The Consequences of a Warming Arctic: An Overview of the Results of the Arctic Climate Impact Assessment (ACIA)

Michael MacCracken
Chief Scientist for Climate Change Programs
Climate Institute, Washington DC, and
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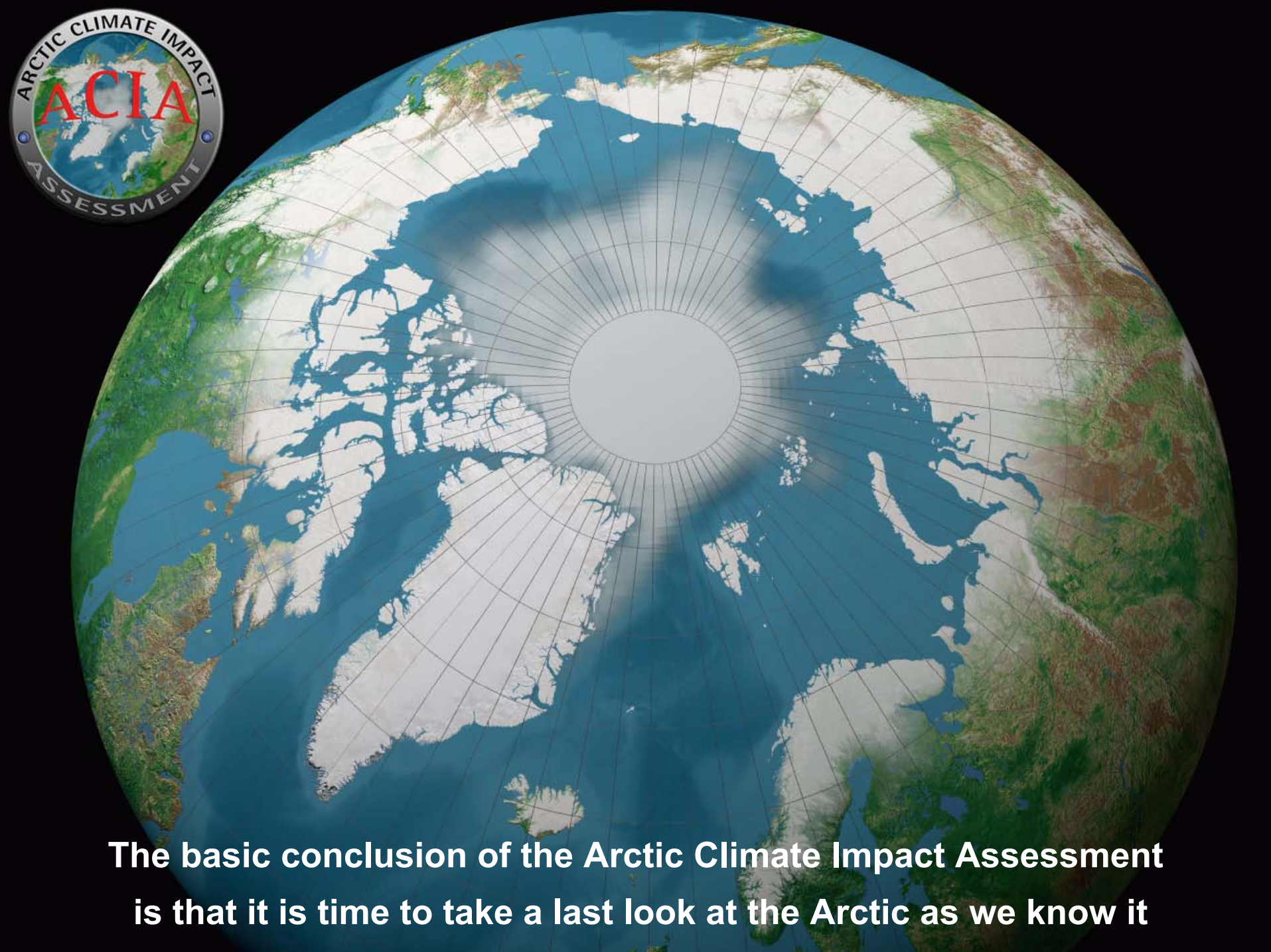
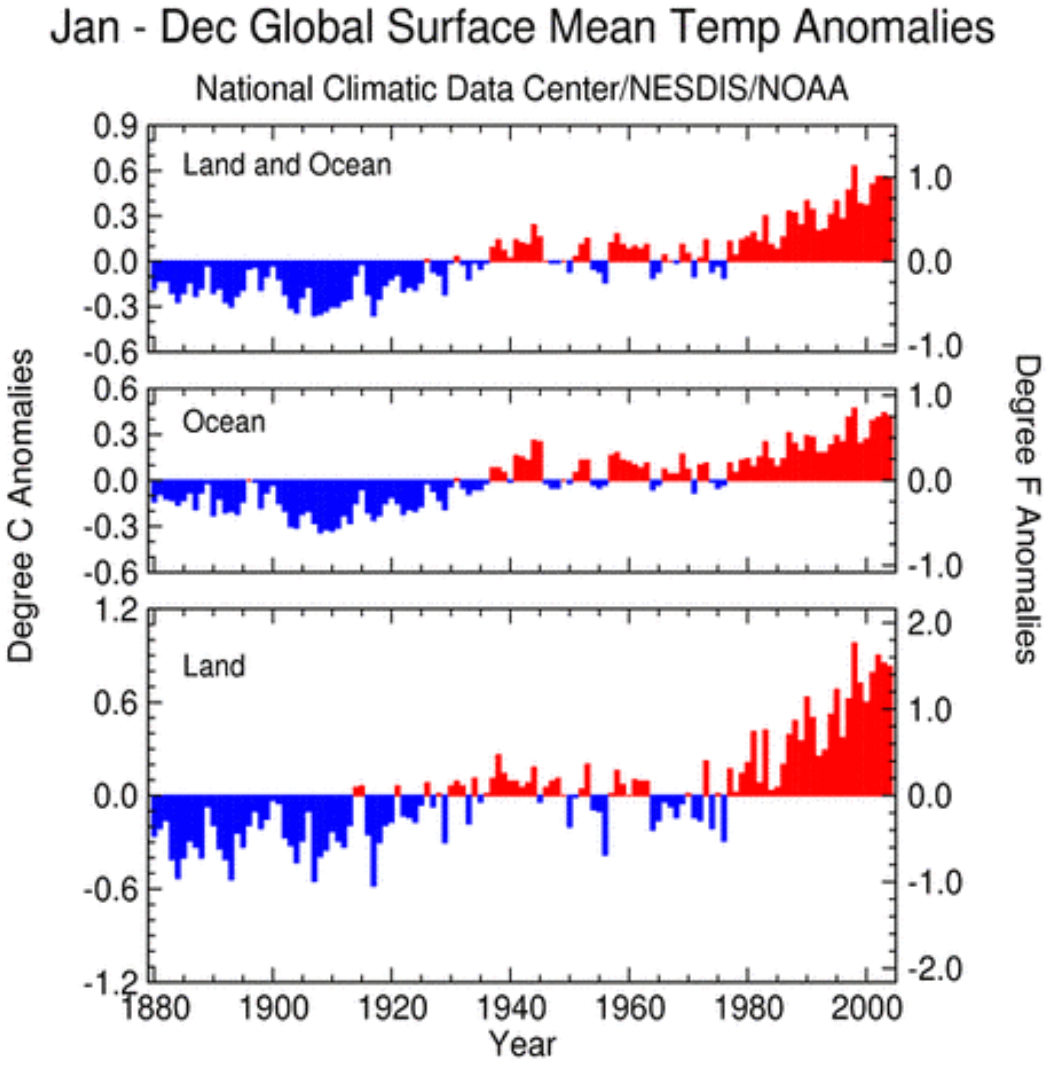


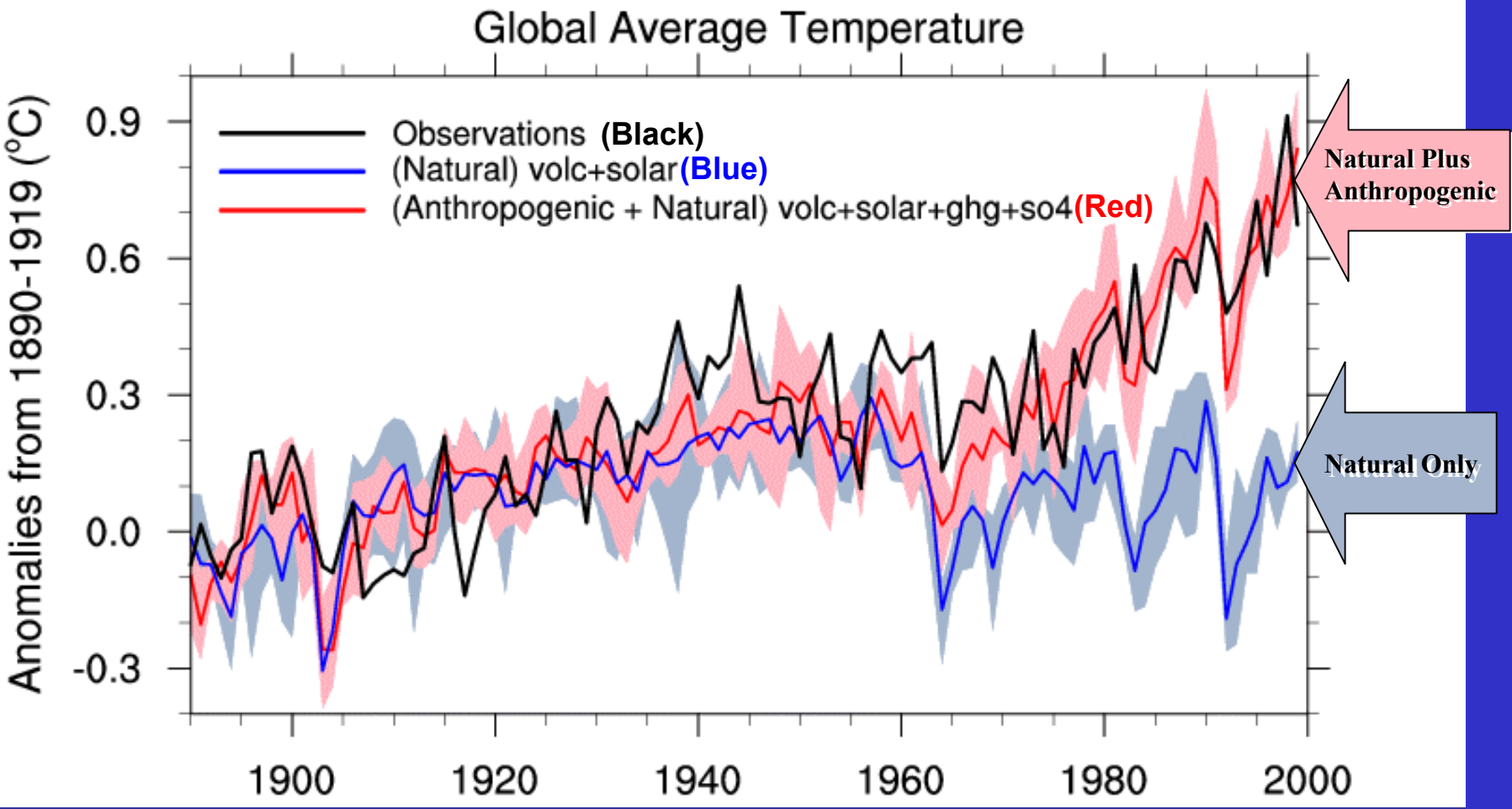
The basic conclusion of the Arctic Climate Impact Assessment is that it is time to take a last look at the Arctic as we know it

Public discussion has focused on *global* warming of 0.8ºC, with land areas warming more rapidly than the oceans



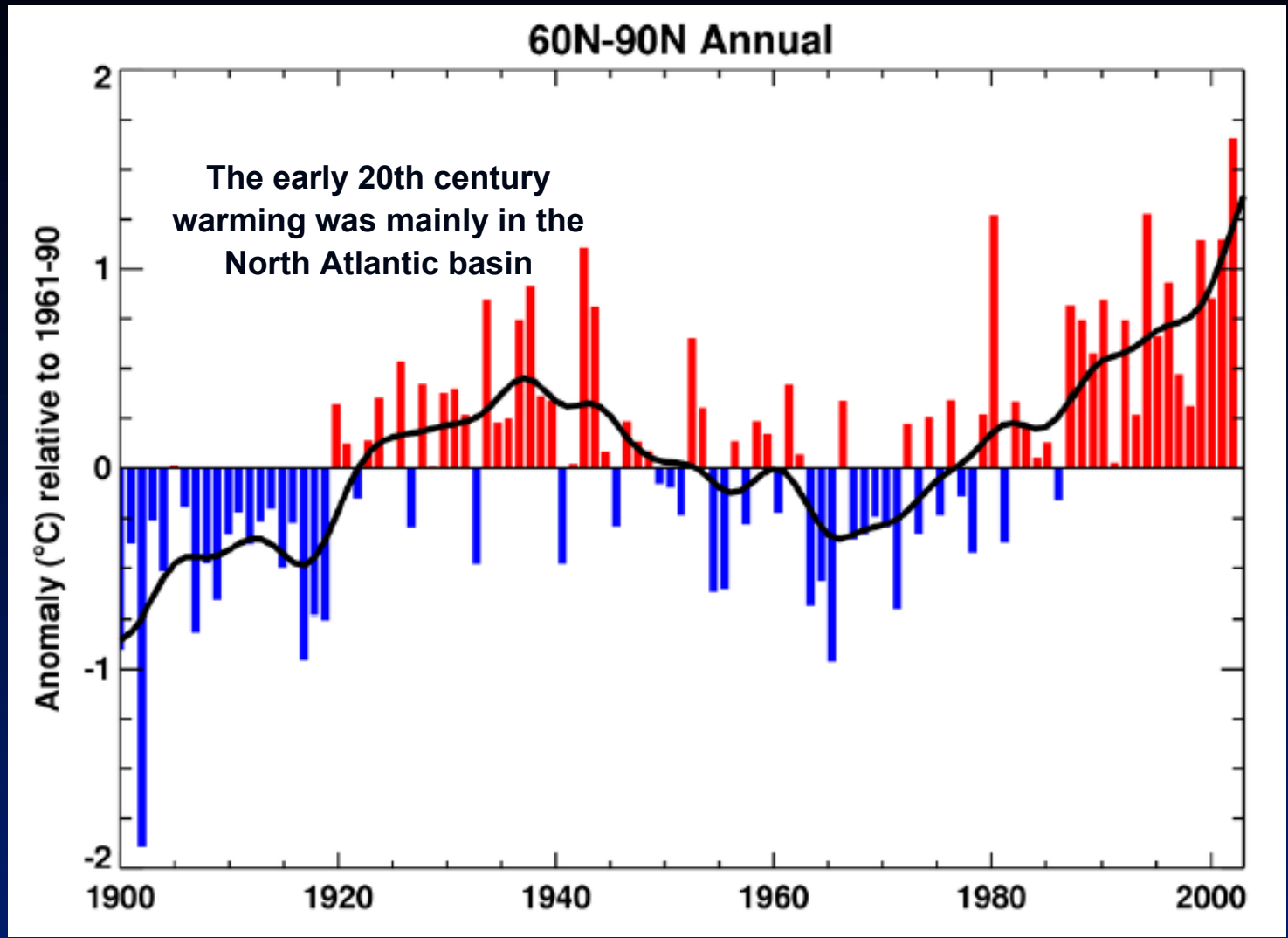
Source: NOAA/NCDC through 2005

Analysis of the multi-decadal changes and "forcings" over the 20th century indicate that human activities are playing an increasing role

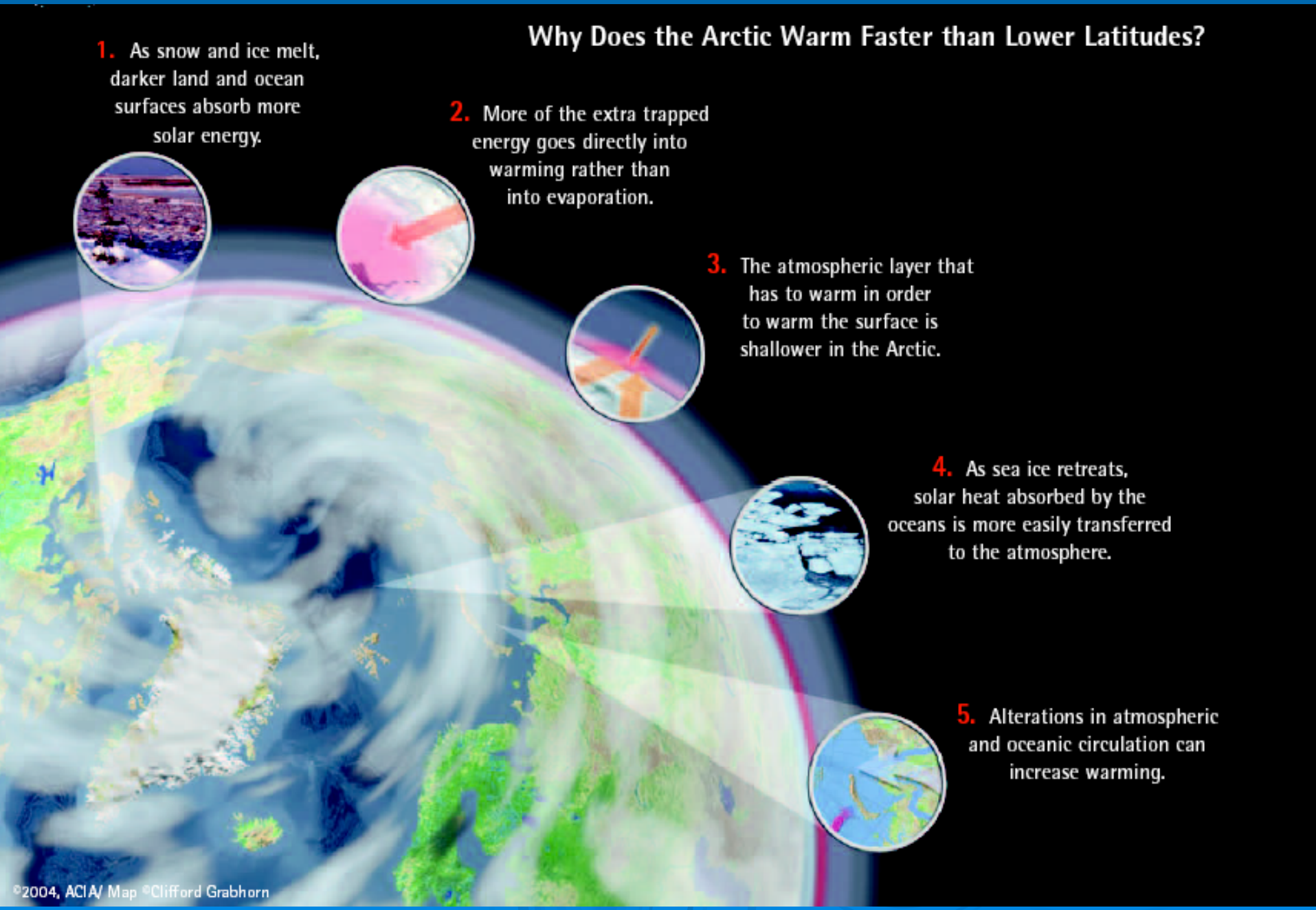


NCAR Climate Simulations

Warming in the Arctic has been larger than for the globe, nearly 2ºC (3.5 º F) since about 1900



Why Does the Arctic Warm Faster than Lower Latitudes?

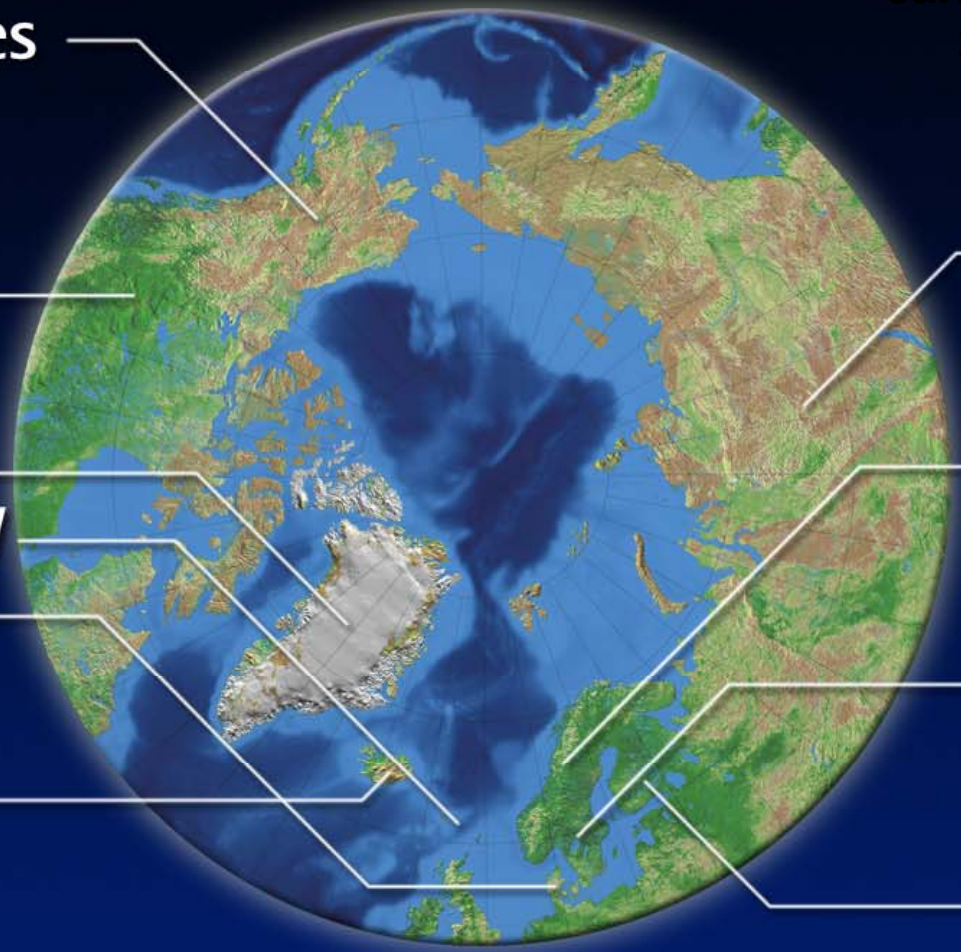


It is important to understand that
"Global Warming" will be experienced in distinct ways
in each region, and we must look at impacts regionally
to gain a sense of their influences on both
the region's and the world's environment and society.
The Arctic is one of the most vulnerable regions!


