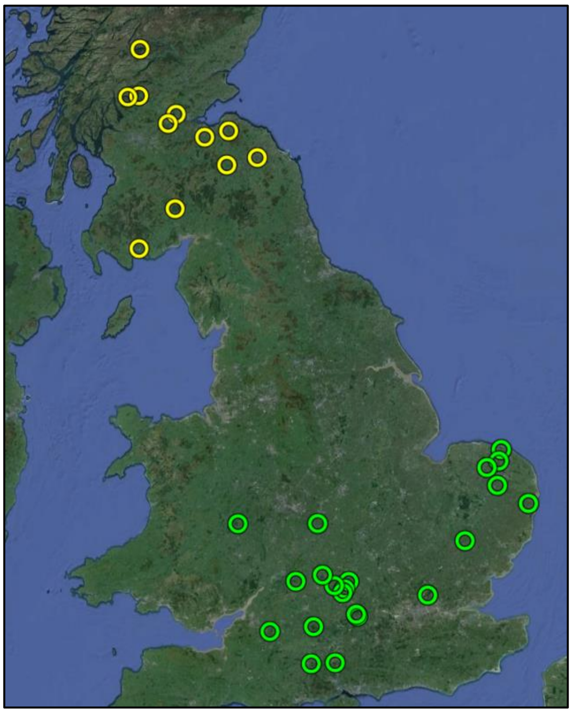
Early exploration of Oak Dendrochronology in Scotland



Despite a faltered start, the development of the Scottish Oak network is progressing. We now have data from 11 new locations from Rannoch down to Dumfries and Galloway. The site elevations range from about sea level up to 250 masl. As you will see, I believe latitude and elevation are going to be important factors understanding the climatic controls on growth across this network. On average we have sampled just over 20 trees per site and have measured both ring-width and latewood Blue Intensity (BI) from the samples. There is NO published paper on the utilisation of BI from hardwoods, so the results I show below provide only a rough first cut.

Site Names	Site	Trees Sampled	MSL (years)	Elevation (masl)	Latitude	Longitude
Rannoch (Carie)	RAN	24	170.1	255-265	56°40'59.99"N	4°15'49.15"W
Leny	LEN	30	102.0	110	56°15'9.79"N	4°16'12.29"W
Loch Katrine	KAT	23	126.9	120-130	56°14'40.14"N	4°32'2.70"W
Balgownie Wood	BLG	17	105.5	75	56° 4'33.96"N	3°38'5.64"W
Callender Park	CAL	18	188.5	60	55°59'29.95"N	3°46'6.45"W
Gifford	GIF	29	167.7	120-130	55°54'19.77"N	2°45'22.22"W
Roslin	ROS	29	187.7	110-120	55°51'21.69"N	3° 9'24.85"W
Hirsel Esate	HIR	21	160.9	20-30	55°39'8.25"N	2°17'21.09"W
Abbotsford	ABB	20	166.6	120-135	55°35'41.20"N	2°47'19.91"W
Kier Wood	KRW	29	155.8	80-90	55°13'7.70"N	3°48'36.68"W
Cardoness House	CRD	22	157.7	20	54°51'14.76"N	4°14'4.92"W

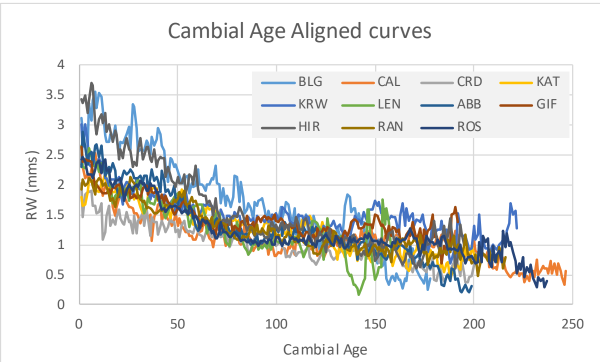
For larger scale comparative analysis, I also use ring-width chronologies from southern England that were used for the following two studies. These data were shown to express some degree of moisture limited stress. We did not go further north as we quickly lost the precipitation signal.

