High-resolution radiocarbon chronologies and synchronization of records

I. Hajdas[1], D. Lowe[2] and R. Newnham[3]

[1]ETH/PSI, Ion Beam Physics, Zurich, Switzerland; hajdas@phys.ethz.ch
[2]Department of Earth and Ocean Sciences, University of Waikato, Hamilton, New Zealand
[3]School of Geography, University of Plymouth, UK

^{14}C wiggles — age plateaus and jumps

It is now accepted that the precise dating of certain periods is complicated by extreme variability of atmospheric ^{14}C content shown at times in the 14C calibration curve. This complication arises from variations in atmospheric ^{14}C content and is known as wiggles in the calibration curve. Radiocarbon age 'plateaus', are caused by a decrease in the atmospheric ^{14}C concentration and appear as a slowing down of the 14C clock such as occurred during the Younger Dryas (YD) chronozone. In effect, similar ^{14}C ages apply across a range of up to 500 calendar years. The opposite is observed when atmospheric ^{14}C levels increase so that the ^{14}C clock appears to speed up. In such cases, which include the beginning of the YD and Pre-Boreal intervals, the true age of a sample, taking dating errors into account, may spread across a comparatively wide ^{14}C age range.

The fluctuations of atmospheric ^{14}C content ($\Delta^{14}C$) are driven by changes in the ^{14}C production rate due to variations in the geomagnetic field and solar activity, and by changes in the carbon cycle related to climate change (Hughen et al., this issue). However, the intricate connection between variable atmospheric ^{14}C content and climate change still remains to be resolved (Goslar et al., 1999). Whatever the underlying reasons for the $\Delta^{14}C$ fluctuations, they are not only a source of complication but also offer means of resolution. Specifically, the application of wiggle-matching and Bayesian statistical techniques provide a basis for high precision ^{14}C chronologies for key proxy records from terrestrial and marine sites around the globe. These improved chronologies may, in turn, provide new clues to better resolve the causes for $\Delta^{14}C$ fluctuations (as well as to better understand the functioning of the climate system as a whole).

High-resolution ^{14}C timescales

An increasing trend towards high-resolution climate records, in particular from polar ice cores has generated demand for comparable high-resolution ^{14}C dating and comparison with other paleo-records of the last 40-50 kyr from terrestrial and marine archives. Although the presence of ^{14}C plateaus and wiggles is seen as problematic in this regard, recent dating of key sequences from peat bogs and lakes has shown ways of bypassing the problem (Hajdas et al., 1993, Hajdas et al., 1995, Kilian et al., 2000). Hajdas et al. (2004) used a wiggle-matching method to fit sequences of ^{14}C data to the calibration curve and thereby provide a means of more precise calibration. Other applications have used wiggle matching to the calibration curve to develop a floating chronology for terrestrial varve sequences (e.g., Hajdas et al., 1993, 1995). This method has also been applied to marine records used to extend the calibration curve (Hughen et al., 1998). The Bayesian approach to 14C calibration uses the stratigraphic order of samples to constrain the calibrated age ranges (Ramsey this issue, Ramsey 2001). Associated improvements in chronostratigraphic precision raise the confidence with which the timing of events or features of interests can be compared between spatially disparate records, as briefly illustrated below.

