LESSONS FROM THE ICE AGES FOR OUR CLIMATE FUTURE IN A WARMING WORLD

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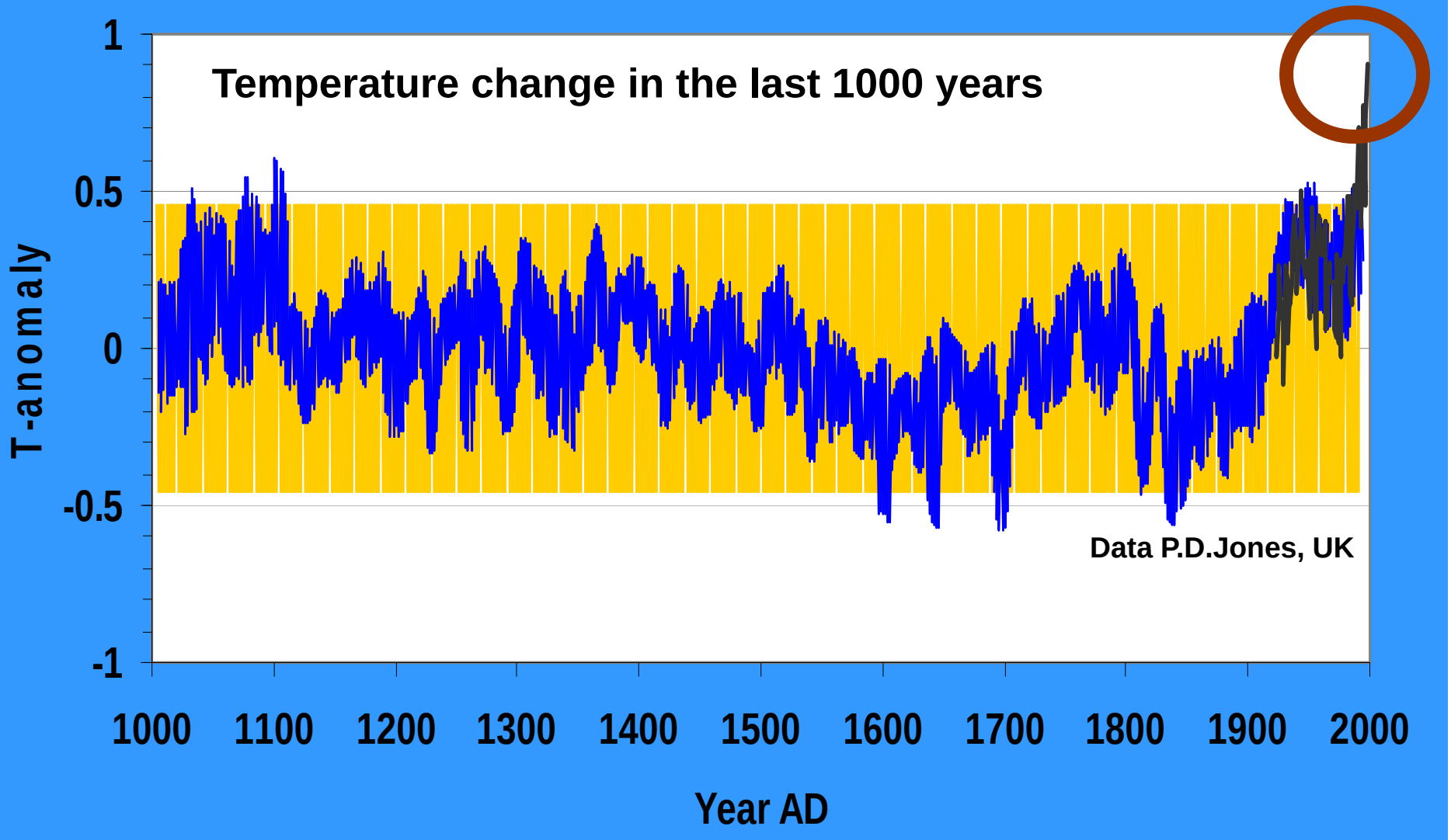
In the following presentation, I shall explore the question how the ocean will react to global warming.

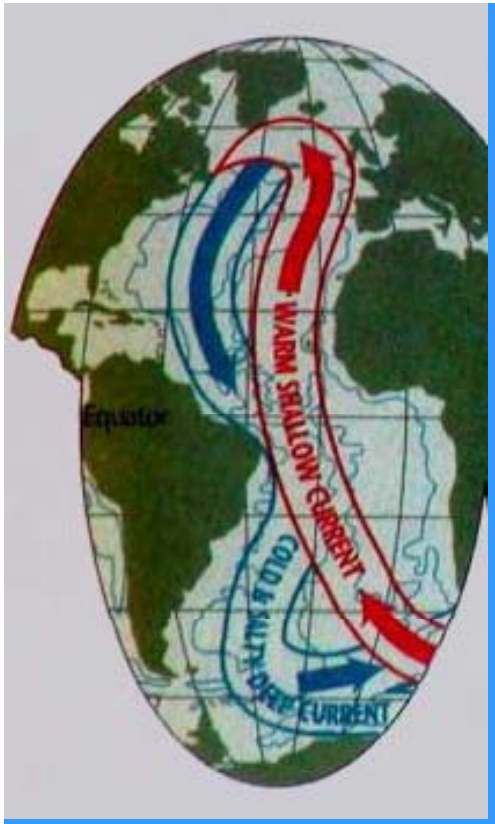
None of the suggested responses are in any way certain -- the ocean's reaction is unpredictable. However, we can obtain certain clues from how it behaved in the geologically recent past. I maintain that:

- **Global warming is real; there is no surprise**
- **The future has no analog in the past**
- **Albedo feedback is a prime mover in climate change**
- **We don't understand the carbon cycle very well**
- **We don't understand ocean productivity very well**
- **The lack of understanding does not imply that nothing is happening: Ignorance is not bliss.**

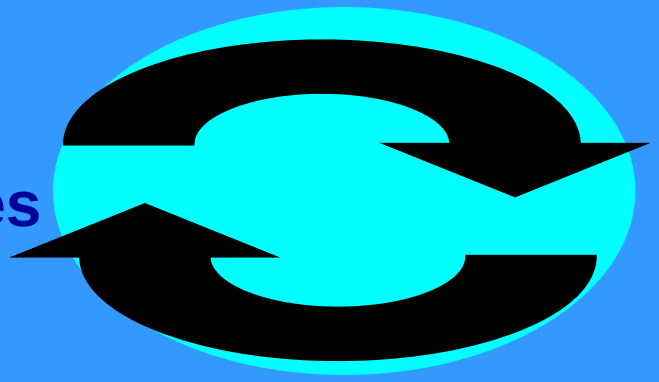
GLOBAL WARMING HAS BEEN GOING ON FOR SOME TIME

The most recent 50 years are unusually warm, especially the last 2 decades. It is expected.





WHAT ABOUT THE OCEAN'S RESPONSE?

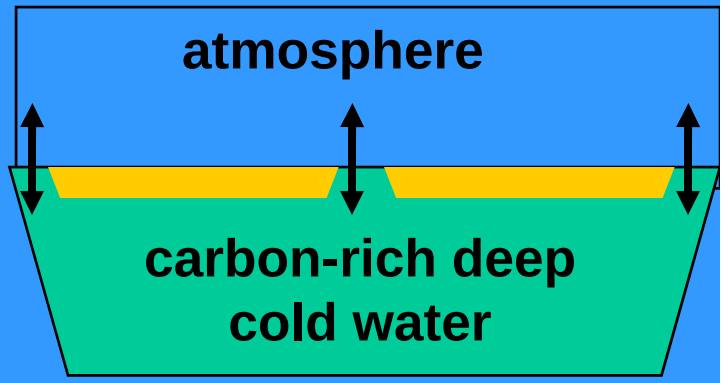


•PHYSICS

The ocean redistributes heat. How will this change?

•CHEMISTRY

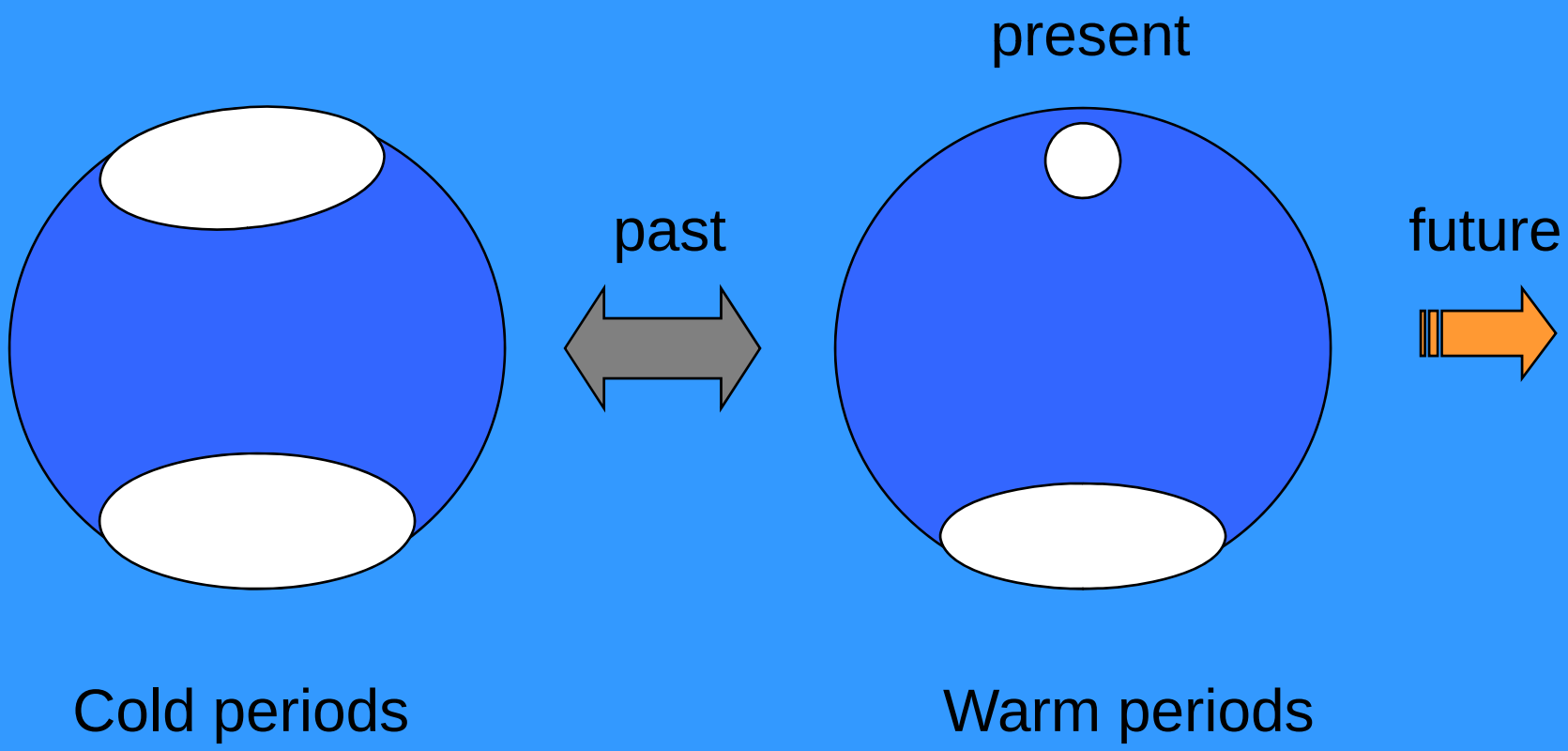
The ocean takes up excess carbon from the air. How will this change?



