Large-scale natural variability and anthropogenic trends in multiple ocean ecosystem stressors

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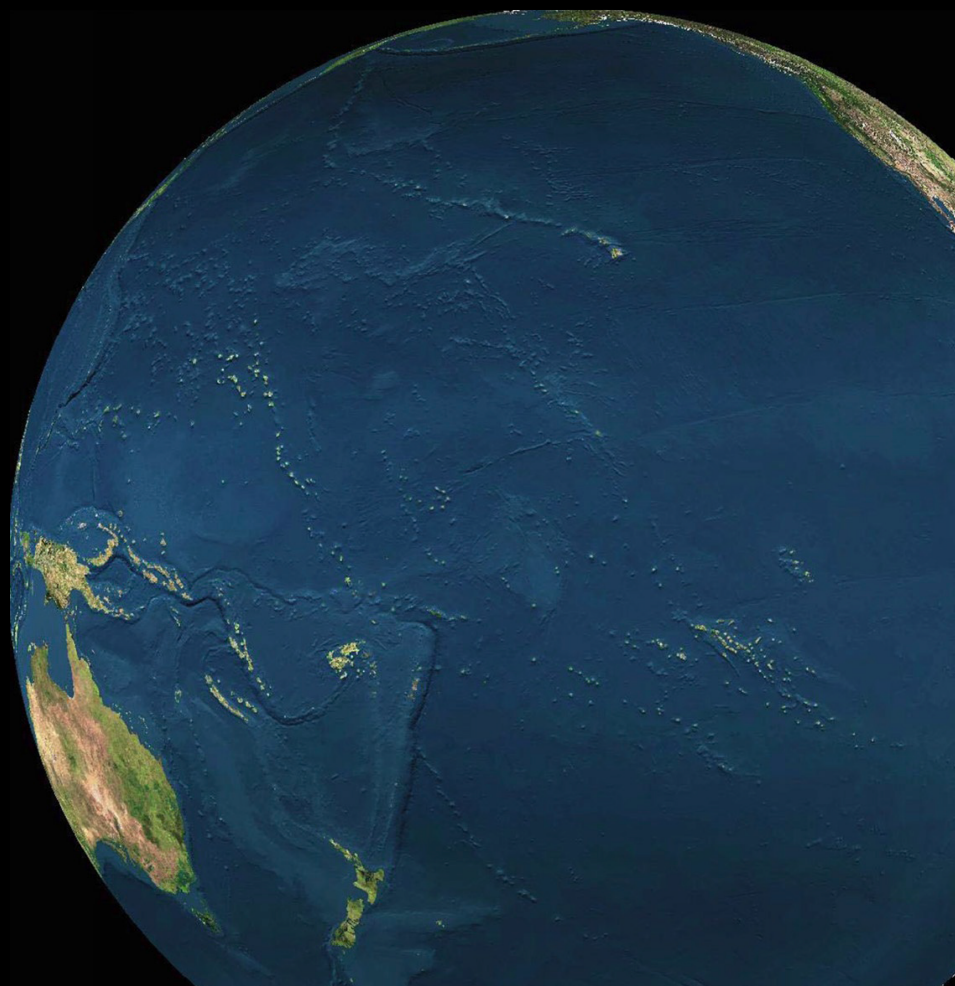
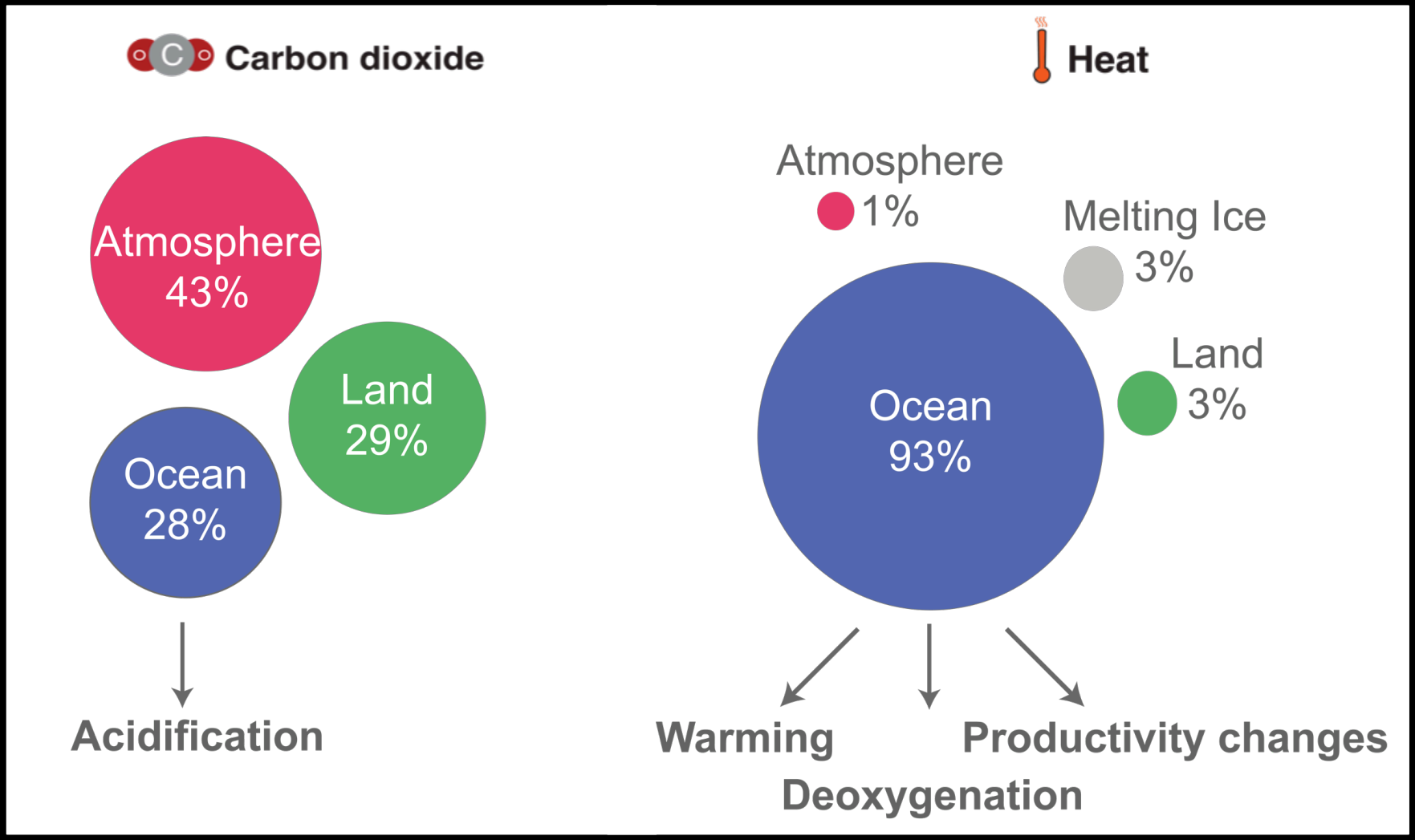
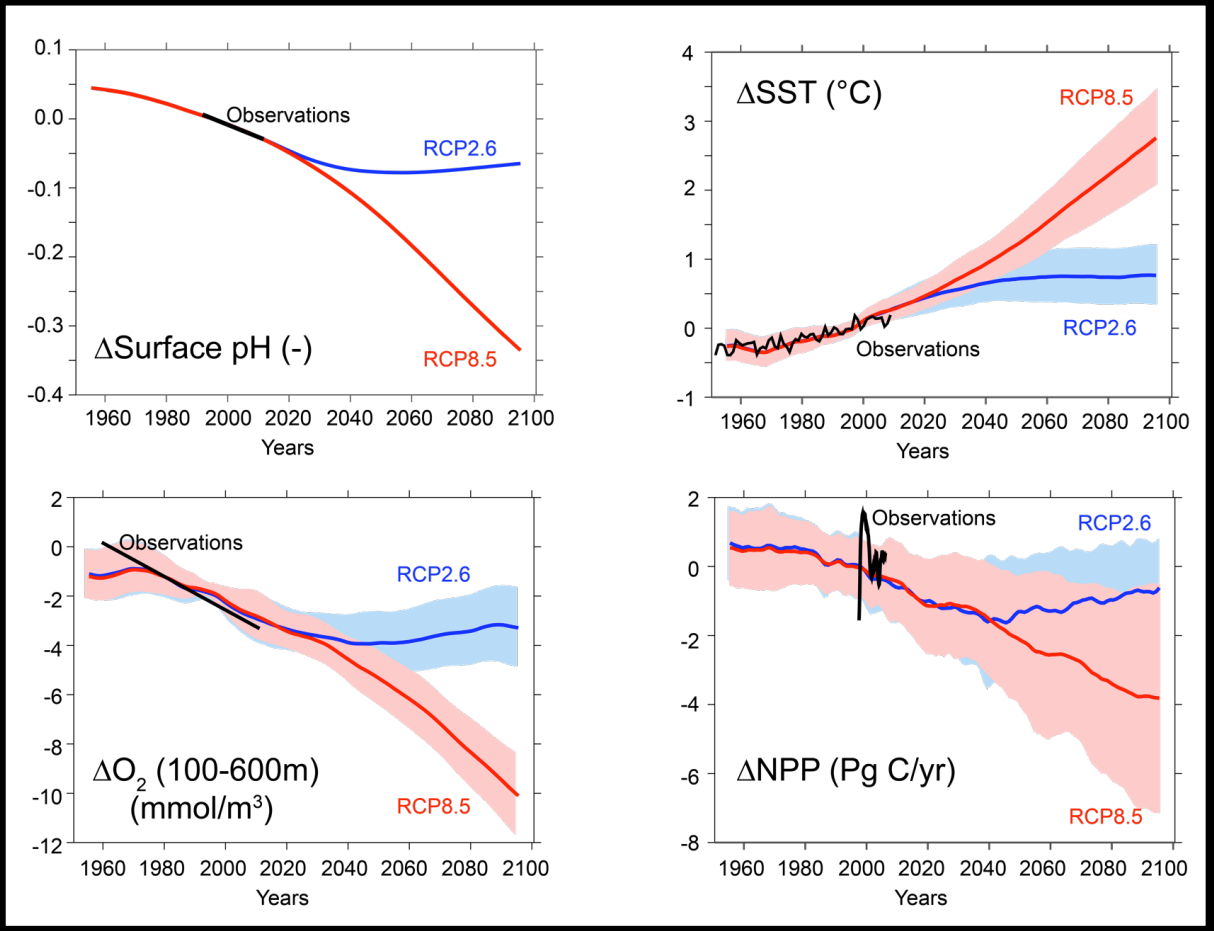
Niki Gruber, Erich Fischer



Ocean moderates climate change, but ..



