Supporting Information for "Marine ecosystem changepoints spread under ocean warming in an Earth System Model"

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time series	best-fitting model	ΔAIC	ΔBIC
$N(0,1)$	Constant Mean	-2.5	-7.7
$(2t-1)+N(0,1)$	Trend	-0.9	-8.7
$(2H(t-50)-1)+N(0,1)$	Mean Changepoint ($n=1$, $t=50$)	-42.7	-40.1
$(2t-1)+(2H(t-50)-1)+N(0,1)$	Trend Changepoint ($n=1$, $t=50$)	-20.7	-12.9

Table S1. Example showing that changepoint detection (or lack thereof) is robust to the superposition of a trend. Four timeseries are considered, with $t = 0 \ldots 100$: 1. a standard Gaussian random noise, 2. (1) with a linear trend moving from -1 when $t = 0$ to +1 when $t = 100$ superimposed (i.e. using the standard minimum signal-to-noise ratio of 2 from the time of emergence literature e.g. (Dutkiewicz et al., 2019)), 3. (1) with a step function moving from -1 when $t < 50$ to +1 when $t > 50$ (and zero when $t = 50$) is simperimposed, and 4. (1) with both the step function and the trend superimposed. A constant function, a trend, a mean changepoint function, and a trend changepoint function (i.e. statistical models 1-4 from the text) are fit to each time series; the difference in the Akaike and Bayesian Information Critera (ΔAIC and ΔBIC, which are smallest for the best-fitting model) are given for each best-fitting model versus the next-best model. In both of the cases with (without) a step-function, a model with (without) one changepoint at $t = 50$ is best-fitting, irrespective of whether or not the trend is included. Note that $n = 1$ and $t = 50$ are not chosen *a priori* and the ΔAIC and ΔBIC values do not change with repeated draws from $N(0, 1)$.

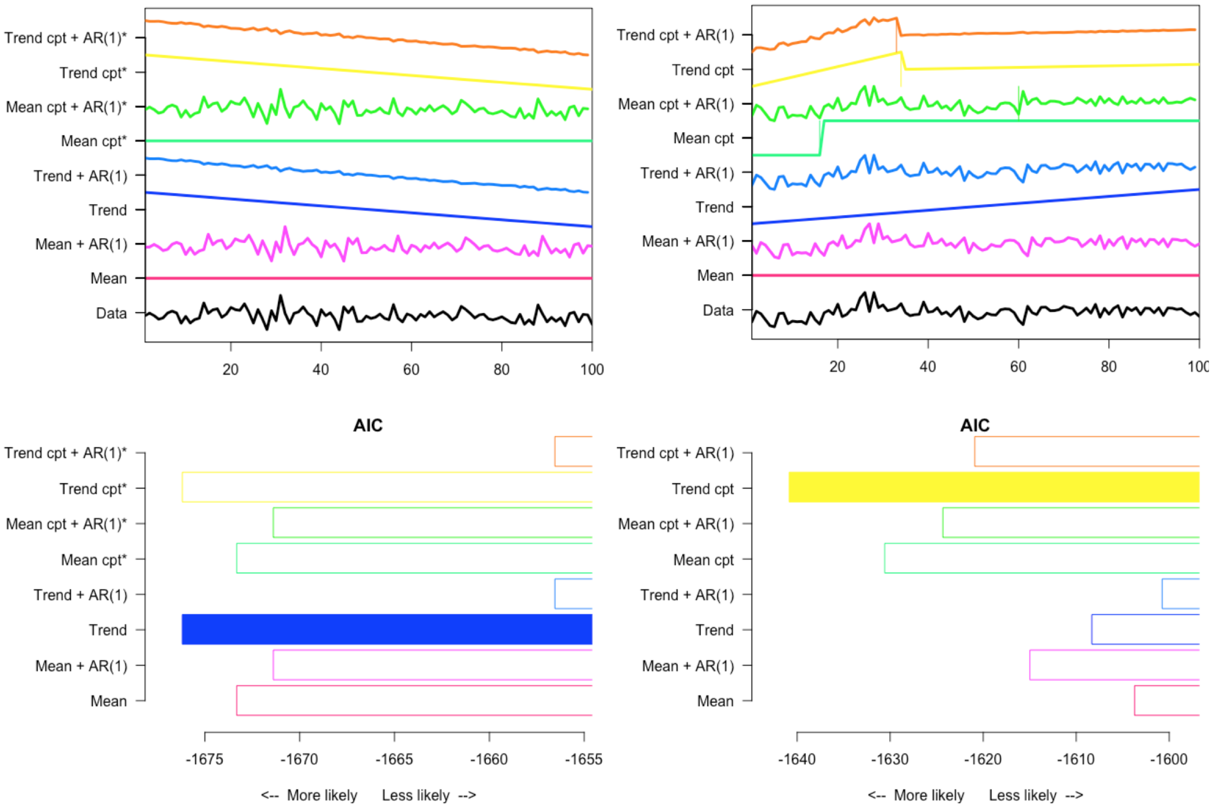

Figure S1. Example time series (both of nitrate in the 21st century (RCP8.5) simulation at 46°S) and standard output from the *EnvCpt* package. Left panels are at 178°W (no changepoint) and right panels are at 162°W (one changepoint). Top panels are fits of the different models and bottom panels are each model's Akaike Information Criterion (AIC) value, the lowest of which corresponds to the best fit.