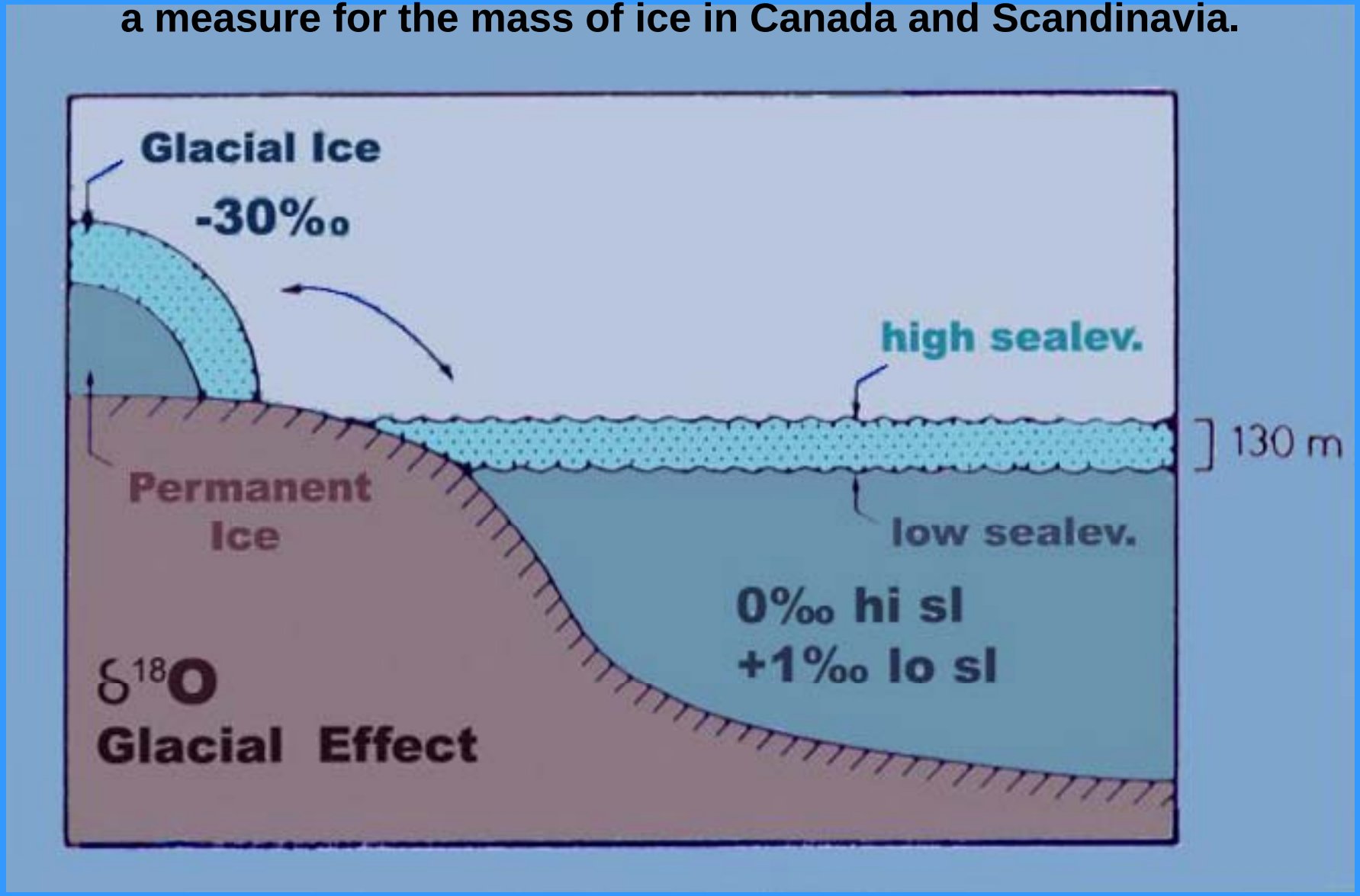
•BIOLOGY

The ocean produces food for people. How will this change?

- **Global warming is real; there is no surprise**
- **The future has no analog in the past**

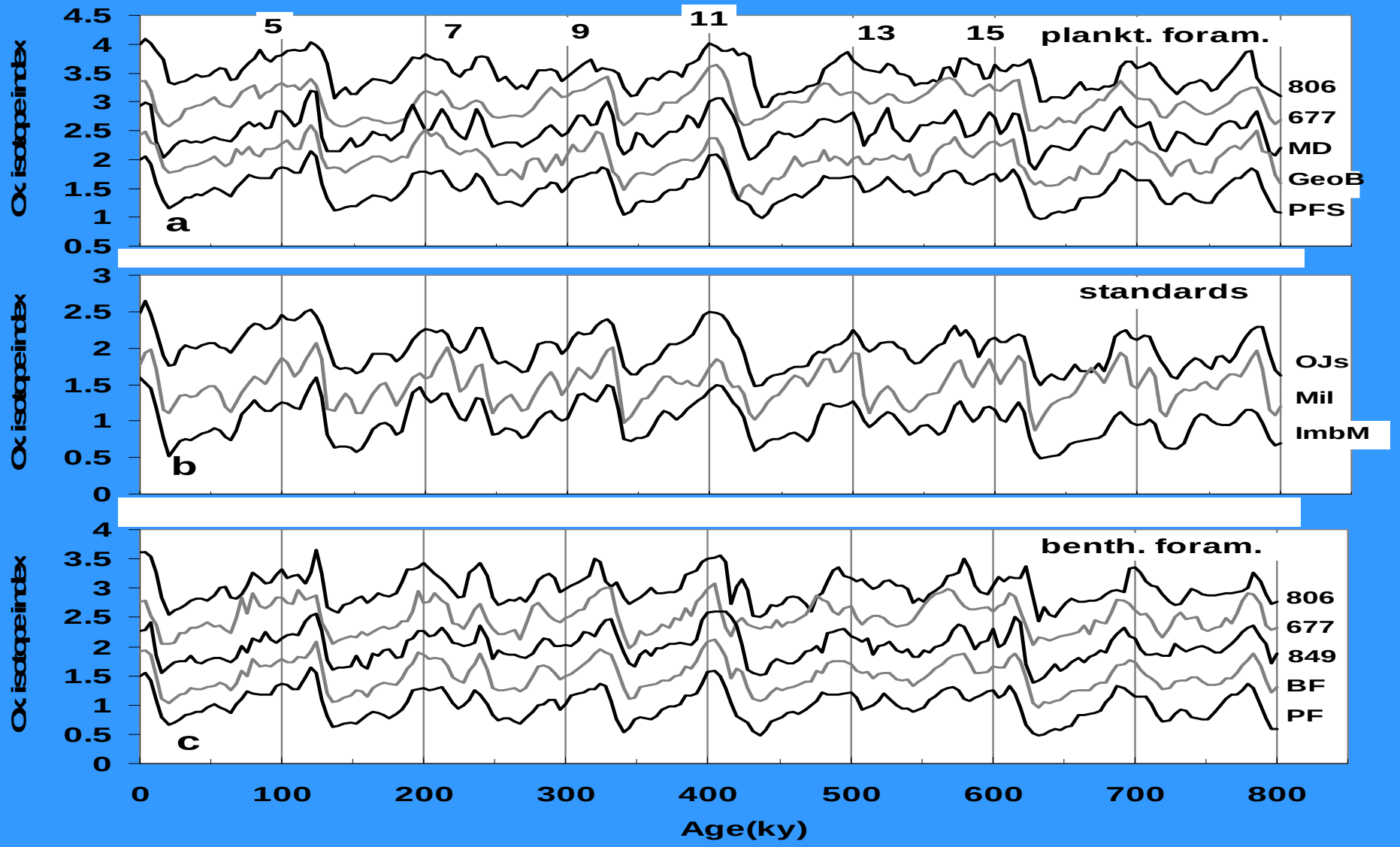


The change in the ratio of the two oxygen isotopes in the seawater is a measure for the mass of ice in Canada and Scandinavia.



To reconstruct ice-age climate we need to know the amount of ice.

