Stochastic modelling and prediction of monthly surface temperature: StocSIPS

StocSIPS

Stochastic Seasonal to Interannual Prediction System

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McGill Physics

Preprocessing

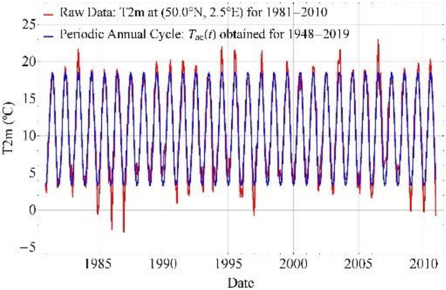
The temperature at every location is:

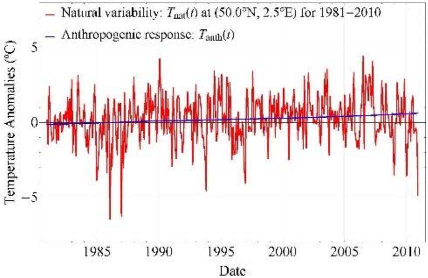
$$T(x,t) = T_{\mathrm{ac}}(x,t) + T_{\mathrm{anth}}(x,t) + T_{\mathrm{nat}}(x,t)$$

$$T_{\mathrm{anth}}(x,t) = \lambda_{2\times\mathrm{CO_2eq}}(x)\log_2\left[\rho_{\mathrm{CO_2eq}}(t)/\rho_{\mathrm{CO_2eq,pre}}\right]$$

$\lambda_{2\times\mathrm{CO_2eq}}(x)$ is the transient climate sensitivity at position x related to the doubling of atmospheric equivalent-CO_2 concentrations.

Example at position (50.0°N, 2.5°E):





Scaling

The fluctuations of the natural variability satisfies:

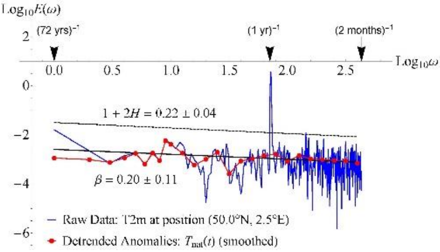
$$\langle |\Delta T(\Delta t)| \rangle \propto \Delta t^H$$

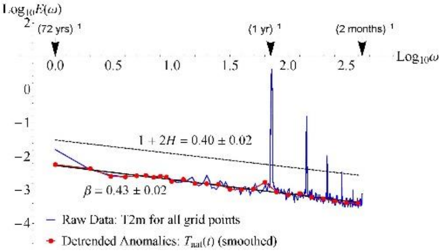
Equivalently for the spectrum:

$$E(\omega) \propto \omega^{-\beta}$$

with $\beta = 1 + 2H$

Spectrum:



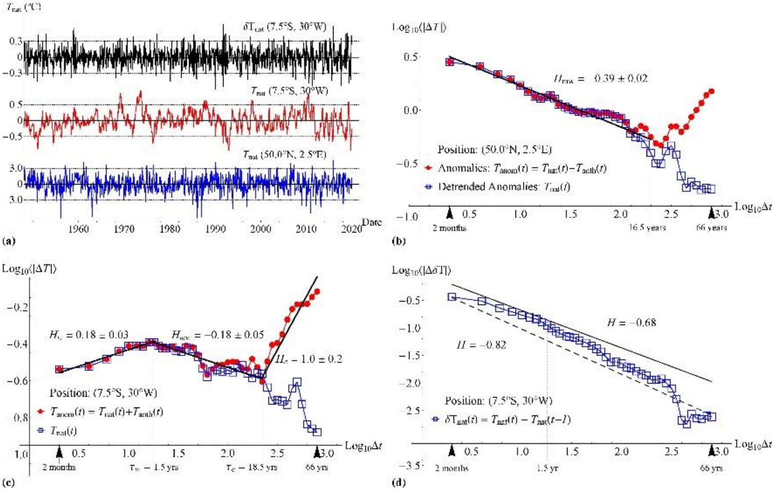


Scaling

Either the detrended anomalies $T_{\text{nat}}(t)$ or its first differences $\delta T_{\text{nat}} = T_{\text{nat}}(t) - T_{\text{nat}}(t-1)$ show a single scaling regime for time scales between one month and many decades with fluctuation exponent:

