Substitute models for static shift in 2D

Kristina Tietze[1,2], Oliver Ritter[1,2], Ute Weckmann[1,3]

1 Helmholtz Centre Potsdam - German Research Centre For Geosciences GFZ, Department 2, Section 2.2, Telegrafenberg, 14473 Potsdam
2 Free University Berlin, Department of Earth Sciences, Malteserstr. 74-100, 12249 Berlin
3 University of Potsdam, Department of Geosciences, Karl-Liebknecht-Str. 24, 14476 Potsdam

Contact: kristina.tietze@gfz-potsdam.de

Introduction

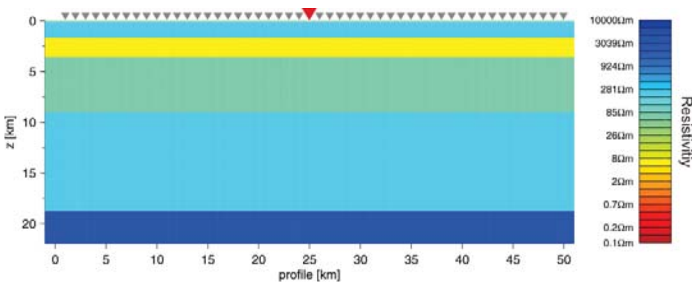
MT practitioners often down-weight apparent resistivity TE mode data prior to 2D inversion to avoid problems with static shift, obviously assuming that static shift of the TM mode is handled automatically by the inversion. Static shift is caused by conservation of charges at local conductivity discontinuities which are small with respect to the inductive scale length.

Here we present a class of shallow conductivity anomalies which can produce significant up- or downwards shifted TM mode apparent resistivity curves (static shift in the TE mode cannot be simulated with 2D modeling). We examine how this static shift is reproduced by 2D inversion and show that the results are strongly influenced by grid design and regularization. We conclude that modern 2D inversion packages are not optimized to handle static shift. Our results also indicate that it is no good reason to assume that static shift cancels out on average.

2D substitute structures for static shift

As 2D models only allow for conductivity changes in one of the horizontal directions, static shift can only be accounted for in one component (TM) and re-produced by forward modeling.

Fig. 1 (right): Starting from a 1D layered half-space (LH) model (Fig. 1a) 2D inhomogeneities were added to the resistivity model just below/at the surface (Figs 1b-g, left panel). TE and TM model responses were calculated for frequencies between 10^3 Hz and 10^{-3} Hz directly above the center of the inhomogeneities. The 2D forward computations are compared to the 1D LH results indicated by crosses (Figs 1b-g, right panel).



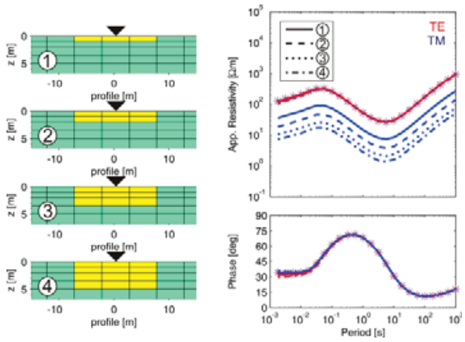


Fig. 1b (left): A 15 m wide 10 Ωm conductor with a thickness varying from 1 m to 5 m causes downward shift of the TM resistivity curves. The shift increases in dependence of the block thickness, i.e. the extent of the horizontal resistivity contrast. The amount of static shift which can be generated by extending the conductive inset downwards is limited. At some point the structure is becoming inductively effective.

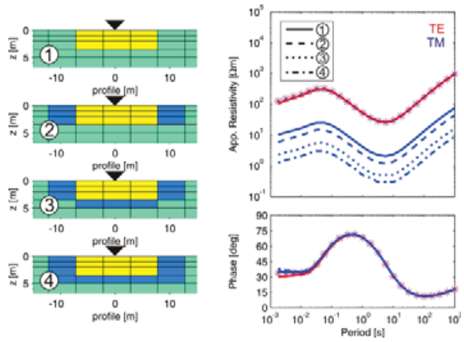


Fig. 1d (left): Enhancing the conductivity contrast by padding the conductor with resistive (10^3 Ωm) cells TM downward shift is increased. Structures of this type can be observed in inversion models below static shift affected sites when static shift is not taken into account during inversion (cf. pane view in Fig. 2c (2)).

