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Reworked Coccoliths as runoff proxy for the last 400 years: The case of Gaeta Gulf (central Tyrrhenian Sea, Central Italy)

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ABSTRACT

We present the results of a high resolution study carried out on a shallow water sediment core, recovered in the central Tyrrhenian Sea to reconstruct the runoff history of the catchment basin of Volturno and Garigliano rivers (Gulf of Gaeta, Italy), over the past ~400 years. We compared the abundance distribution pattern of Reworked Coccoliths to the surface runoff model simulation for the Volturno and Garigliano hydrographic river basins, the Global Historical Climatology Network index, the Palmer drought severity index, the Tevere river discharge anomaly, the average summer rainfall in Southern Italy and the reconstructed North Atlantic Oscillation signal. This comparison suggested that the biotic signal of the Reworked Coccoliths may be used to detect climatic events from local to "global" scale. The calcareous nannofossil assemblages as well as their diversity index are modulated by oscillation in solar activity, where minima in solar activity correspond to minima calcareous nannofossil diversity and *vice versa*. In particular, the antiphase correlation between the abundance of Reworked Coccoliths and the North Atlantic Oscillation index, which modulates winter precipitation, suggests that this biotic index could be used as a reliable proxy to reconstruct the variations in the hydrographic basin runoff of the Volturno and Garigliano rivers. In addition, power spectral and wavelet analysis carried out on both signals documented the occurrence of climatic cycles of the duration of about 95 yr. From 1900 AD upwards, a turnover in the periodicity from 95 yr climatic cycles to 22–26 yr cycles occurred in the Reworked Coccoliths signal, suggesting a strong control of solar forcing (Hale cycle) over the last century.

1. Introduction

The study of historical records, aimed toward a better understanding of the Earth's climatic system and a more accurate prediction of its future evolution, is one of the most important priorities of the scientific community (e.g., Clark et al., 1999; Nakicenovic and Swart, 2000). Despite conflicting opinions regarding the reliability of paleoclimatic "proxies" and the consistency of results obtained from simulation models, applied for the reconstruction of past climate, the study of time series remains a valid analytical tool for the study of the Earth's dynamic processes especially in conditions that differ from those of the present and has proven to be crucial in the determination of the reliability of medium and long term predictions models (i.e., Hansen et al., 1988; Hoffert and Covey, 1992; Karl and Trenberth, 1999; Nakicenovic and Swart, 2000; Webb et al., 1998). Within this framework the marine environment offers a unique opportunity to monitor the past climate changes (e.g., Bradley et al., 2003; Jones et al., 2009, 2001). One of the main issues for the scientific community is the reconstruction of past significant hydrological events in the marine areas that ultimately control the chemistry of the sea water, the nutrient supply, the food availability and the overall marine ecosystem.

The Mediterranean area is a transition zone between the continental influences of Europe, Asia, and the north-African desert, and the interaction of the Atlantic Ocean and the Mediterranean Sea (Harding et al., 2009). The Mediterranean climate is strongly influenced by its complex orography and its location within the boundary between subtropical and mid-latitude atmospheric patterns (Lionello et al., 2006; Trigo et al., 2006). Atmospheric circulation patterns of the northern hemisphere, influence climate variability in the Mediterranean region (Combourieu Nebout et al., 2002; Fletcher et al., 2012; Jalut et al., 2009; Roberts et al., 2012). Particularly, the North Atlantic

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Oscillation (NAO) is one of the dominant atmospheric circulation patterns in the North Atlantic sector, with considerable influences on winter temperature/precipitation throughout the Eurasian continent and North Eastern America (Greatbatch, 2000). In Italy, the NAO index modulates winter precipitations (Benito et al., 2015; Brunetti et al., 2002; Caloiero et al., 2011; López-Moreno et al., 2011; Tomozeiu et al., 2002). Positive NAO conditions foster warm and dry winters, the opposite occurs with negative NAO index (Benito et al., 2015; López-Moreno et al., 2011; and references within). Due to this geographical configuration, the Mediterranean represents a unique laboratory to study the interaction between continental and marine environments. In particular, the sedimentary record of continental shelf areas represents a natural repository for monitoring past short-term climate oscillations and the past hydrological events, the controlling mechanisms of which are difficult to predict and model (i.e., Budillon et al., 2005; Di Bella et al., 2014; Goudeau et al., 2015; Grauel et al., 2013a, 2013b; Incarbona et al., 2010a; Lirer et al., 2014; Oldfield et al., 2003; Piva et al., 2008; Taricco et al., 2009; Vallefuoco et al., 2012). Recently, Benito et al. (2015) proposed a wide review of the Holocene flooding events in the Mediterranean region suggesting that a centennial-to-multi-centennial seesaw pattern, associated with a bipolar hydroclimatic conditions, existed in the Mediterranean during the Holocene. However, none of the datasets reported in this review had been collected from marine coastal environments, where river flow regime strongly controls the marine ecosystem evolution (Boesch et al., 2001; Cloern, 2001; Humborg et al., 2008; Paerl et al., 2014; Rabalais et al., 2001). Further studies using fossil archives are thus required to quantitatively document the riverine freshwater inputs and to foresee their possible future trend in order to assess their impact on marine ecosystem.

