corresponds to	: 0.15 Km

3. Mesosphere Data (Up to 100 Km)

No. of Range Bins	: 40
No. of FFT Points	: 128
No. of Coherent integrations	: 64
No. of In-Coherent Integrations	: 1
Interpulse Period	: 1000 μ Sec

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Pulse Width : 16 µ Sec
Beam : 10°
One Range bin Corresponds to : 2.5 Km

4.1 Power Spectrum Plots:

Power Spectrum plots obtained for the data before and after cleaning is observed in the figures 4.1.1 to 4.1.8, it is observed that Denoising technique has better height coverage and also increased signal detectability when the echo is weak or there is low SNR.

Doppler Power Spectrum for North

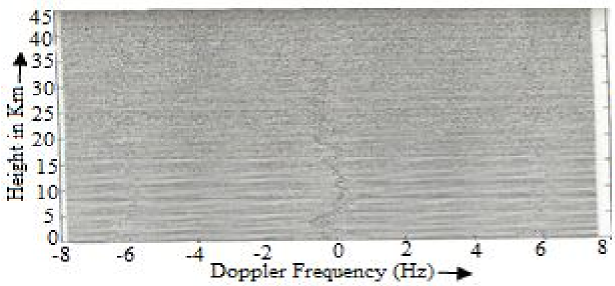

Figure 4.1.1: Before Denoising

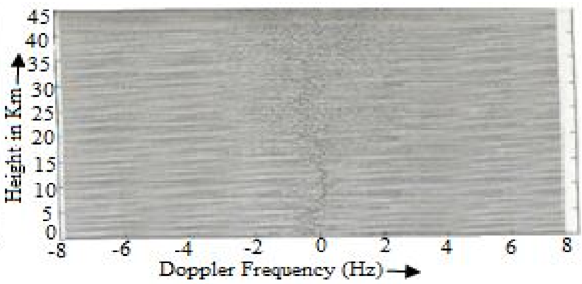

Figure 4.1.2: After Denoising

o

Doppler Power Spectrum for South

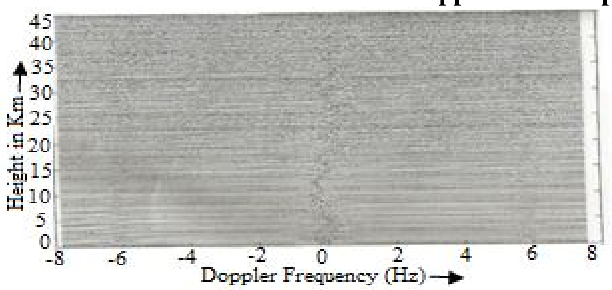

Figure 4.1.3: Before Denoising

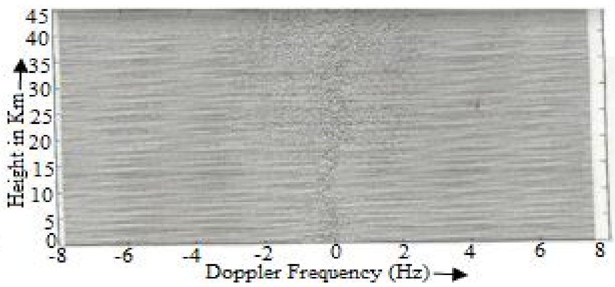

Figure 4.1.4: After Denoising

Doppler Power Spectrum for West

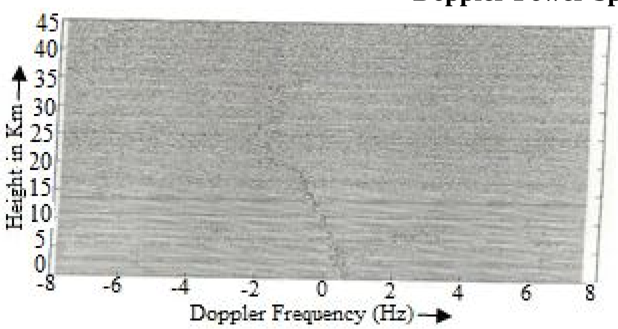

Figure 4.1.5: Before Denoising

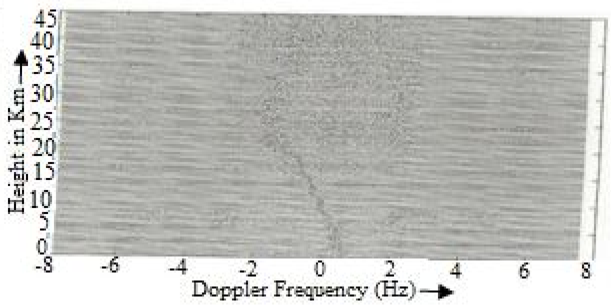

Figure 4.1.6: After Denoising

Doppler Power Spectrum for Zenith – X & Zenith - Y

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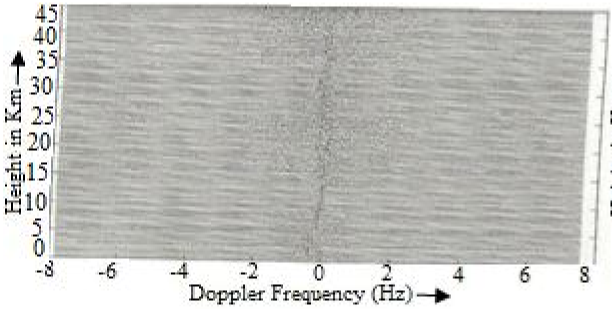

Figure 4.1.7: Before Denoising (Zenith – X)

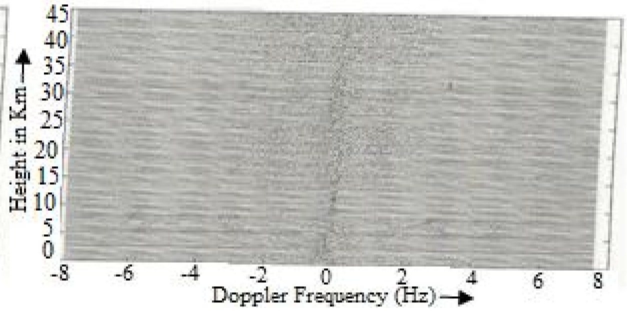

Figure 4.1.8: After Denoising (Zenith – Y)

4.2 Doppler Frequency Plots:

Figures 4.2.1 to 4.2.6 are the plots showing Doppler frequencies at different heights.

