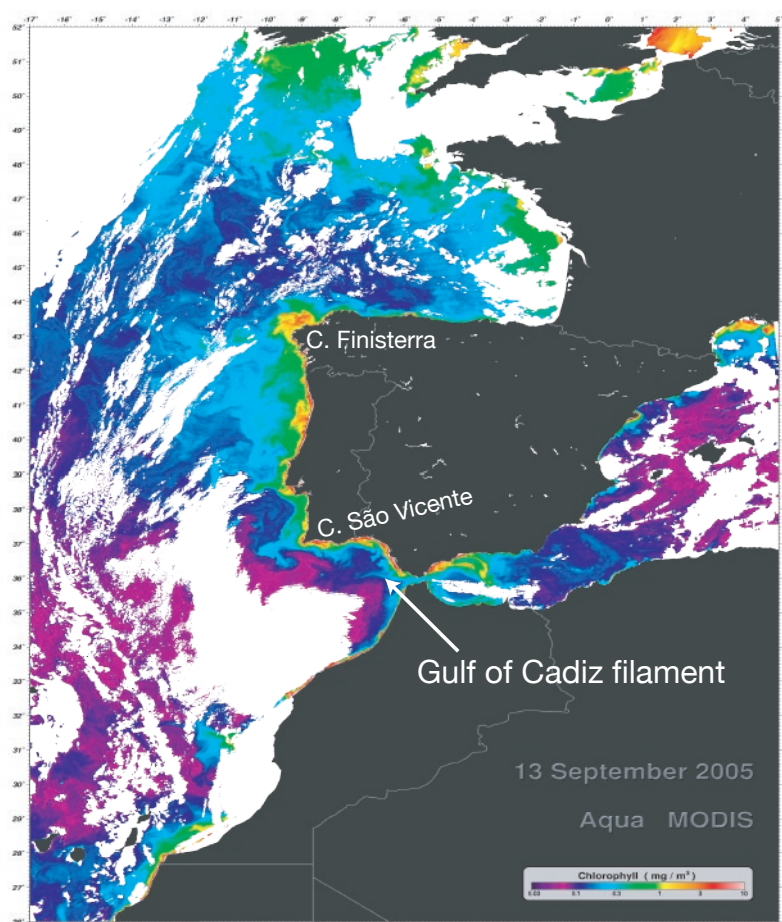
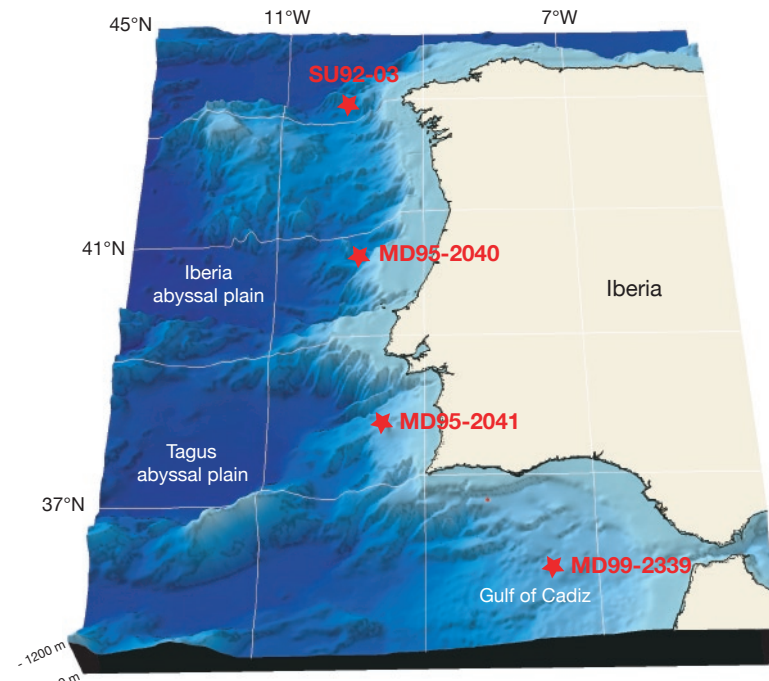


Southward Shift of Export Productivity Maxima During Glacial Cold Periods off the Western Iberian Margin

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The western Iberian margin marks the northern boundary of the North Atlantic's eastern boundary upwelling system. Nowadays, upwelling along this margin occurs mainly during the period from May to late September/ early October. Previous studies have shown that increased trade wind strength during the Last Glacial Maximum (ca. 21±2 ka ago) led to enhanced upwelling related productivity along the Portuguese and Northwest African margins. Here we present export productivity reconstructions for the last 48 ka (ka = kilo/ thousand Anno years) along a core transect from 43°N to 36°N with particular focus on the impact of North Atlantic cooling events on the productivity along this margin.

