Analysis of methodological and physical bias on borehole temperature reconstructions from a pseudo-proxy approach.

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Summary

- First, we evaluate the assumption of a strong coupling between surface air temperature (SAT) and ground surface temperature (GST) variations at long time scales, which is central for borehole temperature reconstructions.

- In order to explore the evolution of the long-term SAT–GST relationship, we have used last millennium (LM) ensemble of both All- and single-forcing simulations form the Community Earth System Model-LM Ensemble (CESM-LME; Otto-Bliesner et al. 2016)

-The results indicate that SAT–GST coupling is strong at global and above multi-decadal timescales in CESM-LME. However, at local to regional scales this relationship experiences considerable long-term changes mostly after the end of the 19th century. Land use land cover (LULC) changes stand as the main driver for locally and regionally decoupling SAT and GST.

-In light of these findings, we subsequently assessed the potential effects on SAT reconstructions from the borehole method in pseudo-proxy experiments using the same set of simulations from the CESM-LME. First, a heat-conduction forward model has been used to estimate subsurface temperature-anomaly profiles using simulated GST as boundary conditions. Then, singular value decomposition inversion (SVD) has been applied to reconstruct LM GST variations from the simulated profiles.

-The Results show that the SVD inversion is able to retrieve the long-term GST variations over the LM when an appropriated coverture of borehole logs is available. However, due to the limited spatio-temporal distribution of the actual borehole network, there is a lost in the accuracy to retrieve the simulated GST 20th century trends. Furthermore, in the surrogate reality of the CESM-LME the SAT-GST decoupling, due to the influence of LULC and GHG forcings, leads to a slightly underestimation of SAT warming during the industrial period. The level of impact is, however, highly depended on the realization of internal variability.

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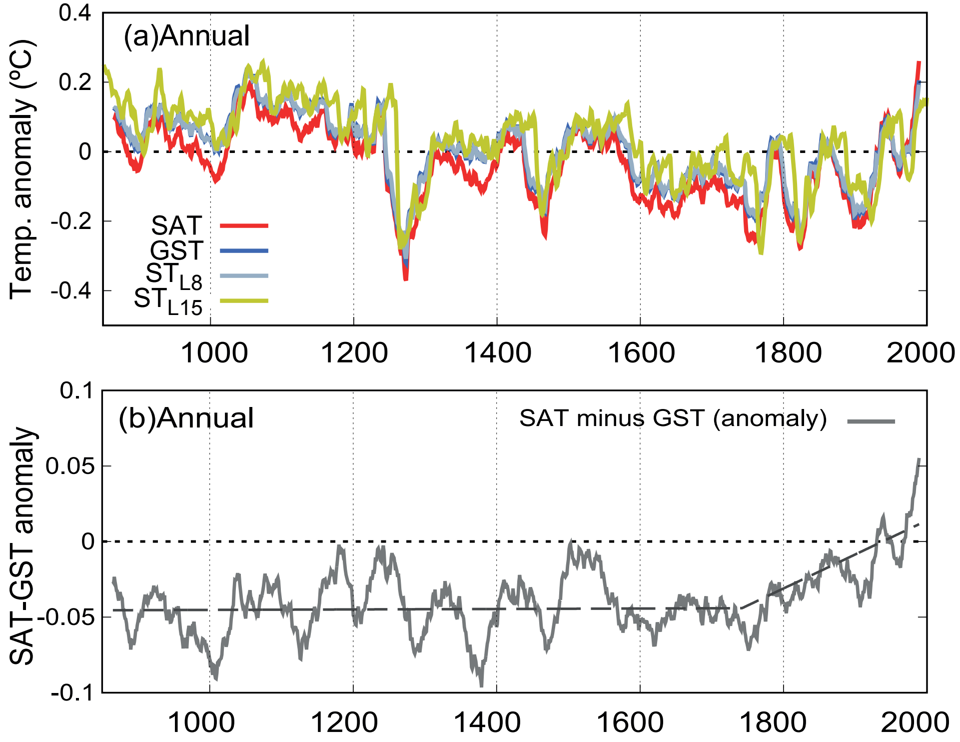

Figure 1. The LM evolution of SAT, GST, soil temperature at 1 m (STL8) and 42 m (STL15) depth shows a strong coupling between SAT and soil temperatures at global scale as depicted in a) since soil temperatures closely track SAT anomalies in the All-F ensemble. However, it is still evident the existence of a relatively small offset between SAT and GST that grows backwards in time. The differences between them in b) show a long-term change in the SAT-GST relationship. A positive trend starting at the 18th century indicates a warmer SAT relative to GST in industrial times.

