Introducing "ToE MIP"
Time of Emergence
Model Intercomparison Project
for Ocean Biogeochemistry

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Changes in the ocean carbon cycle and sink are imminent.

But when and where will these changes first be emergent?

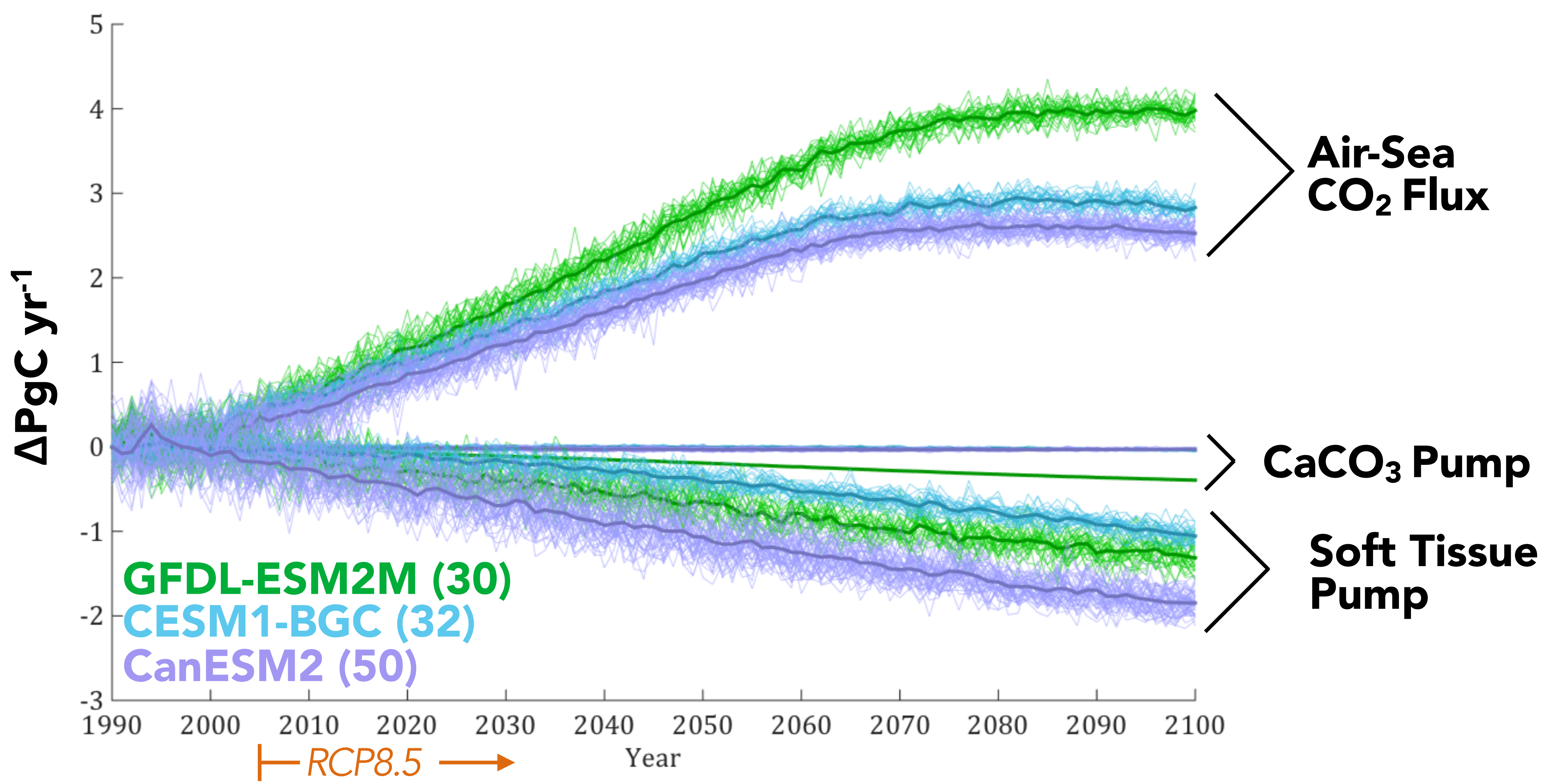
Emergence calculations done with the CMIP5 ensemble obscure physical structures and linkages between variables. Emergence calculations done with 1 Large Ensemble cannot consider model dependency. Emergence calculations done with Pre-Industrial noise cannot consider variance changes, or retrieve an anthropogenic signal at local scales without smoothing techniques.

Here, we use 3 Large Ensembles, evaluate emergence of anthropogenic changes in the components of the ocean carbon pump.

Begin calculations at 1990, the approximate beginning of the ocean observing era. Use Large Ensembles as an Observing System Simulation Experiment (OSSE).

The Ocean Carbon Pump's

1. Solubility (emergence approximated by Air-Sea CO_2 Flux)
2. Biological
   a. Hard Tissue ($CaCO_3$)
   b. Soft Tissue (Organic Carbon)



ensemble documentation: *Rodgers et. al.* 2015 *McKinley et. al.* 2016 & *Long et. al.* 2016 *Christian et. al.* 2014

Emergence Calculations

1. Start in 1990
2. Emergence occurs when **SNR > 2** (~95% Confidence Interval)

   where ***Signal is the mean*** of the 30-50 ensemble trends between 1990 and a given year

   and ***Noise is the standard deviation*** of the 30-50 trends
3. Done at grid-cell level (locally), regionally and globally

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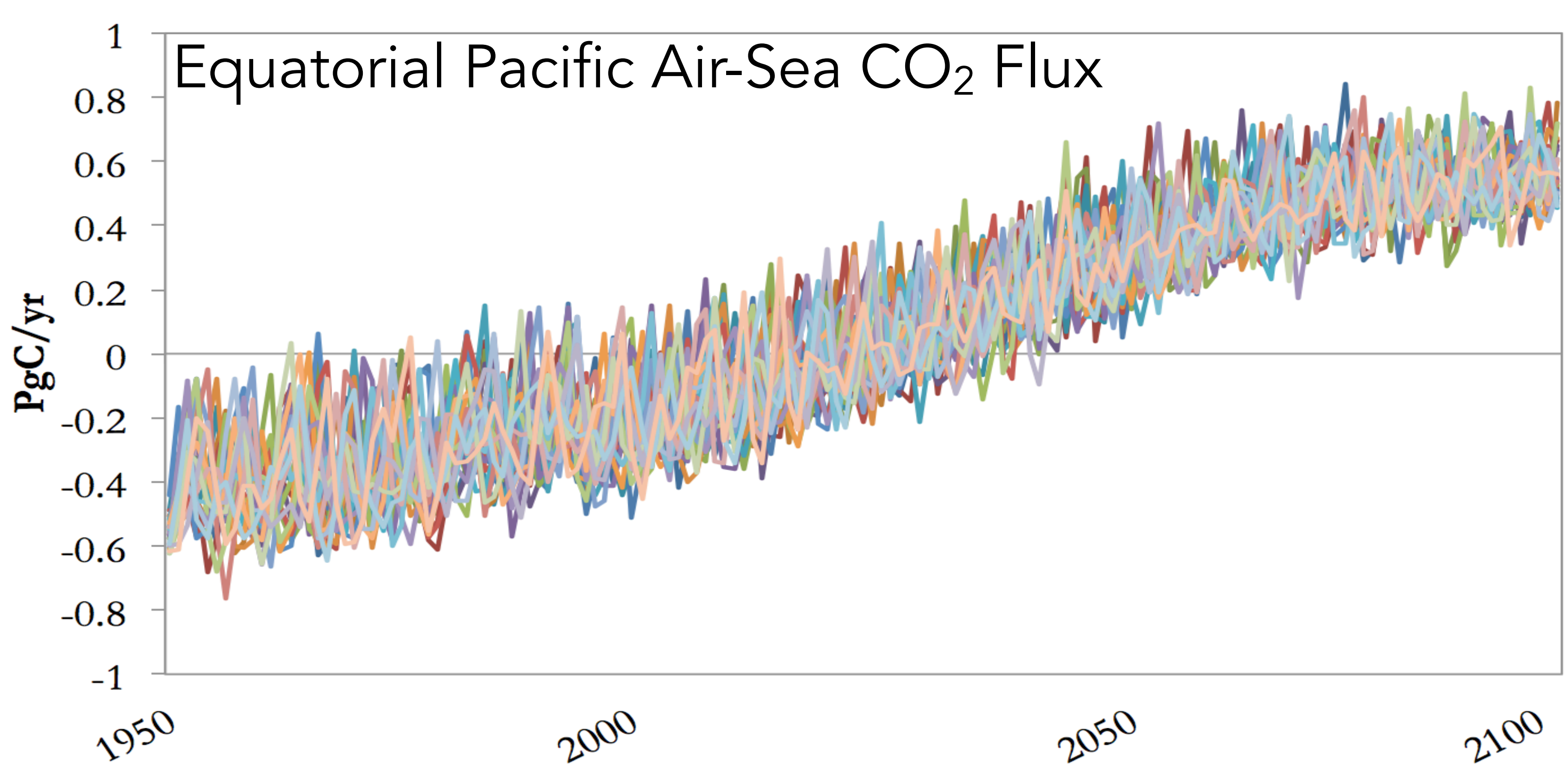

