Using tropical archives of precipitation isotopic composition to assess the credibility of projected changes in precipitation

Camille Risi[1], Sandrine Bony[1], Françoise Vimeux[2]
[1] LMD/IPSL, CNRS, Paris, France, [2]LSCE/IPSL, Gif-sur-Yvette, France
*contact: camille.risi@lmd.jussieu.fr

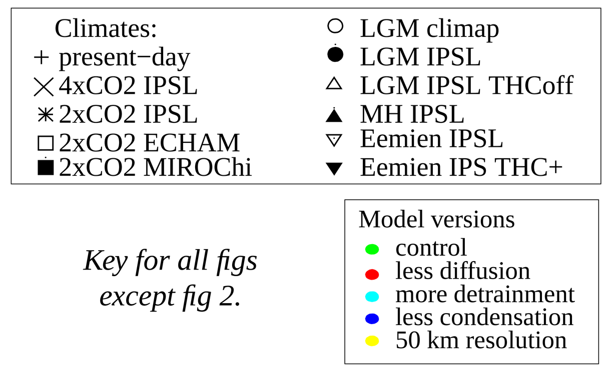
Introduction

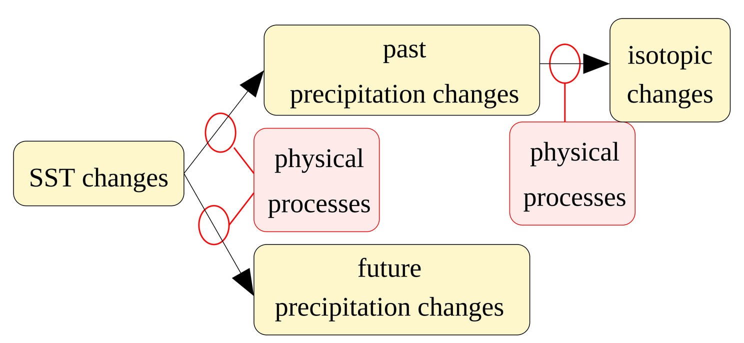
Can we assess the credibility of future tropical precip projections using past changes?

1. if a model is better for the past, is it better for the future? -> are there common mechanisms? e.g. same response to SST gradients?
2. proxy for past precip changes? -> use $\delta^{18}O_p$ archives (ice cores, speleothems...)?

Method

- atmospheric GCM with isotopes: LMDZ-iso ([3])
- set of 11 climates (defined by imposed SSTs) × small PPE
- $\delta^{18}O$ data: [4, 5, 1]





