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# Contrasting impacts of Dansgaard–Oeschger events over a western European latitudinal transect modulated by orbital parameters

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ABSTRACT

Terrestrial and marine proxies (pollen, planktic and benthic foraminiferal oxygen isotopes, alkenone- and foraminifer-derived sea-surface temperatures (SSTs), ice-rafted debris) from IMAGES deep-sea cores MD95-2042 and SU81-18 (37°N, 10°W), MD99-2331 and MD03-2697 (42°N, 9°W), and MD04-2845 (45°N, 5°W) show that western European and offshore environments were strongly affected by Dansgaard–Oeschger (D–O) and Heinrich (H) events. We concentrate here on latitudinal variability in the forest cover extent and composition of western Europe during the succession of D–O events, showing new pollen records for core MD04-2845 and for marine isotopic stages (MIS) 3 and 4 of core MD99-2331. In general, cold SSTs characteristic of Greenland stadials were contemporaneous with the expansion of semi-desert or steppic vegetation while Greenland interstadials were synchronous with the expansion of forest. Our data reveal that the amplitude of Atlantic and Mediterranean forest expansions differs for any given D–O warming during the glacial period (74–18 ka). In the western Mediterranean, D–O 16–17 and D–O 8 and 7 (corresponding to minima in precession) were associated with strong expansion of forest cover contrasting with weak expansion of forest cover during D–O 14 and 12; the opposite pattern is revealed at the Atlantic sites. Further north, the strongest Greenland warmings are recorded for D–O 19, 11 and 8. This contrasting latitudinal climatic scenario is compared with other northern hemisphere records, revealing similarities between the Mediterranean climate and the Asian monsoon regime, which may relate to a summer atmospheric teleconnection between the two regions comparable to the present-day situation. Parallels between Mediterranean climate enhancement and peaks in global methane ($CH_4$) during the last glacial period suggest a significant role of monsoon activity in determining $CH_4$ emission from wetlands.



## 1. Introduction

Many studies have provided evidence for the hemispheric extent of the D–O events (review by Voelker, 2002). Low-latitude records have shown that high-latitude temperature changes are associated with shifts in the ITCZ locations modifying climate in the tropical belt (e.g. Peterson et al., 2000). The wide geographical impact of D–O events is moreover supported by the high-resolution methane ($CH_4$) record from the analysis of air bubbles in polar ice cores showing increases during the D–O warming events (Brook et al., 1996). However, a number of questions remain about the regional expression of D–O events. For example, were the D–O events associated with a large temperature change in Greenland also characterized by large climate changes at lower latitude? If D–O events do not have a similar global expression, what underlies the regional differences? A related problem is the identification of the major $CH_4$ sources during the succession of D–O events: while it is accepted that the major $CH_4$ sources were located in the northern hemisphere during the last glacial epoch, their precise location is still under debate (Brook et al., 1996; Dällenbach et al., 2000). Modelling studies suggest that the strongest changes in wetland productivity in response to climate changes took place in the high northern latitudes (Van Huissteden, 2005) but the modulation of the D–O signal in the $CH_4$ record by precession suggests a mid-low latitude origin for this signal (Flückiger et al., 2004). Answering these questions requires

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climatic records of the impact of D–O events across a northern latitudinal transect.

Cycles of forest cover expansion and contraction are observed at orbital and sub-orbital timescales in many European terrestrial pollen records during the Quaternary (Tzedakis, 2005). However, only a small number of North American and Asian pollen records reveal D–O variability (Igarashi and Oba, 2006; Feng et al., 2007; Jiménez-Moreno et al., 2007). Increases in forest cover extent in the European temperate region are considered an unambiguous indication of past increases in temperature and precipitation. However, many poorly dated and sometimes low-resolution local sequences do not allow the reliable identification of the vegetation and climate response to the specific D–O events of the Last Glacial Period (e.g. Pons and Reille, 1988; Follieri et al., 1998). In contrast, marine pollen records which incorporate the identification of D–O and H events based on the high-resolution analysis of planktic foraminiferal $\delta^{18}$O, ice-rafted debris, *N. pachyderma* (s) and sea-surface temperatures (SSTs) have permitted the accurate characterization of the response of the southern European forest cover to D–O climatic variability (Combourieu Nebout et al., 2002; Sánchez Goñi et al., 2002; Masson-Delmotte et al., 2005a; Sánchez Goñi, 2006).