The global-scale evolution of stressors in the 21st century



Warming up, turning sour, losing breath (and food)

The quadruple whammy for ocean life

Frölicher et al. (2016, Global Biogeochem. Cycles)
see also Bopp et al. (2013)

Reduction in global fisheries catch potential

NEWS & VIEWS

FISHERIES

Climate change at the dinner table

An innovative use of catch statistics shows that climate change has already influenced the composition of species in fisheries around the world, and thereby the fish that we eat. SEE LETTER P.365

MARK R. PAYNE

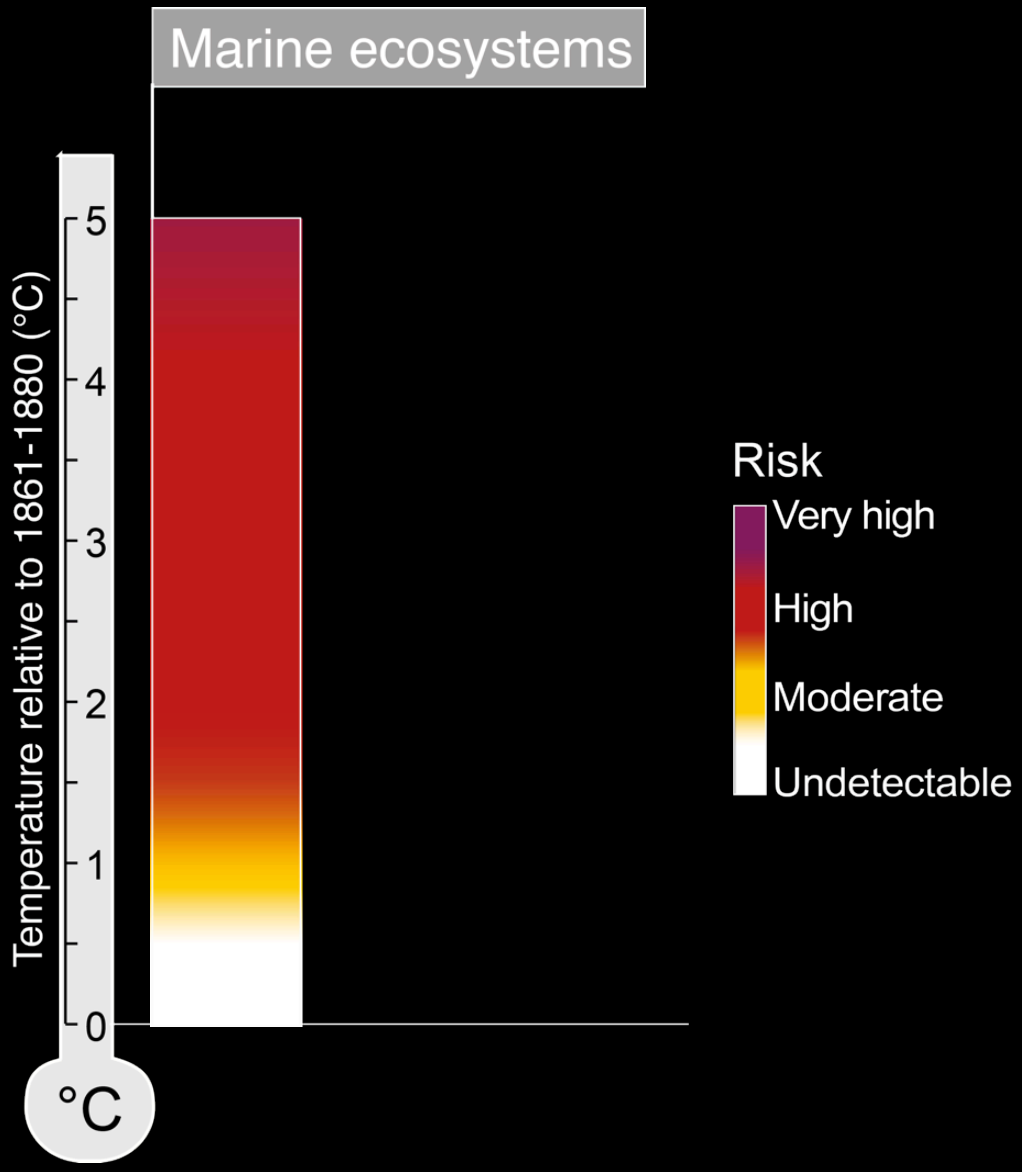
Fisheries scientists tend to view climate change as a dark cloud on the horizon: potentially problematic in the future, but not of immediate concern. Over the multi-decadal to centennial scale, warming, acidification and deoxygenation of the oceans are expected to have significant impacts on marine ecosystems and fisheries[1]. By contrast, other problems, such as the global overfishing crisis[2], are immediate and pressing and have rightly garnered the field's attention for the past decade. However, on page 365 of this issue, Cheung *et al.*[3] present startling evidence that global fisheries catches have already changed in a manner associated with the warming trend — climate change is suddenly an unexpected guest at dinner.

Changes in the spatial distribution of species are one of the major predicted impacts of climate change on marine ecosystems[4]. Marine species tend to occupy the full range of temperatures that they can physiologically tolerate and therefore, on a broad scale, their distributions closely track temperature boundaries

Figure 1 | Mullet on the move. Cheung and colleagues' study[3] shows that the catch composition of

based on Cheung, Reygondeau, Frölicher (2016, Science)

Risk for marine organisms and ecosystems



Modified from IPCC AR5 Synthesis Report (2014)

Outline

1. The ocean at risk

   or how ocean ecosystem services cause troubles

2. Sources of uncertainties in projections of multiple stressors

   or how important is natural variability on global and regional scale?

3. Impacts on marine organisms and ecosystem services

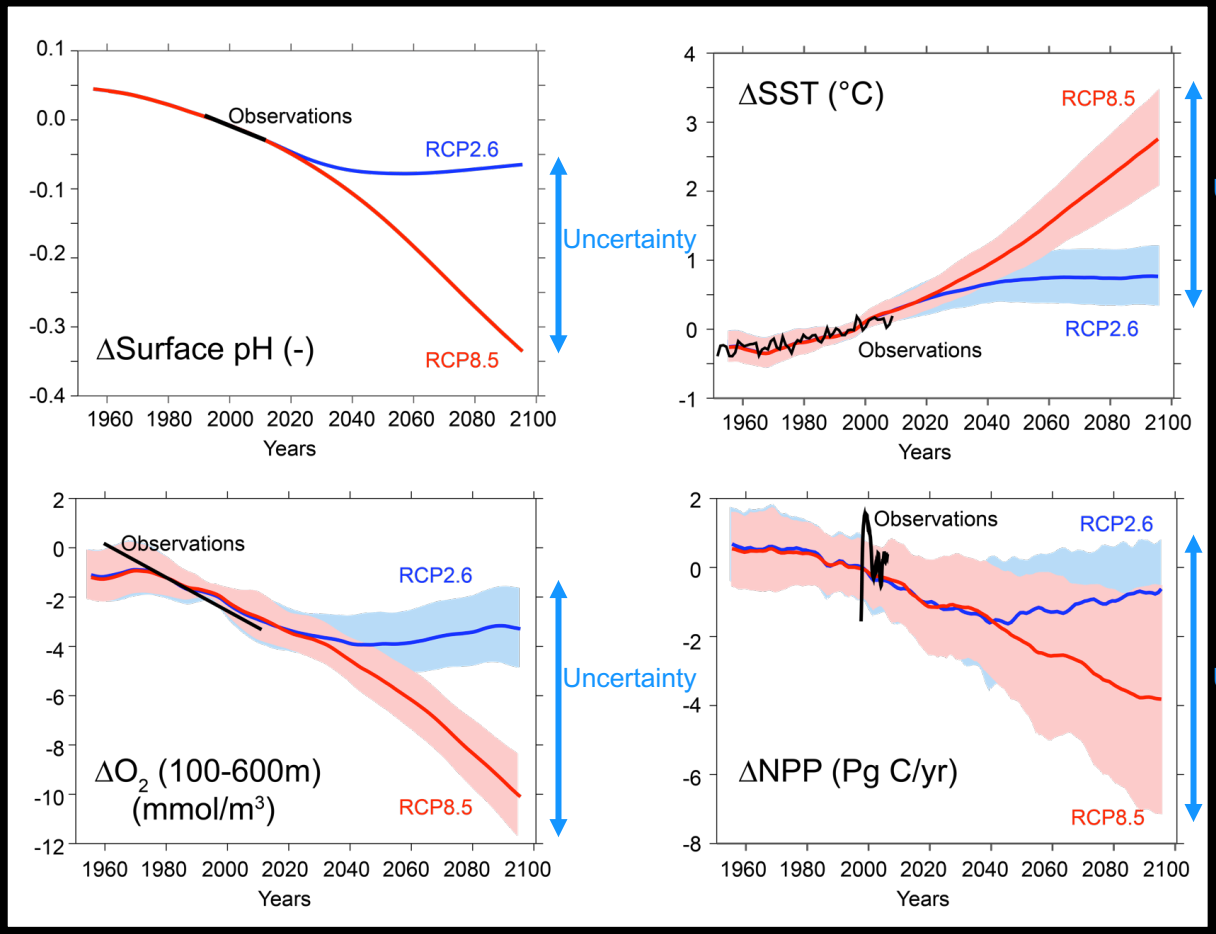
   or what are the benefits to marine fisheries of meeting the 1.5°C target?