(a) At lower altitudes (1-10 Km) where SNR will be around 10 dB to 0 dB, there is no deviation in the computation of Doppler frequency. So, Denoising of the signal is not essential till 10 Km. But Denoising may be necessary for lower altitudes for processing the data collected during thunder storms, Monsoon rains etc. as SNR will be very less during these times.

(b) At higher altitudes because of vey low SNR's the computation of Doppler frequency is difficult without denoising. The probability of detecting the exact echo is less at these altitudes. However with denoising it is possible to improve the probability of detection of exact echo and thus computation of Doppler frequency can be found more accurately.

(c) The figure 4.2.1 is the plot obtained for Doppler frequency indicates that up to 20 Km there is no much deviation; from 20 Km there is a deviation of 0.4 Hz in the computation of Doppler frequencies with and without denoising. Figure 4.2.2 indicates that up to 18 Km there is no much deviation, from 20 Km onwards there is a deviation of 1.5 Hz in the Doppler frequencies with and without denoising. Figure 4.2.3 shows that up to 12 Km the deviation is minimum and after 12 Km there is a deviation of around 6 Hz in the Doppler frequencies with and without denoising

(d) The figure 4.2.4 is the plot obtained for Doppler frequency indicates that there is a deviation of -0.2 Hz between 16 km and -1 Hz from 18 Km in the computation of Doppler frequencies with and without denoising. The figure 4.2.5 is the plot obtained for Doppler frequency indicates that there is no deviation in the computation of Doppler frequencies with and without denoising. Similarly for the plot shown in figure 4.2.6.

