Trend removal and filtering of TEC data by empirical mode decomposition

Irina Kirichenko, Denis Kogogin, Igor Nasyrov, Denis Maksimov

Kazan Federal University

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Outline of the Report

Various methods of TEC data processing

To analyze raw TEC data (from dual frequency measurements of phase), we need to detect TEC variations. To detect TEC variations, it is necessary to perform the procedures of detrending and digital filtering. The natural trend in raw TEC data depends on the change along the line of sight (LOS) elevation angle between GNSS site and navigational satellite, and, accordingly, is associated with the distance from this satellite to the GNSS receiver's.

In the most works the following techniques used to detrend data: the moving average and high-order polynomial.

To filter TEC variations: the moving average (one most often uses), the Butterworth filter and other methods (much less often).

Importantly

Various methods of trend removal and filtering TEC variations can significantly affect the interpretation of experimental TEC data.

The new method of processing TEC data

The method of empirical mode decomposition (EMD) of signals used in this work is relatively new, but no less reliable, than previously announced raw TEC data processing methods. The method was proposed by **Norden Huang** in 1995. In 1998, the method was extended by the Hilbert transform and generalized to analyze any time data [1].

This method allows processing nonlinear and nonstationary signals, since it does not require any a priory data about the signal since the trend is extracted from the signal itself. This fact makes it possible to use it effectively in systems for automatic analysis and processing big data of GNSS measurements, especially in the task of removing the trend from the raw TEC data.

[1] *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 nonstationary time series analysis**, Proc. R. Soc. Lond. A, 454, 1971, 1998, pp. 903–995, doi: 10.1098/rspa.1998.0193

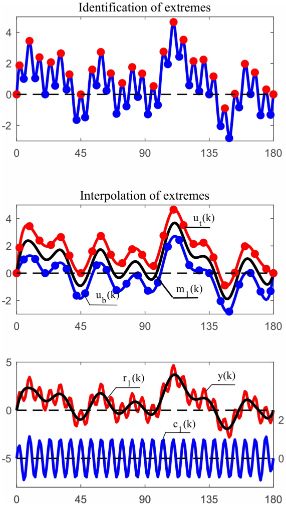
Description of the method

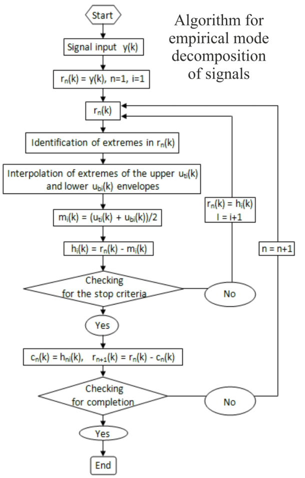
This method it is decomposing any source signal into components called intrinsic mode functions (IMF), and residual trends.

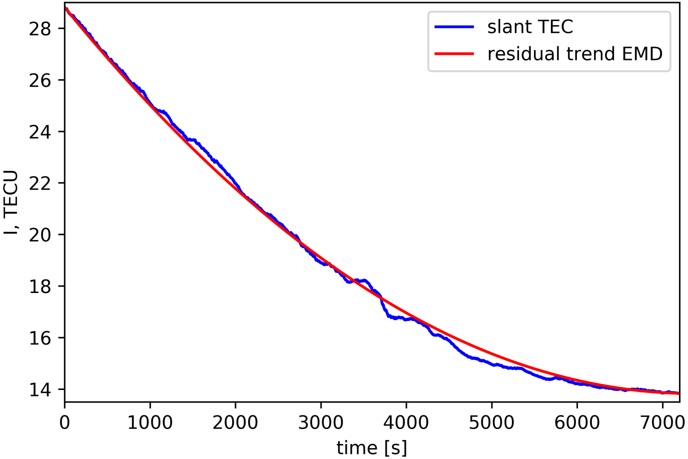
It is necessary that every IMF correspond to the following properties:

- Number of extreme points and the number of intersections of this function with the abscissa axis must not exceed one.
- At any point in the function, the average value of the envelopes defined by local maxima and local minima must be zero.

