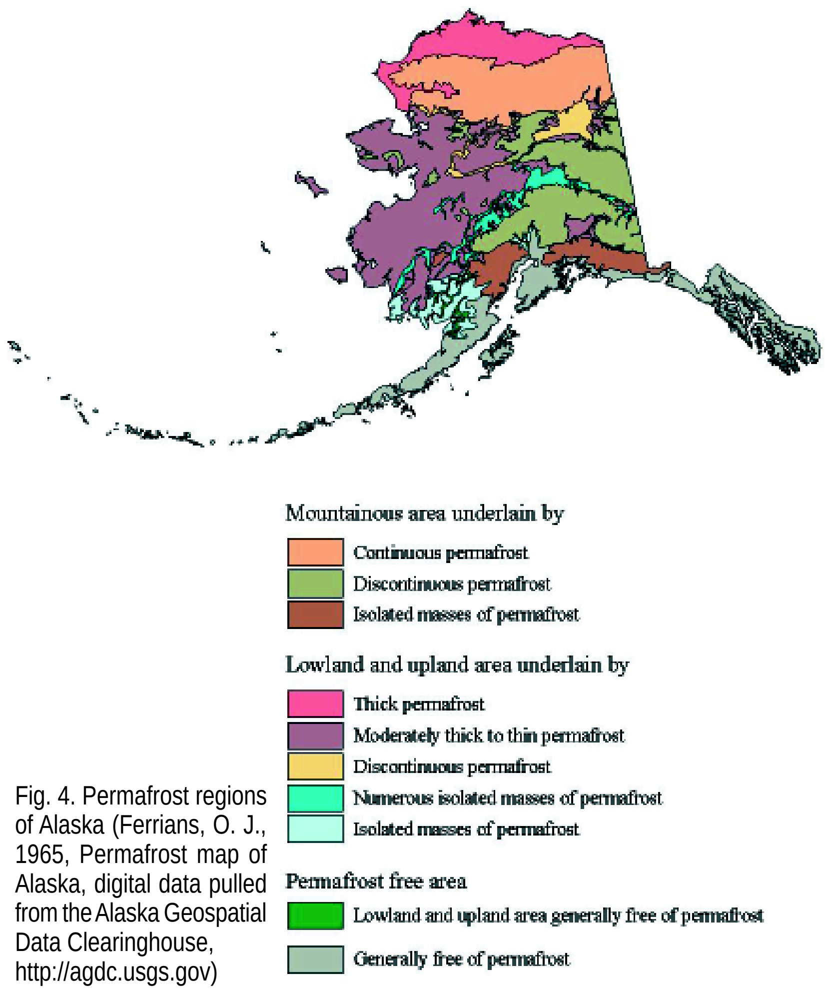
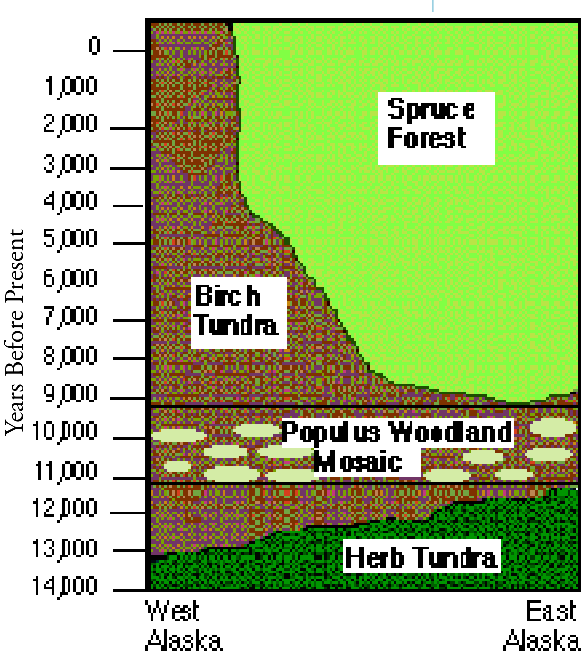


Fig. 4. Permafrost regions of Alaska (Ferrians, O. J., 1965, Permafrost map of Alaska, digital data pulled from the Alaska Geospatial Data Clearinghouse, http://agdc.usgs.gov)

the 20th century there has been a warming to 1940, followed by a cooling, and a strong warming since the 1960s. Warming has been up to 1.5°F (1°C) per decade over the last three decades in the annual mean, with the largest warming occurring in the interior and arctic regions. In winter the increase has been even bigger, up to 3°F (2°C) per decade (Chapman and Walsh, 1993). Some Alaskan records show that a very large warming, of about 3°F (2°C), occurred suddenly around 1977 and has persisted since then. Similar warming is occurring throughout the circumpolar arctic region, and has been accompanied by extensive melting of glaciers and thawing of permafrost (Osterkamp, 1994), and reduction of sea ice extent and thickness (Chapman and Walsh, 1993; Wadhams, 1990; see also Chapter III). The climate has also become wetter over the century, but the trends are smaller and more spatially mixed. Alaska experienced a 30% increase over the region west of 141 degrees (i.e., all of Alaska except the panhandle) between 1968 and 1990.