Wilson, R., Miles, D., Loader, N.J., Melvin, T., Cunningham, L., Cooper, R. and Briffa, K., 2013. A millennial long March–July precipitation reconstruction for southern-central England. Climate Dynamics, 40, pp.997-1017.

Cooper, R.J., Melvin, T.M., Tyers, I., Wilson, R.J. and Briffa, K.R., 2013. A tree-ring reconstruction of East Anglian (UK) hydroclimate variability over the last millennium. Climate Dynamics, 40, pp.1019-1039.

Raw non-detrended chronologies

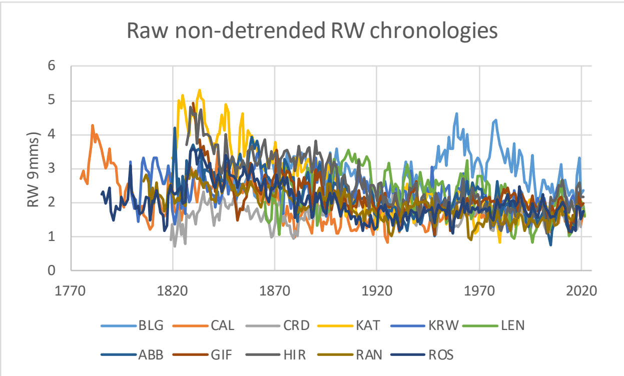
As would be expected there is a range of growth rate differences expressed in the ring-width data. Balgownie Wood (BLG) and Hirsel (HIR) express greatest RW values, while the coastal Cardoness House (CRD) site expresses the lowest growth rates. All sites show a "classic" negative exponential decline in RW values from the juvenile years to recent period (see left).

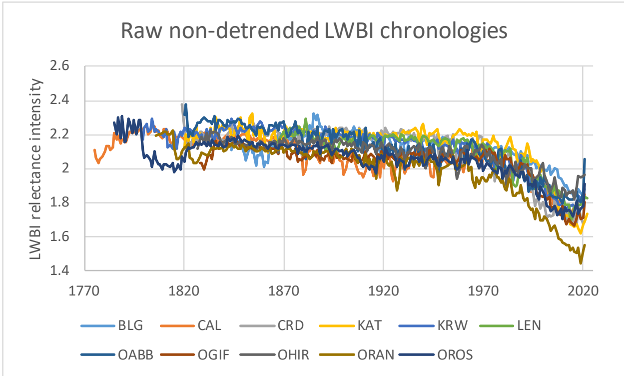


Site	Total mean RW (mms)	mean RW 1st 50 yrs (mms)	mean RW 1st 100 yrs (mms)	Mean tree height (m)	Bulk Density (g/cm3)
RAN	1.39	1.83	1.59	16.85	0.68
LEN	1.66	1.96	1.61	18.10	0.71
KAT	1.55	1.83	1.62	18.07	0.70
BLG	2.64	2.81	2.33	19.01	0.73
CAL	1.28	1.75	1.43	18.79	0.68
GIF	1.56	1.93	1.67	24.52	0.71
ROS	1.41	2.00	1.62	16.96	0.67
HIR	1.78	2.70	2.13	31.71	0.61
ABB	1.54	2.19	1.74	25.24	0.64
KRW	1.68	2.04	1.78	23.63	0.70
CRD	1.21	1.45	1.29	10.93	0.72

On the next page, the raw non-detrended calendar dated chronologies are shown. In the 20th century, the only site that expresses rather anomalous growth RW trends is Balgownie Wood (BLG) from the mid-1940s but this simply reflects that we sampled a bunch of rather young trees at this location but does reflect the complex nature of this rather human impacted woodland.

