Climate fields of the last millennium from terrestrial climate archives and isotope-enabled GCMs

UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

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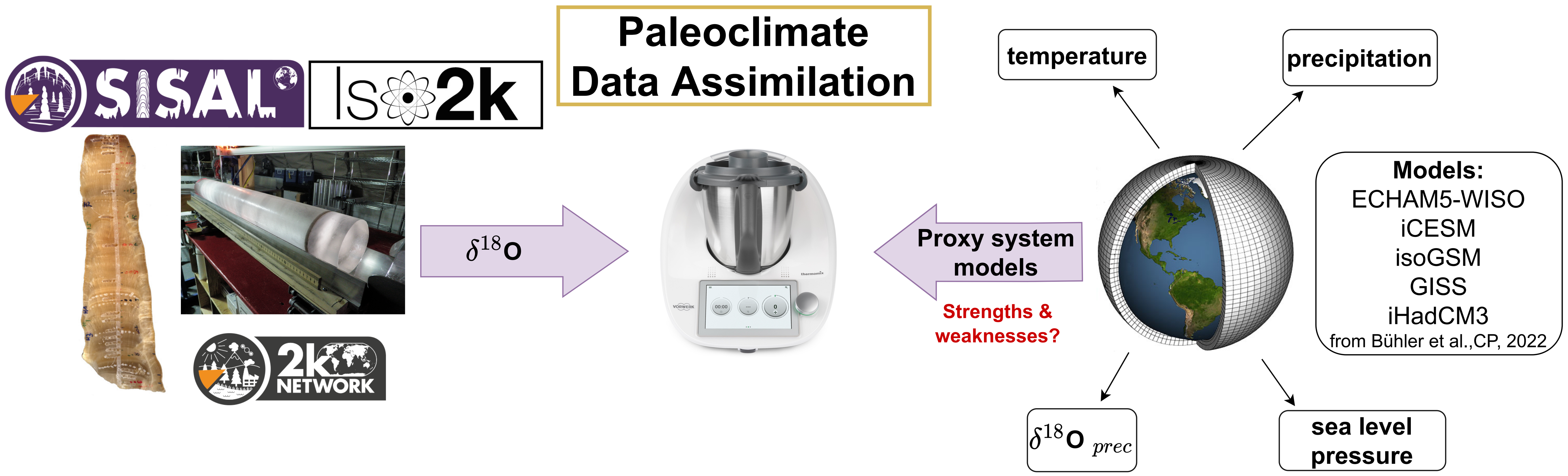


Speleothems can inform climate field reconstructions by using multi-time scale PaleoDA with isotope-enabled GCMs.

STARTING POINT

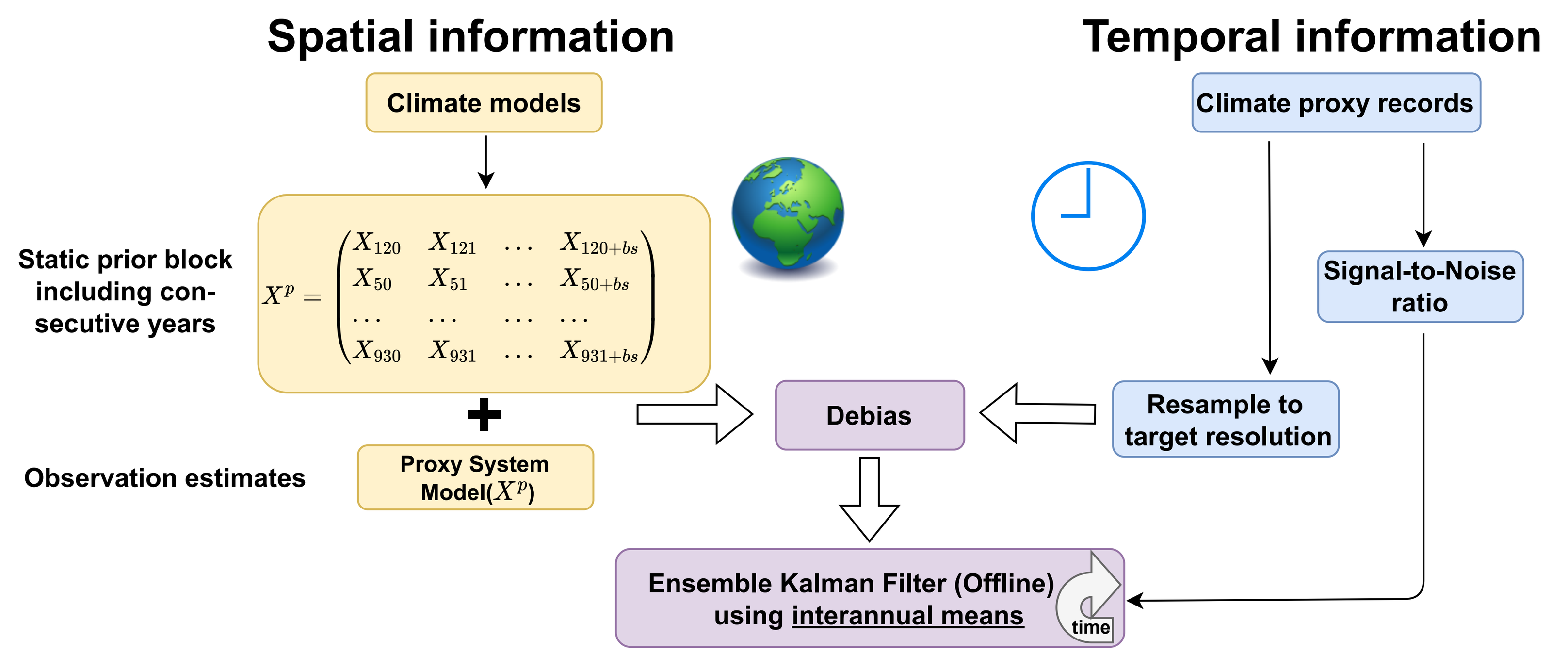
- Speleothems & ice cores record decadal to centennial climate variability
- Last millennium reconstructions as LMR [1] or PHYDA [2] mostly rely on tree-rings from the Northern Hemisphere
- δ^{18}O from speleothems can hardly be calibrated to instrumental temperature/precipitation due to coarse temporal resolution
- Existing Paleoclimate Data Assimilation reconstructions do not systematically include speleothems
- Speleothem data can potentially fill tropical proxy data deserts

LEADING QUESTIONS

- Does using low-resolution proxy records and a multi-time scale approach improve the **reconstruction of temporal variability**?
- How do **individual archive types** contribute to the reconstruction?
- How do **model differences** and **biases** affect the reconstructions?

