Novel non-linear processing methods of VLF signals for seismic-ionospheric precursor detection: Evaluation of Zhao-Atlas-Marks and Hilbert-Huang Transforms

C. Skeberis, Z.D. Zaharis, T.D. Xenos,
S. Theochari, S. Spatalas, D. Arabelos,
M.E. Contadakis
Aristotle University of Thessaloniki,
Thessaloniki, Greece

Introduction

The earthquake activity contributes to ionospheric variability.

Extensive studies point to the conclusion that the Earth’s lithosphere interacts with the atmosphere prior to a strong seismic event, resulting in the generation of an anomalous electric field that affects the electron content of the ionosphere.

Introduction

- However, the seismo-ionospheric interaction is considered a local event, in the sense that only a certain area over the ground is affected by the earthquake, and its size is a function of the magnitude of the event.
- On the contrary, solar activity, which is the primary contributor to ionospheric variability, affects the ionosphere as a whole, producing more global effects compared to the localized phenomena of seismo-ionospheric coupling.
- The challenge therefore is to distinguish between the seismic-generated D-layer fluctuations and the fluctuations attributed to solar activity.
- The problem becomes more and more complicated when other smaller magnitude disturbances of undefined origin appear in the received signal, characterized as geophysical or ionospheric noise .

Introduction

Thus the need arises to investigate the application of post processing methods of extracting spectra from VLF signals in order to detect disturbances that can be attributed to seismic-ionospheric precursor phenomena

The methods tested are the:

- Wavelet Transform (WT) as a benchmark method
- Improved Hilbert-Huang Transform (noise assisted HHT)
- Zhao-Atlas-Marks (ZAM) Distribution

A normalization of the VLF signals received is applied.

Data and measurements

VLF Transmitters:

Frequency (Hz)	Station Call	Location	Country	Lat/Lon
19.580	GBZ	Anthorn	UK	54.912, -3.277
20.270	ICV	Tavolara	Italy	40.923, 9.731
21.750	HWU	Le Blanc	France	46.708, 1.241
37.500	ICE	Keflavik	Iceland	63.959, -22.542

Receiver: Thessaloniki, Greece (40.69N 22.78E) developed by Elettronika Srl

Part of the International Network for Frontier Research on Earthquake Precursors (INFREP)

Data and measurements

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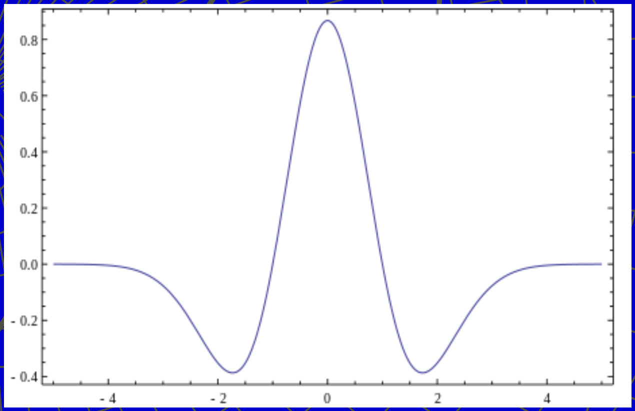
The VLF stations have been monitored over a period of four years.

Method and Analysis/CWT

- Wavelet Transform (WT) is used as a benchmark method.
- Able to construct time-frequency representation with very good frequency localization.
- Mother Wavelet used in this study is the Mexican Hat.



Method and Analysis/HHT

- Hilbert-Huang Transform is an adaptive method for processing non-linear and non-stationary signals.
- 2 Step process:
- EMD decomposes a real signal into its functional components,which are known as Intrinsic Mode Functions (IMF)

- Then a Hilbert Amplitude Spectrum is constructed from the output of the EMD

Method and Analysis/HHT

- In order to overcome the known issues of HHT with mode mixing and frequency separation, the Improved HHT is used.
- EMD in step 1 is replaced with Complete Ensemble Empirical Mode Decomposition with Adaptive Noise (CEEMDAN).
- Multiple White Gaussian noise samples of a set standard deviation are added to the signal and the resulting signal decomposed by the application of EMD

Method and Analysis/ZAMD

Zhao-Atlas-Marks Distribution (ZAMD) is an improvement of the generalized form of the time-frequency representation (GTFR) introduced by Cohen

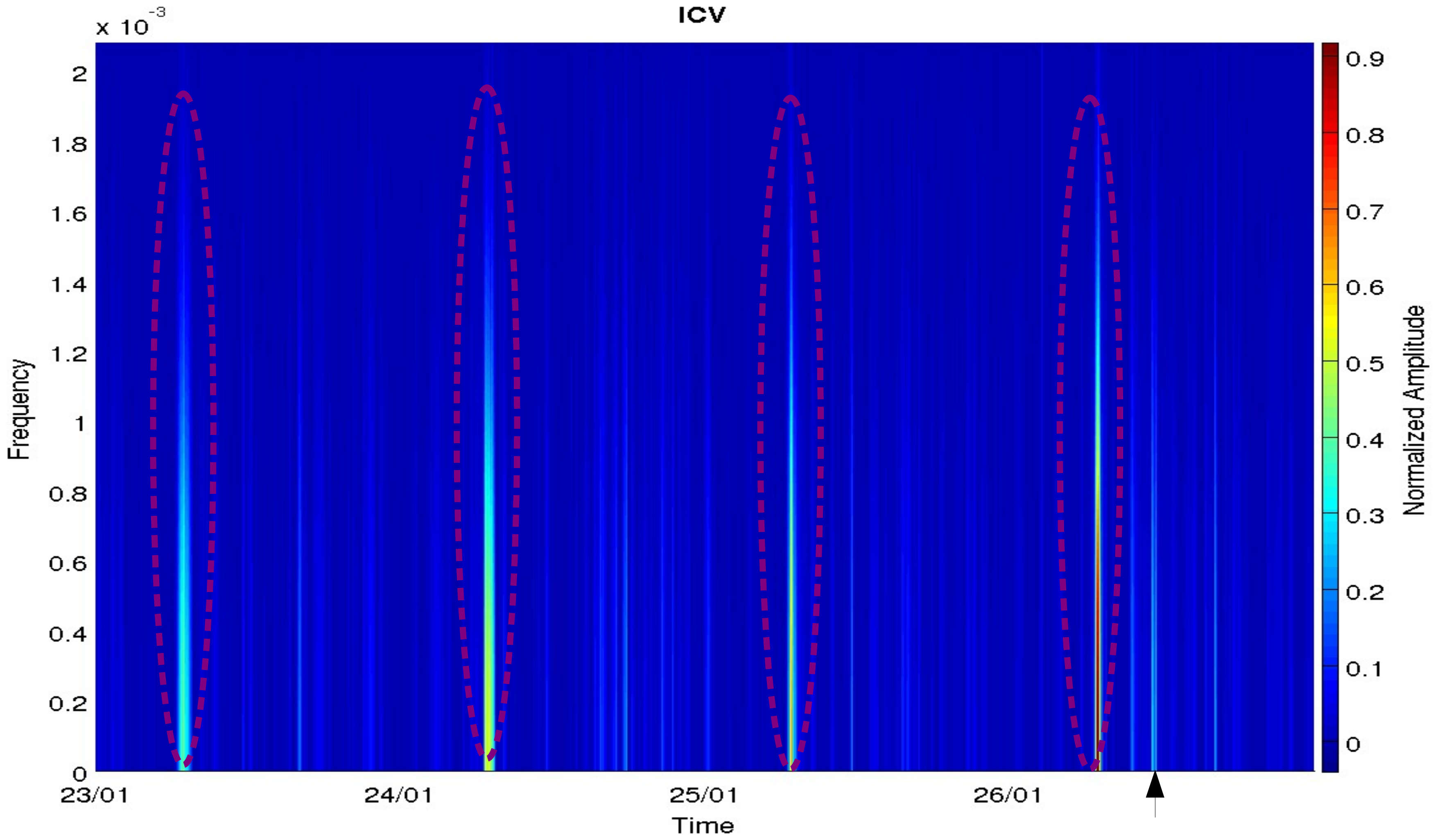
ZAMD uses a cone-shaped kernel which provides improved cross-term suppression and higher resolution in the derived spectrum.

