Future Imperfect: The Mid-Pliocene Warm Period as Analog for the Coming North Atlantic

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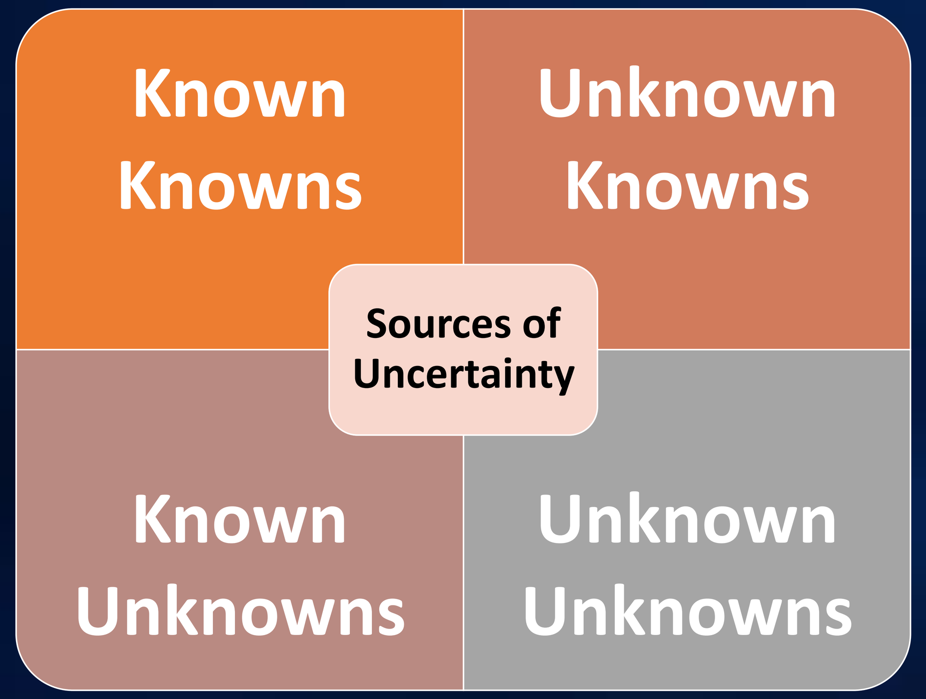
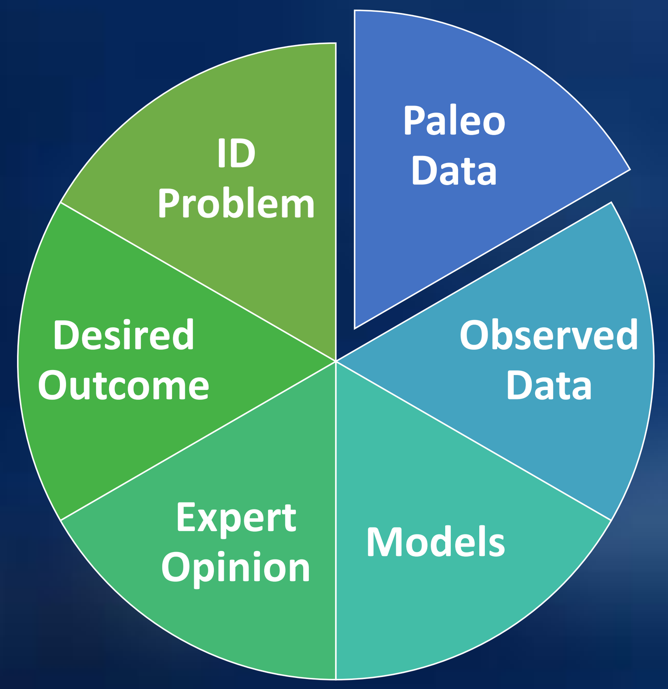
How Can Paleoclimate Data Inform Future Policy?

A fundamental part of successful decision-making is correctly identifying sources of knowledge and ignorance. Decision-makers understandably focus on putting to work the knowledge in hand, as well as identifying uncertainty arising from answers they know they don't know and questions they aren't even aware of yet, i.e. the so-called "unknown unknowns". Equally important is uncertainty introduced by a failure to correctly incorporate all sources of existing knowledge that might be relevant to the problem, i.e. eliminating "unknown knowns". Paleoclimate data that have direct or indirect applicability to policy questions, but remain untapped as a source of information, represent an instance of such unknown knowns.



