Reworking the MUSIC Algorithm to Mitigate MSTID Direction Estimation Bias Associated with SuperDARN Radar Field-of-View

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Introduction

Multiple signal classification (MUSIC) describes theoretical and experimental techniques for determining the parameters of various wavefronts arriving at an antenna array from measurements made on the signals received at the array elements [1]. This technique can be implemented as an algorithm to provide asymptotically unbiased estimates of the strength and direction of the received signals, the polarization, noise/interference, direction of arrival, and several other parameters. It was first used with SuperDARN data by *Samson et al*. [2] and then by *Bristow et al*. [3]. Further advancements were made to reimplement the algorithm in Python to study the climatology of medium-scale traveling ionospheric disturbances (MSTIDs) by *Frissell et al*. [4]. However, one major overlook in the process is the bias caused by the radars used to plot these MSTIDs. This project revisits this algorithm, explores the origin of the radar bias and ways to mitigate it, and discusses the preliminary actions taken to integrate the algorithm into DARNtids.

Plots of Simulated MSTIDs

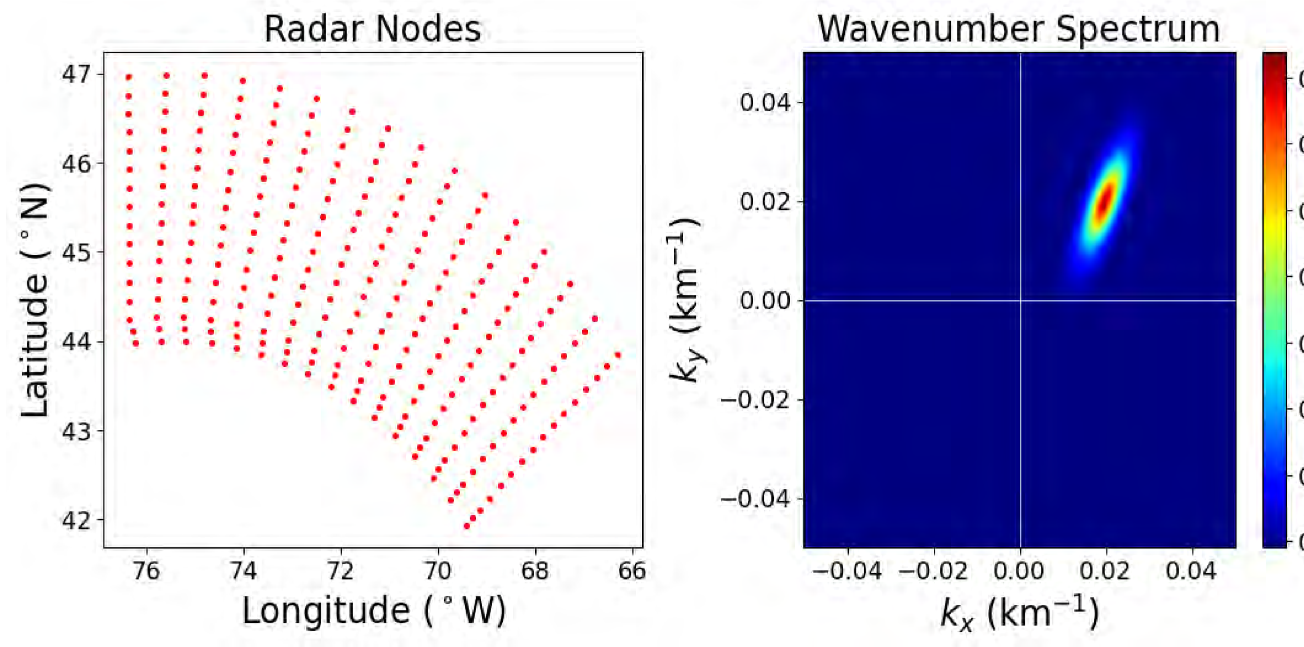

Figure 1: This plot shows us the tradition output plot of the music algorithm for a simulated MSTID.

- A goal of the MUSIC algorithm is to determine the propagation direction of MSTIDs. These directions can be observed by plotting the wavenumber spectrum.
- The current algorithm uses information extracted from all beams and gates of the radar.
- This algorithm skews our final plots by adding a stretched shape in the TID's wavenumber display.
- The main cause of this distortion in the plots is the difference in distance between each point on the radar.
- With DARNTIDS, we will be eventually able to account for radar bias particularly imposed by each SuperDARN radar.

