

2. CLIMATE TRENDS AND SCENARIOS¹

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2.1 Long-term Global Climate Changes

Large changes in global climate have occurred in the past. As the Earth cooled gradually tens of millions of years ago, ice sheets began to form in the polar regions. There is evidence for initial glaciation in the Antarctic approximately 40 million years ago (during the Eocene), and in parts of the Arctic approximately 20 million years ago (during the Miocene). The first large-scale continental glaciation in the northern hemisphere occurred approximately 5 million years ago. For the last 3 million years, ice ages have occurred in roughly 100,000-year cycles². We are presently experiencing a warm period between ice ages.

Analysis of cores³ from the Greenland and Antarctic ice sheets indicates that global temperature was approximately 8°C lower during ice ages than it is today. The results of this change were obviously profound. The last ice age peaked approximately 20,000 years ago with an ice sheet several kilometers thick covering large parts of Northern Europe and North America. Sea level at that time was as much as 100 meters lower than it is today.

The ice-core records also show a remarkable correlation between temperature and the carbon dioxide (CO₂) content of the atmosphere⁴. While the relationship between these two parameters has yet to be fully explained, one appears to amplify the other.

The ice-core records also show dramatic short-term fluctuations in climate, which cannot be due to astronomical factors but have, as yet, no satisfactory explanation.

All of this evidence confirms that:

- ◆ climate is variable and probably chaotic in nature, although recent research suggest that there may be preferred patterns, such as El Niño-Southern Oscillations, which could be predictable,
- ◆ we do not fully understand the dynamics, and
- ◆ future changes will be difficult to predict.

A new man-made factor in the equation is air pollution on a global scale. From the onset of the industrial revolution, human activities have increased production of “greenhouse” gases, principally CO₂, methane, chlorofluorocarbons (CFCs), nitrous oxide, and water vapor. These gases occur naturally in the atmosphere, trapping heat which would otherwise escape from the Earth. In current concentrations, however, they exacerbate warming, especially over land in the polar regions and in winter. We refer to this as “the greenhouse effect.”

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² The 100,000-year ice-age cycle is believed to be driven primarily by variations in the Earth's orbit around the sun (Milankovitch 1930).

³ The temperature record is reconstructed primarily through analysis of oxygen-isotope ratios in the ice cores.

⁴ Atmospheric CO₂ is determined through chemical analysis of air bubbles entrapped in the ice.

In addition to promoting warming, CFCs have catalyzed significant reductions in stratospheric ozone over the last several decades. Ozone in the upper atmosphere serves to filter incoming UV radiation. The reduction in the ozone layer has been documented annually over Antarctica and intermittently over the Arctic.

Contrary to the effect of greenhouse gases, particulate pollution (aerosols) such as sulfur dioxide (SO₂) block incoming solar radiation and, thereby, promote cooling.

Reduction of biomass in all environments will also have a long-term effect on climate. The greatest decrease in biomass has occurred in the Amazon, Southeast Asia, and the rain forests of Northwest North America, where forests continue to be cleared for agricultural use, logging, mining, and industrial development. Also, industrial pollution has reduced a fundamental component of plant biomass (phytoplankton) in the world's oceans.

2.2 Recent Global Climate Changes and Trends

Analysis of the entire global record indicates that, over the last 100 years, global climate has warmed approximately 0.5°C (Figure 2.1); the last few years have been the warmest on record. Figure 2.2a (Chapman and Walsh 1993) shows that temperatures in northern North America and Asia over the last 30 years are as much as 2.0°C/decade warmer in winter. Summer trends are much less pronounced (Figure 2.2b).

Models of greenhouse effect have predicted at least this much warming. Some researchers have argued that particulate pollutants (aerosols, which block incoming solar radiation) have depressed the warming effect in industrialized regions. Climate trends in the Arctic more clearly exhibit the amount of warming predicted by the models than do trends in industrialized latitudes.