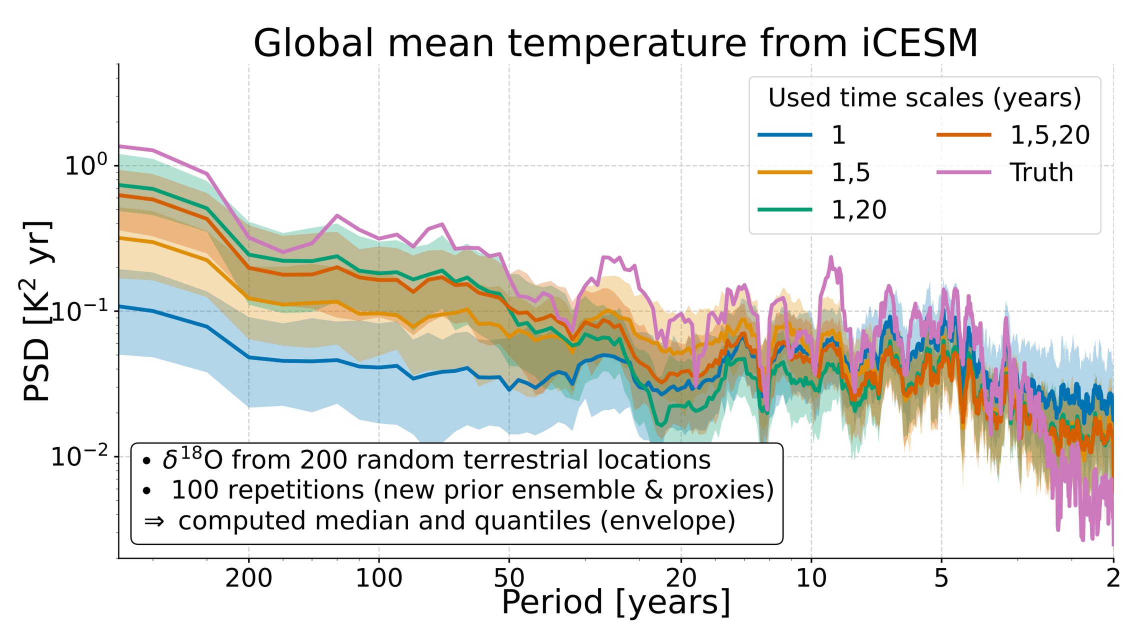
References and further plots:
tinyurl.com/paleoda
Contact: mathurin@choblet.com

MULTI-TIME SCALE DATA ASSIMILATION [3]



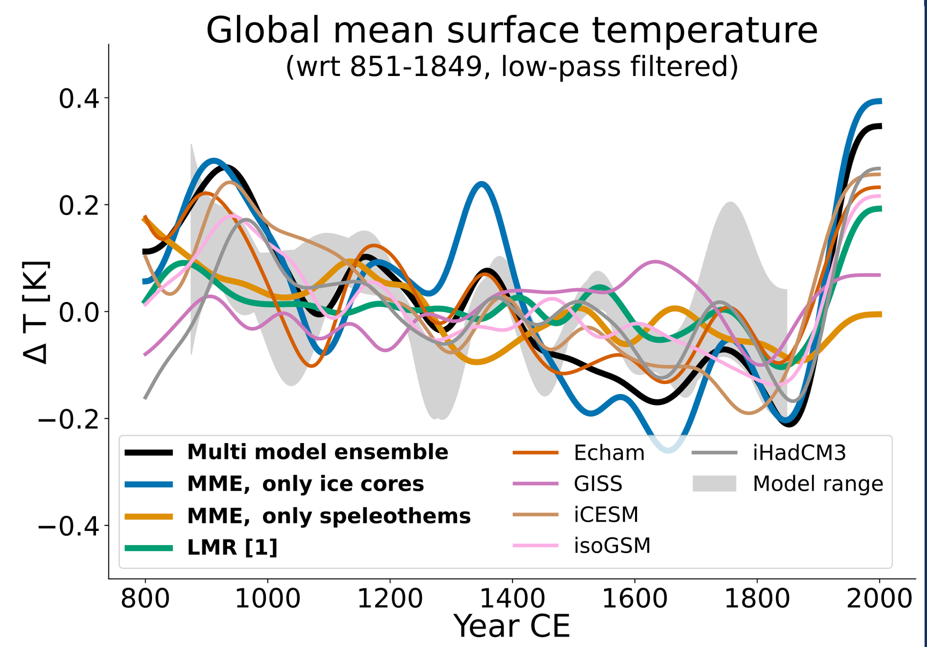
Mechanism: Interpolation based on covariance-structure from models

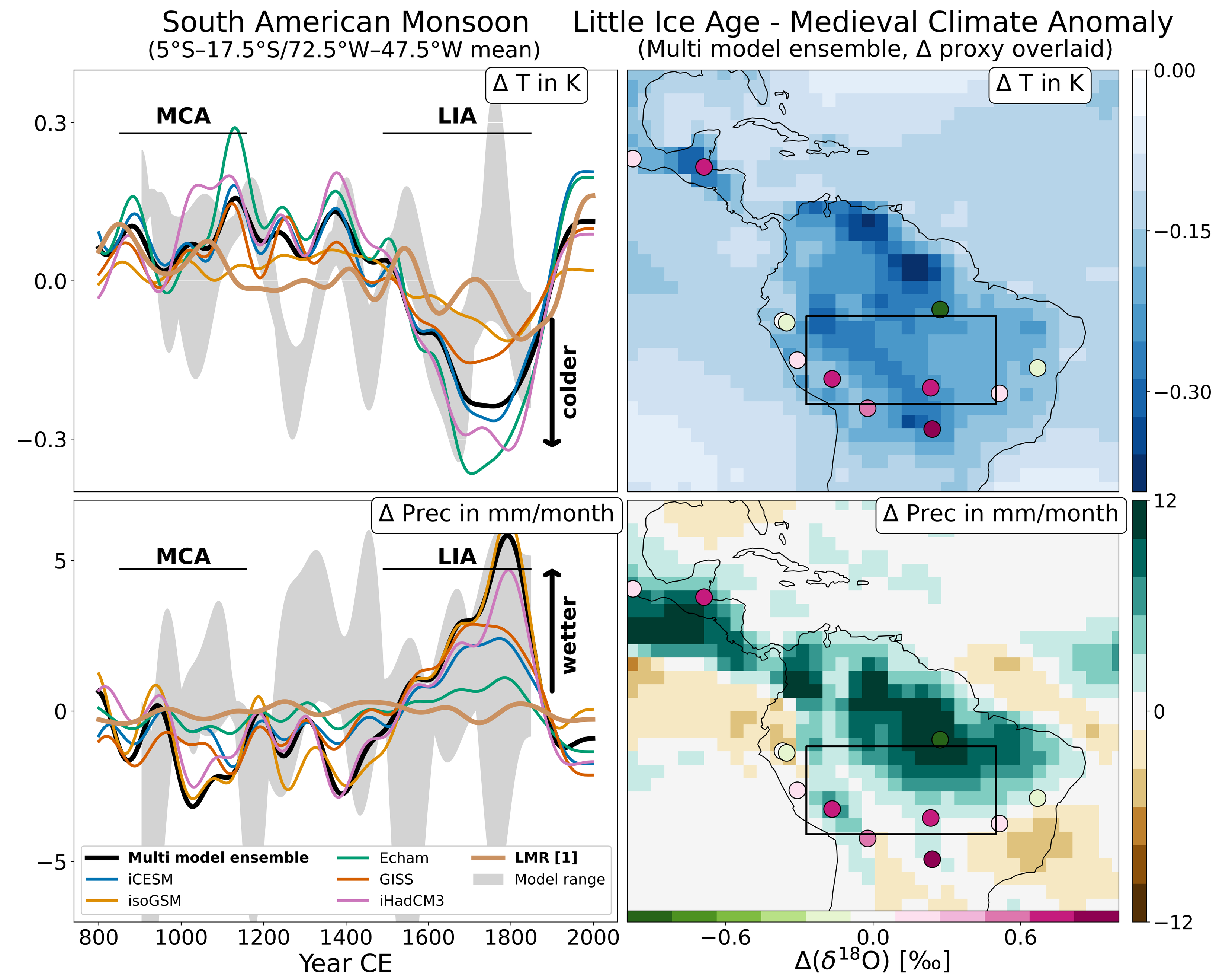
Spectral analysis:
Pseudoproxy Experiments show improved reconstruction of multi-decadal variability