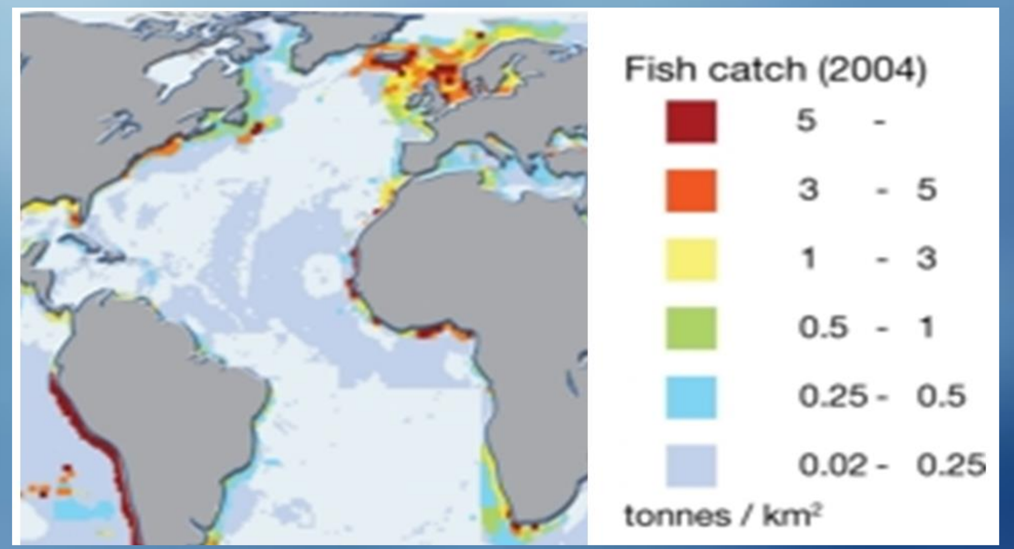
Left: Sources of knowledge and ignorance interact to produce areas of uncertainty for decisionmakers. Paleoclimate data can often go unused, a source of "unknown knowns" that could benefit policymakers. **Right**: Paleoclimate data complements traditional decision-making concerns.



Although past instances of enhanced greenhouse warming exist, differences in other boundary conditions (e.g. continent position) complicate direct comparisons. The mid-Pliocene Warm Period (mPWP) occurred recently enough (~3 mya) that such boundary conditions are broadly similar to our own, while greenhouse gas (GHG) levels were similar to those expected in the near future. The mPWP thus offers a "ground truth" of the response of the climate to elevated GHG levels, independently of climate models. Including information about the response of mPWP to GHGs provides a wider breadth of knowledge about the magnitude and uncertainty of future change for making policy.

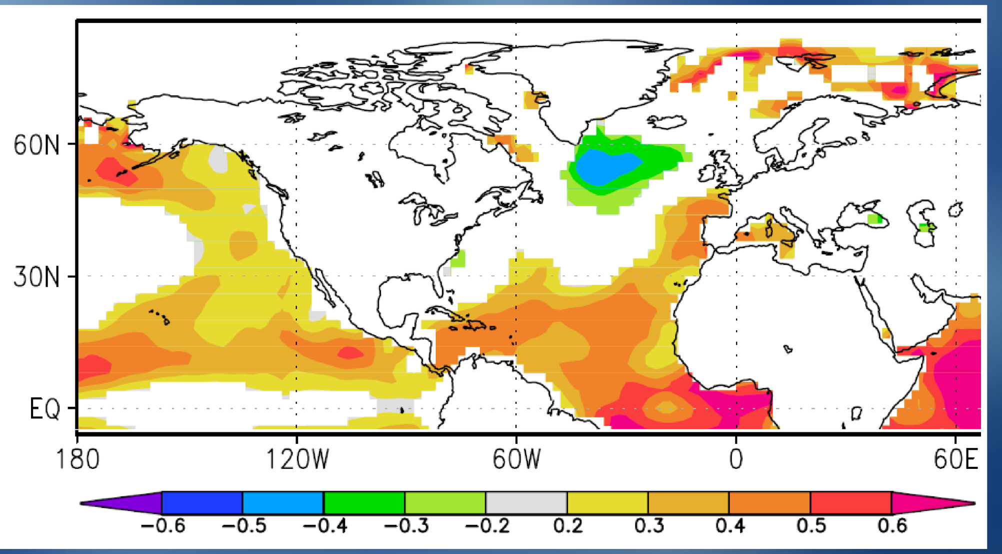
North Atlantic Fisheries under Climate Change

$ The North Atlantic represents a highly valuable region for global fisheries production, with annual catches exceeding 5 tonnes/km² in some areas. A number of studies have described declines across many North Atlantic fisheries, ranging from the collapse of Atlantic cod to perhaps all predatory fish. Overharvesting, climatic variability, regulatory changes, and other drivers have been invoked to explain these reported declines. Effective fisheries management is required to ensure the recovery and/or maintenance of North Atlantic stocks. Such effective fisheries management in the North Atlantic must necessarily consider the potential impact of climate changes due to anthropogenic emissions of greenhouse gases, such as changes in sea surface temperatures (SSTs), salinity (SSS), and dissolved oxygen (DO).



