

The effect of noise in sea surface temperature on marine primary production

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Ocean Optics XXVII, Ghent, Belgium, 13th - 18th September 2026

This work was supported by the Croatian Science Foundation under the project number HRZZ IP-2022-10-8859.

Thermal performance function and noise

Thermal performance functions can be used to model the dependence of phytoplankton growth rate on temperature. A recently published universal thermal performance function by Arnoldi et al. (2025) reads:

$$\mu(T) = \mu_m \exp\left(\frac{T - T_o}{T_c - T_o}\right) \left(1 - \frac{T - T_o}{T_c - T_o}\right), \quad (1)$$

where T_o is the optimal performance temperature, T_c is the critical temperature and μ_m is the maximal growth rate. If temperature is a normally distributed random variable with mean $\langle T \rangle$ and standard deviation σ , the average growth rate then becomes:

$$\langle \mu(T) \rangle = \mu_m \exp\left(\frac{T - T_o}{T_c - T_o} + \frac{\sigma^2}{2(T_c - T_o)^2}\right) \left[1 - \frac{T - T_o}{T_c - T_o} - \frac{\sigma^2}{(T_c - T_o)^2}\right]. \quad (2)$$

A comparison of the two functions is given below. At lower temperatures noise acts favourably and increases the average growth rate, whereas at higher temperatures noise acts to suppress the average growth rate.

