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A Novel Approach to Improve the Smoothening the Wind Profiler Doppler Spectra Using Empirical Mode Decomposition with Moving Average Method

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Abstract: The dedicated VHF clear-air atmospheric radars built in the late 70s and early 80s were found to be capable of observing atmospheric parameters such as the three-dimensional wind vector. These radars measure wind continuously. Wind profiling radars yield real-time lower atmospheric wind profiles in continuous unattended operation. These profilers are necessary to measure the wind profile and Signal to Noise Ratio (SNR) by detecting the echoes of the wind profiler. The lower atmospheric signals, which are processed in the present work has been obtained from the LAWP radar at National Atmospheric Research Laboratory (NARL), Gadanki, India. This paper discusses estimation of the wind profile using Empirical Mode Decomposition with Moving Average Method (EMDMA). Effective Doppler shift for LAWP data is obtained by using Empirical Mode Decomposition with Moving Average and compared with the Doppler obtained for LAWP data using Windowing Techniques. Results shows that there is an effective Doppler shift after using Empirical Mode Decomposition with Moving Average.

Keywords: Doppler shift, Empirical Mode Decomposition, Wind Profiler, Signal to Noise Ratio.

I. INTRODUCTION

The Lower Atmospheric Wind Profiler is used for conducting research in the lower atmosphere [1]. National Oceanic and Atmospheric Administration (NOAA) developed the technology for operational wind profilers, and in the early 1980s deployed the Colorado wind-profiling network consisting of five VHF and one UHF radars. National Atmospheric Research Laboratory (NARL) at Gadanki (13.47°N, 79.18°E) near Tirupati, India, has been operating this wind profiler at 1280 MHz. This wind profiler used for studying structure and dynamics of the lower atmosphere. These radars employ bi-phase coding with complementary codes, to achieve better range resolution with maximum average power.

Wind profiles are very important for studying meteorological phenomena and for weather forecasting. These wind profilers receive the echoes from the atmosphere in the height range from about 100m to 4-5Km. These wind profiler radars are pulse Doppler Radars, coherent and very high sensitive. The radar works on the principle of Doppler effect. The range and the radar scattering cross-section of the target are measured by using time delay with reference to the transmitted pulse and the received signal power. These wind profilers are also called Pulse Doppler Radars.

Whatever the signals received by the LAWP Radar, it contains both signal and noise. By reducing the noisy signal in the received data will improves the SNR. It can be possible by using different algorithms. This can be done already by using windowing Techniques. But Doppler shift for the LAWP data, which can be obtained after de-noising using wavelets has not much effective. To get effective smoothness in Doppler shift for LAWP data, one of the technique can be use called Empirical Mode Decomposition with Moving Average.

II. LOWER ATMOSPHERIC WIND PROFILER RADAR

The Lower Atmospheric Radars operate typically in the VHF (30 –300 MHz) and UHF (300 MHz – 3GHz) bands. Nowadays Radars were extensively used for obtaining the wind information (wind profiler). Doppler radar capability for probing the atmosphere, wind profiling radars have been used successfully for meteorological research and they have been considered for routine operations. Wind profilers are expected to have a growing impact upon weather forecasting, atmospheric research environmental pollution monitoring, climate, air traffic control and many more. It is therefore important that the wind measurements of these radars are both accurate and reliable. This network of systems has provided important insight into the optimal design details for an operational network [2]. The wind profile can be measured at these frequencies, even in rainfall season. However, these wind profilers have a serious limitation that their inability to measure high resolution winds in the first few kilometers. Wind profiler radars are relatively less sensitive and low cost systems, which use less power and smaller antenna and used for both research and operational applications.

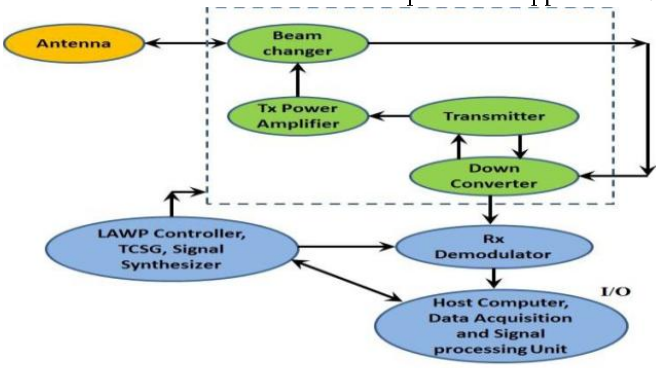

Fig. 1: Block diagram of LAWP Radar

This wind profiler or Boundary Layer (BL) radar as it probes the lower part of the atmosphere (up to about 5 km) and operating in the frequency band 900-1400 MHz are popular for measuring the wind vector by making use of variations in amplitude and frequency of radio waves which are transmitted from a radar system. The height resolution of this profiler is 100 m or better. The features of high spatial resolution and fast system recovery time require operation at frequencies near 1000 MHz.