ARCTIC CLIMATE IMPACT
ACIA
ASSESSMENT
With their world changing so rapidly, the people of the Arctic wanted and needed more information about the changes and how best to prepare and adapt-- leading to the undertaking of the Arctic Climate Impact Assessment (ACIA)

IMPACTS OF A WARMING ARCTIC

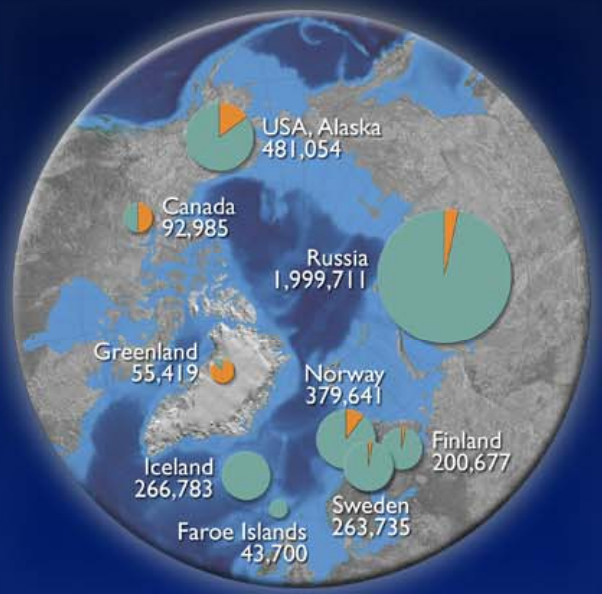
The Arctic Council has eight national members



IMPACTS OF A WARMING ARCTIC

The Arctic Council also includes six councils of Indigenous Peoples

- Aleut International Association
- Arctic Athabaskan Council
- Gwich'in Council International
- Inuit Circumpolar Conference
- Russian Association of Indigenous Peoples of the North
- Saami Council

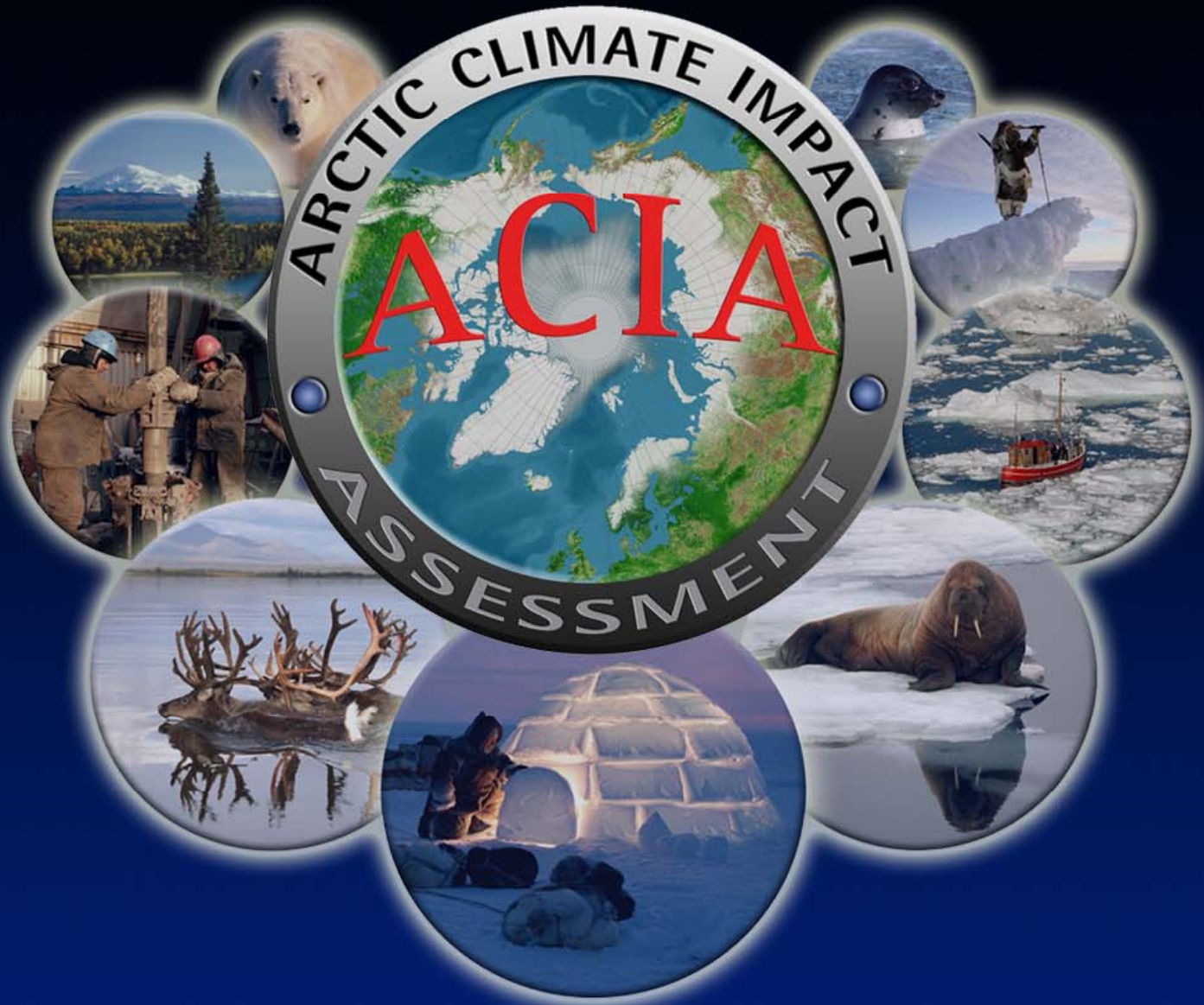


ACIA's Unique Approach

"Nowadays snows melt earlier in the springtime. Lakes, rivers, and bogs freeze much later in the autumn. Reindeer herding becomes more difficult as the ice is weak and may give way… All sorts of unusual events have taken place. Nowadays the winters are much warmer than they used to be. Occasionally during winter time it rains. We never expected this; we could not be ready for this. It is very strange… The cycle of the yearly calendar has been disturbed greatly and this affects the reindeer herding negatively for sure…"

An observation by Larisa Avdeyeva, an elder from Lovozero, Russia in 2002,

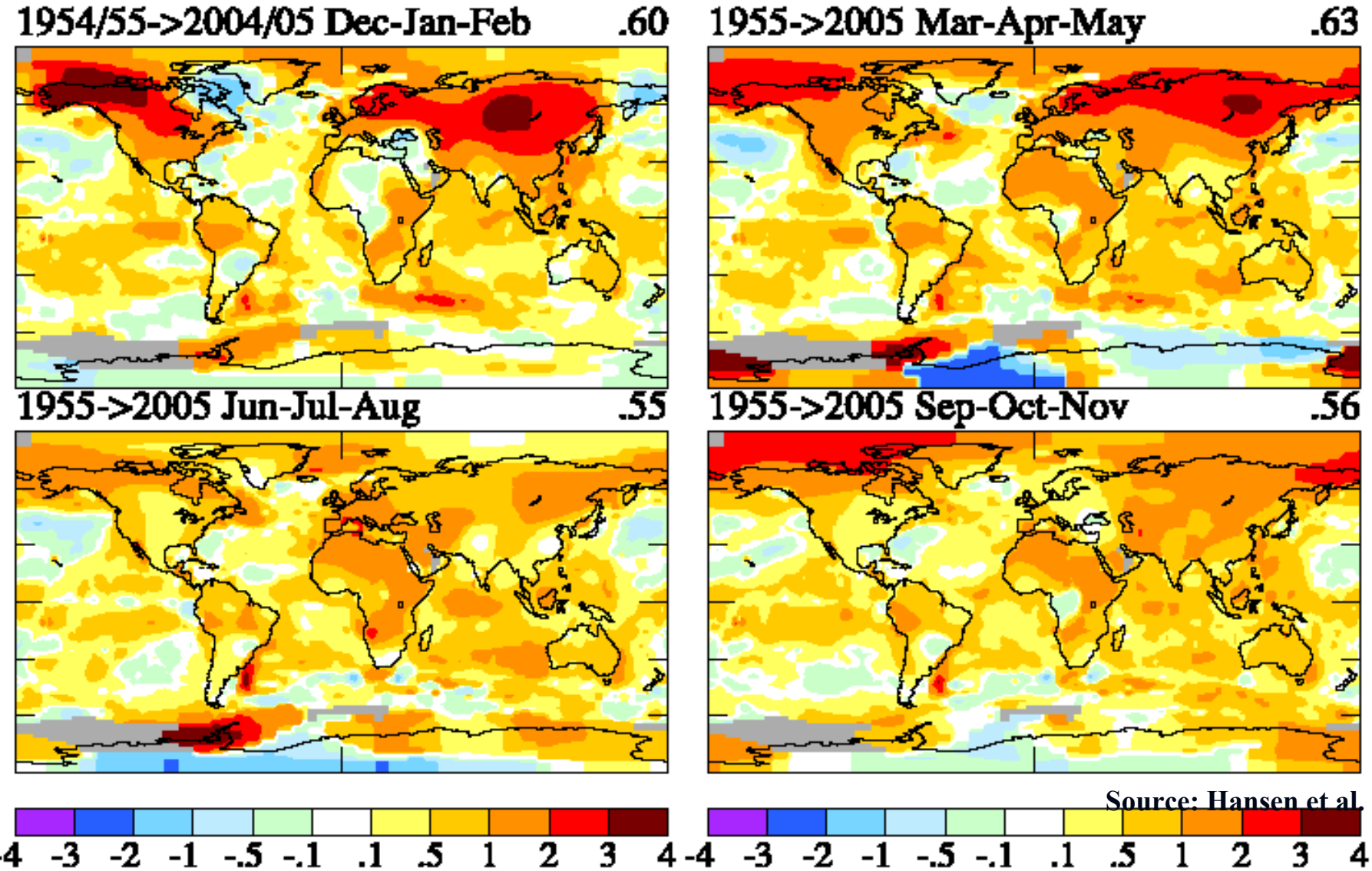
IMPACTS OF A WARMING ARCTIC



ACIA's Ten Key Findings

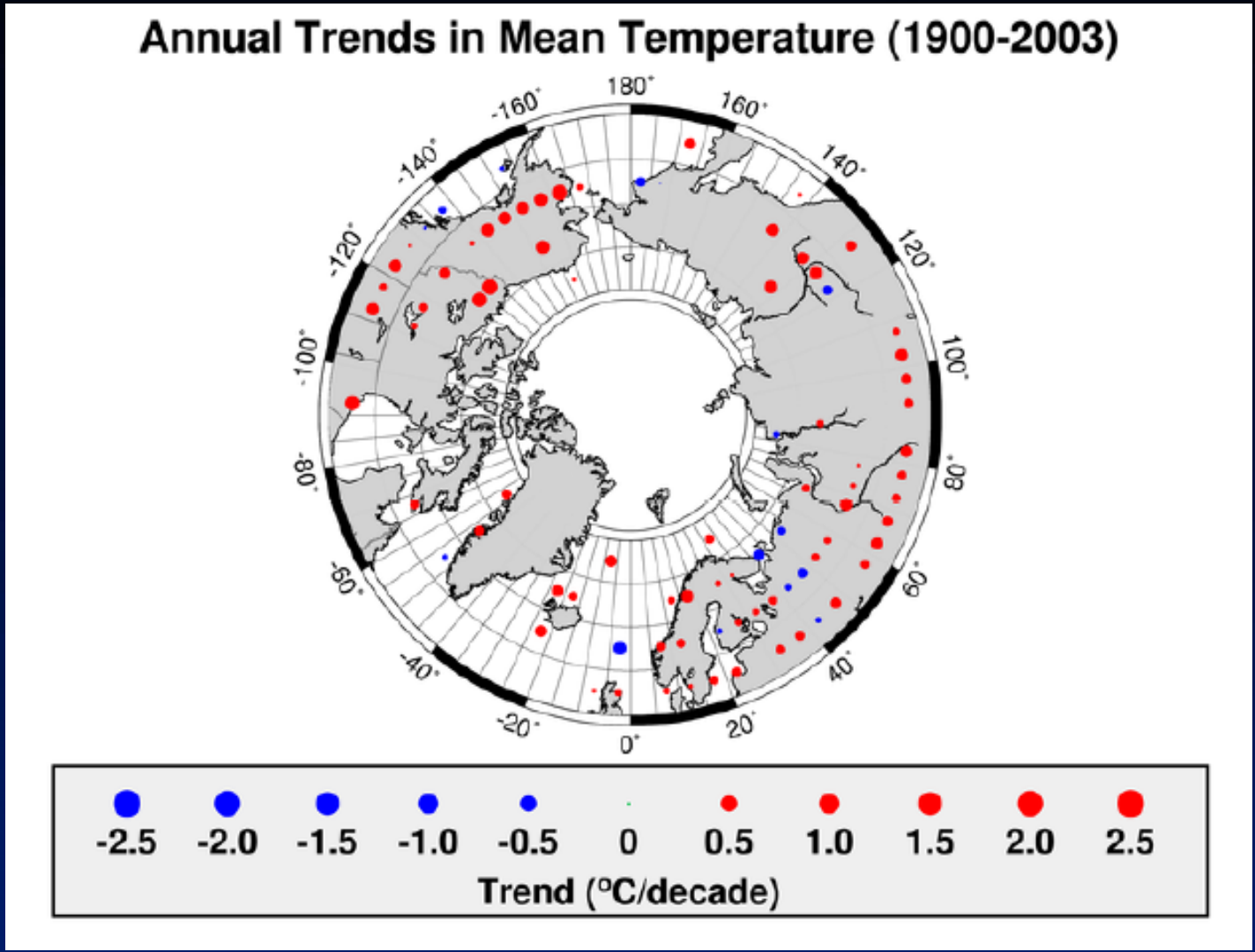
1. Arctic climate is now warming rapidly and much larger changes are projected;
2. Arctic warming and its consequences have worldwide implications;
3. Arctic vegetation zones are very likely to shift, causing wide-ranging impacts;
4. Animal species' diversity, ranges, and distribution will change;
5. Many coastal communities and facilities face increasing exposure to storms;
6. Reduced sea ice is very likely to increase marine transport and access to resources;
7. Thawing ground will disrupt transportation, buildings, and other infrastructure;
8. Indigenous communities are facing major economic and cultural impacts;
9. Elevated ultraviolet radiation levels will affect people, plants, and animals; and
10. Multiple influences interact to cause impacts to people and ecosystems.

Warming has occurred in all four seasons over the past 50 years, especially in the Arctic



Source: Hansen et al.

IMPACTS OF A WARMING ARCTIC

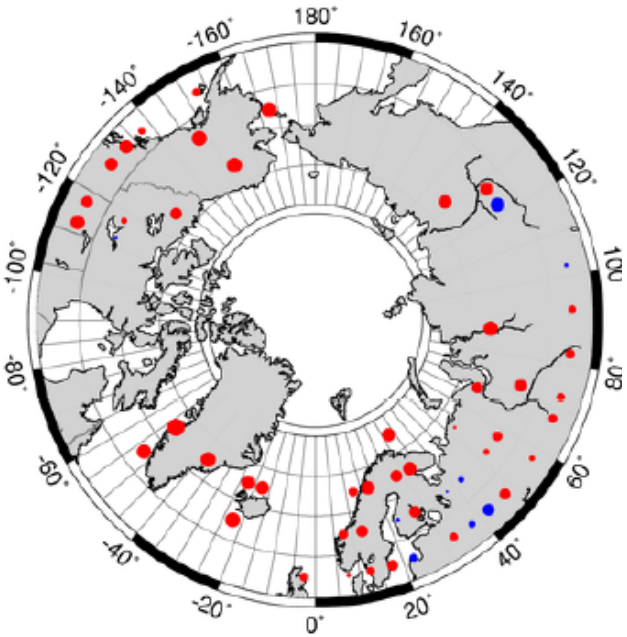


IMPACTS OF A WARMING ARCTIC

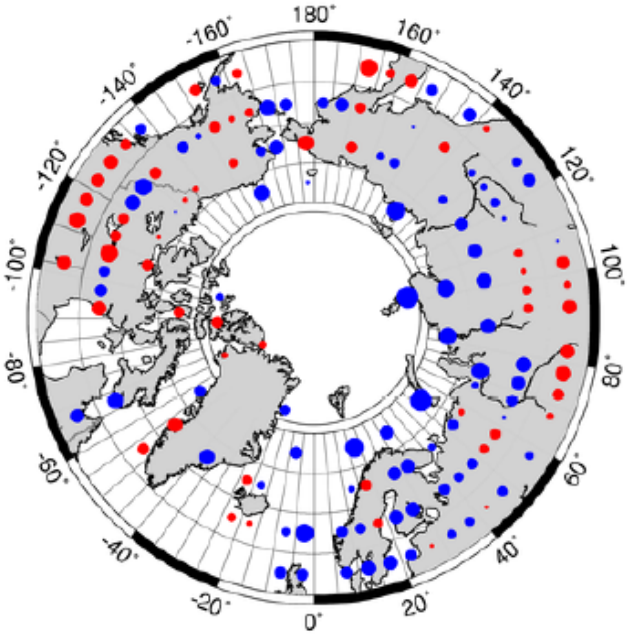
Trends in Mean Temperature

Annual

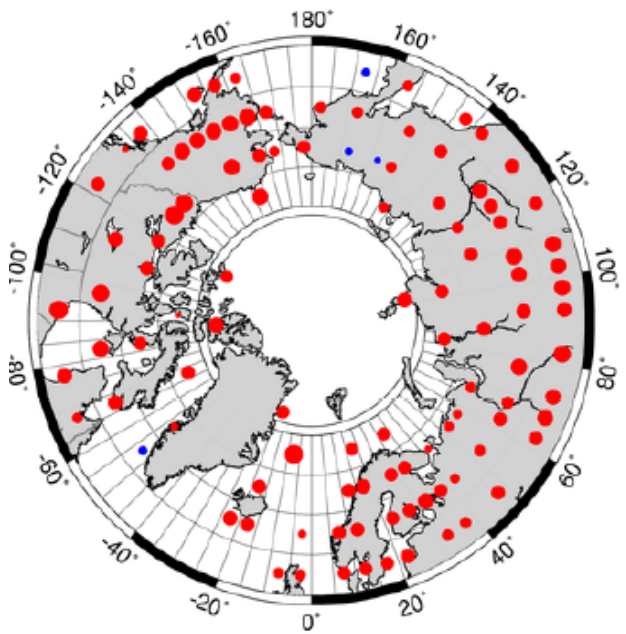
(1900-1945)

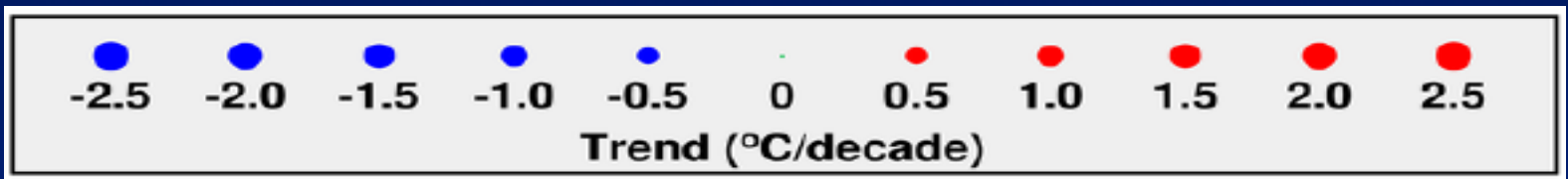


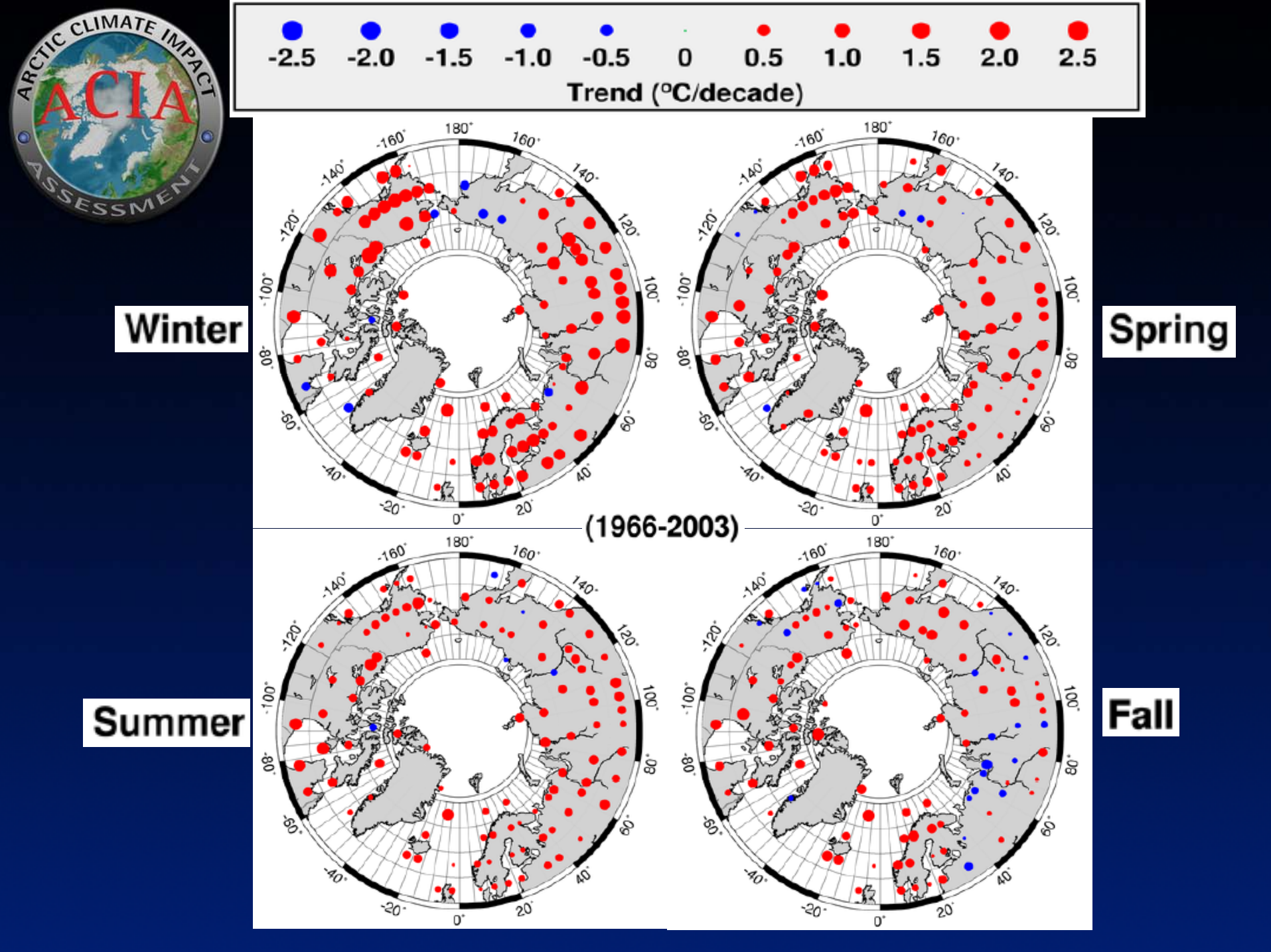
(1946-1965)



(1966-2003)





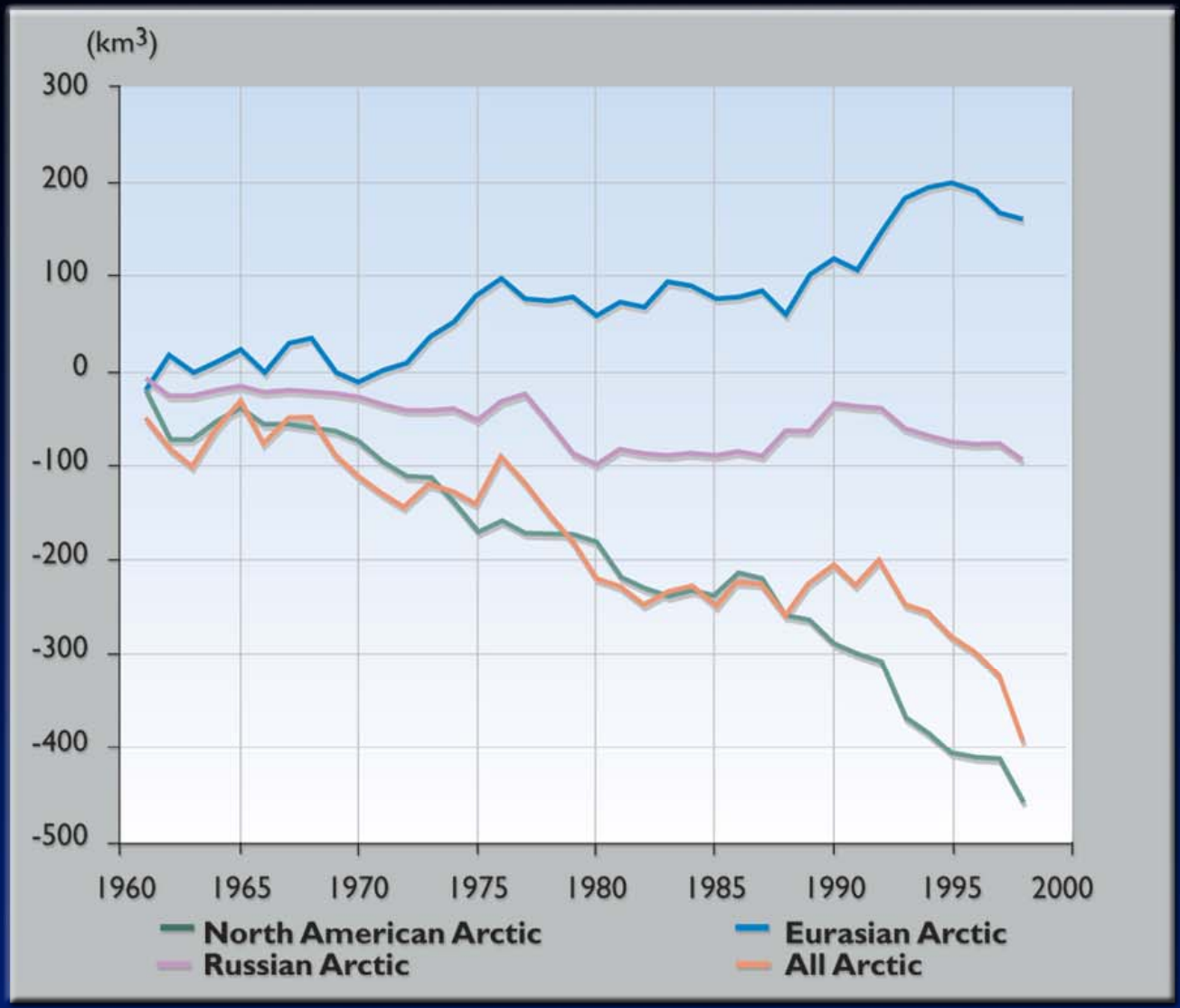

ARCTIC CLIMATE IMPACT
ACIA
ASSESSMENT
-2.5 -2.0 -1.5 -1.0 -0.5 0 0.5 1.0 1.5 2.0 2.5
Trend (°C/decade)
Winter
Spring
(1966-2003)
Summer
Fall

Over the Past 30 Years, the Arctic Region Has Experienced Major Changes in its Climate

- Increases in surface and oceanic temperatures,
- Large reductions in sea ice and glacier volume,
- Increases in river runoff and sea level,
- Overall increases in precipitation,
- The thawing of permafrost,
- Shifts in the ranges of plant and animal species, and
- Major impacts on the residents of the circumpolar Arctic region.