MSTID Plotting Limiting Gates

- In the process of plotting MSTIDs, we are currently investigating strategies to refine the representation by selecting the optimal selection of beams and gates from the data of the radar's entire FOV.
- In restricting the gates in our plotted data, we observed that the plots exhibited a skew in a direction transverse to the gates.
- This effect stretches out the plot, distorting the figure and elongating it transversally, compromising the accuracy of our plots.

The plotted figures form limiting the gates

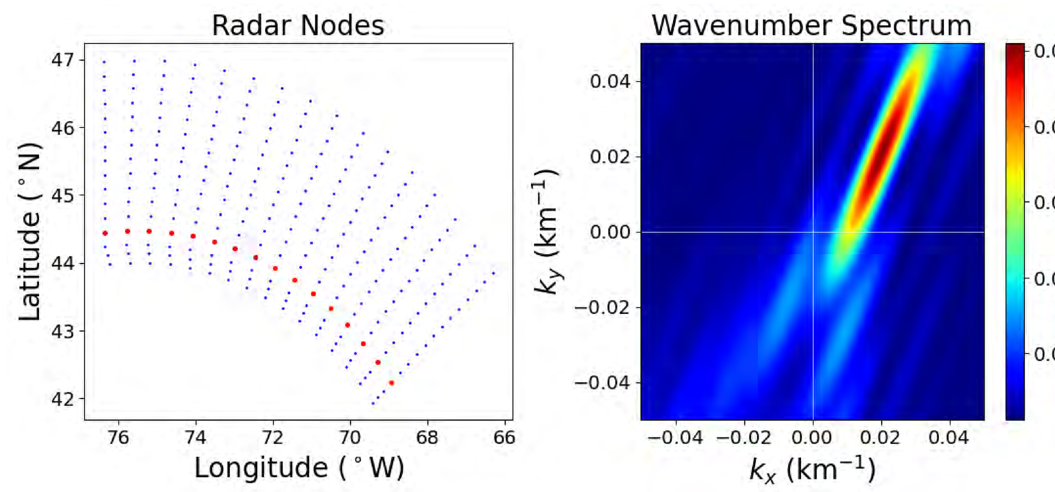

Figure 2: This plot shows us a restricted gate plot, only using one singular gate in comparison to using all the beams and gates. For the same simulated MSTID in Fig. 1.

MSTID Plotting Limiting Beams

- Similar to our exploration of plotting and restricting radar gates, we have identified an issue where horizontal skewing occurs in the plotted beams.
- This skewing effect stretches the data, leading to distorted plots that compromise the accuracy of our plots.
- The significance of this skewing becomes apparent when assessing the center of the MSTID and its trajectory and direction of travel. When the plot skewing takes place, it disrupts the accuracy of this information. Distorting our understanding of the MSTIDs position and direction.

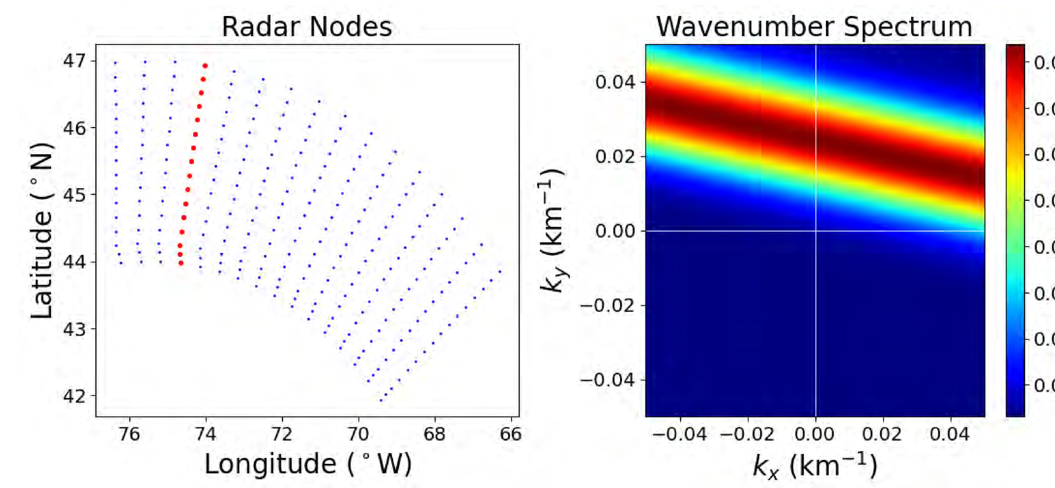

Figure 3: This plot shows us a restricted beam plot, only using one singular beam in comparison to using all the beams and gates. For the same simulated MSTID in Fig. 1.

