SNOW AND ICE

The Earth's surface contains many forms of snow and ice, including sea, lake, and river ice; snow cover; glaciers, ice caps, and ice sheets; and frozen ground. Climate change can dramatically alter the Earth's snow- and ice-covered areas because snow and ice can easily change between solid and liquid states in response to relatively minor changes in temperature. This chapter focuses on trends in snow, glaciers, and the freezing and thawing of oceans and lakes.

WHY DOES IT MATTER?

Reduced snowfall and less snow cover on the ground could diminish the beneficial insulating effects of snow for vegetation and wildlife, while also affecting water supplies, transportation, cultural practices, travel, and recreation for millions of people. For communities in Arctic regions, reduced sea ice could increase coastal erosion and exposure to storms, threatening homes and property, while thawing ground could damage roads and buildings and accelerate erosion. Conversely, reduced snow and ice could present commercial opportunities for others, including ice-free shipping lanes and increased access to natural resources.

Such changing climate conditions can have worldwide implications because snow and ice influence air temperatures, sea level, ocean currents, and storm patterns. For example, melting ice sheets on Greenland and Antarctica add fresh water to the ocean, increasing sea level and possibly changing ocean circulation that is driven by differences in temperature and salinity. Because of their light color, snow and ice also reflect more sunlight than open water or bare ground, so a reduction in snow cover and ice causes the Earth's surface to absorb more energy from the sun and become warmer.

Summary of Key Points

Arctic Sea Ice. Part of the Arctic Ocean is covered by ice year-round. The area covered by ice is typically smallest in September, after the summer melting season. The minimum extent of Arctic sea ice has decreased over time, and in September 2012 it was the smallest on record. Arctic ice has also become thinner, which makes it more vulnerable to additional melting.

Glaciers. Glaciers in the United States and around the world have generally shrunk since the 1960s, and the rate at which glaciers are melting has accelerated over the last decade. The loss of ice from glaciers has contributed to the observed rise in sea level.

Lake Ice. Most lakes in the northern United States are freezing later and thawing earlier compared with the 1800s and early 1900s. Freeze dates have shifted later at a rate of roughly half a day to one day per decade, while thaw dates for most of the lakes studied have shifted earlier at a rate of half a day to two days per decade.

Community Connection: Ice Breakup in Two Alaskan Rivers. Regions in the far north are warming more quickly than other parts of the world. Two long-running contests on the Tanana and Yukon rivers in Alaska—where people guess the date when the river ice will break up in the spring—provide a century's worth of evidence revealing that the ice on these rivers is generally breaking up earlier in the spring than it used to.

Snowfall. Total snowfall—the amount of snow that falls in a particular location—has decreased in most parts of the country since widespread records began in 1930. One reason for this decline is that more than three-fourths of the locations studied have seen more winter precipitation fall in the form of rain instead of snow.

Snow Cover. Snow cover refers to the area of land that is covered by snow at any given time. Between 1972 and 2013, the average portion of North America covered by snow decreased at a rate of about 3,500 square miles per year, based on weekly measurements taken throughout the year. However, there has been much year-to-year variability.

Snowpack. The depth or thickness of snow on the ground (snowpack) in early spring decreased at about three-fourths of measurement sites in the western United States between 1955 and 2013. However, other locations saw an increase in spring snowpack. The average change across all sites for this time period amounts to about a 14 percent decline.

Arctic Sea Ice

This indicator tracks the extent and age of sea ice in the Arctic Ocean.

KEY POINTS

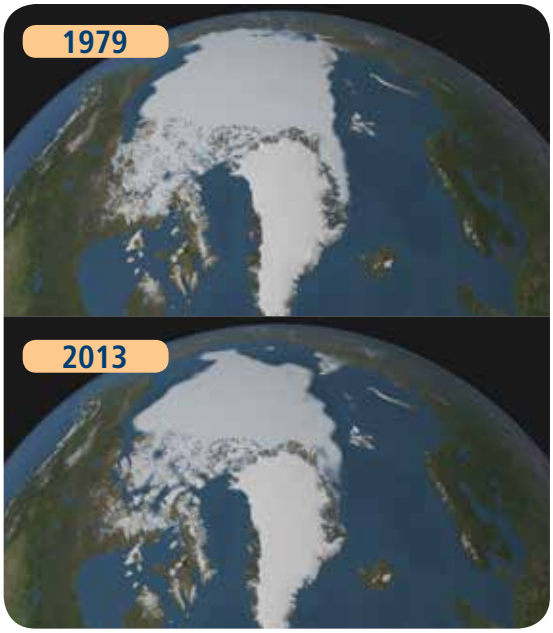
- September 2012 had the lowest sea ice extent on record, 49 percent below the 1979–2000 average for that month.
- The September 2013 sea ice extent was nearly 700,000 square miles less than the historical 1979–2000 average—a difference more than twice the size of Texas (see Figure 1).
- Although the annual minimum of sea ice extent typically occurs in September, all months have shown a decreasing trend in sea ice extent over the past several decades. The largest decreases have occurred in the summer and fall.[1, 2]
- Evidence of the age of Arctic sea ice suggests an overall loss of multi-year ice. The proportion of sea ice five years or older has declined dramatically over the recorded time period, from more than 30 percent of September ice in the 1980s to 7 percent in 2013. A growing percentage of Arctic sea ice is only one or two years old. This thinning of Arctic ice makes it more vulnerable to further melting.

Sea ice is an integral part of the Arctic Ocean. During the dark winter months, sea ice essentially covers the entire Arctic Ocean. In summer, some of this ice melts because of warmer temperatures and long hours of sunlight. Sea ice typically reaches its minimum thickness and extent in mid-September, when the area covered by ice is roughly half the size of the winter maximum. The ice then begins expanding again.

The extent of area covered by Arctic sea ice is an important indicator of changes in global climate because warmer air and water temperatures are reducing the amount of sea ice present. Because sea ice is more reflective than liquid water, it plays a significant role in the Earth's energy balance and keeping polar regions cool. (For more information on the effects of surface color on reflecting sunlight, see the Snow Cover indicator on p. 68.) Sea ice also keeps the air cool by forming a barrier between the cold air above and the warmer water below. As the amount of sea ice decreases, the Arctic region's ability to stabilize the Earth's climate is reduced, potentially leading to a "feedback loop" of more absorption of solar energy, higher air temperatures, and even greater loss of sea ice.

The age of sea ice is also an important indicator of Arctic conditions, because older ice is generally thicker and stronger than younger ice. A loss of older ice suggests that the Arctic is losing ice faster than it is accumulating it.

Dwindling Arctic Sea Ice



Source: NASA, 2014[3]

Changes in sea ice can directly affect the health of Arctic ecosystems. Mammals such as polar bears and walruses rely on the presence of sea ice for hunting, breeding, and migrating. These animals face the threat of declining birth rates and restricted access to food sources because of reduced sea ice coverage and thickness. Impacts on Arctic wildlife, as well as the loss of ice itself, are already restricting the traditional subsistence hunting lifestyle of indigenous Arctic populations such as the Yup'ik, Iñupiat, and Inuit.

