Source: Kaczka R, Malik I, Owczarek P, Gärtner H, Helle G, Heinrich I (eds.) (2009): TRACE - Tree Rings in Archaeology, Climatology and Ecology, Vol. 7. GFZ Potsdam, Scientific Technical Report STR 09/03, Potsdam, pp. 226.

Bringing the "climate" back to British tree-rings

Wilson, R.

School of Geography & Geosciences, University of St Andrews, Scotland, U.K.
Email: rjsw@st-andrews.ac.uk

Introduction

Large scale, annually resolved reconstructions of past temperatures for the last 1000 years (Mann et al. 1999, Briffa 2000, Esper et al. 2002, D'Arrigo et al. 2006) are important to not only provide information on past climatic variability (IPCC 2007), but also to constrain climate model scenarios for the 21st century and aid attribution studies (Hegerl et al. 2007). Such large scale reconstructions however, are derived from relatively few proxy series which are sparsely located and are unable to provide detailed spatial climatic information. There is therefore a need to produce new, long temperature reconstructions for regions where currently little or no proxy data exist.

With a general bias towards studying large scale temperature trends for the last 1000 years (IPCC 2007), the importance of understanding past precipitation variability is often overlooked, despite its likely greater influence on economic stability than temperature changes. This is especially true in Europe, where drought has less of an impact than in the United States. Despite the successful development of almost spatially complete millennial long tree-ring (TR) based estimates of precipitation and drought indices for much of North America (Cook et al. 2004), similar spatial analyses are not yet possible for Europe. This is mainly due to the sparse nature of long (> 500 years) precipitation sensitive TR records (Brázdil et al 2002, Wilson et al. 2005), although recent work by Nicault et al. (2008) has produced 500-year long spatial drought reconstructions for the Mediterranean region. However, the record breaking central European floods in 2002, the widespread European drought in 2003 and the recent wet summers in the United Kingdom, not only demonstrate the need for a better understanding of past precipitation variability, but also highlight the importance of developing new long precipitation sensitive proxy records to place the recent period into a longer term context.

Palaeoclimatology in the United Kingdom

There are surprisingly few continuous millennial-scale proxy records for the United Kingdom. Quantified millennia long reconstructions have been developed from speleothems (NW Scotland - Proctor et al. 2000, 2002) and water table estimates using testate amoebae (Multiple regions in the UK - Charman et al. 2006), but these proxy records are difficult to interpret due to conflicting influences of both temperature and precipitation. Qualitative climatic information has also been developed using historical documents (Lamb 1995).

TR records have been utilised from several locations around the Northern Hemisphere to successfully produce annually resolved millennial or longer local/regional reconstructions of temperature (Esper et al. 2003, Luckman & Wilson 2005, Linderholm & Gunnarson 2005, Buntgen et al. 2005, 2006, Wilson et al. 2007, Grudd 2008) and precipitation related indices (Stahle & Cleaveland 1992, Grissino-Mayer 1996, Ni et al. 2002, Salzer & Kipfmueller 2005). However, in the United Kingdom, dendroclimatology is problematic due to either weak or mixed climatic signals, as noted in long (> 1000 years) English oak records (Kelly et al. 2002), or the inability of extending temperature sensitive living Scots pine (*Pinus sylvestris* L.) records in the Highlands of Scotland which only go back ~200-300 years (Hughes et al. 1984, Fish 2007).

This extended abstract describes ongoing dendrochronological research at the University of St. Andrews that aims to rectify the current paucity of long TR based proxy records in the United

Kingdom which should allow the reconstruction of both temperature (from Scots pine) and precipitation (from Oak) for the last millennium.

Scots Pine

Schweingruber et al. (1978, 1979) showed in their seminal studies that the maximum density of annual conifer rings, measured using x-ray microdensitometry, yields a strong and consistent proxy of past summer temperatures. Using data obtained from ring-width (RW) and maximum latewood density (MXD) from several pine sites throughout the Highlands of Scotland, Hughes et al. (1984) showed it was possible to reconstruct summer temperatures from AD 1721- AD 1975. Figure 1a highlights the strong calibration using the original Hughes et al. (1984) data (locations shown in figure 1b) where the linear combination of both RW and MXD parameters explains 65% of the temperature variance.

