Model-based Predictions and Projections of North Atlantic Climate Variability and Change

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1. **Overview of GFDL and climate models**
2. **GFDL seasonal to multidecadal predictions & projections with "SPEAR"**
3. **Decadal to multidecadal projections of the AMOC and climatic impacts**
4. **Summary**

GFDL: Geophysical Fluid Dynamics Laboratory, part of OAR (Oceanic and Atmospheric Research)

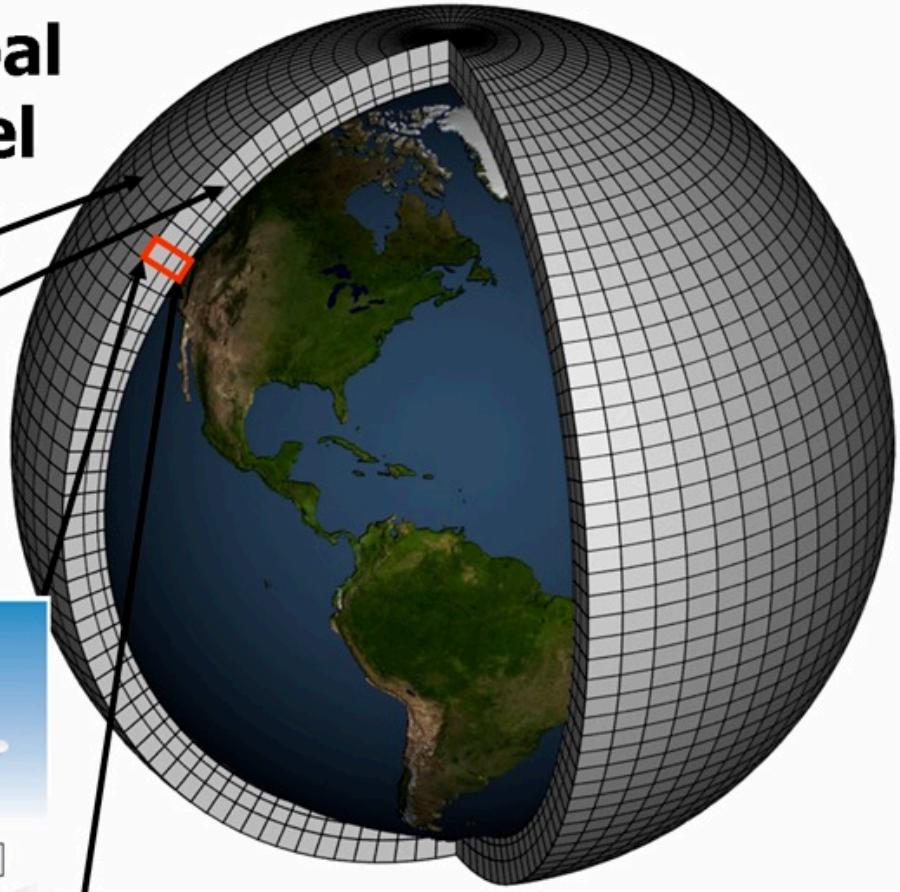
➔ Focus on building and using computer models of the Earth System to both improve our understanding of how the Earth's climate system works and to improve predictions on weather to climate change time scales