Limiting Both Beams and Gates

- The significance of skewing in the MUSIC plots becomes apparent when assessing the center of the MSTID and its trajectory and direction of travel. When the plot skewing takes place, it disrupts the accurate of this information. Distorting our understanding of the MSTIDs position and its direction.
- Our approach combines the information we gained from both limiting the beams and the gates to produce plots with a reduced bias from the superDARN radars. While this is not perfect the final output plots are more desirable than our previous ones.
- Here, in the next plot we simply increase the number of beams and gates until the figure is not skewed fits a more circular shape.
- The MSTIDs plots must show circular shapes since they were purposefully simulated that way.
- With the final plots being circular in shape our directional data and positional data have greater accuracy than before.

Balancing Beam and Gate Plots

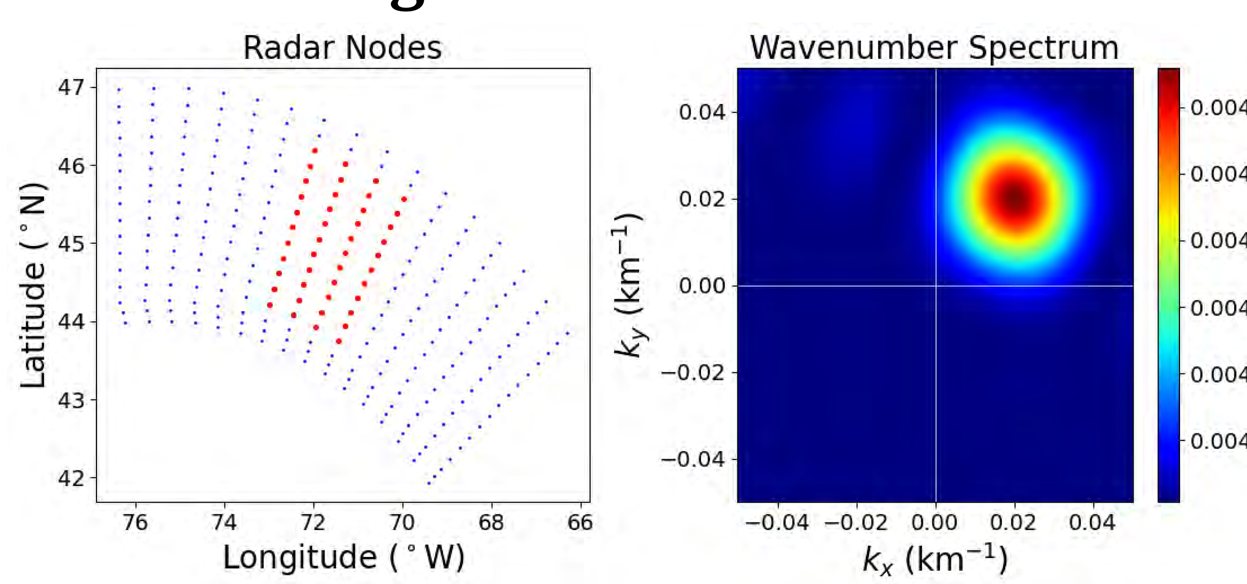

Figure 4 : This plot shows us a restricted beam and gate plot 4 gates by 11 beams which has the proportional ratio of a square.

Integrating MUSIC into DARNtids

- Recently, we have taken a series of steps to begin implementing this reworking of the MUSIC algorithm into the DARNtids GitHub repository.
- Firstly, we determined it was critical to determine exactly what time variable(s) are inputted into the MUSIC algorithm in DARNtids.
- The MUSIC algorithm conducts analysis on 2 hour time periods from a date range time segment to another time segment.
- We determined that if we were able to find these indexes in the large codebase, it would allow us to find an entry point for incorporating the changes made to the MUSIC algorithm into the DARNtids repository.
- This directly led to the generate_mongo_list() function, which we recently discovered has the variables we need for implementation: currentDate and nextDate.
- As future work, we will begin integrating these changes to mitigate MSTID direction estimation bias for all members of SuperDARN utilizing the DARNtids repository.