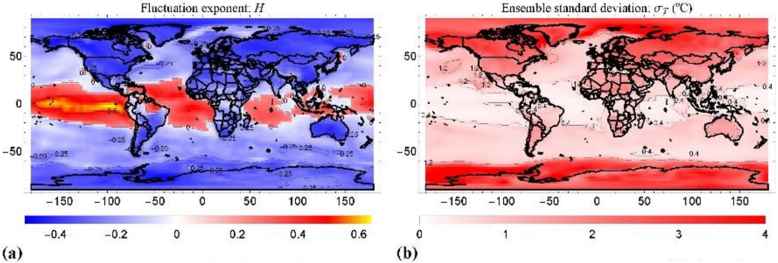
$$-1 < H < 0$$

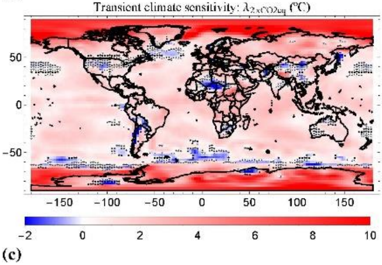
Examples at (50.0°N, 2.5°E - land) and (7.5°S, 30°W – tropical ocean) :



Stochastic modelling

The natural variability, T_{nat} (or its first differences, δT_{nat}) can be modeled by a <u>fractional Gaussian noise (fGn)</u> process with parameters σ (volatility) and H (fluctuation exponent). We assume the series have zero mean. The raw temperature at every location is determined by only 3 parameters (σ, H, $\lambda_{2\mathrm{xCO2eq}}$):

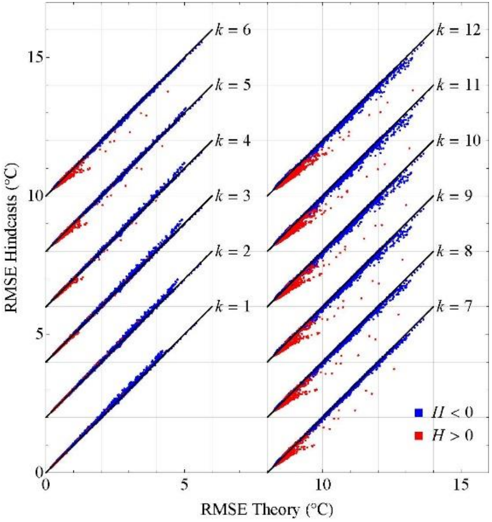




In the region with $H > 0$ (tropical ocean), the first differences δT_{nat} are modeled by an fGn process, with fluctuation exponent $H - 1$.