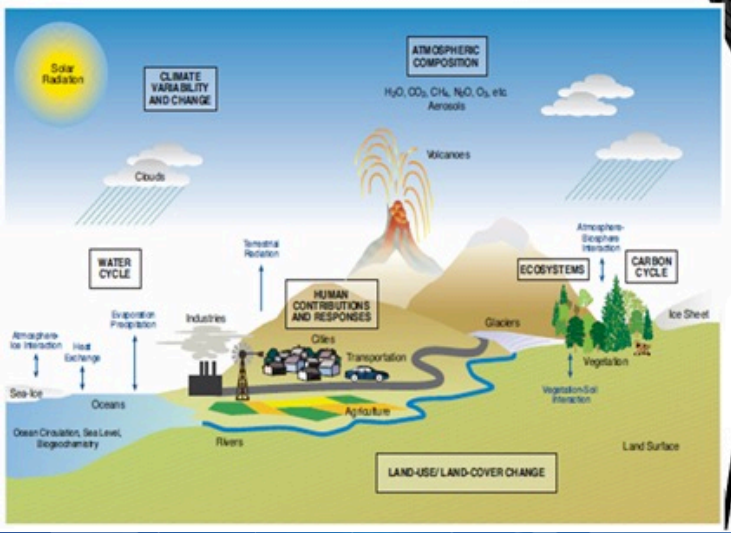
Located in Princeton, NJ

Schematic for Global Atmospheric Model

Horizontal Grid (Latitude-Longitude)

Vertical Grid (Height or Pressure)





Within each grid cell, solve equations:
- conservation of momentum, mass, energy
- chemical reactions, radiative transfer

Some key considerations:

Size of grid box for ocean (varies from 200 km 3 km, depending on computer)

Is the ocean model “coupled” to an atmosphere model?

➔ **Small-scale oceanic processes (eddies, topographic effects, etc) may not be well resolved!**

SPEAR: Seamless system for Prediction and EArth system Research

➔ Using latest generation component models:
AM4 (atmosphere), **MOM6** (ocean), **SIS2** (sea ice), **LM4** (land)

	Atmosphere resolution	Ocean resolution	
SPEAR_LO	100 km	50-100 km	*Global scale climate, decadal prediction*
SPEAR_MED	50 km	50-100 km	*Regional hydroclimate and extremes, seasonal prediction*
SPEAR_HI	25 km	50-100 km	*Major hurricanes, seasonal prediction*
SPEAR_HI_25	25 km	8-25 km	*In development*

SPEAR routinely used for:

- Seasonal climate prediction (part of North American Multimodel Ensemble, NMME)
- Decadal climate prediction
- Multidecadal climate projections

How do we use models for predictions and projections?

Predictions
(Initial Value Problem)

Projections
(Boundary Value Problem)

Observations
ARGO floats in ocean, atmos temp, winds, moisture, etc

SPEAR Prediction/Projection model

Seasonal predictions
North American Multimodel Ensemble (NMME), every month

Decadal predictions
Internationally coordinated once per year

Atmospheric composition changes (aerosols, greenhouse gases, etc)

SPEAR Prediction/Projection model

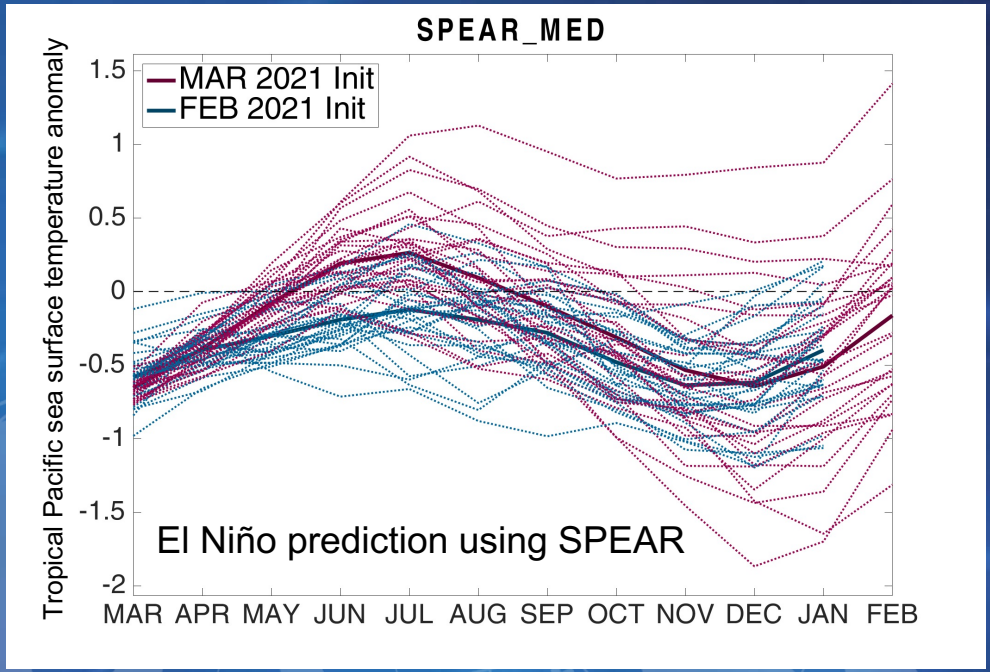
Multidecadal to centennial climate projections
(not initialized)

