On the use of IPCC-class models to assess the impact of climate on living marine resources

Effects of Climate Change on the World's Oceans

Workshop W2: Climate Change Projections for Marine Ecosystems: Best Practice, Interpretation and Limitations

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Review

On the use of IPCC-class models to assess the impact of climate on Living Marine Resources

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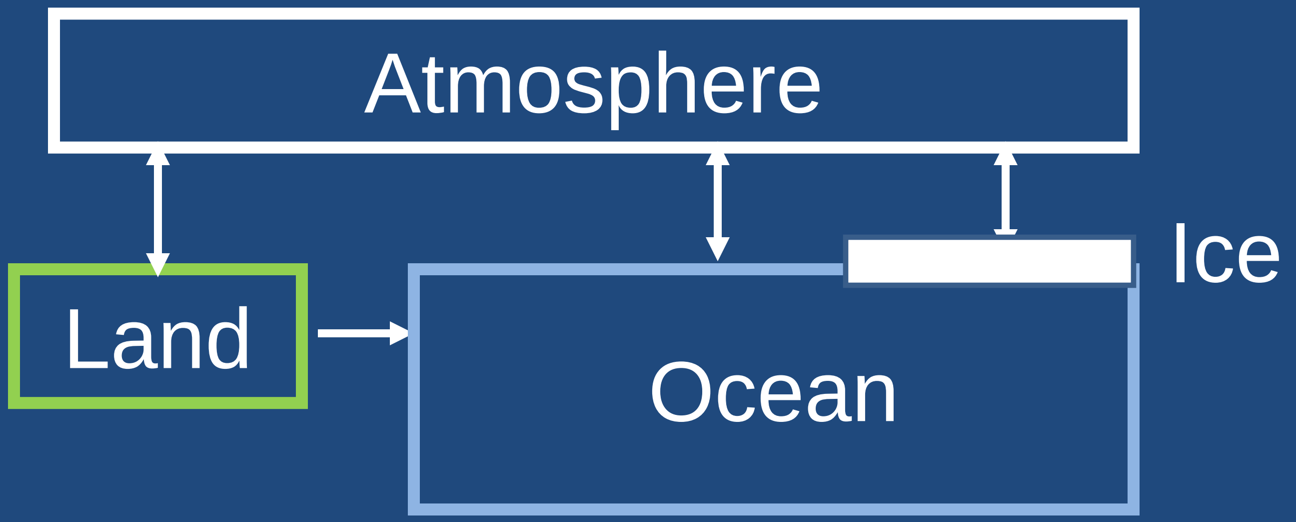
Outline for this talk:

- Challenges in applying climate models to assess the impacts of climate change on Living Marine Resources (LMRs)
- New climate model developments for CMIP5/IPCC-AR5
- Building Living Marine Resource models for climate change impacts projections
- Suggestions for a path foreward

Outline for this talk:

- Challenges for applying climate models assessed by the IPCC to LMR impacts studies
  - Century-scale physical climate projection basics
  - Climate variability versus climate change
  - Model biases and inter-model spread
  - Coarse climate model resolution

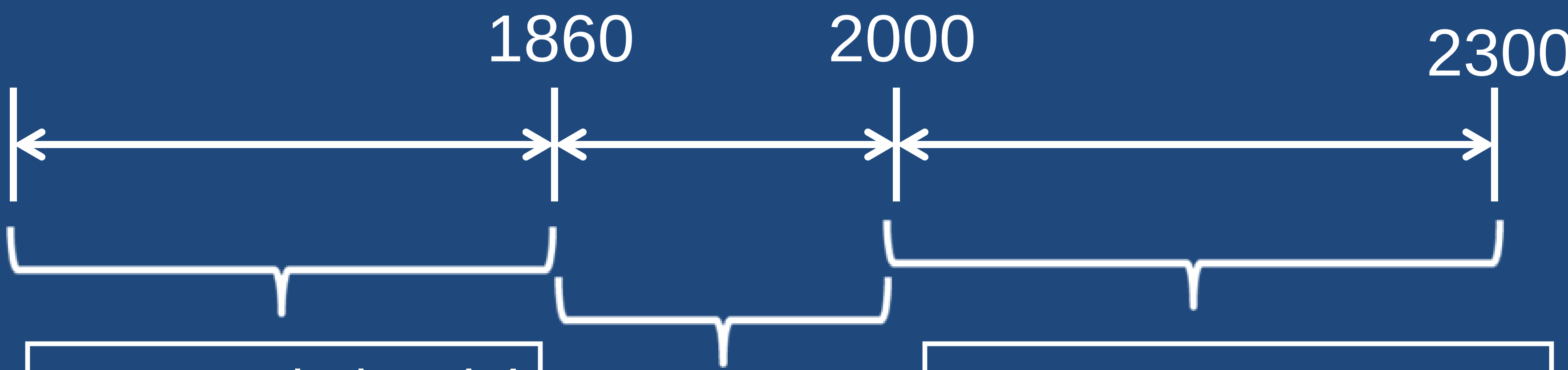
Century-scale physical climate model projections



Objectives:

- Simulate and understand the causes of historical climate change (1860-present)
- Make global projections of climate change over the next century, including and estimate of uncertainty.

Century-scale climate model projections



Long pre-industrial control: Greenhouse gases set to 1860 levels, run for multiple centuries to allow climate to settle into a quasi-equilibrium

Historical period forced by observed GHG's, volcanoes, and solar forcing etc.

100-300 year projection under different scenarios for future greenhouse gas emissions

Implications of experimental design

- The only aspects of the historical simulation that link it to a given year are the solar insolation at the top of the atmosphere, volcanoes, greenhouse gases, and aerosols.

- The statistical properties of climate variability may be captured by a model, but it will not be "in phase" with the historical record.

Century-scale climate projections provide weak constraints on climate in the next decade

