The ACER pollen and charcoal database: a global resource to document vegetation and fire response to abrupt climate changes during the last glacial period


DOI
10.5194/essd-9-679-2017

Publication date
2017

Document Version
Final published version

Published in
Earth System Science Data

License
CC BY

Link to publication

Citation for published version (APA):
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Abstract. Quaternary records provide an opportunity to examine the nature of the vegetation and fire responses to rapid past climate changes comparable in velocity and magnitude to those expected in the 21st-century. The best documented examples of rapid climate change in the past are the warming events associated with the Dansgaard–Oeschger (D–O) cycles during the last glacial period, which were sufficiently large to have had a potential feedback through changes in albedo and greenhouse gas emissions on climate. Previous reconstructions of vegetation and fire changes during the D–O cycles used independently constructed age models, making it difficult to compare the changes between different sites and regions. Here, we present the ACER (Abrupt Climate Changes and Environmental Responses) global database, which includes 93 pollen records from the last glacial period (73–15 ka) with a temporal resolution better than 1000 years, 32 of which also provide charcoal records. A harmonized and consistent chronology based on radiometric dating (\(^{14}\text{C}, {^{234}}\text{U}/^{230}\text{Th}, \text{OSL}), {^{40}}\text{Ar}/^{39}\text{Ar}-\text{dated tephra layers}) has been constructed for 86 of these records, although in some cases additional information was derived using common control points based on event stratigraphy. The ACER database compiles metadata including geospatial and dating information, pollen and charcoal counts, and pollen percentages of the characteristic biomes and is archived in Microsoft Access at https://doi.org/10.1594/PANGAEA.870867.

1 Introduction

There is considerable concern that the velocity of projected 21st-century climate change is too fast to allow terrestrial organisms to migrate to climatically suitable locations for their survival (Loarie et al., 2009; Burrows et al., 2011, 2014; Ordonez et al., 2013). The expected magnitude and velocity of 21st-century climate warming is comparable to abrupt climate changes depicted in the geologic records, specifically the extremely rapid warming that occurred multiple times during the last glacial period (Marine Isotope Stages (MISs) 4 through 2; 73.5–14.7 ka). The estimated increases in Greenland atmospheric temperature were 5–16 °C (Capron et al., 2010) and the duration of the warming events between 10 and 200 years (Steffensen et al., 2008). These events are a component of longer-term millennial-scale climatic variability, a pervasive feature throughout the Pleistocene (Weirauch et al., 2008); the events were originally identified from Greenland ice archives (Dansgaard et al., 1984) and in North Atlantic Ocean records (Bond and Lotti, 1995; Heinrich, 1988) and termed Dansgaard–Oeschger (D–O) cycles and Heinrich events (HE).

D–O events are registered worldwide, although the response to D–O warming events is diverse and regionally specific (see, e.g., Fletcher et al., 2010; Harrison and Sanchez Goñi, 2010; Sanchez Goñi et al., 2008) and not a linear response to either the magnitude or the duration of the climate change in Greenland. Given that the magnitude, length and regional expression of the component phases of each of the D–O cycles varies (Johnsen et al., 1992; Sanchez Goñi et al., 2008), they provide a suite of case studies that can be used to investigate the impact of abrupt climate change on terrestrial ecosystems.

The ACER (Abrupt Climate change and Environmental Responses) project was launched in 2008 with the aim of creating a global database of pollen and charcoal records from the last glacial period (73–15 ka) which would allow us to reconstruct the regional vegetation and fire changes in response to glacial millennial-scale variability and evaluate the simulated regional climates resulting from freshwater changes under glacial conditions. Although there are 232 pollen records...
covering the last glacial period worldwide, only 93 have sufficient resolution and dating control to show millennial-scale variability (Harrison and Sanchez Goñi, 2010). It was necessary to reevaluate and harmonize the chronologies of these individual records to be able to compare patterns of change from different regions. In this paper, we present the ACER pollen and charcoal database, including the methodology used for chronological harmonization and explore the potential of this data set by comparing two harmonized pollen sequences with other palaeoclimatic records. Such a comparison illustrates the novel opportunities for the spatial analyses of the impacts of global climate events using this research tool.

