Testing the JULES Model for predicting spatio-temporal variations in stable carbon isotopes over the United Kingdom

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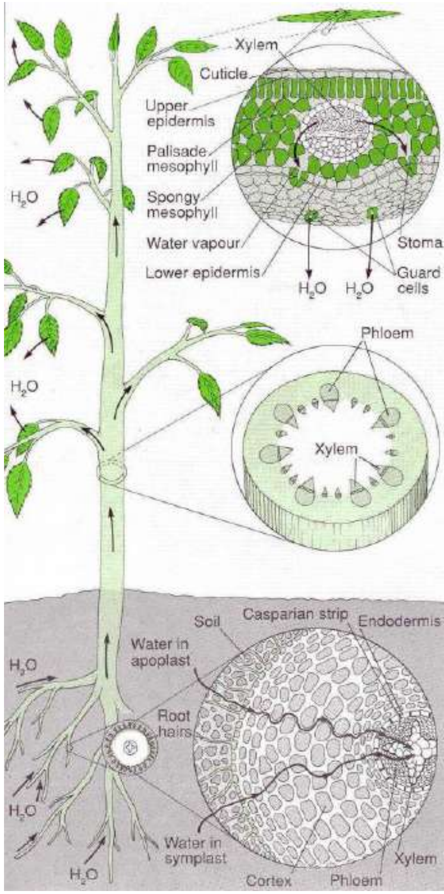
Stable Carbon Isotopes in Trees



Photosynthesis:

$$\mathbf{CO_2 + H_2O \rightarrow (CH_2O)_n + O_2}$$

Isotopic Fractionation: simple model (Farquhar *et al*., 1982)

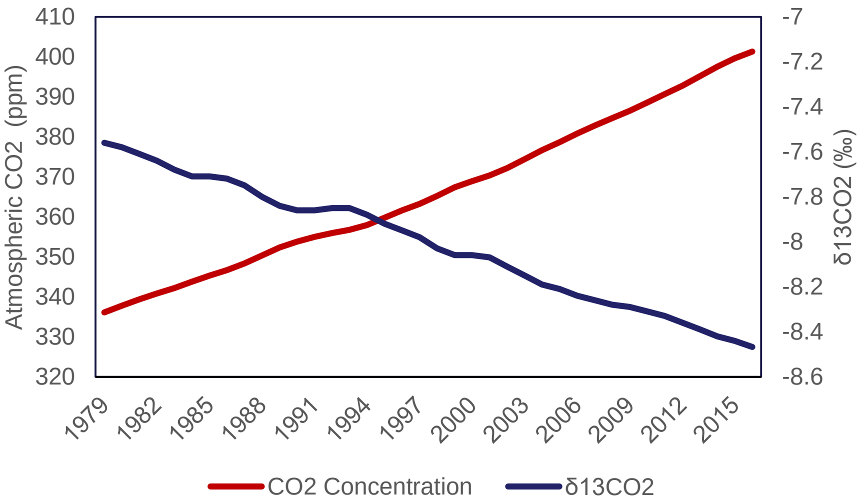
$$\delta^{13}C_{TR} = \delta^{13}C_{atm} - a - (b-a)(c_i/c_a)$$

a (4.4‰) = fractionation due to CO_2 diffusion through the stomata
b (28 ± 2‰) = fractionation during carboxylation by RuBisCO
C_i and C_a are the CO_2 concentration of leaf-intercellular space and ambient air, respectively

Isotopic Discrimination: (Belmecheri & Lavergne, 2020)

$$\Delta^{13}C = \frac{\delta^{13}C_{atm} - (\delta^{13}C_{TR} - d)}{1 + (\delta^{13}C_{TR} - d)/1000}$$

d = sum of post-photosynthetic fractionations between leaf and plant material



Research Questions

How effective is JULES in terms of modelling the ^{13}C record of UK broadleaf trees?

