Decadal Climate Variability and Prediction

1. **Introduction to Decadal Climate Variability**

2. **The Atlantic Multidecadal Oscillation**

3. **The Pacific Decadal Oscillation**

4. **Decadal Prediction**

The Cube…

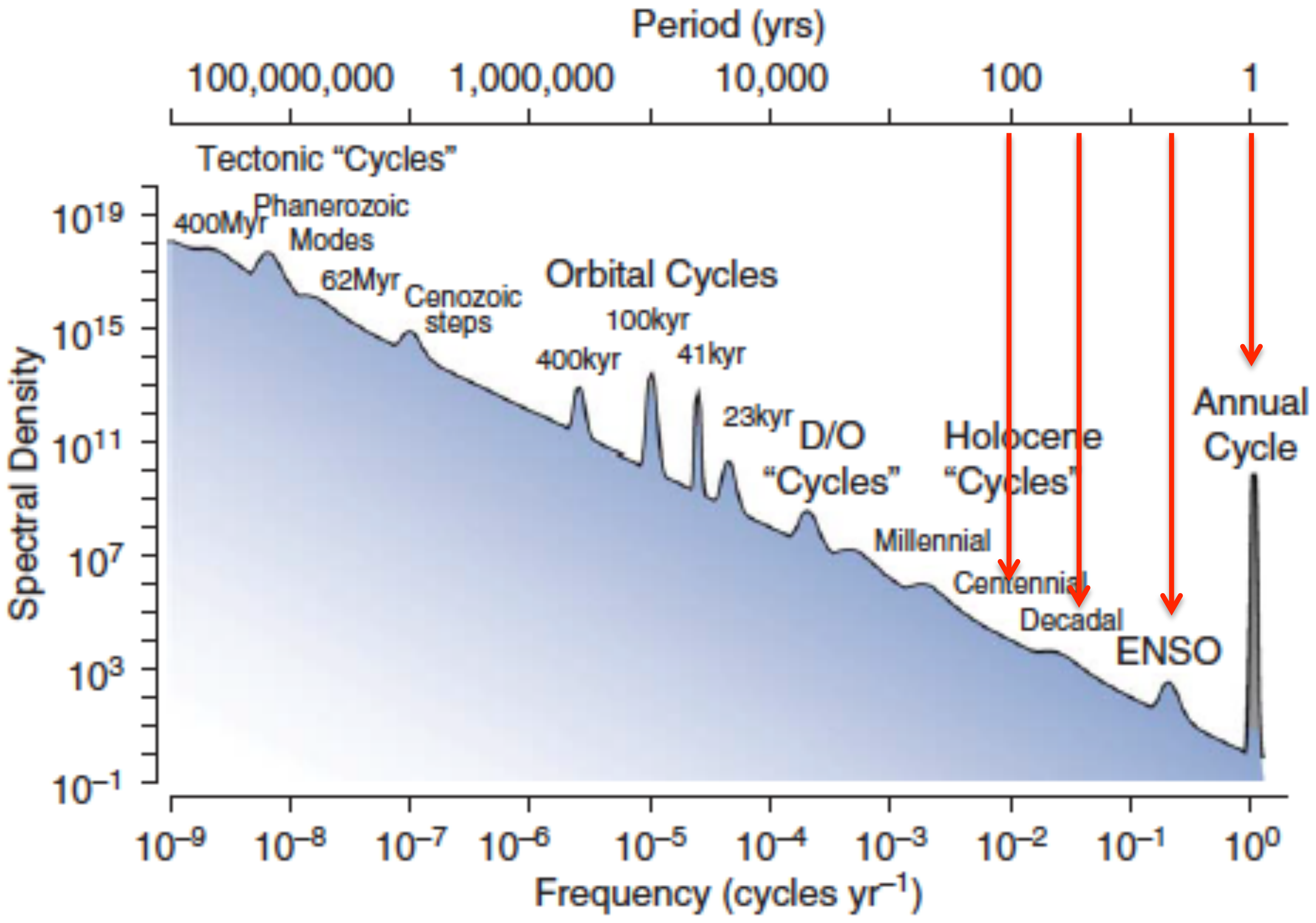
Without touching or moving the cube in any way make a prediction of what is on the bottom of the cube

Use the blank paper to record what your group thinks is on the bottom

DO NOT PEAK – EVEN AFTER YOU ARE DONE

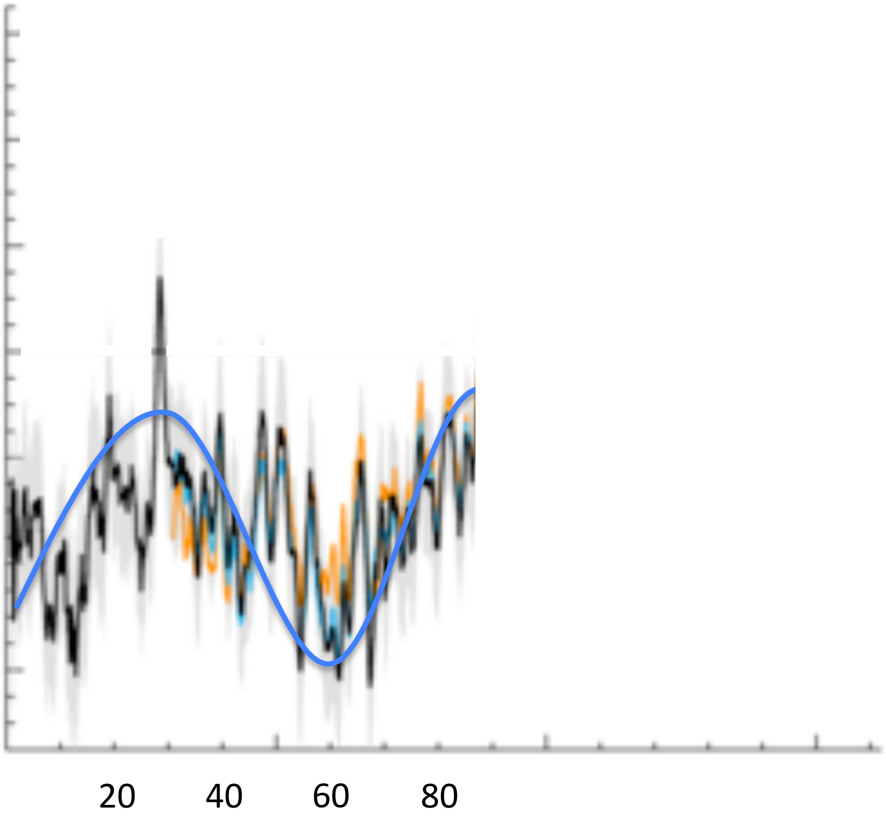
“Climate is now recognized as being continuously variable, on all scales of time”

J. Murray Mitchell Jr., Quaternary Research, 1976

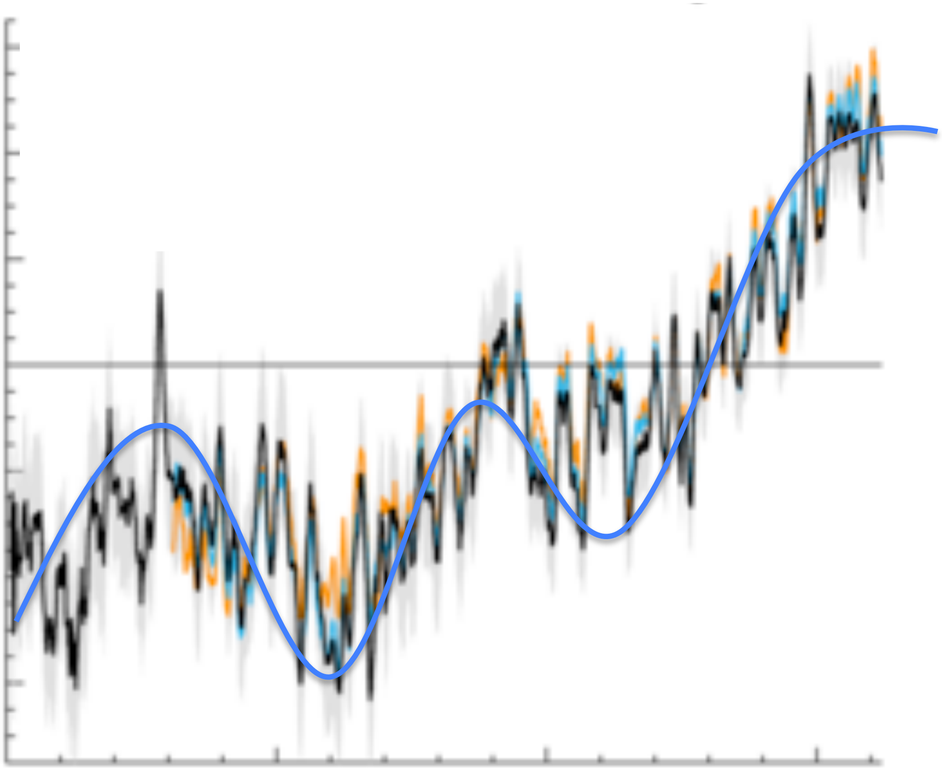


Bartlein, Encyclopedia of Quaternary Science, 2006

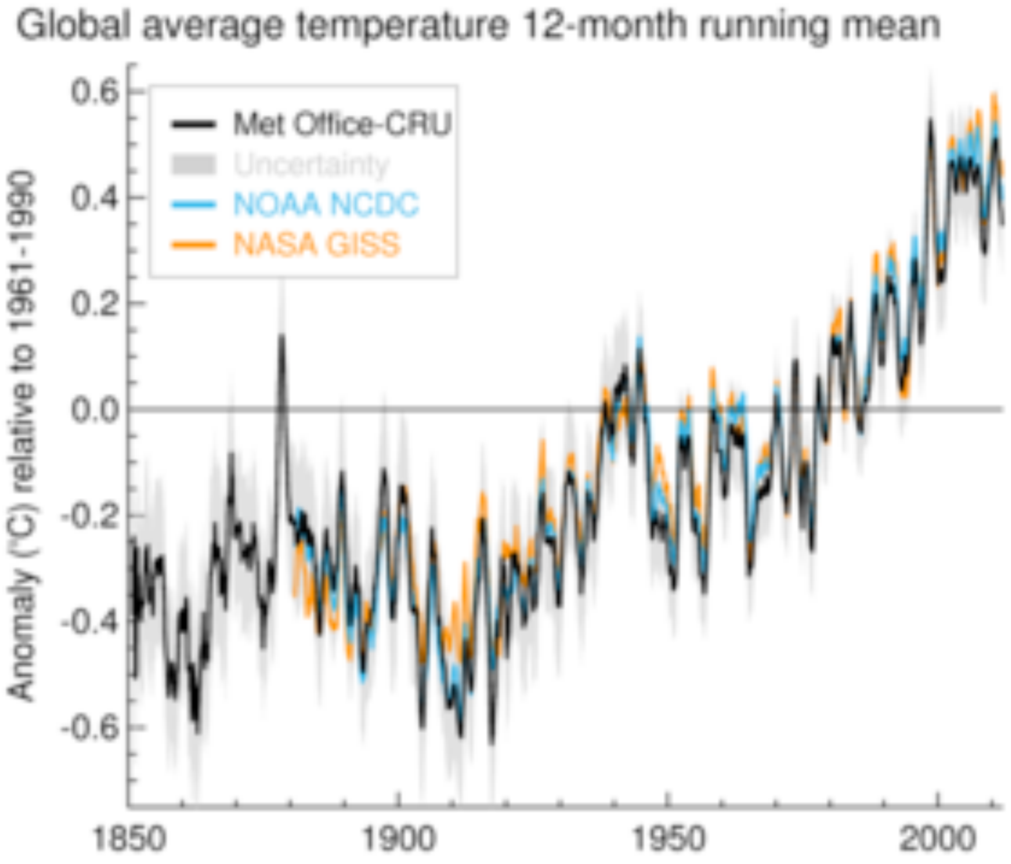
Make a Prediction…



… was anyone right?



Example 1: Global temperature

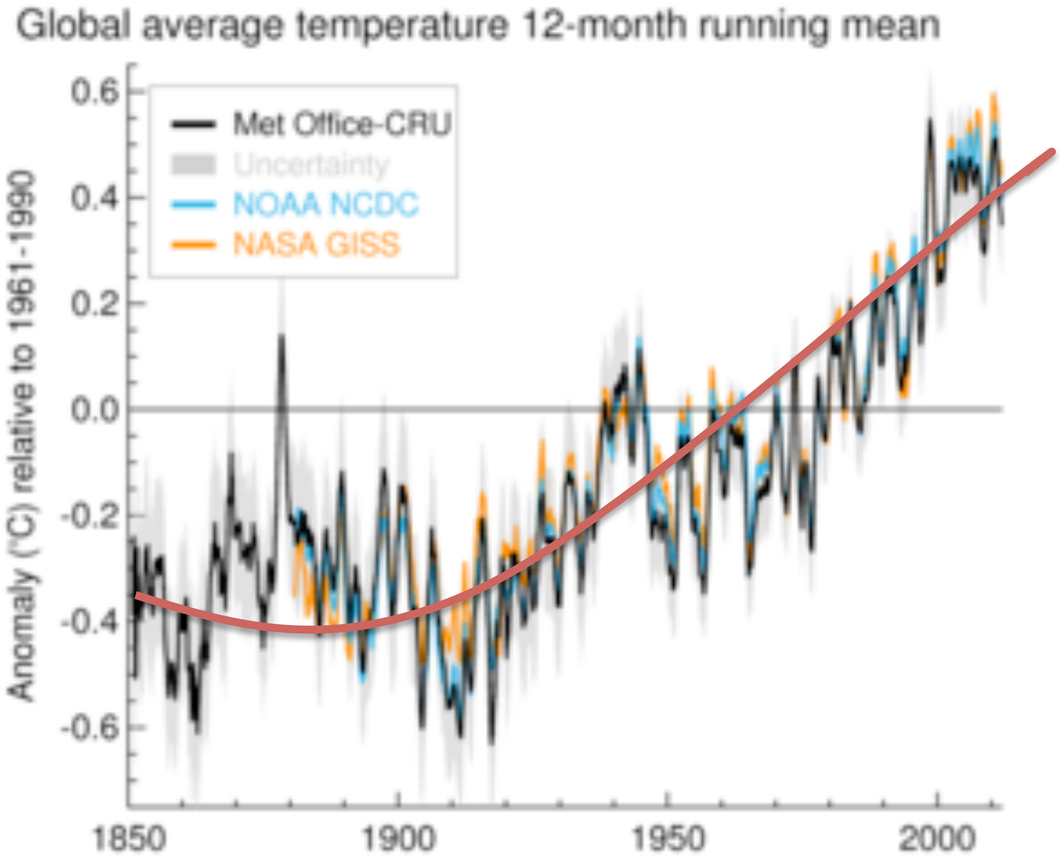


From www.metoffice.gov.uk

NEWSWEEK published an article in 1975 worried about global cooling and a new ice age!!

