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Dinoflagellate cyst based modern analogue technique at test — A 300 year record from the Gulf of Taranto (Eastern Mediterranean)

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ABSTRACT

To test the performance of dinoflagellate cyst based palaeoenvironmental reconstructions derived via the modern analogue technique (MAT) and a non-quantitative method, we have compared, reconstructions of mixed layer temperature, sea surface temperature and mixed layer salinity of a well dated site from the Gulf of Taranto, to instrumental data of air temperature, precipitation and river discharge. Two hypotheses are tested: the reconstructions of dinoflagellate cyst based MAT improve when a) a local reference dataset rather than an extra-regional reference dataset is used, b) the reference and downcore datasets are corrected for species specific preservation prior to analysis. This is achieved by executing four experiments based on different reference datasets 1) a North Atlantic dataset including all species, 2) a North Atlantic dataset including degradation resistant species, 3) a Mediterranean dataset including all species, 4) a Mediterranean dataset including degradation resistant species only.

We show that MAT based reconstructions improve when a local rather than an extra-regional reference dataset is used. Exclusively including species resistant to degradation improves the reconstruction if an extra-regional reference dataset is used, but leads to considerable loss of variability if the local reference dataset is used.

Both MAT-based and qualitative reconstructions correlate to instrumental data for industrial times. For pre-industrial times, MAT reconstructions of variability in temperature and salinity do not co-vary with variability in the instrumental data, whereas qualitative reconstructions provide a relatively good fit. We suggest this to be a result of the anthropogenic influence on coastal marine ecosystems existing today at the majority of the coastal sample sites in the reference dataset. As a result, conditions at these sites do not correspond to pre-industrial conditions. We advise users of dinoflagellate cyst transfer functions to pay more attention to this aspect.

1. Introduction

Accurate quantitative estimates of past oceanographic conditions form essential input data of numerous palaeoceanographic, palaeoecological and palaeo-climatic model studies. During the last decades quantitative reconstructions based on organic-walled dinoflagellate cysts using the modern analogue technique (MAT) have been increasingly applied, notably to reconstruct upper water temperatures and sea ice cover (see e.g. de Vernal et al., 2001; Bringué and Rochon, 2012; de Vernal et al., 2013; Van Nieuwenhove et al., 2013; Gibb et al., 2014; Ouellet-Bernier et al., 2014). Since their first use there have been discussions about the applicability of this technique for dinoflagellate cyst research and its usability has been criticized with mathematical as well as biological arguments (e.g. Dale, 2001; Dale and Dale, 2002; Telford, 2006). Unfortunately, most discussions have been carried out orally during conferences and workshops and only very few systematic studies have been performed that test, evaluate and optimize the method for dinoflagellate research (Peyron and de Vernal, 2001; Telford, 2006; Telford and Birks, 2009; Telford and Birks, 2011; Guiot and de Vernal, 2011a, b; Milzer et al., 2014). Here we contribute to the discussion by putting the modern analogue technique to test in the region with the world longest instrumental time-series of temperature and precipitation.

The MAT transfer function method quantitatively reconstructs past environmental variables by comparing the cyst assemblage of a fossil sample with those in a modern day reference dataset for which the environmental conditions at the sampling sites are known. Quantitative reconstructions of each variable for the fossil samples are obtained by identifying a pre-fixed number of most analogue samples in the modern reference dataset (for dinoflagellate cyst MAT generally 5 samples are selected) and calculating a mean of their corresponding environmental parameter values, weighted by the values of the used similarity metric. The most important assumption of the method and any transfer function in general, is that the environmental variables to be reconstructed are controlling the occurrence and distribution of the fossilized parts of organisms in the sediments. If such a causal relationship between

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the environmental variable and the distribution of the fossil organism exists, the environmental parameter can be derived from the fossil assemblage.

The general way to test to which degree a variable can be assumed to be an important steering variable and whether this environmental variable can be reconstructed with a transfer function, is to perform a multivariate ordination analysis such as redundancy analysis (RDA) or canonical correspondence analysis (CCA) on the modern reference dataset. Ecophysiologically meaningful environmental variables that explain a prominent amount of variation in the reference dataset might be employed for a transfer function approach. The potential accuracy of a MAT reconstruction is obtained by a cross-validation test. Here, a subset of the reference dataset is selected, the so-called calibration subset. Reconstructions for these samples are established using only the remaining portion of the reference dataset, the so-called, verification subset (e.g. de Vernal et al., 2001; Radi and de Vernal, 2008; Bringué and Rochon, 2012). Then the RMSEP (Root Mean Squared Error of Prediction) is calculated giving an estimate of how well the reconstructions correspond to the actual environmental parameters. In dinoflagellate cyst based MAT studies the verification subset is generally 1/6th of the total reference dataset whereas the calibration subset forms the remaining 5/6 of the reference dataset (e.g. Bonnet et al., 2012; Ouellet-Bernier et al., 2014). Telford (2006) and Telford and Birks (2009) discovered that compared to other transfer function methods, MAT is particularly susceptible to the problem of spatial autocorrelation. For the dinoflagellate cyst reference datasets used at that time, they discovered that the autocorrelation, at least for salinity, was region specific. They furthermore showed that for this reason MAT based salinity reconstructions published prior to 2009 were not significant. As a reaction to these comments Guiot and de Vernal (2011a) tested the validation method of MAT on both a previously unprocessed (raw) calibration dataset and a calibration dataset where the data were geographically gridded resulting in a spatially even density of samples. Results of this study show that the gridding of the reference database reduces the noise, leading the authors to suggest that gridding improves the performance of MAT.

