New approaches to constructing age models: OxCal4

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Introduction

When looking at past changes in the climate and their impact on the environment, timing is all-important. This is not so much because we want to know exactly when something happened but because we want to know how fast and in what order the changes occurred. For this reason, very well dated records, such as ice-cores, play a major role in our understanding of past climate. For most environmental records we need to make use of less precise dating methods, such as radiocarbon or Uranium series, sometimes in conjunction with relative dating information from varves or deposition-rate models. In order to improve overall dating precision, assumptions are also sometimes made about the synchronous nature of climate change—assumptions that can result in circular reasoning when we come to interpret the results.

Age models with uncertainties

It is an unfortunate fact that once we put together a lot of information from different sources, we introduce considerable uncertainties in our age estimates. This is particularly true in the case of radiocarbon dating, where the calibration process results in complex probability distributions that are frequently multimodal. In order to get back to something that is easier to deal with, simple best-fit age models are often applied. However, while this approach may be useful for putting a record roughly onto an absolute timescale, it is not good enough if we wish to compare the timing of events between records with good accuracy and precision. To do so, we need ways of estimating our uncertainties in age at all points in the records and to recover as much relative date information as possible.

For these reasons there has been increasing interest in methods for combining information from different sources. For over a decade now, such approaches have been used in archeological studies where we frequently have relative date information and increasingly these methods are being used in other disciplines (Buck and Millard, 2004). This is in part due to the widespread availability of software such as OxCal (Bronk Ramsey, 1995), BCal (Buck et al., 1999) and DateLab (Jones and Nicholls, 2002) for performing such analyses. In recent years, such methods have also been applied to deposition models, particularly for peat (see for example Blaauw and Christen, 2005). At the 19th international radiocarbon conference held in Oxford in April 2006 (http://c14.arch.ox.ac.uk/conference.html) there were several papers presented on developments in age-depth modeling, including the new age-depth models included in the OxCal program.

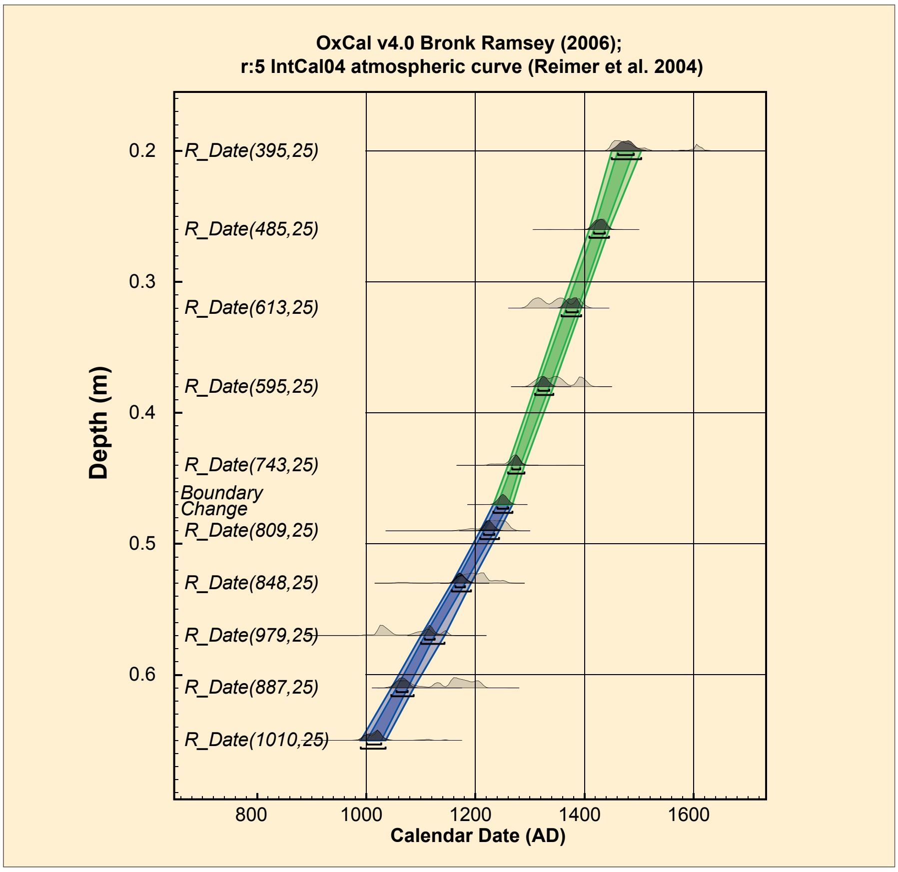

Figure 1: A typical age-depth model from OxCal4 with a series of radiocarbon-dated samples. In this case, the model allows for random fluctuation in deposition rate and for a change in the nature of the sedimentation at a depth of 0.47m. In each sample, a simple calibrated probability distribution function (PDF; light grey), the modeled PDF (dark grey) and the age depth model at the 68% and 95% probability levels (colored bands) are shown. This example is taken from the online manual for the program.

Deposition models in OxCal version 4

OxCal is a computer program for analysis of chronological information. It is freely available for online use or for download to PC or Mac from http://c14.arch.ox.ac.uk/oxcal.html. Although it is most often used for the straightforward calibration of radiocarbon dates, it can also be used to build chronological models of various kinds, using a range of different dating techniques. Previous versions of the program enabled the stratigraphic order of samples to be constrained within a sequence, and also catered for the special case of known age gaps when 'wiggle-matching' radiocarbon-dated tree-ring sequences to the calibration curve.

