Identifying and Representing Global Climates for Hydrology: Bimodal seasonal behaviour is rare

We show a way to describe bimodal patterns in monthly averaged climate data to summarize climates in a few numbers without large loss of information

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1. Simple sine curves can't describe tropical bimodal climate behaviour

Sine curves can describe monthly climates but don't work well in some tropical regions (Fig. 1), because these climates don't follow a sine curve (e.g. double monsoons, Fig. 2).

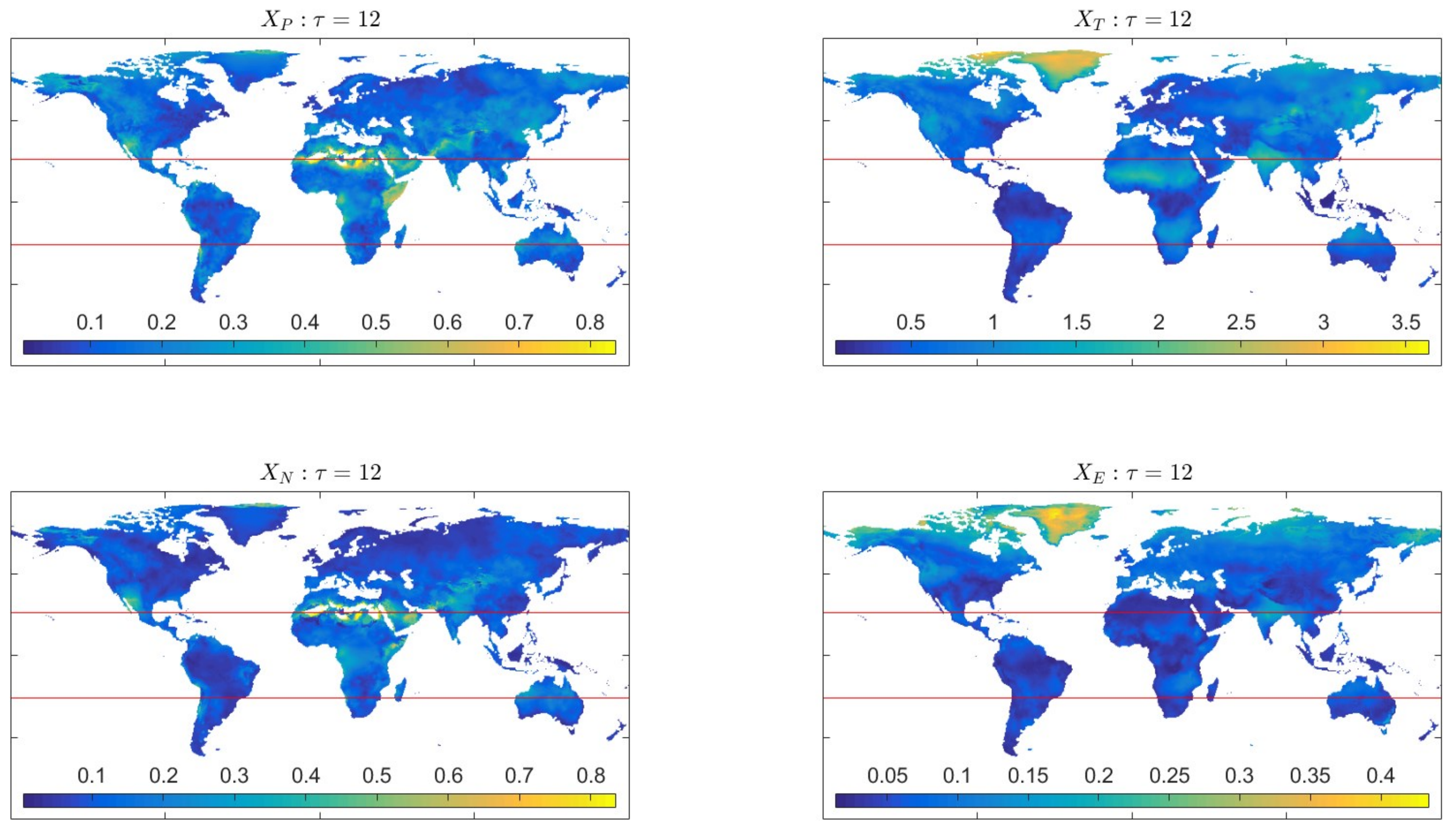


Fig 1: Sine curve fit for monthly average precipitation P and temperature T (top) and storm frequency N and potential evapotranspiration E (bottom). Higher values (yellow) indicate worse fits.

