Transient signal analysis on a 3-D electrical conductivity structure in the Earth's mantle

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We report a new time-domain approach for estimating a global 3-D electrical conductivity structure in the Earth.   In the previous induction studies, the frequency responses of the earth to the external disturbances were estimated from the number of single observatory data sets by assuming a P10-type geometry for the external source field. Because of these limitations, the response functions shorter than several days cannot be used for the inversion, although the responses with the periods between 1 hour to several days are sensitive to the conductivity structure in the upper mantle. In our new approach, the temporal and spatial variations of the external source fields and the response functions are determined by using the Spherical Harmonic Analysis (SHA). The geomagnetic field variations during large magnetic storms are utilized for the analysis to ensure high levels of short period signals. Since the traditional frequency domain approach is not appropriate to analyze the geomagnetic variations during the magnetic storms, we employ a time-domain method. In our approach, SHA is applied to every points of time to obtain the time series of the external and internal fields, and the response functions are calculated in time domain. Results of the SHA for several storm time signals indicate that, among the external fields, q10 component is dominant during the magnetic storms. Besides q10 component, q21 and s21 components have significant signal levels at the later stage of the magnetic storm. These degree two components represent the daily variation. Signal levels of the other higher degree components are one to two orders of magnitude smaller than the degree 1 and 2 components. From the analysis, it can be concluded that the external field during the storm time is represented by degree 1 and 2 components. These external fields can be used as realist source fields for the induction study. At this time scale, all the internal components can be considered to be the induced field due to the external sources. Reflecting the dominance of q10 component in the external source field, g10 component dominates in the induced field. In the higher degree components, signal levels are high only at around the onset of the magnetic storm. For a spherical symmetric conducting sphere, each harmonic component behaves independently with each other. On the other hand, couplings between the different modes occur when the lateral conductivity heterogeneity exists. Hence, the induced fields consist of the field induced in the spherical symmetric part of the electrical conductivity distribution and the field induced by the lateral heterogeneity. The large amplitude of the higher degree components around the onset of the magnetic storm, where an abrupt increase of q10 component is observed, indicates that the large q10 component of the external source may be the main cause of the induction caused by the lateral heterogeneity. The separated external field and the induced field are the basis for the study of the electrical conductivity distribution of the mantle. Response functions can be calculated from these fields. As mentioned above, both the radial distribution and the lateral heterogeneity of the electrical conductivity seem responsible to the induced field. Hence, the results of the separation can be used to obtain the 3-Dimensional structure of the mantle. For the analysis of transient signals, we developed a new method to calculate the induction of the heterogeneous earth in time domain (Hamano, 2002). This method can be efficiently used to analyze transient geomagnetic variations to estimate the 3-D conductivity structure of the earth. Since the method directly solves the temporal variation of the expansion coefficients corresponding to the source field, which is also expanded by the spherical harmonics, the method can work together with the results of the spherical harmonic analysis.