Large ensembles – EXPENSIVE!

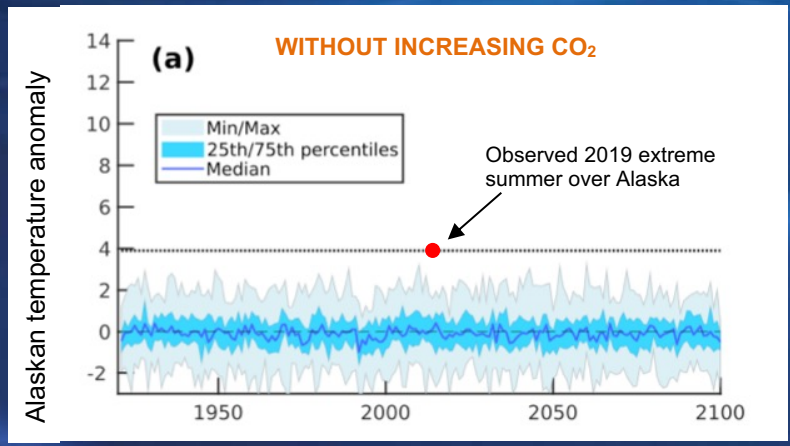
Predictions *versus* Projections

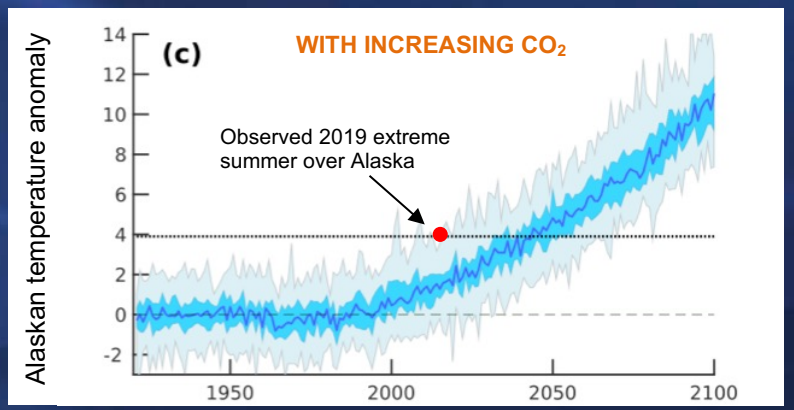
Prediction of tropical Pacific Sea Surface Temperature for next 12 months

(predictions initialized March 1, 2021)



Projection of changing likelihood of extreme summer temperatures over the 21st century



