PALLIATION OF FACTORS THAT SEVERELY AFFECT THE PROCESSING OF ATMOSPHERIC RADAR SIGNAL THROUGH SEGMENT METHOD

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ABSTRACT
Atmospheric Radars are used for ground based remote sensing of Earth's atmosphere. They work on the principle that backscatter is received from the radio refractive index fluctuations encountered by the transmitted electromagnetic wave. The refractive index fluctuations are due to turbulent inhomogeneities produced due to varying temperature, pressure, humidity and also due to air currents in the atmosphere. These changes are driven by solar influence on the Earth. Radar backscatter is received along the antenna beam directions which are usually within 0° to 20° from the Zenith. The time domain signal output of the receiver is converted into frequency domain to derive the line-of-sight mean Doppler shift, signal strength and width of the signal spectrum. The physical parameters related to these spectral parameters are line-of-sight speed, turbulence radar cross-section and turbulence intensity. The received signal spectrum consists of system and background noise along with the signal. Also external and system generated interference could contaminate the signal. The backscattered signal strength depends on the number of scatterers in the radar beam resolution volume. Received signal strength also has a seasonal variation.

In the present work different methods of computation of noise have been investigated. Further the estimation of spectral parameters done. Strategies of coping with interference and signal discontinuity worked out. Algorithms for automated processing of several days of radar data under varying radar operational parameters, interference and signal discontinuity have implemented.

Key words: Radar Backscatter, Hildebrand & Sekhon and Segment Noise Level Estimation, Interference and Signal Discontinuity, Moments estimation, SNR Computation.

1. INTRODUCTION
Our knowledge of the state of the Earth's atmosphere is highly dependent upon the instruments we use for measuring it. The parameters of primary interest are temperature, pressure, humidity, precipitation, and wind. Meteorological instruments have been refined over the years and routine surface measurements of these parameters have been made throughout the world since the nineteenth century. However, it was not until the 20th century that we began to get a systematic look at the space and time variability of the atmosphere as a function of height above the ground. A significant advance in this area was made some decades back with the development of the MST Radar.
Radar is a general technique, which has wide range of variability depending on the type of targets to be measured. Radar can be designed to measure a bullet speed, while another may observe a planet. The target of Radar under study is the earth’s atmosphere; we refer this kind of Radar as atmospheric Radar. NARL has been operating at 53 MHz atmospheric Radar (Mesosphere, Stratosphere and Troposphere Radar) for studying structure and dynamics of lower, middle and upper atmosphere. The wind velocity of the atmosphere in different height regions is estimated from the Doppler shift of time-sampled echoes using Doppler Beam Swinging (DBS) technique.
Atmospheric Radar signal analysis techniques deviate slightly from the other Radars used for military and surveillance applications. The atmosphere is diffuse and provides weak backscatter compared to the returns from hard targets like airplanes and missiles. The primary techniques used for atmospheric Radars include DBS and Spaced Antenna (SA). Atmospheric Radars are used for ground based remote sensing of Earth’s atmosphere. They work on the principle that backscatter is received from the radio refractive index fluctuations encountered by the transmitted electromagnetic wave. The refractive index fluctuations are due to turbulent inhomogeneities produced due to varying temperature, pressure, humidity and also due to air currents in the atmosphere. These changes are driven by solar influence on the Earth.
Radar backscatter is received along the antenna beam directions which are usually within 0° to 20° from the Zenith. The time domain signal output of the receiver is converted into frequency domain to derive the line-of-
sight mean Doppler shift, signal strength and width of the signal spectrum. These parameters are derived from the power spectrum after estimation and subtraction of noise in the spectrum. The physical parameters related to these spectral parameters are line-of-sight speed, turbulence Radar cross-section and turbulence intensity. The received signal spectrum consists of system and background noise along with the signal. Also external and system generated interference could contaminate the signal. The backscattered signal strength depends on the number of scatterers in the Radar beam resolution volume. Received signal strength also has a seasonal variation.

2. OBJECTIVE
This paper mainly deals with the different methods of computation of noise, Estimation of spectral parameters and Strategies of cope with interference and signal discontinuity using an objective method based on Gaussian statistics [2]. Algorithms for automated processing of several days of Radar data under varying Radar operational parameters, interference and signal discontinuity presented and discussed by Segment method [3].

To cope with the signals contaminated with noise we have to subtract the noise from signal having noise using various methods like Correlation, Hildebrand & Sekhon and Segment method. By comparing the results choose the best method to eliminate the factors affecting the Radar signals.