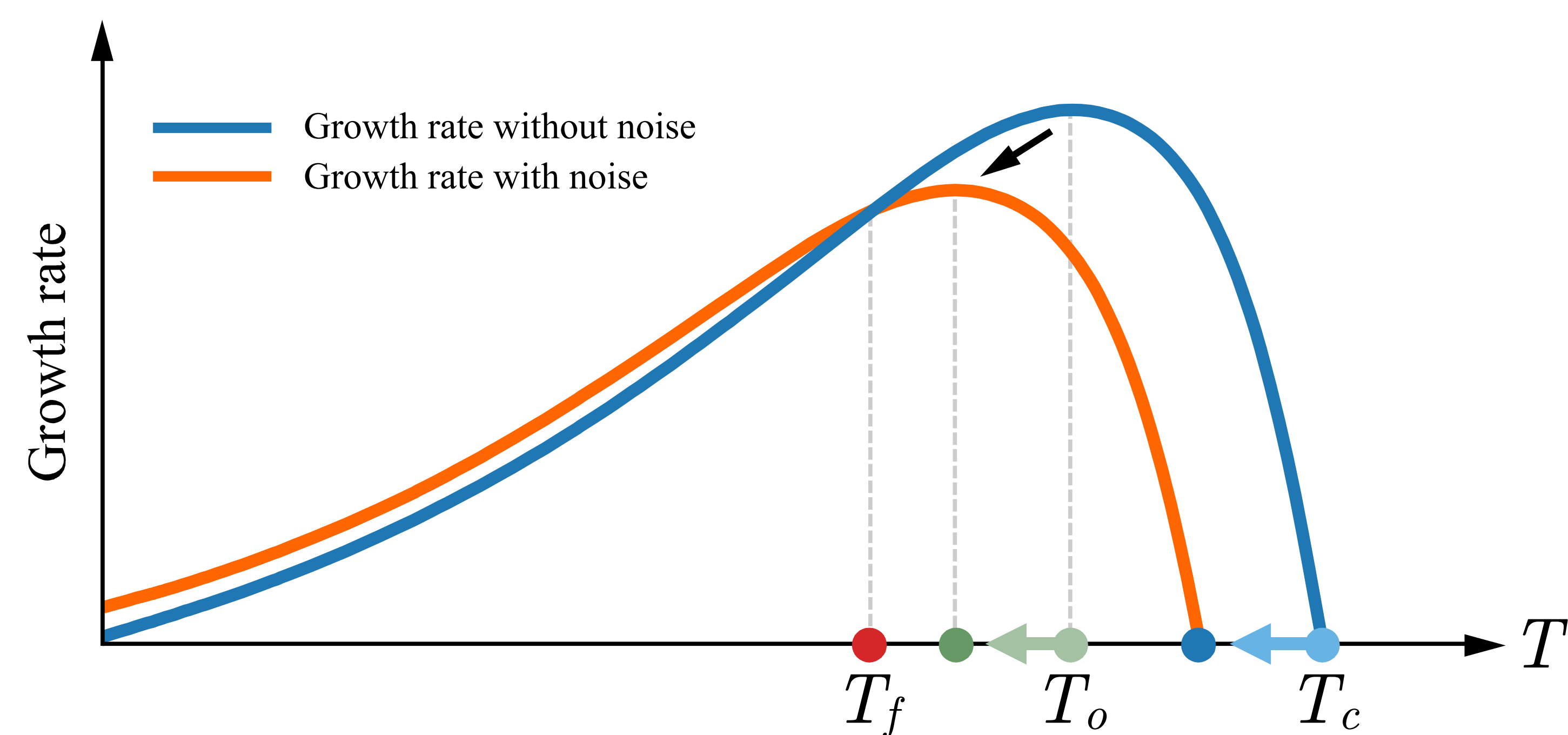


Figure 1: Plot of the universal thermal performance function (1) given in blue and its average (2) given in orange. The average is calculated by assuming a normally distributed noise around a fixed temperature. The thermal performance function has a maximum at the optimal temperature T_o and goes to zero at the critical temperature T_c . Upon averaging the optimal temperature and the critical temperature both shift to lower temperatures.

Noise in sea surface temperature

A typical sea surface temperature (SST) signal consists of a trend, seasonal cycle and noise. To get at the noise term the deterministic signal has to first be removed. Here we used global SST data and at each point the mean, the trend and the seasonal cycle were estimated and removed. Subsequently, a Gaussian distribution was fitted onto the remaining anomalies signal. The standard deviation of this fit was taken as a measure of noise in the SST signal at each location.

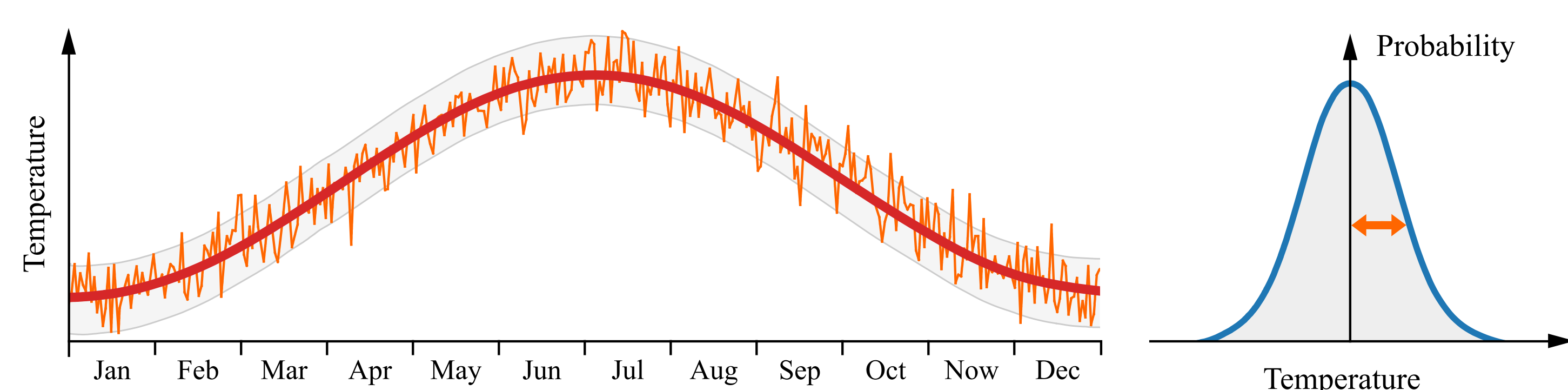


Figure 2: A depiction of a seasonal cycle of SST. The red curve represents the seasonal cycle, the orange line represents a single realization of the SST signal and the grey region represents climatological variability. Once the trend and the seasonal cycle had been removed the remaining variability is treated as noise (shown on the right). A Gaussian is fitted to the noise and the standard deviation of the fit is taken as a measure of noise intensity.

