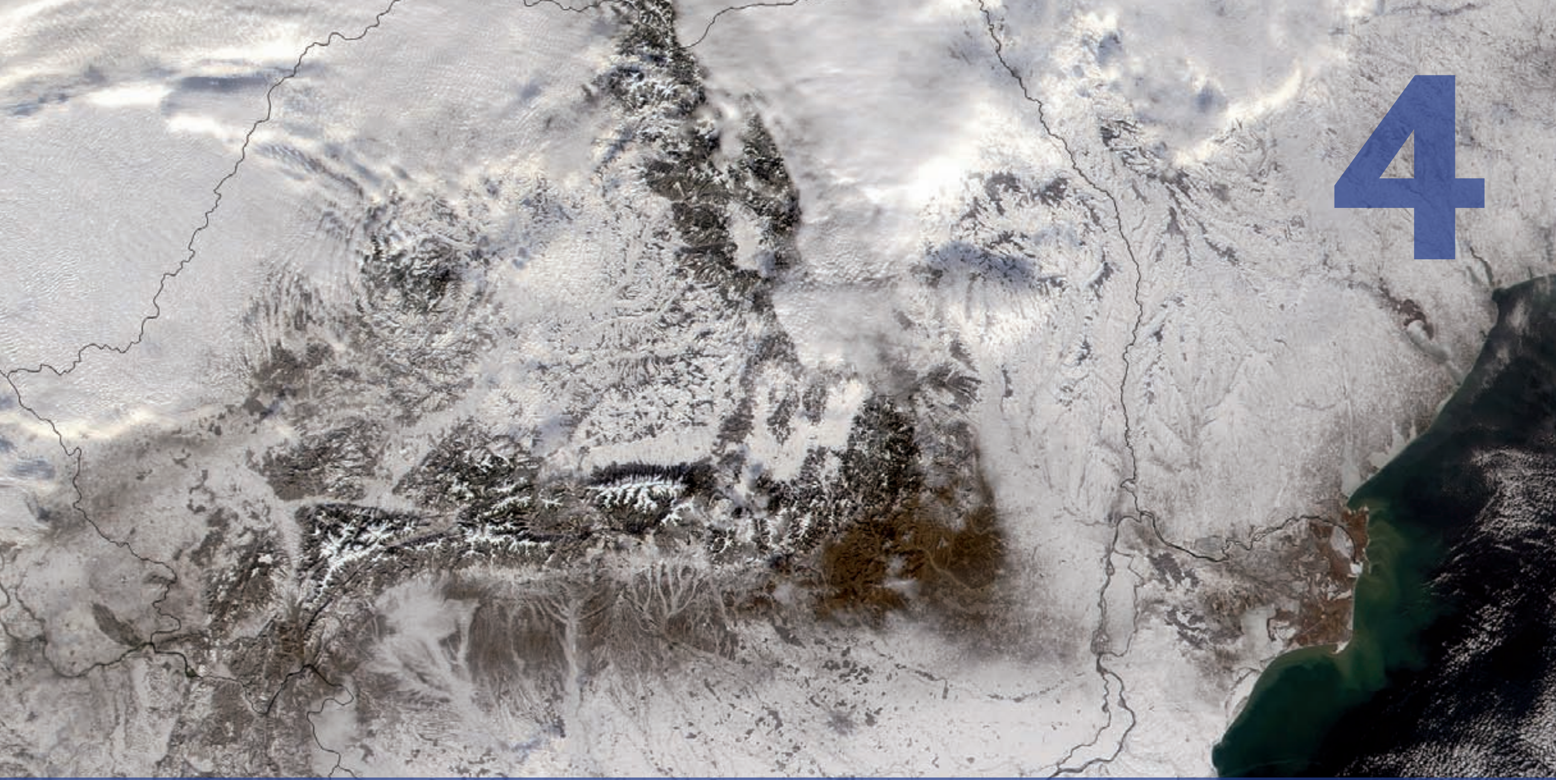

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Snow

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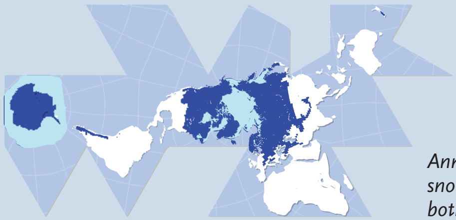
Snow

