GEOSTATISTICAL INTERPRETATION OF PALEOCEANOGRAPHIC DATA OVER LARGE OCEAN BASINS — REALITY AND FICTION

Christian Schäfer-Neth
Sonderforschungsbereich 313
Universität Kiel
Heinrich-Hecht-Platz 10
D-24118 Kiel, Germany

Carme Hervada-Sala
Dept. de Física i Enginyeria Nuclear
Universitat Politècnica de Catalunya
c/Colom 1
E-08222 Terrassa, Spain

Vera Pawlowsky-Glahn
Dept. Matemàtica Aplicada III
Universitat Politècnica de Catalunya
c/Jordi Girona Salgado 1-3
E-08034 Barcelona, Spain

Karl Stattegger
Geologisch-Paläontologisches Institut
Universiät Kiel
Olshausenstraße 40-60
D-24098 Kiel, Germany

ABSTRACT

A promising approach to reconstruct oceanographic scenarios of past time slices is to drive numerical ocean circulation models with sea surface temperatures, salinities, and ice distributions derived from sediment core data. Set up properly, this combination of boundary conditions provided by the data and physical constraints represented by the model can yield physically consistent sets of three-dimensional water mass distribution and circulation patterns. This idea is not only promising but dangerous, too. Numerical models cannot be fed directly with data from single core locations distributed unevenly and, as it is the common case, scarcely in space. Conversely, most models require forcing data sets on a regular grid with no missing points, and some method of interpolation between punctual source data and model grid has to be employed. An ideal gridding scheme must retain as much of the information present in the sediment core data while generating as few artifacts in the interpolated field as possible. Based on a set of oxygen isotope ratios, we discuss several standard interpolation strategies, namely nearest neighbour schemes, bicubic splines, Delaunay triangulation, and ordinary and indicator kriging. We assess the gridded fields with regard to their physical consistence and their implications for the oceanic circulation.

DATA BASE AND CIRCULATION MODEL

The data used here comprises a set of 133 oxygen isotope ratio estimates for the summer surface waters of the Last Glacial Maximum 21 500 years B.P., expressed as $^0\!/_{00}$ vs. standard mean ocean water. The sediment core locations are indicated by dots throughout the figures. Due to the effects of evaporation, precipitation, and runoff, these isotope ratios covary with sea surface salinity and can thus be used as a proxy of the latter. Generally, low isotope values will result in low salinities and vice versa, and more important, isotope ratio gradients correspond to salinity gradients that may cause oceanic fronts associated with intense currents. (For a more detailed description of data sources and relations between temperatures, isotopes, and salinities, see [4].) To test whether an interpolation is appropriate for modelling, it is checked to what extent the salinity field, the modelled current system, and the glacial sea surface temperature and wind field are physically consistent with each other.

The ocean circulation model uses a spherical coordinate system, where the North Pole has been rotated to 180W/30N for the sake of numerical efficiency. The spacing between the model grid points is 0.5 degrees of rotated longitude and latitude, yielding an almost equidistant grid covering the area under consideration (Fig. 1). All interpolations were carried out after transforming the conventional geographical coordinates of the sediment core locations into this rotated frame of reference. (For comments on geostatistics using spherical/geographical coordinates, see [5].) Because spatial variations smaller than twice the model's grid spacing cannot be represented properly by the model, every interpolated field shown here was smoothed two times by applying a nine-point moving average prior to plotting. The contour interval was set to $0.1^0/_{00}$ for each of the figures.

METHODS AND RESULTS

Nearest-Neighbour Scheme

The field shown in Fig 1. was gridded with the GMT-system [6,7] `nearneighbor`-routine. According to the results of the variogram analysis (Fig. 4), the search radius was set to 16 degrees, using a single-sector search.

Most characteristic of this field are numerous bands of steep horizontal gradients. If converted to salinity and used for model forcing, the model would generate sharp density fronts along these bands associated with narrow currents. These fronts and currents would be completely artificial for two reasons: (i) They are not supported by the glacial sea surface wind and temperature data (not shown here). (ii) They could not persist in the real ocean for much longer than a couple of days, whereas the sediment data represent averages over 3000 years of stable glacial conditions.