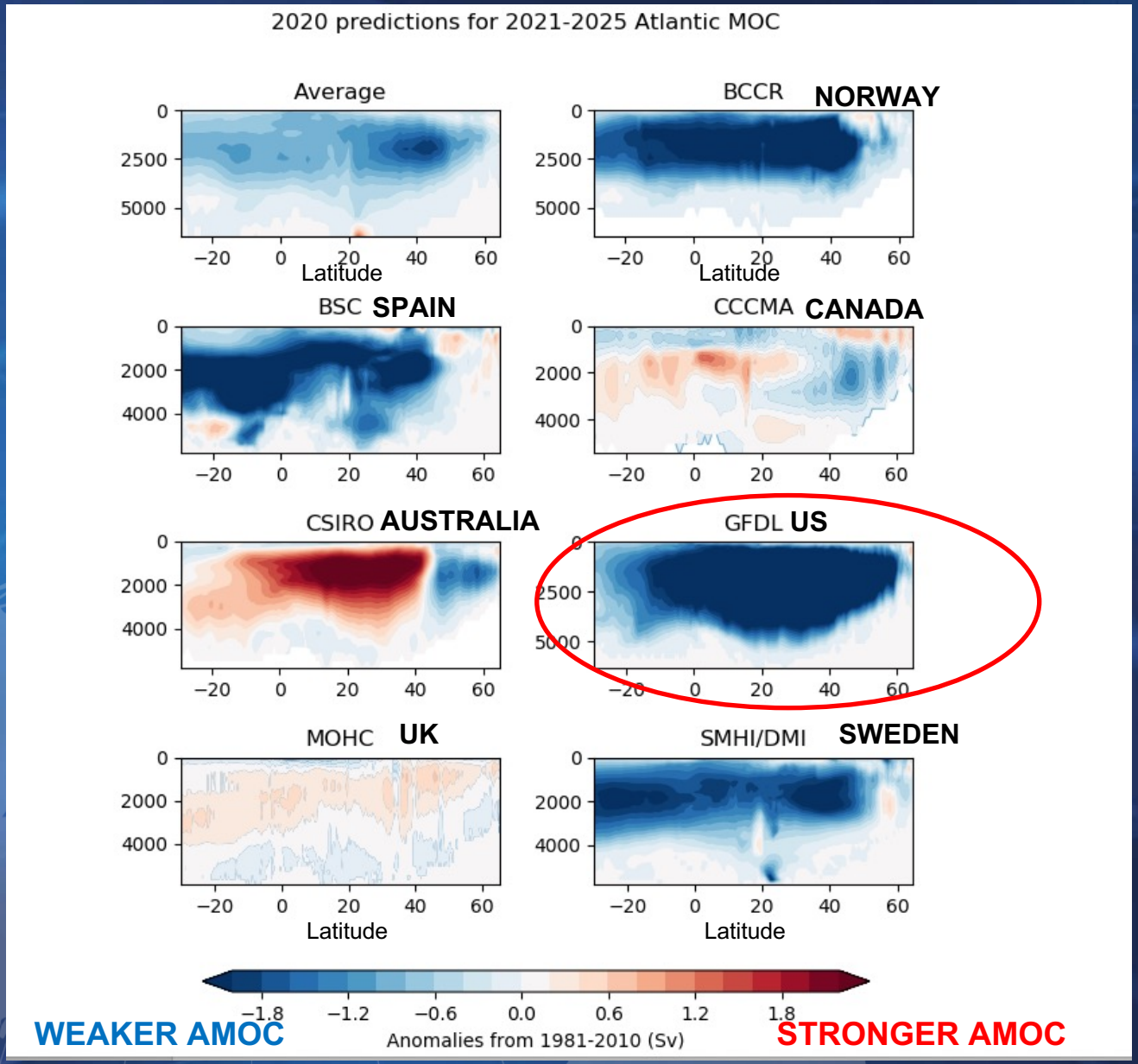


Weidman et al., in revision

Using same system (SPEAR) for both predictions and projections gives increased confidence

International effort at decadal scale predictions of the AMOC

(drawing on climate models from around the world)



Process:

Input observed ocean conditions to the model and ask it to predict evolution of the Atlantic over the next 5-10 years.

