Dynamical Downscaling in Service of Living Marine Resource Management

Photo Credit: Douglas Alden, SIO

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What is Dynamical Downscaling?

Similar to General Circulation Models: solving equations of thermo- and fluid dynamics but in a smaller, higher resolution region

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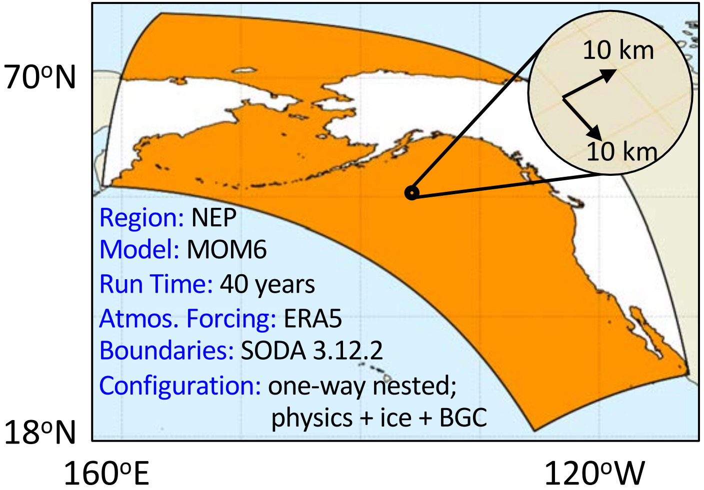
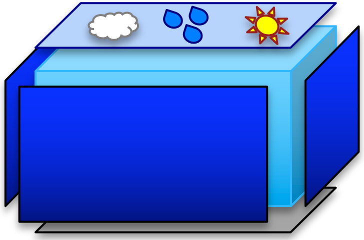
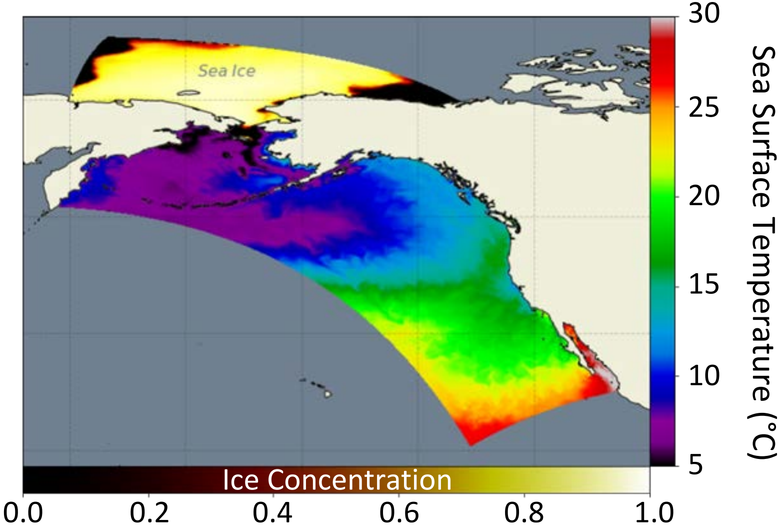
Northeast Pacific Domain



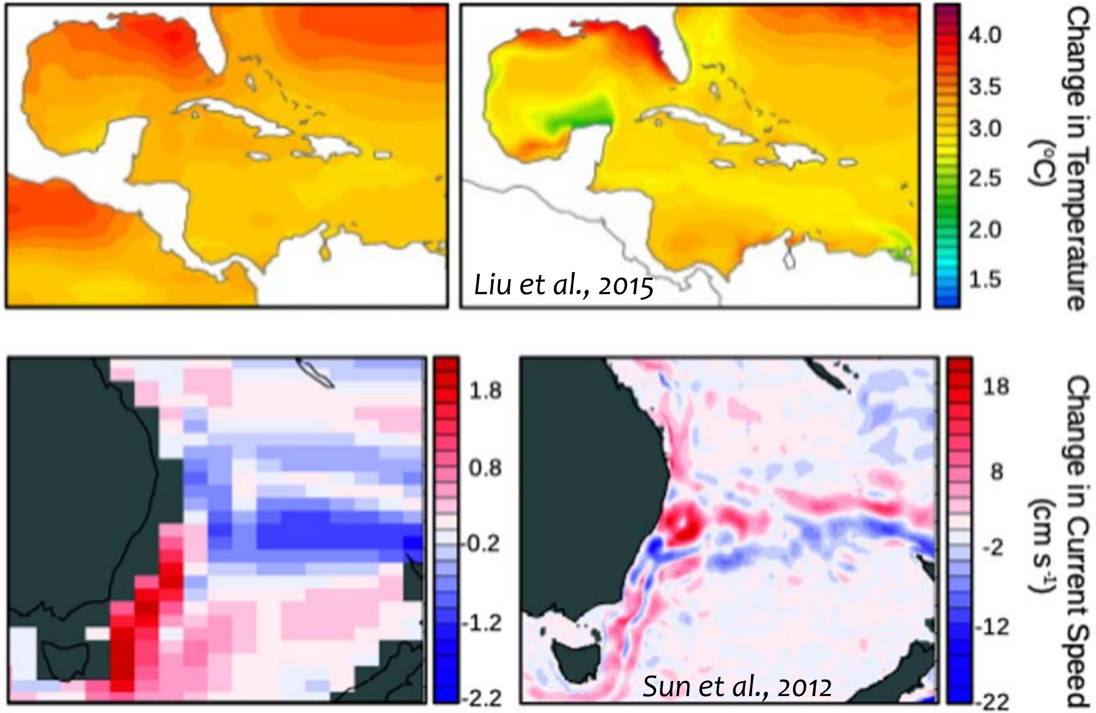




Why Downscale?