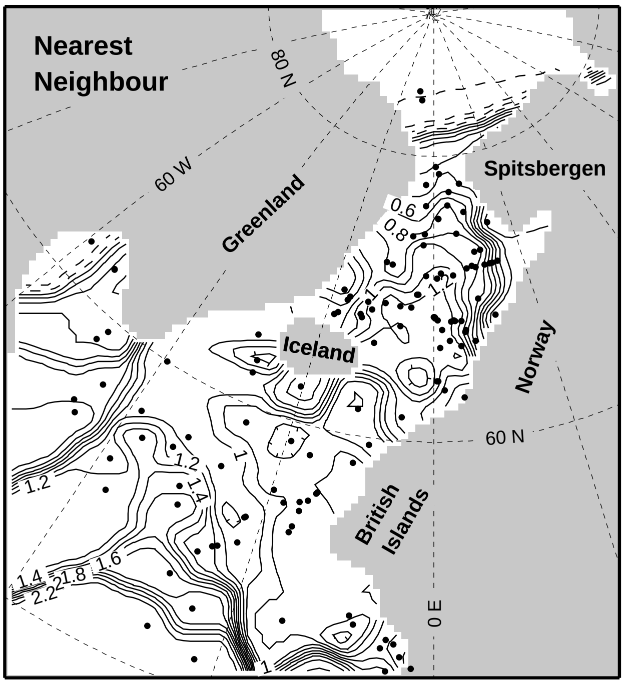

Fig. 1: Interpolated oxygen isotope data obtained by the nearest-neighbour algorithm as implemented by [6,7]. Dots indicate sediment core locations. Contour interval = $0.1^0/_{00}$.

Spline Interpolation

Using bicubic natural splines for interpolation results in the distribution displayed in Fig. 2, obtained with the GMT [6,7] `surface`-routine. Again, the search radius was set to 16 degrees.

In contrast to the nearest-neighbour method, splines tend to produce isolated minima and maxima around source data points with extreme values, here for example south and southwest of Iceland. Driving a circulation model with salinities computed from this field yields a circulation field with small eddies surrounding these extrema. Such eddies are physically inconsistent for the same reasons as the artificial bands discussed above.

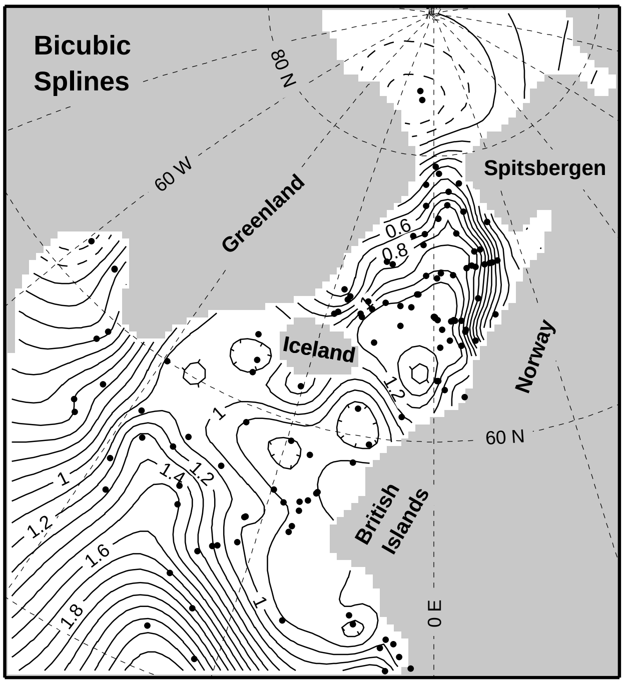

Fig. 2: Interpolated field obtained by bicubic splines [6,7].

Triangulation

Fig. 3 presents the output of the GMT [6,7] `triangulate` tool. At first glance, this method generates less inconsistencies than splines or nearest neighbours. Especially between Iceland and Greenland, triangulation performs much better. Through this channel, the real ocean can only develop currents paralleling the coasts like the East Greenland Current, associated with alongshore salinity (and oxgen isotope) isolines. The first two methods fail with respect to this.

