EMT – Empirical mode decomposition-based Magneto-Telluric processing

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State-of-the-art

- Electrical impedance is defined as relation between electrical and magnetic field in frequency domain
- Windowing and Fourier transforming of electrical and magnetic time series to estimate impedance statistically
- Typically assume a stationary signal (Fourier Transform)

Problem

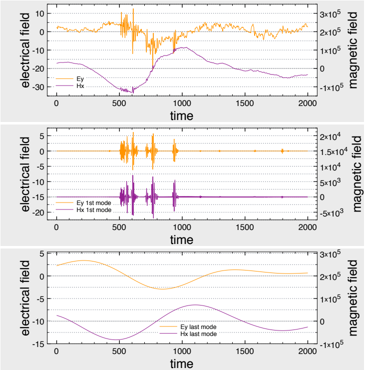
Joint MT signal and noise can be non stationary[1],[2] and inseparable.

Motivation

Make use of a non stationary method to retrieve spectral information from electrical and magnetic time series.

[1] L. Szarka,"Geophysical aspects of man-made electromagnetic noise in the earth – a review", Surv Geophys, 1987.
[2] A. Junge, "Characterization of and correction for cultural noise", Surv Geophys, 1996.

example data: E_y and H_x



Empirical Mode Decomposition[3],[4]

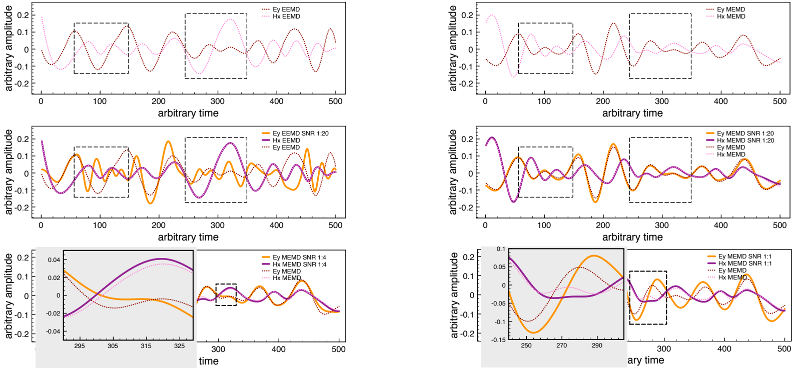
- extracts oscillatory modes
- naturally non stationary and data adaptive
- modes are defined to be locally zero-mean
- ensures computation of a meaningful analytic signal for each mode

[3] N. E. Huang, Z. Shen, S. R. Long, M. C. Wu, H. H. Shih, Q. Zheng, N. C. Yen, C. C. Tung, and H. H. Liu, "The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis", Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, vol. 454, no. 1971, pp. 903–995, Mar. 1998.
[4] J. Chen and M. Jegen-Kulcsar, "Empirical model decomposition and Hilbert Huang Transform (HHT) in MT data processing", 2008.

Algorithm

Multivariate Empirical Mode Decomposition (MEMD)

Comparison between EMD and MEMD[5] for different noise levels



[5] N. Rehman and D. P. Mandic, ”Multivariate empirical mode decomposition”, Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, vol. 466, no. 2117, pp. 1291–1302, Mar. 2010.

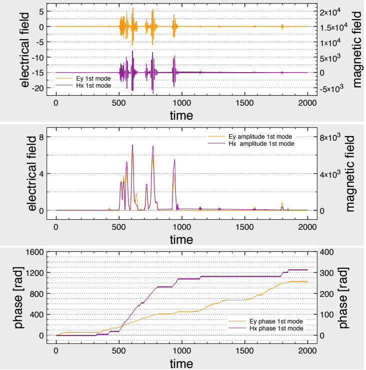
Algorithm

Amplitude Phase Demodulation[6]

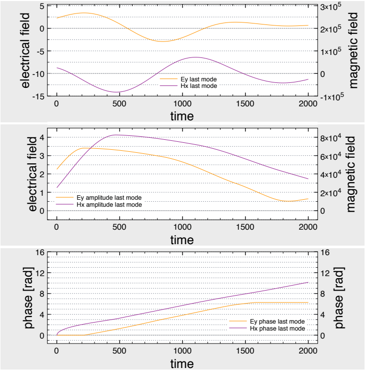
Analytic signal – retrieving spectral information from the modes

- Zero-mean modes can be demodulated (amplitude and oscillation)

Mode with short time scale



Mode with long time scale

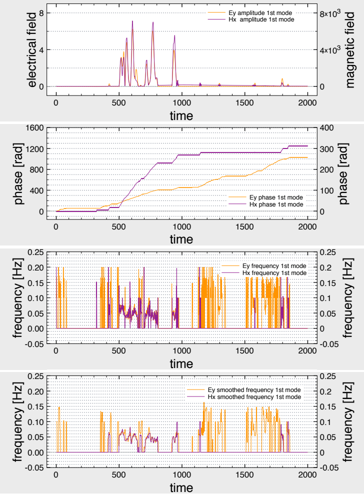


[6] N. Huang, Z. Wu, S. Long, K. Arnold, and X. Chen, "On instantaneous frequency", Adv. Adapt. Data Anal, 2009.