Secondly calculate the moments (Total power, Doppler shift and Doppler spread) and to palliate the interference and the signal jumps at one or many range gates in the Doppler profiling develop an algorithm that has to maintain signal continuity at higher. Compute the SNR, convert into decibels to plot in MATLAB then compare the results with the Atmospheric Data Processor (ADP) [4] software output for different seasonal data with the help of MST real time data obtained from the MST Radar facilitate situated at National Atmospheric Research Laboratory (NARL) at Gadanki (13.47°N, 79.18°E) near Tirupati, India.

3. EXPERIMENTAL SETUP
To cater to the different aspects of scientific studies, Radar provides flexibility in setting various system parameters. The parameters of the Radar parameters are selected based on the target physical properties to be observed.

The parameters to be set during start of experiment are,

- Pulse width (pwd)
- Inter pulse period (ipp)
- Number of coherent integrations (ncoh)
- Number of incoherent integrations (nincoh)
- Number of beams (nbeam)
- Antenna beam look angles
- Number of range bins (nrgb)
- Range of observation
- Number of scan cycles (nscan)

The pulse width (pwd) is selected from 1μs to 32μs to get an atmospheric height range resolution of 150m to 4.8km. The inter pulse period (ipp) from 150μs to 16000μs is related to maximum observable height range of 22.5km to 2400km. The number of beams (nbeam) is selected based on type of the experiment. The number of coherent integrations (ncoh) is user selectable, which is based on the maximum target velocity. The number of FFT points (nfft) is used for Fourier transformation. It is selectable in multiples of 2n and is related to target velocity resolution. The target observational height window, number of range bins (nrgb), number of scan-cycles (nscan) is dependent on observation height range and time duration.

3.1 Online signal processing and data recording
The MST Radar data processing is usually partly on-line and partly off-line. The on-line processing significantly compresses the data via time averages and usually produces power spectra and the off-line calculations involve parameter extraction. Once the Radar transmits high power 53 MHz radio frequency (RF) pulse into the atmosphere using phased antenna array, the RF pulse propagates through the atmosphere, minute amount of signal is backscattered due to the density, pressure, temperature and humidity variations of the atmosphere. The motion of target induces frequency shift in the back-scattered carrier frequency.

The mono-static Radar back-scattered signal is received by the same antenna. The received signal is amplified in low noise amplifier (LNA), and then down converted to receive intermediate frequency (Rx-IF) at 5MHz using 48MHz. Rx IF signal is converted to base-band video using quadrature mixer operating at 5MHz. The Rx-IF and video amplifiers bandwidth implement matched filter to maximize SNR. The analog video signals are digitized and processed in real time. The digital correlator / decoder perform the cross-correlation of received signal with the transmitted pulse. Coherent integration [7] of echoes of successive RF pulses is performed to boost the SNR.
and online signal processing ends with archiving time series (digitized I and Q signals) or Doppler spectrum after incoherent integrations, if any.

3.2 Offline data processing using MATLAB

The purpose of off-line data processing is parameterization of the Doppler spectrum. This is performed in the following steps in the developed MATLAB software program.

a. Read header and assign parameter values.

b. Fetch and arrange time and frequency series data corresponding to each height / range-bin.

c. Normalization.

d. Computation of Power Spectral Density (PSD) and DC removal for each height.

e. Incoherent integration and Estimation of noise floor by Hildebrand and Sekhon method for each height.

f. Estimation of the first three lower order spectral moments.

g. Estimation of Wind Vector, storing output parameters and plotting.

The MST Radar’s time-series and frequency data is in specific format in binary mode arrangement in frames corresponding to echoes from each beam. The Radar experiments are usually conducted in \( n_{scan} \) number of scan cycles with each scan consists of \( n_{beam} \) number of beams, thus providing multiple frames of data. A header precedes each frame data, which contains experiment specification parameter values. The binary header length is 128-byte and data is in binary 32-bit format. The structure of frequency series data arrangement is depicted in the following table for each frame.