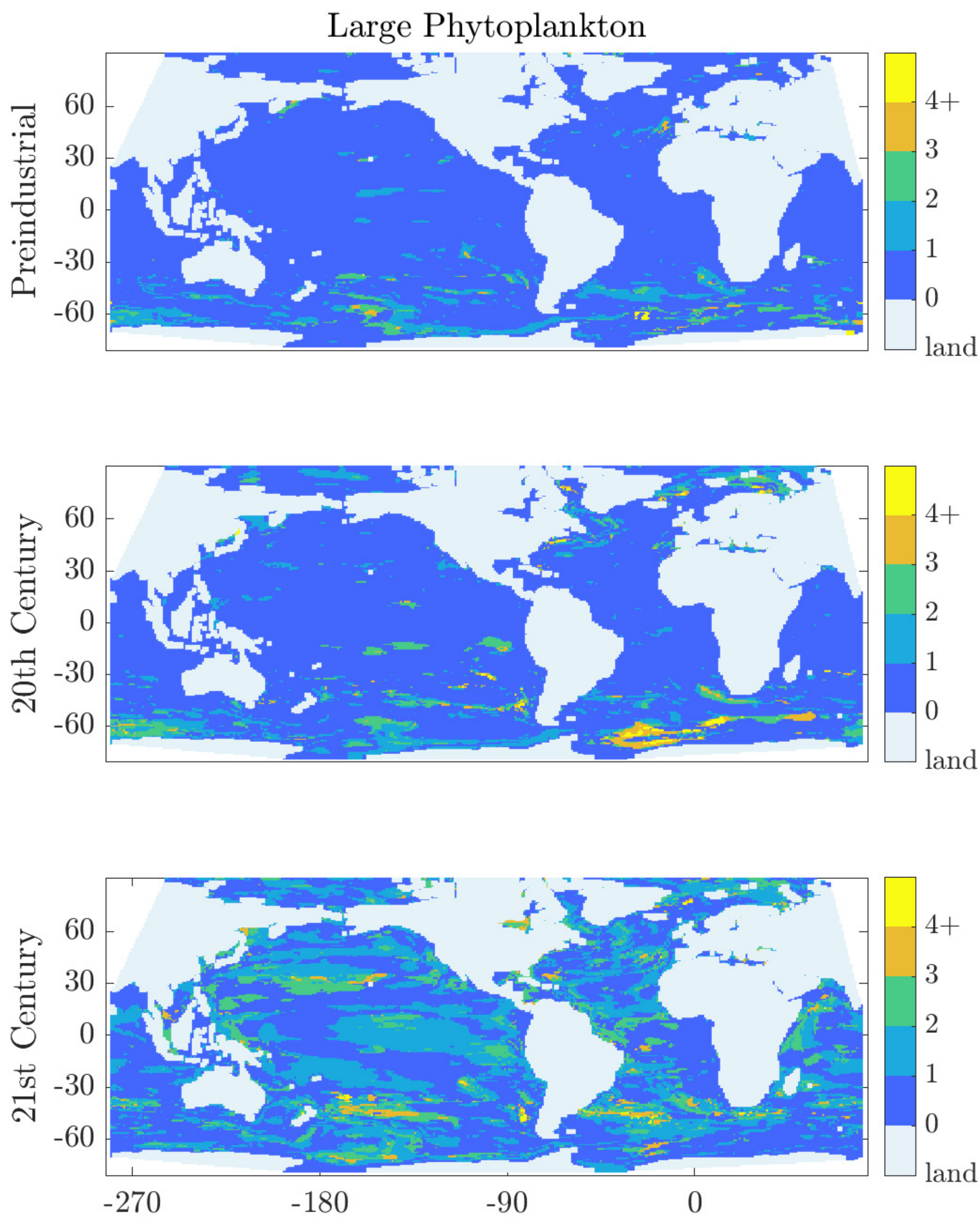

Figure S2. Maps of number of changepoints for each simulation for large phytoplankton.

