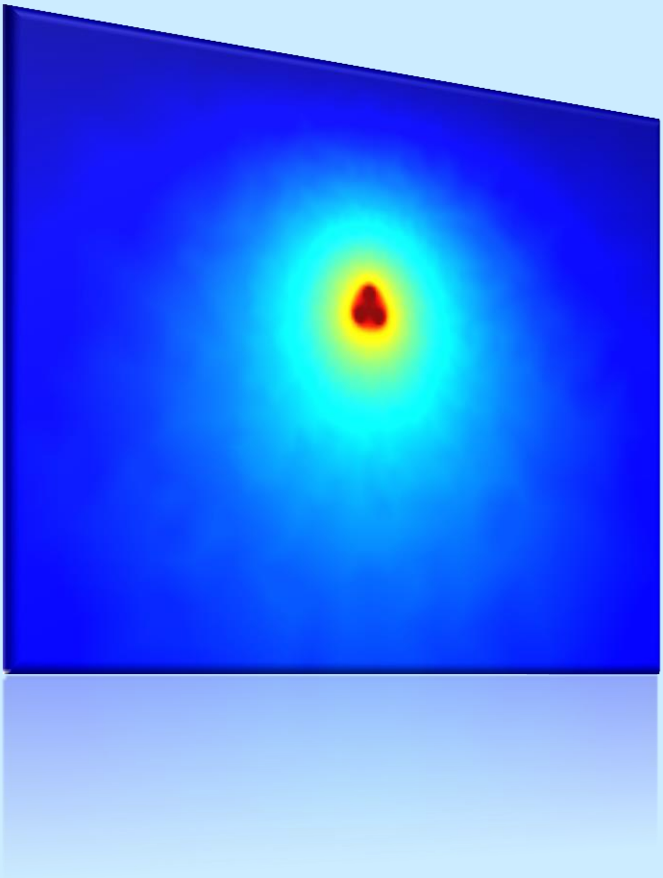
Prediction of

Sediment Temperatures

FIELAX

Information Brochure



$$\partial_t T(\vec{\mathbf{x}},t) - \nabla\cdot(\kappa(\vec{\mathbf{x}})\nabla T(\vec{\mathbf{x}},t)) = \frac{H(\vec{\mathbf{x}},t)}{\rho c_v}$$

Measuring temperatures in marine sediments

Over the last decade FIELAX has gained an enormous amount of experience with thermal measurements in different marine environments. Starting with classical heat flow probe measurements in soft deep-sea sediments, FIELAX has not only further developed its measuring devices to allow measurements in shallow water regions but also the knowledge base and understanding of thermal transportation processes in marine sediments from both, natural and artificial sources.

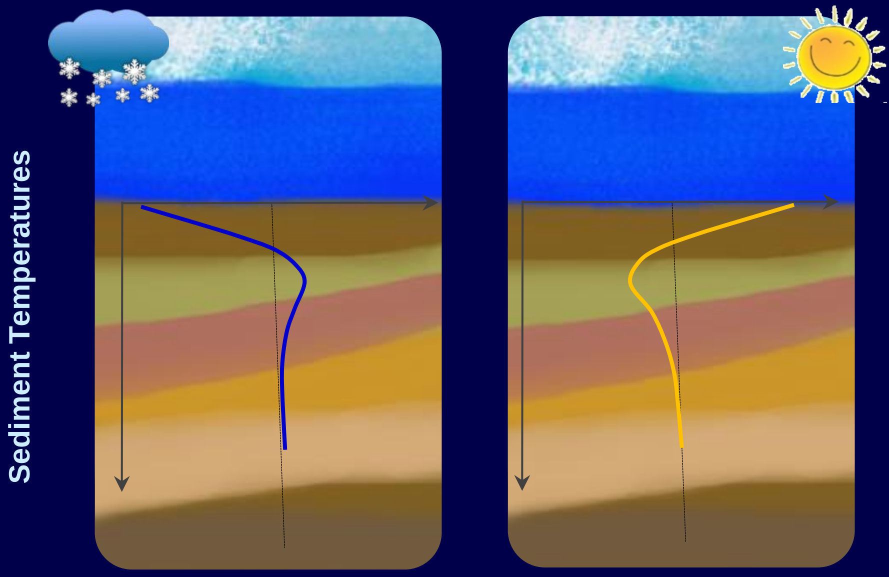
In general, marine sediment temperatures are controlled by the amount of heat exchange with the water above and the deeper regions of the earth´s mantle, as well as on the thermal properties of the sediment. With the growing use of renewable energy from offshore wind farms, power cables as a heat source in marine sediments have become more relevant, as the transportation of electric energy via these cables leads to transmission losses, with the resulting thermal energy dissipating to the surrounding medium.