2 Data and methods

2.1 Compilation of the records

The ACER pollen and charcoal database includes records covering part of or all of the last glacial period with a sampling resolution from a few centuries to less than 1000 years, which allows the identification of centennial-scale vegetation changes similar in duration to the current global climate change. These records were collected as raw data, through direct contact with researchers or from the freely available European and African Pollen Databases. Four records were digitized from publications using the Grapher™ 12 (Golden Software, LLC) because the original data were either lost (Kalaloch: Heusser, 1972 and Tagua Tagua: Heusser, 1990) or are not publicly available (Lac du Bouchet: Reille et al., 1998 and Les Echets: de Beaulieu and Reille, 1984). These digitized records are available as pollen percentages rather than raw counts. All the records are listed and described in https://doi.org/10.1594/PANGAEA.870867.

2.2 Harmonization of database chronologies

The chronology of each of the records was originally built as a separate entity. In order to produce harmonized chronologies for the ACER database, decisions had to be made about the types of dates to use, the reference age for the “present” (b2k or the year 1950), the choice of calibration curve, the treatment of radiocarbon age reservoirs, and the software used for age-model construction.

Radiometric ages ($^{14}$C, $^{235}$U/$^{230}$Th, optically stimulated luminescence (OSL), $^{40}$Ar/$^{39}$Ar) and radiometrically dated tephras are given preference in the construction of the age models. The tephra ages were obtained either through direct $^{40}$Ar/$^{39}$Ar dating of the tephra or $^{14}$C dating of adjacent organic material (Table 1). When a radiometric or tephra date was obtained on a unit of sediment, the depth of the midpoint of this unit was used for the date in the age modeling. Both the age estimate and the associated errors (SD) are required for age-model construction. When the positive and negative standard deviations were different, the larger value was used for age-model construction. In cases where the error measurements on the radiometric dates were unknown (e.g., site F2-92-P29), no attempt was made to construct a harmonized age model.

Measured $^{14}$C ages were transformed to calendar ages, to account for the variations in the atmospheric $^{14}$C/$^{12}$C ratio through time. Radiocarbon ages from marine sequences were corrected before calibration to account for the reservoir effect whereby dates have old ages because of the delay in exchange rates between atmospheric CO$_2$ and ocean bicarbonate and the mixing of young surface waters with upwelled old deep waters. We used the IntCal13 and Marine13 calibration curves for terrestrial and marine $^{14}$C dates, respectively (Reimer et al., 2013), which are the calibration curves approved by the radiocarbon community (Hajdas, 2014). Although studies have shown that the radiocarbon ages of tree rings from the Southern Hemisphere (SH) are ca. 40 years older than Northern Hemisphere (NH) trees formed at the same time (Hogg et al., 2013), this difference is smaller than the laboratory errors on most of the $^{14}$C dates, and, since the Marine13 calibration curve does not distinguish between SH and NH sites, we use the NH IntCal13 calibration curve for all the records.

The Marine13 calibration curve includes a default 400-year reservoir correction. We adjusted this correction factor for all the 26 marine records included in the database using the regional marine reservoir age ($\Delta R$) in the Marine Reservoir Correction Database (http://calib.org/calib/). For 20 marine records, the correction factor was based on a maximum of the 20 closest sites within 1000 km to a specific site; for the remaining six marine records this factor was based on a maximum of the 20 closest sites within 3000 km. When $\Delta Rs$ were homogeneous, a value ±100 years, over this area we used the mean of the 10 sites within 100 km to provide a reservoir correction for the site. When there was heterogeneity in $\Delta R$ values within the 3000 km target area, we selected only the sites with homogeneous $\Delta R$ within 100–200 km. Temporal variations in $\Delta R$ were not taken into account since they are currently not well established for many locations.