In addition to long-term warming trends, the climate has shown strong multi-year cycles, which are now known to be coupled to large-scale climate oscillations: the 2- to 5-year El Niño/ Southern Oscillation (ENSO) in the Pacific, and the interdecadal (approx. 15-year) Arctic Oscillation (AO) of which the Pacific Decadal Oscillation (PDO) and the North Atlantic Oscillation (NAO) are part. Although the AO is less well known than ENSO, it now appears that its effect on climate and resources is even more important. Like ENSO, the AO is a pattern of oscillation in the climate that includes changes in ocean and atmosphere temperatures, winds, and precipitation. These oscillations lead to complex effects on marine ecosystems and forests. The effect of the AO on salmon stocks is particularly

Fig. 5. Simplified scheme of vegetation development in Alaska from the last glacial period to the present. The horizontal axis represents an east-west transect across the state at the approximate latitude of Fairbanks.

striking. The origin and mechanism of these changes are not known, but may reflect combined effects of changes in streamflow, and the nutrient content, temperature, and vertical stability of coastal waters. Thompson and Wallace (1998) have analyzed the Arctic Oscillation and its associated components, the PDO and NAO. The climate of the northern hemisphere is clearly affected by the AO, but the combination of the AO and ENSO, which also influences climate, cannot explain the observed climate trends. Nor can solar variability. Overpeck et al. (1997) have shown that the difference is due to greenhouse warming which is already being observed in the Arctic.

Table 2. Annual mean temperature increases in Alaska as modeled by two GCMs, compared with three-decade observed trends extrapolated linearly to the years 2030 and 2100. The range in values shows differences among the various regions of Alaska.

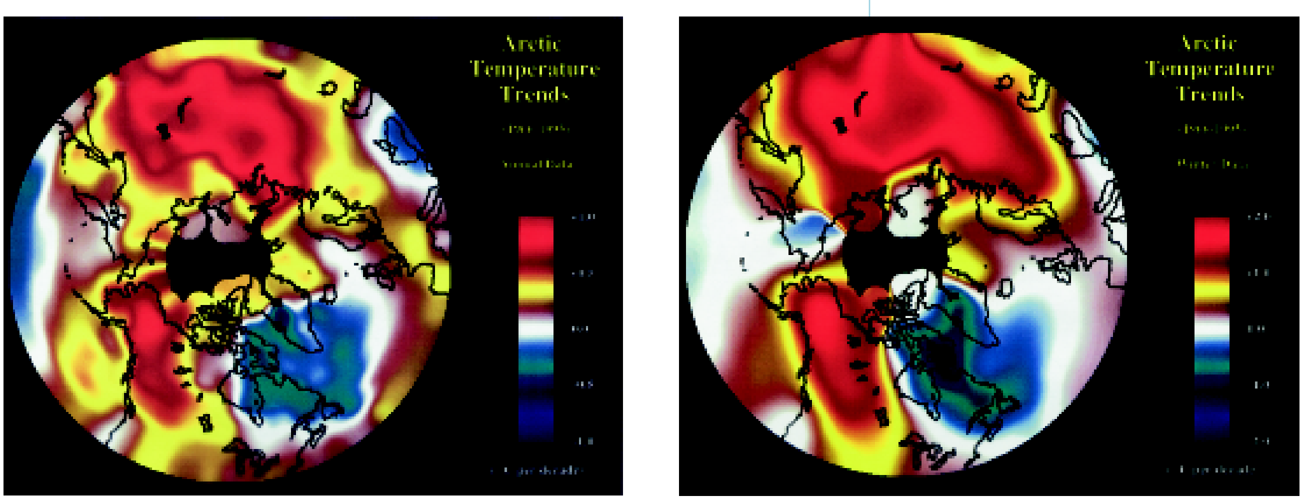
	Year 2030	Year 2100
Canadian Model	3–6° F (1.5–3.5° C)	9–18° F (5–10° C)
Hadley Model	3–4.5° F (1.5–2.5° C)	7–12° F (4–6.5° C)
Extrapolated Observed Trends	2–4.5° F (1–2.5° C)	5.5–14.5° F (3–8° C)

Future Climates

Because of the large scale of climate variations within Alaska, General Circulation Model (GCM) predictions for different regions also vary somewhat (Tao et al., 1996). Two GCMs were used to project future climates in Alaska, the Canadian Climate Model and the United Kingdom Hadley Center Model. In Alaska, the strong projected trends toward a warmer, wetter climate broadly continue the trends observed in recent decades. In the Canadian and Hadley models, projected warming is smallest in the south and southeast, largest in the northwest, and is strongest in winter. The Canadian model projects the largest warming trends: annual-average temperature in the southeast increases 2.7°F (1.5°C) by 2030 and 9°F (5°C) by 2100, in the northwest 6.3°F (3.5°C) by 2030 and more than 18°F (10°C) by 2100. The strong warming in this model is accompanied by near-total summer melting of arctic sea ice by 2100. In the Hadley model, annual-average warming ranges from 2.7–4.5°F (1.5–2.5°C) by 2030, and 7.2–11.7°F (4.0–6.5°C) by 2100 with only slight loss of sea ice.