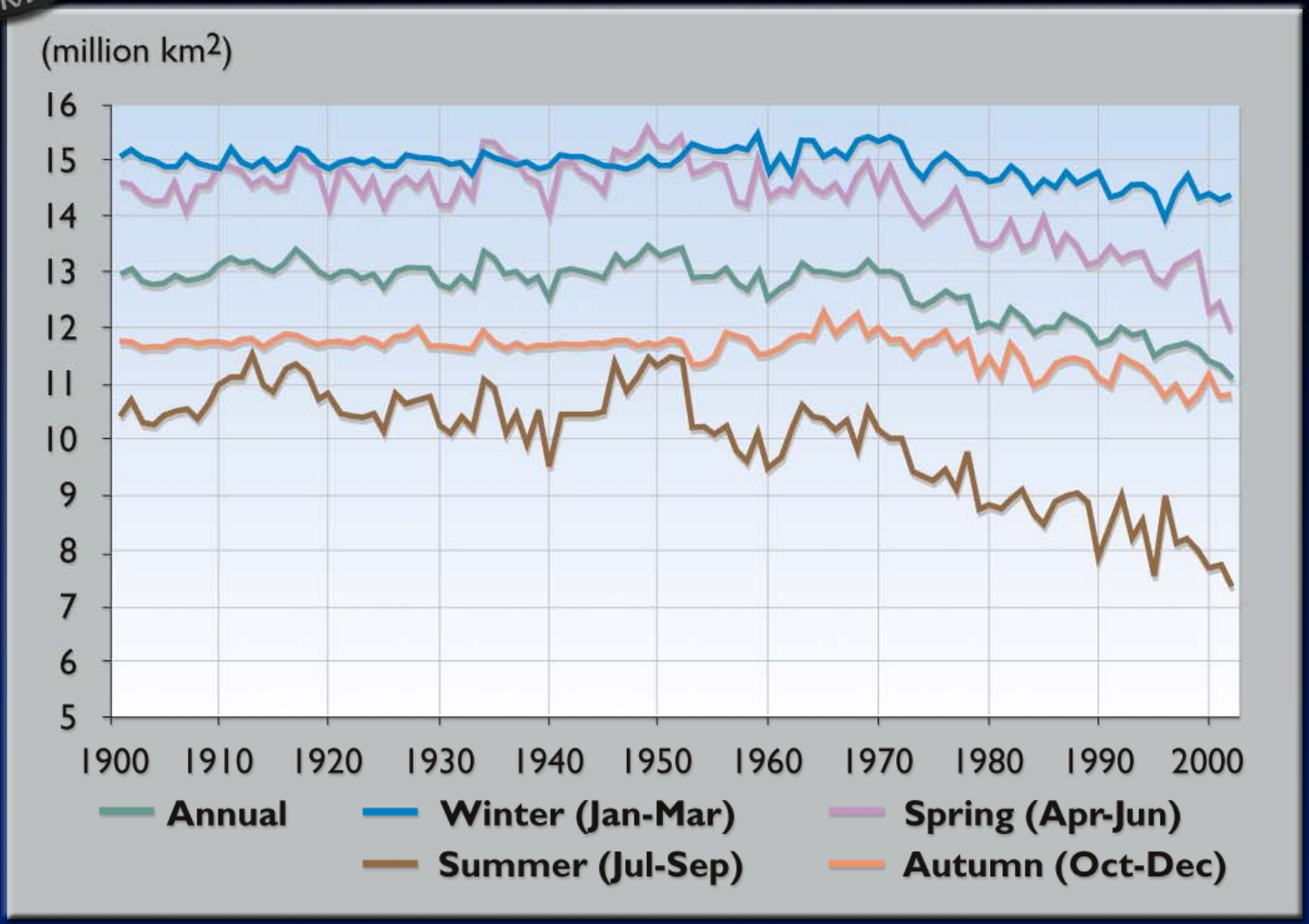
IMPACTS OF A WARMING ARCTIC

Cumulative Change in Volume of Arctic Glaciers
(since 1960)



IMPACTS OF A WARMING ARCTIC

Observed seasonal Arctic sea-ice extent (1900-2003)



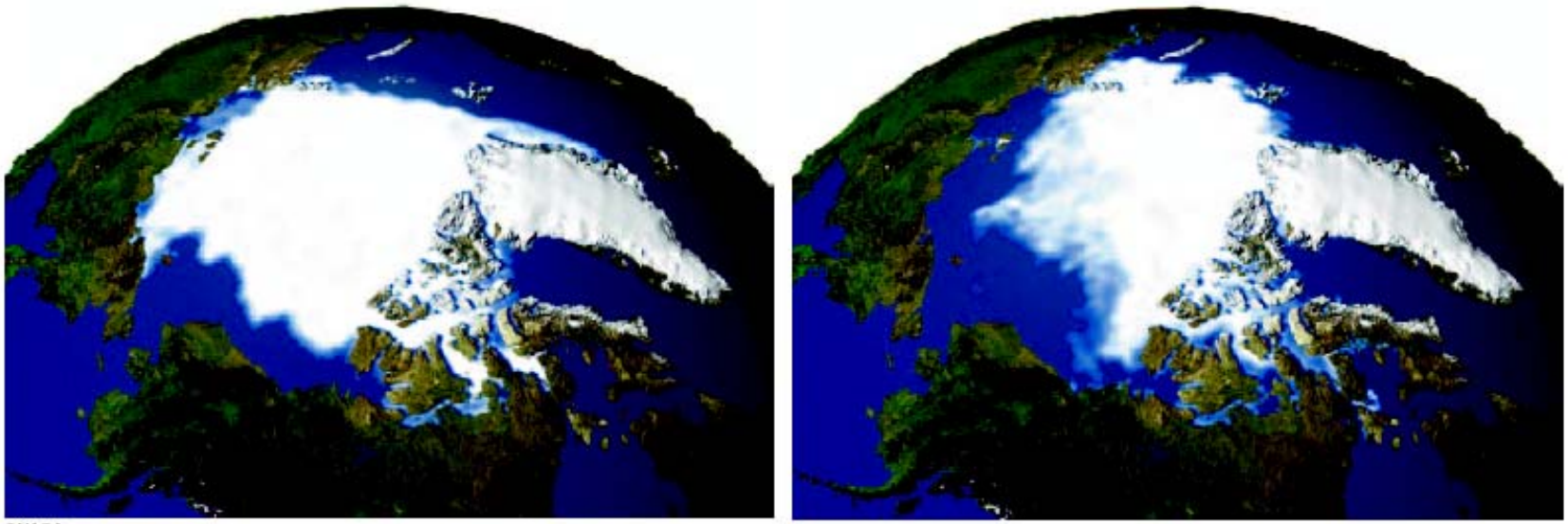
Minimum Extent of Arctic Ocean Sea Ice Cover

September 1979

September 2003

Observed sea ice September 1979

Observed sea ice September 2003

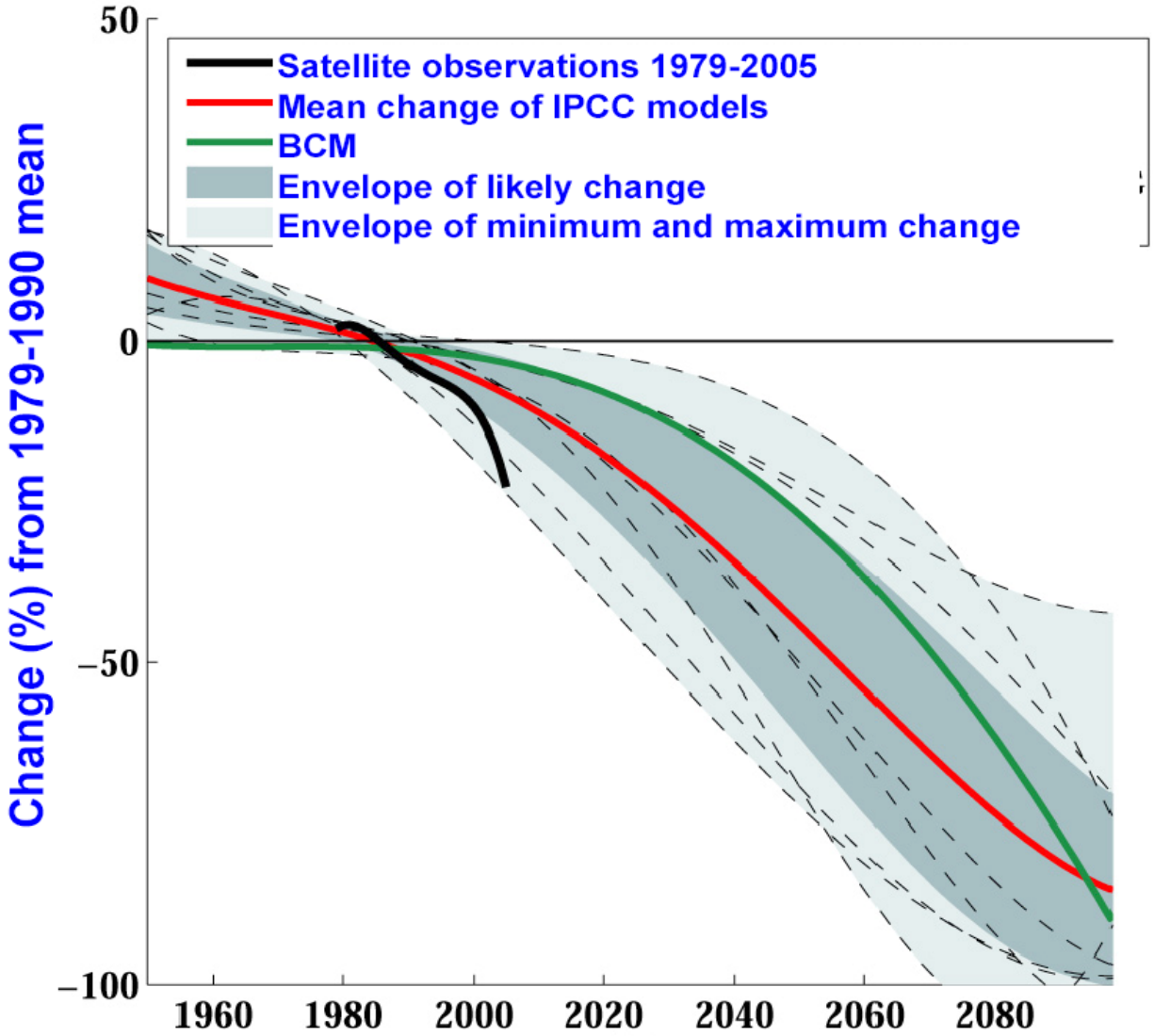


©NASA

The two images above, constructed from satellite data, compare arctic sea ice concentrations in September of 1979 and 2003. September is the month in which sea ice is at its yearly minimum and 1979 marks the first year that data of this kind became available in meaningful form. The lowest concentration of sea ice on record was in September 2002.

The extent of September ice cover has continued to decrease since 2003

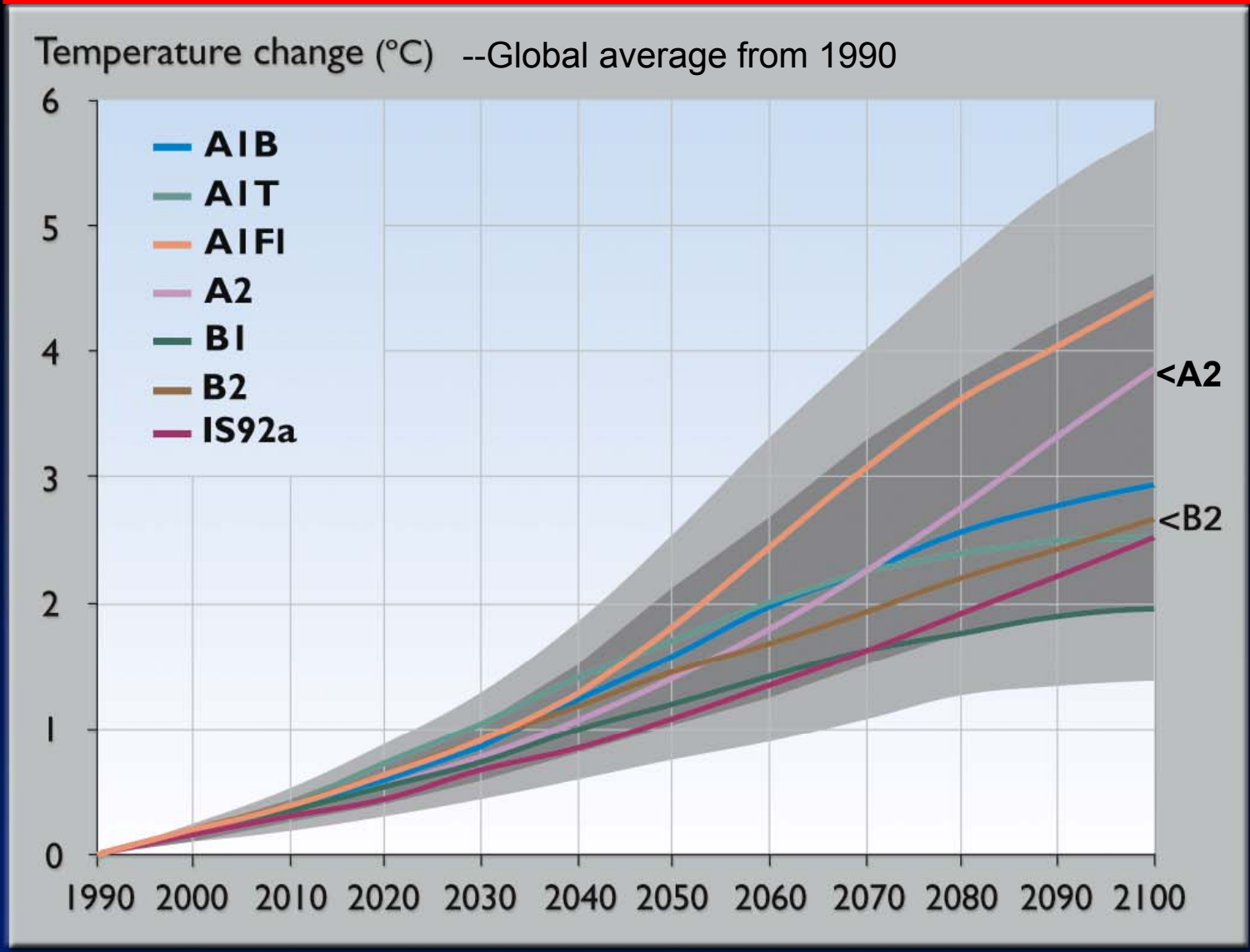
Models Project Sharp Reductions in Arctic Sea Ice--and the Sea Ice is Actually Melting Even More Rapidly (from Sorteberg, cited by J. Eystein--2005)



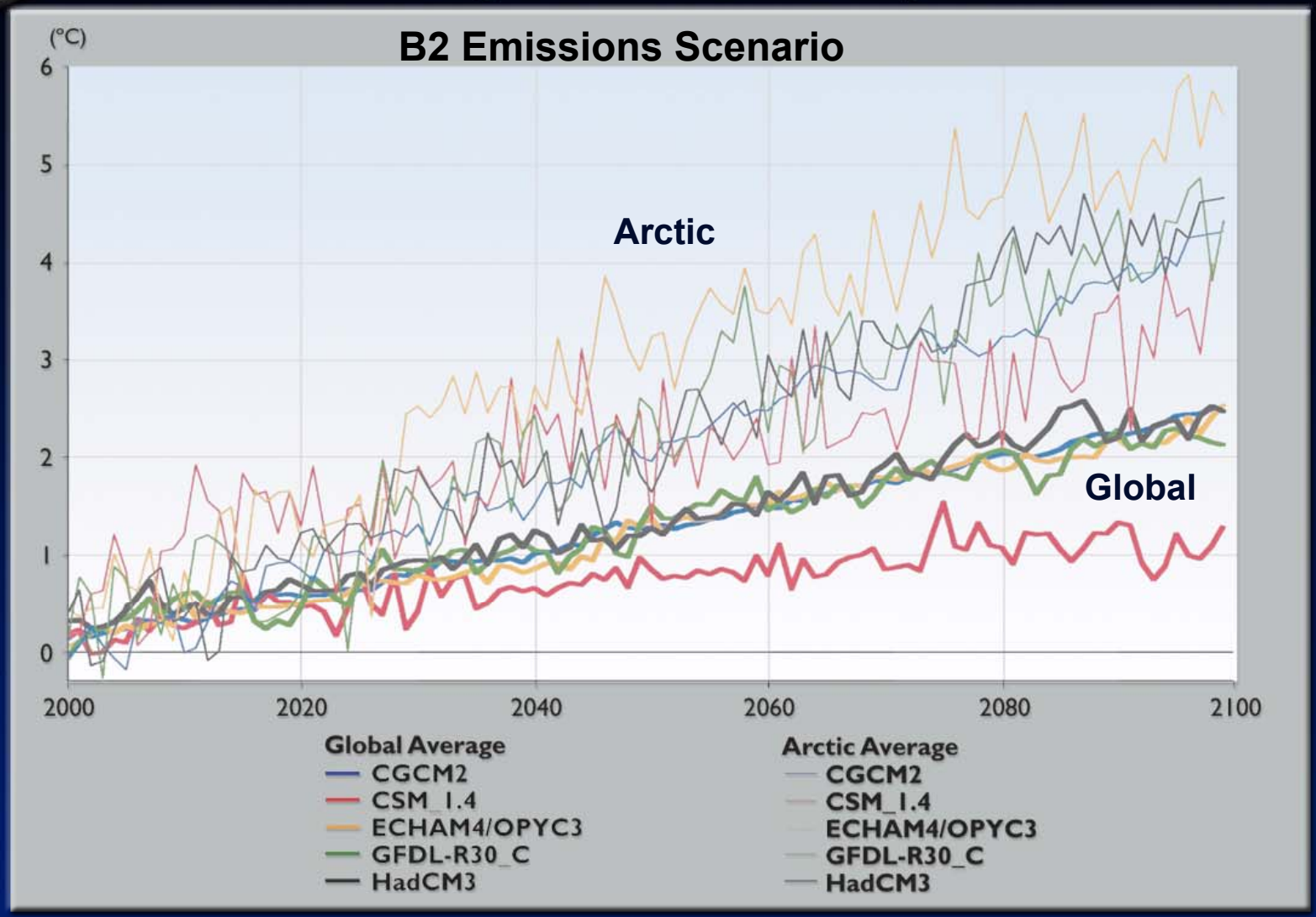
Melting of the Arctic sea ice will reduce the effectiveness of the Northern Hemisphere's "air conditioner," leading to winter and summer warming

For the 21st century, even a modest emissions scenario causes *global* warming of 2-4ºC

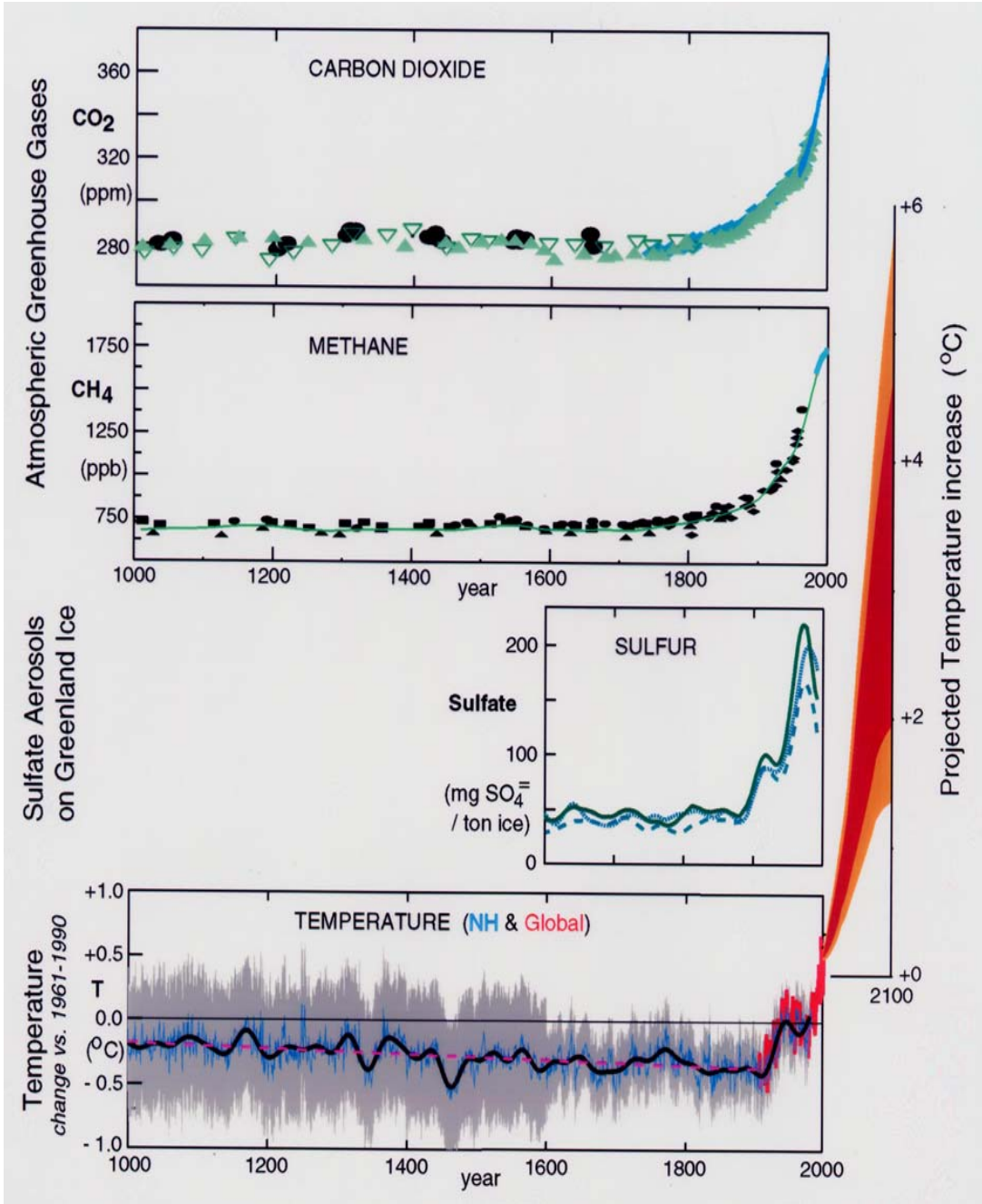
ACIA's analysis focused mostly on the relatively conservative B2 emissions scenario