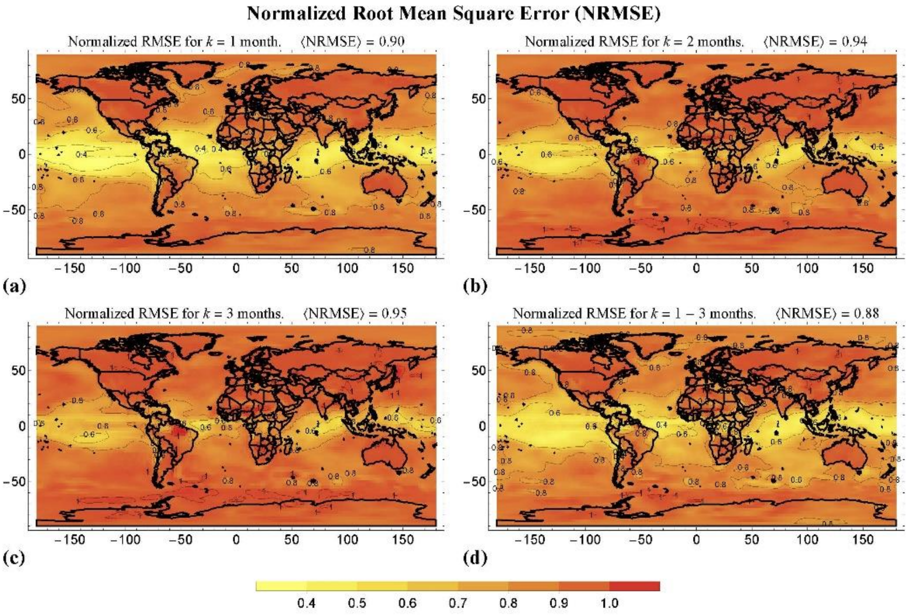
Model validation

We performed monthly hindcasts for the verification period 1951-2019 using as observational reference NCEP/NCAR Reanalysis interpolated to a 2.5° latitude × 2.5° longitude grid across the globe for a total of 73 × 144 = 10512 grid points.

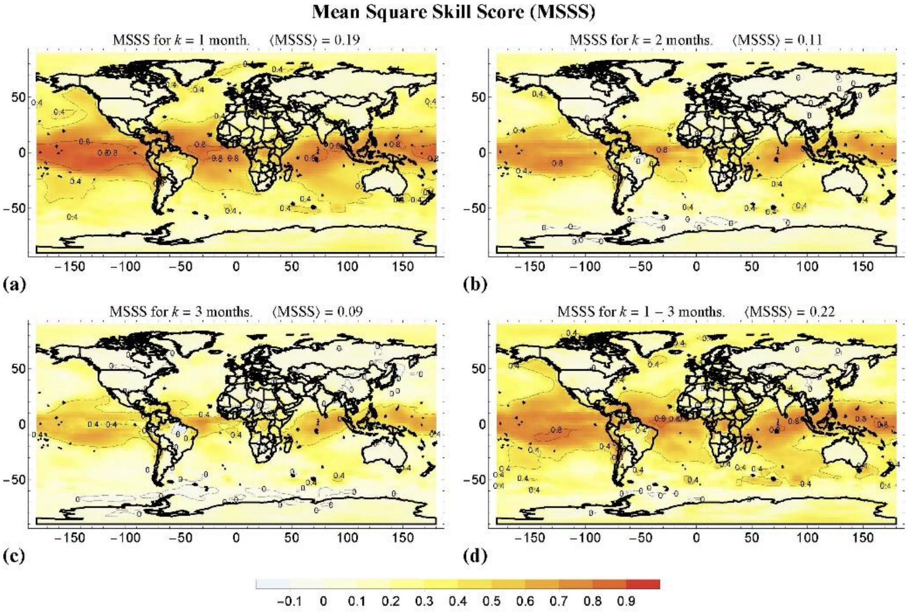


Comparison between the $\mathrm{RMSE}_{\mathrm{nat}}$ obtained from hindcasts and the theoretical $\mathrm{RMSE}_{\mathrm{nat}}^{\mathrm{theory}}$ predicted by the theory for different forecast horizons, k, from 1 to 12 months. The black line at 45° is a reference indicating perfect agreement between theory and verification results. The blue points represent locations where $H < 0$ and the natural variability is modeled as an fGn process and the red points are for places where $H > 0$ and we have to take the first differences.