Method and Analysis

- HHT provides filter bank capabilities by making Intrinsic Mode Function (IMF) selection thus allowing us to focus on specific frequency ranges

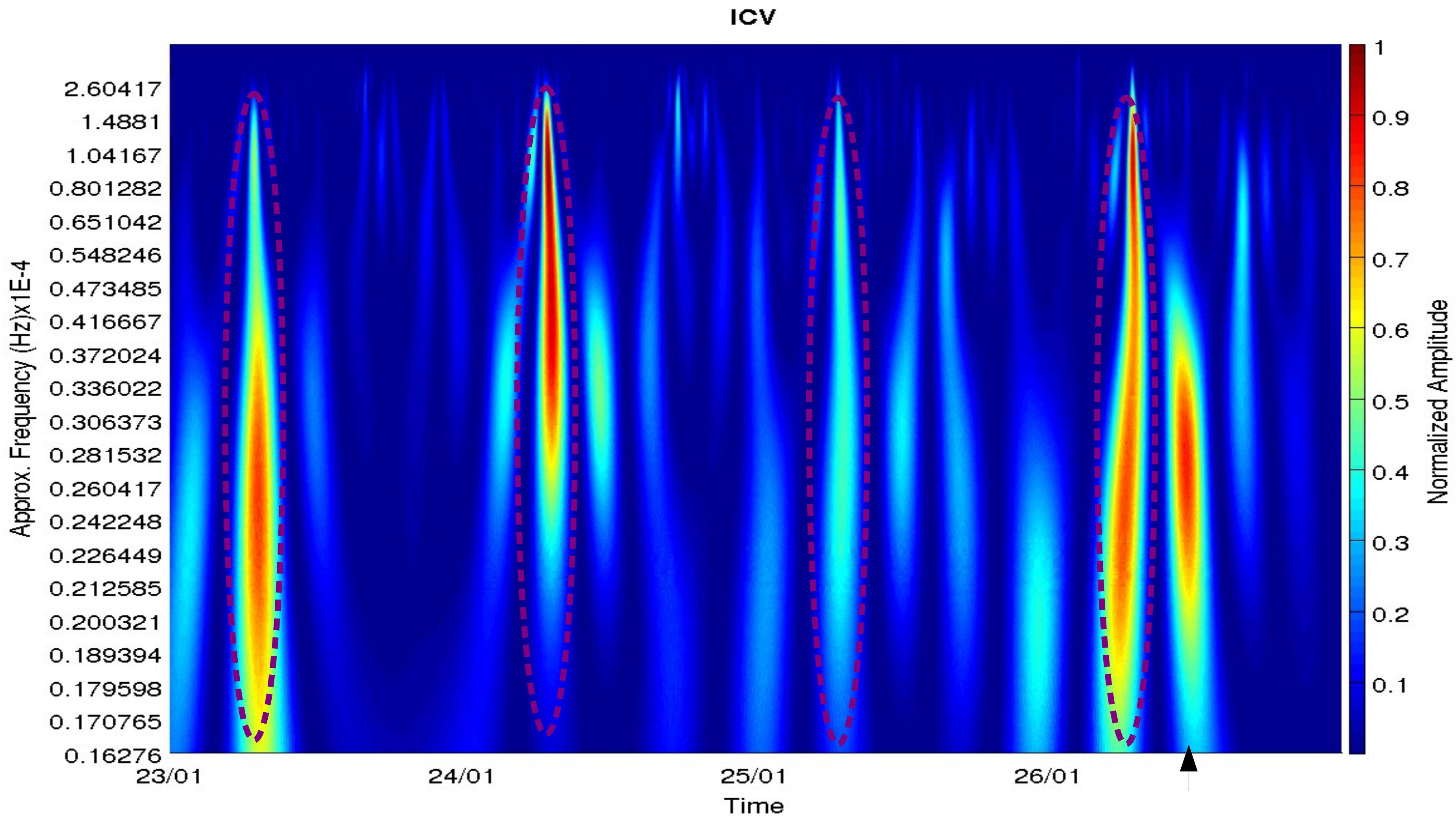
- ZAM on the other hand has no filtering capability like HHT but has an emphasis on improving frequency resolution and thus provides improved cross-term suppression.

