--- Supplementary material cp-2019-25 ---

Evaluating model outputs using integrated global speleothem records of climate change since the last glacial

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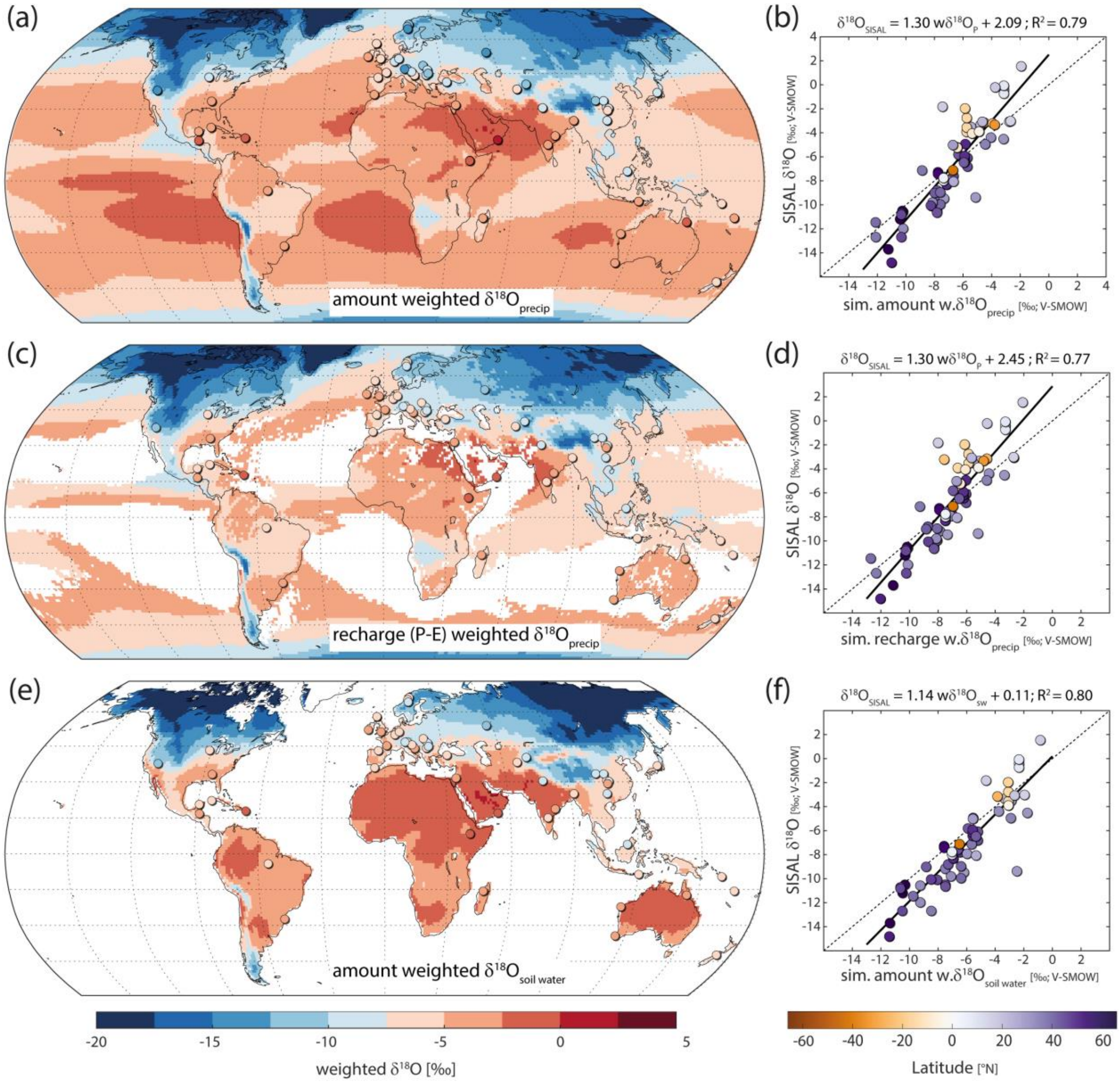
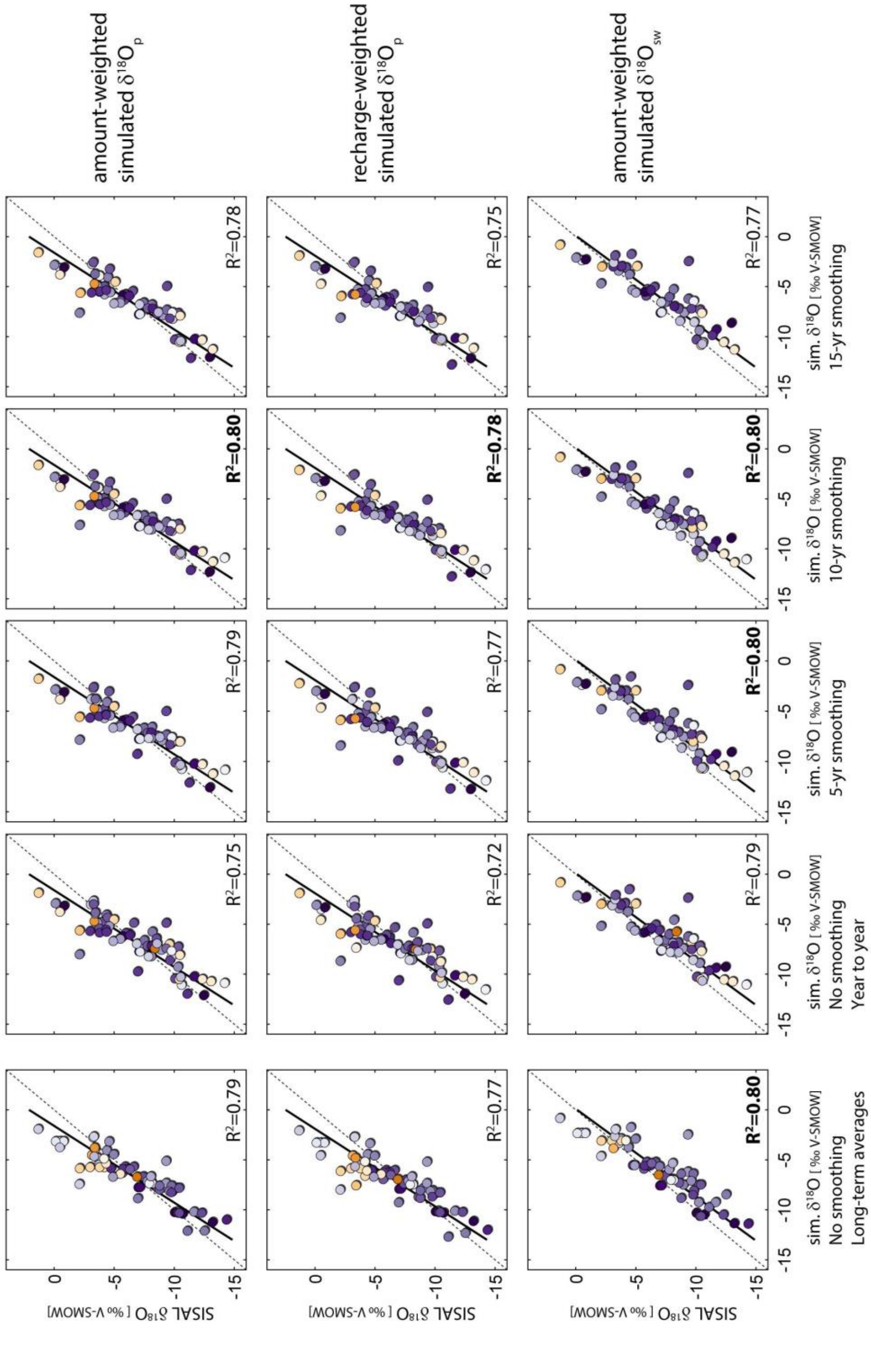
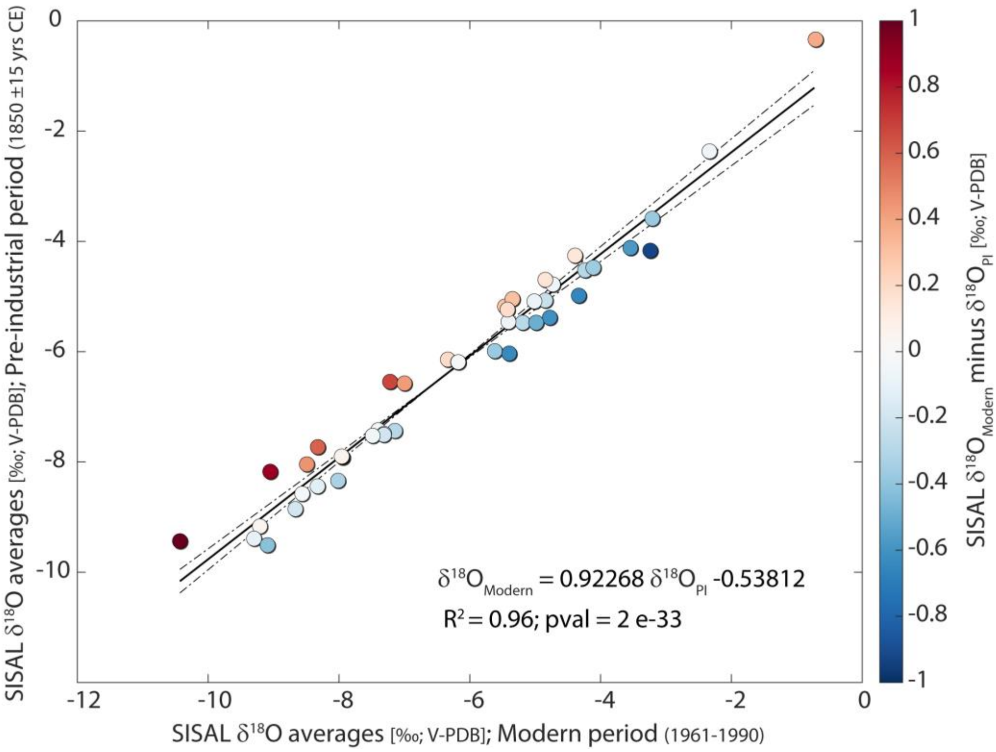
Supplementary Figure 1: Data-model comparison for the modern period (1958–2013) using three methods to treat the simulated data: **(a, b)** $\delta^{18}O$ in precipitation weighted according to the monthly precipitation amount. **(c, d)** $\delta^{18}O$ in precipitation weighted according to the monthly potential infiltration calculated as precipitation (P) minus evapotranspiration (E) when P-E > 0. **(e, f)** soil water $\delta^{18}O$ weighted according to the monthly soil moisture content (i.e. soil water bucket). (a, c, e) show the data-model agreement. (b, d, f) show the linear regressions of simulated $\delta^{18}O$ vs SISAL $\delta^{18}O$ data.