2. We vary the sine's period to address this

We create sine curves that describe P, T, N and E (rainfall, temperature, pet, storm frequency) and evaluate them against objective functions *X*. Seasonal length *(τ)* is set at 12 for unimodal and 6 for bimodal sines. N & E formulas like P:

$$T(t) = \bar{T} + \delta_T \left[2\pi \frac{t+3-s_T}{\tau}\right] \qquad X_T = \sum_{t=1}^{12} \frac{|T(t) - T_t|}{12} \quad [°C]$$

$$P(t) = \max\left(0, \bar{P}\left[1 + C_r + \delta_P \sin\left(2\pi \frac{t+3-s_P}{\tau}\right)\right]\right) \qquad X_P = \frac{1}{12}\sum_{t=1}^{12} \frac{|P(t) - P_t|}{\bar{P}} \quad [-]$$

$$C_r = -0.001 * \delta_P^4 + 0.026 * \delta_P^3 - 0.245 * \delta_P^2 + 0.2432 * \delta_P - 0.038$$

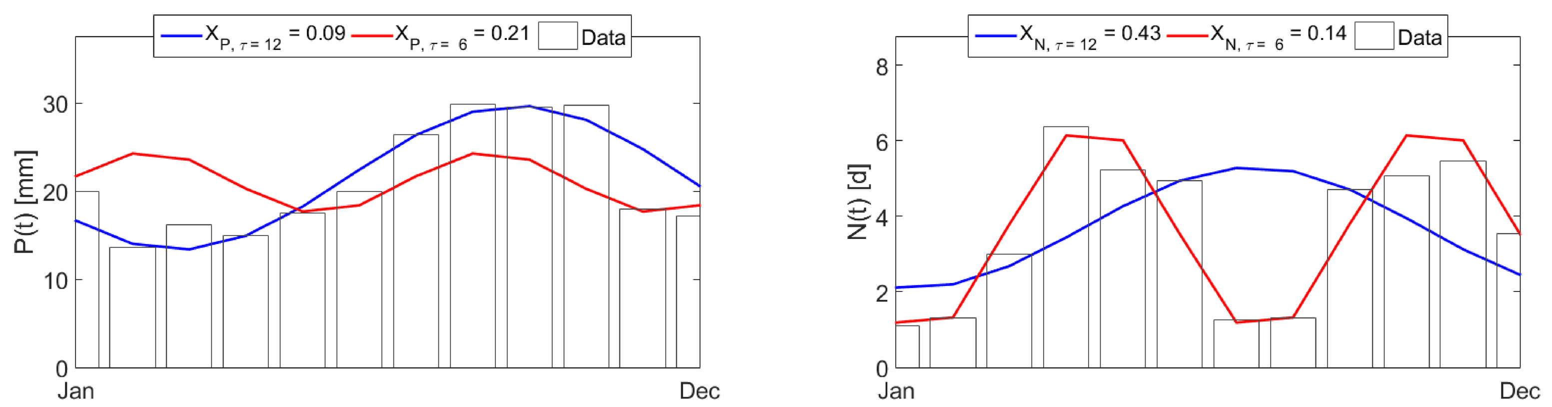


Fig 2: Example of unimodal (l) and bimodal (r) climate and best uni– and bimodal sine curve approximation of each. For certain climates certain types of sine curve are the obvious choice.

3. Literature tells us to expect bimodal rainfall climates in approximately 10% of the tropics

Climatology literature tells us to expect bimodal rainfall P in only a few tropical regions (Fig. 3). We test where bimodal sine curves have better objective function values than the unimodal sines.