The only thing I want to highlight from the raw Latewood BI (LWBI) raw chronologies is the step change in values around the 1960s-70s. LWBI data are the inverted form of the raw Blue Reflectance data – this means that the darker heartwood and lighter sapwood are expressed by high/low LWBI values. This colour change imposes a significant problem for traditional detrending methods, but for the flexible functions used for historical dating, this will not be a problem. More importantly, I believe it will be possible to use these LWBI data to identify the heartwood/sapwood transition. I am involved in another project where we need to correct for such trends for a dendroclimatic study and hopefully later in the year, we might have a workable method that can return the most likely HW/SW transition year. It will be interesting to compare these results with actual HW/SW date estimates.



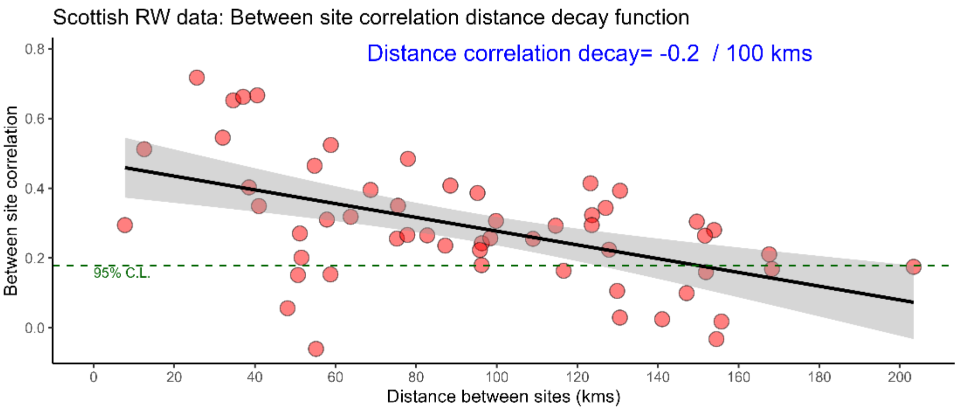


***Distance decay correlation*.**

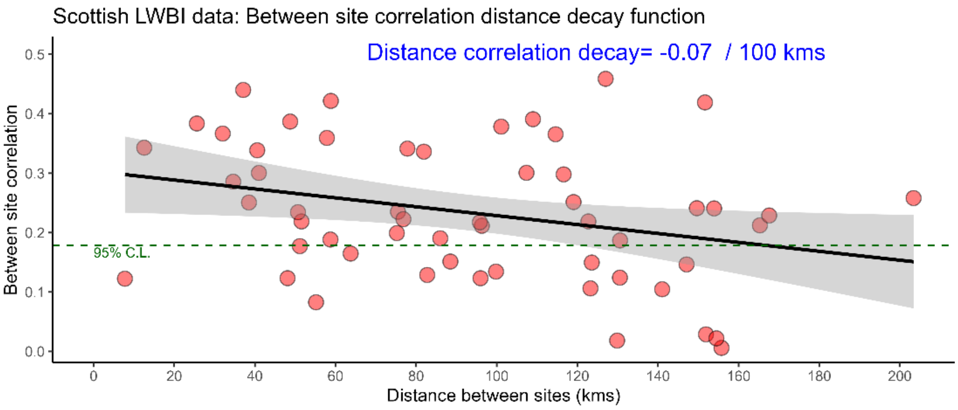
The geography and climatology of southern England is quite different to Scotland. To get a “feel” how crossdating between sites (and parameters) may be affected by these very different regional changes, I calculated the between chronology correlation value as well as the distance between the sites. This allows the plotting of a distance correlation decay function. The chronologies were developed by detrending using a very flexible function (30-year spline) which essentially removes all decadal and longer-term trends (including the HW/SW colour bias). The Scottish data results were calculated over the 1900-2020 period while the English data calculations were made over 1840-1978. These periods simply represent the common well replicated period between all sites for the two regional datasets. Results are shown individually for each parameter in the three plots below with all the data being combined in the final fourth plot.