Figure 3 shows a map of the standard deviation of noise in SST obtained in the above manner. Figure 4 shows the ratio of noise to the amplitude of the seasonal cycle.

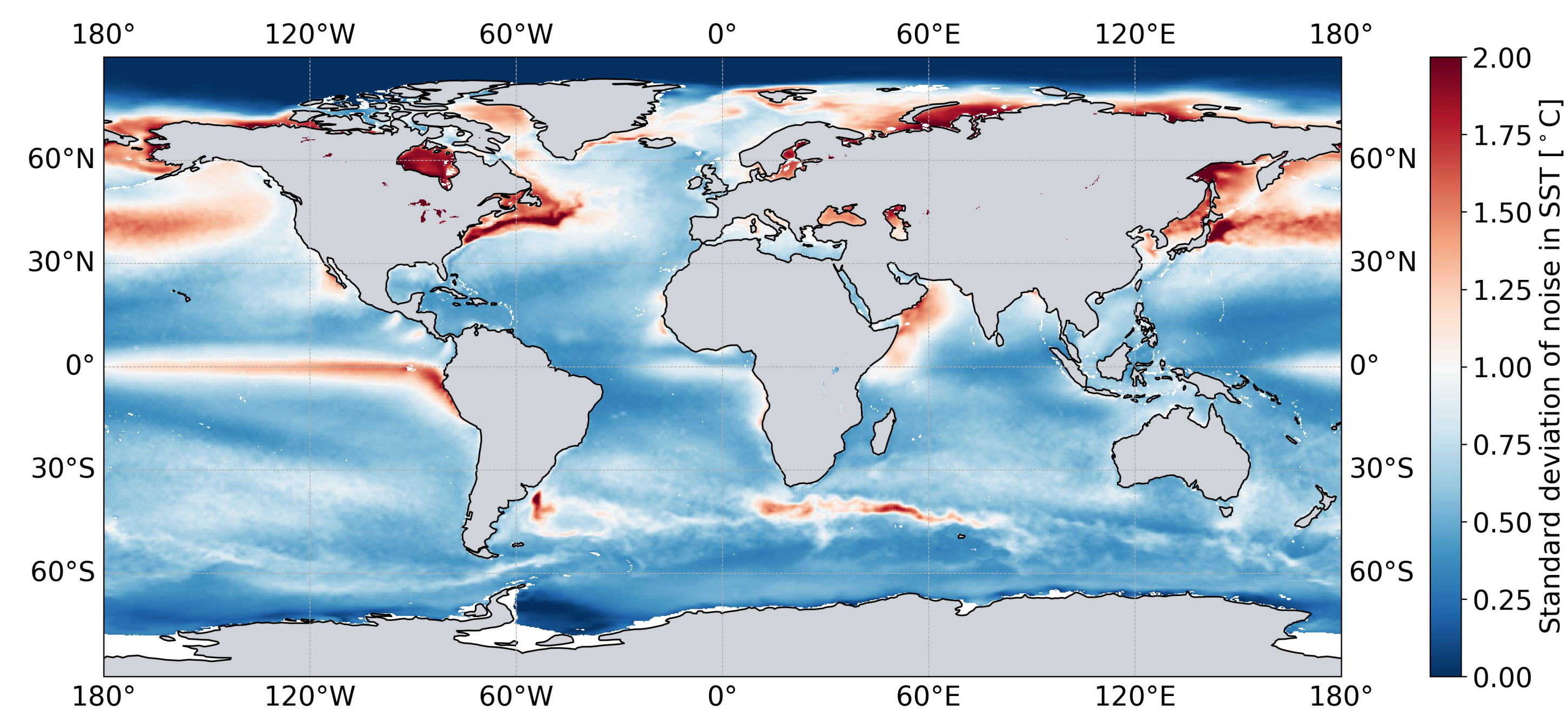


Figure 3: A map of standard deviation in sea surface temperature noise term (SST).

