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Hiroshima, Japa

# Challenges in understanding ocean climate variability and change and its impacts: Temporal and spatial scales and multi-forcings

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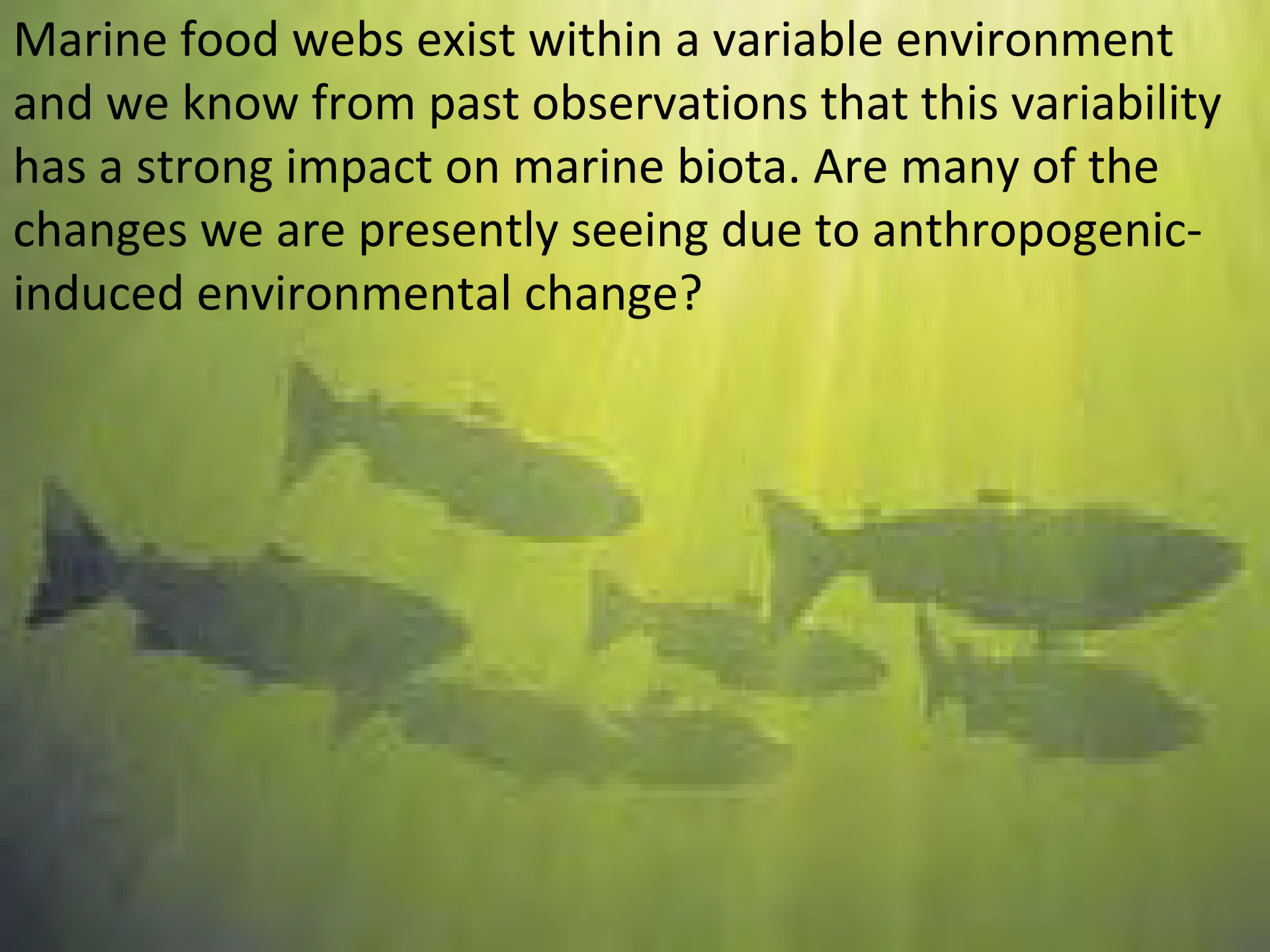
Marine food webs exist within a variable environment and we know from past observations that this variability has a strong impact on marine biota. Are many of the changes we are presently seeing due to anthropogenic-induced environmental change?



# Outline

- Climate Variability and Change
  - Climate (long-term average: 30-yr av.) and climate variability (months to millennia)
  - Signal-to-Noise (variability) Ratio
  - Multiple Frequency of physical forcing
  - Attribution of observed changes
  - Surprises and Uncertainties
- Impacts of climate variability and change
  - Multiple forcings on ecology
- Summary