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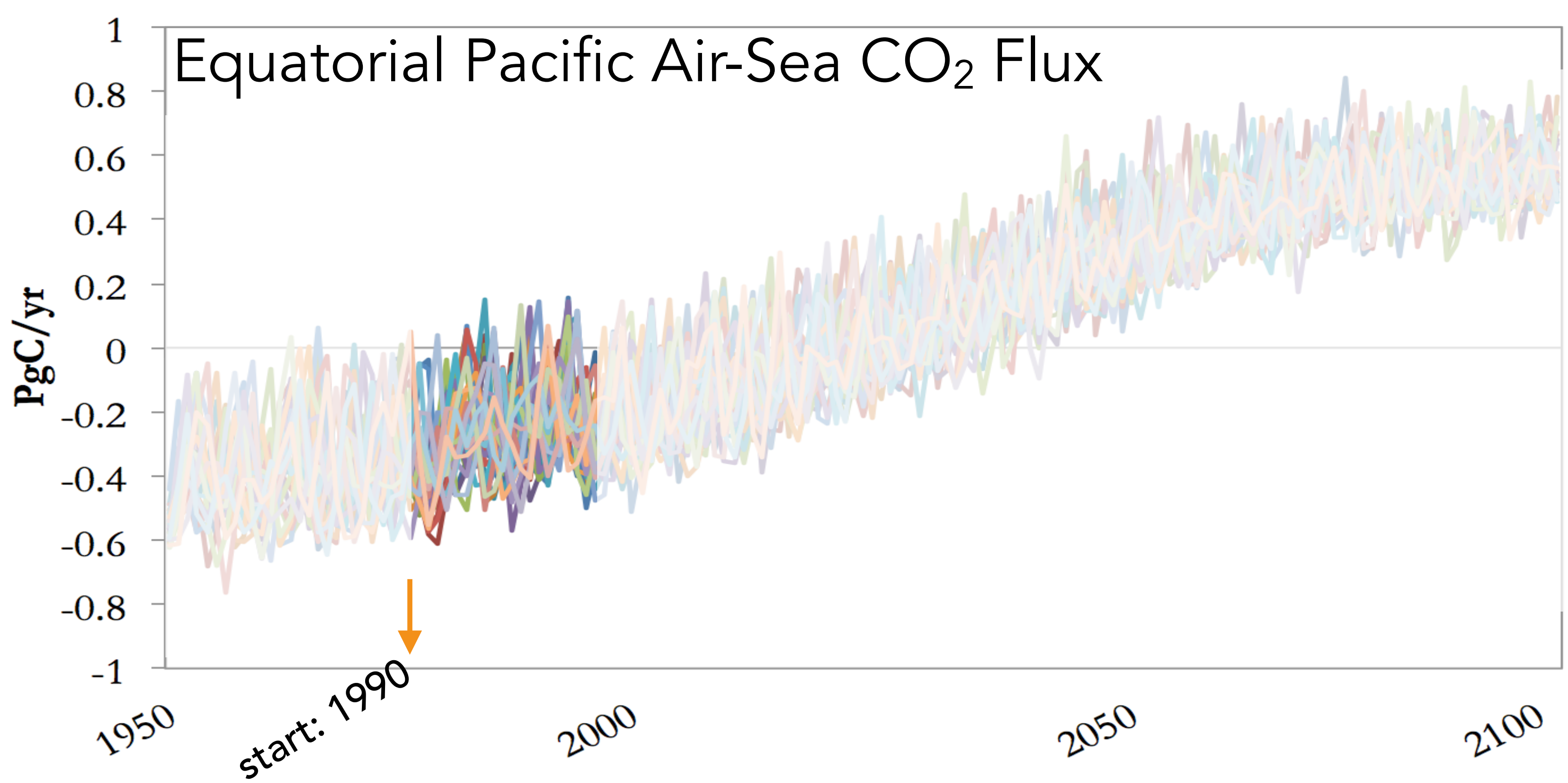

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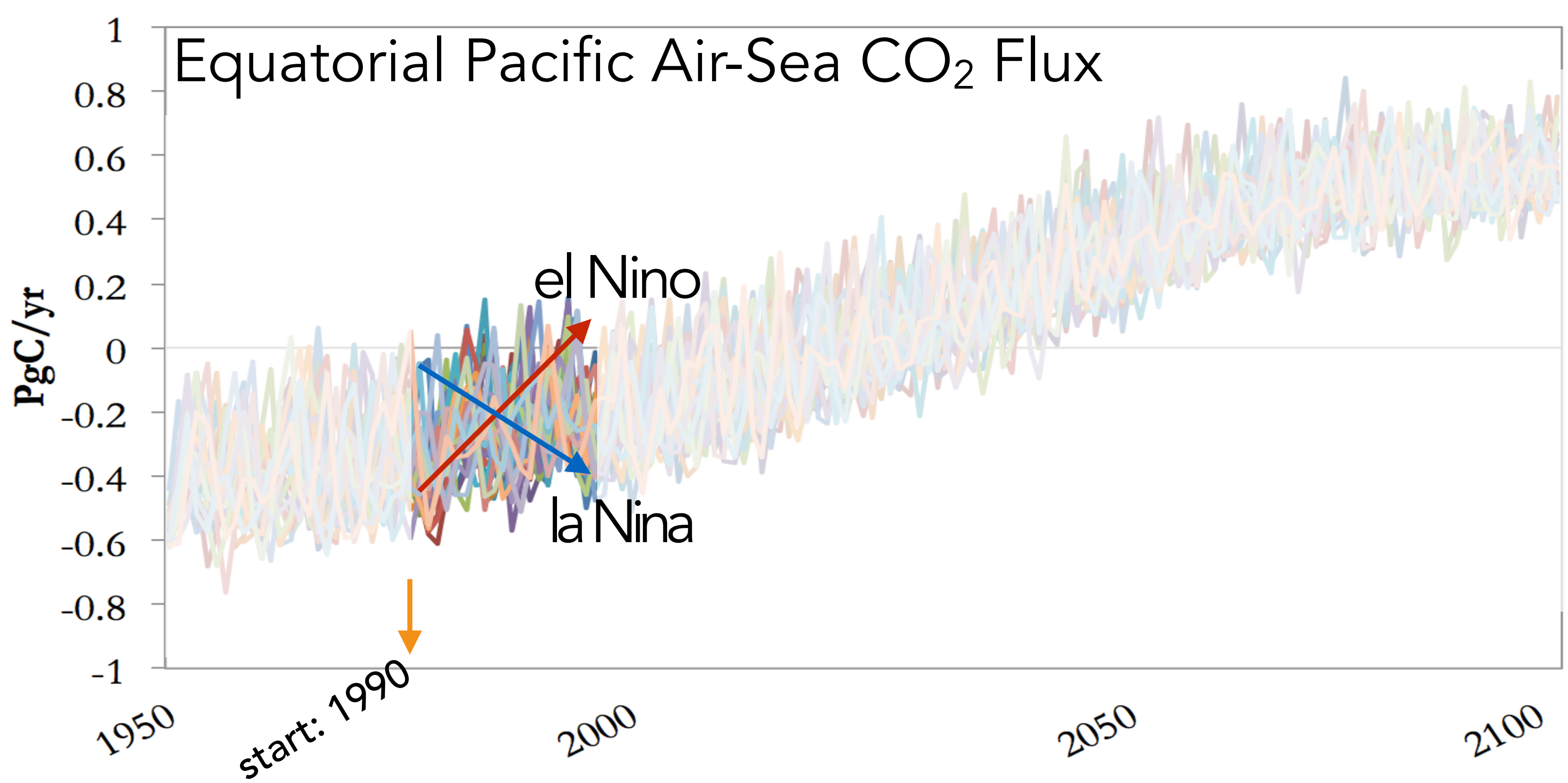