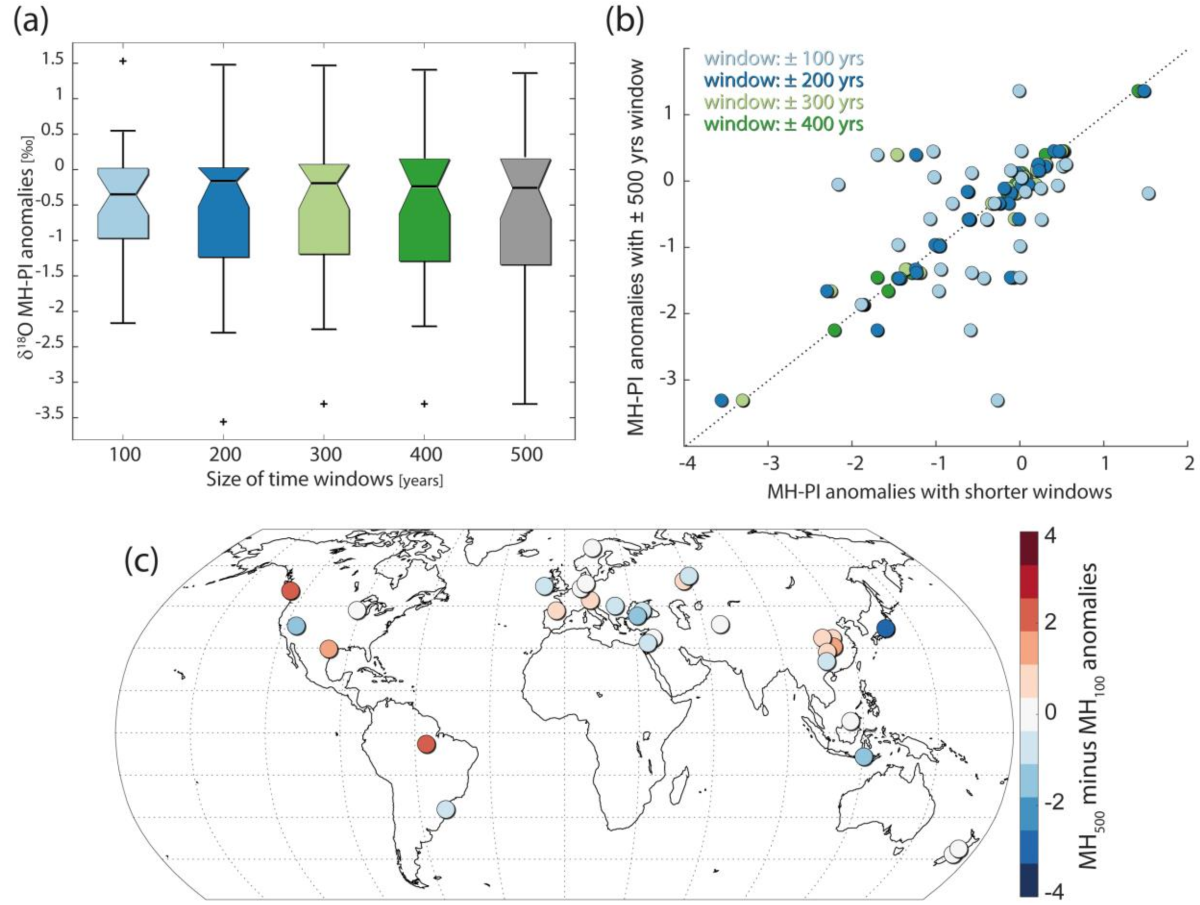
Supplementary Figure 2: Linear regressions between SISAL δ^{18}O and simulated amount-weighted δ^{18}Oprecip (top row), recharge weighted δ^{18}O (middle row) and amount weighted δ^{18}Osw for the period (1958–2013 CE). Data used in first column are long-term SISAL and ECHAM5-wiso data (as in Supplementary Figure 1). Second column is the regression on a year to year basis (i.e. using simulated data only for the years for which SISAL data is available). Third, fourth and fifth columns are the same as the latter after applying a smoothing of 5- 10- and 15-yrs respectively. The smoothing was applied using the 5, 10 and 15 years previous to the SISAL's sample date and all years carried the same weight on the mean value. Solid black line is the regression line. Dashed grey line is the 1:1 line. Correlation coefficients (R^2) are at the bottom right of each panel.