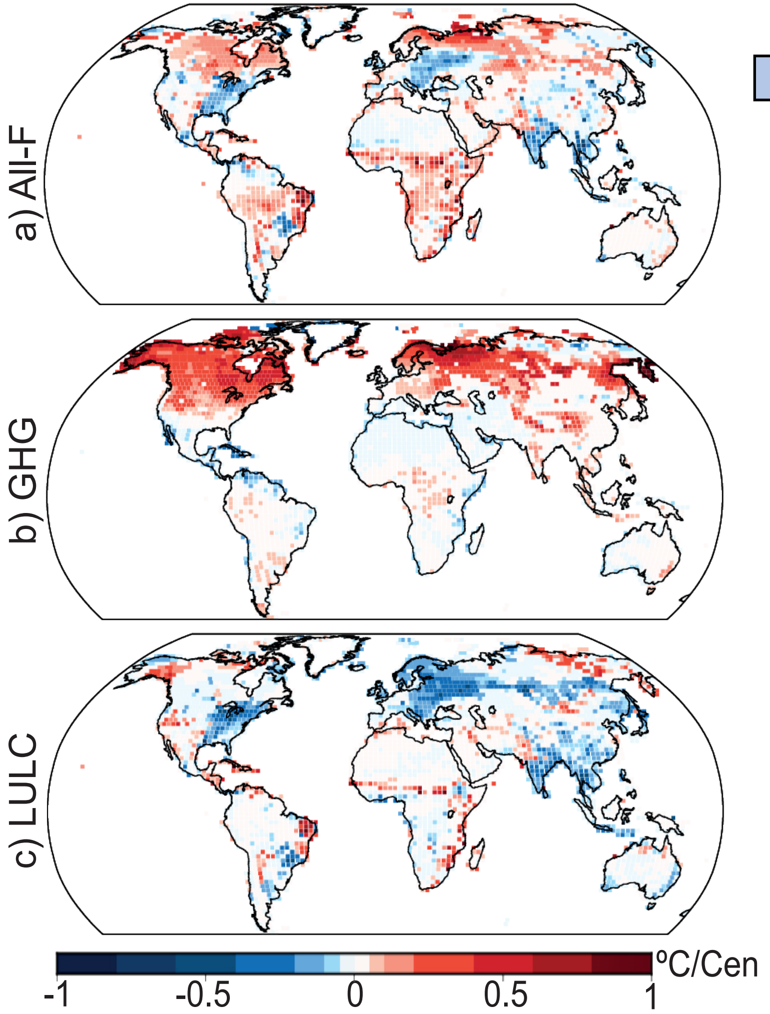

Figure 2. The spatial distribution of SAT minus GST trends over the industrial period shows warmer SAT relative to GST as indicated by positive trends (reddish) over the northernmost part of North America, Fennoscandia, northeast Russia and some areas of central Eurasia in the All-F simulations (a). On the other hand, for central and eastern European areas as well as the eastern US, the Indian subcontinent and southeastern Asia there is a warmer GST relative to SAT as indicated by negative trends (bluish).

The GHG-only and the LULC-only ensembles (b and c, respectively) suggest that the positive SAT minus GST trends described above over the northern high latitudes are dominated by the influence of the GHG forcing. On the contrary, the negative SAT-GST trends are dominated by the influence of LULC (e.g Central Europe and the Indian subcontinent)