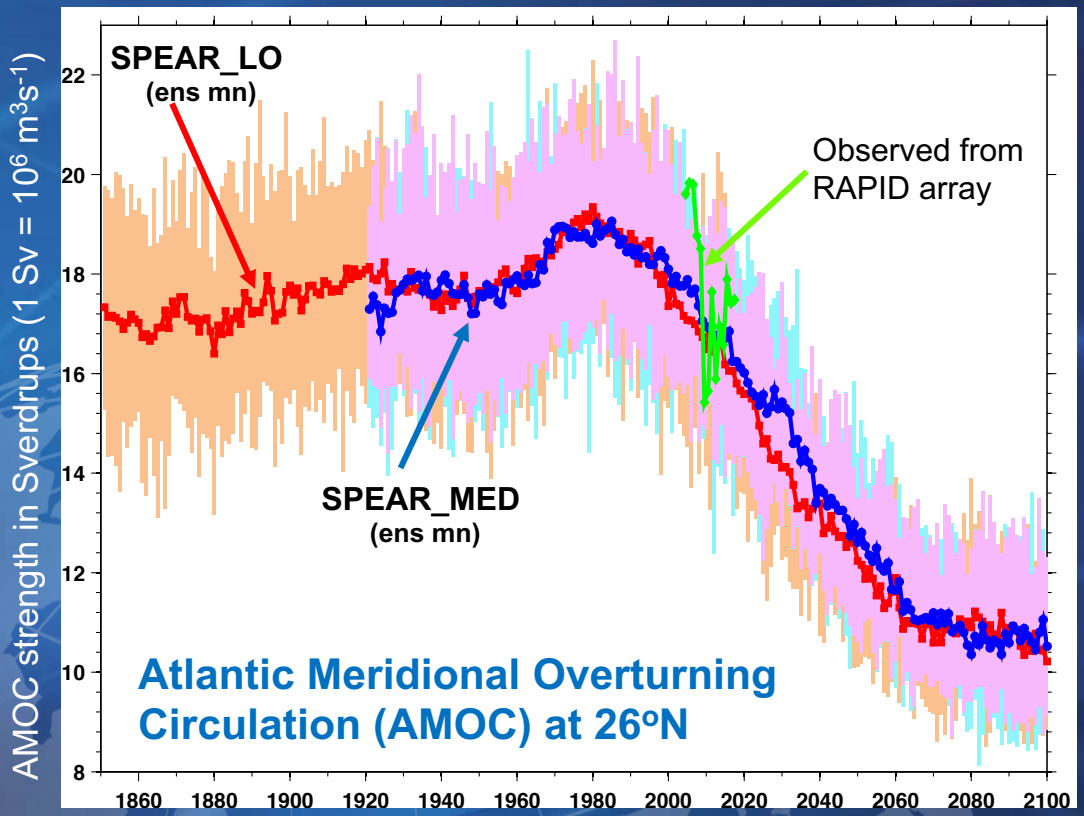
Consensus:

AMOC weakening over the next 5 years

https://hadleyserver.metoffice.gov.uk/wmolc/

Seasonal/Decadal prediction model is used to generate 30-member ensembles of projections for 1851-2100.

- 1851-2010: Use observed atmospheric composition
- 2011-2100: Use projected atmospheric composition from SSP5-85



30-member ensembles using both SPEAR_LO (100 km atmosphere) and SPEAR_MED (50 km atmosphere)

