Sferic signals for lightning sourced electromagnetic surveys

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SUMMARY

Lightning strikes generate electromagnetic (EM) waves, known as sferics, which are used in passive Audio-Frequency Magnetotelluric (AMT) and Geomagnetic depth soundings (GDS). Global lightning networks detect sferics and catalogue the time and location of up to four million lightning strikes per day. In this research, we use lightning network data and model earth-ionosphere waveguide propagation to predict time of arrival, azimuth, and amplitude for each known sferic in our time series EM data.

Since conductors effectively rotate electromagnetic fields, we can in principle infer the location and geometry of local and regional structures by calculating the rotation of measured data from their predicted arrival azimuths.

Key words: Lightning, Electromagnetics, Magnetotellurics.

Lightning strikes generate electromagnetic waves (sferics) that propagate around the world. At an electromagnetic survey site sferic energy can be used to determine subsurface resistivity structure through audio frequency magnetotelluric (AMT) or audio frequency magnetic (AFMAG) methods (Chave and Jones, 2012). We studied lightning network data to see if we can shed any new light on these methods.

Lightning Network Data and sferic signals

The GLD360 network operated by Vaisala measures the time of group arrival of a sferic relative to GPS time and triangulates a source location using a network of sensors and a waveform recognition algorithm (Said et al., 2010). GLD360 locations for lightning strikes detected during an AMT survey are shown on Figure 1. GLD360 also provides lightning stroke peak current estimates (Figure 2), which are log normally distributed.

In the field, the time available for data acquisition is often limited. Sferic signal levels are thus set by the global lightning activity occurring within each acquisition window. Both lightning peak current and propagation distance affect signal levels at an electromagnetic survey site (Hennessy and Macnae 2017). Unfortunately, for surveys carried out far from the equator, typical signals are sourced by distant lightning strikes and are generally observed as low amplitude sferics in time series electromagnetic data (Garcia and Jones, 2002). Figure 3 shows extremely low frequency (ELF) vertical electric field amplitudes modelled for a great circle propagation path around the earth (Nickolaenko et al., 2010). Powerful vertical electric dipole sources (e.g. vertical lightning with ~100 kA currents) occurring within 100 km of a survey site would be ideal sources for AMT and AFMAG surveys due to their associated high amplitude electromagnetic fields. Figure 4 demonstrates how the ratio of horizontal magnetic and horizontal electric fields can be used to estimate the apparent resistivity of a conductive half space (Bannister, 1967; Zonge, 1991).

