PROCEEDINGS OF SCIENCE

PoS(RFI2024)052

# A Fast Implementation of the Algorithm GMAP-TD for Clutter Interference Mitigation in Weather Radar

---

**M.E. Amoia,**[a,b,*] **M. Hurtado,**[a,d] **J.I. Fernández Michelli**[a,b] **and F. Renolfi**[d]

[a] *National University of La Plata (UNLP)*
*La Plata, Argentina*
[b] *National Scientific and Technical Research Council (CONICET)*
*Argentina*
[c] *Research Institute of Electronics, Control and Signal Processing (LEICI)*
*La Plata, Argentina*
[d] *INVAP*
*Argentina*

*E-mail:* matias.amoia@ing.unlp.edu.ar

Ground clutter represents a significant challenge in Doppler weather radar systems, often masking weather signals and biasing the estimation of meteorological parameters. The Gaussian Model Adaptive Processing in Time Domain (GMAP-TD) algorithm offers a robust solution for clutter mitigation but suffers from high computational burden. In this paper, we introduce a novel implementation of GMAP-TD, termed GMAP-TD-FC (Fast Computation GMAP-TD), which retains the original algorithm's effectiveness while significantly reducing computation time. Our approach employs the diagonalization of the clutter autocorrelation matrix, enabling the precomputation of filter components and reducing the computational complexity. Simulation results show that the accuracy of the proposed algorithm remains as good as that of GMAP-TD while improving the processing speed, making it well-suited for real-time radar operations.

*Radio Frequency Interference Conference (RFI2024)*
*14-18 October 2024*
*Bariloche, Argentina*

---

[*] Speaker

## 1. Introduction

Coherent pulsed radars use the Doppler frequency shift to measure target movement, a principle that Doppler weather radars exploit to estimate the Doppler spectrum of hydrometeors [1]. The Doppler spectrum reveals information on weather phenomena like rain or hail and aids in severe storm forecasting. For single-channel radars, this spectrum is generally modeled as a Gaussian function, characterized by power, mean frequency, and spectrum width [2]. However, ground clutter —often the strongest component— along with internal and external noise, interferes with the signal of interest, complicating the detection of weather echoes.

Conventional filtering methods such as MTI and notch filters inadequately handle clutter in weather radars, as these filters distort the weather spectrum, leading to biased parameter estimations. The GMAP algorithm attempts to address this by filtering clutter in the frequency domain and recovering the weather spectrum [3]. However, finite series approximations lead to spectral leakage, which GMAP mitigates using aggressive tapering windows at the cost of reduced SNR.

Adaptive time domain filtering methods, like PTDM, achieve better performance but are computationally demanding [4]. GMAP-TD improves on GMAP by filtering in the time domain, allowing application to radar data with staggered PRT [5].

This paper introduces the Fast Computation GMAP-TD (GMAP-TD-FC) algorithm, which enhances real-time processing for weather radar by maintaining GMAP-TD's estimation performance with reduced computation time, at the expense of a higher memory cost.

## 2. Mathematical Fundamentals

The mathematical foundations of the GMAP-TD algorithm are well established in the literature [5]. This section provides a brief overview of the signal models and processing steps relevant to our implementation. For a more detailed treatment, refer to Nguyen et al.

The GMAP-TD algorithm relies on established signal models [5], where the Doppler power spectral density (PSD) of the received radar signal is the sum of the weather, clutter, and noise components [3]. Typically, the weather and clutter spectra are modeled as Gaussians, while noise remains flat. For the received signal $x$, modeled as a zero-mean multivariate complex random variable of size $M$ (number of pulses in the radar dwell), the autocorrelation matrix $\mathbf{R_x}$ is given by [5]:

$$\mathbf{R_x} = E[xx^H] = \mathbf{R_w} + \mathbf{R_c} + \mathbf{R_n} \tag{1}$$

Where $\mathbf{R_w}$, $\mathbf{R_c}$, $\mathbf{R_n}$ represent the autocorrelation matrices of weather, clutter and noise respectively. The GMAP-TD algorithm applies a clutter filter matrix $\mathbf{A}$ of dimension $M \times M$ to the time sample data, producing a filtered output $y = \mathbf{A}x$ with an autocorrelation matrix $\mathbf{R_y} = \mathbf{A}\mathbf{R_x}\mathbf{A}^H$. For clutter suppression, $\mathbf{A}$ is defined to approximate a white noise process in the absence of a weather signal (i.e., $\mathbf{R_w} = 0$), resulting in:

$$\mathbf{R_y} = \mathbf{A}(\mathbf{R_c} + \sigma_n^2\mathbf{I_M})\mathbf{A}^H \approx \sigma_n^2\mathbf{I_M} \tag{2}$$

Following [5], $\mathbf{A}$ is defined as:

$$\mathbf{A} = \left(\mathbf{R_c}/\sigma_n^2 + \mathbf{I_M}\right)^{-1/2} \tag{3}$$

Building on the established models, we extend the mathematical framework, taking advantage of the properties of the clutter autocorrelation matrix $\mathbf{R_c}$. Since $\mathbf{R_c}$ is a covariance matrix, it possesses key properties: it is Hermitian (i.e., $\mathbf{R_c} = \mathbf{R_c}^H$) and positive definite. These characteristics imply that $\mathbf{R_c}$ can always be diagonalized.