Apart from mathematical concerns using MAT there are biological and geological issues that need to be considered. For instance, plankton studies document that the most important environmental factors steering the dinoflagellate occurrence and dispersion can differ between regions (e.g. Smayda and Reynolds, 2003; Smayda and Trainer, 2010; Trainer et al., 2010). This aspect made Dale and Dale (2002) to suggest that global reference datasets might be less suitable for reconstructing local environmental conditions compared to more regionally defined datasets.

A basic assumption when performing dinoflagellate cyst based transfer functions is that the fossil dinoflagellate cyst assemblage reflects the upper water association at the sampling site, at times of deposition. This assumption does not hold if the cyst associations in the fossil dataset have been altered post-depositionally or the association is not autochthonous. The latter aspect forms one of the major critics in previous studies (Dale, 2001; Telford, 2006). Unfortunately this aspect has not been intensively studied and investigations that clearly show dinoflagellate cysts to be relocated are extremely rare. So far only occasional regionally restricted transport could be unequivocally documented (see references in e.g. Zonneveld and Brummer, 2000; Zonneveld et al., 2013a). Global and local studies on the geographic distribution of dinoflagellate cysts show that the sedimentary cyst associations reflect in detail upper ocean conditions with strong association changes along marine boundaries such as frontal systems. This suggests that lateral relocation for dinoflagellate cysts might be low. Sediment trap studies indicate that dinoflagellate cysts do not settle as individual particles but most likely as aggregates and fecal pellets, as such increasing their sinking velocity and minimizing the risk of lateral transport (e.g. Zonneveld et al., 2010a; Zonneveld et al., 2010b; Price and Pospelova, 2011; Bringué et al., 2013). In contrast to this, others suggest that lateral transport might be considerable (e.g. Matthiessen, 1994; Dale, 1996). For instance, long distance cyst transport by bottom waters and sediment flows was suggested based on sediment trap studies in the central and North Atlantic Oceans (Dale, 1992; Dale and Dale, 1992). However, despite the limited information about lateral relocation of cysts, this aspect nowadays is not considered to be a major drawback for the use of transfer functions.

Another aspect that has obtained no attention yet with respect to the performance of transfer functions, is the post-depositional species selective degradation of dinoflagellate cysts. During the last decades it has become obvious that the sedimentary dinoflagellate cyst association can be altered post-depositionally by species selective aerobic degradation (see e.g. Zonneveld et al., 2008b; Zonneveld et al., 2010b; Bogus et al., 2014 and references therein). The rate at which this process alters the cyst associations depends on e.g. the sedimentation rate, the bottom/pore water oxygen concentration and the sediment composition. It is maximal at sites with well ventilated bottom waters and oxygen penetrating into the sediment pores and minimal where bottom-pore waters are anoxic. In these first cases the degree of alteration increases downcore with the surface sample being less affected compared to the downcore samples. This can lead to large discrepancies between the downcore cyst associations and the surface sediment association without any changes in steering environmental parameters. A potential solution of this problem could be to exclude degradation sensitive cyst species from both the reference and downcore datasets and constrain the record on so-called “resistant” species that are not affected by aerobic degradation.

In this study we contribute to the discussion about the usability of MAT by testing two working-hypotheses: a) reconstructions are better if a regional reference dataset rather than an extra-regional reference dataset will be used and (b) reconstructions are better when only degradation resistant species are included in the analysis. The testing of these hypotheses is achieved by performing MAT analyses based on two reference datasets; 1) extra-regional, 2) regional (Fig. 1) and by performing two analyses per reference dataset, a) with all dinoflagellate cyst species included and b) by including only degradation resistant species. We established downcore reconstructions of seasonal and annual sea surface temperature, mixed layer temperature and mixed layer salinity by executing 4 MAT analyses: 1) all species included, extra-regional reference dataset, 2) only resistant species included, extra-regional reference dataset, 3) all species included, regional reference dataset, 4) only resistant species included, regional reference dataset.

Oceanic conditions are often reconstructed with qualitative methods (e.g. Chen et al., 2011, 2013; Milzer et al., 2014; Pospelova et al., 2015). These methods use changes in dinoflagellate cyst assemblages to reconstruct past upper ocean environmental conditions. Often ratios are calculated between species groups with contrasting cyst distribution in modern sediments with respect to an upper ocean gradient of a certain environmental parameter.

To gain insight into the extent ti which MAT-based and qualitative reconstructions (QR) reflect real changes in upper ocean environmental conditions, MAT and QR are being compared to instrumental data. Region of focus is the Gulf of Taranto (southern Italy), host of a well dated downcore cyst record covering the last 300 years (Chen, 2011; Zonneveld et al., 2012). This record has a temporal resolution of approximately 2 years. MAT based reconstructions of surface water temperature, mixed layer water temperature and mixed layer salinity as well as QR of upper water temperature and river discharge are compared to instrumental data of changes in local temperature, northern Italian precipitation and Po-river discharge during the last 100–300 years derived from the world-wide longest instrumental records (Zanchettin et al., 2008; Camuffo and Bertolin, 2012a, 2012b; Camuffo et al., 2013; Camuffo et al., 2014). This provides us the unique situation of actually being able to compare downcore reconstructions of past environmental conditions with instrumental data.