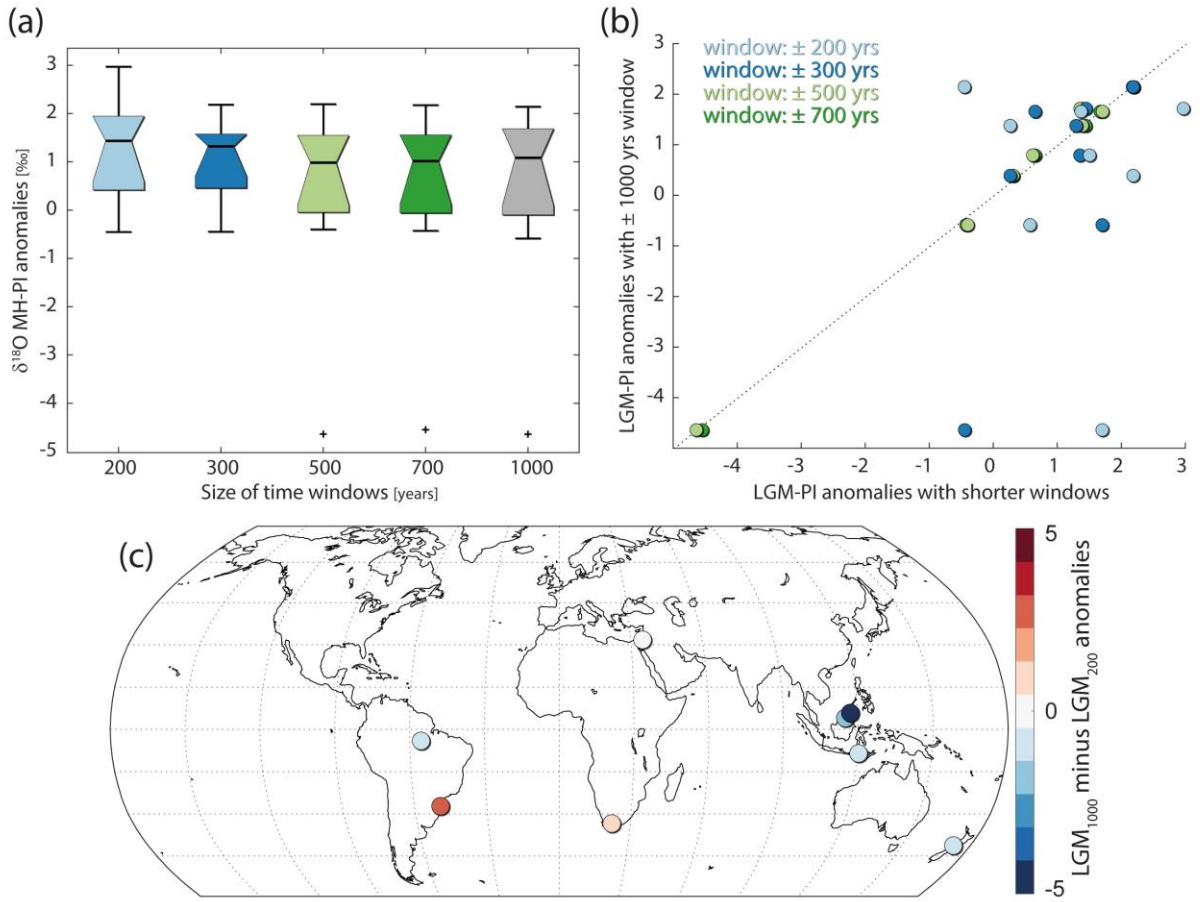
Supplementary Figure 3: Linear regression between SISAL $\delta^{18}O$ averages during the modern period (1961-1990 CE) and the pre-industrial (1850±15 CE). Colour bar shows the difference between the two time periods in ‰ V-PDB.