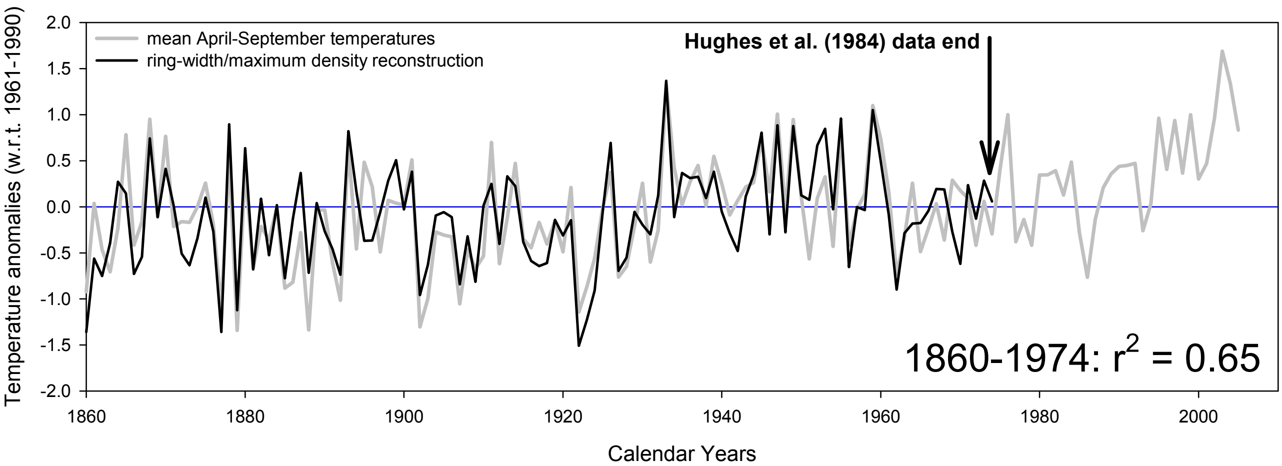

Figure 1a: Calibration (1860-1974) results between the combined (using linear multiple regression) RW and MXD derived from Scotland and April-September mean temperatures (Brohan et al. 2006).

Despite the clear potential of using Scots pine for dendroclimatic reconstruction, one of the elusive aims for working with pine in Scotland is extending the living pine chronologies back in time, as has been done with oak (Crone & Mills 2002). ^{14}C dating of sub-fossil pine material found preserved in peat bogs has, however, been used to provide information on the spatial and temporal distribution of pine in Scotland over the last ~ 8000 years (Ward et al. 1987, Bridge et al. 1990, Gear & Huntley, 1991). However, dendrochronological techniques could not be applied to the samples in these studies due to the relatively short length (due to decay) of the samples (~100 years) and the fact that many of the samples were taken from the root stock of the trees (the stems being rotted away) where the tree rings are highly distorted.

The key to extending the Scottish living pine chronologies therefore lies NOT in using incomplete, distorted pine samples from peat bogs, but finding sources of complete stems where clearly-defined, long TR sequences can be found. In Scandinavia, very long (> 5000 years) pine RW chronologies have been developed using sub-fossil wood preserved in the sediments of small lakes (Eronen et al. 2002, Gunnarson & Linderholm 2002, Grudd et al. 2002, Linderholm & Gunnarson 2005, Grudd 2008). To date, no equivalent attempt has been made in Scotland to find pine material in small lochans.

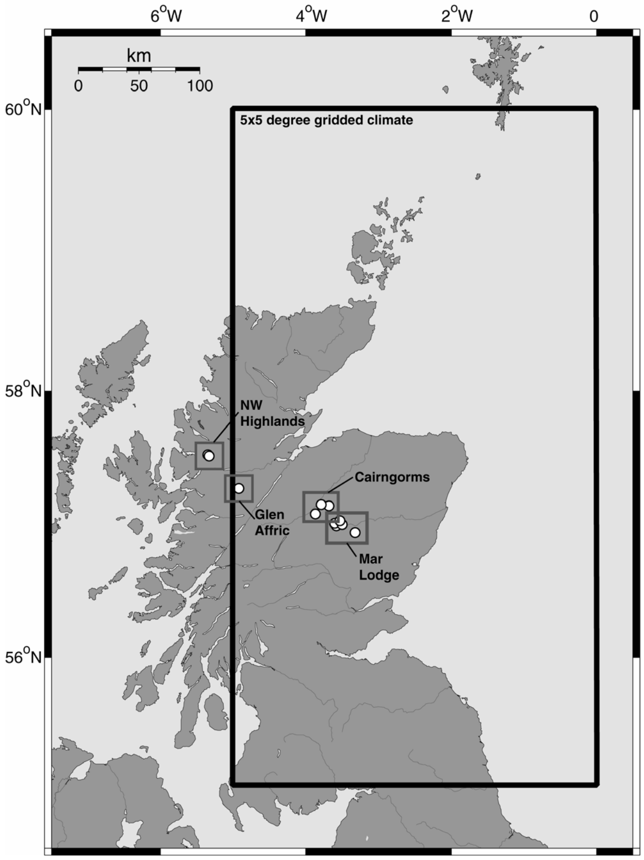

Figure 1b: Location map of existing living pine network. The Hughes et al. (1984) study used samples taken from the NW Highlands, Glen Affric and Mar Lodge regions. The Cairngorm samples are recent additions (Fish 2007). Green box denotes the gridded temperature data (Brohan et al. 2006) utilised for the calibration in Figure 1a.