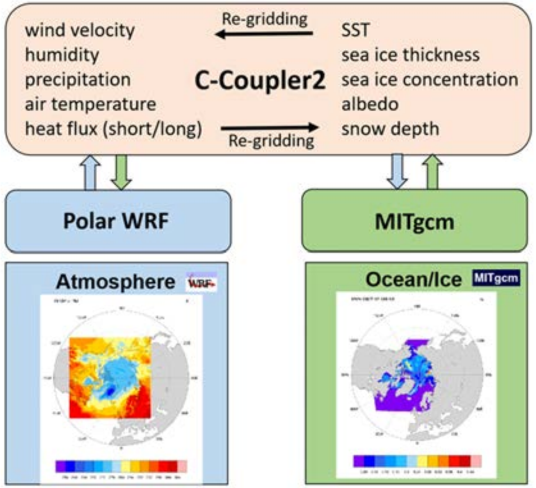
Allows for resolution of LMR-critical ocean features and the impact of local effects on large scale trends

Dynamical downscaling permits mechanistic simulation of unprecedented ocean states (vs. observation-based statistical downscaling which is defined by historical conditions)



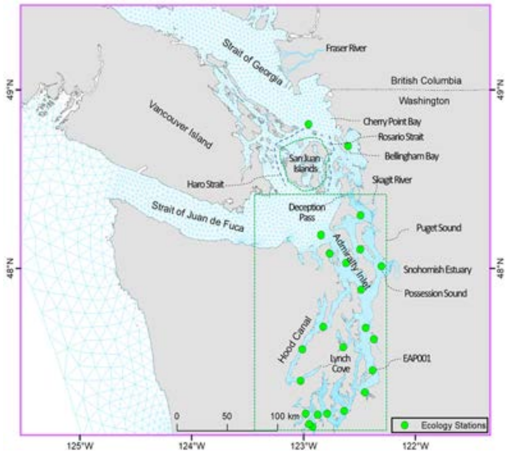
Exciting Dynamical Downscaling Capabilities

Atmospheric Coupling

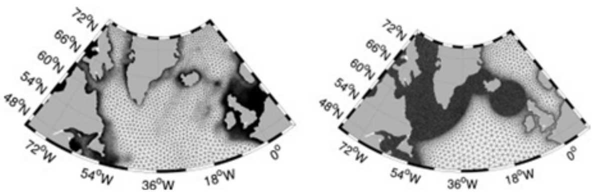


Ren et al., 2021

Unstructured/ Stretched Grids

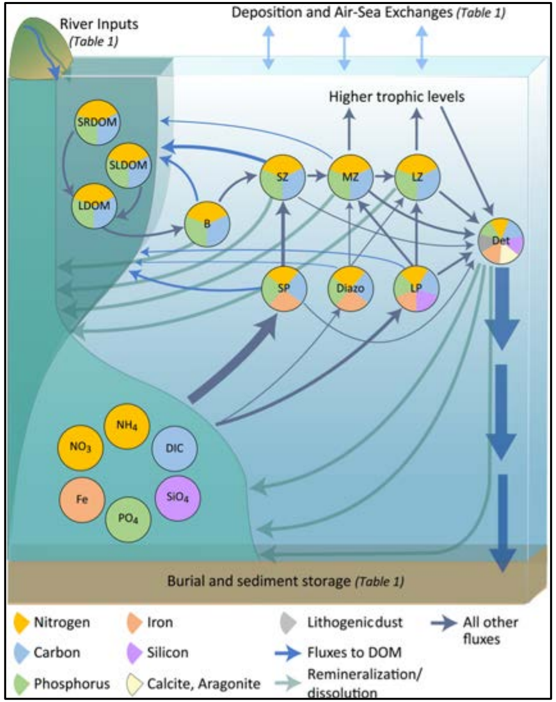


Khangaonkar et al., 2019



Danilov et al., 2013

Biogeochemical Models



COBALT, 33 tracers. *Stock et al., 2019*

Reality: Computational Costs Necessitate Tradeoffs

Domain Size & Resolution

Model Complexity & Comprehensiveness: Inclusion of Biogeochemical, Hydrological, Ice, Ecosystem, Wave Models