1. Precipitation response to SST changes

1.1 In LMDZ

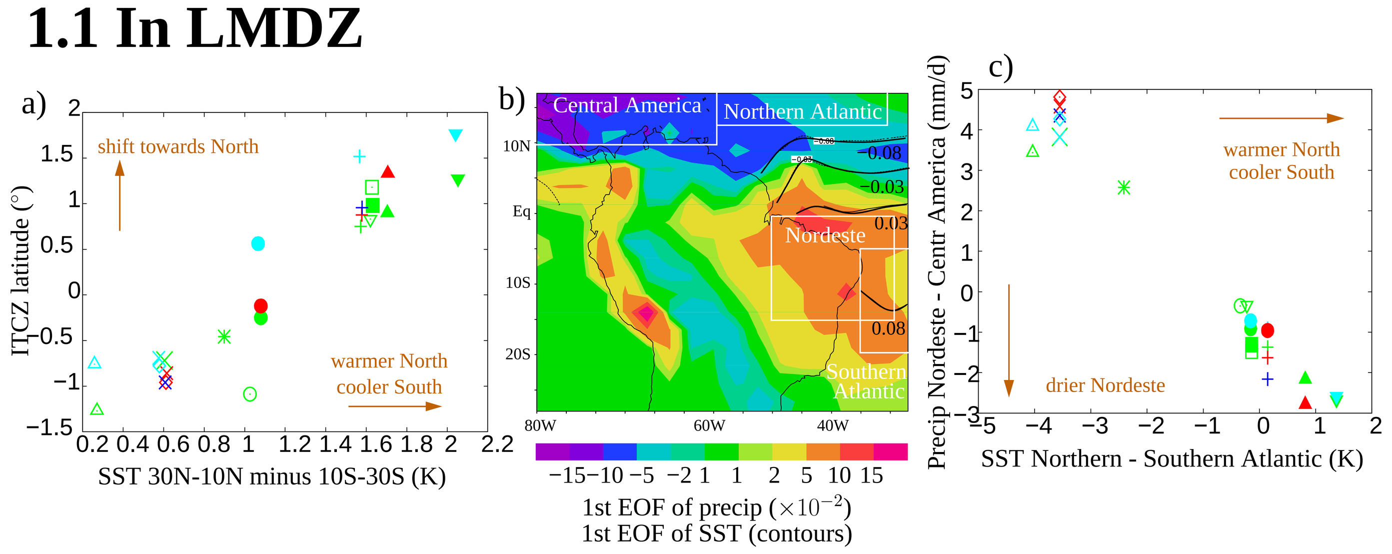


Fig 1. a) Response at the global scale: ITCZ latitude as a function of inter-hemispheric SST gradient.
⟹ for all climates, the ITCZ shifts towards the warmer hemisphere following an near-constant slope.
b) PCA analysis among all climates for control version: 1st EOF of precipitation (shaded) and of SST (contours) in the South American region. Correlation between corresponding PCs is 0.92.
c) precipitation dipole in South America as a function of inter-hemispheric SST gradient in the Atlantic
⟹ precip in Nordeste responds to inter-hemispheric gradient in the Atlantic following near-constant slope.
⟹ relatively robust to model physics

1.2 Comparison with CMIP5

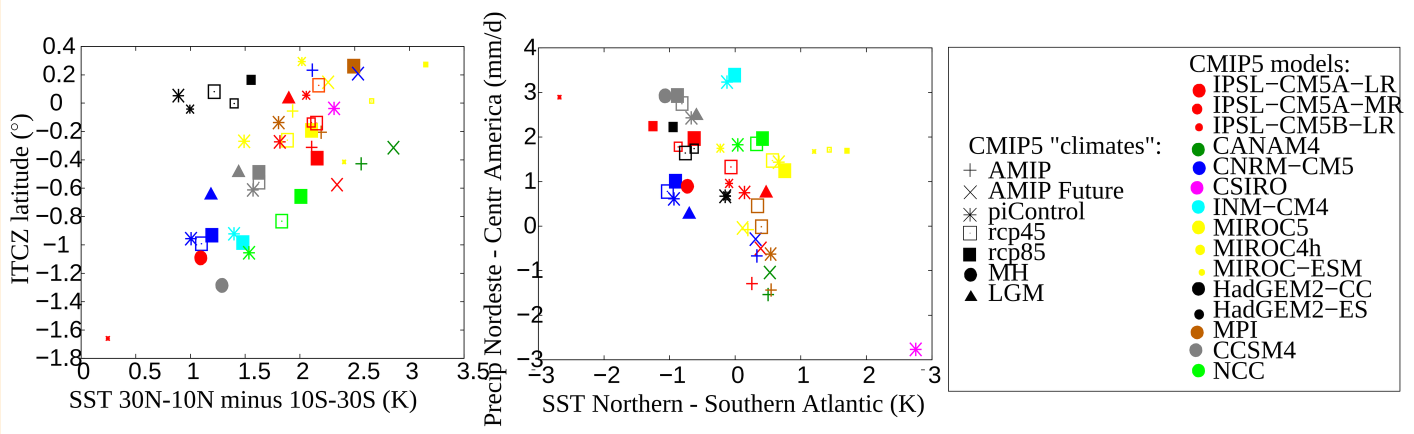


Fig 2. Same as fig 1 but for CMIP5 simulations
⟹ similar relationship as in LMDZ across climates and models for some models, with different slopes
⟹ qualitatively different behavior for others

