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THE INDIAN MST RADAR SIGNAL (WINDS, WAVES) PROCESSING WITH AN ATMOSPHERIC DATA PROCESSOR (ADP) METHOD

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Abstract: When processing atmospheric radar data to estimate wind parameters, power spectrum is a key factor. The need for new data-dependent approaches is driven by the existing algorithms' poor resolution and high side lobe level issues. For the purpose of estimating the power spectral density, an atmospheric data processor (ADP) that is non-parametric and hyper parameter-free is presented. By minimising the weighted least square fitting criterion, this method can be used with a single snapshot. For the simulated data, the ADP method offers precise amplitude and frequency estimation. Indian MST (mesosphere, stratosphere, and troposphere) radar is where the data for the study mentioned above were gathered. ADP is used to calculate the power spectrum and Doppler frequency. This study also uses Global Positioning System Sonde data to calculate and validate zonal (U), meridional (V), and wind speed (W). It is shown and evaluated how well the spectral estimation performance of ADP works.

Keywords: Spectral estimation, Indian MST radar, ADP, GPS

1. Introduction

With a resolution of 150 m, Indian MST radar provides data on winds above 3.5 km. The Indian MST radar's Doppler beam swinging (DBS) method determines the three wind components U, V, and W. The data is gathered by the radar using multiple beam positions with a 16-second coded pulse and a 100-second inter pulse period (IPP) [1-4]. By applying the fast Fourier transform to the complex time series data, it is possible to obtain the online Doppler power spectra for each range bin (FFT) [5-7]. Offline data processing includes the steps of DC removal, average noise level estimation, interference removal, and incoherent integration [8]. The signal strength, mean Doppler shift, and half width of the spectrum are indicated by the 0th, 1st, and 2nd moments, respectively. The MST radar's ability to detect and estimate wind speed depends on an accurate estimation of the Doppler frequency [9-10]. The National Atmospheric Research Laboratory (NARL), Gadanki, Andhra Pradesh, India, has created a programme for processing the radar data. The atmospheric data processor (ADP) is its official name (Anandan 2002). Up to a certain height, the ADP can reliably estimate the Doppler

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frequencies [11-14]. The ADP is unable to estimate the Doppler frequencies and, consequently, the wind speed at higher altitudes because the signals are heavily contaminated with noise. Several algorithms have been used, as can be seen in the literature, to precisely estimate the Doppler frequencies from Indian MST radar data. Radar is used with the bispectral estimation algorithm (Anandan et al. 2001) at a high computational cost [15-18]. The multitaper-based spectral estimation (Anandan et al. 2004) has been used to analyse the radar data and has the benefit of reducing variance. The spectral peak broadening is present, though [19]. To estimate the Doppler spectra, an adaptive estimation technique has been presented, with specific parameters to adaptively track the signal in the range of the Doppler spectral frame (Anandan et al. 2005). Numerous techniques, including cepstral thresholding and wavelet-based denoising (Thatiparthi et al. 2010, Reddy and Reddy 2010a, b), have also been used to estimate the Doppler spectrum and then calculate wind velocities after cleaning the spectrum. The claim that a polyphase method was used to estimate the spectrum using uniform filter banks [20-21]. Prior to ADP estimation using Blackman-Tukey and minimum variance methods, recent studies used principal component analysis (PCA) on the Indian MST radar data (Uma Maheswara Rao et al. 2014). All currently used spectral estimation techniques for atmospheric radar data fall into one of two categories: parametric or nonparametric estimation techniques. However, nonparametric methods have global leakage (peaking at unwanted frequencies) and local leakage, while parametric methods need the prior knowledge of some parameters (main beam limits). In this study, the spectrum of indian MST radar data obtained from NARL is estimated using the atmospheric data processor (ADP) [22-23]. For both simulated and real-time data, the ADP algorithm, which is based on weighted least squares minimization, is found to produce excellent results.

2. Data Model

A complex baseband signal with uniformly spaced inphase (I) and quadrature (Q) phase components makes up the MST radar data that the NARL collects. Let $\{y_n\}^N{}_{n=1}$ be the complex data obtained by combining C complex exponentials with frequencies in a weighted manner to $\{\Omega_r\}_r{}^N{}_{=1}$ є $[0,\Omega_{max}]$.

$$y_n = \sum_{r=1}^{C} q_r \, e^{jw_r} t_n + e_n \quad (1)$$

Where C is a small number, the sampling time instants, denoted by $\{t_n\}^N{}_{n=1}$, can be distributed unevenly. The q_r is the additive white Gaussian noise component corresponding to the n^{th} sampling time is the magnitude associated with the r^{th} frequency component Ω_r , e_n.