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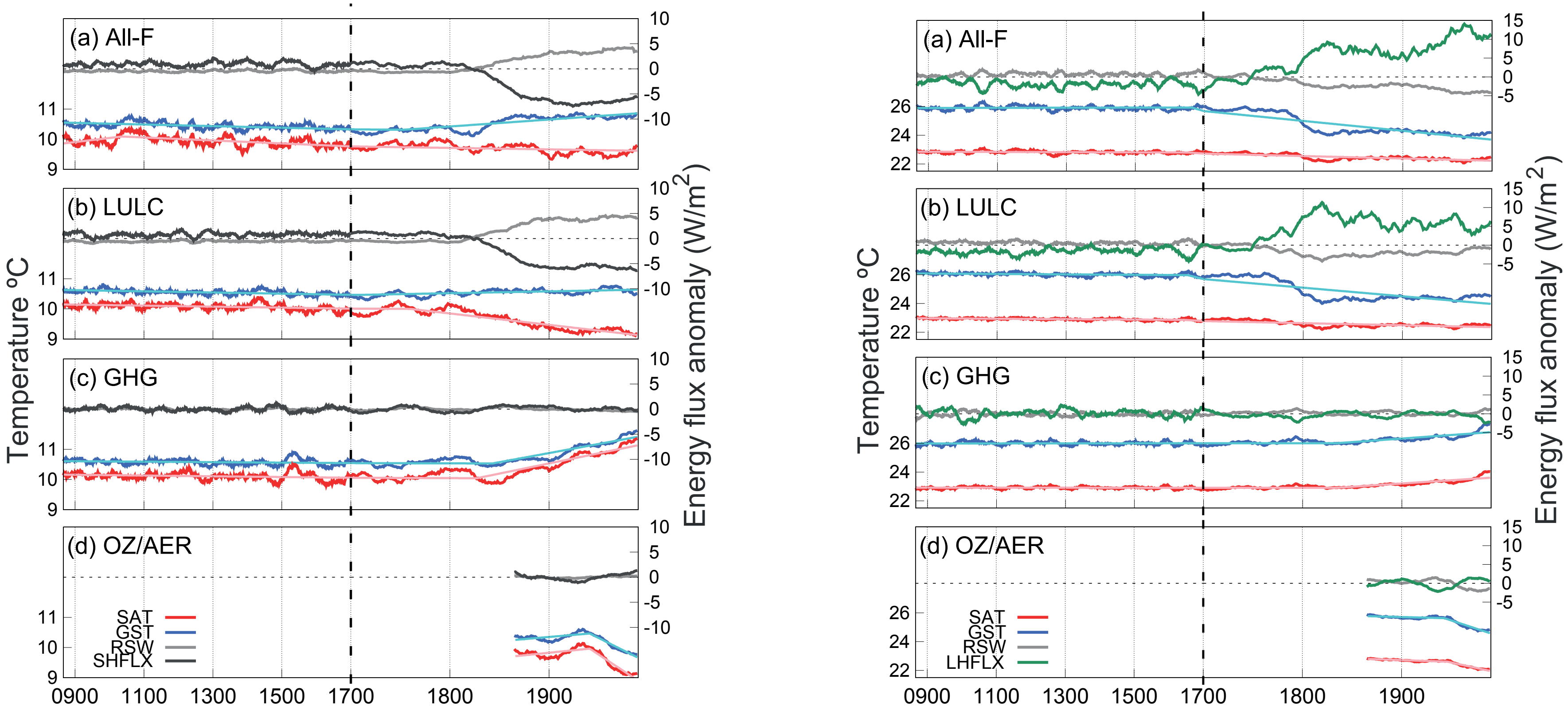

Figure 3. Regionally, several circumstances account for impacting SAT–GST long-term coupling. Here, we show two cases (40◦ N, 82◦ W and 12◦ S, 40◦ W; left and right, respectively) in which long-term SAT-GST decoupling occurs. Note that SAT and GST are strongly coupled until approximately the 18th century. Then, SAT and GST diverge as a response to changes in the energy fluxes at the surface. Long-term variations in reflected shortwave radiation (RSW) and surface sensible/latent heat flux (left/right; SHFLX and LHFLX, respectively) are driving these effects. Both of these examples illustrate the long-term SAT-GST decoupling as a response to LULC. Note that in the two cases the response of the LULC single-F is similar to the response of the All-F case whereas the GHG and OZ/AER cases do not show such a similar response. Therefore, we can attribute the SAT-GST decoupling to the effect of LULC changes. Such a variation in the long-term SAT-GST relationship suggest that inversion of BTPs under such characteristics would yield unreliable information of the past SAT variations. Thus, imposing a physical source of bias to this temperature reconstruction method.

