Reply to reviewer 2

We thank the reviewer 2 for its interesting comments. However some remarks appear to us a little bit excessive and devalued for palynology in marine sediments and need clearly to be discussed.

1) The referee states about the exclusion of *Pinus* from the pollen sum and writes that it changes radically the vegetation composition in Mediterranean region.

A –The pollen analyses in marine sediments correspond to an image slightly disturbed of the vegetation: it integrates the composition of vegetation (with altitudinal belting) on a regional scale which integrate the transport and depositional processes of pollen grains. Nevertheless, when we compare the marine core pollen diagrams (shown in an additional diagram excluding *Pinus*) and the close terrestrial ones, we note a clear similarity in the vegetation changes. This is particularly well demonstrated in the paper of Fletcher et al. (2008): they compare the pollen data analysed from the marine core MD 95-2043 located in the Alboran Sea, close to the core detailed in this study and the Spanish peat bog diagram of Padul. They reconstruct remarkably close vegetation changes during the Late-glacial and the Holocene.

B- As said by the referee, *Pinus* is a key-Mediterranean taxa today and during the Holocene but probably not during the last deglaciation. Referee states that we underestimate forest with exclusion of pine. We have kept in mind that *Pinus* may be sometimes one of the components of the vegetation. Nevertheless, it remains impossible to know the exact contribution of this taxon in the vegetation in such marine records as well as in all other pollen records (marine and continental), and it remains very difficult to separate the different pine species from pollen grains only. Then, we agree that our record could show a modified image of changes in regional vegetation organized in altitudinal belts, in the mountains of Spain and Morocco. Nevertheless, our data show a *Pinus* reduction of 10% during the YD, H1 and H2, associated to a 10-15% increase in steppe taxa also recorded in the diagram including *Pinus* (see additional material); these pollen assemblages changes reflect changes in the composition of vegetation and thus in climate. A similar decrease in

Pinus values is recorded in the Padul sequence during H1 event (Pons and Reille, 1988).

C - Referee says that *Pinus* is drought tolerant, yes, but in some limits and it depends on the species! Carrion (2002) and Carrion et al. (2007) show that *Pinus* occurs above 1500 m in the southern Spain during the Holocene but not during the post glacial, while Pons and Reille (1988) find this taxa around 780 m during the Last Glacial Maximum. Cheddadi et al. (2009) find *Pinus* only in very low quantity in Ifrah lake (Morocco). Moreover, in the Mediterranean area, several authors have already demonstrated that *Pinus* was restricted to refugia zones during the late glacial and deglaciation. Its behaviour follows *Quercus* and other deciduous trees (Carrion, 2000; Cheddadi and Bar-Hen, 2008). Then, we consider that the high percentages recorded in marine cores during the glacial time represent an artefact corresponding to the well-known over-representation of pine in sediments due to transport and conservation (Heusser and Balsam, 1977), and do not indicate the occurrence of a pine forest in this area during the LGM. Based on these observations, we confirm our decision to exclude this taxon in the ODP 976 pollen assemblages and also in those modern pollen dataset to provide a climate reconstruction as reliable as possible.

D- Referee states that if we exclude *Pinus* from the biomisation process, the climate reconstructions could be worth because *Pinus* allows to differenciate forest biomes. He states that we “underestimate precipitations where desert/steppe taxa dominate”, and we “overestimate precipitation when deciduous trees dominate”.

- The exclusion of *Pinus* could change the perception of vegetation associations. However, the previous pollen-based climate reconstructions based on marine sediments are generally in agreement with the results obtained from terrestrial sequences in the Mediterranean region, as well for the temperature and precipitation signal and for different time periods (e.g. Sanchez-Goni et al., 2002, 2005; Desprat et al., 2005; Bout-Roumazeille et al., 2007; Kotthoff et al., 2008, Kageyama et al., 2005).