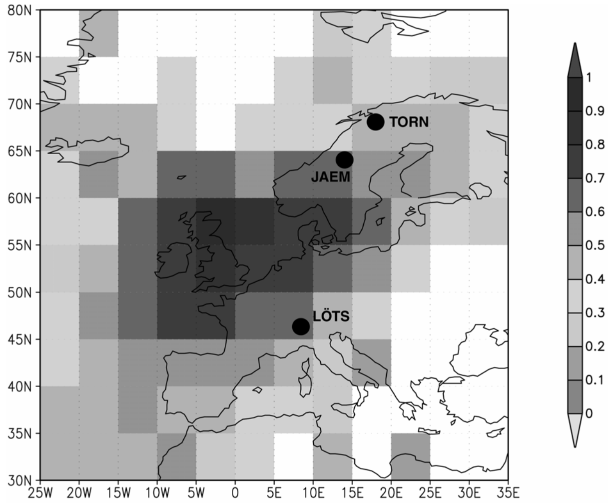

Figure 1c: Spatial correlations (1860-1974 for April-September) between the relevant grid over Scotland (Figure 1a) with gridded (5x5 degrees) temperatures over Europe (Brohan et al. 2006). The dots show the locations of the only millennial long TR based reconstructions in Europe: TORN = Torneträsk (Grudd 2008); JAEM = Jaemtland (Gunnarson & Linderholm 2002; Linderholm & Gunnarson 2005); LÖTS = Lötschental (Büntgen et al. 2005, 2006).

Scots pine has existed in some areas of Scotland for about 8000 years (Bennett 1995, Shaw & Tipping 2006). The present distribution of pine is much reduced compared to its maximum extent around 5700 years ago and the remaining pine woodlands are protected by government policy and non intervention management so that they are theoretically self-sustaining in perpetuity (Colin Edwards, Forest Research, pers. comm). Palynological analysis in the Scottish Highlands has shown that pine has grown continuously for the last ~ 8000 years in the Glen Affric and Cairngorm regions (Shaw & Tipping 2006, Fig. 1b). These regions are therefore important critical areas for locating sub-fossil pine remains.

Climatologically, Scotland is distinct from Europe due to its proximity to the North Atlantic. The influence of the North Atlantic Oscillation (NAO) is especially strong upon Scottish climate (Cook et al. 2002, Folland et al. in press). Figure 1c shows a spatial correlation map between gridded temperatures relevant to Scotland (Fig. 1b) and gridded temperatures across Europe for April-September mean temperatures (the reconstructed season in figure 1a). Also shown are the locations of the existing 1000+ year long TR based reconstructions of past summer temperatures in Europe. Acquiring a similar TR based palaeoclimate reconstruction from Scotland would not only fill an important spatial gap within the European region, but will also provide important information on the past behaviour of the NAO.

The Scottish Pine Project: Current Status

Current work is focussing on identifying appropriate locations where sub-fossil pine material exists. Initial surveys are being undertaken in regions where it is known that pine has grown continuously for many thousands of years (e.g. The Cairngorms and Glen Affric; Fig. 1b). In June 2008, a survey of lochs was made through the North-West Cairngorms. A few sub-fossil pine stems were found in many small lochans (even ones above the present tree-line). However, a particularly abundant amount of material was noted in two lochs in the Rothiemurchus Estate (OS coordinates: NH8907). A preliminary reconnaissance sampling field trip was undertaken in September 2008 to acquire samples for carbon dating to ascertain the rough time frame that the material represents. In total, 25 samples have been collected, many of which contain over 150 rings (Fig. 2). One noteworthy observation is the green colour that some of the samples (especially those from Loch an Eilein) developed after contact with the air. Discussions with colleagues in Scandinavia (Håkan Grudd of Stockholm University and Risto Jalkanen of the Finnish Forest Research Institute, pers. comm.) suggest that these samples could well be over 1000 years old.

Figure 2: Preliminary sub-fossil pine test samples taken from Loch an Eilein and Loch Gamhna in September 2008.

English Oak

Compared to Scots pine, there is no shortage of historical material (e.g. beams etc) that enable the development of millennial long Oak TR chronologies in the United Kingdom (Baillie 1995, Crone & Mills, 2002). During the late 1970s, several labs throughout the United Kingdom produced long oak chronologies for different regions around Britain. While dating of oak samples had been established, the question arose as to whether the RW data could be used to derive information on past climate. To that end, Pilcher & Baillie (1980) developed eight oak chronologies, three from Scotland and five from England, with which to perform dendroclimatic analyses. Despite the success of identifying strong climatic signals in TR chronologies for the American southwest (Fritts, 1976), the identification of such signals in British oak remained elusive (Pilcher & Baillie, 1980). Hughes et al. (1978), however, found that oak could sometimes show a definite climate response and such data could be used to look at temporal and spatial climatic changes. In the 1980s, this work was extended by Dr. Keith Briffa, of the University of East Anglia, who showed that reasonable calibrations of both moisture stress and sea level pressure could be developed from Oak RW data. A recent study conducted by Kelly et al. (2002) expanded on these results but highlighted the mixed nature of the climatic signal in extreme (i.e. wide and narrow) ring-width years.

The English Oak Project: Current Status

In collaboration with Dr. Dan Miles of the Oxford Tree-Ring Laboratory, and building upon the work by Briffa (1984), we are focussing entirely on living and historic Oak RW data from south-central England where oak RW data from this region was noted to show the strongest moisture stress signal (Briffa 1984). To date we have compiled a data-base of 235 living RW series and 990 historical RW series (Fig. 3).