LAWP radar has applications beyond wind profiling. It is being extensively used for atmospheric research and operational meteorology. It can measure the complete Doppler spectrum of atmospheric targets with a time resolution on the order of 1 min and a range resolution of about 100m. Since they provide almost continuous measurement of wind over a range of altitudes, they provide detailed information on vertical structure and wind variability. Vertically directed beams provide for direct measurement of vertical motions. In addition to wind and wind variability, the Doppler wind profiler provides measurement of signal strength and Doppler spectral width. It has yielded valuable data for the research community with respect to the winds, ABL and precipitation.

LAWP Radar system Specifications:

- ❖ Operating frequency is 1280 MHz
- ❖ Wind profiling Technique is Doppler Beam Swinging.
- ❖ Minimum height range is 100m
- ❖ Maximum height range is about 3-6 km in clear air and up to 12 km during precipitation
- ❖ Type of Antenna is Active patch array 16 x 16 (2.8m x 2.8m)
- ❖ Type of Tx/Rx is Solid-state TR modules (256)
- ❖ Pulse length range is 0.25μs to 8 μs
- ❖ System recovery time is < 0.5μs

Doppler Beam Swinging:

To measure the atmospheric winds the wind profilers use either Doppler Beam Swinging (DBS) technique or Spaced Antenna (SA) technique. Generally DBS technique uses a minimum of three radar beam orientations (Vertical, East-West, and North- South) to derive the components of the wind vector.

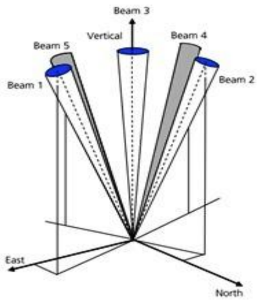

Fig. 2: Antenna Configuration for Doppler Beam Swinging Technique

One antenna beam is pointed toward the zenith, and two or four beams are pointed at off-zenith angles in the range 10-20^0 off-zenith with orthogonal azimuths (three beam systems) or orthogonal and opposite azimuths (five beam systems) as shown in figure 2. Spaced Antenna technique measures the temporal and spatial variation of field pattern of radar signals which are partially reflected or scattered from refractive index irregularities in the atmosphere. The antenna is pointed vertically. The spectral or complex autocorrelation analysis yields an estimate of the vertical velocity.

The profiler is operated in a pre-selected sequence of beam directions. Comparison of the received echo with the transmitted pulse permits the determination of the Doppler frequency. For each height, the radial velocities measured from the three beams are used to derive the east-west (zonal), north-south (meridional), and vertical components of the wind, U, V and W respectively.

III. DATA PROCESSING

The received signals are converted into quadrature base band signals using the down converter and quadrature detection. The Data processing steps include pulse compression, coherent integration, spectral processing steps like clutter removal, incoherent integration etc.

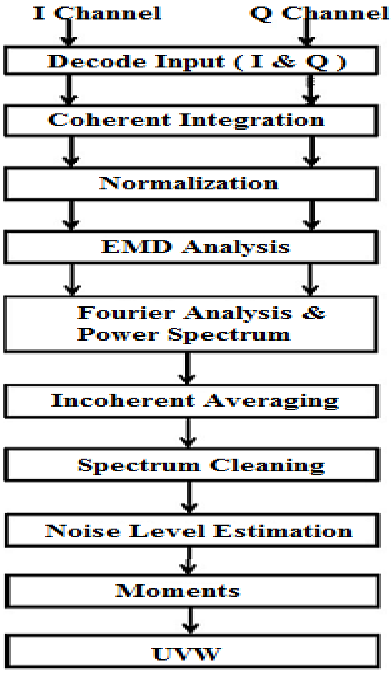

Fig. 3: Data processing steps of LAWP Radar

The average transmit power, which is the product of peak power and duty ratio (τ /T), where T is the inter-pulse period. The Profiler's Range Resolution is equal to $c\tau$ /2. The time series complex data {(I_i, Q_i), i = 0, 1. . N_{FFT} - 1} is subjected to FFT to obtain the complex Doppler spectrum {(X_i, Y_i), i = 0. . . N_{FFT} - 1} of the received echoes. I_i and Q_i are the in-phase and quadrature components in time series data, X_i and Y_i are the real and imaginary components of the complex Doppler spectral data, and N_{FFT} is the number of time series points.

To improve the signal detectability and to get greater height resolutions at higher heights wind profilers use coding schemes preferable complimentary codes. These code lengths will vary from 8/16/32/64. The received coded signals will be decoded in the processor after digitisation. The signals are added each range bin wise. The number of averages depends on the signal dynamics in the atmosphere. Signal being coherent and noise being incoherent signal will build up. After the coherent integration the Doppler spectra is computed using Empirical Mode Decomposition Technique (EMD). From the Doppler, the velocity can be estimated. To further improve SNR averaging of spectra per beam is done. However this depends on the dynamics of the atmosphere.

In general, the echo power due to a single pulse is very weak compared to the noise power and echoes received over a large number of successive pulses are averaged to improve the detection capability. Therefore, large number of pulses need to be transmitted within the given integration interval. Otherwise, radar should be able to transmit pulses at a fast rate for better detection.