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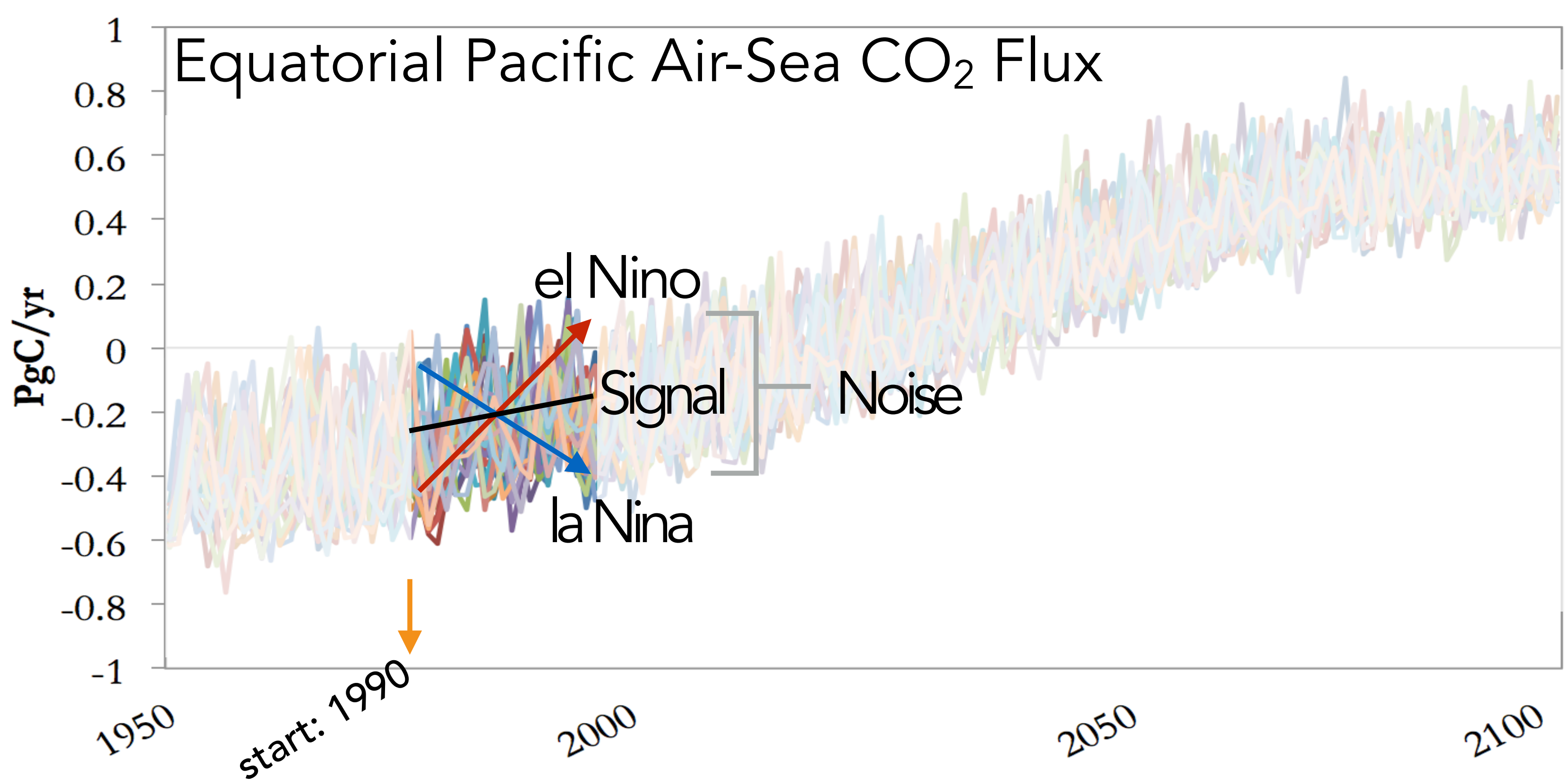

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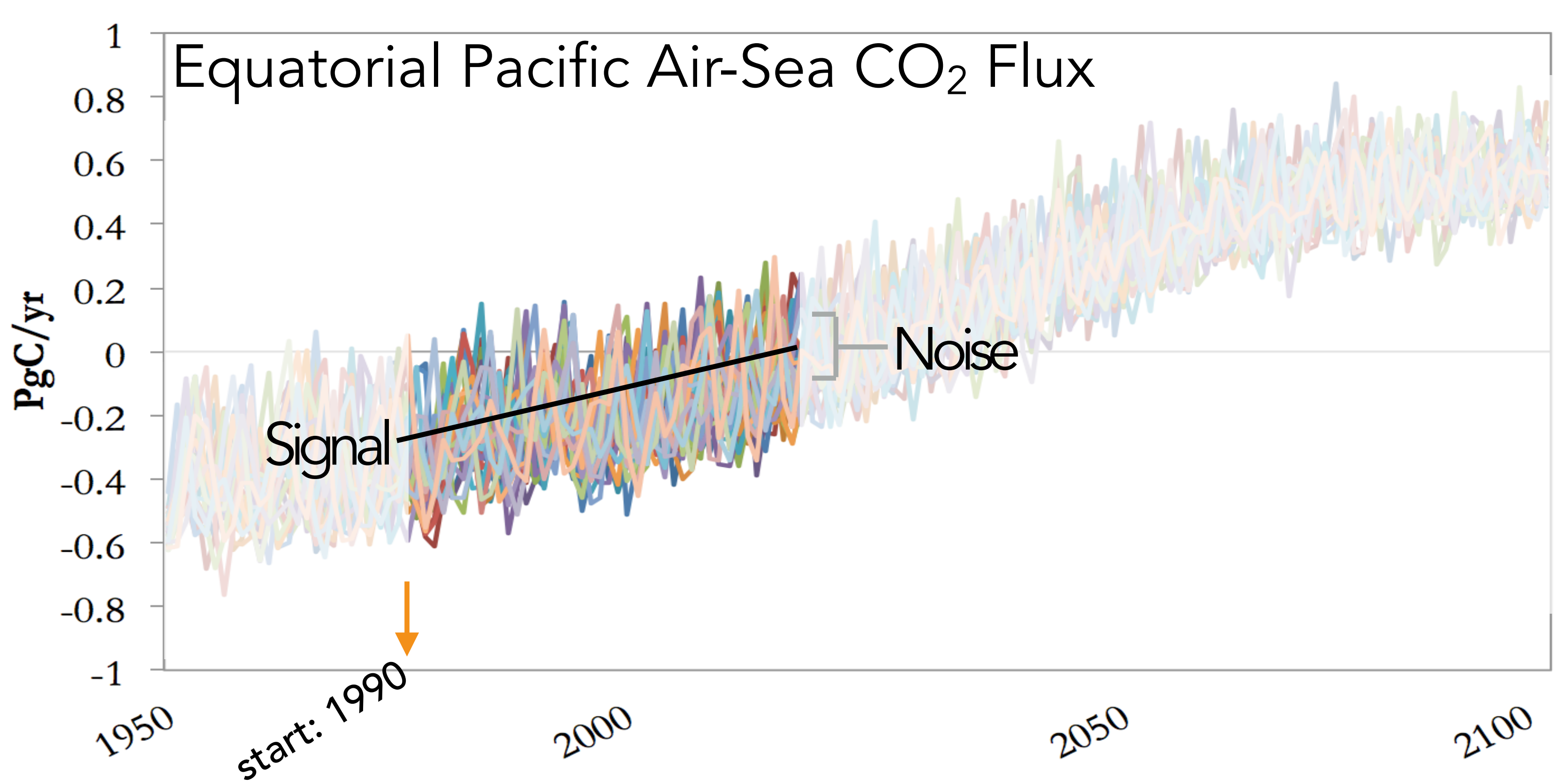

