Decadal climate prediction: physical underpinnings and future prospects

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1. What is the physical basis for decadal climate prediction?

2. Current state of decadal prediction systems

3. Future prospects

Drivers for decadal climate variability

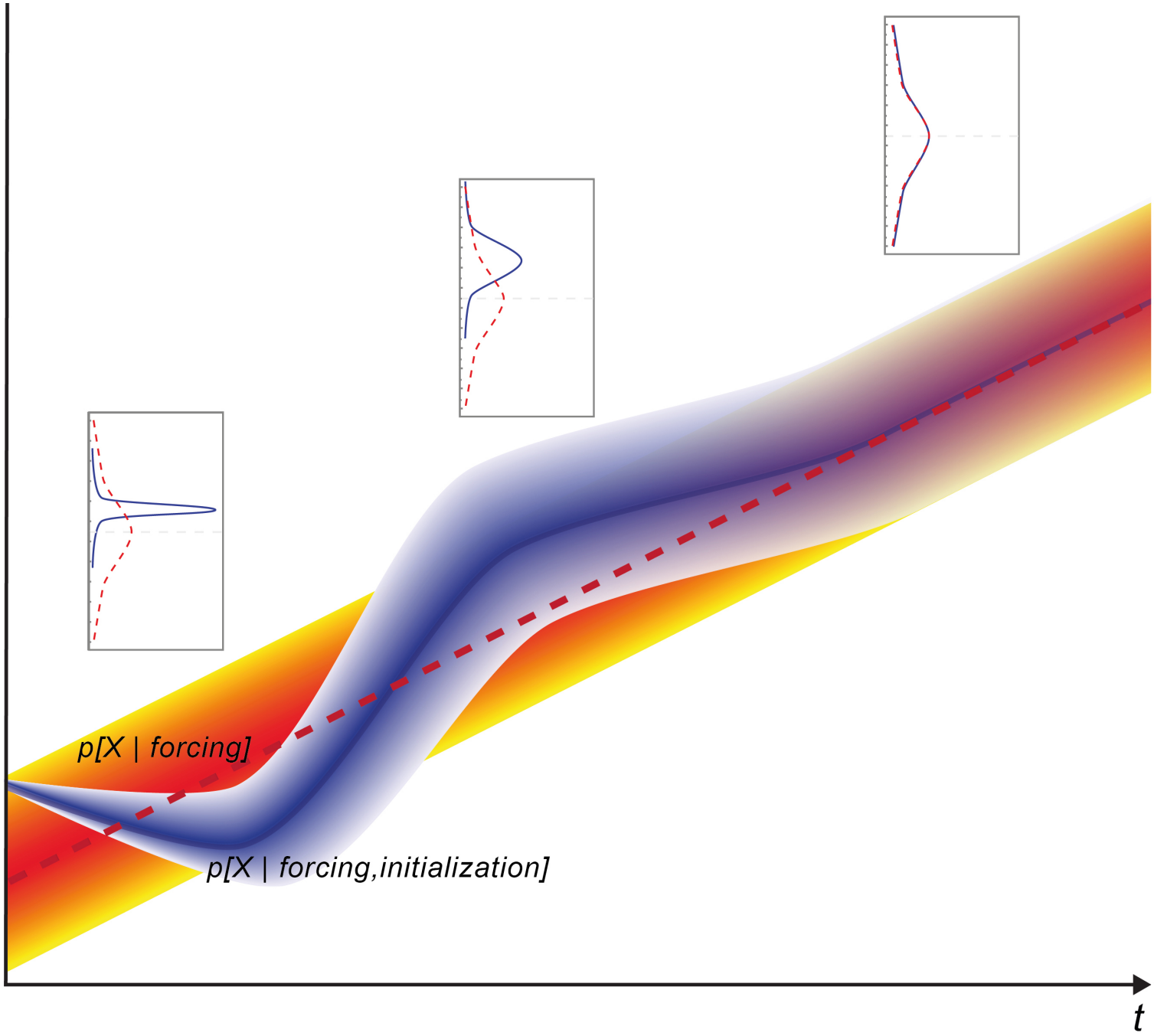
Decadal climate variations composed of at least two components:

- ***Internal variability of the coupled climate system***
- ***Response of the climate system to external forcing changes (greenhouse gases, etc)***

➔ **Most climate change projections typically focus on the response to radiative forcing changes.**

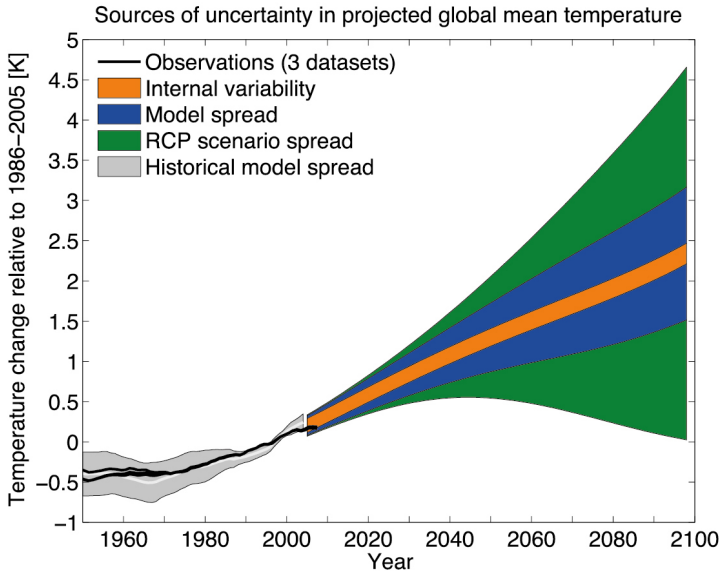
➔ **However, there is substantial internal variability in the climate system on decadal scales.**

Key question: Can we produce better predictions for the coming decades if we use initial condition of the climate system in addition to the response to radiative forcing changes?