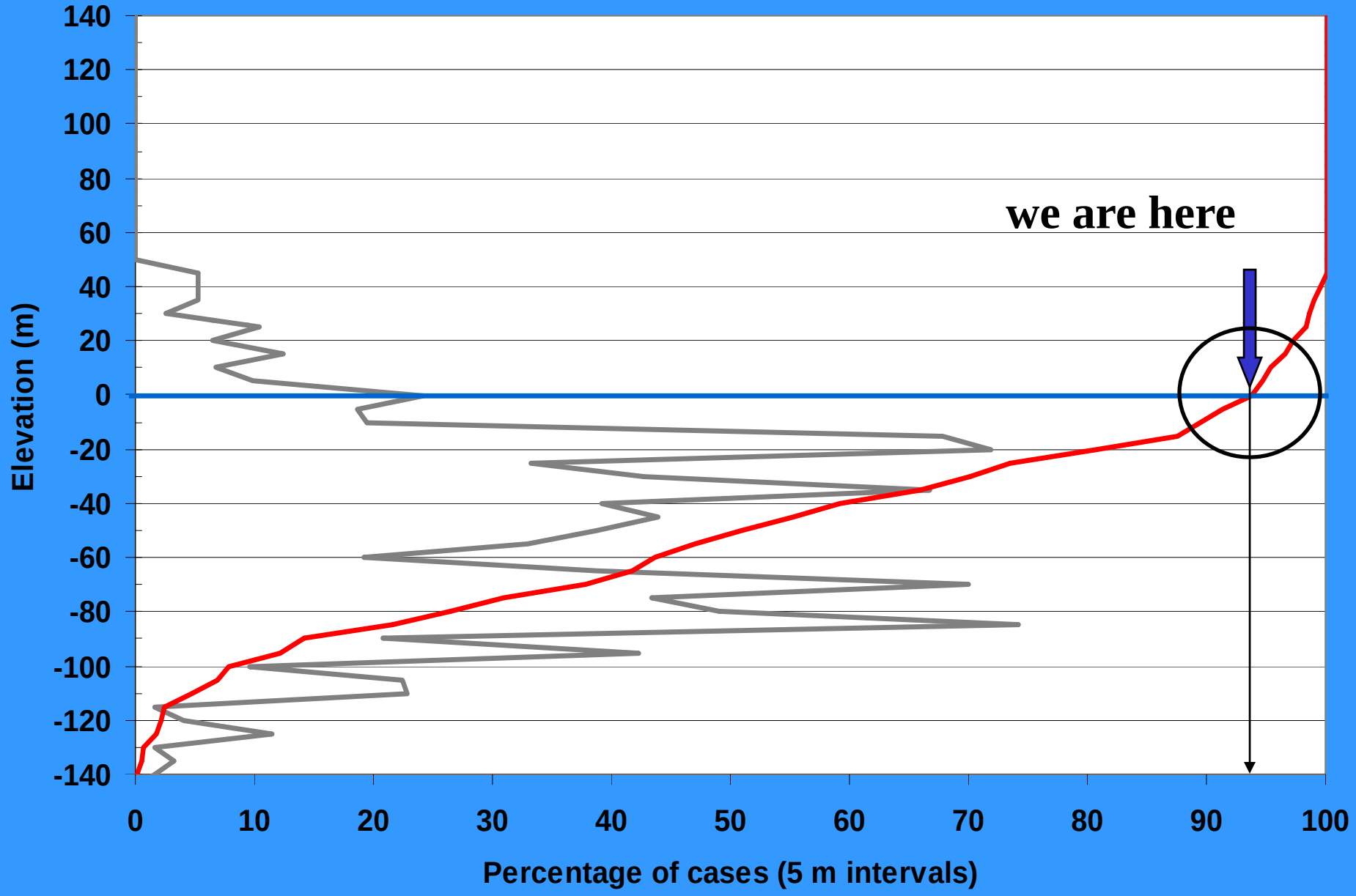
Oxygen isotope stratigraphy



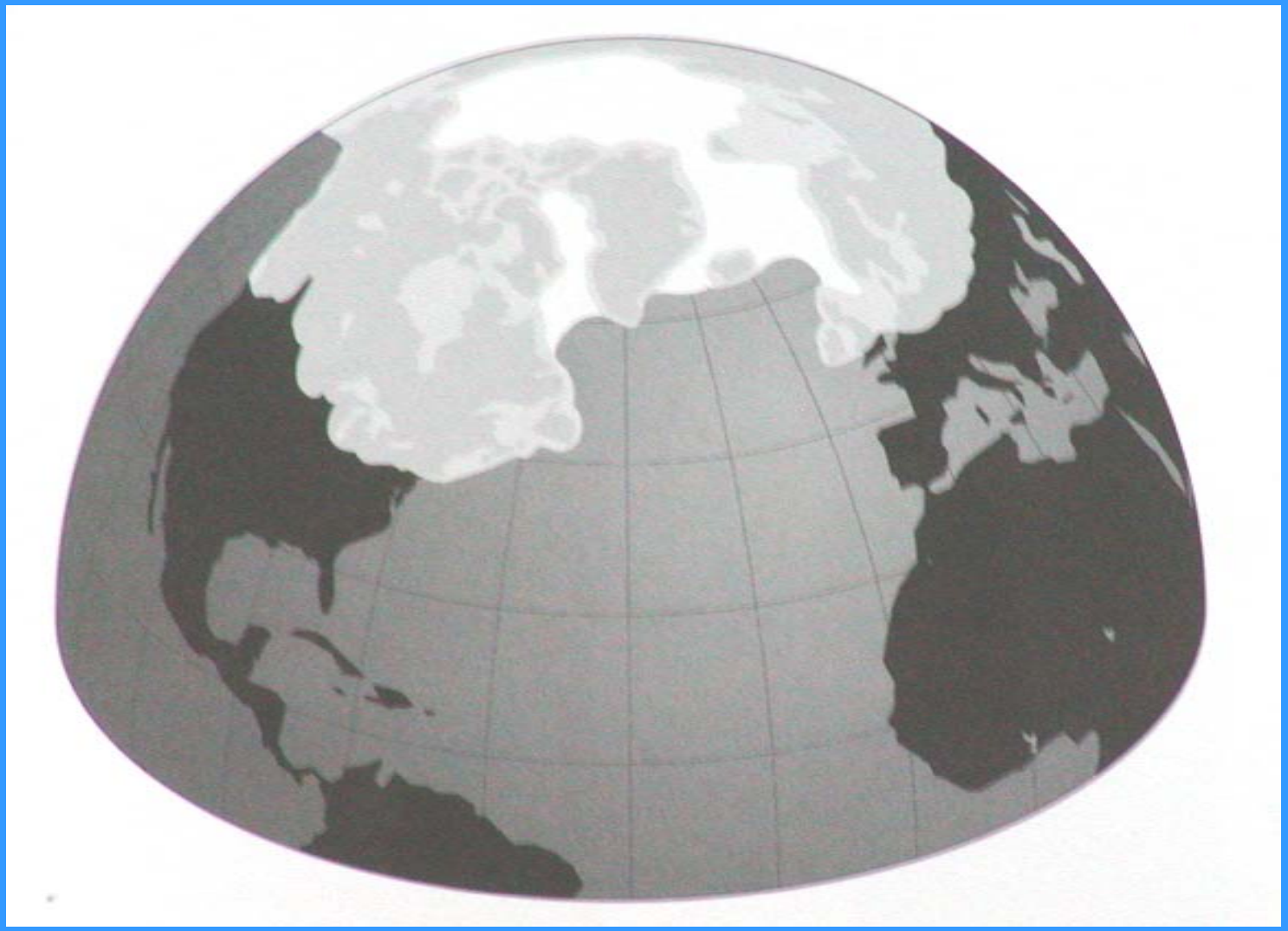
Ice age climate provides a series of experiments on the response of the ocean to climate change.

Histogram of sealevel curve, based on deep-sea oxygen isotope stratigraphy

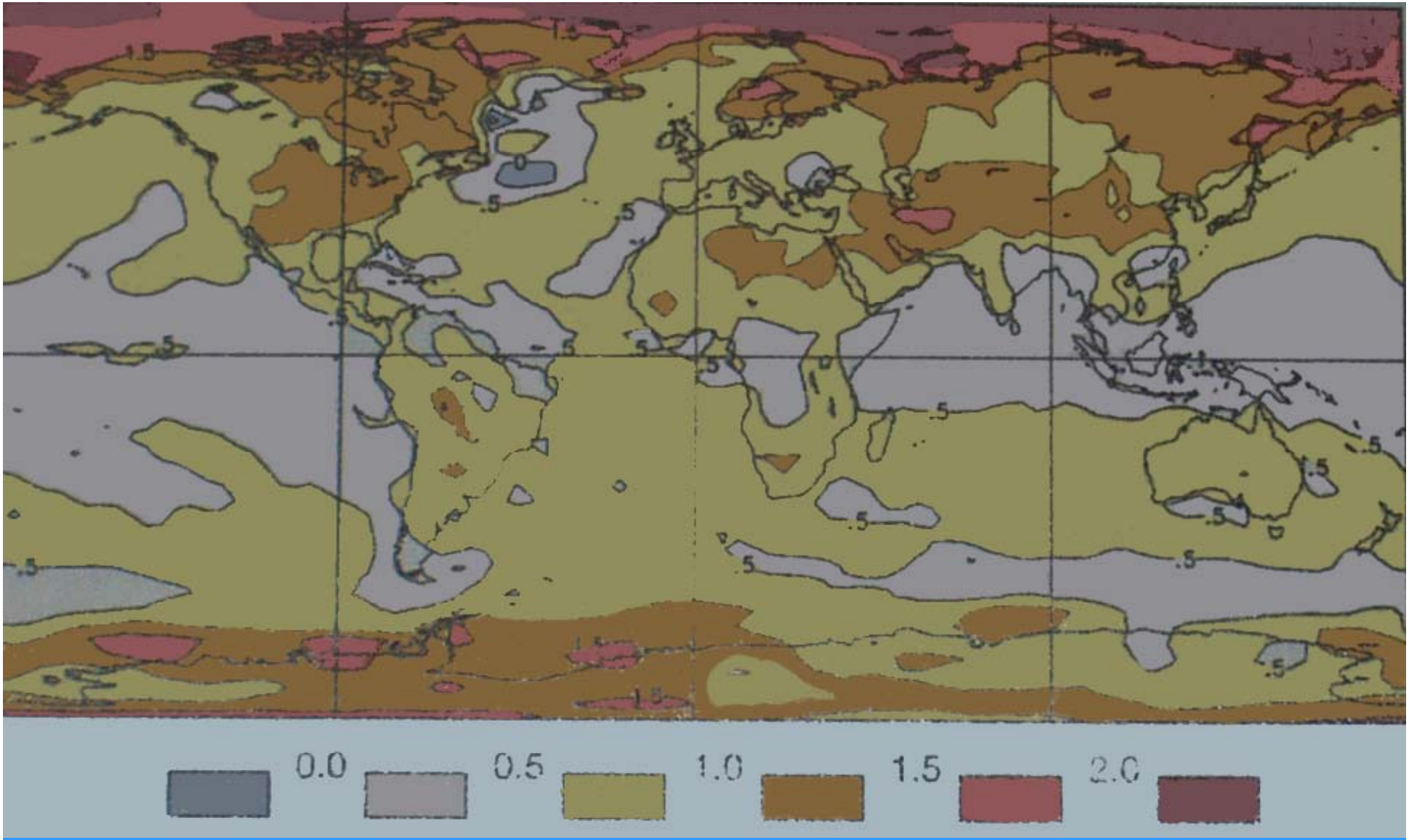
we are living in an unusually warm time with a high sealevel stand



Fact: The greatest changes in ice mass through time are in the high latitudes of the northern hemisphere.



Lesson: The greatest climatic changes may be expected for this region in the future also.



Predicted changes in surface air temperature for the decade 2020-2030, relative to the decade 1990-2000.

Source: Canadian Centre for Climate Modelling and Analysis, Meterological Service of Canada.

Francis W. Zwiers, Nature 416, 690 (2002).

Greatest change: high latitudes.

- **Global warming is real; there is no surprise**
- **The future has no analog in the past**
- **Albedo feedback is a prime mover**

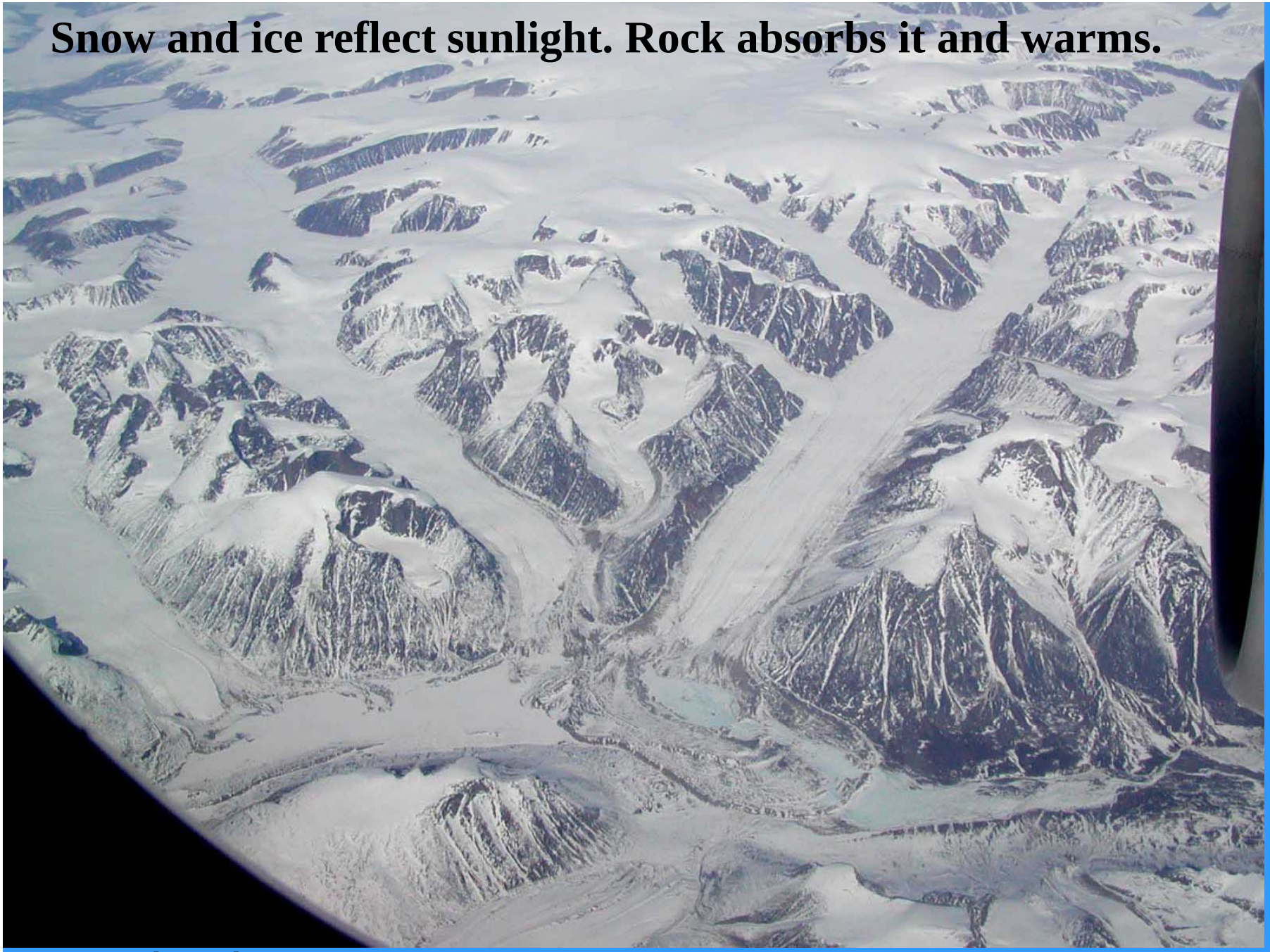
Contrast sea ice vs. open sea:

The ice readily reflects the sunlight. The water does not, but warms.

White Mtns., Ca

Whenever we witness rapid climate change, we must turn to albedo for positive feedback. Once snow goes, it goes fast.