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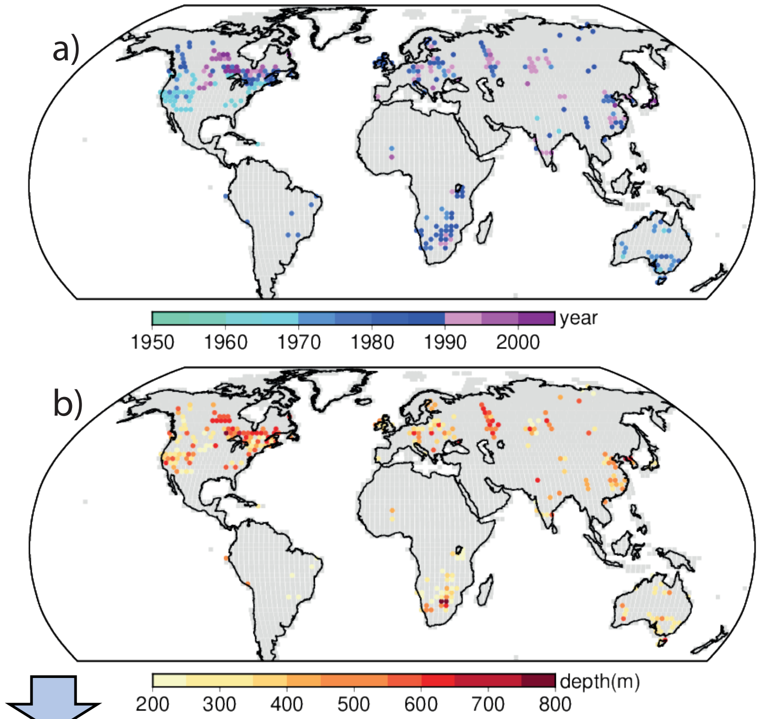

Figure 4. The spatial distribution of global borehole network indicates a predominantly midlatitude distribution over the Northern Hemisphere. In addition there is a large variability in logging date (a) and depth (b). This represents a set of methodological constraints due to the spatio-temporal sampling of borehole sites.