As a result of our experience and continued passion to lead the way and develop new technologies in this sector, FIELAX presents it's latest development: 2D and 3D temperature evolution calculations in marine sediments. The models incorporate the geothermal heat flow, measured thermal properties of the sediments as well as temperature variations through seasonal variations of the bottom water temperature. As a result the models determine temperature distributions resulting from superimposition of seasonal, natural temperatures and those induced by internal sources such as power cables, the latter also time-dependent.

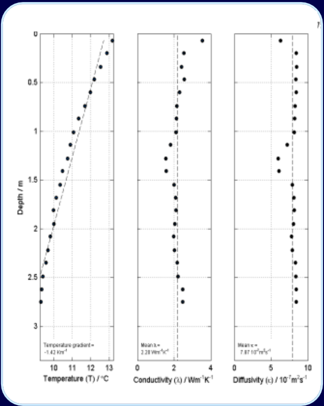
Computational models using in-situ measured sediment properties and water temperatures can be used for estimating the dissipation mechanisms of thermal energy and the environmental impact of submarine power cables. The power cable design can be optimized if the thermal properties and prevailing temperatures in the sediments are understood. The models can give the minimum burial depth respecting the latest environmental guidelines, providing alternative and more feasible options for cable laying.

Seasonal forcing from bottom water temperature variations

In shallow water regions such as the Baltic and North Seas the sediment temperatures naturally vary with season. While in the winter sediment temperatures increase with depth, with the higher temperatures reflecting the influence of the water in the summer before, the temperature in the summer decrease with depth with the lower temperatures reflecting the influence of the winter before. The peak-to-peak amplitude of seasonal temperature variations can be as high as 18 K and their residual may reach down to a sediment depth of up to 10 m. The dashed line below describes the constant background geothermal gradient, (the global average value is 0.03K/m).

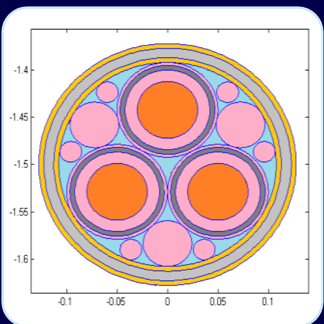


Sediment thermal properties



Realistic (measured) thermal properties such as the thermal conductivity or thermal diffusivity are essential for realistic modeling and evaluation of thermal heat transfer processes. This is of particular importance in the North and Baltic Seas, where heterogeneous sediments prevail. The principle for the measurements of depth-dependent thermal properties originates from the classical method of determining steady state heat flow values from deep sea sediments (Marine Heat Flow Measurements - Information Brochure).

Power cable properties



The effect of cable heating on the surrounding environment depends on the power cable configuration, basically the resistivity determined by material and diameter of the conductor, and the actual burial depth. By incorporating realistic cable properties into the models the assessment of the minimum burial depth and/or the maximum heating of the cable constrained by environmental guidelines (2K-criterion) is possible.

The effect of bottom water temperature variations

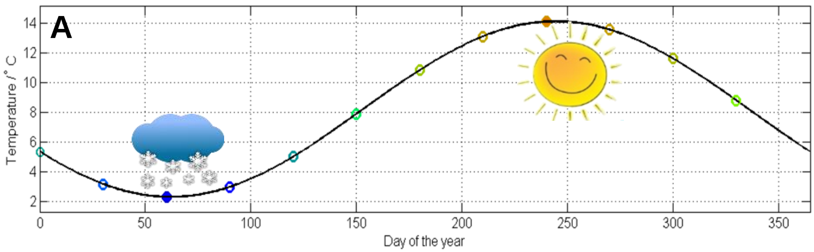
The effect of seasonal heating and cooling on the temperature distribution in marine sediments can be calculated by solving the one-dimensional heat transfer equation using bottom water temperature variations as boundary condition at the surface. Recorded water temperatures from measuring stations in the North and Baltic Seas, which are operated by the Federal Maritime and Hydrographic Agency (BSH) of Germany can be approximated by an annual sine defined by the mean temperature, the amplitude and a phase shift.