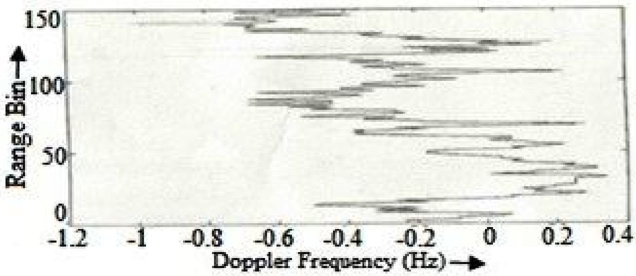

Figure 4.2.1: For North

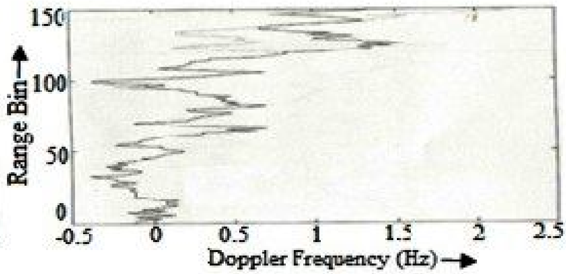

Figure 4.2.2: For South

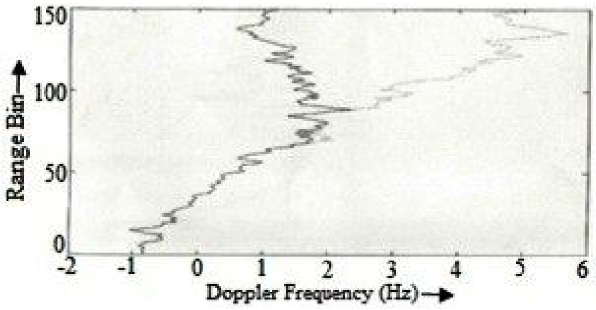

Figure 4.2.3: For East

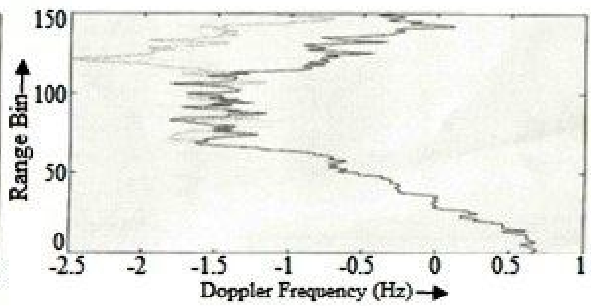

Figure 4.2.4: For West

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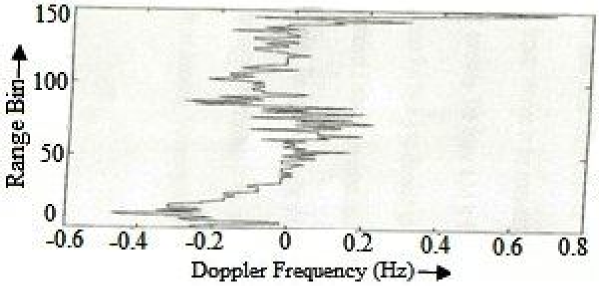

Figure 4.2.5: For Zenith - X

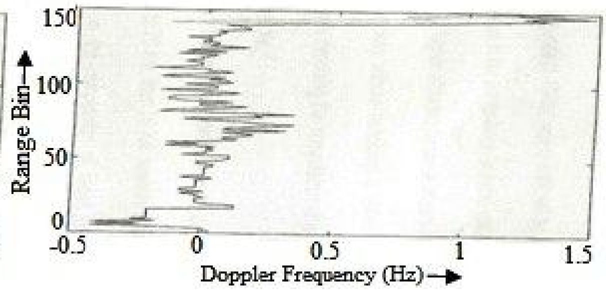

Figure 4.2.6: For Zenith - Y

4.3 Radial Velocity Plots:

Figures 4 .3.1 to 4.3.6 are the plots showing radial velocities at different heights.

(a) At lower altitudes (1-10 Km) where SNR will be around 10 dB to 0 dB there is no deviation in the computation of radial velocity.

(b) At higher altitudes because of very low SNR’s the computation of radial velocity without denoising is difficult to compute accurately. However with denoising the computation of radial velocity can be found more accurately.