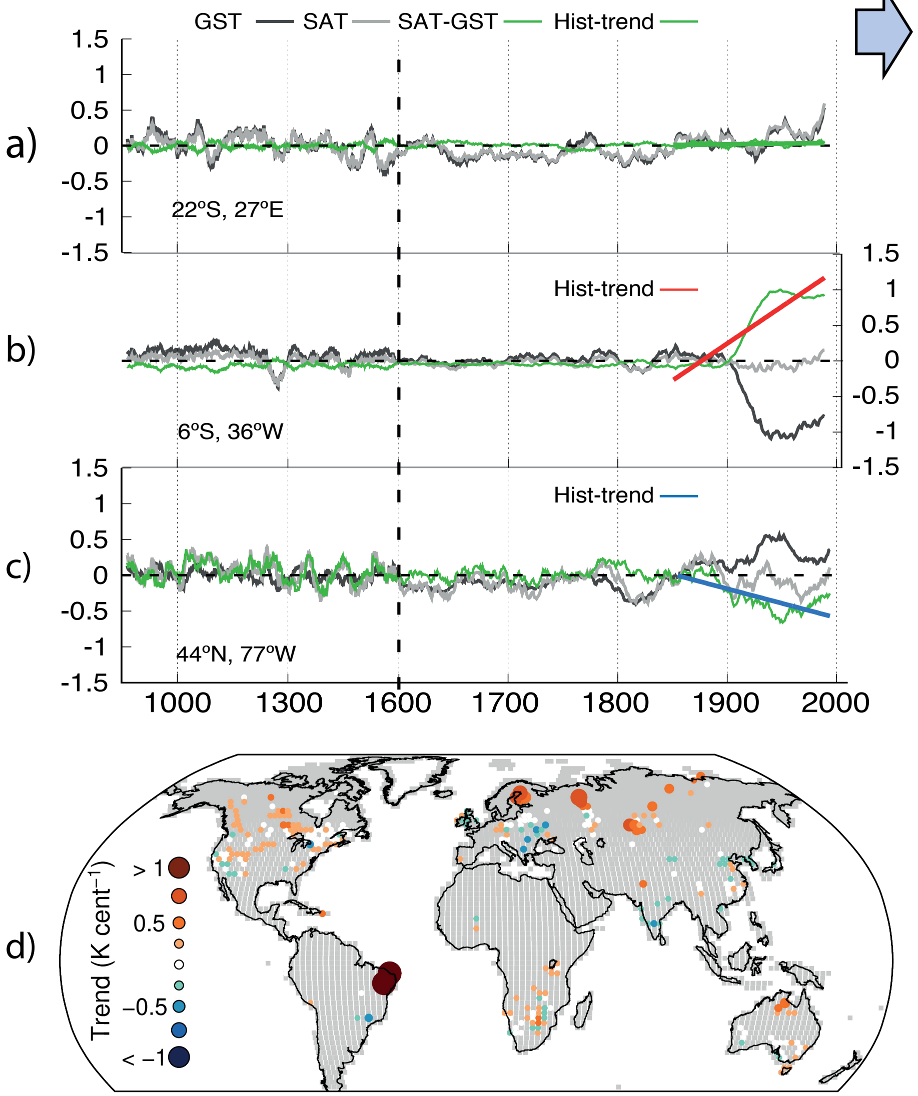

Figure 5. In addition to the methodological issues, we have evaluated the evolution of SAT minus GST trends over the LM at each grid point where a borehole location exists in the All-F ensemble. The latter provide an spatial view (d) of both the methodological constrains and physical SAT-GST decoupling.

Here, a case in which SAT-GST coupling remains stable during the whole LM is shown (a). Note that there is no trend in the SAT – GST differences. This case represents the ideal strong SAT–GST coupling situation from which the GST would constitute a good proxy of the SAT. Second, two cases in which the SAT–GST long-term relationship experiences significant variations are depicted (b and c). In b), the sharp decrease in GST around 1900 CE results in a positive trend in the SAT – GST differences, represented in red, indicating a warmer SAT relative to the GST. In c), the SAT tends to be colder than GST during the industrial period, thus leading to a negative trend represented in blue. The colors in d) correspond to the colors in b) and c).

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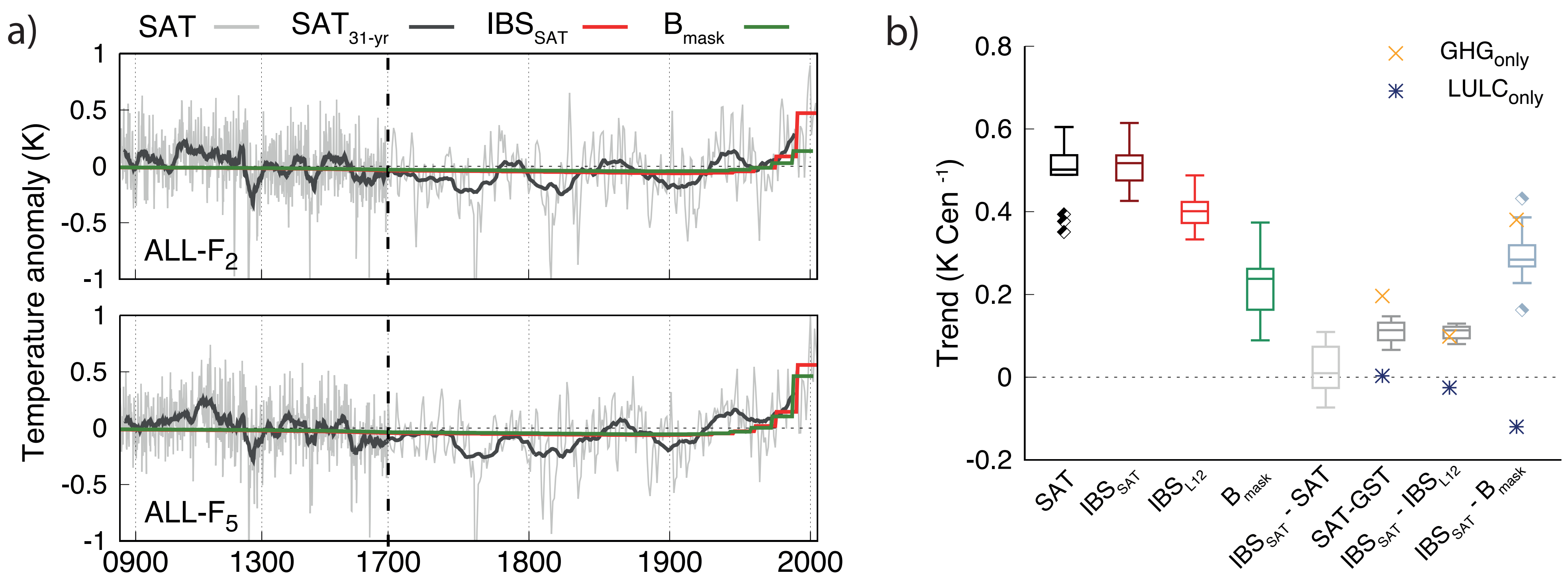