This diagonalization significantly reduces the computational complexity while preserving the essential characteristics of the original signal. By expressing $\mathbf{R_c}$ in its diagonal form, we can split the computation of the filter into a fixed and an adaptive part. The fixed part can be precomputed and applied uniformly across all range cells, while the adaptive part involves adjusting the Clutter-to-Noise (CNR) ratio for each specific range cell.

To further detail, consider the normalized autocorrelation matrix $\tilde{\mathbf{R}}_\mathbf{c}$ with unit power, where $\mathbf{R_c} = P_c\tilde{\mathbf{R}}_\mathbf{c}$. This matrix can be diagonalized as follows:

$$\tilde{\mathbf{R}}_\mathbf{c} = \mathbf{V}\mathbf{D}\mathbf{V}^H, \tag{4}$$

where $\mathbf{V}$ is a unitary matrix whose columns are the eigenvectors of $\tilde{\mathbf{R}}_\mathbf{c}$, and $\mathbf{D}$ is a diagonal matrix containing the corresponding eigenvalues. The clutter filter is then expressed as:

$$\mathbf{A}^2 = \left(\frac{P_c}{\sigma_n^2}\mathbf{V}\mathbf{D}\mathbf{V}^H + \mathbf{I_M}\right)^{-1}. \tag{5}$$

By using the Woodbury matrix identity and operating, this expression simplifies to:

$$\mathbf{A} = \mathbf{V}\,\mathsf{diag}\left(\frac{1}{\sqrt{1 + \mathsf{d_m CNR}}}\right)\mathbf{V}^\mathsf{H} \tag{6}$$

where $d_m$ are the eigenvalues of $\mathbf{R_c}$ and $\mathsf{CNR} = \mathsf{P_c}/\sigma_\mathsf{n}^2$ is the Clutter-to-Noise Ratio.

This formulation shows that the diagonalization of $\mathbf{R_c}$ is unique and does not change across range cells; only the CNR varies. Note that computing equation (3) involves inverting an $M \times M$ matrix for each range cell, with a computational cost of $O(M^3)$, and also requires computing a matrix square root, which entails diagonalization. In contrast, equation (6) only requires performing the diagonalization once, after which all operations are reduced to scalar computations. This diagonalization significantly reduces the computational burden by allowing the precomputed fixed part of the filter to be reused for every range cell in the dwell, making the algorithm highly efficient for real-time applications.

## 3. Simulation

To evaluate the computational efficiency and the accuracy in parameter estimation of the proposed algorithm, Monte Carlo simulations were conducted. The power levels of the noise, clutter, and weather signals were kept constant across all simulations, as were the spectral widths. The Monte Carlo simulations were performed by varying the central frequency of the weather signal, covering positive frequencies from 0 to the Nyquist frequency $(f_{nyq})$.

Figure 1 illustrates the significant reduction in computation time achieved by the GMAP-TD-FC algorithm compared to the original GMAP-TD method for uniform PRT data. It is notable that the computation time for both algorithms is slightly higher at frequencies close to 0. This behavior is attributed to the increased number of iterations required to accurately reconstruct the Gaussian shape of the spectrum due to the greater overlap between the weather spectrum and the clutter spectrum in this frequency region. The reduction in computation time is even more pronounced for staggered PRT data, as shown in Figure 2. In this case, the computation time remains relatively consistent across all frequencies. This occurs because the modified filter **A** for staggered PRT introduces notches not only at 0 but also at $0.4 f_{nyq}$ and $0.8 f_{nyq}$, as discussed in [5].

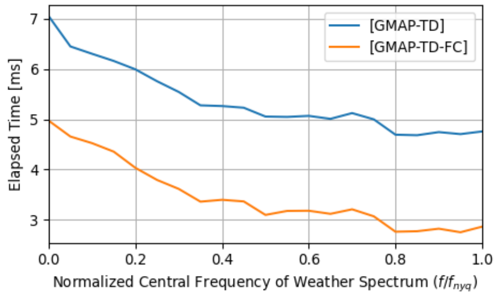

**Figure 1:** Computation time of GMAP-TD and GMAP-TD-FC for uniform PRT.

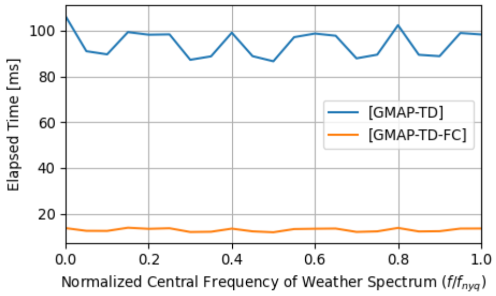

**Figure 2:** Computation time of GMAP-TD and GMAP-TD-FC for staggered PRT.

Figure 3 shows the mean bias and standard deviation in the estimation of the parameters of interest for both algorithms with uniform PRT, while Figure 4 presents the results for staggered PRT. The findings indicate that there is no degradation in the accuracy of parameter estimations when using the GMAP-TD-FC algorithm. This verifies that the reduction in computation time does not compromise the quality of the estimations.