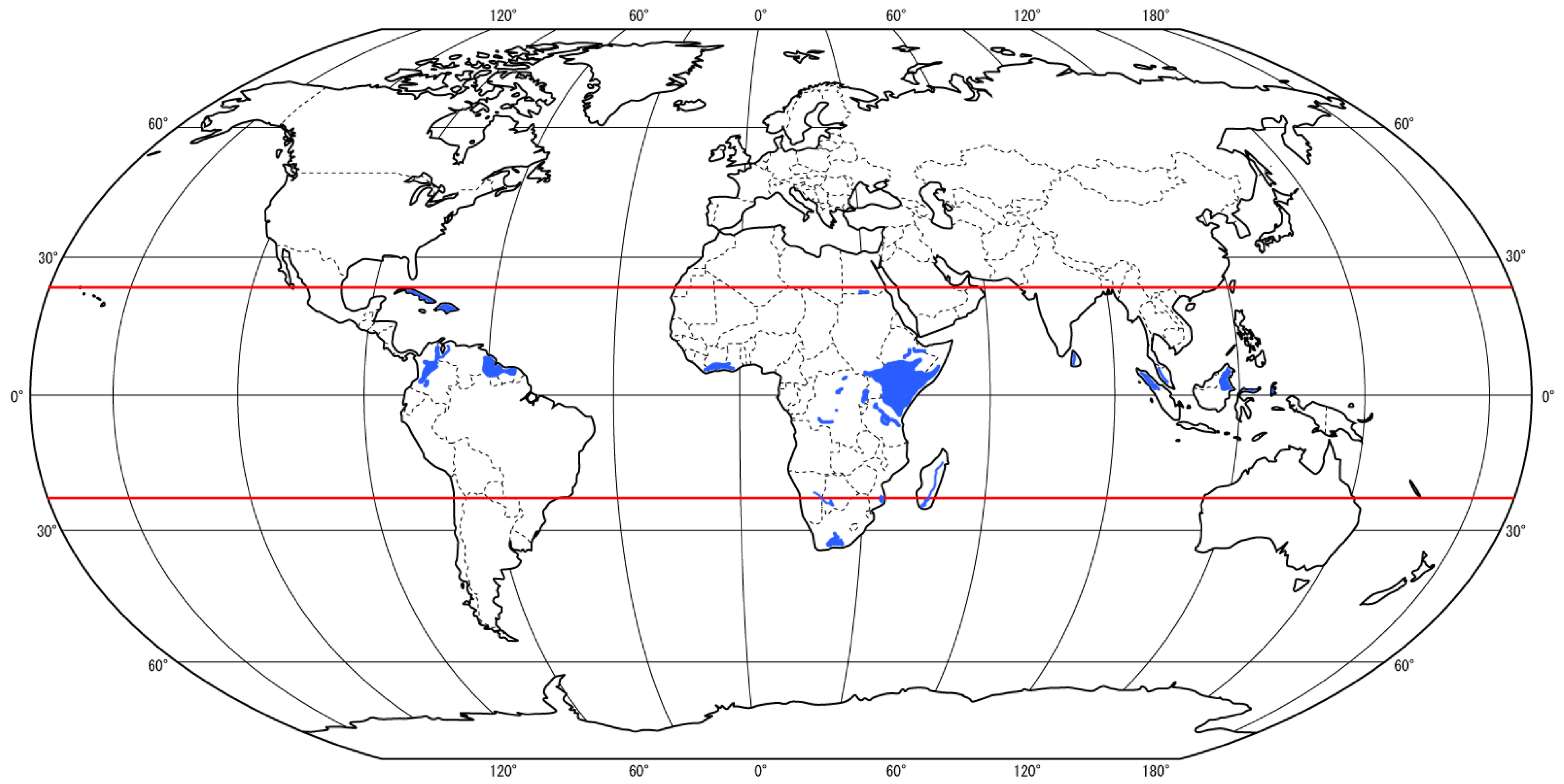


Fig 3: Blue shading shows areas with reported bimodal rainfall (literature excludes Peru and Bolivia). There is no readily available literature for storm frequency N, nor for temperature T and potential evapotranspiration E.

4. Our method works for most of these locations

The success of our method (Fig. 4; non-zero values of $X_{P,\tau=12} - X_{P,\tau=6}$) applied to bimodal rainfall gives confidence in the results obtained for N, T and E that can't be compared to literature.