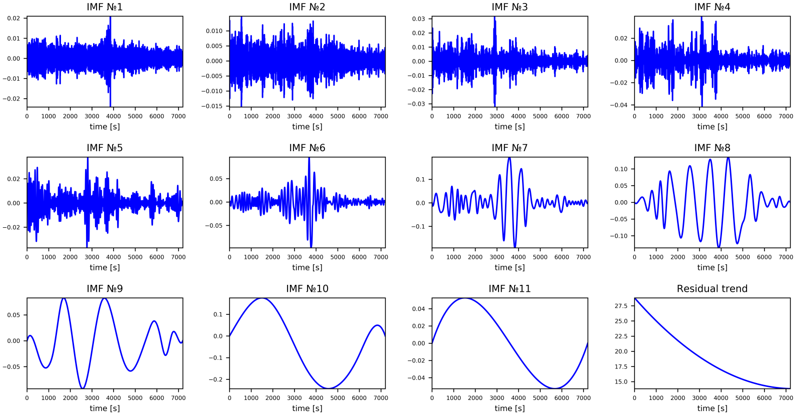
Algorithm for EMD of signals



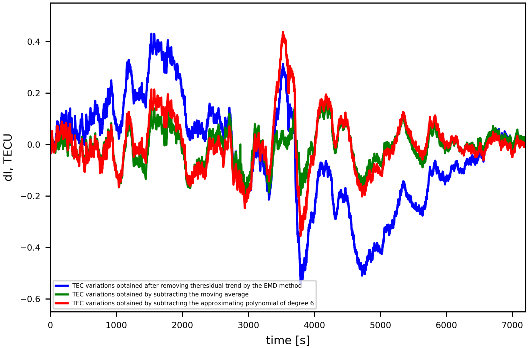




Raw TEC data is shown in blue line, and the residual trend obtained by empirical mode decomposition is shown in red line.



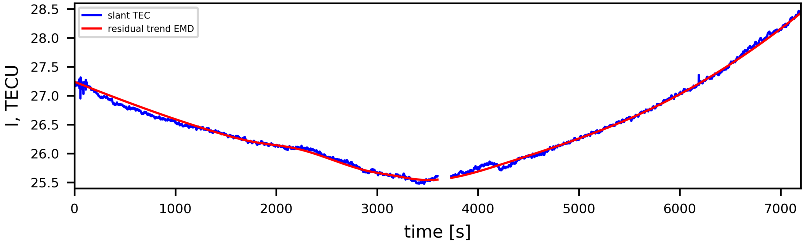
All intrinsic mode functions and residual trend selected using the method of EMD for the TEC data shown the previous slide.



TEC variations obtained by various methods of trend removal.

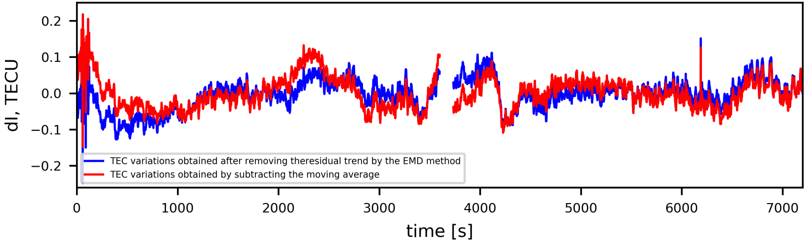
- blue line — TEC variations obtained after removing the residual trend by the empirical mode decomposition method;
- green line — TEC variations obtained by subtracting the moving average;
- red line — TEC variations obtained by subtracting the approximating polynomial of degree 6

Trend from TEC data (with break). The method of EMD



- blue line — raw TEC data with a break;
- red line — residual trend obtained by the empirical mode decomposition method.

TEC variations from TEC data (with break). EMD and moving average



- blue line — TEC variations obtained by removing the residual trend using the empirical mode decomposition method;
- red line — TEC variations obtained by subtracting the moving average.

Conclusion

- It is shown that the method of empirical mode decomposition can be used to remove the trend from raw TEC data.
- This method allows processing nonlinear and nonstationary signals, since it does not require any a priory data about the signal since the trend is extracted from the signal itself.
- This method allows you to remove the trend from the TEC data even if the data contains breaks.
- This method can be effectively used in automatic big data processing systems of GNSS measurements, especially in the task of removing the trend from the raw TEC data.

Open question

A lot of important information on the physics of processes is contained in each intrinsic mode function, however the study of this question in the work was not carried out. This issue requires a separate careful study in the future.

Additional information and Acknowledgements

The source code (python scripts) of the examples of the application of the method of empirical mode decomposition shown in the presentation is available at the url link Yandex Disk and QR code above.

Acknowledgements

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Related Links

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 nonstationary time series analysis**, Proc. R. Soc. Lond. A, 454, 1971, 1998, pp. 903–995, doi: 10.1098/rspa.1998.0193.

N. E. Huang and Samuel S.P. Shen **The Hilbert-Huang transform and its applications**, World Scientific Publishing Co. Pte. Ltd., 2005, 311 p, doi: 10.1142/5862.

N. E. Huang and Z. Wu **A review on Hilbert–Huang transform: Method and its applications to geophysical studies**, Rev. Geophys., 46, 2, 2008, p. RG2006. doi: 10.1029/2007RG000228.

Authors

Irina Kirichenko — Student of the Kazan Federal University. 18 Kremlyovskaya street, Kazan, Russia, 420008.
E–mail: *irishka.kirichenko@yandex.ru*

Denis Kogogin — PhD, Assistent of the Kazan Federal University. 18 Kremlyovskaya street, Kazan, Russia, 420008.
E–mail: *Denis.Kogogoin@kpfu.ru*

Igor Nasyrov — PhD, Associated professor of the Kazan Federal University. 18 Kremlyovskaya street, Kazan, Russia, 420008.
E–mail: *Igor.Nasyrov@kpfu.ru*

Denis Maksimov — Student of the Kazan Federal University. 18 Kremlyovskaya street, Kazan, Russia, 420008.
E–mail: *meinica_macs@mail.ru*

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denis.kogogin@gmail.com; igor.nasyrov@gmail.com