The first thing to point out is that the inter-site correlation for the English oak RW chronologies is substantially stronger than for Scotland. This is perhaps not surprising due to the complex geographical context of the Scottish sites, but on average in southern England, one can crossdate successfully between sites over quite large distances (up to at least 300 kms). Phooey – dendrochronology is easy in England 😉. In Scotland, the average between site correlation drops below the significance (95% line) at around 150 kms and basically shows there is a 0.2 correlation decrease for every 100 kms. The Scottish situation is therefore much more complex – likely representing a range of site-specific issues from different local climates (much more homogenous in southern England) to quite different site types. The Cardoness House site, for example, are trees growing literally metres from the beech on the north side of the Solway Firth. These trees were rather short, with small diameters and much slower growth rates.

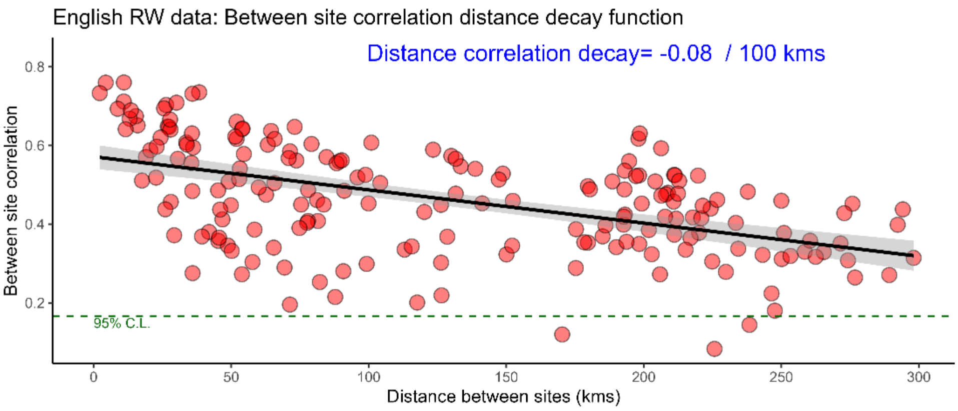
Overall, looking at the Scottish sites, LWBI shows weaker correlation values compared to RW. To be honest, when we first started looking at Oak, I had NO expectation that LWBI would even show a common signal between the sites, so I think we need to look at this as a positive outcome. We have so far used the same settings (and scanner systems) as we have used for pine and other conifers, so it is very likely that we can improve on these early results using the high resolution Atrics camera system we have. What is perhaps further encouraging for the LWBI data, is that the rate of correlation decrease with distance is much less than for RW. In fact, the rate of LWBI correlation decrease (0.07 / 100 kms) is marginally lower than we see for the English RW data (0.08 / 100 kms) so we maybe be able to crossdate over large distances than we could with RW. More sites will be needed to fully test this, however.



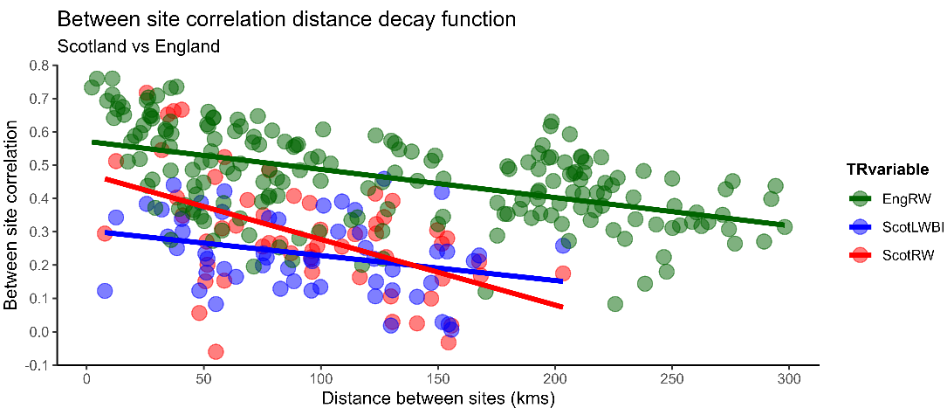
Scottish RW data: Between site correlation distance decay function
Distance correlation decay= -0.2 / 100 kms
Between site correlation
95% C.L.
Distance between sites (kms)