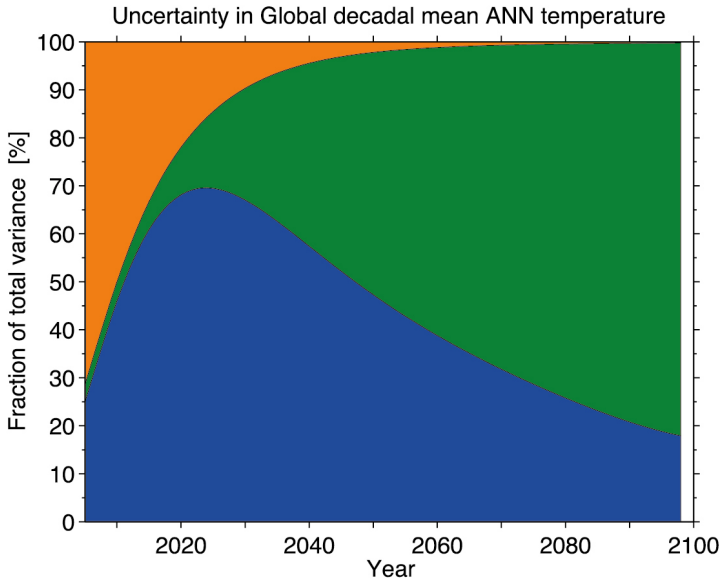
IPCC AR5 Box 11.1

(a)



Internal variability can be a significant source of uncertainty on decadal time scales, especially on regional spatial scales.

(c)



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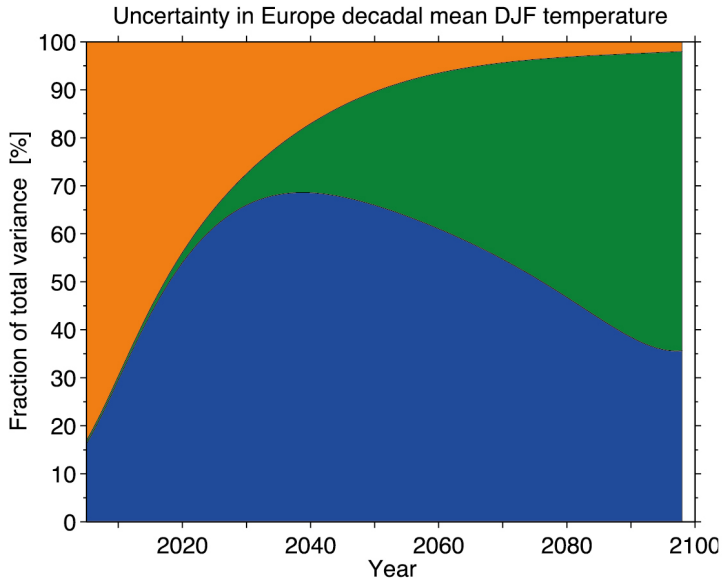
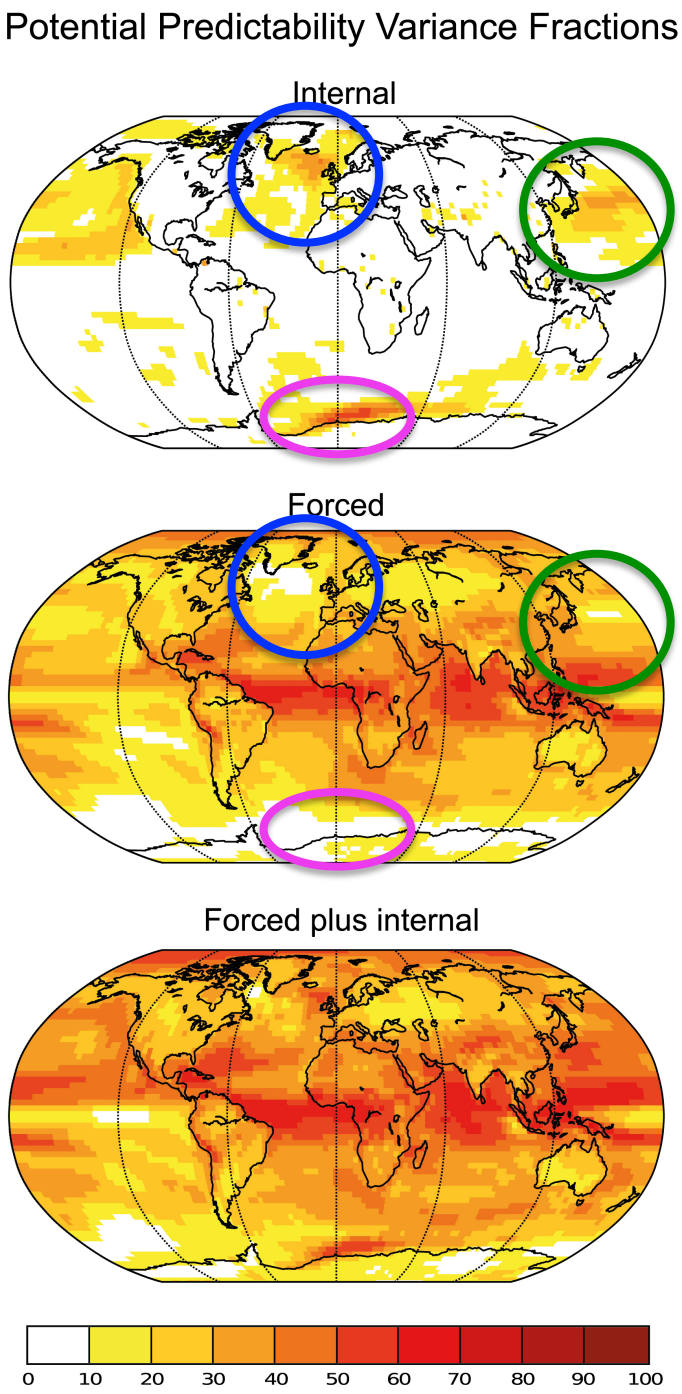


