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Underground heat conduction near a spherical inhomogeneity: theory and applications

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A large underground inhomogeneity, such as a salt dome or cavity, is known to disturb the subsurface temperature field. Such anomalies appear in many geophysical surveys. Detection and knowledge of the magnitude of these disturbances is the objective of both near surface and deep borehole temperature surveys aimed at delineating the inhomogeneities. It also impacts surface temperature history analysis which reconstructs past climate change in an effort to study the recent global warming. This work is aimed at quantifying these effects by solving, for the first time, a problem of heat conduction in Earth's subsurface in the presence of a spherical inhomogeneity. Both the steady state temperature field pertaining to the constant geothermal gradient and the time dependent field caused by a surface jump in temperature are solved. A solution is derived for both cases as an infinite series of spherical harmonics and Bessel functions (in the Laplace domain) for the steady and unsteady problems, respectively. It is found that an accurate solution can be achieved by a small number of terms. The results are illustrated and analyzed for a given accuracy and for a few values of the governing parameters. The general solution can be simplified considerably for asymptotic values of the parameters. Comparison with the exact solution shows that these approximations are accurate for a wide range of parameter values. Some examples of applying the solution to the geophysical methods stated above are discussed. In the case of ground surface temperature history reconstruction from borehole temperature profiles, all current methods assume one-dimensional heat conduction. We present calculations of the anomalies generated near inhomogeneities in the presence of a sudden change in surface temperature used to model climate change. Though the sphere is an idealized shape, the simplicity of the solution makes possible a general analysis toward gaining a better understanding of the process. Furthermore, it can be employed for preliminary assessment of the impact of a body and may serve as a benchmark for numerical solutions.

Reference:

A. Rabinovich, G. Dagan and T. Miloh, "Heat conduction in a semi-infinite medium with a spherical inhomogeneity and time-periodic boundary temperature", **International Journal of Heat and Mass Transfer**, 55 (2012) 618-628.