

## ***Interactive comment on “Calcareous nannofossil assemblages from the Central Mediterranean Sea over the last four centuries: the impact of the little ice age” by A. Incarbona et al.***

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We thank the two anonymous referees who provided helpful and stimulating comments on the paper ‘Calcareous nannofossil assemblages from the Central Mediterranean Sea over the last four centuries: the impact of the little ice age’ by A. Incarbona, P. Ziveri and others. We followed general and specific comments from both referees in order to improve the revised version of the manuscript. Among others, we took into account suggestions about the organization of the paper, the usefulness of some figures and we have made it shorter and more concise. In the following paragraphs we focus on the conceptual questions raised by reviewers.

Both referees argue that more focus on the Little Ice Age (LIA) is needed, since this event is clearly stated in the title. Indeed, the title should be read as ‘what calcareous nannofossils can tell us about the last four centuries in the central Mediterranean Sea’, while the impact of the LIA implies the most important natural climatic event that occurred during this interval and was recognized in our study’. Many noteworthy questions, other than the impact of the LIA, cannot be overlooked. The LIA is sensibly deemphasized since data from cores C90-1M and St 272 that do not contain sedimentary levels older than about AD 1800 and therefore do not significantly cover the LIA interval. An important result of our study concerns the response of calcareous nannofossil assemblages to global warming. Changes in the structure of the coccolithophore community over the last few decades integrate results of recent leading researches that report that rising atmospheric CO<sub>2</sub> might impact on the calcification rate of coccoliths of particular species, such as *Emiliana huxleyi* (Iglesias-Rodriguez et al., 2008; Langer et al., 2009).

The most important comment of Referee #1 concerns paleoproductivity considerations on Section 6.1 and is articulated in three parts. Firstly, we can only suppose that environmental conditions remain stable when taxa’s relative abundance fluctuations are confined to the standard error deviation. Indeed, the error is not so wide given the very high number of coccoliths counted, about 600 specimens on average per sample and over 1000 for *F. profunda* countings in cores St 342 and St 407 (Table 1 in Supplementary Material). Secondly, in several papers a direct link between water depth and *F. profunda* percentage values (Okada, 1983; Incarbona et al., 2008b) has been demonstrated. However, these studies point out that this species can hardly be considered a real bathymetric proxy, but a variable water depth might reflect different hydrological conditions, for example linked to nutrient availability. Studies on living coccolithophores demonstrate that *F. profunda* is commonly found in the lower photic zone, below 50 m water depth, in the major ocean basins as well as in the Mediterranean Sea (Knap-pertsbusch, 1993). Since core C90-1M was recovered in waters deeper than 100 metres, we can hypothesize that depth at this site is not a limiting factor. On the other hand,

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satellite imagery demonstrates that C90-1M has been the most productive site for the last ten years among the investigated areas, possibly due to its proximity to the coast and resultant increasing fertilization. Thirdly, we appreciated the valuable idea that increased *F. profunda* percentage values might reflect an increase in productivity in the lower photic zone. This argument has been widely explored for late Quaternary eastern Mediterranean sapropel layers (e.g. Castradori, 1993; Giunta et al., 2003, 2006). The eastern Mediterranean Sea is today characterized by a deep pycnocline/nutricline, which lies well below the photic zone. On the basis of Neogloboquadrinids (planktonic foraminifera) and *F. profunda* abundance increases and circulation modelling, it has been supposed that the failure of deep water mass formation would have led to the shoaling of intermediate waters into the photic zone. Since the intermediate water mass is nutrient enriched, this process could have fueled the blooming of phytoplankton in relatively deep layers, the so-called deep chlorophyll maximum (Rohling and Gieskes, 1989; Rohling, 1991; Castradori, 1993; Myers et al., 1998). The Sicily Channel hydrographic condition is very different, with seasonally controlled primary productivity levels and phytoplankton blooms mainly triggered by winter vertical mixing (Knappertsbusch, 1993). High-resolution geochemical and micropaleontological studies support the assertion that the present day productivity model has been maintained for the last five glacial-interglacial cycles (e.g. Sprovieri et al., 2003, 2006; Di Stefano and Incarbona, 2004; Incarbona et al., 2008a, 2008b, 2009). In particular, the detailed study of the distribution of *F. profunda* on the Sicily Channel sea floor, together with satellite-derived productivity values, is a robust evidence of the ecological meaning of this species (Incarbona et al., 2008a, 2008b). On this basis, *F. profunda* increase in abundance in this region can be interpreted as a decrease in primary productivity levels, rather than witness to the development of a deep chlorophyll maximum.