Summary

Snow exerts a huge influence on climate, through its high reflectivity, insulating properties, and cooling of the atmosphere, and on surface hydrology, through its effects on water resources in many parts of the world. Mean monthly snow-cover extent in the Northern Hemisphere has decreased at a rate of 1.3 per cent per decade during the last 40 years, with greatest losses in the spring and summer months. Climate models project significant decreases in snow cover by the end of this century, with reductions of 60 to 80 per cent in snow water equivalent (depth of water resulting from snow melt) in most mid-latitude regions. Increases are projected for the Canadian Arctic and Siberia. Higher temperatures and rises in snow line are projected for many mountain regions. Changes in snow cover, such as the formation of ice layers in snow due to increased frequency of snow thaw, have widespread impacts as snow is an important ecological factor. Snow-cover changes also have impacts on human well-being and economic activities, including water resources, agriculture, animal husbandry, transportation and winter recreation such as skiing.



Annual maximum snow-cover extent in both hemispheres

Snow: frozen precipitation in the form of ice crystals that fall in soft, white flakes.

Snow on land (Northern Hemisphere) (annual minimum ~ maximum):

Area Covered (million square km)	1.9 ~ 45.2
Potential Sea Level Rise (cm)	0.1 ~ 1

Source: IPCC 2007[1a]

Introduction to snow

Snow occurs predominantly on the northern continents, on the sea ice of the Arctic Ocean and on Antarctica. On the Northern Hemisphere continents, snow covers a maximum mean area of 45.2 million km^2, typically in January. The minimum snow-cover extent usually occurs in August and covers a mean area of 1.9 million km^2, most of which is snow on the Greenland ice sheet and on mountain glaciers. As a result, snow cover is the surface characteristic responsible for the largest annual and interannual differences in surface reflectivity (albedo) in the Northern Hemisphere (Figure 4.1). In the Southern Hemisphere, excluding the 14.5 million km^2 area of Antarctica, terrestrial snow covers a much smaller area, mostly in the Andes and Patagonia, and it plays a smaller role in global climate. Limited summer melt occurs in the Antarctic Peninsula and on the coasts of western Antarctica.

Snow is an important climate variable. Due to its high albedo, snow cover increases the amount of sunlight reflected from Earth's surface. The low thermal conductivity of snow insulates the ground, and its cold, moist surface affects the transfer of heat and moisture to and from the atmosphere. Thus, snow cover exerts a signifi-