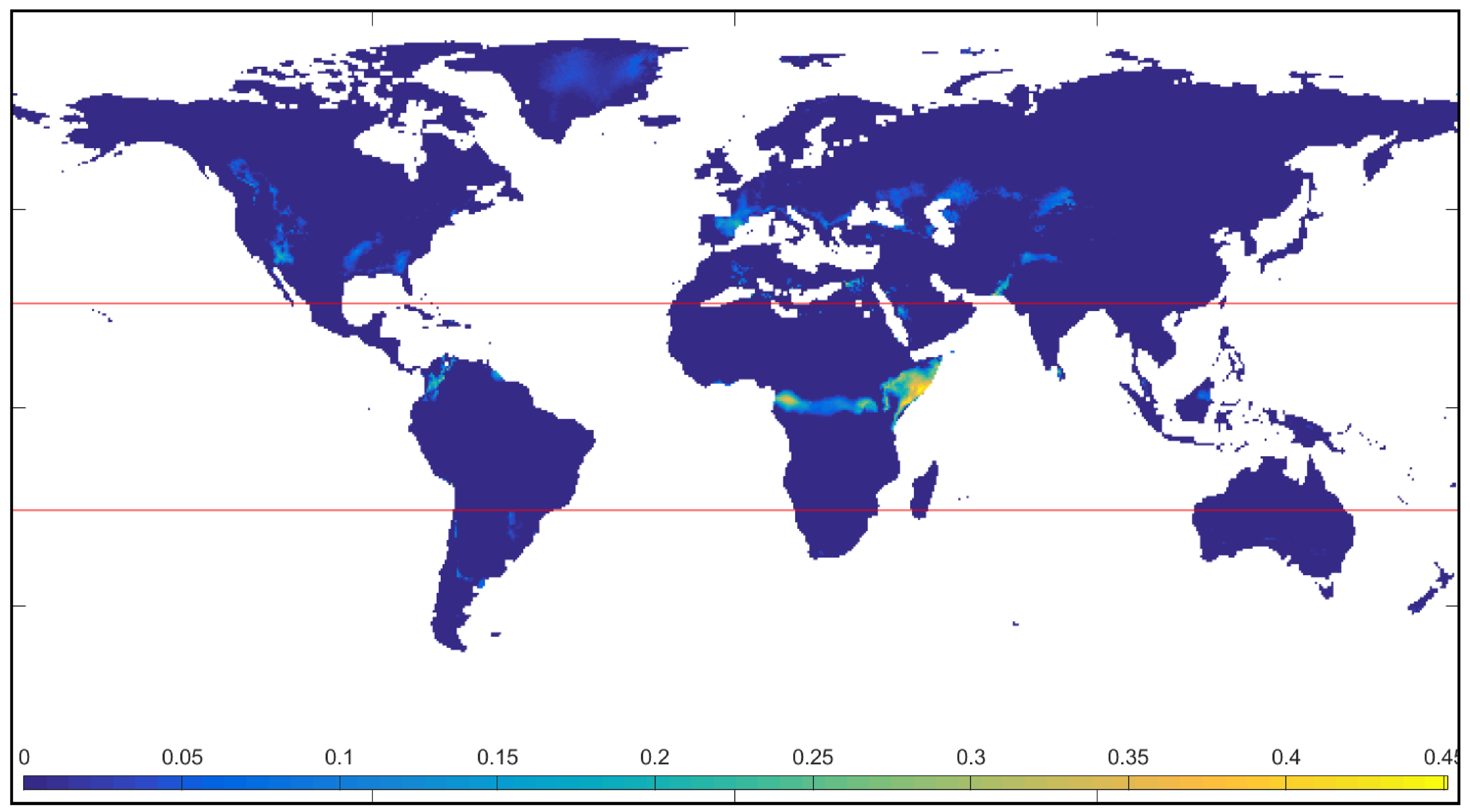


Fig 4: Location and size of improvements in X_P value using bimodal sine curves for P. Non-zero values indicate an improvement [-].

5. Bimodal sines can improve P and N fits but differences are marginal for T and E

Findings for bimodal N (->) sine curves are similar in location and magnitude to P. T and E only show marginal improvements (Fig. 5).