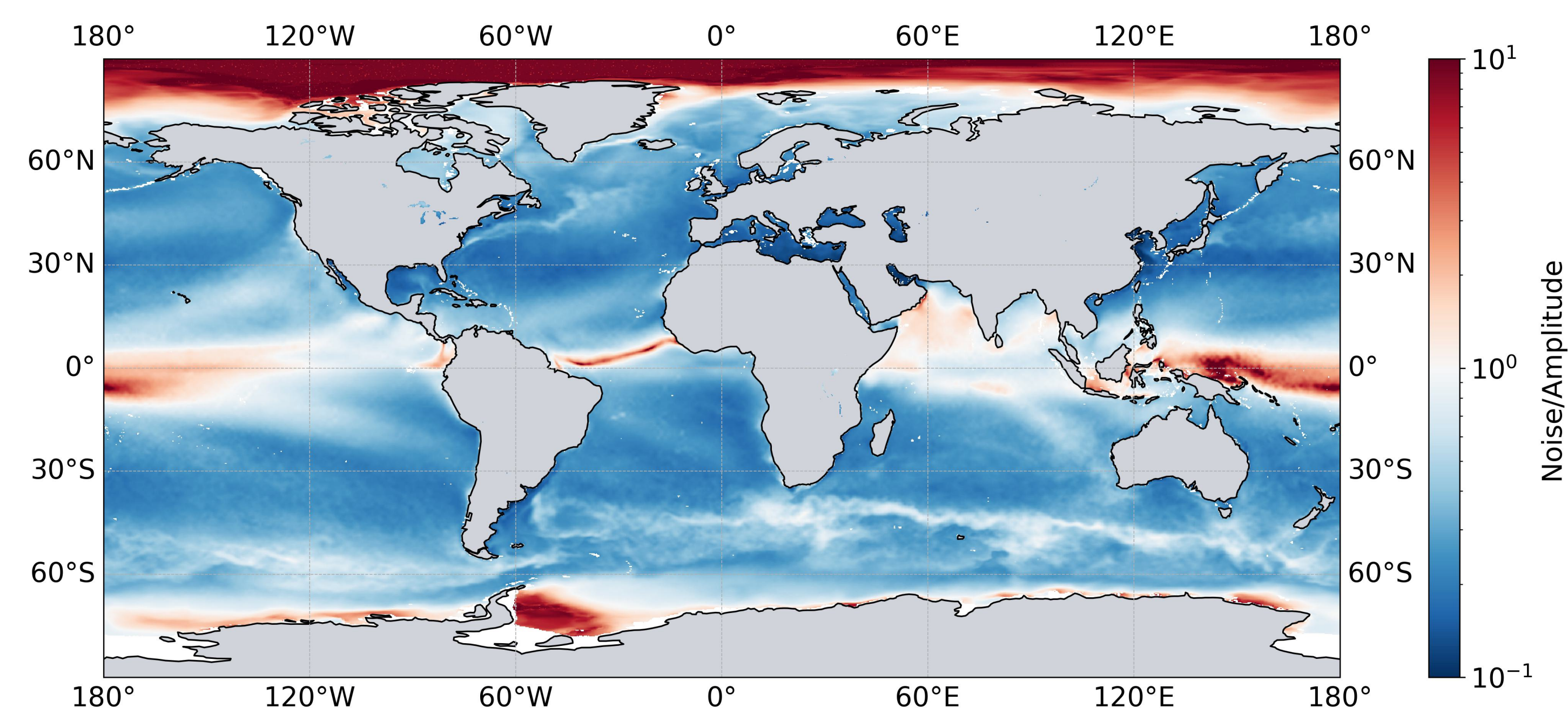


Figure 4: A map of SST noise standard deviation in relation to the amplitude of the seasonal cycle.