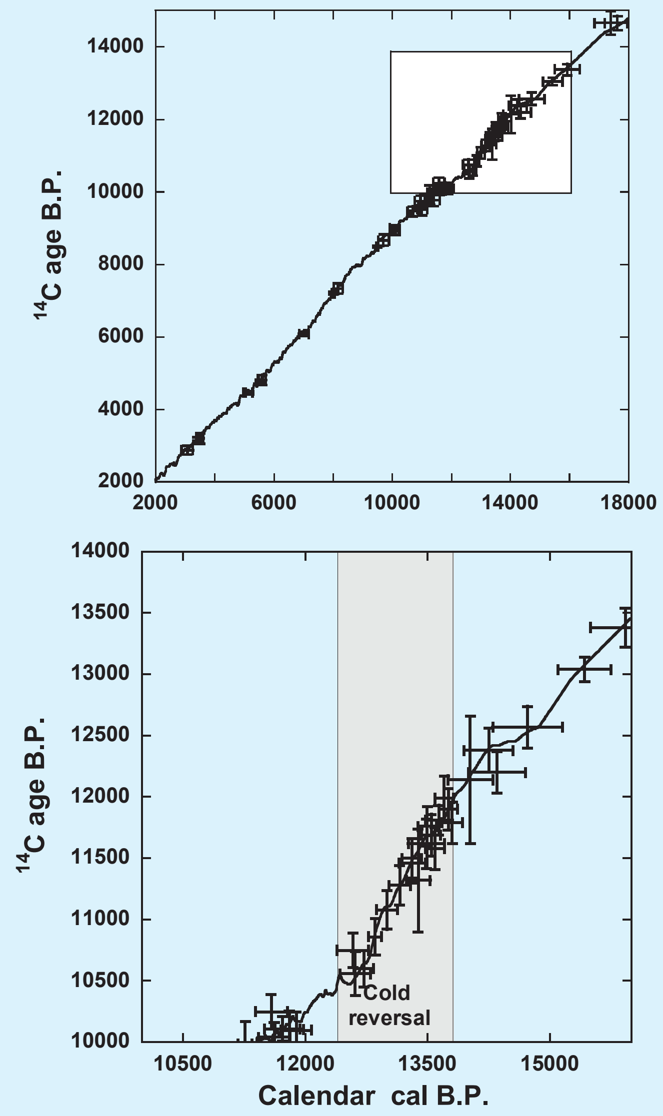

Figure 1: Combined age data set (including all independent tephrochronological ages) from Kaipo Bog late-glacial sequence wiggle-match fitted using OxCal v3.10 to the calibration curve INTCAL04. Lower panel shows a close-up of the pre-Holocene interval. The cold reversal period, defined by palynology, is marked.

Northern hemisphere records

A striking example is the dating of cold events that occurred at the close of the last deglaciation around 12-10 kyr BP (14 to 12.5 kyr cal BP). Until recently, reliable dating of this interval was hampered by the lack of a dendrochronological calibration curve, and by the age plateau and rapid jumps that characterize the YD (see above). Extension of the calibration curve and the new data sets of INTCAL98 and INTCAL04 (Stuiver and Reimer 1998, Reimer et al., 2004) have enabled reconstruction of the fluctuations in atmospheric ^{14}C content during the YD, and provided the basis for wiggle-matching ^{14}C chronologies. The characteristic ^{14}C changes have themselves become time markers. For example, the chronology established for the Kråkenes Lake sequence (Norway) was the first to show the coincidence between a dramatic change in ^{14}C ages (11-10.6 kyr BP) and the onset of cooling at the beginning of the YD (Gulliksen et al., 1998). This coincidence has subsequently been observed in other records from European lakes, such as: Soppensee (Switzerland), Holzmaar (Germany), (Hajdas et al., 1993, 1995), Madtjärn (Sweden) and Gościąż (Poland) (Goslar et al., 1999). High-resolution ^{14}C dating of a deglacial cold event found on Kodiak Island also showed that Alaska experienced cooling which was synchronous with the YD in the North Atlantic region (Hajdas et. al. 1998).

Southern Hemisphere Records

The radiocarbon dating of the New Zealand Franz-Joseph Glacier re-advance at ca. 11 kyr BP (Denton and Hendy 1994) sparked debate on the global extent of YD cooling and drew attention to records from the Southern Hemisphere. A high-resolution ^{14}C chronology for the Kaipo Bog sequence from New Zealand provides further insight into a cold reversal that preceded early Holocene warming (Hajdas et al., 2006). In total,, 51 age points for Kaipo Bog were fitted to the INTCAL04 calibration curve (Reimer et al., 2004) via the OxCal (version 3.10) sequence calibration (Ramsey, 2001) (Fig. 1), which uses a Bayesian approach that incorporates known parameters into the fitting procedure. In this case, the known stratigraphy—age superposition with depth—defined the fitting procedure. This procedure resulted in reduced errors for calibrated ages and gave a continuous sequence of calendar ages independent of ^{14}C age plateaus or wiggles. Based on this chronology, cooling at Kaipo commenced between 13,820 and 13,590 cal yr BP (12,030 ± 90 ^{14}C yr BP) and ended ~1000 years later between 12,800 and 12,390 cal yr BP (10,790 ± 70 and 10,600 ± 90 ^{14}C yr BP). This improved chronology reveals that the cold event was not synchronous with the YD, an alternative scenario possible with the original chronology (Newnham & Lowe, 2000). High-resolution radiocarbon chronologies from two Patagonian sites, Huelmo (Chile) and Mascardi (Argentina) (Hajdas et. al. 2003) have also shown that the cold events observed in those two records preceded the YD chronozone by some 500 years but terminated close to the end of the YD.