Observations ZAMD



Recorded on 23-26 of January 2014 prior the Mw=6.1 Earthquake (2014-01-26 13:55:43.0 UTC) that occurred in Greece (Ionian Sea)(Arrow denotes the time of the earthquake)

Observations CWT



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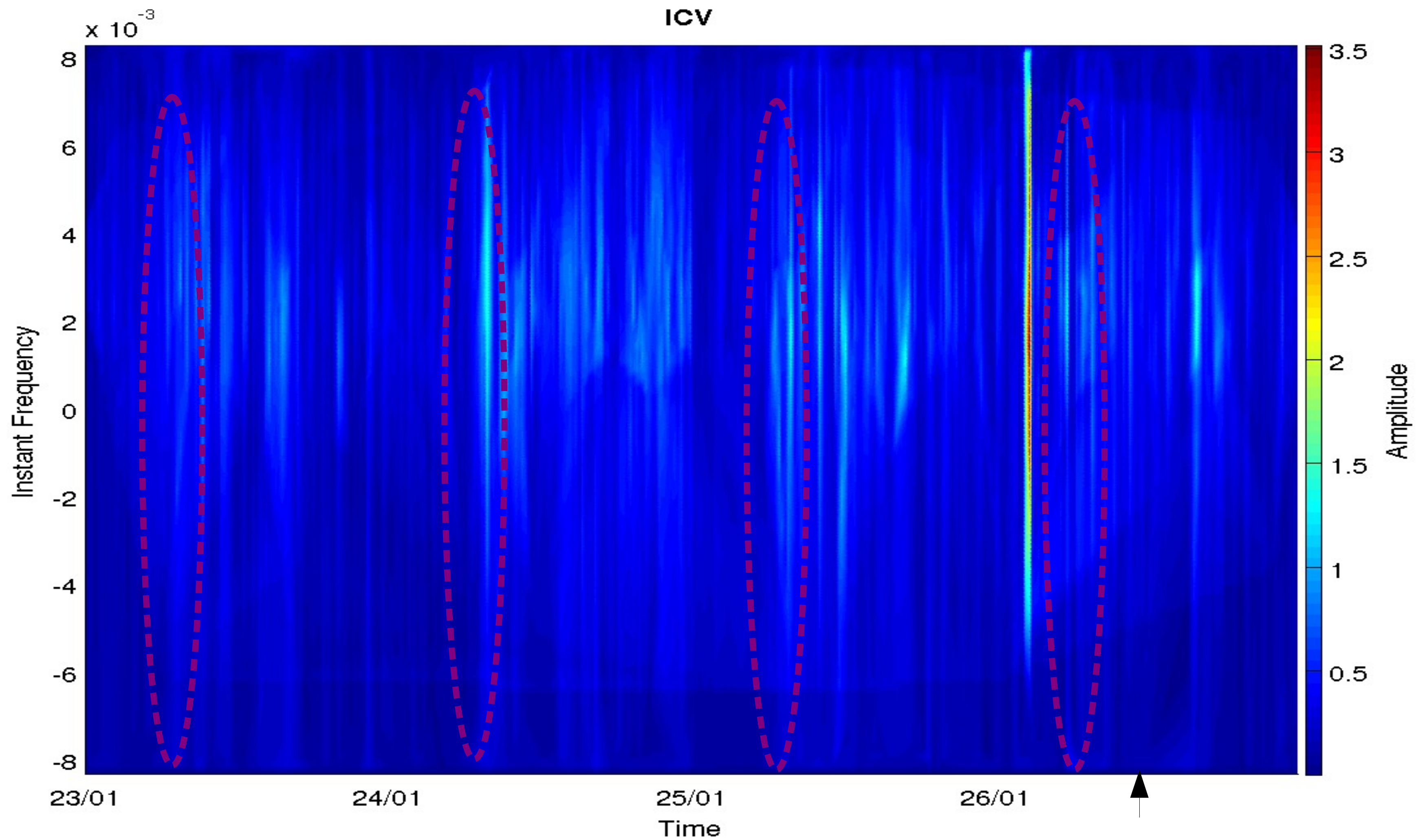
Observations HHT



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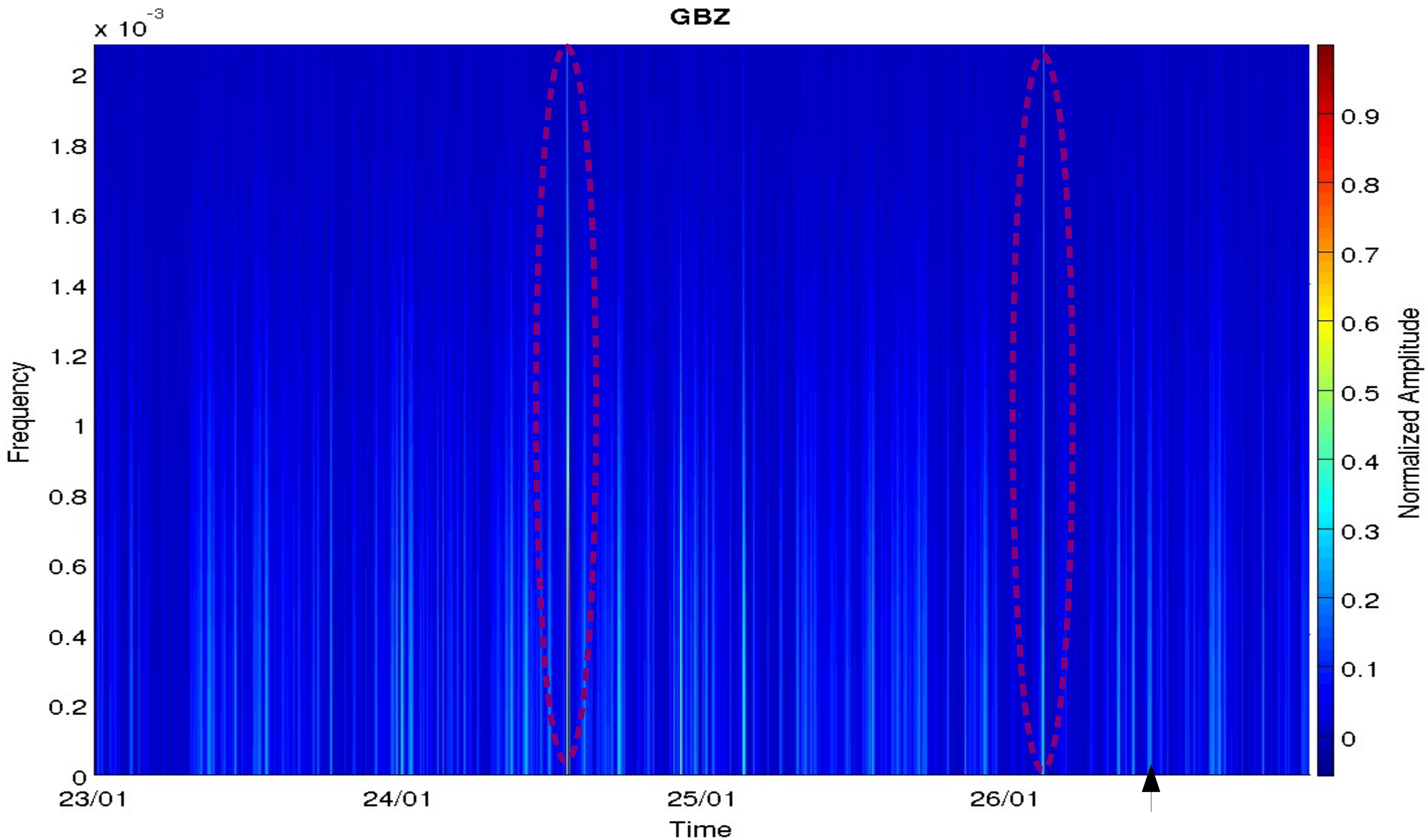
Observations ZAMD