4. Ocean extreme events

   or have we overlooked a potential serious problem?

5. Conclusions

The global-scale evolution of stressors in the 21st century

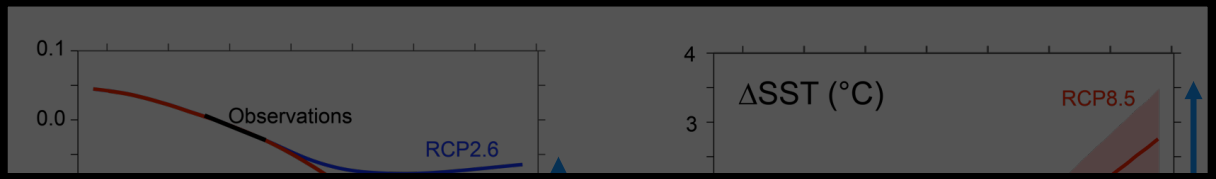


Climate model projections have large uncertainties

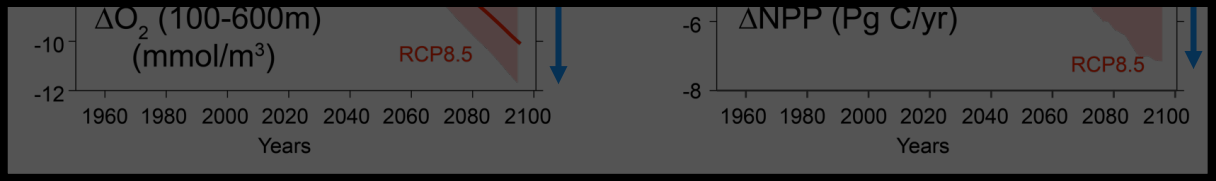
Changes occur on top of regional and natural variability

Frölicher et al. (2016, Global Biogeochem. Cycles)

The global-scale evolution of stressors in the 21st century

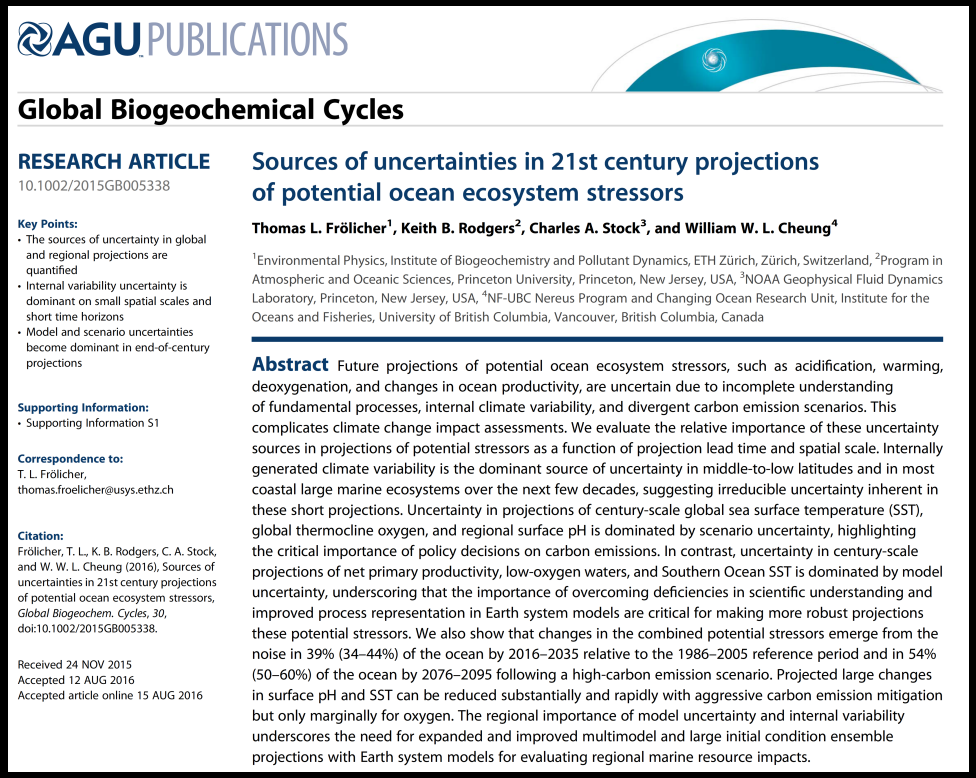


Decision makers and regional impact assessment modelers would like quantitative projections of future changes in ocean ecosystem stressors on regional scale, especially for the next few decade



Frölicher et al. (2016, Global Biogeochem. Cycles)

Questions



AGU PUBLICATIONS

Global Biogeochemical Cycles

RESEARCH ARTICLE

10.1002/2015GB005338

Key Points:
- The sources of uncertainty in global and regional projections are quantified
- Internal variability uncertainty is dominant on small spatial scales and short time horizons
- Model and scenario uncertainties become dominant in end-of-century projections

Supporting Information:
- Supporting Information S1

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Sources of uncertainties in 21st century projections of potential ocean ecosystem stressors

Thomas L. Frölicher[1], Keith B. Rodgers[2], Charles A. Stock[3], and William W. L. Cheung[4]

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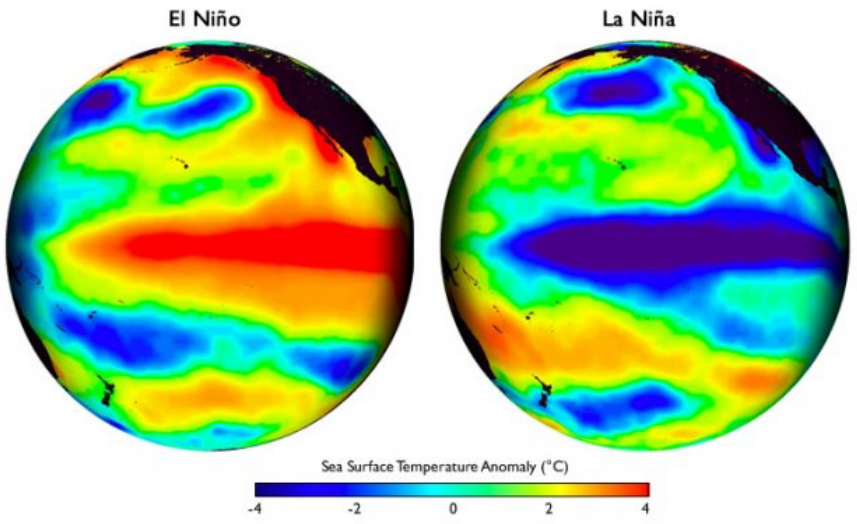
Abstract Future projections of potential ocean ecosystem stressors, such as acidification, warming, deoxygenation, and changes in ocean productivity, are uncertain due to incomplete understanding of fundamental processes, internal climate variability, and divergent carbon emission scenarios. This complicates climate change impact assessments. We evaluate the relative importance of these uncertainty sources in projections of potential stressors as a function of projection lead time and spatial scale. Internally generated climate variability is the dominant source of uncertainty in middle-to-low latitudes and in most coastal large marine ecosystems over the next few decades, suggesting irreducible uncertainty inherent in these short projections. Uncertainty in projections of century-scale global sea surface temperature (SST), global thermocline oxygen, and regional surface pH is dominated by scenario uncertainty, highlighting the critical importance of policy decisions on carbon emissions. In contrast, uncertainty in century-scale projections of net primary productivity, low-oxygen waters, and Southern Ocean SST is dominated by model uncertainty, underscoring that the importance of overcoming deficiencies in scientific understanding and improved process representation in Earth system models are critical for making more robust projections these potential stressors. We also show that changes in the combined potential stressors emerge from the noise in 39% (34–44%) of the ocean by 2016–2035 relative to the 1986–2005 reference period and in 54% (50–60%) of the ocean by 2076–2095 following a high-carbon emission scenario. Projected large changes in surface pH and SST can be reduced substantially and rapidly with aggressive carbon emission mitigation but only marginally for oxygen. The regional importance of model uncertainty and internal variability underscores the need for expanded and improved multimodel and large initial condition ensemble projections with Earth system models for evaluating regional marine resource impacts.

Frölicher et al. (2016, Global Biogeochem. Cycles)

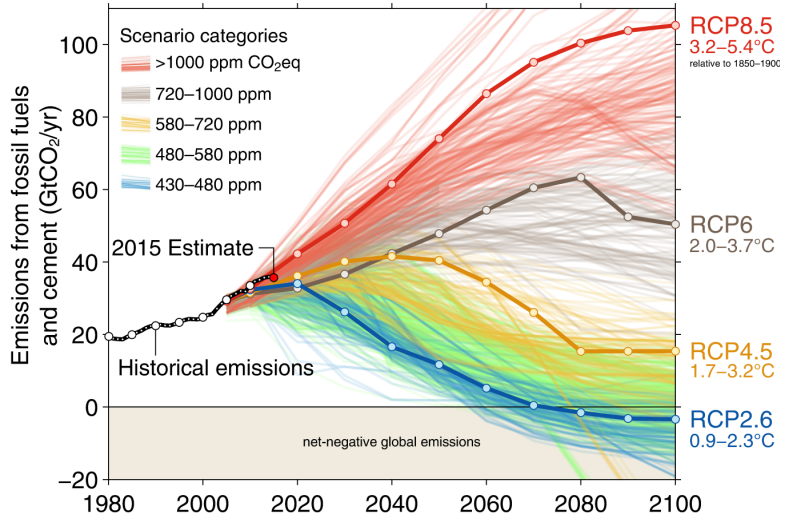
- What are the sources of uncertainties on global and regional scales?
- Does the source of uncertainty vary with region, time horizon and ocean ecosystem driver variable?