(**A**) Bottom water temperature variations approximated by a sinusoidel wave with a mean value of 8.2 °C, an amplitude of 5.9 K and the minimum on day 62 of the year is shown exemplary.

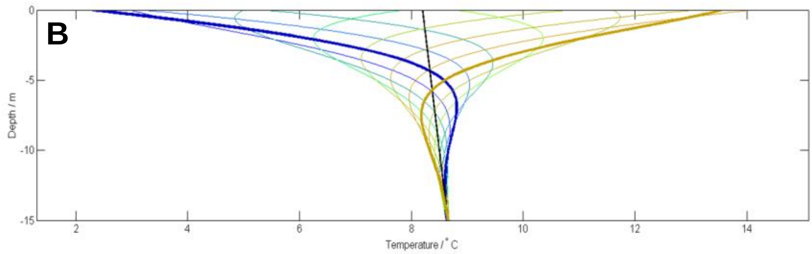
(**B**) Analytical solution of the one dimensional heat transfer equation with seasonal forcing from the surface for a homogenous sediment characterized by a thermal diffusivity of $8*10^{-7} m^2 s^{-1}$. The sediments experience a large temperature range over one year in the upper meters. With increasing depth the covered temperature range gets smaller. In the winter (solid blue line) sediment temperatures increase with decreasing depth, with the higher temperatures reflecting the influence of the water in the summer before. In the summer (solid orange line) the temperature depth profile shows a mirror-inverted curve with depth.

(**C**) Finite element modeled annual evolution of temperatures from natural seasonal bottom water variations. The seasonal influence is detectable down to several meters depth. The attenuation of the amplitude with depth is clearly visible and so is the delay of the temperature. Each temperature depth profile contains the bottom water temperatures from the last three to four months.