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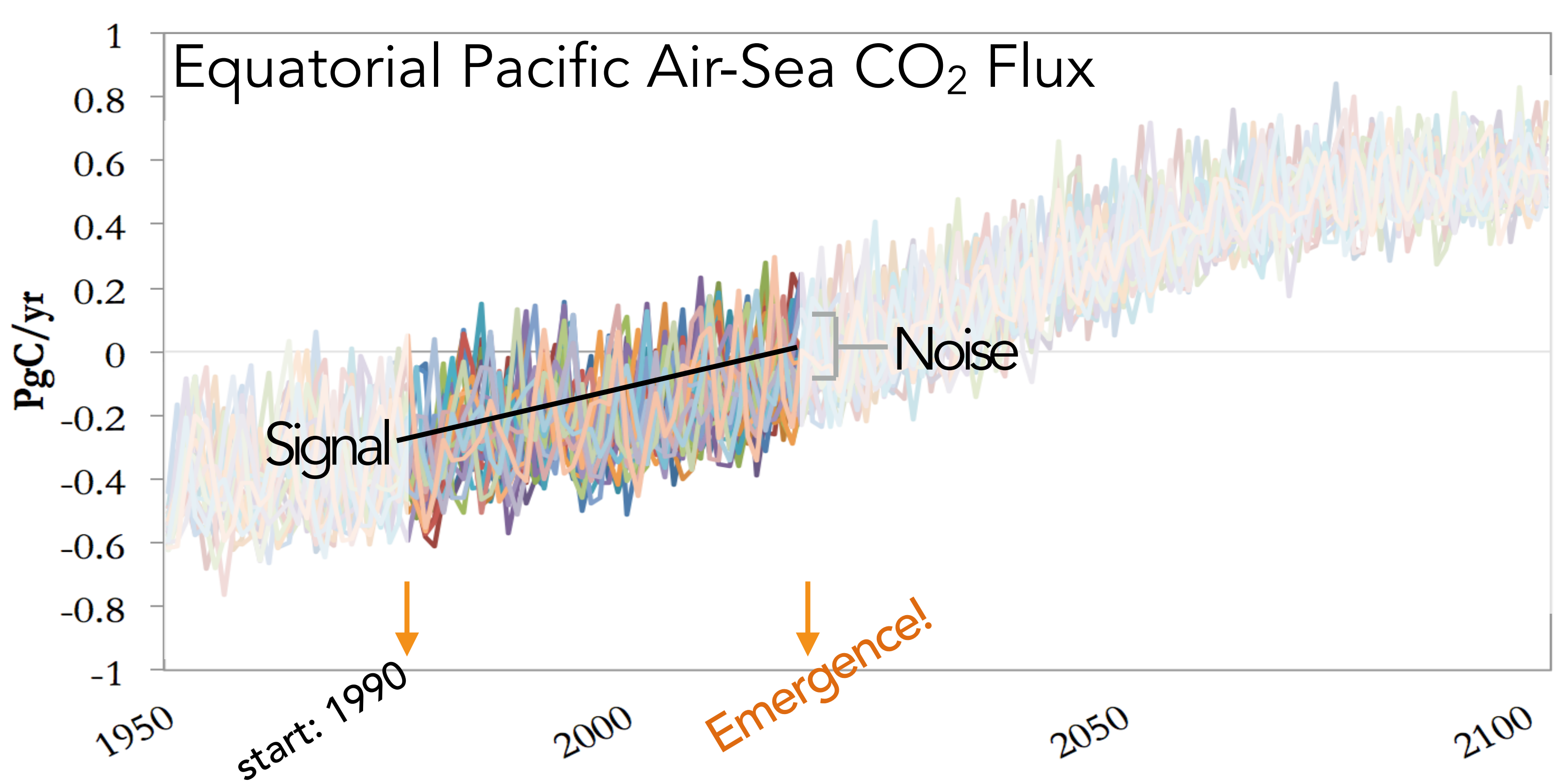
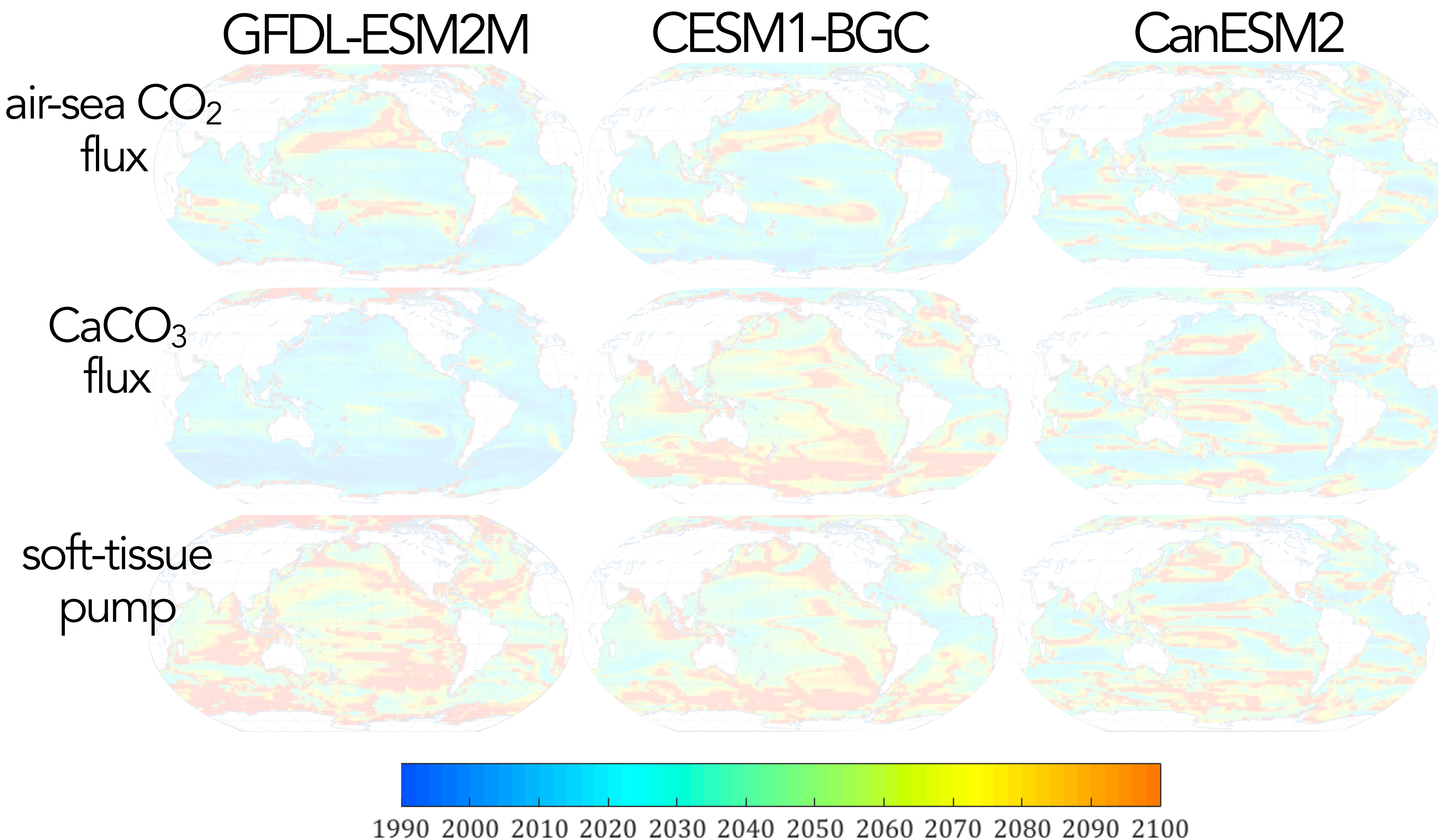