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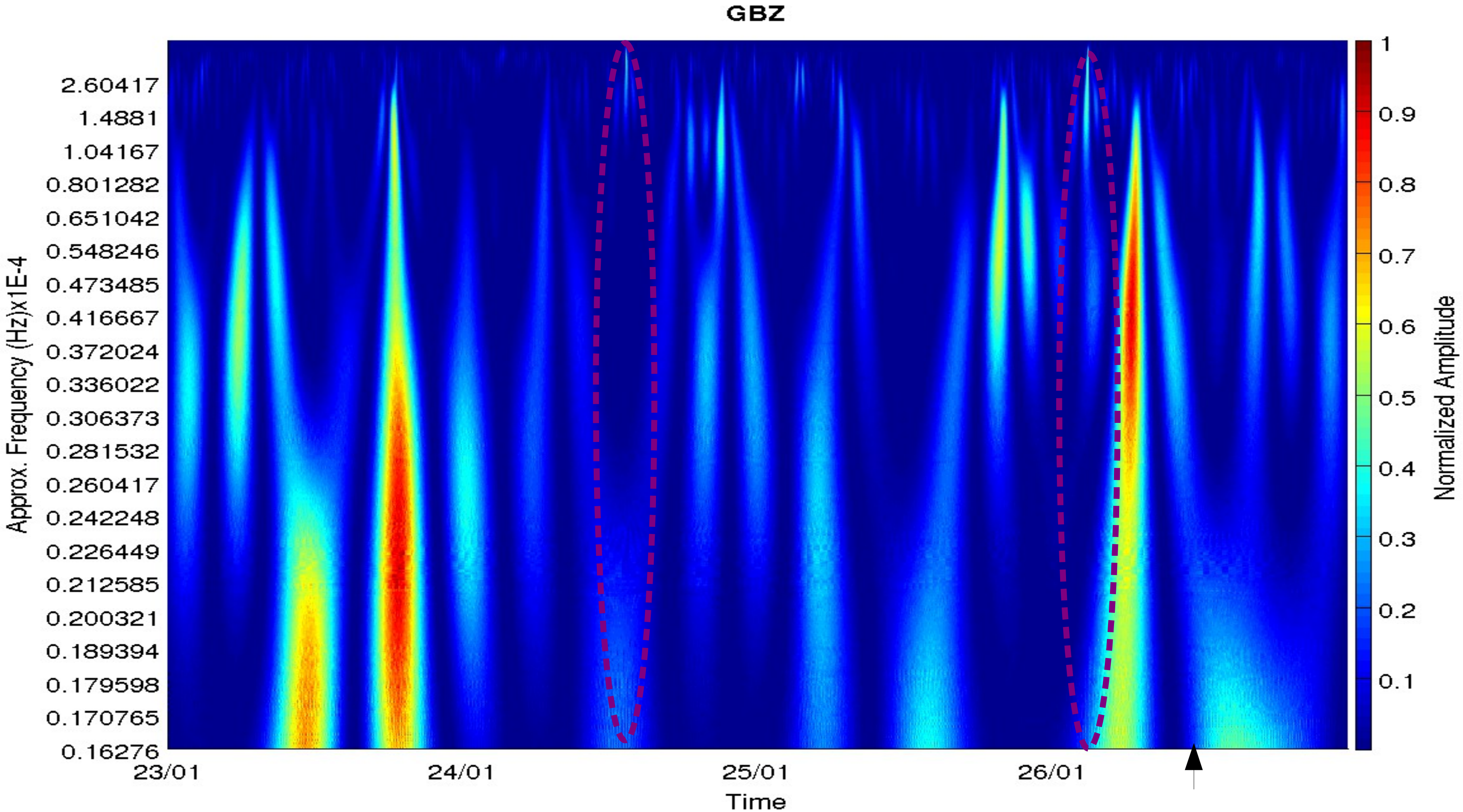

