Development and application of methods to evaluate temporal changes in subsurface resistivity structures using magnetotellurics(Digest_要約)

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論文題目	Development and application of methods to evaluate temporal changes in subsurface resistivity structures using magnetotellurics （地磁気地電流法を用いた地下比抵抗構造の時間的変動評価手法の開発と応用）		

（論文内容の要旨）

Time-lapse magnetotelluric (MT) exploration has been conducted for a detailed discussion on temporal changes in subsurface resistivity structures, especially around geothermal areas. However, two challenging subjects remain: cultural noise effects and source-dependent bias stemming from spatially-heterogeneous source currents. Cultural noise mixed in observed electromagnetic (EM) data can yield large estimated errors of MT responses, which result in failure to detect time-varying impedances. Then this study supposes establishment of the plane-wave assumption, in which incident EM fields are horizontally uniform and geomagnetic temporal variations have no spatial gradient. If this assumption is not satisfied, MT responses are biased and shift from their true values.

This study presents a theory describing the bias within MT responses arising from localized source currents. Subsequently, an improved algorithm of Frequency-Domain Independent Component Analysis for processing noisy MT data (FDICA-MT) was proposed for removing the noise effects. For excluding the source-dependent bias within impedances, a technique to assess spatial gradients of geomagnetic temporal variations from several geomagnetic spectrograms using Multi-Channel Nonnegative Matrix Factorization (MC-NMF) was developed. By applying these methods to the EM data acquired at the Kakioka magnetic observatory, the temporal variations in MT responses owing to changes in the subsurface resistivity structure were well detected.

The background, purposes, and structure of this study, reviews of related preceding studies, and unsolved essential problems that motivated this study are introduced in Chapter 1.

Chapter 2 formulates equations of EM fields by supposing localized source currents. On the basis of these equations, Chapter 3 calculates MT responses by changing the vertical and horizontal distances between an observation site and the source current. Consequently, MT responses shift from the true values and vary dependent on the distances. Because these distances change temporally, for an exact interpretation of time-varying MT impedances, check of the condition of ionospheric currents is indispensable. Furthermore, the mathematical underpinnings for the source-dependent bias and the plane-wave assumption were noted.

Chapter 4 presents FDICA-MT, which was designed to separate noise directly from observed data. For checking the noise-reduction performance, FDICA-MT was applied to the EM data acquired at Kakioka. The results revealed that the MT responses derived by FDICA-MT were smoother and have smaller error than those by a conventional method. The robustness of the noise-reduction performance of FDICA-MT was tested quantitatively by analyzing the EM data including synthetic noise components. Although the conventional technique breaks down when more than half of the time-series data are contaminated, FDICA-MT was able to estimate MT responses correctly and with small estimated errors. Furthermore, the proposed method was applied to the EM data acquired in the Chugoku district and at the outer rise

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region off Japan Trench. FDICA-MT yielded higher quality impedances even from real noisy data than the conventional tool.

Chapter 5 presents MC-NMF, which can assess anomalous geomagnetic events that have different spatial gradients from others. The method can work at the time–frequency domain, in which information regarding the geomagnetic temporal variations is included roughly as much as in the time-series data. This study clarified that such anomalous events caused shifts in inter-station transfer functions (IS-TFs) between the geomagnetic data acquired at the Kakioka and Memambetsu magnetic observatories. Subsequently, the year-to-year changes in IS-TFs between Kakioka and Kanoya, Kakioka and Memambetsu, and Kanoya and Memambetsu were calculated. Although the polarity should be opposite, some IS-TFs exhibit the same polarity as those derived by swapping the output and input data. The results from MC-NMF, numerical examples, and the mathematical proof indicated that the spatial gradients of geomagnetic temporal variations cannot always be assessed on the basis of the IS-TFs if anomalous geomagnetic events are mixed in the geomagnetic data. However, MC-NMF was able to evaluate the anomalous events. Hence, by using IS-TFs with MC-NMF, the spatial gradients of geomagnetic fields can be correctly calculated.

Chapter 6 analyses time-varying impedances from the EM data acquired at Kakioka during 2000–2004. FDICA-MT was employed for removing the noise effects on the MT responses. The interpretation from Chapter 3 and the method of MC-NMF presented by Chapter 5 were used for excluding the impedances affected by the source-dependent bias. Although the MT responses became stable by removing these adverse effects, the temporal variations appeared only in the amplitudes. Because of the synchronized changes throughout the frequencies, they can be considered to result from the temporal variations caused by the static shift. The MT responses shifted widely owing to an increase in the precipitation at Kakioka. On the basis of the geological structures at Kakioka, the rainfall may cause the local resistivity heterogeneities, which are probably the origins of the static shift. Additionally, numerical simulations showed that a 10% decrease in the near-surface resistivity yields the upward and downward shifting in the amplitudes of MT impedances, which corresponded to the observed variations. Such a decrease due to the rainwater incursion is plausible and accordingly, the time-varying amplitudes of the impedances can be considered to reflect the temporal changes in local heterogeneities stemming from precipitation. Therefore, this study succeeded in extracting time-shifting MT responses that result from the temporal variations in the subsurface electrical environment at Kakioka. Furthermore, because of suppressing the noise effects and source-dependent bias, the detected changes have small temporal-scales. By applying the scheme employed in this study, time-varying MT impedances can be exactly detected, which indicates that MT is effective for monitoring subsurface resistivity structures.

Chapter 7 summarizes the concluding remarks, contributions of this study to the field of natural resource engineering, and future works that can be expected to be yielded by applying the techniques, results, and interpretations of this study.