- Is the interannual variability observed in the tree-ring $\Delta^{13}C$ records well reproduced by JULES?
- Are the trends in $\Delta^{13}C$ inferred from tree rings similar to those predicted by JULES?
- What are the spatio-temporal patterns of $\Delta^{13}C$ across UK?

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Joint UK Land Surface Model

- JULES version 5.6 + new carbon isotopic capability (Lavergne et al. under review)
- Model driven by WFDEI-WATCH meteorological data over 1979 – 2016

+ Prentice *et al*. (2014) stomatal model:

$$c_i = (c_a - \Gamma^*)\frac{\xi}{\xi + \sqrt{D}} + \Gamma^*$$

$$\xi = \sqrt{\beta\frac{(K+\Gamma^*)}{1.6_{\eta^*}}}$$

JULES

Joint UK Land Environment Simulator

- Γ^* = photorespiratory compensation point
- β = cost factors of transpiration and carboxylation at 25°C
- *K* = Michaelis-Menten constant for Rubisco-limited photosynthesis
- η^* = viscosity of water relative to that at 25°C

+ Farquhar *et al*. (1982) discrimination model:

$$\Delta^{13}C = a\frac{c_a - c_i}{c_a} + b\frac{c_c}{c_a} - f\frac{\Gamma^*{}_c}{c_a} + a_m\frac{c_i - c_c}{c_a}$$

- a (4.4‰) = fractionation due to CO_2 diffusion through the stomata
- b (28 ± 2‰) = fractionation during carboxylation by RuBisCO
- C_i and C_a = leaf intercellular and ambient partial pressure of CO_2
- f (12±4‰) = photorespiratory fractionation effects
- a_m (1.8‰) = mesophyll fractionation effects

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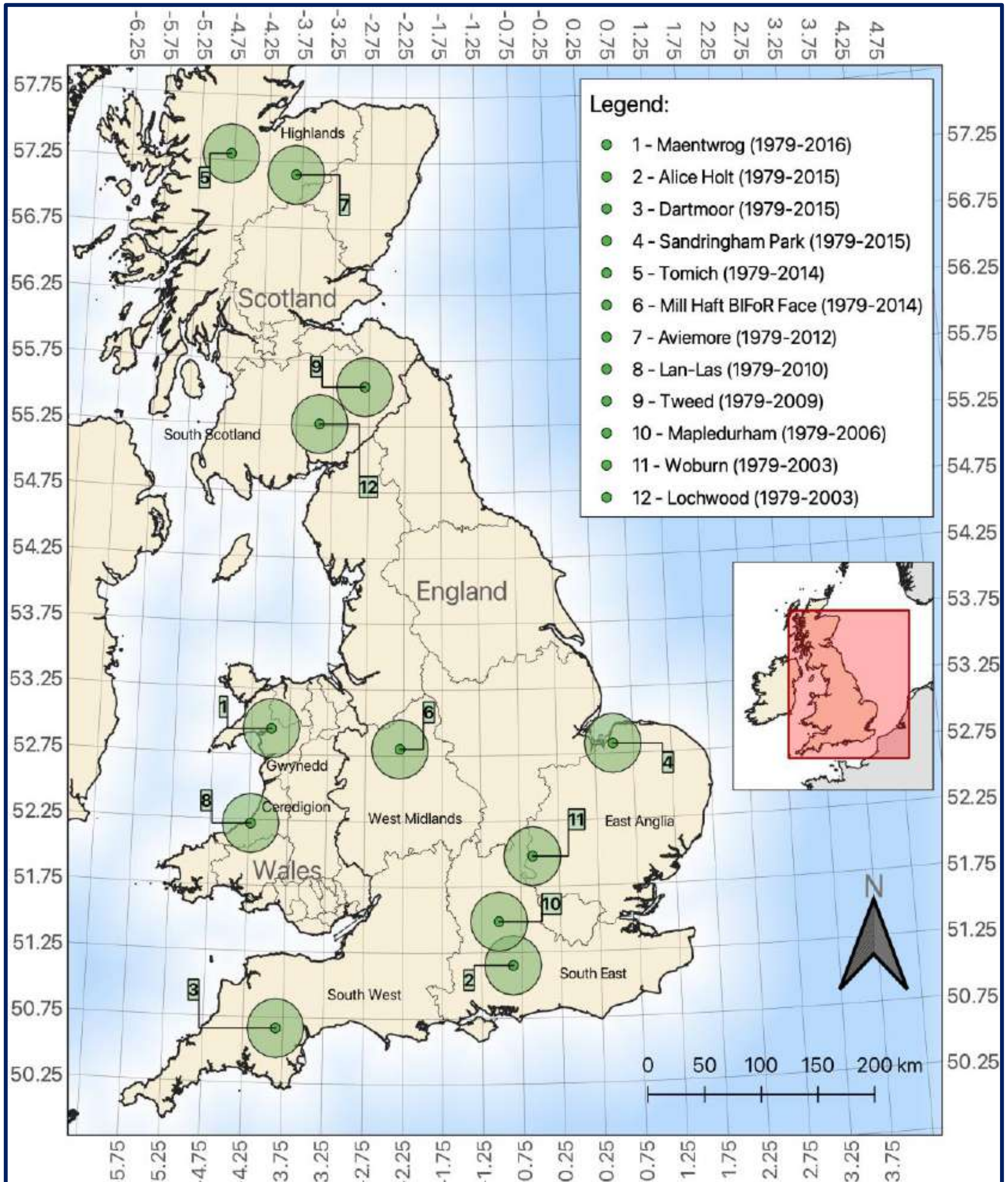
Site Information



