Chapter 6

Adaptive tracking of Doppler Echoes

6.1 Introduction

Wind profile from MST radar data is computed by processing the Doppler profile obtained from the spectral data in at least three non-coplanar beam positions. The primary MST radar data consists of amplitude spectra spanning the desired Doppler frequency window for each range bin in the range window. This spectrum has to be processed for each range bin to get the total wind profile in the height region.

The method adopted for identifying the signal and computing the three low-order spectral moments is central to the problem of extracting information from the Doppler spectrum of the MST radar signal. The conventional method of analyzing the MST radar spectral data is done by tracking the prominent spectral peak with highest amplitude in each range bin and computing first three spectral moments and signal to noise ratio. This simple method is satisfactory for processing lower altitude ranges where the SNR is quite high. But at higher altitudes where SNR is low, this method may pick false spectral peaks. In edition, the presence of any electromagnetic interference or outliers make the reliable detection of the signal is still difficult.

6.2 Existing algorithms to improve Doppler peak detection

A median estimator or consensuses average method was suggested [Fischler and Boltes, 1981, May and Strauch, 1989 and Wilfong et al., 1993] to be used instead of a simple averaging of the spectra before computing the spectral moments to improve the performance of the Doppler peak detection algorithm. The main motivation for the consensus algorithm was to extend the reliable averages to low SNR signals. These methods eliminate contamination (echoes from flying objects such as aircraft, birds etc) in the average by editing the data before averaging. The problem with both the median and consensus methods, however, is that they depend upon the number of data points to
be good (noise free), which is around one third of the total samples in consensus algorithm, in order to give a reliable estimate. Merritt [1995] developed a more effective method that makes use of the signal statistics to selectively average the data and that is not restricted by the desired good data points. Approaches to filtering the time series data prior to spectral processing and modifications to the spectral processing were considered by May and Strauch [1998] and Jordan and Lataitis [1997] to address clutter issues. All of these statistical averaging techniques and filtering techniques are intended mainly to deal with spectral data contaminated with signals from non-atmospheric sources such as ground clutter, aircraft, birds, insects, etc.

For identifying signals from regions of low SNR, which would improve the reliability and height coverage of Doppler profiles, some kind of an adaptive method needs to be used. An adaptive method based on constructing chains of profiles by maximizing an energy function and using a neural network approach for detecting the most likely profile has been developed by Clothiaux et al. [1994]. The performance of the method has been successfully demonstrated with 404 MHz wind profiler spectral data taken in low-altitude mode that showed extensive periods when either the SNR was poor or the atmospheric signal power was significantly less than that of the ground clutter. A wind confidence algorithm [National center for Atmospheric Research (NCAR) Improved Moments algorithm (NIMA)] and an automatic moments estimation technique [NCAR Wind and Confidence Algorithm (NWCA)] were developed and implemented for wind profilers [Morse et al., 2002 and Goodrich et al., 2002]. The NIMA method implements combinational mathematical analysis, fuzzy logic synthesis, and global image processing algorithms. Anandan et al. [2001] developed another method of adaptive data processing that has been found to perform consistently well under a wide range of SNR conditions of atmospheric signals that are free from interference and ground clutter. The method is based on tracking the signal in the range-Doppler spectral frame making use of certain criteria for adaptively setting the parameters of the SNR threshold, Doppler velocity window and wind shear threshold. All these methods have yielded reliable detection of the Doppler echoes to a maximum range of about 22 km under favorable conditions.
6.3 Simplified Adaptive Tracking Method

An Adaptive Tracking Method (ATM) is developed in this work on the same lines of one which is developed by Anandan et al. [2001] with some simplifications to be used on the profiles which are processed by the wavelet based denoising technique described in the earlier chapters. This method works around parameters that get updated constantly so as to optimize the tracking performance. The parameters used for adaptive signal tracking in a range Doppler frame are the Doppler velocity window (DVW), wind shear and signal to noise ratio (SNR). In the case of SNR, a threshold value is specified that applies for the entire range-Doppler frame. In the SNR computation, the noise power is computed over the full bandwidth of the amplitude spectrum. The SNR threshold is chosen to be 15dB (after several trails) above the mean noise level estimated for the highest range bin in noise region.