As a result of snow and ice feedbacks, warming in the Arctic is projected to be roughly twice the global increase



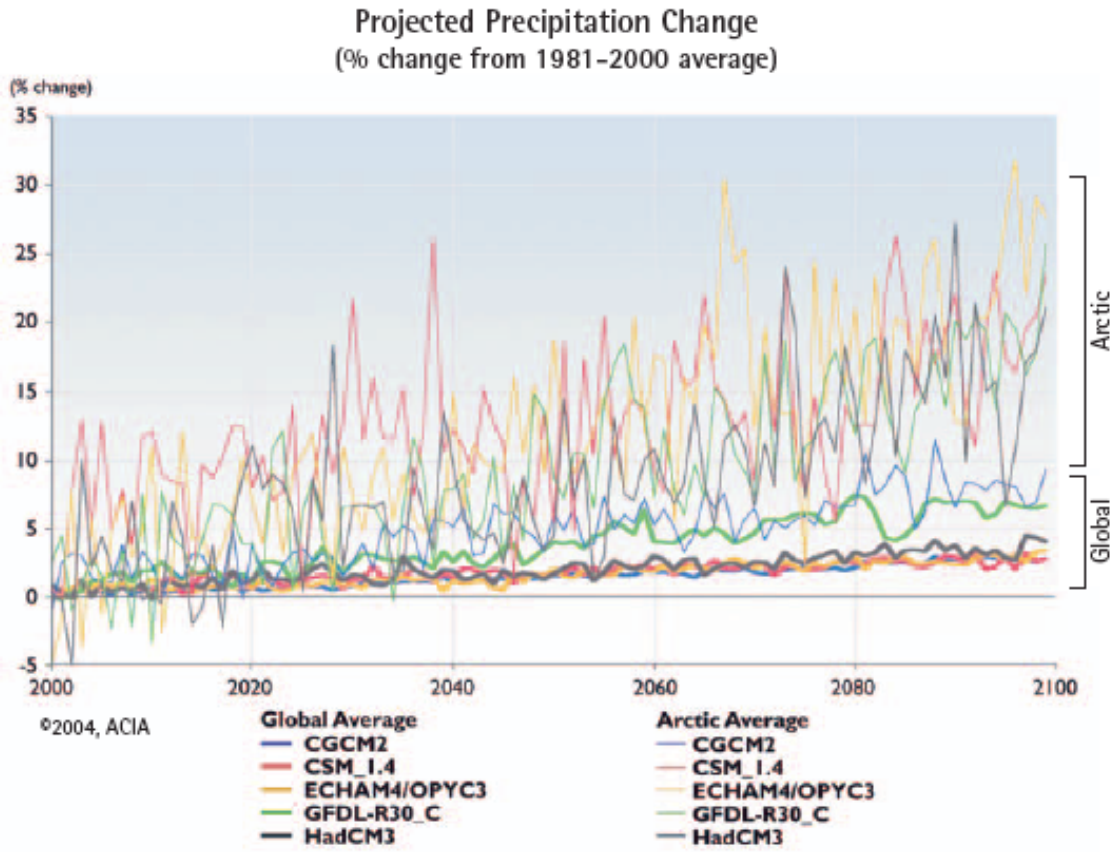
The projected increase in global average temperature could result in global temperatures being higher than they have been in tens of millions of years



Source: IPCC TAR, 2001 and M. Prather

IMPACTS OF A WARMING ARCTIC

1 Arctic climate is now warming rapidly and much larger changes are projected.



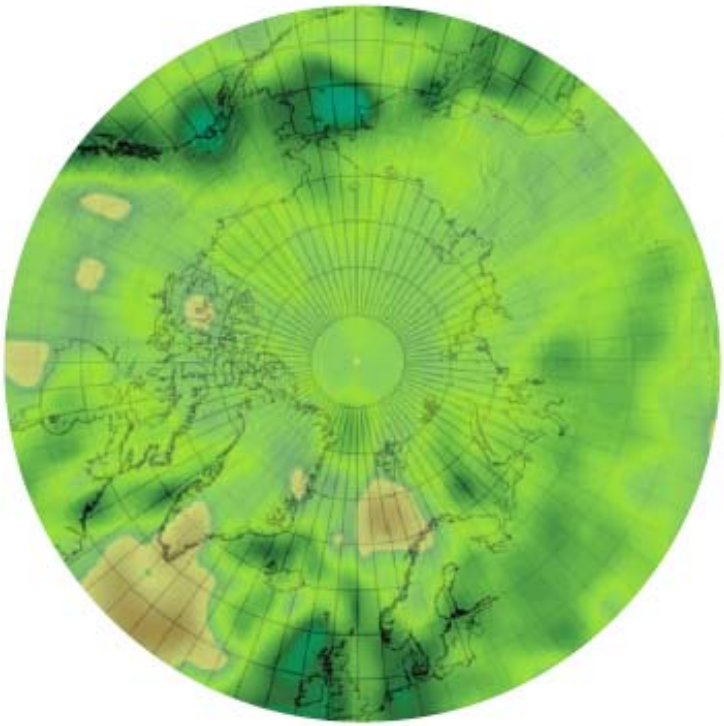
This graph shows percentage changes in average precipitation projected by the five ACIA climate models for the B2 emissions scenario. The heavy lines at the bottom are projected average **global** precipitation changes and the thinner lines above are projected **arctic** precipitation changes. As the results show, the precipitation increases are projected to be much greater in the Arctic than for the world as a whole. It is also apparent that the year-to-year variability is much greater in the Arctic.

IMPACTS OF A WARMING ARCTIC

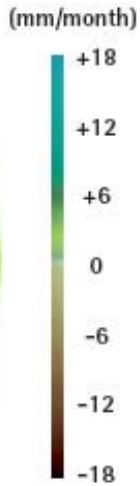
1 Arctic climate is now warming rapidly and much larger changes are projected.

Average of Results from the 5 Models Used by ACIA

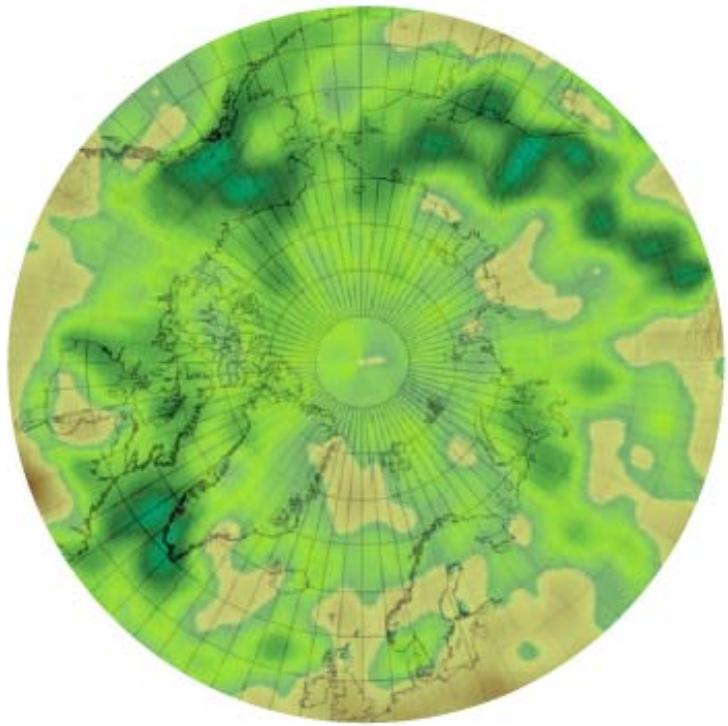
Projected Precipitation Change
from 1980-1999 to 2070-2089 in mm/month (Feb)



©2004, ACIA/ map ©Clifford Grabhorn



Projected Precipitation Change
from 1980-1999 to 2070-2089 in mm/month (Aug)



©2004, ACIA/ map ©Clifford Grabhorn

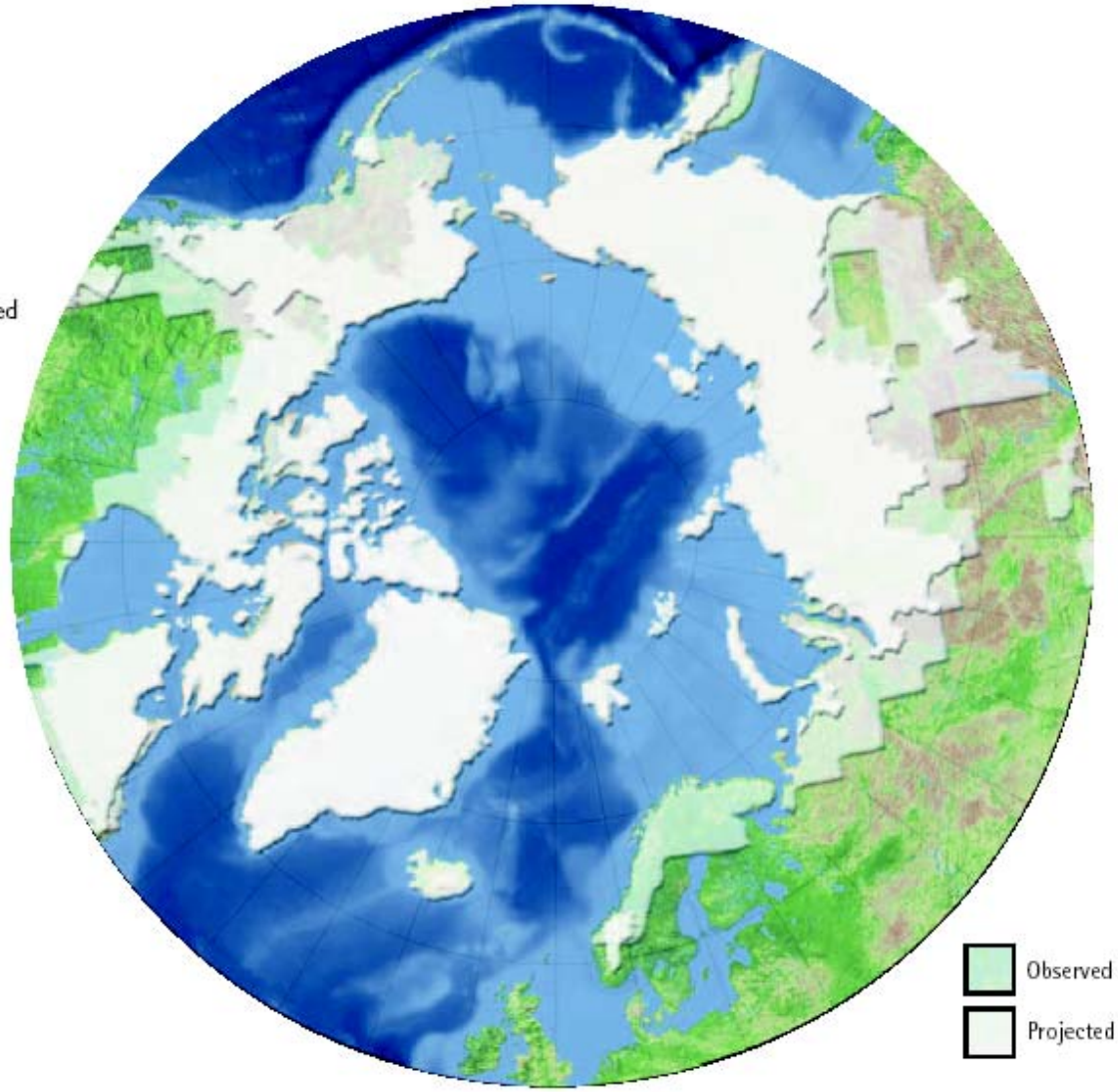
Theses maps show the projected precipitation change in mm per month, calculated by the ACIA climate models. On these maps, dark green indicates that precipitation is projected to increase by about six mm per month from the 1990s to the 2090s.

IMPACTS OF A WARMING ARCTIC

1 Arctic climate is now warming rapidly and much larger changes are projected.

Snow Cover Observed and Projected (May)

May snow cover is projected to decrease substantially throughout the Arctic. The gray area in the figure shows the current extent of May snow cover. The white area is the projected area of May snow cover in the 2070 to 2090 time period based on ACIA model projections. The large-scale pattern of projected snow cover retreat in spring is apparent.



IMPACTS OF A WARMING ARCTIC

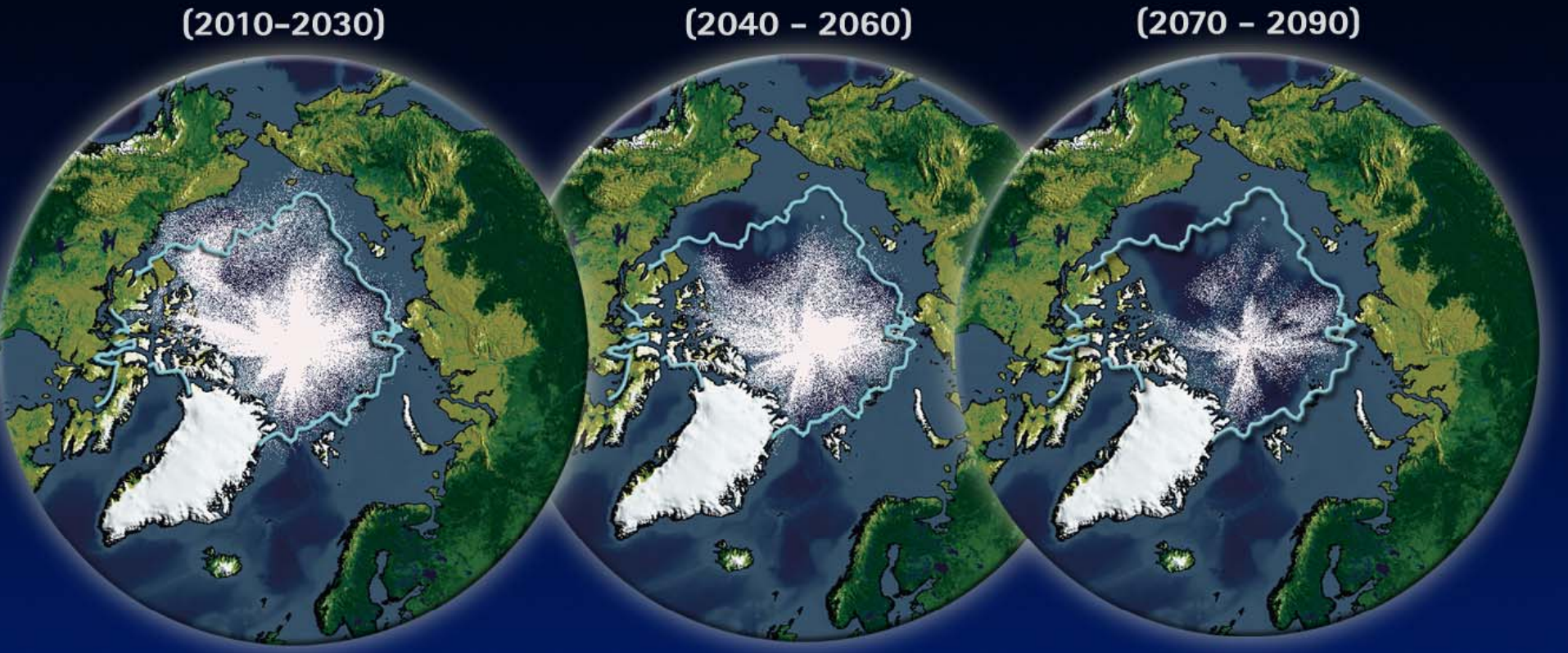
Minimum Projected Sea Ice Extent (2010-2030)

Blue line gives boundary of minimum extent at present.

White dots give approximate indication of concentration of sea ice

IMPACTS OF A WARMING ARCTIC

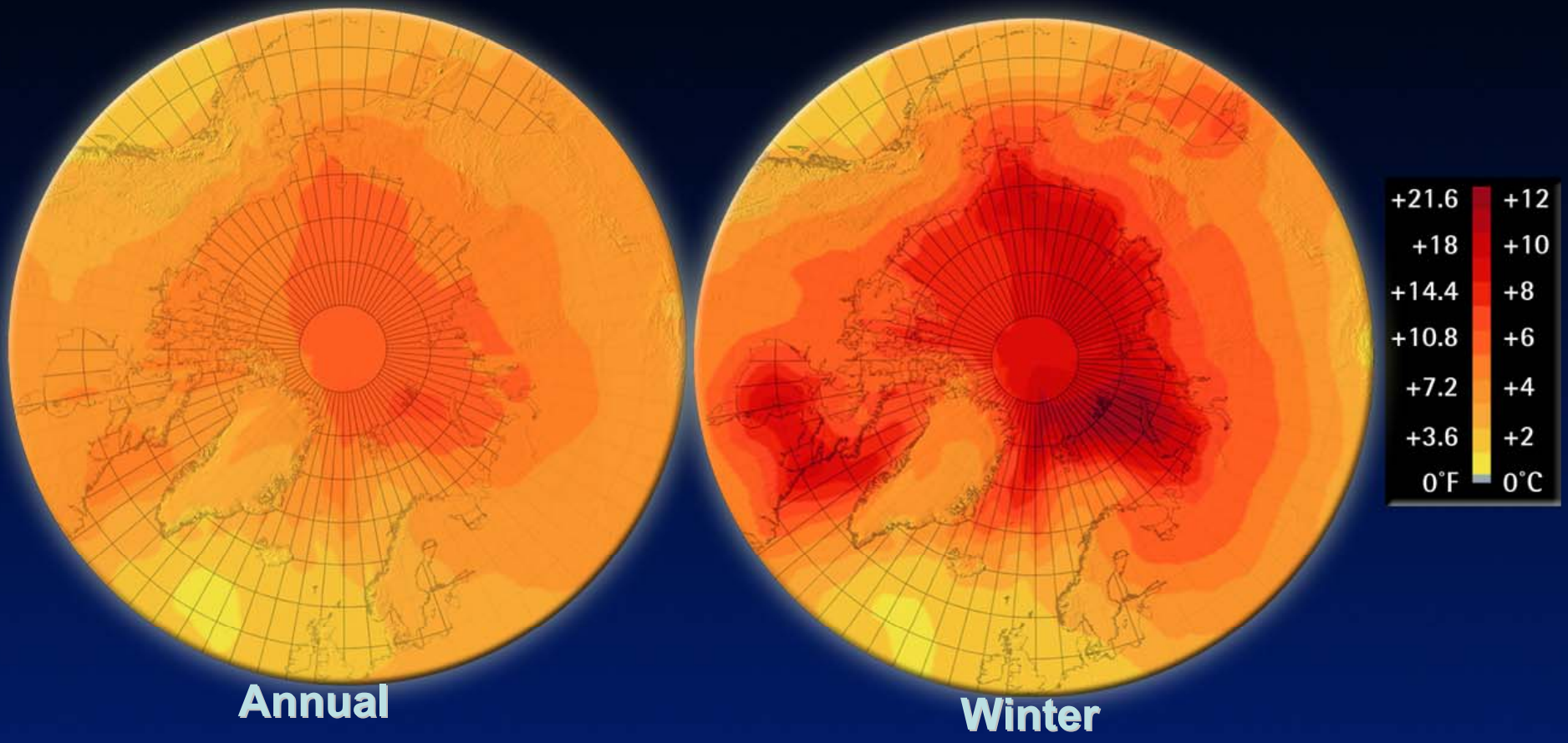
1 Arctic climate is now warming rapidly and much larger changes are projected.