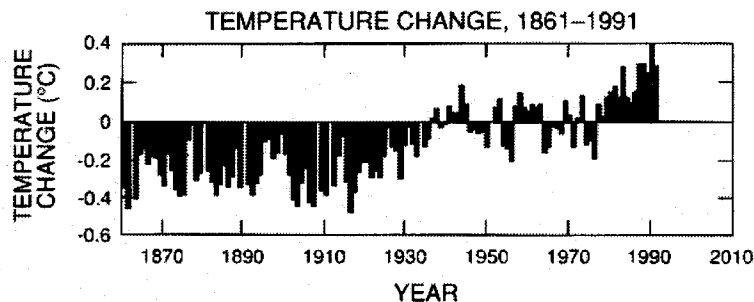
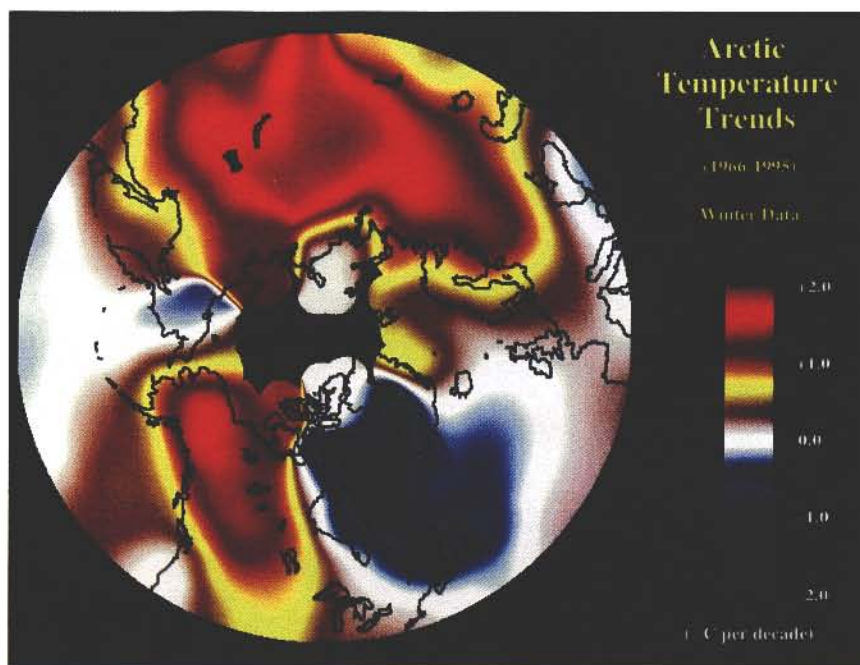
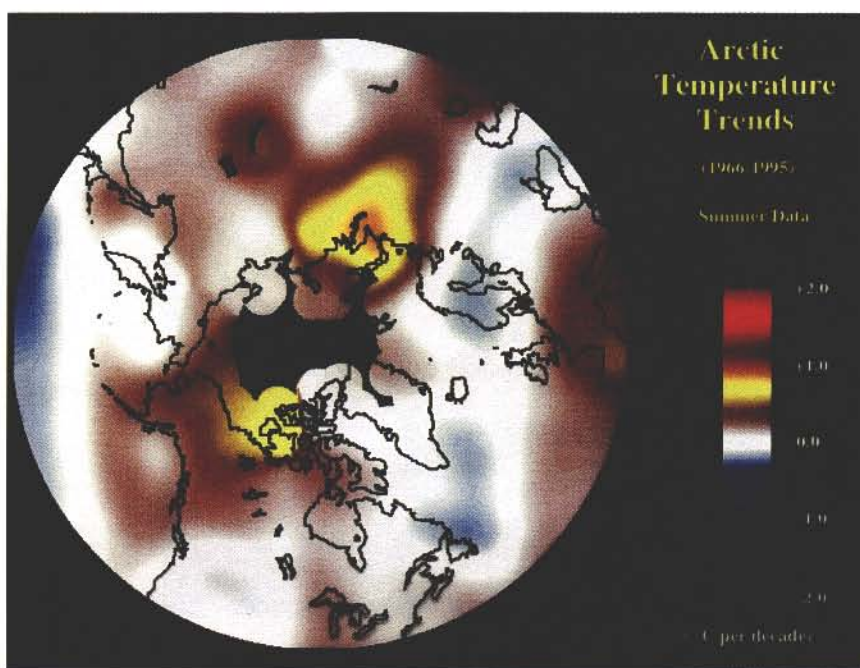


Figure 2.1. Global temperature increased from 1861-1991. 1990 and 1991 were two of the four warmest years since worldwide records began to be kept in the 19th century; 1990 and 1991 closed out the warmest decade on record.