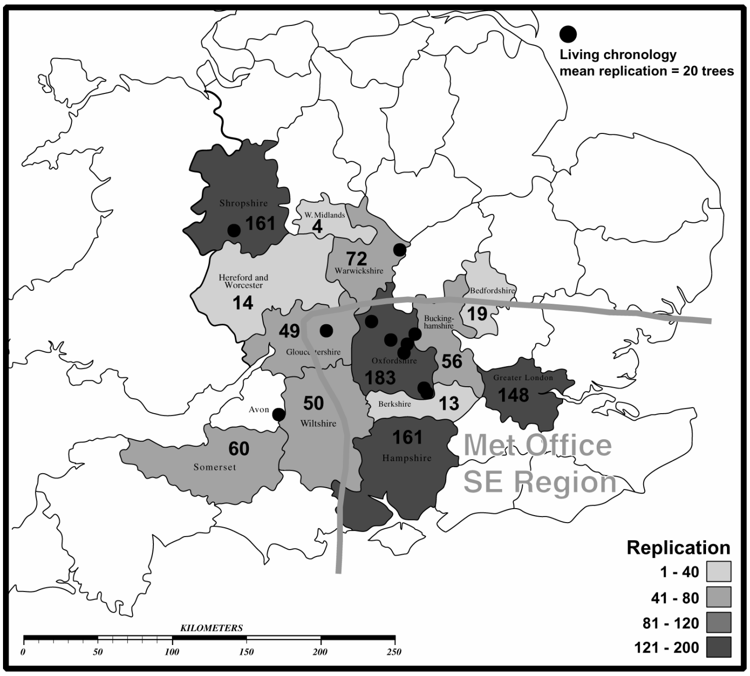

Figure 3: Map showing location of living Oak chronologies use, and the current spatial density of historical Oak RW data.

Data collation is an ongoing process and using the Expressed Population Statistic (Wigley et al., 1984) about 30 series are needed to acquire a robust mean composite series. However, as the longer term goal is to capture more secular scale variability, the data will be processed using the relatively noisy Regional Curve Standardisation (RCS) method (Cook et al. 1995, Briffa et al. 1996), and we therefore feel that for any particular period, a minimum of 50 series would be ideal. Although, the EPS value is currently above the often cited ideal of 0.85 (Figure 4D), the current data-set falls below this 50 series threshold in the 11th and 17th centuries and during the period of overlap around 1800 (Figure 4A). The period of overlap between the living and historic data (Figure 4E) is a crucial validation period to (1) ensure that the historic data show the same signal as the living data, but also (2) when the RCS method is applied, this period ensures that the relative level between the living and historic data is correct (i.e. no biases due to differing populations in the RW data-set).