# The World is Warming

Source: United Nations World Meteorological Organization

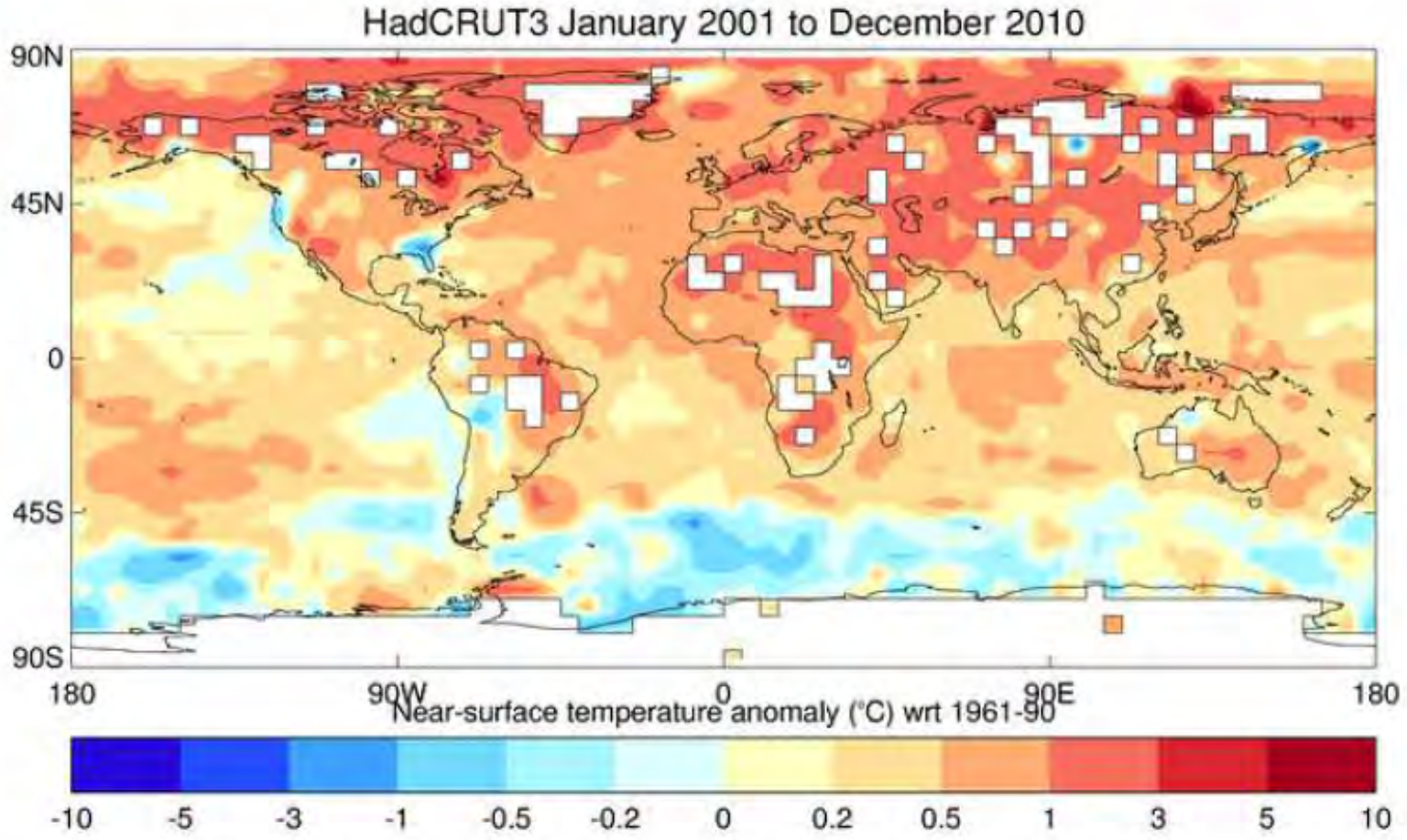



**Figure 1 Global decadal temperature changes with respect to long-term average 1961-1990**

# Changing Climate

Cryospheric evidence includes:

Loss of Sea Ice

Melting Ice Caps

Receding Glaciers

# ...and on land

Greening of the North

Permafrost Degradation

Increasing Fires



# …and in the ocean.

e.g. Bleaching of Coral Reefs

Healthy Reef

Bleached Reef from exposure to high temperatures

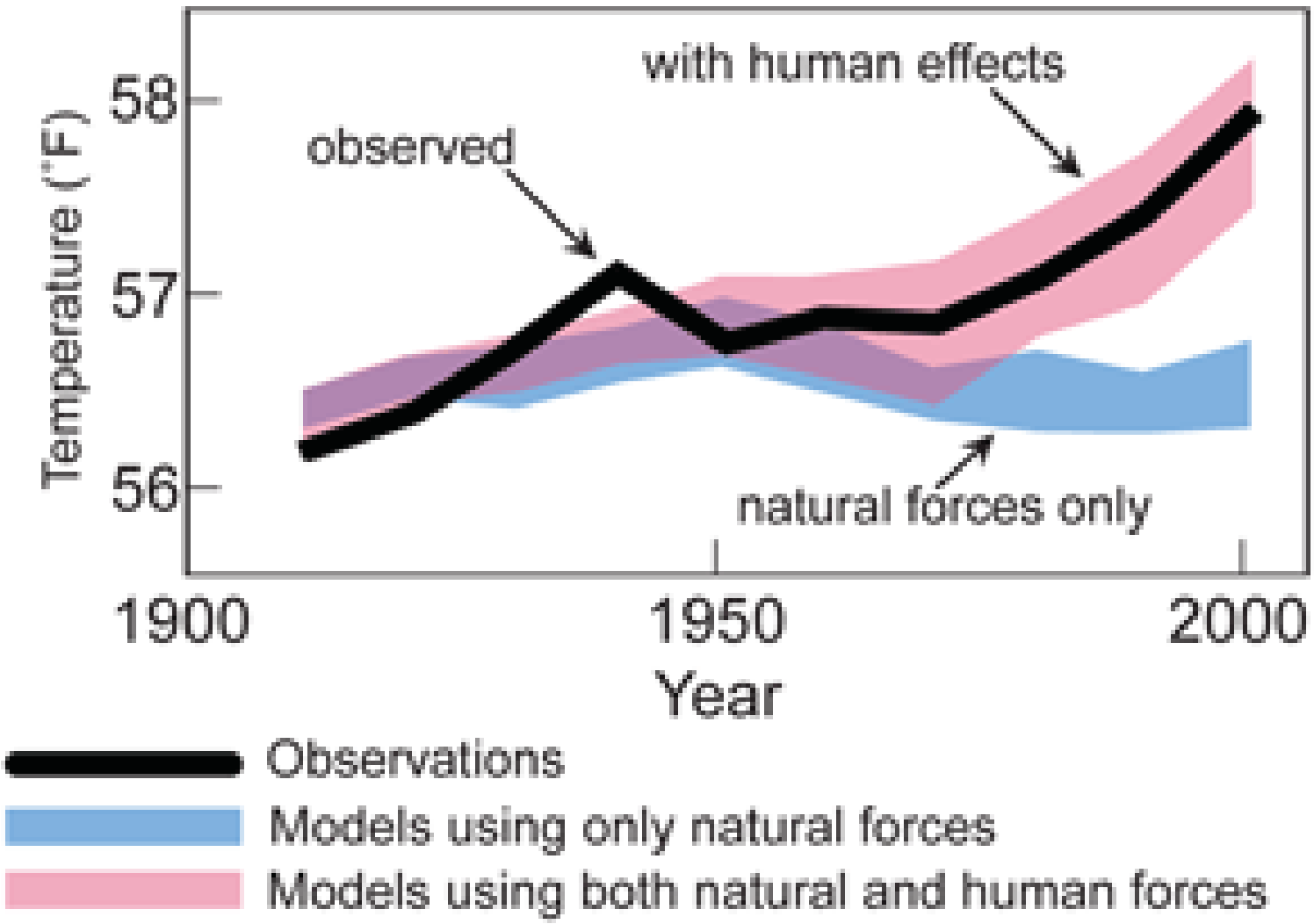
## But is warming anthropogenic-induced?