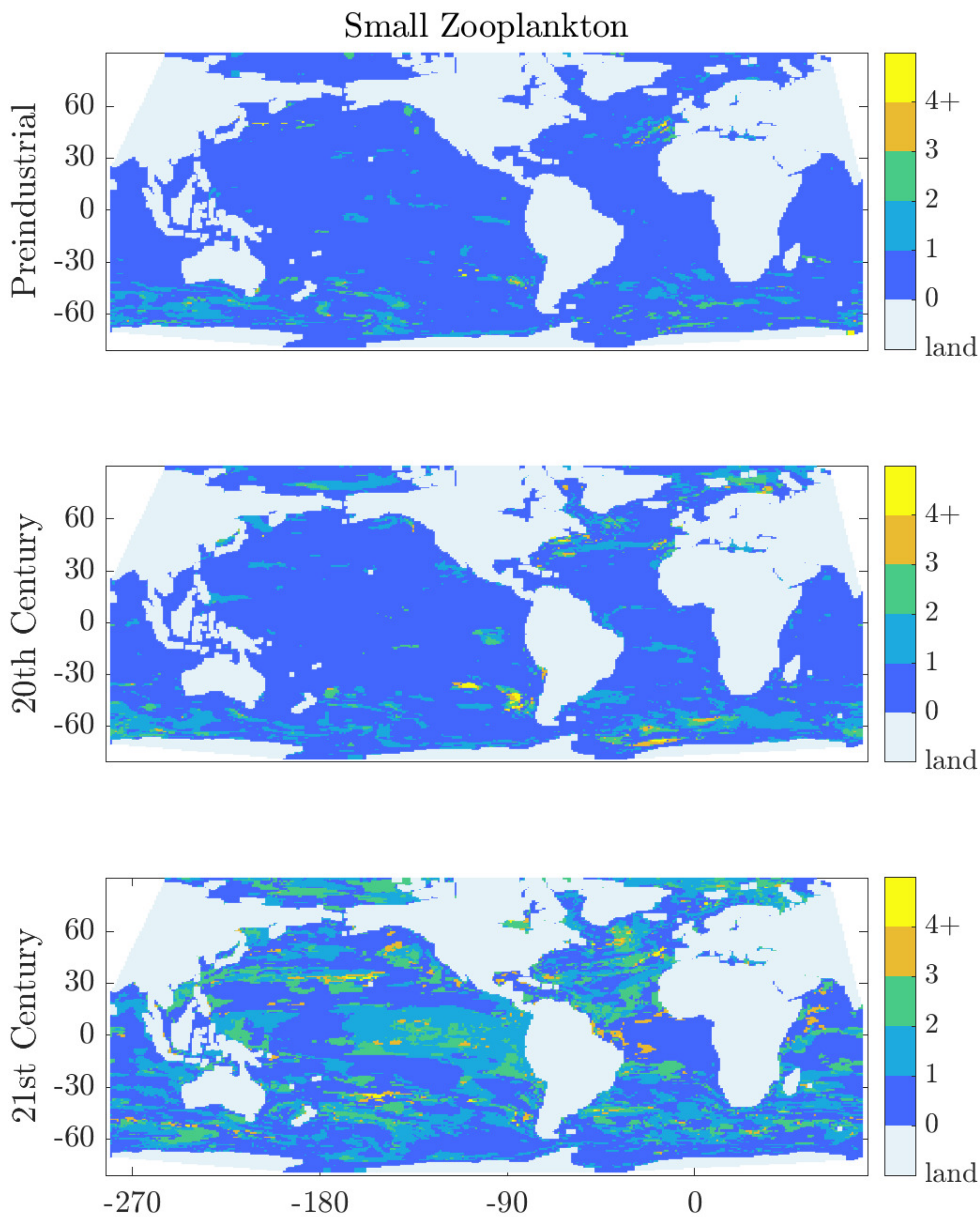

Figure S3. Maps of number of changepoints for each simulation for small zooplankton.

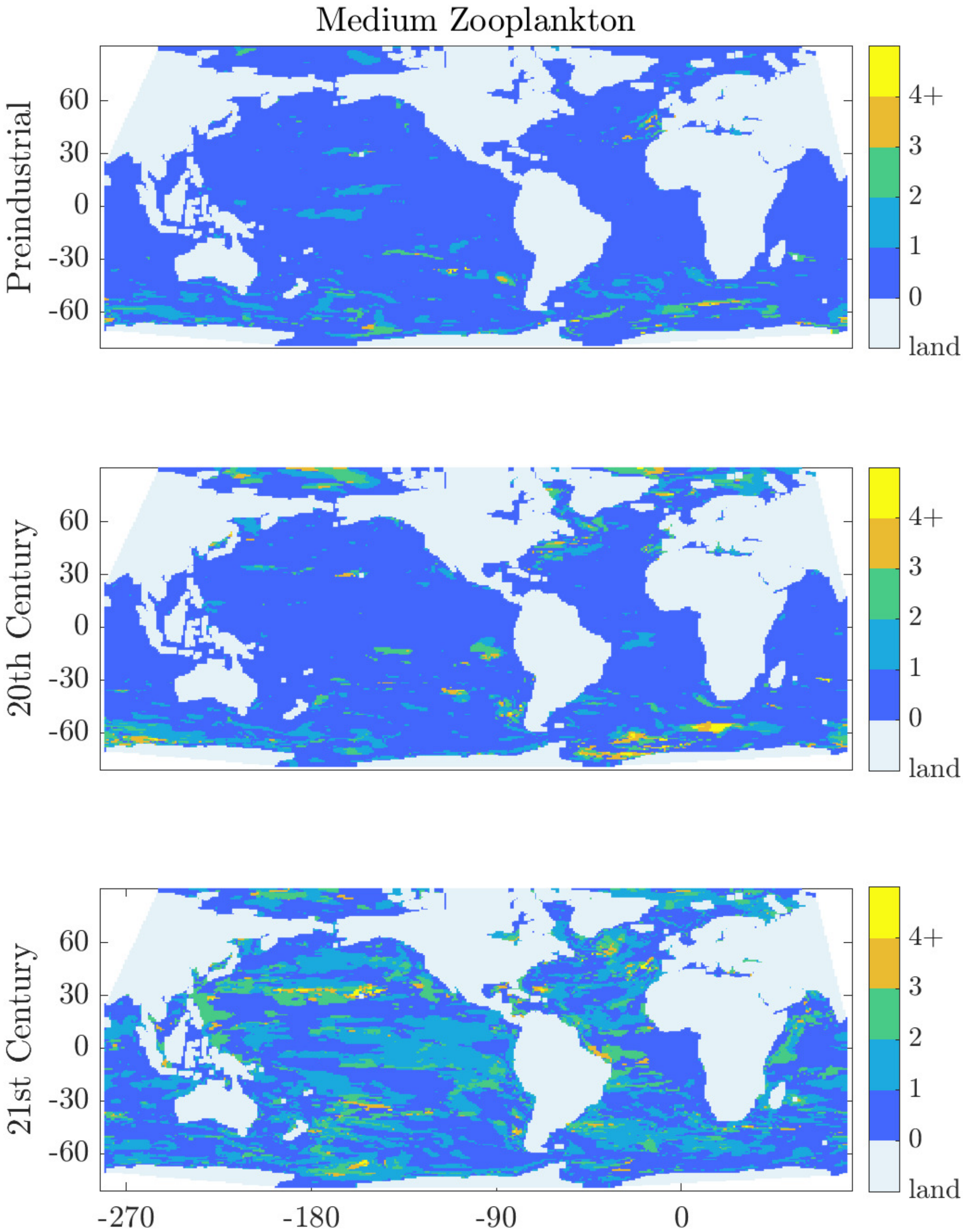
Medium Zooplankton
Preindustrial
20th Century
21st Century
60
30
0
-30
-60
4+
3
2
1
0
land
-270
-180
-90
0

Figure S4. Maps of number of changepoints for each simulation for medium zooplankton.