Boundaries & Forcing: One-way Nested vs. Coupled

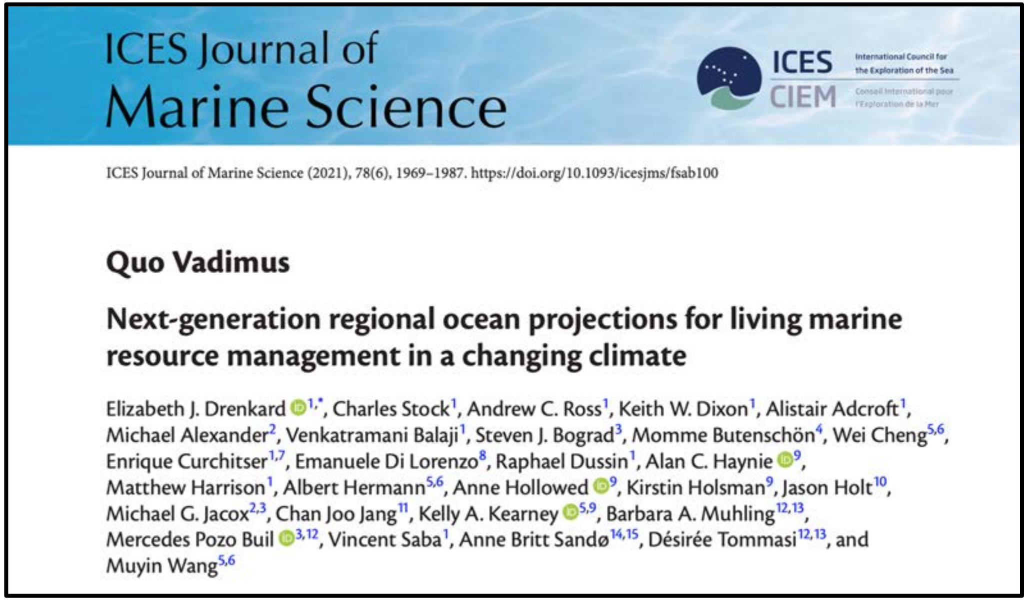
Simulation Duration: Time Slice vs. Transient Simulations

Ensemble Size: Number of Simulations to Represent Uncertainty

Facilitating LMR Management Decisions for an Uncertain Future

Synthesis Paper Inspired by 2015 WKSICCME Workshop
“Modeling Effects of Climate Change on Fish and Fisheries”

Recommendations for **climate change** ocean downscaling studies given limited computational resources



ICES Journal of
Marine Science

ICES CIEM

International Council for the Exploration of the Sea

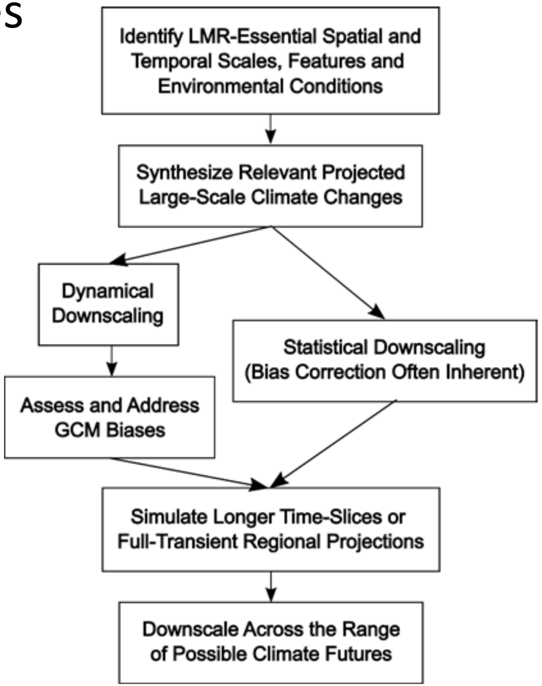
Conseil International pour l'Exploration de la Mer

ICES Journal of Marine Science (2021), 78(6), 1969–1987. https://doi.org/10.1093/icesjms/fsab100

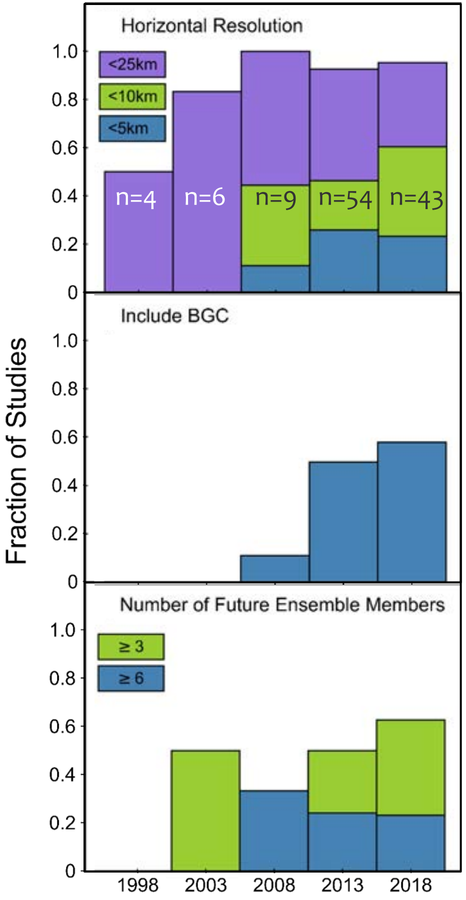
Quo Vadimus

Next-generation regional ocean projections for living marine resource management in a changing climate