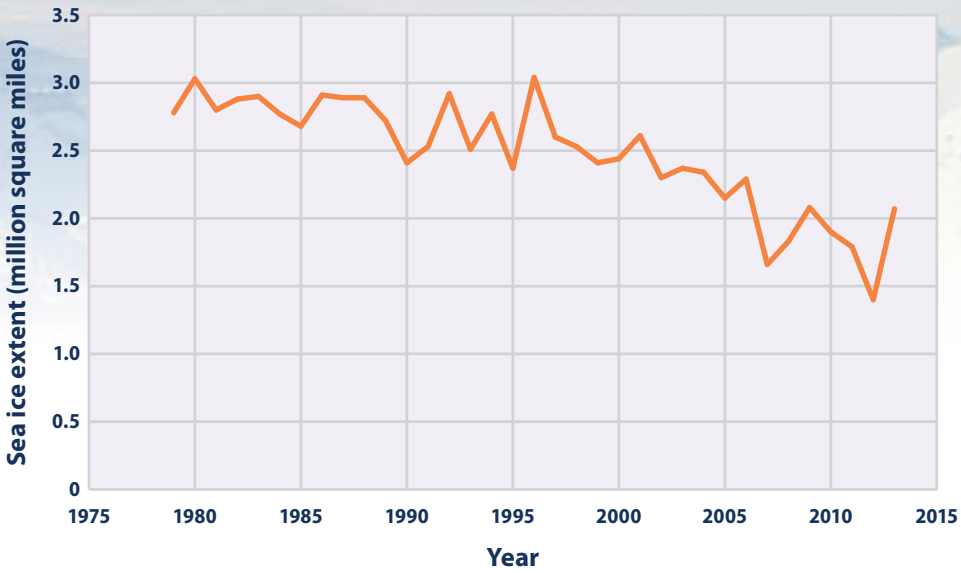
While diminished sea ice can have negative ecological effects, it can also present commercial opportunities. For instance, reduced sea ice opens shipping lanes and increases access to natural resources in the Arctic region.

ABOUT THE INDICATOR

Figure 1 presents trends in Arctic sea ice extent from 1979, when extensive measurements started, to 2013. Sea ice extent is defined as the area of ocean where at least 15 percent of the surface is frozen. This threshold was chosen because scientists have found that it gives the best approximation of the edge of the ice. Data are collected throughout the year, but for comparison, this indicator focuses on the average sea ice extent in September of each year. This is because September is typically when the sea ice extent reaches its annual minimum after melting during the spring and summer. Data for this indicator were gathered by the National Snow and Ice Data Center using satellite imaging technology.

Figure 2 examines the age of the ice that is present in the Arctic during the week in September with the smallest extent of ice. By combining daily satellite images, wind measurements, and data from surface buoys that move with the ice, scientists can track specific parcels of ice as they move over time. This tracking enables them to calculate the age of the ice in different parts of the Arctic. Although satellites started collecting data in 1979, Figure 2 only shows trends back to 1983 because it is not possible to know the full age distribution until the ice has been tracked for at least five years.

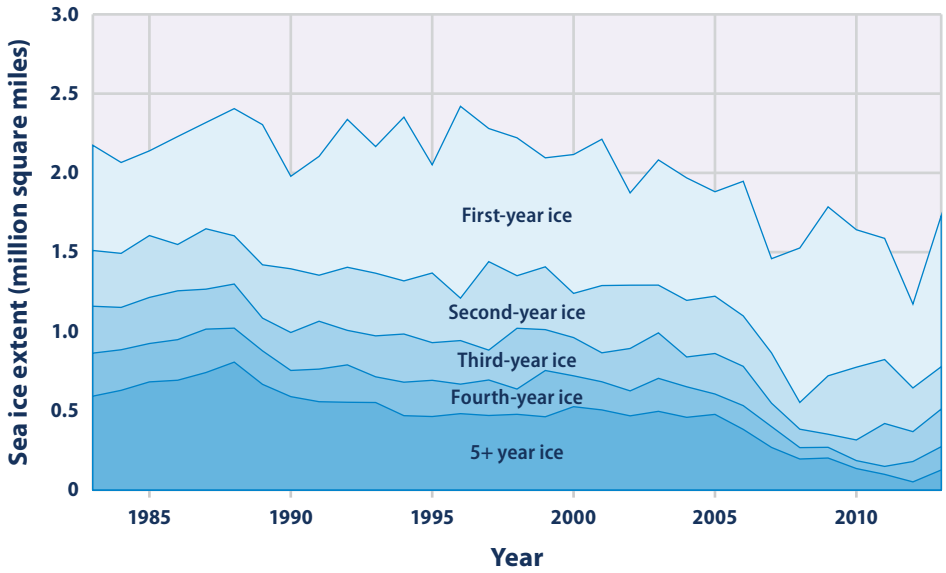
Figure 1. September Monthly Average Arctic Sea Ice Extent, 1979–2013



This figure shows Arctic sea ice extent from 1979 through 2013 using data from September of each year, which is when the minimum extent typically occurs.

Data source: NSIDC, 2013[4]

Figure 2. Age of Arctic Sea Ice at Minimum September Week, 1983–2013



This figure shows the distribution of Arctic sea ice extent by age group during the week in September with the smallest extent of ice for each year. The total extent in Figure 2 differs from the extent in Figure 1 because Figure 1 shows a monthly average, while Figure 2 shows conditions during a single week.

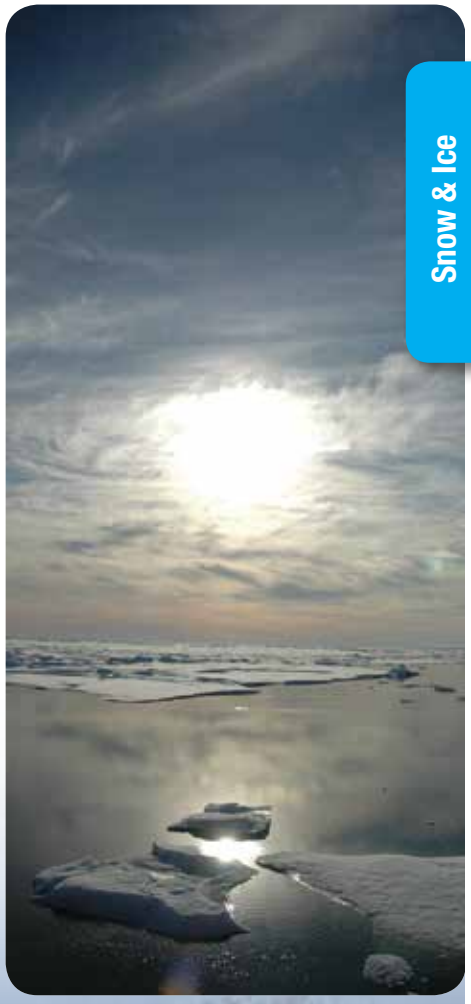
Data source: NSIDC, 2013[5]

INDICATOR NOTES

Increasing temperatures associated with climate change are not the only factor contributing to reductions in sea ice. Other conditions that may be affected by climate change, such as fluctuations in oceanic and atmospheric circulation and typical annual and decadal variability, also affect the extent of sea ice. Determining the age of ice is an imperfect science, as there are cases where a small amount of older ice might exist within an area classified as younger, or vice-versa.

DATA SOURCES

The data for this indicator were provided by the National Snow and Ice Data Center. Data for Figure 1 are also available online at: http://nsidc.org/data/seaice_index/archives.html, while Figure 2 is based on an analysis by the University of Colorado and a map published at: http://nsidc.org/arcticseaicenews/2013/10. The National Snow and Ice Data Center produces a variety of reports and a seasonal newsletter analyzing Arctic sea ice data.