IPCC AR5 Fig. 11-4



Estimates of potential predictability of 5-year mean temperature from radiative forcing and internal variability

Key Point: On multi-year to decadal scales, radiative forcing is the dominant source of potential predictive skill, with the exception of a few regions.

IPCC AR4 Fig. 11.1

Components of Dynamical Prediction and Projection Systems

- **Observing Systems**
- **Assimilation Systems**
- **Models**
- **Changing radiative forcing**

Initial Value Problem
(synoptic to seasonal prediction)

Boundary Value Problem
(multi-decadal to centennial projection)

Decadal Predictions and Projections

Goal: ***Unified system for predictions and projections from seasonal to decadal to centennial time scales.***

Key point: ***Such systems are also highly relevant for understanding and attribution of observed climate changes.***

Drivers for decadal climate variability

For internal variability, are there phenomena that lend predictability?

- Daily weather prediction: mid-latitude storms, air-masses, fronts
- Seasonal prediction: ENSO
- Decadal??

Paradigm: There are decadal-scale oceanic variations that may be predictable and of climatic relevance. These include:

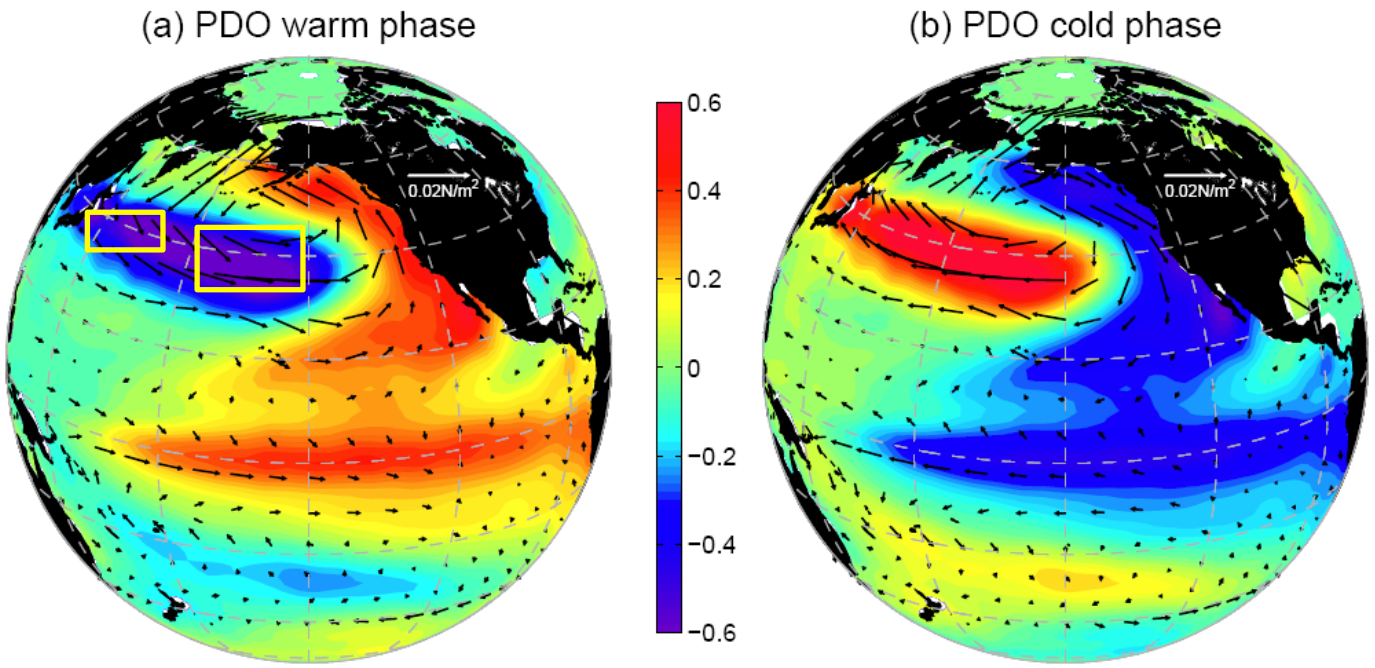
(a) Pacific Decadal Oscillation (PDO)