For periods beyond the limit of $^{14}$C dating (~ 45 ka) and for the few records without radiometric dating, additional chronological control points were obtained based on “event stratigraphy”, specifically the identification of D–O warming events and MIS boundaries (Table 1). No assumption was made that core tops were modern for both marine and terrestrial cores. The ages of D–O warming events and those of the MIS boundaries were based on the stratigraphy of core MD95-2042, from the southern Iberian margin (Table 1). The similarity of the planktonic foraminifera $\delta^{18}$O record from MD95-2042 to the $\delta^{18}$O record from Greenland allowed us to match ages of individual D–O cycles, while the benthic foraminifera $\delta^{18}$O record from MD95-2042 allowed us to match ages of MIS boundaries (Shackleton et al., 2000). Both D–O and MIS ages were directly transferred to the MD95-
Table 1. Harmonized control points used for age models when radiometric ages ($^{14}$C, OSL, $^{40}$Ar/$^{39}$Ar, $^{234}$U/$^{230}$Th) were not available.

<table>
<thead>
<tr>
<th>Event stratigraphy</th>
<th>GICC05 b1950 age ka</th>
<th>Tephra layers</th>
<th>ACER chronology age $^{14}$C</th>
<th>ACER age ka</th>
<th>Uncertainties $^{11,27}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>K-Ah$^{12}$</td>
<td>6.28 6.84</td>
<td>8.53</td>
<td>130</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Mazama Ash$^{13}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotoma$^{14}$</td>
<td>10$^{3}$</td>
<td></td>
<td></td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>U-Oki$^{15}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Onset Holocene</td>
<td>11.65 11.65</td>
<td>18.88</td>
<td>21</td>
<td>230</td>
<td></td>
</tr>
<tr>
<td>Rotorua$^{14}$</td>
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<td></td>
<td></td>
<td>50</td>
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<tr>
<td>MIS 1/2 D–O 1</td>
<td>14.6 14.6</td>
<td>14.7</td>
<td>93</td>
<td>95</td>
<td></td>
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<tr>
<td>Rerewhakaaiai$^{16}$</td>
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<td>NYT$^{17}$</td>
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<td>Sakate$^{18}$</td>
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<td>Y-2$^{19}$</td>
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<td></td>
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<tr>
<td>Kawakawa/Oruanui$^{20}$</td>
<td>21.30 21.30</td>
<td></td>
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<td>MIS 2/3 D–O 2</td>
<td>23.29 23.29</td>
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<tr>
<td>D–O 3</td>
<td>27.73 27.73</td>
<td></td>
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<tr>
<td>D–O 4</td>
<td>28.85 28.85</td>
<td>24.83</td>
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<td>AT$^{12}$</td>
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<td>313.25</td>
<td>32.45</td>
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<td>D–O 5</td>
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<tr>
<td>D–O 6</td>
<td>33.69 33.69</td>
<td>33.69</td>
<td>606</td>
<td>661</td>
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<tr>
<td>D–O 7</td>
<td>35.43 35.43</td>
<td>35.43</td>
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<tr>
<td>TM-18</td>
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<td>38.17</td>
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<td>Y-5$^{19}$</td>
<td>39.28$^{3}$</td>
<td>39.28$^{3}$</td>
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<td>D–O 9</td>
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<td></td>
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<td>D–O 10</td>
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<td>817</td>
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<tr>
<td>D–O 11</td>
<td>43.29</td>
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<td>868</td>
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<tr>
<td>D–O 12</td>
<td>46.81</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breccia zone$^{21}$</td>
<td>43.29 43.29</td>
<td>46.81</td>
<td>955</td>
<td>956</td>
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</tr>
<tr>
<td>D–O 13</td>
<td>49.23</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>D–O 14</td>
<td>54.17</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>TM-19</td>
<td>553.25</td>
<td>55.75</td>
<td>2000</td>
<td>1196</td>
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<tr>
<td>D–O 15</td>
<td>55.75</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>D–O 16</td>
<td>58.23</td>
<td></td>
<td></td>
<td>1256</td>
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</tr>
<tr>
<td>MIS 3/4 D–O 17</td>
<td>59.39</td>
<td></td>
<td></td>
<td>1287</td>
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<tr>
<td>onset HS 6</td>
<td>64.6$^{9}$</td>
<td>64.6$^{9}$</td>
<td>1479</td>
<td>1518</td>
<td></td>
</tr>
<tr>
<td>D–O 18</td>
<td>65$^{9}$</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
The classical age-modeling approach in the CLAM software across deglaciation and stadial time periods. We therefore use accumulation rate very well, and such shifts are not uncommon (Parnell et al., 2008) do not handle sudden shifts in accumulation as radiocarbon determinations. The modern reference date is taken as 1950 AD (BP), since this is the reference date for the construction of the age model. Ages in 40Ar/39Ar or 40K/40Ar. The afforestation episodes were attributed to a D–O warming. These uncertainties limit the discussion of the timing of European tree colonization during a D–O warming. The uncertainties for the event-based ages up to D–O warming. Note that only a limited number of D–O events were used to constrain the age models of the European records (Supplement Table S1); i.e., not all the afforestation episodes were attributed to a D–O warming event. The uncertainties for the event-based ages up to D–O 17 are from data summarized in Wolff et al. (2010) and from AICC_2012 in NGRIP ice SD (Bazin et al., 2013) for older events. These uncertainties limit the discussion of the timing of European tree colonization during a D–O warming.