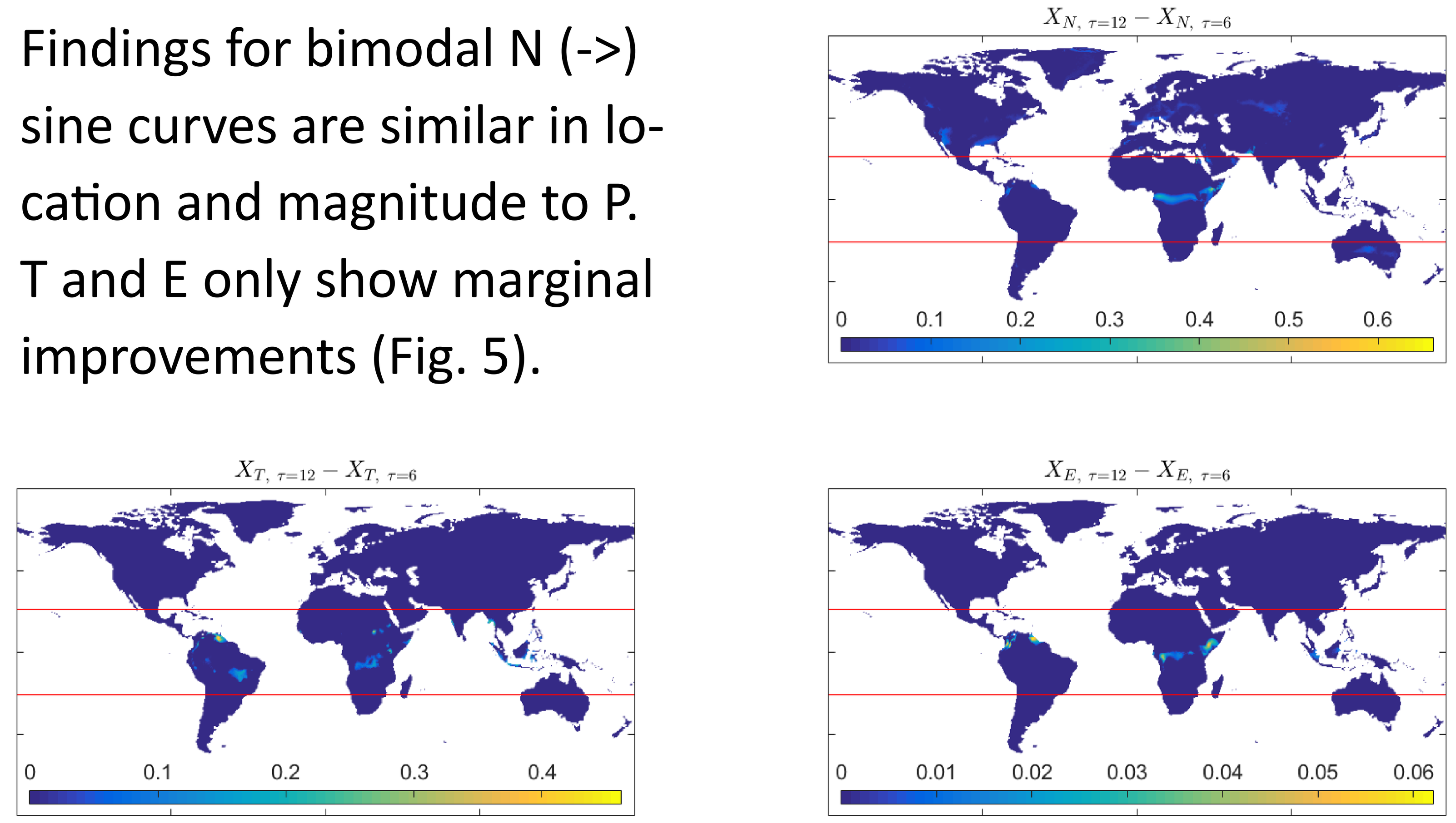


Fig 5: Non-negative values show improvement gained by using bimodal sine curves for storm frequency N (top right, decrease in monthly error in %, as X_P equation), temperature T (left, decrease in monthly error in °C, see X_T equation), and pet E (right, decrease in monthly error in %, as X_P).

We find three levels of suitability of bimodal sines (Fig. 6):

1. It works well due to distinct seasonality.
2. It works but doesn't matter in objective function terms due to high means and low seasonality.
3. It could work better due to asymmetry in either timing or magnitude of the climate seasonality.