Glaciers

This indicator examines the balance between snow accumulation and melting in glaciers, and it describes how glaciers in the United States and around the world have changed over time.

KEY POINTS

- On average, glaciers worldwide have been losing mass since at least the 1970s (see Figure 1), which in turn has contributed to observed changes in sea level (see the Sea Level indicator on p. 50). A longer measurement record from a smaller number of glaciers suggests that they have been shrinking since the 1940s. The rate at which glaciers are losing mass appears to have accelerated over roughly the last decade.
- All three U.S. benchmark glaciers have shown an overall decline in mass balance since the 1950s and 1960s and an accelerated rate of decline in recent years (see Figure 2). Year-to-year trends vary, with some glaciers gaining mass in certain years (for example, Wolverine Glacier during the 1980s). However, most of the measurements indicate a loss of glacier mass over time.
- Trends for the three benchmark glaciers are consistent with the retreat of glaciers observed throughout the western United States, Alaska, and other parts of the world.[6] Observations of glaciers losing mass are also consistent with warming trends in U.S. and global temperatures during this time period (see the U.S. and Global Temperature indicator on p. 28).

A glacier is a large mass of snow and ice that has accumulated over many years and is present year-round. In the United States, glaciers can be found in the Rocky Mountains, the Sierra Nevada, the Cascades, and throughout Alaska. A glacier flows naturally like a river, only much more slowly. At higher elevations, glaciers accumulate snow, which eventually becomes compressed into ice. At lower elevations, the "river" of ice naturally loses mass because of melting and ice breaking off and floating away (iceberg calving) if the glacier ends in a lake or the ocean. When melting and calving are exactly balanced by new snow accumulation, a glacier is in equilibrium and its mass will neither increase nor decrease.

In many areas, glaciers provide communities and ecosystems with a reliable source of streamflow and drinking water, particularly in times of extended drought and late in the summer, when seasonal snowpack has melted away. Freshwater runoff from glaciers also influences ocean ecosystems. Glaciers are important as an indicator of climate change because physical changes in glaciers—whether they are growing or shrinking, advancing or receding—provide visible evidence of changes in temperature and precipitation. If glaciers lose more ice than they can accumulate through new snowfall, they ultimately add more water to the oceans, leading to a rise in sea level (see the Sea Level indicator on p. 50). The same kinds of changes occur on a much larger scale within the giant ice sheets that cover Greenland and Antarctica, potentially leading to even bigger implications for sea level. Small glaciers tend to respond more quickly to climate change than the giant ice sheets. Altogether, the world's small glaciers are adding roughly the same amount of water to the oceans per year as the ice sheets of Greenland and Antarctica. During the last two decades, they added more water overall to the oceans than the ice sheets did.[7]

ABOUT THE INDICATOR

This indicator is based on long-term monitoring data collected at selected glaciers around the world. Scientists collect detailed measurements to determine glacier mass balance, which is the net gain or loss of snow and ice over the course of the year. A negative mass balance indicates that a glacier has lost ice or snow. If cumulative mass balance becomes more negative over time, it means glaciers are losing mass more quickly than they can accumulate new snow.

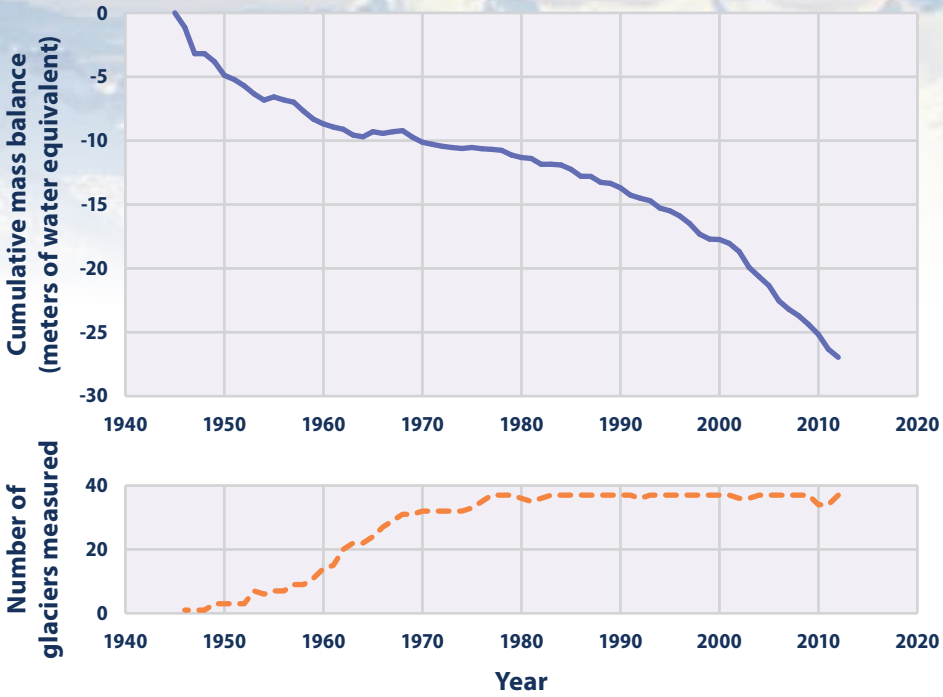
Figure 1 shows trends in mass balance for a set of 37 reference glaciers around the world that have been measured consistently since the 1970s, including a few that have been measured since the 1940s. Data from these reference glaciers have been averaged together to depict changes over time. Figure 2 shows trends for three "benchmark" glaciers: South Cascade Glacier in Washington state, Wolverine Glacier near Alaska's southern coast, and Gulkana Glacier in Alaska's interior. These three glaciers were chosen because they have been studied extensively by the U.S. Geological Survey for many years and because they are thought to be representative of other glaciers nearby.

This indicator describes the change in glacier mass balance, which is measured as the average change in thickness across the surface of a glacier. The change in ice or snow has been converted to the equivalent amount of liquid water.

Photographs of McCall Glacier, Alaska, 1958 and 2003

Sources: Post, 1958;[8] Nolan, 2003[9]

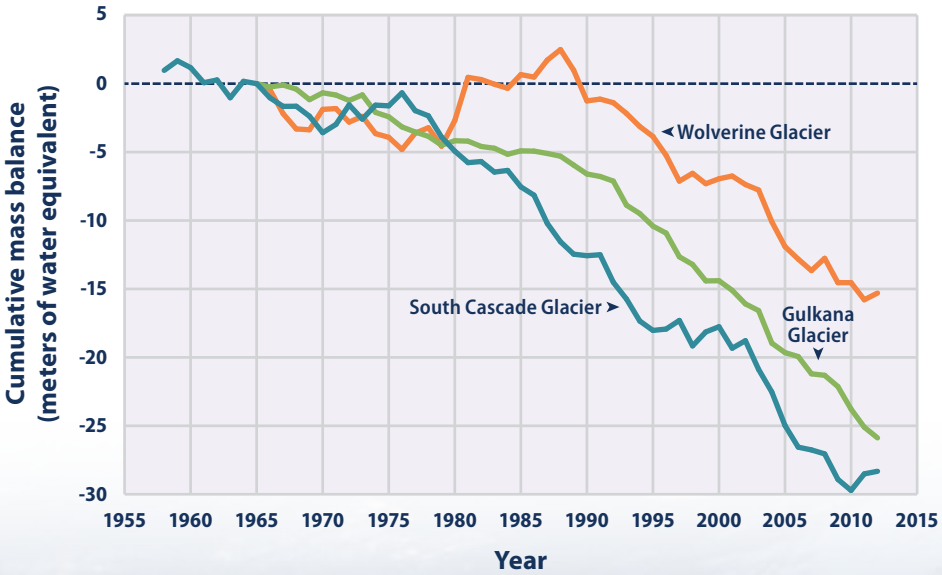
Figure 1. Average Cumulative Mass Balance of "Reference" Glaciers Worldwide, 1945–2012



This figure shows the cumulative change in mass balance of a set of "reference" glaciers worldwide beginning in 1945. The line on the graph represents the average of all the glaciers that were measured. Negative values indicate a net loss of ice and snow compared with the base year of 1945. For consistency, measurements are in meters of water equivalent, which represent changes in the average thickness of a glacier. The small chart below shows how many glaciers were measured in each year. Some glacier measurements have not yet been finalized for the last few years, hence the smaller number of sites.