*this was not the *scientific* consensus at the time though

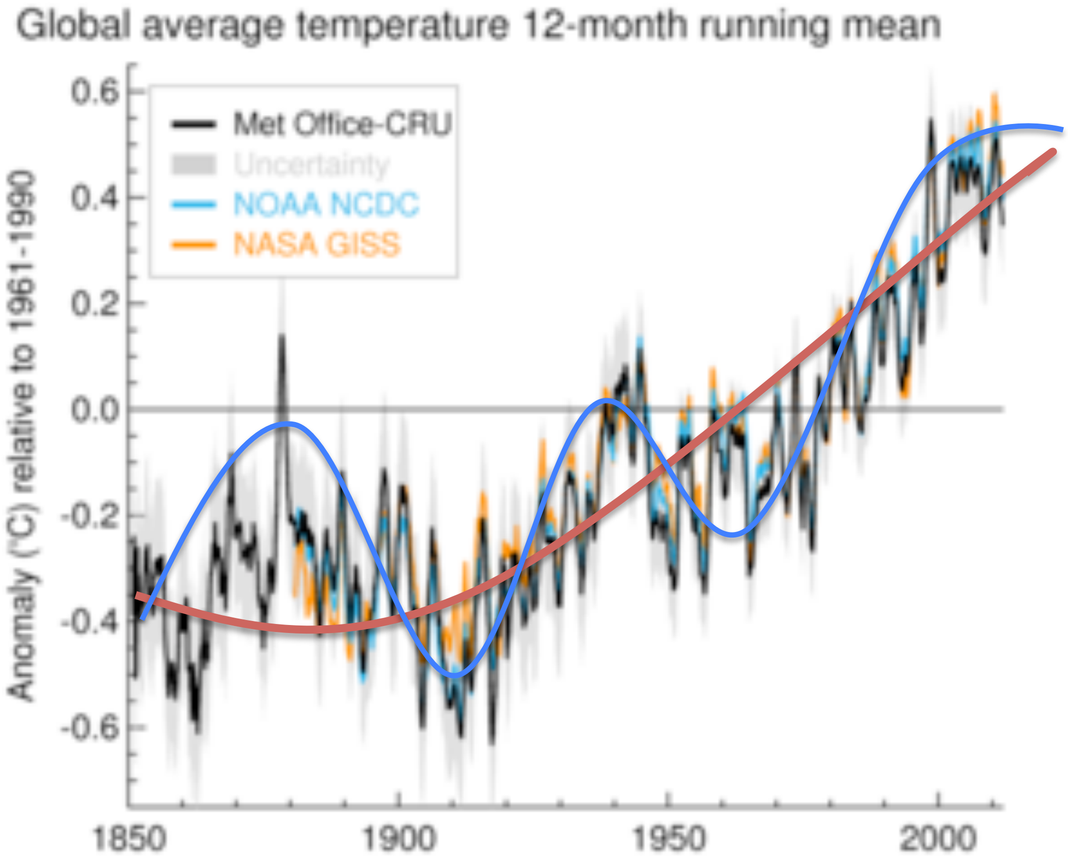
Example 1: Global temperature



It is important to consider decadal variations on top of any long term trend

From www.metoffice.gov.uk

Example 1: Global temperature



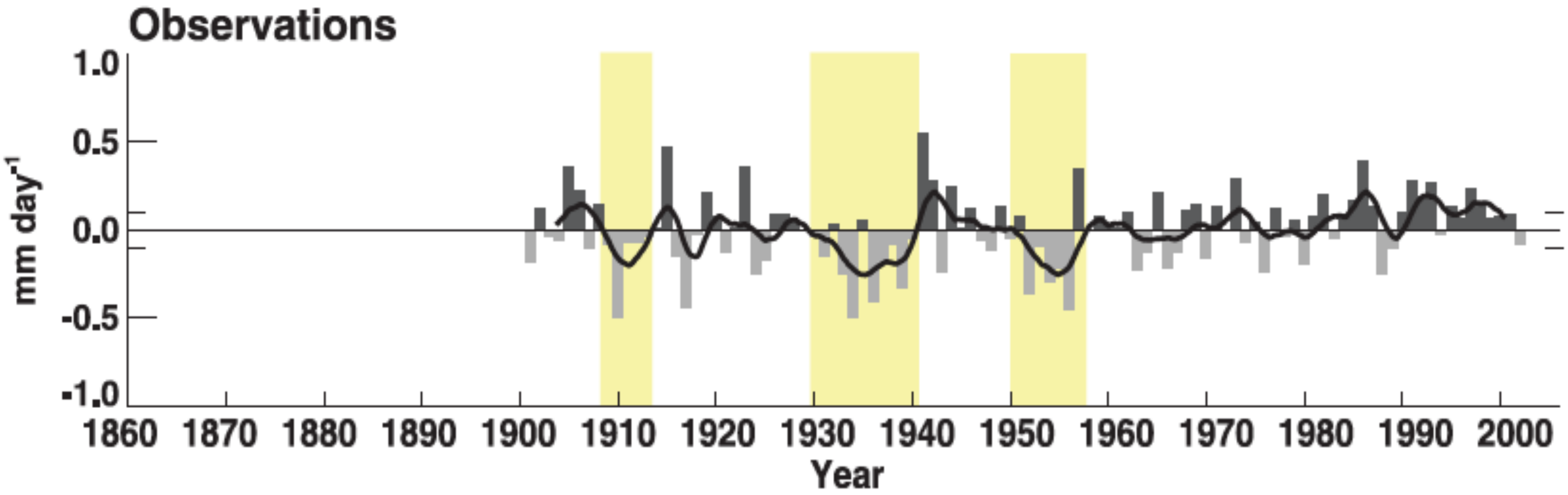
It is important to consider decadal variations on top of any long term trend

Decadal variability alternately disguises and accentuates the secular warming trend

From www.metoffice.gov.uk

Example 2: The US Dust Bowl

Rainfall

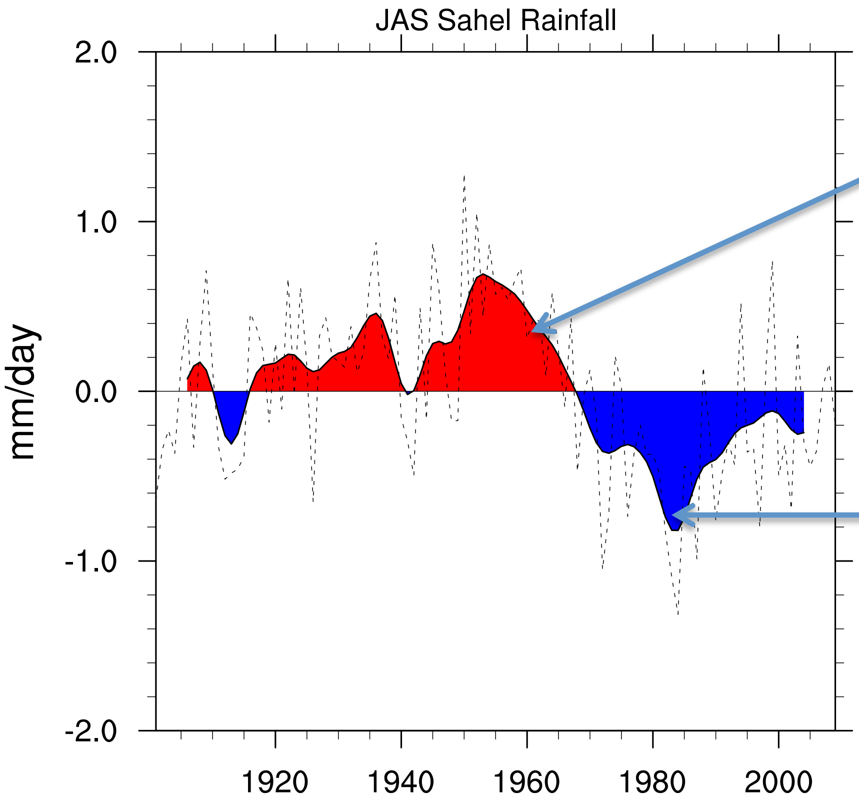


McCrary and Randall, J. Climate, 2010

During 1930s, US experienced one of the most devastating droughts of the past century. Affected ~2/3 of US, parts of Mexico and Canada

Drought is a example of decadal climate variability that the public understand.

Example 3: Sahel Drought



Wet conditions in 50s and 60s

Drought in 70s and 80s:

* Affected 20 countries, 150 million people
*30 million were in urgent need of food aid
*10 million refugees seeking food and water
*100,000 to 250,00 deaths

“An improved understanding of decadal climate variability is very important because stakeholders and policymakers want to know the likely climate trajectory for the coming decades for applications to water resources, agriculture, energy, and infrastructure development.”

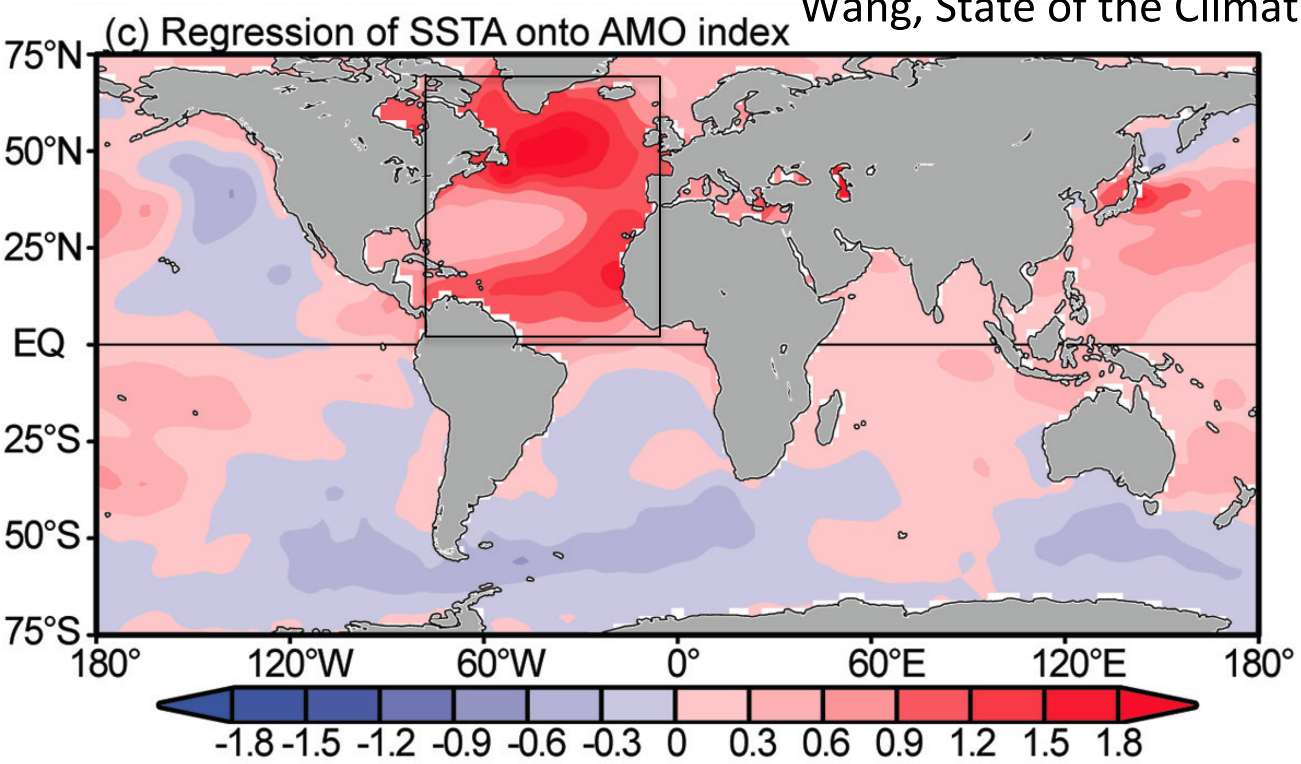
Mehta et al., BAMS, 2011

2) The AMO:

Atlantic Multidecadal Oscillation

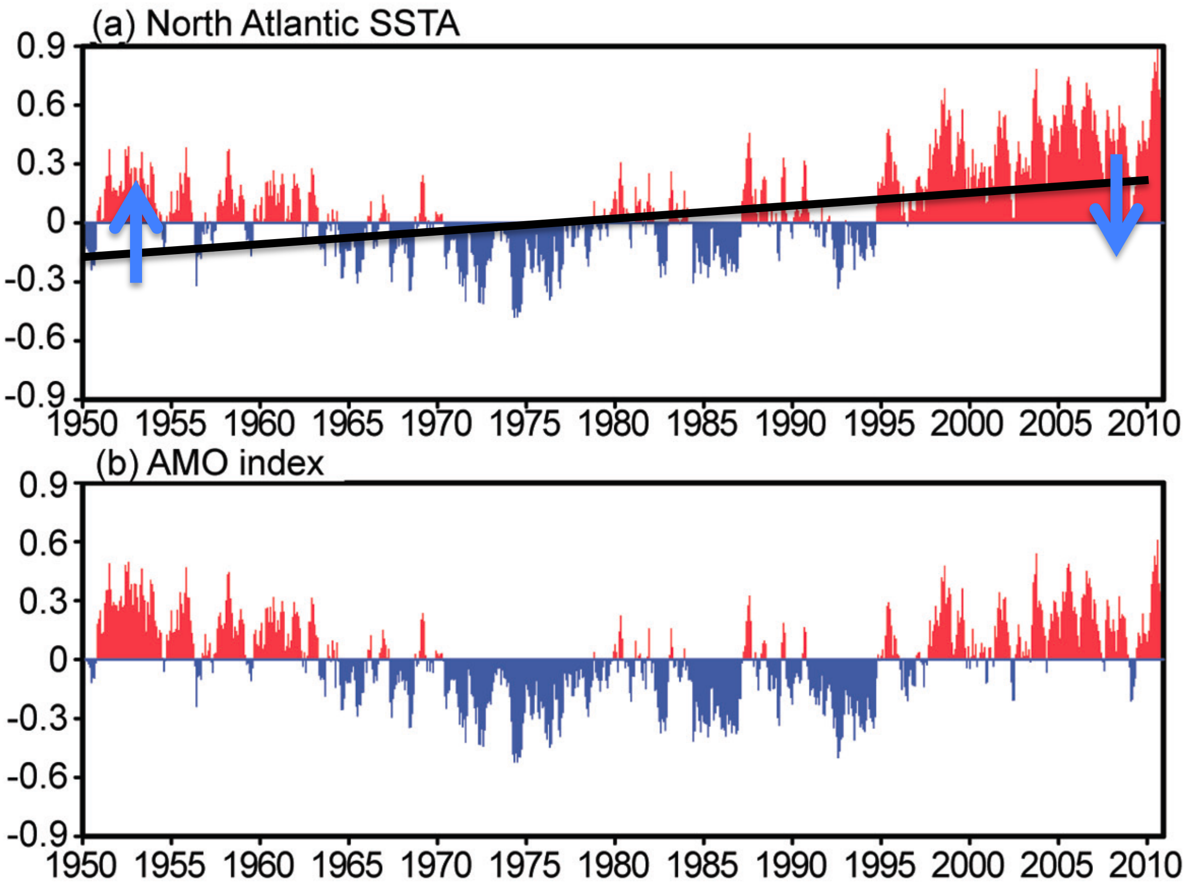
AMO Spatial Signature

Wang, State of the Climate 2010, BAMS, 2011



Positive signal over whole North Atlantic – horseshoe pattern
Weak SST signal across over global ocean regions

The AMO Index

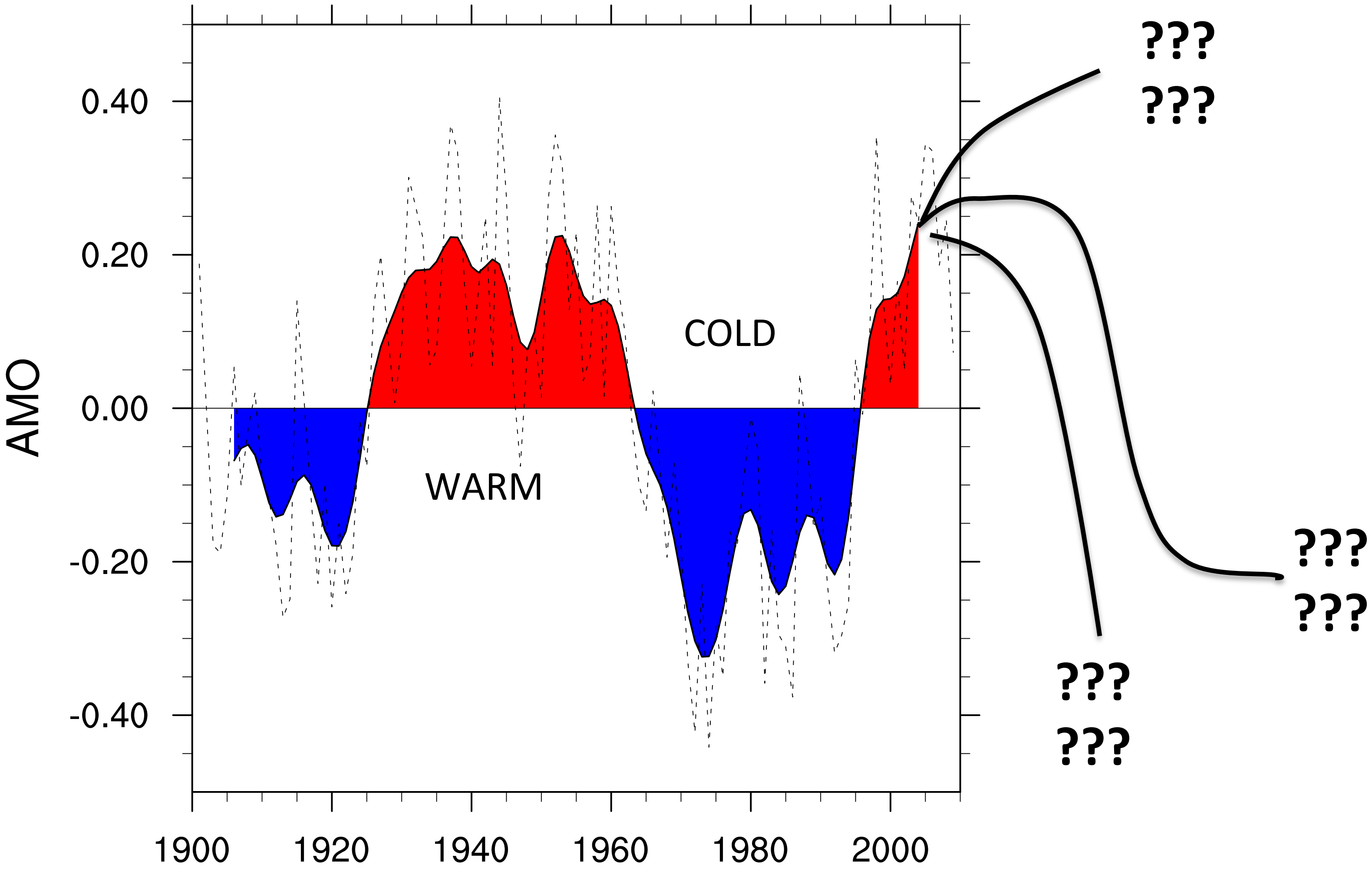


The AMO index is the ***detrended*** SST anomalies in the North Atlantic

Removing basic global warming signal – we want the decadal climate variability

Wang, State of the Climate 2010, BAMS, 2011

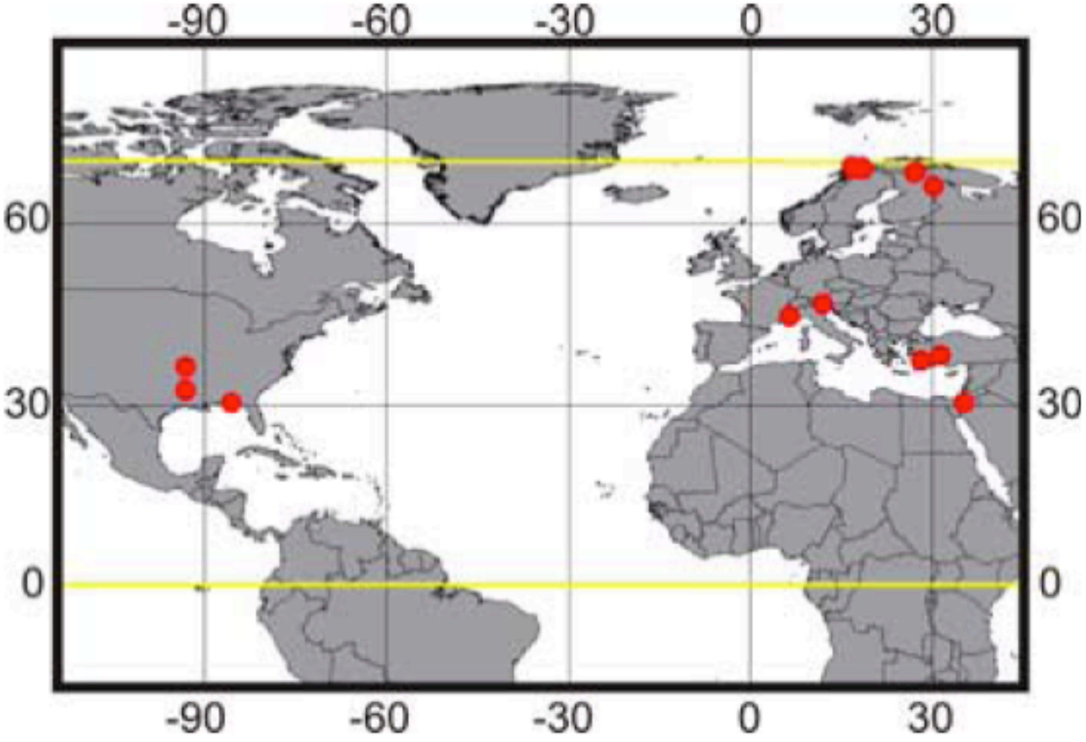
The AMO index: SST anomalies averaged over 0° - 70°N, 75° - 10°W
detrended
low-pass-filtered (extracts the decadal variations)



Did the AMO exist before 1900?