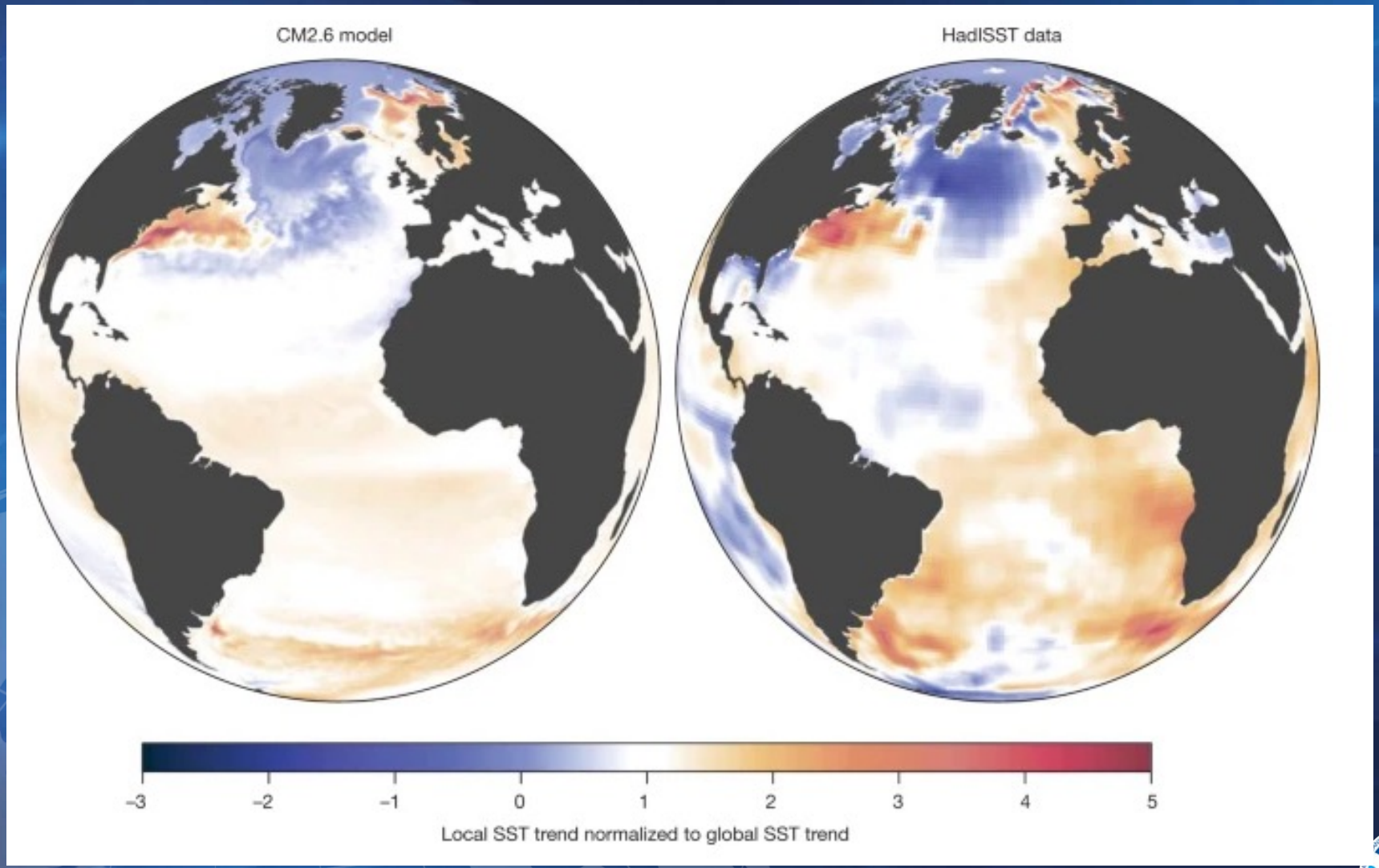
Observations from RAPID array fall within model spread.

Large ensembles help to separate the signal of climate change from the noise of climate variability