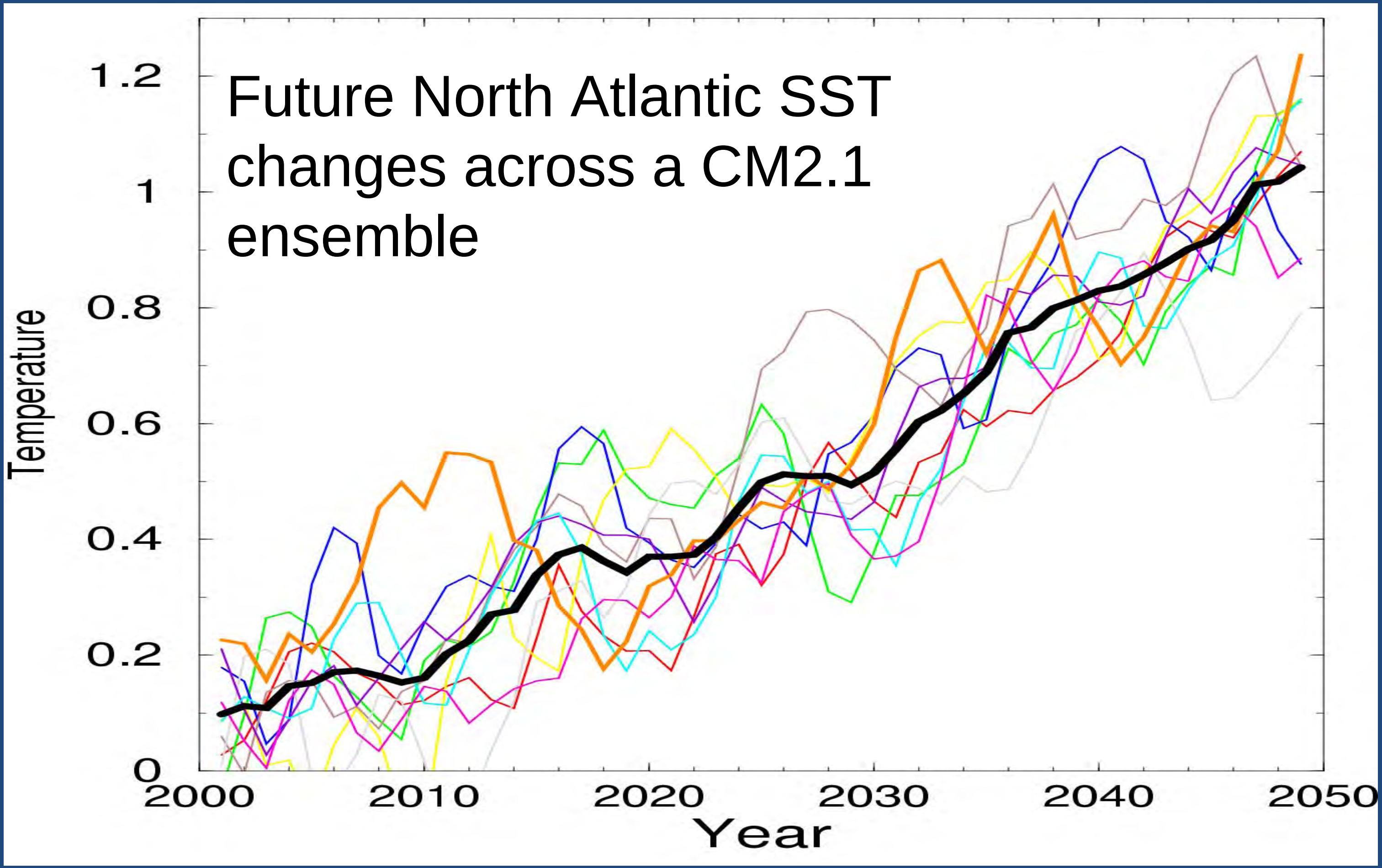
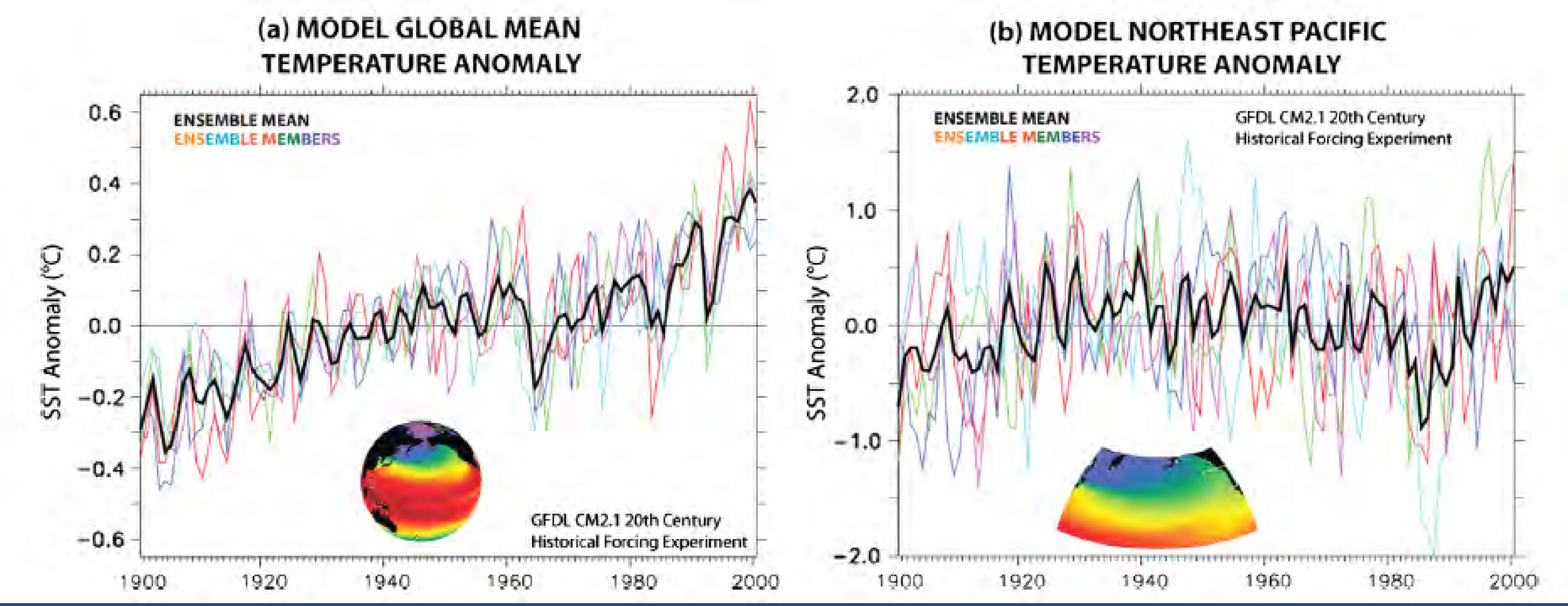


Figure courtesy of Tom Delworth/GFDL Climate Change Variability and Prediction Group

Variability is generally more prominent at regional scales



Stock et al., 2011, Prog. Oceanogr. 88, 1-27

Climate variability in century-scale physical climate models

- Many climate models produce realistic representations of prominent modes of climate variability
- Can use climate change projections to study climate variability, but don’t expect to be “in phase” with observed variability
- Ensemble means and focusing on differences between multi-decadal averages across century time-scales helps isolate the climate change trend