Non-radiocarbon dates are presented in the same BP notation as radiocarbon determinations. The modern reference date is taken as 1950 AD (BP), since this is the reference date for the GICC05 chronology (Wolff et al., 2010).

Bayesian age modeling (e.g., using OxCAL, Bchron or BACON) requires information about accumulation rates and other informative user-defined priors (Blaauw and Christen, 2011) that are difficult to obtain for the relatively long ACER records. Moreover, BACON and Bchron (Haslett and Parnell, 2008; Parnell et al., 2008) do not handle sudden shifts in accumulation rate very well, and such shifts are not uncommon across deglaciation and stadial time periods. We therefore use the classical age-modeling approach in the CLAM software (Blaauw, 2010), implemented in R (R Development Core Team, 2016), to construct the age model.

Several age models were built for each record using the calibrated distribution of the radiometric dates: (a) linear interpolation between dated levels; (b) linear or higher-order polynomial regression; and (c) cubic, smoothed or locally weighted splines (Supplement Table S1). For general guidance, we have selected the age model that has goodness-of-fit values that are among the lowest but that are not necessarily the lowest (Supplement Table S2). The linear interpolation model was favored because it is generally the most parsimonious solution for records with no age reversals. For regression and spline models, the selection of the model was based on a combination of visual inspection and goodness-of-fit values; this allows the selection of the model including most of the outliers and realistic changes in sedimentation rates. If none of the regression or spline models provided a better fit, we built age models after excluding outliers proposed by the original authors (Supplement Table S1). The database includes information on the single “best” age model and the 95 % confidence interval estimated from the 10 000 iterated age–depth models (weighted mean) for every sample depth.

### 2.3 The structure of the database

The ACER pollen and charcoal data set is archived in a Microsoft Access relational database. There are six main tables (Fig. 1).
Figure 1. ACER database structure in ACCESS format.

1. Site Metadata. This table includes the original site name, geographical coordinates (latitude and longitude in decimal degrees, elevation in meters above or below sea level) and additional metadata including site type (marine or terrestrial), basin size and catchment size. Basin size and catchment size determine the size of the area sampled by the record (or pollen source area: see Prentice, 1988) but are not always recorded in the original publication or known very accurately. A categorical classification (small, medium, large, very large) is recorded in the database where these categories are specified by ranges in square kilometers. The details of the original publication of the data are also given in this table.