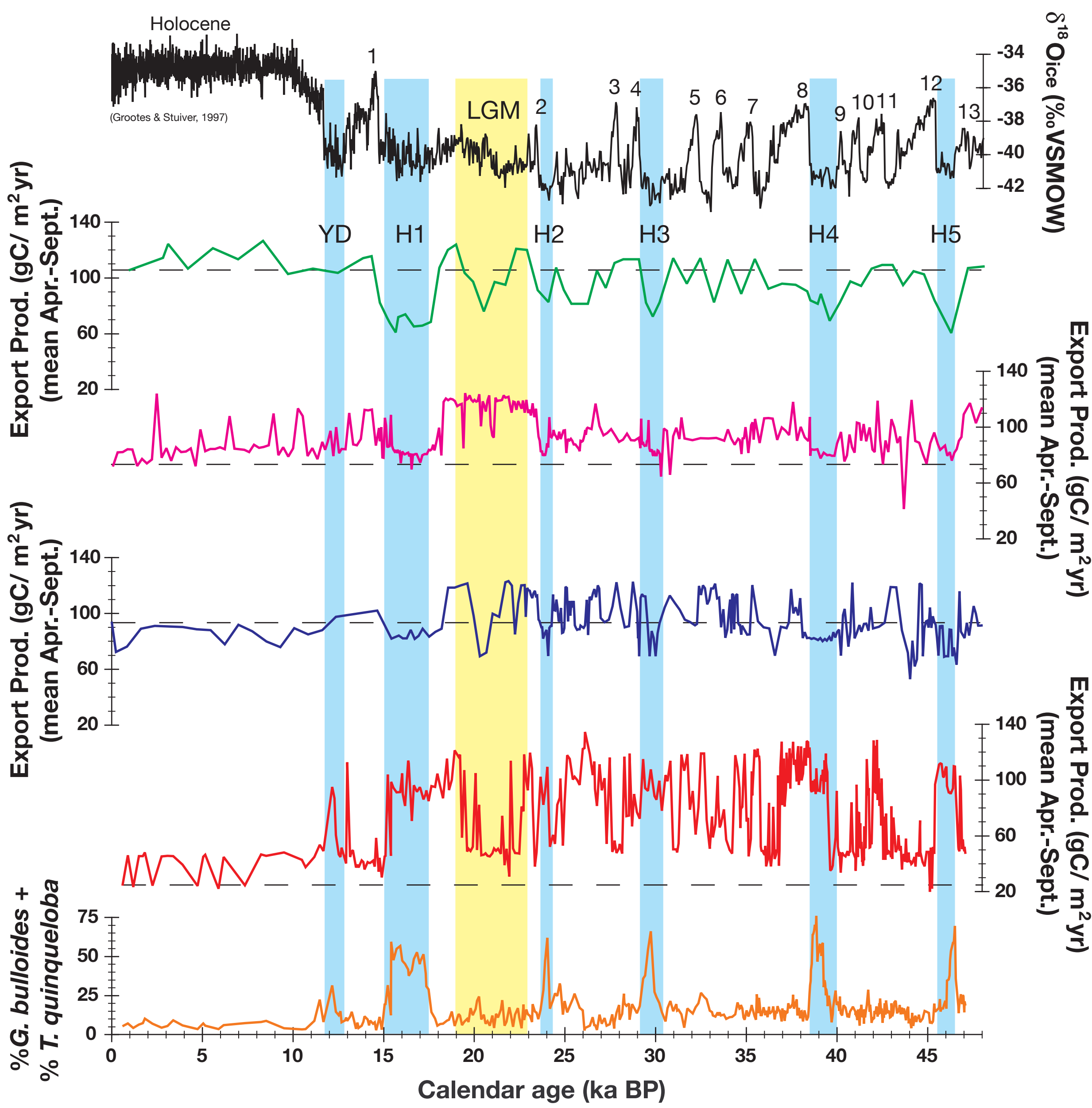
Cores SU92-3, MD95-2040 and MD95-2041 monitor changes in the upwelling filaments in their region, while core MD99-2339 is located in the oligotrophic waters of the central Gulf of Cadiz. Export productivity estimates are based on the respective planktonic foraminifera fauna and calculated with a modern analog transfer function (SIMMAX) (Salgueiro et al., submitted). Modern analog export productivity values are derived from the modern primary productivity data of Antoine et al. (1996) that was transferred into export productivity values following Eppley and Petersen (1979). Export productivity values shown here are means for the interval from April to September (spring and summer).