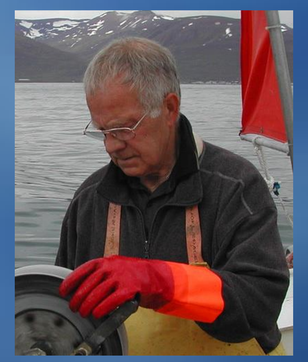
Annual catch (tonnes/km2) from global fisheries (Ahlenius, UNEP/GRID-Arenda 2008).

? Despite this need for informed policy, uncertainty about climate change in the region persists. Models, while skillful in modeling the climate at global scales, often have difficulty realistically simulating regional-scale behavior. The models fail to accurately reproduce North Atlantic SSTs over the instrumental record, indicating potential biases that can affect projections forward in time. Additionally, model results can differ greatly from evidence derived from paleoclimatic proxy-based reconstructions of our climatic past. The reconstructed North Atlantic climate of the mPWP (~3mya) differs markedly from model simulations, even after model-observation bias correction. Models underestimate warming in the region by several degrees Celsius. Policy based on climate models alone will dramatically underestimate the potential magnitude and uncertainty of change for the region.



Correlation between CMIP3 (A1B multi-model mean) and observed Jan. SSTs, from 1901-2000. An especially large mismatch in the North Atlantic exists.

Who Benefits from Including Paleoclimate Data?



Gieri
Iceland
Fisherman

Gieri is an independent fisherman nearing the end of his working career. Declining catches and a general lack of interest in fishing among family members makes him concerned about the prospects of anyone continuing the business. Gieri is considering selling his boat and gear, but would prefer to pass the business on to a relative. Gieri has heard that the warming ocean will bring more fish from lower latitudes to the relatively cooler waters of Iceland, which is a happy prospect. But these fish may have different habits and require different gear than the fish he catches now. The new fish might outcompete the traditionally caught fish in his area. How the fish community in his area responds to warming is therefore of great interest to Gieri.

Maria
Greece
Policymaker

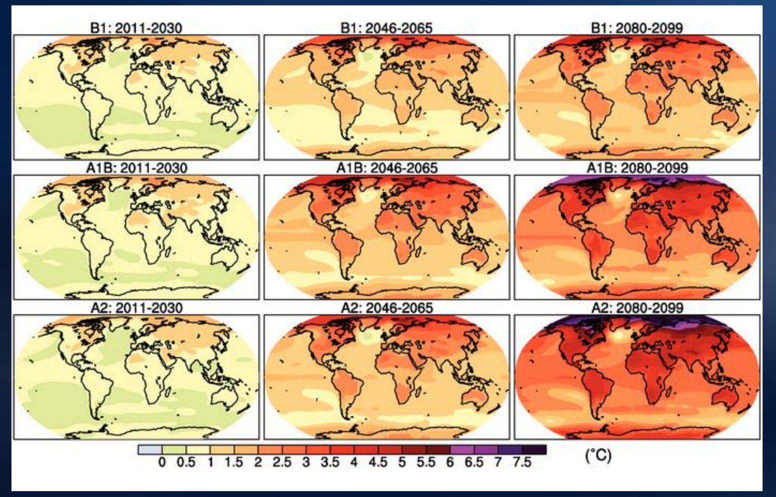
Although Maria is not from a North Atlantic nation, she is a Fisheries Minister for an international, intergovernmental body regulating fishing. Maria negotiates with member nations over the amount of fish that can be safely caught while preserving the stocks (TAC), which requires balancing competing and at times conflicting desires from scientists, industry groups, and governments. Maria is aware of the impact of non-fishing pressures on fishing stocks, such as variability in climate. She fights to ensure that such variations in stocks aren't confused for successful recovery from overfishing. Maria is trying to ensure that the new human influence on the climate is likewise taken into account when setting appropriate catch limits.