Supplementary Figure 4: Impact of using time-windows shorter than the convention of ± 500 yrs on SISAL MH-PI anomalies. **(a)** Boxplots of the global $\delta^{18}O$ MH-PI anomalies across time window widths. **(b)** Anomalies using windows of 100 to 400 yrs versus the anomalies calculated using the conventional 500 yrs. **(c)** Differences between MH-PI anomalies using 500 and 100 yrs.



Supplementary Figure 5: Impact of using time-windows shorter than the convention of ± 1,000 yrs on SISAL LGM-PI anomalies. **(a)** Boxplots of the global δ^{18}O LGM-PI anomalies across time window widths. **(b)** Anomalies using windows of 200 to 400 yrs versus the anomalies calculated using the conventional 1,000 yrs. **(c)** Differences between LGM-PI anomalies using 1,000 and 200 yrs



Supplementary Section: Multivariate analysis

Methods:

Univariate multilinear analyses were applied on both speleothem and simulated $\delta^{18}O$ data for the three time periods (i.e. modern, MH and LGM). The analyses consisted in exploring the data to verify the statistical premises of a linear relationship between the variables, and if verified, selecting the best multilinear model based on a step-wise selection between the most complete linear regression model (e.g. see equation below) and the simplest one (e.g. $\delta^{18}O_y = constant$). In all univariate multilinear models, the dependent variable was $\delta^{18}O$ and the independent variables would include the $\delta^{18}O$ either from another data source (SISAL, OIPC, ECHAM5-wiso) and the same time period (modern, MH, LGM), or from another time period but the same data source. The analyses were made using the R software (R Core Team, 2015) following Zuur et al. (2010) scripts. The general equation of the applied model can be expressed as:

$$\delta^{18}O_y = a + b \cdot \delta^{18}O_x + c_i \cdot (lat \cdot lon \cdot elevation) + \varepsilon_i$$

Where y and x refer to the two data sources used (in ‰ V-SMOW); a, b and c_i are the coefficients of each independent variable and their interaction, respectively, and ε_i are the residuals. Longitude and latitude are expressed as degrees N and E, respectively, and elevation is in meters above sea level. The elevation in ECHAM5-wiso was used for MH and LGM time periods whereas SISAL elevation was used for the modern.

Results:

Our multivariate analysis shows that incorporating variables other than SISAL's $\delta^{18}O$ and simulated $w\delta^{18}Op$ in the comparison (e.g. a parameter to account for latitudinal changes) does not improve the results from the simple linear regression in Figure 3. Nevertheless, our best multivariate linear model for the modern period includes the latitude as a significant variable for explaining, for example, the linear SISAL-ECHAM relationship in the modern period. This indicates that the geographical position of the samples has to be taken into account in order to better capture the linear relationship between the modern SISAL values and the modern ECHAM5-wiso experiments.

Supplementary Table 1: Results of the best multivariate linear regression models. Superindices are the statistical significance of the coefficients as ([a]) p-val < 0.01, ([b]) 0.01 < p-value < 0.05 and ([c]) 0.05 < p-value < 0.1. n is the number of observations for each model and R^2 is the correlation coefficient (either adjusted or not). $: Elevation was removed from the original complete model because it increases the Variance Inflation Factor (VIF) to values higher than 10. The combinations not in this table (e.g. ECHAM5-wiso MH vs LGM or ECHAM5-wiso LGM vs modern) did not yield any significant correlation.

y	**OIPC**	**ECHAM5-wiso mod**	**SISAL-MH**	**SISAL-LGM**	**ECHAM5-wiso LGM**
x	**SISAL mod**	**SISAL-mod**	**SISAL-mod**	**SISAL-MH**	**ECHAM5-wiso MH**
intercept	0.463	-3.357 [a]	-1.197 [a]	1.43	0.786 [a]
d18O (x)	0.93 [a]	0.623 [a]	9.29 E-1 [a]	1.006 [a]	0.883 [a]
Latitude	-0.007	0.013 [b]	1.12 E-2	-0.064 [b]	-0.050 [a]
Longitude	-0.003	0.0031	-2.18 E-3	-0.003	0.001
Elevation	-1.81 E-4 c	$	$	$	$
Interaction lat*lon			-2.20 E-4 a	4.04 E-4	3.69 E-4 a
Interaction lon*elev					
R2 (adjusted)	0.81 (0.79)	0.78(0.77)	0.92 (0.91)	0.83 (0.78)	0.84(0.80)
n	66	72	28	20	20

Reference list

R: A Language and Environment for Statistical Computing, R Foundation for Statistical Computing: http://www.R-project.org, 2015.

Zuur, A. F., Ieno, E. N., and Elphick, C. S.: A protocol for data exploration to avoid common statistical problems, Methods in Ecology and Evolution, 1, 3-14, https://doi.org/10.1111/j.2041-210X.2009.00001.x, 2010.