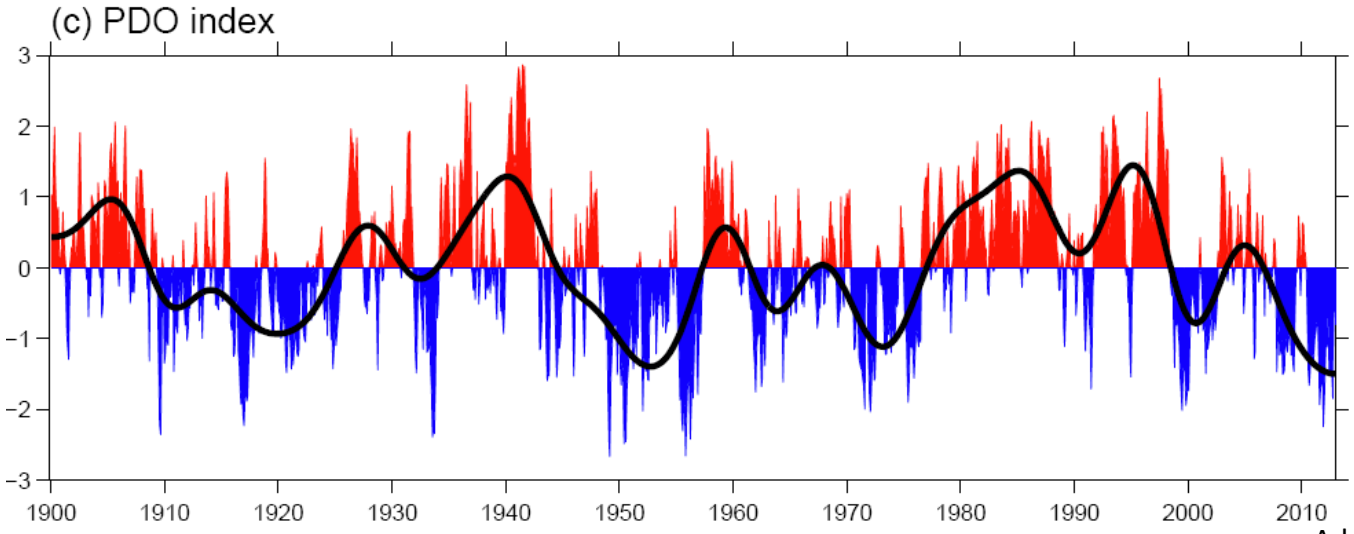
(b) Atlantic Multidecadal Oscillation (AMO), likely associated with the Atlantic Meridional Overturning Circulation (AMOC)

(c) Others? Southern Ocean processes?

Mahajan et al., 2011

PDO in observation (HadISST)



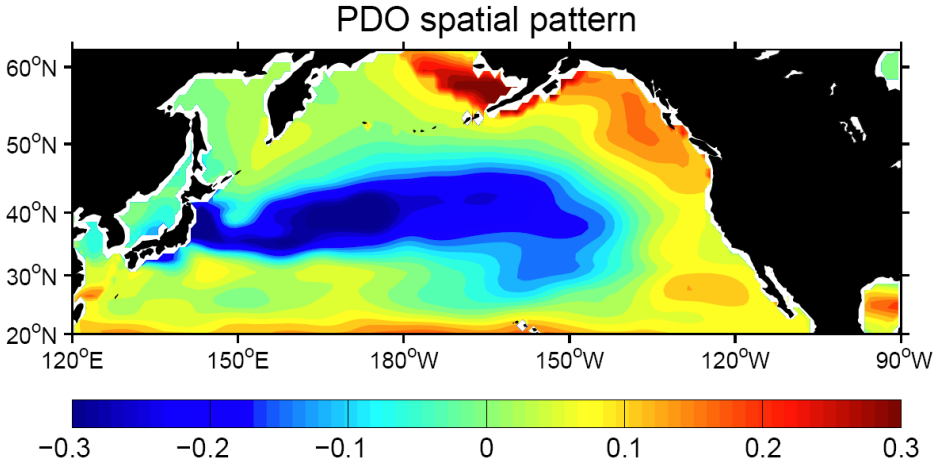


Definition of PDO index: the leading principal component of SST in the North Pacific (poleward of 20°N)

Time scale:
15-25yr, 50-70yr
(Minobe 1997)

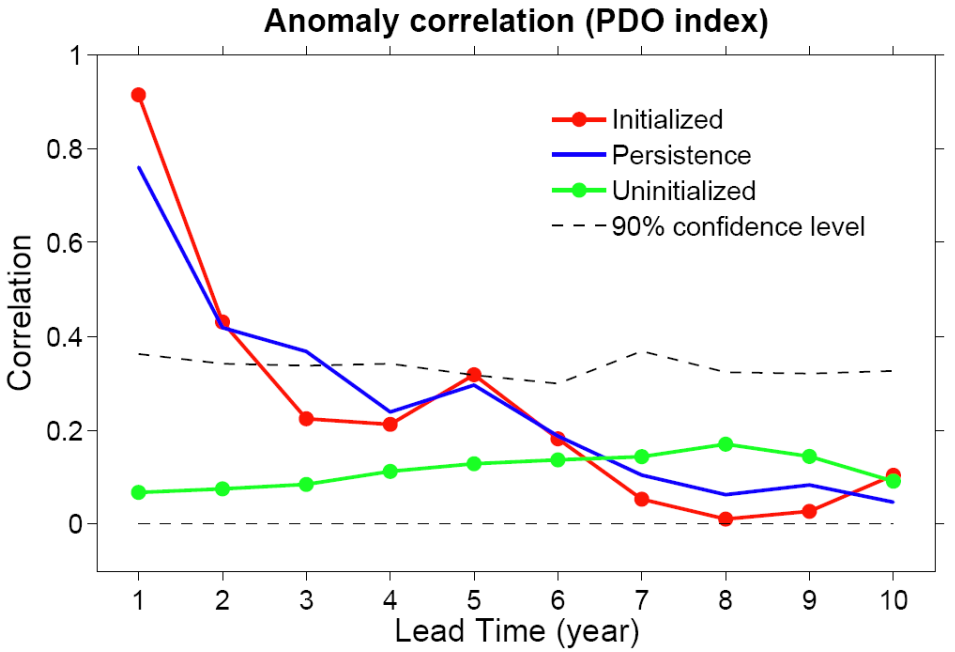
Adapted from Zhang and Delworth, in review