Sources of projection uncertainty

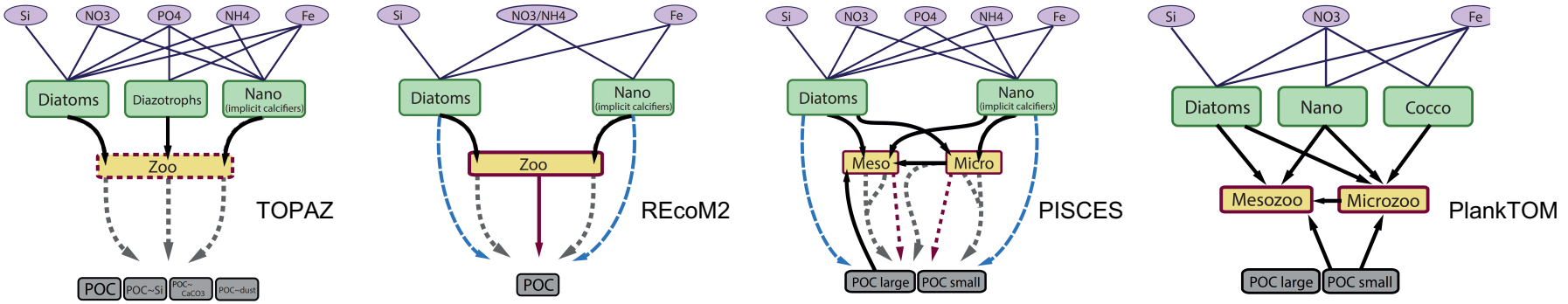
Internal variability uncertainty



Scenario uncertainty



Model structural uncertainty

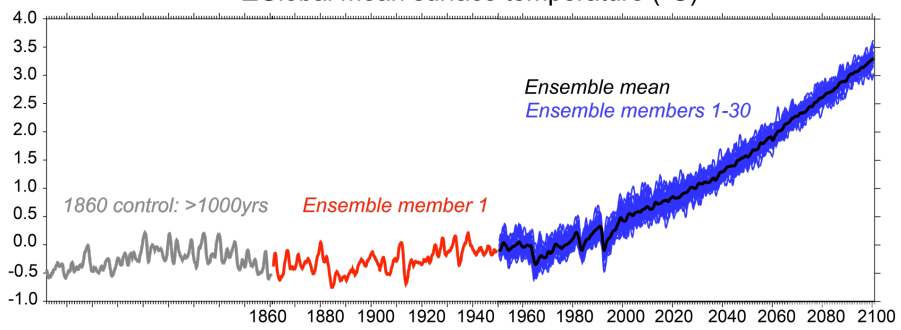


Laufkötter (2015, PhD thesis)

Attribution framework developed by Hawkins and Sutton (2009, 2011)
see also Lovenduski et al. (2016, 2017)

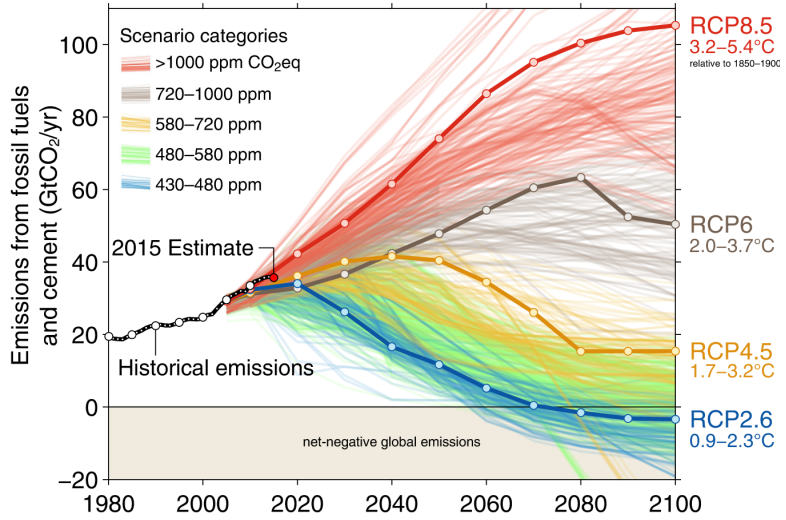
Sources of projection uncertainty

GFDL ESM2M large ensemble

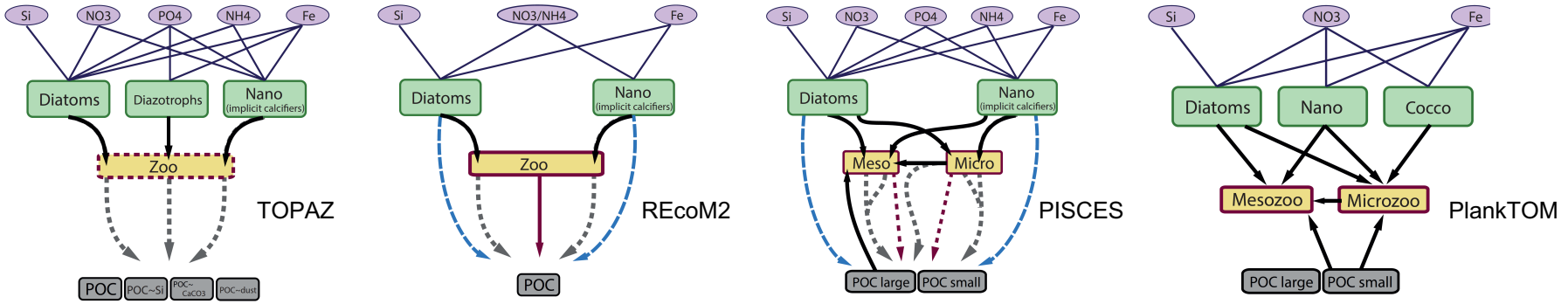


Rodgers, Lin, Frölicher (2015, Biogeosciences)
Von Känel, Frölicher, Gruber (2017, GRL in press)

Scenario uncertainty



Model structural uncertainty



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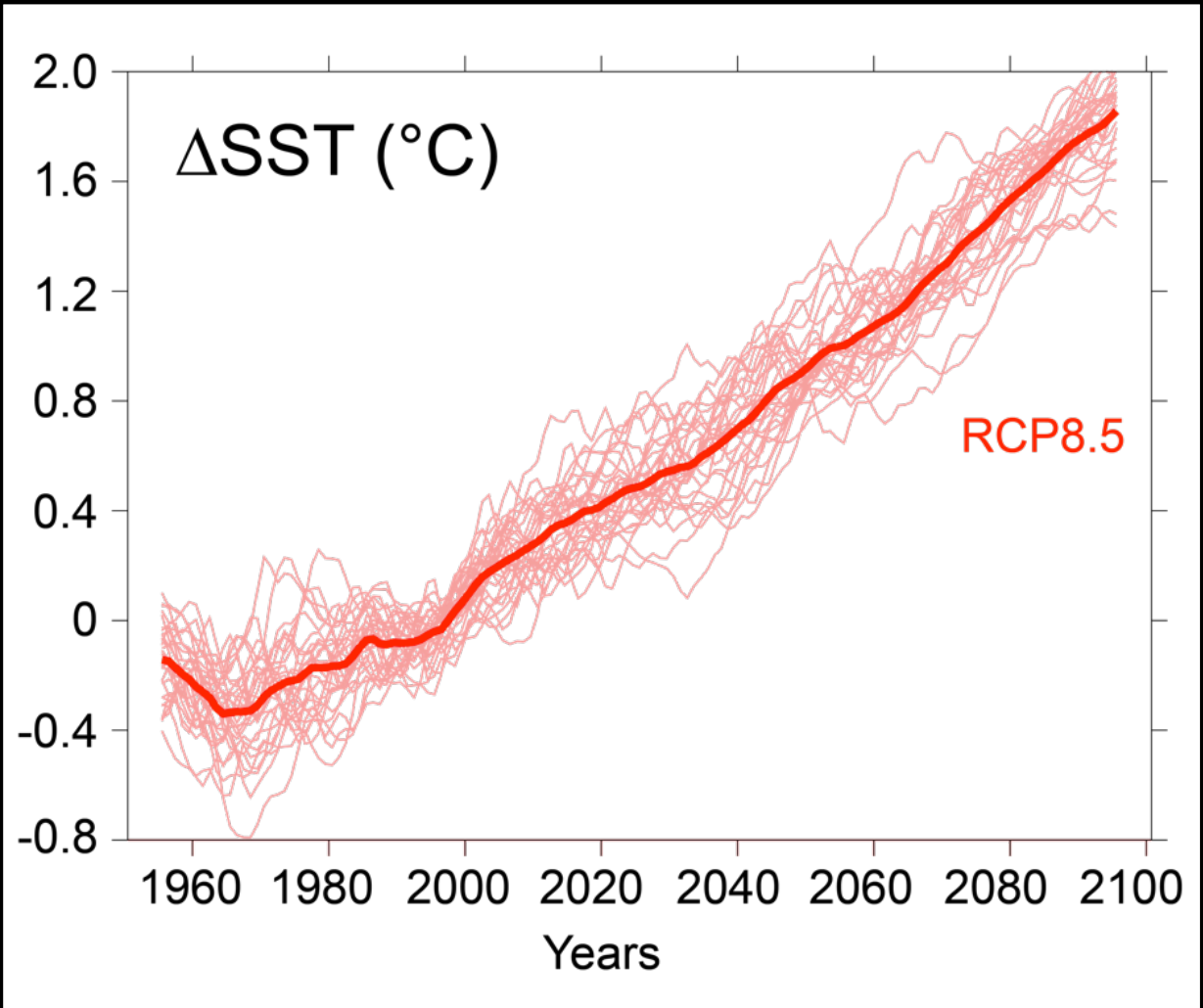
Projected SST changes in the Humboldt Current System