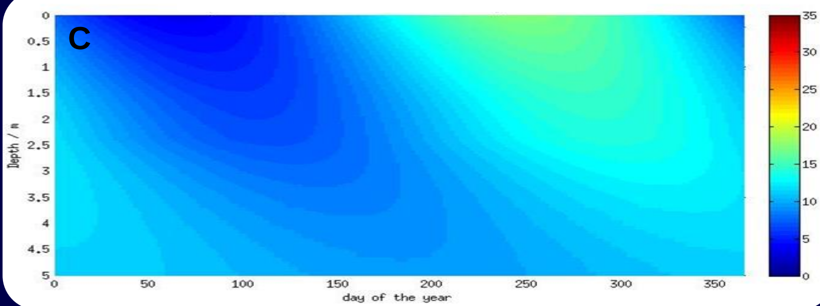
Annual Bottom Water Temperatures



Analytic solution

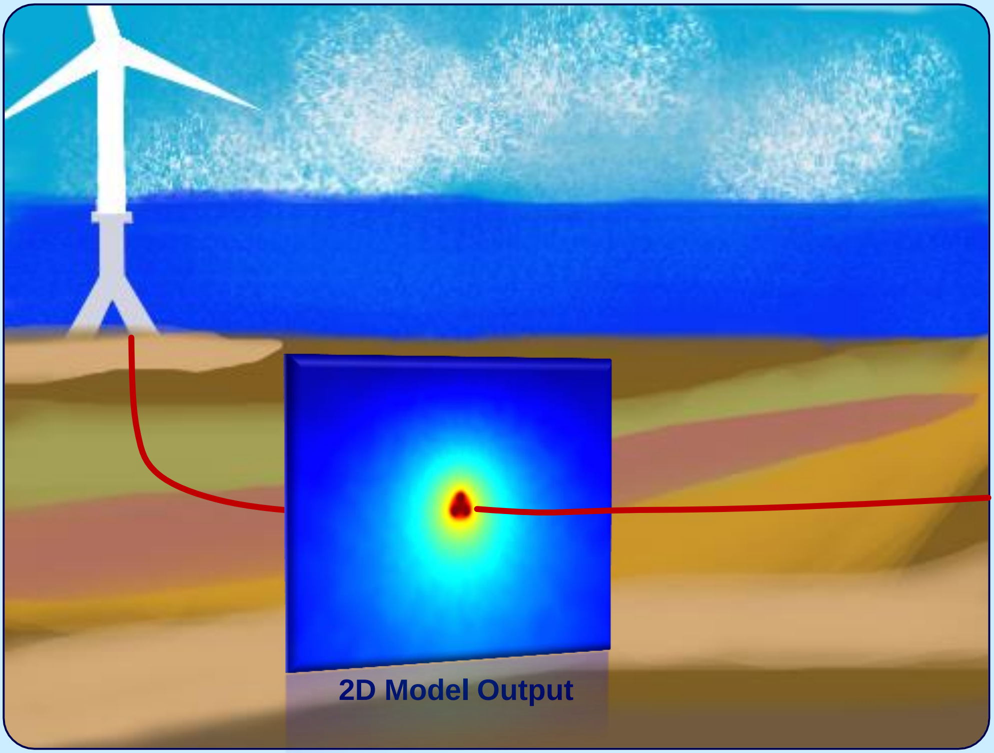


FE modeling result



2D Model

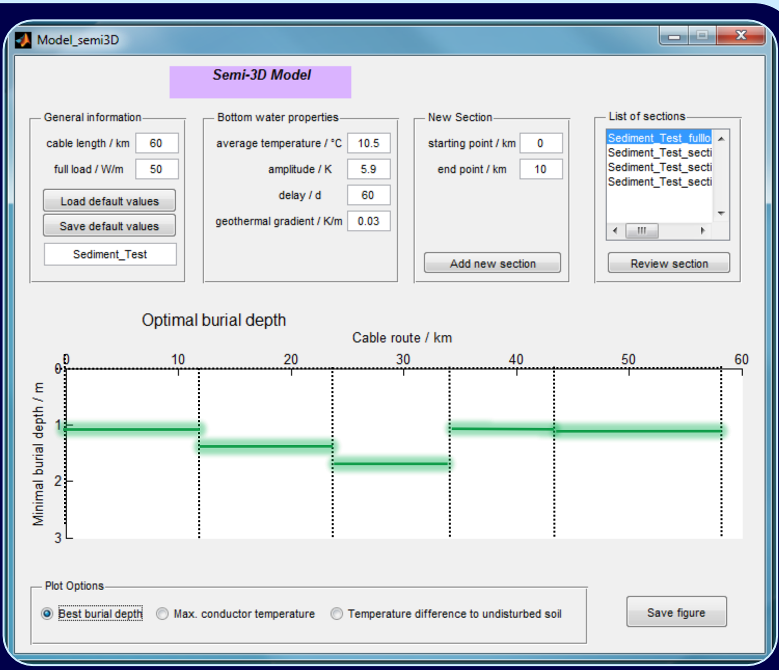
The 2D model is a Finite-Element-Method (FEM) based model for the temperature field in and around submarine power cables. The 2D model calculates the temperature in and around a buried energy cable in a vertical plane across the cable. The model includes heterogeneous properties of the sediments (e.g. thermal diffusivity), seasonal heating and cooling through bottom water temperature variations, and heating through time-dependent power loss from the submarine power cable. The thermal properties of the sediment are assumed to be horizontally homogeneous. Result of the 2D model is the temperature field in and around the submarine power cable.



Semi 3D Model – Determining the optimal burial depth

The main method for protecting submarine cables is by trenching them into the seabed. The burial depth of energy cables is an enormous cost-factor, thus a realistic minimum burial depth can save time and money. Using the semi 3D model, the minimum burial depths along a cable route can be determined. Therefore the cable route is divided into subsections of varying thermal diffusivities. For each subsection an individual model calculation is performed, allowing assessment of the minimum burial depth and/or the maximum heating of the cable constrained by the 2K-criterion. Modeling the temperature fields with realistic thermal properties can reduce the minimum burial depth notably compared to conservative estimations. The temperature impact can be minimized more when burying the cable in a high-thermal-diffusivity layer rather than a few decimeters deeper in a low-thermal-diffusivity layer.