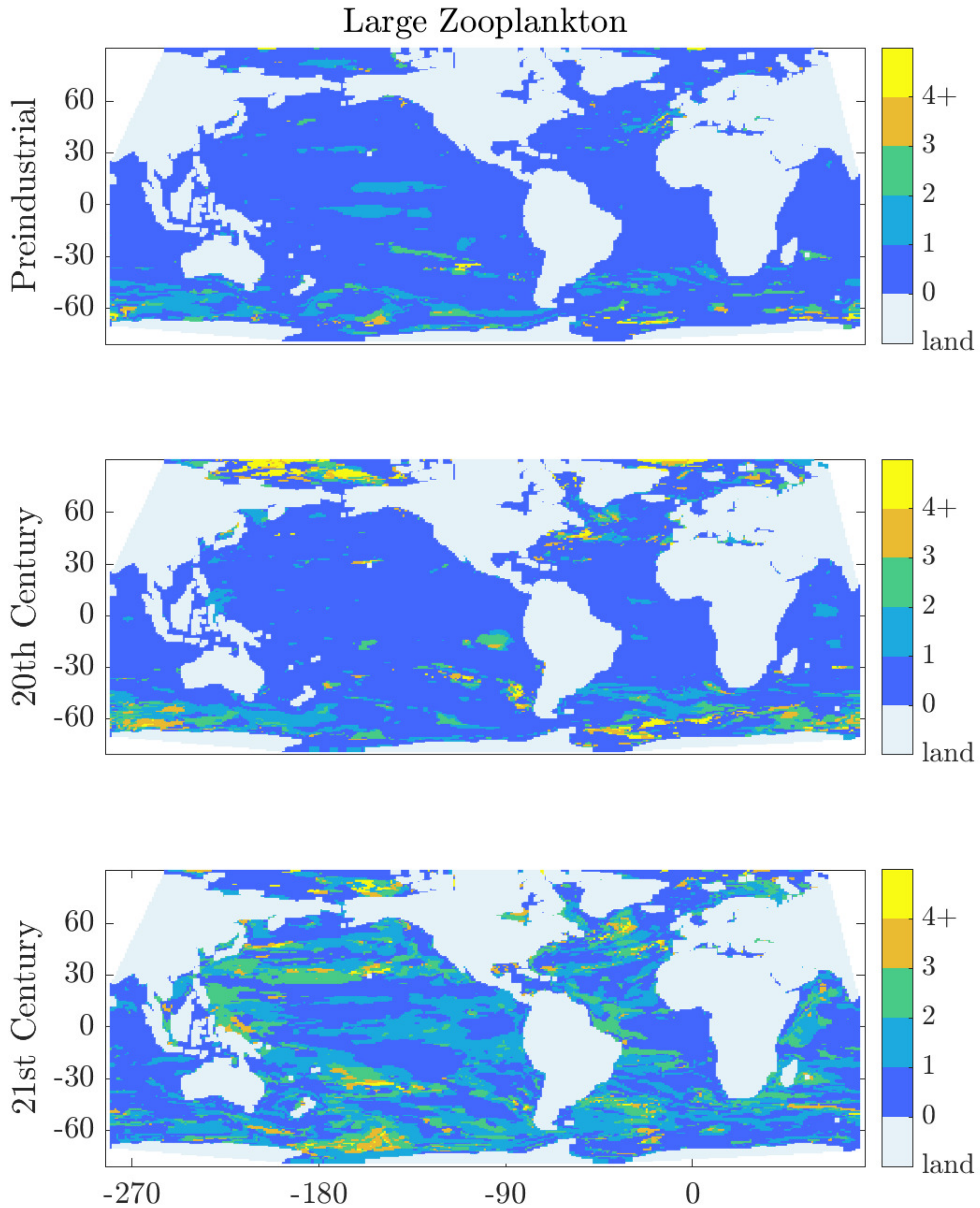

Figure S5. Maps of number of changepoints for each simulation for large zooplankton.

