WHY DO WE NEED TO KNOW THE ELECTRICAL RESISTIVITY STRUCTURE OF OCEANIC LITHOSPHERE?

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SUMMARY

Regional-scale continental magnetotelluric (MT) programs such as AusLAMP are naturally bounded by the continental shelf and electrically-conducting seawater. Within a few hundred kilometres of the coastline, long-period MT data may be strongly influenced by induction in the seawater, a phenomenon known as the coast-effect. Thus, 3D inversion of gridded long-period MT data for continental lithosphere models requires good constraints on the resistivity of the seawater, oceanic crust and upper mantle, and into the asthenosphere.

In this paper, we discuss the concept of a horizontal adjustment distance. This is the horizontal distance away from a major contrast in electrical conductance at which the anomalous electric fields are attenuated by a factor of 1/e from a 1D response, and is somewhat analogous to the more widely-known skin-depth concept. For seafloor MT, this adjustment distance can be thousands of kilometres. Inland, the effect depends on the conductance of the sedimentary cover, and the depth-integrated resistivity of the upper crust, and can vary from a few kilometres to hundreds of kilometres. We discuss the implications in terms of 3D smooth inversion that inherently minimises gradients in subsurface resistivity and suggest that the coast effect may be significantly underestimated in some continental models.

Key words: Magnetotellurics, oceanic lithosphere, horizontal adjustment distance, 3D inversion

INTRODUCTION

Large-scale grids of long-period magnetotelluric (MT) data are being collected across the globe in programs such as AusLAMP and the USArray. Such data are being used to generate 3D models of electrical resistivity of the continental lithosphere and asthenosphere to depths of several hundred kilometres (Robertson et al., 2016).

Smooth 3D inversions such as ModEM (Kelbert et al., 2014) will inherently minimise large gradients in electrical resistivity, and thus the range of model resistivities is generally between 10^3 and 10^0 Ω.m. Smoothing is most significant where few or no observation sites exist, and for continental grids the data gaps are for areas of oceanic lithosphere that adjoin active or passive margins, where typically no seafloor MT observations are available. It has been known for some time using long-offset marine controlled source EM measurements that the oceanic lithosphere can be extremely resistive, of order at least 10^4 Ω.m directly beneath the oceanic moho and probably to a depth of about 50 km or so, at which point conduction increases with temperature (Cox et al., 1986). The consequence of a resistive oceanic upper mantle is that the contrast in electrical conductance at the ocean-continent boundary potentially affects MT measurements hundreds of kilometres inland and out on the ocean floor. Smooth models therefore may not capture the significance of this boundary.

In this poster, we discuss the importance of the horizontal adjustment distance, first identified by Ranganayaki and Madden (1980) and developed by Weaver and Dawson (1992) to include the frequency dependence. The horizontal adjustment distance is not widely known, and is analogous to the EM vertical skin-depth. It is the horizontal range above 1D structures over which the anomalous field is attenuated by a factor of 1/e. As a 2D phenomenon, it is manifest in the TM mode electric field response. We show that the effect of conductance contrast at a passive coastline may stretch hundreds of kilometres inland, particularly in areas with sedimentary cover over a resistive continental crust such as occurs for many cratons.

METHOD AND RESULTS

A simple analytical model of a coastline is shown in Figure 1. The model consists of a surface thin-sheet layer with finite conductance given by the term τ with subscripts o and c for ocean and continent respectively. On the left side, typical ocean depths of 5 km with seawater resistivity of 0.3 Ω.m leads to a conductance of $\tau_o \approx 16{,}000$ S; by contrast the conductance of 5 km of continental crust is approximately bound between $\tau_c \approx 5$ S (for 10^3 Ω.m crystalline crust) and $\tau_c \approx 500$ S (for a deep sediment basin of 10 Ω.m).

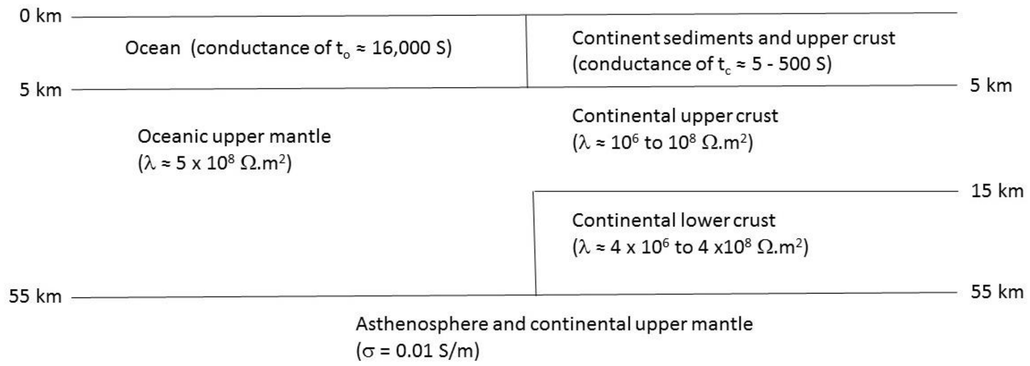

Figure 1: Model configuration for the horizontal adjustment distance.