PDO predictability (EOF Projection method)



Spatial pattern of the leading EOF of the internal HC deviations in the historical run during 1961-2013

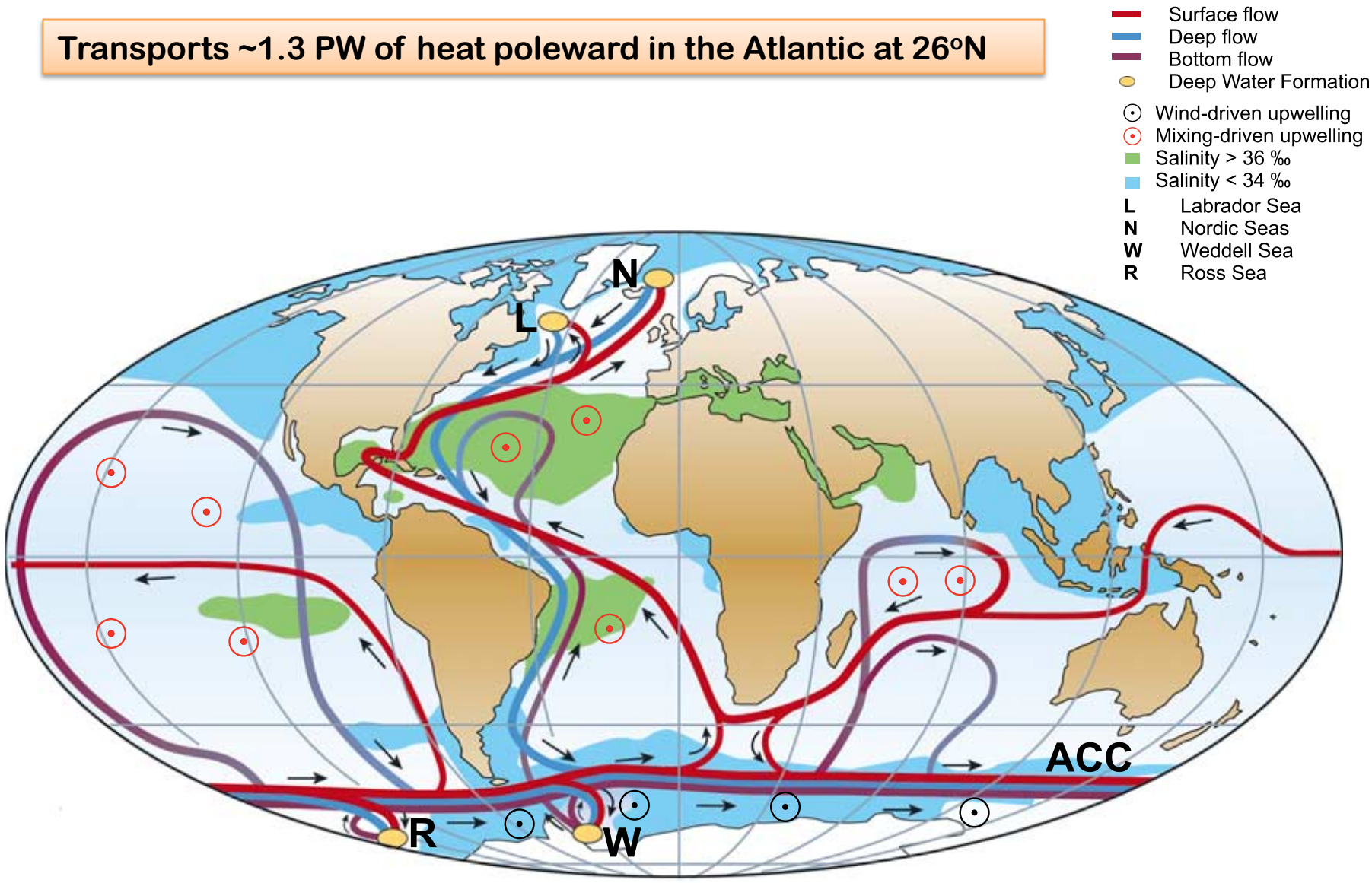
Correlation : Hindcast versus Observation