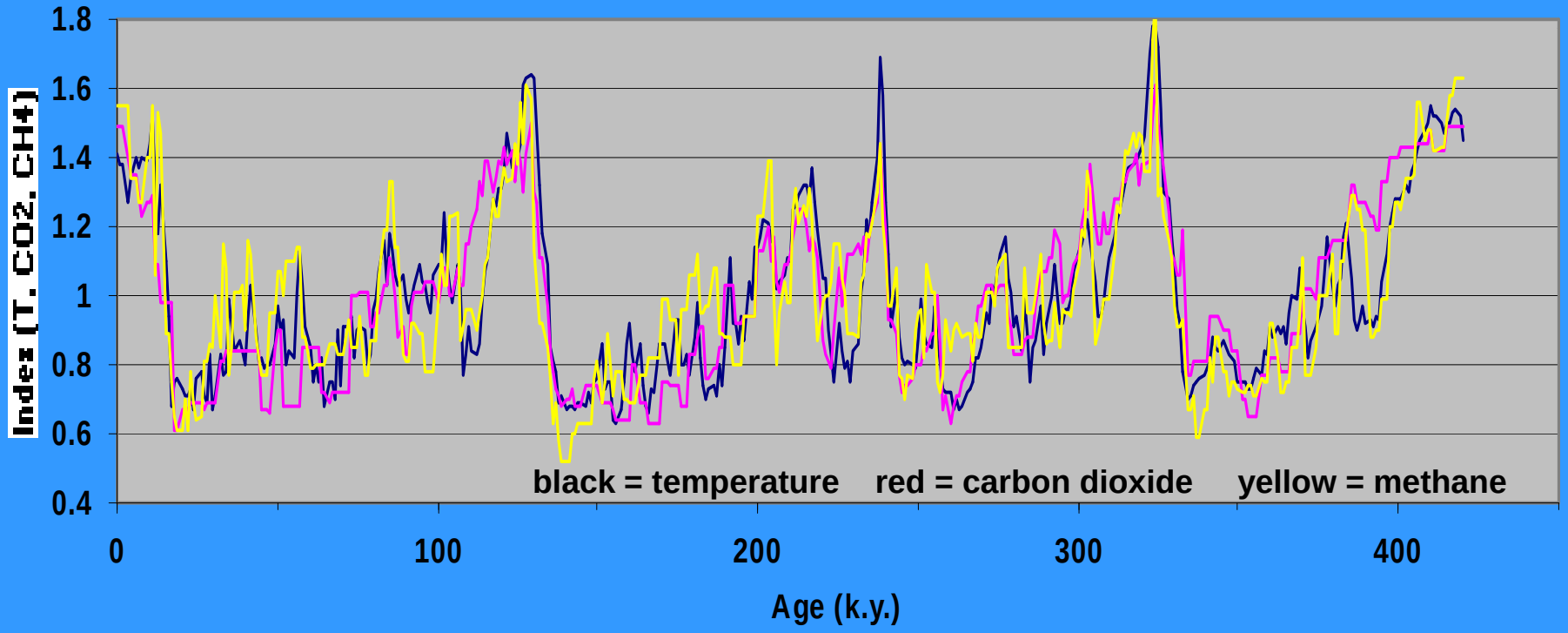
Snow and ice reflect sunlight. Rock absorbs it and warms.



Over Canada, Hudson Bay region

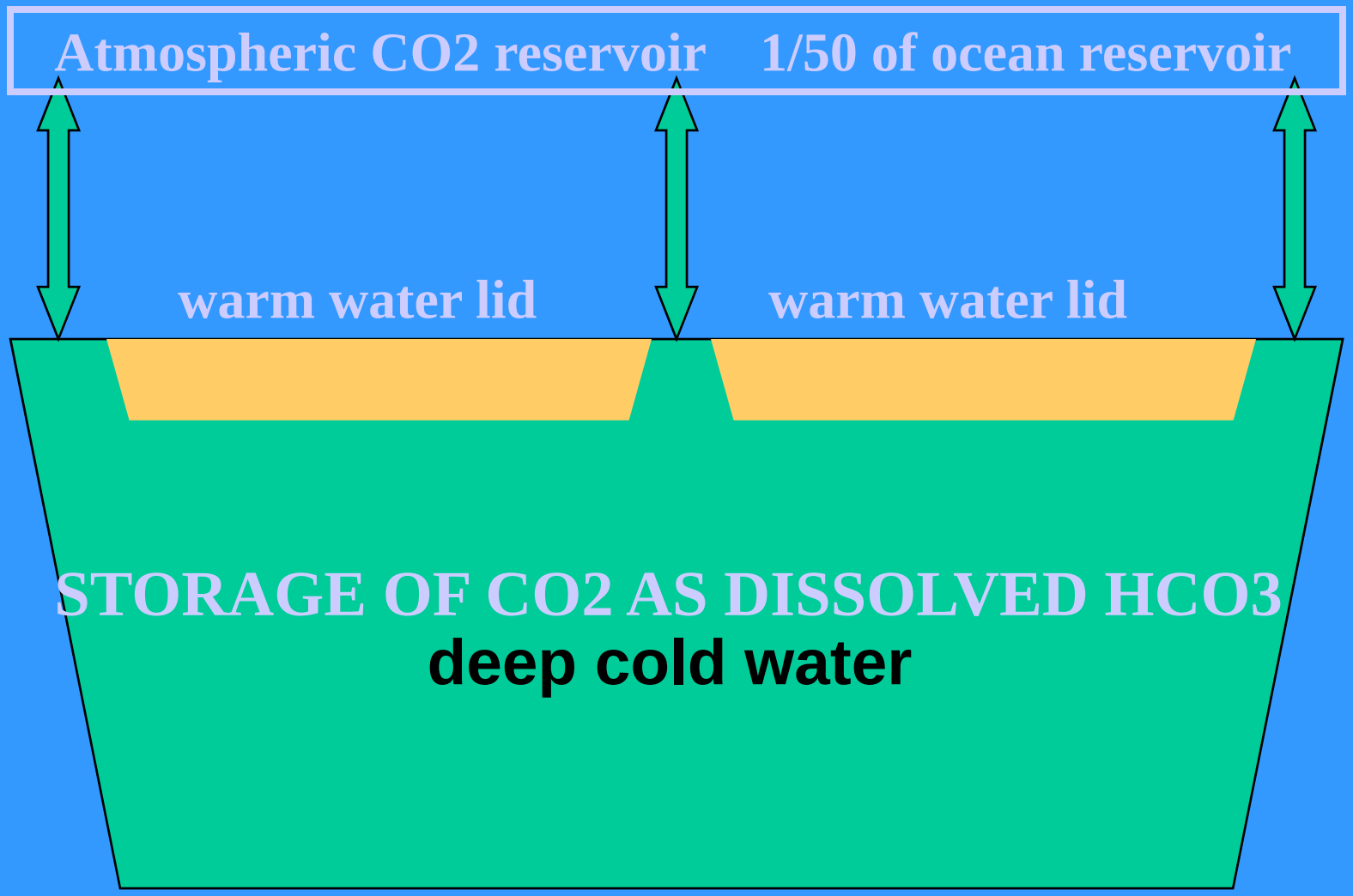
Note retreat and separation of glacier tongues.

- Global warming is real; there is no surprise
- The future has no analog in the past
- Albedo feedback is a prime mover in climate change
- **We don't understand the carbon cycle**

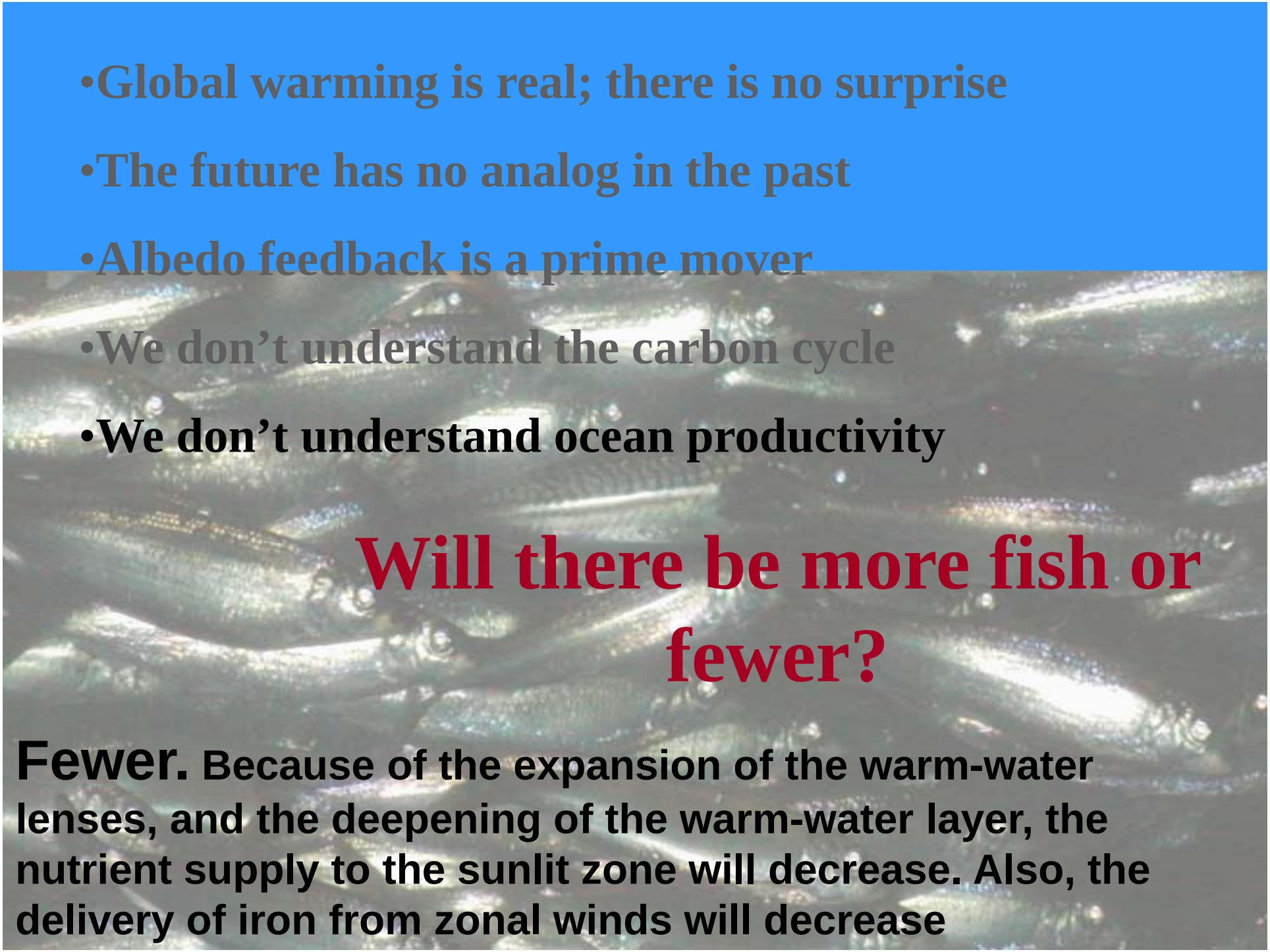


Ice core data (AA, Petit et al., 1999) show that carbon dioxide and methane fluctuated in synch with ice age cycles. The mechanisms are not understood.

Regulation of atmospheric CO2 by exchange with the ocean (The exchange is mediated by both physical and biological processes)



We do not know how this system will react to warming and meltwater input. Expectation: it will become less efficient.