Elizabeth J. Drenkard[1,*], Charles Stock[1], Andrew C. Ross[1], Keith W. Dixon[1], Alistair Adcroft[1], Michael Alexander[2], Venkatramani Balaji[1], Steven J. Bograd[3], Momme Butenschön[4], Wei Cheng[5,6], Enrique Curchitser[1,7], Emanuele Di Lorenzo[8], Raphael Dussin[1], Alan C. Haynie[9], Matthew Harrison[1], Albert Hermann[5,6], Anne Hollowed[9], Kirstin Holsman[9], Jason Holt[10], Michael G. Jacox[2,3], Chan Joo Jang[11], Kelly A. Kearney[5,9], Barbara A. Muhling[12,13], Mercedes Pozo Buil[3,12], Vincent Saba[1], Anne Britt Sandø[14,15], Désirée Tommasi[12,13], and Muyin Wang[5,6]



Progression of Climate Change, Ocean Downscaling Studies



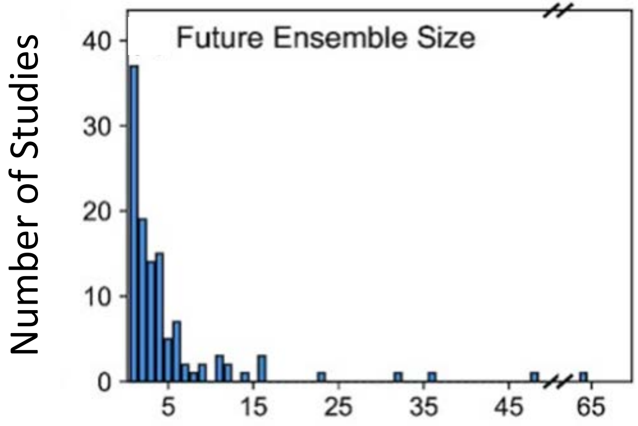
- Increase in the number of ocean downscaling climate change studies (n values)
- Increase in horizontal resolution
- More ocean downscaling studies including BGC
- Increase in number of ensemble members

Many of these studies are more "proof of concept" in nature and not necessarily intended for operational forecasting

Drenkard et al., 2021

Challenge of Adequately Representing Uncertainty

In order to provide actionable forecasts, we need to represent the range and likelihood of possible conditions/futures.



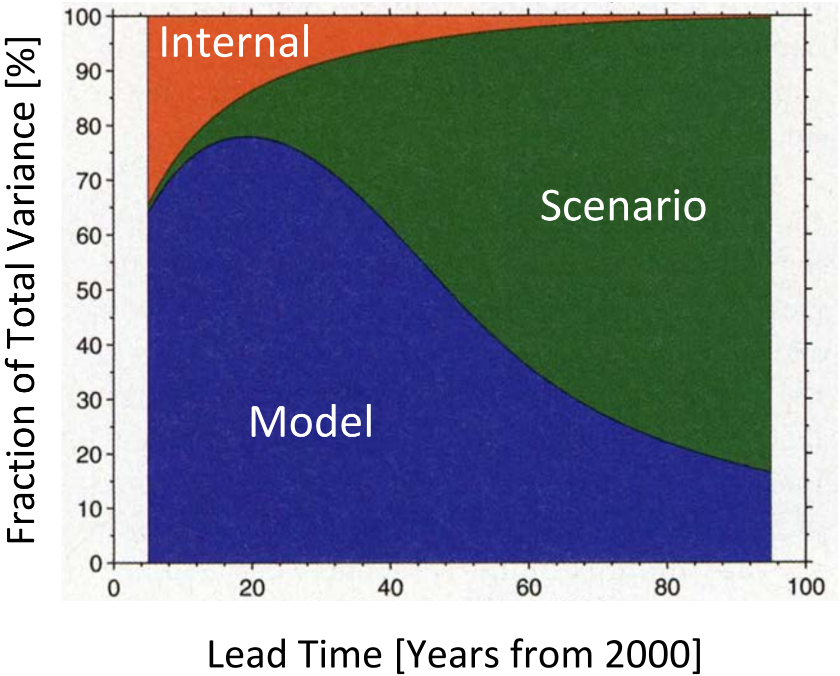
Drenkard et al., 2021

Many of the reviewed climate change ocean downscaling studies consider fewer than 5 ensemble members

Strategic ensemble design requires consideration of the various forms of uncertainty; it is likely intractable to dynamically downscale ALL potential sources of uncertainty

Uncertainty Varies by Time Horizon

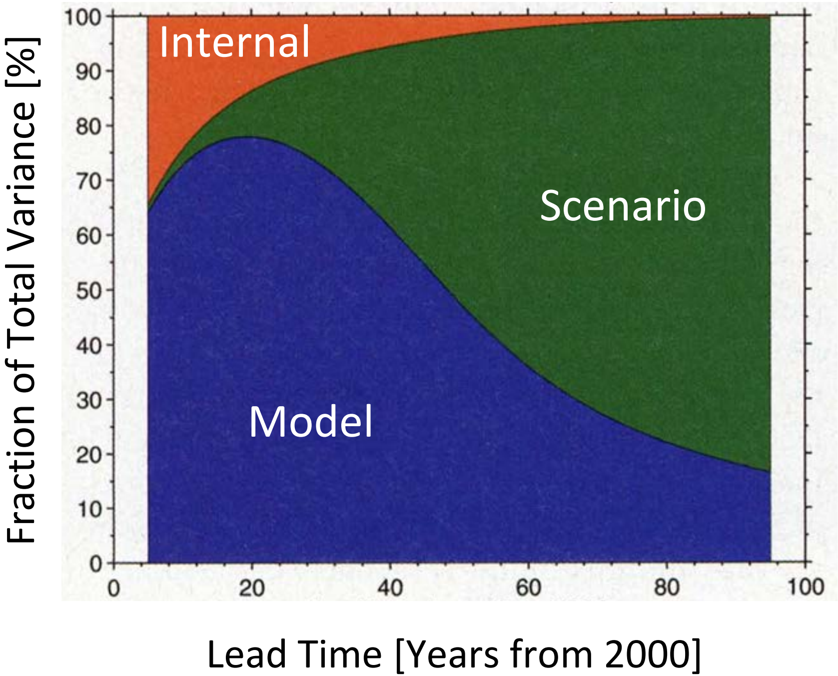
Global Decadal Mean Surface Air Temperature



