Dynamical Downscaling in Service of Living Marine Resource Management

Liz Drenkard
NOAA, OAR, Geophysical Fluid Dynamics Laboratory

Photo Credit: Douglas Alden, SIO
What is Dynamical Downscaling?

Similar to General Circulation Models: solving equations of thermo- and fluid dynamics but in a smaller, higher resolution region.
What is Dynamical Downscaling?

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

Liu et al., 2015

Sun et al., 2012
Exciting Dynamical Downscaling Capabilities

**Atmospheric Coupling**
- wind velocity
- humidity
- precipitation
- air temperature
- heat flux (short/long)
- SST
- sea ice thickness
- sea ice concentration
- albedo
- snow depth

C-Coupler2

- Polar WRF
- MITgcm

**Unstructured/ Stretched Grids**

- Khangaonkar et al., 2019

**Biogeochemical Models**

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

Ren et al., 2021

Danilov et al., 2013
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 WKSICCMCE 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**


**Quo Vadimus**

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


---

Identify LMR-Essential Spatial and Temporal Scales, Features and Environmental Conditions

Synthesize Relevant Projected Large-Scale Climate Changes

Dynamical Downscaling

Assess and Address GCM Biases

Statistical Downscaling (Bias Correction Often Inherent)

Simulate Longer Time-Slices or Full-Transient Regional Projections

Downscale Across the Range of Possible Climate Futures
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*
In order to provide actionable forecasts, we need to represent the range and likelihood of possible conditions/futures.

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

Fraction of Total Variance [%]

Lead Time [Years from 2000]

Hawkins & Sutton 2009
Uncertainty Varies by Field

Global Decadal Mean Surface Air Temperature

California Current Large Marine Ecosystem Sea Surface Temperature Change

Mike Jacox

Fraction of Total Variance [%]

Lead Time [Years from 2000]

Hawkins & Sutton 2009
Uncertainty Varies by Field

Global Decadal Mean Surface Air Temperature

California Current Large Marine Ecosystem Primary Productivity Change

Fraction of Total Variance [%]

Internal Variability

Scenario Uncertainty

Model Uncertainty

Internal

Scenario

Model

Hawkins & Sutton 2009
Toss “bad” GCMs; span variable-dependent uncertainty envelope
Uncertainty Can Also Vary by Location

Sources of Near-term (2016-2035) Uncertainty

Scenario
- Green
Model
- Blue
Internal
- Orange

Frölicher et al., 2016
Sources of Near-term (2016-2035) Uncertainty

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.
Muhling et al. (2018):

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