Planning tool for determining the optimal burial depth



2D Model – Annual variation of sediment temperatures

With the 2D Model the annual variations of the sediment temperature for different power loss scenarios can be calculated. The examples show the annual variations for a submarine power cable buried in 1.5 m depth and different power loss scenarios:

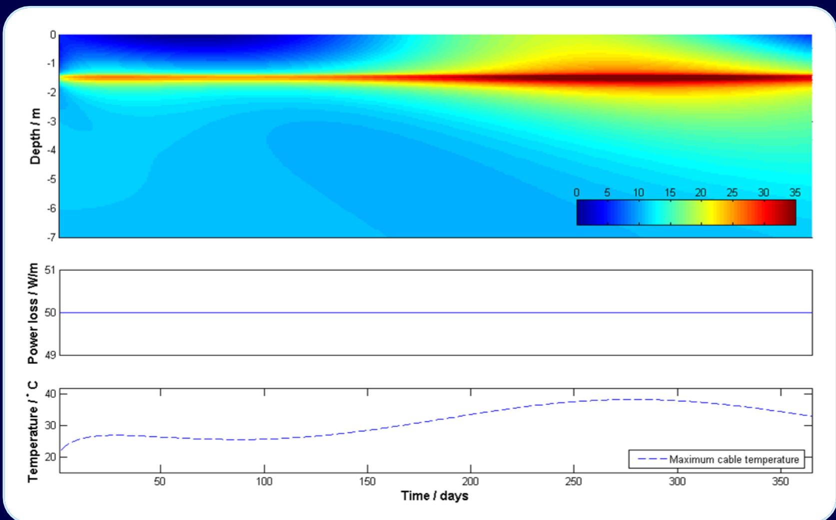
(**A**) Constant power loss of 50 W/m, turned on at day 1,

(**B**) Peak loss of 50 W/m at day 30

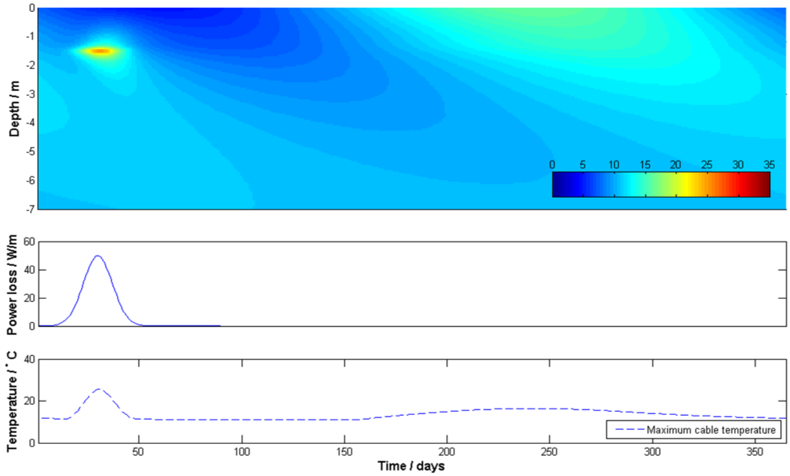
(**C**) Realistic power loss time series adopted from wind data.

All examples show the calculated sediment temperatures at the top, the power loss scenario in the middle and the resulting maximum cable temperatures. These calculations also allow determining the temperature deviation in 20 cm depth between a point vertically above the cable and a reference point in 12 m horizontal distance (2K-criterion).

