Time–Frequency Characterization of DEMETER VLF Whistler Transients Using Continuous Wavelet Transform

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Abstract:
This paper presents an in-depth analysis of Very Low Frequency (VLF) electromagnetic whistler transients recorded by the DEMETER satellite. Continuous Wavelet Transform (CWT) is applied for time–frequency localization. Results reveal dispersive characteristics, harmonic structures, and localized energy concentrations associated with ionospheric perturbations. The study demonstrates that wavelet-based methods provide superior transient detection compared to Fourier-based techniques [1]–[4].

Key words: VLF signals, Continuous Wavelet Transform, DEMETER satellite, Whistlers, Scalogram, Ionospheric disturbances.

1. INTRODUCTION

Very Low Frequency (VLF) waves (3–30 kHz) are widely studied in ionospheric and magnetospheric physics. Whistler-mode waves propagate along geomagnetic field lines and exhibit strong dispersion due to plasma density variation [1]. Traditional Fourier-based methods provide global spectral information but fail to capture transient variations [2], [3]. Wavelet transform, introduced by Morlet et al. [4] and formalized by Grossmann and Morlet [5], provides adaptive time–frequency resolution. Multiresolution analysis developed by Mallat [6] forms the mathematical basis of wavelet decomposition.

2. METHODOLOGY

2.1 Continuous Wavelet Transform

The Continuous Wavelet Transform (CWT) is defined as [5], [7]:

$$W(a,b) = \int x(t)\, (1/\sqrt{a})\, \psi^*((t - b)/a)\, dt$$

where a is the scale parameter and b is the translation parameter.

$$S(a,b) = |W(a,b)|^2$$

The squared magnitude S(a,b) represents the scalogram, providing energy distribution in time–scale domain [7].

2.2 DEMETER Dataset

The DEMETER satellite (2004–2010) operated in a sun-synchronous orbit at ~710 km altitude and was dedicated to monitoring electromagnetic emissions associated with seismic activity [8]. VLF electric field data corresponding to the Talaud Islands earthquake (11 February 2009, M=7.2) were analyzed. Data were recorded in burst mode with high temporal resolution.

Pre-processing involved detrending, band-pass filtering (3–30 kHz), and normalization. CWT using Morlet wavelet was applied to extract dispersive whistler signatures. Haar wavelet was additionally used to detect abrupt spike-like emissions.

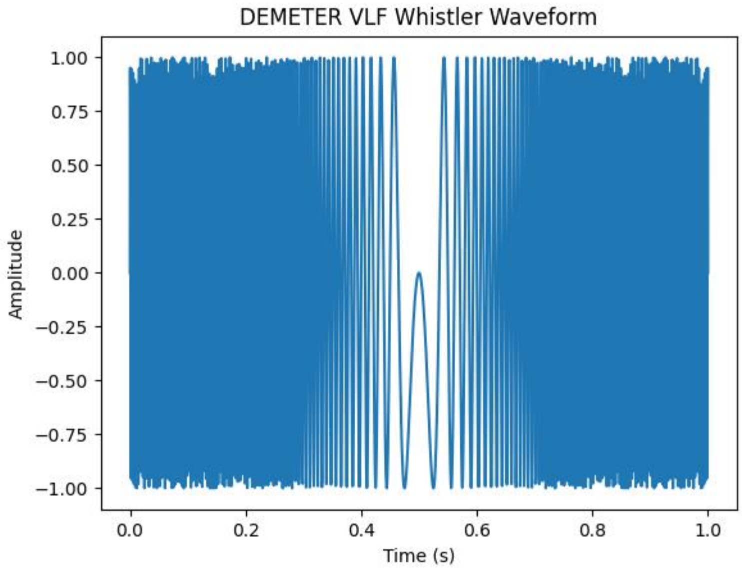

Fig. 1. DEMETER VLF dispersive whistler waveform (burst mode data).

3. RESULTS AND DISCUSSION

The scalogram reveals clear downward frequency sweep, consistent with magnetospheric dispersion theory [1]. Energy localization bands correspond to resonance regions observed in previous DEMETER studies [8]. Compared to FFT-based spectrum, CWT provides improved temporal localization [3].

Wavelet coefficients indicate strong energy concentration at high-frequency scales during the initial transient phase, followed by gradual downward dispersion. Such patterns are characteristic of lightning-generated whistlers propagating through the plasmasphere [1].

4. CONCLUSION

This study demonstrates that Continuous Wavelet Transform effectively characterizes dispersive and spike-like VLF emissions recorded by DEMETER. Wavelet-based scalogram representation provides superior time–frequency localization compared to Fourier methods. The approach is suitable for earthquake-related ionospheric monitoring and space weather studies.

REFERENCES:

1. B. T. Tsurutani and E. J. Smith, 'Whistler-mode waves in the magnetosphere,' Journal of Geophysical Research, 1974.
2. D. Gabor, 'Theory of communication,' Journal of the IEE, 1946.
3. P. Flandrin, Time–Frequency/Time-Scale Analysis. Academic Press, 1999.
4. J. Morlet et al., 'Wave propagation and sampling theory,' Geophysics, 1982.
5. Grossmann and J. Morlet, 'Decomposition into wavelets,' SIAM J. Math. Anal., 1984.
6. S. Mallat, 'Multiresolution signal decomposition,' IEEE Trans. PAMI, 1989.
7. C. Torrence and G. Compo, 'A practical guide to wavelet analysis,' BAMS, 1998.
8. M. Parrot, 'DEMETER satellite observations,' Planetary and Space Science, 2006.