RESULTS

- Comparable GMT signals, mainly from the ice cores
- South American hydroclimate reconstruction shows potential of including speleothems
- Larger variability than LMR [1]
- Prior dependency: different δ^{18}O-tsurf/prec sensitivity

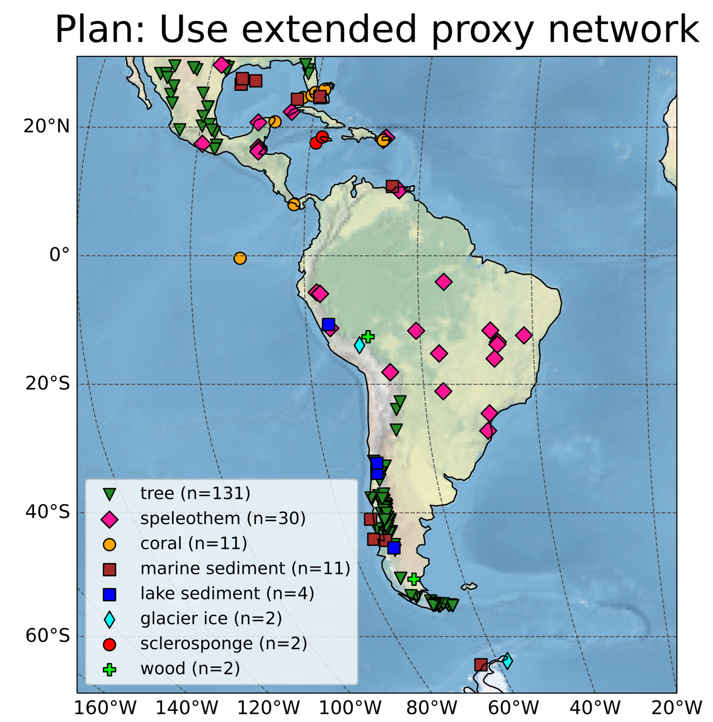




WORK IN PROGRESS

- Include other proxy archives from PAGES2k, Iso2k, ...
- Which **climate phenomena** can our reconstruction help understand (SAMS, SAM, ITCZ shift,...)?
- Explore **methodological uncertainties** and covariance structures of models

⇒ Best procedure to capture them?



Poster appendix for Climate fields of the last millennium from terrestrial climate archives and isotope-enabled GCMs

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Contents

1 References on poster

1.1 Numbered references:

[1] Tardif, Robert, Gregory J. Hakim, Walter A. Perkins, Kaleb A. Horlick, Michael P. Erb, Julien Emile-Geay, David M. Anderson, Eric J. Steig, and David Noone. "Last Millennium Reanalysis with an expanded proxy database and seasonal proxy modeling." Climate of the Past 15, no. 4 (2019): 1251-1273.

[2] Steiger, Nathan J., Jason E. Smerdon, Edward R. Cook, and Benjamin I. Cook. "A reconstruction of global hydroclimate and dynamical variables over the Common Era." Scientific data 5, no. 1 (2018): 1-15.

[3] Steiger, Nathan, and Gregory Hakim. "Multi-time scale data assimilation for atmosphere-ocean state estimates." Clim. Past Discuss 11, no. 4 (2015): 3729-3757.

1.2 Model data references can be found in

– Bühler, Janica C., Josefine Axelsson, Franziska A. Lechleitner, Jens Fohlmeister, Allegra N. LeGrande, Madhavan Midhun, Jesper Sjolte, Martin Werner, Kei Yoshimura, and Kira Rehfeld. "Investigating stable oxygen and carbon isotopic variability in speleothem records over the last millennium using multiple isotope-enabled climate models." Climate of the Past 18, no. 7 (2022): 1625-1654.

1.3 Proxy record databases

SISALv2

Comas-Bru, Laia, Kira Rehfeld, Carla Roesch, Sahar Amirnezhad-Mozhdehi, Sandy P. Harrison, Kamolphat Atsawawaranunt, Syed Masood Ahmad et al. "SISALv2: a comprehensive speleothem isotope database with multiple age–depth models." Earth System Science Data 12, no. 4 (2020): 2579-2606.

Iso2k

Konecky, Bronwen L., Nicholas P. McKay, Laia Comas-Bru, Emilie P. Dassié, Kristine L. DeLong, Georgina M. Falster, Matt J. Fischer et al. "The Iso2k database: a global compilation of paleo-δ 18 O and δ 2 H records to aid understanding of Common Era climate." Earth System Science Data 12, no. 3 (2020): 2261-2288.

Further proxy record databases used for bottom right figure (and not for reconstructions performed for the poster)

Pages2k

PAGES2k Consortium. "A global multiproxy database for temperature reconstructions of the Common Era." Scientific data 4 (2017).

Breitenmoser tree-ring dataset

Breitenmoser, P., Stefan Brönnimann, and David Frank. "Forward modelling of tree-ring width and comparison with a global network of tree-ring chronologies." Climate of the Past 10, no. 2 (2014): 437-449.

PHYDA database (for Breitenmoser tree-ring dataset)

Steiger, N., K. Horlick, R. Tardif, M. Erb, J. Emile-Geay, E. Steig, and G. Hakim. "A global collection of paleoclimate proxy time series over the Common era, Zenodo (2018)."

2 Methodology

A thorough treatment of the Paleoclimate Data Assimilation method can be found in the master's thesis of the presenting author, which is publicly available under the following link: https://heibox.uni-heidelberg.de/f/215b873aee154346b217/. It also comprises a comprehensive description of the reconstruction parameters for the global mean temperature and South America reconstructions.

A manuscript for a reconstruction focussed on tropical South America is currently in preparation.

3 Temporal variability spectra

To assess the skill of the multi-time scale PaleoDA algorithm to reconstruct temporal variability, Pseudoproxy experiments (PPEs) have been performed over 1000 simulated years. For each experiment, 200 terrestrial pseudoproxy locations have been selected. The global mean temperature has then been reconstructed based on the δ^{18}O values from these locations. A Signal-to-Noise ratio of 0.5 has been chosen for the creation of the noisy time series. The following number of pseudoproxy locations have been selected for the individual experiments and time scales:

- Annual experiment (1): 200 pseudoproxies
- 1,5: 100 annual pseudoproxies, 100 5-year averaged pseudoproxies
- 1,20: 100 annual pseudoproxies, 100 20-year averaged pseudoproxies
- 1,5,20: 100 annual pseudoproxies, 50 5-year averaged pseudoproxies, 50 20-year averaged pseudoproxies

The authors are aware, that the number of employed data points over the whole reconstruction period is not equal in the different experiments. PPEs with an adjusted number of locations have been performed in the master's thesis of the presenting author (Choblet, 2022). Each experiment has been repeated 100 times with different prior ensemble members (100) and pseudoproxy locations.

The spectra have been generated with the multi-taper method (mtm) of the Pyleoclim package (Khider et al.). The GMT curves have been detrended, but not standardized, which is important to compare the absolute variability of each time series.