Scottish LWBI data: Between site correlation distance decay function
Distance correlation decay= -0.07 / 100 kms
Between site correlation
95% C.L.
Distance between sites (kms)



English RW data: Between site correlation distance decay function
Distance correlation decay= -0.08 / 100 kms
Between site correlation
95% C.L.
Distance between sites (kms)



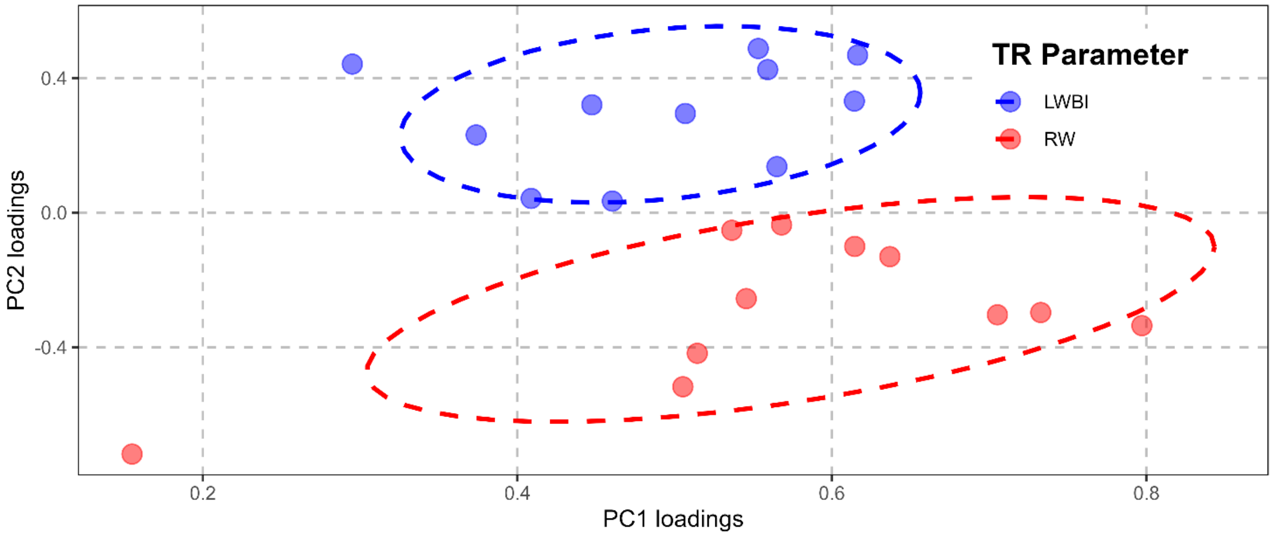
Between site correlation distance decay function
Scotland vs England
Between site correlation
Distance between sites (kms)
TRvariable
EngRW
ScotLWBI
ScotRW

Signals represented by the different parameters.

Firstly, a principal component analysis of the Scottish RW and LWBI 30-year spline chronologies over the 1900-2020 period was performed (figure below). ALL chronologies load positively on PC1 which suggests that there is a degree of common variance between all the parameter chronologies. However, PC2 clearly delineates the RW and LWBI data with LWBI expressing positive loadings on PC2 while RW based loadings are negative.

These results suggest that although there is some common variability between the datasets, the RW and LWBI can be treated as essentially independent variables. So – we are again in the realm of multi-parameter dendrochronology. More on this as I explore further multi-parameter crossdating.

So, what environmental signals could these parameters represent?



Correlation response functions.

Well – a first start is to explore what, if any, relationship with climate these data express.