- How can we tell if it did or didn’t?

Did the AMO exist before 1900?



12 tree ring sites (1567-1990), detrended

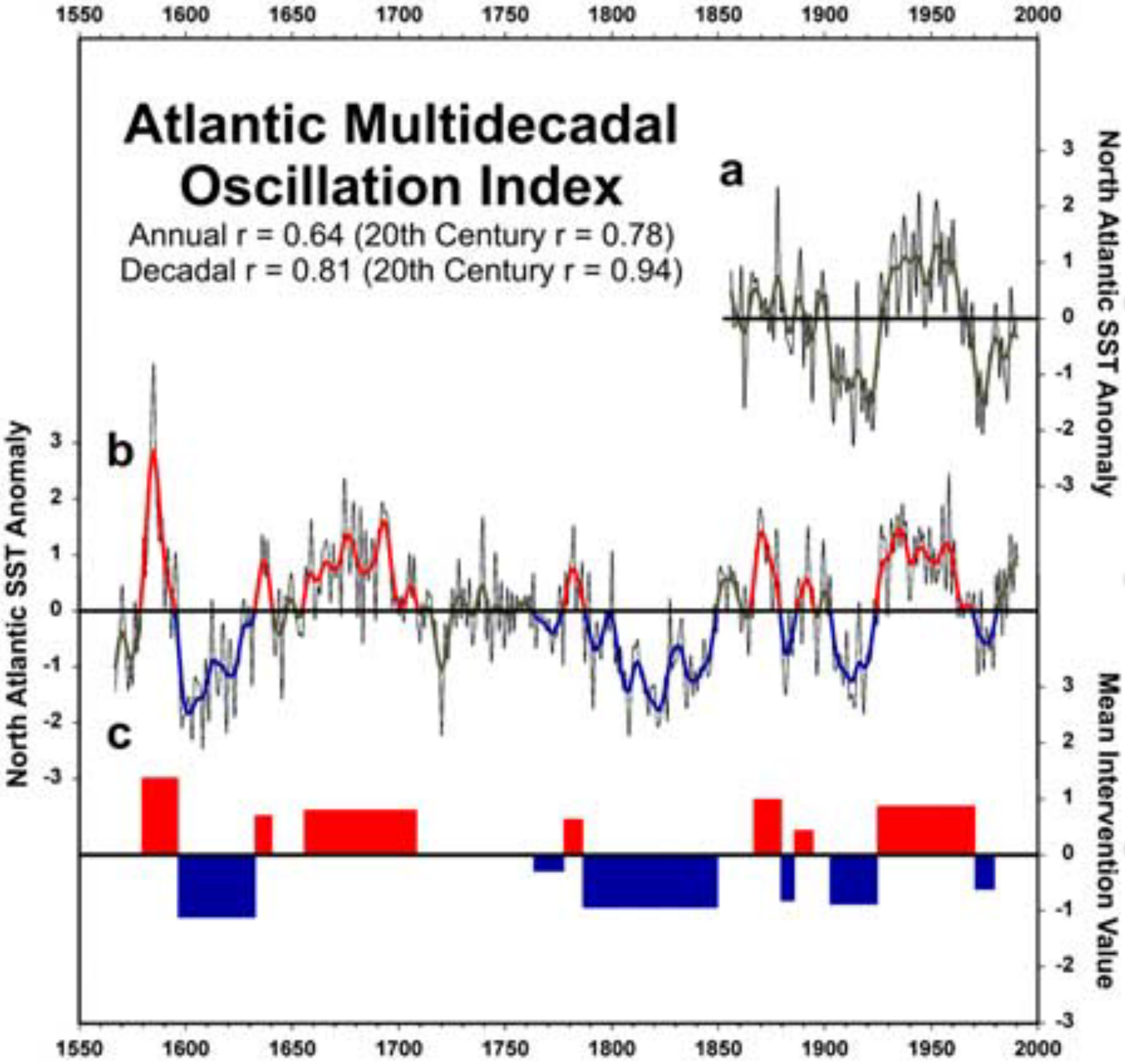
Calibration period (1922-1990)

Verification period (1856-1921)

Reconstruct a time series of the AMO index that agrees with SST instrument measurements but can be extended back in to the past

Gray et al., Geophys. Res. Lett., 2004

AMO Reconstruction from Tree Ring Data



SST observations (in-situ/satellite)

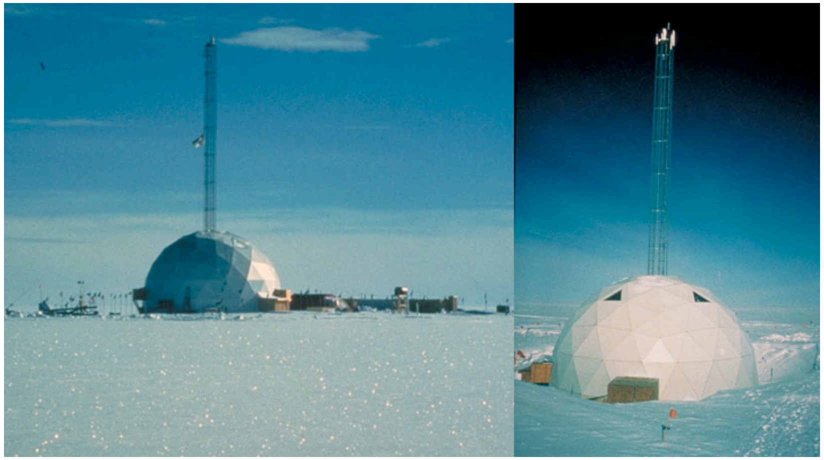
AMO Index from tree rings

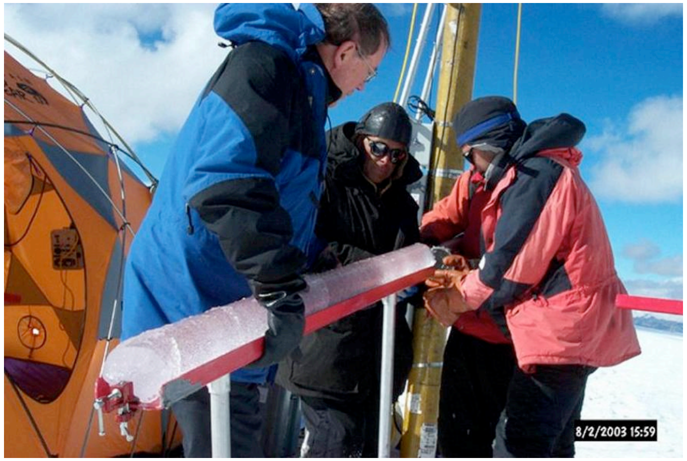
Warm/Cold AMO periods

Principle Sources of Proxy Data for Paleoclimate Reconstructions

- Glaciological (Ice Cores)
  - Oxygen isotopes
  - Physical properties
  - Trace element & microparticle concentrations

The Greenland Ice Sheet Project 2 drill site, located on the Greenland ice sheet at 72.6° N and 38.5° W at an elevation of 3,207 meters.



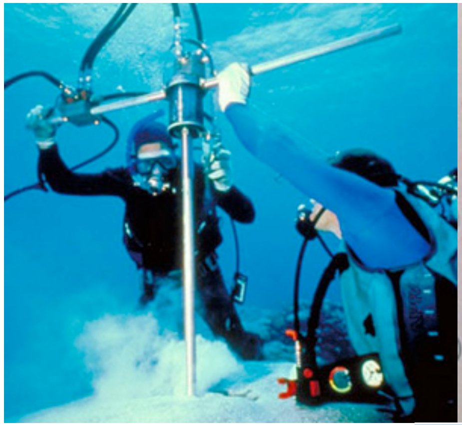


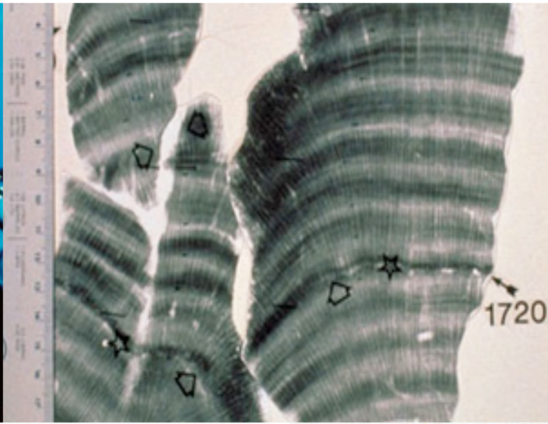
Closeup view of layers within a different sample; arrows indicate lighter summer layers (right).

Peru:http://bprc.osu.edu/Icecore/Quelccaya2003.html http://eo.ucar.edu/staff/rrussell/climate/paleoclimate/ice_core_proxy_records.html

Principle Sources of Proxy Data for Paleoclimate Reconstructions

- Geological
  - A. Sediments
    - 1. Marine (ocean sediment cores)
      - i) Organic sediments (planktonic & benthic fossils)
        - Oxygen isotopes
        - Faunal & floral abundances
        - Morphological variations
      - ii) Inorganic sediments
        - Mineralogical composition & surface texture
        - Distribution of terrigenous material
        - Ice-rafted debris
        - Geochemistry
    - 2. Terrestrial
      - Periglacial features
      - Glacial deposits & erosional features
      - Glacio-eustatic features (shorelines)
      - Aeolian deposits (sand dunes)
      - Lacustrine deposits/varves (lakes)
  - B. Sedimentary Rocks
    - Facies analysis
    - Fossil/microfossil analysis
    - Mineral analysis
    - Isotope geochemistry





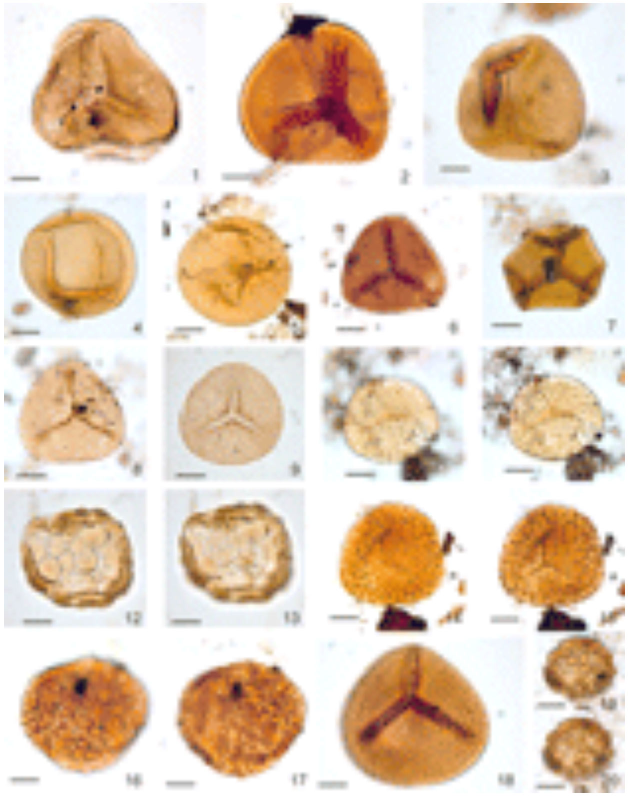
Scientists in SCUBA gear use a drill to extract a coral sample from Clipperton Atoll (lower) This X-ray image of coral samples from the Galapagos Islands clearly shows the banded growth pattern

The ship JOIDES Resolution (top left) has recovered thousands of sediment cores from the ocean floor with a drilling rig. Scientists aboard the ship (top right) clean and prepare one of the 9.5 meter-long cores soon after it was pulled up from the deep ocean. The long cores are cut into shorter segments and split lengthwise down the middle. (lower)

http://www.windows2universe.org/earth/climate/CDcourses_investigate_climate.html

Principle Sources of Proxy Data for Paleoclimate Reconstructions

- Biological
  - Tree rings (width, density, isotope analysis)
  - Pollen (species, abundances)
  - Insects



http://palynology.geoscienceworld.org/content/34/1/3.figures-only

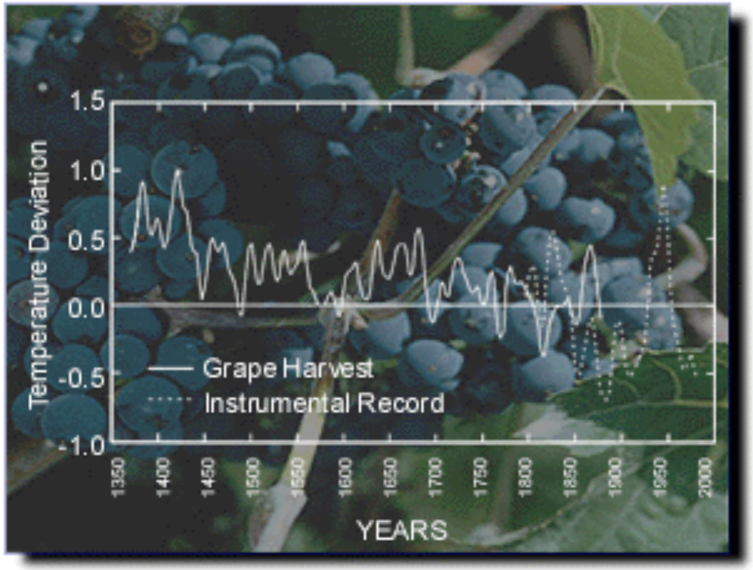
Principle Sources of Proxy Data for Paleoclimate Reconstructions

- Historical

meteorological records

parameteorological record (environmental indicators)

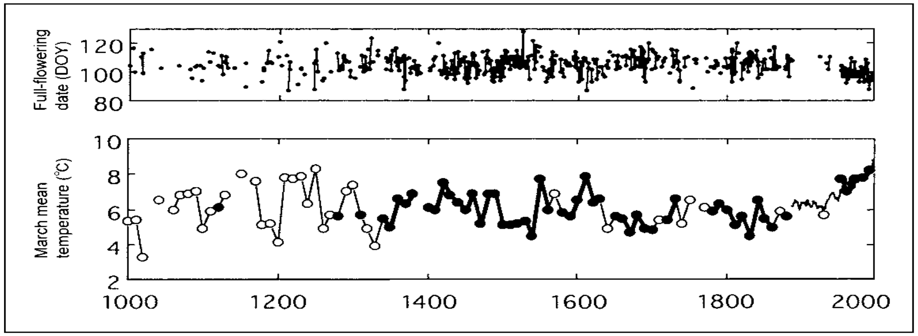
phenological records (biological indicators)



The example above demonstrates how historical grape harvest dates were used to reconstruct summer temperatures (April - September) in Paris from 1370 - 1879. [From Bradley, 1990; based on data from Le Roy Ladurie and Baulant, 1980.]