3.1 ECHAM spectra

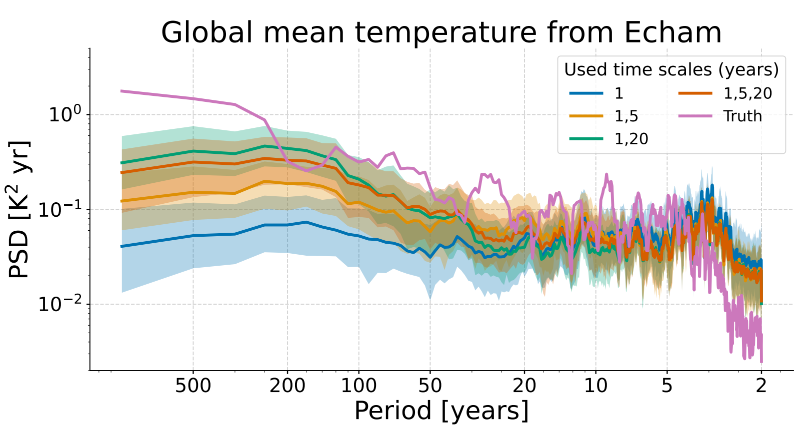

Figure 1. Power spectral densities of reconstructed global mean temperature using pseudoproxies on multiple time scales. The model that has been used as a prior is ECHAM. The pseudoproxies have been generated from δ^{18}O with an SNR of 0.5 and the PSM-light configuration for the simulated δ^{18}O at 200 proxy record locations. The noise has been added to the pseudo proxy records after averaging the time series to the higher time scales.

3.2 iHadCM3 spectra

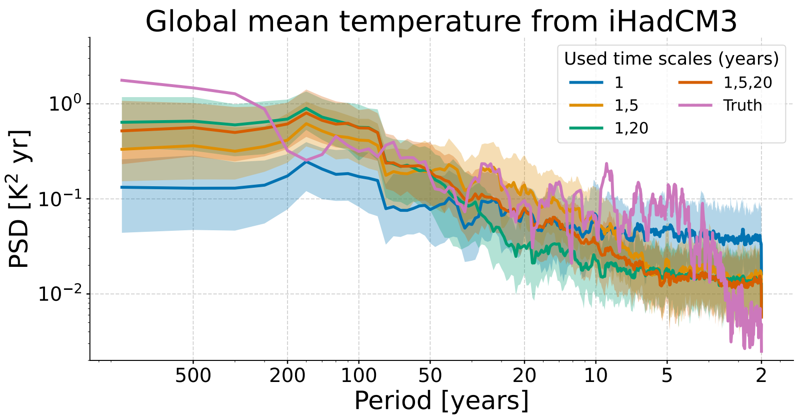

Figure 2. Same as figure 1 for iHadCM3.

3.3 isoGSM spectra

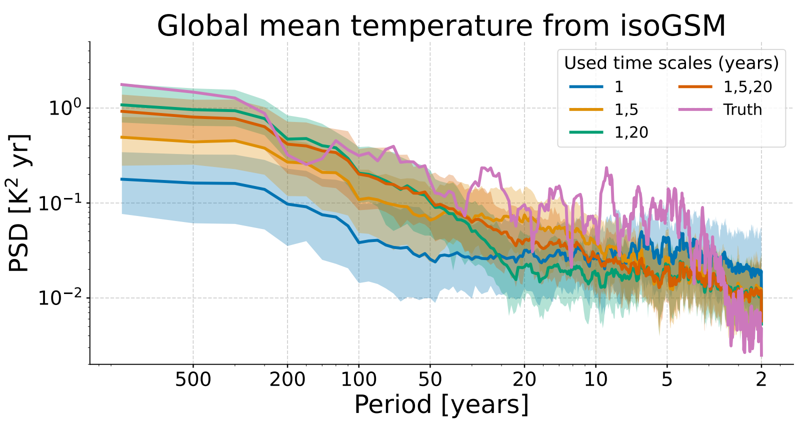

Figure 3. Same as figure 1 for isoGSM.

3.4 GISS spectra

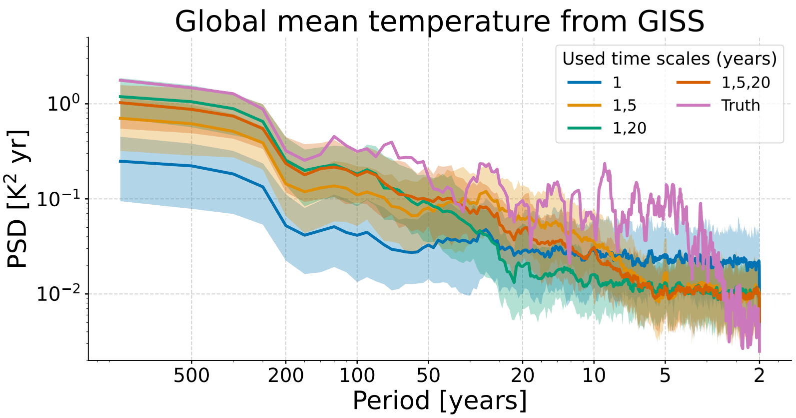

Figure 4. Same as figure 1 for GISS.

4 Global mean temperature plots

The following figures are part of Choblet (2022).

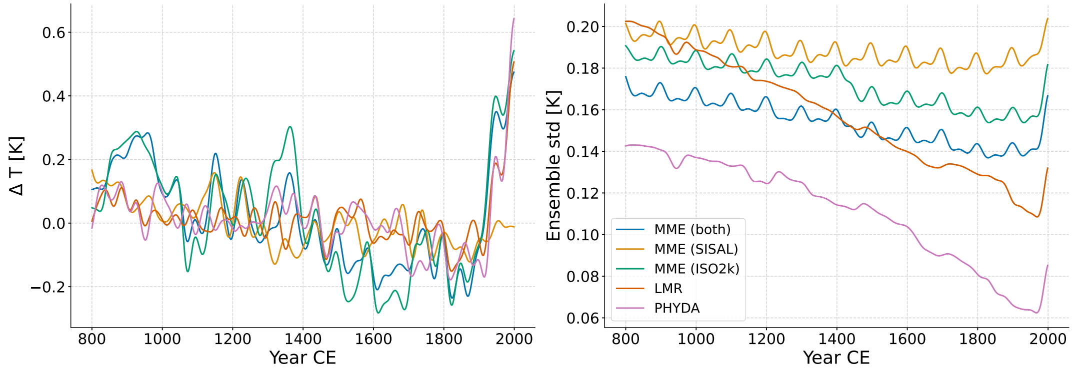

Figure 5. The reconstructed GMTs from the individual and joint SISAL (speleothems) and Iso2k (ice cores) databases in comparison to the LMR and PHYDA reconstructions are shown in the left panel. The uncertainties of the reconstructions are shown in the right panel. The periodicity is an artefact from the prior block in the multi-time scale approach. The time series have been low-pass filtered with a 50 year Butterworth filter.