Data sources: WGMS, 2013,[10] 2014[11]

Figure 2. Cumulative Mass Balance of Three U.S. Glaciers, 1958–2012



This figure shows the cumulative mass balance of the three U.S. Geological Survey "benchmark" glaciers since measurements began in the 1950s or 1960s. For each glacier, the mass balance is set at zero for the base year of 1965. Negative values indicate a net loss of ice and snow compared with the base year. For consistency, measurements are in meters of water equivalent, which represent changes in the average thickness of a glacier.

Data sources: O'Neel and Sass, 2013;[12] USGS, 2014[13]

Glaciers Shown in Figure 2

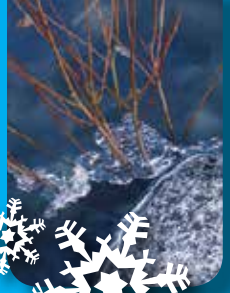
INDICATOR NOTES

The relationship between climate change and glacier mass balance is complex, and the observed changes at specific reference or benchmark glaciers might reflect a combination of global and local variations in temperature and precipitation. Individual glaciers also vary in their structure, flow, and response to climate. Slightly different measurement and analysis methods have been used at different glaciers, but overall trends appear to be similar.

Long-term measurements are available for only a relatively small percentage of the world's glaciers. This indicator does not include the Greenland and Antarctic ice sheets, although two decades of satellite data suggest that these ice sheets are also experiencing a net loss of ice.[14] Continued satellite data collection will allow scientists to evaluate long-term trends in the future.

DATA SOURCES

The World Glacier Monitoring Service compiled data for Figure 1, based on measurements collected by a variety of organizations around the world. The U.S. Geological Survey Benchmark Glacier Program provided the data for Figure 2. These data, as well as periodic reports and measurements of the benchmark glaciers, are available on the program's website at: http://ak.water.usgs.gov/glaciology.



Lake Ice

This indicator measures the amount of time that ice is present on lakes in the United States.

KEY POINTS

- The lakes covered by this indicator are generally freezing later than they did in the past. Freeze dates have shifted later at a rate of roughly half a day to one day per decade (see Figure 1).
- Thaw dates for most of these lakes show a general trend toward earlier ice breakup in the spring (see Figure 2). Thaw dates have grown earlier by up to 23 days in the past 107 years, except for two lakes that remained unchanged (see Figure 3). None of these lakes were found to be thawing later in the year.
- The changes in lake freeze and thaw dates shown here are consistent with other studies. For example, a broad study of lakes and rivers throughout the Northern Hemisphere found that since the mid-1800s, freeze dates have occurred later and thaw dates have occurred earlier, both shifting at an average rate of 0.8 days to one day per decade.[15]

The formation of ice cover on lakes in the winter and its disappearance the following spring depends on climate factors such as air temperature, cloud cover, and wind. Conditions such as heavy rains or snowmelt in locations upstream or elsewhere in the watershed also affect the length of time a lake is frozen. Thus, ice formation and breakup dates are key indicators of climate change. If lakes remain frozen for longer periods, it can signify that the climate is cooling. Conversely, shorter periods of ice cover suggest a warming climate.

Changes in ice cover can affect the physical, chemical, and biological characteristics of a body of water. For example, ice influences heat and moisture transfers between a lake and the atmosphere. Reduced ice cover leads to increased evaporation and lower water levels, as well as an increase in water temperature and sunlight penetration. These changes, in turn, can affect plant and animal life cycles and the availability of suitable habitat. Additionally, ice cover affects the amount of heat that is reflected from the Earth's surface. Exposed water will absorb and retain heat, making the Earth's surface warmer, whereas an ice- and snow-covered lake will reflect more of the sun's energy and absorb less. (For more information on ice and snow reflecting sunlight, see the Snow Cover indicator on p. 68.)

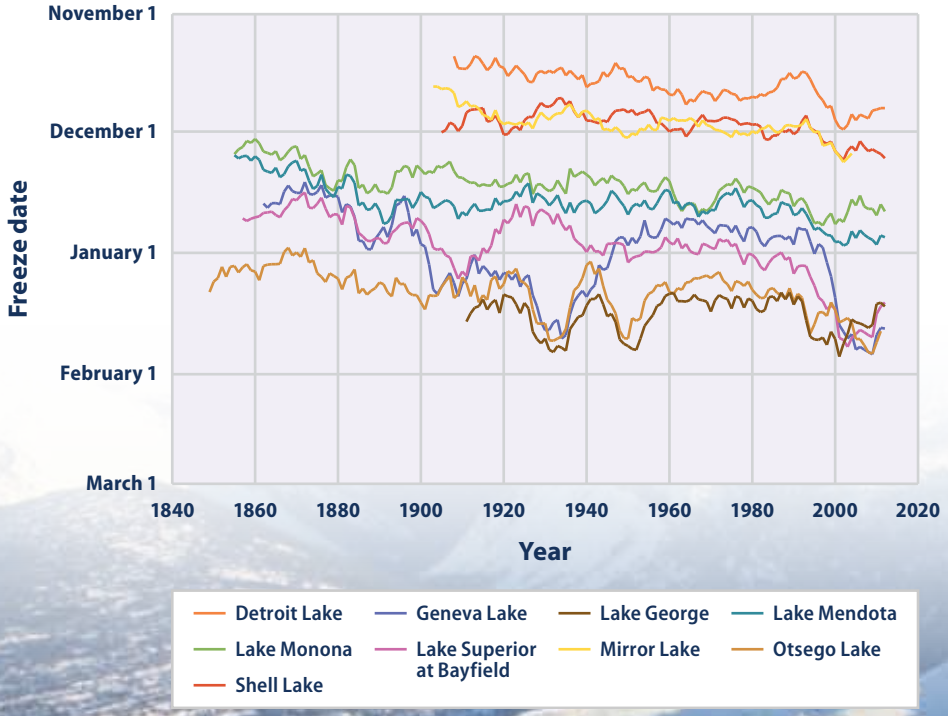
The timing and duration of ice cover on lakes and other bodies of water can also affect society—particularly in relation to shipping and transportation, hydroelectric power generation, and fishing. The impacts can be positive or negative. For example, reduced ice cover on a large lake could extend the open-water shipping season but require vessels to reduce their cargo capacity, as increased evaporation leads to lower water levels.