Moreover, the MAT has been validated on the modern training sets. Two tests have been performed, one with *Pinus (*Bordon et al., *2009)*, and the second without *Pinus (*Dormoy et al.., this issue*)*. Both tests show high correlations and good RMSE.

For example, the annual precipitation shows a correlation between the observed and the reconstructed values of 0.75 with *Pinus* and 0.8 without *Pinus.* For the temperature of the coldest month, R=0.84 with *Pinus* and 0.94 without *Pinus.*

Moreover, as another validation test, we have included *Pinus* in the ODP 976 climate reconstruction (additional figure). This figure doest not show significant statistical differences, except for one sample during the Younger Dryas. Therefore to be able to better detect minor vegetation and climate changes, we confirm our choice to exclude *Pinus* in the pollen diagram and in the climate reconstruction.

- Referee states that pine is eurythermic and present in all forest biomes and not in non woodland biomes and that it can induce a bias in our reconstructions.

As referee said, *Pinus* can occur in several woodland biomes. Nevertheless, we consider that the woodland biomes are also determined by other taxa such as *Quercus*, for temperate deciduous forest or warm mixed forest and such as *Cedrus* (sometimes by *Abies*) for cool mixed forest and temperate deciduous forest. Cheddadi et al. (2009) show that in southern Spain, conifers where not very expanded (< 20 %) before 13 kyr and that all trees were nearly absent around 18-20 kyrs (at most 20%). This definitively shows that the *Pinus* percentages are stongly over-estimated during the period 20 to 10 kyr in the ODP976 and do not represent the real *Pinus* expansion although it is a major component of the Mediterranean vegetation. In addition, if we keep *Pinus* in our reconstructions, the non woodland biomes developed at low to mid altitude during the cold events are not well-reconstructed because of the over-representation of *Pinus*. These biomes correspond to the biome steppe that is correlated to changes towards cold conditions in marine environments in the same area (Combourieu Nebout et al., 2002). Lot of papers (partly referenced in our paper) has shown the development of steppe or semi desert in the Mediterranean at this time. Then it would not be useful to keep pine in the biomisation developed in this study. Its is of note that the biomes and climate parameters reconstructed here remain very close to those recorded by the continental studies and by GCMs simulations (Allen et al., 2002; Bordon et al., in press, Kageyama et al., 2005, Brewer et al., same CPD issue). We finally decided to exclude *Pinus* from the pollen sum because of its overrepresentation (not representative of the real vegetation composition), and then permit to all biomes to have a better expression. Moreover, our results are strongly consistent with other

papers focused on Mediterranean climate changes from terrestrial records which indicate cold and dry climate and steppe biomes during the glacial and the H2 event, the H1 and the Younger Dryas (e.g. Allen et al., 2002; Bordon et al., in press). In conclusion, we don't underestimate the *Pinus* problem but we decide, as in other marine core studies, to exclude *Pinus* because it is really the only way to get the most accurate climate reconstructions from marine cores in the Mediterranean.

2) Reliability of marine pollen data

The reviewer 2 states that a minimum of 100 pollen grains is not enough to support our conclusion and especially the reconstruction methodology.

We think this comment very surprising. Does the referee really want to mean that almost 100% of the marine pollen data are unreliable? (e.g. Naughton et al., 2007; Fletcher et al., 2008, Sanchez Goni et al., 2002, 2005, 2008; Desprat et al., 2006; Kotthoff et al., 2008, Roucoux et al., 2005; Cheddadi and Rossignol-Strick, 1995; Rossignol-Strick, 1999; Rossignol-Strick and Paterne, 1999; Zonneveld, 1996; Shackleton et al., 2002, and also in other part of the world, Heusser and Balsam, 1977; Hooghiemstra et al., 1992, 1995, 2006, ….). And all the climatic quantifications based on marine data, done on different cores and over different time periods would also be unreliable? (e.g. Sanchez Goni et al ., 2002, 2005; Desprat et al., 2005; Kotthoff et al., 2008; Klotz et al, 2006 ….).