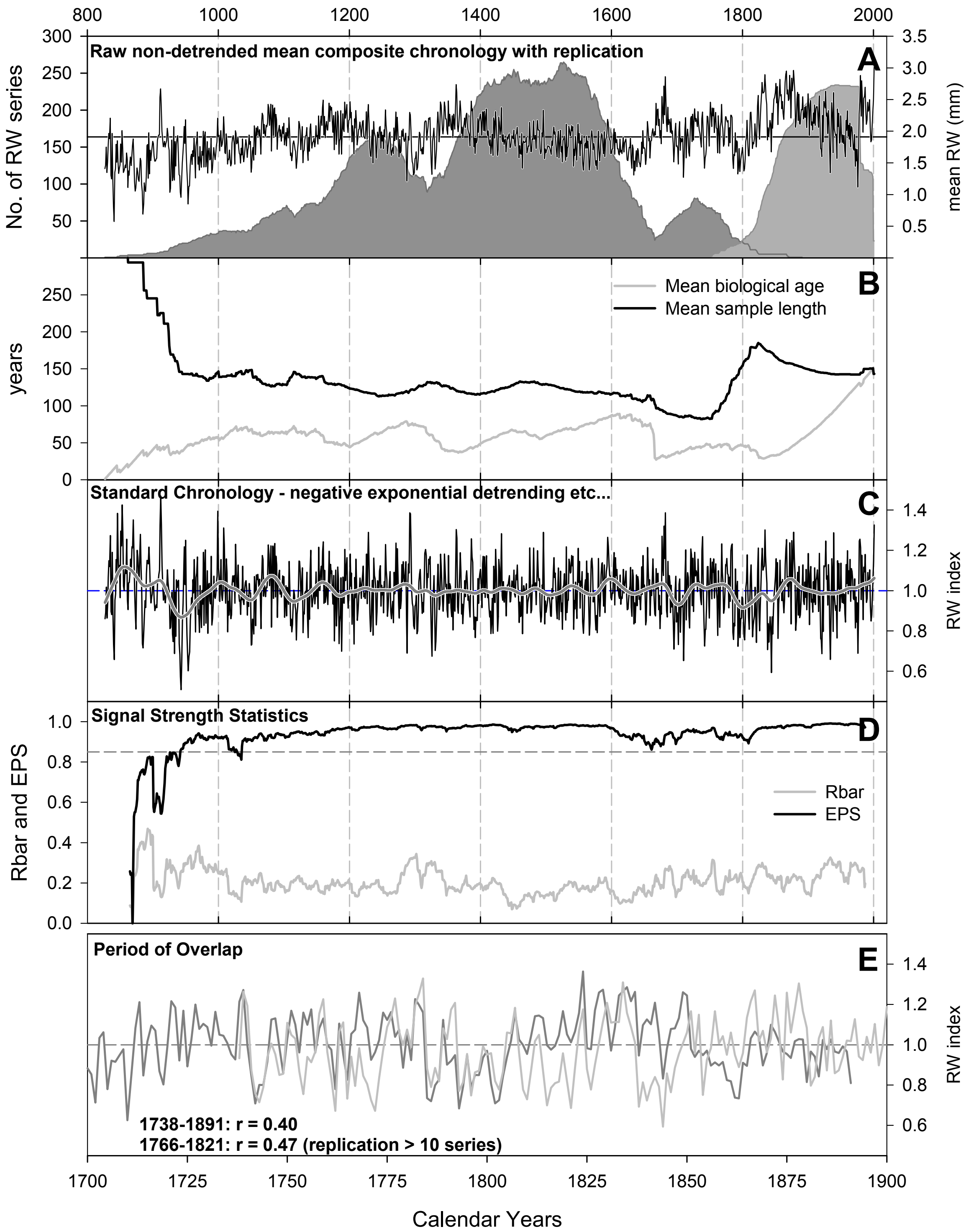

Figure 4: South-central England Oak composite chronology: A: Raw non-detrended chronology with replication histogram; B: Mean biological age and sample length; C: Standard chronology after individual series have been detrended using negative exponential or regression (negative or zero slope) function functions; D: RBAR and EPS statistics; E: Period of overlap between standard living and historic chronologies.

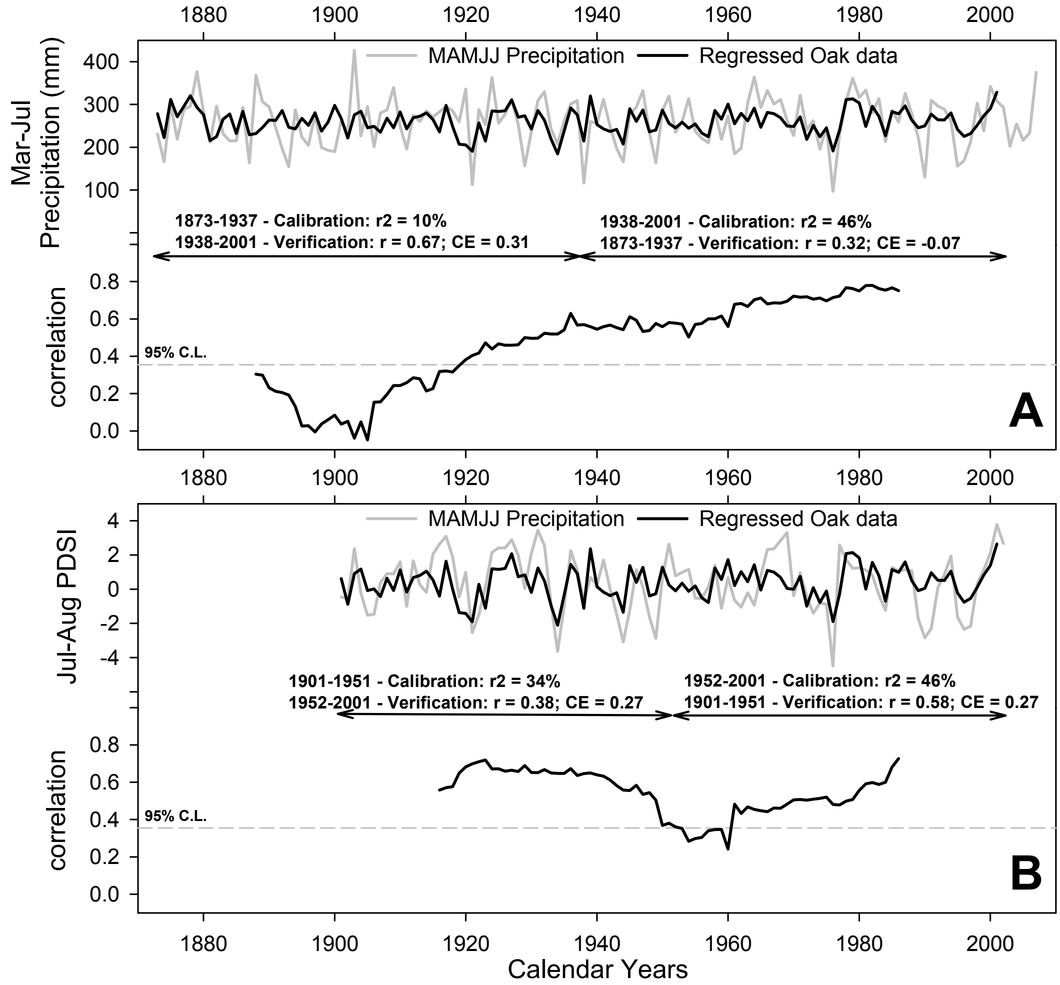

Figure 5A: Preliminary calibration and verification against the Met Office SE regional precipitation series (Alexander & Jones 2001) for the March-July season. The lower panel is a running 31-year correlation between the two time-series; 5B: but for July-August Palmer Drought Severity Index *(PDSI) (van der Schrier et al. 2006).*