2. Sample data. The table records the identification number of each sample (sample ID) at each site (site ID) and provides the depth of the sample (in centimeters from the surface). At only one site, core MD04-2845, a corrected depth is provided on which the new age model is based. The pollen count type (raw pollen count, pollen percentages given by the authors or digitized percentage) is also given. The original age of the sample according to the published age model when available and the age determined from the best CLAM model (the minimum and the maximum at 95%, the accumulation rate, and the type of model used to obtain this age) are given.

3. Pollen data. The pollen data are recorded as raw counts or as the pollen percentage of each pollen and spore morphotype identified. The table records the identification number of each sample (sample ID), the taxon name and count/percentage. The taxa names were standardized across cores with respect to the accepted use of terms such as type presented in different pollen determination key publications (e.g., Moore et al., 1991; Faegri et al., 1989), and abbreviations and obvious spelling mistakes were removed. The names are listed in a supplementary Excel file at https://doi.org/10.1594/PANGAEA.880501.

4. Charcoal data. The table records the identification number of each sample (sample ID). The charcoal data are recorded by depth (in centimeters from the surface), and information is given on the quantity and unit of mea-
measurement and on the data source. Charcoal abundance is quantified using a number of different metrics; for the majority of abundances, these are given in concentrations, and for a few of them, they are given in percentages.

5. Original dating information. This table contains information on dating for each core at each site. The core name from the original publication is given, and the table provides information on date type (conventional $^{14}$C, AMS (accelerator mass spectrometer) $^{14}$C, $^{234}$U/$^{230}$Th, OSL, $^{40}$Ar/$^{39}$Ar, annual laminations, event stratigraphy, TL (thermoluminiscence)), the average depth assigned to the data in the age-model construction, the dating sample thickness, laboratory identification number, material dated (bulk, charcoal, foraminifera, pollen, tephra, wood), measured radiometric age and associated errors. The marine reservoir age (and associated error) and the radiocarbon calibration curve used in the construction of the original age model, and the original calibrated age, are also given. Dates that are based on recognized events are also listed and identified by the name of the event (event name) and the type of record in which it is detected (tracer used). The column “is_used” corresponds to the dates used by the authors for building the original age models.

6. ACER dating information. The ACER dating information table duplicates the original dating information file, except that it provides information about the explicit corrections and the harmonized control points used to produce the ACER age models (Table 1). Specifically, it gives the calibration curve used (no calibration, IntCal13, Marine13) and the local reservoir age (and uncertainty) for marine cores.

The ACER database allows archiving multiple cores retrieved at the same site (site name followed by the name of the core). In such a case, an age–depth model is constructed for each core and archived in the database. Additional tables document the codes used in the main tables for, e.g., basin type, basin size, date type, material dated, calibration curve and biome percentage table, which includes selected biomes provided by the authors (Table 2). The taxa defining the pollen percentages of the main forest biomes are those originally published by the authors in the Quaternary Science Reviews special issue (Fletcher et al., 2010; Hessler et al., 2010; Jimenez-Moreno et al., 2010; Takahara et al., 2010). The taxa defining the pollen percentages of the main biomes from Africa (sites Mfabeni and Rumuku) Australia (sites Caledonia Fen and Wangoom) and New Zealand (site Kohuora) not included in this issue are described in the Supplement.

Each table of the ACCESS database is also available as .csv file: (a) site, (b) sample (original depth–age model and ACER depth–age model), (c) dating info (original dating information), (d) dating info ACER (harmonized dating information from this work), (e) pollen data (raw data or digitized pollen percentages; pollen percentages of different biomes) (Table 2), (f) unique taxa in database (list of all the identified taxa) and (g) charcoal data (raw or digitized).

3 Results

3.1 The ACER pollen and charcoal database

ACER database comprises all available pollen and charcoal records covering all or part of the last glacial period (73 to 15 ka) as of July 2015. It contains 93 well-resolved pollen records (≤1000 years between samples), 32 of which include charcoal data, from all the major potential present-day biomes (Fig. 2). There are 2486 unique pollen and spore taxa in the database.