Time of Emergence Maps



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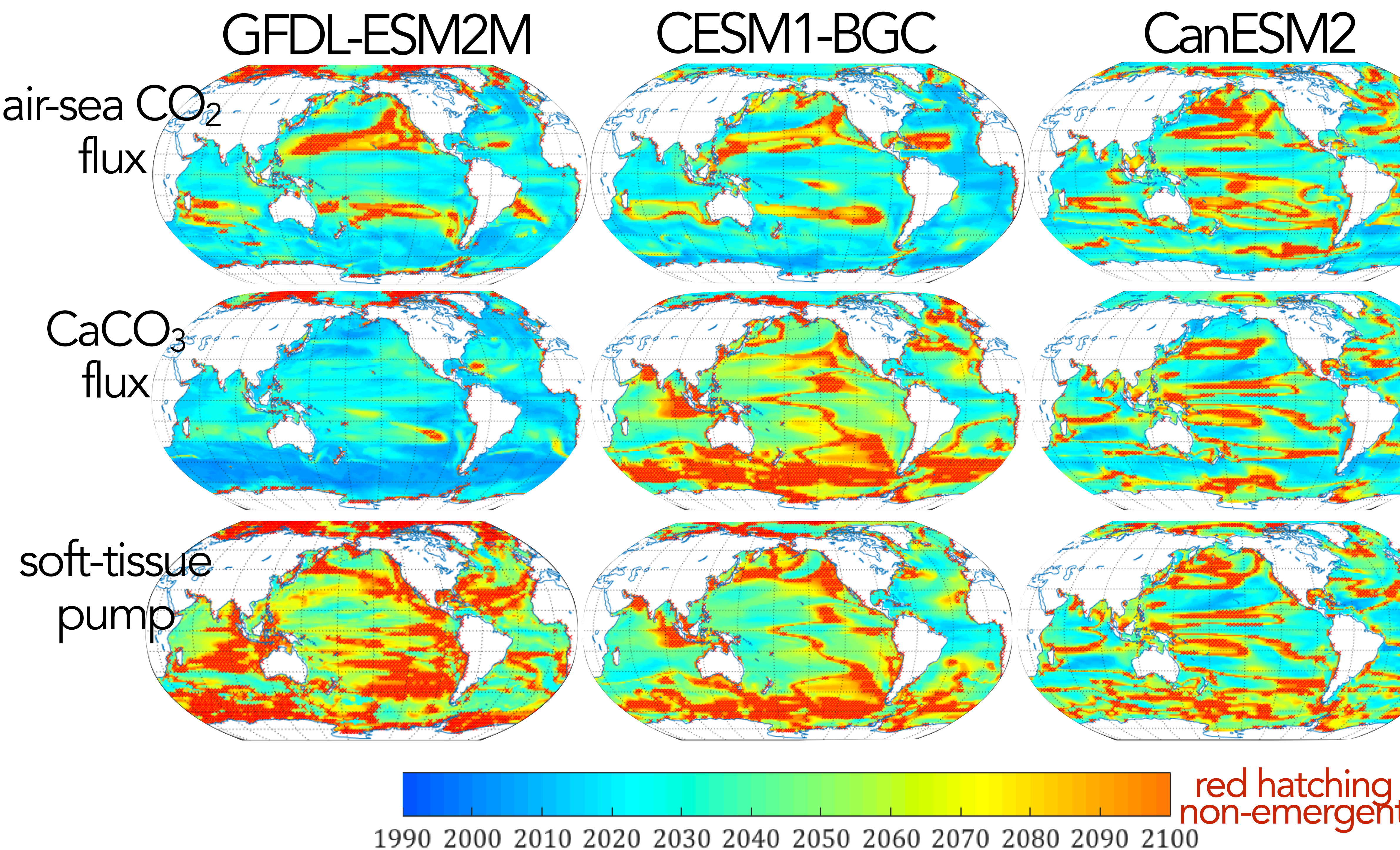
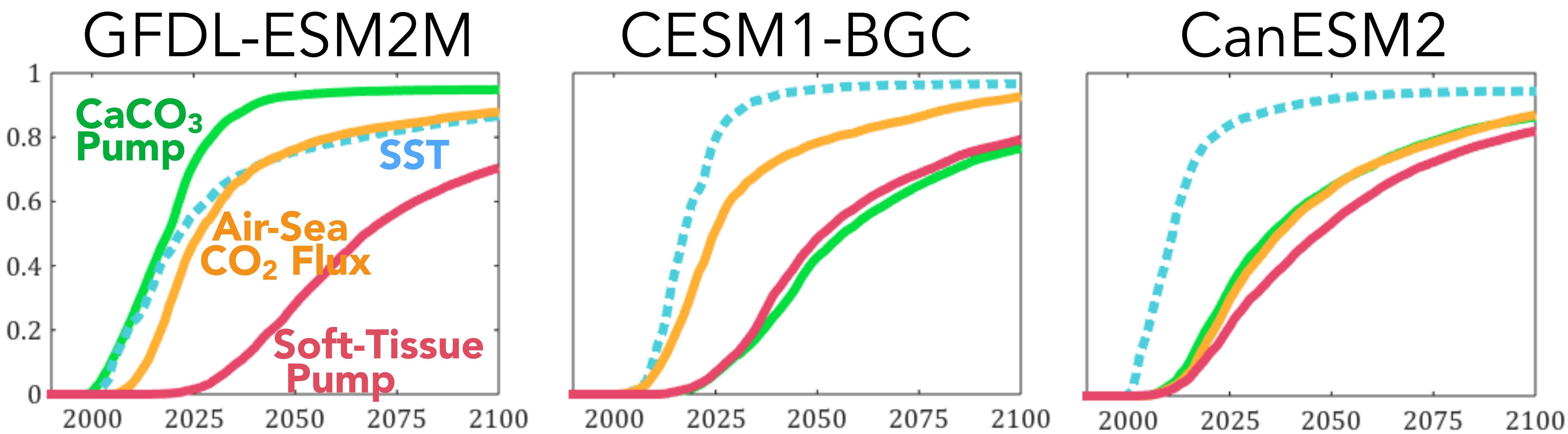


Fraction of Ocean with Emergent Anthropogenic Trend



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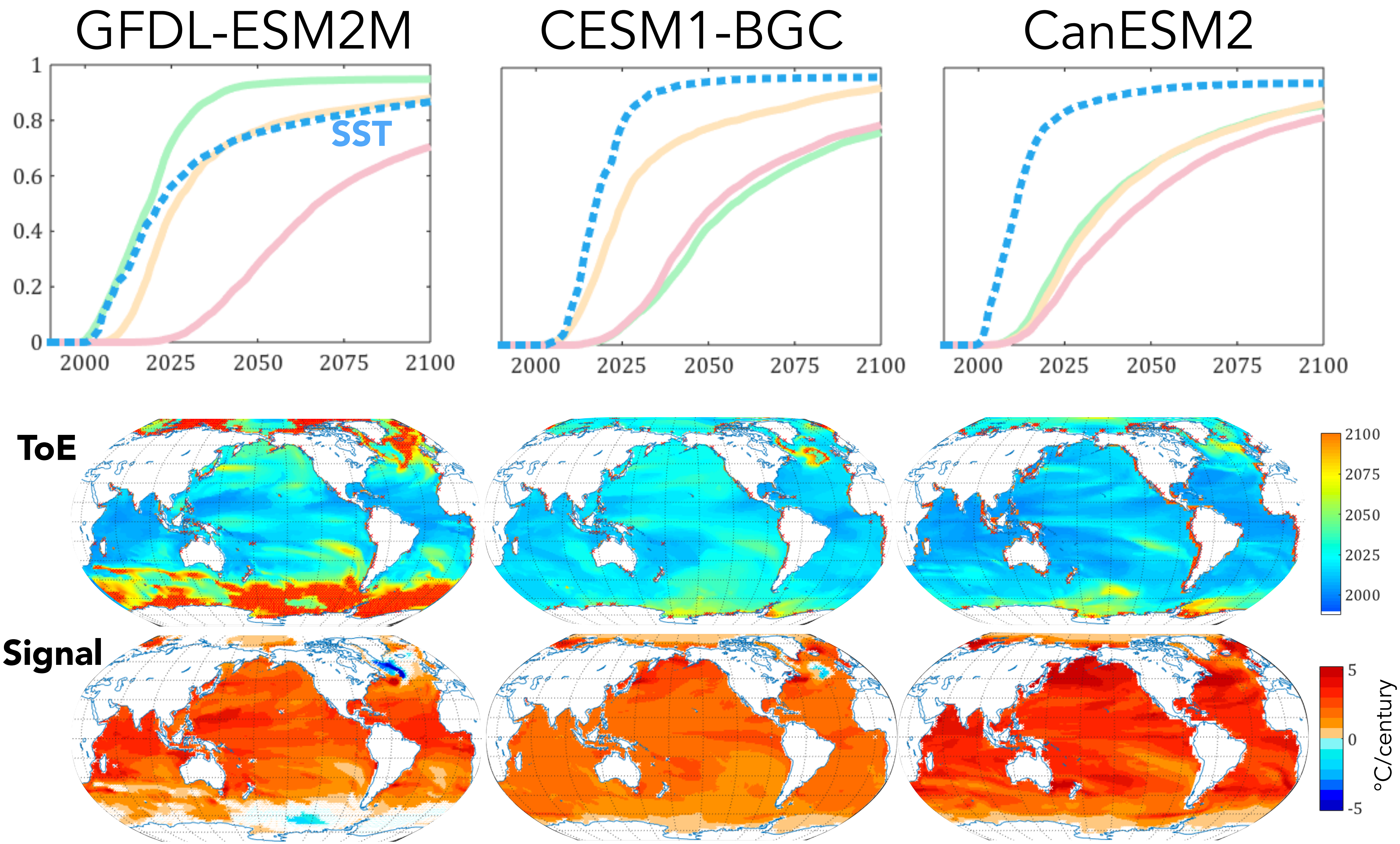