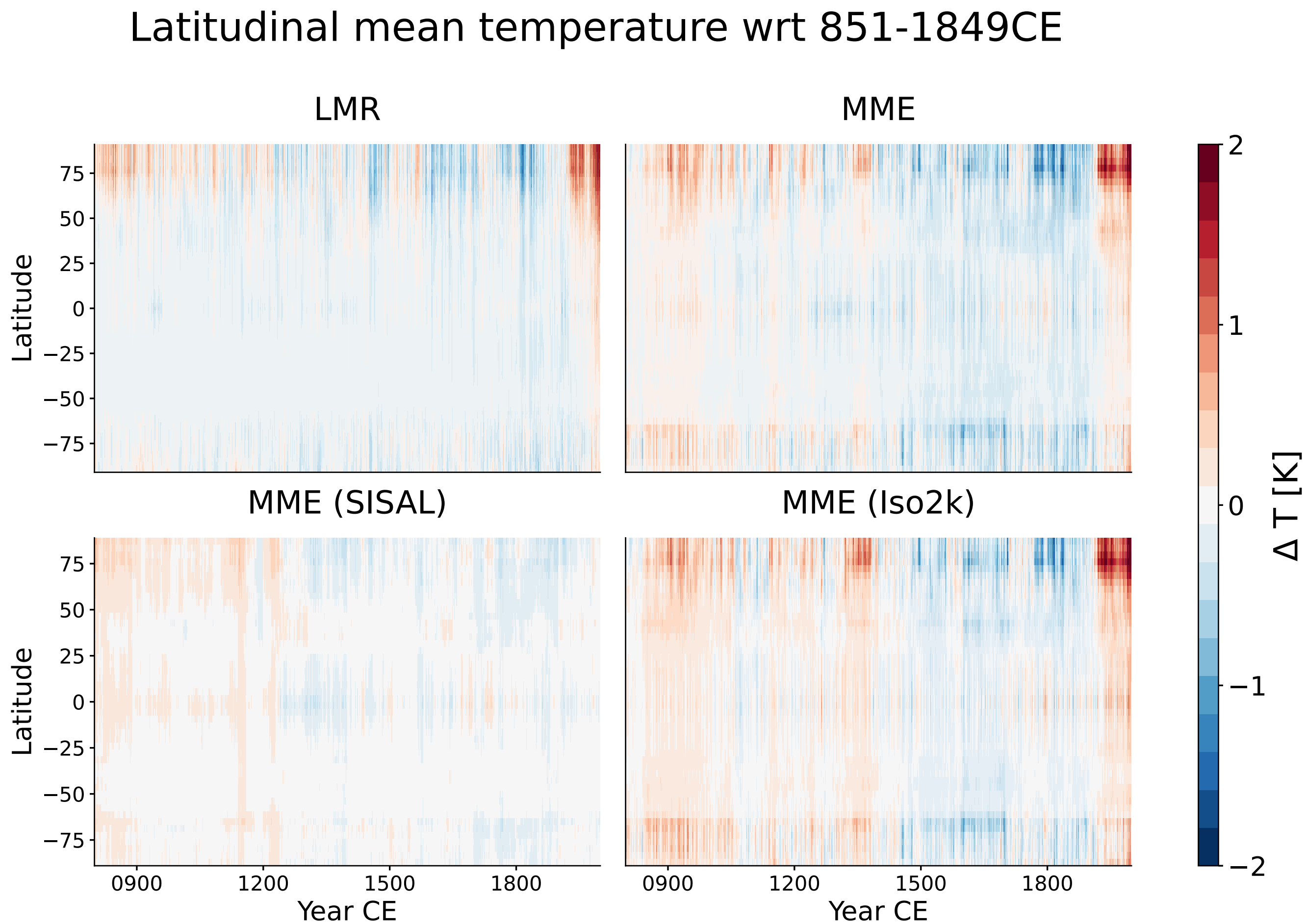

Figure 6. Latitudinal mean temperature anomalies over time (Hovmöller diagram). The upper left panel shows the LMR reconstruction, the upper right panel the results from the MME reconstruction using both the speleothems and ice cores. The lower panel show the reconstructions using only speleothems (SISAL) and ice cores (Iso2k). In comparison to the top right figure of the poster, the time series have not been filtered. The apparent coarser resolution of MME in comparison to LMR stems from the multi-time scale approach. 851-1849CE was used as the reference period.

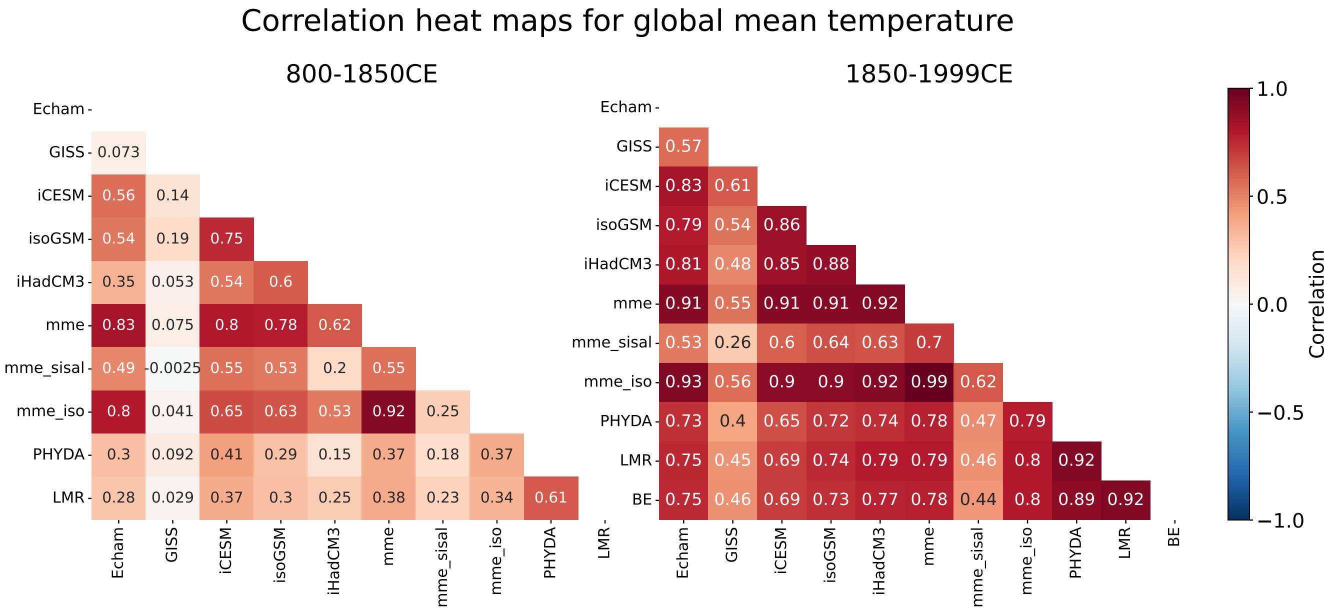

Figure 7. Heat map visualizing the correlation between the time series in top right figure of the poster. The correlations are computed separately for the PI (left panel) and the CWP (right panel). The time series have not been detrended to assess similarity including the cooling and warming trends. No filtering of the signals has been performed. The CWP evaluation also includes the correlation with the observational GMT from the Berkeley Earth dataset (BE) (Rohde and Hausfather). `mme_sisal` and `mme_iso` refer to the multi model ensemble reconstructions with the separate SISALv2 and Iso2k database records. The 95% confidence intervals of the correlations can be found in Choblet (2022).