IMPACTS OF A WARMING ARCTIC

2 Arctic warming and its consequences have worldwide implications.

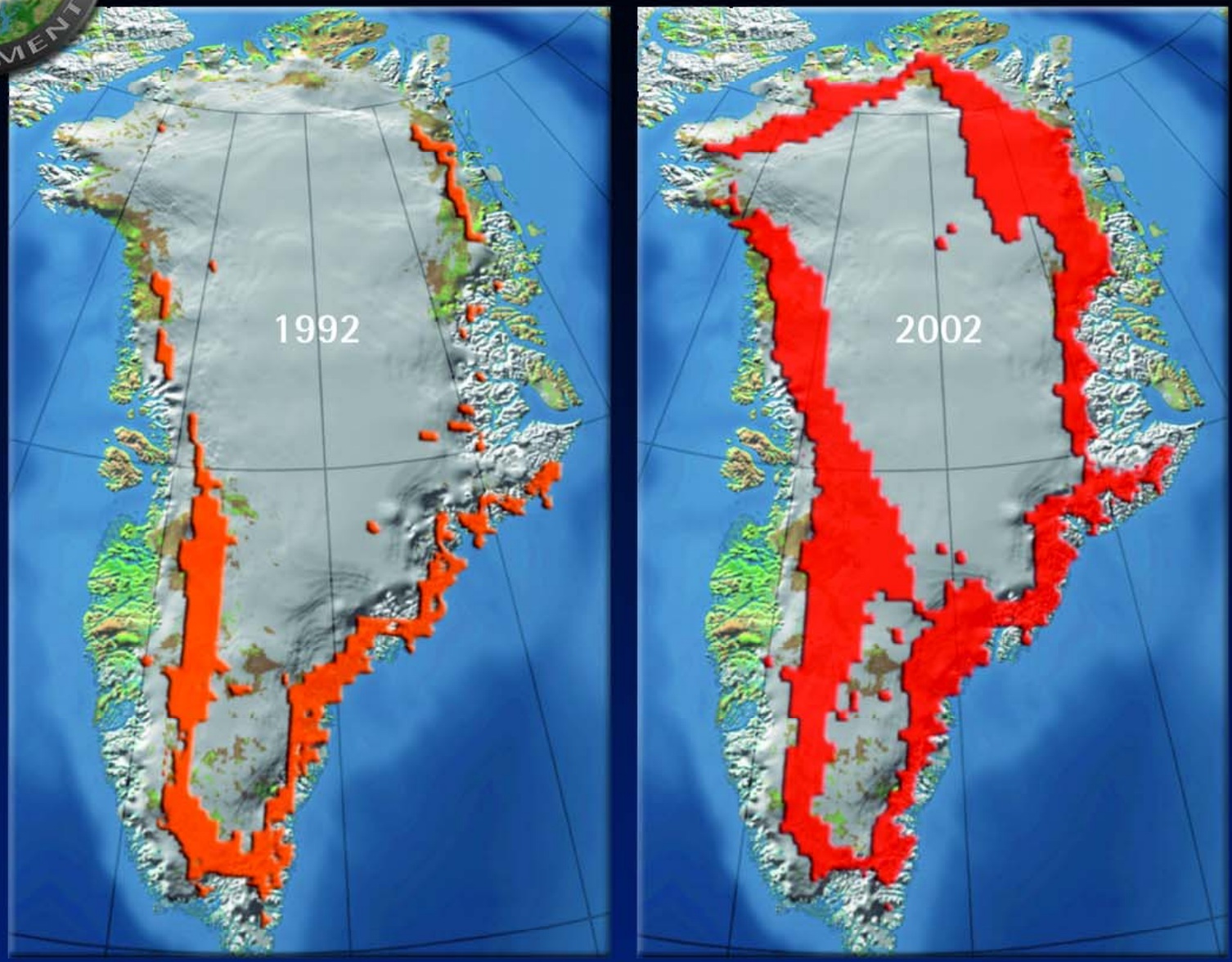
Amplified warming in the Arctic contributes to warming in the middle latitudes



Average result for end of 21st Century from the 5 models used by ACIA

IMPACTS OF A WARMING ARCTIC

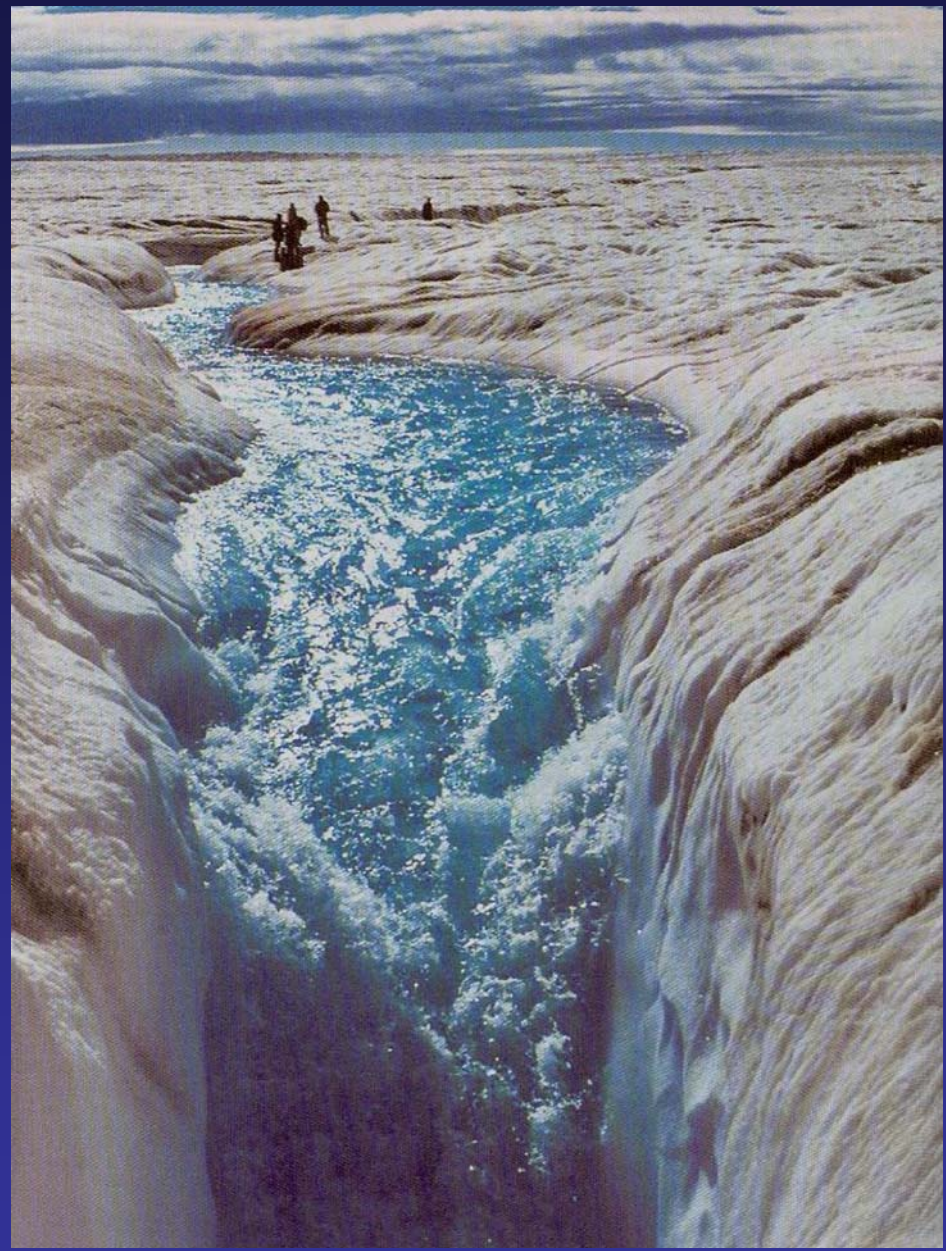
Greenland Ice Sheet Melt Extent



The Greenland Ice Sheet Dominates Land Ice in the Arctic

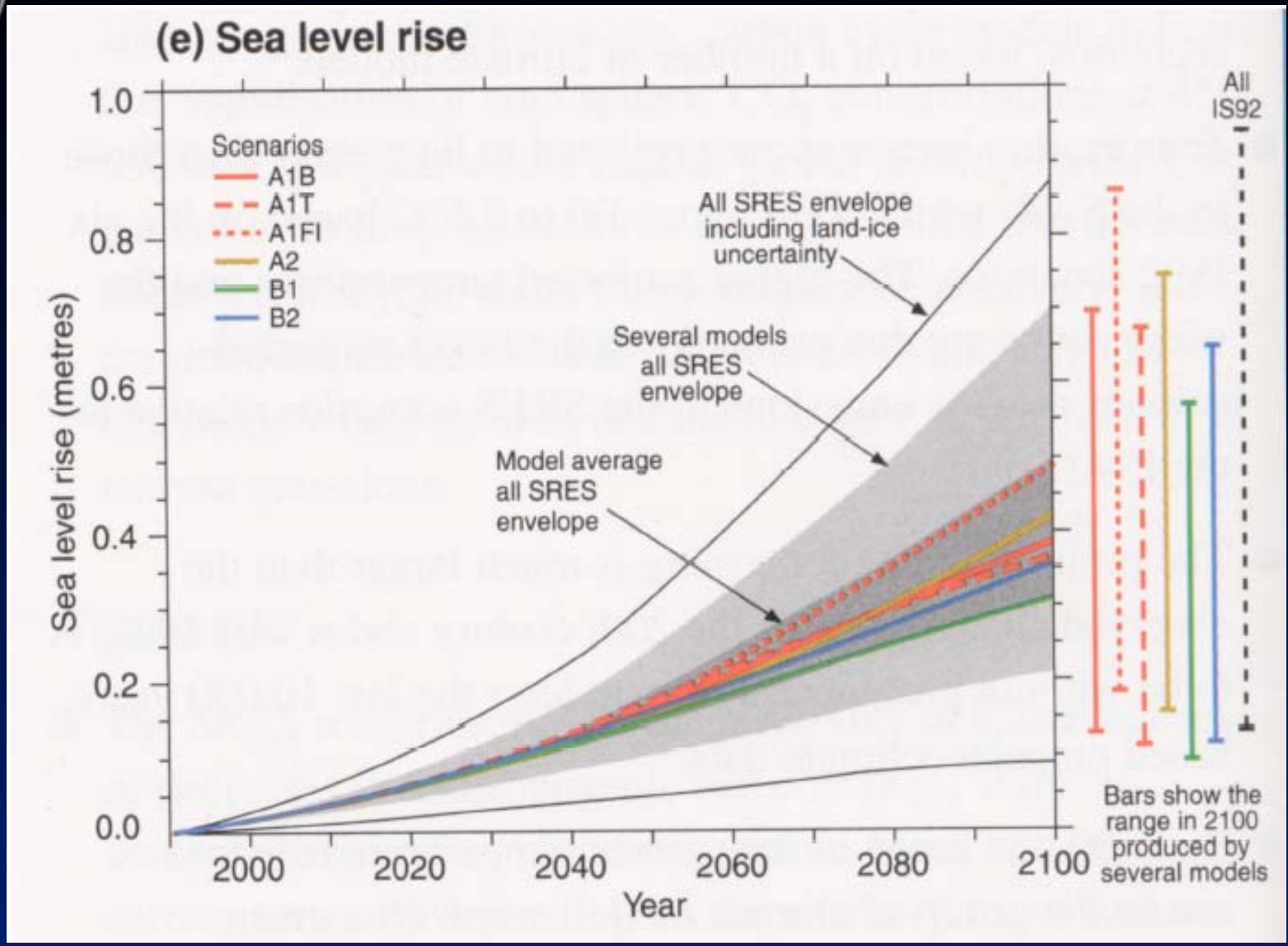
Over the past two decades, the melt area on the Greenland ice sheet has increased on average by about 0.7%/year (or about 16% from 1979 to 2002).

There is preliminary paleoclimatic evidence suggesting the Eemian sea level rise of a few meters occurred over a few centuries with rapid melting of about half of the Greenland ice Sheet.



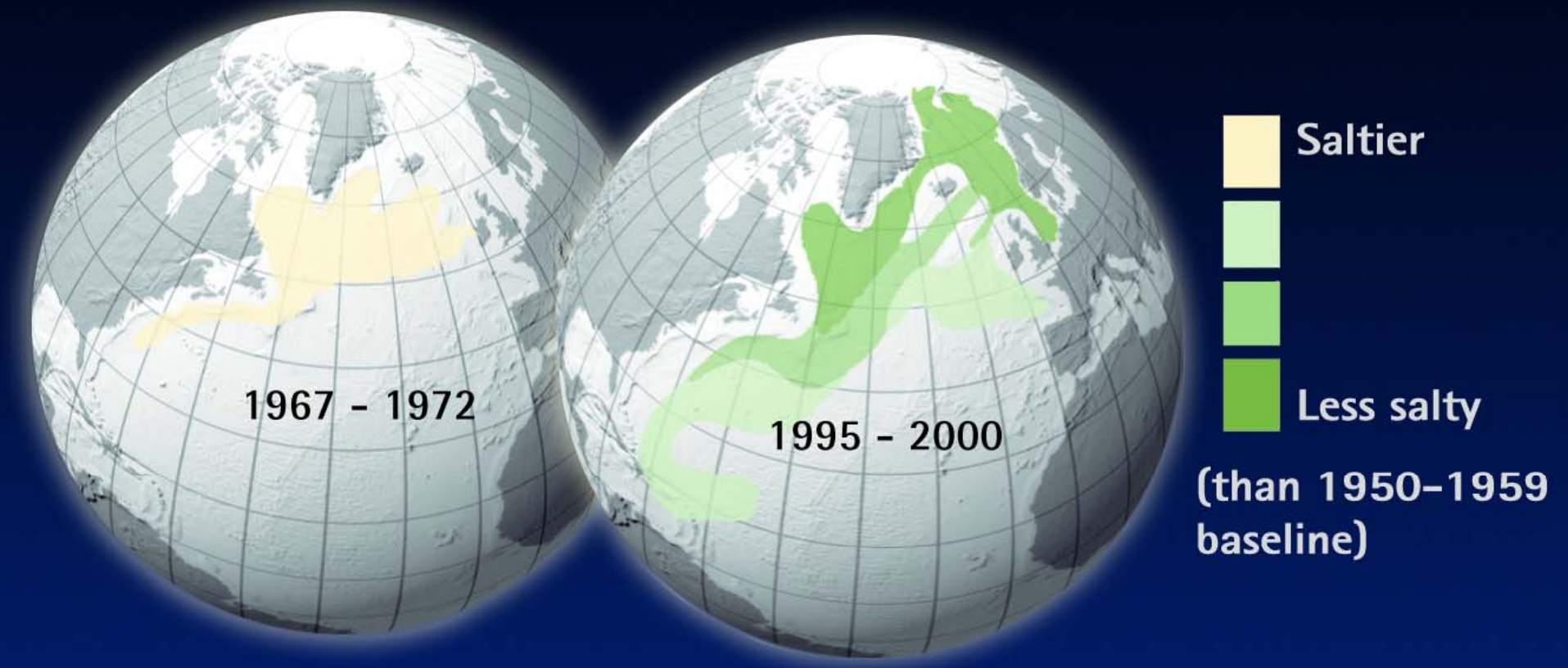
Source: Business Week Aug. 2004

IMPACTS OF A WARMING ARCTIC



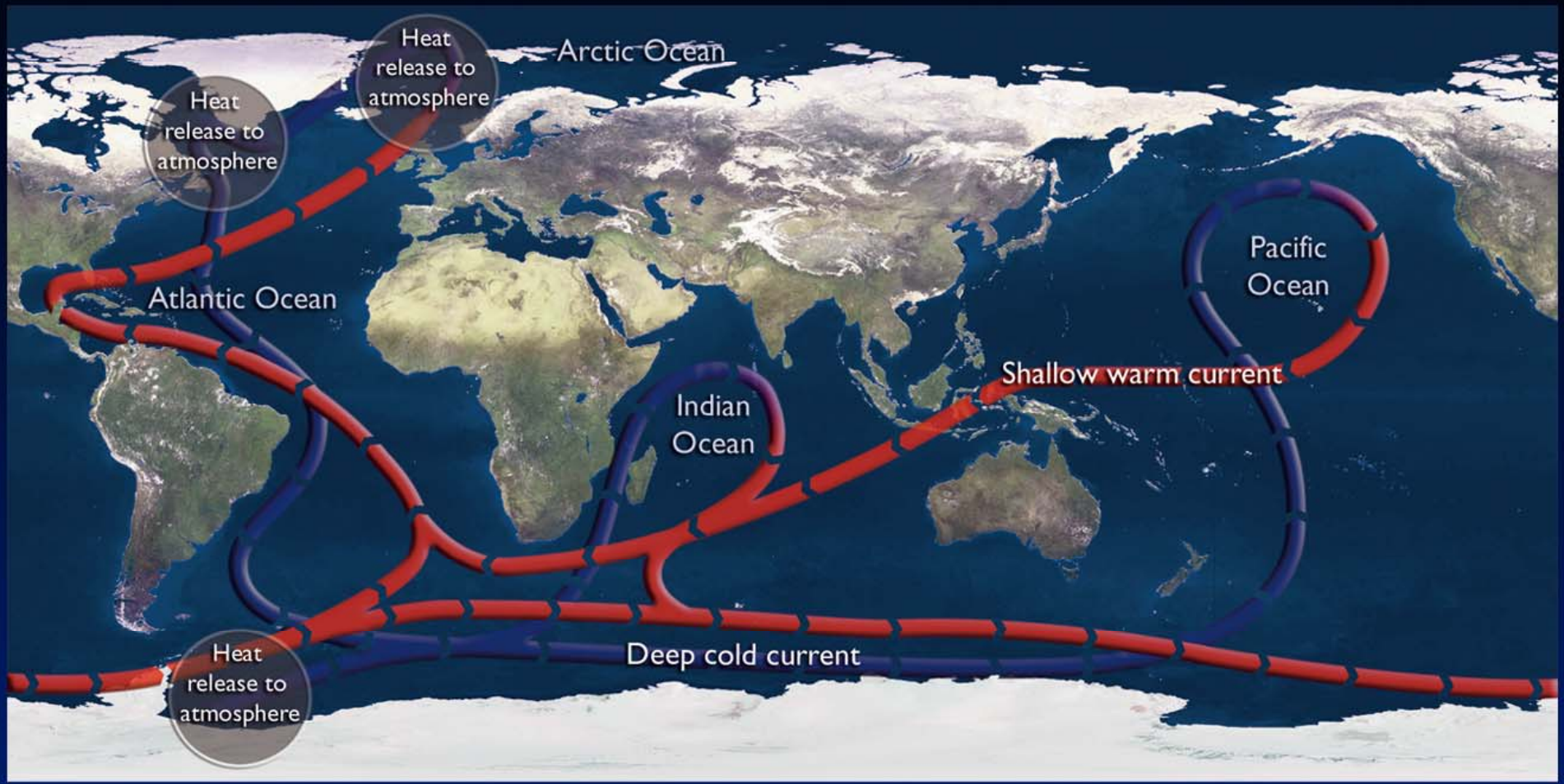
IMPACTS OF A WARMING ARCTIC

Melting glacial ice and increased river runoff may be freshening the North Atlantic



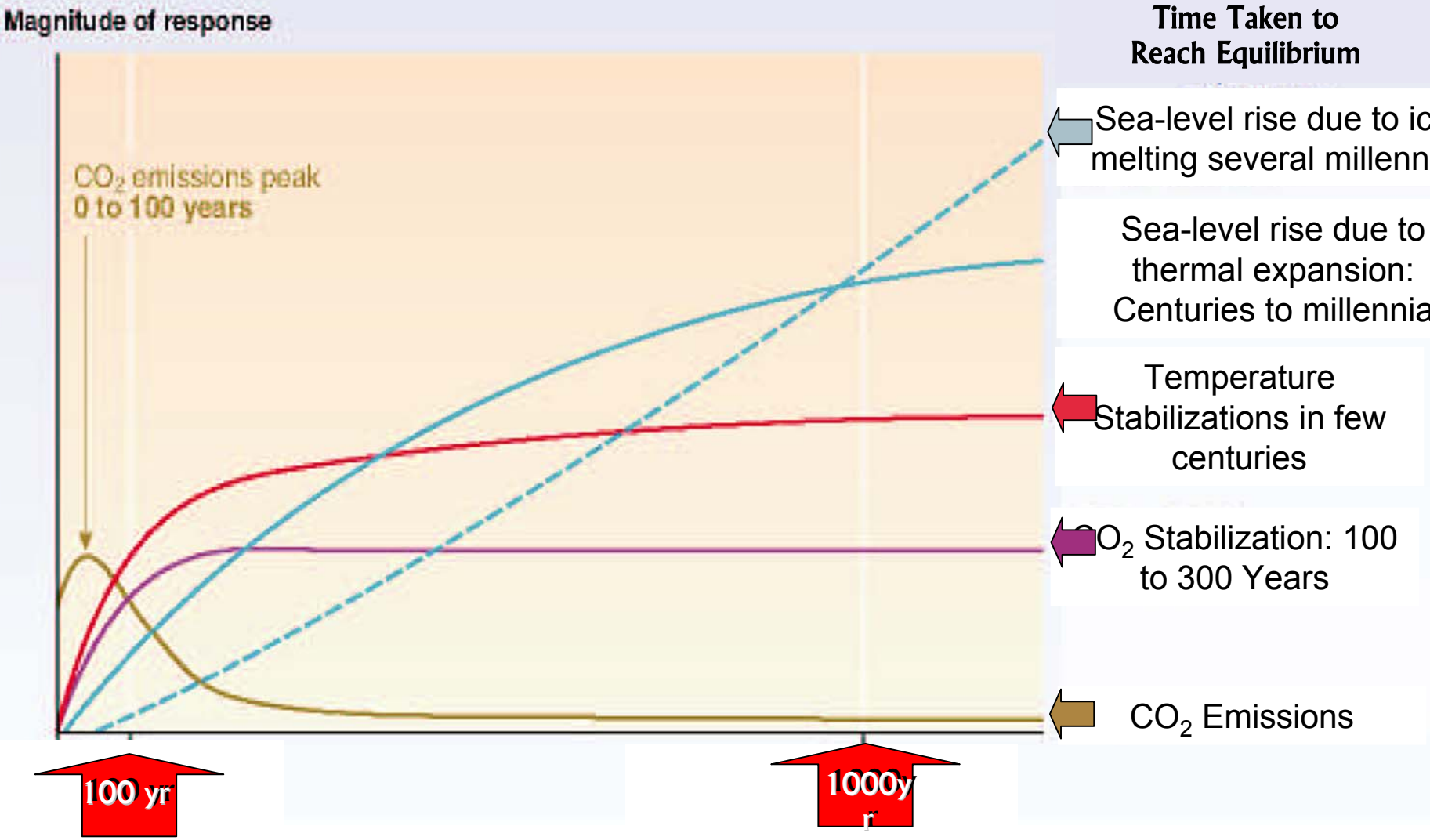
IMPACTS OF A WARMING ARCTIC

Freshening of the North Atlantic could slow the global Thermohaline Circulation



Conversely, Kerry Emanuel argues an increase in the number and intensity of tropical cyclones could alter ocean mixing in the tropics and accelerate the THC

The CO_2 Concentration, Temperature, and Sea Level Continue to Rise Long after Emissions are Reduced

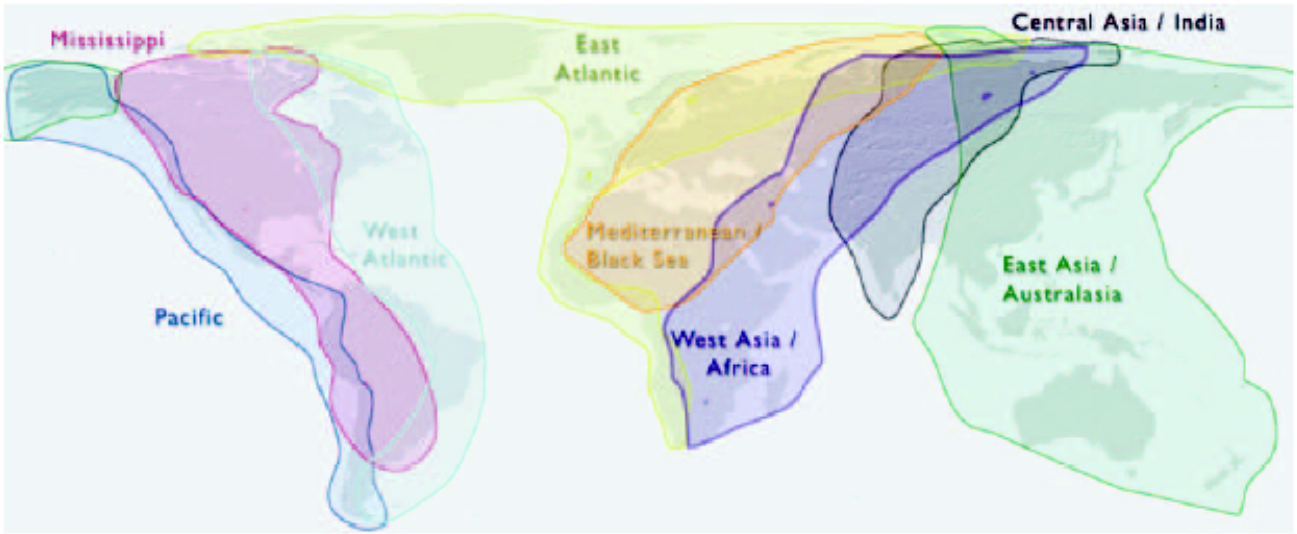


IMPACTS OF A WARMING ARCTIC

2 Arctic warming and its consequences have worldwide implications.

Climatic and ecological changes in the Arctic will also affect the habitats of birds, fish, and marine mammals that breed and grow in the Arctic during summer

Migratory Bird Flyways

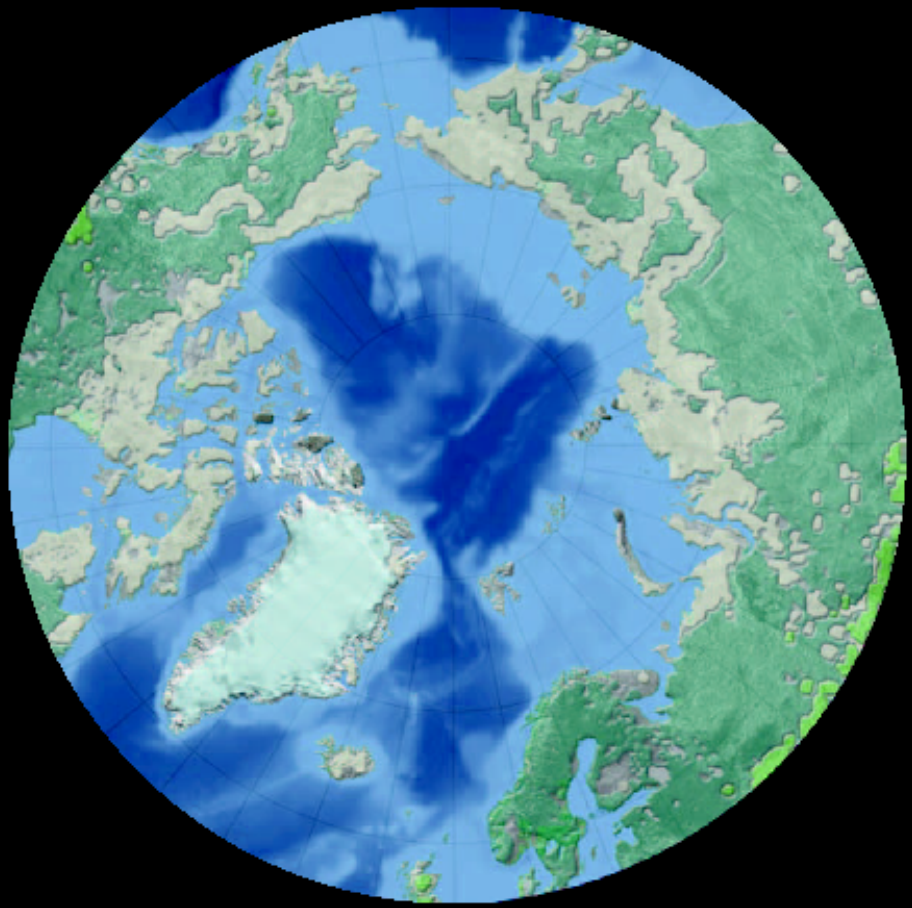


Several hundred million birds migrate to the Arctic each summer and their success in the Arctic determines their populations at lower latitudes. Important breeding and nesting areas are projected to decrease sharply as treeline advances northward, encroaching on tundra, and because the timing of bird arrival in the Arctic might no longer coincide with the availability of their insect food sources. At the same time, sea-level rise will erode tundra extent from the north in many areas, further shrinking important habitat for many living things. A number of bird species, including several globally endangered seabird species, are projected to lose more than 50% of their breeding area during this century.