The severe problem of triangulation is the need for an additional extrapolation technique for the areas with no data. Besides filling in these gaps, the extrapolation must also avoid artificial features at the lateral limits of the source data region, like, for example, the sharp bending of isolines visible near the southern margin.

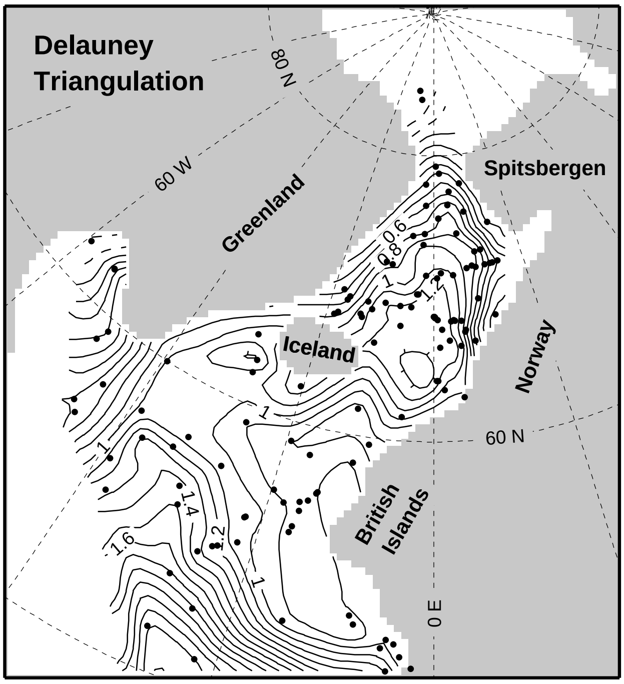

Fig. 3: Interpolated field obtained using triangulation [6,7]. Note the large gaps requiring further extrapolation.