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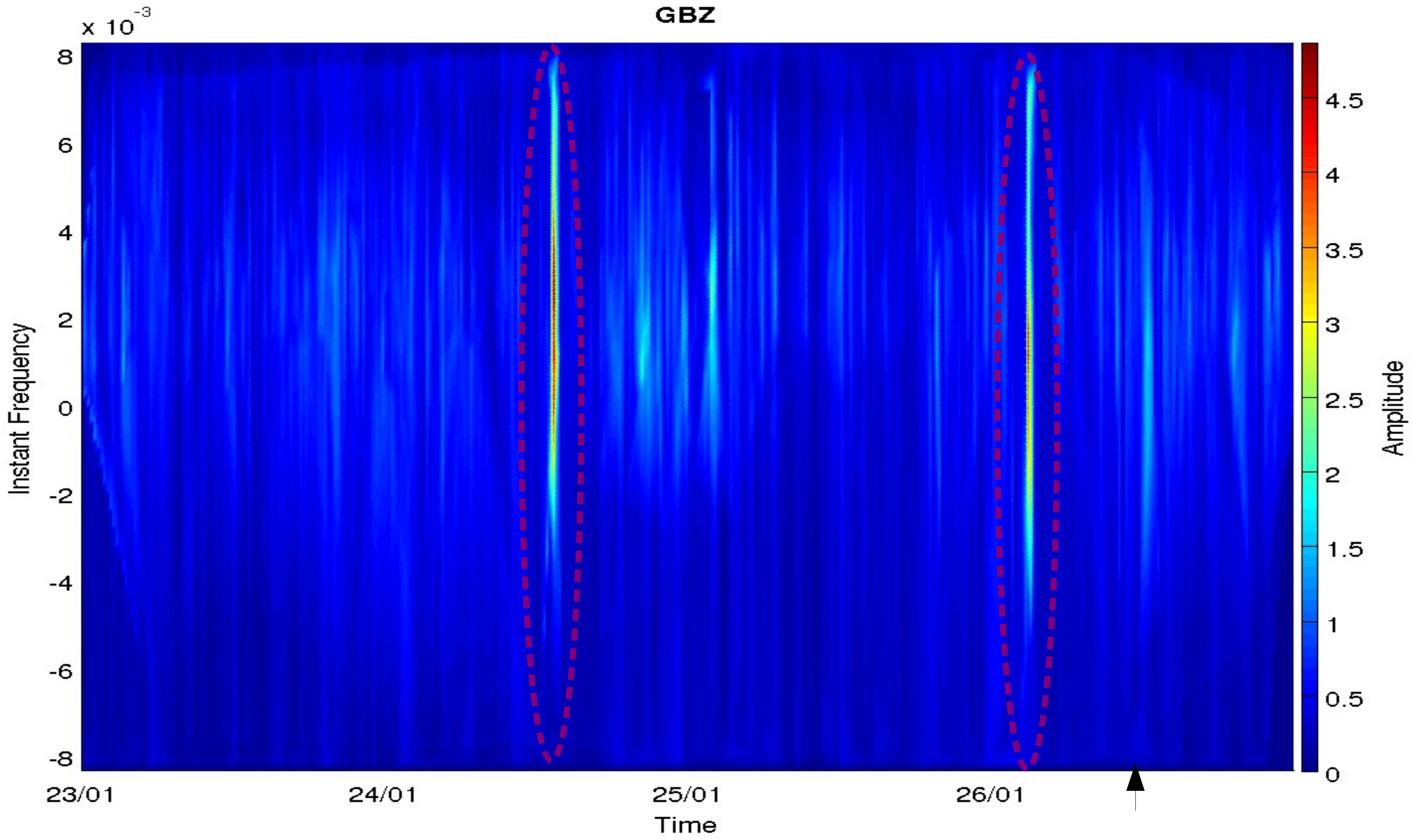

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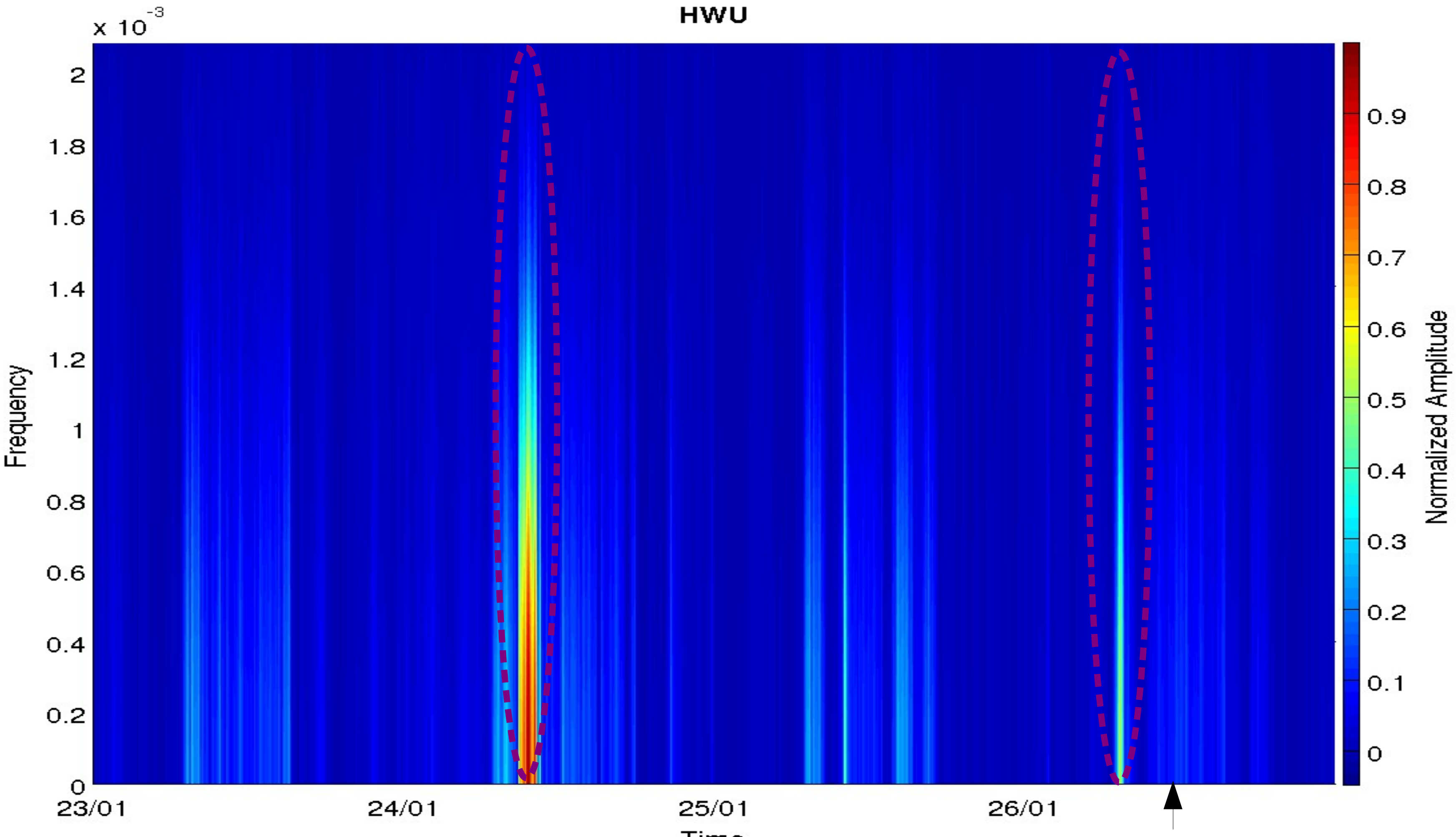