IMPACTS OF A WARMING ARCTIC

3 Arctic vegetation zones are very likely to shift, causing wide-ranging impacts.

Current Arctic Vegetation



- Ice
- Polar Desert / Semi-desert
- Tundra
- Boreal Forest
- Temperate Forest

Present day natural vegetation of the Arctic and neighboring regions from floristic surveys.

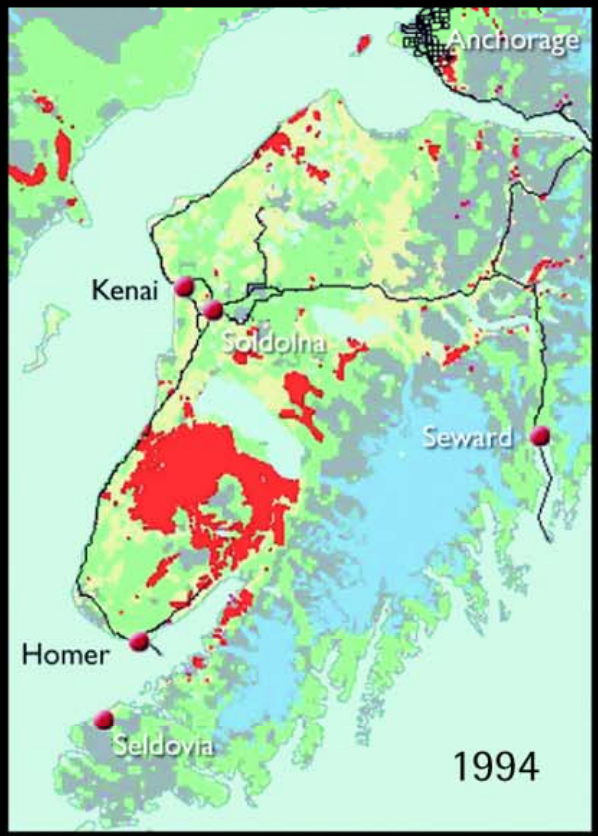
Projected Vegetation, 2090-2100

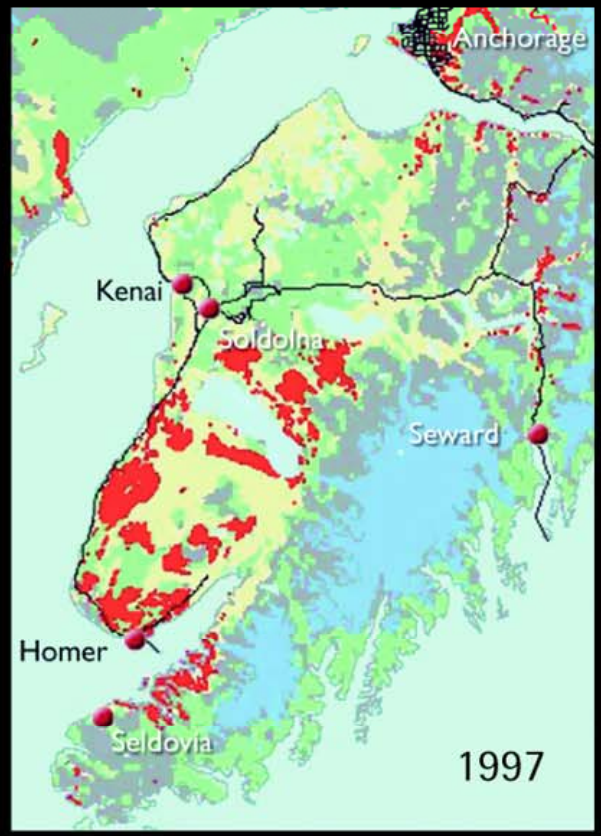
- Ice
- Polar Desert / Semi-desert
- Tundra
- Boreal Forest
- Temperate Forest
- Grassland

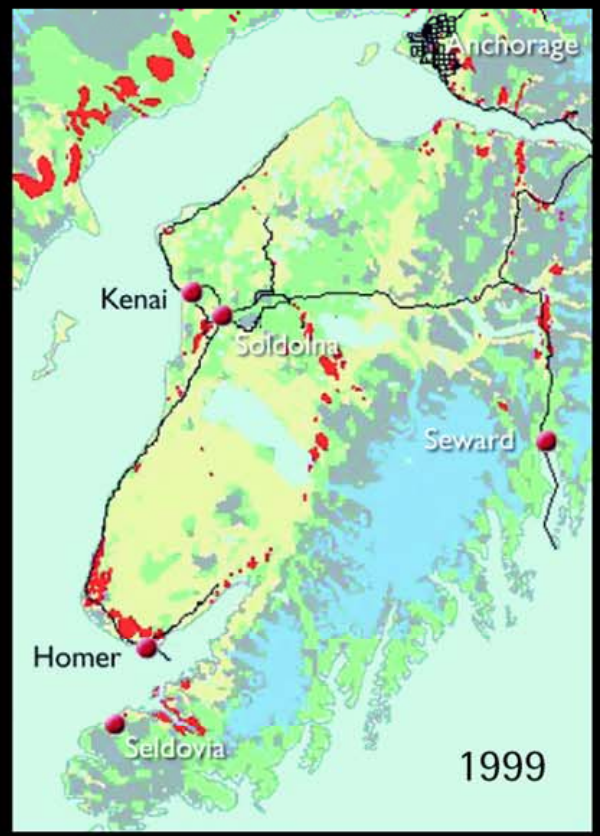
Projected potential vegetation for 2090-2100, simulated by the LPJ Dynamic Vegetation Model driven by the Hadley2 climate model.

IMPACTS OF A WARMING ARCTIC

Spruce Beetle Activity Kenai Peninsula 1994–1999





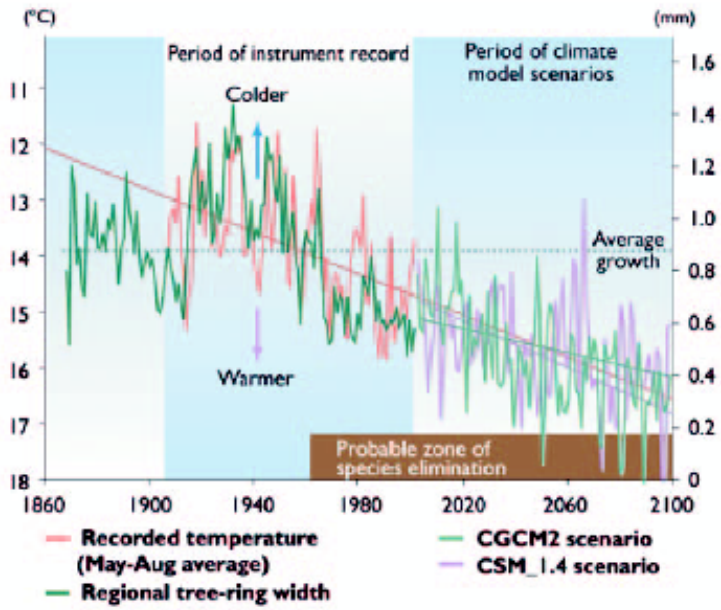


- Tree Mortality due to SBB
- Past Tree Mortality due to SBB
- Forest
- Non-Forest
- Glacier

IMPACTS OF A WARMING ARCTIC

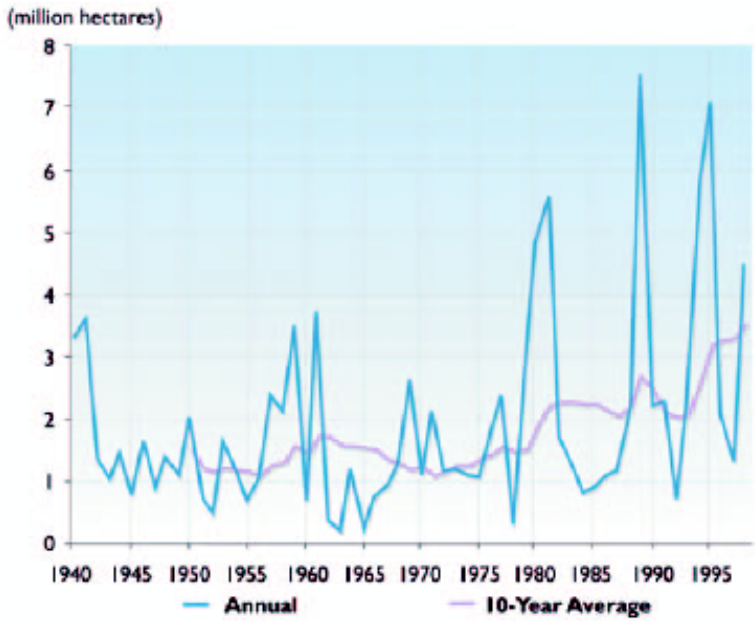
3 Arctic vegetation zones are very likely to shift, causing wide-ranging impacts.

Black Spruce Response to Warming



The graph shows the relationship of summer temperatures at Fairbanks, Alaska and relative growth of black spruce, historically and for two future warming scenarios. Average summer temperature is an excellent predictor of black spruce growth, with warm years resulting in strongly reduced growth. By 2100, temperatures projected by both scenarios would not allow the species to survive.

Boreal Forest Burned in North America

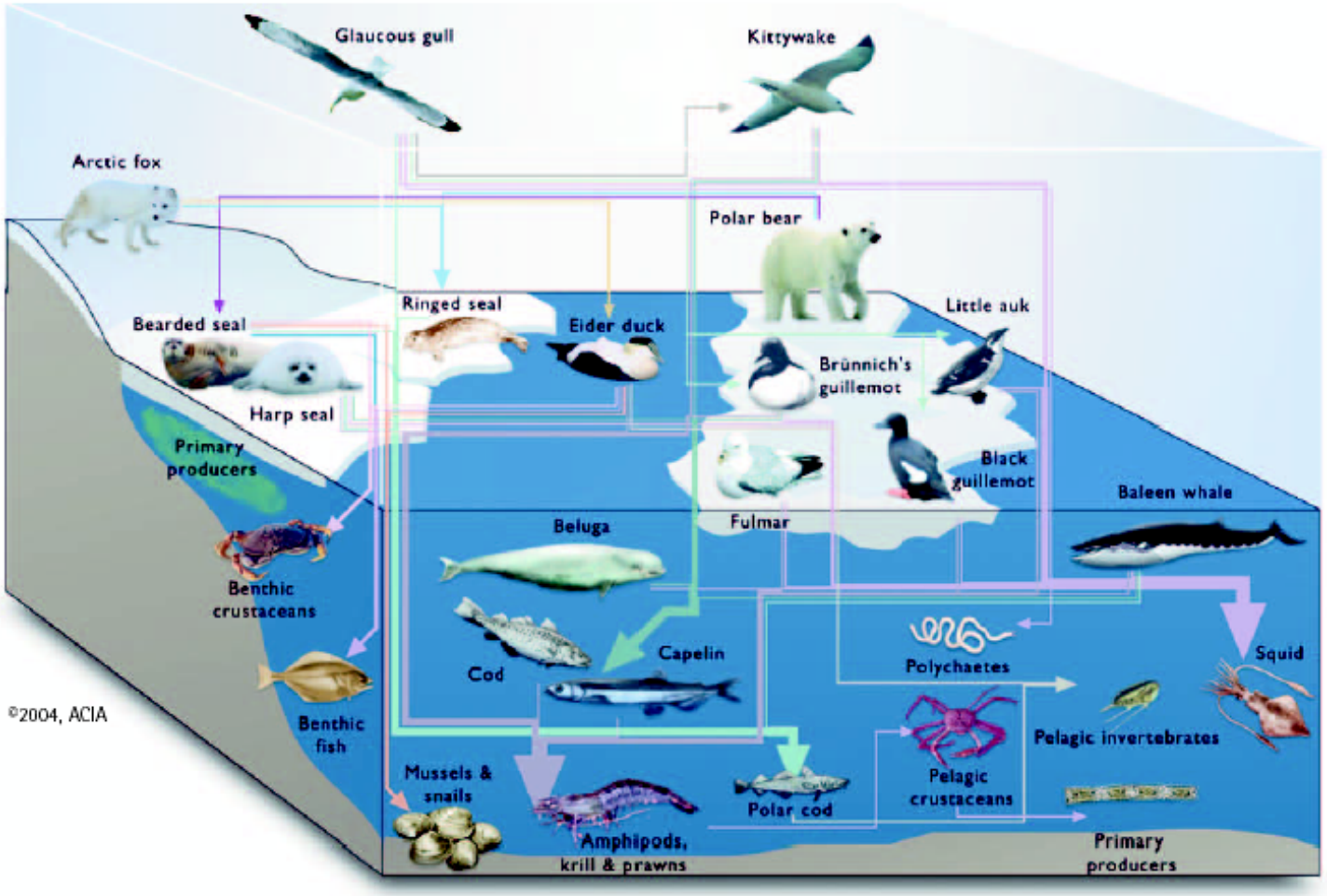


The graph shows the area of North American boreal forest that burned each year, in millions of hectares. The average area burned has more than doubled since 1970, coinciding with climatic warming in the region.

IMPACTS OF A WARMING ARCTIC

4 Animal species' diversity, ranges, and distrubution will change.

Arctic Marine Food Web

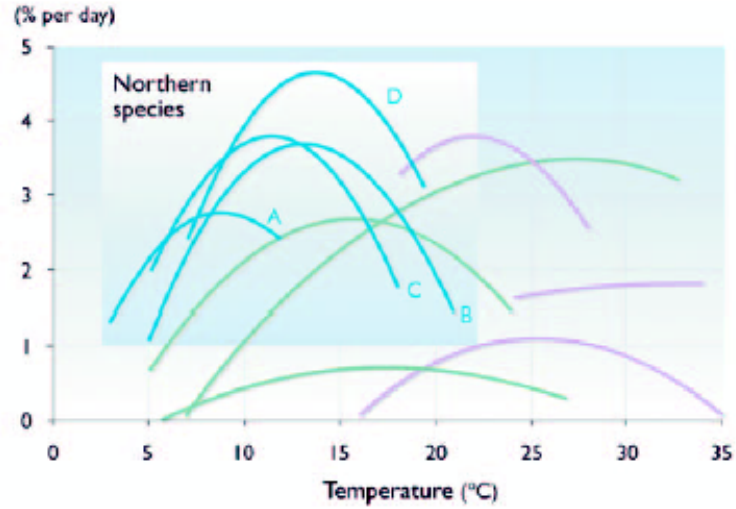


Research in the Beaufort Sea suggests that ice algae at the base of the marine food web may have already been profoundly affected by warming over the last few decades.

IMPACTS OF A WARMING ARCTIC

4 Animal species' diversity, ranges, and distrubution will change.

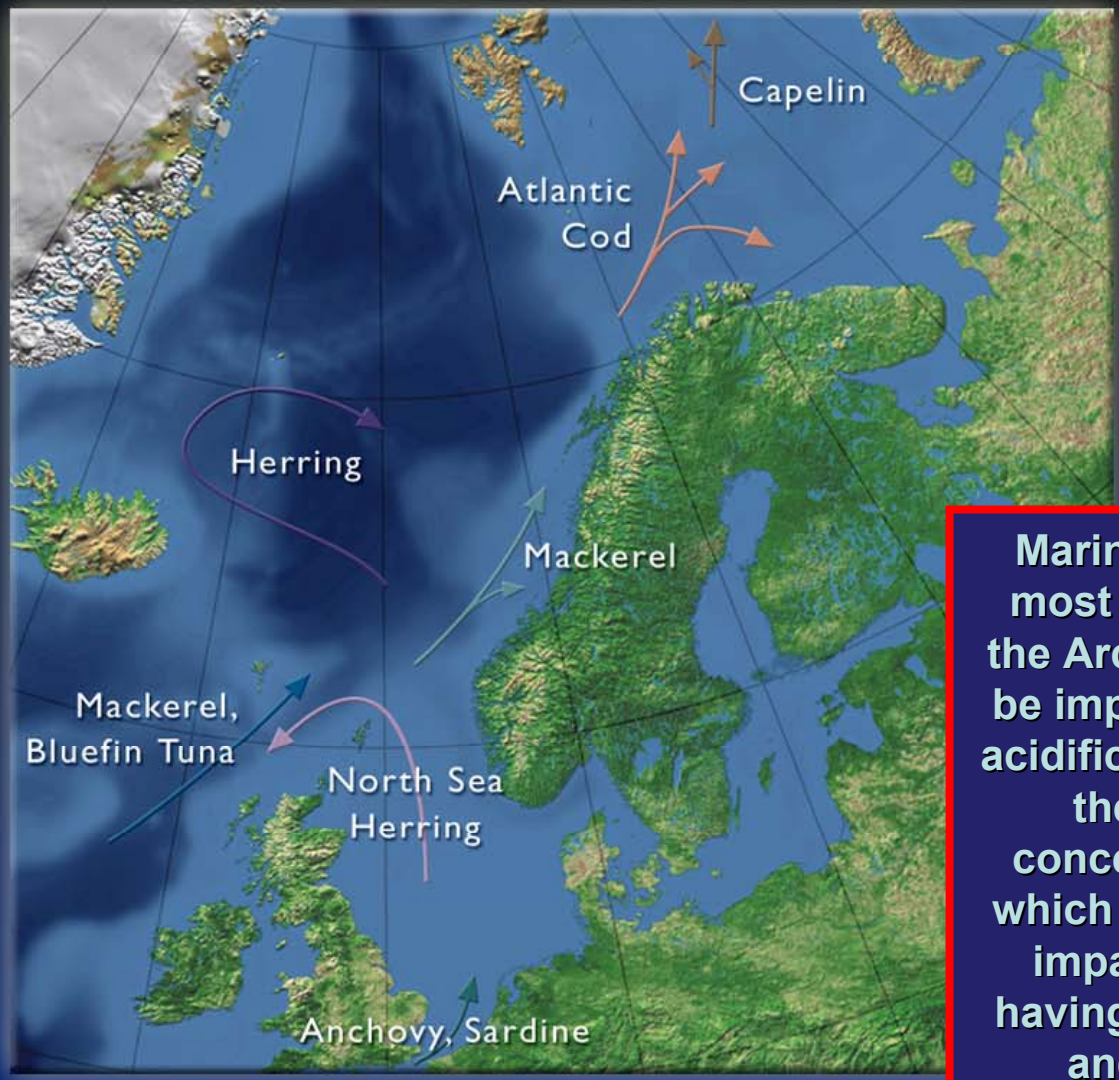
Fish Growth Rate and Temperature



These growth curves (in percent per day) for various fish species illustrate that growth typically increases with rising temperature up to a certain point and then declines as temperature continues to rise. Northern species (A. Arctic char, B. lake cisco, C. lake trout, and D. brook trout - all in blue) are grouped toward the lower temperatures on the left, and have a more peaked curve, indicating only narrow and typically low temperature ranges over which optimal growth is achieved. This suggests that their ability to adapt to a warming climate is likely to be quite limited. The unlabeled growth curves are for various lower latitude species.