Bottom line: PDO predictive skill up to ~2 years

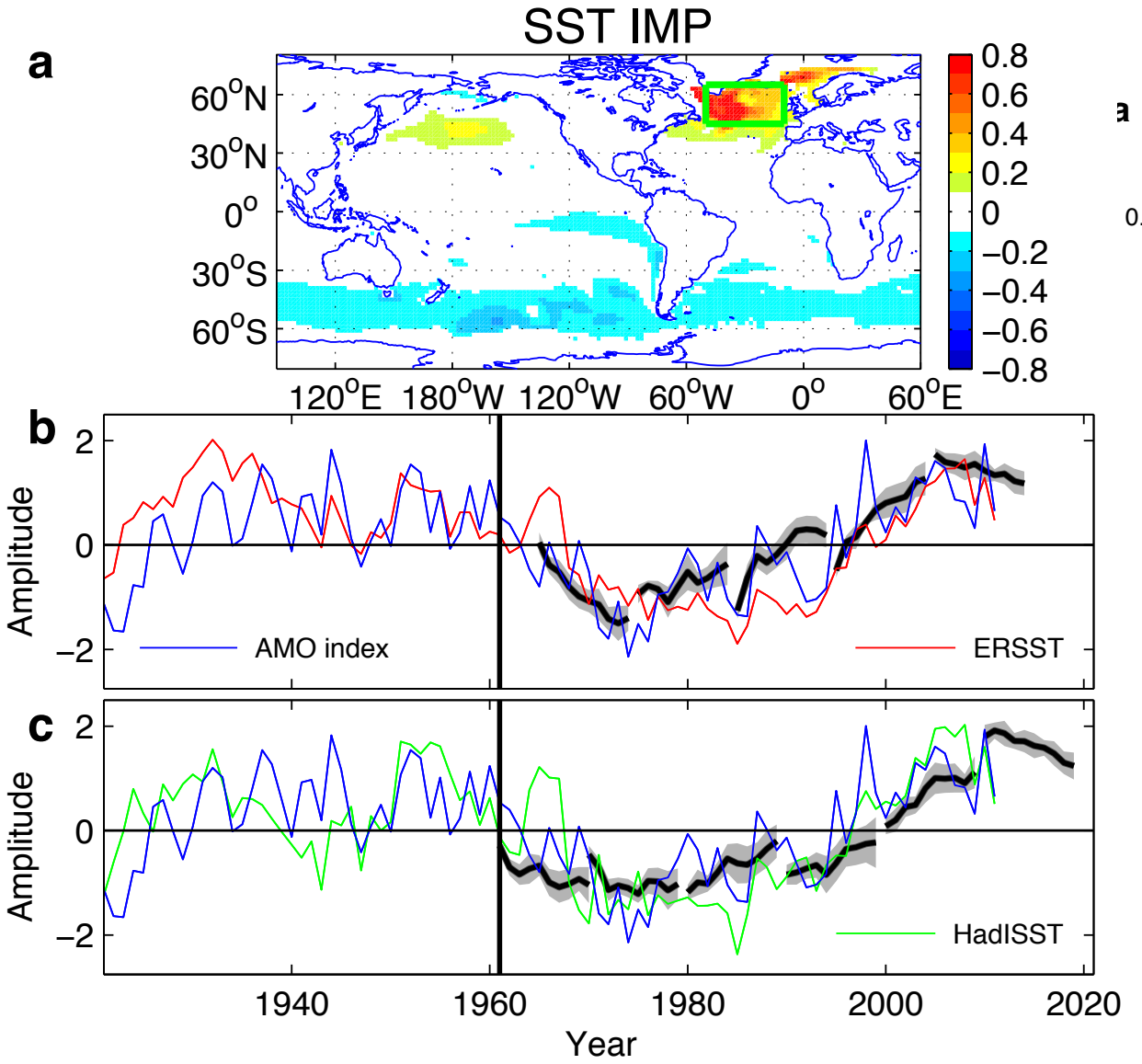
Adapted from Zhang and Delworth, in review

Transports ~1.3 PW of heat poleward in the Atlantic at 26°N

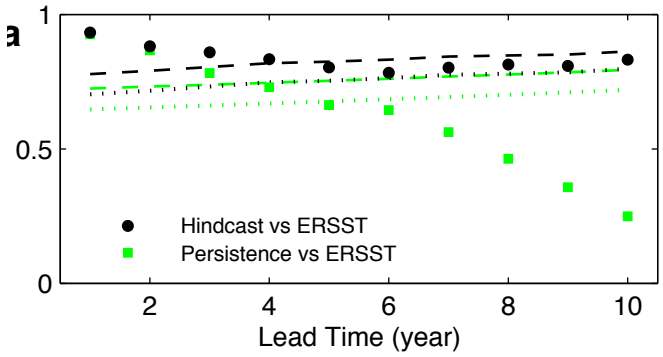


Kuhlbrodt, 2007

Most predictable pattern from APT (average predictability time) analysis resembles Atlantic Multidecadal Variability/Oscillation