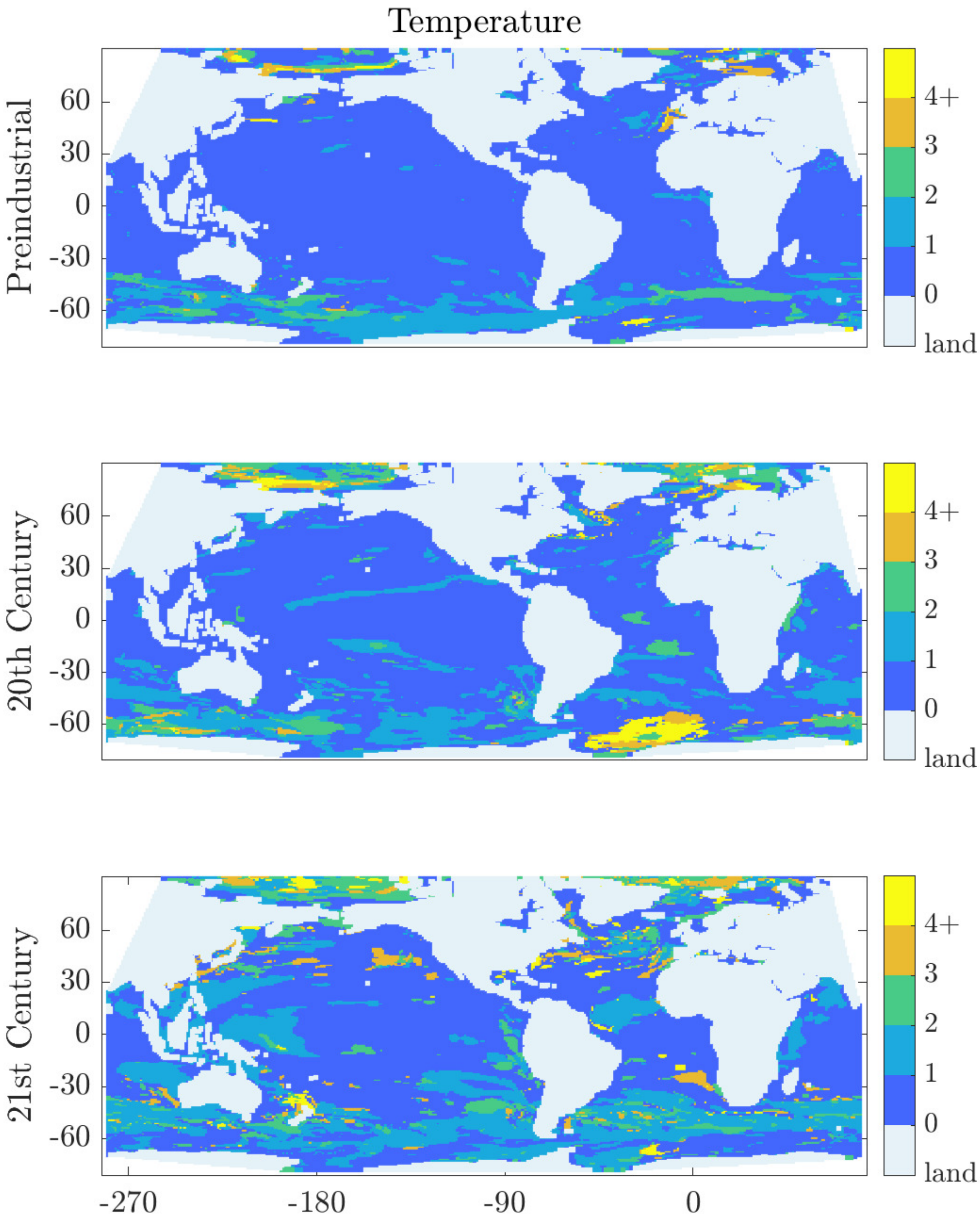

Figure S6. Maps of number of changepoints for each simulation for temperature.

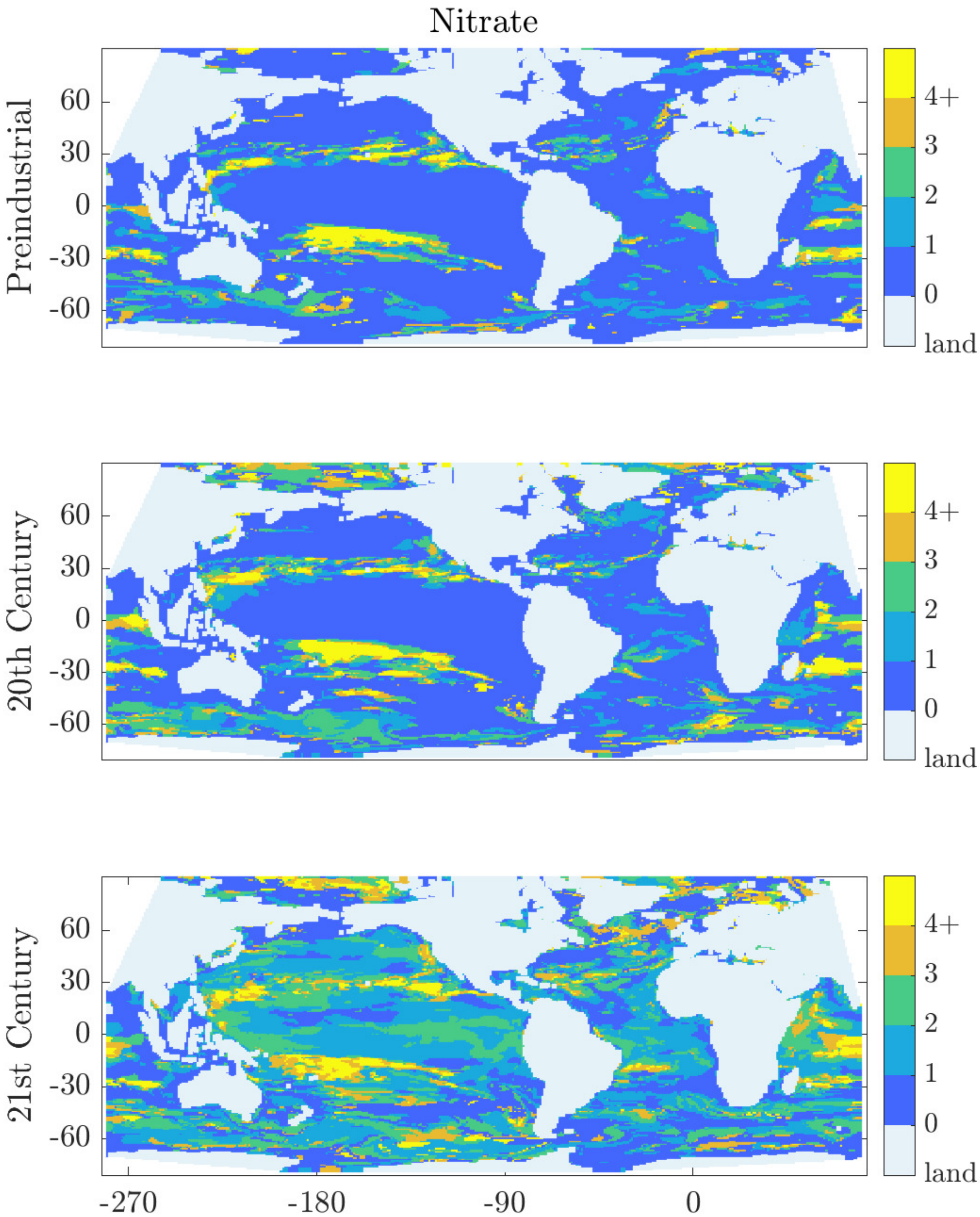

Figure S7. Maps of number of changepoints for each simulation for nitrate.