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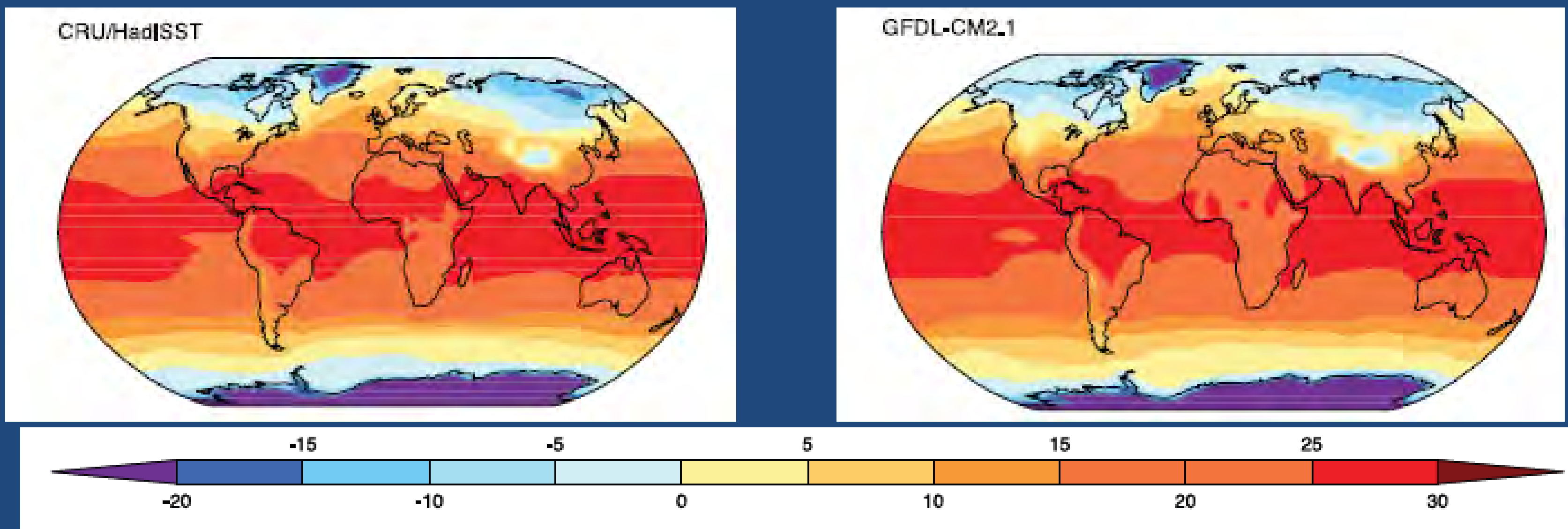
Large-scale distributions of many physical climate variables are captured by climate models