During glacial warm periods like the Greenland (Dansgaard-Oeschger) interstadials 1 - 13, when climatic conditions differed less from modern ones than during the cold periods, upwelling occurred along the western Iberian margin. The exception to the rule is Interstadial 8 when productivity in the Cape Finisterra filament did not increase. On the other hand, productivity was high in the central Gulf of Cadiz (MD99-2339). In general, the modern gradient in export productivity – with higher values in the north – also existed during warm periods of the last glacial and absolute values were either in the modern range or slightly higher. Except for Interstadial 8, interstadial periods were associated with productivity minima in the central Gulf of Cadiz – in agreement with modern day conditions. Glacial export productivity values were, however, 20 gC/m² yr higher than the more recent ones indicating that glacial nutrient levels were higher than modern ones.

During the glacial cold periods – the Greenland stadials and Heinrich events – subpolar surface waters advanced as far south as the Gulf of Cadiz, carrying melting icebergs with them during Heinrich events. Off the northern Iberian margin the cold and fresher surface waters during Heinrich events suppressed upwelling resulting in the lowest export productivity values of the last 48 ka, in particular off Cape Finisterra. The less cold stadial events were also associated with lower productivity off Cape Finisterra, while the signal is more mixed in the filament off Porto. Off Sines, export productivity was reduced during some stadial and Heinrich events, but not all of them. In the Gulf of Cadiz, on the other hand, export productivity peaked during Heinrich events and Greenland stadials with values similar for both. Values reached >100 gC/m² yr, more than triple the interstadial or recent productivity. Increased productivity in the Gulf of Cadiz seems to be linked to a persistent Strait of the Gibraltar filament and potentially frontal upwelling during Heinrich events.

During the Last Glacial Maximum (LGM), export productivity was high along the western Iberian margin and low in the Gulf of Cadiz. However, both off Cape Finisterra and off Sines, export productivity was reduced for the interval between 21.5 and 20 ka hinting to changing climate boundary conditions during the LGM.

Variations in Export Productivity



GISP2 ice core/
Greenland

SU92-3 43.2°N 10.1°W
today: seasonal upwelling

MD95-2040 40.6°N 9.9°W
today: seasonal upwelling

MD95-2041 37.8°N 9.5°W
today: seasonal upwelling

MD99-2339 35.9°N 7.5°W
today: oligotrophic waters

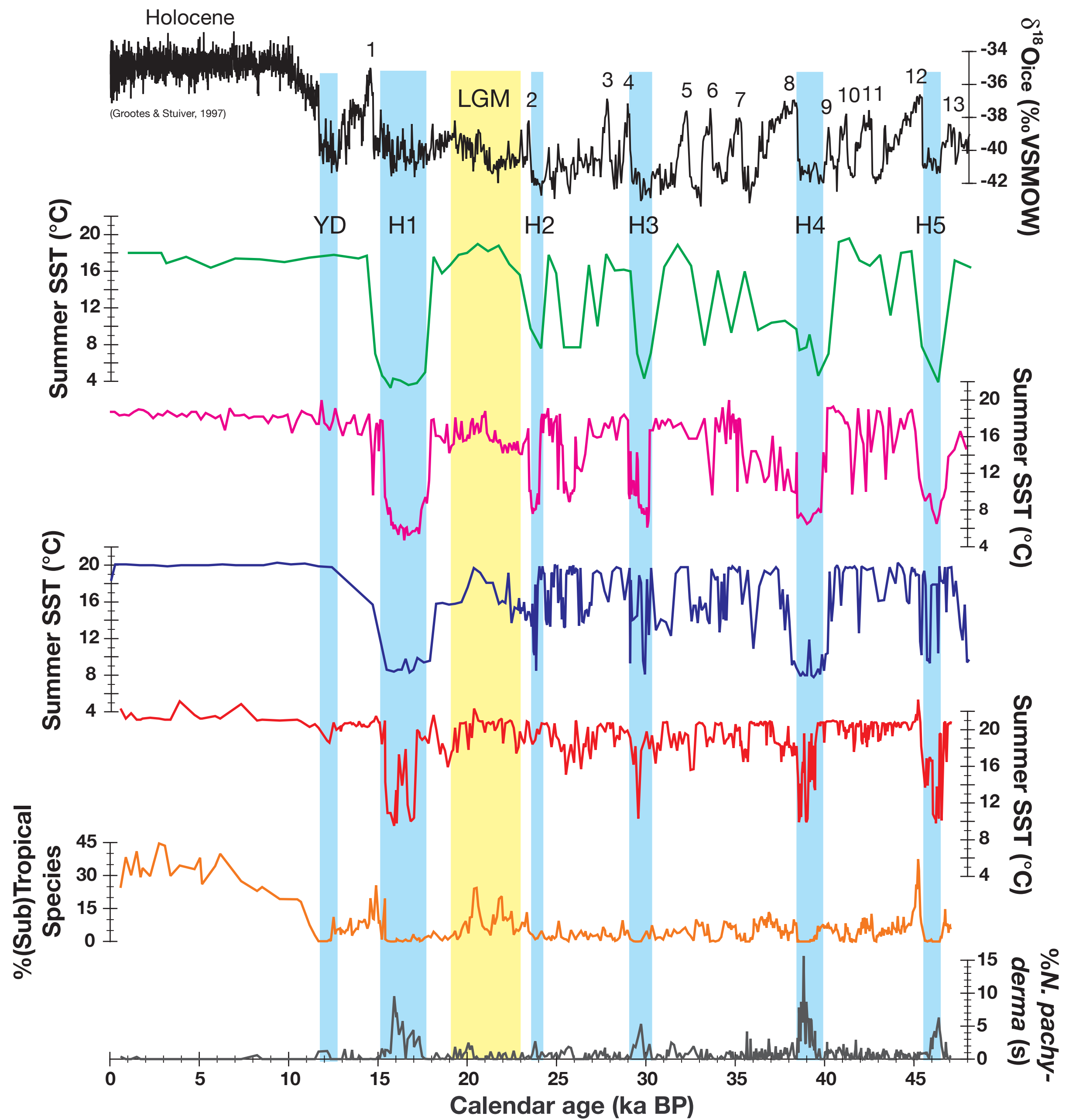
Off Cape Finisterra, export productivity was on a similar level to today during glacial warm periods. During glacial cold periods, production was reduced with a stronger impact by the Heinrich meltwater events.