with the large GFDL ensemble



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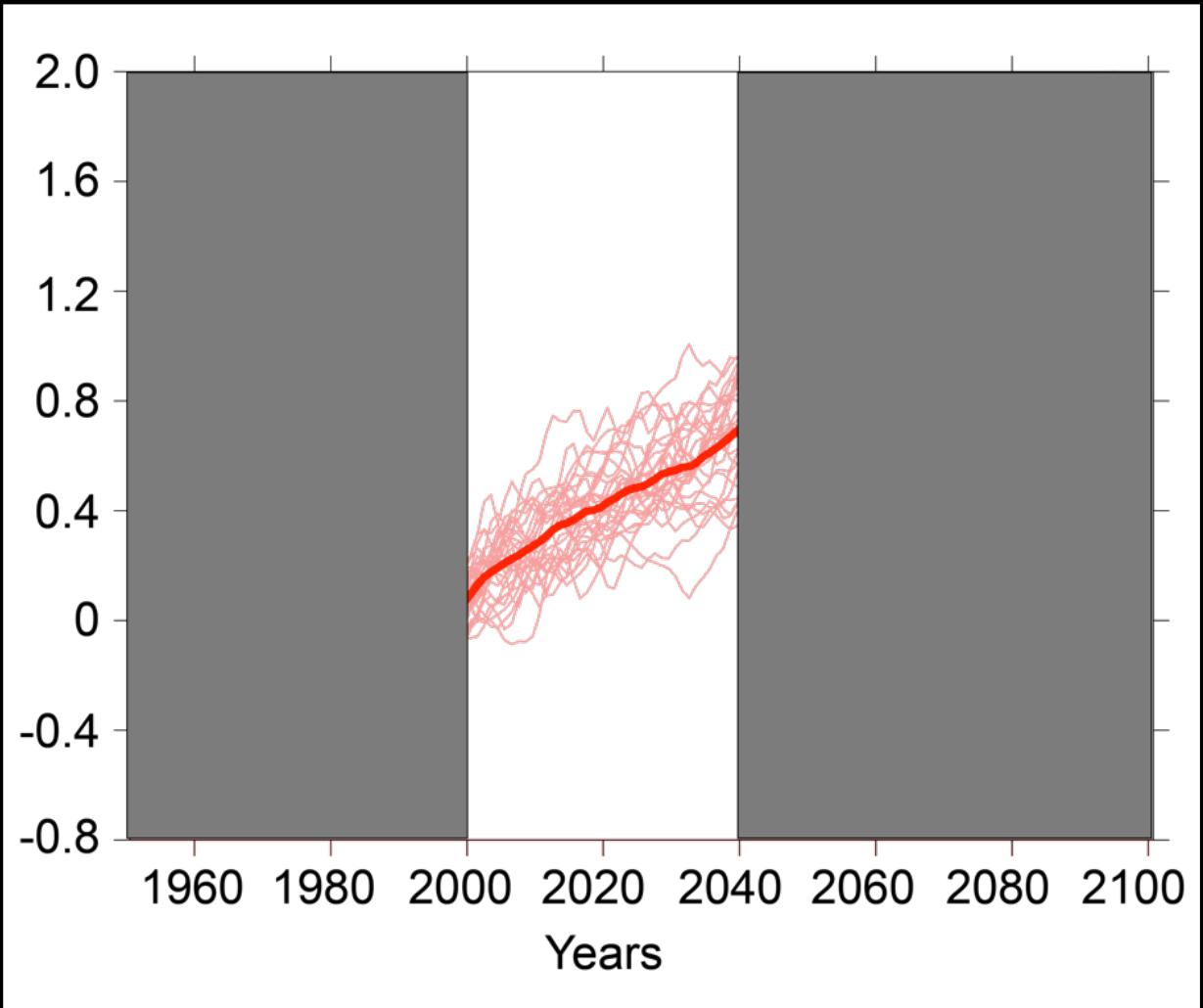

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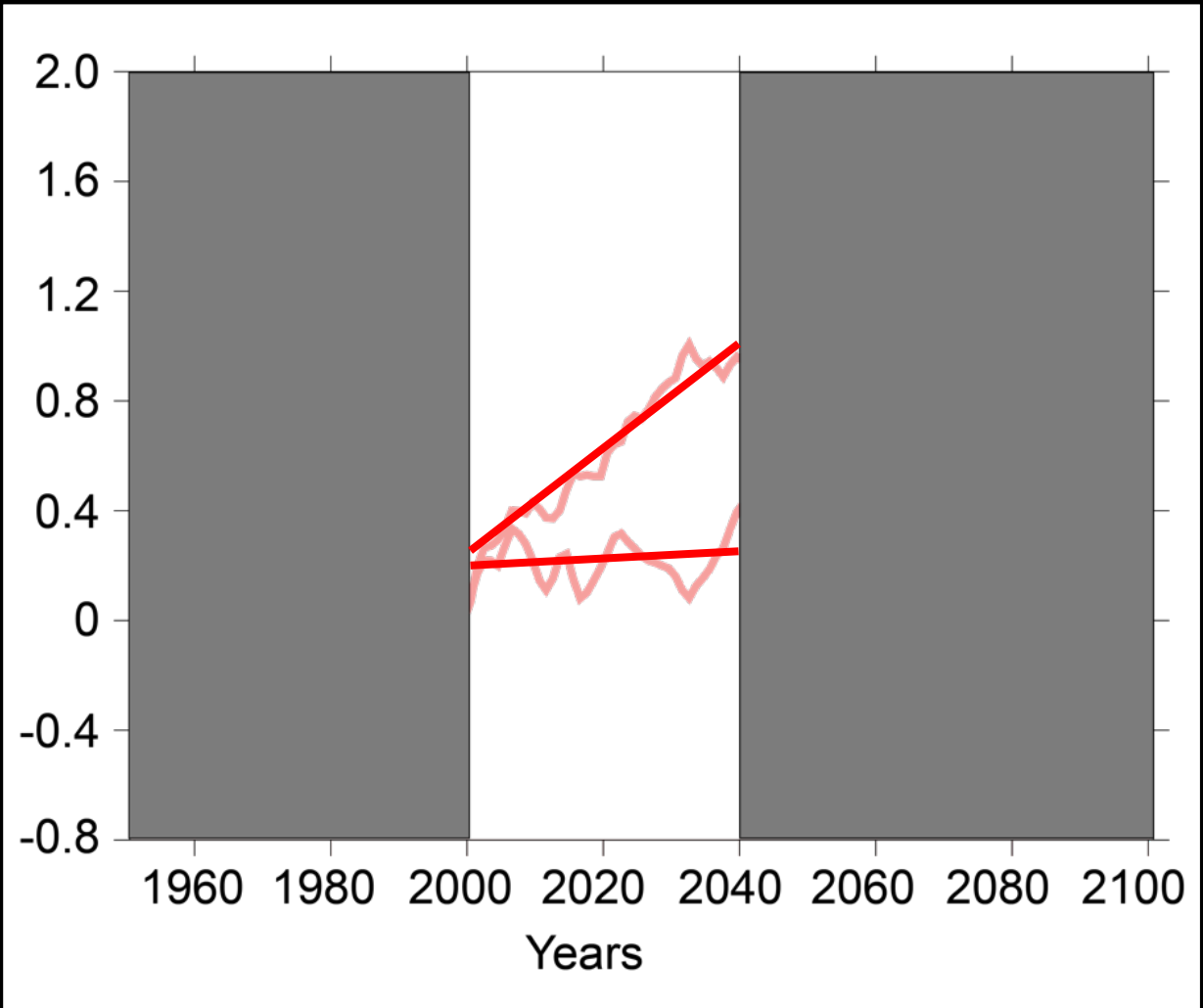
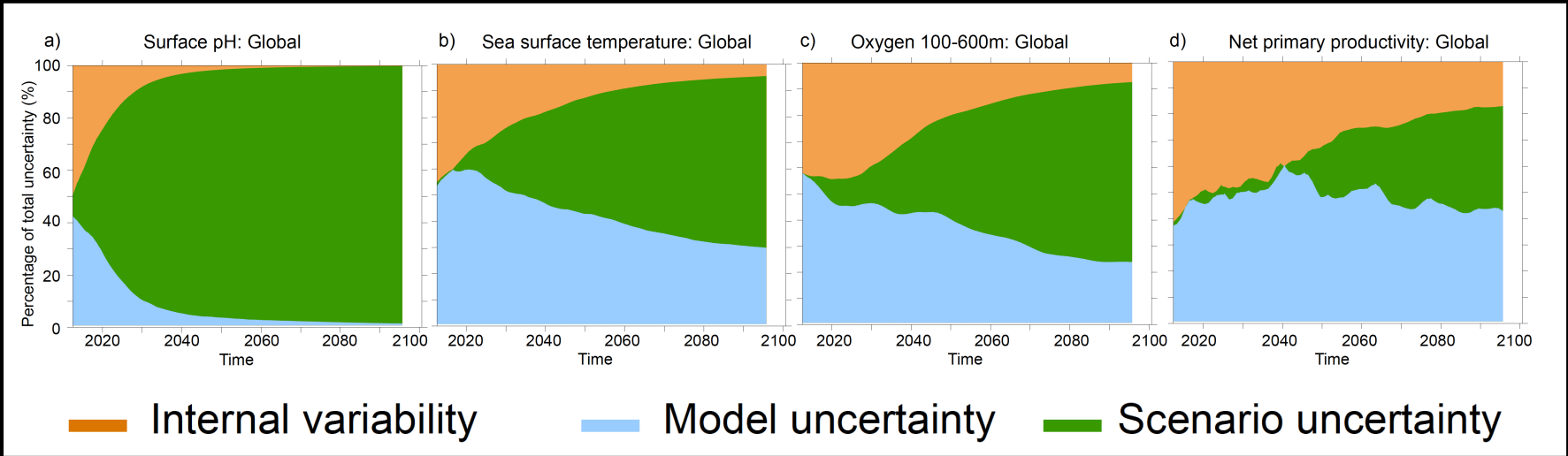
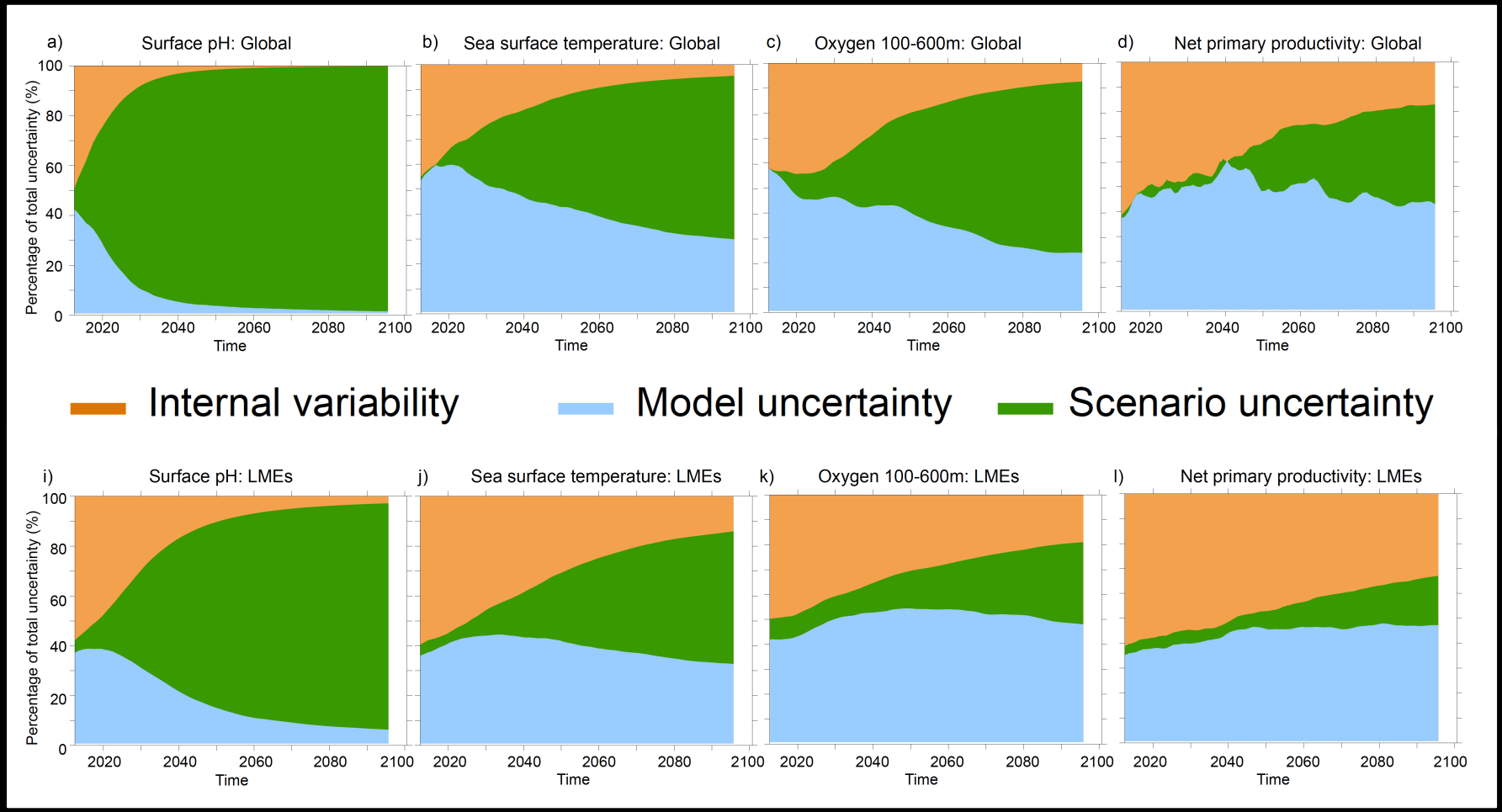