Site	Length (years)	Lat/Lon	Elevation (meters)	Dominant Species
Maentwrog	38	52.95, -3.99	27 – 55	*Q. petraea*
Alice Holt	37	51.18, -0.85	107	*Q. robur*
Dartmoor	37	50.67, -3.84	217	*Q. petraea*
Sandringham Park	37	52.83, 0.50	38	*Q. robur*
Tomich	36	57.30, -4.80	184	*Q. petraea*
Mill Haft	36	52.80, -2.30	108	*Q. robur*
Aviemore	34	57.15, -3.84	300	*Q. robur*
Lan-las	32	52.22, -4.22	111	*Q. petraea*
Tweed	31	55.55, -2.80	190	*Q. robur*
Mapledurham	28	51.50, -1.00	70	*Q. robur / Q. petraea*
Woburn	25	51.98, -0.58	150	*Q. robur*
Lochwood	25	55.27, -3.43	175	*Q. robur*

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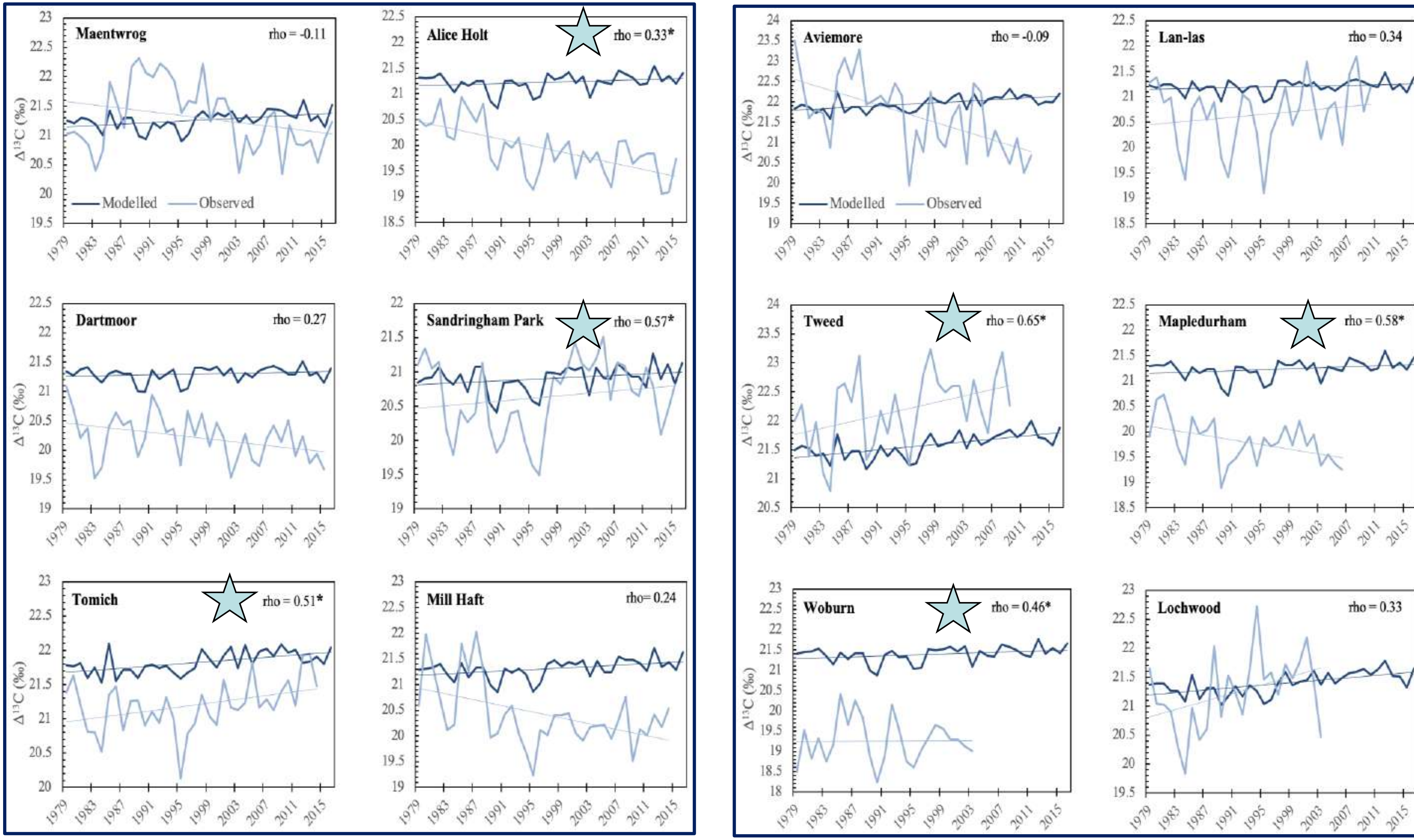
Modelled vs Observed Δ^{13}C