IMPACTS OF A WARMING ARCTIC

Possible Changes in Fish Distribution



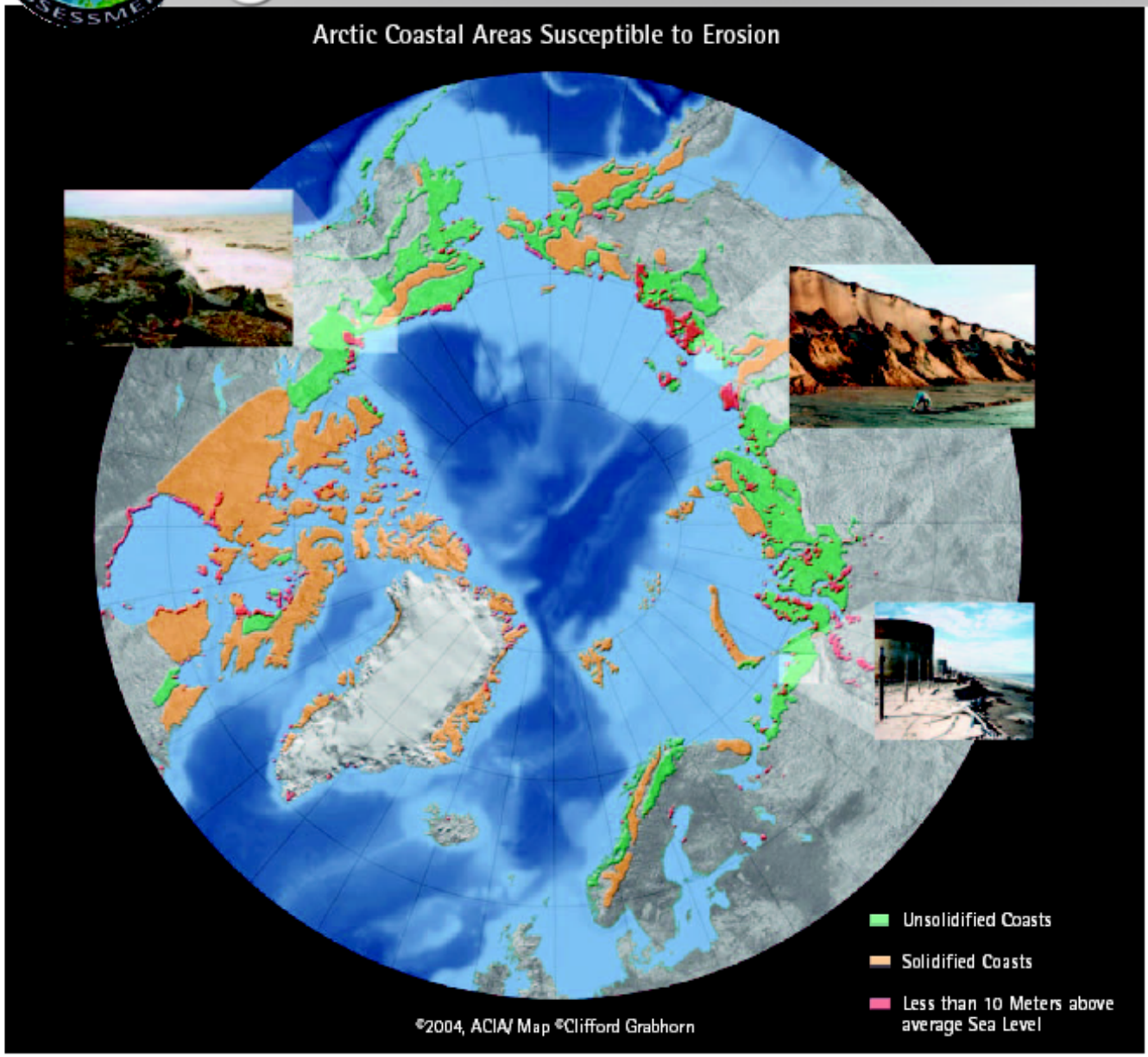
Marine food chains, most immediately in the Arctic, are likely to be impacted by ocean acidification caused by the rising CO_2 concentration itself, which are expected to impact organisms having calcium shells and structures

Hudson Bay

An early indicator of the changing climate

IMPACTS OF A WARMING ARCTIC

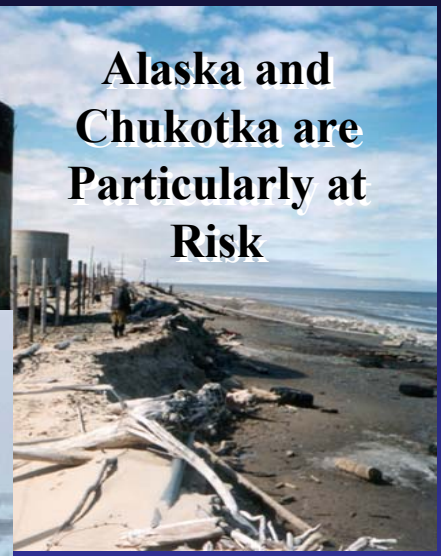
5 Many coastal communities and facilities face increasing exposure to storms.



Sea ice retreat allows storm waves to grow in size and increase coastal damage

The vulnerability of a coastline to erosion depends on sea level, the properties of the coastal materials, and environmental factors such as tectonic forces and wave action. Unsolidified arctic coasts (in green) containing variable amounts of ground ice, are more susceptible to erosion than solidified coasts (in orange). Unstable coastal environments are shown in the inset photographs from the Pechora, Laptev, and Beaufort Sea coasts. Tectonic forces create uplift in some places, including the Canadian Archipelago, Greenland, and Norway, and subsidence in others, such as along the Beaufort Sea and Siberian coasts. Areas (in red) in which elevation is less than 10 meters above average sea level are particularly vulnerable.

Many coastal communities and facilities face increasing exposure to storms.

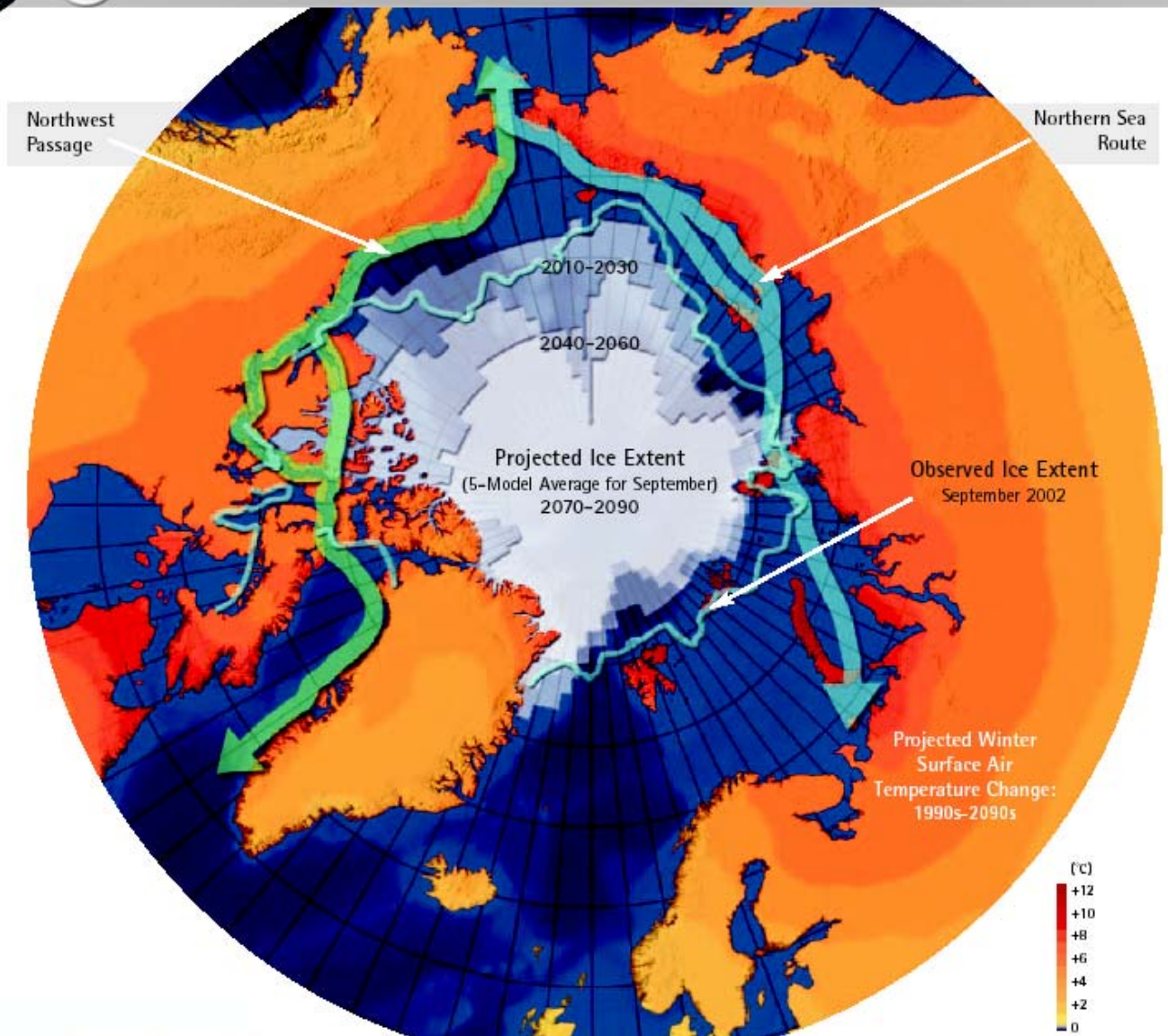


Alaska and Chukotka are Particularly at Risk

- **Severe coastal erosion will be a growing problem as rising sea levels and a reduction in sea ice allow higher waves and storm surges to reach shore.**
  - Along some Arctic coastlines, thawing permafrost weakens coastal lands, adding to their vulnerability.
  - The risk of flooding in coastal wetlands is projected to increase, with impacts on society and natural ecosystems.
  - In some cases, communities and industrial facilities in coastal zones are already threatened or being forced to relocate, while others face increasing risks and costs.

IMPACTS OF A WARMING ARCTIC

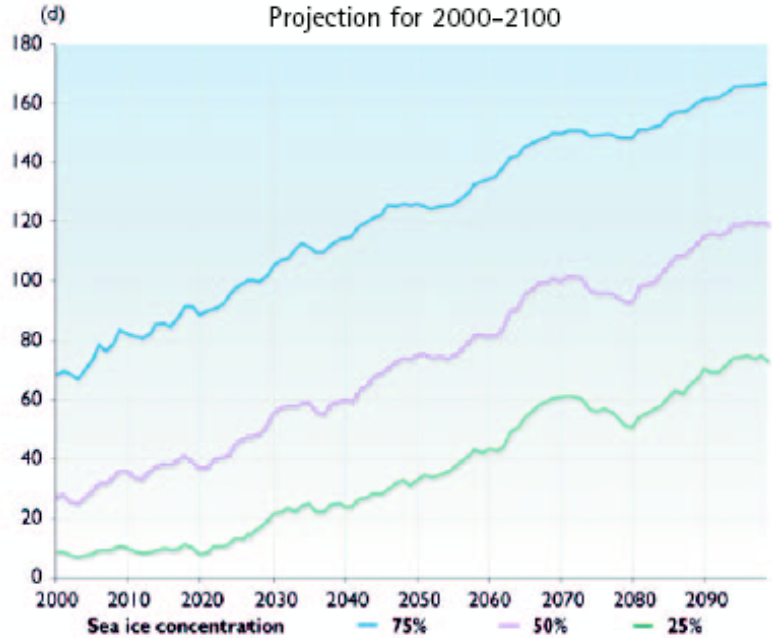
6 Reduced sea ice is very likely to increase marine transport and access to resources.



IMPACTS OF A WARMING ARCTIC

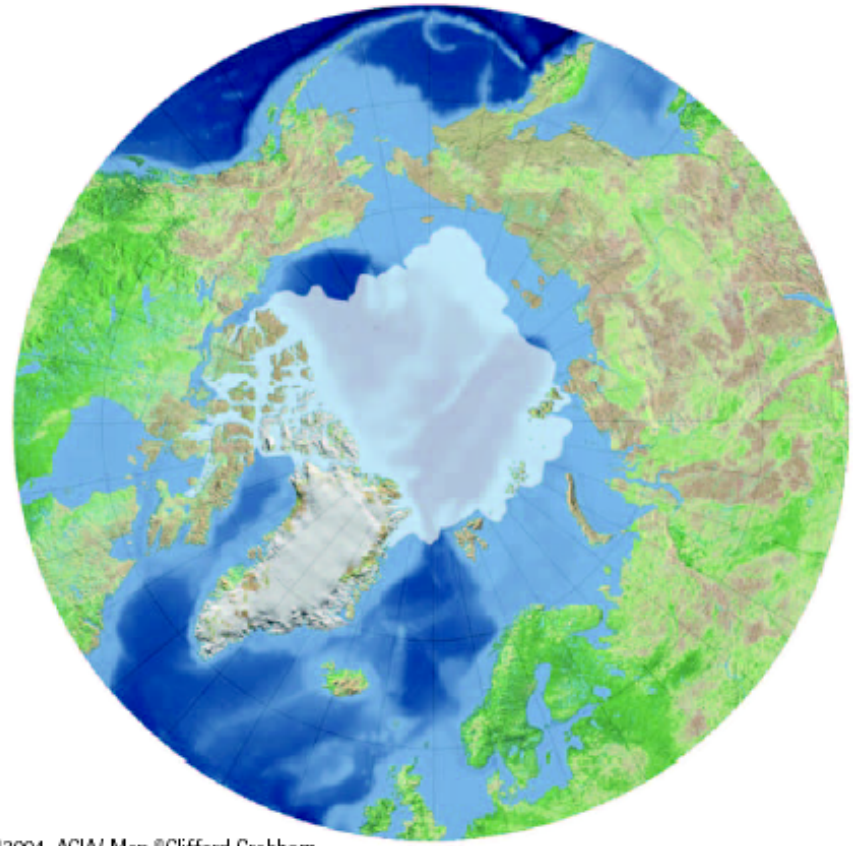
6 Reduced sea ice is very likely to increase marine transport and access to resources.

Northern Sea Route Navigation Season
Projection for 2000–2100



The graph shows the projected increase in days of the navigation season through the Northern Sea Route as an average of five ACIA model projections.

Observed Sea Ice Cover
September 16, 2002

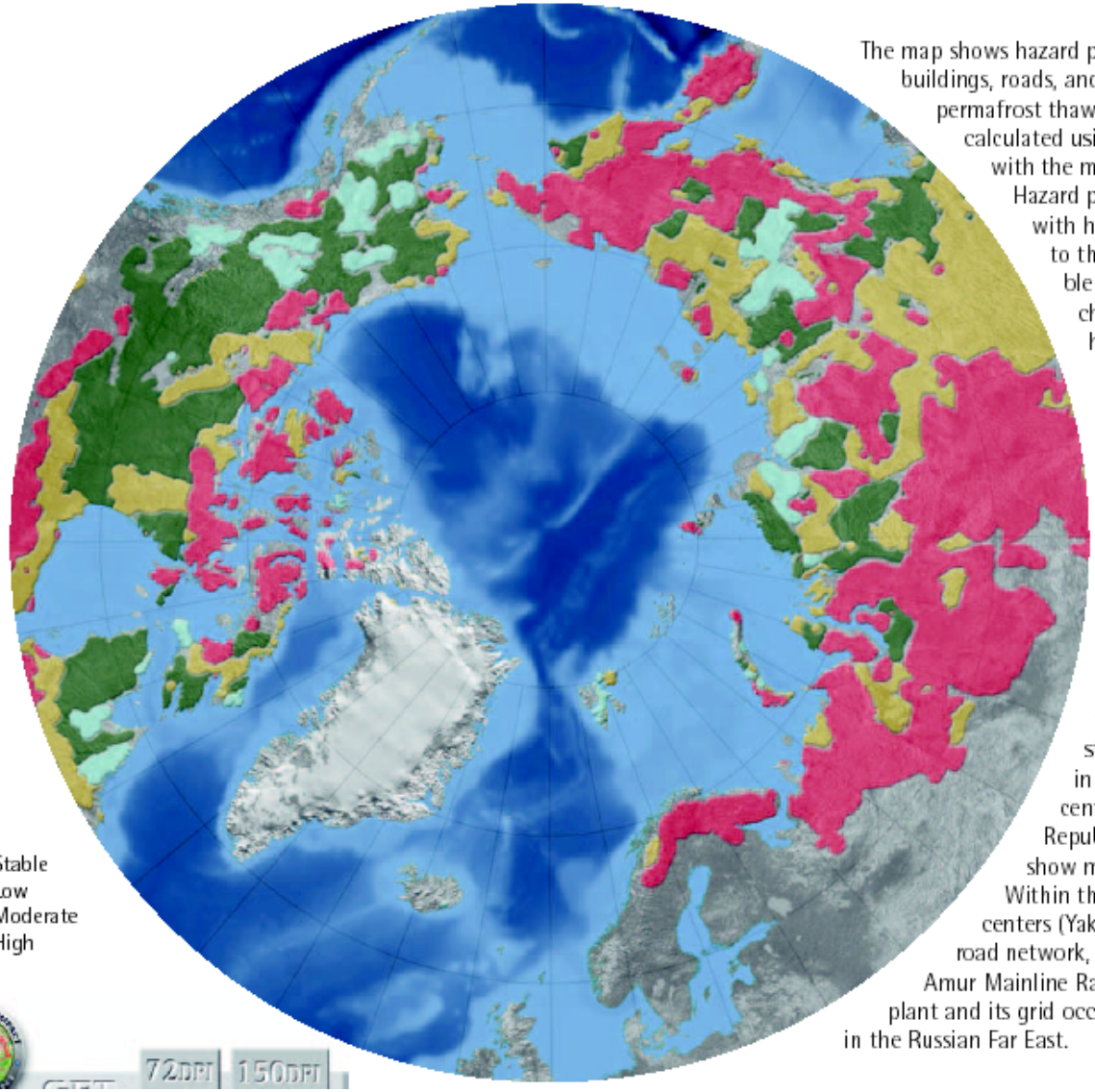


The satellite image of sea-ice extent for September 16, 2002 provides a good illustration of marine access around the Arctic Basin. Such low summer minimum ice extents create large areas of open water along much of the length of the NSR. The further north the ice edge retreats, the further north ships can sail in open water on trans-Arctic voyages, thereby avoiding the shallow shelf waters and narrow straits of the Russian Arctic.

IMPACTS OF A WARMING ARCTIC

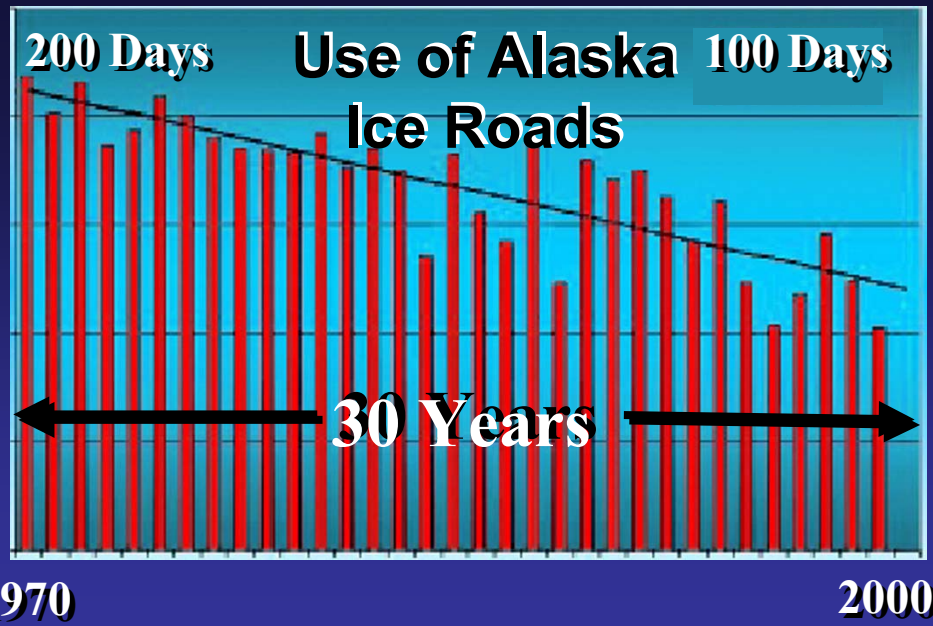
7 Thawing ground will disrupt transportation, buildings, and other infrastructure.

Infrastructure at Risk by 2050 Due to Permafrost Thaw



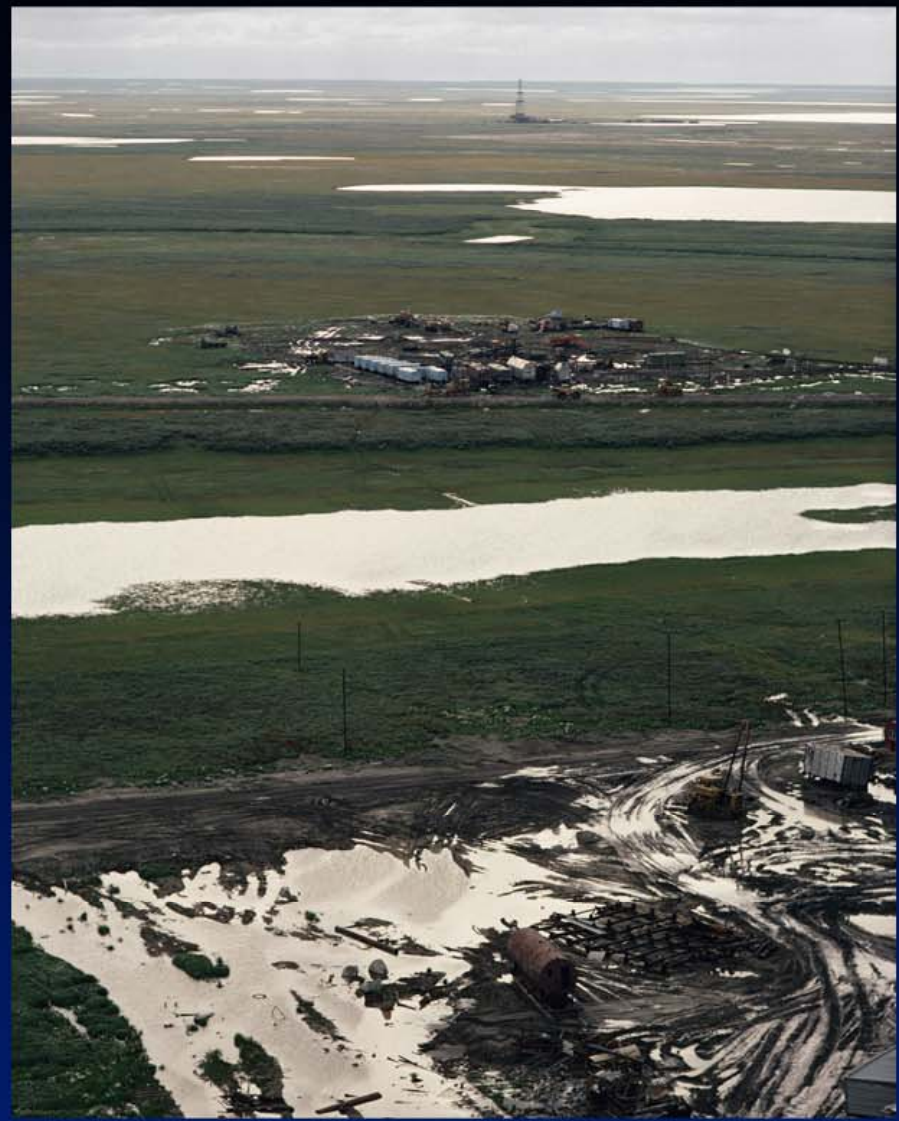
The map shows hazard potential by risk level for buildings, roads, and other infrastructure due to permafrost thaw by the middle of this century, calculated using the Hadley climate model with the moderate B2 emissions scenario. Hazard potential is partitioned into areas with high, moderate, and low susceptibility to thaw-induced settlement. Areas of stable permafrost, which are not likely to change, are also shown. A zone in the high and moderate risk category extends discontinuously around the Arctic Ocean, indicating high potential for coastal erosion. Also within these bands are population centers (Barrow, Inuvik) and river terminals on the Arctic coast of Russia (Salekhard, Igarka, Dudinka, Tiksi). Transportation and pipeline corridors traverse areas of high hazard potential in northwestern North America. The area containing the Nadym-Pur-Taz natural gas production complex and associated infrastructure in northwest Siberia also falls in the high-risk category. Large parts of central Siberia, particularly the Sakha Republic (Yakutia), and the Russian Far East show moderate or high hazard potential. Within these areas are several large population centers (Yakutsk, Noril'sk, Vorkuta), an extensive road network, and the Trans-Siberian and Baikal-Amur Mainline Railroads. The Bilibino nuclear power plant and its grid occupy an area of high hazard potential in the Russian Far East.

Thawing ground will disrupt transportation, buildings, and other infrastructure.



- Transportation and industry on land, including oil and gas extraction and forestry, will increasingly be disrupted by the shortening of the periods during which ice roads and tundra are frozen sufficiently to permit travel.
- As frozen ground thaws, many existing buildings, roads, pipelines, airports, and industrial facilities are likely to be destabilized, requiring substantial rebuilding, maintenance, and investment.