The new version of the program caters for a much wider range of deposition models. These models were first discussed at the INTIMATE workshop in Iceland in September 2005 (Bronk Ramsey, in press). They range from the loose constraint that dates must be in a particular order (called the Sequence model) to the rigid assumption that the deposition is assumed to be uniform in nature with a constant rate (called the U_Sequence model). Both of these models have been implemented before in several software packages. However, the true situation usually lies between these extremes and a model that allows for random fluctuations in deposition (called the P_Sequence model) is also included and should be appropriate in a much wider range of situations. In many cases, where there are large-scale exposures or multiple cores, the degree of fluctuation in deposition rate can be independently assessed, in other cases this needs to be assessed from the nature of the sediments, or from the dating information itself.

Figure 1 shows one such simple age-depth model and Figure 2 shows the effect of the model on our estimate for the age of one particular sample in the series. The main advantage of using such mod-

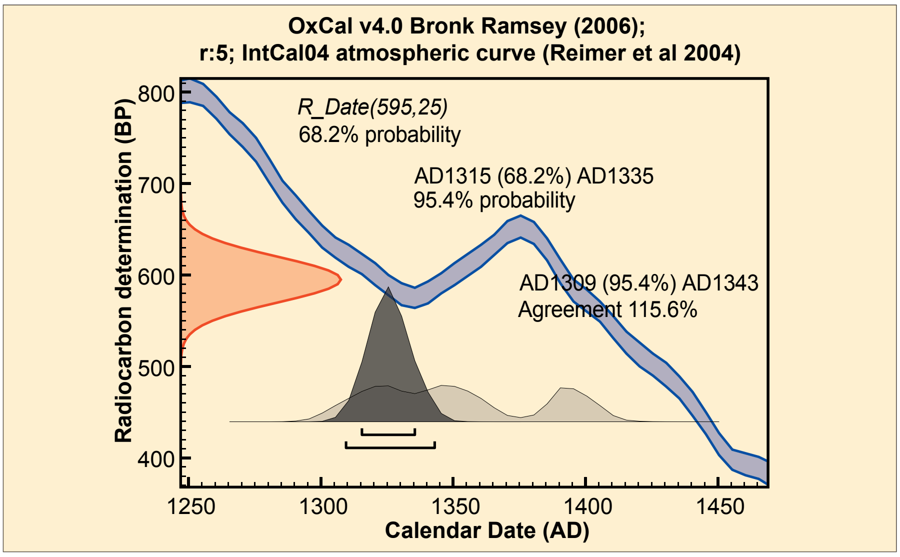

Figure 2: A typical radiocarbon calibration probability distribution (light grey) based on the radiocarbon determination represented by the normal distribution (left axis; red). The result of the overall age model on this particular sample is shown in dark grey. Such resultant probability distributions can be generated for any point in the deposition model (including levels not directly dated).

els is that you get a realistic assessment of the uncertainty of age at any depth. This is important if deciding whether changes or events recorded in a sequence are really synchronous with those in other similarly modeled sequences.

Integrating temporal information into one model

Although generating age-depth models with properly estimated uncertainties is certainly an advance, in many ways the real power of this approach is the ability to integrate information from several different records together. If we have truly synchronous markers, such as tephra, present in the records, then this information can be incorporated into an overall model giving better chronological resolution and, more critically, good relative date information between the records in question—even at some distance from the tie points. In other cases, the tie points might link the chronology to that of the ice cores and allow comparison of climatic information from very different locations.

The other positive aspect of a numerical model of this kind is that it can easily be used to generate other information of interest, for example, the age difference between two events, or the deposition rate for a segment of a particular record. The information obtained in this way is also given in the form of a probability distribution function, with properly assessed uncertainties.

Conclusions and prospects

The questions that need to be addressed in the study of past changes in the Earth require a chronological resolution that pushes our dating techniques to their limit. In this context, we can no longer generate age models by simply drawing straight lines through our data; we need to estimate the uncertainties in our age models and we need to allow for the kinds of natural fluctuations that take place in deposition.

The suite of models now available in OxCal (Bronk Ramsey, 2007), and in other analysis packages such as BPeat (Blaauw and Christen, 2005) allow us to start to address these issues in a comprehensive way. In some cases, such an approach may simply tell us that the information we have is not sufficient to answer some of the key questions. However, in other cases, the ability to integrate information from so many different sources may allow us to see patterns and processes in action that had previously been obscure.

Note

More information on the methods discussed in the article, including links to the program are given on:
http://c14.arch.ox.ac.uk/oxcal.html

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21st century suck-in or smear: Testing the timing of events between archives

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Introduction

Proxy-archives are frequently compared with other data in order to imply teleconnections between regions. Well-known examples of widely recorded past climate events are the last glacial-interglacial transition, the “8.2 kyr event”, and the “Little Ice Age”. Although we do not question the existence of these events, reported synchronicity between archives could have been caused by age-modeling errors, mistaken interpretations of proxy data, or even by “wishful-thinking”. Archives could have been tuned to other archives, age-models selected subjectively, non-responsive sites neglected, or suggestive lines drawn connecting events between archives. It is this potentially dangerous practice of sucking-in or smearing of events (cf. Baillie, 1991; Wunsch, 2006) that we will discuss here. We apply recently developed methods (Blaauw et al., in press) to test the timing of events between two well-dated archives.

Common approaches

Let’s start with a short review of the usual steps to date and compare non-annual archives:

1) Single archives are dated by, for example, radiocarbon at several depths.
2) These dated levels, with their often considerable chronological uncertainties, are reduced to point estimates (e.g. the midpoints of the calibrated ranges for ^{14}C dates).
3) A single curve is drawn through these points (e.g. linear interpolation, regres-