Fatou
Senegal
Student

Fatou's family, like many others in Senegal, has moved to the coast to try to improve their lives by joining the relatively productive fisheries industry. Fatou's father complains that corrupt officials are selling illegal leases to foreign industrial fishing trawlers, which are decimating the artisanal fisheries. Although organizations like the one Maria is running know this illegal leasing is a problem, progress in reducing it has been slow. Like Gieri, Fatou knows that the warming oceans might lead to fish moving to cooler waters, outside of the range her father and brothers can effectively fish. Fatou has also heard her brothers worry about whether this will result in even more illegal leases to the foreign fishers, as everyone races to catch the fish before they move away

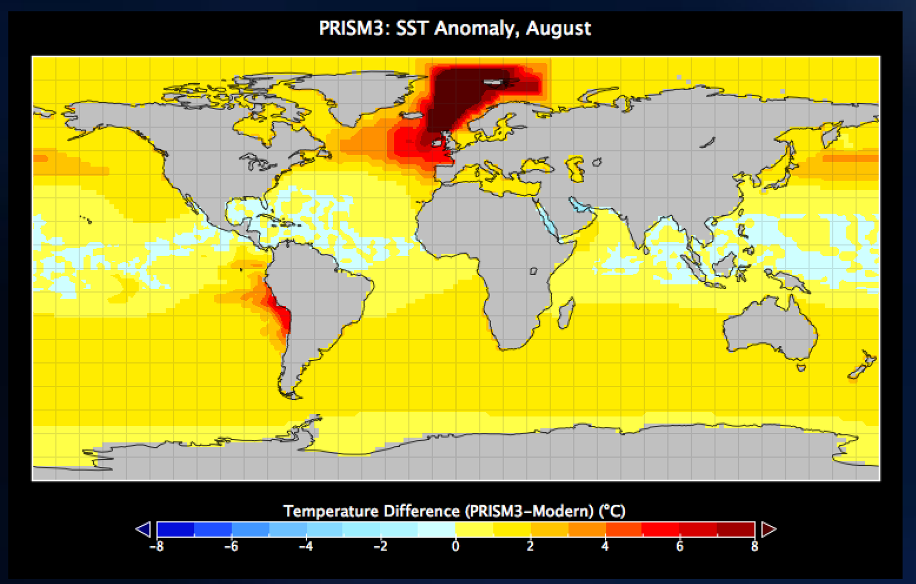
Climate Model and Mid-Pliocene Ocean Data

CMIP3 (Third Climate Model Intercomparison Project).
The Third Climate Model Intercomparison Project (CMIP3) was created to collect and store coupled ocean-atmosphere general circulation modeling experiments for preindustrial, 21st century, and 22nd century periods. This archive consists of model output from the major climate modeling centers around the world, and is the same data used in the creation of the IPCC's Fourth Assessment Report. Data are available for individual realizations of model experiments with differing initial conditions, as well as "multi-model mean" averages across all realizations from all models, which emphasizes the forced component of climate over time and smooths out model error and high frequency variability. Output for SST, SSS, and DO for preindustrial and 22nd century (using the A1B emissions scenario) will be used.



CMIP3 projections of increases in global surface warming under three emissions scenarios (IPCC AR4, 2007).

PRISM (Pliocene Research, Interpretation and Synoptic Mapping)
Much of our present understanding of the mPWP is due to the work of the Pliocene Research, Interpretation and Synoptic Mapping (PRISM) project. The PRISM project is a multi-institutional effort led by the U.S. Geological Survey, in collaboration with institutions in the US and UK. The most recent products from PRISM are the PRISM3 and PRSIM3D reconstructions. PRISM3 is a global SST reconstruction, based on data from ocean, sea ice, and vegetation multiproxy records. PRISM3D represents a marked advancement over previous reconstructions in that it also incorporates deepwater ocean proxy data, and thus creates a three-dimensional ocean field. mPWP data for SSS and DO will be created using relationships between these variables and SSTs and sea ice from modern observations and PlioMIP simulations.