- Global warming is real; there is no surprise
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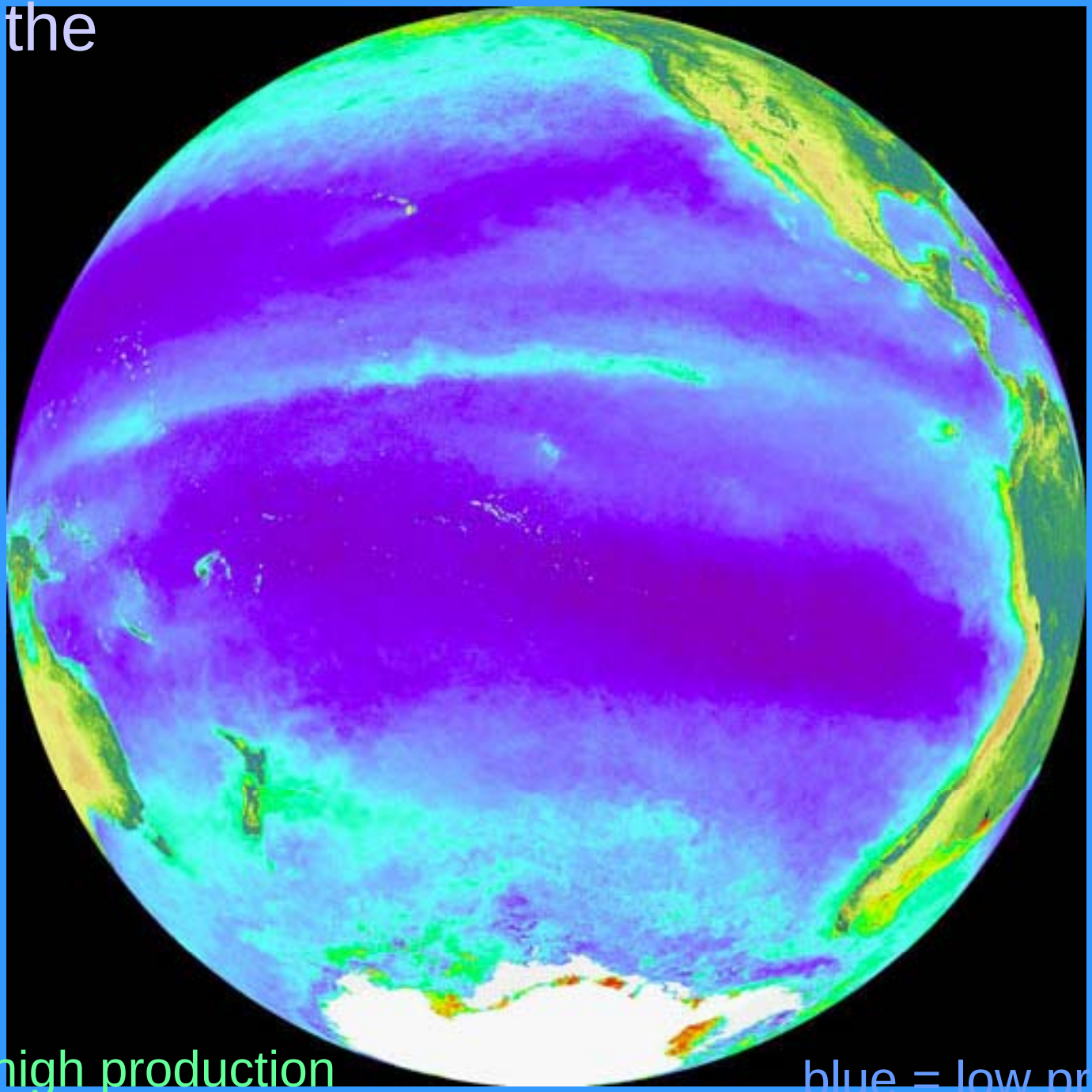
- We don't understand the carbon cycle
- We don't understand ocean productivity

Will there be more fish or fewer?

Fewer. Because of the expansion of the warm-water lenses, and the deepening of the warm-water layer, the nutrient supply to the sunlit zone will decrease. Also, the delivery of iron from zonal winds will decrease

where the food is



green = high production

blue = low production

Redistribution of heat

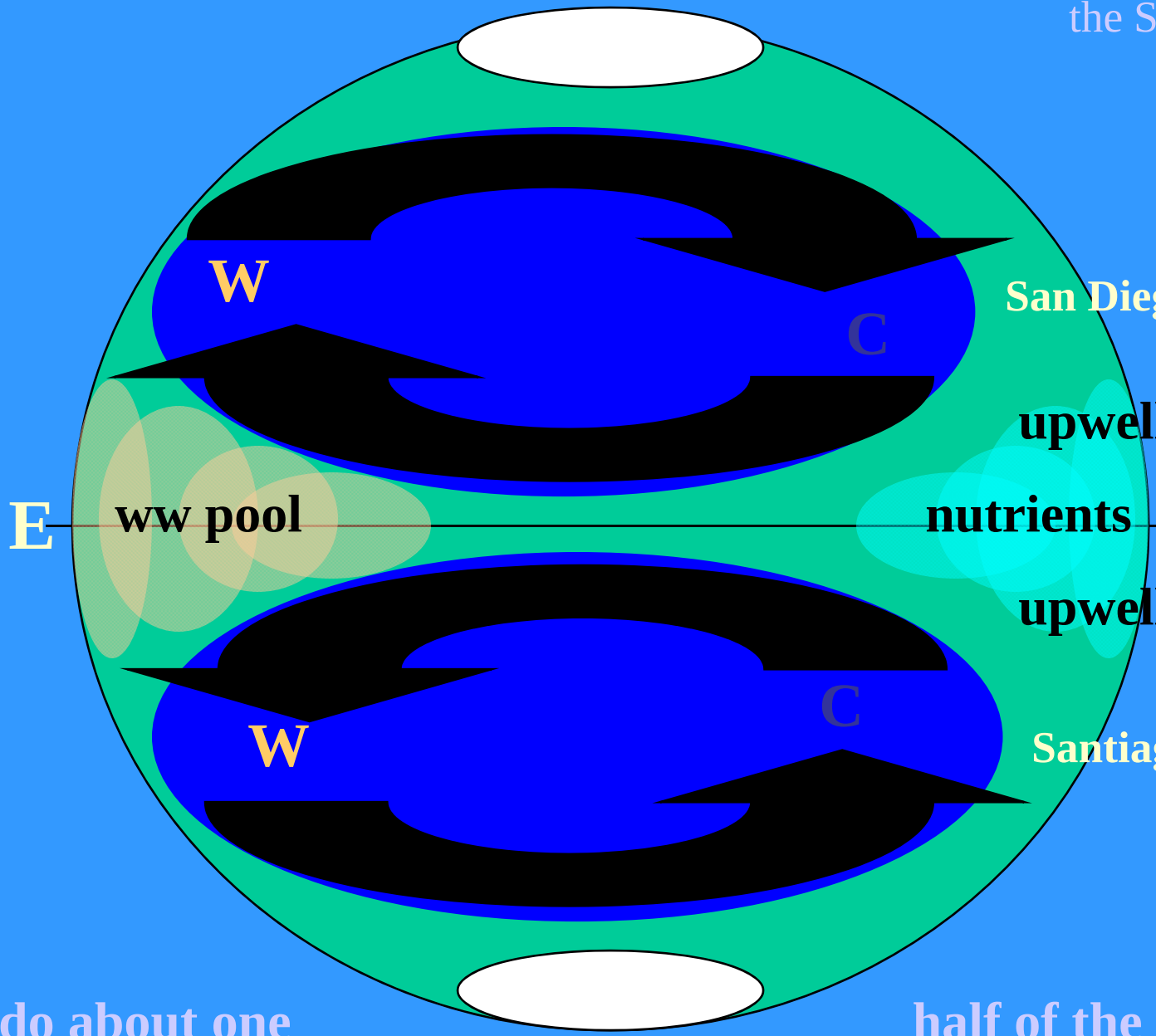
Ocean circulation

brings warm water

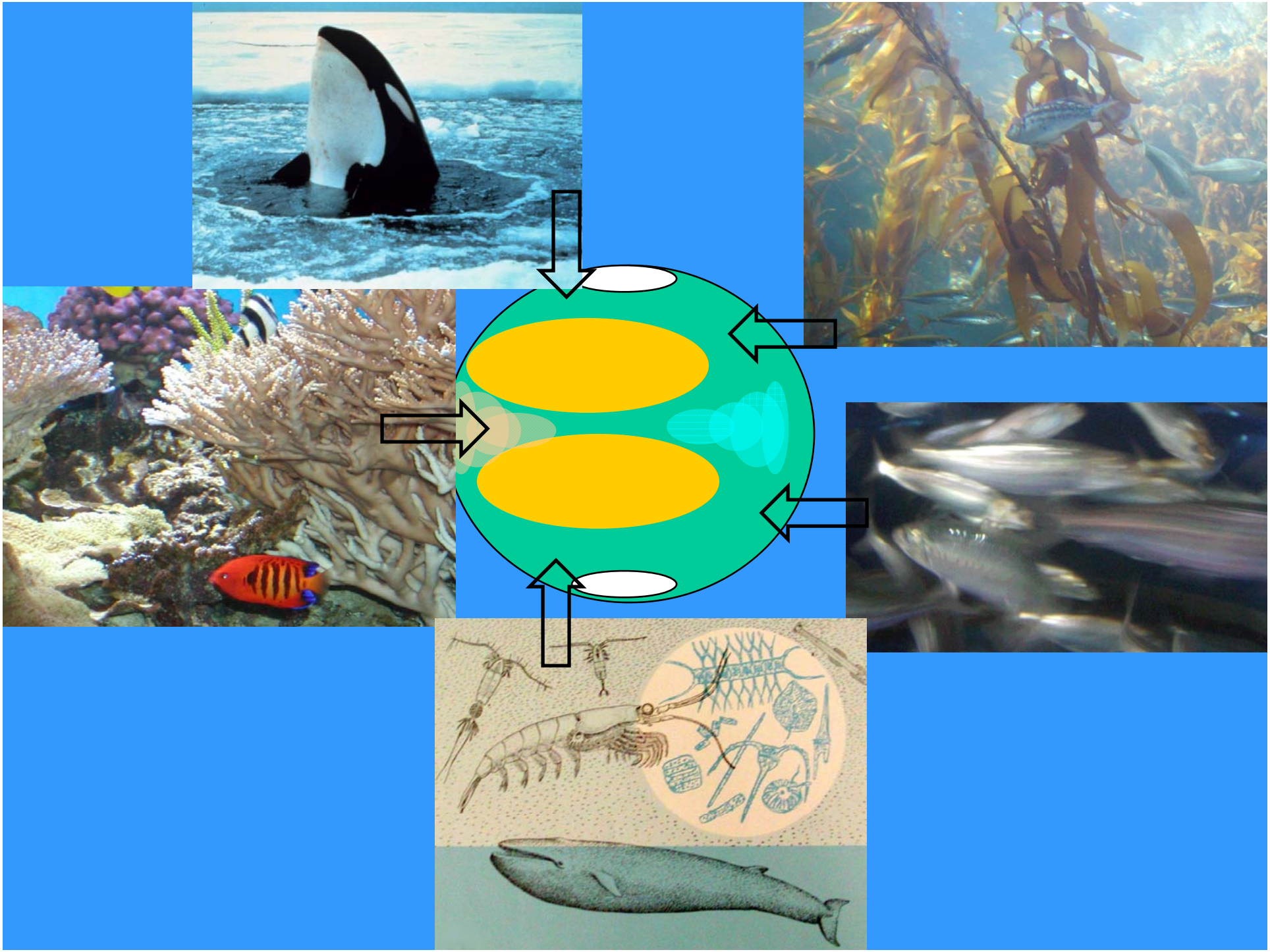
into cold regions

and cold water

into the tropics



Ocean currents do about one half of the job, the other half is done by winds and the water vapor in the air

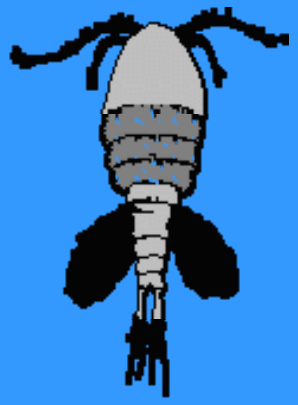


To predict what will happen to fish, we must explore what happens to their food.