# Is temperature rise due to Anthropogenic Forcing?

**For Attribution of Cause of Observed Changes Requires**

- **Matches Theory**
- **Consistency of multiple observations**
- **Has been predicted**
- **Most reasonable explanation among competing hypotheses**

# Climate Model Indications and the Observed Climate




IPCC, 2007

# Is temperature rise due to Anthropogenic Forcing?

**For Attribution of Cause of Observed Changes Requires**

- **Matches Theory** Y
- **Consistency of multiple observations** Y
- **Has been predicted** Y
- **Most reasonable explanation among competing hypotheses** Y

# Global Scale

Indeed, temperature and precipitation trends and patterns, Arctic sea ice changes, as well as models provide very strong case for anthropogenic-induced climate change at the Global Scale.

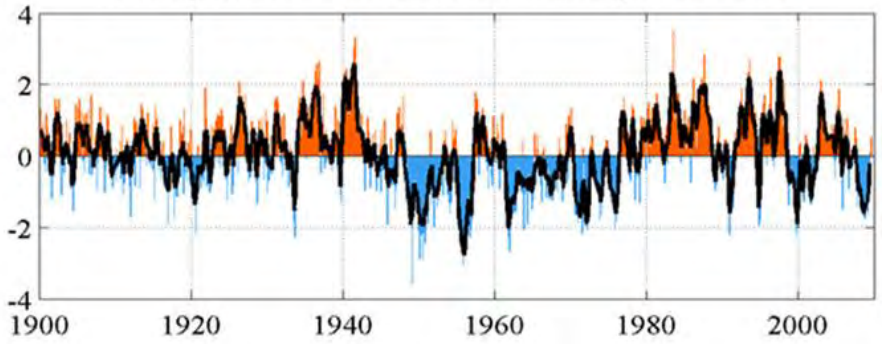
# Regional Scale

But at the regional scale it is often difficult to distinguish anthropogenic warming signal from decadal and multi-decadal variability, especially when we have short time series (even a few decades).

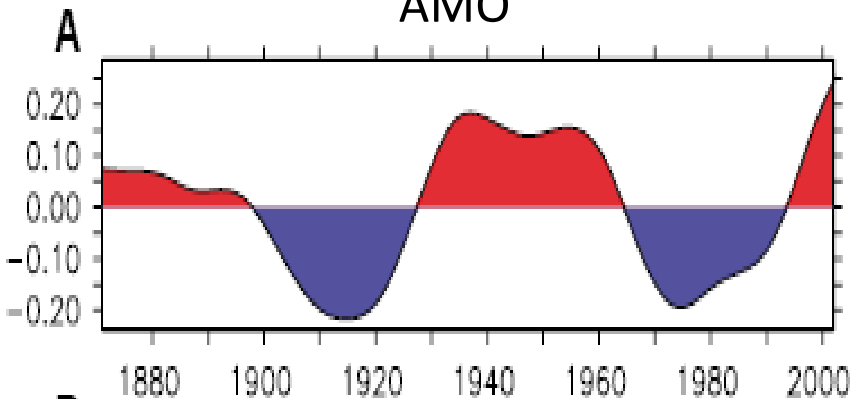
# Physical Forcing occurs at Various Frequencies

Forcing occurs at various time scales, including seasonal, multiannual, decadal, multidecadal, trend, etc.