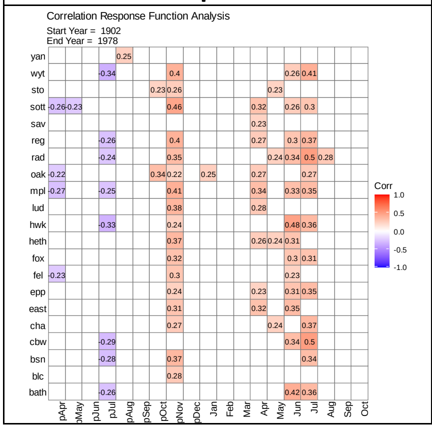
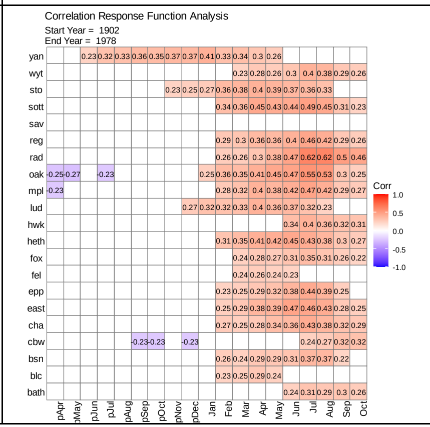
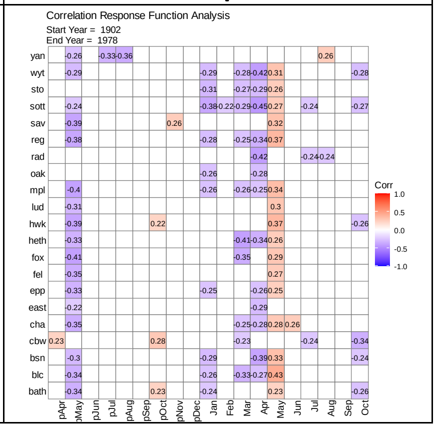
For comparison with the English data and ensuring consistency, the tree-ring and climate data were transformed to 1st differences and the correlation analysis performed over the common 1901-1978 period. A note of warning for interpretation: 1st difference transformation imposes negative autocorrelation on the time-series, so previous year's correlations will be inverse of those of the current year. I would advise to only focus on current year climate response in the figures below.

Large, gridded climate datasets were used encompassing the whole domain of the networks for southern England and Scotland. This is not optimal for some sites, especially in Scotland due to the more complex climatology, but the analysis should still provide a rough first estimate of any potential climate signals represented in these data.

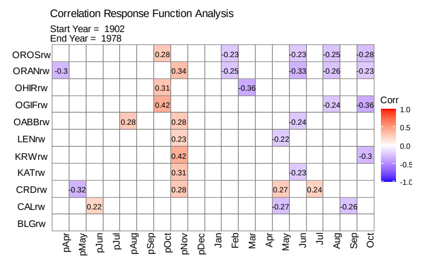
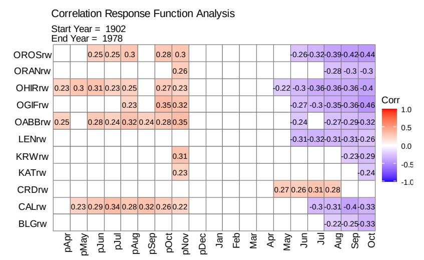
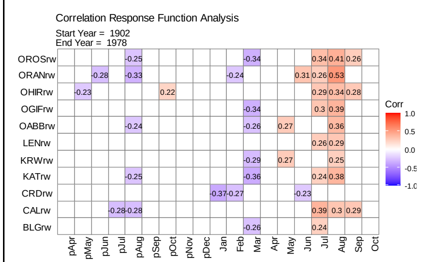
The English oak RW data show no surprises (see next page). These data were used by Wilson et al. (2013) and Cooper et al. (2013) to derive precipitation reconstructions for southern England and East Anglia. These relationships are not that strong and are now surpassed by the strong precipitation signals represented in the oxygen isotope data (see Neil's work). However, the positive correlations noted for most sites against growing season precipitation (April-July) and PDSI (drought index) indicate that the ***southern England oak trees are, at least, mildly moisture stressed***. The correlations with temperature are more complex and the negative correlations with winter/spring again suggest some degree of water stress although the positive correlation with May is intriguing.

The Scottish oak RW data show generally weak negative correlations with growing season precipitation and perhaps more consistent, but still weak, negative correlations with PDSI. Perhaps, rather surprisingly, the RW data express significant correlations with July-August temperatures, with some sites expressing a broader seasonal response. Rannoch expresses the strongest RW vs mean temperature response which, as it is the highest elevation site, might indicate true temperature limitation expressed in these data. The CRD site is the only site that might express a touch of moisture limitation response that we see in the southern English RW data.