Harmonized age models were constructed for 86 out of the 93 records (Supplement Table S2). The seven sites without harmonized age models are F2-92-P29 (no radiocarbon age errors available), Bear Lake (pollen was counted on one core but sample depths could not be correlated with the cores used for dating), EW-9504 and ODP 1234 (original age models based on correlation with another core, but tie point information was not available), Okarito Pakihi (no dating information available) and Wonderkrater borehole 3 (multiple age reversals). Lake Consuelo, Rice Lake and Wonderkrater have multiple cores (Consuelo: CON1 and CON2; Rice Lake: Rice Lake 79 and Rice Lake 81) but composite depth records were lacking. Given the focus of this study, age models were created only for Lake Consuelo CON1 and Wonderkrater borehole 4 (CON2 and borehole 3 only cover the Holocene). Age models are available for the two cores from Rice Lake, with a hiatus between the two records of about 2000 years (oldest sample at 16 000 cal yr BP in core 79 and youngest one at 18 000 cal yr BP in core 81). These two cores have to be merged prior to future data analysis. The well-known site of La Grande Pile (de Beaulieu and Reille, 1992) is not included in the ACER database because the high-resolution data are not publicly available, and the poor quality of the .pdf support precluded its digitalization. Other sequences, such as Sokli in Finland, were fragmented and could not be used (Supplement Table S1). These sites are shown at the bottom of the Supplement Table S1.

3.2 Harmonized vs. original age models

We generated a total of 774 different age models by applying the different models available in CLAM (linear interpolation, linear regression, 3 orders of higher polynomial regression, cubic spline, and two smooth splines at 0.3 and 0.6 of freedom and locally weighted spline with different smoothing) to each of the 86 sites compiled. The age models of 45 records are based on linear interpolation (Supplement Ta-
Table 2. Biomes for which the pollen percentages data are included in the ACER database. Bo forest: boreal forest; Te forest: temperate forest; WTe forest: warm temperate forest; Tr forest: tropical forest; Subtr forest: subtropical forest; SE Pine forest: southeastern Pine forest; Gr: grasslands and dry shrublands; Sav: savannah. In Europe, Te forest refers to Mediterranean and Atlantic forests.

<table>
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<tr>
<th>Europe</th>
<th>North America</th>
<th>Tropics</th>
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<th>New Zealand</th>
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<td>SE Pine Forest</td>
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Figure 2. Map with location of the 93 marine and terrestrial pollen sites covering part of or all the last glacial period (MISs 4, 3 and 2). Sites have better resolution than 1 sample per 1000 years. Present-day potential natural vegetation after Levavasseur et al. (2012).
The ACER database also has the potential to reconstruct land cover changes through time to evaluate changes in vegetation–albedo feedback, to recover the expansion and contraction of different taxa during the D–O cycles (i.e., using isolines), to perform spatial climatic reconstructions, and to evaluate climate and vegetation models dealing with the rapid climatic variability. The construction of vegetation and climate maps.
Figure 3. (a) Linear age model of the marine core MD95-2043 and (b) third-order polynomial age model of the terrestrial sequence Valle di Castiglione (Italy). Red line: original age model with the control points. Black line: harmonized age model based on radiometric dating and event stratigraphy. Blue: calibrated $^{14}$C distribution. Green: non-$^{14}$C age distribution ($\text{Ar}/\text{Ar}$, OSL, event stratigraphy). Grey shading: age uncertainties.

Figure 4. (a) Linear age model of the marine core ODP 1233 C and (b) linear age model of the terrestrial sequence Toushe (Taiwan). Red line: original age model with the control points. Black line: harmonized age model based on radiometric dating and event stratigraphy. Blue: calibrated $^{14}$C distribution. Green: non-$^{14}$C age distribution ($\text{Ar}/\text{Ar}$, OSL, event stratigraphy). Grey shading: age uncertainties.

for different time slices and evaluating model simulations can be continuously improved by implementing the ACER database version 1 (July 2015) with new chronologically harmonized sites.

4 Data availability

Data used for this study are available at https://doi.org/10.1594/PANGAEA.870867 (Sánchez Goñi et al., 2017).