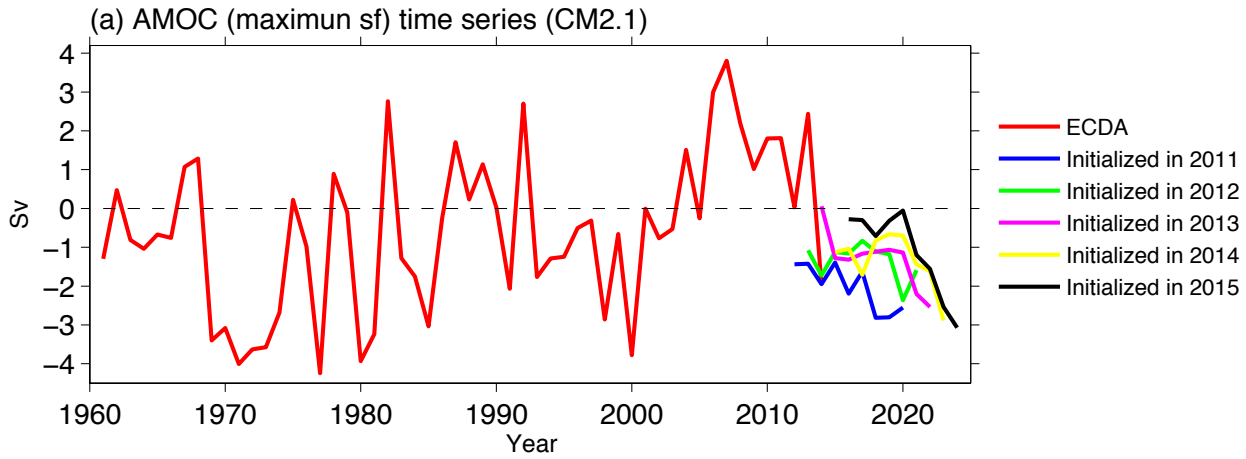
Yang et al., Journal of Climate, 2013

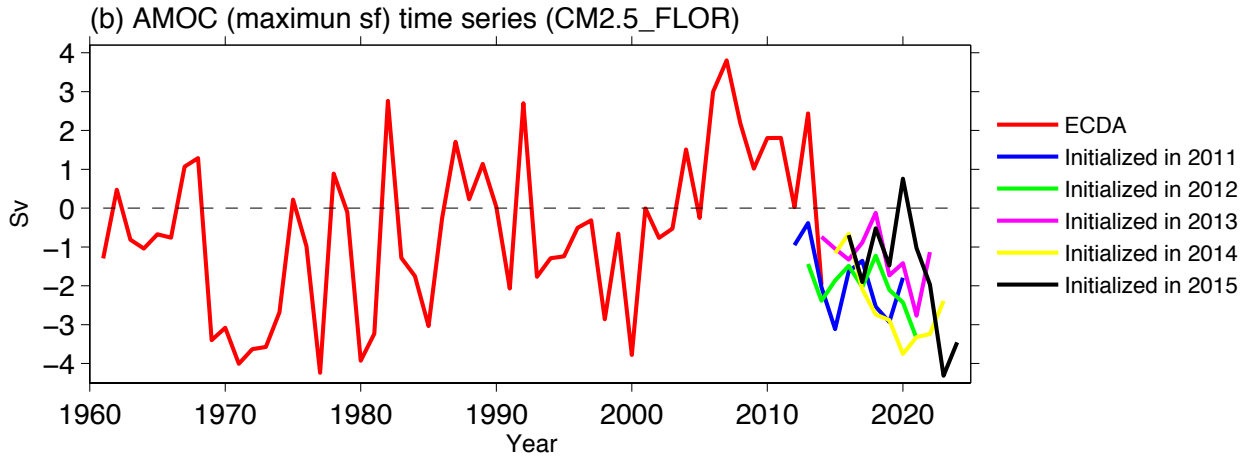


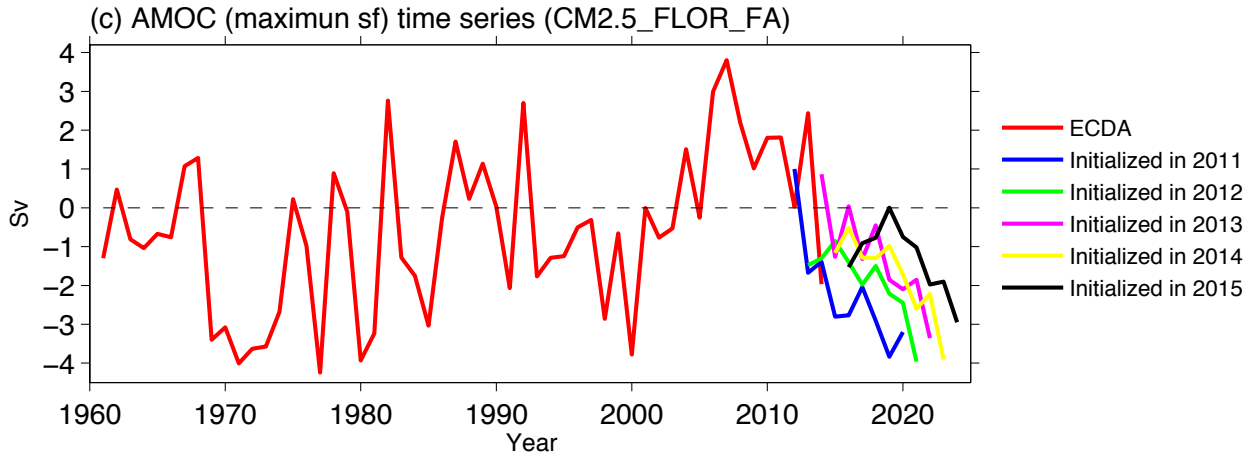
There are also indications of possible predictability of Atlantic hurricane activity on multi-year time scales, but much more work is needed related to:

- *role of radiative forcing*
- *changing observing system*
- *shortness of observed record*