Calibration and verification experiments against both precipitation (Figure 5a) and the Palmer Drought Severity Index (PDSI - Figure 5b) show a more time stable relationships with PDSI using the Oak RW composite record. It is not yet clear why the Oak RW response with precipitation is non-significant during the late 19th and early 20th centuries although it may simply reflect the quality of early instrumental precipitation records. This is the focus of ongoing studies. However, the preliminary results with the PDSI data (Figure 5b) are encouraging and agree with similar results obtained by Briffa (1984).

Conclusion

This extended abstract has detailed ongoing dendrochronological research at the University of St. Andrews that aims to develop millennial length climate sensitive TR proxy records for Scotland (temperature from pine) and central-southern England (precipitation/drought from oak). We must stress, however, that much work remains.

Of the two projects, the English Oak project is the most advanced, but further work must (1) address calibration issues against precipitation, (2) sample more living sites outside Oxfordshire (Figure 3), as well as (3) infill periods where replication is relatively low. Future research also aims to explore the potential of measuring stable isotopes (Loader et al. 2008) and early wood vessel area (Fonti & Garcia Gonzalez 2008) to add to the climatic information that can be currently gleaned from the RW data. Extending the Scottish pine chronologies is a huge challenge as the between tree common signal is not particularly strong using RW data alone and even if sub-fossil material could be found covering the last 1000 years, it may not be easy to identify a probabilistically strong cross match with current pine chronologies. Through collaboration with Drs. Coralie Mills and Anne Crone of AOC Archaeology we hope to partly improve the 'signal' and extend reference chronologies by sampling historic structures from the Scottish Highlands. Lastly, we are also experimenting with measurements of blue reflectance, a proxy for MXD measurements (McCarroll et al. 2002, Campbell et al. 2007), which appear to have a stronger signal strength than the RW data and may aid the crossdating of the sub-fossil samples.

This is an exciting time for British dendroclimatology. The preliminary results presented in this extended abstract highlight the potential of developing 1000-year long TR based temperature and drought reconstructions for Scotland and southern-central England. These records would fill in an important gap in the European and global proxy networks and, after a ~25 year wait, will finally bring the "climate" back to British tree-rings.

Acknowledgements

This work is partly funded by the EU project "Millennium" (0170028) and would not have been possible without the collaborative help/advice of Dan Miles, Terri Fish, Neil Loader, Coralie Mills, Anne Crone, Keith Briffa, Tom Melvin and Colin Edwards.

References

Alexander, L.V., Jones, P.D. (2001): Updated precipitation series for the U.K. and discussion of recent extremes. *Atmospheric Science Letters*, doi:10.1006/asle.2001.0025.

Baillie, M.G.L. (1995): A Slice Through Time: Dendrochronology and Precision Dating. B.T. Batsford Ltd., London.

Bennett, K.D. (1995): Post-glacial dynamics of pine (Pinus sylvestris L.) and pinewoods in Scotland. Our Pinewood Heritage. Bell & Bain, Glasgow.

Brázdil, R., Stepánková, P., Kyncl, T., Kyncl, J. (2002): Fir tree-ring reconstruction of March–July precipitation in southern Moravia (Czech Republic), A.D. 1376–1996. *Climate Research* 20: 223–239.

Bridge, M.C., Haggart, B.A., Lowe, J.J. (1990): The history and palaeoclimatic significance of subfossil remains of Pinus sylvestris in blanket peats from Scotland. *Journal of Ecology* 78: 77-99.

Briffa, K.R. (1984): Tree-climate relationships and dendroclimatological reconstruction in the British Isles. Ph.D. dissertation, University of East Anglia, Norwich, UK.

Briffa, K., Jones, P., Schweingruber, F.H., Karlen, W., Shiyatov, G. (1996): Tree ring variables as proxy climate indicators: problems with low-frequency signals. In: Jones, P., Bradley, R.S., Jouzel, J. (eds): Climatic variations and forcing mechanisms of the last 2,000 years. Springer, Berlin Heidelberg New York, pp 9–41.

Briffa, K. (2000): Annual climate variability in the Holocene: Interpreting the message from ancient trees. *Quaternary Science Reviews* 19: 87–105.

Brohan, P., Kennedy, J.J., Harris, I., Tett, S.F.B., Jones, P.D. (2006): Uncertainty estimates in regional and global observed temperature changes: A new data set from 1850, J*. Geophysical Research* 111, D12106, doi:10.1029/2005JD006548.