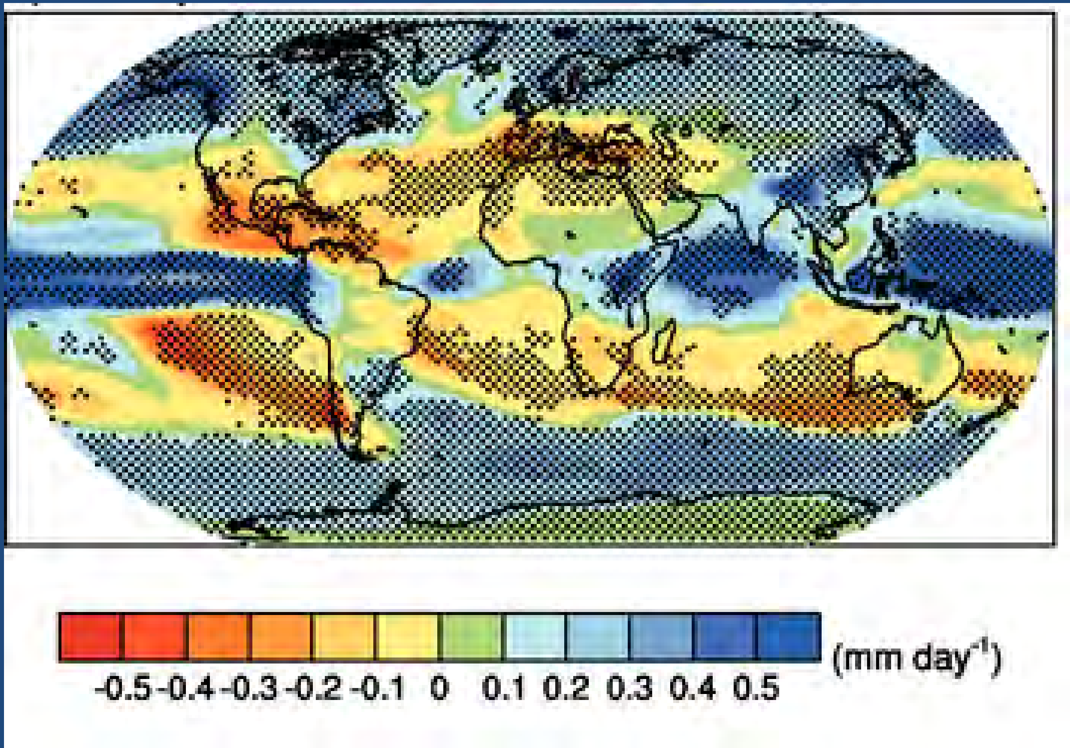


-20 C Temperature 30 C

Source: IPCC AR4 WG1 report, chapter 8

Climate models agree on many broad-scale climate changes over the next century

Precipitation change, A1B, 2080-2099 – 1980-1999

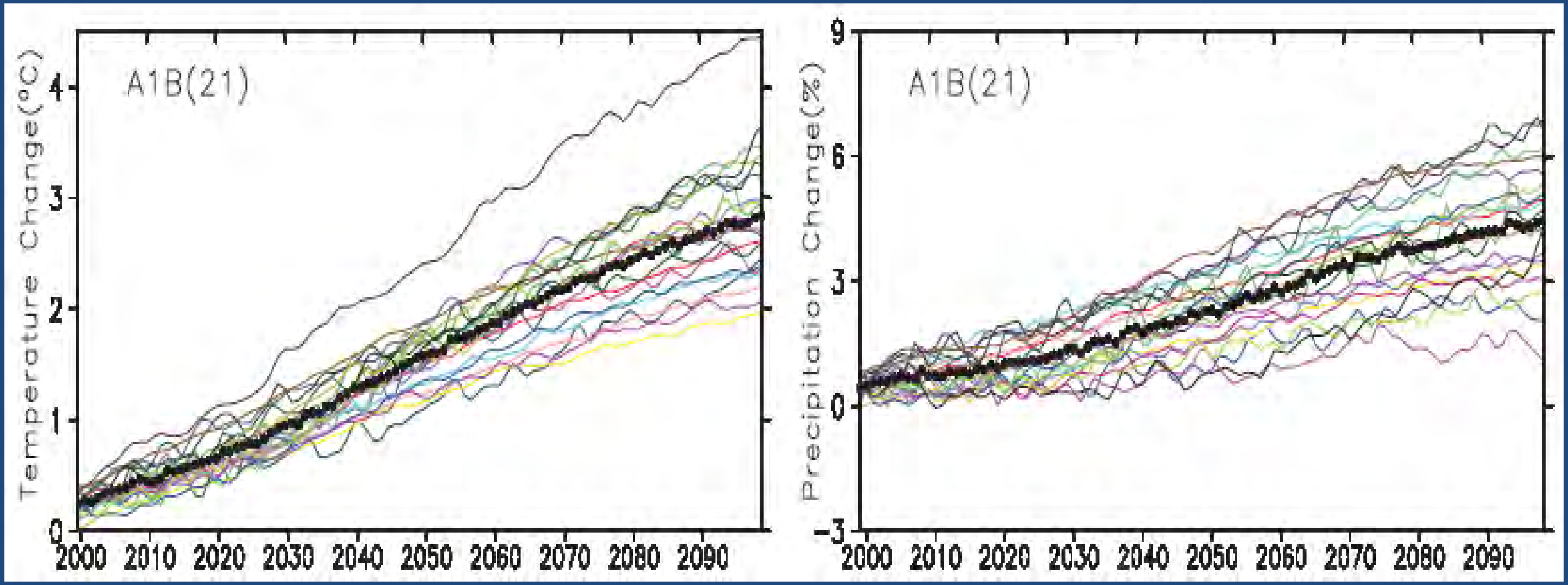


Stippling in places where at least 80% of models agree on sign of change

Meehl et al., Chapter 10, IPCC AR4 WG1 Report

Climate model projections can have considerable inter-model spread

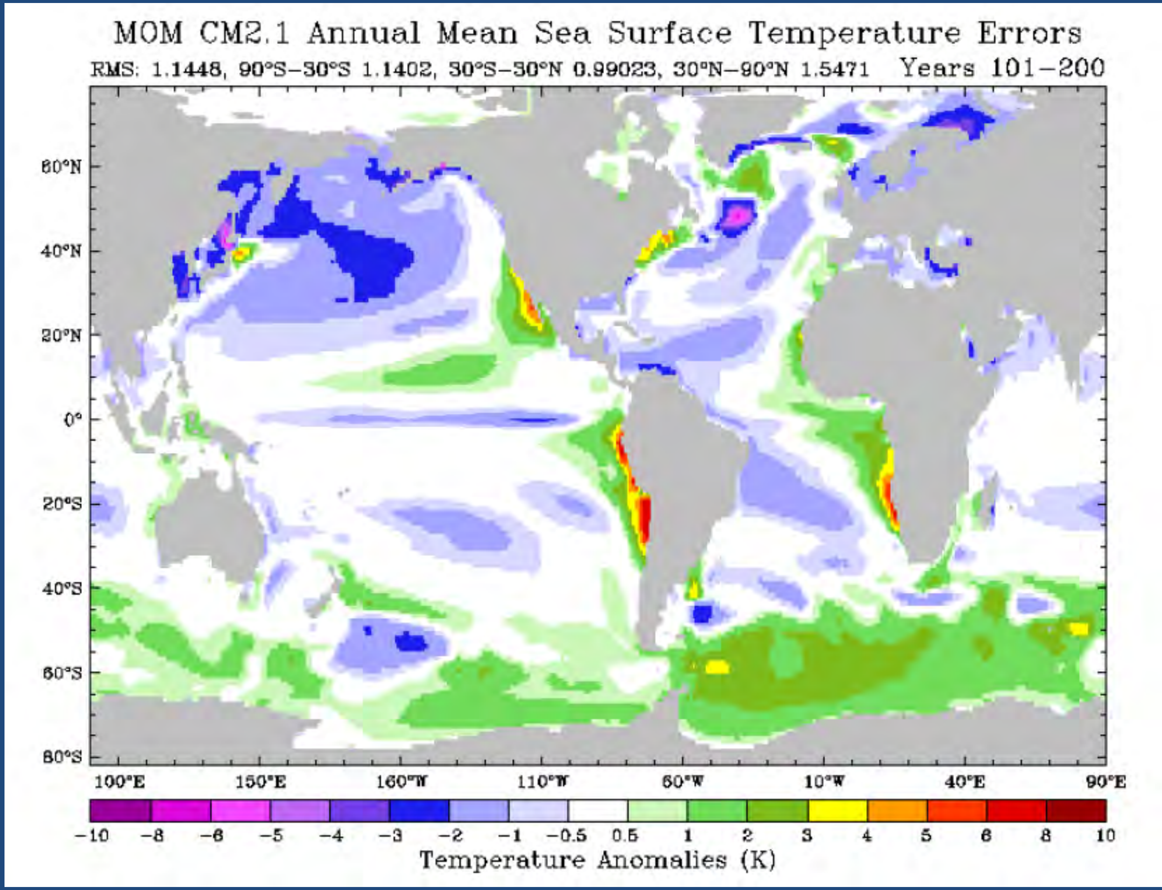
Global Temperature　　　Global Precipitation



Considering a multi-model ensemble of solutions is critical for estimating uncertainty, but detailed diagnosis of single models essential for diagnosing mechanisms

Meehl et al., Chapter 10, IPCC AR4 WG1 Report

Substantial biases may exist at regional scales



Bias corrections or applying projected changes to observed climatology provide ways forward, but it will take continued improvements to climate model dynamics to fully address this issue.

Stock et al., 2011, Prog. Oceanogr. 88, 1-27

Should I weight models based on skill metrics?

- Active area of research that could reduce uncertainty due to inter-model spread
- No accepted method - many cases where a model's ability to match contemporary regional features was unrelated to a model's ability to match the warming trend (don't draft a pitcher to be a hitter)
- Present default is not to weight, though some "culling" of highly aberrant simulations may be necessary (e.g., Overland et al., J. Climate, 24(6) 2011)

Stock et al., 2011, Prog. Oceanogr. 88, 1-27

Should I weight models based on skill metrics?