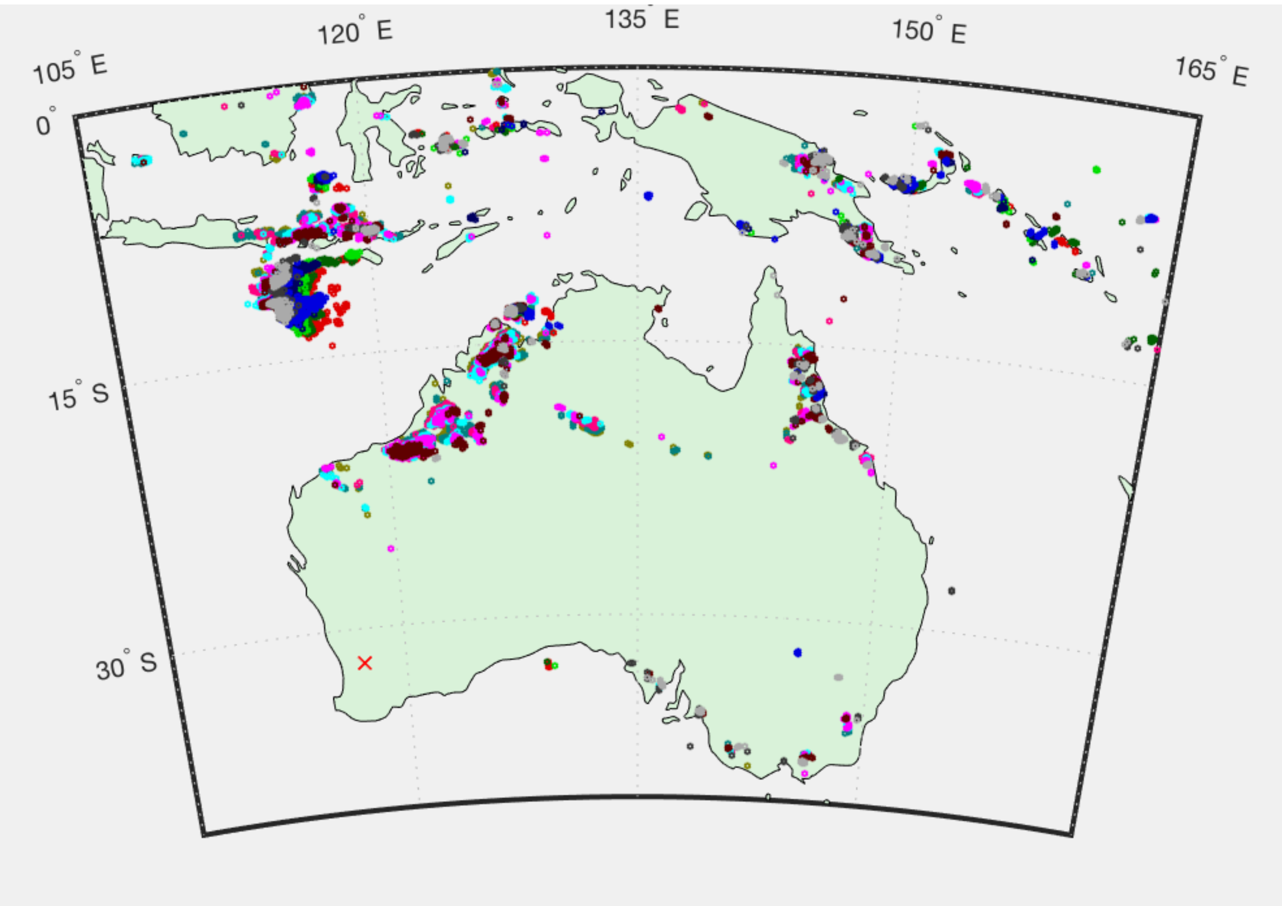

Figure 1: Map showing lightning strikes occurring during profile AMT survey (red cross). Lightning strikes are coloured by their associated soundings located on a profile of 13 stations.