2. $\delta^{18}O_p$ response to precipitation changes

2.1. $\delta^{18}O_p$ changes in the tropics: spatial scale, model evaluation

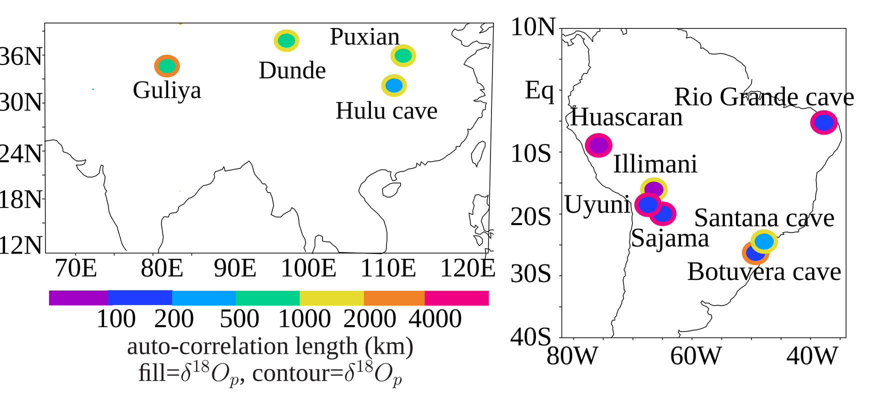


Fig 3. Location of $\delta^{18}O$ archives used in this study. Colors indicate the average radius for which auto-correlation of $\delta^{18}O_p$ (fill) and $\delta^{18}O_v$ (contour) among all climates is >0.8 in control version.
⟹ little spatial coherency of $\delta^{18}O_p$ in South America in model
⟹ good spatial coherency of vapor isotopes

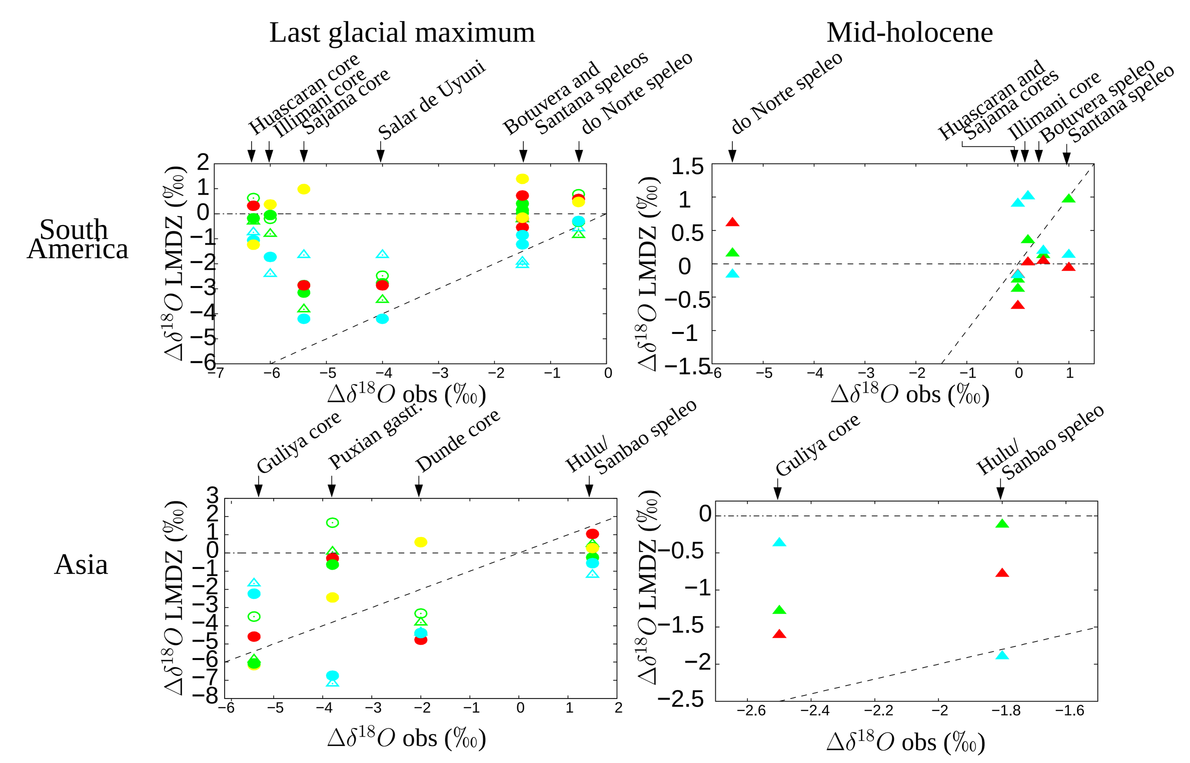


Fig 4. Model data comparison for LGM and MH.
⟹difficult to simulate LGM depletion in South America

2.2. Processes controling $\Delta\delta^{18}O_p$

Decomposition of $\Delta\delta^{18}O_p$ by calculating partial derivatives of:

$$R_p = R_v + (R_p - \alpha_{loc} \cdot R_v) + (\alpha_{loc} \cdot R_v - R_v)$$

$$R_v \simeq \frac{R_{oce}/\alpha_i}{\alpha_K \cdot (1 - h_i) + h_i} \cdot \left(\frac{h_{loc} \cdot q_s(T_{loc})}{q_s(T_i)} \right)^{\alpha_{loc} - 1}$$