- If you do weight, weighting choices should be discussed as a prominent scientific aspect of the work and ideally justified on empirical and theoretical grounds

Stock et al., 2011, Prog. Oceanogr. 88, 1-27

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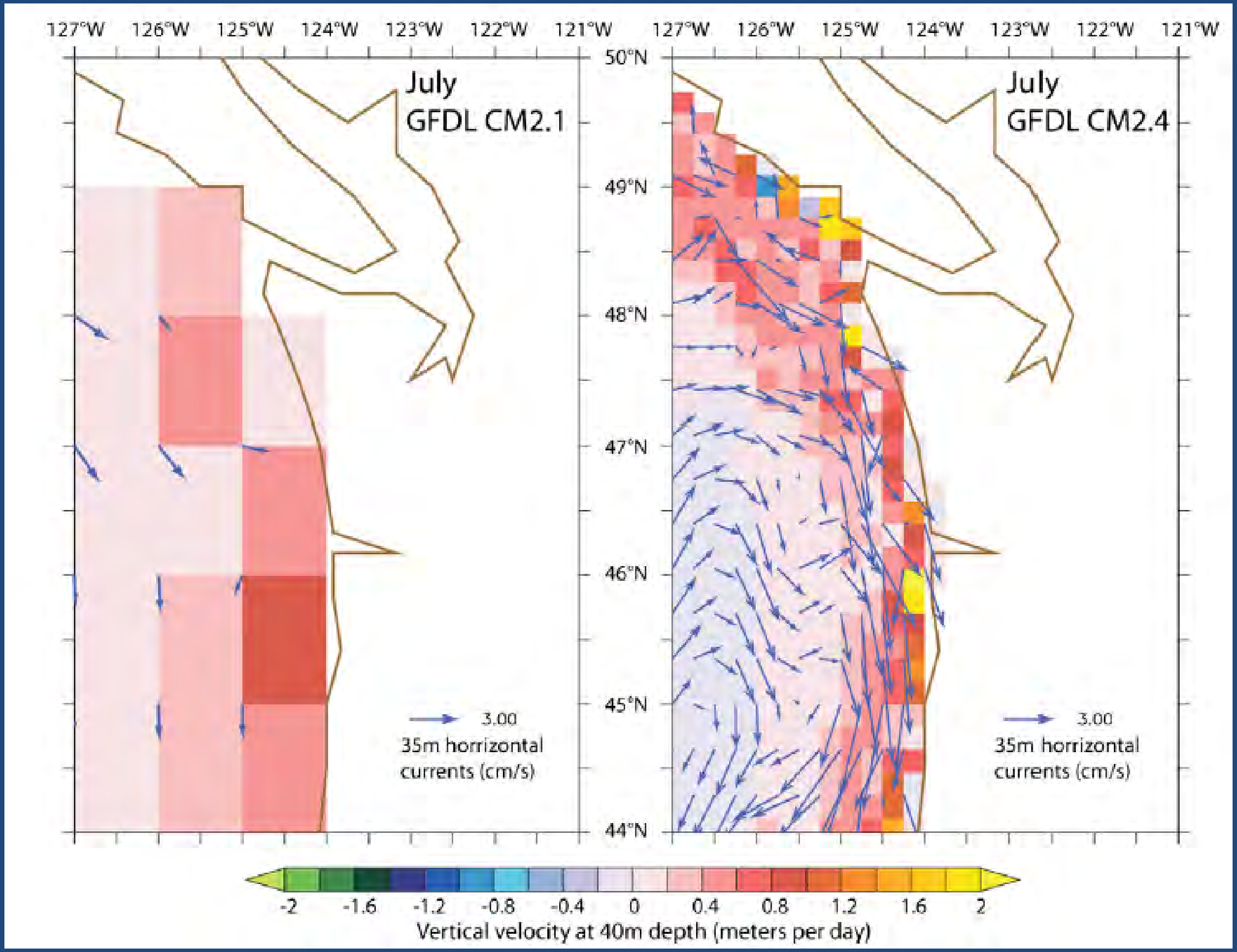
The ocean model resolution of most climate models is ~1-2 degrees; atmosphere is ~2-3 degrees



Stock et al., 2011, Prog. Oceanogr. 88, 1-27

Statistical downscaling

- Rely on statistical relationships between resolved, larger-scale features and unresolved finer-scale features.
- Relatively low computational cost but:
  - Must assume stationarity in the statistical relationship
  - Selecting relevant predictors can be difficult – multiple predictors may work equally well (e.g., Vecchi et al, 2008, Science, 322).
  - Requires long observational time series to establish relationships

Stock et al., 2011, Prog. Oceanogr. 88, 1-27

Is it sensible to add the projected changes from a coarse climate model to finer-scale regional climatologies when assessing the magnitude and direction of potential climate changes?

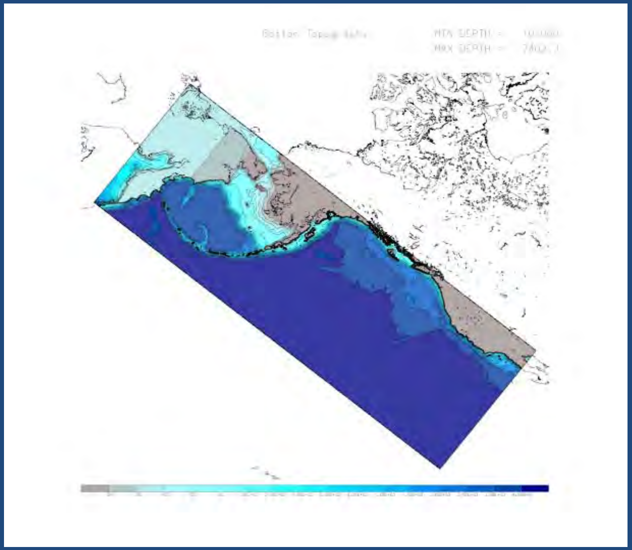
- Projected change can be thought as the product of two things:
  - A large-scale signal driven by radiative changes linked to greenhouse gases and aerosols
  - Changes in local dynamics
- Climate models can capture the first part, but have very limited representations of the second.

Stock et al., 2011, Prog. Oceanogr. 88, 1-27

Key question:

Is there a significant regional-scale dynamical feedback that may significantly alter (or reverse) changes resulting from perturbations to the large-scale radiative forcing?

Dynamical downscaling to translate basin-scale dynamics to shelf responses



Slide courtesy of K. Hedstrom, E. Curchitser

- One-way nesting decouples regional and global, two-way allows feedbacks
- Still subject to large-scale global model biases
- Biogeochemical Boundary conditions are dynamic (Rykaczewski, S3, Thursday)
- Inconsistencies between nested and global runs complicate interpretation
- Two-way nesting creates a new climate model.