## 4. Conclusions

This paper presents the Fast Computation GMAP-TD (GMAP-TD-FC) algorithm, which offers a significant reduction in computation time for clutter interference mitigation in weather radar systems, without compromising estimation accuracy. By exploiting the eigenvalue descomposition of the clutter autocorrelation matrix $\mathbf{R_c}$, the proposed algorithm efficiently separates the computation into fixed and adaptive components. The fixed component can be precomputed and uniformly applied across all range cells in the dwell, while the adaptive component adjusts for the Clutter-to-Noise Ratio (CNR) specific to each range cell.

Simulation results demonstrate that GMAP-TD-FC achieves a substantial decrease in computation time compared to the original GMAP-TD algorithm, particularly when applied to radar data with staggered PRT. Additionally, the performance evaluation shows that the proposed method maintains the accuracy of weather parameter estimation, confirming that the faster computation does not compromise the quality of the results.

The combination of reduced computational complexity and preserved estimation accuracy makes GMAP-TD-FC highly suitable for real-time applications in weather radar systems.

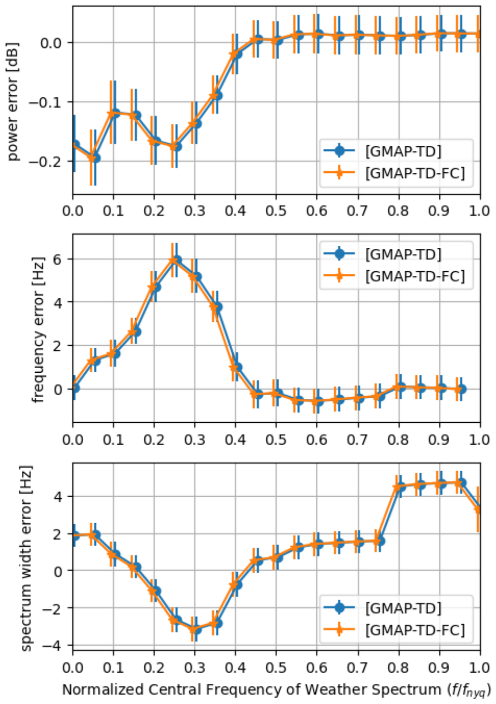

**Figure 3:** Bias and standard deviation in estimation of weather parameters for uniform PRT.

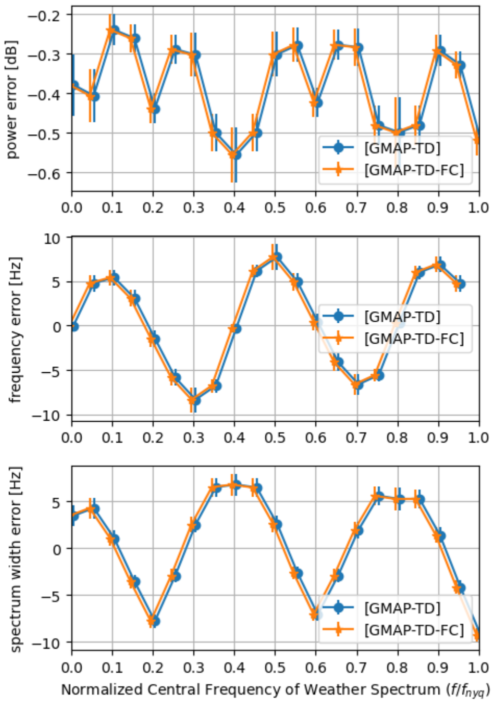

**Figure 4:** Bias and standard deviation in estimation of weather parameters for staggered PRT.

## 5. Acknowledgement

This work is supported by UNLP (Grant 11-I-257), CONICET (Grant PIP-1515), and INVAP.

## References

[1] R.J. Doviak, D.S. Zrnic, D.S. Sirmans, “Doppler weather radar,” *Proceedings of the IEEE*, **67**, 11, pp. 1522–1553, 1979.

[2] V.N. Bringi, V. Chandrasekar, Polarimetric Doppler Weather Radar: Principles and Applications, Cambridge University Press, 2001.

[3] A.D. Siggia, R.E. Passarelli, “Gaussian model adaptive processing (GMAP) for improved ground clutter cancellation and moment calculation,” *Proceedings of ERAD*, **2**, pp. 421–424, Apr. 2004.

[4] C.M. Nguyen, D.N. Moisseev, V. Chandrasekar, “A parametric time domain method for spectral moment estimation and clutter mitigation for weather radars,” *Journal of Atmospheric and Oceanic Technology*, **25**, 1, pp. 83–92, 2008.

[5] C.M. Nguyen, V. Chandrasekar, “Gaussian model adaptive processing in time domain (GMAP-TD) for weather radars,” *Journal of Atmospheric and Oceanic Technology*, **30**, 11, pp. 138–139, 2013.