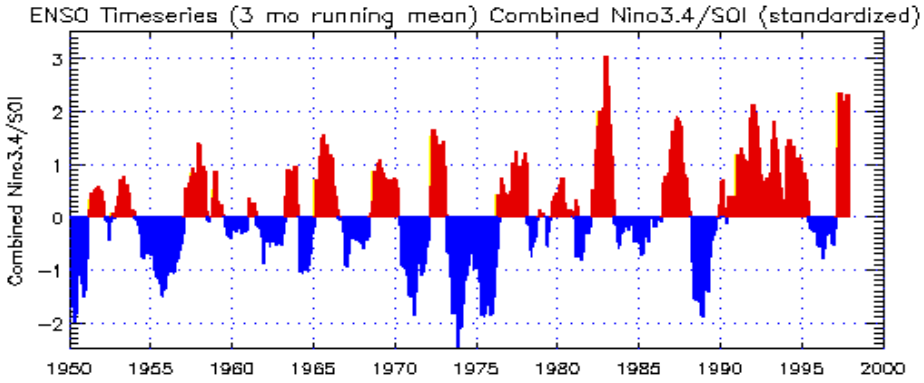
PDO



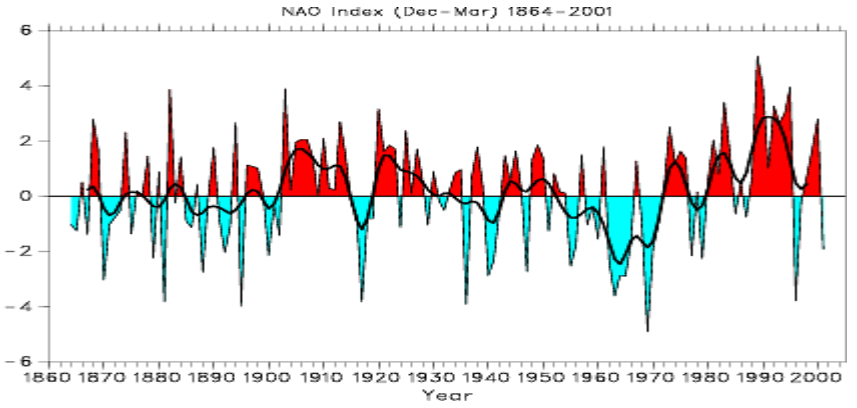

AMO




ENSO

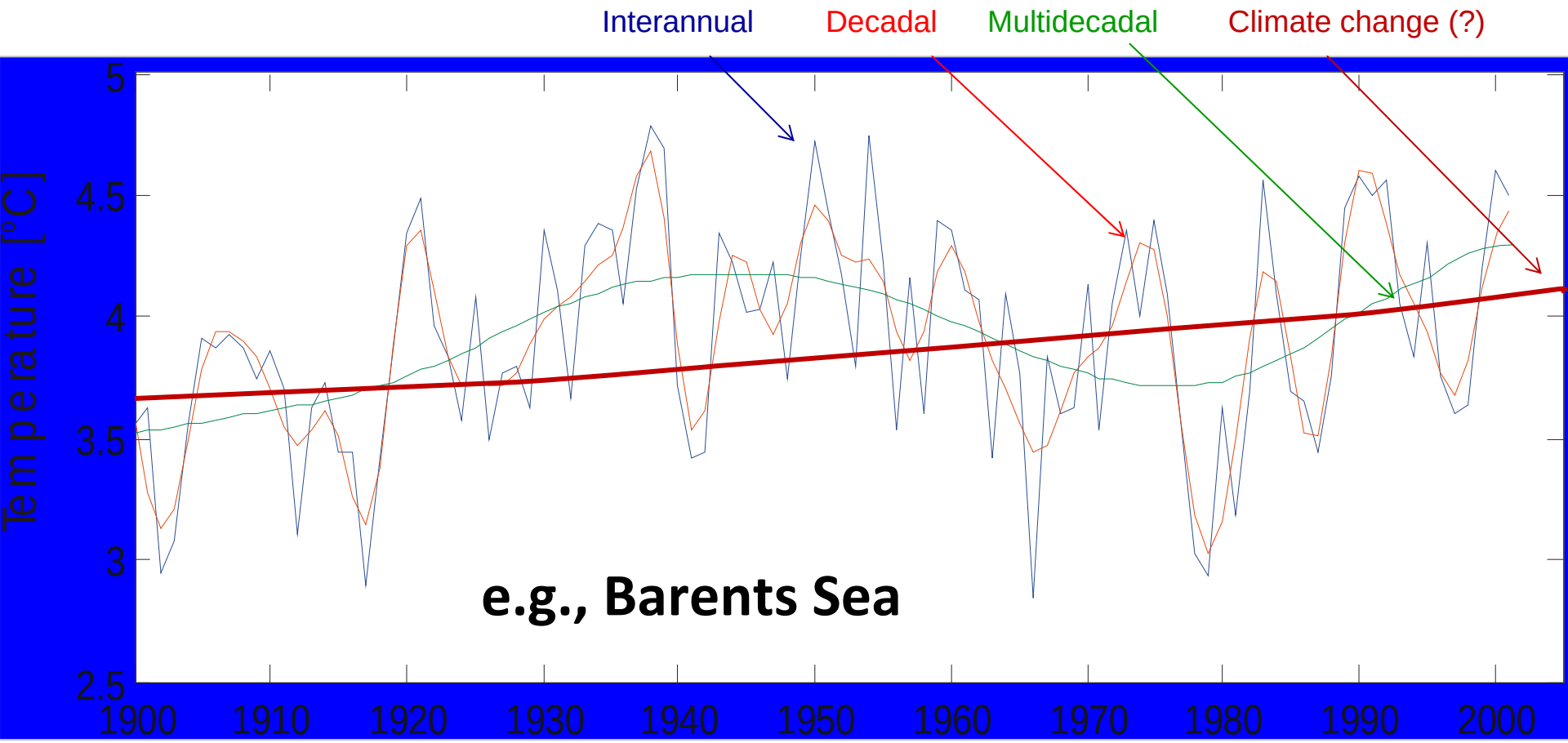



NAO




NOAA-CIRES Climate Diagnostics Center

# In reality, local temperature signal is result of all of these forcings.




Data source: The Kola Section, PINRO, Murmansk

Ecology responds to the combined signal!