<table>
<thead>
<tr>
<th>Table 1: MST Radar power spectrum header information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data header (128 bytes)</td>
</tr>
<tr>
<td>Range bin 1 : No. of FFT points</td>
</tr>
<tr>
<td>Range bin 2 : No. of FFT points</td>
</tr>
<tr>
<td>...</td>
</tr>
<tr>
<td>Last Range bin : No. of FFT points</td>
</tr>
</tbody>
</table>

No. of FFT points:

| 0 | -\( \delta f \) | ..... | \( \pm f_{max}/2 \) | ..... | +\( \delta f \) |

Total vol. of data in a frame = No. of FFT points \* No. of range bin \* 4 bytes

![Figure 1: Processing steps for extraction of parameters from received data](image-url)
4. NOISE ESTIMATION

In general, it is assumed that the “input” noise is a random variable normally distributed and having a white spectrum. Our aim is to verify this assumption with experimental data coming from ST [5] Radar spectra. Usually HS method is used to estimate the noise level it works on the principle of taking threshold and eliminating the power below the level as assuming it to be noise. Whereas, for the SG method, each segment includes eight consecutive densities and an average between the two small ones has been taken. Figure 2 shows an example of the mean values of average noise, obtained with the HS and SG methods respectively.

SG method is chosen due to its fastness relative to the HS method; it leads to an underestimation of the mean noise level especially when the number of values included into the segments is small. A large number of consecutive values cannot be used due to the risk of including atmospheric or clutter signal. Instead of an increase of the number of data per segment, the two lowest values may be averaged.

![Figure 2: Noise estimation using HS & SG methods for a real time MST radar data for higher range bin.](image)

5. 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 were proposed by Woodman [6].

![Figure 3: The beam- power, mean Doppler and Doppler spread.](image)

The spectral moments [6] namely power, mean Doppler shift and Doppler spread were consistently matching with the ADP results upto the height region of 13.5 km where signal is strong.

7. EXPERIMENTAL RESULTS

The power spectral density plot in figure 4; shows peak normalized power spectra for each height. Power spectrum of all heights up to 25 km has been plotted with Doppler shift in x-axis and height in y-axis. In the lower height, the SNR was strong and clear peak can be observed. In the upper height region, the SNR is poor and signal peak detection using the conventional methods does not provide satisfactory results. SNR

![Figure 4: Power spectral density plot showing peak normalized power spectra for each height.](image)
deterioration with height and trace merging with noise can be observed with all beams data collected for DBS wind vector estimation.

![Figure 4: MST Radar mean Doppler, SNR and Noise level plots.](image)

The proposed algorithm has identified the interference in the frame and has efficiently reduced its effect on the received signal in each range bin. It is observed that the algorithm working fine for a single interference data with a consistent nearby values. The proposed algorithm is inconsistent to find the multiple interferences in the received signal. It has tested for different seasonal data taken from the MST radar. The plotted results were compared with the ADP software result which looks fair. This algorithm can improve to identify the interference automatically even under multiple interference.

![Figure 4: Mitigation of interference by algorithm using Matlab.](image)

SNR has improved appreciably with the mitigation of DC noise, interference Clutter, and signal discontinuity there after the spectrum fitted with Gaussian using Matlab and the corresponding signals were plotted for various seasonal data. The algorithm for both time domain and frequency domain are capable to plot the noise level, SNR, radial velocity and Doppler spread effectively till 25 kms.

![Figure 5: Signal discontinuity at higher altitudes and its corresponding signal tracking using algorithm.](image)
6. FLOWCHART

CONCLUSION
Hildebrand & Sekhon (HS) and Segment (SG) [2; 3] methods were implemented to find the noise levels in the offline MST radar signal processing. SG method is simpler and faster compared to the power spectral density method (HS) method. Due to number of iterations involves in processing the data. Algorithm to mitigate the interference worked well with the single interference whereas in consistent if it is applied to the data that has
multiple interferences. Signal discontinuity problem rectified using the algorithm; for limited range bins it has shown good results. Proposed algorithm tested on different seasonal data obtained from the MST radar, the final MATLAB results are matched with the ADP results and the height coverage can be considerably enhanced compared to the conventional method. For the low SNR case, the height coverage for the adaptive and conventional methods is about 20 and 10 km, respectively; the corresponding heights for the high SNR case are 25 and 15 km. Thus the method has considerable advantage over the conventional method in extracting information from the MST radar signal spectrum, particularly under low SNR conditions that are free from interference and ground clutter.

FUTURE SCOPE
Algorithm can be extended by working on higher altitudes by applying wind shear parameters technique which is used to adaptively track the signal in the range–Doppler spectral frame to identify the signals using five candidate peaks [8] per range gate. The program can be upgraded from single greatest peak moment estimation method to get upper height wind velocity estimations using neural networks algorithm proposed by E. E. Clothiaux. [9].

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REFERENCES

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