The pollen count problem in marine sediments has often been discussed and it has been admitted a long time ago that the pollen sum in such sediments rarely reaches those of continental ones (e.g. Heusser and Balsam, 1977; Hooghiemstra et al., 1992, 1995, 2006, Turon, 1984). Its true that with a basic sum of at least 100 - without *Pinus* – pollen grains could appear low in comparison with the standard counts of at least 300-500 (always including *Pinus*) classically counted in terrestrial data. However, this value has been validated a long time ago for the pollen analyses in marine environments by correlation with the SST values (e.g. Heusser and Balsam, 1977). Moreover, the reliability of the results obtained in marine cores is accepted by the paleoecologist community as a regional image of the vegetation (Heusser and Balsam, 1977; Hooghiemstra et al., 1992, 1995, 2006).

In our study, we mentioned that we have counted at least 100 grains except pine grains. It means that we have counted only 100 pollen grains in few samples BUT in almost all the samples we have counted around 200 grains except *Pinus* which correspond to around 300 to 1300 grains counted, *Pinus* included. This precision can be added in the text. Such pollen sum is reliable according to classic palynology and higher than the reliable sum validated in marine cores. In addition, at least 20 taxa have been determined in each sample: the interpretation and climate reconstructions is then of course not based on two taxa (as in the extreme examples of the reviewer) but at least 20 taxa.

The referee states that: pollen events are represented by only one sample
It is true for only one event in the upper part of our record. The others are expressed by two or more samples. Sometimes pollen samples are very close due to the high resolution of our record and perhaps it is not easy to see that. Percentage changes of 5-10 % are often considered as significant to express a change in vegetation as well in marine as in continental record. Referee may have a look to the new pollen diagram with *Pinus* (see additional data) and see that pollen events are also expressed there in temperate curve as in semi desert one.

3) Answer to other comments

p. 672: Referee has a doubt about the sensitivity of Mediterranean to climate related to its intermediate position, and asks more references.
It has been mentioned in the last IPCC report that changes in climate will particularly affect the Mediterranean environments with regard to water resources. Giorgi (2006) has shown that Mediterranean is one of the hotspot for sensitivity to climate change in the future. One of the reasons of this particular sensitivity corresponds to its intermediate location under influence of tropical masses in summer and boreal masses in winter (Lionello et al., 2006). The rapid response of its ecosystems to climatic changes has been shown throughout the Mediterranean vegetation history. Mediterranean vegetation have thus responded to each climate event even the tenuous ones (e.g. Pons et al., 1995 ; Combourieu Nebout, 1993; Suc et al., 1999; Klotz et al., 2006). Some references can be added in the text.

p.674 : The referee asks more details about the core site.

We can add some precisions as follow: there are no anoxic sediments in this part of the Mediterranean area. The sapropel anoxic layers are essentially restricted to the central and eastern Mediterranean. In the Alboran Sea, the sedimentation is based on continuous homogeneous clays (Comas et al., 1996). The ODP 976 sediments do not show problems such as reworking or turbidites: all data on the sediments composition are presented in the ODP Leg 161 Report (Comas et al., 1996).

In this area, during the LGM, the decrease in sea level do not open large land surface because the shelf is relatively narrow and the slope steep (see data on the Alboran Sea bathymetry in ODP Leg 161 volume, Comas et al., 1996).

No major fluvial input has been detected from the north and the south. Concerning the prevailing wind direction, today, this zone in under the westerlies influences with input from the south during the dryer periods (H1, H2, YD). More precisions can be found in Bout-Roumazeille et al., (2007). We already refer to this paper in the text p.678, but we can also add few sentences following the referee suggestion.

P 675: Referee would like to add an age-depth model scheme.

We can add such a graph with the age model and the error bars, and better discuss the chronology based for the Holocene period.

p. 676: see earlier comments about the amount of pollen grains counted per sample.