- precip-vapor disequilibrium: $R_p - \alpha_{loc} \cdot R_v$
- temperature effect through Rayleigh: $q_s(T_{loc})$, $q_s(T_i)$
- relative humidity effect through Rayleigh: h_{loc}
- α's: α_{loc} and α_i
- residual: incudes effects of upstream convection

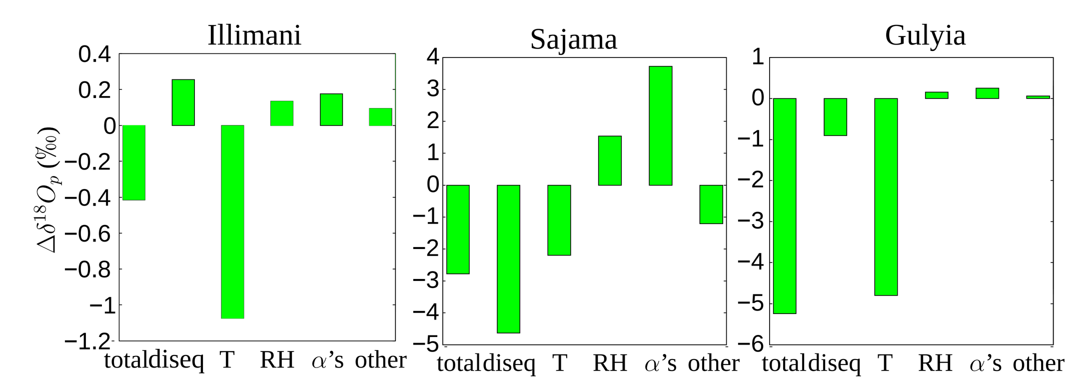


Fig 5. Decomposition of $\delta^{18}O_p$ at Illimani and Gulyia for LGM-PD changes in LMDZ control simulation.
⟹ strong temperature signal (dominates on all Asia sites)
⟹ small effect of other processes, e.g. upstream convection, but could be missing term explaining LGM underestimated depletion
⟹ in South America, compensation of components (and degree of compensation varies with sites and model versions, especially precip disequilibrium)