ARRANGED BY DR. YASUYUKI AONO, WITH PERMISSION FROM THE KYOTO UNIVERSITY LIBRARY

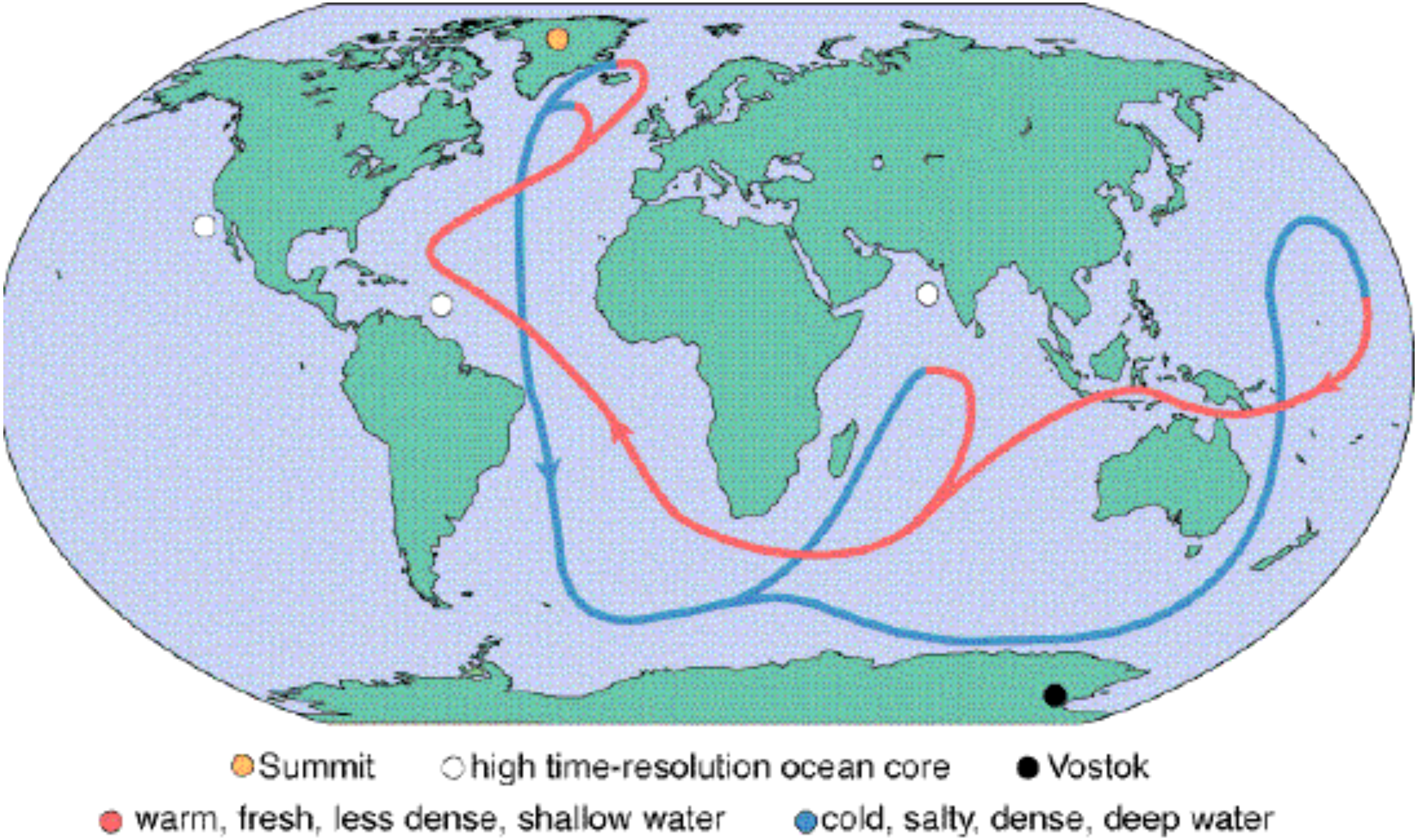
Old court diaries and records let us know the past dates of the cherry blossom festivals in Kyoto. This diary of Tokistune Hiramatsu, a well-known court figure of the Edo era, provides the following entry on April 14, 1644: "In Seiryoden Palace, Kyoto, we enjoyed watching cherry blossoms and took sake provided by the emperor." The translation of the highlighted sentence is shown in red. The black entry is the date, according to the Japanese calendar.



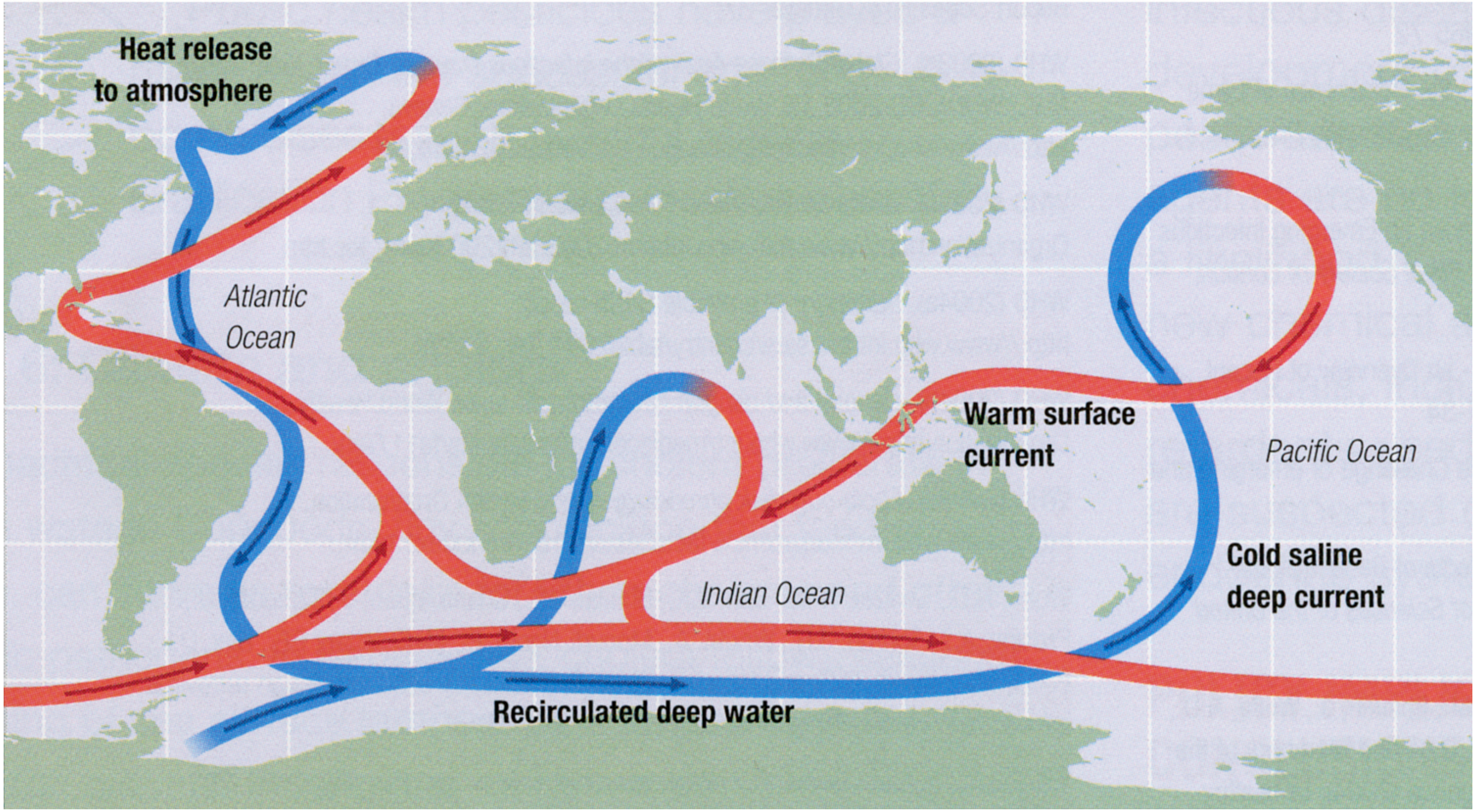
COURTESY OF DR. YASUYUKI AONO AND YUKIO OMOTO, 1994

The Thermohaline Circulation (THC)

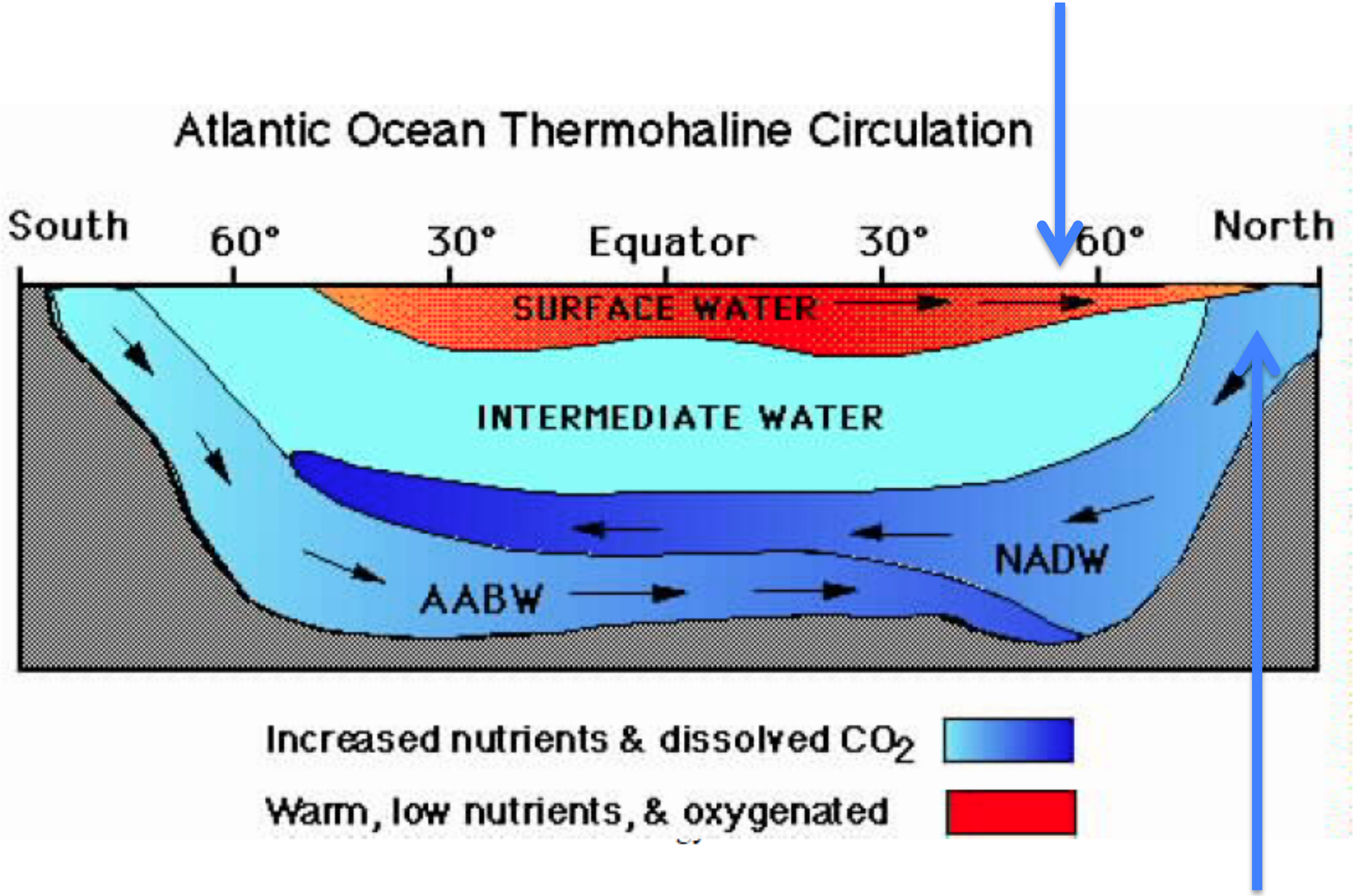
Atlantic Meridional Overturning Circulation (AMOC)



Global Ocean Conveyor Circulation

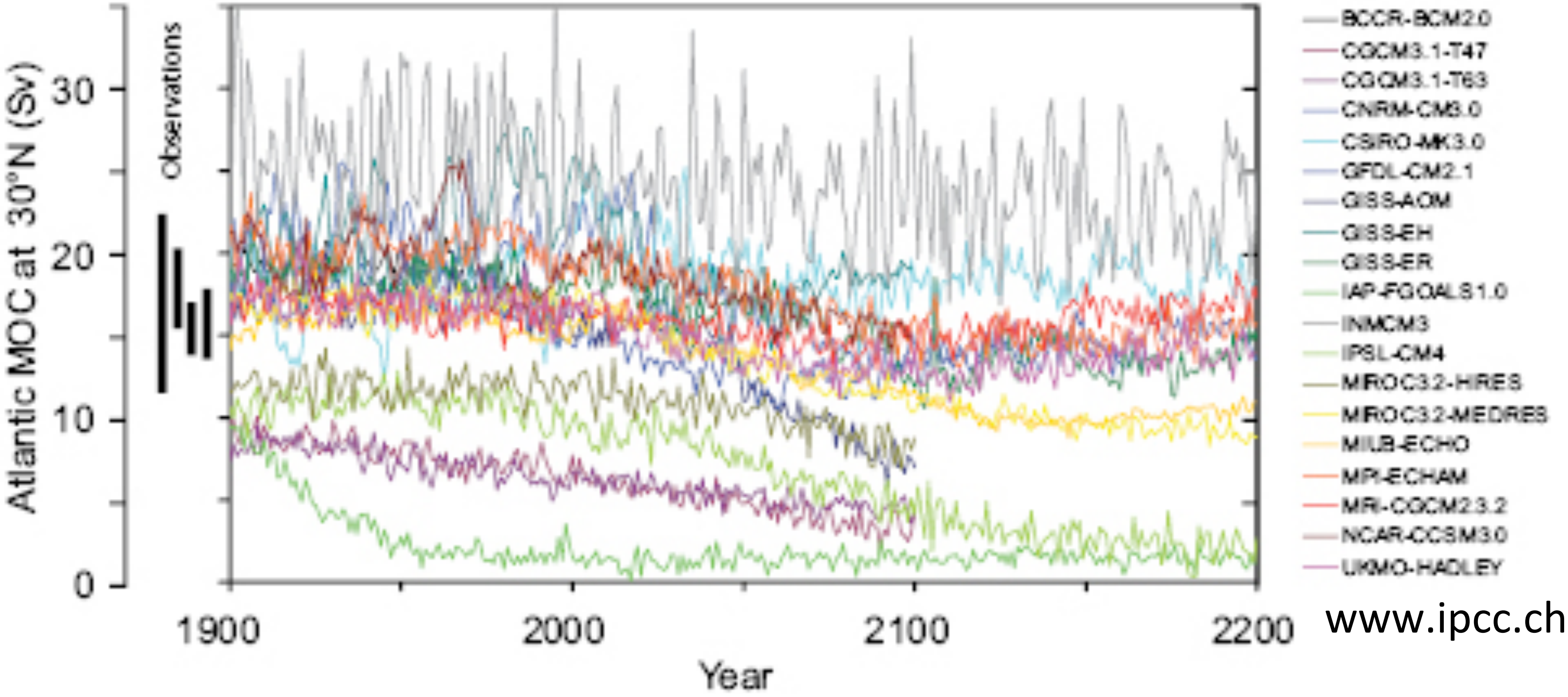


Warm N. Atlantic



Sinking in N. Atlantic

Future changes in the THC (Atlantic Meridional Overturning Circulation)

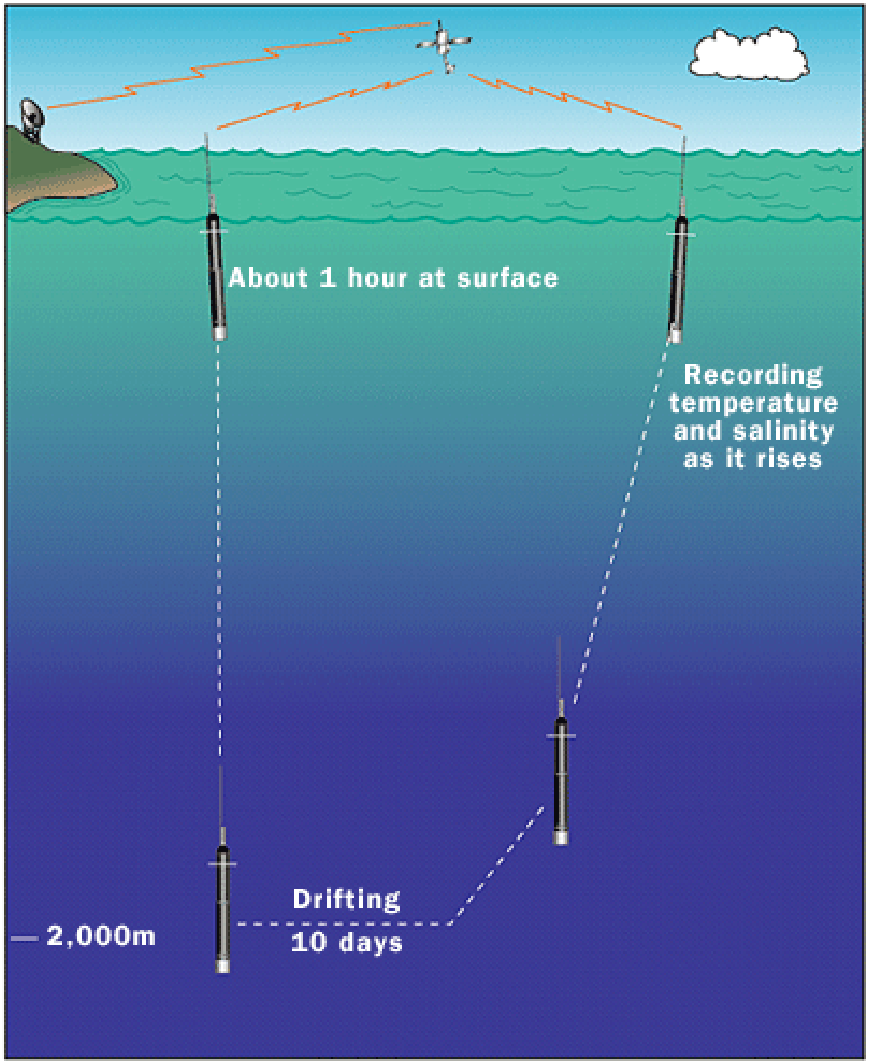


www.ipcc.ch

Future: weakening of THC due to higher temperatures and more rain (freshwater is less salty)