Southern England RW data

Precipitation	PDSI	Mean Temperatures
		

Scotland RW data

Precipitation	PDSI	Mean Temperatures
		

The oak LWBI data further suggests that the oak trees maybe well represent trees that are more temperature limited with again positive correlations for months between May and August (see next page). However, the strongest correlations are noted, inversely, against precipitation and more significantly with PDSI. These correlations suggest a complex relationship with climate suggesting that both RW and LWBI show a positive response with temperature, but excess moisture is also detrimental to these growth parameters. More complex modelling is of course needed, BUT, it is clear that the climate signal expressed in the English and Scottish data are very different and we appear to be at rather different ends of the ecological range of Oak in the UK. One might assume that as we go further north (and for higher elevations), the temperature response might increase.

Scotland LWBI data

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<tr><th>Precipitation</th><th>PDSI</th><th>Mean Temperatures</th></tr>
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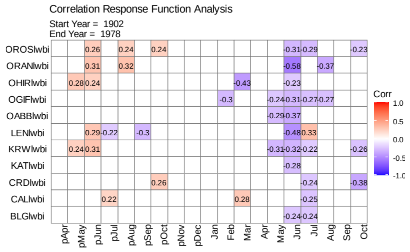
<td>
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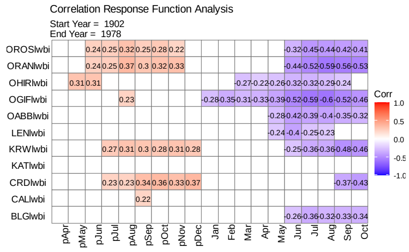
<td>
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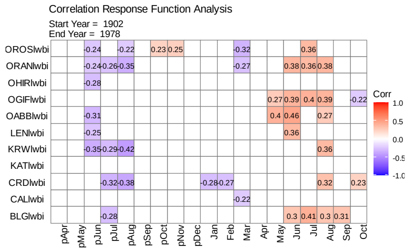
<td>
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Final Musings

This is a first look at the expanding Scottish Oak network. There are of course other sites where we have RW data from earlier samplings (e.g. Lochwood etc), but ideally, we need to go back and revisit them (or close by) so we can measure LWBI for these locations also.

Some early observations:

- I am pretty sure that the LWBI data can be used to derive estimates of heartwood and sapwood counts. I think this will be relatively straightforward to code up in R.
- Crossdating over space is significantly more complex in Scotland than for southern England.
    - Between site correlations for RW are substantially weaker in Scotland than southern England and the distance decay functions suggest that quite small regions will need to be identified to create coherent regional reference chronologies for provenancing. As the oak chronology network expands, we should be able to use cluster analysis methods to better quantify coherent regional groups.
    - LWBI does express a common signal between sites (I am happily surprised by this result), but for near distant sites, the between site correlation is weaker than for RW. However, over larger distances, it is stronger than RW.
    - Might be worth thinking about creating LWBI living/historic composite records where we have dated historical material provenanced to specific regions.
    - The different signals expressed by both RW and LWBI again suggests the potential for multi-TR-parameter crossdating. More on this to come later in the year. I am presenting on this methodology at the TRACE conference.
- Hopefully high-resolution imaging methods (i.e. not scanners) will improve the signal strength of the LWBI data.
- Although much weaker than what we see with pine, most of the Scottish sites provide evidence for some degree of temperature limitation, but excess precipitation may also be a factor. This needs further examination of course. A 1st difference transform of the data is not the best approach to explore such relationships. These results are just guides at the moment.
    - The strongest correlations are negative between LWBI and PDSI. Could this relationship be justifiably used to create a hydroclimate reconstruction for some regions? Will be tricky to minimise the heartwood/sapwood colour bias and retain useful decadal and longer-term information. However, life without a challenge is a boring life!!