Off Porto, glacial export productivity values were higher than modern ones but also here Heinrich events led to productivity minima.

Off Sines, the pattern is similar to the Porto region, but overall productivity values did not increase as much as off Porto.

In the Gulf of Cadiz, glacial productivity was always higher than today indicating that the climate conditions allowed the replenishment of nutrient during deep winter mixing. Glacial warm periods were associated with lower productivity, possibly linked to fall and winter blooms like today. The exception is Interstadial 8 (38.3 - 37 ka) when productivity remained high. During this interstadial the westerlies wind belt must have been shifted southward, which resulted in suppressed upwelling off Cape Finisterra and increased upwelling in the Gulf of Cadiz. Glacial cold periods - with the exception of the LGM – record the highest productivity values in the whole record. The high productivity implies a more constant presence of the Strait of Gibraltar filament and thus more persistent westerlies at this latitude, probably linked to the southward shift of the Polar Front. During Heinrich events, the high production is associated with a dominance of *G. bulloides* and *T. quinqueloba* in the planktonic foraminifer fauna and this could indicate also frontal upwelling contributing to the high productivity.

Surface water conditions



GISP2 ice core/
Greenland

SU92-3 43.2°N 10.1°W
off Cape Finisterra

MD95-2040 40.6°N 9.9°W
Porto seamount

MD95-2041 37.8°N 9.5°W
off Sines

MD99-2339 35.9°N 7.5°W
Central Gulf of Cadiz

Holocene (last 11 ka) sea surface temperatures (SST) were relative stable along the margin with a high contribution of Azores current derived sub-tropical waters in the Gulf of Cadiz.

During Heinrich events, when icebergs that broke off the ice sheets on North America, Greenland, Scandinavia and Britain traveled across the North Atlantic and left ice-rafted debris and meltwater behind, SST off Iberia cooled by 6 to 10°C with stronger cooling on the northern margin, which is located within the major ice-rafting belt. During most Heinrich events subpolar waters penetrated as far south as the Gulf of Cadiz (also evidenced by the presence of the polar foraminifer species *N. pachyderma* (s)), but cooling on the southern margin was less and often also for shorter periods.

Cooling during other Greenland stadials, when ice-rafting was more restricted to the subpolar gyre and the Nordic Seas, SST off Iberia cooled by 4-6°C. However, between 45 and 40 ka, colder surface waters did not reach the Gulf of Cadiz. As during Heinrich events, southward penetration of subpolar waters is associated with a southward shift of the Polar Front.

During most of the glacial period the Gulf of Cadiz acted like a “warm pool”. However, the lower % of subtropical and tropical species in the planktonic foraminifer fauna shows that overall hydrographic differed from modern and Holocene (= interglacial) ones.