Significant P < 0.05

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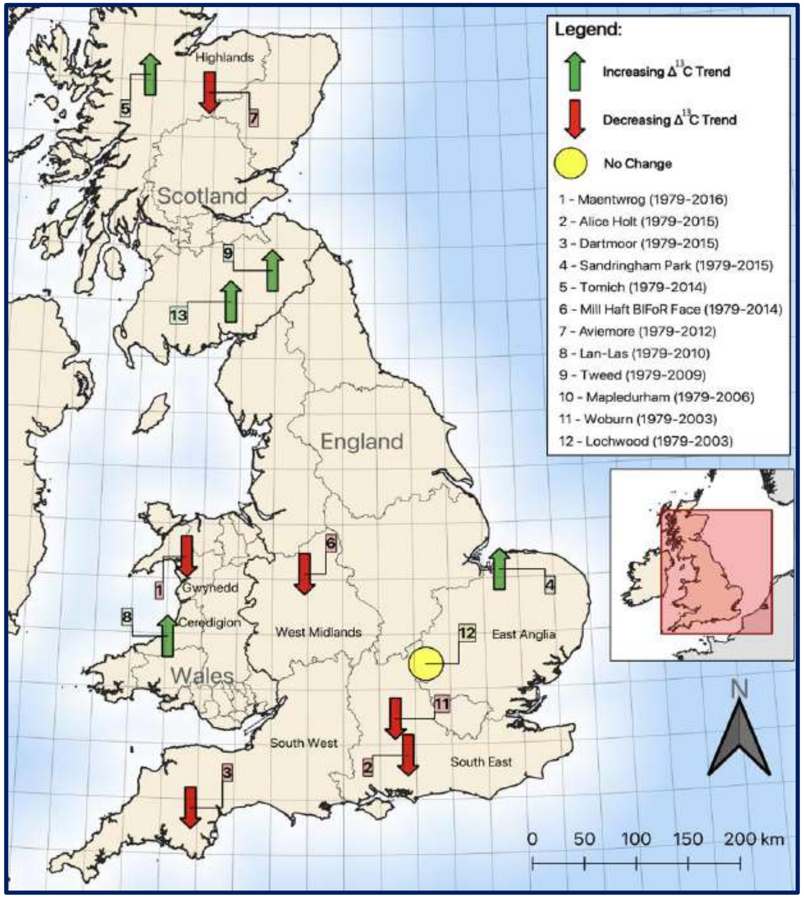
$\Delta^{13}C$ Interannual Variability (IAV) and Trend

Interannual variability, IAV (expressed as standard deviation from the mean) of the modelled and observed $\Delta^{13}C$

	Maentwrog	Alice Holt	Dartmoor	Sandringham Park	Tomich	Mill Haft	Aviemore	Lan-las	Tweed	Mapledurham	Woburn	Lochwood
Observed Variability	0.57	0.50	0.39	0.53	0.37	0.64	0.90	0.65	0.62	0.43	0.55	0.65
Modelled Variability	0.16	0.17	0.13	0.19	0.16	0.19	0.18	0.12	0.20	0.18	0.19	0.19



- **Observed IAV in $\Delta^{13}C_{TR}$ partially captured but dampened by JULES**
- **While predicted $\Delta^{13}C$ increase in all sites, $\Delta^{13}C_{TR}$ tend to increase in Scotland but to decrease in England**
  → different precipitation regimes?
- **More UK-wide tree-ring isotopic measurements needed to confirm these spatio-temporal trends**