ABOUT THE INDICATOR

This indicator analyzes the dates at which lakes freeze and thaw. Freeze dates occur when a continuous and immobile ice cover forms over a body of water. Thaw dates occur when the ice cover breaks up and open water becomes extensive.

Freeze and thaw dates have been recorded through human visual observations for more than 150 years. The National Snow and Ice Data Center maintains a database with freeze and thaw observations from more than 700 lakes and rivers throughout the Northern Hemisphere. This indicator focuses on 14 lakes within the United States that have the longest and most complete historical records. The lakes of interest are located in Minnesota, Wisconsin, New York, and Maine.

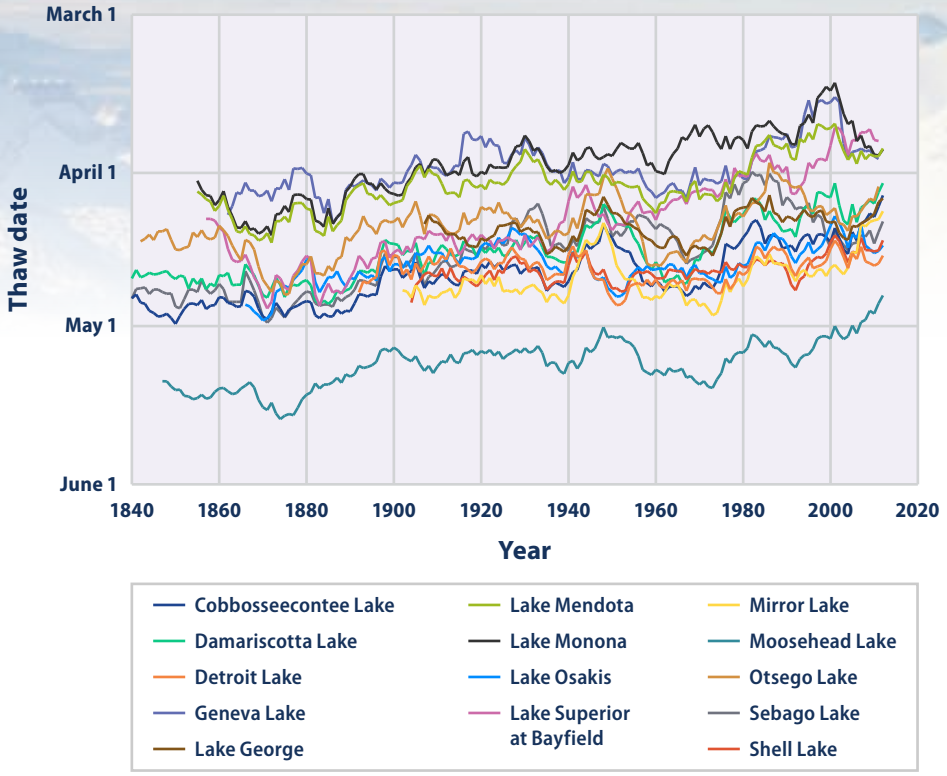
Figure 1. Date of First Freeze for Selected U.S. Lakes, 1850–2012



This figure shows the "ice-on" date, or date of first freeze, for nine U.S. lakes. The data are available from as early as 1850 to 2012, depending on the lake, and have been smoothed using a nine-year moving average.

Data source: Various organizations[16]

Figure 2. Date of Ice Thaw for Selected U.S. Lakes, 1850–2012



This figure shows the "ice-off" date, or date of ice thawing and breakup, for 14 U.S. lakes. The data are available from as early as 1850 to 2012, depending on the lake, and have been smoothed using a nine-year moving average.

Data source: Various organizations[17]

Figure 3. Change in Ice Thaw Dates for Selected U.S. Lakes, 1905–2012

This figure shows the change in the "ice-off" date, or date of ice thawing and breakup, for 14 U.S. lakes during the period from 1905 to 2012. All but two of the lakes have red circles with negative numbers, which represent earlier thaw dates. The other two lakes have not experienced a significant change in thaw dates. Larger circles indicate larger changes.

Data source: Various organizations[18]

INDICATOR NOTES

Although there is a lengthy historical record of freeze and thaw dates for a much larger set of lakes and rivers, some records are incomplete, with breaks ranging from brief lapses to large gaps in data. This indicator is limited to 14 lakes with sufficiently complete historical records. The four Maine lakes and Lake Osakis only have data for ice thaw, so they do not appear in Figure 1 (first freeze date).

Data used in this indicator are all based on visual observations. While the procedures for making observations of lake ice are consistent over time, visual observations by individuals are open to some interpretation and can differ from one individual to the next. In addition, historical observations for lakes have typically been made from a particular spot on the shore, which might not be representative of lakes as a whole or comparable to satellite-based observations. Considerations for defining the thaw date are specific to each lake.

DATA SOURCES

Data through 2004 for most lakes were obtained from the Global Lake and River Ice Phenology Database, which is maintained by the National Snow and Ice Data Center. These data are available at: http://nsidc.org/data/lake_river_ice. More recent data were obtained from state, local, and other organizations that collected or compiled the observations.

Ice Breakup in Two Alaskan Rivers

KEY POINTS

- The Tanana and Yukon rivers both demonstrate long-term trends toward earlier ice breakup in the spring. The ice breakup dates for both the Tanana and Yukon rivers have shifted earlier by six to seven days over their respective periods of record.
- Despite the overall trend toward earlier breakup, the most recent breakup dates for both rivers are within the range of historical variation.

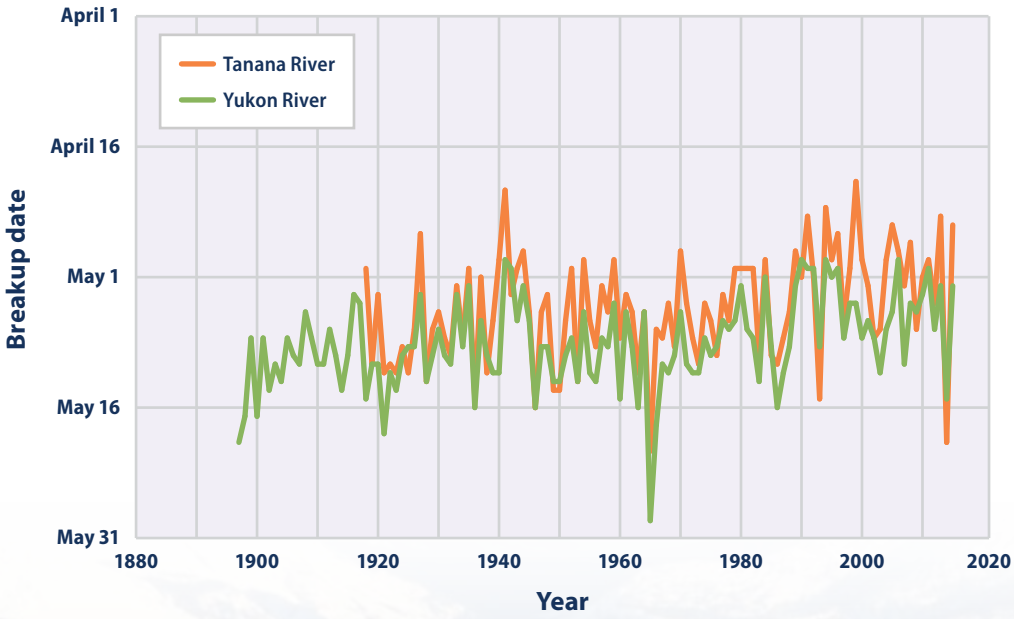
Regions in the far north are warming more quickly than other parts of the world, and this pattern is expected to continue[19,20] (see the Arctic Sea Ice indicator on p. 58; for more information about regional temperature changes, see the U.S. and Global Temperature indicator on p. 28). The Tanana and Yukon rivers in Alaska provide a particularly noteworthy record of northern climate because, for a century or more, local citizens have recorded the date when the ice on these rivers starts to move or break up each spring. In fact, some towns have annual competitions to guess when ice breakup will occur.