sunlight

phyto-plankton

nutrients
N, P, Fe



zoo-plankton

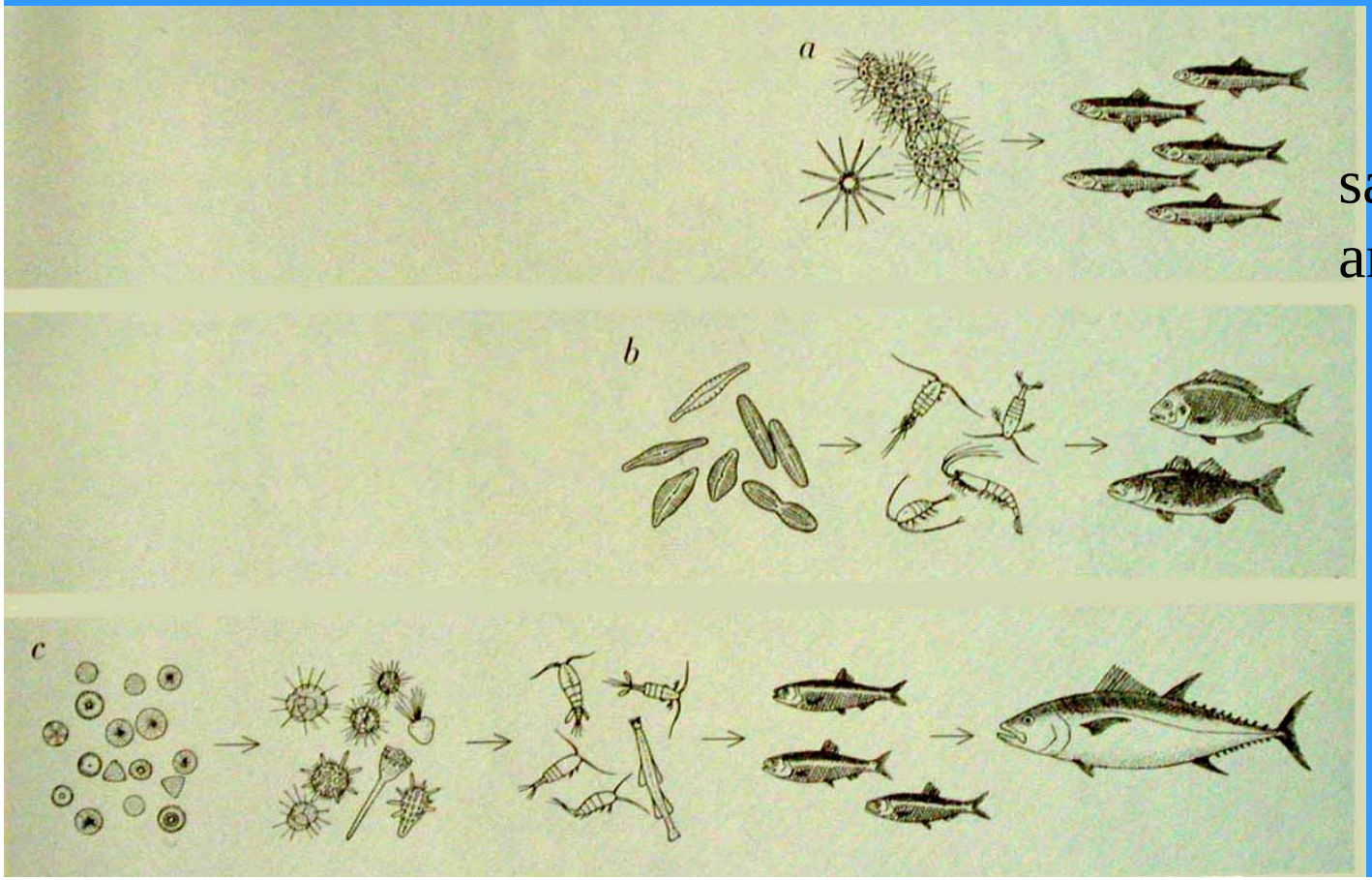
FISH

THE FOOD CHAIN

The food chain is short in upwelling regions.

It is long in the open ocean away from land.

A long food chain leaves little for the top predator.



short

sardine, herring, anchovy

medium

long

tuna

As upwelling systems suffer, the short food chain habitats disappear, and predators that depend on a highly productive sea will greatly diminish.

The Atlantic cod is such a predator. Overfishing has brought it to the brink of ecologic extinction.

A decrease in productivity will make recovery unlikely.

Seabirds depend on high productivity of the sea.

They are very vulnerable to a decrease in productivity.

Breeding colonies on Helgoland, North Sea

SIGNS OF PROBLEMS ALREADY EXIST:

- decrease of production in the California Current
- increase in El-Ninyo abundance and intensity
- bleaching of coral reefs

A decrease in productivity is documented in the CalCOFI data collected by Scripps.

Press Release:

Climatic Warming and the Decline of Zooplankton in the California Current

Since 1951, the biomass (living weight) of zooplankton off southern California has decreased by 70%.

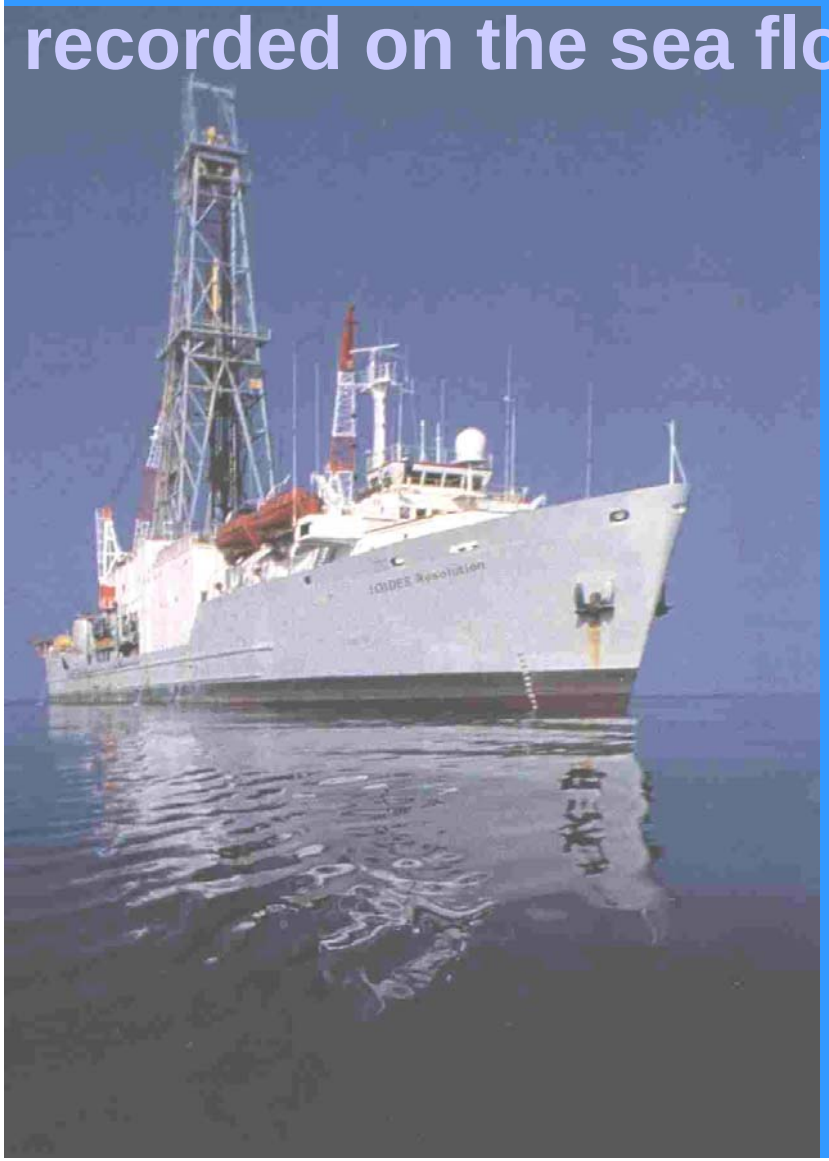
During that same period, the surface layer of the ocean warmed considerably. The warm water layer prevents the upwelling of nutrient-rich cold water.

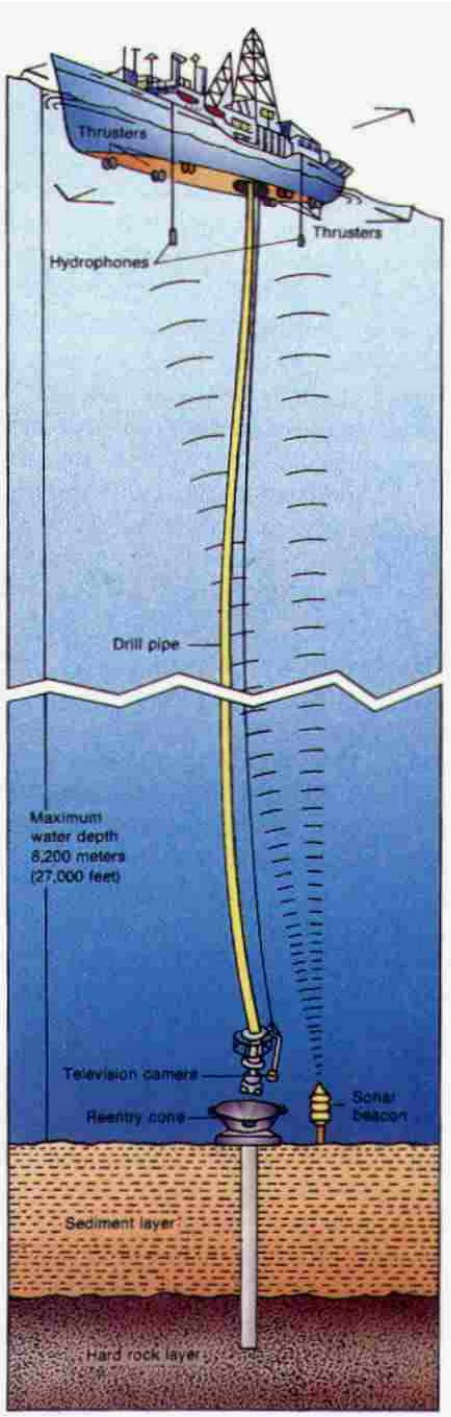
D. Roemmich, J. McGowan, 1995, *Science 267*, 1324-1326.

Photo E. Venrick, SIO

Will the trend reverse? We don't know.

A decrease in productivity upon warming is expected from the geologic record of the ice ages, as recorded on the sea floor.



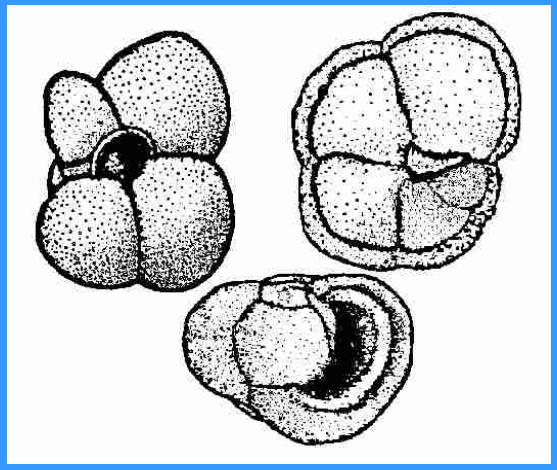


M. Yasuda, SIO

The necessary information is in microscopic fossils, that is, the remains of very small planktic and benthic organisms and in the chemistry of the sediment.