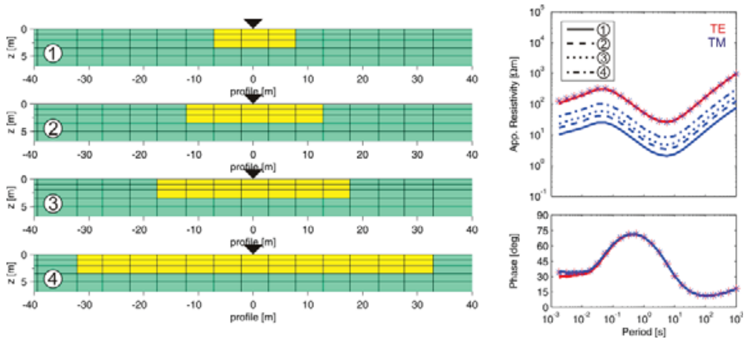


Fig. 1c (left): For a fixed thickness of 3 m the lateral dimensions of the 10 Ωm-block were altered between 15 m and 65 m. With increasing block width, the static shift effect becomes smaller as the lateral resistivity contrast which is responsible for the distortion of the electrical field moves away from the site location.

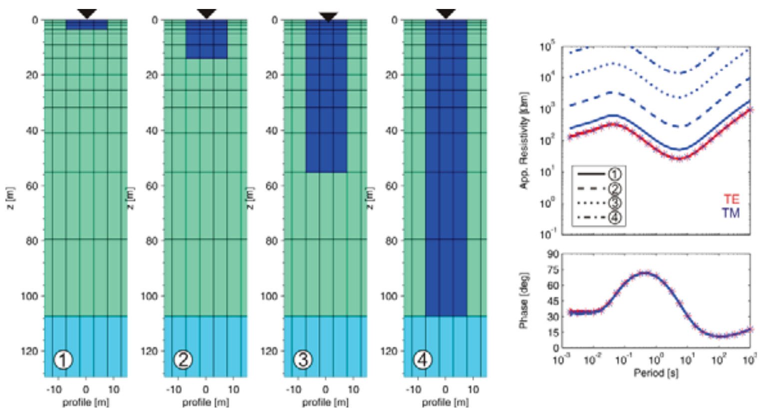


Fig. 1e (left): Placing a highly resistive block (10^4 Ωm) with a width of 15 m and varying thicknesses between 5 m and 110 m beneath the site results in upward shift of the TM mode. Static shift increases with increasing vertical block dimensions.

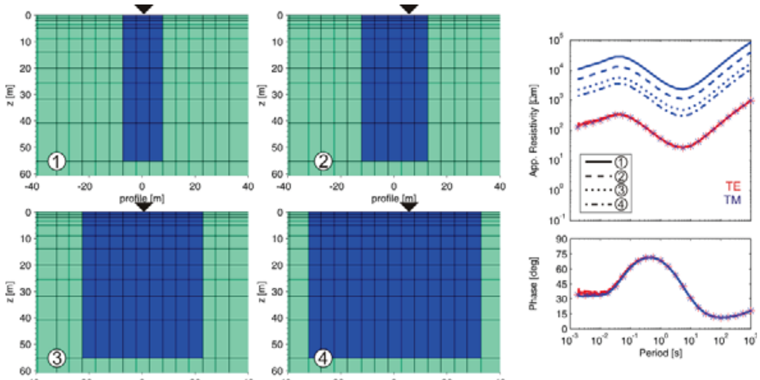


Fig. 1f (left): For a fixed thickness of 55m the lateral extent of the 10^4 Ωm-block was altered between 15 m and 65 m. As seen for the 10 Ωm-block, the static shift effect becomes smaller with increasing block width as the resistivity contrast distorting the electrical field moves away from the site location.