An exhaustive data analysis of the Mediterranean river discharge is strongly impaired by the lack of data, especially in the south-eastern parts of the basin. This issue, together with the necessities of climate change and impact studies, has fostered the development of alternative methods to estimate large-scale budgets for present and future climate conditions. Some methods are based on empirical relations between runoff, precipitation, and temperature fields (Biondi et al., 2002; Brunetti et al., 2006; Gou et al., 2007; Gray et al., 2011; Mariotti et al., 2008; Sun et al., 2013; Wirth et al., 2013), while other methodologies focus on the surface integration of the runoff fields produced by climate models or on the development of macroscale hydrological models (Alberico et al., 2014).

Within this framework, the identification of paleoclimatic "proxies" useful to document the past hydrological events is very important. Coccolithophores are calcifying unicellular planktonic algae, whose distribution is controlled by environmental parameters within the photic zone of the oceans (e.g. temperature, salinity, sunlight). The variation in abundance of selected taxa can be used as an excellent proxy for recognizing climate changes. Their exoskeletons, composed of tiny calcareous platelets (coccoliths), are abundantly found in the fossil record: their long evolutionary story (Late Triassic–present day), high evolutionary turnover, and phenomenal abundance in marine sediments make them ideal fossils for high-resolution biostratigraphic studies as well as for paleoclimatic reconstructions (Bown, 1998; and reference within). The reworked specimens generally bias the biostratigraphic signal. However, in shelf-dominated and river-dominated areas, the Reworked Coccoliths (RC) can provide useful information about land-ocean dynamic, sediment transport (Bonomo et al., 2014; Ferreira and Cachão, 2005; Ferreira et al., 2008), and allow to account for the continental terrigenous fluxes which are useful for paleoclimatic studies and to reconstruct large scale runoff oscillation (Incarbona et al., 2010a; Sprovieri et al., 2006).

Here, we present the results of a high resolution study carried out on a sediment core, recovered at 93 m depth in the Gulf of Gaeta (GoG) (central Tyrrhenian Sea). The distribution pattern of Reworked Coccoliths is compared with some indexes which mainly reflect variability of precipitations and river discharge in the studied area and Mediterranean basin:

- The 5-year running average (mm ∗ daily^{-1}) of the Surface Runoff model simulation (UTMEA CLIM group — EU project CIRCE, http://utmea.enea.it/projects/circe/) of the Volturno and Garigliano river hydrographic basins, from 1950 to 2013.
- The National Climatic Data Center Global Historical Climatology Network V2 index (GHCN), which is as in Mariotti et al. (2008) and represents the area-averaged annual mean precipitation anomalies (six years running means) of the Mediterranean area, between 1903 and 2004.
- The Palmer drought severity index (PDSI) is as in Mariotti et al. (2008), 1903–2002. The PDSI was created by Palmer (1965) with the intent to measure the cumulative departure (relative to local mean conditions) in atmospheric moisture supply and demand at the surface (Dai et al., 2004). The oscillations of this index, which reflects the combined effect of precipitation and surface temperature changes, highlight wetter (positive values) or drier (negative values) conditions of land surface.
- The summer rainfall data set, from the original rain gauge network of the Centro Funzionale of Calabria region, represented as percentage ratio of the moving 10-year average rainfall (time interval 1929–2003) to the average value of the decade 1994–2003 (Caloiero et al., 2011).
- The monthly discharge anomalies time series for the Tevere river (units are % of climatology) is that of Mariotti et al. (2008) for the time interval 1924–1993, and represents a good index of the precipitation variability in the central Italy. Historical river discharge time series is derived from the Mediterranean Hydrological Cycle Observing System project regional database (Mariotti et al., 2008).
- The North Atlantic Oscillation (NAO) reconstructed signal (Trouet et al., 2009).

This research aims to reconstruct the runoff history of the catchment basin of the Volturno and Garigliano rivers over the past ~400 years using RC.

2. Study area

The Tyrrhenian Sea is the deepest major basin in the western Mediterranean Sea (Astraldi et al., 1994). The circulation is overall cyclonic triggered by the Modified Atlantic Water (MAW), located in the upper 100–200 m of the water column, entering off the northern Sicilian coast and establishing a northward current along the western Italian coast (Fig. 1a) (Artale et al., 1994; Krivosheya and Ovchinnikov, 1973; Millot, 1987; Pierini and Simioli, 1998). According to this circulation pattern the GoG has a cyclonic vortex that interacts with the superficial (down to 10 m depth) and the intermediate (from 10 to 100 m water depth) layers. This pattern is more characteristic during the winter, when a NW water flow dominates. In the summer, although it preserves its cyclonic character, it also shows smaller cells and reduced dynamics, with an S and SE direction of the water movements (Fig. 1b). Moreover, according to De Pippo et al. (2003) two zones with two different circulation regimes are present: a coastal zone (<50 m depth) with closed cyclonic and anticyclonic circulations, and an offshore zone (>120 m depth) influenced by a mainly northern flow.

The study area is characterized by the presence of two major rivers, the Volturno and Garigliano (Fig. 1b). These rivers are the two longest of southern Italy (175 km and 38 km) with an estimated mean discharge of 80 $m^3 s^{-1}$ and 120 $m^3 s^{-1}$ and a catchment basin of 5550 km^2 and 5020 km^2, respectively (Iermano et al., 2012). The littoral zone is also conditioned by two minor rivers, the Regi Lagni and Agnena channels with a catchment basin of about 1095 km and of 209 km^2, respectively. The marine area in front of the Volturno river mouth consists of a wide