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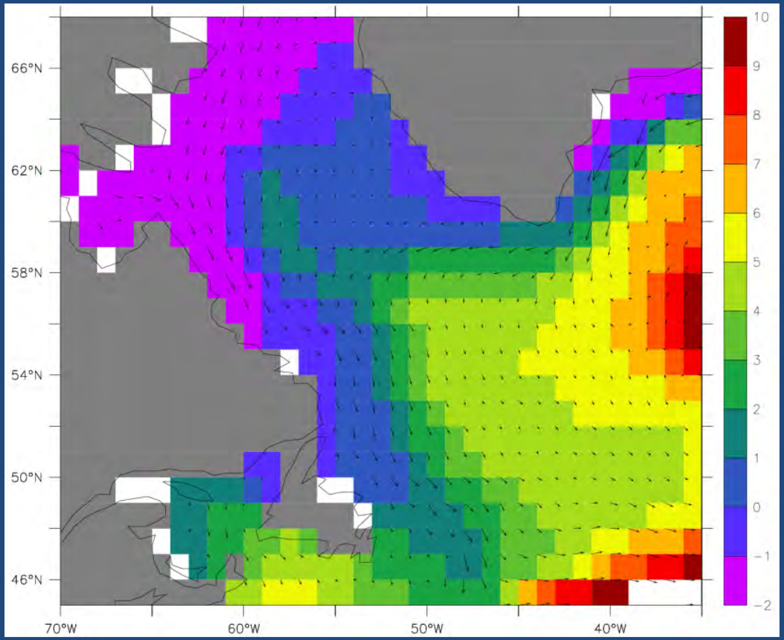
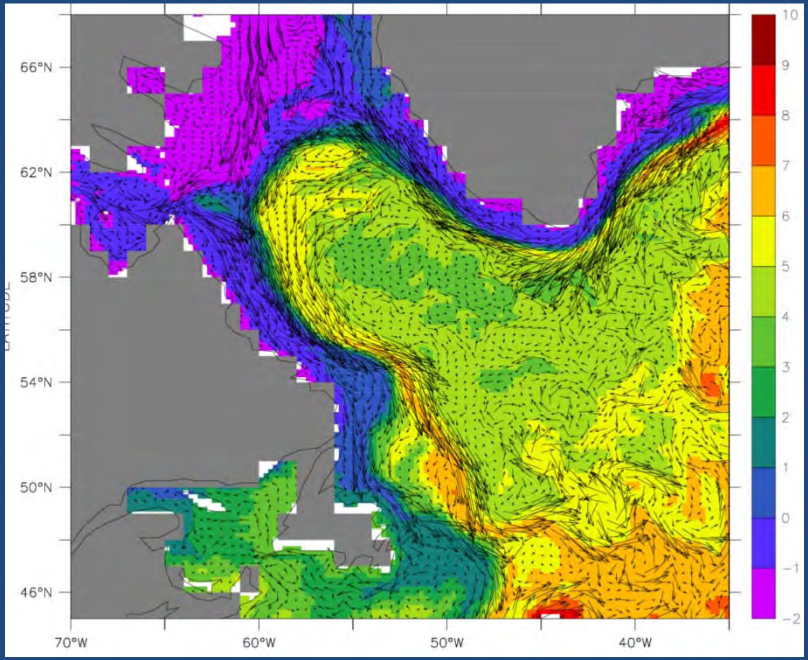
Refined resolution Climate models





It is becoming increasingly feasible to run long time-scale climate simulations at resolutions ~0.25 deg. In the ocean or higher

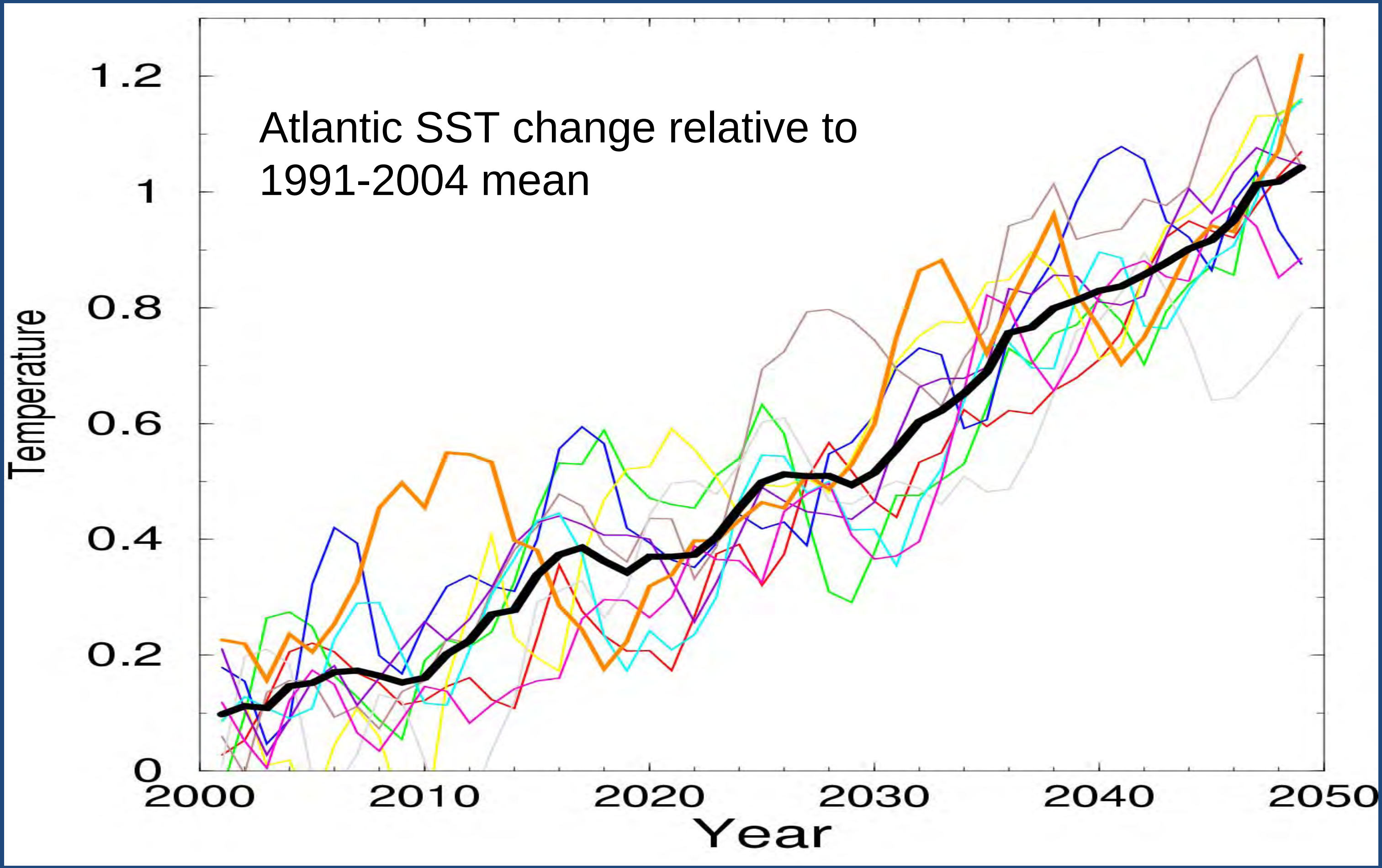
Refined resolution AOGCMs

- Could fundamentally improve the resolution of shelf-scale processes and basin-shelf interactions in climate models
- Computational costs increase with the cube of horizontal grid refinement
- Processes that were once sub-grid scale are now resolved: parameterizations must be reformulated; some large-scale features may look worse.
- May address some biases, but not all biases rooted in resolution.