Figure 6. a) shows the SAT evolution over the LM and the pseudo reconstructed GST in two member of the All-F ensemble from: 1) Ideal borehole scenario in which it is assumed the existence of borehole logs at every model grid point (IBS; red line and box) and 2) a more realistic approach in which the real-world spatio-temporal distribution of the global borehole network is considered (B-mask; green line and box). Note that the IBS case closely resembles the long-term evolution of SAT whereas the B-mask case diverges during the las few decades. The box-and-whiskers plot (b) illustrates the 20th century trends over land for SAT, IBS_{SAT}, IBS_{GST}, B-mask and the differences between them for the 13 member of the All-F ensemble. The crosses and asterisks stand for the ensemble medians of the GHG- and LULC-only ensembles (3 members each). Note that IBS_{SAT} is able to retrieve the 20th century SAT trends. However, the IBS_{GST} misses some of the SAT warming (SAT-GST and IBS_{SAT}-IBS_{GST}). The latter is the result of the physical SAT-GST decoupling. Furthermore, the B-mask case introduces biases that can range between > 0.2 and 0.4 K per century (IBS_{SAT}-Bmask). The ensemble median of the single-F experiments shows a larger contribution from GHG forcing than LULC at a global scale. The spread in the boxes indicates the effect of internal variability.

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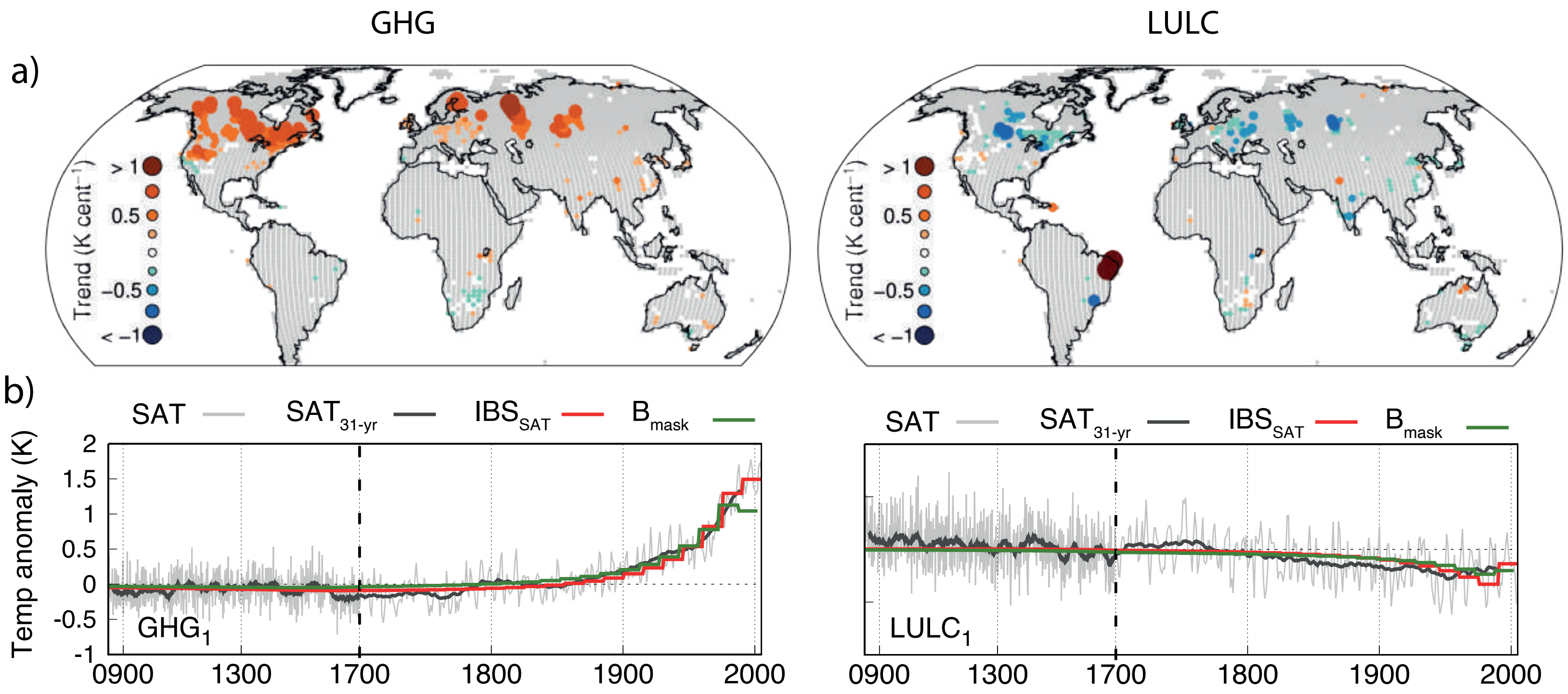