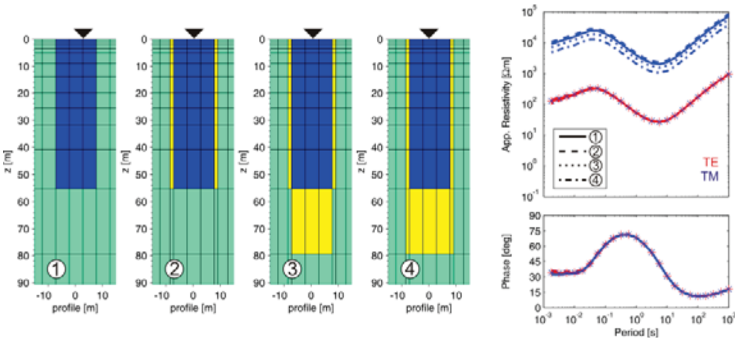


Fig. 1g (left): Padding the resistive block with a thin column of conductive (10 Ωm) cells increases the upward shift of the TM resistivity curve slightly. The horizontal padding cells must be very small horizontally to prevent inductive effects.

As expected, the TE resistivity curves and the phase curves of both, TM and TE, modes are mostly unaffected by these very small scale structures.

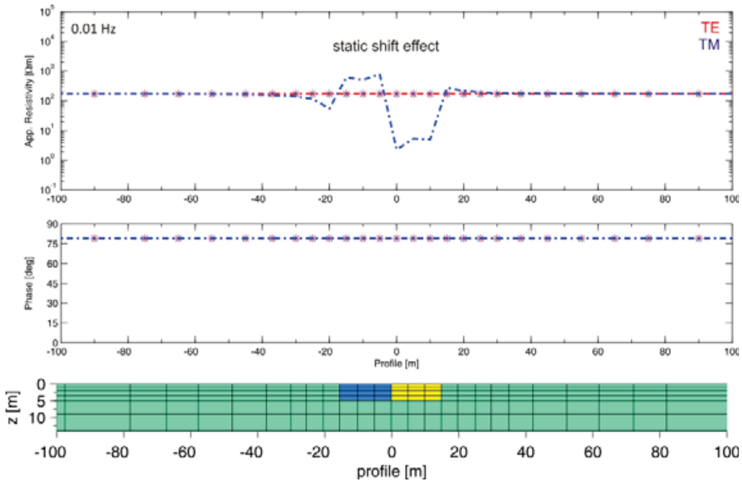


Fig. 1h (left): Distortion of the TM apparent resistivities is due to static shift as the skin depth exceeds 15 km for ρ=10 Ωm and f=0.01 Hz. The downward shifting effect above the good conductor is significantly stronger than the upward shift above the resistive block, although resistivity contrasts of the two blocks to the background are the same. Static shift values along this profile do not sum up to zero. The figures above indicate that structures causing upwards shift have to have a larger vertical extent to produce the same amount of shift.

So, it is at least questionable if a zero sum/average assumption for static shift values, which is often applied in inversion schemes, is appropriate.

2D Inversion

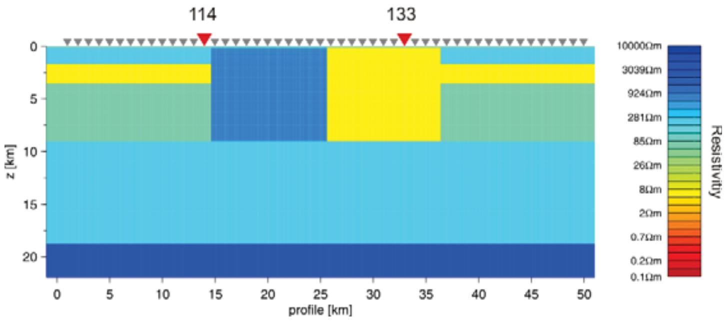


Fig. 2a (left): A 2D resistivity model was created by adding a low and a high resistive block to the layered half-space model (cf. Fig. 1a). Data were calculated for 50 sites along a 50km long profile with 1 km site spacing adding 2.5% Gaussian noise.