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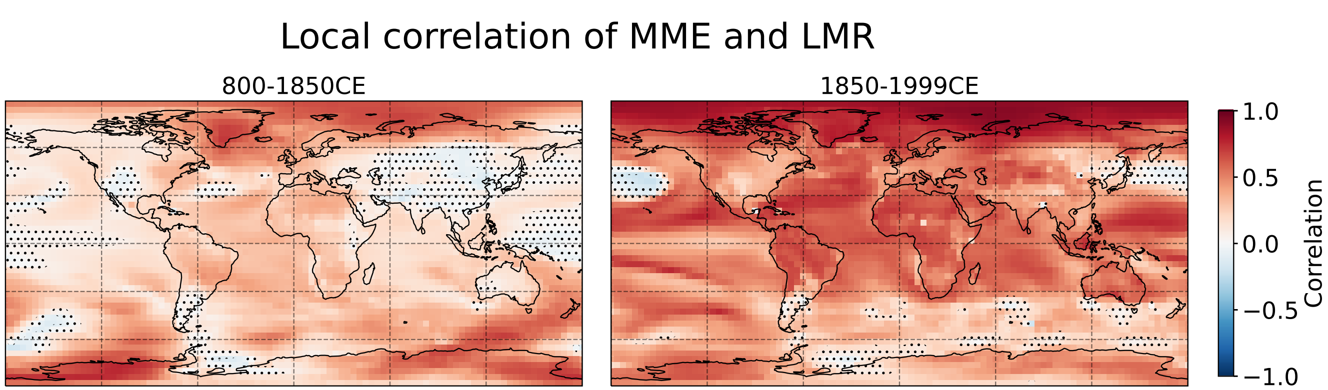
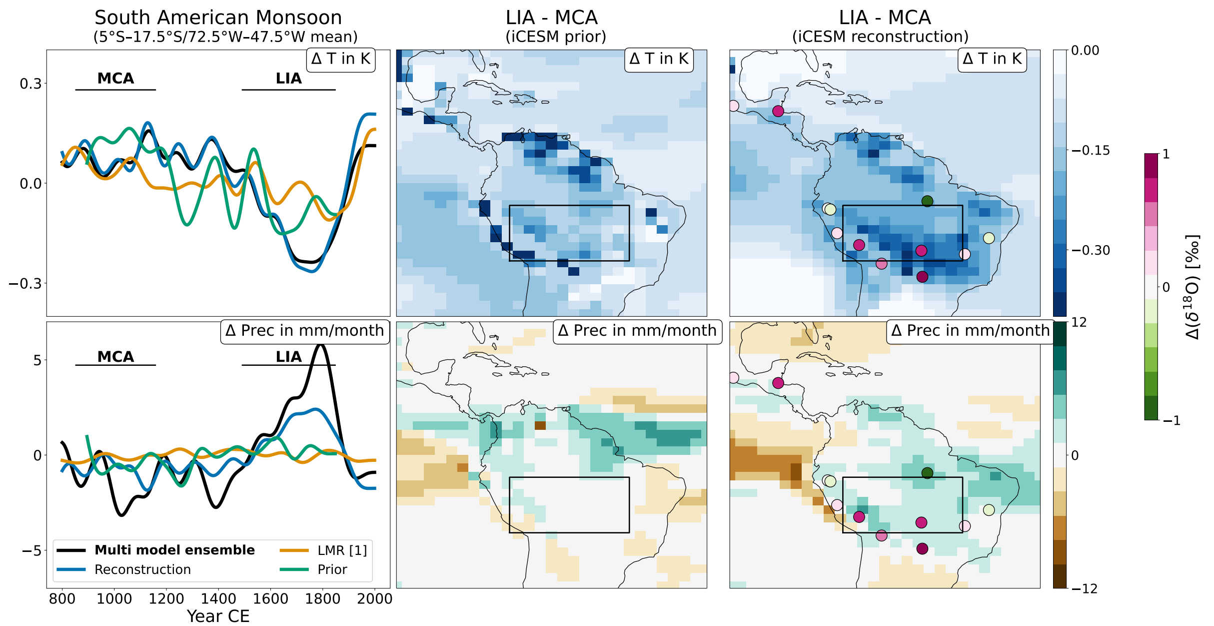


Figure 8. Correlation fields between the MME reconstruction (using both databases) and the LMR. The left panel shows the correlation for the PI (800-1850CE) and the right panel for the CWP (1850-1999CE). The local time series have not been filtered. The time series have not been detrended. The stippling indicates non-significant correlations ($p>0.05$).

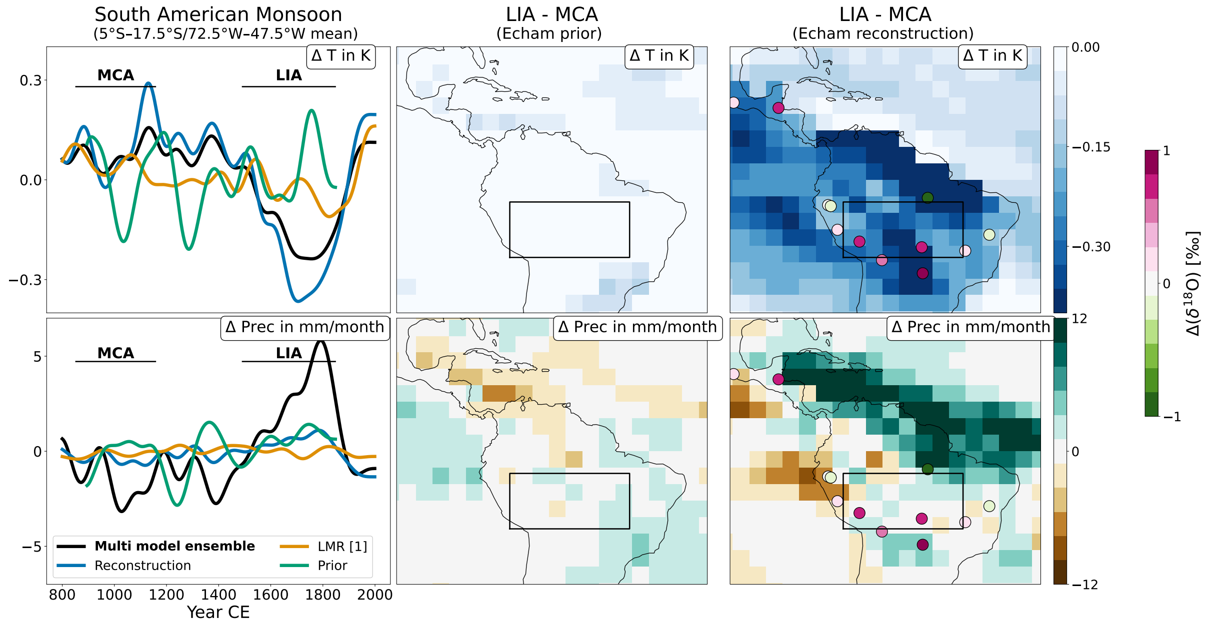
5 South America Plots

In the following, the central right plot on the poster, which shows the monsoon index strength and MCA-LIA difference is shown for the individual model priors (center panels) and single model prior reconstructions (right panels).