# Signal-to-Noise Ratio

- Signal-to-Noise Ratio, where signal is climate change, i.e. the trend, and noise is the background or natural variability.
- For Kola Section during warming period of the multidecadal variability: Trend/Multidecadal= 0.2ºC/1.0ºC=0.2 over 30 yr.
- Largest problem when signal-to-noise ratio is low, such as in the polar regions.

# One must be Cautious as sometimes there are Possibilities of Surprises – Indirect Effects

Potential Arctic warming connections in mid-latitudes


Winter 2009-2010 was most extreme in 145 years of measurements

# Climate summary

There is strong evidence at the global scale for anthropogenic-induced climate changes.

On the regional or local scales, observed warming may or may not be part of global warming signal, depending upon the strength of local, especially low-frequency, climate variability.

Message: Not all warming is "global warming".

# What about Ecosystem Impacts?

Lots of evidence for global biological responses in the marine environment to warming including large-scale distributional shifts both horizontally and vertically, changes in phenology, productivity,  etc.

IPCC AR5, initial assessment in terms of level of detection and attribution to climate change is that for the ocean (based on distribution, phenology, abundance, hypoxia), they are both high (although this is not final assessment)

# Again, what about at the regional level?

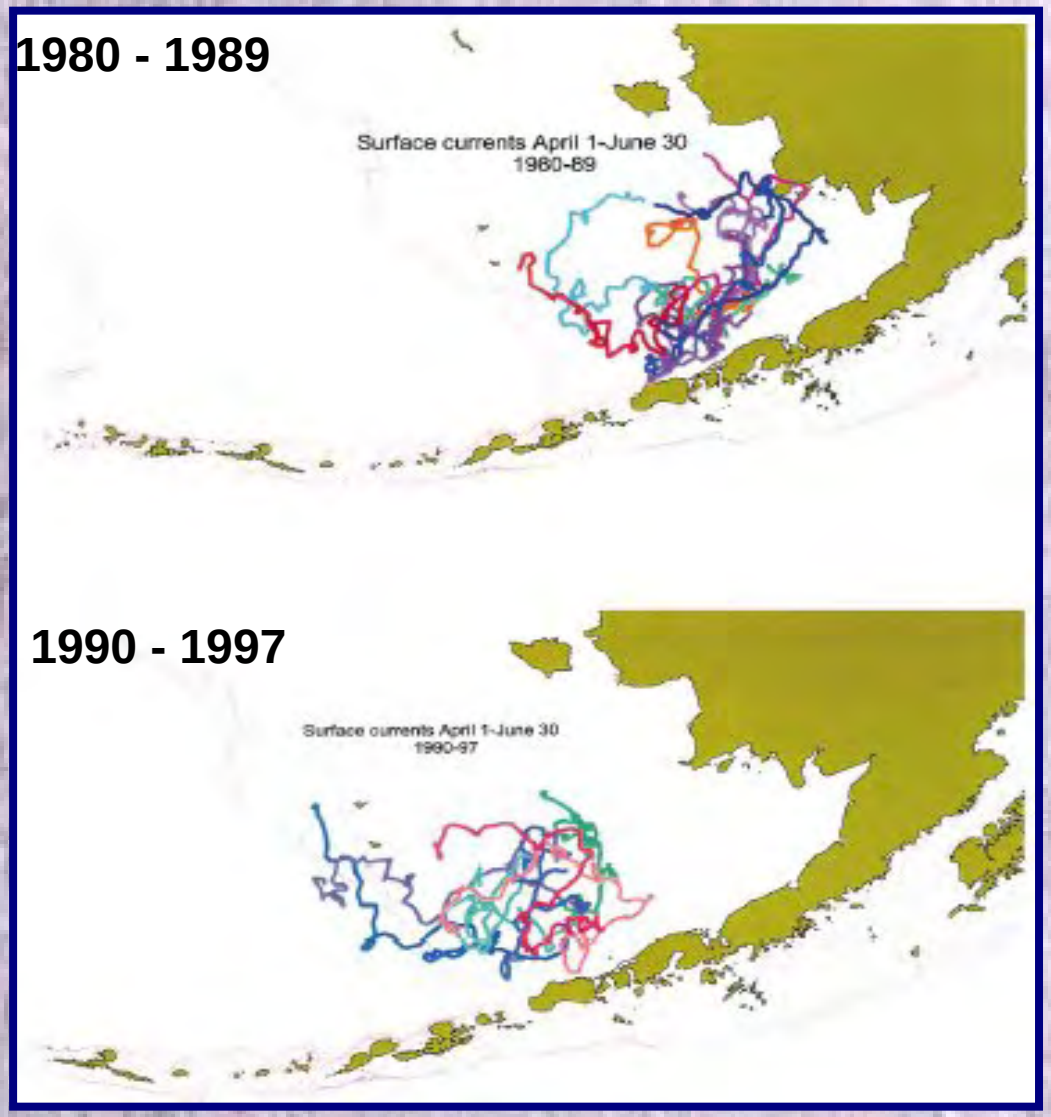
The ecosystem response to climate variability depends on the frequency of the forcing.