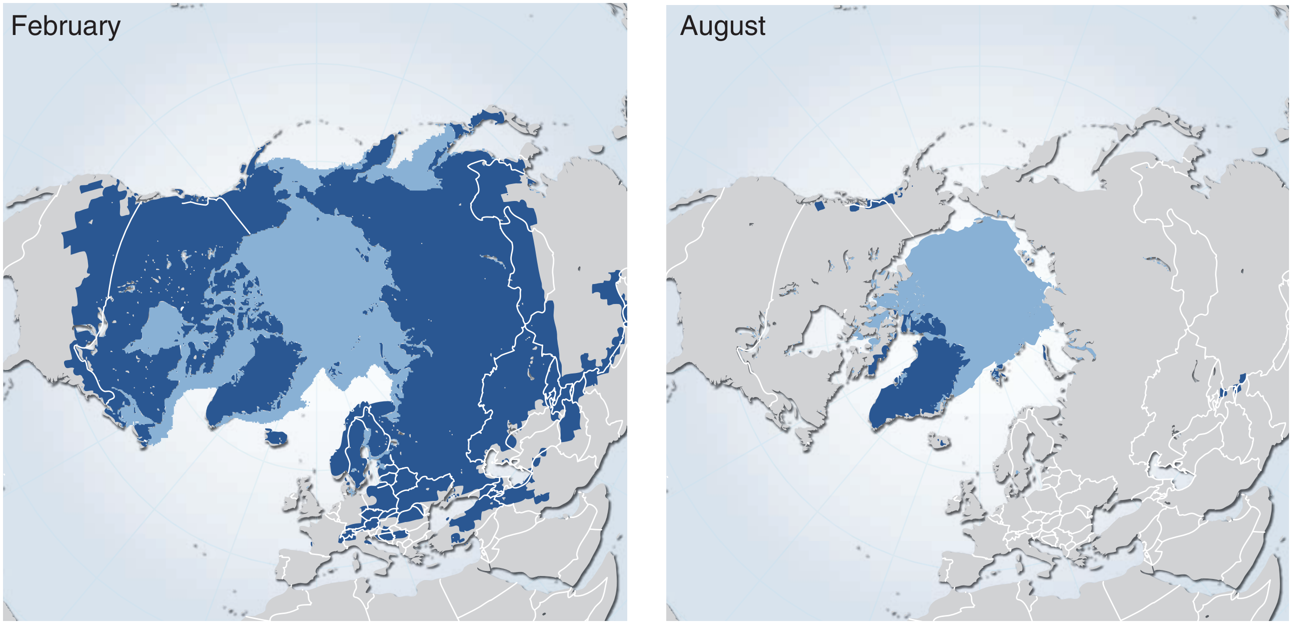


Figure 4.1: Mean snow-cover extent (dark blue) and sea-ice extent (light blue) in the Northern Hemisphere between 1966 and 2006, for February and August. The difference in snow cover between seasons causes significant differences in the surface reflectivity (albedo).

Source: Based on Armstrong and Brodzik 2005[1]

cant influence on climate and hydrology. Snow cover affects large-scale atmospheric circulation. Early season snow-cover anomalies in the Northern Hemisphere, for example, are known to lead to changes in atmospheric circulation. Autumn snow cover can also affect climate on a seasonal scale, with impacts extending into the subsequent winter. Snow cover is also a sensitive indicator of regional climate variability and change. Realistic simulation of snow cover in models and forecast schemes is essential for simulating surface energy balance and predicting winter water storage and year-round runoff.

Snow cover influences human activities directly and indirectly. Seasonal snow cover is the main source of runoff in many mountain regions, and over one billion people depend on it for their water supplies. Snow is a major factor in transportation, winter sports, agriculture and animal husbandry such as reindeer herding. It influences ecosystems and is important for conservation of biodiversity.

Trends and outlook for snow

Snow accumulation and melt are governed primarily by air and soil surface temperature, precipitation, wind and surface relief. Precipitation determines the overall amount of snow but air temperature determines whether the precipitation falls as rain or snow and governs the rate of snow melt. The recent rise in global temperatures, and the warming trends predicted for the future (see Chapter 3) thus affect global snow cover.

Data from satellite monitoring (see box on measuring snow cover extent) from 1966 to 2005 show that mean monthly snow-cover extent in the Northern Hemisphere is decreasing at a rate of 1.3 per cent per decade (Figure 4.2). For the calendar year of 2006 average snow-cover extent was 24.9 million km², which is 0.6 million km² less than the 37-year average[2]. In the Northern Hemisphere, spring and summer show the strongest decreases in snow-cover extent. Satellite observations of snow-cover extent show a decreasing trend in the Northern Hemisphere for every month except November and December, with the most significant decreasing trends during May to August[3]. The average Northern Hemisphere snow-cover extent for March and April decreased by 7.5 ± 3.5 per cent from 1922–2005[4] (Figure 4.3).