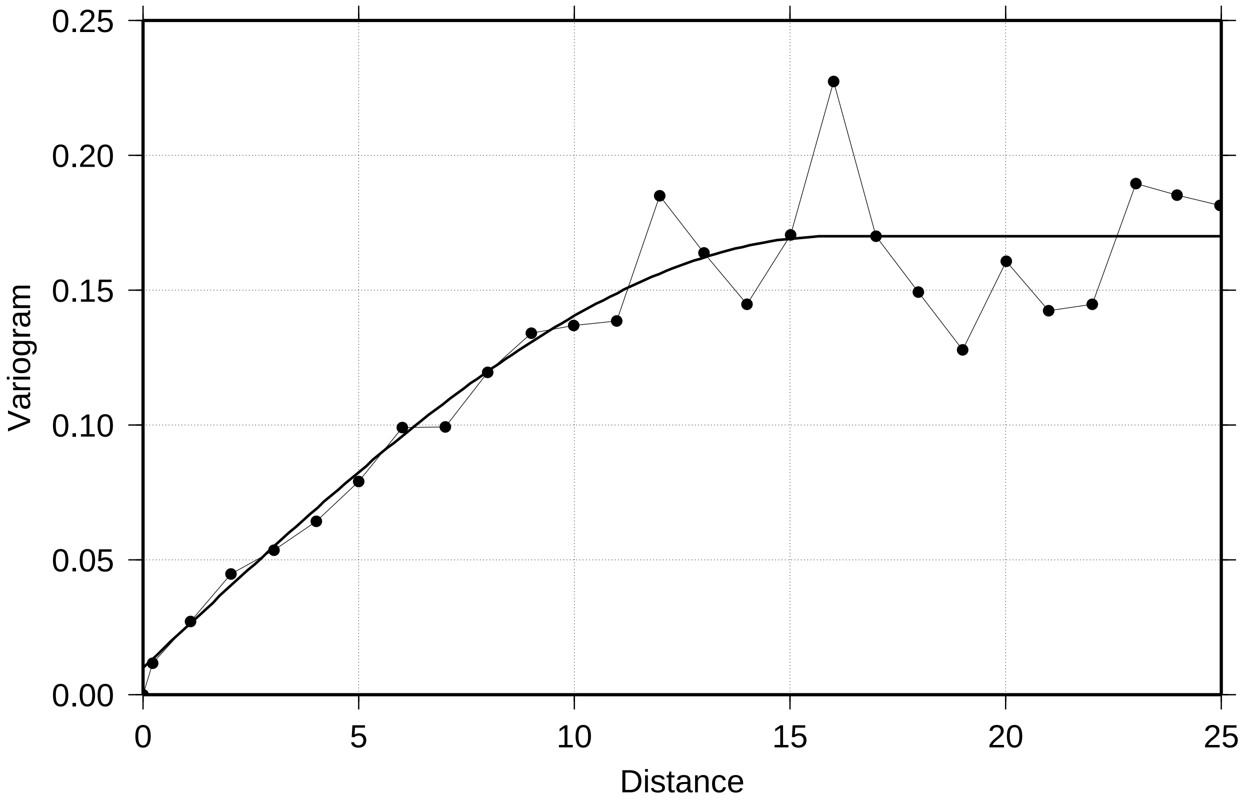

Fig. 4: Experimental variogram (dots) of the isotope data and spherical variogram model (heavy line). Model parameters: nugget = 0.01, sill = 0.16, and range = 16.

Kriging I

The gridding methods discussed so far do not provide error margins for the interpolated values. These can be estimated using variogram analysis and kriging. With the GSLIB [1] program `gamv2` we obtained the omnidirectional experimental variogram shown in Fig. 4, that can be best fitted by a spherical model with a sill of 0.16, a range of 16, and a small nugget effect of 0.01.

Using this model for ordinary point kriging with `okb2d` (GSLIB) gave the oxygen isotope field shown in Fig. 5. It is somewhat smoother than the triangulation result without having the difficulties with lacking data. However, between Greenland and Iceland, the same irreal curvature of isolines can be seen as in the spline-interpolated field.

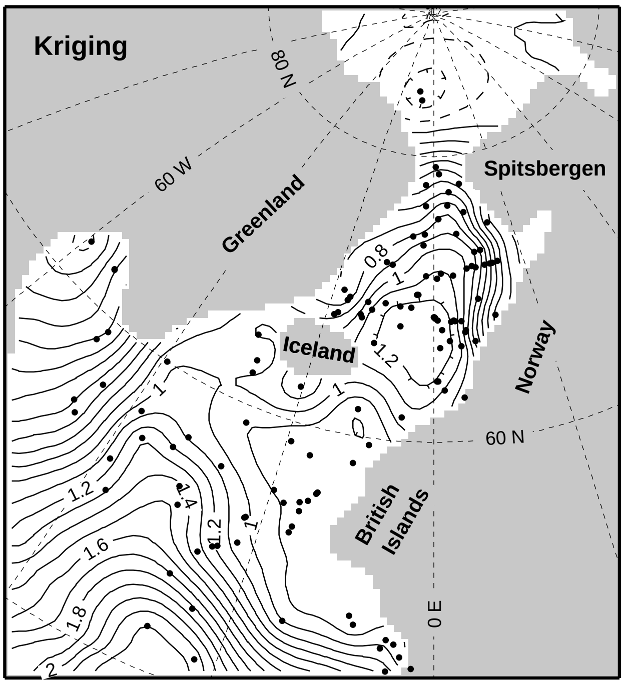

Fig. 5: Interpolated field obtained by kriging [1,2] with the variogram model from Fig. 4.

Kriging II

To mitigate the problem of isolines not paralleling the coast where the currents can be expected to be parallel, we first generated a 0/1 land/water mask for the model domain. From this mask, a spherical omnidirectional indicator variogram with a sill of 0.25, a range of 19.5, and no nugget effect could be derived. By kriging with GEO-EAS [2] we obtained a field with zeros over model land points, ones over ocean points, and a smooth transition at the coasts [3].

This field was finally multiplied with the kriged data shown in Fig. 5, thus turning the isolines in a longshore direction and lowering the values of the interpolated field at the coasts.