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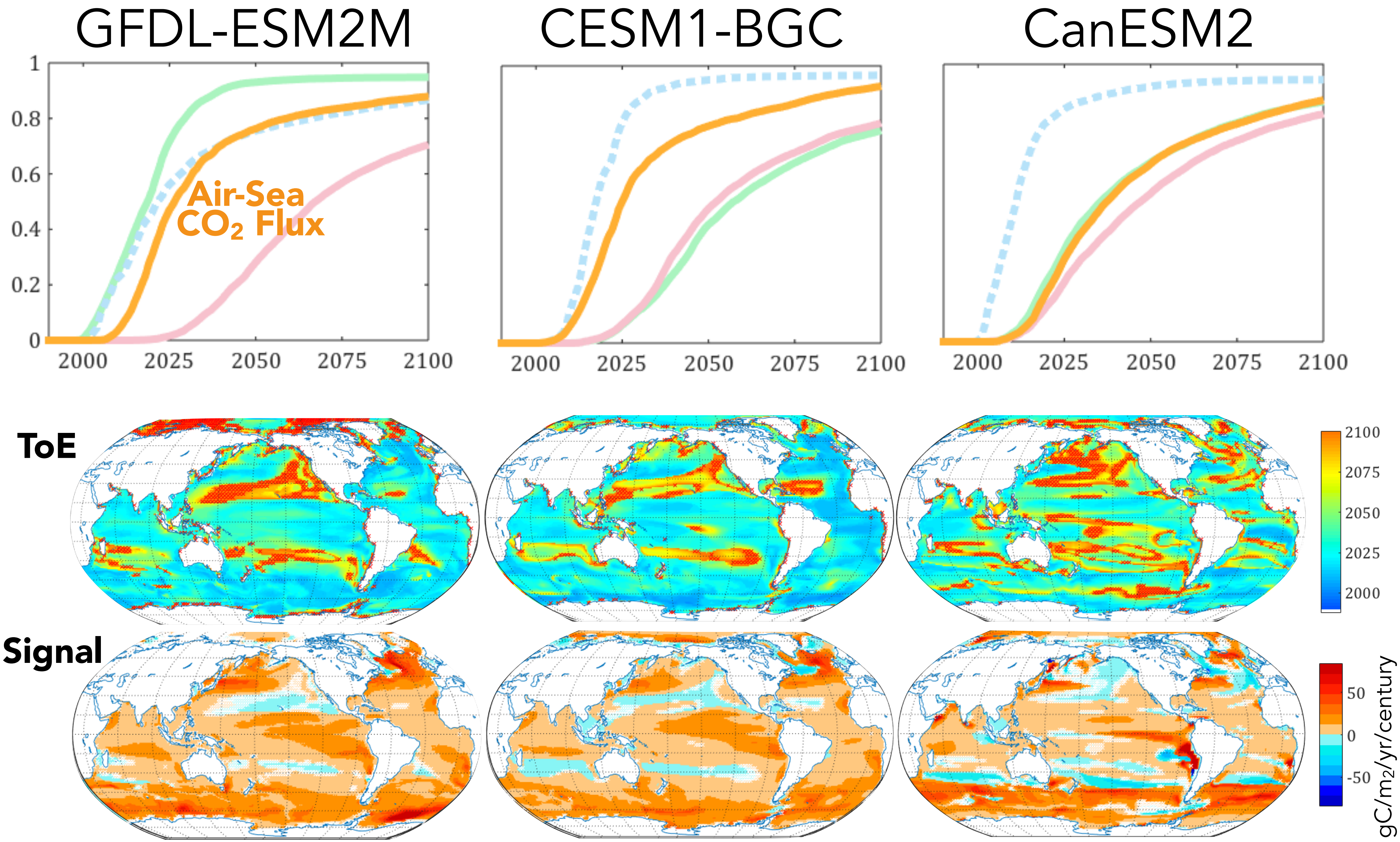

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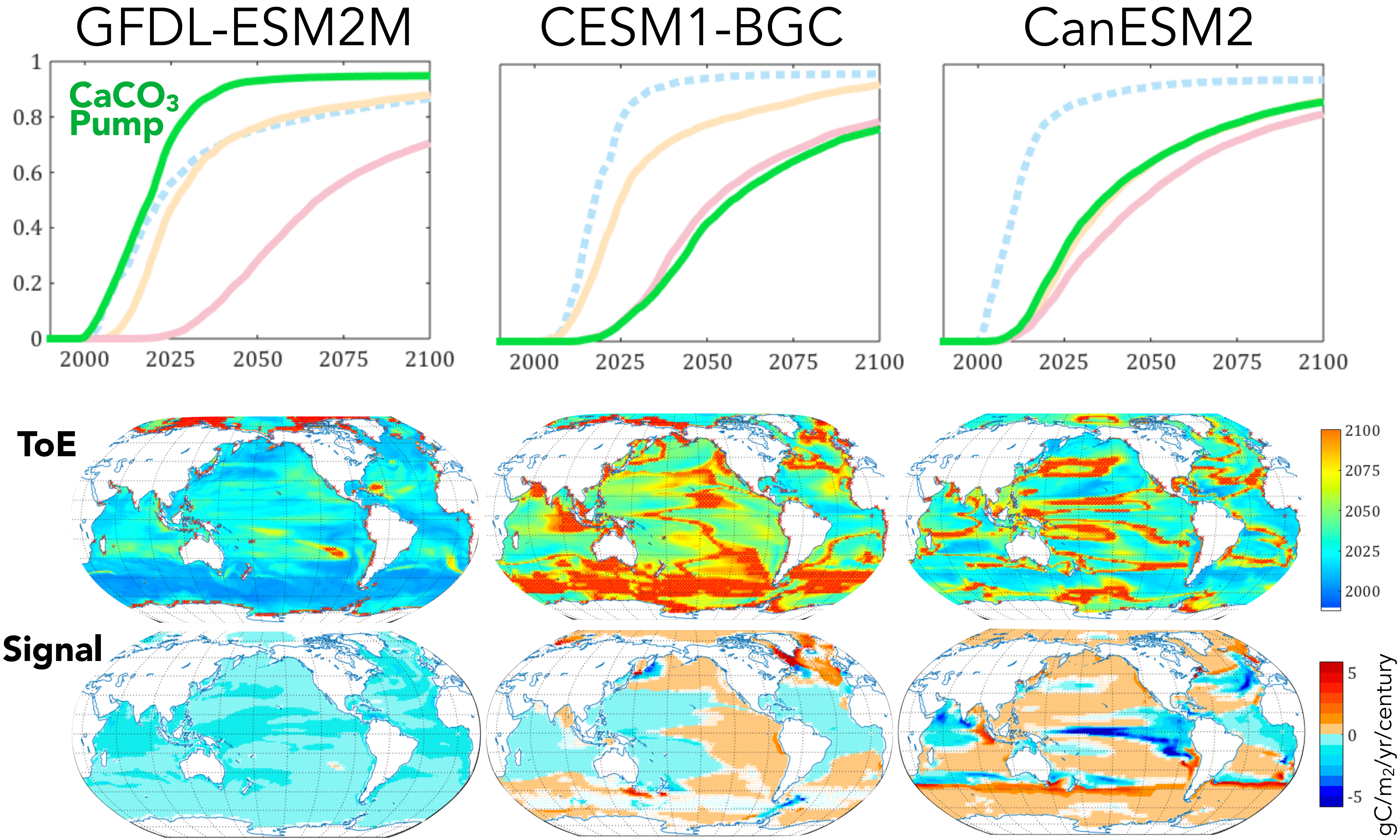