Figure 7. **T**he maps illustrate the SAT minus GST trends over the 20[th] century in the GHG- and LULC-only ensembles. If compared to the map in figure 5d, the positive trends over the mid and high latitudes in the northern hemisphere for the All-F ensemble, are dominated by the influence of the GHG forcing. On the contrary, negative values over eastern Europe are the response to LULC cover changes. Globally the SAT-GST decoupling is dominated by the GHG influence. The latter can be also observed in the evolution of the time series in the bottom panel. A simple visual inspection suggests that the GHG case portrays a response similar to the ALL-F estimates (Fig. 6a) since the IBS and the B_{mask} cases diverge during the last few decades of the simulated period. On the other contrary, in the LULC case there is no such similarity to the ALL-F cases.

Main conclusions

- The results indicate that SAT–GST coupling is strong at global and above multi-decadal timescales in CESM-LME. However, at local to regional scales this relationship experiences considerable long-term changes mostly after the end of the 19th century. Land use land cover (LULC) changes stand as the main driver for locally and regionally decoupling SAT and GST, due to the changes in the energy fluxes at the surface. Snow cover feedbacks due to the influence of GHG forcing are also important for corrupting the long-term SAT–GST coupling.

- Results show that the SVD inversion is able to retrieve the long-term GST variations over the LM when an appropriated coverture of borehole logs is available. However, due to the limited spatio-temporal distribution of the actual borehole network, there is a lost in the accuracy to retrieve the simulated GST 20th century trends, with the temporal logging of the BTPs as the main sampling issue. Furthermore, in the surrogate reality of the CESM-LME the SAT-GST decoupling, due to the influence of LULC and GHG forcings, leads to a slightly underestimation of SAT warming during the industrial period across the CESM-LME. The level of impact is, however, highly depended on the realization of internal variability.

The results of this work are included in the following published research articles:

[1] Melo-Aguilar, C., González-Rouco, J. F., García-Bustamante, E., Navarro-Montesinos, J., and Steinert, N.: Influence of radiative forcing factors on ground–air temperature coupling during the last millennium: implications for borehole climatology, Clim. Past, 14, 1583–1606, https://doi.org/10.5194/cp-14-1583-2018, 2018.
[2] Melo-Aguilar, C., González-Rouco, J. F., García-Bustamante, E., J., Steinert, N., Jungclauss, J., Navarro, J. and Roldán-Gómez P.: Methodological and physical biases in global to subcontinental borehole temperature reconstructions: an assessment from a pseudo-proxy perspective, Clim. Past, 16, 453–474, 2020 https://doi.org/10.5194/cp-16-453-2020.