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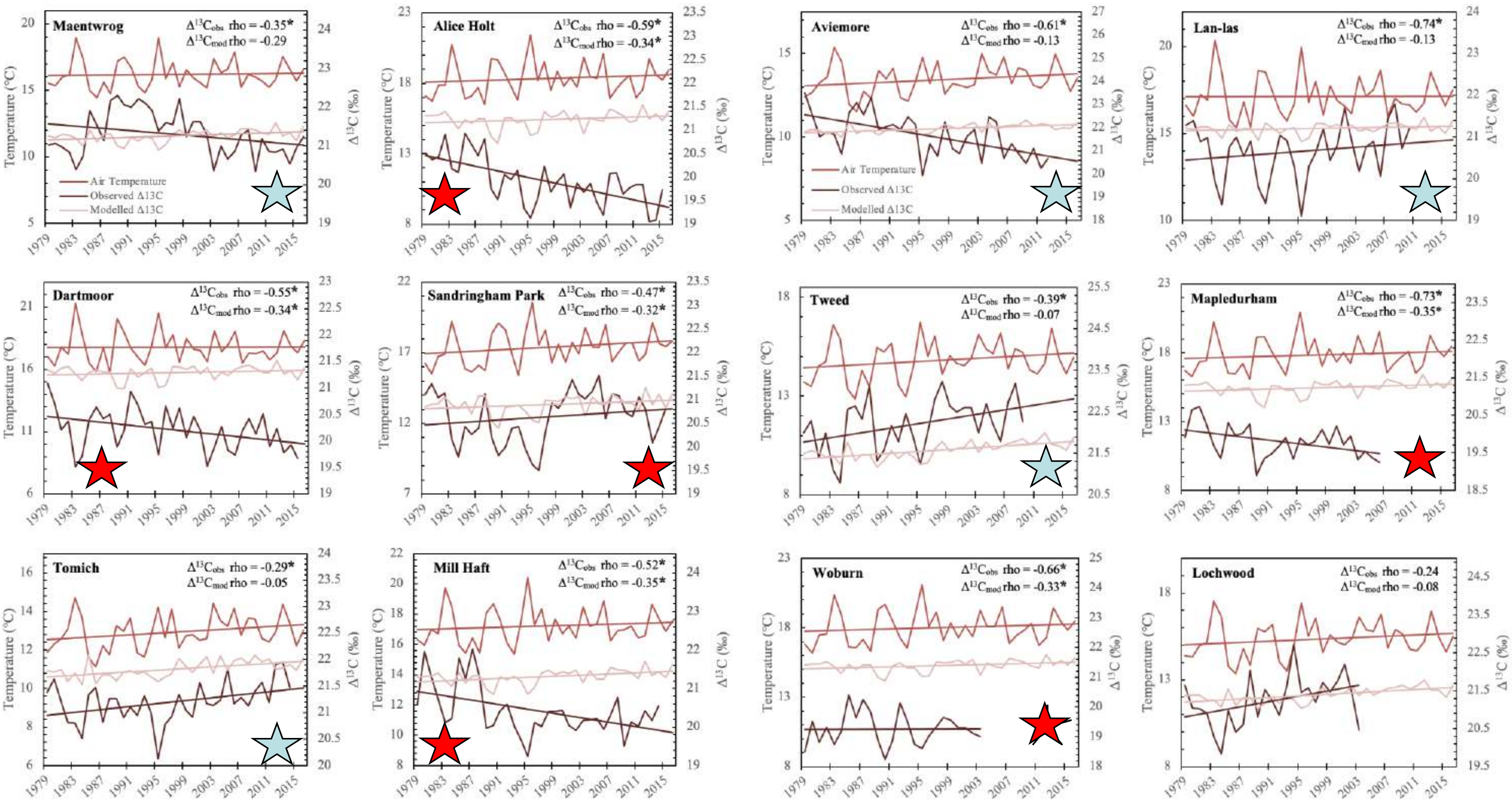
Observed & Modelled Δ^{13}C versus Air Temperature



☆ Significant at p <0.05 only for observed Δ^{13}C

★ Significant at p <0.05 for both observed and modelled Δ^{13}C

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Possible Causes of Dampened JULES $\Delta^{13}C_{leaf}$ Signal

- Stem respiration more sensitive to changes in T_{air} and soil moisture than leaf respiration (Diao et al., 2020)
  → greater changes in reconstructed $\Delta^{13}C_{TR}$ than expected $\Delta^{13}C_{leaf}$

- Modelled $\Delta^{13}C_{leaf}$ less sensitive to climate than observed $\Delta^{13}C_{TR}$ (Bodin et al., 2013)

- Parameterization of stomatal and photosynthesis models may not be completely realistic

+ uncertainties in the simulated $\Delta^{13}C$ values (e.g. post- photosynthetic fractionations)

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Conclusions

- JULES predicts relatively well $\Delta^{13}C$ variations in 6 out of 12 sites.

- More tree-ring sampling in UK required to confirm spatio-temporal trends in observed $\Delta^{13}C$.

- $\Delta^{13}C$ derived from tree rings is sensitive to T_{air} in most sites, but this pattern is only reproduced by JULES in 6 out of 12 sites
→ JULES tends to underestimate the effect of T_{air} on $\Delta^{13}C$

- Dampening of IAV in predicted $\Delta^{13}C$ values very likely due to the lower sensitivity to climate variations of predicted $\Delta^{13}C$ compared to tree ring-based $\Delta^{13}C$

Future research – defining how much of the variability in $\Delta^{13}C_{TR}$ is explained by climate?

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