

Finite difference analyses of Schumann resonance and reconstruction of lightning distribution

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The ultimate goal of this study is to establish a method to draw the world map of lightning activity by observing Schumann resonance spectra collected at a few ground-based observatories. As an early stage, the present study deals with the computation of extremely low frequency (ELF) propagation associated with the Schumann resonance phenomena, and the reconstruction algorithm for source lightning location based on measured Schumann resonance data.

Schumann resonance is the global ELF phenomenon that occurs in the spherical shell between the Earth's surface and the ionosphere, the resonant frequencies are about 8, 14, 20, etc. Hz, corresponding to the first, second and third modes. The Schumann resonant spectra mostly depend on the distance between the source lightnings and the observation points, which allows us to deduce the information on the source lightnings from the measured spectra.

For the identification of lightning distribution by using measured Schumann spectra, there are two essential problems to be solved, which are the computation of Schumann spectra, i.e. the forward problem, and resolving the inverse problem.

As the forward problem, we adopt the finite difference method in the frequency domain. The finite difference equations are derived in terms of discretized magnetic fields in the spherical coordinates with introducing the azimuthal symmetry for simplicity when the source lightning is assumed to be a vertical Hertzian dipole. The most reliable electron and neutral density models in the atmosphere and the ionosphere, IRI2000 and NRL-MSISE can be used to consider the loss of ELF resonances. The numerical results show the reasonable resonant frequencies, and the computed field distribution provides us with understanding ELF behaviour.

The inverse problem for the reconstruction is formulated using the computed spectra as a set of basis functions, to identify lightning distributions with respect to the distances from any observatories to the global thunderstorm centers. The Tikhonov's regularization is introduced to consider properly the solution in the presence of unknown noise. Numerical experiments allow us to evaluate properties and precision of the solution in the absence or in the presence of noise in the initial spectral data.

The inverse problem is applied to the experimental data collected at a field site in Japan, and distribution of global lightning activity is reconstructed for the data covering the period from March to December, 1999. Even though it is not established to estimate accurately intensities of identified lightning activities, the reconstructed results show a reasonable set of distances from the observatory to well-known global thunderstorm centers. They moreover indicate the seasonal drift of lightning activity.

For the proper identification, we also apply the linear prediction to corrected data to be separated into transient and steady components before the discrete Fourier transform. Also, we consider the existence of $1/f$ noise in the inversion to introduce additional basis functions of the fractional exponent of $(1/f)$.