2.3. Precipitation vs temperature control?

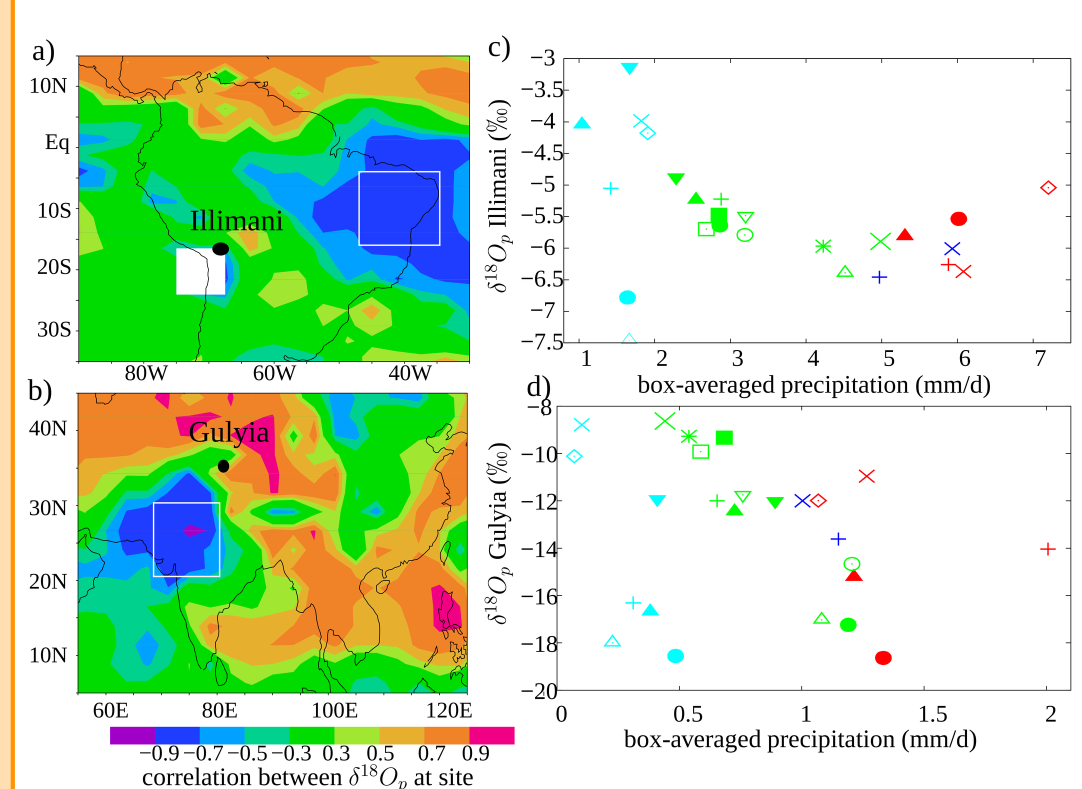


Fig 6. Precipitation control.
a,b) Correlation of $\delta^{18}O_p$ at Illimani and Gulyia as a function of precipitation around among all climates.
c,d) $\delta^{18}O_p$ at Illimani and Gulyia as a function of box-mean precipitation
⟹ apparent robust link for control version
⟹ link depends on model physics

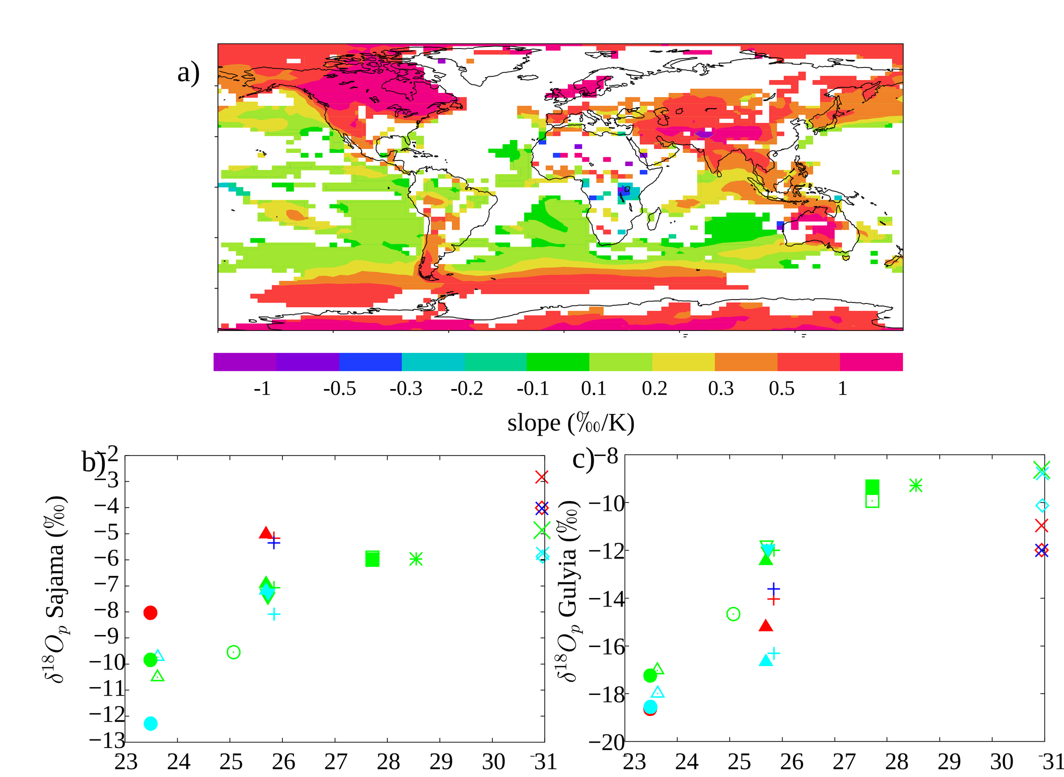


Fig 7. Global SST control.
a) Slope of linear regression of $\delta^{18}O_p$ as a function of tropical-mean SST among all climates, for r>0.63.
b,c) $\delta^{18}O_p$ at Illimani and Gulyia as a function of box-average precipitation
⟹ significant temperature controls in Asia and Andes

2.4. Observational constraints?

Can we use present-day observations of shorter term variability to discriminate the most realistic isotopic response to precip changes?
⟹we use nudged simulations for 2002-2009.