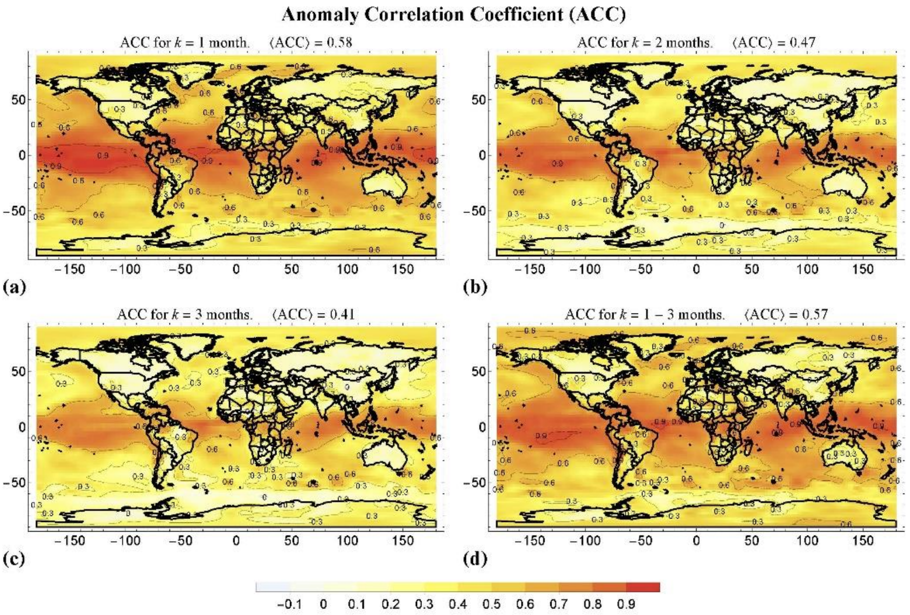
Hindcast verification



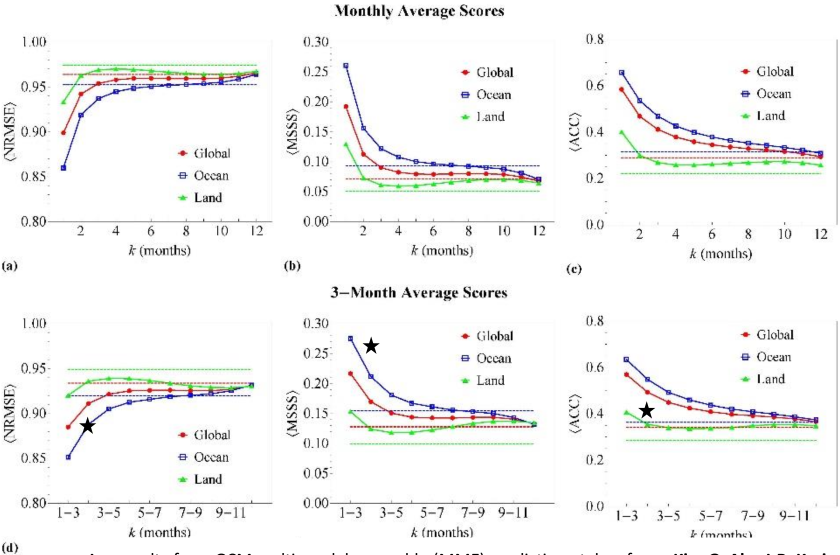
Hindcast verification



Hindcast verification



Hindcast verification



★ Are results from GCM multi-model ensemble (MME) predictions taken from: **Kim G, Ahn J-B, Kryjov VN, et al (2016) Global and regional skill of the seasonal predictions by WMO Lead Centre for Long-Range Forecast Multi-Model Ensemble. Int J Climatol 36:1657–1675. doi: 10.1002/joc.4449**

Conclusions

StocSIPS performance

-Anomalies: StocSIPS has higher skill than GCMs for two months and longer.
-Actuals: Higher skill at all lead times due to direct forecasting of real world climatology.
-StocSIPS relative advantage: increases with lead time and is higher over land than oceans.

StocSIPS' advantages include

-No data assimilation
-No ad hoc post processing
-No need for downscaling
-Speed (for an infinite ensemble): (factor 10^5- 10^6)

References:

- Del Rio Amador, L. and Lovejoy, S. (2019) *Clim Dyn*, **53**: 4373. https://doi.org/10.1007/s00382-019-04791-4
- Lovejoy, S., Del Rio Amador, L., Hébert, R. (2017) In *Nonlinear Advances in Geosciences*, A.A. Tsonis ed. Springer Nature, 305–355 DOI: 10.1007/978-3-319-58895-7