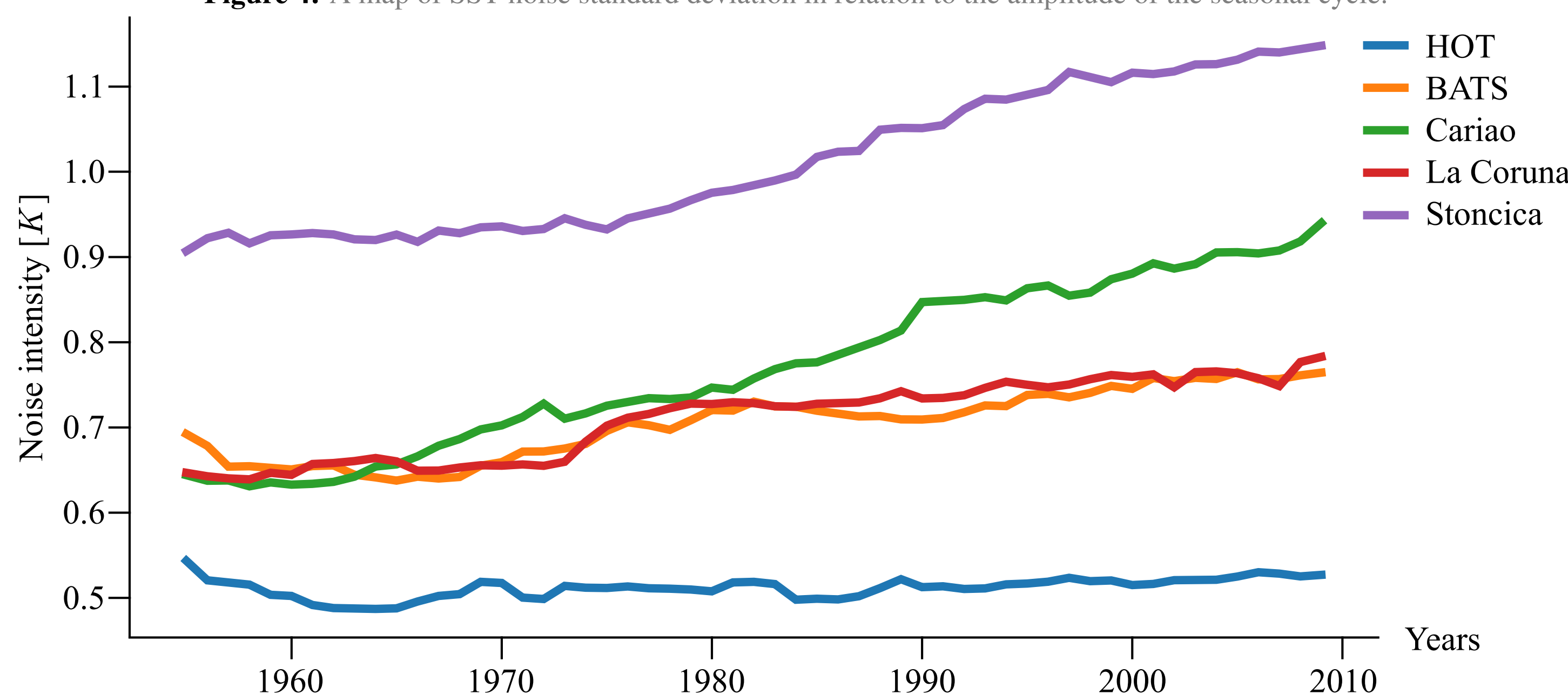


Figure 5: Time series of the standard deviation in SST at: HOT (blue curve), BATS (orange curve), Cariaco (green curve), La Coruna (red curve) and Stončica (purple curve). The time series were obtained by calculating 30 year moving climatologies of the noise term at each station. As can be seen the noise intensity is increasing at 4 out of these 5 stations.