Global-scale fractional uncertainty



Frölicher et al. (2016, Global Biogeochem. Cycles)

Global vs. local-scale fractional uncertainty

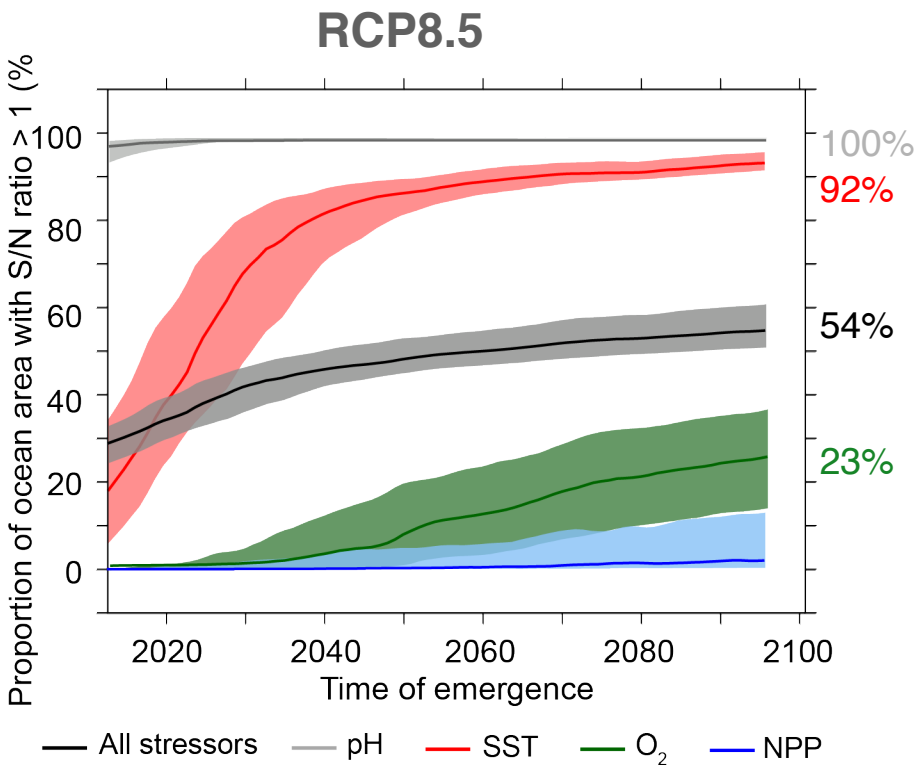


Frölicher et al. (2016, Global Biogeochem. Cycles)

Question

When does the signal move outside of the internal variability range?

Changes in the combined stressors emerge from the noise in 54% of ocean



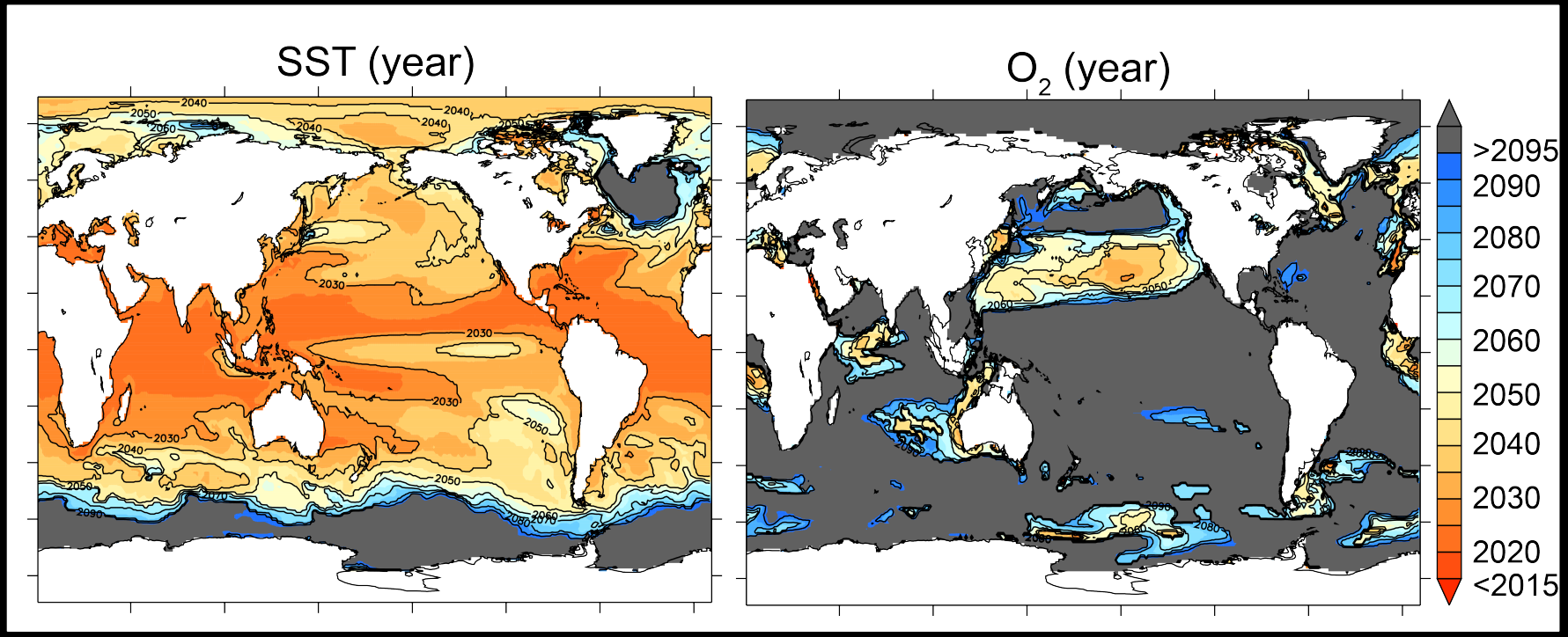
Time of emergence: S/N > 1

Signal S:
Amplitude of forced changes for RCP8.5 relative to 1986-2005

Noise N:
Internal variability + model uncertainty

Frölicher et al. (2016, Global Biogeochem. Cycles)

High risk of impacts in low latitudes



Frölicher et al. (2016, Global Biogeochem. Cycles)

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   or what are the benefits to marine fisheries of meeting the 1.5°C target?

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   or have we overlooked a potential serious problem?