As predicted by the models, temperature increases are greatest in winter and over high-latitude land masses, primarily because of the feedback effects of snow. Trends are less obvious in the Central Arctic Ocean, where data is more limited. While the observed changes vary by region and in some areas even include cooling (e.g., Soviet ice-station data), overall warming trends in the Arctic are clear.



a



b

Figure 2.2. a. Observed trends of arctic winter mean temperatures from 1966-1995. Temperatures in northern North America are as much as 2°C/decade warmer in winter (Chapman and Walsh unpublished). b. The same analysis as in Figure 2.2a, but for summer. Summer trends are much less pronounced than winter trends.

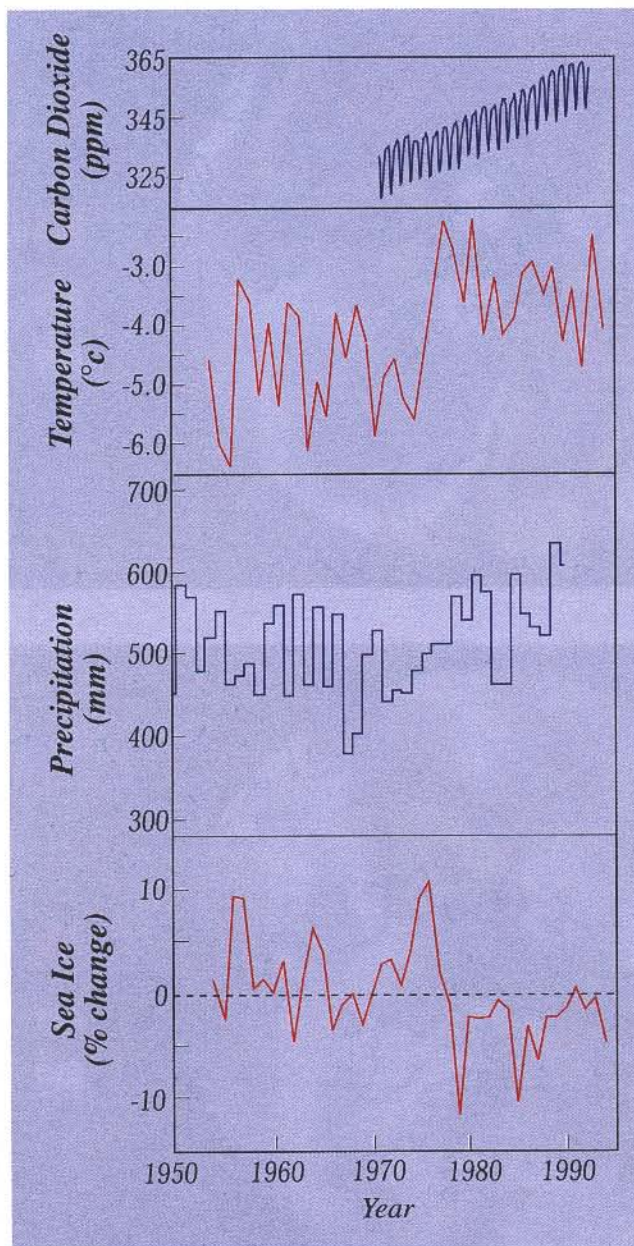


Figure 2.3. Climate-related observations in the Alaska region:
 a) Atmospheric CO₂ concentrations at Barrow (Conway et al. 1994);
 b) Combined annual air temperatures at Anchorage, Fairbanks, Nome
 and Barrow (Bowling pers. comm.); c) Precipitation in Alaska west of
 141° (Groisman et al. 1994); d) Changes in sea-ice extent in the Bering
 Sea (Niebauer pers. comm.).

2.3 Observed Climate-related Trends in the Arctic

Climate-related trends based on direct measurements in Alaska and its surrounding oceans are shown in Figure 2.3. Carbon dioxide (CO₂) concentrations in the atmosphere have been measured at Barrow since 1971 (Conway et al. 1994); these show the same upward trend that is observed worldwide. Air temperatures for Anchorage, Fairbanks, Nome, and Barrow were analyzed by Bowling (pers. comm.) for the period 1954-1994. Considered together, they show a step increase of nearly 2°C around 1977; the warmer temperatures have persisted since then. Sea-ice extent shows a step decrease of about 5% in the Bering Sea in approximately 1977 (Niebauer pers. comm.); the lower extent has persisted since then. Precipitation in Alaska west of 141° (not including Southeast Alaska) has increased since 1970 (Groisman et al. 1994).