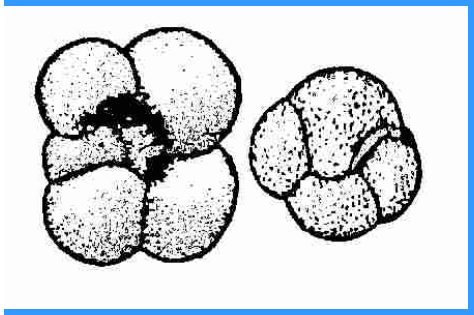
Radiolarians

A. Sanfilippo, SIO



Warm-water foraminifers

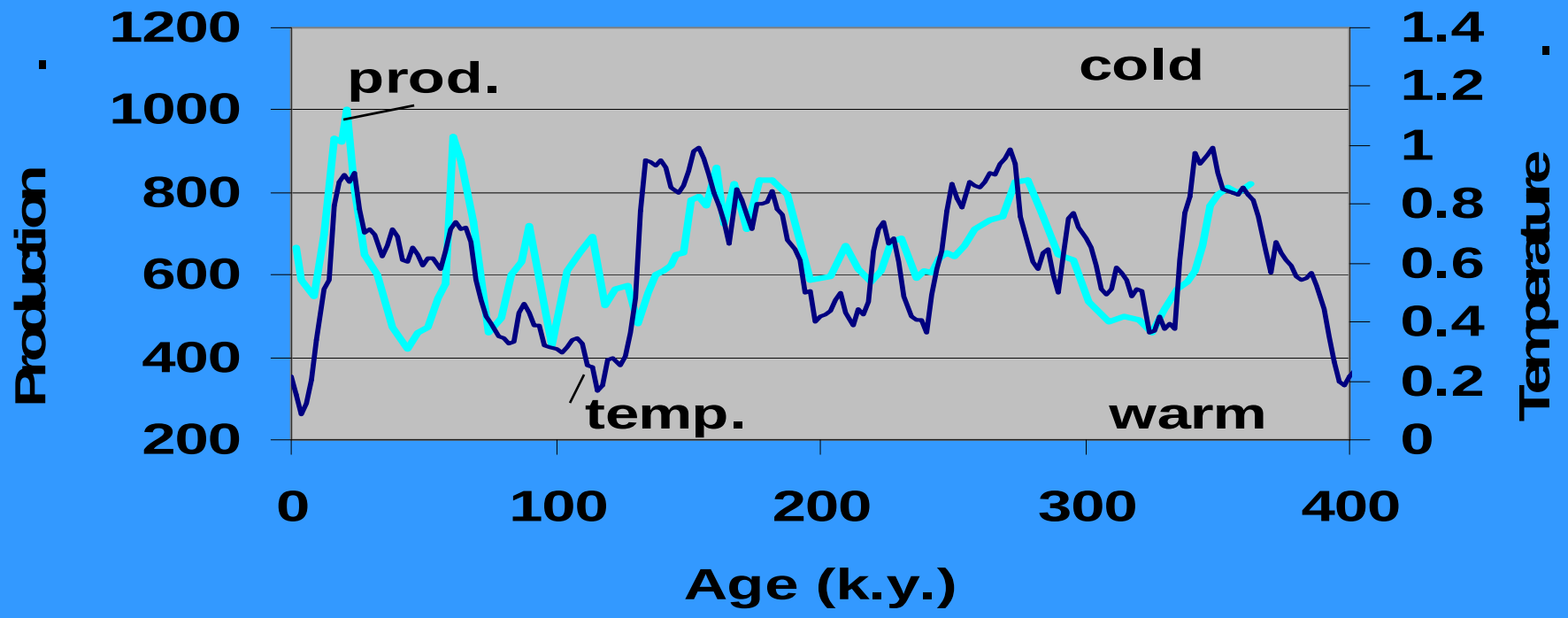
F. Parker, SIO



cold water foraminifers

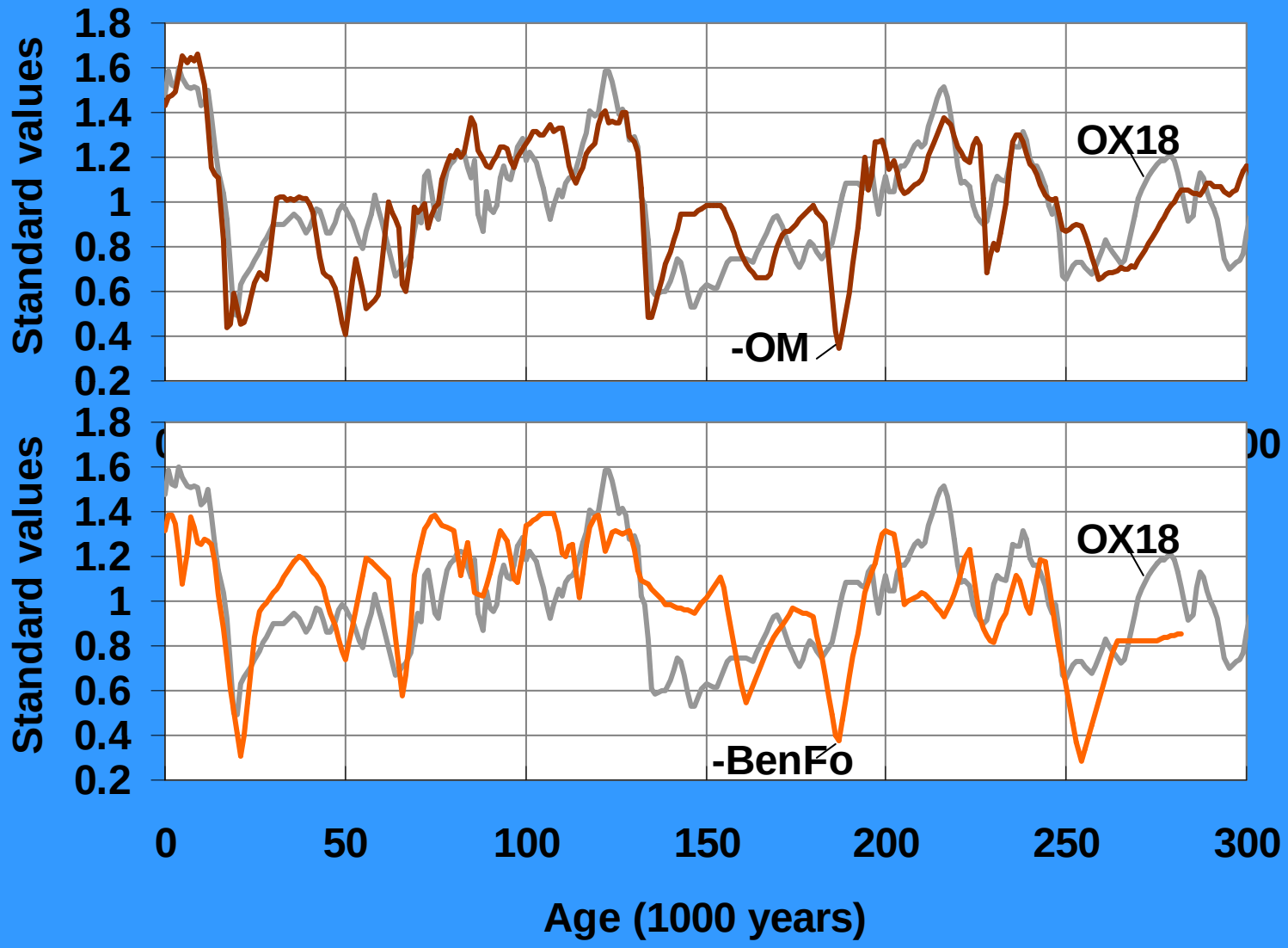
Invariably, when checking the record of upwelling regions, in the coastal domain or along the equator, the productivity is higher during glacial periods than during interglacial ones.

Eastern equatorial Pacific -- based on Ba content of sediment



A. Paytan SIO

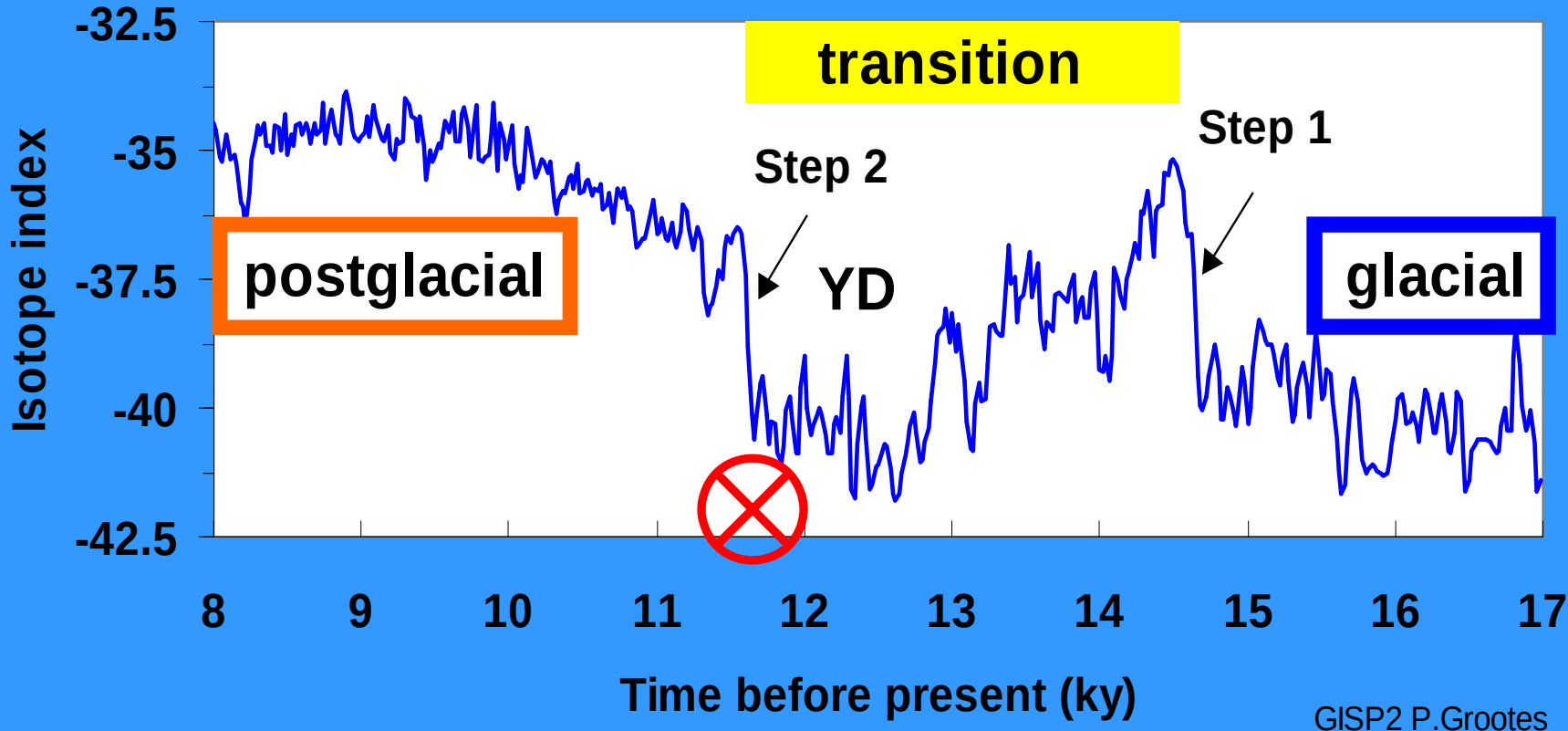
Productivity off Africa, Walvis Ridge



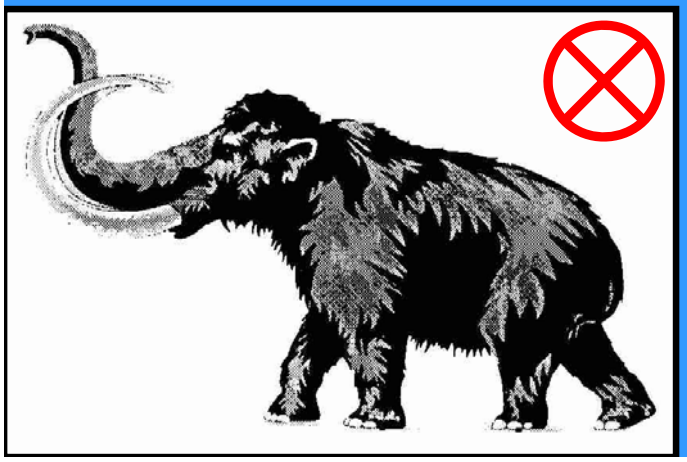
OX18, warm & cold, OM, organic matter; BenFo, benthic foraminifers = measure of production.