5. Conclusions

The Paris Agreement

- Holding the increase global mean temperature to well below 2°C above preindustrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C

- 147 of ~~197~~ 196 parties have ratified the convention

The Paris Agreement

Translating the Paris Agreement into impact-related targets facilitates communication of the benefits of mitigating climate change to policymakers and stakeholders.

- Holding the increase global mean temperature to well below 2°C above preindustrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C
- 147 of ~~197~~ 196 parties have ratified the convention

Climate change impact on fisheries

FISHERIES

Large benefits to marine fisheries of meeting the 1.5°C global warming target

William W. L. Cheung,[1]* Gabriel Reygondeau,[1] Thomas L. Frölicher[2]

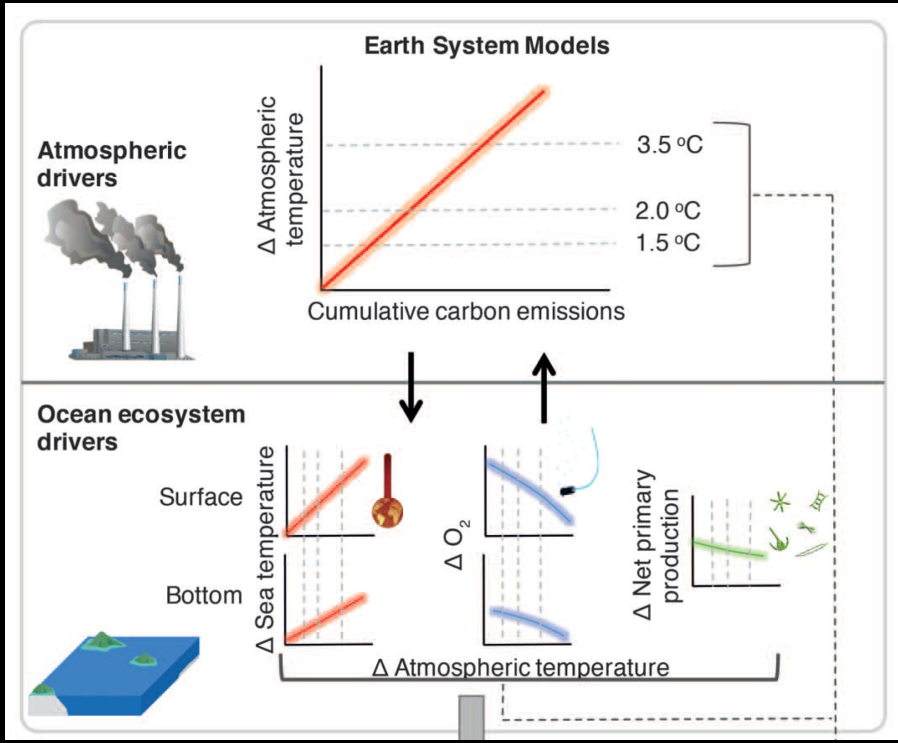
Translating the Paris Agreement to limit global warming to 1.5°C above preindustrial level into impact-related targets facilitates communication of the benefits of mitigating climate change to policy-makers and stakeholders. Developing ecologically relevant impact-related targets for marine ecosystem services, such as fisheries, is an important step. Here, we use maximum catch potential and species turnover as climate-risk indicators for fisheries. We project that potential catches will decrease by more than 3 million metric tons per degree Celsius of warming. Species turnover is more than halved when warming is lowered from 3.5° to 1.5°C above the preindustrial level. Regionally, changes in maximum catch potential and species turnover vary across ecosystems, with the biggest risk reduction in the Indo-Pacific and Arctic regions when the Paris Agreement target is achieved.

Cheung, Reygondeau, Frölicher (Science, 2016)

What are the benefits to fisheries of moving towards the Paris Agreement's target?

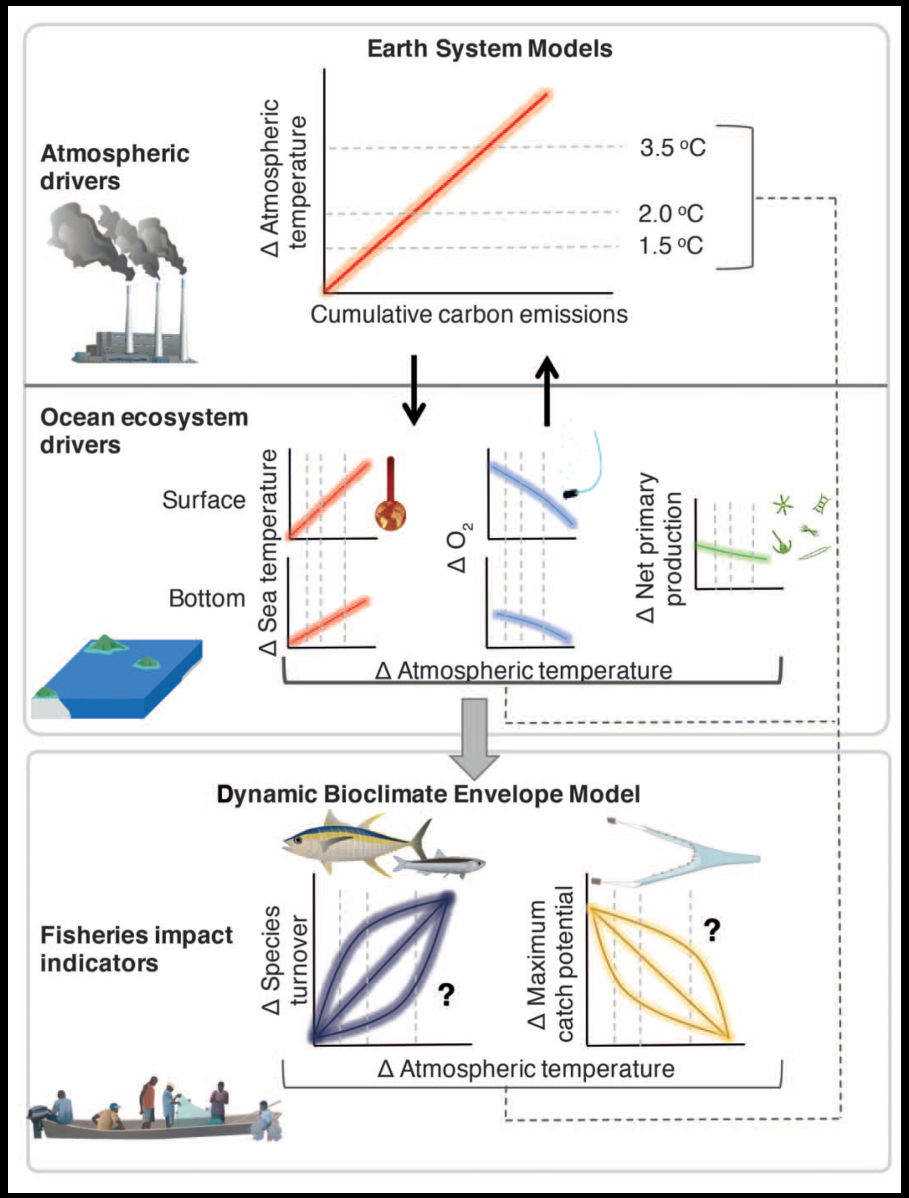
The Nippon Foundation - University of British Columbia
NEREUS PROGRAM
Predicting Future Oceans

Modeling framework



- 19 (3) Earth System Models
- 2 future scenarios:
  - RCP8.5: about 4-5°C
  - RCP2.6: about 2°C

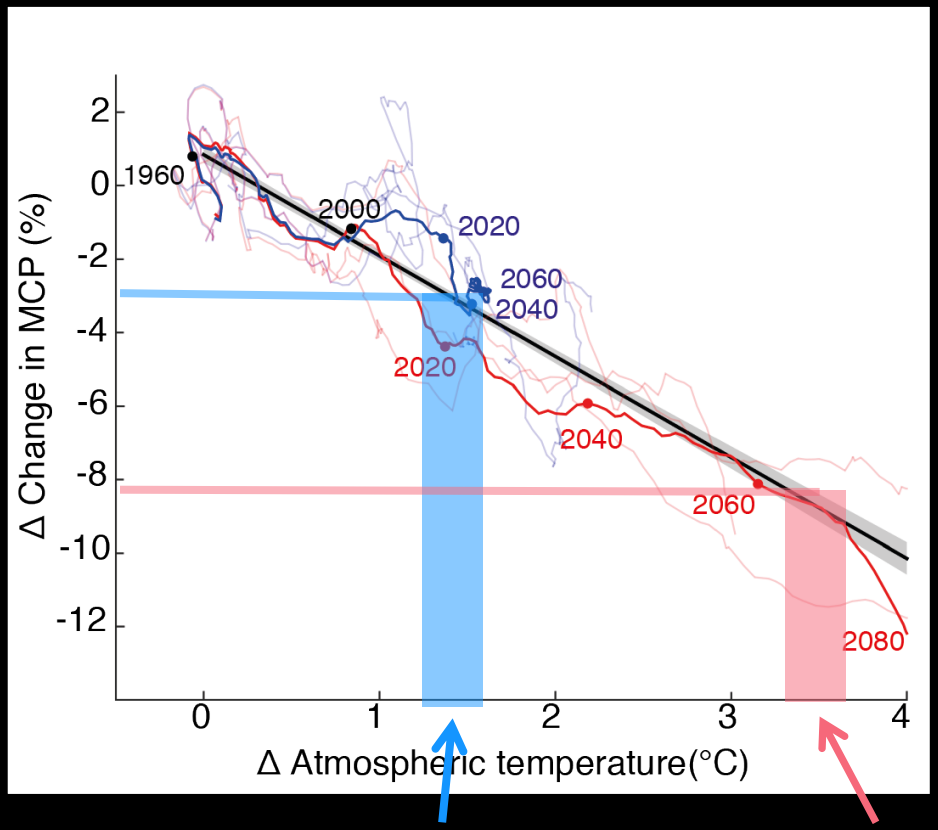
Modeling framework



- 19 (3) Earth System Models
- 2 future scenarios:
  - RCP8.5: about 4-5°C
  - RCP2.6: about 2°C
- Marine species distribution model that simulates interactions between changes in ocean conditions, ecophysiology, population dynamics, dispersal, habitat productivity
- > 890 exploited fish and invertebrates