While more refined-resolution simulations (~1/8-1/4 degree) will be available in IPCC AR5, most will have resolutions similar to those in IPCC AR4.

Stock et al., 2011, Prog. Oceanogr. 88, 1-27

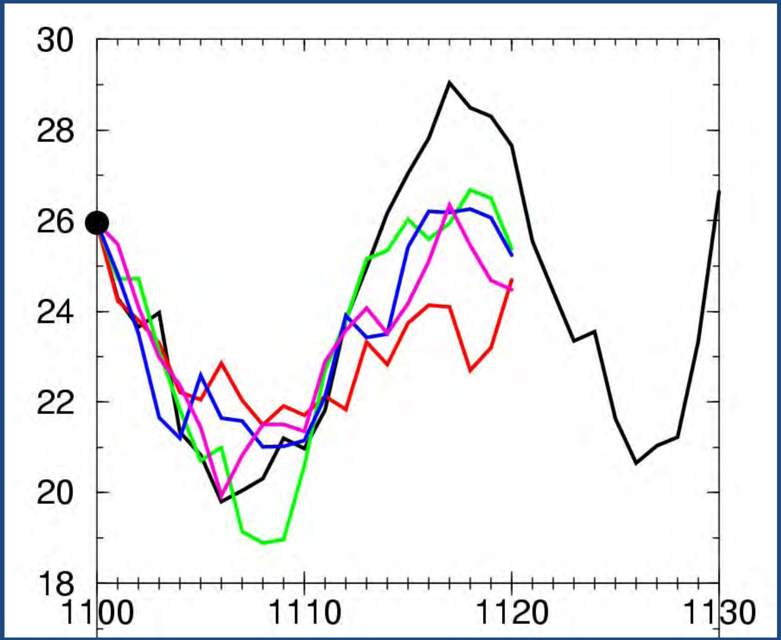
Decadal prediction experiments: Can we predict which trajectory the real climate system will follow?

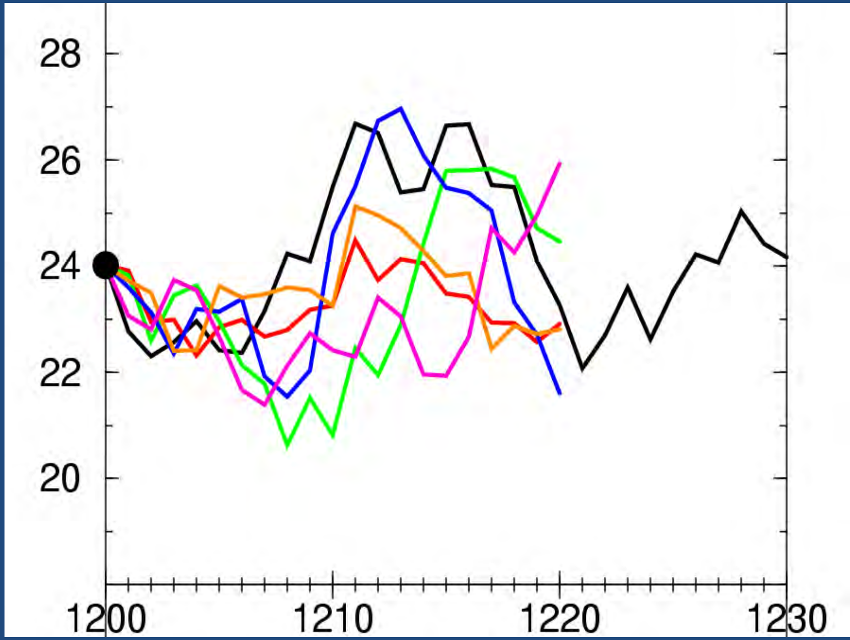


Figures courtesy of Tom Delworth/GFDL Climate Change Variability and Prediction Group