5 Conclusions

The ACER pollen and charcoal database (ACER 1.0) comprises all available pollen and charcoal records covering part or all of the last glacial period, as of July 2015. We foresee future updates of the ACER database by the research community with newly published pollen and charcoal records. For consistency, age models for new sites should be constructed using the strategy described here.
Figure 5. Pollen (green: warm temperate forest; red: tropical forest) and charcoal (black) curves from six sites plotted against the harmonized age model.
Figure 6. Comparison of pollen sequences from the Toushe Basin (Taiwan) and the SW Iberian margin (cores MD95-2042 (Desprat et al., 2015; Sanchez Goñi et al., 2008) and SU 81-18 (23 500–10 000 cal years BP) (Lézine and Denéfle, 1997)) for the interval 73–23.5 ka. Green line: new harmonized age model; dashed red line: original age model. Grey vertical bands indicate the duration of GI 8, GI 16–17 and GI 19. Also shown are the comparison with the Greenland temperature record (black) (Huber et al., 2006; Landais et al., 2005; Sanchez Goñi et al., 2008), the atmospheric CH₄ concentration (blue) record (Chappellaz et al., 1997; Flückiger et al., 2004), compiled Hulu Cave δ¹⁸O speleothem records (PD in purple, MSD in green and MSL in blue) (Wang et al., 2001) and the precession index (Laskar et al., 2004). Note the mismatch in the timing of GI 19 between the Greenland and pollen harmonized age models and the chronology of Hulu Cave.
The harmonization of the ACER age models in the ACER 1.0 database increases the consistency between records by (a) calibrating all the radiocarbon dates using the recommended IntCal13 and Marine13 calibration curves, (b) using the same ages for non-radiometric control points and basing these on the most recent Greenland ice core chronology (GICC05), and (c) using the CLAM software to build the age models and taking account of dating uncertainties. While these harmonized age models may not be better than the original models, they have the great advantage of ensuring comparability between pollen and charcoal records from different regions of the world. As we have shown in the preliminary analyses of monsoon-related vegetation changes during D–O 8 and D–O 19, this will facilitate regional comparisons of the response to rapid climate changes.

The same strategy for age-model harmonization is now being applied to the sea-surface temperature records from the last glacial period that have been compiled by the ACER-INTIMATE group (http://www.ephe-paleoclimat.com/acer/ACER%20INTIMATE.htm). This will ensure that the terrestrial and marine databases share a common chronological framework, a considerable step towards improving our knowledge of the interactions between oceans and land that underlie the nature and timing of abrupt climatic changes.

The Supplement related to this article is available online at https://doi.org/10.5194/essd-9-679-2017-supplement.

Author contributions. MFSG, SD and ALD developed the harmonized age models, ALD developed the ACER database in ACCESS, FB participated in the construction of age models, and JMPM extracted the pollen percentage of the dominant biomes from ACER%20INTIMATE database (http://www.ephe-paleoclimat.com/acer/ACER%20INTIMATE.htm). This will ensure that the terrestrial and marine databases share a common chronological framework, a considerable step towards improving our knowledge of the interactions between oceans and land that underlie the nature and timing of abrupt climatic changes.

Acknowledgements. The members of the ACER project wish to thank the QUEST-DESIRE (UK and France) bilateral project, the INQUA International Focus Group ACER and the INTIMATE-COST action for funding a suite of workshops to compile the ACER pollen and charcoal database and the workshop on ACER chronology that allow setting the basis for harmonizing the chronologies. We thank Maarten Blauw for constructive discussions leading to the construction of age models. Josué M. Polanco-Martinez was funded by a Basque Government postdoctoral fellowship (POS_2015_1_0006) and Sandy P. Harrison by the ERC Advanced Grant GC2.0: unlocking the past for a clearer future. We thank Vincent Hanquiez for drawing Fig. 2.

Edited by: Hannes Grobe
Reviewed by: Thomas Giesecke and one anonymous referee

References