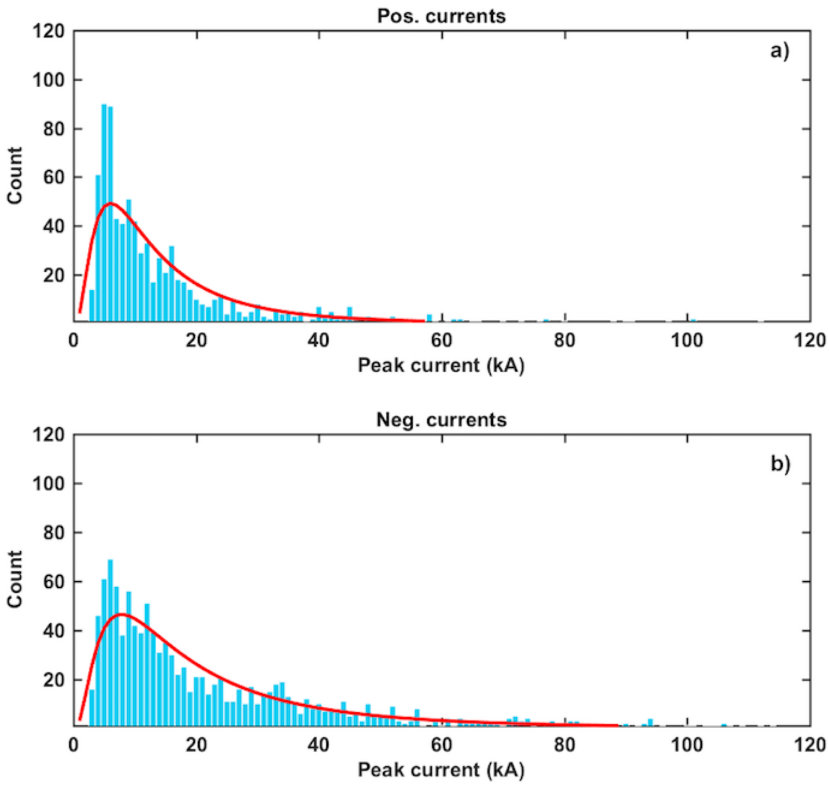

Figure 2: Log normally distributed lightning peak currents typical of storm systems.

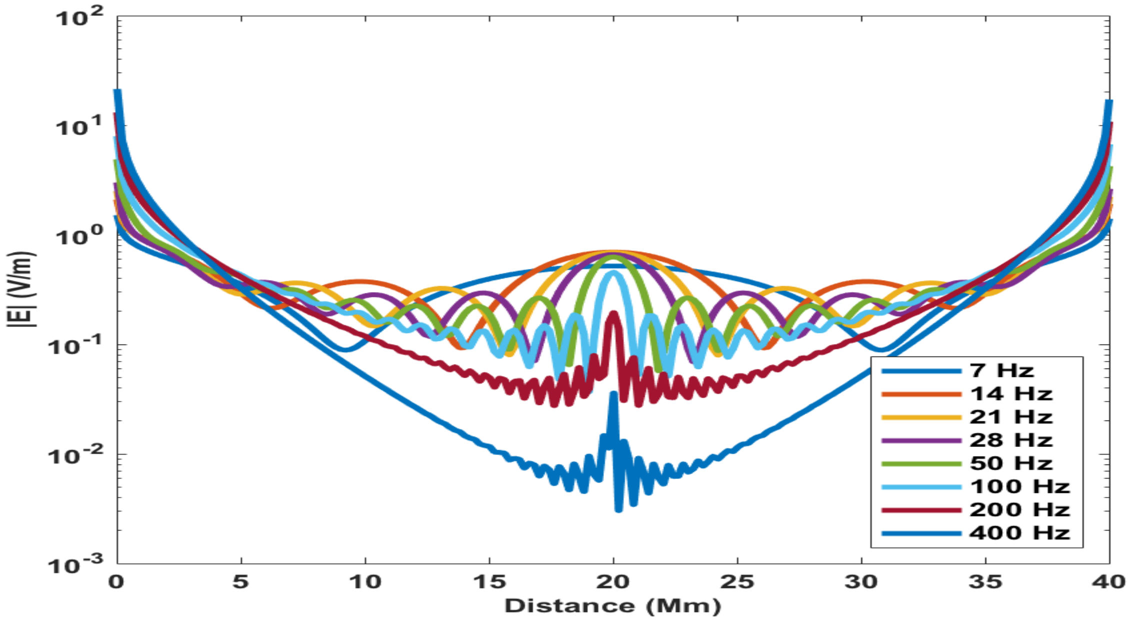

Figure 3: ELF propagation of the vertical electric field through the earth-ionosphere waveguide.

