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Late Pleistocene–Holocene radiolarian paleotemperatures in the Norwegian Sea based on artificial neural networks

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Abstract

Artificial Neural Networks (ANN) were trained by using an extensive radiolarian census dataset from the Nordic (Greenland, Norwegian, and Iceland) Seas. The regressions between observed and predicted Summer Sea Temperature (SST) indicate that lower error margins and better correlation coefficients are obtained for 100 m (SST_{100}) compared to 10 m (SST_{10}) water depth, and by using a subset of species instead of all species. The trained ANNs were subsequently applied to radiolarian data from two Norwegian Sea cores, HM 79-4 and MD95-2011, for reconstructions of SSTs through the last 15,000 years. The reconstructed SST is quite high during the Bølling–Allerød, when it reaches values only found later during the warmest phase of the Holocene. The climatic transitions in and out of the Younger Dryas are very rapid and involve a change in SST_{100} of 6.2 and 6.8 °C, taking place over 440 and 140 years, respectively. SST_{100} remains at a maximum during the early Holocene, and this Radiolarian Holocene Optimum Temperature Interval (RHOTI) predates the commonly recognized middle Holocene Climatic Optimum (HCO). During the 8.2 ka event, SST_{100} decreases by ca. 3 °C, and this episode marks the establishment of a cooling trend, roughly spanning the middle Holocene (until ca. 4.2 ka). Successively, since then and through the late Holocene, SST_{100} follows instead a statistically significant warming trend. The general patterns of the reconstructed SSTs agree quite well with previously obtained results based on application of Imbrie and Kipp Transfer Functions (IKTF) to the same two cores for SST_0. A statistically significant cyclic component of our SST record (period of 278 years) has been recognized. This is close to the de Vries or Suess cycle, linked to solar variability, and documented in a variety of other high-resolution Holocene records.

Keywords: Artificial neural networks; Radiolarians; Nordic seas; Late Pleistocene; Holocene

1. Introduction

The Nordic Seas, together with the Labrador Sea, represent today the main site of convection for the deep waters alimenting the North Atlantic Deep

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Water, i.e. the deep return flow of the large-scale overturning circulation. The environmental variables and processes linked to deep-water formation in this area (temperature, salinity and density characteristics of the incoming surface waters, heat release to the atmosphere, sea-ice extent, brine formation) exert a direct control on regional and hemispheric climate. In fact, the thermohaline overturning circulation regulates the heat balance at these high northern latitudes, and during past climate cycles it has shown different equilibrium states (Ganopolski and Rahmstorf, 2001). As these have a direct impact on the climate of surrounding landmasses, it is of interest to reconstruct the changes in the temperature of the main surface water body (i.e. the Norwegian Current) in this climatically sensible area over the Late Pleistocene–Holocene interval, including the last deglaciation.

A broad range of different statistical methods has been used, during the past few decades, to reconstruct paleoclimate. They range from Imbrie and Kipp Transfer Functions (IKTF) (Imbrie and Kipp, 1971) to Canonical Correspondence Analysis (ter Braak, 1986), Modern Analog Technique (MAT) (Hutson, 1979), modern analog with similarity index method (SIMMAX) (Pflaumann et al., 1996), the Revised Analog Method (RAM) (Waelbroeck et al., 1998), Weighted Averaging Partial Least Squares (WA-PLS) (ter Braak and Juggins, 1993; Birks, 1995), and Artificial Neural Networks (ANN) (McCulloch and Pitts, 1943; Malmgren and Nordlund, 1997).

Several of these techniques were successfully used to extract paleoclimatic information from census data based on different microfossil groups. IKTF has been applied to radiolarians from the Pacific Ocean (Moore, 1973; Molina-Cruz, 1984; Pisias et al., 1997), the Southern Ocean (Abelmann et al., 1999; Cortese and Abelmann, 2002), the Atlantic Ocean (Morley, 1979), and the Nordic Seas (Bjørklund et al., 1998; Dolven et al., 2002; Cortese et al., 2003). In this paper, ANNs were trained on the basis of radiolarian relative abundance data from surface sediment samples collected in the Nordic Seas, and the trained ANNs were applied to high-resolution down-core records from the eastern Norwegian Sea (cores HM79-4 and MD95-2011). We will present the main results obtained from the network calibration phase, and the obtained SST_{100} (Summer Sea Temperature at 100 m) estimates. The down-core paleotemperature predictions based on ANN will be discussed in relation to other Late Pleistocene–Holocene paleoclimatic records.

2. Methods

2.1. "Artificial" neural networks and statistical testing procedures

Artificial Neural Networks (ANN) are "self-adjusting" computer systems that can "learn" by continuously going back and changing a set of parameters in the model to reduce the error between a desired output and an actual output, i.e. in our case finding the optimal model for reconstructing SST_{100} from a given dataset. Our ANNs were trained on the basis of radiolarian census data collected from 161 surface sediment samples (Fig. 1, inset) from the Nordic Seas (Cortese et al., 2003). In order to reconstruct paleotemperatures, the ANNs were then applied to down-core radiolarian census data from two cores, HM79-4 and MD95-2011 (Dolven et al., 2002), sampled in the eastern Norwegian Sea (Fig. 1). Two different ANN programs, the NeuroGenetic Optimizer (NGO, version 2.5; ©BioComp Systems, Inc.) and the iModel (version 1.5, ©BioComp Systems, Inc.), were initially used to assess which of them worked best. We found, based on three test runs, that the NGO generated slightly lower error rates than the iModel, so we used the NGO software in the ensuing analyses. We used the Root-Mean-Square Error of Prediction (RMSEP), which is the square root of the sum of the squared differences between the observed and predicted values for all observations in the test set divided by the number of such observations, to estimate the prediction error. We also made three separate training runs for 10 and 100 m water depth using the NGO, in order to assess the lowest RMSEP (Table 1), and found that the reconstruction of temperatures at 100 m provides best results (average RMSEP = 0.77; average r = 0.96).

In our analyses, the original data were automatically subdivided by the software into a training and a test set using a random procedure. For the 161 surface sediment samples included in the dataset, 120 samples were used as the modelling/training set, and the