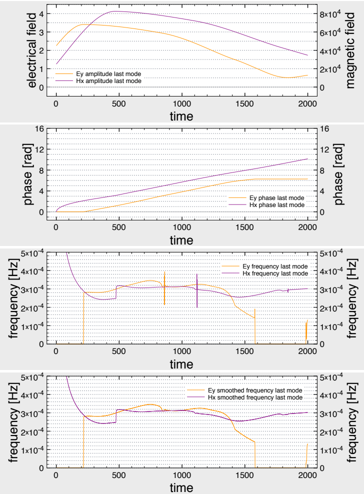
Algorithm

Analytic Signal and Instantaneous Parameters

Mode with short time scale

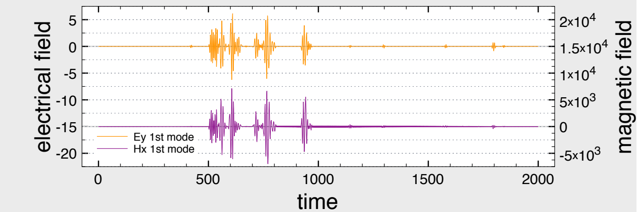


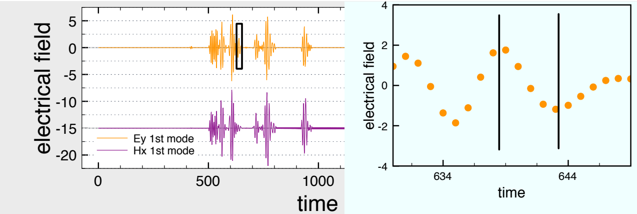
Mode with long time scale



Algorithm

Statistical Independency and Identical Distributions





Independent and Identically Distributed Data

- Extrema define modes => Points between extrema are dependent.
- For data independency, select one point between two extrema.
- Data points do not stem from identical distribution (non stationary).
- Distributions are similar (Pareto with similar parameters), which is sufficient due to robustness of applied Bootstrap operation[7].

[7] R. Y. Liu, "Bootstrap procedures under some non-iid models", The Annals of Statistics, pp. 1696–1708, 1988.

Bootstrap Algorithm

Robust Principal Component Analysis[8]

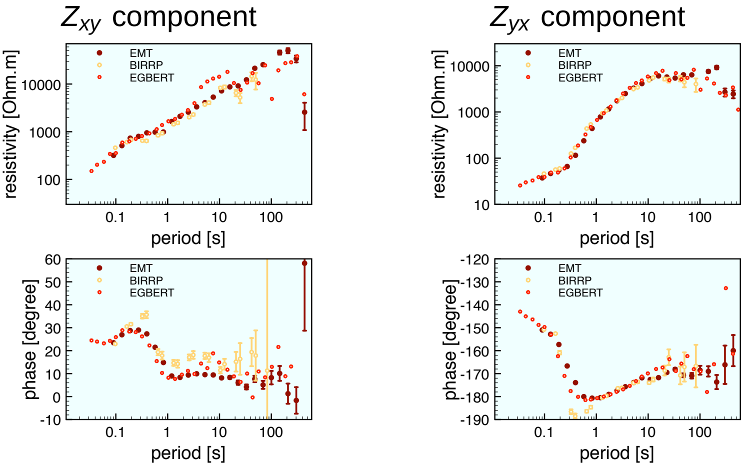
- Compute major robust principal components from data (including remote channels) as predictor.
- Robust linear least squares regression of data on predictors for impedance estimate.

- Derive confidence in impedance estimates from bootstrap results.

[8] G. D. Egbert, "Processing and interpretation of electromagnetic induction array data", Surv Geophys, 2002.

Example

From a volcanic zone in northern Spain (Poster A406, Th 17.30–19.00)



The data is processed with one reference station in case of BIRRP and EMT. Both sites were situated close to farming activity.

[8] G. D. Egbert, "Processing and interpretation of electromagnetic induction array data", Surv Geophys, 2002.
[9] A. D. Chave and D. J. Thomson, "Bounded influence magnetotelluric response function estimation", Geophysical Journal International, vol. 157, no. 3, pp. 988–1006, Jun. 2004.

- We present a non stationary broadband MT processing algorithm, which is not limited to quasi-stationary signal and noise.
- Uses instantaneous parameters, therefore local noise does not effect the measurement globally (e.g. spikes).
- Analytic signal remains in time and frequency domain, therefore offers potential for new time and frequency domain filters (e.g. parameter gradient restrictions).

1. Multivariate Empirical Mode Decomposition (MEMD)
2. Amplitude Phase deModulation (APM) to compute Instantaneous Parameters (IP)
3. Generate analytic signal (complex spectral data)
4. Find independent data
5. Organize data in frequency domain
6. Estimate transfer functions
    1. Compute major robust principal components from data as predictor
    2. Robust linear least squares regression of data on predictors
    3. Estimate confidence intervals by bootstrapping point 6

Thank You!!