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Exploring Relationships Between Emerging Climate Change Signals and Species Range Shifts

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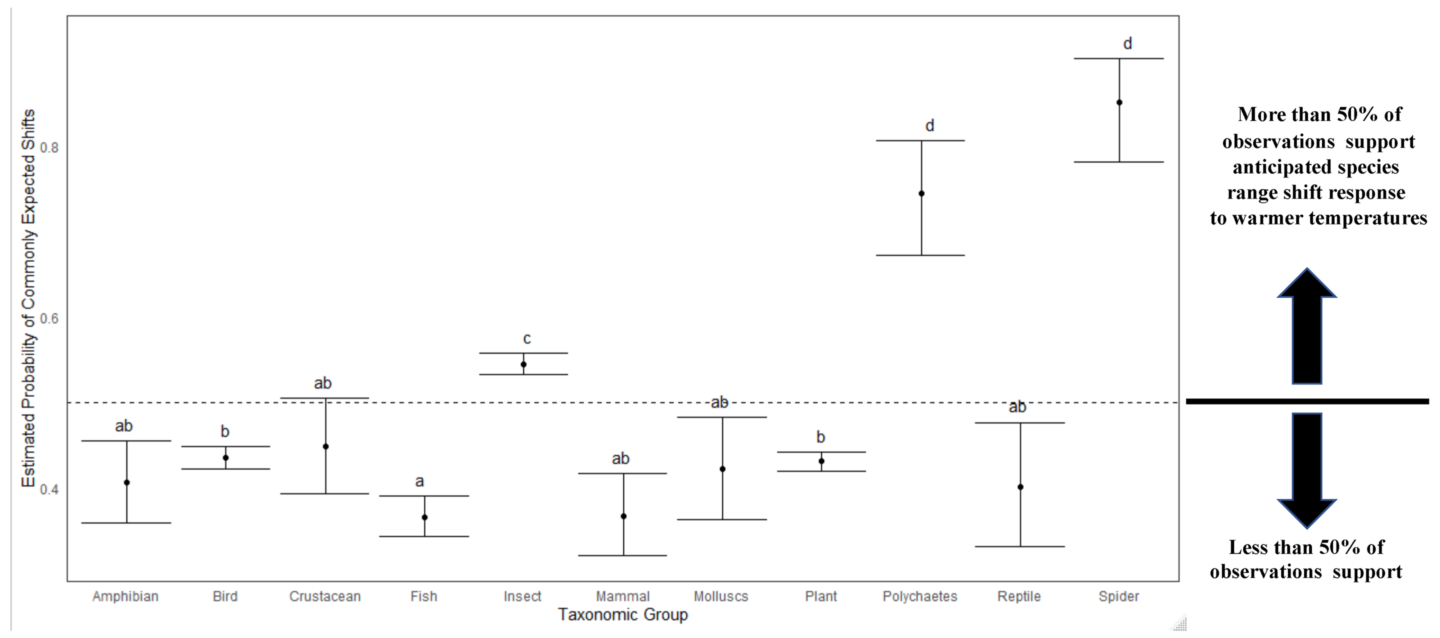
Introduction

Species are expected to shift their distributions to higher latitudes, greater elevations, and deeper depths in response to warming, reflecting an underlying hypothesis that species will move to cooler locations as the climate warms. However, less than half of all species are shifting as expected when considering warmer temperatures (shown below).



Rubenstein and Weiskopf et al. in review

Climate change is heterogenous, which complicates our understanding of species exposure to both the rate and magnitude of change in the climate. Species also have different tolerance thresholds to the climate, and other underlying changes important to localized climate are simultaneously occurring, such as land cover characteristics.

This study tackles the first problem related to species exposure to regional climate change (historical and plausible future) using large ensembles of Global Climate Models (GCMs). These ensembles use the same GCM to simulate the climate many times by varying the model initial conditions. Hence, there are many realizations of the historical and future climate from a single GCM, which helps to better sample the anthropogenically forced trend to increasing greenhouse gas emissions **(Signal)** and the natural climate variability **(here year-to-year Noise)**. These simulations help us to better answer the following questions:

Has a climate change signal emerged for biologically relevant temperature metrics (considering different sequences of natural climate variability)?