A simple stochastic growth model

Here we compare the results generated with a simple stochastic growth model, with a temperature dependent growth term (1), which uses SST with and without noise to highlight the importance of noise on the time evolution of phytoplankton biomass.

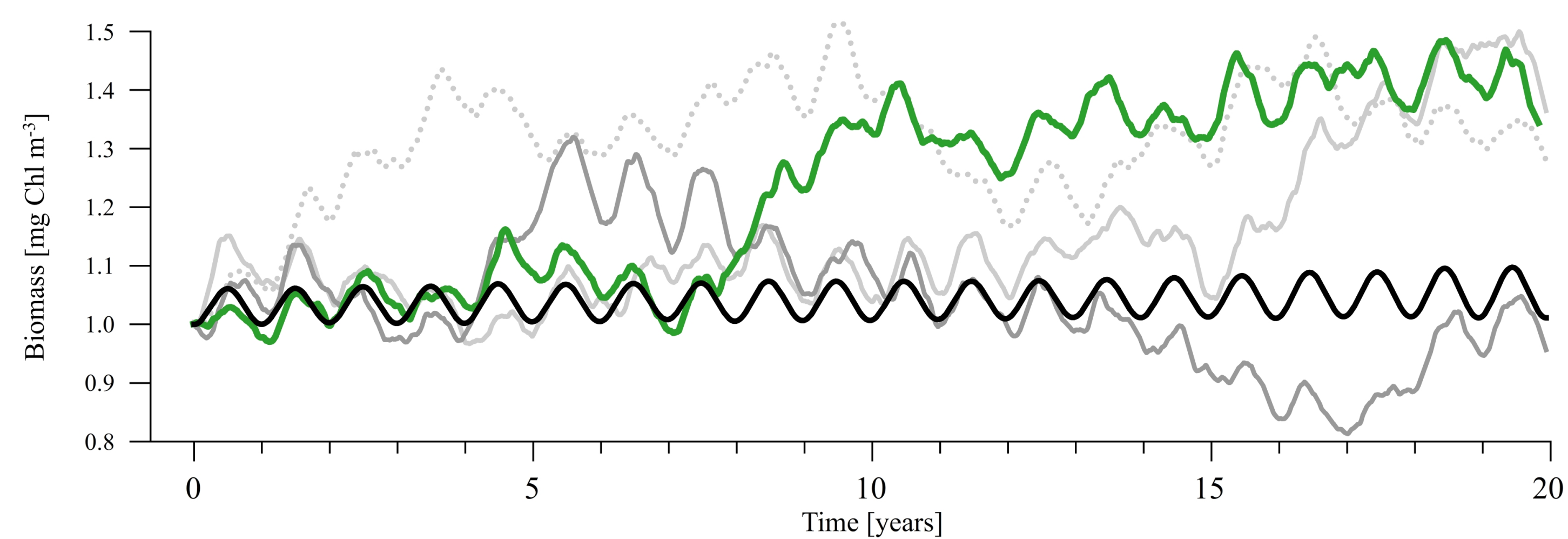


Figure 6: Time series of phytoplankton biomass obtained by running a simple growth model with noise in SST (grey and green curve) in comparison to the model run without noise in SST. When run without noise affecting the growth rate the model goes to a stable cycle (black curve), while when it is run with noise affecting the growth rate different dynamics emerge as evident by the grey and green curves. Each curve is another model run.

References

Arnoldi, J.-F., Jackson, A. L., Peralta-Maraver, I., Payne, N. L. (2025). A universal thermal performance curve arises in biology and ecology. *Proceedings of the National Academy of Sciences*, 122(43), 1-7. doi: 10.1073/pnas.2513099122