Büntgen, U., Esper, J., Frank, D., Nicolussi, K., Schmidhalter, M. (2005): A 1052-year tree-ring proxy for Alpine summer temperatures. *Climate Dynamics* 25: 141-153.

Büntgen, U., Frank, D., Nievergelt, D., Esper, J. (2006): Summer temperature variations in the European Alps, A.D. 755-2004. *Journal of Climate* 19: 5606-5623.

Campbell, R., McCarroll, D., Loader, N., Grudd, H., Robertson, I., Jalkanen, R. (2007): Blue intensity in Pinus sylvestris tree rings: developing a new palaeoclimate proxy. *The Holocene* 17(6): 821-828

Charman, D.J., Blundell, A., Chiverrell, R.C., Hendon, D., Langdon, P.G. (2006): Compilation of non-annually resolved Holocene proxy climate records: Stacked Holocene peatland palaeo-water table reconstructions from northern Britain. *Quaternary Science Reviews* 25: 336-350.

Cook, E., Briffa, K., Meko, D., Graybill, D., Funkhouser, G. (1995): The 'segment length curse' in long tree-ring chronology development for palaeoclimatic studies. *The Holocene* 5: 229–37.

Cook, E., D'Arrigo, R., Mann, M.E. (2002): A well-verified, multiproxy reconstruction of the winter North Atlantic Oscillation index since AD 1400. *Journal of Climate* 15: 1754–1764.

Cook, E.R., Woodhouse, C.A., Eakin, C.M., Meko, D.M., Stahle, D.W. (2004): Long-Term Aridity Changes in the Western United States. *Science* 306: 1015-1018.

Crone, A., Mills, C.M. (2002): Seeing the wood and the trees: dendrochronological studies in Scotland. *Antiquity* 76: 788-794.

D'Arrigo, R., Wilson, R., Jacoby, G. (2006): On the long-term context for late 20th century warming. *Journal of Geophysical Research* 111, D03103, doi:10.1029/2005JD006352.

Eronen, M., Zetterberg, P., Briffa, K., Lindholm, M., Meriläinen, J., Timonen, T. (2002): The supra-long Scots pine tree-ring record for Finnish Lapland: Part 1, chronology construction and initial inferences. *The Holocene* 12: 673-680.

Esper, J., Cook, E., Schweingruber, F.H. (2002): Low-frequency signals in long tree- ring chronologies for reconstructing past temperature variability. *Science* 295: 2250-2253.

Esper, J., Shiyatov, S.G., Mazepa, V.S., Wilson, R.J.S., Graybill, D.A., Funkhouser, G. (2003): Temperature-sensitive Tien Shan tree ring chronologies show multi-centennial growth trends. *Climate Dynamics* 21: 699-706.

Fish, T. (2007): Dendroecological studies of Scots Pine in the Glen Affric Region of Scotland. Unpublished MSc thesis. University of Edinburgh.

Folland, C., Knight, J., Linderholm, H., Fereday, D., Ineson, S., Hurrell, J. (2008): The Summer North Atlantic Oscillation: past, present and future. *Journal of Climate* (in press).

Fonti, P., Garcia Gonzalez, I. (2008): Earlywood vessel size of oak as a potential proxy for spring precipitation in mesic sites. *Journal of Biogeography*, doi: 10.1111/j.1365-2699.2008.01961

Fritts, H.C. (1976): Tree Rings and Climate. London: Academic Press Ltd.

Gear, A.J., Huntley, B. (1991): Rapid changes in the range limits of Scots pine 4000 years ago. *Science* 251: 544-547.

Grudd, H., Briffa, K.R., Karlén, W., Bartholin, T.S. Jones, P.D., Kromer, B. (2002): A 7400-year tree-ring chronology in northern Swedish Lapland: natural climatic variability expressed on annual to millennial timescales. *The Holocene* 12: 657-665.

Grudd, H. (2008): Torneträsk tree-ring width and density AD 500 - 2004: A test of climatic sensitivity and a new 1500-year reconstruction of north Fennoscandian summers. *Climate Dynamics*. Published Online 30 January 2008, doi:10.1007/s00382-007-0358-2.

Gunnarson, B., Linderholm, H. (2002): Low-frequency summer temperature variation in central Sweden since the tenth century inferred from tree rings. *The Holocene* 12: 667-671.

Hughes, M.K., Gray, B., Pilcher, J., Baillie, M., Leggett, P. (1978): Climatic signals in British Isles tree-ring chronologies. *Nature* 272: 605-606.

Hughes, M.K., Schweingruber, F.H., Cartwright, D., Kelly, P.M. (1984): July-August temperature at Edinburgh between 1721 and 1975 from tree-ring density and width data. *Nature* 308: 341-343.

Kelly, P.M., Leuschner, H.H., Briffa, K.R., Harris, I.C. (2002): The climatic interpretation of pan-European signature years in oak ring-width series. *The Holocene* 12: 689-694.

Lamb, H. (1995): *Climate, History and the Modern World.* Routledge, London, ed. 2.