IMPACTS OF A WARMING ARCTIC



IMPACTS OF A WARMING ARCTIC

8. Indigenous communities are facing major economic and cultural impacts.

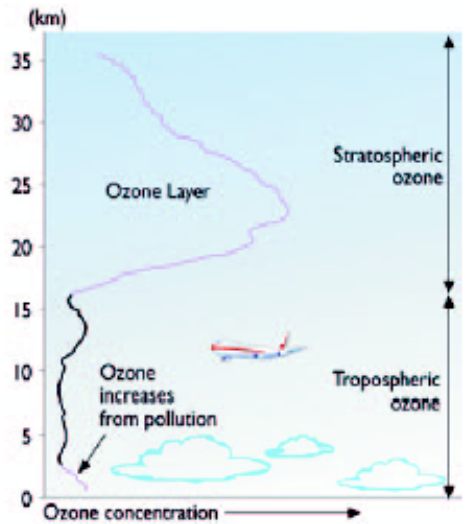
- Indigenous knowledge and observations provide an important source of information about climate change. This knowledge, consistent with complementary information from scientific research, indicates that substantial changes have already occurred.
- Changes in species' ranges and availability, access to these species, a perceived reduction in weather predictability, and travel safety in changing ice and weather conditions present serious challenges to human health and food security, and possibly even the survival of many cultures.
- Many Indigenous Peoples depend on hunting polar bear, walrus, seals, and caribou, herding reindeer, fishing, and gathering, not only for food and to support the local economy, but also as the basis for cultural and social identity.

IMPACTS OF A WARMING ARCTIC

IMPACTS OF A WARMING ARCTIC

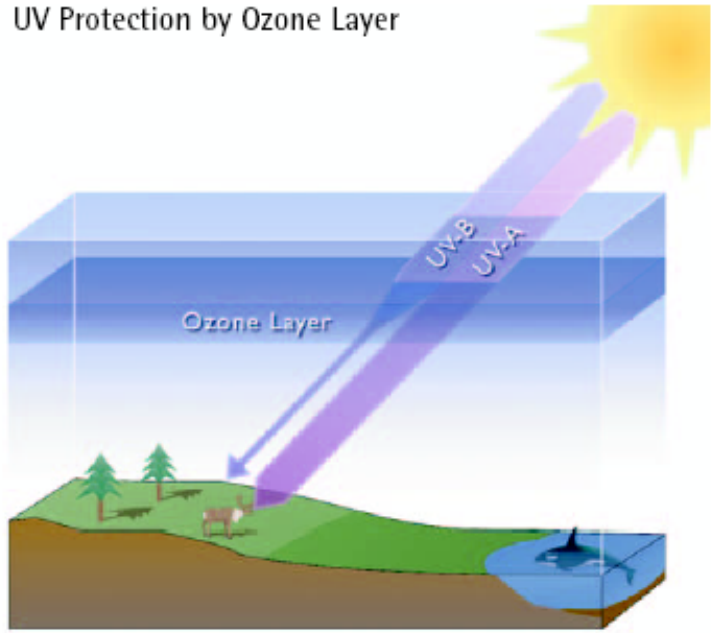
9 Elevated ultraviolet radiation levels will affect people, plants, and animals.

Ozone in the Atmosphere



Most ozone resides in the stratosphere, relatively high above the earth's surface, where it protects life on earth from excess UV radiation. Increases in ozone levels occur near earth's surface as a result of pollution. This ground-level ozone, also known as smog, causes respiratory problems in humans and other negative impacts. The discussion in this report concerns stratospheric ozone, not ground-level ozone.

UV Protection by Ozone Layer

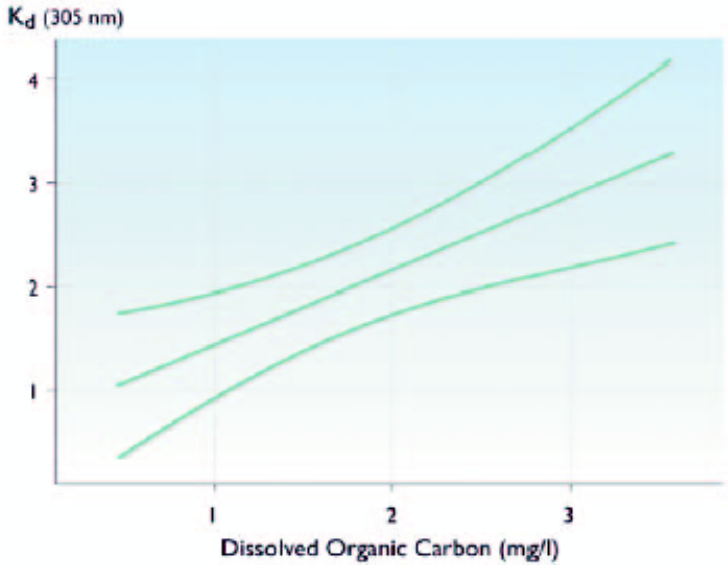


The stratospheric ozone layer absorbs some of the ultraviolet radiation from the sun. UV-B radiation is most strongly absorbed by ozone, greatly reducing the amount that reaches the earth. UV-A and other types of solar radiation are not strongly absorbed by ozone. Human exposure to UV increases the risk of skin cancer, cataracts, and a suppressed immune system. UV exposure can also damage plant and animal life on land, in the oceans, and in rivers and lakes.

IMPACTS OF A WARMING ARCTIC

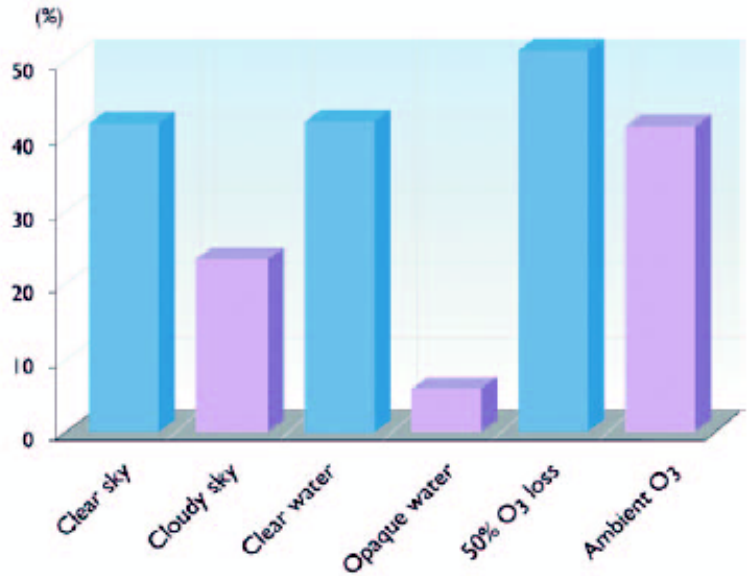
9 Elevated ultraviolet radiation levels will affect people, plants, and animals.

Atlantic Cod Embryos and UV



Atlantic cod embryos are sensitive to UV radiation. If protected from UV exposure, whether by stratospheric ozone, clouds, or dissolved organic carbon, their survival improves sharply. This graphic illustrates the level of protection provided by the organic matter content of the water column, with survival improving with increasing levels of dissolved organic matter. Climate change could affect levels of dissolved matter in water.

Zooplankton Embryos and UV

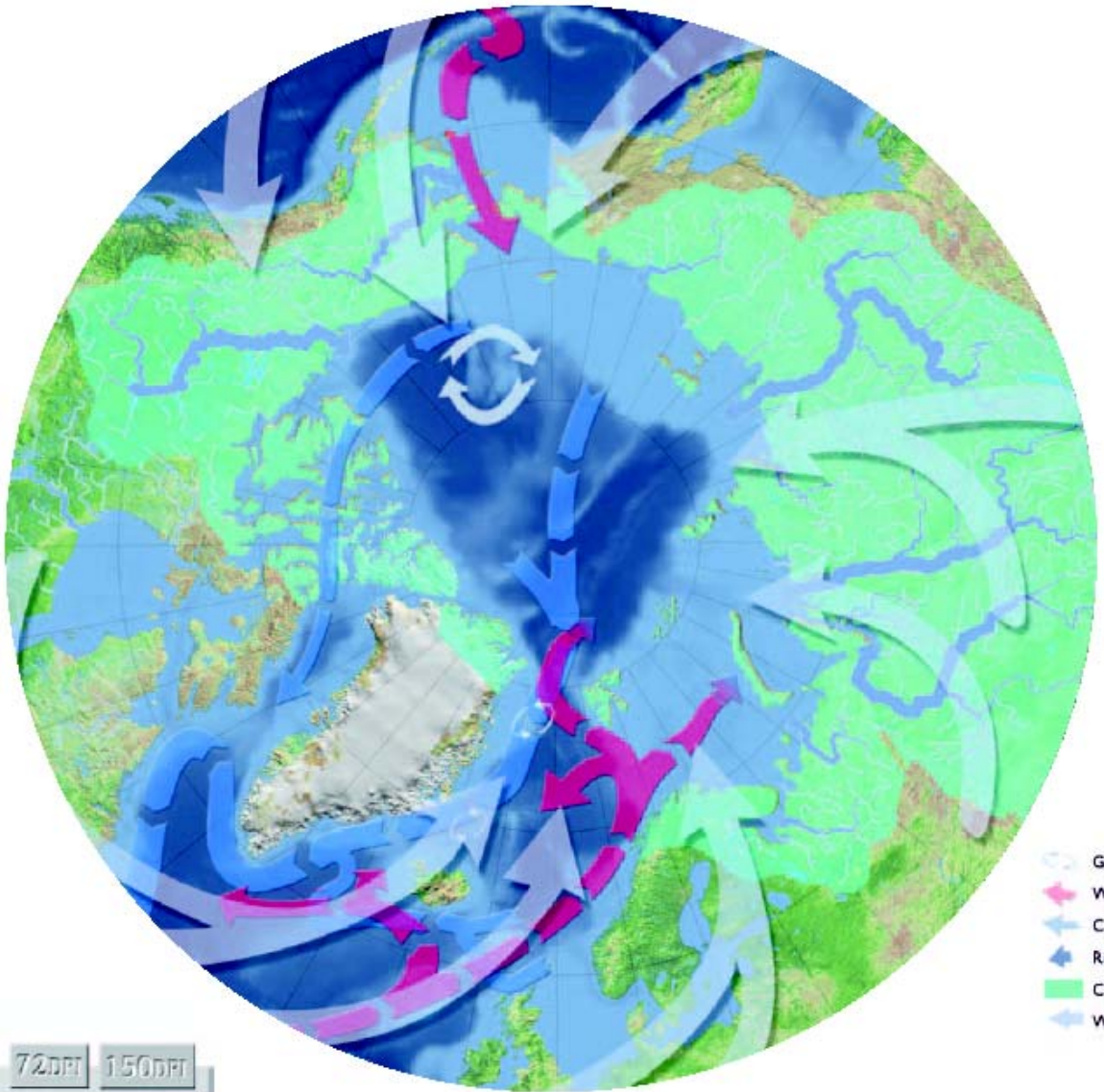


Model simulations of the relative effects of selected variables on UV-induced death in *Calanus finmarchicus*. The graph illustrates that clouds, water opacity, and ozone all reduce embryo deaths due to UV, but that the opacity of the water column has the strongest protective effect of the three variables. Zooplankton are an essential part of the marine food chain.

IMPACTS OF A WARMING ARCTIC

10 Multiple influences interact to cause impacts to people and ecosystems.

Wind, Rivers, and Ocean Currents Bring Contaminants into the Arctic



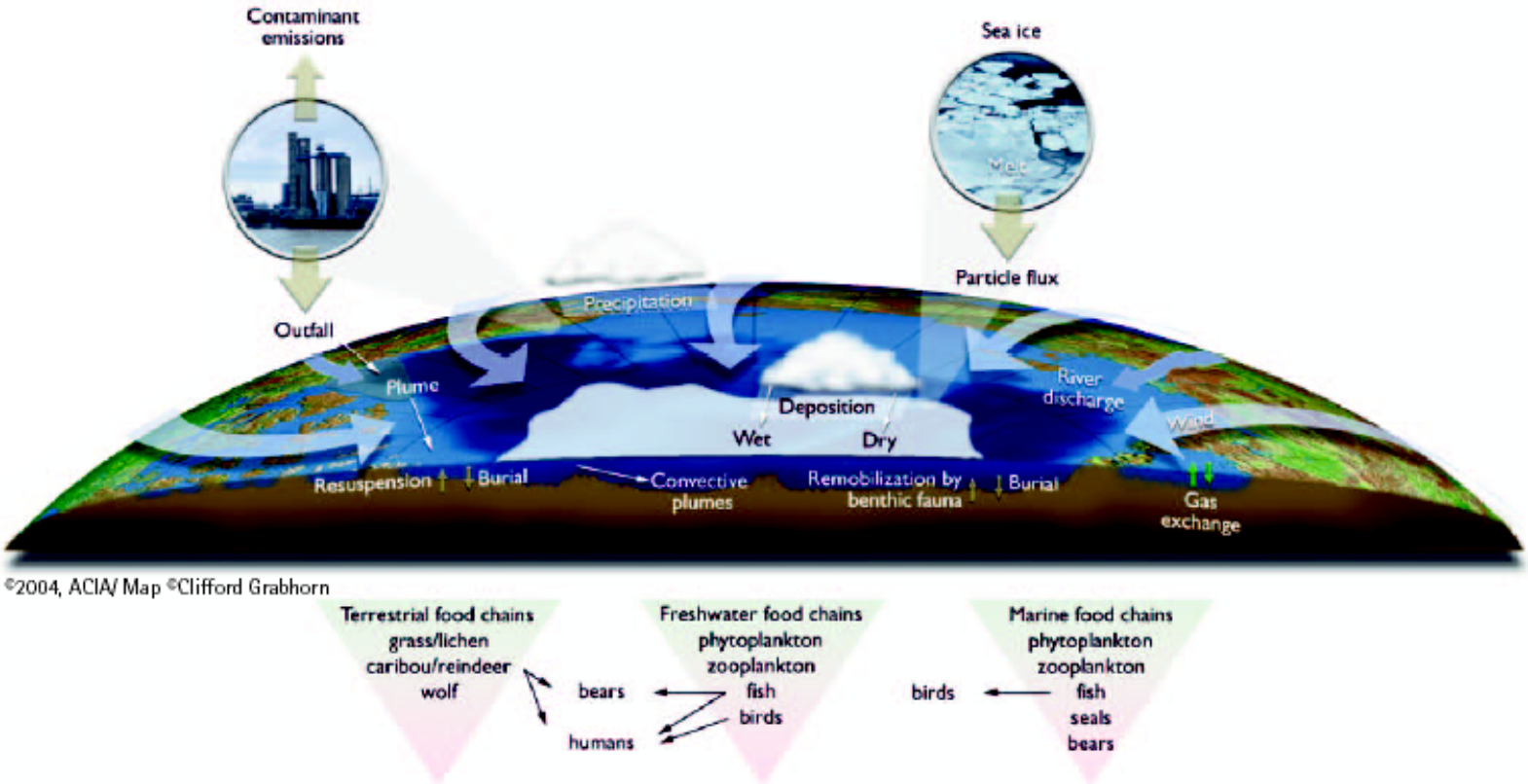
Contaminants emitted in northern industrial areas are transported to the Arctic where they may become concentrated as they move up the food chain.

- Gyre
- Warm Currents
- Cold Currents
- River Outflows
- Catchment Area for Arctic
- Wind Flow

IMPACTS OF A WARMING ARCTIC

10 Multiple influences interact to cause impacts to people and ecosystems.

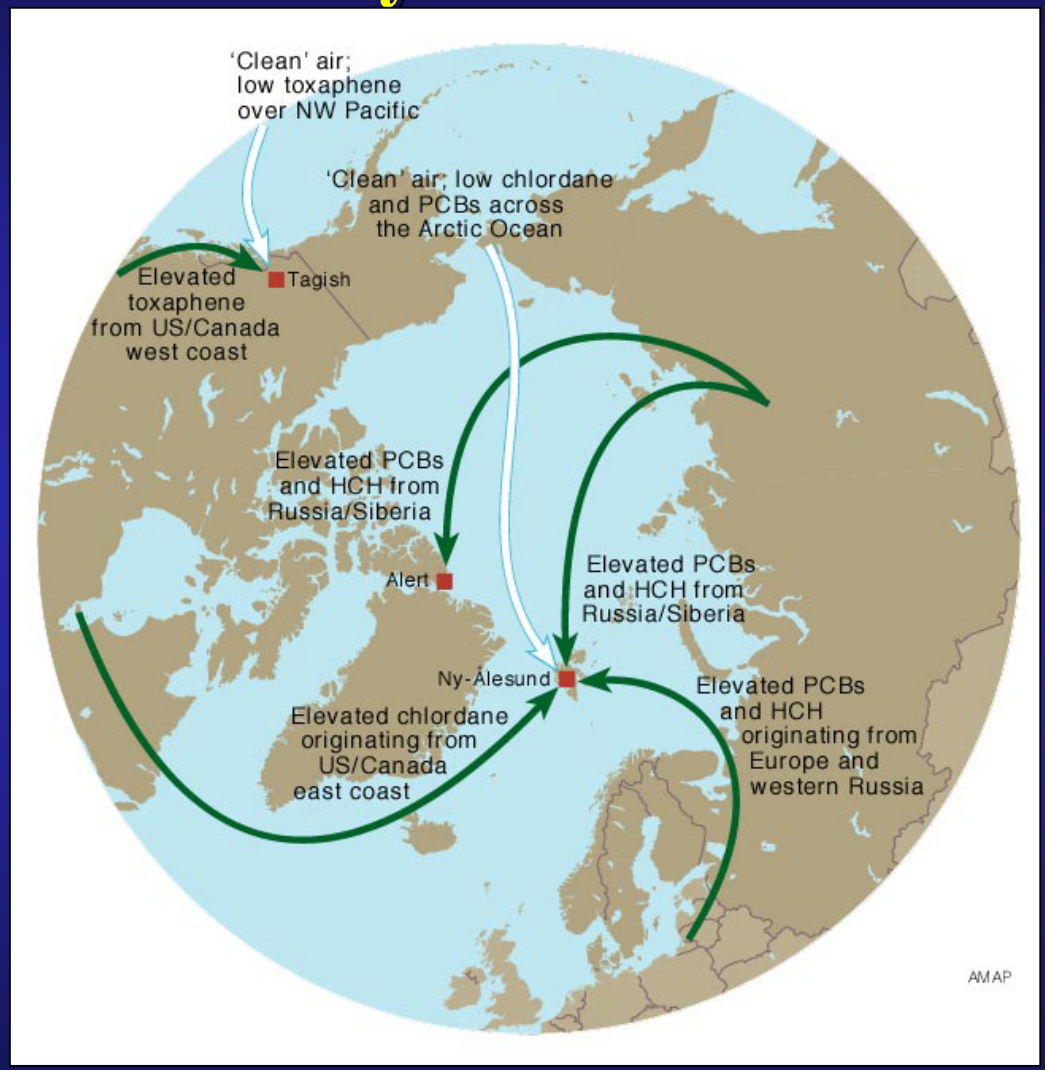
Contaminant Pathways



Contaminants including persistent organic pollutants and heavy metals transported to the Arctic from other regions are among the major environmental stresses that interact with climate change.

10. Multiple influences interact to cause impacts to humans and ecosystems

Climate change occurs in the context of other stresses including chemical pollution, oil spills, over-fishing, ozone depletion, and cultural and economic changes. **Changes in climate often interact with other changes in ways to increase the impacts, such as pathways for pollutants.**

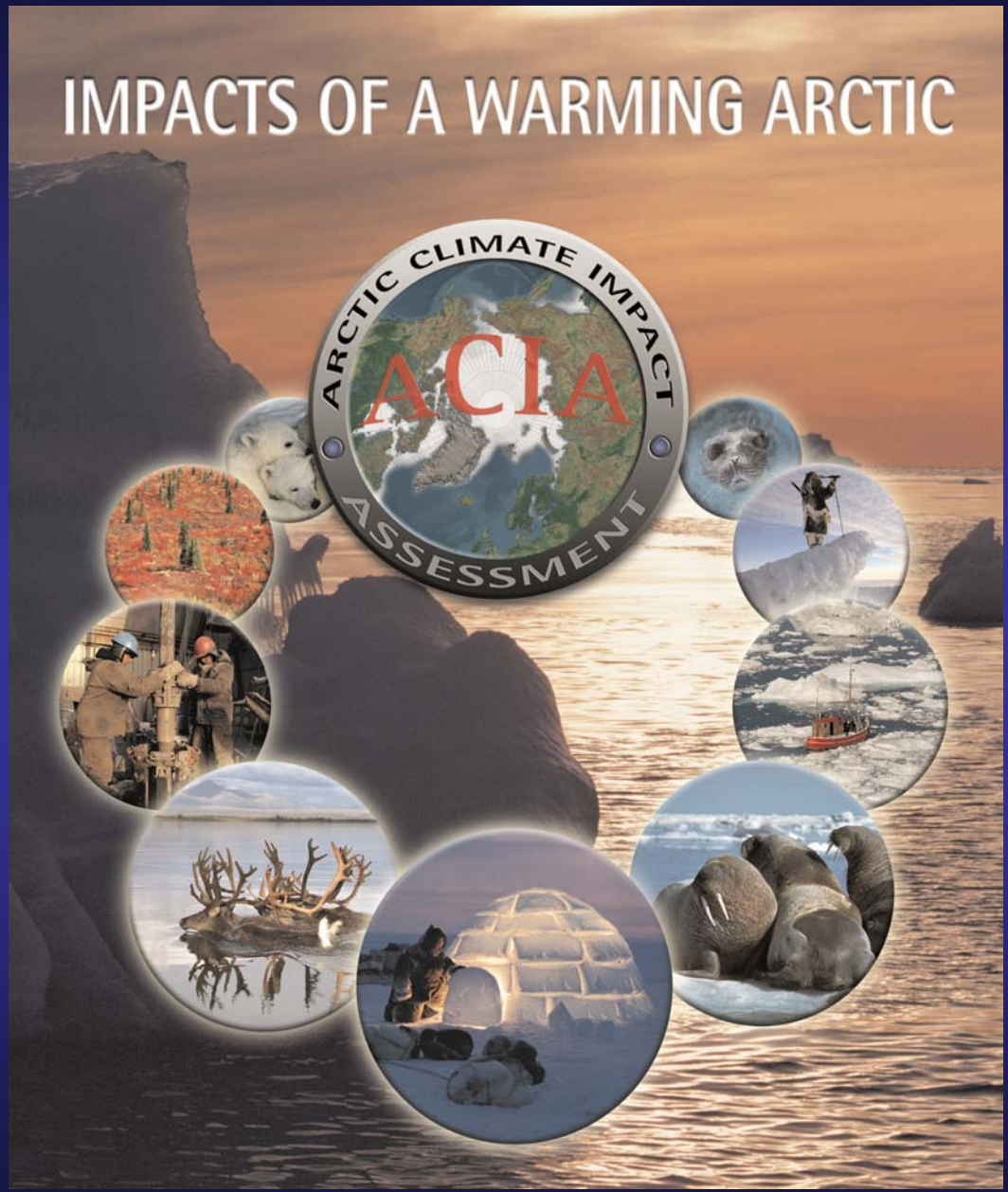


Long range oceanic and atmospheric pathways for POPs that enter the Arctic are influenced by changes in climate.


The Arctic provides a Preview of Earth's Future Climate
10 Years of Change in Arctic is a Preview for the next 25 Years in the Rest of the world.

Available from Cambridge University Press and

on the Web at http://amap.no/workdocs/



The *Overview* volume was published in November 2004

The *Foundation* volume with 18 technical chapters was published in 2005