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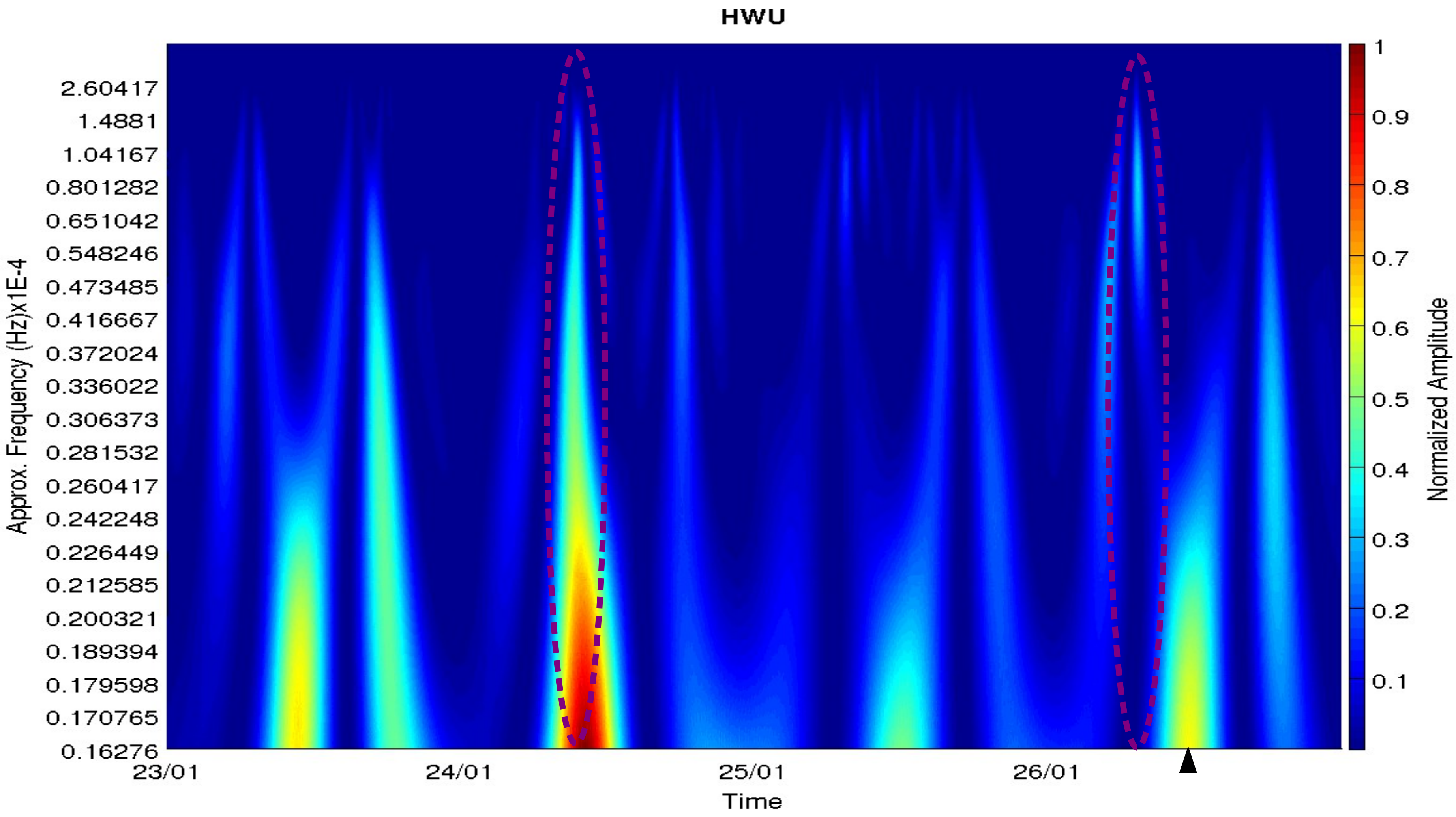
Observations CWT



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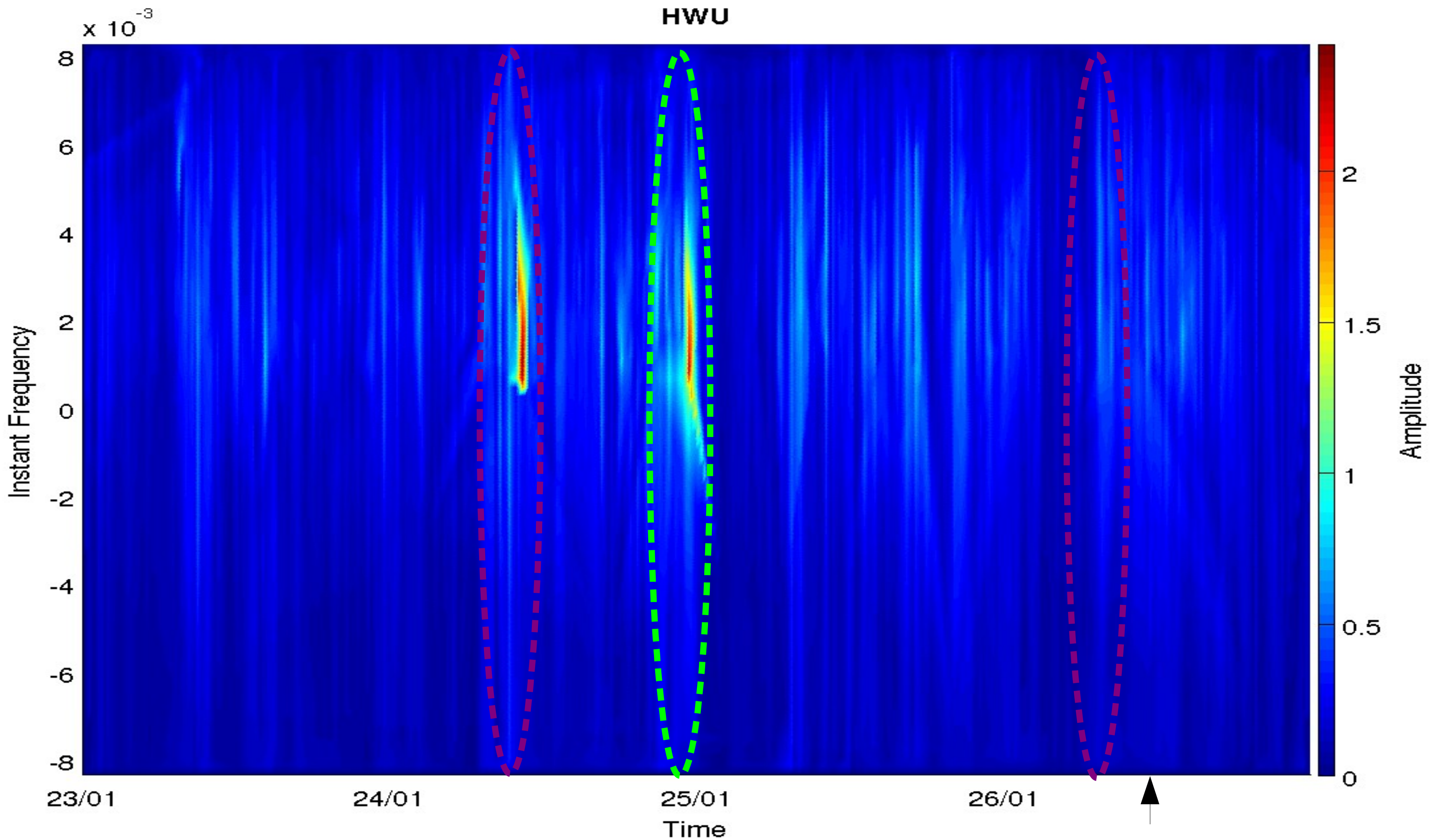