Since 1917, the Nenana Ice Classic competition on the Tanana River in central Alaska has paid several million dollars in winnings to the people who come closest to guessing the exact date and time of day when the river ice will break up. A similar tradition exists in Dawson City on the Yukon River, just across the border in Canada, where breakup dates have been recorded since 1896.

River ice breakup is more than just a friendly competition, though. Ice breakup is an important time of transition for communities that rely on these relatively remote and unmodified (wild) rivers for transportation, subsistence hunting and fishing, and other needs. In addition, early thawing can lead to severe ice movement, jamming, damage to infrastructure, and destructive floods.[21]

The data collected by these communities highlights how the river ice breakup dates in Nenana and Dawson City have changed over time. Both towns use the same method to measure the exact time of river ice breakup. Residents place a tripod on the ice in the center of the river. This tripod is attached by a cable to a clock on the shore. When the ice under the tripod breaks or starts to move, the tripod moves, pulling the cable and stopping the clock.

Figure 1. Ice Breakup Dates for Two Alaskan Rivers, 1896–2014



This figure shows the date each year when ice breaks up at two locations: the town of Nenana on the Tanana River and Dawson City on the Yukon River.

Data sources: Nenana Ice Classic, 2014;[22] Yukon River Breakup, 2014[23]

Town Locations on the Tanana and Yukon Rivers

NOTES

Besides climate change, natural year-to-year variations and other factors such as local development and land use patterns can influence ice breakup dates. The two locations featured here are relatively remote and undeveloped, so the ice breakup dates are more likely to reflect natural changes in weather and climate conditions. However, corresponding measurements of water conditions and air temperature would be useful to help understand the connection between changes in river ice breakup and changes in climate.

DATA SOURCES

Ice breakup dates for the Tanana River at Nenana and the Yukon River at Dawson City have been recorded and made publicly available as part of two long-running, community competitions: the Nenana Ice Classic and the Yukon River Breakup. The data shown here and other information can be found online at: www.nenanaakiceclassic.com and http://yukon-riverbreakup.com. Data records of ice breakup dates for these two rivers are also archived by the National Snow and Ice Data Center at: http://nsidc.org/data/lake_river_ice.

Snowfall

This indicator uses two different measures to show how snowfall has changed in the contiguous 48 states.

KEY POINTS

- Total snowfall has decreased in many parts of the country since widespread observations became available in 1930, with 57 percent of stations showing a decline (see Figure 1). Among all of the stations shown, the average change is a decrease of 0.19 percent per year.
- In addition to changing the overall rate of precipitation, climate change can lead to changes in the type of precipitation. One reason for the decline in total snowfall is because more winter precipitation is falling in the form of rain instead of snow. More than three-fourths of the stations across the contiguous 48 states have experienced a decrease in the proportion of precipitation falling as snow (see Figure 2).
- Snowfall trends vary by region. The Pacific Northwest has seen a decline in both total snowfall and the proportion of precipitation falling as snow. Parts of the Midwest have also experienced a decrease, particularly in terms of the snow-to-precipitation ratio. A few regions have seen modest increases, including some areas near the Great Lakes that now receive more snow than they used to (see Figures 1 and 2).

Snowfall is an important aspect of winter in much of the United States. Many people depend on snow to provide water when it melts in the spring—including 60 million people in the western United States[24]—and many communities rely on snow for winter recreation. Some plants and animals also depend on snow and snowmelt for survival. The amount of snow that falls in a particular area directly influences both snow cover and snowpack, which refer to snow that accumulates on the ground (see the Snow Cover indicator on p. 68 and the Snowpack indicator on p. 70).

Warmer temperatures cause more water to evaporate from the land and oceans, which leads to more precipitation, larger storms, and more variation in precipitation in some areas. In general, a warmer climate will cause more of this precipitation to fall in the form of rain instead of snow. However, some places could see more snowfall if temperatures rise but still remain below the freezing point, or if storm tracks change. Areas near large lakes might also experience more snowfall as lakes remain unfrozen for longer periods, allowing more water to evaporate. In contrast, other areas might experience less snowfall as a result of wintertime droughts.

Changes in the amount and timing of snowfall could affect the spawning of fish in the spring and the amount of water available for people to use in the spring and summer. Changes in snowfall could also affect winter recreation activities, like skiing, and the communities that rely on these activities.

ABOUT THE INDICATOR

This indicator tracks total snowfall as well as the percentage of precipitation that falls in the form of snow versus rain. These data were collected from hundreds of weather stations across the contiguous 48 states.

Total snowfall is determined by the height of snow that accumulates each day. These measured values commonly appear in weather reports (for example, a storm that deposits 10 inches of snow). Figure 1 shows how snowfall accumulation totals changed between 1930 and 2007 at more than 400 weather stations. These stations were selected because they had high-quality data for this entire time period.

Figure 2 shows trends in the proportion of total precipitation that falls in the form of snow during each winter season. This is called the "snow-to-precipitation" ratio, and it is based on comparing the amount of snowfall with the total amount of precipitation (snow plus rain) in each year. For this comparison, snow has been converted to the equivalent amount of liquid water. These data are available from 1949 to 2014.

INDICATOR NOTES

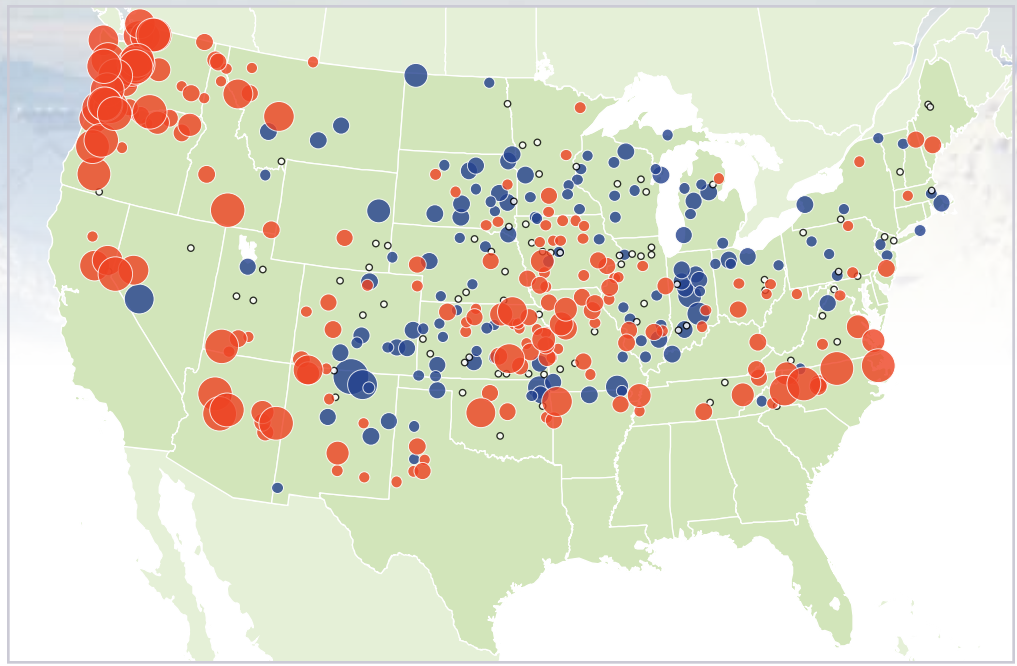
Several factors make it difficult to measure snowfall precisely. The snow accumulations shown in Figure 1 are based on the use of measuring rods. This measurement method is subject to human error, as well as the effects of wind (drifting snow) and the surrounding environment (such as tall trees). Similarly, snow gauges for Figure 2 may catch less snow than rain because of the effects of wind. However, steps have been taken to limit this indicator to weather stations with the most consistent methods and the highest-quality data.[25] As a result, some parts of the country have a higher station density than others.