(c) Figure 4.3.1 shows that the deviation in the computation of radial velocity is less up to 20 Km, from 20 Km onwards there is a deviation of around 1.2 m/sec in the computation of radial velocities with and without denoising. Figure 4.3.2 indicates that there is no much deviation up to 18 Km, from 18 Km the deviation is around 4 m/sec. Figure 4.3.3 indicates that up to 12 Km there is no much difference; from 12 Km onwards the deviation is around 14 m/sec in the computation of radial velocities with and without denoising. The figure 4.3.4 is the plot obtained for radial velocity indicates that there is no deviation up to 16.5 Km, from 16.5 Km there is a deviation of 3 m/sec in the computation of radial velocity with and without denoising. The figure 4.3.5 is the plot obtained for radial velocity indicates that there is no deviation in the computation of radial velocity with and without denoising. Similarly for the plot shown in figure 4.3.6.

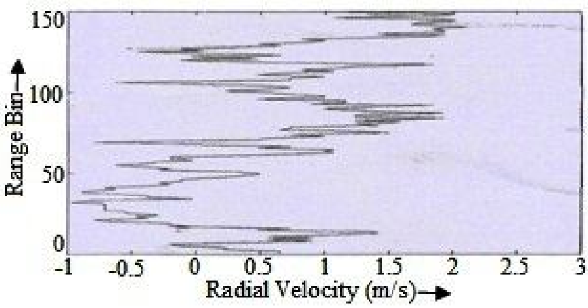

Figure 4.3.1: For North

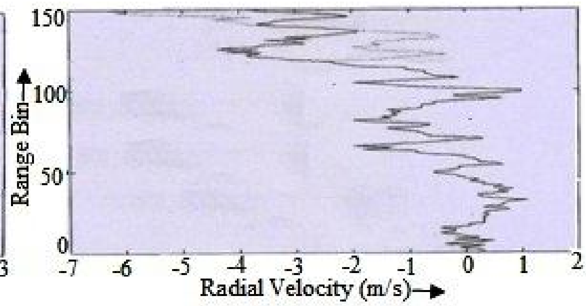

Figure 4.3.2: For South

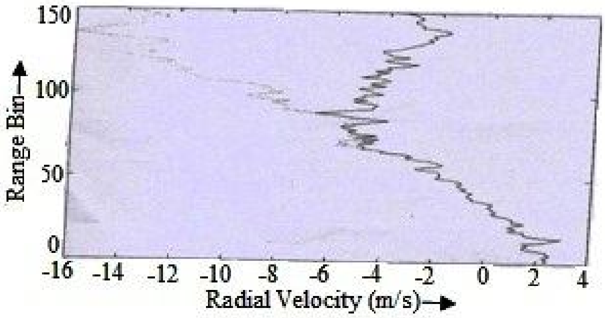

Figure 4.3.3: For East

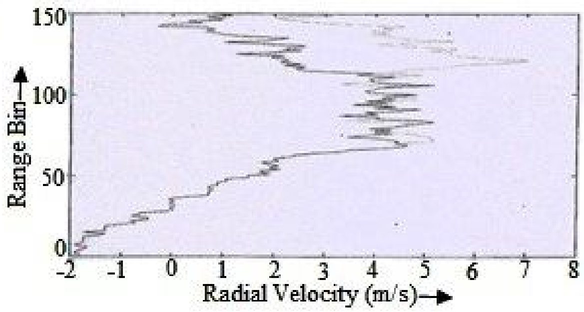

Figure 4.3.4: For West

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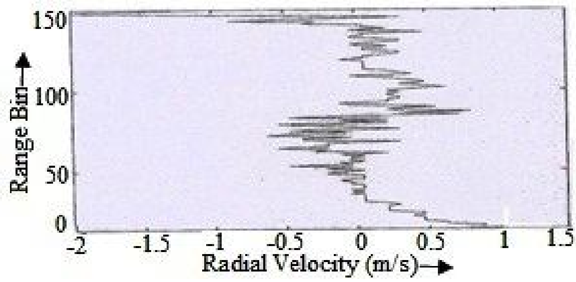