T↑ Density↓ : Less sinking, less warm water from tropics, N. Atlantic cools

Observing the Ocean is Hard…

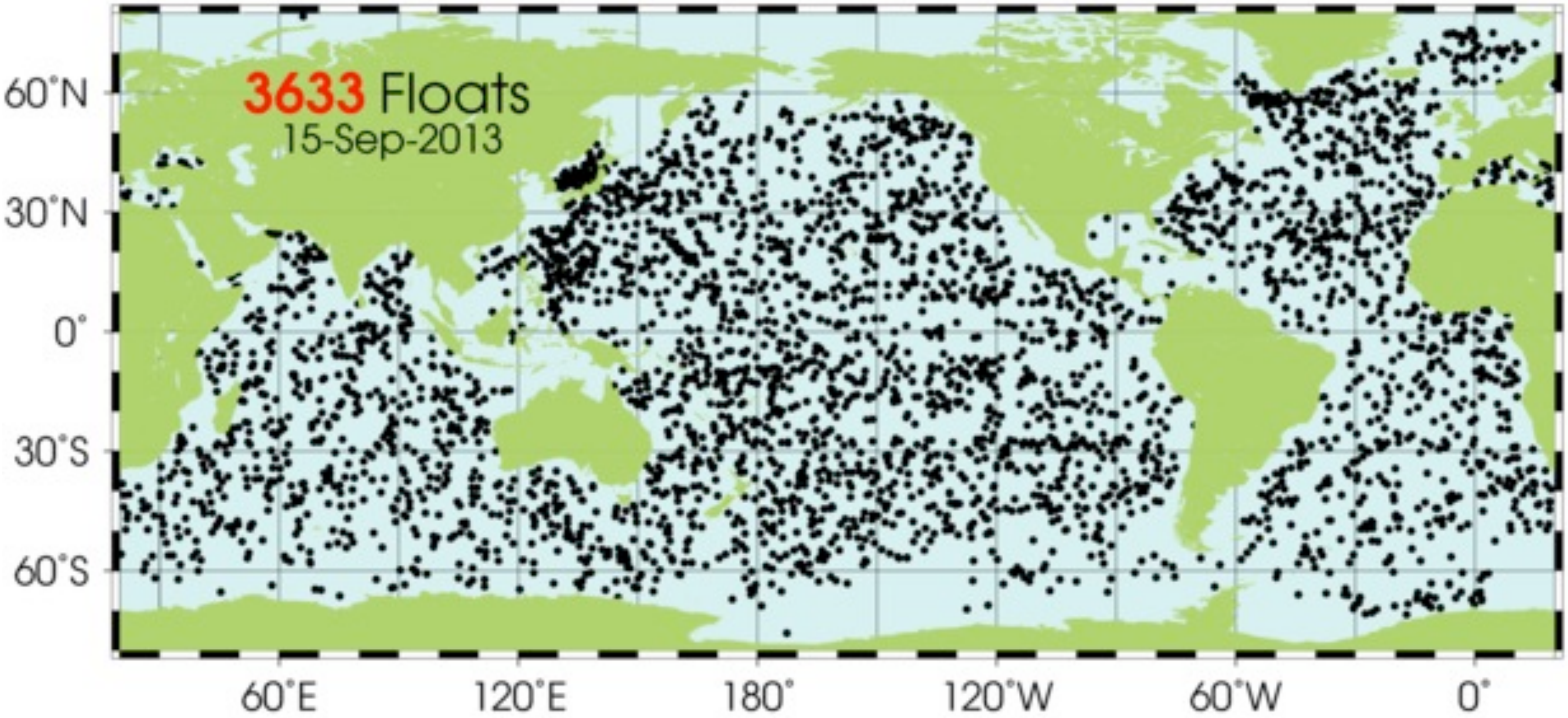


To observed the THC we need to measure below the surface as deep as possible

This isn’t easy

ARGO floats have really helped

http://www.argo.ucsd.edu/



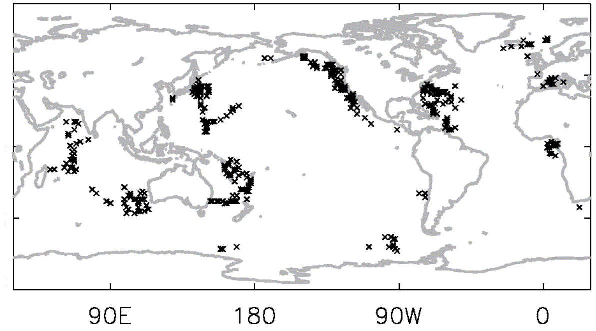
Locations of ARGO floats

What regions are missing floats??

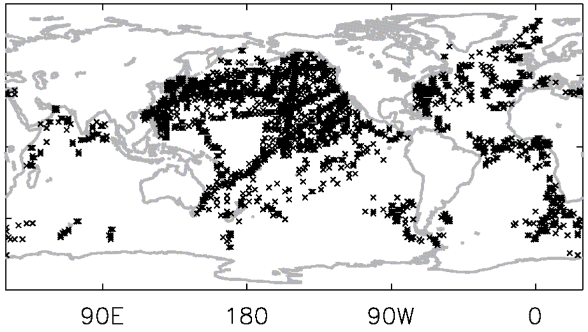
To measure the THC, and how it modulates the AMO we need a long term record

ARGO float locations over the past 50 years…

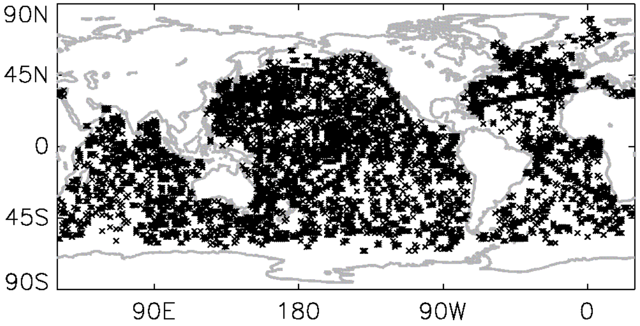
1960



1980



2007



We need something in addition to observations to supplement our understanding of the ocean and how it impacts the atmosphere

What can General Circulation Models models tell us?

Long (~1400 year) model integrations with HadCM3 able to simulate the observed pattern and amplitude of the AMO (Knight et al., 2005)

Model did not include any fluctuations in external forcing (greenhouses gases, aerosols, etc.)

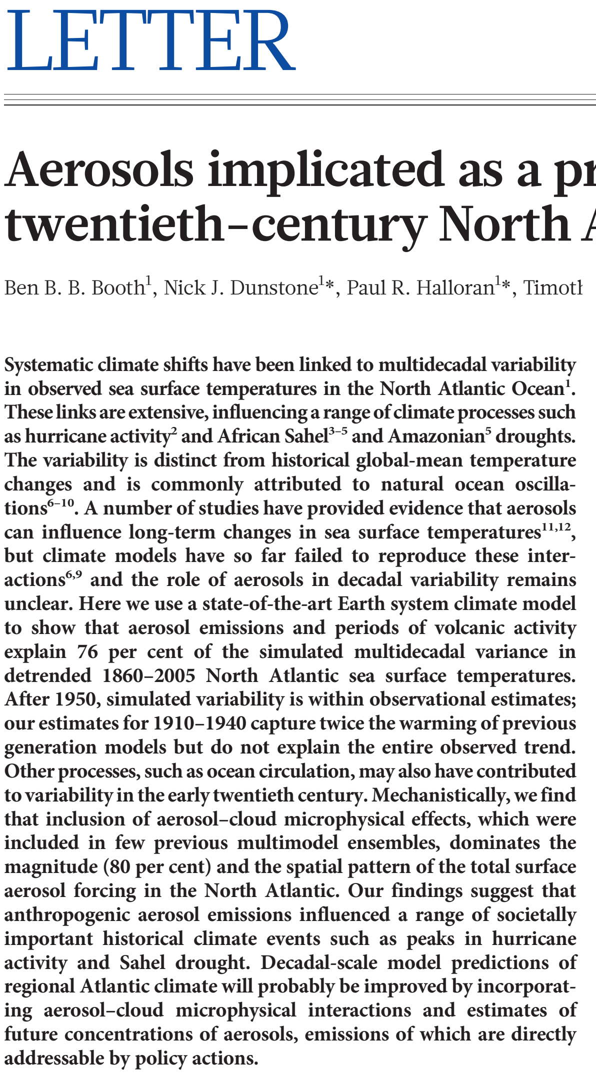
→ suggests AMO is internal climate variability persisting for many centuries

→ Model hints that AMO results from variability in the oceanic THC

Is it all natural?

Ottera et al., Nat. Geosc., 2010

Booth et al. Nature, 2012



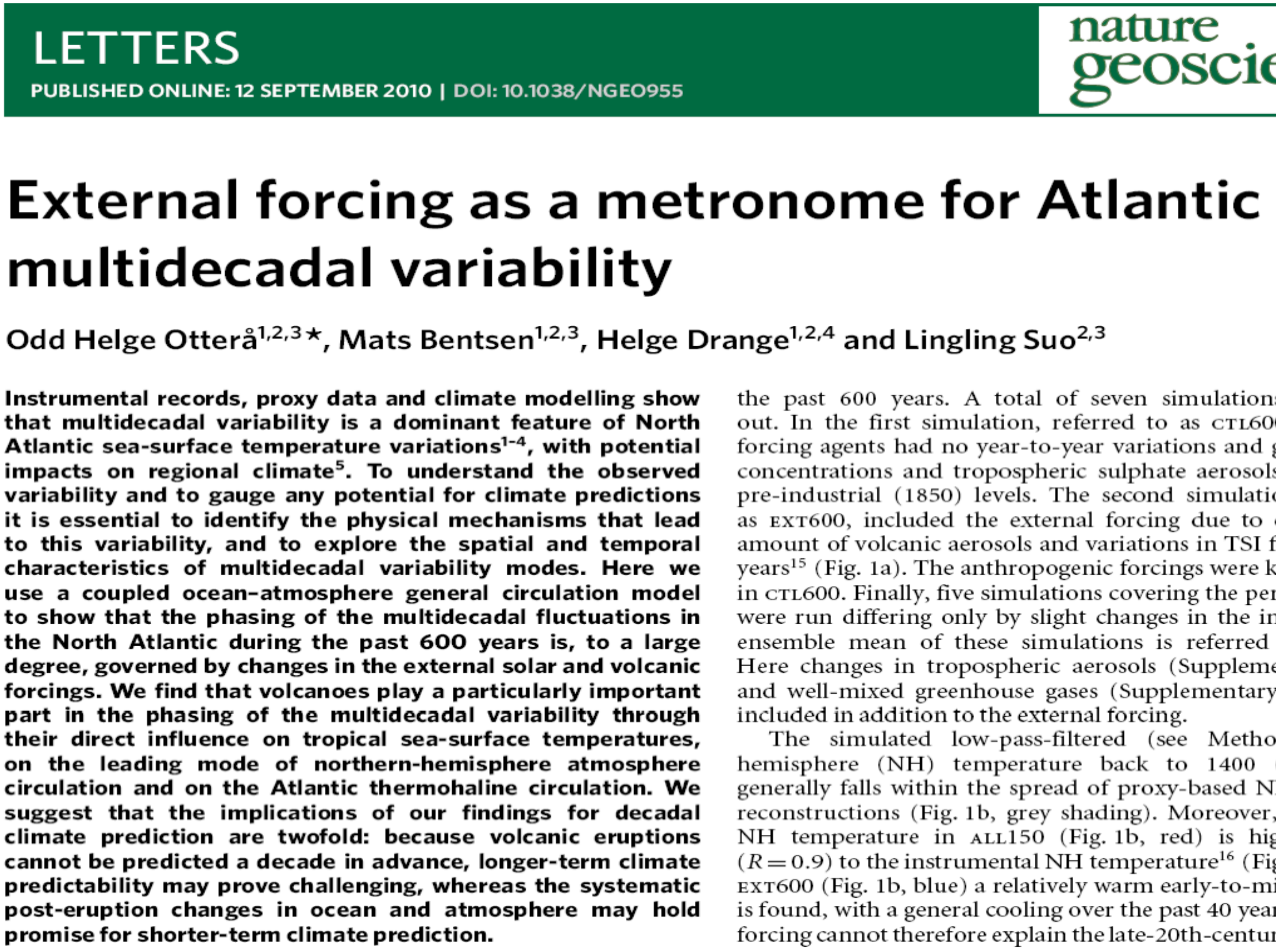
LETTER

doi:10.1038/nature10946

Aerosols implicated as a prime driver of twentieth-century North Atlantic climate variability

Ben B. B. Booth[1], Nick J. Dunstone[1]*, Paul R. Halloran[1]*, Timotl

Systematic climate shifts have been linked to multidecadal variability in observed sea surface temperatures in the North Atlantic Ocean[1]. These links are extensive, influencing a range of climate processes such as hurricane activity[2] and African Sahel[3–5] and Amazonian[5] droughts. The variability is distinct from historical global-mean temperature changes and is commonly attributed to natural ocean oscillations[6–10]. A number of studies have provided evidence that aerosols can influence long-term changes in sea surface temperatures[11,12], but climate models have so far failed to reproduce these interactions[6,9] and the role of aerosols in decadal variability remains unclear. Here we use a state-of-the-art Earth system climate model to show that aerosol emissions and periods of volcanic activity explain 76 per cent of the simulated multidecadal variance in detrended 1860–2005 North Atlantic sea surface temperatures. After 1950, simulated variability is within observational estimates; our estimates for 1910–1940 capture twice the warming of previous generation models but do not explain the entire observed trend. Other processes, such as ocean circulation, may also have contributed to variability in the early twentieth century. Mechanistically, we find that inclusion of aerosol–cloud microphysical effects, which were included in few previous multimodel ensembles, dominates the magnitude (80 per cent) and the spatial pattern of the total surface aerosol forcing in the North Atlantic. Our findings suggest that anthropogenic aerosol emissions influenced a range of societally important historical climate events such as peaks in hurricane activity and Sahel drought. Decadal-scale model predictions of regional Atlantic climate will probably be improved by incorporating aerosol–cloud microphysical interactions and estimates of future concentrations of aerosols, emissions of which are directly addressable by policy actions.



LETTERS

| DOI: 10.1038/NGEO955

nature geoscie

External forcing as a metronome for Atlantic multidecadal variability

Odd Helge Otterå[1,2,3]*, Mats Bentsen[1,2,3], Helge Drange[1,2,4] and Lingling Suo[2,3]

Instrumental records, proxy data and climate modelling show that multidecadal variability is a dominant feature of North Atlantic sea-surface temperature variations[1–4], with potential impacts on regional climate[5]. To understand the observed variability and to gauge any potential for climate predictions it is essential to identify the physical mechanisms that lead to this variability, and to explore the spatial and temporal characteristics of multidecadal variability modes. Here we use a coupled ocean–atmosphere general circulation model to show that the phasing of the multidecadal fluctuations in the North Atlantic during the past 600 years is, to a large degree, governed by changes in the external solar and volcanic forcings. We find that volcanoes play a particularly important part in the phasing of the multidecadal variability through their direct influence on tropical sea-surface temperatures, on the leading mode of northern-hemisphere atmosphere circulation and on the Atlantic thermohaline circulation. We suggest that the implications of our findings for decadal climate prediction are twofold: because volcanic eruptions cannot be predicted a decade in advance, longer-term climate predictability may prove challenging, whereas the systematic post-eruption changes in ocean and atmosphere may hold promise for shorter-term climate prediction.

the past 600 years. A total of seven simulation
out. In the first simulation, referred to as CTL60
forcing agents had no year-to-year variations and
concentrations and tropospheric sulphate aerosol
pre-industrial (1850) levels. The second simulati
as EXT600, included the external forcing due to
amount of volcanic aerosols and variations in TSI f
years[15] (Fig. 1a). The anthropogenic forcings were k
in CTL600. Finally, five simulations covering the per
were run differing only by slight changes in the in
ensemble mean of these simulations is referred
Here changes in tropospheric aerosols (Suppleme
and well-mixed greenhouse gases (Supplementary
included in addition to the external forcing.