Generally, individual organisms tend to respond to higher frequency variability and populations to lower frequency variability. In part, this is due to link between time and space scales. Higher frequency is over smaller spatial scales and lower frequency is over larger spatial scales. Therefore, high frequency forcing only affects a portion of the population, whereas lower frequency forcing affects most or all of the population. This, of course depends on the spatial scale of the population.

# Decadal-Scale Changes in Surface Advection (April - June)

Onshore Advection of flatfish towards nursary grounds

Offshore Advection away from nursary grounds

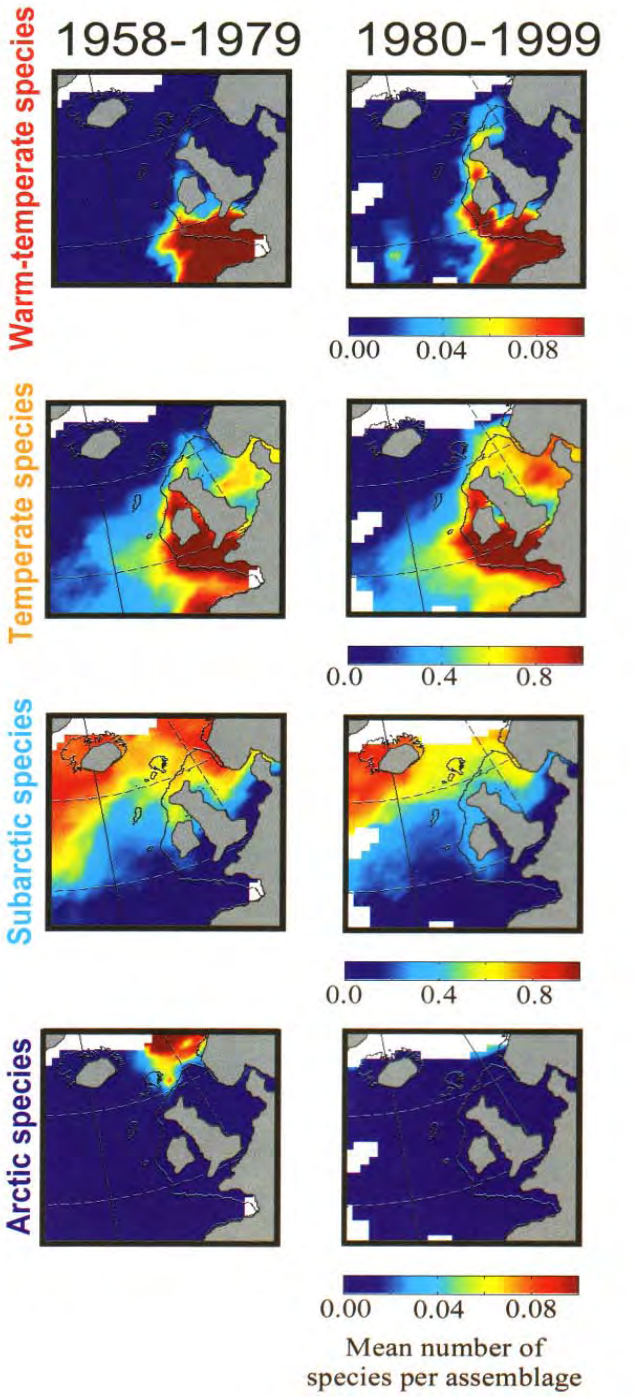



Good recruitment

Poor recruitment

**Wilderbuer et al., 2002**

# Response of Zooplankton to low-frequency forcing (AMO)




**Warm-water species**

**Temperate species**

**Arcto-boreal species**

**Arctic species**

All zooplankton species moved northward in the warm phase of the AMO following the cold phase in the1960s and 1970s.