Hawkins & Sutton 2009

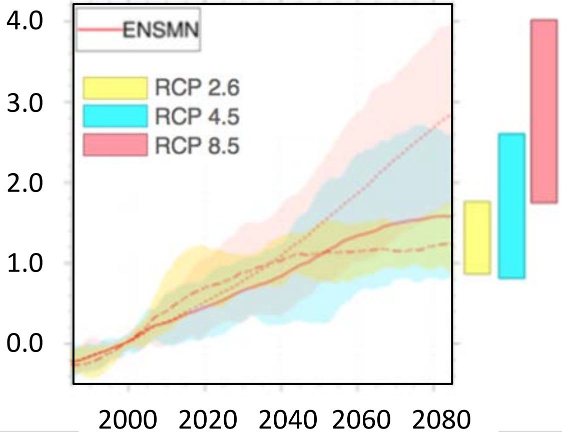
Uncertainty Varies by Field

Global Decadal Mean Surface Air Temperature

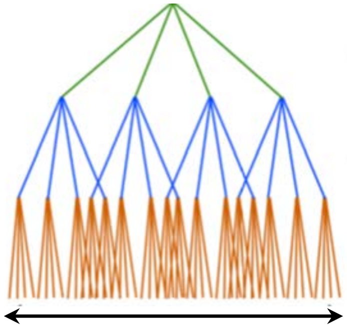


Hawkins & Sutton 2009

California Current Large Marine Ecosystem
Sea Surface Temperature Change



Mike Jacox



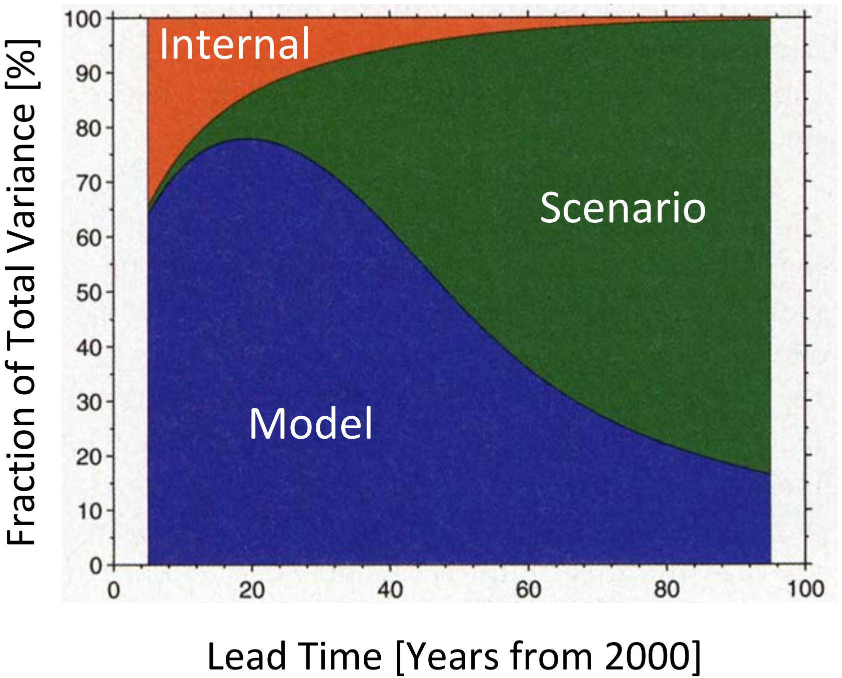
Scenario Uncertainty

Model Uncertainty

Internal Variability

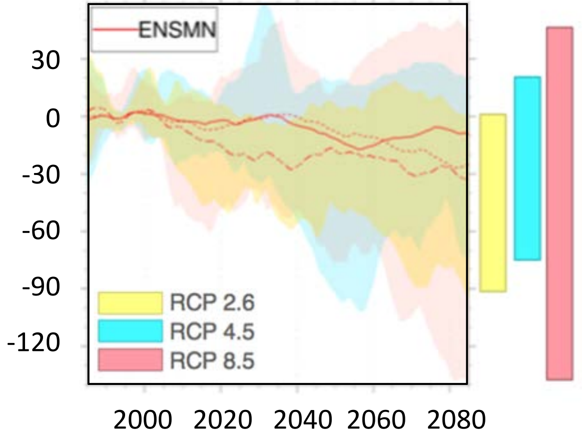
Uncertainty Varies by Field

Global Decadal Mean Surface Air Temperature



Hawkins & Sutton 2009

California Current Large Marine Ecosystem
Primary Productivity Change



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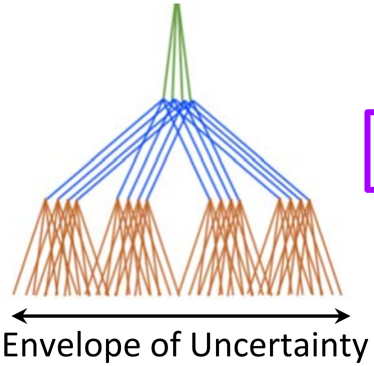