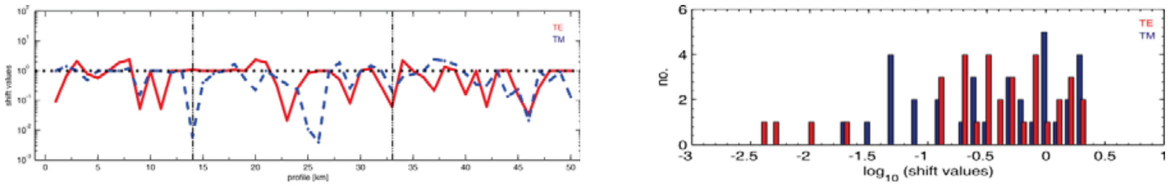


Fig. 2b (above): *Right:* Synthetic shift values *c* were generated obeying a modified logarithmic Gamma-distribution: $\log_{10}(c) = -\Gamma(0.5,2)+0.5$ and $\rho_{shift}=c\rho$. The maximum of the modified distribution is at 10^0, the expected value is $10^{-0.5}$. *Left:* Shift was applied randomly to 2/3 of the sites, independently for TE and TM. The left panel shows the applied shift values for each site along the profile.

Fig. 2c (below): Inversion results for un-shifted (1) and shifted (2)-(4) data for 100 iterations starting from a 100Ωm homogeneous half space, applying a uniform smoothing with τ=10. Error floors were 2% (0.6°) for the phases and 5% and 500% for TM and TE apparent resistivities, respectively.

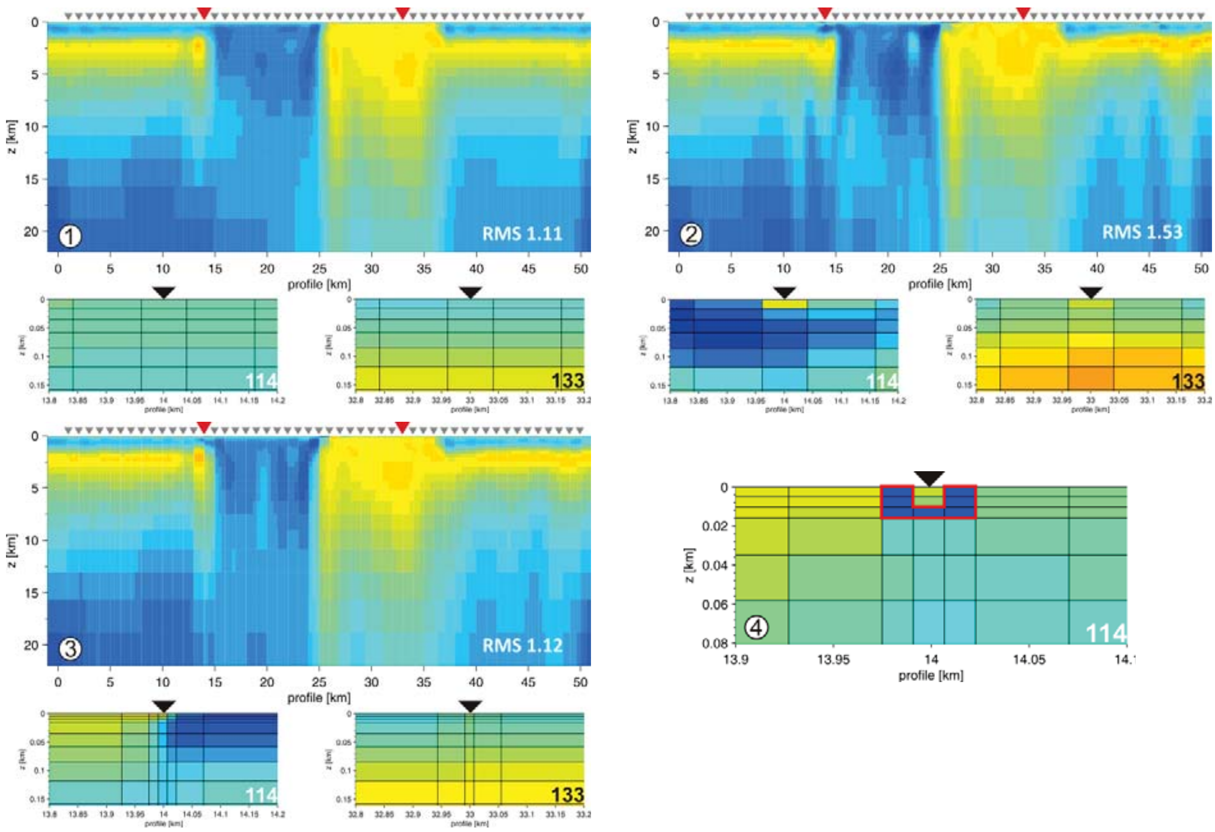
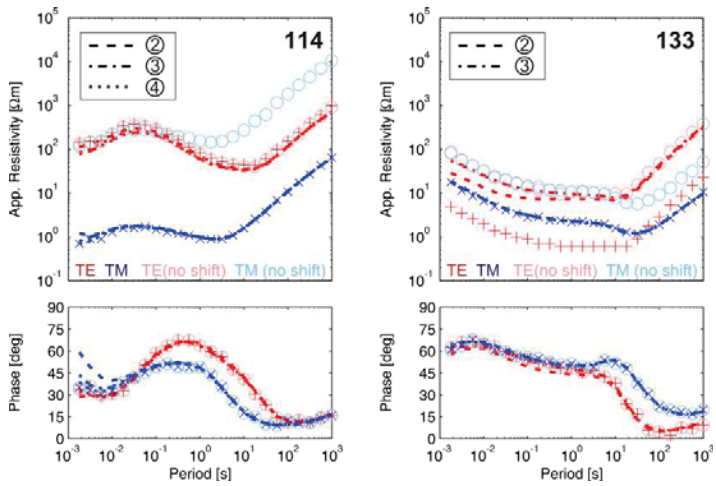