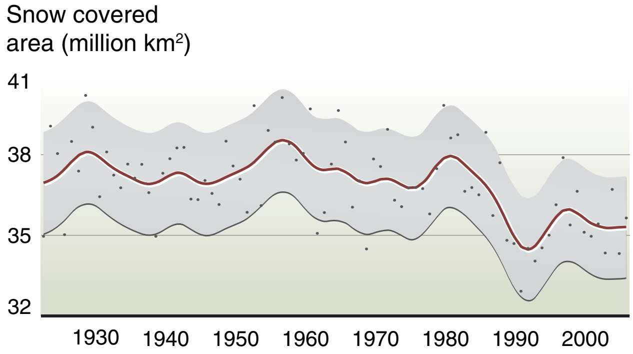


Figure 4.3: Northern Hemisphere snow-covered area (SCA) for the spring (March–April) from 1922–2005. The linear trend shows a decrease in SCA of 2.7 ± 1.5 × 106 km² or 7.5 ± 3.5 %. The shaded area represents the 5 to 95% range of the data.

Source: Based on IPCC 2007[4], updated from Brown 2000[5]

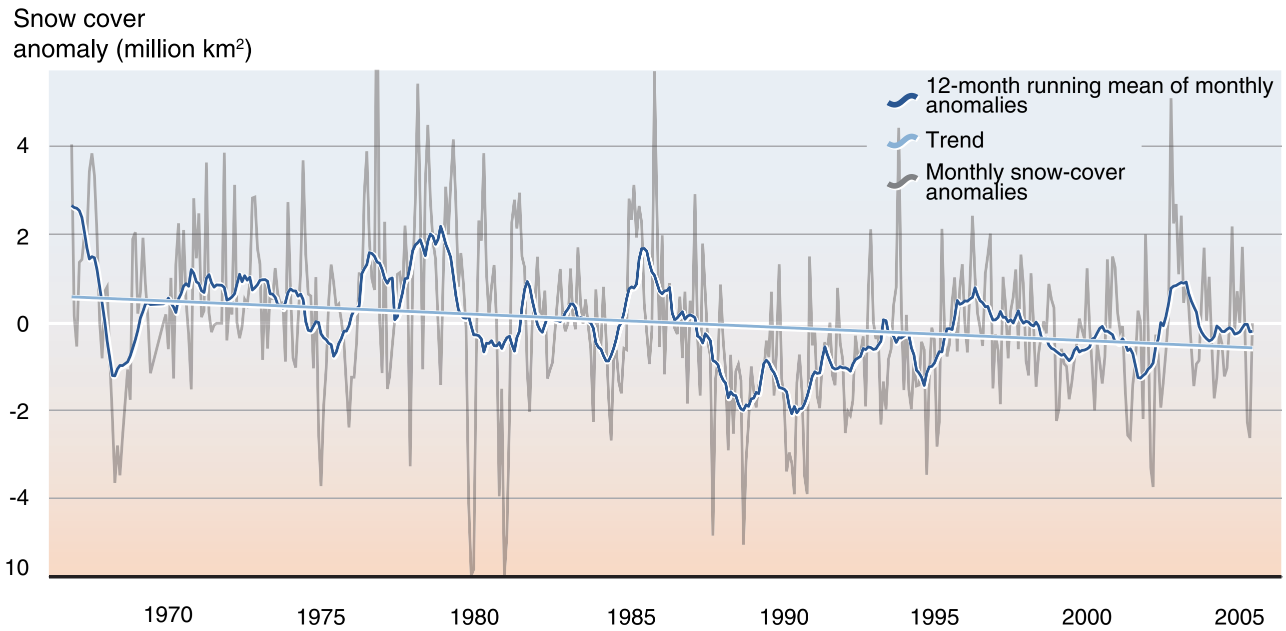


Figure 4.2: Northern Hemisphere snow-cover extent departures from monthly means from 1966 to 2005, with the 12-month running mean also shown. The decreasing trend of –1.3% per decade is significant at the 90% level.