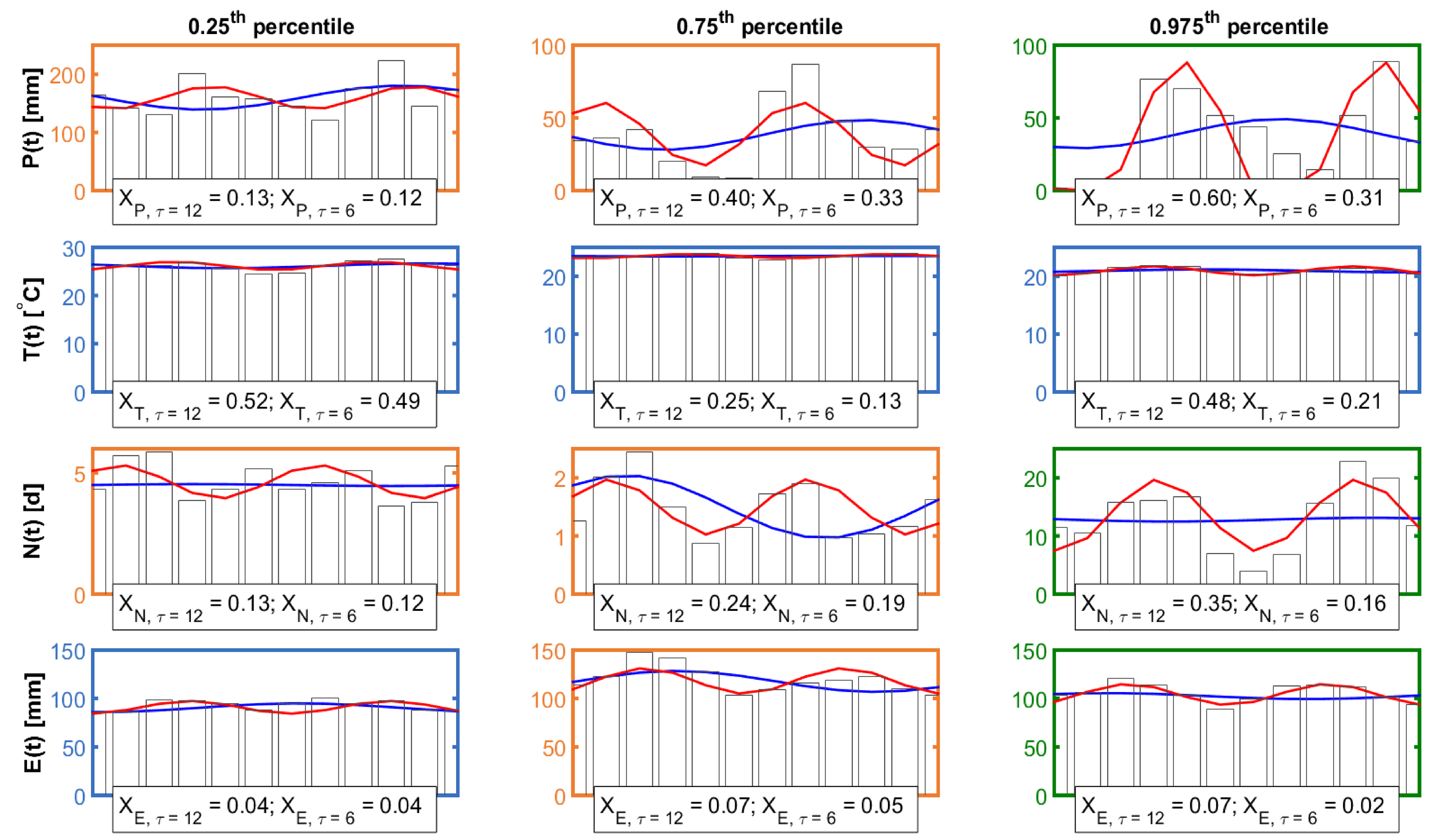
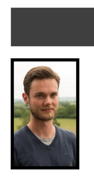


Fig 6: Snapshot of improvements. Colours refer to cases specified in the text above.



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[1] Berghuijs, W. R., & Woods, R. A. (2015). A simple framework to quantitatively describe monthly precipitation and temperature climatology. *International Journal of Climatology*. http://doi.org/10.1002/joc.4544

[2] Harris, I., Jones, P. D., Osborn, T. J., & Lister, D. H. (2014). Updated high-resolution grids of monthly climatic observations - the CRU TS3.10 Dataset. *International Journal of Climatology*, *34* (3), 623–642. http://doi.org/10.1002/joc.3711. Data period 1984-2014 is used, creating a "typical year" by averaging all January's/February's/etc.. 1984-2014 into the typical Jan/Feb/etc..