The grouping of coccolithophore species is a difficult practice, even because of the limited knowledge on their biology and physiology. We followed the approach of Young et al. (1994) who grouped taxa on the basis of coccospheres' functional morphology, slightly modified by taking into account information on biogeographical distribution and

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vertical zonation (Knappertsbusch, 1993; Winter et al., 1994; Ziveri et al., 2004). The Placolith group includes only specimens of Prinsiaceae, adapted to an opportunistic life strategy and eutrophic conditions, and not of Calcidiscaceae (belonging to genus Calcidiscus, Oolithotus and Umbilicosphaera). In fact, the study of living coccolithophores and late Quaternary sedimentary archives in the Mediterranean Sea highlight that only specimens of *Emiliana huxleyi* and *Gephyrocapsa* spp. dominate the assemblages and were probably able to form extended blooms (e.g. Knappertsbusch, 1993; Flores et al., 1997; Incarbona et al., 2009). The upper photic zone (UPZ) group includes taxa that are specialized to live in oligotrophic surface waters, for instance above a permanent or seasonal thermocline at low- middle latitude, exploiting a minimum nutrient flux. The placolith taxon *Umbilicosphaera* spp. is included into the UPZ group, because it is an important component of the coccolithophore community in warm and saline water of oligotrophic gyres and low-latitude oceans (Andruleit et al., 2000, 2003; Andruleit and Rogalla, 2002; Ziveri et al., 2004). The lower photic zone group includes taxa that prefer the lower part of the photic zone, usually below or at the base of the thermocline. Finally, the miscellaneous group includes taxa without a defined (or known) ecology and vertical distribution. Although there is not an objective criterion for grouping taxa and future research will disclose further aspects of ecological preference of species, the division adopted here has been fruitfully exploited in other late Quaternary studies on central Mediterranean sediments (e.g. Di Stefano and Incarbona, 2004; Incarbona et al., 2008b; Di Stefano et al., 2010).

Referee #2 claims scant evidence on the recovery of recent sediments (the last century?) in Sicily Channel box-cores St 272, St 342 and St 407. We think that enough evidence on the chronology of these sediments was provided by  $^{210}\text{Pb}$  radiometric analysis. The methodology is suitable for dating sediments accumulated over a period of 100-200 years. In the present study, the chronology of the last 120 years was directly based on  $^{210}\text{Pb}$  analysis, whereas a model was necessary for older age determinations (Di Leonardo et al., 2006; Tranchida et al., 2010). In fact, recent works based on  $^{210}\text{Pb}$  chronologies and carried out on St 272, St 342 and St 407 sediments

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and other similar box-cores demonstrated the anomalous enrichments of metals, such as Hg, over the last  $\sim$  20-30 years, as likely due to human activity (Di Leonardo et al., 2006; Tranchida et al., 2010).

The distribution of *F. profunda* on the Sicily Channel sea floor led to the proposition of a formula:  $NPP = 885.864 + (-138.963 \times \ln(F. profunda \%))$ ,  $R = 0.837$ ,  $n = 43$ . The equation allows one to change percentage values of the considered species into quantitative primary productivity values (Incarbona et al., 2008a). Interestingly, despite the different oceanographic setting, the equation is very similar to that obtained by Beaufort et al. (1997), following the same procedure in the Indian Ocean. The equation is perfectly suitable to describe the entity of productivity changes in the Sicily Channel over the last four centuries. We preferred indicating the quantitative estimate at St 407 for the most important change, across the LIA (35-40  $gC \times m^{-2} \times a^{-1}$ ), rather than to performing a point-by-point transformation in the Sicily Channel box-cores. The latter option is also possible, given the availability of data from Table 1 in Supplementary Material.

So far, oxygen isotope data are available only from the Tyrrhenian core. We hope that ongoing research might produce stable isotope analysis for Sicily Channel box-cores. Our study shows that oxygen isotope data are very useful for the interpretation of marked fluctuations in the relative abundance of reworked nannofossil specimens. The study of calcareous nannofossil reworking in sedimentary records is not a trivial issue and can be explained by a complex interplay of factors, among others the response to eustatic sea-level fluctuations, proximity to the coast and primary productivity variations (Sprovieri et al., 2003; Di Stefano and Incarbona, 2004; Incarbona et al., 2008b; Incarbona et al., 2009; Incarbona et al., 2010). Results at site C90-1M, with reworking peaks correlated to periods of aridity and vegetation loss rather than to increased Sele River runoff, were definitively not expected. This interpretation is so valuable that it might be invoked in other studies, for instance to peaks in reworking during Dansgaard-Oeschger stadials in the Northeastern Atlantic Ocean, when the Iberian

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Peninsula was characterized by aridity and a steppe vegetation pattern (Roucoux et al., 2001, 2005).

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