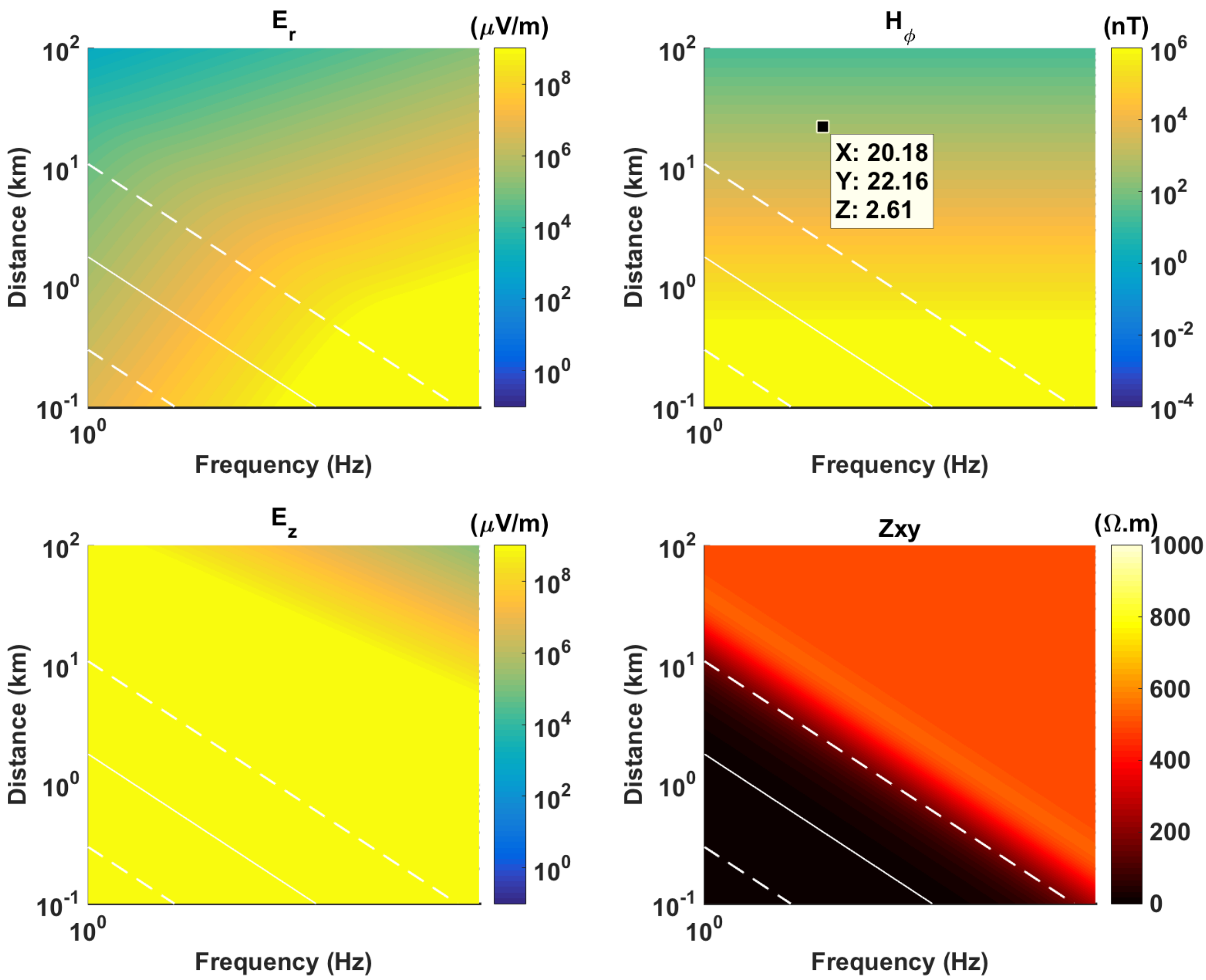

Figure 4: Vertical electric dipole source with 200 kA current sustained over 5 km dipole length. a) radial electric field. b) azimuthal magnetic field. c) vertical electric field. d) Impedance measured in horizontal plane of homogenous earth.

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MODELLING

Lightning Locations, arrival azimuths, and EM coupling.

A steep dipping bedrock conductor can be detected from induced eddy currents caused by changing a magnetic flux through the conductor (Chave and Jones, 2012). Figure 5 shows several models of secondary magnetic field rotated relative to primary magnetic field azimuths. Primary and secondary magnetic field forward models were computed using program Marco (Raiche, 2004). Magnetic field vectors were converted to azimuthal components and the rotation calculated simply as the difference between primary and secondary field azimuths. When the transmitter is located to the east (090) or west (270) the inducing field points along strike and causes no flux to pass through the conductor, see Figure 5a. When the transmitter is located to the north, inducing magnetic fields cause a flux to change through the conductor, and if the conductor is 2-dimensional the secondary field vectors will point in the same direction as the inducing magnetic field and no magnetic rotations are observed (figure 5b). For arrival azimuths demonstrated on figure 5 c and d, secondary magnetic fields are rotated from the inducing primary magnetic fields. Using lightning network data we can extract electromagnetic signals from specific arrival azimuths and experiment with the choice of primary field vectors.