Cheung, Reygondeau, Frölicher (Science, 2016)

Changes in fisheries maximum catch potential in LMEs

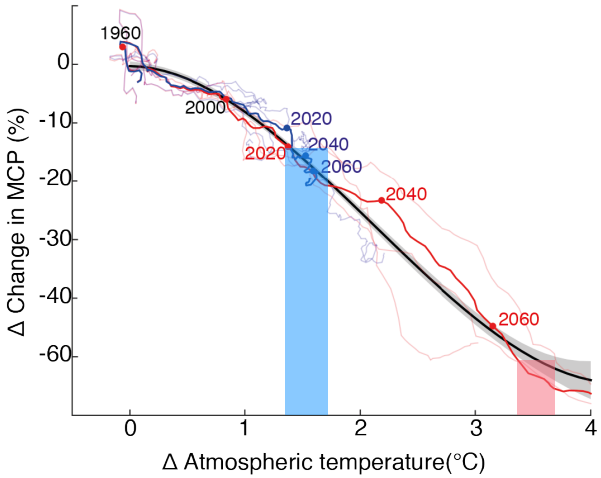


- Maximum catch potential is a proxy for maximum sustainable yield
- Changes in maximum catch potential scales negatively and nearly linearly with atmospheric warming
- -3% per °C warming
- -3.4 x 10^6 t per °C warming

Cheung, Reygondeau, Frölicher (Science, 2016)

Regional changes in maximum catch potential in LMEs

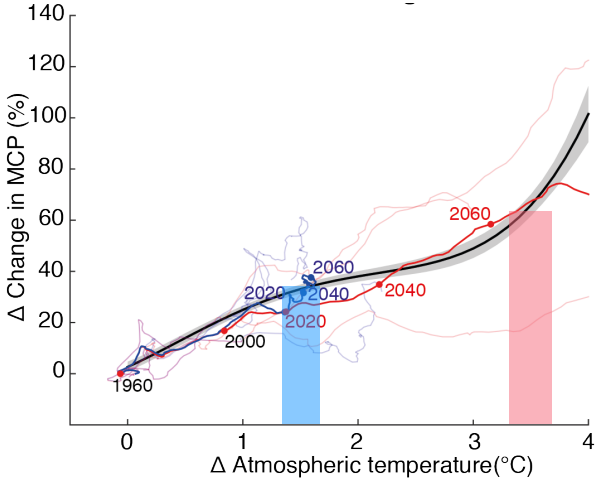
Tropics:
Indo-Pacific LMEs



1.5°C: -10%

3.5°C: -50%

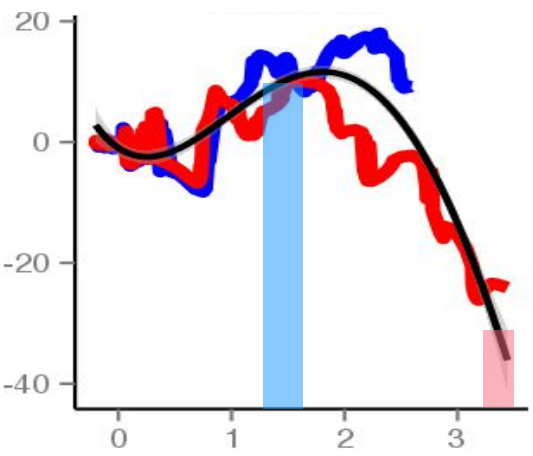
High latitudes:
Arctic LMEs



1.5°C: +30%

3.5°C: +55%

Norwegian Sea

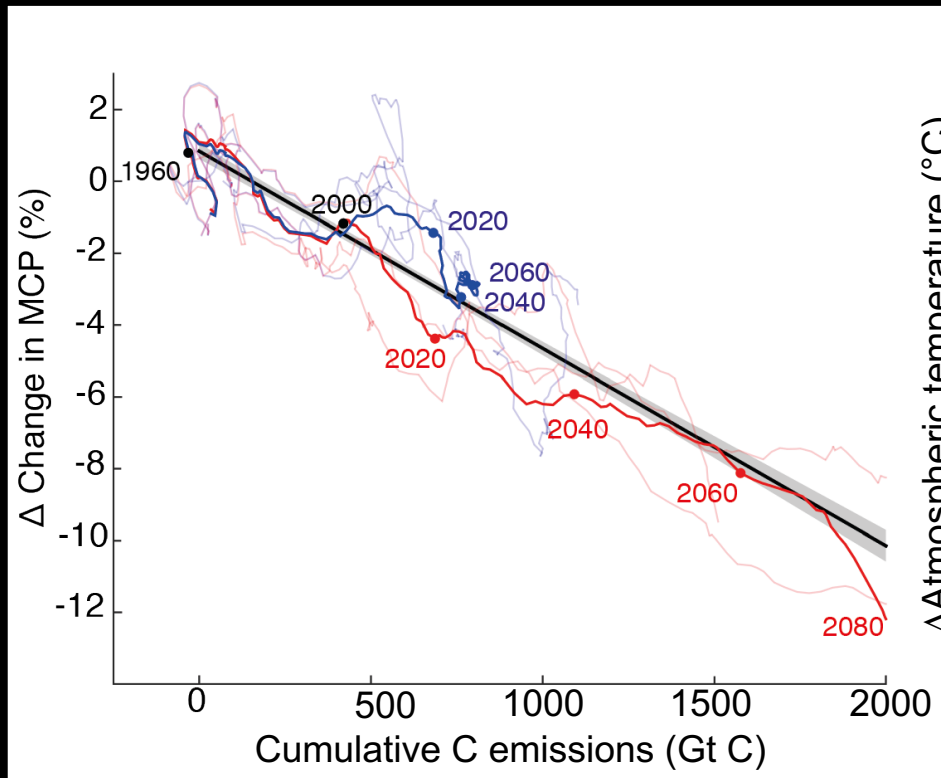


1.5°C: +10%

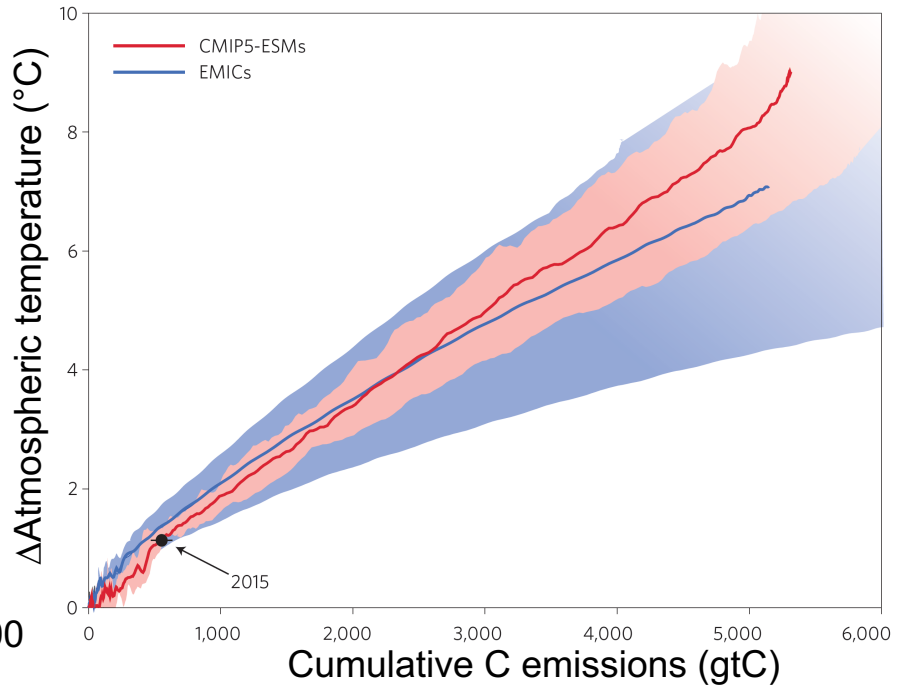
3.5°C: -35%

Cheung, Reygondeau, Frölicher (Science, 2016)

Impact of one tonne of CO_2 emissions on fishing catch



Cheung, Reygondeau, Frölicher (Science, 2016)



Frölicher (Nature Climate Change 2016)

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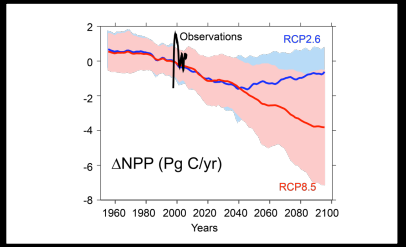
Information

I am happy to provide more information by email if you are interested: thomas.froelicher@usys.ethz.ch

Conclusions

1. Future projections of potential ocean ecosystem stressors are fraught to large uncertainty



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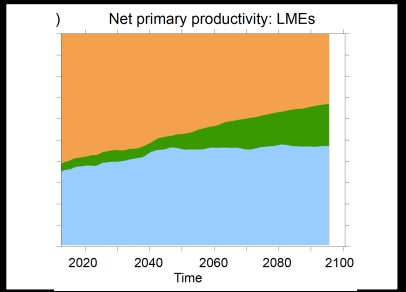
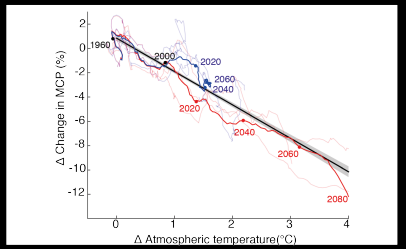


3. Operating within the Paris Agreement substantially reduces risk of impacts on fisheries



4. Global warming has significantly increased the odds of marine heat waves to occur