Here, for the first time, we present the vegetation response to millennial-scale climate changes over a western European latitudinal transect. The southernmost location on this transect (37°N) is represented by the well-dated MD95-2042 and SU81-18 twin palaeoclimatic sequences (Fig. 1). These sequences document in detail the climate evolution of the ocean and southwestern Iberia (Bard et al., 1987; Lézine and Denèfle, 1997; Sánchez Goñi et al., 1999, 2000; Shackleton et al., 2000, 2002, 2003; Thouveny et al., 2000; Pailler and Bard, 2002; Turon et al., 2003; Sánchez Goñi, 2006) over the last climatic cycle and marine isotopic stage (MIS) 2 and 1, respectively. Climatic variability further north is revealed by fluctuations in pollen-derived Atlantic forest cover from the twin cores MD03-2697 and MD99-2331 located at 42°N off northwestern Iberia (Fig. 1). Data published so far illustrate the direct relationship between vegetation, the climate of northwestern Iberia and oceanographic changes during MIS 5, 2 and 1 (Gouzy et al., 2004; Sánchez Goñi et al., 2005; Naughton et al., 2007). In this work, we present new results concerning MIS 4 and 3. In addition, we show here the first multiproxy study of the interval 136–30 ka of core MD04-2845 retrieved at 45°N in the Bay of Biscay which represents the northernmost location of our transect. These vegetation and climate records covering European and eastern North-Atlantic mid-latitudes are compared with quantitative temperature reconstructions further north from Greenland and the Asian monsoon and $CH_4$ concentration records.

## 2. Environmental setting

### 2.1. Climate and vegetation

The climate of western Europe, including the Mediterranean region (36–40°N), is mainly controlled in winter by the North Atlantic oscillation (NAO) index which affects the strength and direction of the northwesterlies (Hurrel, 1995; Trigo et al., 2004). This index is defined as the pressure gradient between the Icelandic lows and the Azores highs. A high (positive) index pushes the westerlies towards the north, triggering dry winters in the Mediterranean region and high rainfall in northern Europe, and is associated with cold temperatures in Greenland. The reverse situation occurs when the NAO index is weak (negative), with increased precipitation in southwestern Europe and relative warming in Greenland. In summer, strong anti-cyclonic cells develop over the sub-tropical eastern Atlantic Ocean, producing the characteristic dry season in the western Mediterranean region (Rodwell and Hoskins, 2001; Eshel, 2002; Alpert et al., 2006). At latitudes above 40°N, these atmospheric configurations result in a wet climate throughout the year, with annual precipitation ~1000 mm, and a mean annual temperature of 10 °C allowing the development of the Atlantic forest (Ozenda, 1982). This forest, reaching up to 60°N, is mainly composed at low elevations of deciduous *Quercus* (oak) associated with *Betula* (birch) on acid soils, or with *Carpinus* (hornbeam) on basic soils. Deciduous *Quercus* with *Fagus* (beech) colonize higher elevations where

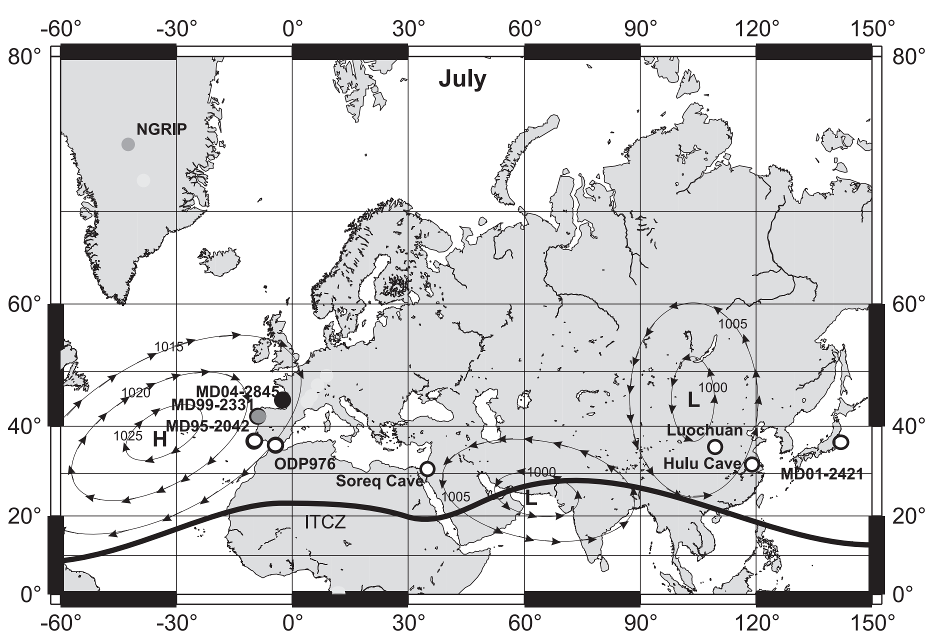


**Fig. 1.** Location of the most important sites mentioned in the text covering the Last Glacial Period. Black circles: new data. Grey circles: partially new data (see Section 3); white circles: published data. Bold wavy line represents the Intertropical Convergence Zone (ITCZ). Also shown are sea-level pressure cells (mb) and surface winds during a situation of present-day summer (July) south Asian monsoon (modified after www.physicalgeography.net/fundamentals/7p.html; data: NECP/NCAR Reanalysis Project, 1959–1997 Climatologies).