If so, when/where does the climate signal emerge for the metric of concern? This is the Time of Emergence (ToE) when the anthropogenically forced signal emerges from the noise of the background natural climate variability[1].

What was the magnitude of the signal at the Time of Emergence (ToE)?

If a signal hasn't emerged within the historical period, do we anticipate a signal will emerge in the future?

Temperature Metrics
Annual Mean
Mean Diurnal Range
Isothermality
Temperature Seasonality
Max. Temperature of Warmest Month
Min. Temperature of Coldest Month
Annual Range
Mean Temperature of Wettet Quarter
Mean Temperature of Driest Quarter
Mean Temperature of Warmest Quarter
Mean Temperature of Coldest Quarter

Calculating the Signal / Noise and Time of Emergence

GCM Data: The Max-Planck Earth System Model **(MPI-ESM)** grand ensemble[2] - 100 realizations of the climate for a historical baseline period (1901-2014) is combined with future realizations of climate (to 2100) for a middle of the road greenhouse gas emission scenario (RCP4.5[3]).

To derive the **Time of Emergence (ToE) for the MPI-ESM,** a trend is first calculated for each GCM realization temperature metric using a gaussian fit by least squares. The degree of smoothing is determined using an automated smoothing parameter with a polynomial fit of 2.

The Signal (S) in time is the ensemble average trend using all of the GCM realizations considering difference between the smooth fit ensemble value in time relative to 1901 (early industrial reference). **The Noise (N)** is simply the standard deviation of the residuals from smooth fit from all GCM realizations and represents the natural climate variability. **A ratio of the Signal/Noise (S/N)** is calculated for each time.

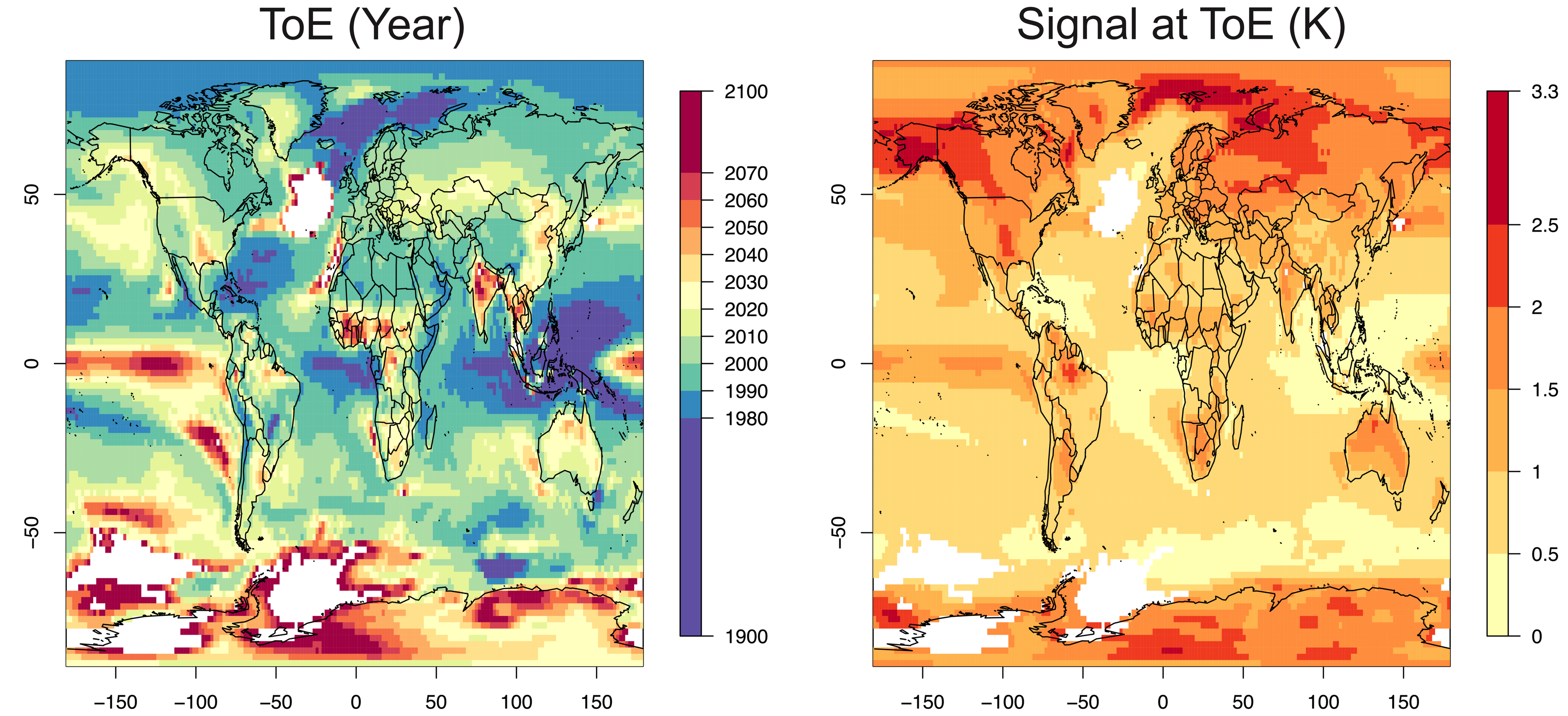
The ToE is the year when the S/N permanently exceeds a threshold of 2. A S/N threshold of 2 is **considered an 'unusual' climate** relative to early-industrial lived experience [3,4]. *Note that different S/N thresholds can be established with lower thresholds for species that are less tolerant to warming and higher thresholds for species that are more tolerant.*