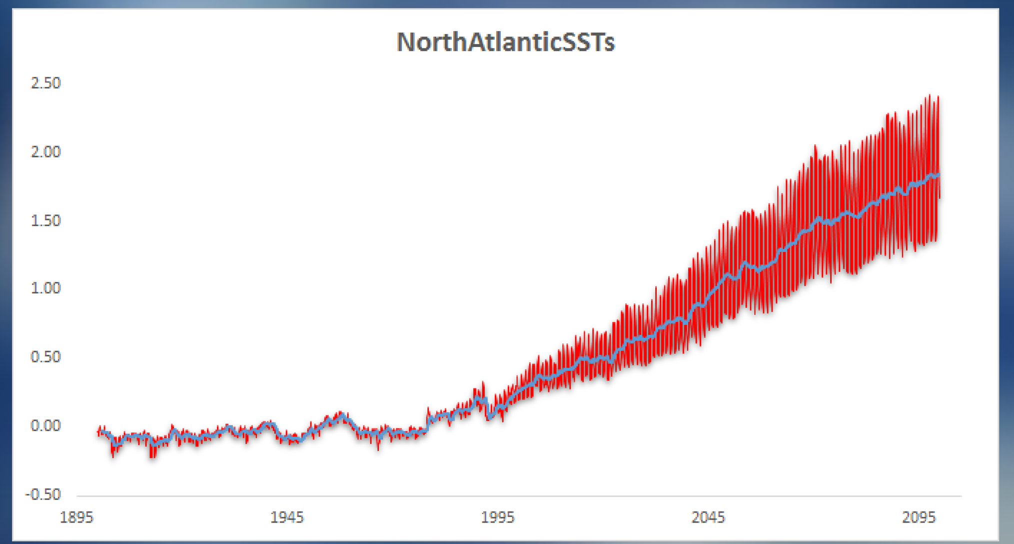
Reconstructed Mid-Pliocene August SSTs relative to modern temperatures. Data from the PRISM3 reconstruction.

Modeling Alternative Oceans and Fisheries

Given the sizeable discrepancy between climate model simulations of the North Atlantic versus both observations and paleoclimatic reconstructions, policy based on model projections alone may underestimate the magnitude of change the region faces in future decades. We propose to force an Ecopath with Ecosim (EwE) fisheries model from the North Atlantic with data from climate model projections, as well as mPWP conditions obtained from proxy data.

Changes in fisheries in response to four alternative North Atlantic oceans will be simulated in EwE:

1) A "control" using CMIP3 preindustrial conditions; 2) a CMIP3 projection of future (A1B scenario) warming; 3) mPWP boundary conditions obtained from the PRISM3 reconstruction; and 4) a hybrid of the climate model output and PRISM3 data. The control simulation will be used to identify potential baseline changes associated with natural variability, which can occur irrespective of which "future" the coming North Atlantic actually resembles. The hybrid CMIP3-PRISM3 simulation will be performed to identify potential differences between transient and equilibrium responses to mPWP-like warming. Exploring the impact of these different potential futures on fisheries can provide policymakers with a broader range of potential oceanic and fisheries impacts from climate change, against which they can design and evaluate management policies. We anticipate greater spatial reorganization of, as well as changes in abundance in, temperature-sensitive species (such as Atlantic cod) in the simulations making use of mPWP data relative to the CMIP3-only forced runs. We also anticipate greater changes in overall fisheries composition under mPWP-informed runs due to greater increases in SSTs. Although these simulations are intended to be physically plausible, due to the inherent dissimilarity of comparing stable mPWP boundary conditions to climate model responses to a specific mix of radiative forcings over a relatively short time period, these simulations are intended to provide a qualitative exploration of the impact of incorporating paleoclimate data, rather than quantitative forecasts of the future.



Projected increase in North Atlantic SST anomalies under A1B emissions scenario, CMIP3 multi-model mean.

Proposed Analyses of Modeling Results

In order to evaluate the differences between simulated scenarios in the EwE model, we propose the following analyses:

ANOVA: Geochemical (i.e. SSTs, SSS, D.O.) ocean data as well as fish community profiles (i.e. relative abundance and relative biomass) will be analyzed using ANOVA. ANOVA will be used in lieu of t-tests in order to reduce the chances of introducing Type I errors. As ANOVA assumes normality, the relativized fish data will be log-transformed. In order to generate multiple "samples" from each scenario, the Monte Carlo function in EwE will be employed, and parameters will be varied by 10 %.

SIMPER: The species most important to the composition of the community profiles will be identified through Similarity Percentage (SIMPER). This analysis will be supported by general linearized model analysis, such as the "manyglm" R package, in order to detect known potential problems SIMPER has in discriminating between highly variable vs. important species. Student's t-tests will be performed to identify potential differences in biomass and abundance of identified important species across simulations.

nMDS: Another method of assessing the structure of any differences between the fish community profiles is the application of non-metric Multi-Dimensional Scaling (nMDS) analyses. cause spurious increases or decreases in dissimilarity tests. Plotting the results of nMDS can also clearly demonstrate (dis)similarity among different groups, conveying the information in a way that is more intuitively understood by policymakers relative to numeric results from statistical testing.