Please see answer point 2: reliability of marine pollen data

p. 676: Referee would like more precisions on the method and states on the relative new parameter: the seasonality.

As it is written p. 676, we have used the MAT developed by Guiot (1990) with no constraint. The reconstruction of the seasonal precipitations is recent (Bordon et al., 2009, Wu et al., 2007). We agree with the reviewer that the validation of the method is a very important step. However we consider that the validation of the seasonality reconstruction is not the purpose of our paper and it is discussed in detail (together with a multi-method approach) in the paper of Dormoy et al., (2009).

Referee also states that among all the 2000 modern pollen samples available in the Mediterranean area, only fewer include *Cedrus* and that these few taxa are located exclusively in Morocco.

We disagree with this assumption because in our modern pollen dataset 200 modern pollen samples include *Cedrus* (10% of the dataset) among which 100 contains *Cedrus* percentages above 0.5%. Moreover, these samples are not exclusively from Morocco. Other samples from Turkish and Syria also contain *Cedrus* pollen grains.

Cedrus corresponds to an important component of one of the possible ecosystems and biome (cool mixed forest) of the studied area. We must be able to reconstruct this biome in our pollen spectra especially in Alboran Sea.

p.677: Yes, summer is JJA and winter is DJF. Some precisions can be added in the text.

p. 678 line 9-11: Referee would like that we clarify the term reliability about the pollen data. We will change the sentence as follow:

The reliability of pollen analysis in marine sediments has already been clearly established according to the comparison of marine surface sediments studies (top cores and/or marine cores) with vegetation studies on adjacent continent (Heusser and Balsam, 1997, Hoogiemstra et al., 1992, 1995, 2006, Turon, 1984, Naughton et al., 2007).

p.678 line 12-18 Referee want to clarify the good correlation with Portuguese margin records.

Due to the Alboran core location, we are able to compare the results with the whole area. Alboran Sea is at the same time under Atlantic and Mediterranean influences due to its position in the western part of the Mediterranean. Therefore we may compare with the Atlantic cores off Portugal (that records the Iberian vegetation changes) especially with regard to the temperate forest changes.

p.680: referee asks more details about the definition in the concerned samples.

The LGM samples which has been attributed to the “Temperate Deciduous” biome are dominated by Cedrus, Ericaceae, Quercus deciduous and other Mediterranean taxa in small %. The occurence of *Quercus deciduous* (assigned to the pft temperate summergreen which belong to the Temperate Deciduous biome) and the few % of Mediterrenean taxa induce the attribution of these samples to the biome temperate deciduous forest. However, as it is noted in the text, there is a lack of present-day analogues for cedar/heath associations.

p.682: The referee states that the threshold between biomes is based on a rather arbitrary method.

The biomisation method defined by Prentice et al. (1996) has been applied to reconstruct the 6 and 18 ka biomes for Africa, China, Eastern North America, Eurasia, Europe, Japan, Australia, Western North America, and South America (this issue). In most of these papers, the pollen-derived biome map have been validated by comparison with the biomes inferred from the potential vegetation (for a numerical comparison, see e.g. Tarasov et al., 1998, Lebamba et al., 2009, this issue). This validation shows that the biome reconstruction is accurate between 60 and 99% depending on the biome and the considered region.

We fully agree with the referee who states that He would not consider a change from one biome to another on the basis on one sample but as mentioned at the end of the part (Reliability of marine pollen data), the lateglacial pollen events depicted here are represented by two or more samples.

p. 684: The oxygen isotope curve mentioned in the text line 14 corresponds of course to the oxygen isotope recorded on the same samples of the ODP 976. Its already written in the text line 15.

We agree with the reviewer about the climatic optimum that is wetter and cooler in the Mediterranean area around 6 ka. In our study, the term of mid Holocene climate optimum corresponds to the maximum forest extension around 8 ka. We can precise the sentence.