Both figures are limited to the winter season. Figure 1 comes from an analysis of October-to-May snowfall, while Figure 2 covers November through March. Although these months account for the vast majority of snowfall in most locations, this indicator might not represent the entire snow season in some areas. Most of the data shown for mountainous regions come from lower elevations (towns in valleys) because that is where weather stations tend to be located.

DATA SOURCES

This indicator shows trends based on two sets of weather records collected and maintained by the National Oceanic and Atmospheric Administration. Figure 1 was adapted from an analysis by Kunkel et al. (2009)[26] based on records from Cooperative Observer Program weather stations. Figure 2 is an updated version of an analysis by Feng and Hu (2007)[27] using data from the U.S. Historical Climatology Network. Additional information about the Cooperative Observer Program is available online at: www.nws.noaa.gov/om/coop. Information about the U.S. Historical Climate Network can be found at: www.ncdc.noaa.gov/oa/climate/research/ushcn.

Figure 1. Change in Total Snowfall in the Contiguous 48 States, 1930–2007



Rate of change (percent per year):

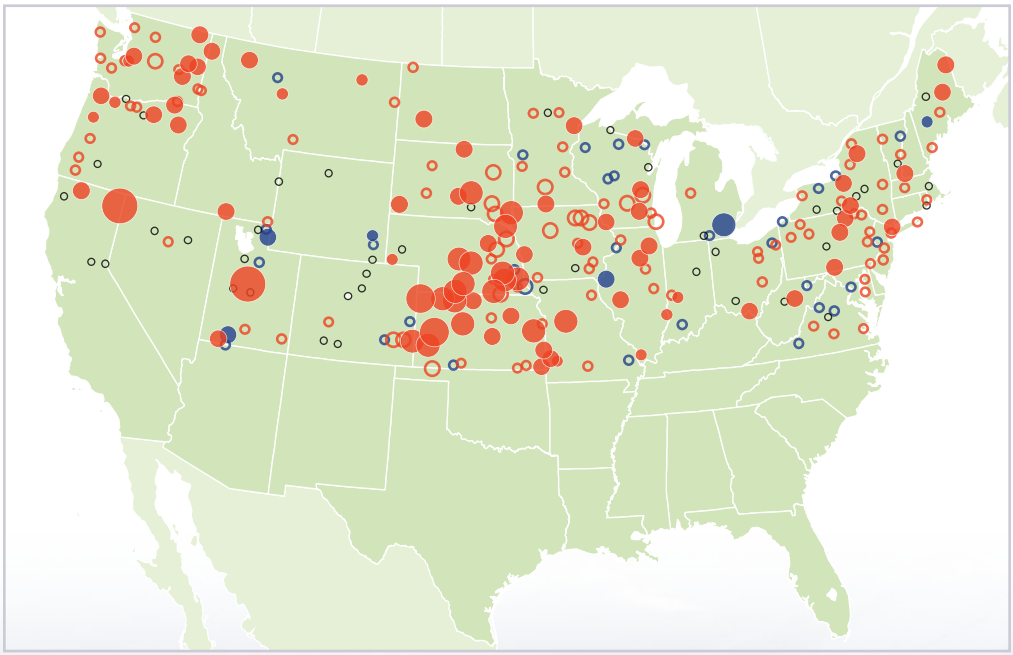
< -1.2	-0.9 to -1.2	-0.6 to -0.9	-0.3 to -0.6	-0.1 to -0.3	-0.1 to 0.1	0.1 to 0.3	0.3 to 0.6	0.6 to 0.9	0.9 to 1.2	> 1.2

Less snowfall ← → More snowfall

This figure shows the average rate of change in total snowfall from 1930 to 2007 at 419 weather stations in the contiguous 48 states. Blue circles represent increased snowfall; red circles represent a decrease.

Data source: Kunkel et al., 2009[28]

Figure 2. Change in Snow-to-Precipitation Ratio in the Contiguous 48 States, 1949–2014



Percent change:

< -40	-30 to -40	-20 to -30	-10 to -20	-2 to -10	-2 to 2	2 to 10	10 to 20	20 to 30	30 to 40	> 40

Lower percentage of snow ← → Higher percentage of snow

Filled circles represent statistically significant trends.
Open circles represent trends that are not statistically significant.

This figure shows the percentage change in winter snow-to-precipitation ratio from 1949 to 2014 at 261 weather stations in the contiguous 48 states. This ratio measures what percentage of total winter precipitation falls in the form of snow. A decrease (red circle) indicates that more precipitation is falling in the form of rain instead of snow. Filled circles represent stations where the trend was statistically significant.

Data source: NOAA, 2014[29]

Snow Cover

This indicator measures the amount of land in North America that is covered by snow.

KEY POINTS

- When averaged over the entire year, snow covered an average of 3.25 million square miles of North America during the period from 1972 to 2013 (see Figure 1).
- The extent of snow cover has varied from year to year. The average area covered by snow has ranged from 3.0 million to 3.6 million square miles, with the minimum value occurring in 1998 and the maximum in 1978 (see Figure 1).
- Between 1972 and 2013, the average extent of North American snow cover decreased at a rate of about 3,500 square miles per year. The average area covered by snow during the most recent decade (2004–2013) was 3.21 million square miles, which is about 4 percent smaller than the average extent during the first 10 years of measurement (1972–1981)—a difference of 120,000 square miles, or approximately an area the size of New Mexico (see Figure 1).
- Decreases in snow cover have largely occurred in spring and summer, whereas fall and winter snow cover have remained fairly steady over the time period studied (see Figure 2). Spring and summer snow cover can have a particularly important influence on water supplies.

Snow cover refers to the amount of land covered by snow at any given time. Naturally, it is influenced by the amount of precipitation that falls as snow. Air temperature also plays a role because it determines whether precipitation falls as snow or rain, and it affects the rate at which snow on the ground will melt. As temperature and precipitation patterns change, so can the overall area covered by snow.

Snow cover is not just something that is affected by climate change; it also exerts an influence on climate. Because snow is white, it only absorbs a small portion of the sunlight that hits it (10 to 20 percent in the case of fresh snow), and it reflects the rest back to space. In contrast, darker surfaces such as bare ground and open water absorb the majority of the energy they receive and heat up more quickly. In this way, the overall amount of snow cover affects patterns of heating and cooling over the Earth's surface. More snow means more energy reflects back to space, resulting in cooling, while less snow cover means more energy is absorbed at the Earth's surface, resulting in warming.