The layer beneath is equivalent to the oceanic upper mantle on the left and the continental crust on the right; with resistivity of 10^4 Ω.m (Cox et al., 1986) the parameter λ defines the resistivity-thickness product between 5 x 10^6 – 5 x 10^8 Ω.m². Beneath this layer on the ocean side is the asthenosphere and continental upper mantle of resistivity ρ = 10^2 Ω.m (and conductivity σ = 10^{-2} S/m).

Weaver and Dawson define the term α as:

$$\alpha = \sqrt{\omega\mu\sigma} \qquad (1)$$

where ω is the angular frequency, and μ is the magnetic permeability of free-space. With this definition, they then define

$$\chi_j = \frac{1}{\lambda\alpha} - \sqrt{\frac{1}{(2\lambda\alpha)^2} - \frac{1}{\tau_j\lambda} + i\alpha^2} \qquad (2)$$

In Equation 2, the index j refers to either the ocean or continental side. Weaver and Dawson (1992) then derive an accurate approximation of the horizontal adjustment distance d as

$$d_j = \frac{\sqrt{\tau_j\lambda}}{\mathrm{Re}\sqrt{1 - \tau_j\chi_j/_\sigma}} \qquad (3)$$

By comparison, Ranganayaki and Madden (1980) used a simpler term for the horizontal adjustment distance r given by

$$r_j = \sqrt{\lambda\tau_j} \qquad (4)$$

This expression is effectively an upper bound of d as it has no frequency dependence.

Using values as defined in Figure 1, we can plot in Figure 2 the adjustment distance on land and to sea for long-period MT 10^1 -10^4 s, and for two scenarios of λ = 5 x 10^8 Ω.m² (oceanic upper mantle dominant) and λ = 5 x 10^6 Ω.m² (continental crust dominant). On each plot are the frequency dependent distance (Equation 3) and frequency independent (Equation 4).

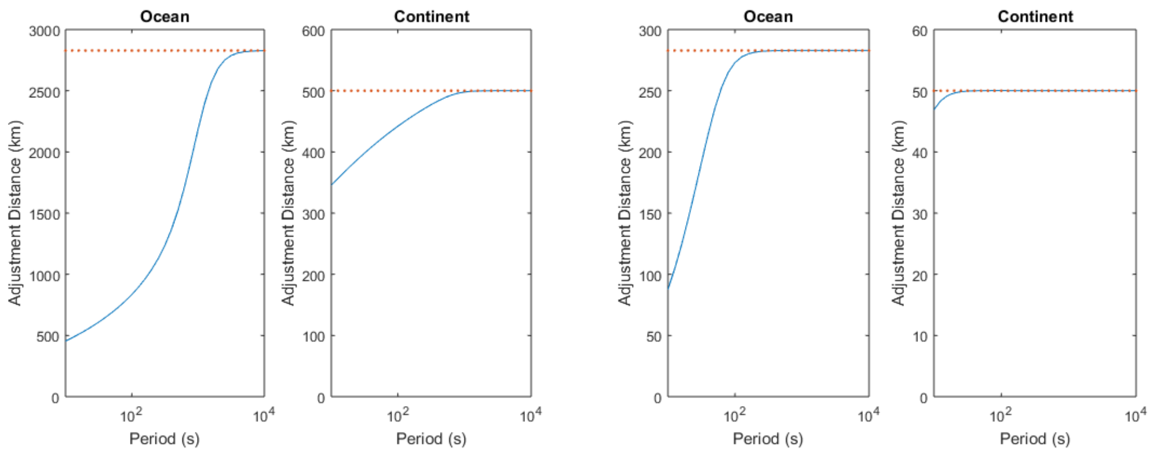

Figure 2: Left-hand panels show the horizontal adjustment distance for the case of λ = 5 x 10⁸ Ω.m² (oceanic upper mantle dominant) for the ocean and continental sides; the two right-hand panels show the case of λ = 5 x 10⁶ Ω.m² (continental crust dominant). In all panels, the blue lines show the frequency dependent adjustment distances from Equation 3 and the red dots are for the frequency-independent limit from Equation 4.

CONCLUSIONS

Results show that with a significantly resistive crust and upper mantle beneath oceans and continents, the horizontal adjustment distance inland from the coast can be hundreds of kilometres. For cases where this layer is more conductive (for example, where the continental lower crust is highly conductive) the adjustment distance is less than a hundred kilometres. Thus, 3D modelling and inversion should accommodate the potential for either case.

Smooth inversion, however, will always inherently minimise sub-surface resistivity distributions as a paradigm, and thus large resistivity values do not generally occur. Moreover, long-period MT sites are usually only recorded on the continental side of the coastline, thus there are no data constraints on the ocean side. Therefore we note that a potential problem is that the coast-effect will often be underestimated and lower observed apparent resistivities at sites within a few hundred kilometres of the coastline will be modelled as lower resistivities in the crust and mantle. The solution is to fix in the oceanic lithosphere resistivity in the inversion as a priori constraint to better represent the inductive effects in the seawater.

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