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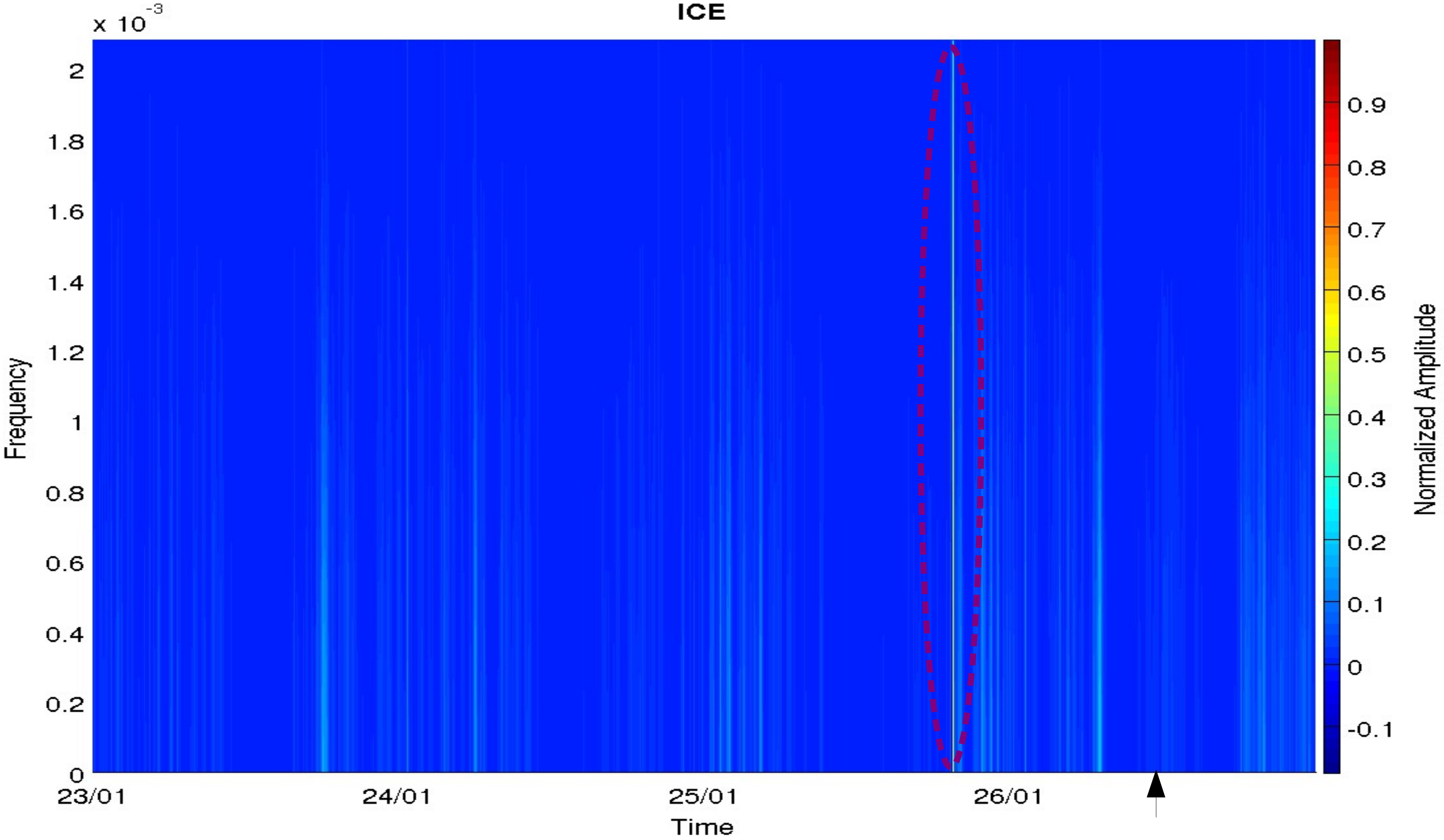