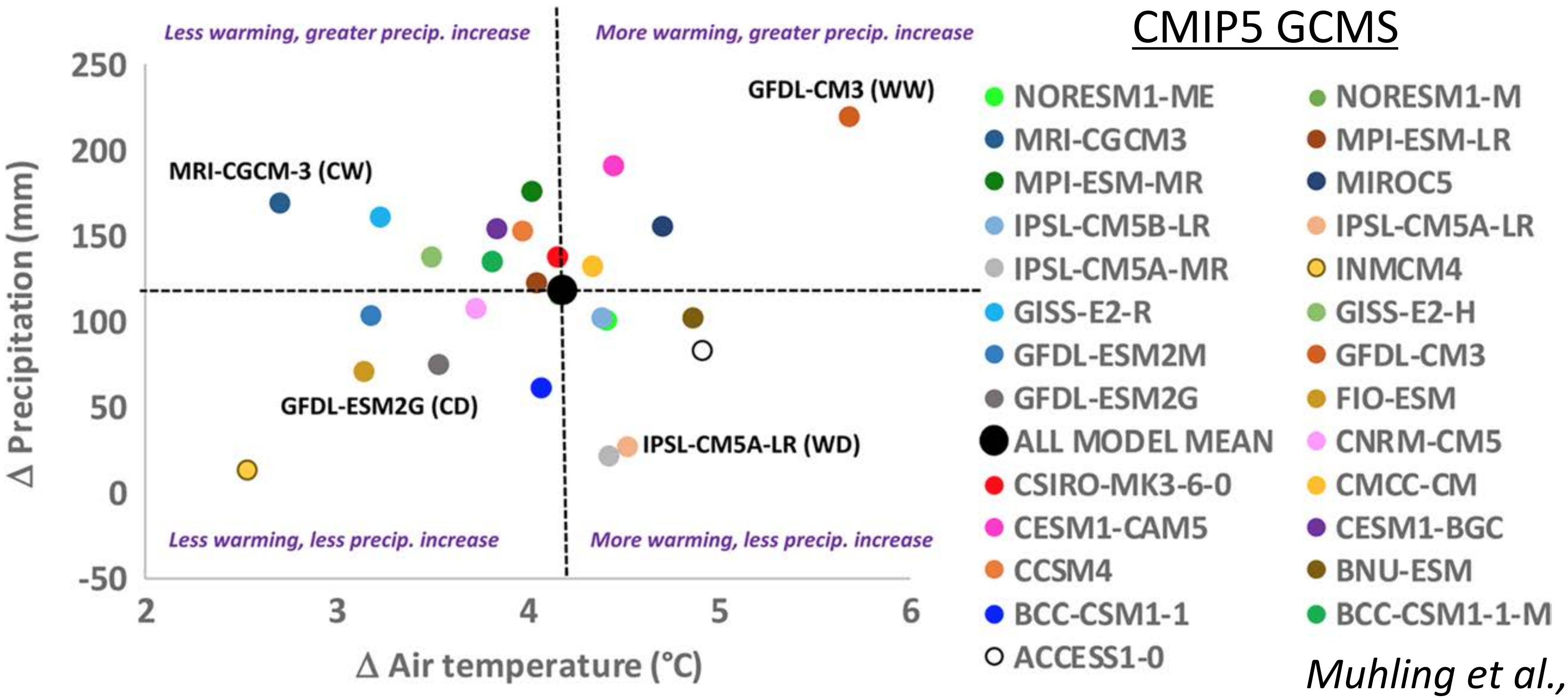
Scenario Uncertainty

Model Uncertainty

Internal Variability

Downscale Across Range of Uncertainty

Toss “bad” GCMs; span variable-dependent uncertainty envelope



Muhling et al., 2017

Uncertainty Can Also Vary by Location

Sources of Near-term (2016-2035) Uncertainty

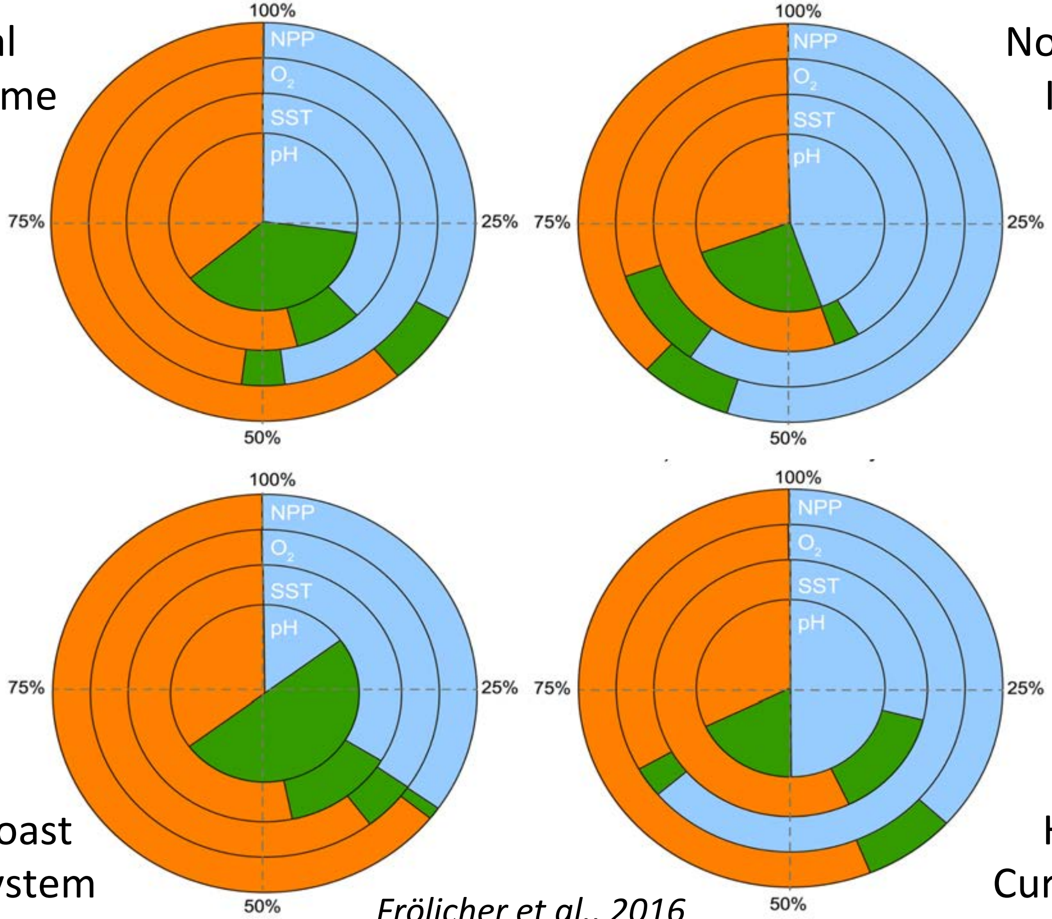
Scenario

Model

Internal

Equatorial Atlantic Biome

North Atlantic Ice Biome



Somali Coast Current System

Humboldt Current System

Frölicher et al., 2016

Challenge of Adequately Representing Uncertainty

Sources of Near-term (2016-2035) Uncertainty

Scenario

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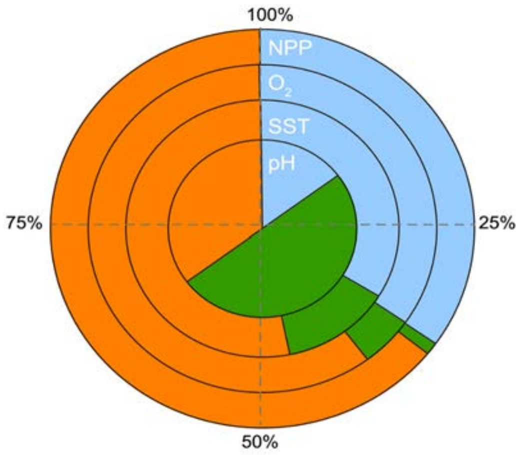
Somali Coast Current System