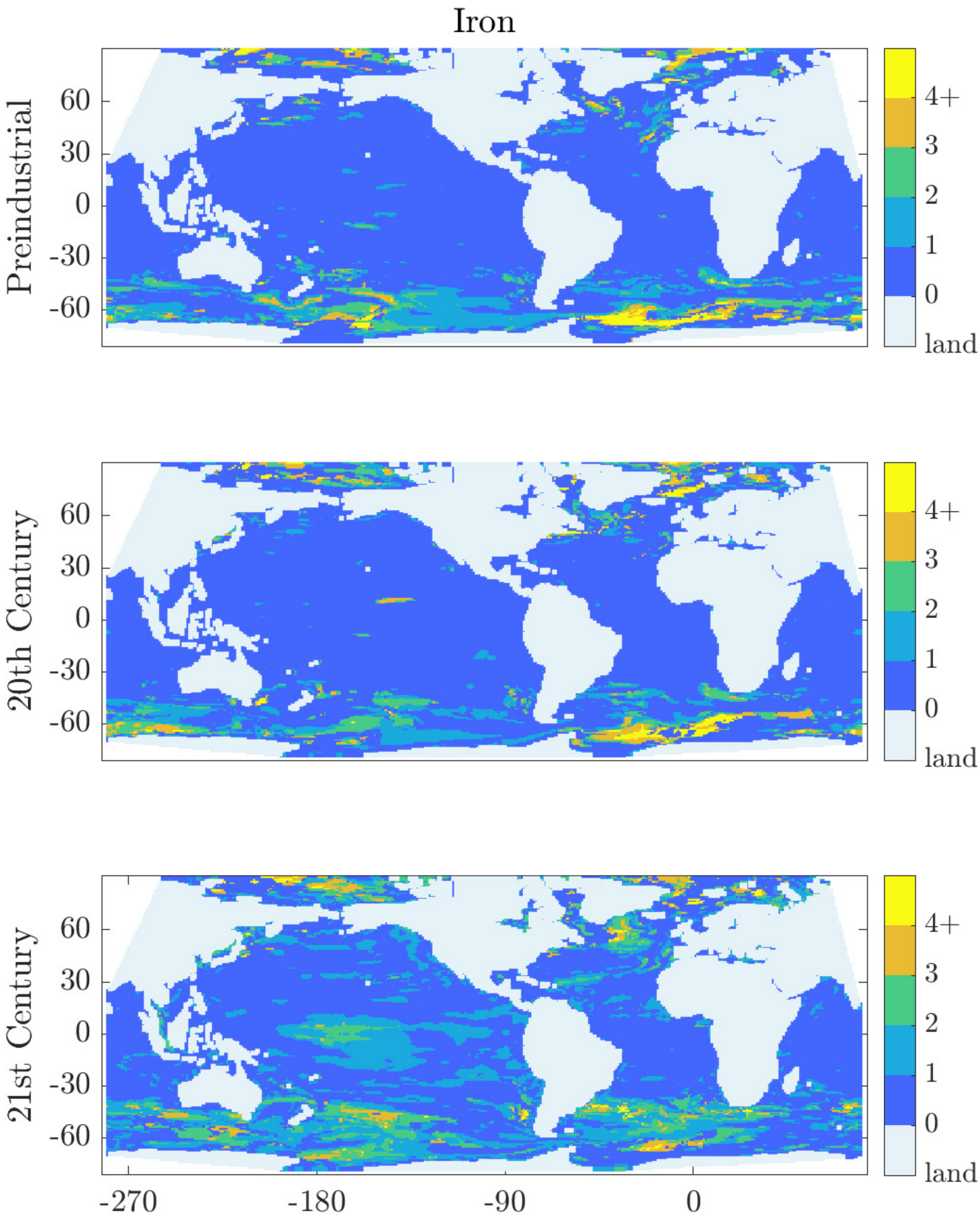

Figure S8. Maps of number of changepoints for each simulation for iron.