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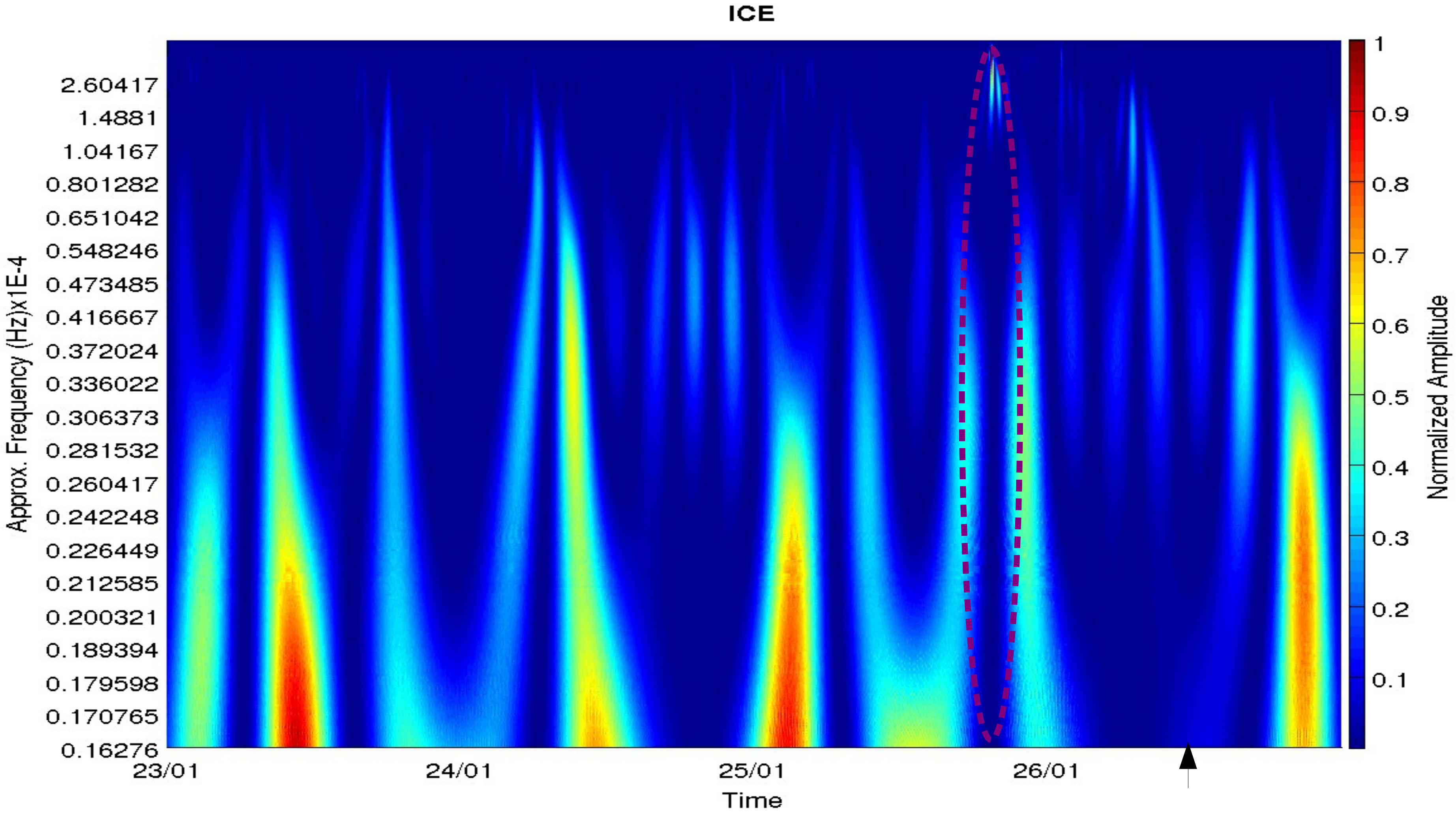
Observations CWT



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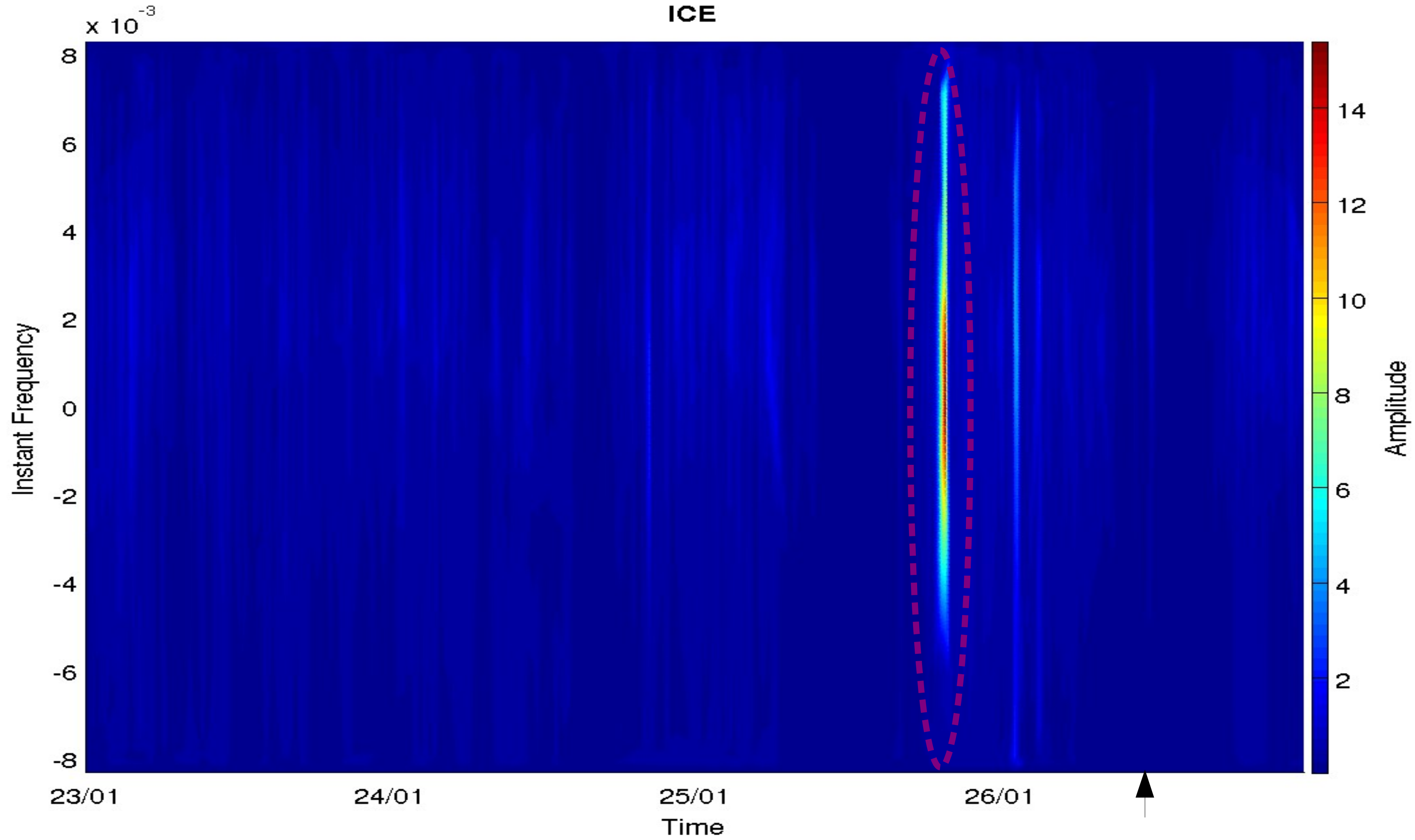

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Conclusions

Each process can provide a clearer depiction of the phenomena

ZAMD provides the most concise diagrams even though it is lacking filtering

Improved HHT is capable of providing filtering to the signal so more disturbances stand out

Thank you