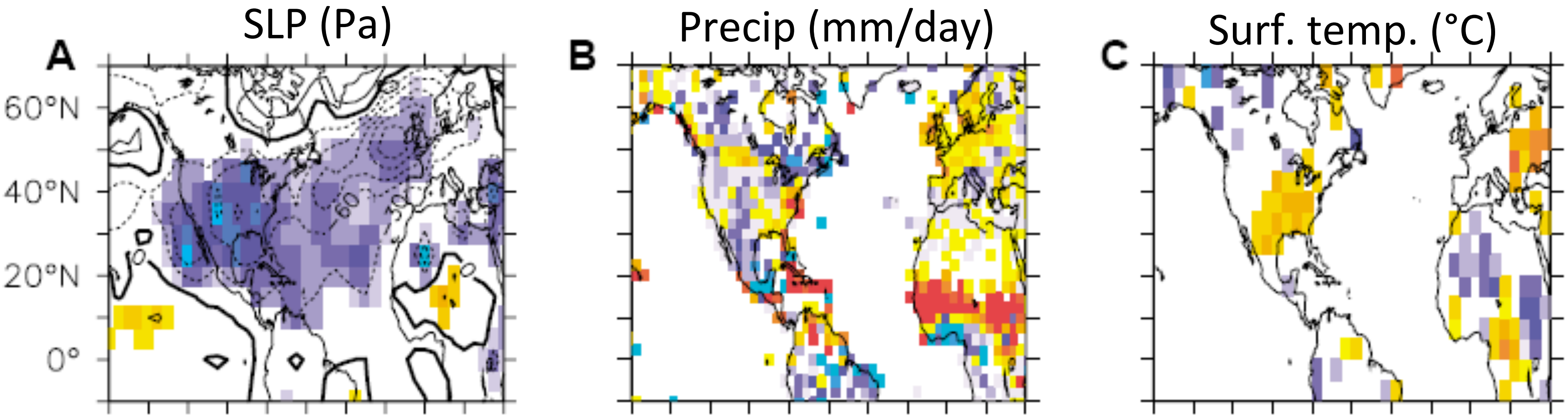
The simulated low-pass-filtered (see Metho
hemisphere (NH) temperature back to 1400
generally falls within the spread of proxy-based N
reconstructions (Fig. 1b, grey shading). Moreover,
NH temperature in ALL150 (Fig. 1b, red) is hig
($R = 0.9$) to the instrumental NH temperature[16] (Fig
EXT600 (Fig. 1b, blue) a relatively warm early-to-mi
is found, with a general cooling over the past 40 year
forcing cannot therefore explain the late-20th-centur

AMO Impacts

- Warm SSTs over N. Atlantic
- What potential impacts are there on surrounding regions?
  - Think of and write down 3 possible impacts. Could be temperature, rainfall, storms, etc…

One method of looking at impacts is to make composite (or averages) of warm and cold period and take the difference (e.g. 1931/60 – 1961/90)

So, when the AMO is in a warm period:

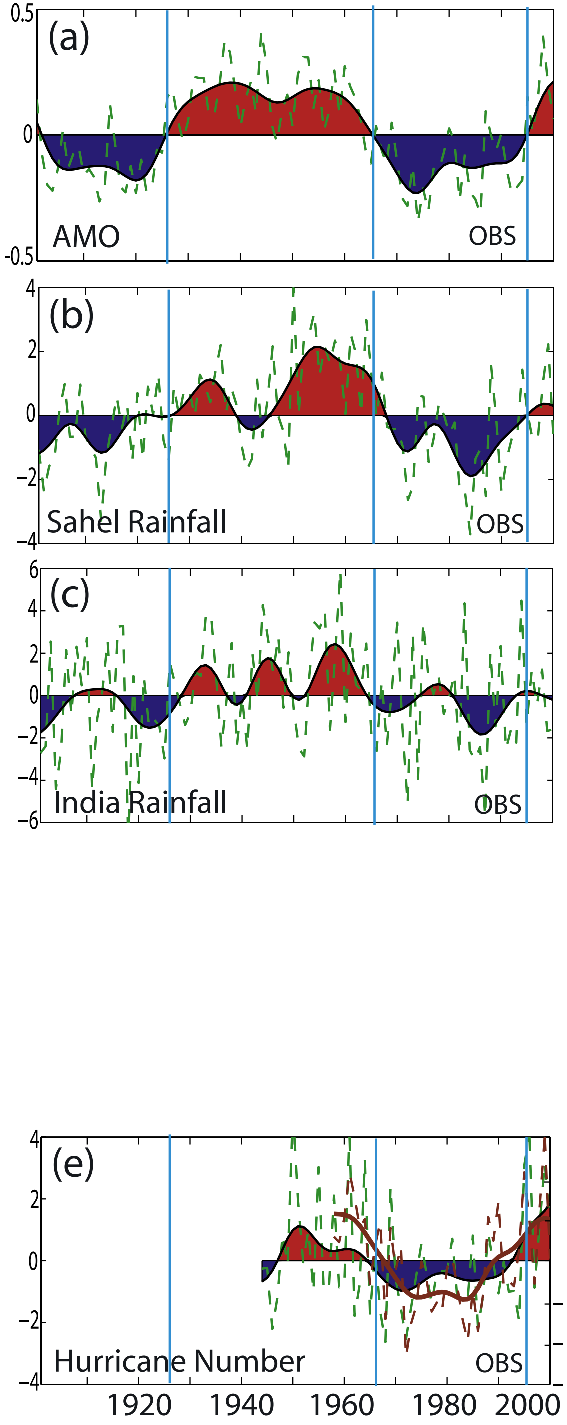


Low SLP across Atlantic and N. America

Wet in West Africa, Europe, dry in central US

Warm in East US

Sutton and Hodson, Science, 2005



AMO Impacts Globally

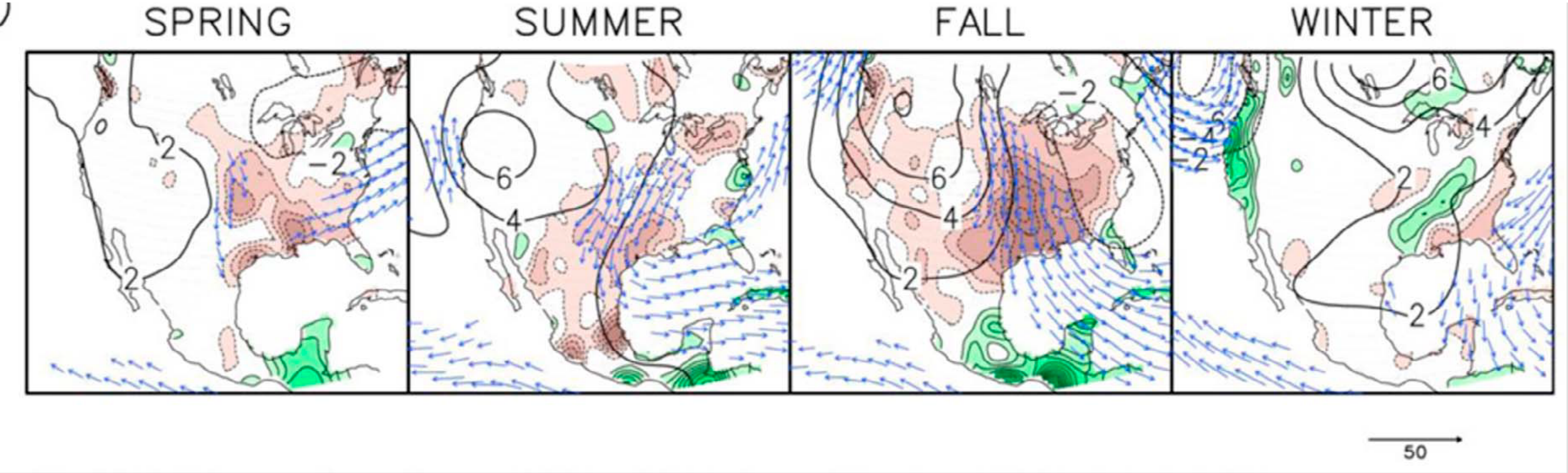
You can also look at correlations between time series….

- Sahel rainfall
- Indian monsoon rainfall
- Hurricane numbers?

Zhang and Delworth, Geophys. Res. Lett., 2006

AMO Impacts in the US

So, when the AMO is in a warm period:

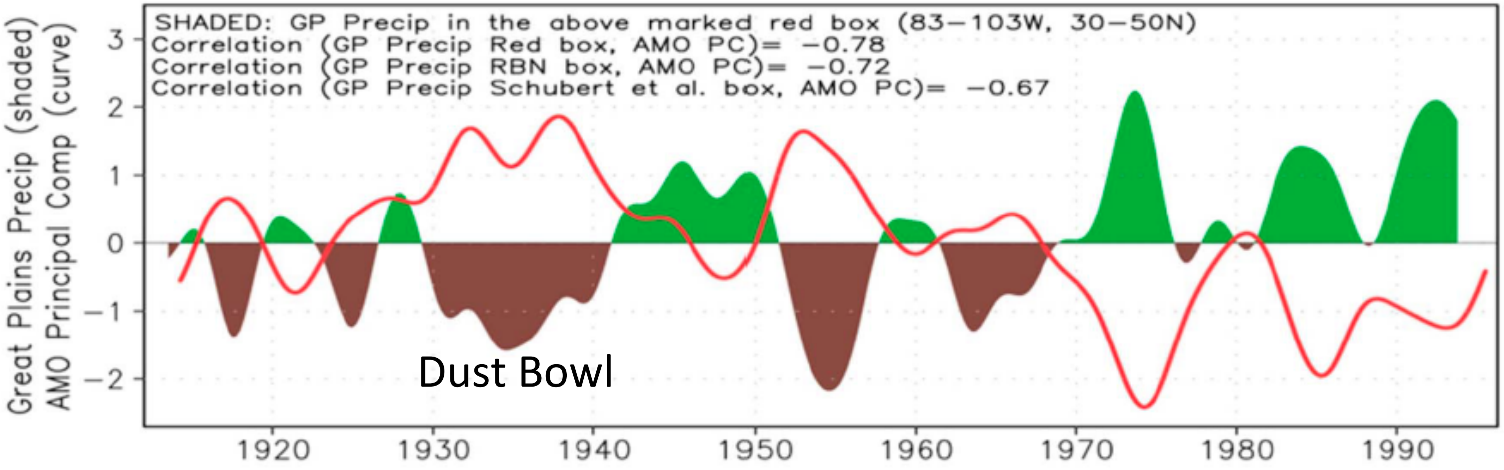


- Dry conditions in Central US, especially in Fall
- Wet conditions in Central America and Florida
- Changes in wind accompany rainfall changes

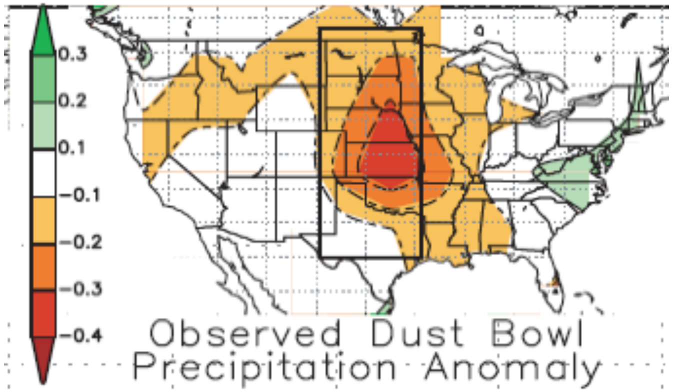
Nigam et. al., Geophys. Res. Lett., 2011

The AMO and the The Dust Bowl

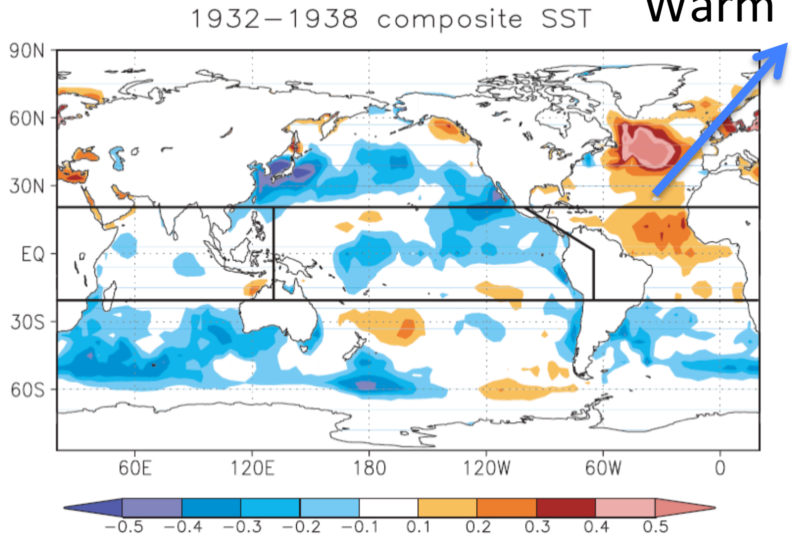
Nigam et. al., Geophys. Res. Lett., 2011



Dust Bowl

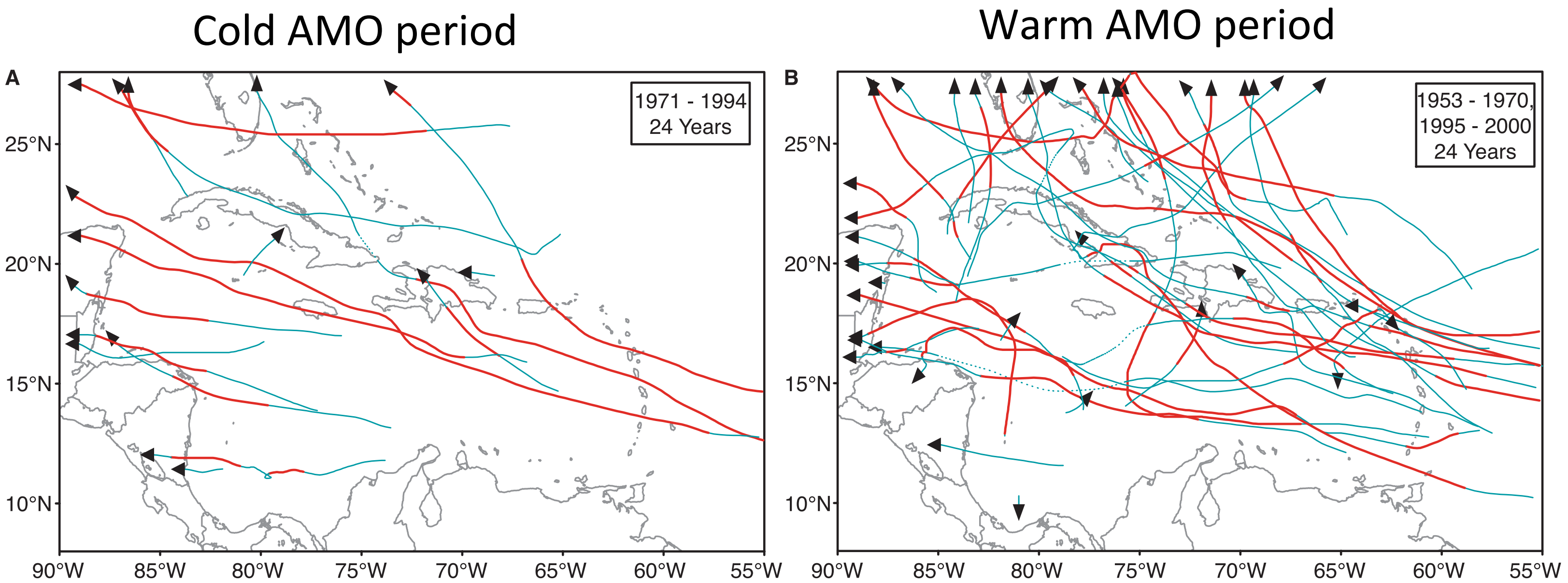


Warm N. Atlantic



Schubert et al., 2004

The AMO and Hurricanes


Cold AMO period

Warm AMO period

Goldenberg et al., Science, 2001

1971 – 1994
Cold N. Atlantic and small Atlantic warm pool
15 major hurricanes, few hit US
Cheap insurance
Little public and industry awareness of climate risk shifts

1953 – 1970 & 1995 - 2000
Warm N. Atlantic and large Atlantic warm pool
33 major hurricanes, lots hit US
Expensive insurance
More public and industry awareness of climate risk shifts

**** Essential to consider decadal changes in hurricanes when assessing impact of climate change ****

Summary: AMO Impacts on Climate

- AMO plays an important role in modulating climate on multidecadal time scales in US and Europe, especially during boreal summer and fall

  - Low pressure centers over SE US and UK
  - Enhanced rain in western Europe, Florida, Sahel and N. Africa
  - Reduced rain central US and Mexico
  - Warm surface temperature anomalies over US and central Europe

- May affect not only mean climate but also frequency of extreme events (US droughts, hurricanes, heat waves)

- Phase change of AMO around 1960 may have caused summertime cooling in US and Europe