GeoB 1028 U.Bremen

EXTINCTION OCCURRED DURING TIMES OF RAPID CLIMATE CHANGE WHEN GOING FROM GLACIAL TO POSTGLACIAL CONDITIONS



GISP2 P.Grootes



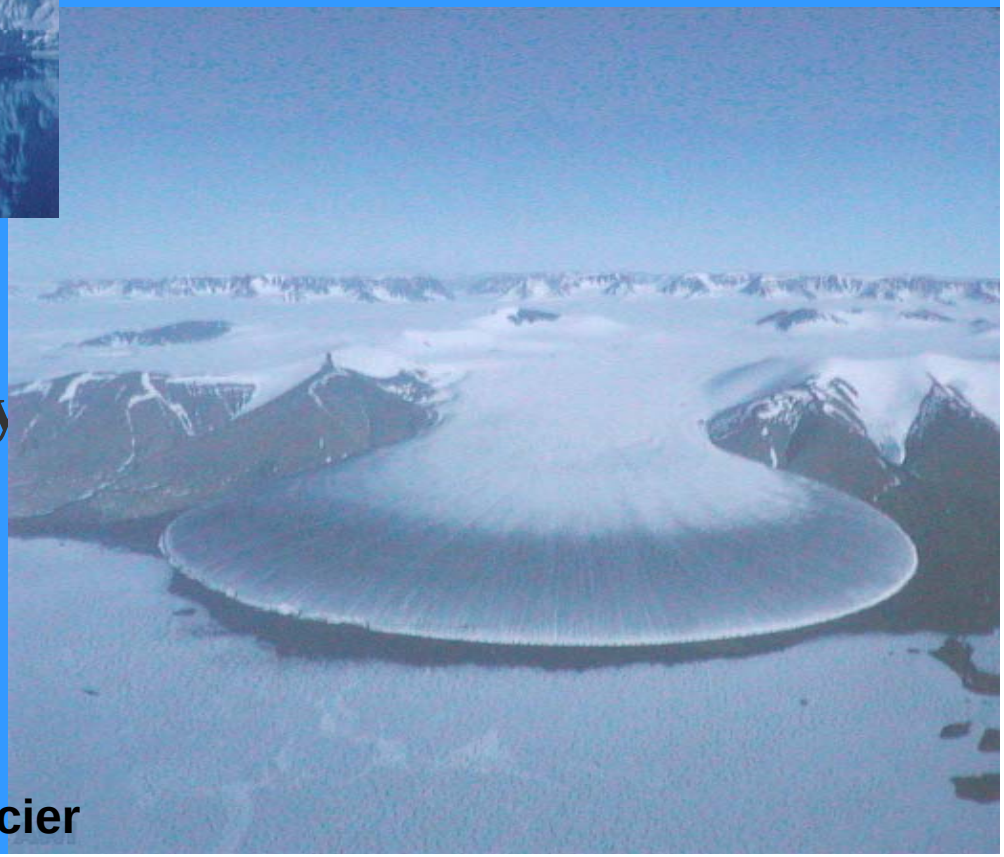
The return to glacial conditions (YD), within the period of transition to postglacial conditions, is a major puzzle and is still unexplained.

The mammoth and many other large mammals became extinct at the time.

What made the ice melt so rapidly? Was it mainly warming?

Antarctic ice shelf

Or was it the gravitational energy stored within the ice sheets themselves that helped produce their collapse?

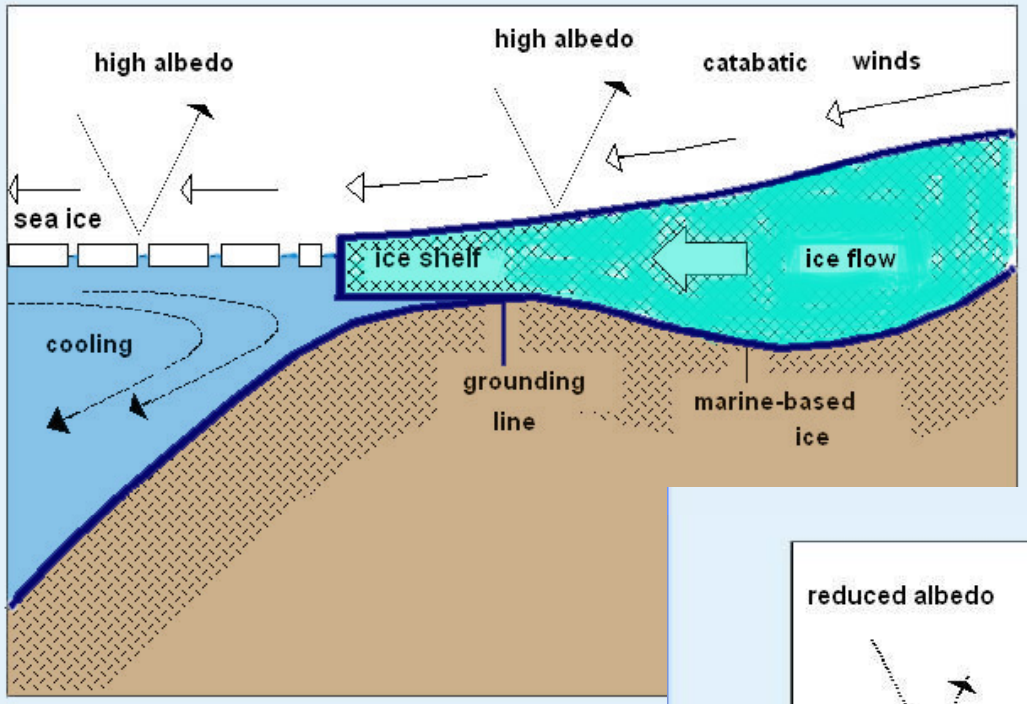


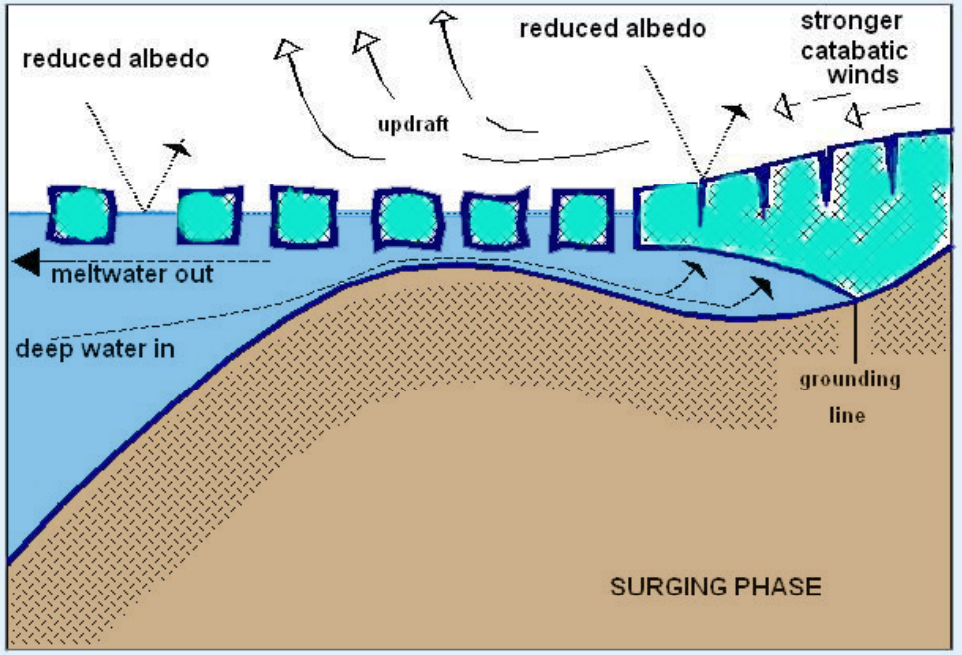
Greenland glacier

To appreciate how ice sheets can collapse, we need only look at Canada today.

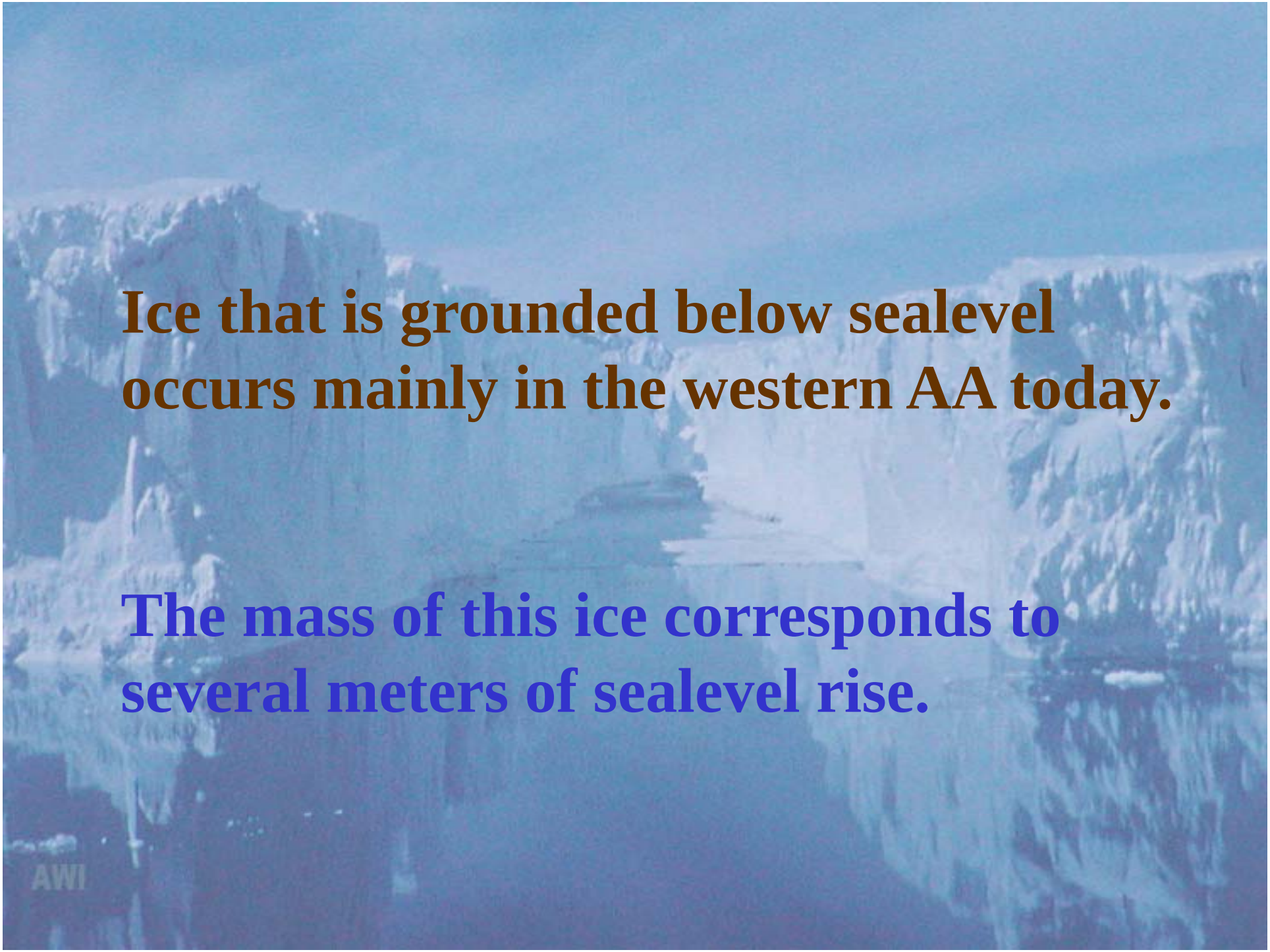
Much of the area covered by the former Canadian glacial ice shield is now under water. Hudson Bay is in the center of the former shield.

Like earthquakes, ice sheet collapse is unpredictable. It becomes more likely with warming.





Ice becomes instable when seawater penetrates below the ice sheet. It happened many times during the ice ages.



Ice that is grounded below sealevel occurs mainly in the western AA today.

The mass of this ice corresponds to several meters of sealevel rise.