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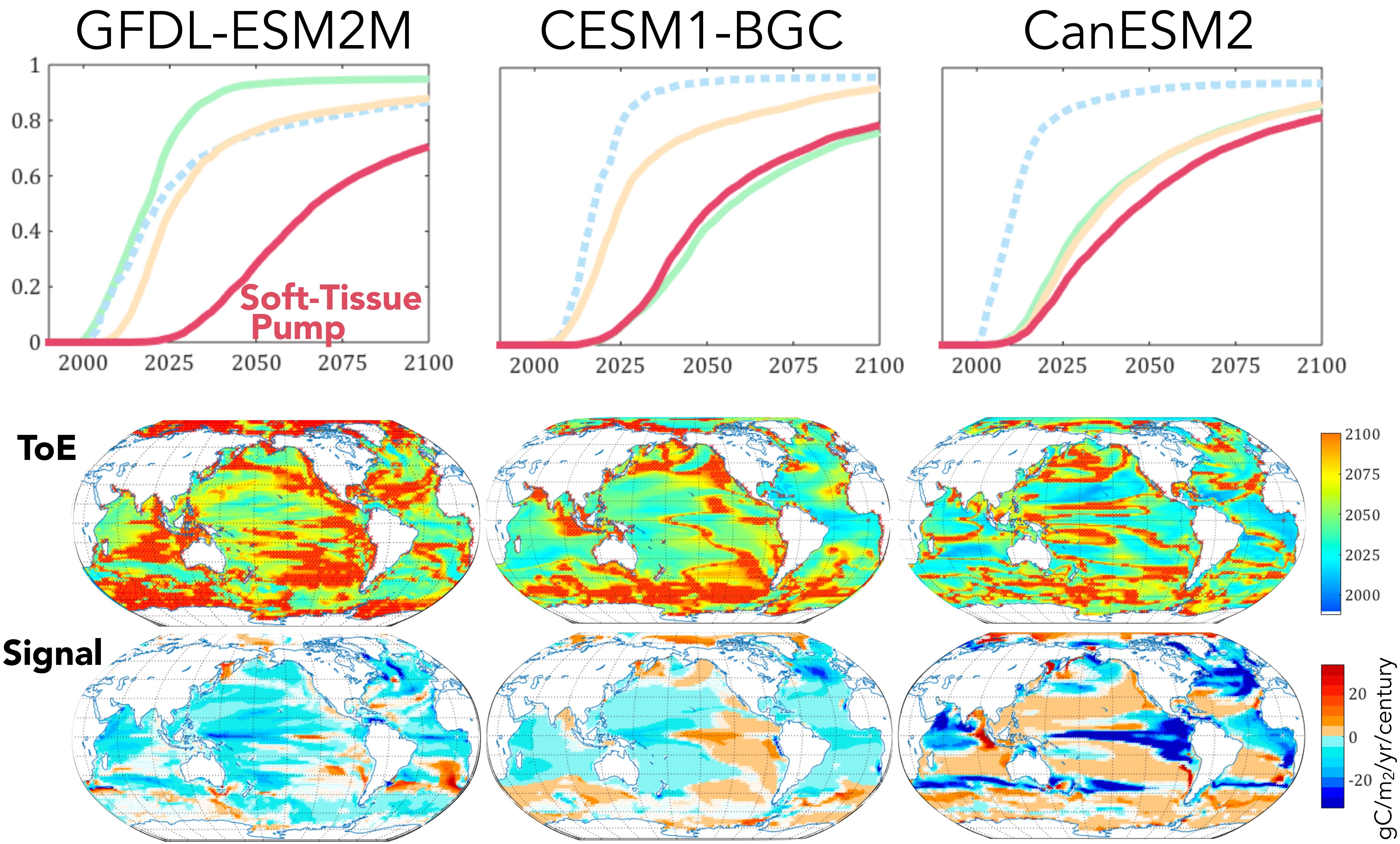
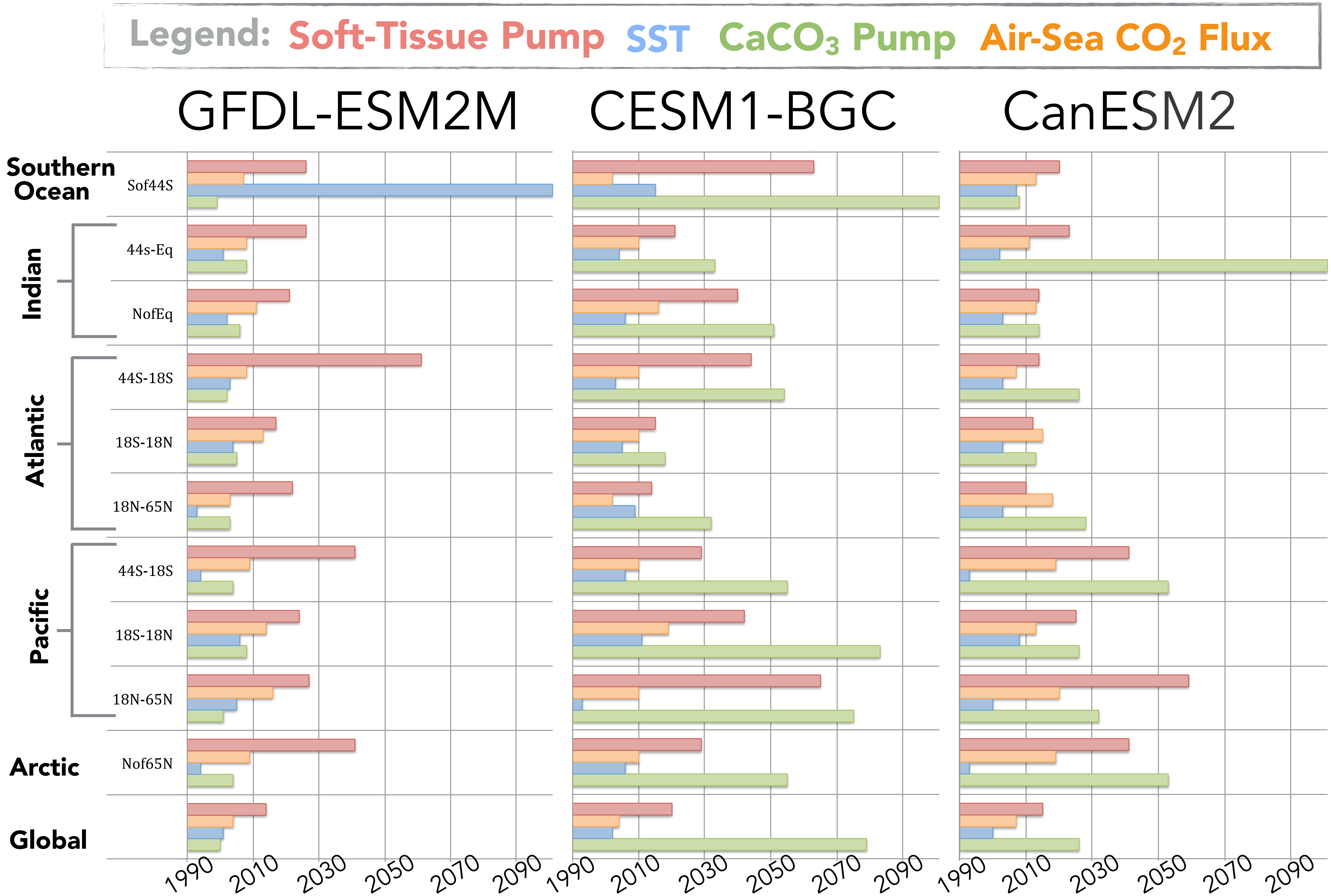