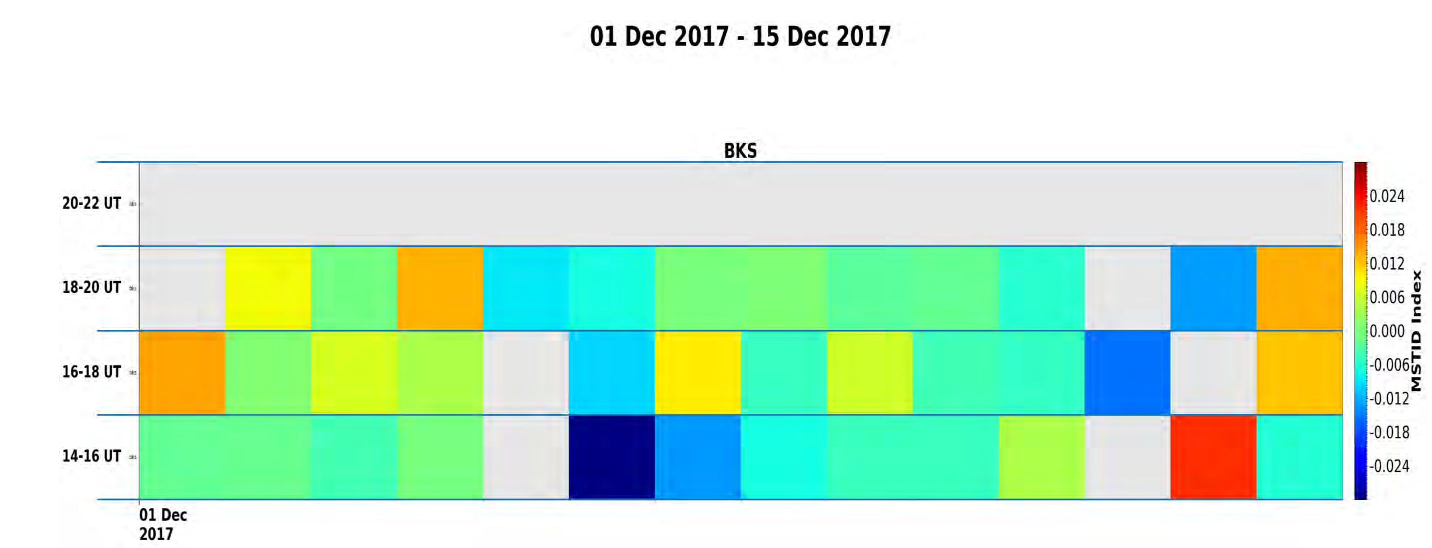

Figure 5: Calendar plot of the Blackstone radar for a two week period, from December 1st, 2017 to December 15th, 2017, after running the current MUSIC algorithm through DARNtids.

Conclusions / Next Steps

- This analysis showed that using the data provided by ALL the beams and the gates of a radar introduces undesirable distortions in the MSTIDs wavenumber plots that lessen the accuracy of the images obtained by the MUSIC algorithm.
- A limited number of beams and gates must be carefully chosen from the total a radar provides so that the MUSIC algorithm propagates fewer numerical errors, introducing less distortion into the plots representing the MSTIDs wavenumbers.
- We plan to develop a searching algorithm that evaluates the contribution made by each beam and gate of radars to the wavenumber plot such that the distortion introduced by the MUSIC algorithm can be minimized.
- The changes made to the MUSIC algorithm to mitigate direction estimation bias will be integrated into the DARNtids library for open-source use cases and purposes.

Acknowledgements

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References

[1] Schmidt, R. (1986). Multiple emitter location and signal parameter estimation. IEEE Trans. Antennas Propag. 34, 276–280.
[2] Samson, J. C., Greenwald, R. A., Ruohoniemi, J. M., Frey, A., and Baker, K. B. (1990). Goose Bay radar observations of earth-reflected, atmospheric gravity waves in the high-latitude ionosphere. J. Geophys. Res. 95, 7693–7709.
[3] Bristow, W. A., R. A. Greenwald, and J. C. Samson (1994), Identification of high-latitude acoustic gravity wave sources using the Goose Bay HF radar, J. Geophys. Res., 99(A1), 319–331.
[4] Frissell, N. A., Baker, J., Ruohoniemi, J. M., Gerrard, A. J., Miller, E. S., Marini, J. P., et al. (2014). Climatology of medium-scale traveling ionospheric disturbances observed by the midlatitude Blackstone SuperDARN radar. J. Geophys. Res. Space Phys. 119, 7679–7697.

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