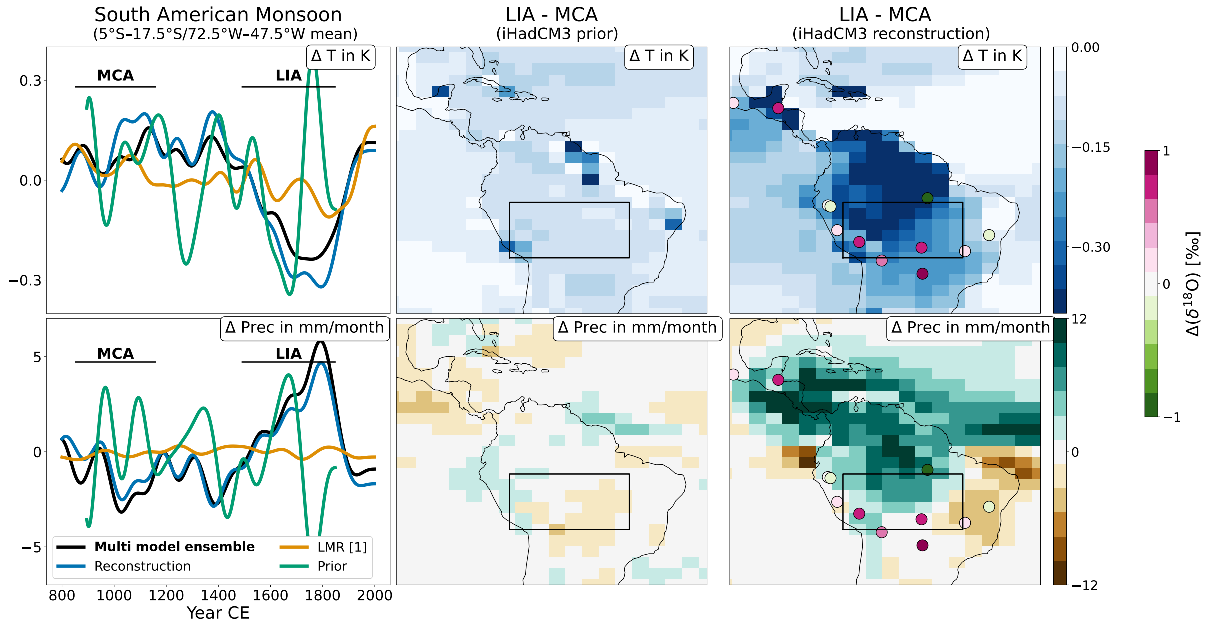
5.1 iCESM



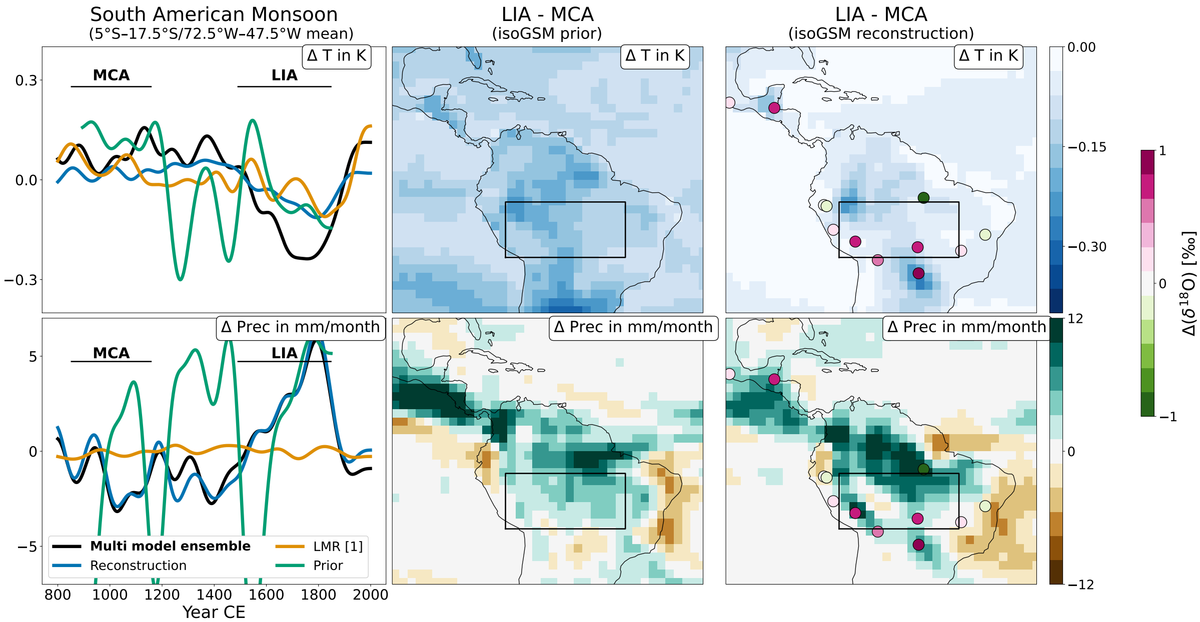
5.2 ECHAM



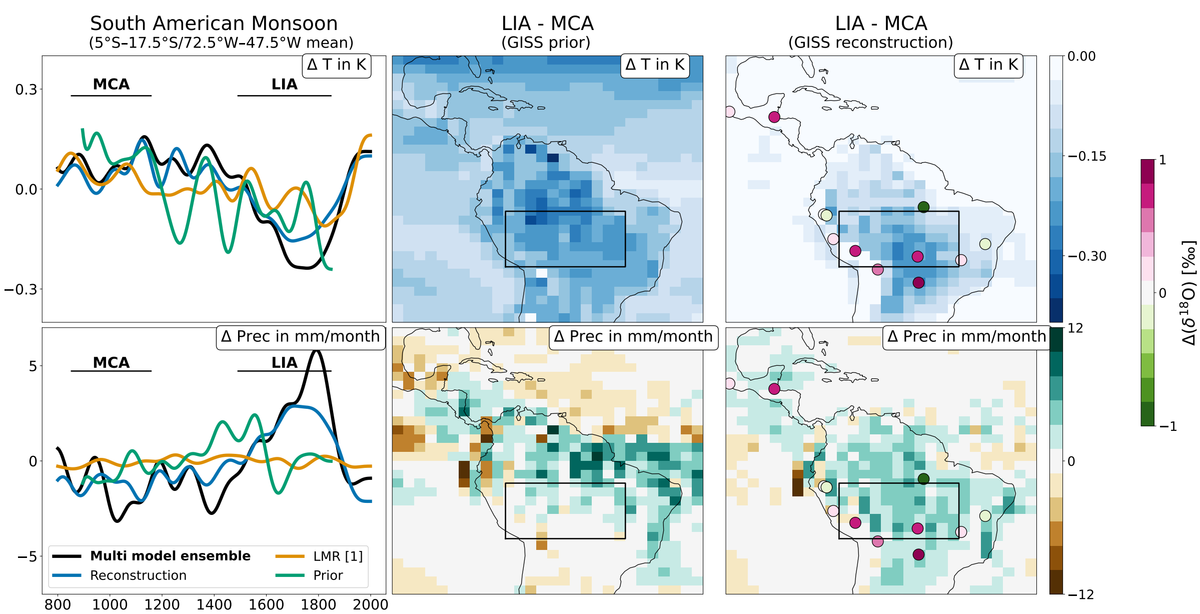
5.3 iHadCM3



5.4 isoGSM



5.5 GISS



6 Abbreviations

CE Common Era

DA Data assimilation

ECHAM ECHAM5/MPI-OM climate model

GCM General Circulation Model

GISS Goddard Institute for Space Studies atmospheric general circulation model

GMT Global mean temperature

iCESM isotope-enabled version of the Community Earth System Model

iHadCM3 isotope-enabled version of the Hadley Centre Coupled Model

Iso2k Database of water isotope values for the past two millennia (Konecky et al.)

isoGSM Isotopes-incorporated Global Spectral Model

ITCZ Intertropical Convergence Zone

SACZ South Atlantic Convergence Zone

K Kelvin

LIA Little Ice Age

LMR Last Millennium Reanalysis (Hakim et al.; Tardif et al.)

MCA Medieval climate anomaly

MME Multi model ensemble

PAGES2k Database for temperature proxies during the last two millennia (Ahmed et al.; Emile-Geay et al.)

PaleoDA Paleoclimate data assimilation

PHYDA Paleo Hydrodynamics Data Assimilation product (Steiger et al.)

PPE Pseudoproxy experiments

prec Precipitation

PSD Power spectral density

PSM Proxy system model (Evans et al.)

SISALv2 Second version of the SISAL speleothem database (Comas-Bru et al.)