Comparing these model-projected changes to the 5°F (3°C) temperature change already observed over the past few decades, they range from half as much again to a doubling by 2030, and a doubling to a tripling of recent changes by 2100. Table 2 summarizes the two model projections for Alaska for years 2030 and 2100 and compares them to three-decade (1966–1995) observed trends (Fig. 6, Chapman and Walsh, 1993, updated) extrapolated

Fig. 6. Observed temperature trends in the Arctic from meteorological stations for the period 1966–1995. Annual mean—left; winter—right. (Chapman and Walsh, 1993, updated)



linearly to the years 2030 and 2100. What this shows is that the projected model trends are not very different from those actually observed in Alaska at present. There is a range of values since there are considerable differences among the various regions of Alaska, with the southeast and interior of Alaska experiencing the greatest warming and the northwest the least.

As a consequence of these changes there will be widespread thawing of permafrost (Fig. 7), accelerated glacier melting, a shorter snow season, thinner and less sea ice and a gradual movement of the boreal forests upslope and northward (BESIS, 1997; 1998; 1999).

Both models project that the Aleutian low-pressure system will grow deeper and may shift slightly to the south, increasing hydrological activity in the region. Under these conditions, Alaska will continue to grow wetter, with annual precipitation increases of 20–25% in the north and northwest, ranging to very little change in the southeast. In term of projected seasonal and spatial distribution of precipitation changes, both the Hadley and Canadian models project that winters are wetter in the east and drier in the west, while summers are drier in southeast Alaska and wetter elsewhere. Winter soil moisture changes with precipitation, but in summer, increased evaporation from the warmed climate exceeds any projected increases in precipitation, so soils dry everywhere in all the models.

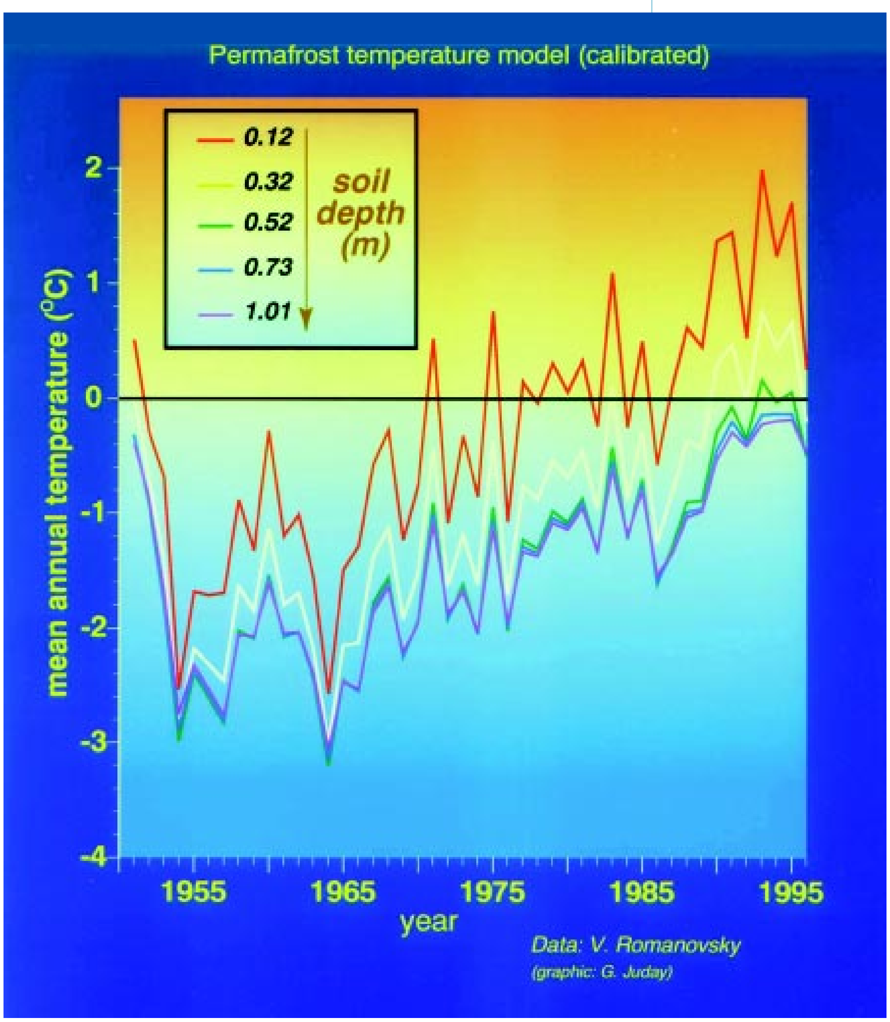


Fig. 7. Change in permafrost temperatures at various depths in Fairbanks, Alaska