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Autonomous Identification of the Morphology of Chorus Elements in The Van Allen Radiation Belts

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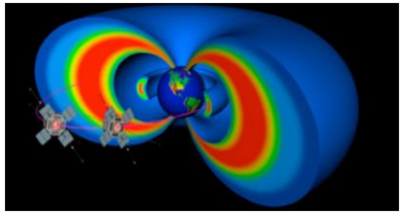

Abstract

We present recently developed computational techniques that enable large-scale autonomous detection of chorus elements over EMFISIS data from the Van Allen probes mission. Our key technical approach is to exploit the locally high signal-to-noise ratio (SNR) of chorus elements against the background hiss-like chorus. Specifically, we employ a combination of signal processing techniques that determine morphological connectivity across SNR maps to extract salient features of individual chorus elements. We present the performance of our algorithm across several case studies of 6-second bursts that exhibit different distributions of chorus elements.

Problem: Challenges to detecting chorus elements autonomously

- Chorus elements do not exhibit uniform features that be modeled easily
- Chorus elements may be buried under hiss-like chorus
- Chorus elements may themselves overlap
- A single element may exhibit significant microstructure

Radon Transform: Used to identify if there is a dominant angle in an extracted feature

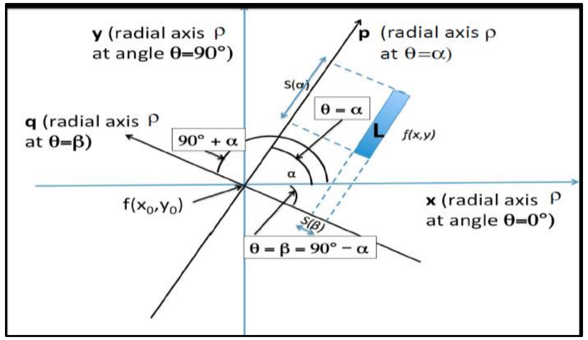

Figure 1. Schematic illustration of the Radon transform

Technical Approach

We apply the following step-by-step approach to the spectrogram of the magnetic field, treating the spectrogram as an image *I(x,y)* with x-axis representing time in seconds, y-axis representing frequency in Hz, and color representing the power spectral density in decibels. Figure 2 shows the step-by-step execution of the algorithm for a case study exhibiting multiple chorus elements. For each step, we refer to the relevant panel in Figure 2 or the computational technique illustrated in Figure 1.

Step 1 (Panel 2): Apply a global noise threshold $\Delta = -100dB$ to *I(x,y)*

Step 2 (Panel 3): Apply a median filter to each pixel (x,y) within a 3x3 pixel window *W(x,y)* centered on the pixel. The median filter replaces the pixel value *I(x,y)* with the median value measured across the 9-pixel distribution defined by *W(x,y).* This step effectively performs a smoothing operation that enhances connectivity between microfeatures within a chorus element against less structured hiss-like chorus in the background.

Step 3 (Panel 4): Evaluate the intensity of the background noise at each pixel (x,y) using a 25th percentile filter over a larger window *N(x,y).*

Step 4 (Panel 5): Evaluate the signal-to-noise ratio (SNR) *S(x,y)* at each panel as:

$$\boldsymbol{S(x,y) = W(x,y) - N(x,y)} \qquad (1)$$

Step 5 (Panel 6): Generate the histogram of the SNR map constructed in Step 4, and select the 75th percentile as the SNR threshold to detect a pixel as part of a chorus element.

Step 6 (Figure 1, Panel 7): Use 8-connectivity between pixels to detect features corresponding to individual chorus elements. The Radon transform (Figure 1) is used to determine whether the selected features follow a dominant angle, as is characteristic of a chorus element. We also eliminate features that span ≤ 5 pixels in frequency range. This avoids choosing features from structured hiss-like chorus which typically exhibits smaller range of frequencies.

Results

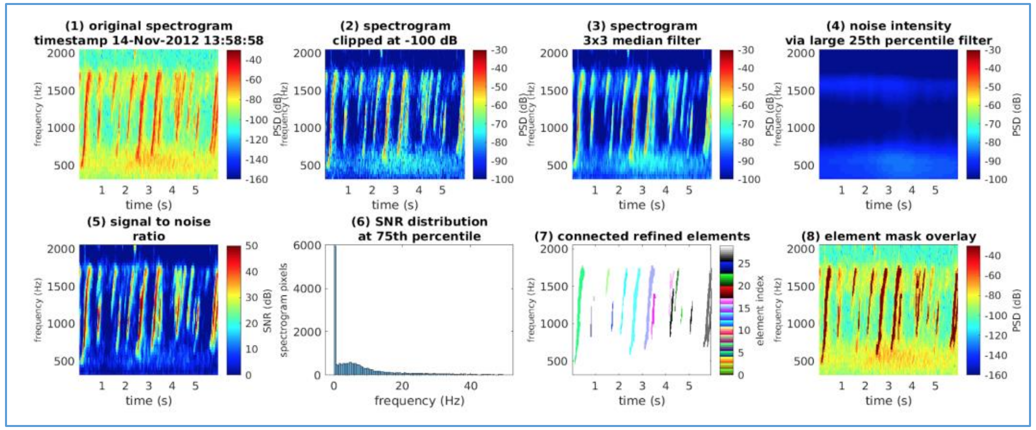

Figure 2. Different steps used in detecting the dominant features of an individual chorus elements within a spectrogram.

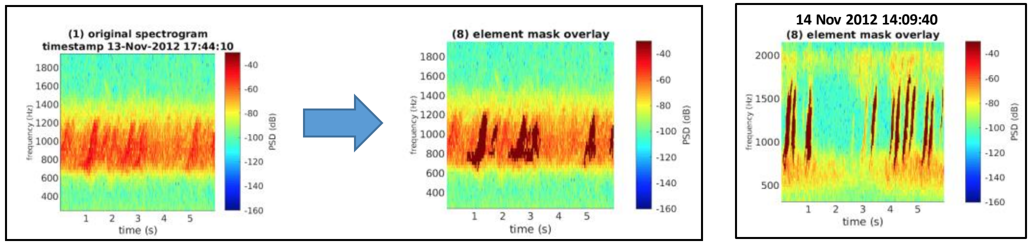

Figure 3. Different case studies showing algorithm performance for different distributions of chorus elements.

Conclusions

- Automated chorus element algorithm allows new types of studies of chorus
- Consistent identification of individual chorus elements, even in the presence of background hiss-like chorus
- Few false detects (No chorus detected where no chorus was present)
- Next steps: Validate algorithm performance across a larger portfolio of case studies

References

[1] Sen Gupta, A., Kletzing, C., et al 2017. Automated identification and shape analysis of chorus elements in the Van Allen radiation belts. *Journal of Geophysical Research: Space Physics*, *122*(12), pp.12-353.

Acknowledgements

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