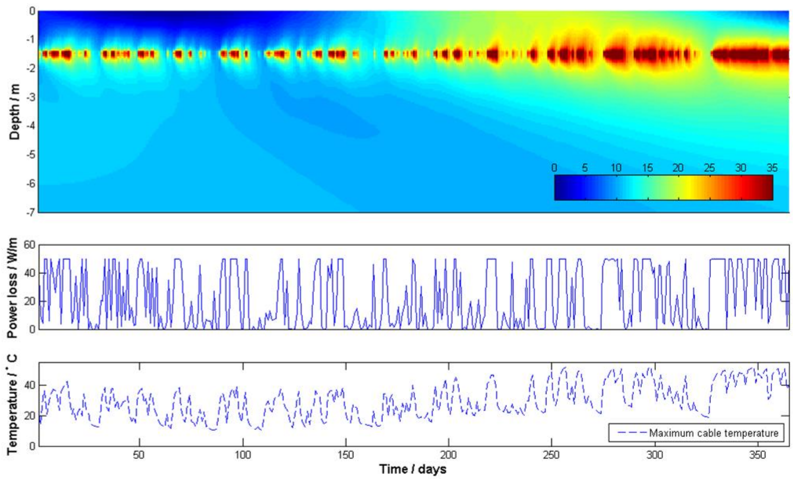
(A) Constant power loss



(B) Peak power loss at day 30



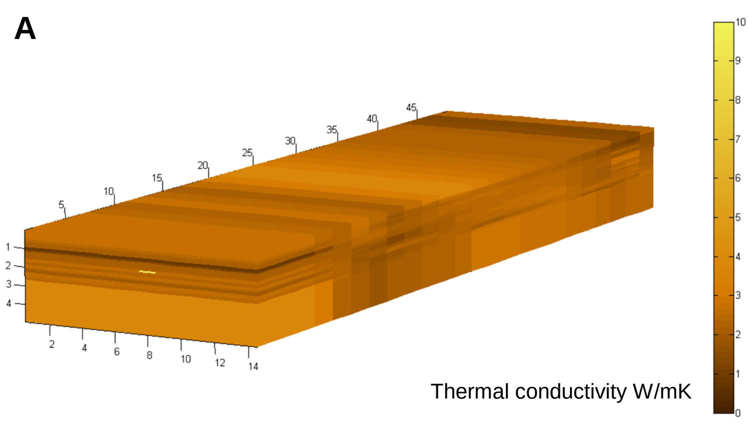
(C) Power loss time series adopted from wind data



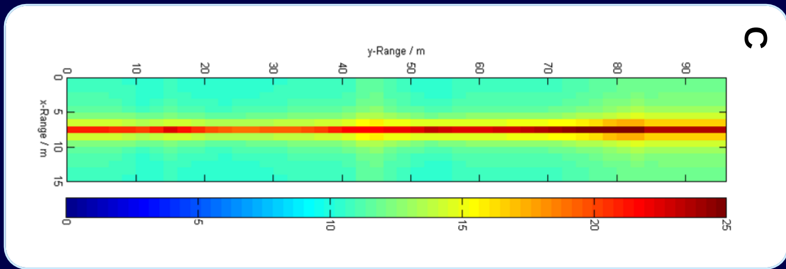
3D Model

With the 3D model seasonal effects as well as influences from heat sinks and sources (such as energy cables or heat exchangers) can be modeled using a Finite-Difference-Algorithm. This method is of advantage for relatively large areas of interest. For the Finite Differences Method (FD) the mesh consists of a rectangular grid with equidistant gridpoints in every direction. Given inputs are measured thermal properties, which are interpolated from several measurements (**A**) and approximated seasonal temperature deviations of the water (green line in **B**). The cable is modeled as a line-source with a constant power loss (blue line in **B**). The 3D model allows to compare the temperature evolution along the power cable in different layers i.e. in burial depth of the power cable (D) and for comparison in e.g. 20 cm depth (relevant depth for the 2K-criterion).

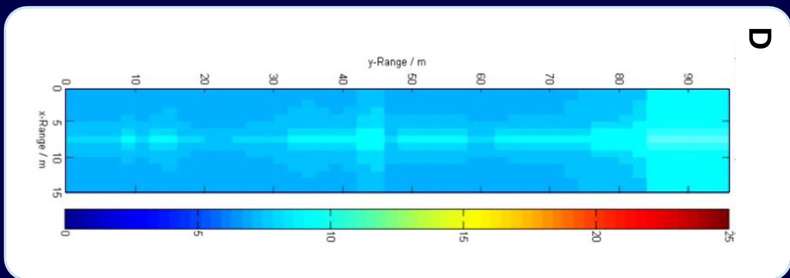
3D Model based on thermal conductivity



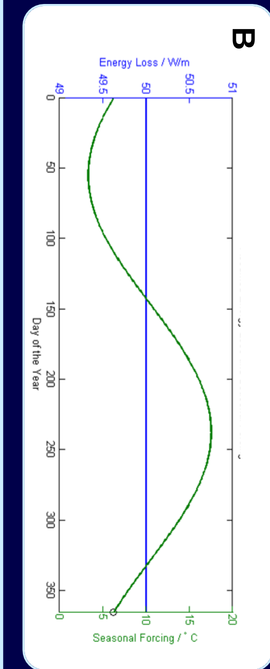
Temperature evolution along the power cable in burial depth after one year