Other data sets for Alaska and the Arctic also indicate a warming trend. Permafrost temperatures measured in boreholes in northern Alaska are 2-4°C warmer than they were 50-100 years ago (Lachenbruch and Marshall 1986). Discontinuous permafrost has warmed considerably and is thawing in some locations (Osterkamp 1994). In Siberia, similar changes have occurred. Northern hemisphere snow extent has decreased during the past two decades (Robinson and Dewey 1990). Sea-ice thickness, a sensitive indicator of climate change, appears to have decreased between 1976 and 1987 (Wadhams 1990); however, the measurements made by upward-looking sonar on nuclear submarines are as yet too scattered to allow reliable conclusions to be drawn. Glaciers also continue to recede. Eight glaciers (7 in Alaska, the other in the state of Washington) showed on average a decrease in thickness of 10 m during the interval between the late 1950's and the mid-1990's, a time span of just under 40 years (Sapiano et al. 1997). All these observations are consistent with a warmer climate in the Arctic, as predicted by the computer models.

In short, Alaska has experienced considerable climatic warming since the 1950s; most of this warming occurred after 1976. Table 2.1 provides a summary, based on an analysis by Chapman and Walsh (1993).

Table 2.1. Observed Climate trends of land and ocean regions of Alaska, by season

Climatic Zone	Air Temperatures (°C/decade) 1960-1990				
	Spring	Summer	Fall	Winter	Year
Arctic (N. of the Brooks Range)	+0.7	+0.3	-0.2	+0.8	+0.4
Interior	+1.0	+0.2	0	+1.2	+0.6
Gulf of Alaska	+0.4	0	+0.1	+0.4	+0.2
Bering Sea	+0.2	+0.2	+0.3	+0.2	+0.2

2.4 Climate Scenarios for Alaska

Current climate models still have a number of deficiencies, including poor representation of cloud and aerosol effects on the climate system. Extrapolation over long time intervals also remains problematical. Nevertheless, the results of modeling agree well with observed trends of climate in Alaska, corroborating the credibility of the Alaskan models. On the basis of these models and observations, a climate scenario can be constructed for Alaska approximately 100 years from now, when the CO₂ content of the atmosphere is expected to have doubled. This is a hypothetical scenario, perhaps only one of a number that may be realistic.

Table 2.2 summarizes this climate scenario. There is general agreement between the modeling results and the extrapolated observations. Both show a warming trend in all of the four regions, particularly in winter, although in two cases, there are large differences in the magnitude of the projected warming.

Table 2.2. Climate Scenario for Alaska (four doubling of CO₂)

Climatic Zone	Temperature °C			Precipitation	
	Model ¹	Observation ² (extrapolated)		Model ¹	Observation ³
Arctic					
Summer	+3	+3	(+0.9)	Wetter	
Winter	+7	+7	(+2.4)	Wetter	
Interior					
Summer	+4	+2	(+0.6)	Wetter	For Alaska west of 141°, precipitation has increased by 30% from 1968 to 1990
Winter	+5	+11	(+3.6)	Wetter	
Gulf of Alaska					
Summer	+4	0	(0)	Wetter	
Winter	+5	+4	(+1.2)	Wetter	
Bering Sea					
Summer	+4	+2	(+0.6)	Wetter	
Winter	+7	+2	(+0.6)	Wetter	

¹ Based on GFDL GCM simulations by Manabe, et al. (1992)

² Based on three-decade trend analyses by Chapman and Walsh (1993) and linear extrapolation to 80-100 years (30-year actual trends in brackets)

³ From DOE worldwide "Trends" based on analysis by Groisman, et al. (1994)

The next steps in improving regional climate scenarios are to use high resolution regional climate models. A meeting of minds between regional modelers and impacts researchers took place at the UK Meteorological Office in Bracknell, UK, in November 1996. It was sponsored by WCRP, EMaPS, and IASC and its goal was to identify the requirements of

regional climate scenarios. Although coupled atmosphere-ice-ocean models exist now for the Arctic (e.g., Lynch et al. 1995) which have much greater resolution than the general circulation models, their use was thought to be premature, considering all the uncertainties of the general circulation models in which the regional models would have to be nested.

Nevertheless, recent experience with observed changes in climate patterns in the Arctic as well as ongoing research to improve our understanding of the physical, natural, and human impacts of climate change scenarios like the one described provide a useful starting point for assessing the consequences of climate change for this region. The following chapters summarize current thinking about the consequences of climate change.

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