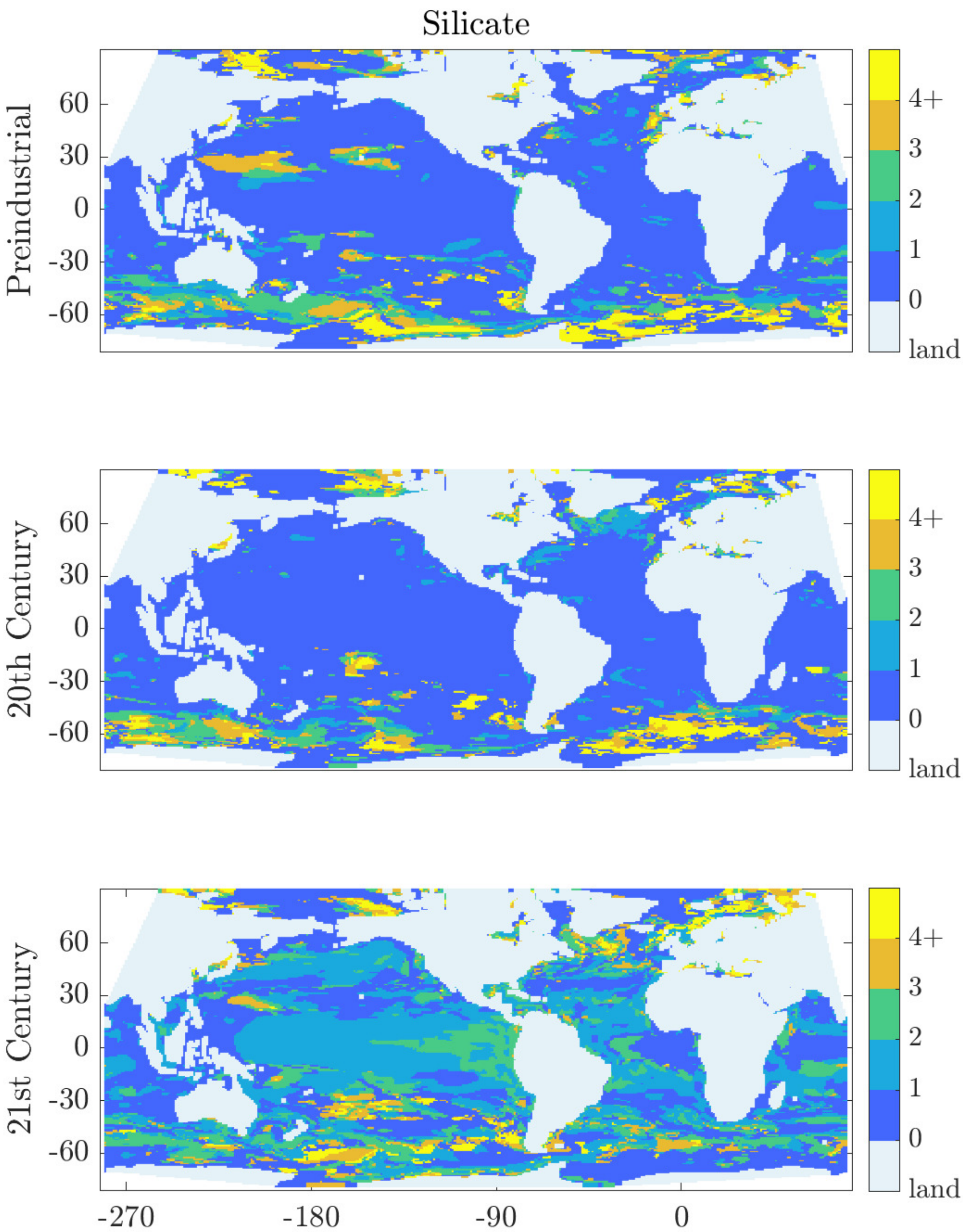

Figure S9. Maps of number of changepoints for each simulation for silicate.

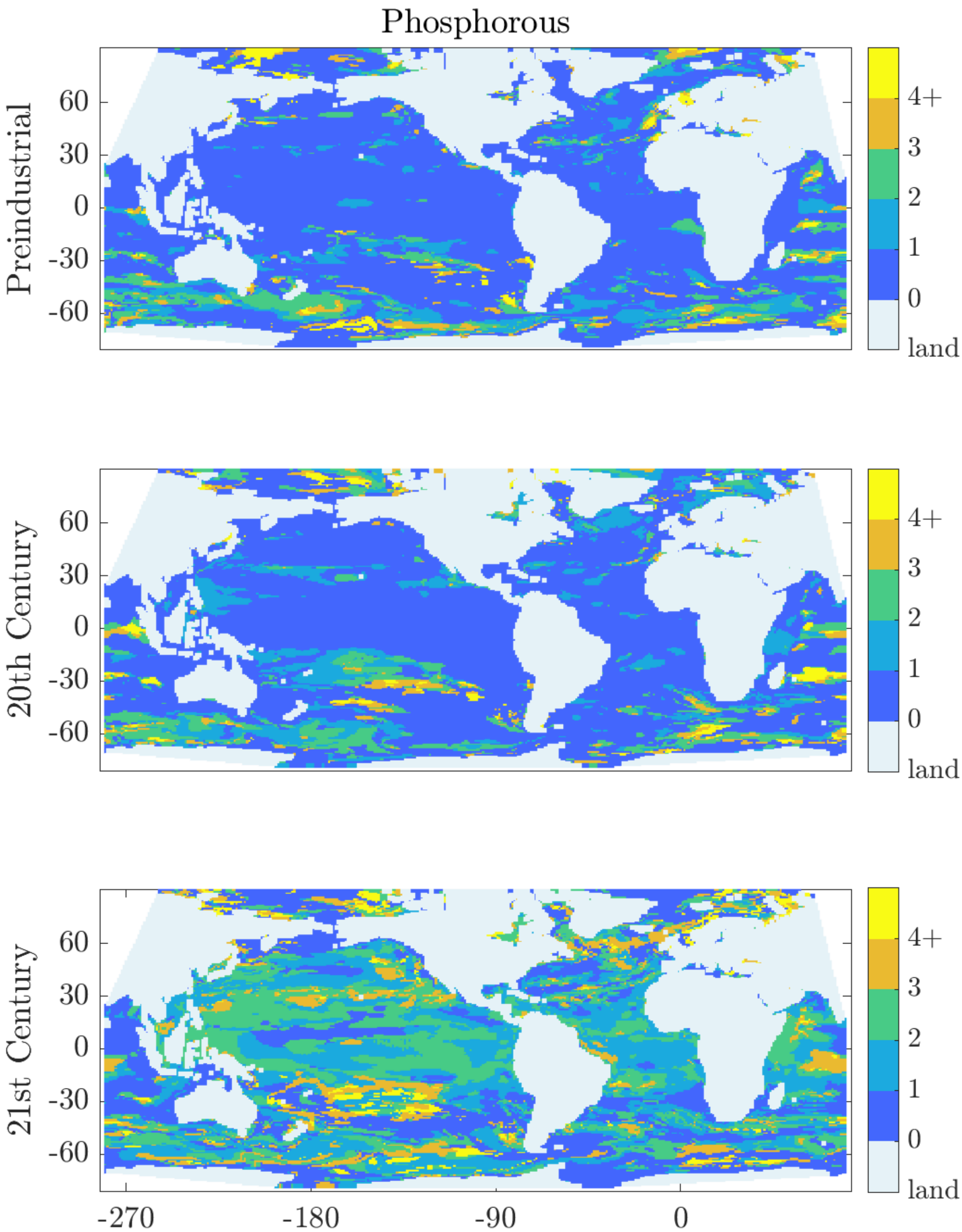

Figure S10. Maps of number of changepoints for each simulation for phosphate.