Source: M.J. Brodzik; data from NOAA snow charts revised by D. Robinson, Rutgers University

Snow covered mountains in Alaska.
Photo: P. Slota/USGS National Wildlife Health Center (US)

Measuring snow-cover extent

Snow-cover fluctuations in the hemispheres are monitored by satellite. Since 1966 the National Oceanic and Atmospheric Administration (NOAA) has produced snow-extent charts on at least a weekly basis[6,7]. Until 1999 the charts were primarily derived from the manual interpretation of satellite images taken within the visible band of the electromagnetic spectrum. Passive microwave data, available since 1978, and other data are now included in the source data for the charts[8,9].

Satellite passive microwave sensors can detect the snow surface through clouds and in darkness but may not detect shallow snow that can be seen in visible band imagery. As a result, time series from microwave and visible data sources can differ. Data sets from both sources show a similar range for maximum Northern Hemisphere snow-cover extent that exceeds 40 million km^2 consistently[1,10,11]. NOAA data, derived primarily from visible band sensors, show a significant decreasing trend in mean monthly snow-cover extent (see text). Microwave data indicate a similar decreasing trend that is not significant at a 90% level. While NOAA data show decreasing trends in every month except for November and December (see text), data from passive microwave sensors is less clear. Both data sets indicate significant decreasing trends during May to August (see text).

Regional trends in snow cover

Examination of regional trends in spring snow-cover duration from 1969–2003 using NOAA snow-cover data shows the western United States to be among the regions with the strongest decreases (Figure 4.4). This supports results from studies based on measurements on the ground[12,13]. Springtime snow cover shows a decline particularly in the Pacific Northwest region of the western United States, where snow water equivalent, a common snow cover measurement equivalent to the depth of water which would result from snow melt, has decreased by as much as 50–75 per cent[13]. This decrease is attributed to an increase in temperature[14]; observations of temperatures in the western United States already show warmer winters[15]. There is abundant evidence of earlier spring warm spells in the western United States since 1950 at elevations below 2500 m, with impacts on snow-cover duration as well as amount. There are more frequent rain-on-snow events and snow melt begins earlier, with stream flows increasing in March and April and decreasing in May and June[16].

In contrast, for most of northern Eurasia there has been a long-term increase in snow depth and the duration of snow cover[17]. At Abisko in subarctic Sweden, increases in snow depth have been recorded since 1913[18]. During 1935–1995, snow-cover duration increased by about four days per decade in northern European Russia and small areas of west central Siberia and decreased by about two days per decade over southern and southeastern Siberia[19].

Outlook for snow cover

Decreases in snow-cover extent and duration will contribute to continued and accelerated temperature increases, due to changes in the albedo of the land surface (see Chapter 3). In Alaska, 95 per cent of recent summer warming trends have been attributed to the decrease in snow-cover duration[20].

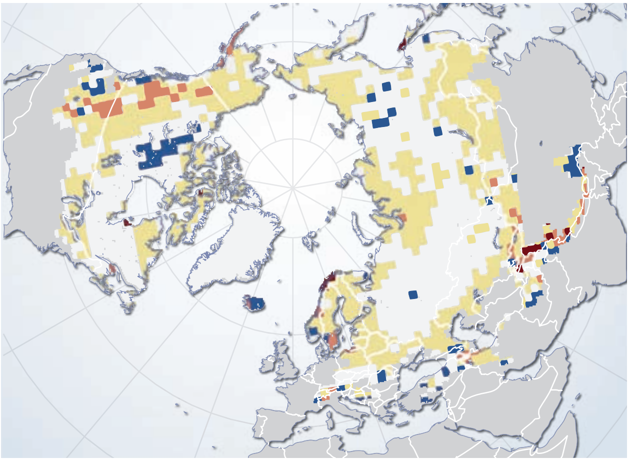


Figure 4.4: Trend (days/year) in spring (February–July) snow-cover duration from 1970–2004 from the NOAA weekly snow-cover dataset. Changes exceeding ~ ±1 represent significant local changes at the 95% level. Greenland was excluded from the analysis.