Time of Emergence & the Signal at Time of Emergence

Below are example plots of the ToE and Signal at the ToE when the S/N ratio exceeds value of 2 for the MPI-ESM and two temperature metrics. White values indicate areas where a signal doesn't emerge by 2100 for the RCP4.5 scenario. For instance, note the later ToE (upcoming decades) that stretches from southern Alaska through central US to Texas for annual mean temperature where the signal at ToE is larger (>2.5K). A signal also emerges in the future for a reduction in the mean diurnal range - mostly in the northern latitudes.

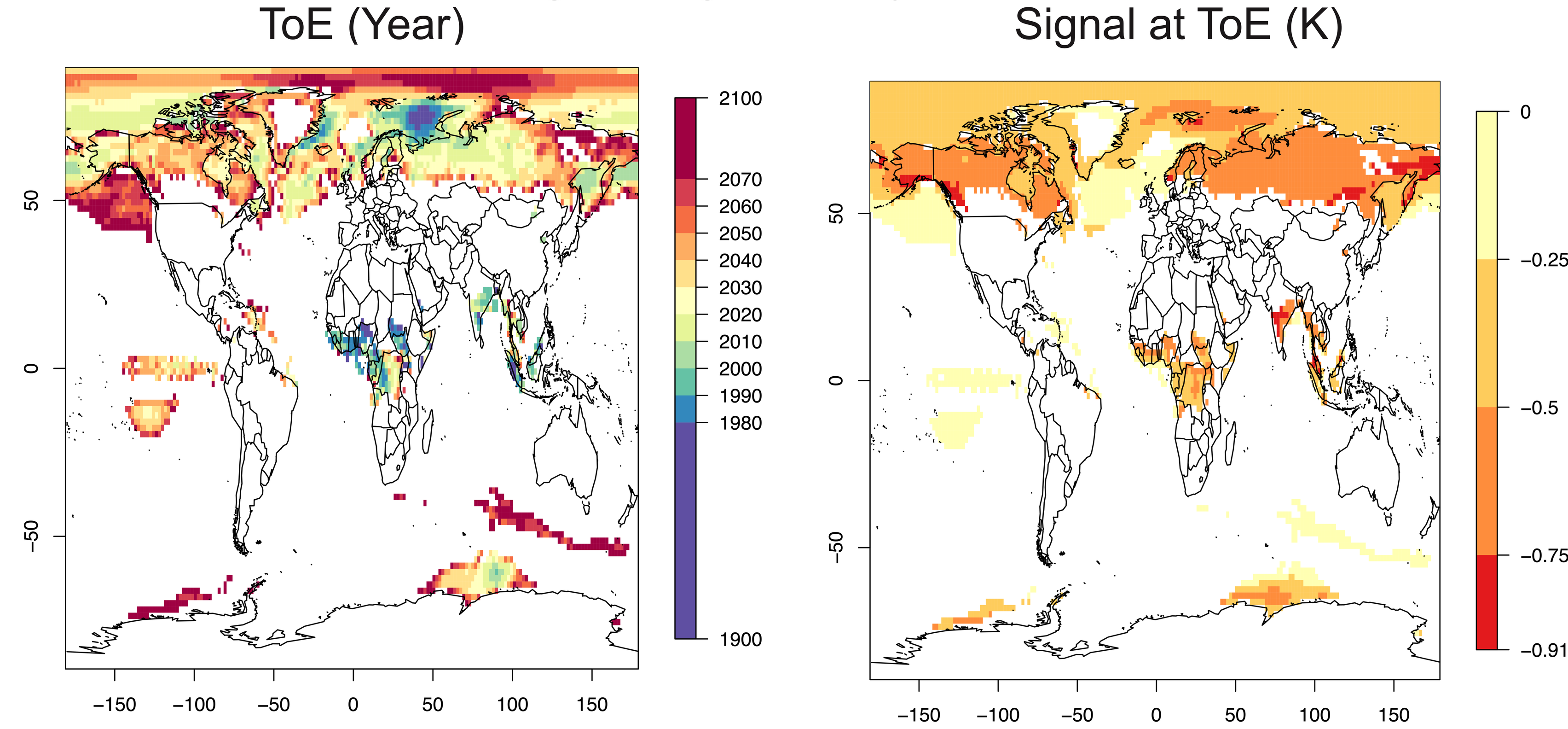
Annual Mean Temperature - Warming

ToE (Year) Signal at ToE (K)