SNR Signal-to-noise ratio

slp Sea level pressure

tsurf Surface temperature

References

Ahmed, M., Anchukaitis, K. J., Asrat, A., Borgaonkar, H. P., Braida, M., Buckley, B. M., Büntgen, U., Chase, B. M., Christie, D. A., Cook, E. R., Curran, M. A. J., Diaz, H. F., Esper, J., Fan, Z.-X., Gaire, N. P., Ge, Q., Gergis, J., González-Rouco, J. F., Goosse, H., Grab, S. W., Graham, N., Graham, R., Grosjean, M., Hanhijärvi, S. T., Kaufman, D. S., Kiefer, T., Kimura, K., Korhola, A. A., Krusic, P. J., Lara, A., Lézine, A.-M., Ljungqvist, F. C., Lorrey, A. M., Luterbacher, J., Masson-Delmotte, V., McCarroll, D., McConnell, J. R., McKay, N. P., Morales, M. S., Moy, A. D., Mulvaney, R., Mundo, I. A., Nakatsuka, T., Nash, D. J., Neukom, R., Nicholson, S. E., Oerter, H., Palmer, J. G., Phipps, S. J., Prieto, M. R., Rivera, A., Sano, M., Severi, M., Shanahan, T. M., Shao, X., Shi, F., Sigl, M., Smerdon, J. E., Solomina, O. N., Steig, E. J., Stenni, B., Thamban, M., Trouet, V., Turney, C. S., Umer, M., van Ommen, T., Verschuren, D., Viau, A. E., Villalba, R., Vinther, B. M., von Gunten, L., Wagner, S., Wahl, E. R., Wanner, H., Werner, J. P., White, J. W., Yasue, K., Zorita, E., and PAGES 2k Consortium: Continental-Scale Temperature Variability during the Past Two Millennia, 6, 339–346, https://doi.org/10.1038/ngeo1797.

Choblet, M. A.: Reconstructing climate fields of the last millennium with data from terrestrial climate archives and isotope-enabled GCMs using Data Assimilation, Master's thesis, Heidelberg, University, https://heibox.uni-heidelberg.de/f/215b873aee154346b217/, 2022.

Comas-Bru, L., Rehfeld, K., Roesch, C., Amirnezhad-Mozhdehi, S., Harrison, S. P., Atsawawaranunt, K., Ahmad, S. M., Brahim, Y. A., Baker, A., Bosomworth, M., Breitenbach, S. F. M., Burstyn, Y., Columbu, A., Deininger, M., Demény, A., Dixon, B., Fohlmeister, J., Hatvani, I. G., Hu, J., Kaushal, N., Kern, Z., Labuhn, I., Lechleitner, F. A., Lorrey, A., Martrat, B., Novello, V. F., Oster, J., Pérez-Mejías, C., Scholz, D., Scroxton, N., Sinha, N., Ward, B. M., Warken, S., Zhang, H., and SISAL Working Group members: SISALv2: A Comprehensive Speleothem Isotope Database with Multiple Age–Depth Models, 12, 2579–2606, https://doi.org/10.5194/essd-12-2579-2020.

Emile-Geay, J., McKay, N. P., Kaufman, D. S., von Gunten, L., Wang, J., Anchukaitis, K. J., Abram, N. J., Addison, J. A., Curran, M. A., Evans, M. N., Henley, B. J., Hao, Z., Martrat, B., McGregor, H. V., Neukom, R., Pederson, G. T., Stenni, B., Thirumalai, K., Werner, J. P., Xu, C., Divine, D. V., Dixon, B. C., Gergis, J., Mundo, I. A., Nakatsuka, T., Phipps, S. J., Routson, C. C., Steig, E. J., Tierney, J. E., Tyler, J. J., Allen, K. J., Bertler, N. A., Björklund, J., Chase, B. M., Chen, M.-T., Cook, E., de Jong, R., DeLong, K. L., Dixon, D. A., Ekaykin, A. A., Ersek, V., Filipsson, H. L., Francus, P., Freund, M. B., Frezzotti, M., Gaire, N. P., Gajewski, K., Ge, Q., Goosse, H., Gornostaeva, A., Grosjean, M., Horiuchi, K., Hormes, A., Husum, K., Isaksson, E., Kandasamy, S., Kawamura, K., Kilbourne, K. H., Koç, N., Leduc, G., Linderholm, H. W., Lorrey, A. M., Mikhalenko, V., Mortyn, P. G., Motoyama, H., Moy, A. D., Mulvaney, R., Munz, P. M., Nash, D. J., Oerter, H., Opel, T., Orsi, A. J., Ovchinnikov, D. V., Porter, T. J., Roop, H. A., Saenger, C., Sano, M., Sauchyn, D., Saunders, K. M., Seidenkrantz, M.-S., Severi, M., Shao, X., Sicre, M.-A., Sigl, M., Sinclair, K., St. George, S., St. Jacques, J.-M., Thamban, M., Kuwar Thapa, U., Thomas, E. R., Turney, C., Uemura, R., Viau, A. E., Vladimirova, D. O., Wahl, E. R., White, J. W., Yu, Z., Zinke, J., and PAGES2k Consortium: A Global Multiproxy Database for Temperature Reconstructions of the Common Era, 4, 170 088, https://doi.org/10.1038/sdata.2017.88.

Evans, M. N., Tolwinski-Ward, S. E., Thompson, D. M., and Anchukaitis, K. J.: Applications of Proxy System Modeling in High Resolution Paleoclimatology, 76, 16–28, https://doi.org/10.1016/j.quascirev.2013.05.024.

Hakim, G. J., Emile-Geay, J., Steig, E. J., Noone, D., Anderson, D. M., Tardif, R., Steiger, N., and Perkins, W. A.: The Last Millennium Climate Reanalysis Project: Framework and First Results, 121, 6745–6764, https://doi.org/10.1002/2016JD024751.

Khider, D., Emile-Geay, J., Zhu, F., James, A., Landers, J., Ratnakar, V., and Gil, Y.: Pyleoclim: Paleoclimate Timeseries Analysis and Visualization With Python, 37, e2022PA004 509, https://doi.org/10.1029/2022PA004509.

Konecky, B. L., McKay, N. P., Churakova (Sidorova), O. V., Comas-Bru, L., Dassié, E. P., DeLong, K. L., Falster, G. M., Fischer, M. J., Jones, M. D., Jonkers, L., Kaufman, D. S., Leduc, G., Managave, S. R., Martrat, B., Opel, T., Orsi, A. J., Partin, J. W., Sayani, H. R., Thomas, E. K., Thompson, D. M., Tyler, J. J., Abram, N. J., Atwood, A. R., Cartapanis, O., Conroy, J. L., Curran, M. A., Dee, S. G., Deininger, M., Divine, D. V., Kern, Z., Porter, T. J., Stevenson, S. L., von Gunten, L., and Members, I. P.: The Iso2k Database: A Global Compilation of Paleo-δ^{18}O and δ^{2}H Records to Aid Understanding of Common Era Climate, 12, 2261–2288, https://doi.org/10.5194/essd-12-2261-2020.

Rohde, R. A. and Hausfather, Z.: The Berkeley Earth Land/Ocean Temperature Record, 12, 3469–3479, https://doi.org/10.5194/essd-12-3469-2020.

Steiger, N. J., Smerdon, J. E., Cook, E. R., and Cook, B. I.: A Reconstruction of Global Hydroclimate and Dynamical Variables over the Common Era, 5, 180 086, https://doi.org/10.1038/sdata.2018.86.

Tardif, R., Hakim, G. J., Perkins, W. A., Horlick, K. A., Erb, M. P., Emile-Geay, J., Anderson, D. M., Steig, E. J., and Noone, D.: Last Millennium Reanalysis with an Expanded Proxy Database and Seasonal Proxy Modeling, 15, 1251–1273, https://doi.org/10.5194/cp-15-1251-2019.