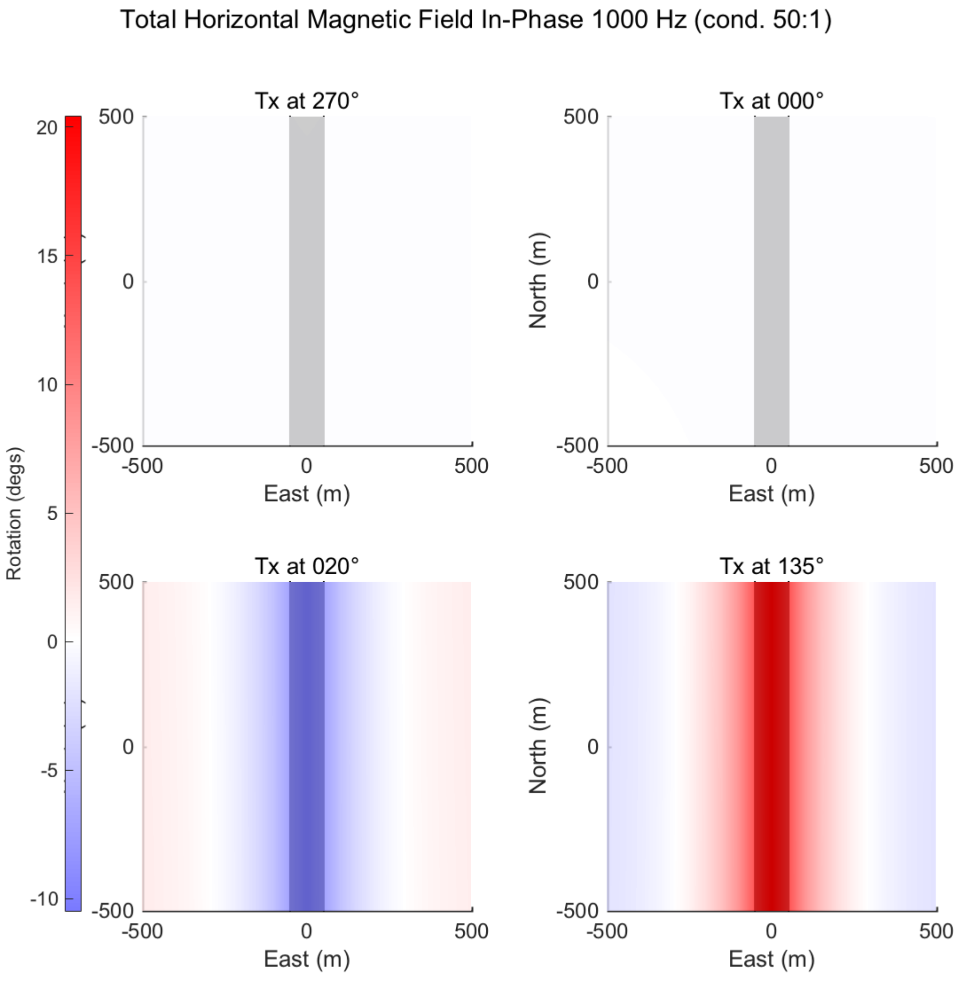

Figure 5: Modelled horizontal magnetic field rotation for 2D conductor using 4 different azimuths to transmitter; a) 270, b) 000, c) 020, d) 135.

CONCLUSIONS

Since lightning locations can be known, we can in principle carry out processing and interpretation using sources that optimally couple to known conductors, or search for anomalies in azimuthal electric and magnetic field coordinates using known sferic azimuths as a reference.

ACKNOWLEDGMENTS

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