Linderholm, H., Gunnarson, B. (2005): Summer temperature variability in central Scandinavian in the last 3600 years. *Geografiska Annaler* 87A (1): 231-241.

Loader, N.J., Santillo, P.M., Woodman-Ralph, J.P., Rolfe, J.E., Hall, M.A., Gagen, M., Robertson, I., Wilson, R., Froyd, C.A., McCarroll D. (2008): Multiple stable isotopes from oak trees in SW Scotland and the potential for stable isotope dendroclimatology in maritime climatic regions. *Chemical Geology* 252: 62-71.

Luckman, B.H., Wilson, R.J.S. (2005): Summer temperature in the Canadian Rockies during the last millennium: a revised record. *Climate Dynamics* 24: 131-144.

Grissino-Mayer, H.D. (1996): A 2129 year annual reconstruction of precipitation for northwestern New Mexico, USA. In: Dean, J.S., Meko, D.M., Swetnam, T.W. (eds): Tree Rings, Environment, and Humanity. Radiocarbon 1996, Department of Geosciences, The University of Arizona, Tucson: 191-204.

Hegerl, G.C., Crowley, T.J., Allen, M., Hyde, W.T., Pollack, H.N., Smerdon, J., Zorita, E. (2007): Detection of human influence on a new, validated 1500-year temperature reconstruction. *Journal of Climatology* 20: 650–666.

Intergovernmental Panel on Climate Change (2007): Climate Change 2007: The Physical Science Basis, Summary for Policy Makers, Boulder, Colorado.

Mann, M.E., Bradley, R., Hughes, M. (1999): NH temperatures during the past millennium: Inferences, uncertainties and limitations. *Geophysical Research Letters* 26: 759–762.

McCarroll, D., Pettigrew, E., Luckman, A. (2002): Blue Reflectance Provides a Surrogate for Latewood Density of High-latitude Pine Tree Rings. *Arctic, Antarctic, and Alpine Research* 34: 450-453.

Ni, F., Cavazos, T., Hughes, M.K., Comrie, A.C., Funkhouser, G. (2002): Cool-season precipitation in the southwestern USA since AD 1000: comparison of linear and nonlinear techniques for reconstruction. *International Journal of Climatology* 22: 1645-1662.

Nicault A., Alleaume S., Brewer S., Carrer M., Nola P., Guiot J. (2008): Mediterranean drought fluctuation during the last 500 years based on tree-ring data. *Climate Dynamics* 31: 227-245.

Pilcher, J.R., Baillie, M.G.L. (1980): Eight modern oak chronologies from England and Scotland. *Tree-Ring Bulletin* 40: 45-58.

Proctor, C.J., Baker, A., Barnes, W.L., Gilmour, M. (2000): A thousand year speleothem proxy record of North Atlantic climate from Scotland. Climate Dynamics. 16: 815-820.

Proctor, C.J., Baker, A., Barnes, W.L. (2002): A Three Thousand Year Record of North Atlantic Climate. Climate Dynamics 19: 449-454.

Salzer, M.W., Kipfmueller, K.F. (2005): Reconstructed Temperature and Precipitation on a Millennial Timescale from Tree-Rings in the Southern Colorado Plateau, U.S.A. Climatic Change 70: 465–487.

Schweingruber, F.H., Fritts, H.C., Bräker, O.U., Drew, L.G., Schär, E. (1978): The x-ray technique as applied dendroclimatology. *Tree-Ring Bulletin* 38.

Schweingruber, F.H., Bräker, O.U., Schär, E. (1979): Dendroclimatic studies on conifers from central Europe and Great Britain. *Boreas*: 427-452.

Shaw, H., Tipping, R. (2006): Recent pine woodland dynamics in east Glen Affric, northern Scotland, from highly resolved palaeoecological analysis. *Forestry* 79: 331-340.

Stahle, D.W., Cleaveland, M.K. (1992): Reconstruction and analysis of rainfall over the southeastern U.S. for the past 1000 years. *Bulletin of the American Meteorological Society* 73: 1947-1961.

van der Schrier, G., Briffa, K.R., Jones, P.D., Osborn, T.J. (2006): Summer moisture variability across Europe. *Journal of Climate* 19: 2818-2834. doi:10.1175/JCLI3734.1.

Ward, R.G.W., Haggart, B.A., Bridge, M.C. (1987): Dendrochronological studies of bog pine from the Rannoch Moor area, western Scotland. In: Ward, R.G.W. (ed.): Applications of Tree-ring Studies: Current Research in Dendrochronology and Related Subjects. *British Archaeological Reports International Series* 333: 215-225.

Wigley, T.M.L., Briffa, K.R., Jones, P.D. (1984): On the average of correlated time series, with applications in dendroclimatology and hydrometeorology. *Journal of Climate and Applied Meteorology* 23: 201–13.

Wilson, R., D'Arrigo, R., Buckley, B., Büntgen, U., Esper, J., Frank, D., Luckman, B., Payette, S., Vose, R., Youngblut, D. (2007): A matter of divergence: tracking recent warming at hemispheric scales using tree ring data. *Journal of Geophysical Research* 112: doi:10.1029/2006JD008318.