Source: R. Brown, Environment Canada; data from D. Robinson, Rutgers University

Shallow snow cover at low elevations in temperate regions is the most sensitive to temperature fluctuations and hence most likely to decline with increasing temperature[4]. In locations where snow accumulates at temperatures close to its melting point, small increases in temperature will have large effects on snow cover. For example, in the Pacific Northwest region of the United States, the temperate snow cover of the Cascade Range of mountains could be reduced by over 20 per cent with an increase in mid-winter temperatures of only 2° C[21].

Mountain regions are particularly sensitive to climate change[22], and increases in mean minimum temperatures are more pronounced at higher elevations than in valleys[23]. Temperatures are projected to continue rising in the mountains of the western United States, with accompanying reductions in snow cover[24]. Similar changes are expected in other mountainous regions of the world. In central Chile, air temperature data from 1975 to 2001 show an increase in elevation of the 0° C isotherm (the line on a map linking points at which the mean temperature is 0° C) by 122 m in winter and 200 m in summer[25]. It is estimated that the snow line of the European Alps will rise about 150 m for every 1.0° C increase in winter temperatures[26]. Climate model projections indicate that the Alps and Pyrenees will experience warmer winters with possible increases in precipitation[27], which, as in the western United States, will raise snow lines, reduce overall snow cover, and decrease summer runoff.

Snow water equivalent and snow-covered area are modelled in General Circulation Model experiments to predict global changes in snow cover. A comparison of results

Local observations of snow-cover changes

In many areas of snow cover, there are local people who rely on the snow for water, recreation, travel, and other activities. Through constant and close interaction with snow, these people develop a great body of knowledge about it. People who possess knowledge of snow include mountain villagers, ski patrollers, mountain climbers, and perhaps more than any other group, Arctic residents, especially Indigenous Peoples. These people have the most interaction with snow, as snow is present for most of the year and they depend on it for their livelihoods.

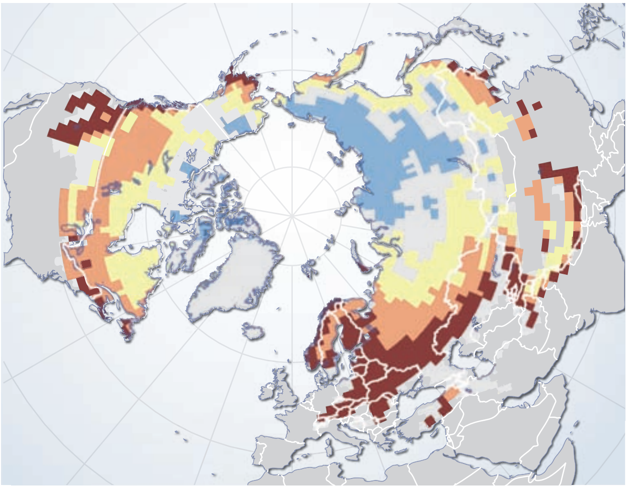
In the Canadian Arctic, Inuit and their ancestors have depended on snow, and held a keen understanding of it, for millennia. Traditionally, Inuit lived in snow houses called *igluit*. The ability to travel depended partly on the condition of snow cover, for example, hard, soft, deep, or drifted snow. Snow forms on the land or sea ice, running parallel with the dominant wind, helped hunters to navigate; this practice is still used by some today (Figure 4.5). Saami reindeer herders in Fennoscandia have also traditionally depended on snow for their activities and survival. Herders closely observe snow conditions and modify their herding strategies accordingly. For example, in hard snow conditions, herders may keep reindeer close together so that strong animals help to crush icy snow layers, allowing weaker animals to graze[30]. If the snow is relatively soft, animals may be allowed to graze a wider area. Today, Inuit no longer live in snow houses and some Saami employ modern technologies, such as helicopters or motorbikes, to herd reindeer. But elders, and many hunters and herders, still possess traditional knowledge about snow. They constantly gain new knowledge about snow and other aspects of the environment, and incorporate this knowledge into their everyday lives.