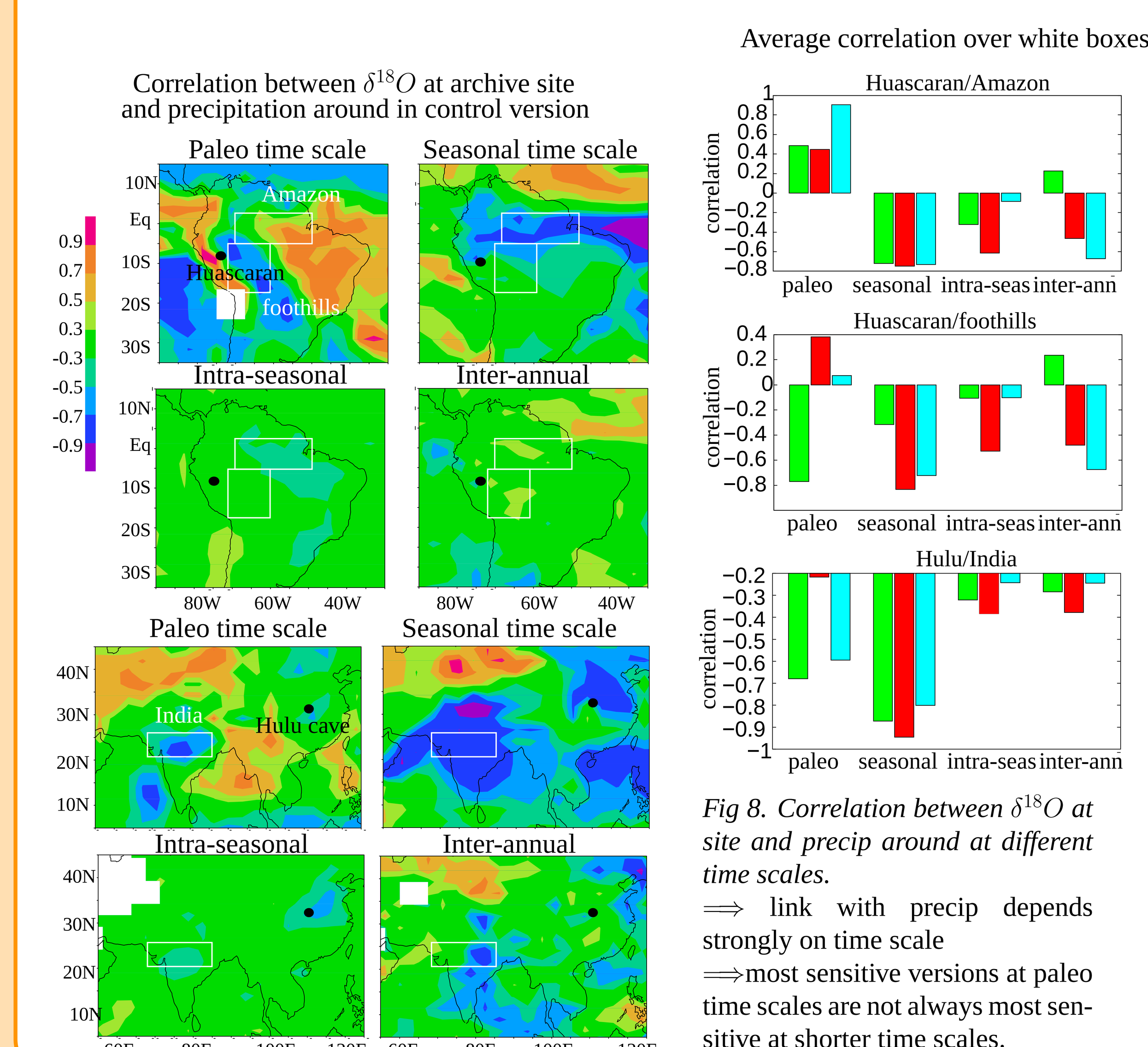


Fig 8. Correlation between $\delta^{18}O$ at site and precip around at different time scales.
⟹ link with precip depends strongly on time scale
⟹most sensitive versions at paleo time scales are not always most sensitive at shorter time scales.

Conclusions

- precip response to SST: common to future and past climates; sensitivity of this reponse to the model physics
- $\delta^{18}O$ record of past precip changes: significant temperature signal; link with precip sensitive to the model physics and to time scale of changes

Perspectives

- complement our PPE/multi-"climate" ensemble: run remaining simulations; analyse CMIP5 in more detail; add "climates" based on CMIP5 SSTs; compare with other isotopic models for common SSTs.
- better understand processes controlling water isotopes: improve theoretical/interpretative framework?
- link differences in precip response to SST changes to differences in model physics: e.g. decomposition of large-scale circulation changes into different components using $\omega = -Q/\Gamma$ (*Bony et al in prep*)
- need data synthesis for paleo $\delta^{18}O_p$ as was done for other temperature, plant available moisture, runoff (e.g. [2])

References

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