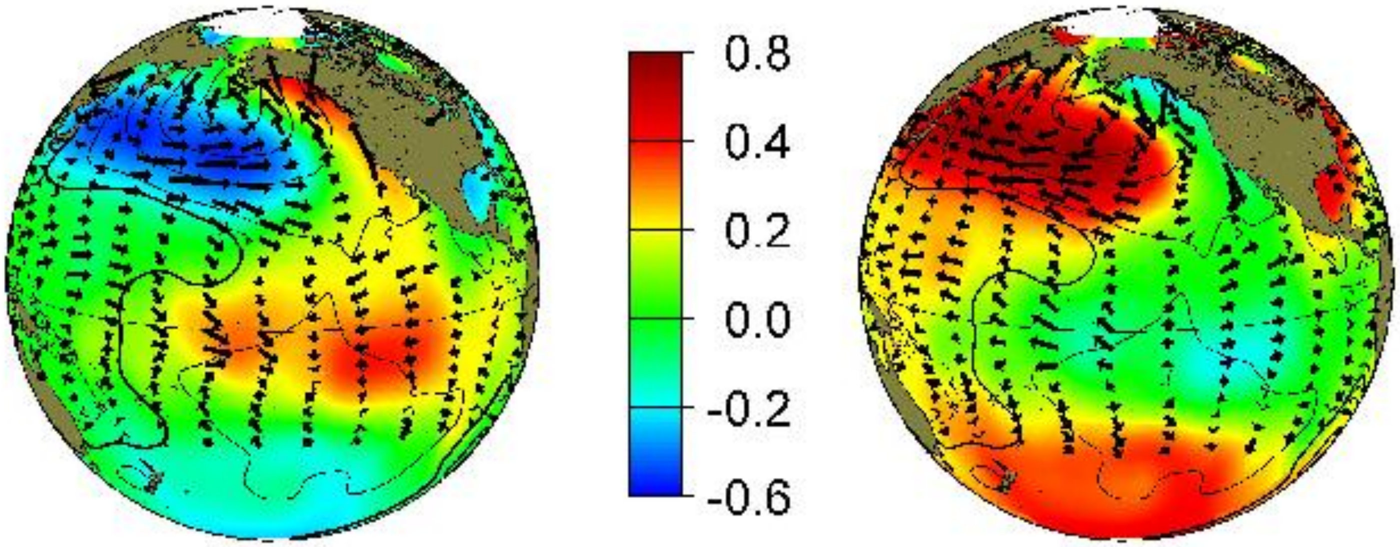
- Most recent phase change (around 1990) may have contributed to rapid warming

<u>MUST CONSIDER THESE DECADAL CHANGES WHEN ASSESSING CLIMATE CHANGE</u>

3) The PDO:

Pacific Decadal Oscillation

Pacific Decadal Oscillation: SST Pattern



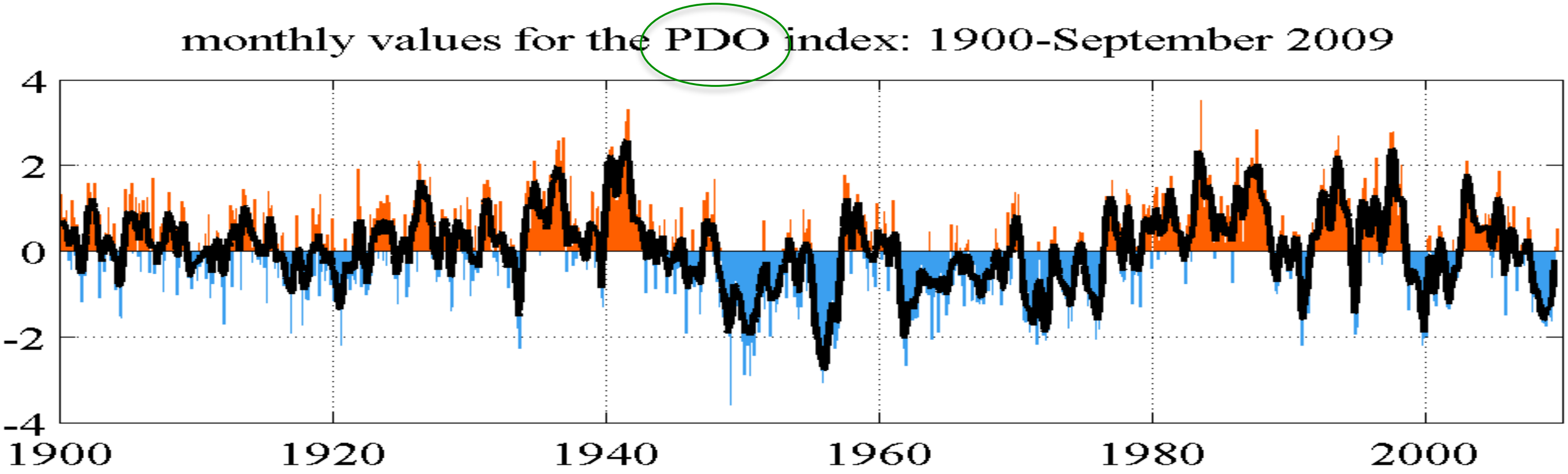
Warm phase

Cold Phase

ENSO-like pattern but strongest SST changes in extratropics

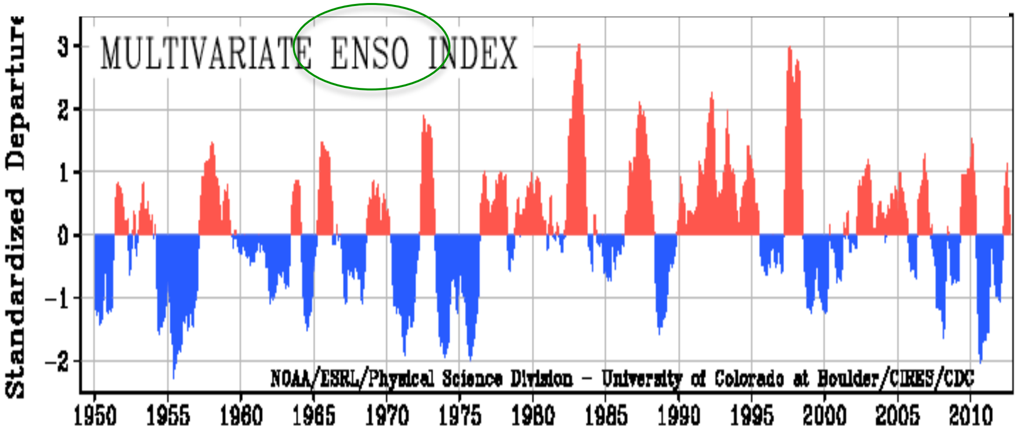
See http://jisao.washington.edu/pdo

Pacific Decadal Oscillation: Timeseries



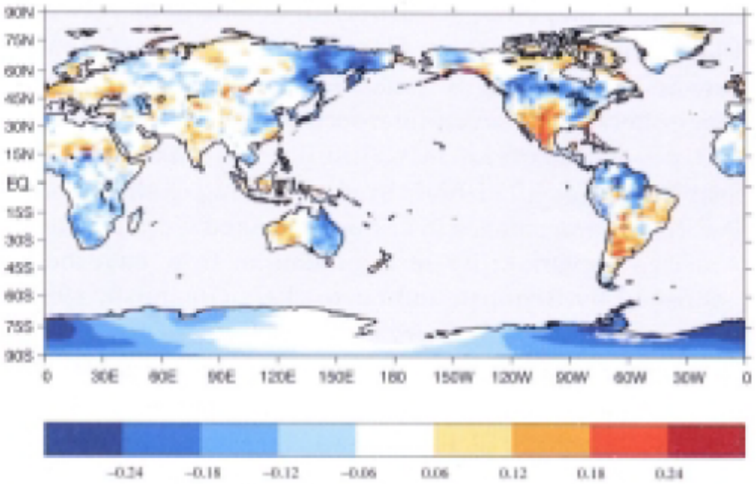
PDO and ENSO are on different time scales

Time series have similarities but are not identical

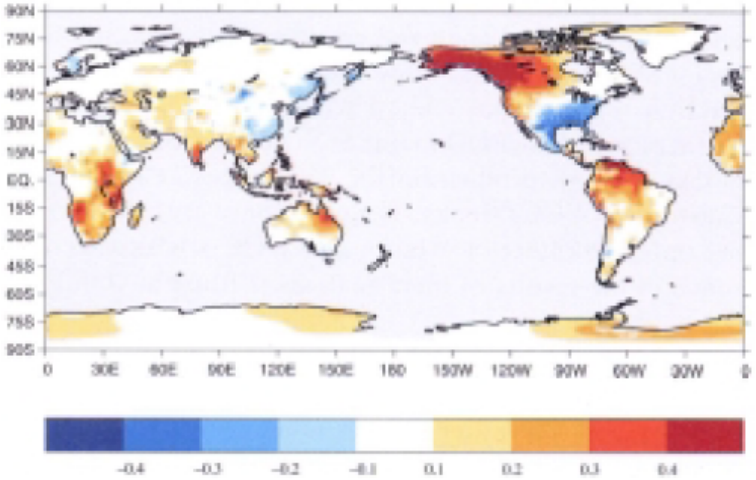


NOAA/ESRL/Physical Science Division – University of Colorado at Boulder/CIRES/CDC

PDO Impacts in US



0.5 Degree Grid November-April Precipitation correlated with November-April PDO index: 1950-96



0.5 Degree Grid November-April Temperature correlations with November-April PDO index: 1950-96

Warm PDO:

- Wet S, SW US
- Dry in NW, Great Lakes

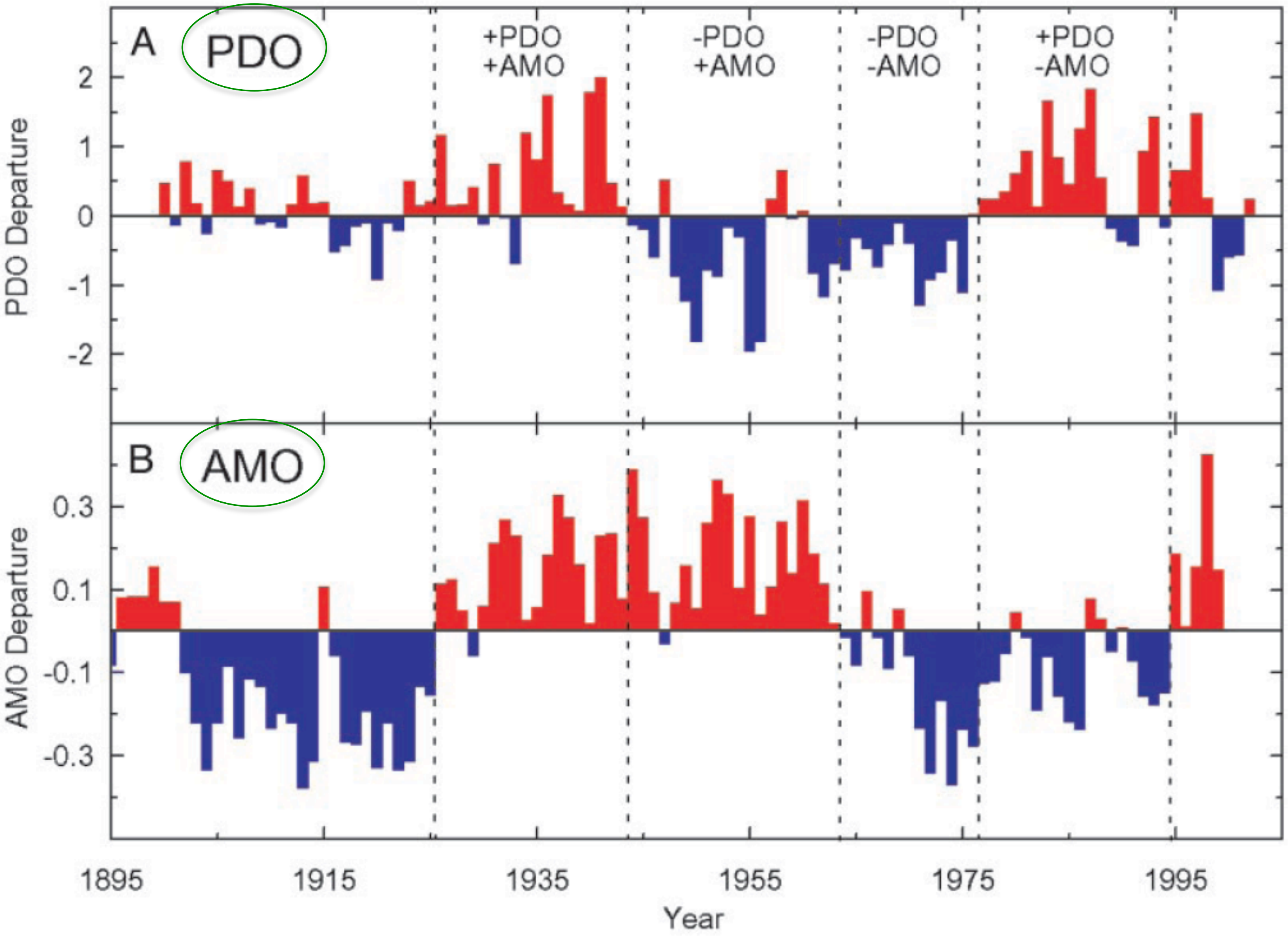
- Warm in E. Canada, Alaska
- Cold in E US

- Snow pack and streamflow in NW US is reduced
- Winter and spring flood risk in NW US is reduced

Mantua and Hare, J. Oceanog., 2002

Combined Impacts

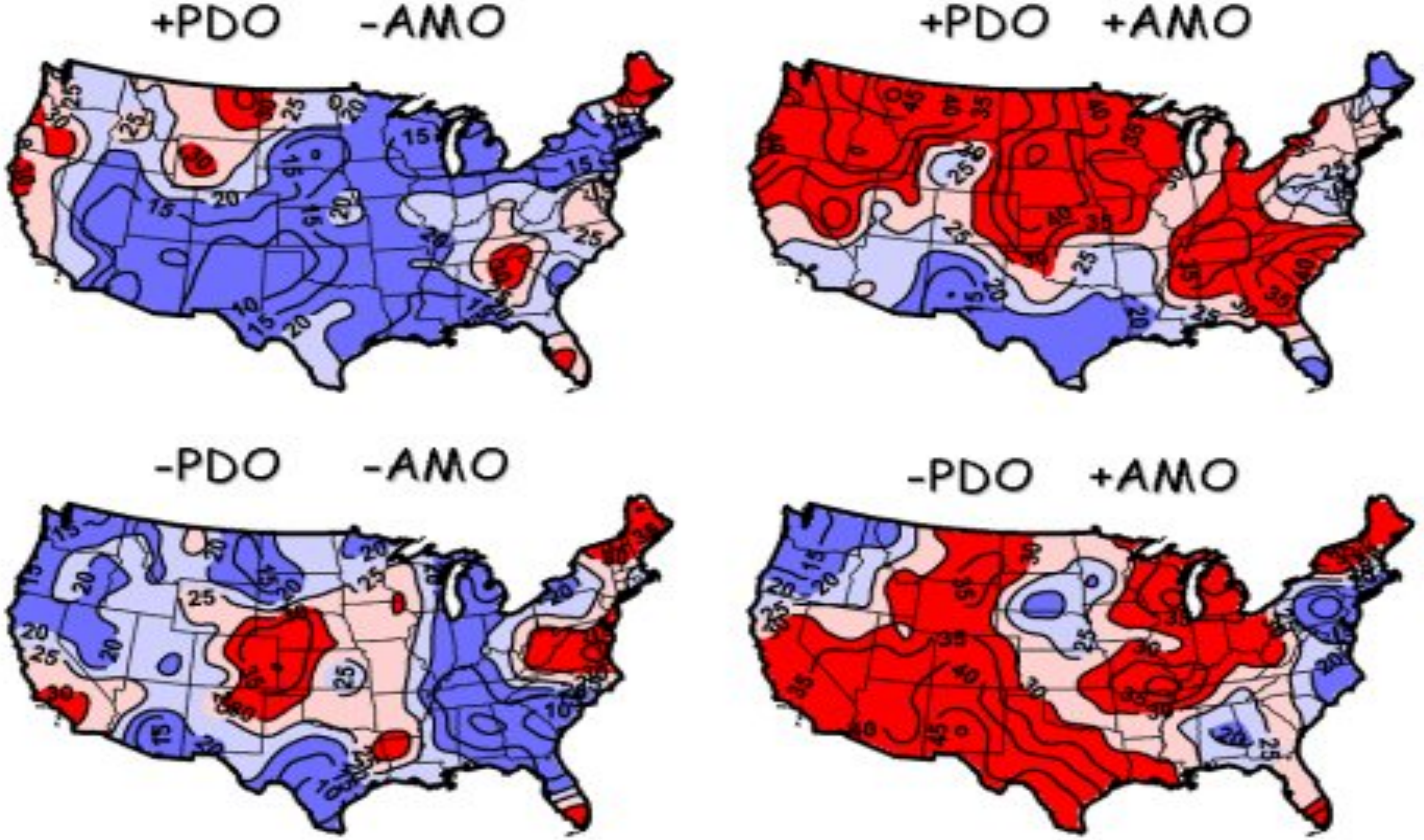
McCabe et al., PNAS, 2004



Note that the PDO and AMO operate on different time scales too!