Temperature evolution along the power cable in 20cm depth after one year

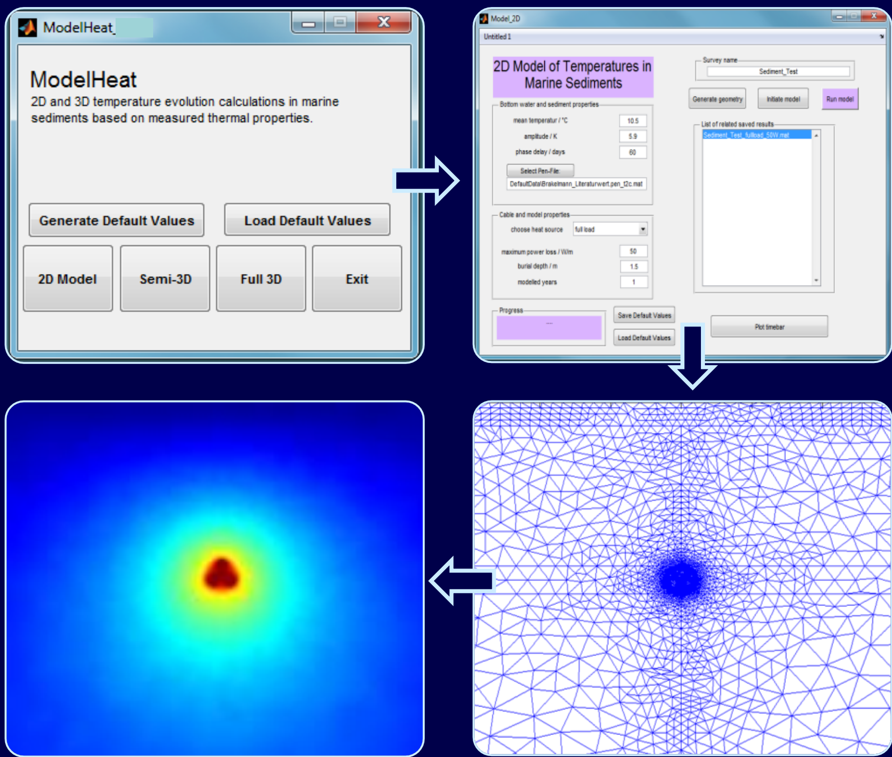


Seasonal forcing / Power loss



ModelHeat

The software package ‘ModelHeat’ integrates the three (Matlab) model types which are described in detail in this brochure. Graphical user interfaces allow to easily set up the parameters characterizing the prevailing sediments, the bottom water temperature variations and the power cable configuration. Once these parameters are set, the model calculations can be started. At first, the geometry is generated and the temperature field initialized. Afterwards, the temperatures for the modeling year are calculated and finally the results visualized.



Publications

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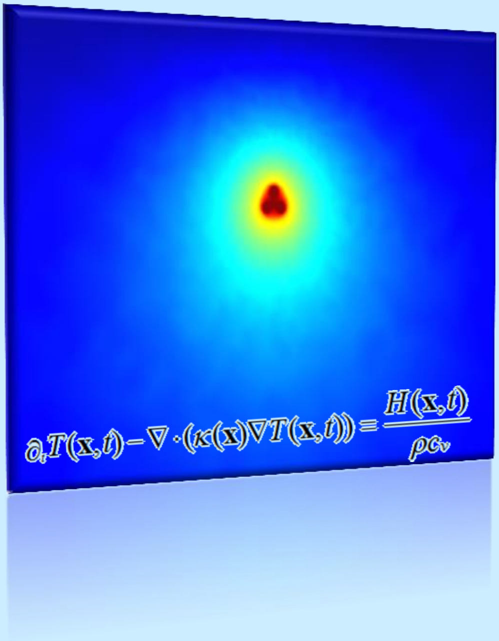
- Müller, C., Miesner, F., Usbeck, R., Schmitz, T. (2013): 2K-criterion: measuring and modelling temperatures and thermal conductivities/diffusivities in shallow marine sediments, Proc. Conference on Maritime Energy 2013, TUHH, Hamburg, pp. 475 – 490
- Miesner, F., Lechleiter, A., and Müller, C. (2015), Reconstructing bottom water temperatures from measurements of temperature and thermal diffusivity in marine sediments, Ocean Sci., 11, 559-571, doi:10.5194/os-11-559-2015.



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Find out more:

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