Many traditional knowledge holders have noticed changes in snow in recent years, along with other changes in the environment and climate. In projects such as the Arctic Climate Impact Assessment, scientists have begun working cooperatively with these people in order to understand environmental change in the Arctic. A number of other projects have documented indigenous knowledge of environmental change in the Arctic, primarily in Alaska and the Canadian Arctic[31–34]. Snow is a common theme in many of these studies. For example, in Nunavik (northern Quebec), residents observe less snow cover in spring time. This restricts travel into the bush by snowmobile to hunt and collect firewood[35]. Less snow in the hills also means fewer cold storage places for fish, which are kept cool in snow patches. This problem is shared by some communities in the Canadian territory of Nunavut[33]. At Clyde River, Nunavut, Inuit observe that permanent snow patches, *aniuvat*, are disappearing and at a quicker rate than in the past. In the community of Baker Lake, Nunavut, changes in snow have already had serious consequences. Changes in wind patterns are packing snow harder than normal, making it difficult or even impossible to build snow houses, which are still used for emergency shelters. Weather events seem to be less predictable to elders in the area, and hunters are being caught in unexpected storms unable to make shelter; several deaths in recent years have been blamed on this change in snow[33,36].

Communities all over the Arctic are living with environmental change and constantly responding to impacts of this change. Snow changes are only one part of this and local observers in the North will acknowledge that snow is bound in a web of environmental processes that are all connected. Knowledge of snow must be accompanied by knowledge of wind, weather, seasons, animals, ice, water, and ocean currents. With their long history in the Arctic and their continued use of the land, ocean, and ice, Arctic Indigenous Peoples play an important role in understanding the Arctic environment and its changes, including snow changes.

Figure 4.5: Arctic Indigenous Peoples have depended on snow for millennia, for example, using snow forms to navigate. This close interaction with snow makes them important observers of snow changes.
Photo: Shari Gearheard

from model simulations to a data set derived from NOAA visible band imagery found the model simulations of annual and interannual variability in snow-covered area to be reasonable at continental to hemispheric scales[28]. At regional scales, however, significant model biases were identified over Eurasia at the southern boundary of the seasonal snow cover. A simulation from one such model projects decreases of 60–80 per cent in monthly maximum snow water equivalent over most middle latitudes by the end of this century (Figure 4.6). The largest decreases are projected over Europe, while simulated increases are seen in the Canadian Arctic and Siberia.



Snow as an ecological factor

The importance of snow as an ecological factor has been recognized by science since at least the beginning of the 20th century[37,38]. However, even today many observations remain anecdotal. In the 1950s, Gjaerevoll[39] analysed the way in which the alpine plant community structure was shaped by snow. Within the past decade, snow manipulation experiments have explored the effects of snow depth and snow-cover duration on plant communities and ecosystem processes[40–42]. Recently, models of snow cover have been applied to ecological problems[43].

Snow cover plays a dual role in terms of temperature regulation. The high albedo of snow cover reduces net radiation, and snow also acts as a heat sink, removing energy from the atmosphere in the form of heat. This means that the presence of snow cover inhibits soil warming until the snow melts, preventing biological activity that requires temperatures above 0°C. However, snow is an efficient insulator, keeping soil temperatures near 0°C and reducing the extremes of temperature experienced by vegetation and soil in the zone under the snow (subnivean cavity). In autumn, the insulation effect of snow on unfrozen ground can even result in fungal decay of the vegetation, which can kill reindeer calves when they eat the vegetation[44]. The subnivean environment is also very humid. Under thin snow packs