The complex data signal can therefore be modelled as

$$y_n = \sum_{r=1}^{R} q_r \, e^{jw_r} \, t_n \quad + \, e_n \qquad (2)$$

The above equation's expanded form is:

$$\begin{bmatrix} y_1 \\ \cdot \\ \cdot \\ \cdot \\ y_N \end{bmatrix} = \begin{bmatrix} e^{j\omega 1t1} & \cdots & e^{j\omega Rt1} \\ \vdots & \ddots & \vdots \\ e^{j\omega 1t} & \cdots & e^{j\omega RtN} \end{bmatrix} \begin{bmatrix} q_1 \\ \cdot \\ \cdot \\ \cdot \\ q_R \end{bmatrix} + \begin{bmatrix} e_1 \\ \cdot \\ \cdot \\ \cdot \\ e_N \end{bmatrix} \qquad (3)$$

The corresponding q_r values will be non-zero for those r values where $q_r \, \epsilon \{\Omega_r\}_{r=1}^{N}$. The formula can vector ally be represented as follows:

$$Y = Dq + e \qquad (4)$$

3. Atmospheric Data Processor (ADP)

The atmospheric data processor is a non-parametric, weighted least squares-based algorithm. It can be applied to spectral estimation for either a single data sequence or multiple data snapshots. Here, we assume that there is only one snapshot. The ADP is use for analysis of data which given by NARL. The ADP first convert r (raw files) to d (spectrum files) then d(spectrum files) to m(moment files) after this m(moment files) to ASCII files.

4. Indian MST Radar Data

For the purpose of this study, the radar data gathered from the Indian MST radar operated at NARL, Gadanki, Andhra Pradesh, is used. One of the 15-scan MST radar data formats, each scan contains signal information from six beam directions (East, West, Zenith-X, Zenith-Y, North, and South). Each beam has 147 height range bins with a resolution of 150 m that range in height from 3.6 km to 25.6 km. There are 512 samples of complex time-series data in each range bin. ADP is used to determine the radar signal's spectrum. Since interference, clutter, and other factors frequently taint echoes, they must be cleaned before analysis. After performing spectrum cleaning on the radar signal, the maximum peak detection method (Anandan et al. 1996) is employed for the estimation of the Doppler profile. The Doppler profiles are used to calculate the Doppler frequencies. After computing the Doppler frequencies, the Doppler velocities are calculated by multiplying each frequency by $c/2f_c$, where c is the speed of light and f_c is the frequency at which the Doppler radar operates. For all 6 beams and 147 range bins, Doppler frequencies and speeds are computed. The vertical Zenith-X and Zenith-Y beams are not used to calculate wind speed because they are in the vertical direction. After that, the wind speed obtained is compared to the corresponding wind speed obtained from a GPS radiosonde (Jagannadha Rao et al. 2003). The IAA method is used to calculate the power spectrum of the data that was collected. When complex time-series data is subjected to the ADP, the basic periodogram method is used to estimate the power spectrum. ADP was used to obtain the Doppler height profiles for four scans of the east beam. The standard deviation for IAA was found to be extremely close to zero, which was the observed significant difference between ADP and IAA. The ADP, IAA, and GPS radiosonde were used to calculate the Zonal, Meridional, and Wind Speed components. The data used in IAA are collected from the reflected echoes from the layers of the atmosphere in the vertical direction without any drift in the horizontal direction, which can be the cause of the minor deviation between 15 and 17.5 km. using the method, the output SNR is obtained (Hildebrand and Sekhon 1974). The ADP was used to calculate the Zonal, Meridional, and Wind Speed components.

5. Results and Discussion

Displayed are the simulation results for the intricate data described in the Data Model. The data samples are produced from a signal made up of three exponentials with frequencies of 0.3100, 0.3150, and 0.1450 Hz and amplitudes of $q_1 = 10e^{j\psi_1}$, $q_2 = 10e^{j\psi_2}$, and $q_3 = 10e^{j\psi_3}$, with a sampling time of 1 s, when N = 200 and C = 3. The phase values $\{\psi_r\}_{r=1}^{3}$ are evenly and independently distributed between [0, 2Π]. The term introduces the noise component, which is simply the usual white noise with a mean and variance of zero. The SNR = 10 log $(\frac{100}{\sigma})$ is the definition of the signal-to-noise ratio (SNR) in decibels (dB) for the data model.