Some early examples that provide grounds for optimism and humility

Atlantic meridional overturning circulation (Sverdrups) in GFDL CM2.1

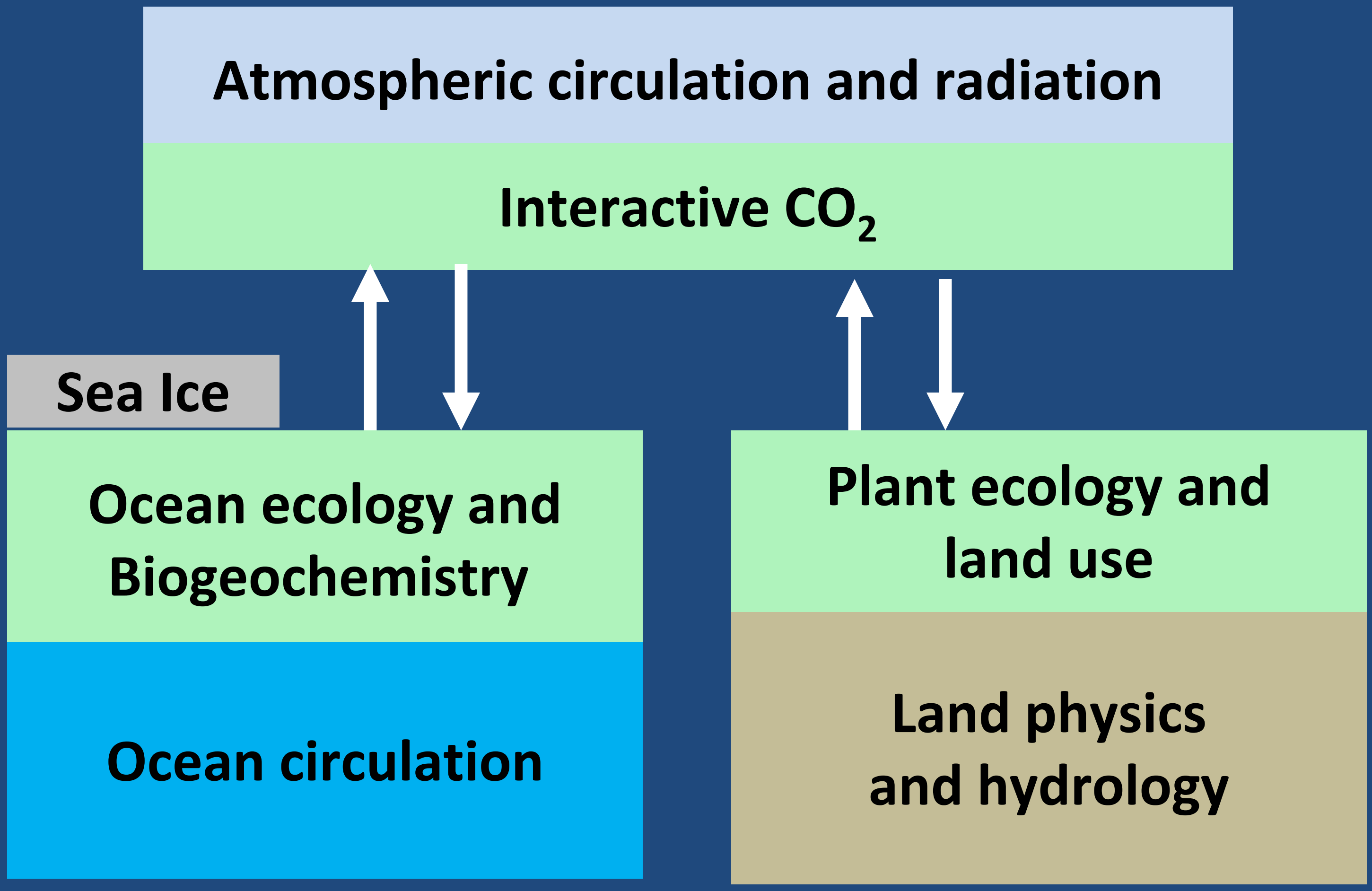




See Keenlyside S3 plenary (Thursday, S3 @ 14:00) for the latest results

Figures courtesy of Tom Delworth/GFDL Climate Change Variability and Prediction Group

Earth System Models: incorporating the biosphere to track carbon exchanges



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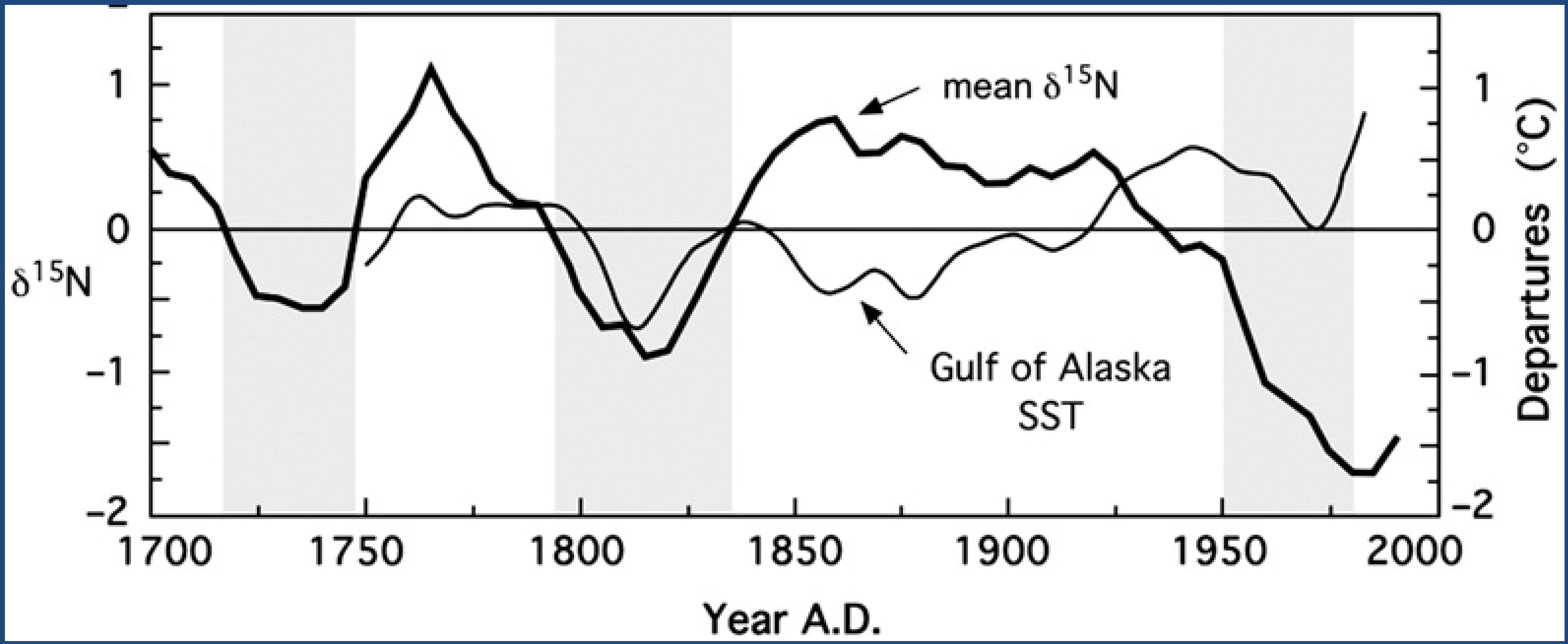
LMRs are complex climate integrators

- Environmental conditions affect LMRs in many ways and effects propagate through complex food webs
- Interactions occur over a large range of interacting scales
- Potential for evolutionary responses that are not well understood
- Responses are often neither gradual nor linear

Botsford et al., Science, Vol. 277, 509-515.

Climate change will create conditions that will generally not have past analogs

Relationship Between Temperature and Sockeye Salmon in the Gulf of Alaska



Finney et al., 2010, Journal of Marine Systems, 79, 316-326

Why do we trust climate model projections?

"There is considerable confidence that climate models provide credible quantitative estimates of future climate change, particularly at continental scales and above. This confidence comes from the foundation of the models in accepted physical principles and from their ability to reproduce observed features of the current and past climate changes."

Randall et al., 2007 (Chapter 8 of IPCC WG1 Report)

Why should we trust ecosystem projections?

- Foundation of models on accepted ecological and physiological principles

- Ability of models to reproduce observed features of the LMR response to current climate and past climate changes

Stock et al., 2011, Prog. Oceanogr. 88, 1-27

Steps toward more robust LMR models for climate/LMR projections:

- More mechanistic LMR models rooted in physiological and ecological principles
- Correlative relationships should have strong mechanistic underpinnings that can be assessed under different climate conditions.
- It may be necessary to consider multiple plausible models (i.e., an LMR model ensemble)
- Sustained time-series and focused process studies are needed to build and test models

Stock et al., 2011, Prog. Oceanogr. 88, 1-27

Support a two-pronged approach articulated by Hollowed et al. (2009):

- Progress can be made by incorporating climate information into existing simple to intermediate-complexity models (being particularly mindful to avoid highly-empirical relationships w/o mechanistic underpinnings)
- Continued efforts to develop, constrain, and couple comprehensive end-to-end models with climate models

Hollowed et al., a framework for modeling fish and shellfish Responses to future climate change, ICES J of MS 66, 1584-1594

Predicting climate change impacts multiple decades into the future is an uncertain business….

- Any climate-ecosystem impacts study will be subject to criticism on grounds of uncertainty.
- Desire for greater certainty must be balanced against the need for incremental progress.
- Scientific merit must be gaged relative to the extent of previous knowledge and frank acknowledgement and discussions of uncertainties where they exist.

Stock et al., 2011, Prog. Oceanogr. 88, 1-27