Line 21, the reviewer writes that the climate reconstruction shows temperature negative anomalies compared to the modern core top sample, so the term warm is

rather misleading here. We agree with the beginning of this remark, but we use here the term warm by comparison with the climate changes occurred before.

Referee states that the anomaly of 0-100 mm is unlikely to be significant and that a validation of the method is required.
We are aware that the precipitation anomaly of 0 to 100 mm at 6 ka corresponds to the limits of the method but the purpose was to point out that our values were similar to other data-based climate reconstructions and GCMs simulations (e.g. Wu et al., 2007). A validation of the method (and also of two other methods) against the modern training set is fully described in Dormoy et al., this issue.

Referee states that we suggest a decline of forest cover when a major taxa (*Pinus*) is excluded from the reconstitution while we may have a pine forest.

When we talk about the forest decline, we mean that the *Quercus deciduous* percentages decrease during the considered period. So, a pine forest may develop at this time. However, the diagram included *Pinus* (see additional data) indicate that *Pinus* remains in regular percentages during the Holocene while herbs and mediterranean taxa percentages increase. This could not correspond to a pine forest but more to the extension of the Mediterranean xerophytic woodlands.

Last point line 28, a slight cooling trend from 7000 to 4000 cal BP is depicted in the figure 4. There is no ambiguity here as the reviewer said, but we admit that this cooling (of about 2 °C) is not very visible given the figure scale.

p. 685 referee says: is there evidence for interpretation of *Artemisia* as anthopogenic?
Our interpretation of the *Artemisia* peak as anthopogenic at the top of the sequence is a first hypothesis. We have no other explanation of such increase during the most recent period of the diagram.

p. 685 referee states that our correlation between the events depicted in the Alboran sea with the events also depicted in other sites is possible because we ignore the chronology of most of the other events shown at the other sites.

We agree with the reviewer that the chronological control is a very important point to correlate past events but we consider that it is not the purpose of this paper to develop our own chronology for the other Mediterranean sites. Each site chronology has already been extensively described by the authors in the papers referred in the text. We have used papers with calibrated ages to see if there is a consistency between the events evidenced here in the Alboran sea and the previous records showing vegetation/climate events during the Holocene.

p. 686, the referee mentioned the difference in amplitude changes between marine SST record and temperature reconstruction deduced from pollen analyses.
The amplitudes of the temperature changes based on alkenones and vegetation are not comparable sensu-stricto given that the two proxies are linked to different biological processes. We only want to show the similar temperature trends, not the amplitudes.

Remarks on figures and tables

Table 2 - author criticize the selected temporal resolution of events
We don't understand this remark. We have to refer to the ages and temporal resolution already published in the cited papers. We don't take the responsibility to change them. For the ODP976 site, we have proposed ages according to our age model.

Table 3 and figure 5 - The referee asks us to change the table 3 by a figure as figure 5.
What does the reviewer mean? Table 3 and figure 5 are complementary and already correspond to the request of the referee.

Figure 1 – The referee states it is useful to show the LGM coastline and the bathymetry.
We can add LGM coast line in the figure but we think that it does not bring a helpful information because the LGM coast line will be drawn very close to the present day one (see comments above about the narrow shelf). The figure 1 will become unclear

with the addition of the bathymetry. So we could propose to add a new figure with the bathymetry.

Figure 2 - The referee would like to add a diagram showing the percentages of arboreal to non arboreal pollen.
The synthetic pollen diagram including *Pinus* (additional data) shows the AP/NAP curve. It is of note that when *Pinus* is excluded, the AP/NAP curve (fig. 4) fits well with the temperate deciduous forest curve.

Figure 3 – In the marine cores, we are never sure that the marine core corresponds really to the modern one. Here, in the ODP 976 the first sample correspond to the depth 5 cm. It is not the top core. This probably could explain the discrepancies between the seasonal temperatures convergence.

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