IV. EMPIRICAL MODE DECOMPOSITION

The Empirical Mode Decomposition (EMD) is one of method for analysing the non-linear and non-stationary signals. This method is used for analysing the multi component sig-nals that breaks them down into a number of amplitude and frequency modulated zero-mean signals, termed Intrinsic Mode Functions (IMFs). EMD expresses the signal as an expansion of basis functions that are signal dependent and are estimated via an iterative procedure called sifting Process.

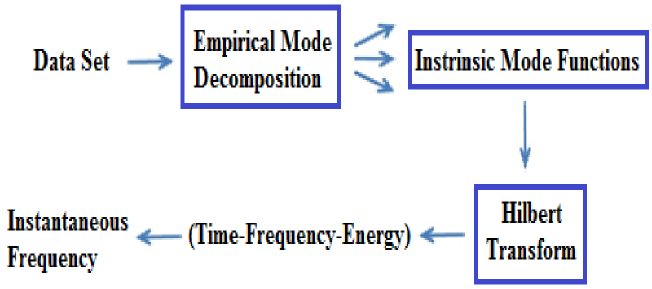

Fig. 4: Flow diagram for the Empirical Mode Decomposition

IMF is a Function that satisfies two conditions:

1. In the whole data set, the number of extrema and the number of zero crossings must either equal or differ at most by one.
2. At any point, the mean value of the "upper envelope" (defined by the local Maxima) and the "lower envelope" (defined by the local minima) must be zero.

The Function of the Hilbert Transform is given by

$$Y(t)\ \frac{1}{\pi}P\int \frac{X(t')}{t-t'}dt' \qquad (1)$$

Where P is the Cauchy Principal Value.
The Analytical Signal is given by

$$Z(t)=X(t)+iY(t)=a(t)e^{i\theta}(t) \qquad (2)$$

Where a(t) is the Magnitude
$\theta(t)$ is the Phase

$$a(t)=[X^2(t)+Y^2(t)]^{1/2} \qquad (3)$$

$$\theta(t)=\arctan(\frac{Y(t)}{X(t)}) \qquad (4)$$

Instantaneous Frequency is given by

$$\omega=\frac{d\theta(t)}{dt} \qquad (5)$$

Moving Average:

There are 512 fft points in the LAWP radar data. To get the smoothening for the echo signal of this radar, we use moving average with 3 points average and this can be done throughtout the data. And same procedure has to be done in different range bins (no. of range bins is 40) also. By using the moving average, the Doppler spectrum can be smoothened and the Doppler profiler of LAWP radar data can be identified easily.

V. RESULTS

Doppler shift of the LAWP data on 31st May, 2014 denoising using Windowing and Empirical Mode Decomposition with moving average method in South direction are shown in figure 5 and 6 respectively.

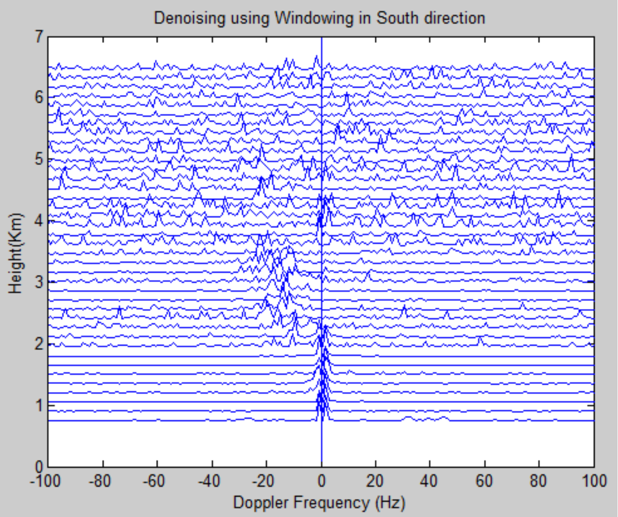

Fig. 5: Denoising Using Windowing in South Direction

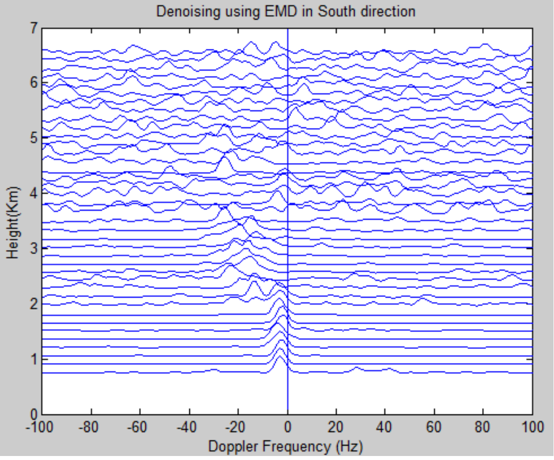

Fig. 6: Denoising Using EMD in South Direction

VI. CONCLUSION

Denoising using Empirical Mode Decomposition with Moving Average has been applied to LAWP Data and compared with the denoising using Windowing Technique. From the above discussion, it is concluded that the improvement of Signal to Noise Ratio (SNR) is observed by comparing denoising using Empirical Mode Decomposition with Moving Average and Windowing Technique.

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