Frölicher et al., 2016

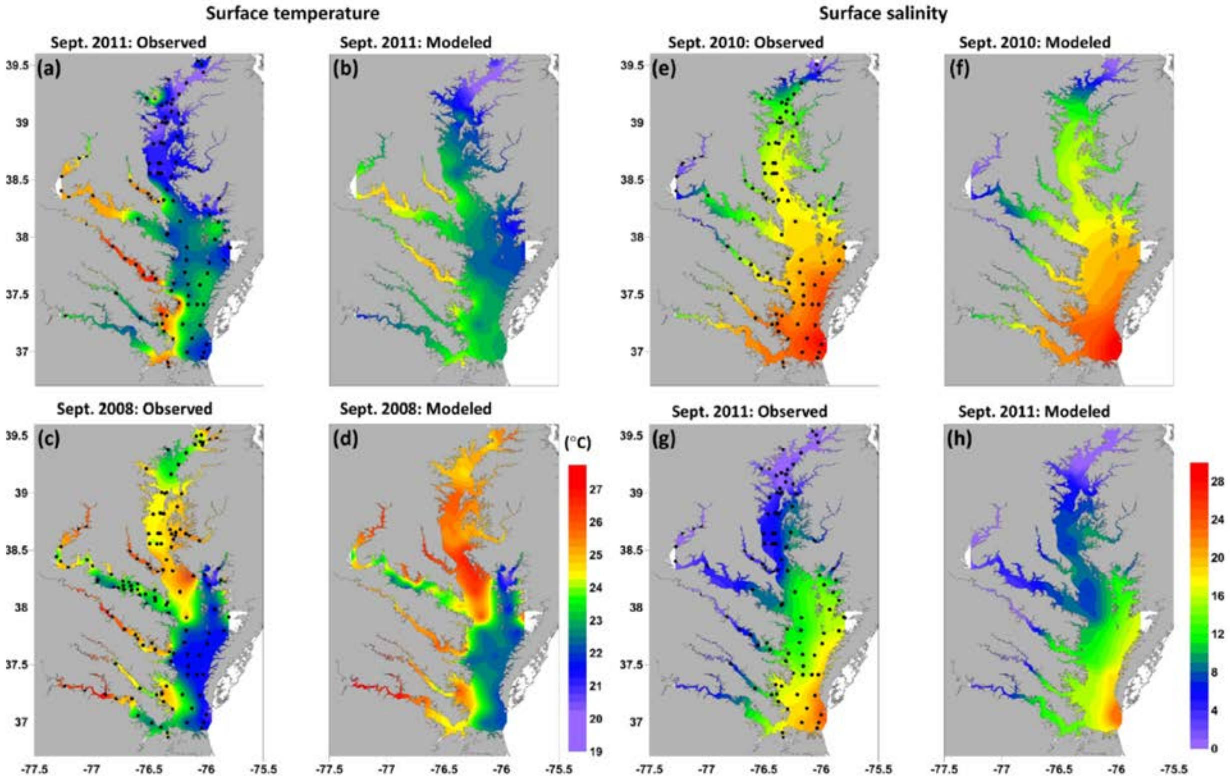
Internal variability represents a larger portion of the uncertainty for shorter-term predictions. This further emphasizes the need for generating larger ensembles

But dynamical downscaling is computationally expensive; employing hybrid/complementary methods could provide a solution

Hybrid Dynamical-Statistical Approaches for Sampling Uncertainty Space

Muhling et al. (2018):

- Chesapeake Bay surface temperature and salinity predicted using statistical downscaling (i.e., model trees) linked to mechanistic water balance model.



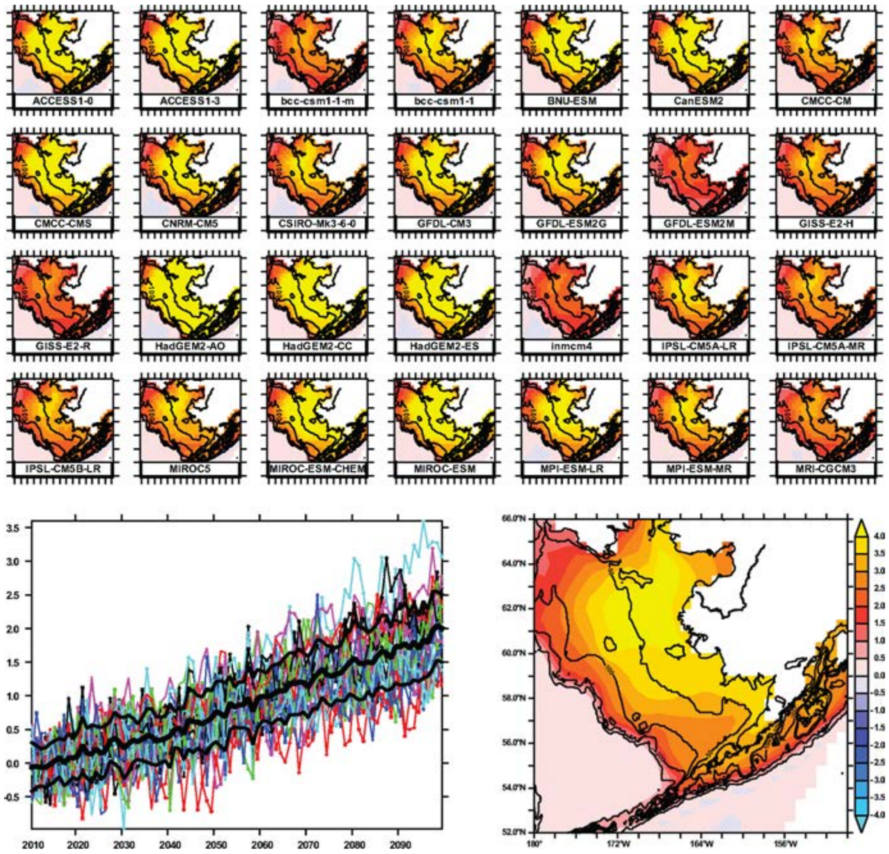
Hybrid Dynamical-Statistical Approaches for Sampling Uncertainty Space

Hermann et al. (2019):

- Identified dominant modes of ocean responses to changes in atmospheric conditions using EOFs and small ensemble of dynamically downscaled projections.

- Projected larger ensemble of GCMs onto these modes, generating additional regional ensemble members and more efficiently spanning a larger range of scenario and model uncertainty.

Change in Bering Sea Bottom Temperature



Summary

Dynamical downscaling is a powerful tool

To go beyond "proof of concept" applications and provide reliable forecasts, we need to sample the range and likelihood of possible conditions. This requires larger ensembles than are typically run to date.

We need to be strategic in using computational resources and consider complementary techniques (e.g., Statistical, Machine Learning) to fill probability space.