The PDO and AMO combined: Drought Frequency

McCabe et al., PNAS, 2004



25% = normal drought frequency

PDO vs. AMO impacts in the US

- AMO+ (warm) : much of US under drought conditions, regardless of PDO state

More than half (52%) of spatiotemporal variance in multidecadal drought frequency over US attributable to combined PDO / AMO influence

Recent US droughts (1996, 1999–2002) associated N. Atlantic warming (positive AMO) and NE and tropical Pacific cooling (negative PDO)

→ Much of the long-term predictability of drought frequency may reside in the multi-decadal behavior of the N. Atlantic

McCabe et al., 2004

“The decadal time scale offers a critical bridge for informing adaption strategies as climate varies and changes”

Meehl et al., BAMS, 2009

Decadal Prediction

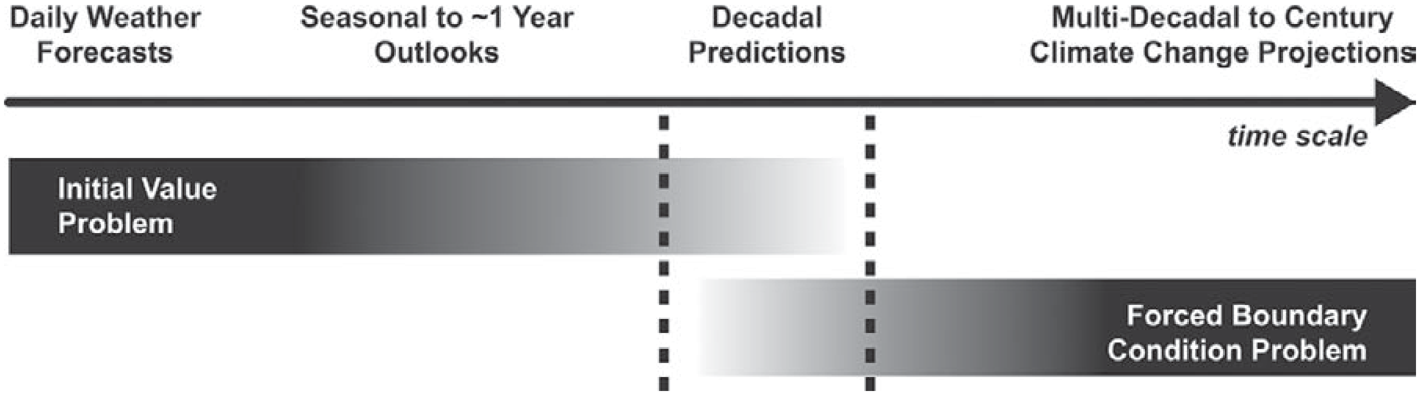
Now we know about ways the climate varies on decadal timescales so the next questions are:

- Is it predictable?

- Can we predict it?

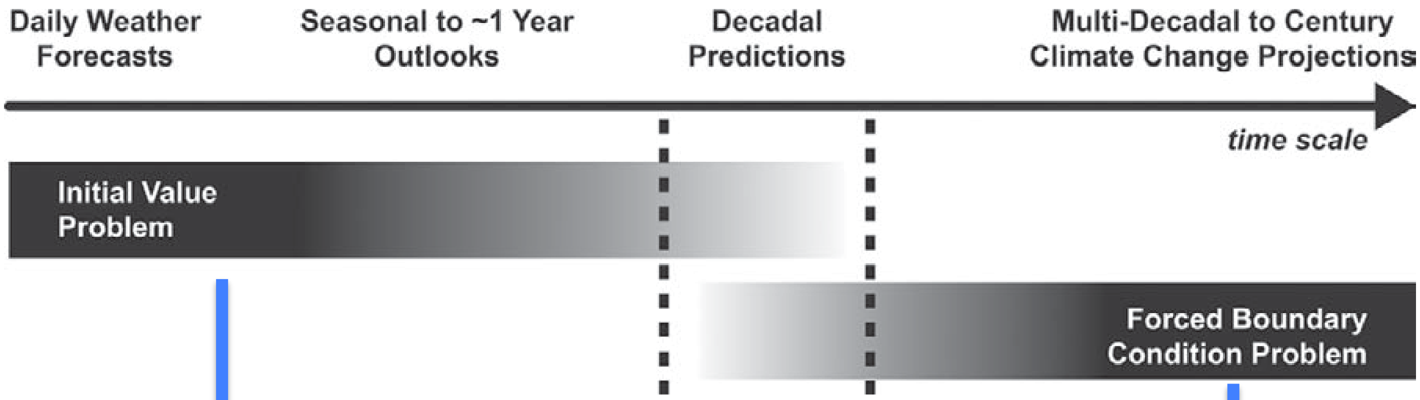
The decadal time scale is widely recognized as a key planning horizon for governments, businesses, and other societal entities

Decadal Predictability



Meehl et al., BAMS, 2009

Decadal Predictability



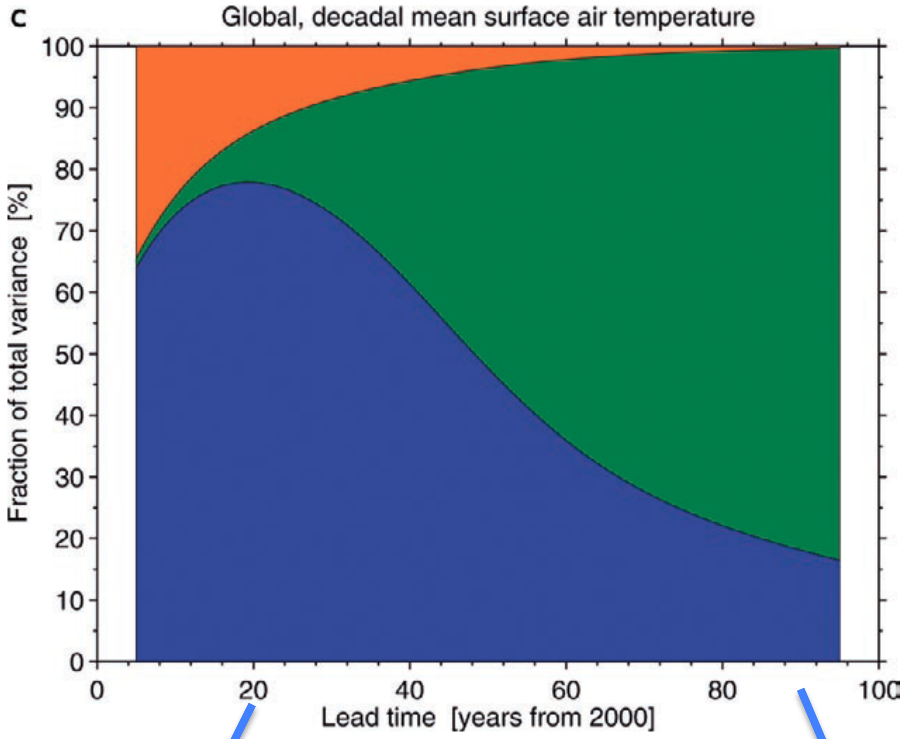
Predictability of the 1st kind

Predictability of the 2nd kind

Predictability of the ?? kind

Meehl et al., BAMS, 2009

Decadal Predictability



ORANGE
Internal Variability: Natural fluctuations in the climate system. AMO, PDO, ENSO etc.

BLUE
Model Uncertainty: Different models respond differently to the same forcing

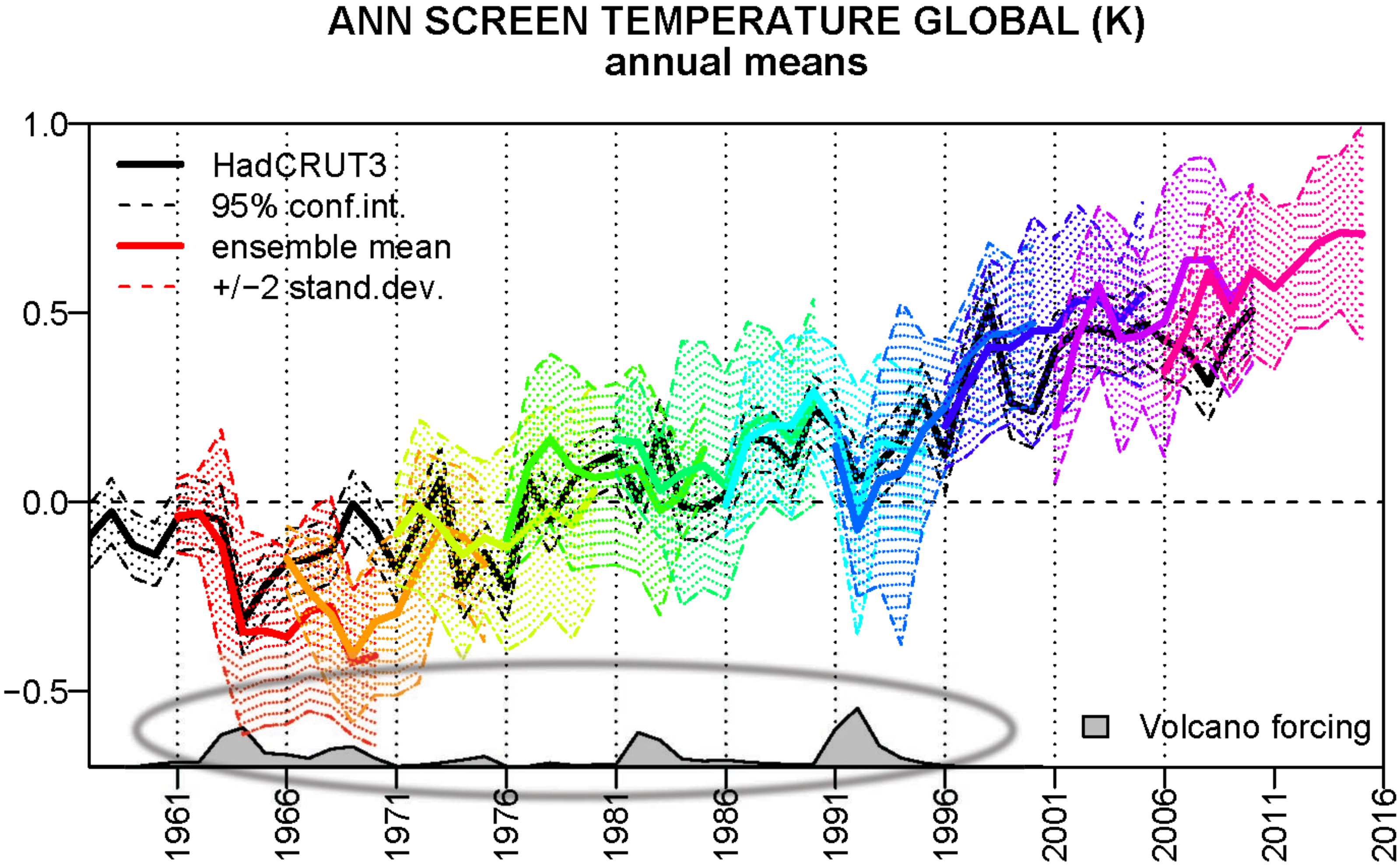
GREEN
Scenario Uncertainty: Changes in future greenhouse gas emission

At decadal scales:
Internal variability and model uncertainty have more importance than scenario

At centennial scales:
Scenario uncertainty is dominant

Hawkins and Sutton, BAMS, 2009

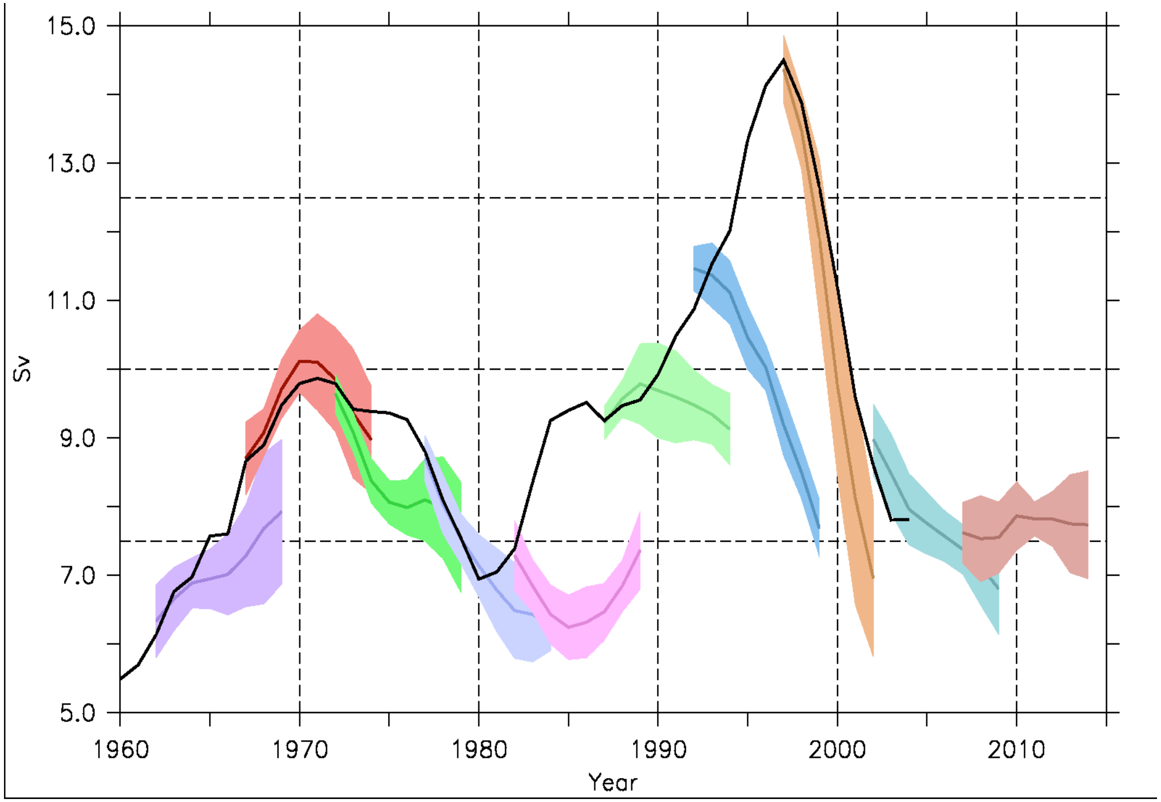
Decadal Hindcast Example



Kirtman, 2011

Decadal Hindcast Example

Hindcast: run a model to assess how well it predicts what has already happened. Compare results to the real world



10 year hindcasts of the Atlantic meridional circulation:

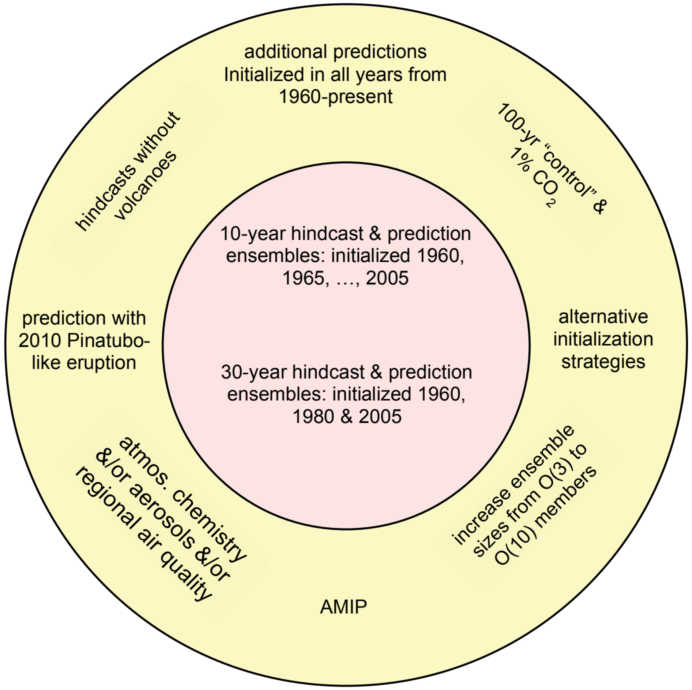
Some are better than others!

Are some periods more predictable than others?

Mignot et al., 2011

Decadal Prediction and the IPCC
(Intergovernmental Panel on Climate Change)

They have begun exploring decadal predictions with lots of new model experiments in the newest climate change models (CMIP5). However…



10-year hindcast & prediction ensembles: initialized 1960, 1965, …, 2005

30-year hindcast & prediction ensembles: initialized 1960, 1980 & 2005

additional predictions Initialized in all years from 1960-present

100-yr "control" & 1% CO_2

alternative initialization strategies

increase ensemble sizes from O(3) to O(10) members

AMIP

atmos. chemistry &/or aerosols &/or regional air quality

prediction with 2010 Pinatubo-like eruption

hindcasts without volcanoes

"Users of CMIP5 model output should take note that decadal predictions with climate models are in an exploratory stage…. The experiments aim to advance understanding of predictability"

Taylor et al., BAMS, 2012

Decadal Prediction Challenges

1) *<u>Initializing</u>*: we need to know the current conditions of the atmosphere and ocean

2) *<u>Improved climate models</u>*: Need climate models to be more accurate, especially in regions with high decadal variability

3) *<u>Ensembles and Uncertainty</u>*: How to represent errors in the initial conditions

4) *<u>Hindcasts and Evaluation</u>*: How to measure how good or bad a prediction is

5) *<u>Providing regional information to users</u>*: Even if we can make a perfect prediction, how do we tell the people who need to know (governments, water managers, businesses etc.)

Murphy et al., 2012

“An improved understanding of decadal climate variability is very important because stakeholders and policymakers want to know the likely climate trajectory for the coming decades for applications to water resources, agriculture, energy, and infrastructure development.”

Mehta et al., BAMS, 2011