Sea surface temperature impacts of AMOC weakening

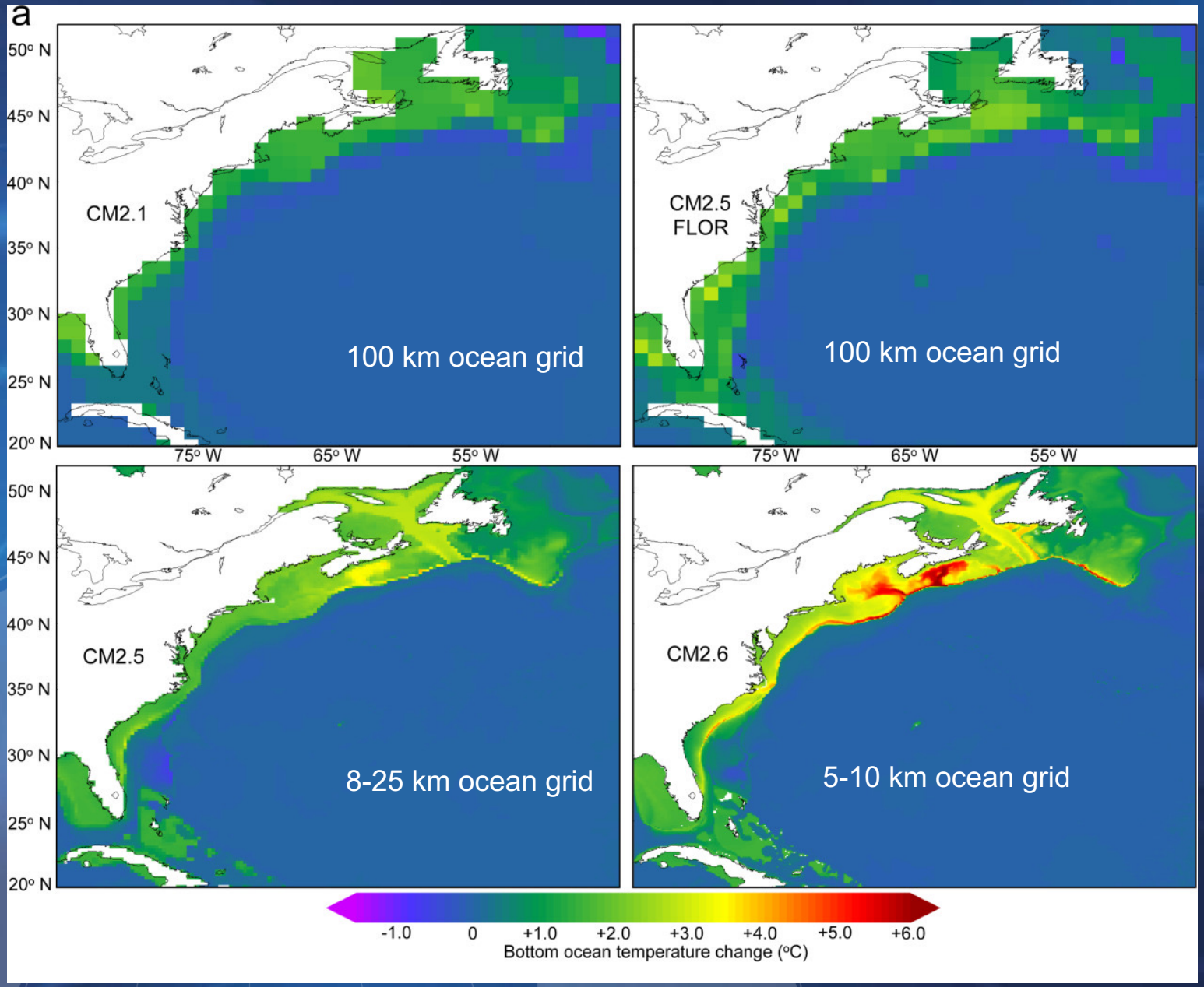
Model based impact

Observed SST trend 1870-2016



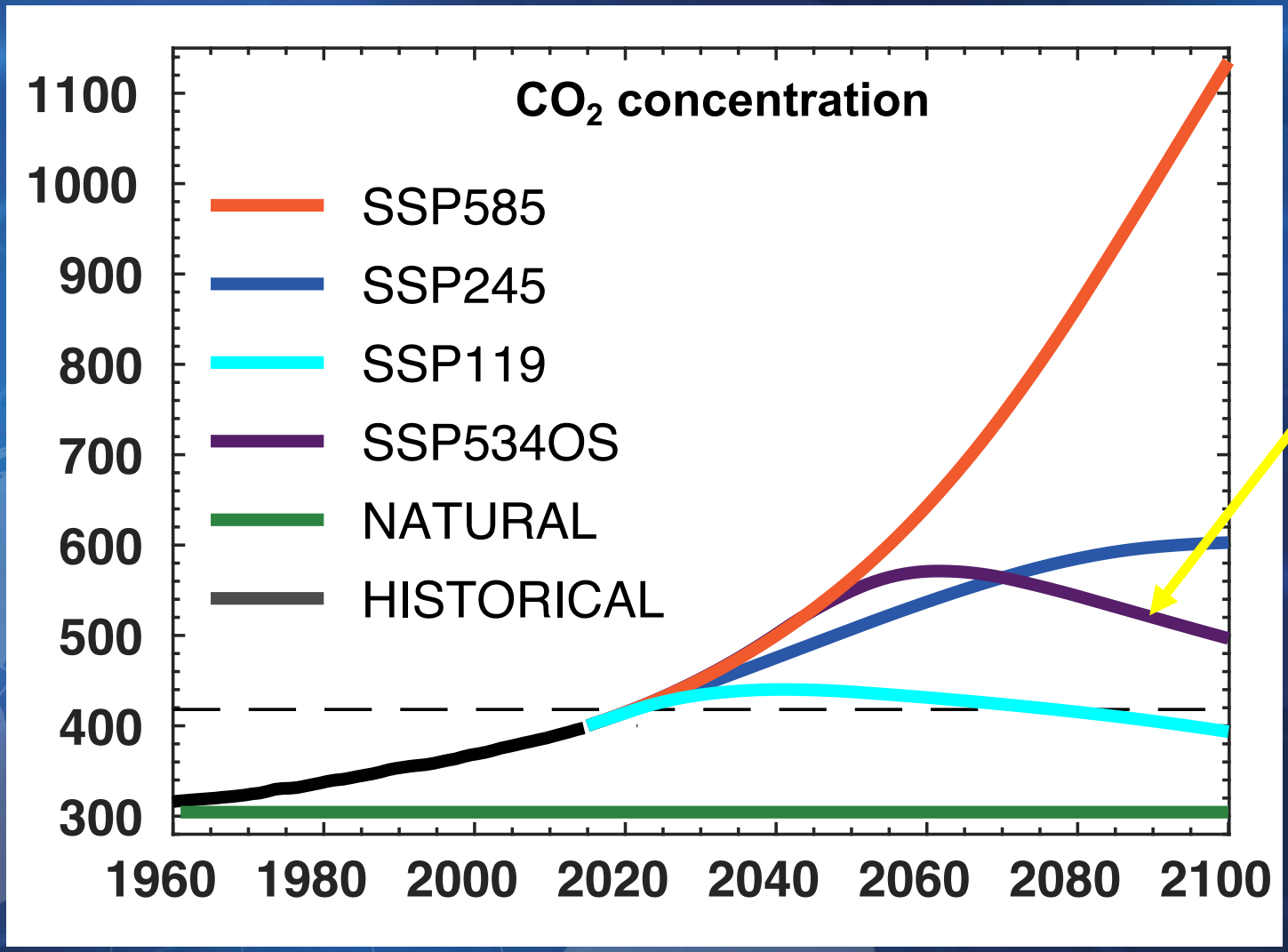
Caesar et al., 2018

Models with progressively finer ocean resolution are able to resolve more smaller scale features.



Subsurface warming and sea level rise along the US Northeast Coast with AMOC weakening.

Can the decline of the AMOC be reversed if greenhouse gas emissions decline in the future?



This is an example of a future scenario with decreasing CO_2.

Summary

- Models provide essential tool for predicting and projecting future evolution of the Atlantic.
- Model resolution (size of grid boxes) is one key limitation for models – computational resources! Physics is also crucial.
- Atlantic is characterized by substantial natural decadal variability.
- Ongoing efforts to predict and project future state of the Atlantic
- Predictions of weakening AMOC over at least the next 5 years
- Declining multidecadal trends of AMOC in response to increasing greenhouse gases
- Key question: how rapidly could such changes be reversed if ghg emissions and concentrations decline in future decades?