The tracking is initiated by the first range-bin whose highest peak was selected as Doppler echo as in almost all cases the SNR is invariably quite high (SNR of 7 dB or more) and the Doppler echo is quite prominent and easily detectable in several lower altitude bins.

From the second range bin onwards, the Doppler peak in a range bin (say i\(^{th}\) bin) is chosen in the following way. First a Doppler window is fixed based on the position of the detected Doppler echo of the previous (i-1) bin. Doppler velocity window limits are set at $\pm 10\%$ of the coherent integration filter bandwidth on either side of the mean Doppler velocity associated with the previous bin since the signal is not to expect to change by more than 10\% of the coherent filter bandwidth from one range bin to the next. The five most prominent spectral peaks are selected as candidate signals within the specified DVW. For example Fig (6.1) shows the spectral peaks in descending order of power level in a range bin. Peaks $S_1$, $S_2$, $S_3$, $S_4$ and $S_5$ represents selected prominent peaks in descending order of power level. For the selected candidate peaks, the three lower order spectral moments and SNRs are computed following Woodman [1985]. Here SNR is calculated by considering the noise in the same bandwidth as that of the signal. Out of the five peaks with in the Doppler velocity window, starting from the peak having highest total power, the peak satisfying the SNR criterion (SNR\(_{th}\)) was chosen as the Doppler echo. If none of the peaks satisfy the SNR criterion, the strongest peak which falls within the permissible wind shear is chosen as Doppler echo. The wind shear threshold was selected based on earlier two range bins. The wind shear threshold for present bin (say i\(^{th}\)
bin) is set by adding the full width of the Doppler velocity peak in present bin to the difference in mean Doppler velocity between present bin (say $i^{th}$ bin) and previous bin ($i-1$). The wind shear threshold set for present bin is used for next range bin to identify prominent peak.

If no Doppler echo was detected in a given range bin that bin is skipped and DVW and wind shear threshold for the next bin is computed from the earlier bins. This algorithm is shown in flow chart Fig (6.2). The procedure is repeated sequentially for all range bins, there by fixing a height-varying DVW and wind shear for the entire frame.

![Figure 6.1: Amplitude spectrum in one range bin](image-url)
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Define DVW, SNR_{th} and bin number (n) = 1

Find highest peak and calculate m_0(n), m_1(n), m_2(n) and SNR(n)

Yes

n = 1

SHEAR_{th}(n+1) = \text{abs}(2 \sqrt{m_2(n)})

A

Find DVW limits and fix DVW

Select 5 peaks (S_1 to S_5) with in DVW and calculate m_0, m_1, m_2 and SNR to all peaks

Arrange 5 peaks in descending order of m_0 and number from S_1 to S_5

Peak number K = 1

B

No

n = n + 1

A
Figure 6.2: Adaptive Tracking Method
6.4 ATM on simulated signals

This algorithm is first applied on simulated signals (described in Chapter 5) before and after denoising to ascertain detectability of the correct Doppler echoes as echo position is known in that case. Figure (6.3) shows effect of Adaptive Tracking Method and denoising on simulated data.

Figure (6.3a) shows the simulated Doppler profile. Here signals were simulated up to range of 3-30 km (180 range bins with one bin for every 150m) as in the case of typical MST radar data. The Doppler shift was varied linearly from 0-2 Hz from lowest range bin to highest range bin as shown by the solid blue colored line in Fig (6.3b). The Doppler echoes were barely observable up to 15 km in this case. The Doppler echoes identified by above described ATM are marked with darker points in figures (6.3b and 6.3c). As can be seen from the Fig (6.3b), the ATM identifies the Doppler echoes correctly up to about 17 km before denoising. The selected peaks by ATM are deviating from the actual location of Doppler echoes from 17 km onwards and are completely off the target at higher ranges. Figure (6.3c) shows how the same ATM is able to pick the correct Doppler echoes after wavelet based denoising the data by using designed wavelet described in the Chapter 4. As can be seen from the Fig (6.3c) it is possible to track the signal up to 24 km after wavelet based denoising.
Figure 6.3: Simulated MST radar profiles (a) Raw data (b) with Adaptive tracking of the Doppler echo and (c) with denoising and Adaptive tracking of the Doppler echoes. Here blue solid line indicates the expected location of the Doppler echoes where as darker points indicate the peaks selected by the Adaptive Tracking Method.