Based on Beaugrand et al., 2002

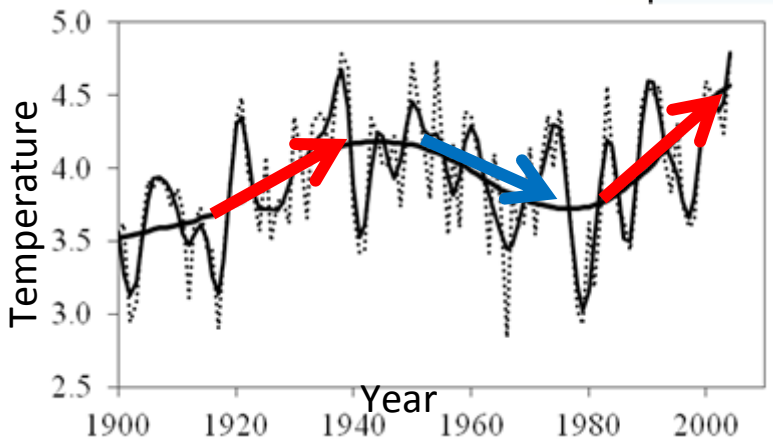
# More changes induced by AMO forcing

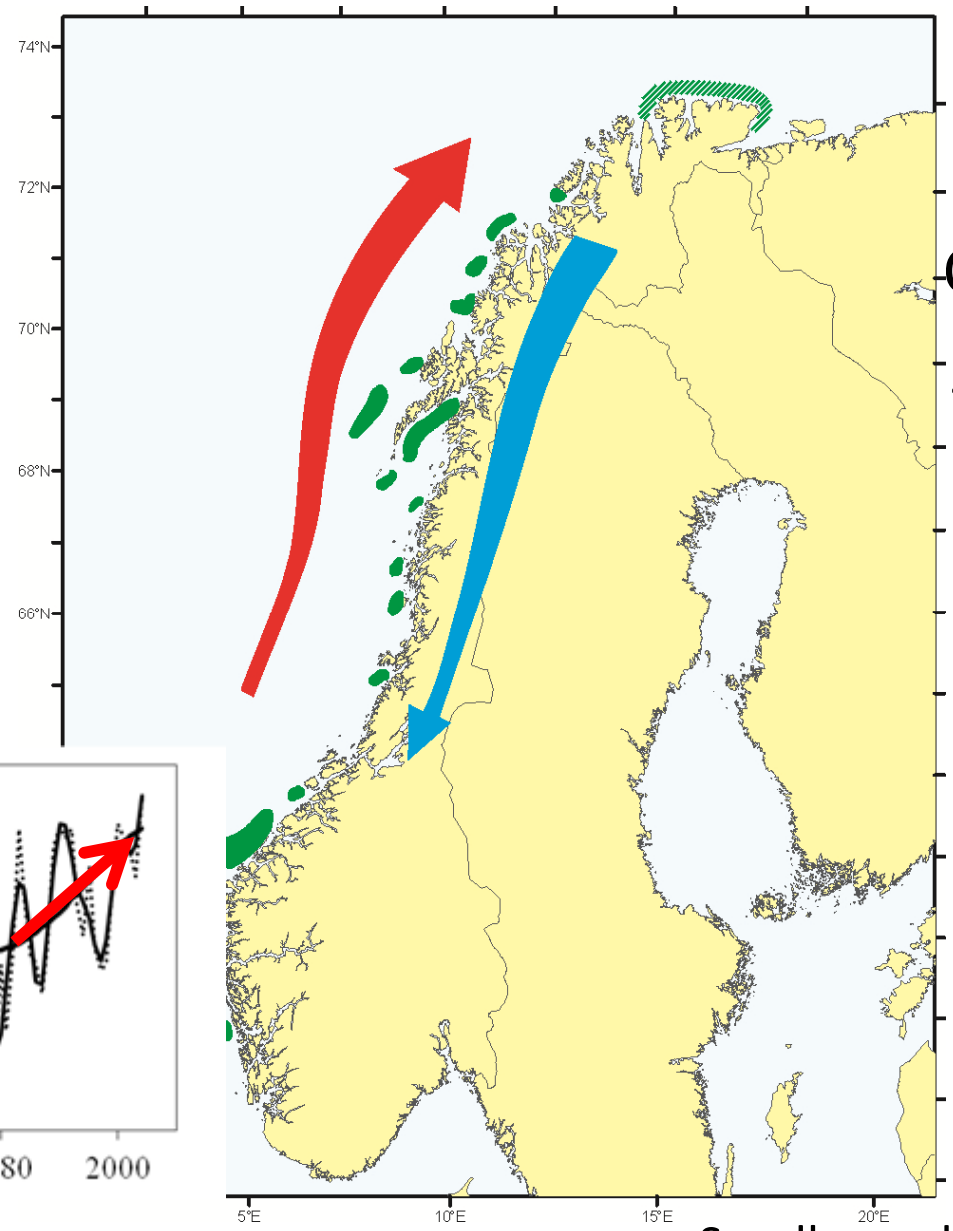
NE Arctic Cod Spawning sites

Warm Period:

-Northward Movement of Spawning Sites

-Population Increase



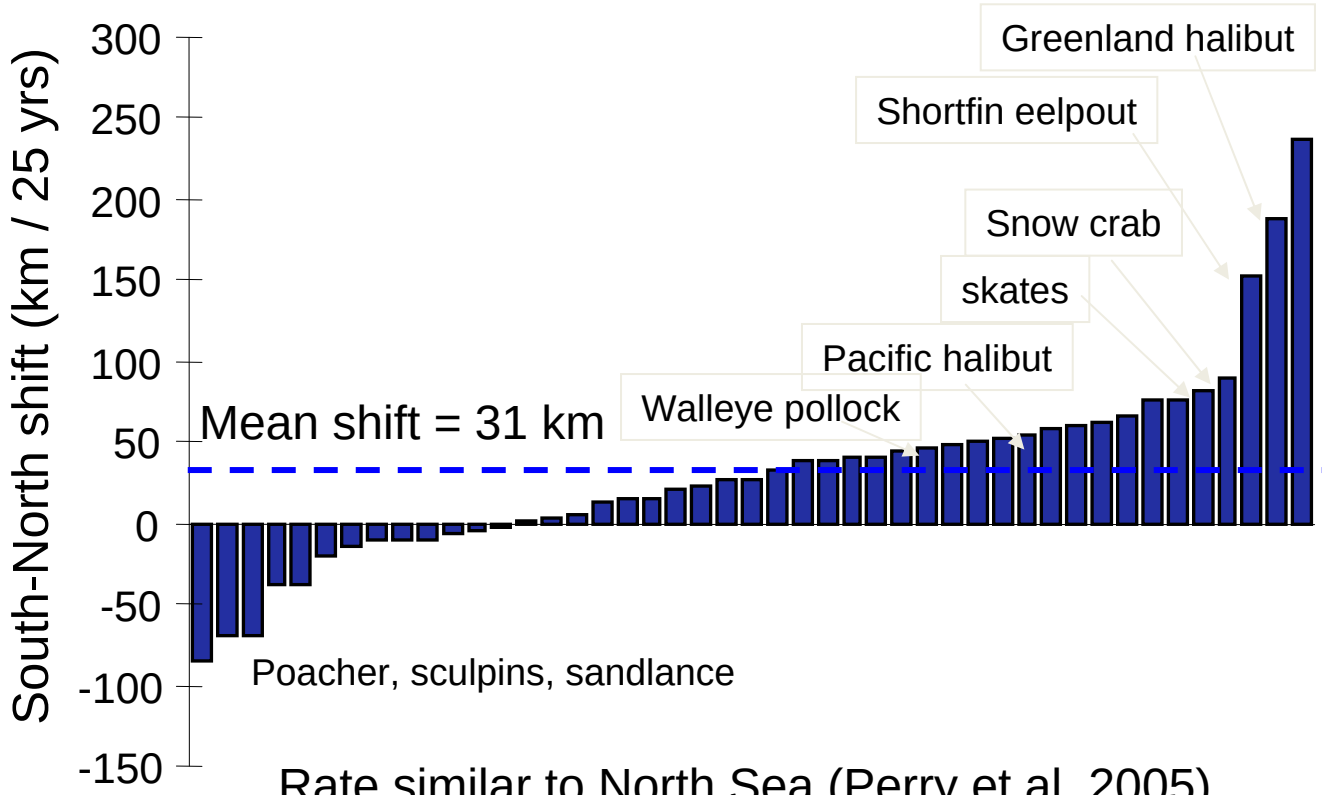

Cold period:

-Southward Movement

-Population Decrease

Sundby and Nakken, 2008

# Northward shift, center of distribution 45 species, Bering Sea 1982-2006




Rate similar to North Sea (Perry et al. 2005)

2-3 times faster than terrestrial mean (Parmesan and Yohe 2003)

Based on Mueter and Litzow, 2008

# Invasive Species

**A 22 kg swordfish 4 years old was caught in Vinjefjorden, Northern Norway November 2006.**

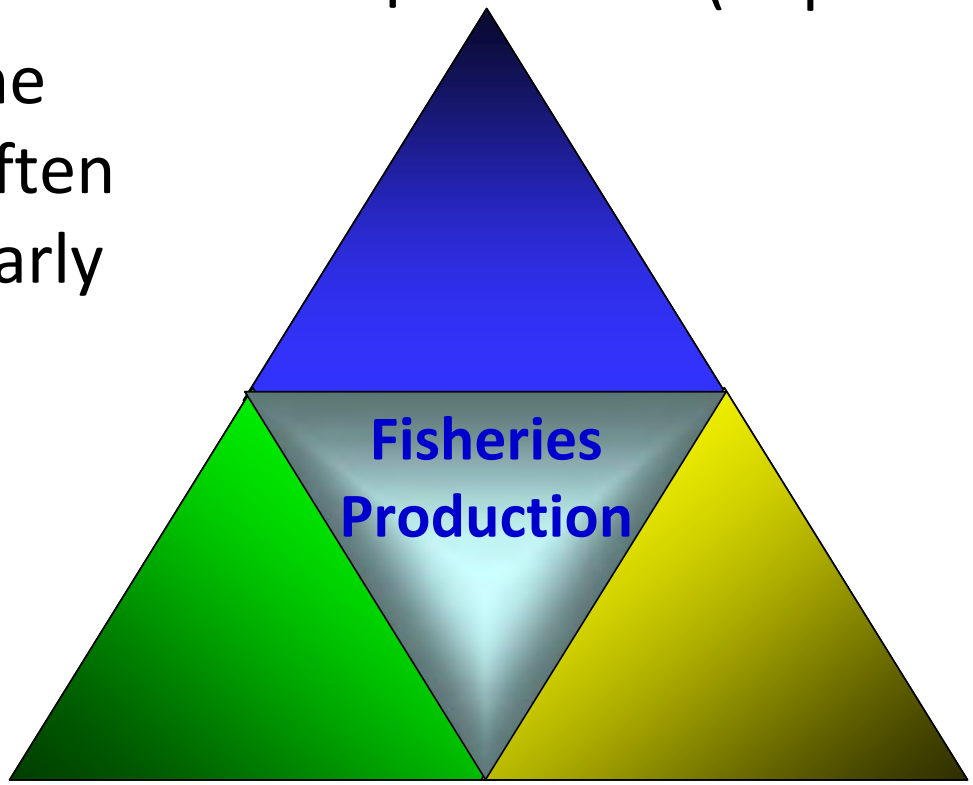
**Lost individual or indicative of things to come under warming conditions?**

Warning:  One must be careful in attributing climate impacts to climate change and especially global climate change, e.g. Bering Sea warming.

Reason: If wrong it makes the public and governments more skeptical of scientific results.

# To make things more difficult, the marine ecosystem responds to more than climate….

These occur at the same time and often interact non-linearly so difficult, if not impossible, to separate out.



# How do we tell if observed ecosystem change is due to Climate?

**For Attribution of Cause of Observed Changes Requires**

- **Matches Theory**
- **Consistency of multiple observations**
- **Has been predicted**
- **Most reasonable explanation among competing hypotheses**

# What do we need? – My list

- Improved AOGCMs
- Regional models
- More emphasis on quantitative estimates (mechanistic modelling) linking biology to climate variability and change, i.e. better understanding of the biophysical processes
- Improved parameterization of the models
- Measure of uncertainty

# Some Concluding Remarks

- Past IPCC scenario model scenarios (and consequently the RCMs based on these) are of limited use for regional climate change assessment
- Hopefully new IPCC models will be improved but expect high model variability
- Some hope for decadal-scale predictions from GCMs
- In spite of difficulties we are seeing big improvements.

# Thank you for your attention!