Fig. 1, 2, 3, 4, 5 shows the height verses SNR in east, west, zenith y, north, south direction power spectrum of the initial test signal produced by the data model without the addition of noise. The signal's spectrum at SNR = 0 dB using by adding 312 zeros to the 200 element time series data and running a 512-point FFT, the periodogram can be obtained. The number R of processing points is assumed to be 512 for IAA. The 100 Monte Carlo simulations were used to generate all of the performance curves. To get different signal-to-noise ratio conditions, we alter the value of σ^2. Additionally, it can be seen that the IAA method outperforms the ADP method in terms of variance characteristics. The GPS and IAA have significant correlation coefficients of 0.8996 and 0.9246, while the GPS and ADP have significant correlation coefficients of 0.843 and 0.85406, respectively.

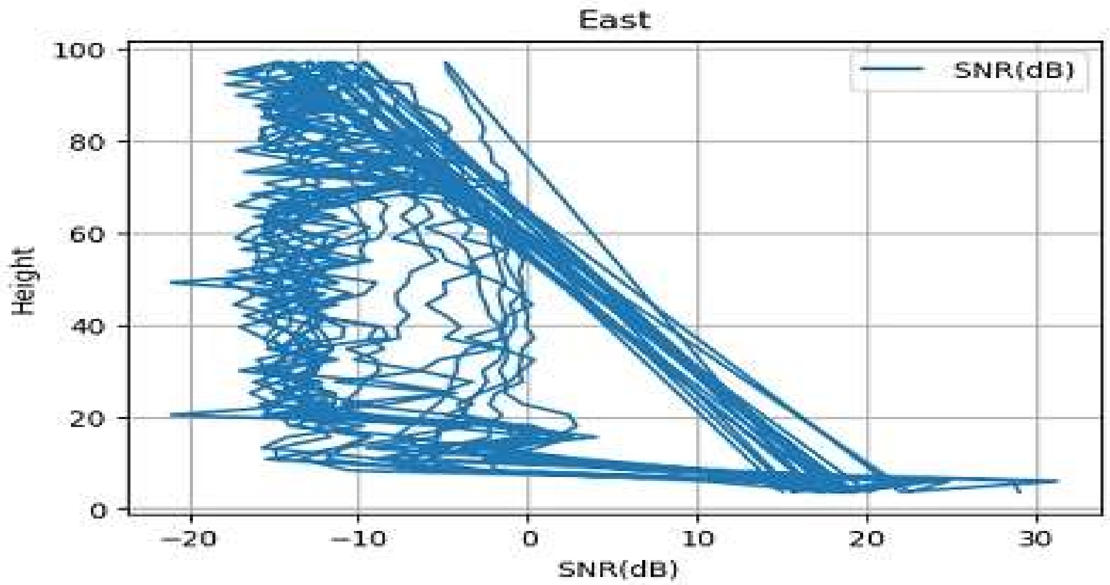

Figure 1: Represent the Height vs SNR (dB) graph for East direction

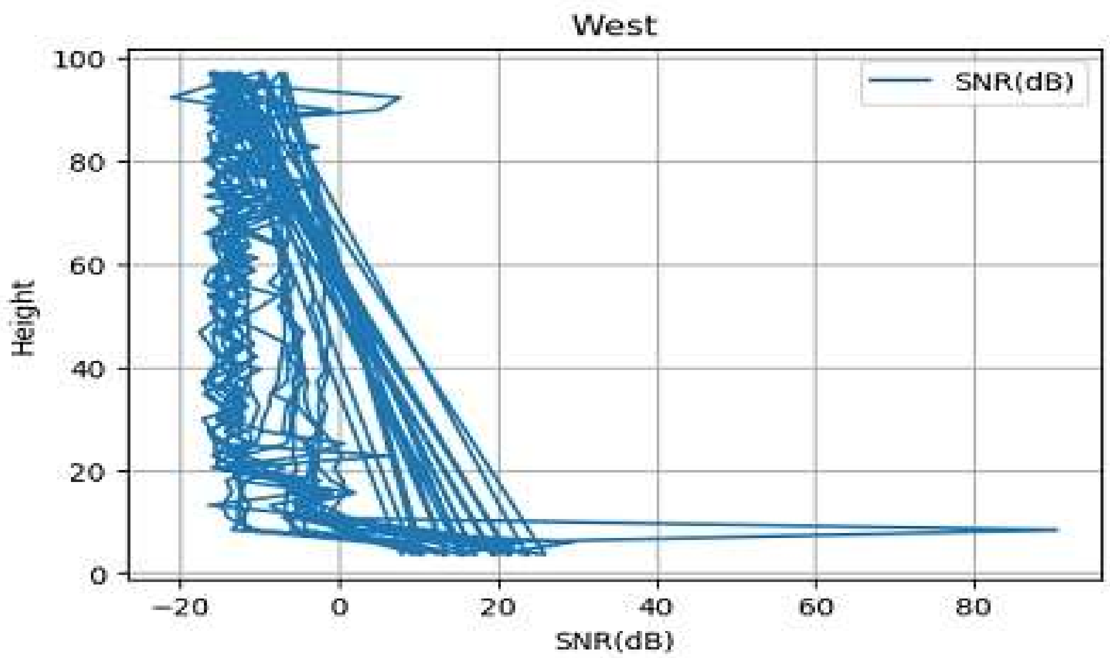

Figure 2: Represent the Height vs SNR (dB) graph for West direction

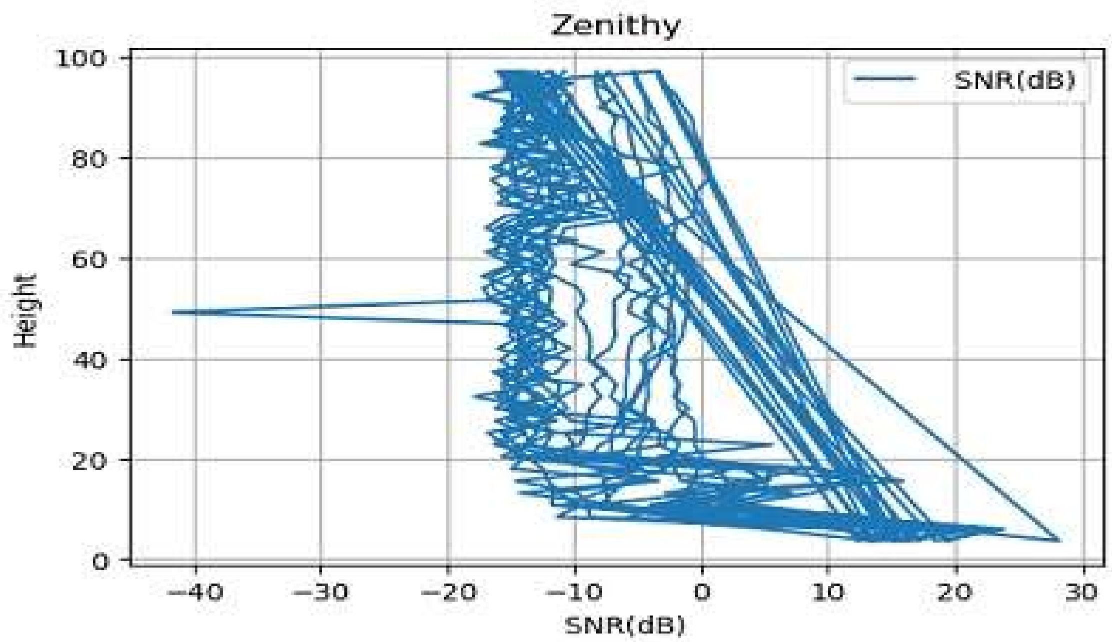

Figure 3: Represent the Height vs SNR (dB) graph for Zenith y-direction

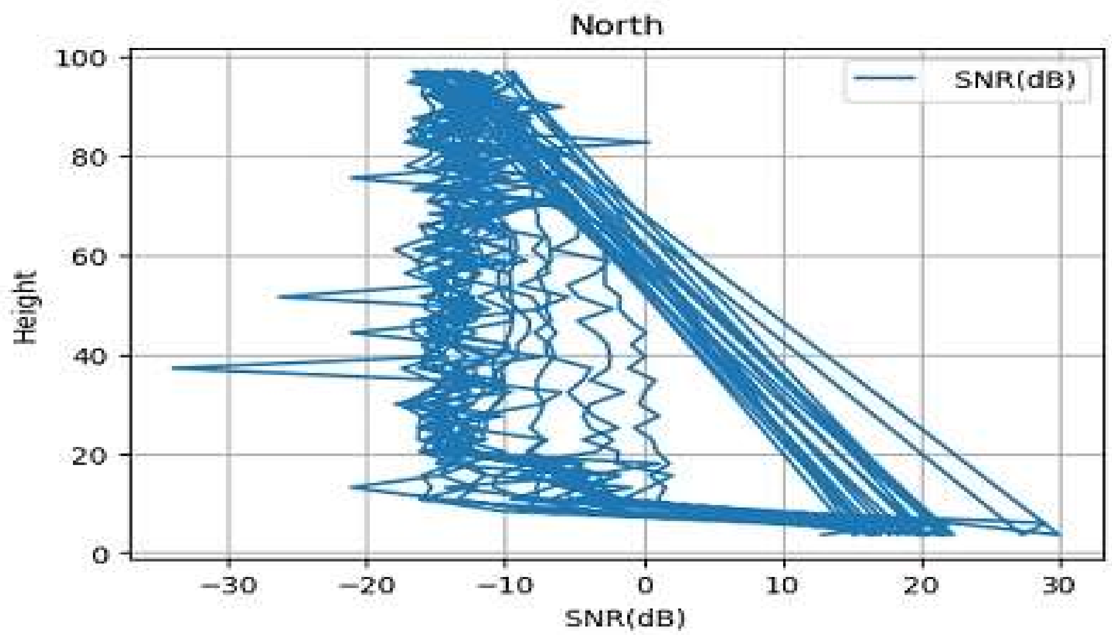

Figure 4: Represent the Height vs SNR (dB) graph for North direction

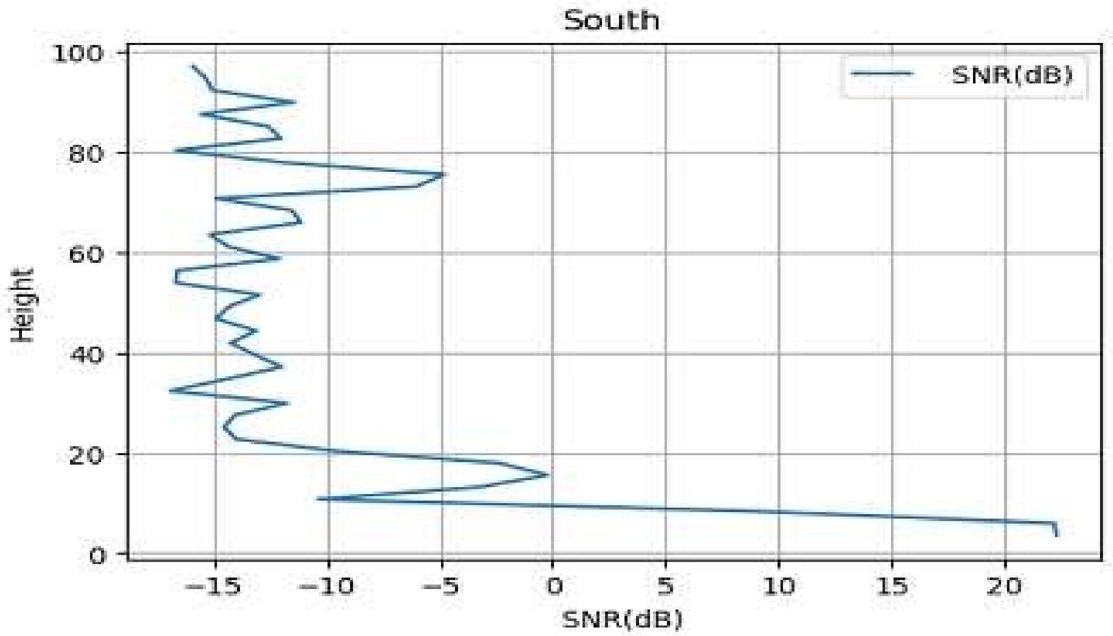

Figure 5: Represent the Height vs SNR (dB) graph for South direction

6. Conclusion

The current study uses the atmospheric radar data to present and apply an iterative weighted least squares-based estimation (IAA). IAA illustrates how the standard deviation and mean Doppler profile deviation have decreased when compared to the current ADP. This demonstrates that IAA performs better than existing algorithms, which have struggled to deliver, particularly in this height range. With IAA, the SNR is significantly improved at higher altitudes, proving the effectiveness and efficiency of the technology. The GPS sonde values are used to verify the wind velocities that the IAA algorithm produced. The IAA method has a high computational complexity but produces better results. This is because the process is iterative and involves matrix inversion.

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