Regional and Global Emergence of Anthropogenic Trends



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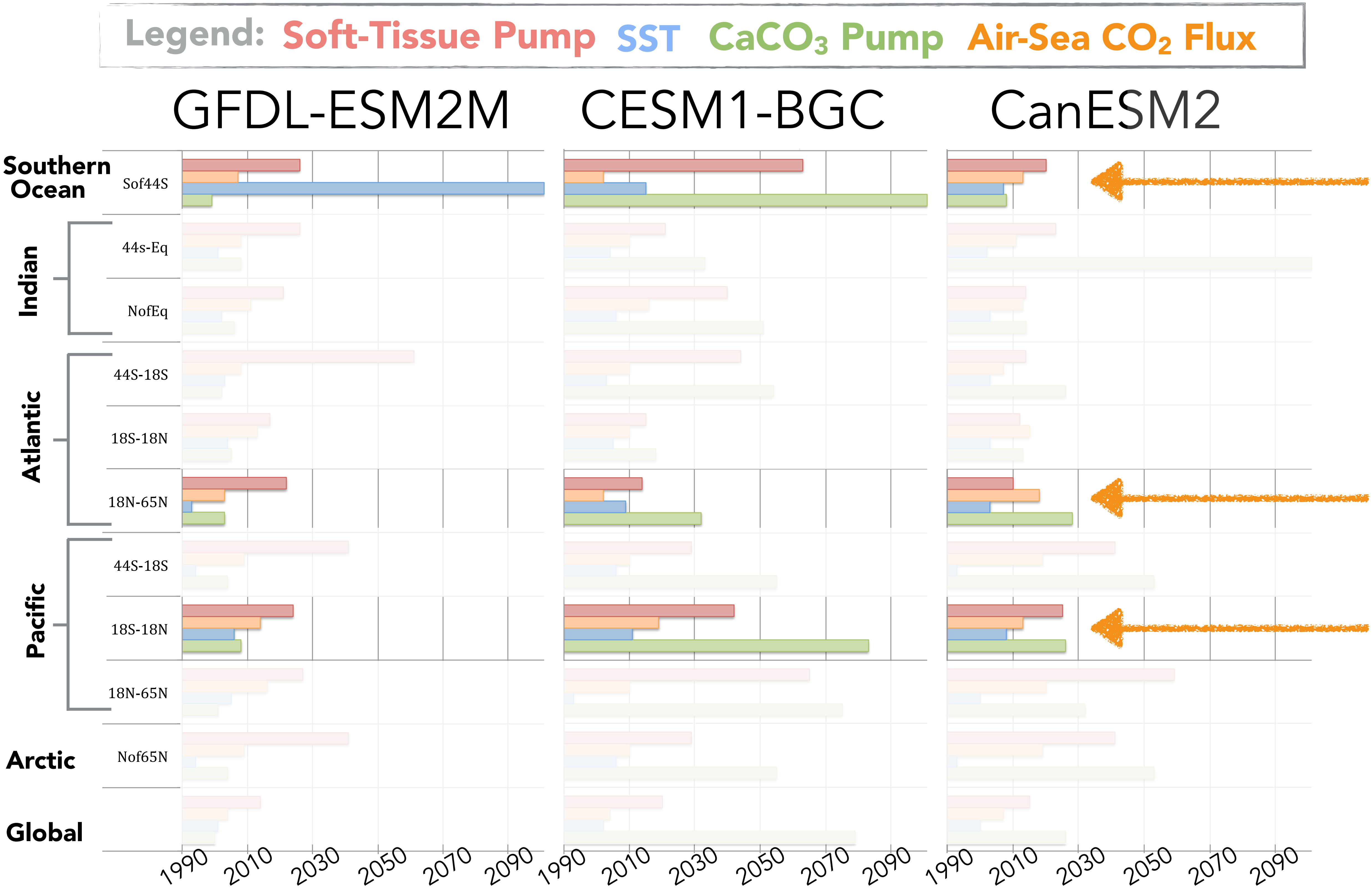
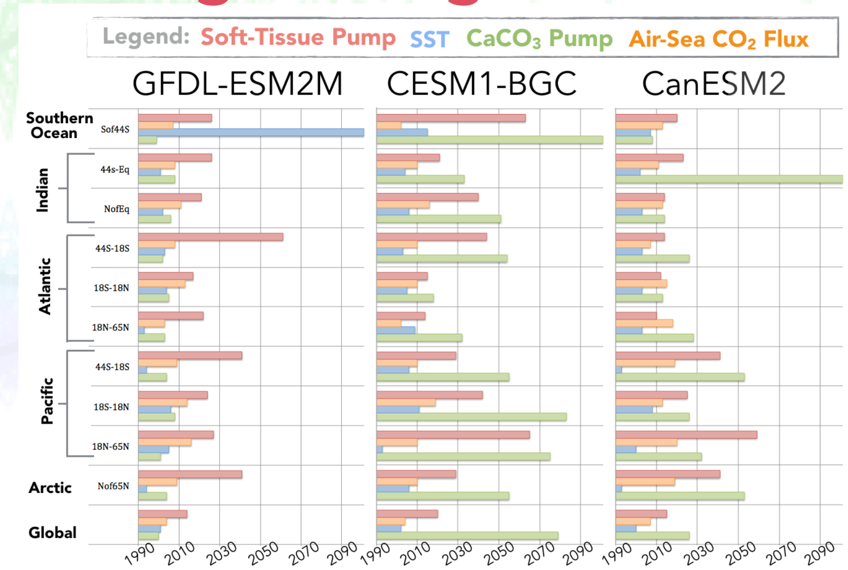


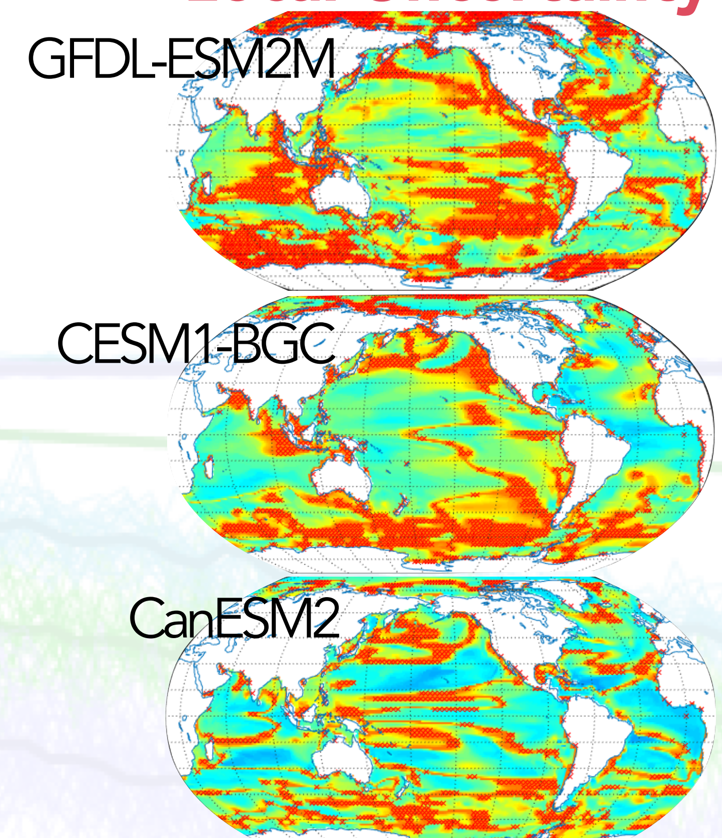
For large-scale, integrated quantities, the 3 large ensembles give a consistent estimate of how long an observing platform needs to be sustained for detection of anthropogenic signals in the ocean carbon sink, pumps and SST (exception $CaCO_3$ pump).

However, if anticipating changes on smaller scales, or specific locations (i.e. the great barrier reef or coral triangle) is desired, then the inter-model uncertainty in emergence times highlights the necessity of having multiple large ensembles.

Regional Agreement



Local Uncertainty



Soft-Tissue Pump