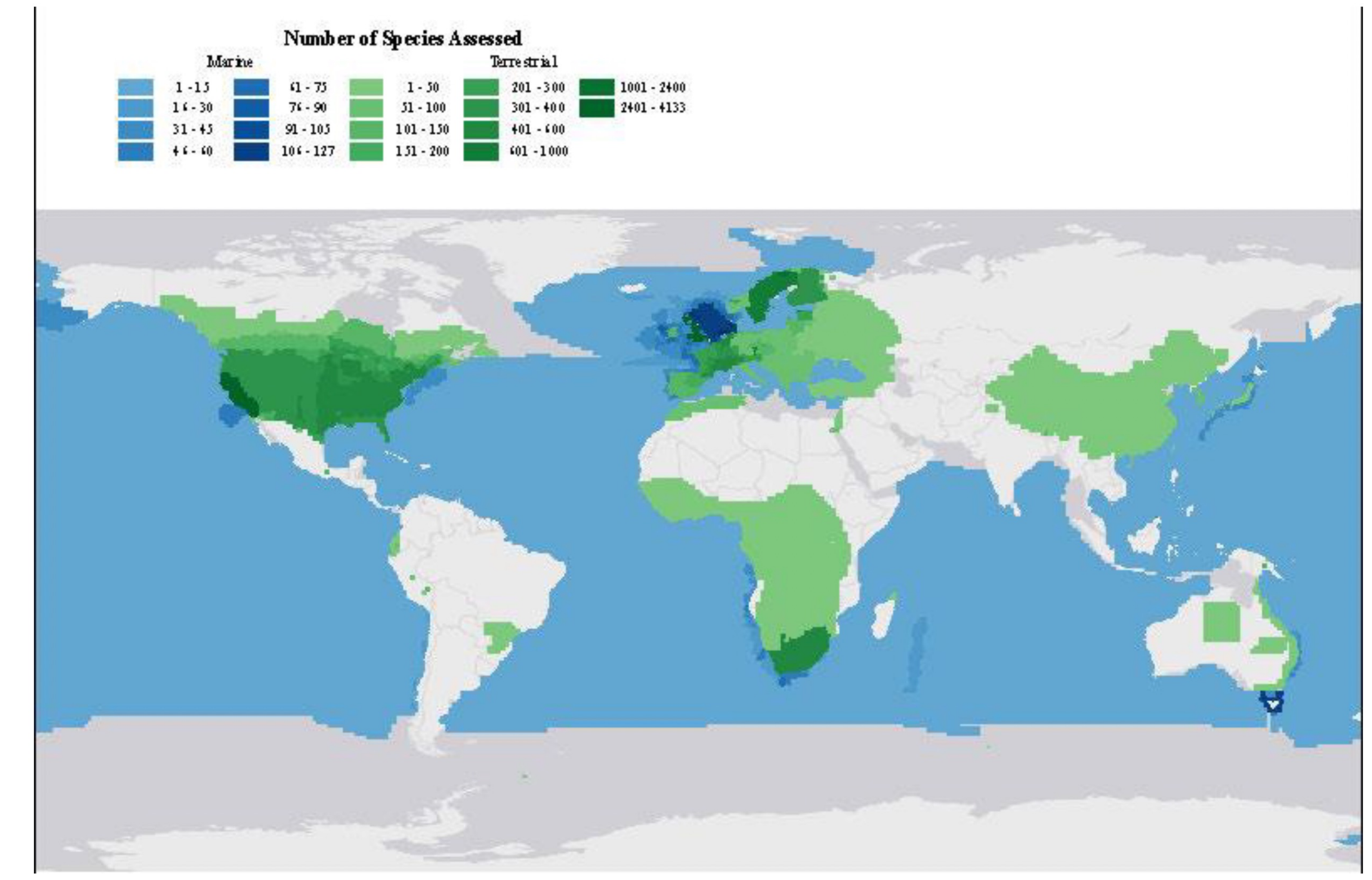


Mean Diurnal Range – Avg. Monthly Reduction for the Year

ToE (Year) Signal at ToE (K)



Species Range Shift (Number of Species Assessed)



Distribution of observed species range shifts observations (by number of species) assessed in a recent systematic literature review. Higher density is found for North America and Europe.

Future : Combining ToE Information with Information about Species Range Shifts

We need to consider how to best combine information about species range shifts with information about ToE and magnitude of climate change signals from multiple GCM large ensembles. For illustration here – one of three GCM large ensembles is shown.

How do we combine the places where we have more confidence about climate change signals in the historical climate with knowledge about observed species range shifts?

Does this improve our understanding of how species are responding to climate change, such as anticipated hypothesis about species shifting towards higher latitudes, elevations, and depths in response to warming?

Can we anticipate where we should focus future species monitoring efforts and possibly when we should focus our attention to these regions, especially if they harbor significant diversity?

We are open to the types of questions we should consider addressing!!

References

[1] Hawkins, E., and R. Sutton (2012). Time of emergence of climate signals. *Geophys. Res. Lett.*, **39**, L01702, https://doi.org/10.1029/2011GL050087.
[2] Maher, N., Milinski, S., Suarez-Gutierrez, et al. (2019). The Max Planck Institute Grand Ensemble: Enabling the Exploration of Climate System Variability. *Journal of Advances in Modeling Earth Systems, 11,* 1-21. https://doi.org/10.1029/2019MS001639
[3] Frame, D., Joshi, M., Hawkins, E. *et al. (2017).* Population-based emergence of unfamiliar climates. *Nature Clim Change* **7**, 407–411. https://doi.org/10.1038/nclimate3297
[4] Hawkins, E., Frame, D., Harrington, L., Joshi, M., King, A., Rojas, M., et al. (2020). Observed emergence of the climate change signal: From the familiar to the unknown. *Geophysical Research Letters*, **47**(6), e2019GL086259. https://doi.org/10.1029/2019gl086259