Vecchi et al.,2013



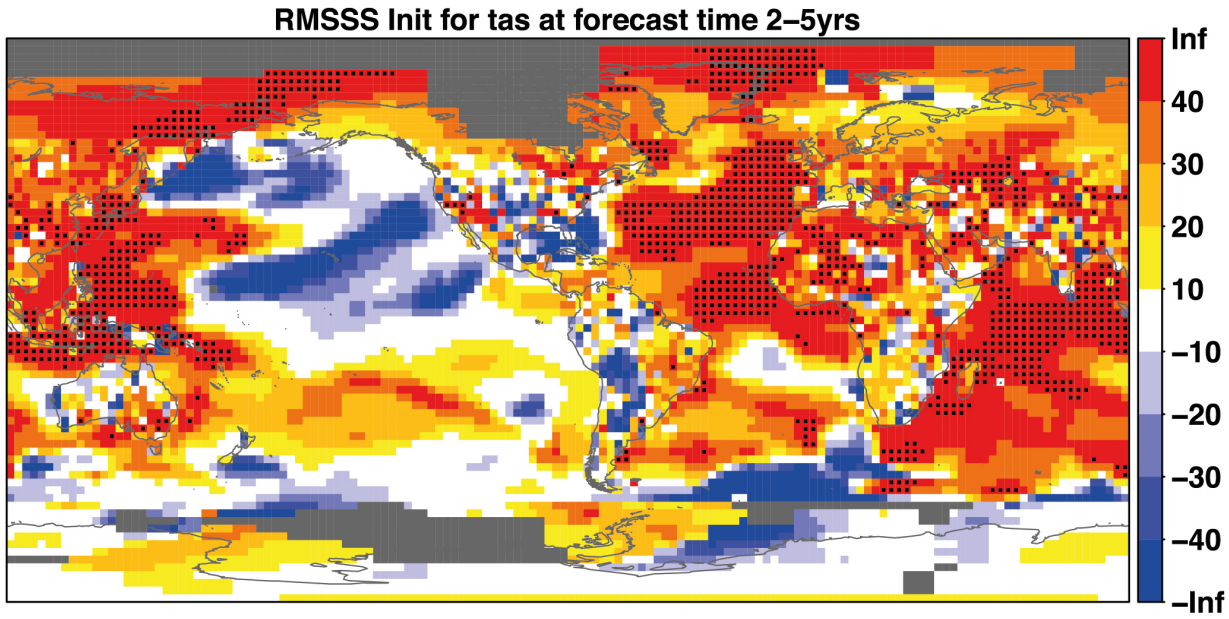


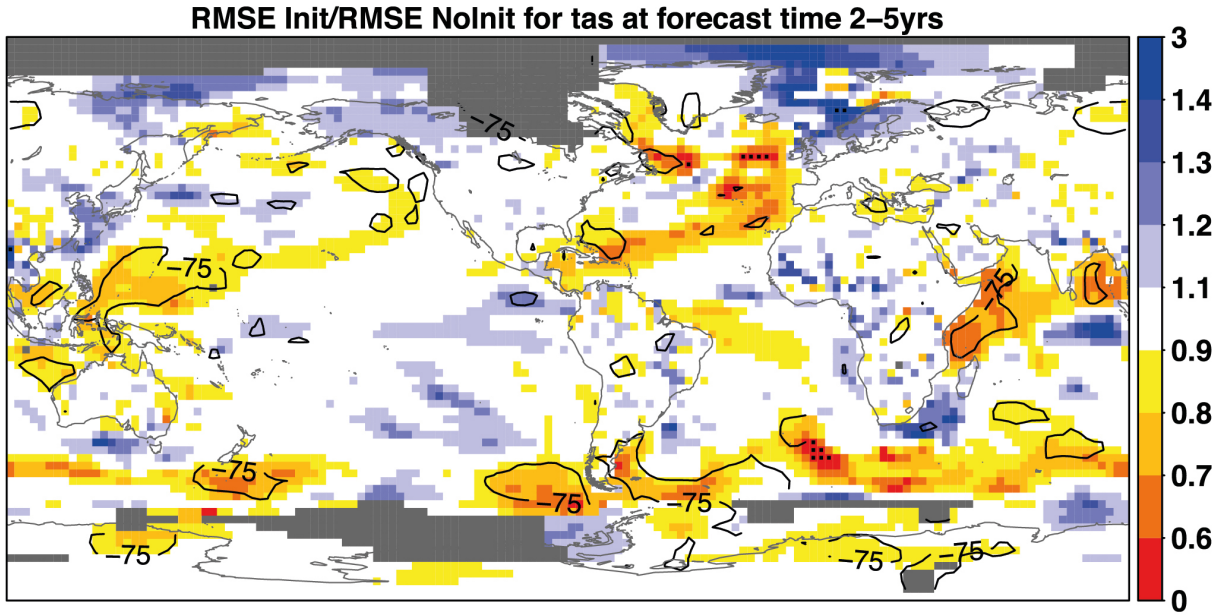


Current AMOC predictions from GFDL multi-model decadal prediction system

- All predictions show weakening AMOC

Multimodel assessment of predictive skill of surface air temperature for years 2-5





Measure of total skill in prediction

Measure of skill from predicting internal variability

"Red" indicates area where predicting internal variability is a meaningful source of skill

IPCC AR5 Fig. 11.4

Summary and Discussion

Climate signals over the coming decade(s) are a combination of:

- Response to changing radiative forcing
- Internal variability of the climate system

To what degree can we predict the internal variability component? And on what spatial and temporal scales?

For *Pacific Decadal Oscillation*, predictability of up to ~2 years.

For *Atlantic Multidecadal Oscillation* (related to AMOC), there exists greater predictability (up to a decade). *Largest decadal scale predictability in climate system is in the extratropical North Atlantic (subsurface temperature) associated with the AMOC.*

However, for both phenomena this translates into limited predictability over continental regions. Largest predictability for ocean heat content in North Atlantic.

Also … some early indications of potential decadal scale predictability for the Southern Ocean.

Summary and Discussion

Is there the potential for greater skill than we can currently realize?

Some factors to consider:

- Models used to estimate predictability may be inadequate
  - Coarse resolution
  - Unresolved processes (mesoscale eddies, shelf processes, sill overflows, …)
  - Air-sea coupling

- Initialization of models is problematic
  - Changing observing system
  - Lack of measurements in the deep ocean
  - Challenges to initialize at high-resolution
  - Model bias!!!

Summary and Discussion

Is there the potential for greater skill than we can currently realize?

Even without additional predictive skill, some factors to consider:

- Large ensembles of simulations over the next several decades are extremely useful to estimate the time-evolving PDF of climate in response to radiative forcing changes
- Initialization of those models adds some level of predictive skill for certain regions and phenomena – North Atlantic Ocean is the most predictable!
- It is CRITICAL to improve our understanding of the dynamics underlying decadal variations to place decadal predictions on a sound theoretical basis
- Even if it is not predictable, a better understanding of decadal variability is crucial for efforts to assess and attribute the underlying causes of observed decadal-scale change