Fig. 2c (above, continued): The model grid was created setting the column widths to 0.5 times of the minimum skin depth p_{min}, for (1) and (2), and was refined to 0.1*p_{min} for (3) and (4) (cf. pane views).

(2) & (3): As smoothing (regularization) is working against sharp resistivity contrasts, the inversion introduces complex and wide-stretched structures below the sites affected by static shift. The refined grid in (3) reduces smoothing lengths for uniform regularization. As a consequence, introduced compensatory structures appear simpler or diminish.

(4) Inversion result after introducing a so-called "tear zone" (feature of WinGLink) at site 114 (red outline). Tear zone inversion does not penalize sharp conductivity contrasts at the outline of the tear zone. Now, the inversion can properly model static shift. The model can account for TM static shift within this zone while obtaining surrounding resistivity values close to the original ones.

Fig. 2d (right) shows un-shifted data, shifted data as symbols and the inversion results (cf. Fig. 2c) for sites 114 and 133 as lines. For periods longer than 10^{-2} s shifted data are fitted well by all inversions. For shorter periods, the inversion struggles to fit the data, especially at site 114 where TM resistivities were shifted downwards by two decades. TM phase responses below 10^{-2} s deviating from forward data clearly show the inductive effects of the near surface structures. Static shift effects decrease with the refined grid (3) and introduction of a tear zone (4).



Summary

Static shift for the TM mode can easily be produced by a range of simple structures at surface being introduced to the regional resistivity models as substitutes for natural structures causing static shift in field data.

To account for TM static shift within 2D inversion, model grids have to be very fine in the vicinity of sites with column widths and thicknesses much smaller than the induction volume of the highest frequency to be analyzed.

Smoothing routinely applied in minimum structure inversions does not allow for the sharp conductivity contrasts required to produce sensible static shift. It would therefore be desirable to be able to apply different smoothing factors to a static shift compensating top layer and the remaining model.