Figure 4.3.5: For Zenith - X

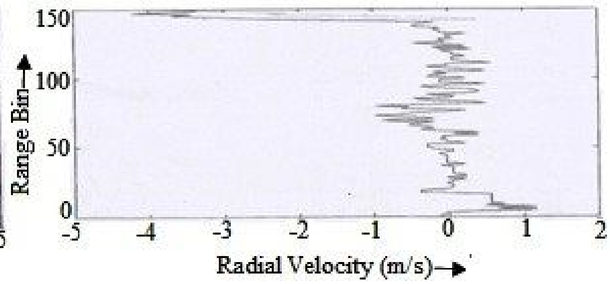

Figure 4.3.6: For Zenith – Y

4.4 Wind Speed Plots:

Figure 4.4.1 indicates that there is no much deviation up to 12 Km and there is a deviation of 35 m/sec from 12 Km onwards in the computation of U component with and without denoising. Figure 4.4.2 indicates that there is no much deviation up to 18 Km and there is a deviation of 12 m/sec from 18 Km onwards in the computation of V component with and without denoising. Figure 4.4.3 indicates that there is no much deviation up to 21 Km and there is a slight deviation of about 1.8 m/sec at 21 Km in the computation of W component with and without denoising. Figure 4.4.6 indicates that there is no much deviation up to 12 Km and deviation of about 7 m/sec from 12 Km to 18 Km and afterwards it is 15 m/sec in the computation of wind speed with and without denoising.

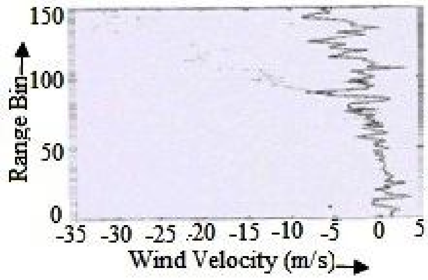

Figure 4.4.1: For U –Component

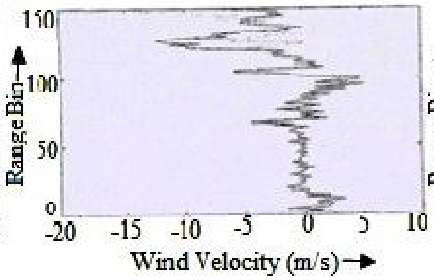

Figure 4.4.2: For V-Component

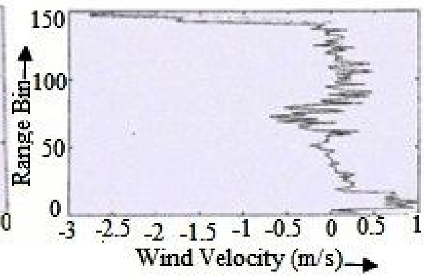

Figure 4.4.3: For W -Component

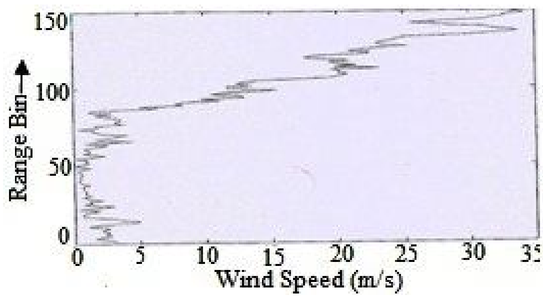

Figure 4.4.4: Before Denoising

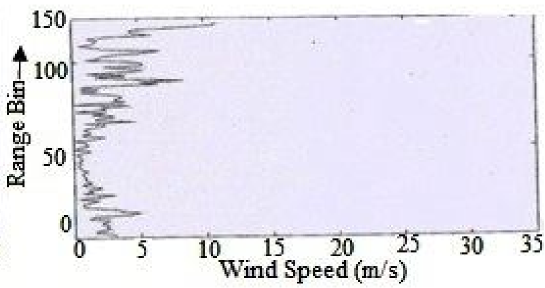

Figure 4.4.5: After Denoising

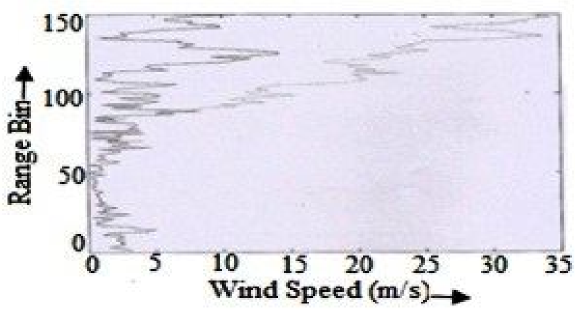

Figure 4.4.6: Wind Speed Before and After Denoising

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