New MT impedance estimators in frequency-domain and time-domain using automatic preselection of time-series data

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論 文 名　：New MT impedance estimators in frequency-domain and time-domain using automatic preselection of time-series data
(時系列データの自動選択を使った周波数領域および時間領域での新しいMTインピーダンスの計算方法)

区　　分　：甲

論　文　内　容　の　要　旨

The magnetotelluric (MT) method is a passive electromagnetic method to infer subsurface electrical conductivity. The MT method is widely used for mineral, petroleum and geothermal exploration and in crust and mantle studies. The main strengths of the method are that it allows a broad range of investigation depths than other geophysical techniques. The MT source is the natural electromagnetic signal from Earth's magnetosphere and ionosphere or global lightning. The MT method assumes that the electromagnetic source locates at a large distance from the measurement area, and the signal propagates as plane waves. The natural signal locates far from the observation site and can be treated as plane waves. On the contrary, the local anthropogenic sources violate the assumption and are considered noise in the MT method.

The first step in MT data processing is to estimate the frequency-domain impedance tensor from the measured time-series data. All MT data interpretations are based on the MT impedance. Therefore, it is very important to obtain a reliable impedance. Any subsequent analysis and high-precision inversion may be meaningless without a high-quality and credible response function. Therefore, studying estimating the MT impedance tensor is the primary issue in improving the magnetotelluric method's effectiveness.

The use of natural sources is both an attraction and a weakness. The nature EM signal is extremely weak, and the cultural noise easily influences it. Artificial disturbances to electromagnetic observations are becoming more serious with urban constructions. The near-field noises produced by human activities such as vehicles, subways, and high-speed railways can easily influence the MT field data. Estimating a reliable impedance can be challenging under the influence of cultural noise. This thesis focuses on researching the noise reduction method of MT time-series data and getting a reliable impedance from the noisy field data. This thesis includes seven chapters.

Chapter 1 introduces the basic theory of the MT method. MT data interpretation is generally divided into two steps. The first step in MT data processing is to estimate the frequency-domain impedance tensor from the measured time-series data. The second step is to do the inversion based on the impedance and finally get the subsurface resistivity structure. All MT data interpretations are based on the MT impedance. Therefore, it is very important to obtain a reliable impedance.

Chapter 2 reviews the signal and noise for the MT method. Generally, the high-frequency signals (> 1 Hz) originate from worldwide thunderstorm activity. In comparison, the low-frequency signals (< 1 Hz) originate from the interaction between solar winds and the Earth's magnetosphere and ionosphere.

Chapter 3 reviews the conventional MT impedance estimation methods. The initial MT impedance estimator is based on the least-squares theory, and the least-squares estimator can be severely disturbed by cultural noise. Removing these disturbances is mainly based on robust statistics, remote reference processing or their combination. Remote reference processing can improve the MT impedance quality when the electromagnetic noise is uncorrelated between the local and remote sites. Robust algorithms aim to detect and reject outliers by a data-adaptive weighting scheme. These methods require reasonable proportions of normal data to yield reliable results, e.g., data with no more than 50% contamination. All statistical algorithms can obtain a reliable result when most of the recorded data is well-behaved.

Chapter 4 proposes a robust estimator based on the windowed FFT for data quality analysis and impedance calculation. In real data processing, we don't know the content of the background noise and whether the method calculated by the conventional robust remote reference estimator is effective for a specific case study. Therefore, it is necessary to know the situation of the background noise. The more effective parameters are proposed to identify the low SNR data, and the Robust Estimator using Data Selection based on LInear Coherence (REDSLIC) for data quality analysis has been developed. The effectiveness of the REDSLIC method was confirmed with simulated and field data.

Chapter 5 presents a robust estimator based on the Hilbert-Huang transformation (HHT). A new robust estimator based on the Hilbert-Huang transform (REHHT) is proposed to process the MT time-series data. REHHT can reduce the influence of noise by selecting the data in the time and frequency domains. In this chapter, the effectiveness of REHHT is demonstrated using simulated and field data.

Chapter 6 evaluates the influence of geomagnetic storms on the MT impedance calculation. Not all MT time-series data include usable information on the electrical conductivity distribution at depth. A low signal-to-noise ratio (SNR) can occur when the natural signal level is comparable to or below the instrument noise level or in the presence of some types of cultural noise. It is well known in MT communities that the natural EM signal increases significantly during a strong geomagnetic storm. The geomagnetic storm is beneficial to MT impedance quality at midlatitudes. In a quiet EM environment, no matter whether there is a geomagnetic storm, I can get a reliable MT impedance tensor. On the other hand, artificial noise dominates the data quality during non-storm days. In the presence of a geomagnetic storm, high SNR data may appear, and I can get a reliable impedance using the storm data. The effect of magnetic storms on MT impedance was verified using MT data obtained in South Africa and the United States.

Chapter 7 summarizes the study and discusses the practical way to reduce the noise of MT time-series data. Any estimators need the high SNR data to get a reliable result; suppose the continuous noise does not contaminate the field data; both REDSLIC and REHHT might get a reliable result. The most serious situation is that the continuous noise contaminates field data, and any approaches may fail to get a reliable result in such cases. The current MT data processing methods can get a reliable result when the noise contaminates the field data intermittently. Artificial disturbances to EM observations are becoming more serious along with urban constructions. The observation occasionally contains continuous noise, and any approach may fail to get a reliable result in such cases. Redoing the MT survey in noisy locations may yield reliable results in time series data between magnetic storms. Magnetic storm data could provide reliable results even for sites contaminated by continuous noise.