In summary, these examples illustrate the potential of high-resolution radiocarbon dating for development of reliable timescales of Holocene and late-glacial records around the globe. Extension further back in time and refinement of the calibration curve will facilitate application of similar approaches to older time periods.

References

Gulliksen, S., Birks, H.H., Possnert, G. and Mangerud, J., 1998: A calendar age estimate of the Younger Dryas-Holocene boundary at Kråkenes, western Norway, *Holocene*, **8**: 249-259.

Goslar, T., Wohlfarth, B., Björck, S., Possnert, G. and Björck, J., 1999: Variations of atmospheric C-14 concentrations over the Allerod-Younger Dryas transition, *Climate Dynamics*, **15**: 29-42.

Hajdas, I., Lowe, D.J., Newnham, R.M. and Bonani, G., 2006: Timing of the late-glacial climate reversal in the Southern Hemisphere using high-resolution radiocarbon chronology for Kaipo bog, New Zealand, *Quaternary Research*, **65**: 340-345.

Newnham, R.M. and Lowe, D.J., 2000: Fine-resolution pollen record of late-glacial climate reversal from New Zealand, *Geology*, **28**: 759-762.

Ramsey, C.B., 2001: Development of the radiocarbon calibration program, *Radiocarbon*, **43**: 355-363.

For full references please consult:
www.pages-igbp.org/products/newsletters/ref2006_3.html

Marine ^{14}C reservoir ages oscillate

P. M. Grootes[1] and M. Sarnthein[2]

[1]Leibniz Laboratory and [2]Institute of Geosciences, Christian Albrechts University, Kiel, Germany; pgrootes@leibniz.uni-kiel.de

The current ^{14}C calibration scale, IntCal04, is tree-ring based up until 12.4 cal kyr BP but relies for the older part, up to 26 cal kyr BP, on surface-ocean data from planktic foraminifera and corals at a number of carefully selected locations (Reimer et al., 2004). In order to do so, it is assumed that a constant global marine reservoir age of 405 ± 22 yr, obtained by box modeling the period AD 1350-1850, and a constant local deviation from this global value, ΔR, can be applied beyond the range of tree-ring calibration. The (local) marine reservoir age under equilibrium conditions is determined by the balance between restricted ocean-atmosphere gas exchange and limited mixing between the mixed layer and the deep ocean. For the selected locations, reservoir ages close to 400 yr indicate that this limited exchange results in a ~5% ^{14}C deficit in the ocean mixed layer. The assumption that this reservoir age has remained constant in the past implies that (i) this mixing balance has been maintained, (ii) the general ocean circulation "pipeline" system, that is the system of thermohaline currents has not changed, and (iii) equilibrium has not been disturbed by changes in the production rate of cosmogenic isotopes, or (iv) in the size of the atmospheric carbon reservoir.

Dramatic climate changes occurred during the early stages of the last glacial to interglacial transition 19-14.5 kyr. They were accompanied by the most fundamental recent changes in ocean circulation, which also likely contributed to major shifts in CO_2 transfer from ocean to atmosphere, leading to the well-known deglacial rise in atmospheric pCO_2 from 190 to 240 ppmv at 14.5 kyr (Monnin et al., 2001; Köhler et al., 2005). For the preceding glacial period, back to the limit of radiocarbon dating around 50 kyr, ice core records provide further evidence for frequent large and rapid changes in climate and low atmospheric CO_2 concentrations in the range of 190 to 230 ppmv. Marine records now have confirmed these findings and shown that these events were in many cases coeval with large changes in the meridional overturning circulation of the oceans. During this period, global sea level also dropped, with stadial-interstadial related fluctuations, to a low of more than 120 m below present sea level at the last glacial maximum (23-19 kyr), before rising over the deglacial and early Holocene to present levels. Reconstructions of the paleointensity of the Earth's magnetic field from various ocean sediments (GLOPIS 75; Laj et al., 2004) give evidence of several episodes with a very weak earth magnetic field leading to increased production of cosmogenic isotopes, especially around 41 kyr BP; the Laschamp Event (Hughen et al., 2004a; Voelker et al., 2000). Thus, it seems that most of the conditions for constant marine reservoir ages—constant basin geometry, ocean circulation, ocean–atmosphere and surface–deep ocean mixing, ^{14}C production, and atmospheric reservoir size—have been violated. Although careful application of U/Th dating, supplemented by volcanic time markers—identified and dated in ice cores and/or terrestrial records—may supply absolute ages for the marine data set, the atmospheric ^{14}C content cannot be reconstructed as long as the local marine reservoir age at each particular point in time is not known.

Therefore, a secure correlation between single events in the ocean and on