Global patterns of biomass burning during the last glacial period

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Sedimentary charcoal records covering part of the last glacial period were synthesized to analyse the response of global biomass burning to rapid climate changes during the so-called Dansgaard-Oeschger “cycles”.

The Global Palaeofire Working Group (http://www.bridge.bris.ac.uk/projects/QUEST_IBGP_Global_Palaeo fire_WG) has updated a database over 700 individual sedimentary charcoal records worldwide (GCD_V2: Daniau et al., in prep). This database provides a powerful tool for studying changes of biomass burning at global and regional scale (Power et al., 2008; Power et al., in press). A focused study of fire records covering the last glacial period (73.5-14.7 ka) allows examination of the response of biomass burning to the rapid climate changes (within 10-200 years) of large magnitude that occur during Dansgaard-Oeschger (D-O) cycle. D-O cycles are characterized in Greenland by a marked warming followed by a cooling. D-O warming event refers here to the initial rapid warming (Sánchez-Goñi and Harrison, in press). The Greenland Interstadial (GI) corresponds to the D-O warming event followed by a first slow phase of cooling. GI end by a precipitous cooling (refers here as D-O cooling event). Greenland Stadial (GS) correspond to the final slow phase of cooling.

Methodology

Sixty-seven sites (11 marine and 56 terrestrial, Figure 1) which have records for some part of the last glacial period were extracted from the database and used to analyse changes in global biomass burning (Daniau et al., in press). Those records present a broad range of quantification methods and units. For the majority, charcoal counts are expressed as concentration/influx of number of particles or area measurements made
on pollen slide or using image analysis. Few records were studied using chemical
assay such as total organic fraction and black carbon concentration, or expressed as
Charcoal/Pollen ratio and percentage dry weight. The data were therefore
standardized to facilitate comparisons between sites and through time. Original
charcoal data (abundance or concentration) were transformed and rescaled to obtain a
common mean and variance for all sites, and detrended to remove orbital time-scale
variability. A Superposed- Epoch Analysis (SEA) was performed on the detrended
charcoal data to examine the pattern of fire around the time of key events, aligning the
charcoal deviations on the ages of the D-O warming and D-O cooling events (Figure
2). When the SEA summary curves fall outside a confidence band determined by
Monte Carlo methods, a significant or systematic response of the variable to some
externally determined event is inferred.

Fire and temperature
Figure 2 illustrates SEAs for the NGRIP oxygen-isotope data and for the global
composite-curve of charcoal data to illustrate the nature of the abrupt climate changes
and the response of global biomass burning to the abrupt warming at the beginning of
the Greenland Interstadials (GI) and the most rapid interval of cooling that delimits
the beginning of Greenland Stadials (GS). A general increase in charcoal levels
during warming (Fig. 2A and B) and a decrease in charcoal levels during cooling
(Fig. 2C and D) suggest a strong correlation between biomass burning and
temperature. Biomass burning increases rapidly during D-O warming events, and
reaches a peak at nearly the same time as temperature. In contrast, biomass burning
decreases significantly at the onset of the GS and then returns to “background” levels
while temperatures remain low (Figs. 2C and D). The response of biomass burning to
the warming events is not the simple inverse of the response to cooling, suggesting a
nonlinear relationship between biomass burning and climate. The association between
rapid warming and increases in biomass burning seen during the glacial period has
also been observed during the last deglaciation at the termination of the Younger
Dryas chronozone (Marlon et al., 2009).

Fire regime and fuel
Changes in charcoal concentration have been described from two marine records off
the European margin and interpreted as changes in biomass burning caused by variations in fuel availability during D-O “cycles” (Daniau et al., 2007; Daniau et al., 2009). Recent syntheses of the glacial vegetation history of Europe, Japan and adjacent parts of the Asian mainland, North America and the tropical regions of South America and Africa (Fletcher et al., in press; Takahara et al., in press; Jiménez-Moreno et al., in press; Hessler et al., in press) suggest that these rapid climate changes had an impact on vegetation globally. Warmings are generally accompanied by shifts from open vegetation to forest or increases in tree abundance. The similarity of variations in global levels of fire and regional vegetation patterns suggest that climate-driven changes in vegetation and biomass productivity (fuel) caused changes in global biomass burning during the last glacial period. During the D-O warming events and GI, increased productivity led to increased fuel availability and promoted fire. Conversely, decreased fire in response to rapid cooling was a consequence of reduced fuel loads from lower productivity. Increase in biomass burning to levels similar to pre-cooling fire regimes during GS may be caused by temperature-driven forest die-back, which would create conditions for increased fire.

Conclusion and outlook
This effort to synthesise charcoal records from the last glacial period allows us to explore changes in global fire regimes during a period of high millennial-scale climate variability. Biomass burning at the global scale apparently responded rapidly to variations in temperature, as recorded in the Greenland ice core. Increases in biomass burning were synchronous with warming whereas decreases in burning followed by a return of fire to previous levels accompanied cooling. Changes in vegetation productivity and fuel availability may explain the inferred variations in biomass burning during D-O cycles. Additional fire records however are needed to derive statistically robust results at a regional scale and better examine fire and climate interactions. Global biomass burning responds to temperature variation, but we also seek to explore the control of seasonality of temperature and precipitation on fire, playing a role in shaping the vegetation (type of biomes, abundance of fuel) but also on the flammability of fuel. We intend to extend the database by adding worldwide long and high-resolution marine and terrestrial charcoal records, in particular from poorly documented North
America, Africa and a large part of Eurasia. There is a great potential for the use of long marine records to document regional fire where terrestrial records are not available. Characterisation of the role of temperature and precipitation on fire would benefit from the close comparison between fire and well-documented high resolution changes in vegetation during D-O rapid climate changes. This could be done in particular in Europe where these rapid changes lead to an alternation between steppe-like environments and different forest biomes.

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Figure 1: Location of marine and terrestrial sites with charcoal records covering all or part of the last glacial period. Figure modified from Daniau et al., in press.
Figure 2:

Superposed Epoch Analysis (SEA) composites illustrating changes in biomass burning associated with D-O warming event (A and B) and D-O cooling event (C and D) with x-axis corresponding to time (before event on the left (negative values) and after event on the right (positive values)). The NGRIP δ¹⁸O SEA composite record for the D-O cycles is shown for comparison. The NGRIP oxygen-isotope data (Wolff et al., in press) were summarized using 20-year-wide bins (the resolution of the data), and also using the same 80-year-wide bins used for charcoal data, for comparison with the SEA of the charcoal data. The confidence intervals are given by Monte-Carlo simulation using the timing of the 20 D-O warming events and 19 D-O cooling events. Figure modified from Daniau et al., in press.
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