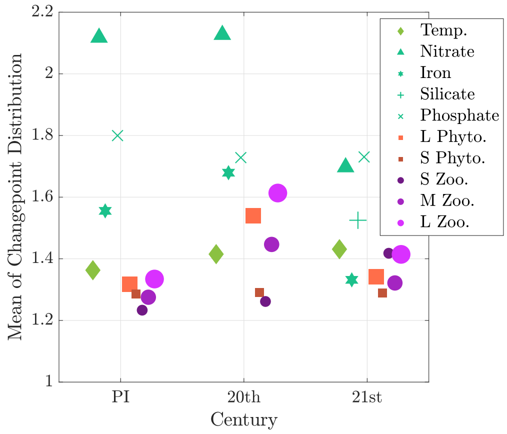

Figure S11. Mean of changepoint distribution (i.e. probability distribution of the number of changepoints per century for locations with one or more changepoints) for each variable and simulation. As most of the ocean has 0, 1, or 2 changepoints per century for all simulations and variables other than nitrate, the value of the mean is primarily reflective of the balance between the area having 1 vs. 2 changepoints per century.

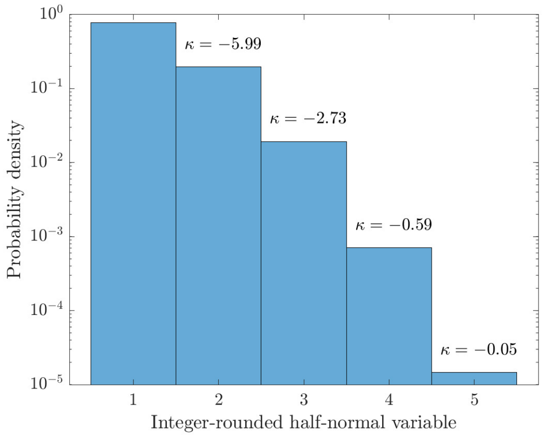

Figure S12. Distributions with different values of kurtosis κ, to illustrate how removing a distribution's tail reduces κ. By the definition of excess kurtosis we use here, a standard half-normal distribution rounded to integers and excluding zero values has a $\kappa = 0$; excluding values 5/4/3/2 and above produces lower κ values (=$-$0.05/0.59/2.73/5.99).

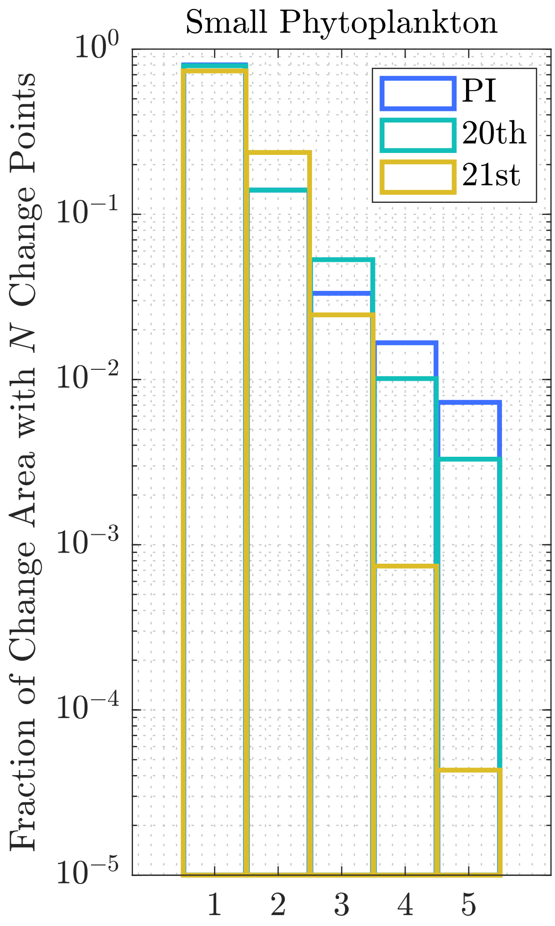

Figure S13. Distribution of the number of changepoints per unit area per century for small phytoplankton. y-axis is logarithmically spaced.

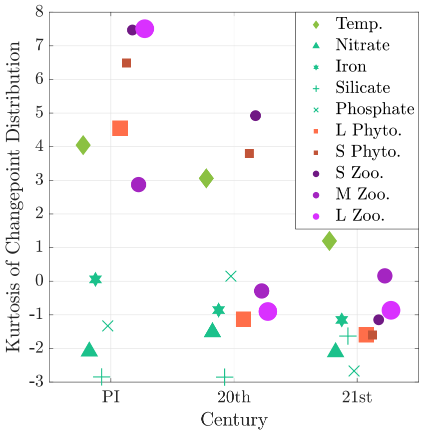

Figure S14. Same as Figure 9 but only for regions with changepoints for a given variable in the PI or 20th century.

References

Dutkiewicz, S., Hickman, A. E., Jahn, O., Henson, S., Beaulieu, C., & Monier, E. (2019). Ocean colour signature of climate change. *Nature communications*, *10*(1), 1–13.