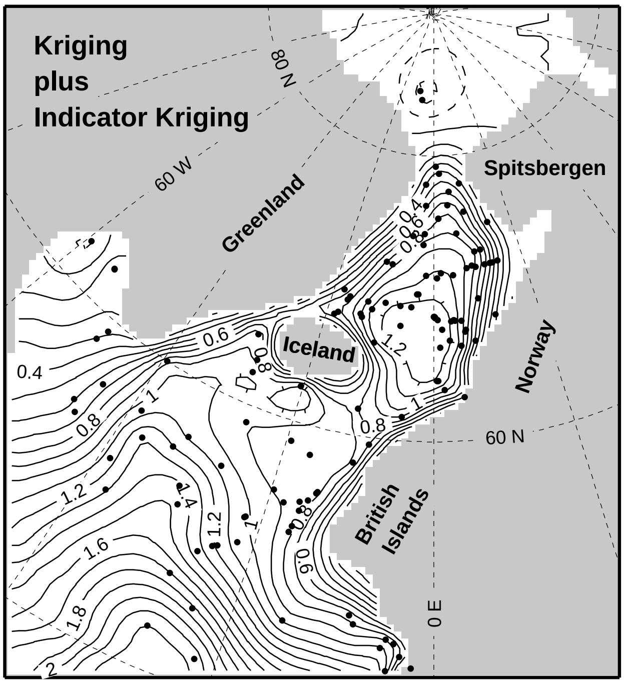

Fig. 6: Like Fig. 5, but modified at the coasts using an indicator-kriged land-water-mask.

SUMMARY

The different interpolation schemes may be summarized by the following table:

Method	Drawbacks	Advantages
Nearest neighbour	Artificial gradients	—
Splines	Local extrema	Extrapolation
Triangulation	Difficult handling of regions with no source data	Smooth fields, no irreal gradients or extrema
Kriging	Does not work if no reliable variogram can be modelled	Smooth fields, no irreal gradients or extrema, error estimates

To this end, nearest neighbour and spline interpolation could not be used for numerical circulation modelling because of the artifacts introduced in the gridded data.

Triangulation (plus extrapolation) and kriging turned out to be appropriate tools that give comparable results. The modelled circulation patterns (not shown here) are quite similar, except of slightly strengthened currents along the coasts of Norway and Greenland in case of the last example with additional coastal modifications. Since the isotope data are representative for summer, the low coastal values could be interpreted as caused by meltwater originating from the glacial ice caps. However, except for the coast of Norway where sediment cores have been taken, this is still speculation.

REFERENCES

[1] DEUTSCH, C.V. and JOURNEL, A.G. - "GSLIB, Geostatistical Software Library and User's Guide". Oxford University Press, New York, Oxford, 1992.

[2] ENGLUND, E. and SPARKS, A. - "GEO-EAS 1.2.1, Geostatistical Environmental Assessment Software User's Guide". Environmental Monitoring Systems Laboratory, Las Vegas, 1991.

[3] PAWLOWSKY, V., OLEA, R.A., and DAVIS, J.C. - Boundary Assessment under Uncertainty: A Case Study. *Mathematical Geology*, **25**, No. 2, 125-144 (1993).

[4] SCHÄFER-NETH, C. - Changes in the Seawater Salinity-Oxygen Isotope Relation Between Last Glacial and Present: Sediment Core Data and OGCM Modelling. *Paleoclimates*, in press (1998).

[5] SCHÄFER-NETH, C., STATTEGGER, K. - Large-Scale Geostatistics: GSLIB and Spherical Coordinates. *IAMG 98 last minute poster*, in prep., (1998).

[6] WESSEL, P. and SMITH, W.H.F. - New Version of the Generic Mapping Tools Released. *EOS Trans. Amer. Geophys. U.*, **76**, pp. 329 (1995).

[7] WESSEL, P. and SMITH, W.H.F. - New Version of the Generic Mapping Tools Released. *EOS Trans. Amer. Geophys. U. electronic supplement*, http://www.agu.org/eos_elec95154e.html (1995).