On a more local scale, snow cover is important for many plants and animals. For example, some plants rely on a protective blanket of snow to insulate them from sub-freezing winter temperatures. Humans and ecosystems also rely on snowmelt to replenish streams and ground water.

ABOUT THE INDICATOR

This indicator tracks the total area covered by snow across all of North America (not including Greenland) since 1972. It is based on maps generated by analyzing satellite images collected by the National Oceanic and Atmospheric Administration. The indicator was created by analyzing each weekly map to determine the extent of snow cover, then averaging the weekly observations together to get a value for each year. Average snow cover was also calculated for each season: spring (defined as March–May), summer (June–August), fall (September–November), and winter (December–February).

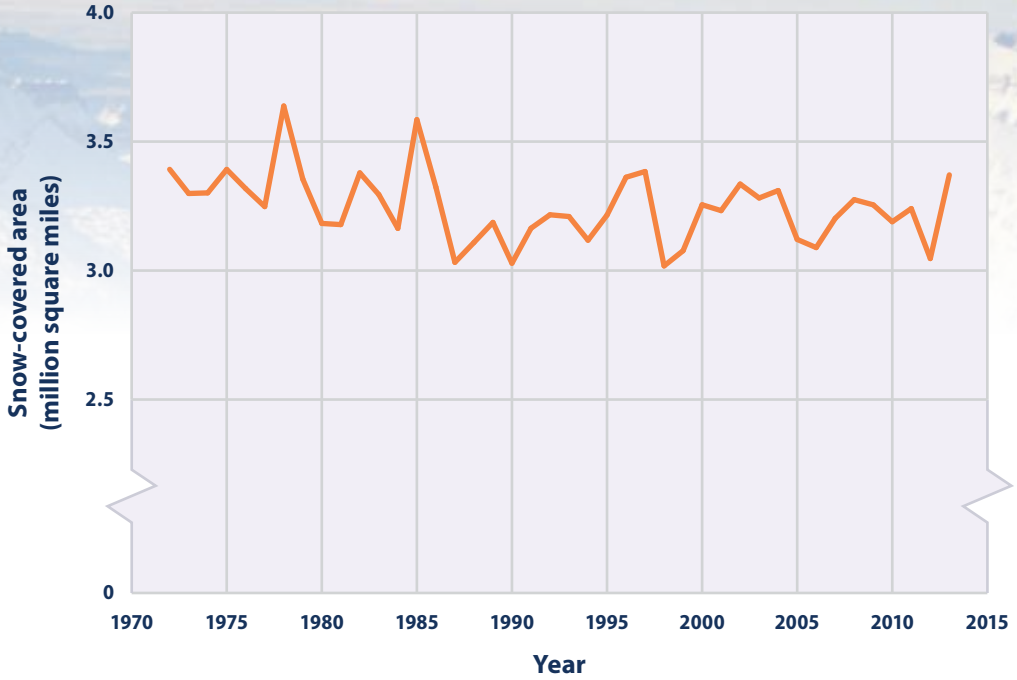
INDICATOR NOTES

Although satellite-based snow cover maps are available starting in the mid-1960s, some of the early years are missing data from several weeks during the summer, which would lead to an inaccurate annual average. Thus, the indicator is restricted to 1972 and later, with all years having a full set of data.

DATA SOURCES

The data for this indicator were provided by the Rutgers University Global Snow Lab, which posts data online at: http://climate.rutgers.edu/snowcover. The data are based on measurements collected by the National Oceanic and Atmospheric Administration's National Environmental Satellite, Data, and Information Service at: www.nesdis.noaa.gov.

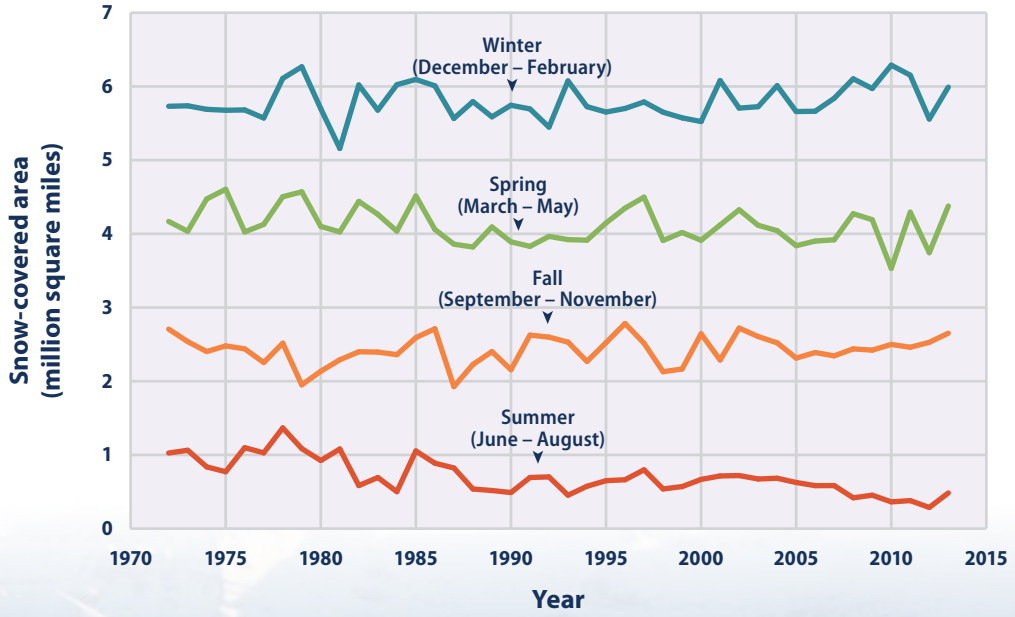
Figure 1. Snow-Covered Area in North America, 1972–2013



This graph shows the average area covered by snow in a given calendar year, based on an analysis of weekly maps. The area is measured in square miles. These data cover all of North America (not including Greenland).

Data source: Rutgers University Global Snow Lab, 2014[30]

Figure 2. Snow-Covered Area in North America by Season, 1972–2013



This graph shows the average area covered by snow during spring (March–May), summer (June–August), fall (September–November), and winter (December–February), based on an analysis of weekly maps. The area is measured in square miles. These data cover all of North America (not including Greenland).

Data source: Rutgers University Global Snow Lab, 2014[31]

Snowpack

This indicator measures trends in mountain snowpack in the western United States.

KEY POINTS

- From 1955 to 2013, April snowpack declined at about three-fourths of the sites measured (see Figure 1). The average change across all sites amounts to about a 14 percent decline.
- In general, the largest and most consistent decreases were observed in Washington, Oregon, and the northern Rockies.
- Some areas have seen increases in snowpack, primarily in the southern Sierra Nevada of California.

Temperature and precipitation are key factors affecting snowpack, which is the amount or thickness of snow that accumulates on the ground. In a warming climate, more precipitation will be expected to fall as rain rather than snow in most areas—reducing the extent and depth of snowpack. Higher temperatures in the spring can cause snow to melt earlier.

Mountain snowpack plays a key role in the water cycle in western North America, storing water in the winter when the snow falls and releasing it as runoff in spring and summer when the snow melts. Millions of people in the West depend on the melting of mountain snowpack for power, irrigation, and drinking water. In most western river basins, snowpack is a larger component of water storage than human-constructed reservoirs.[32]

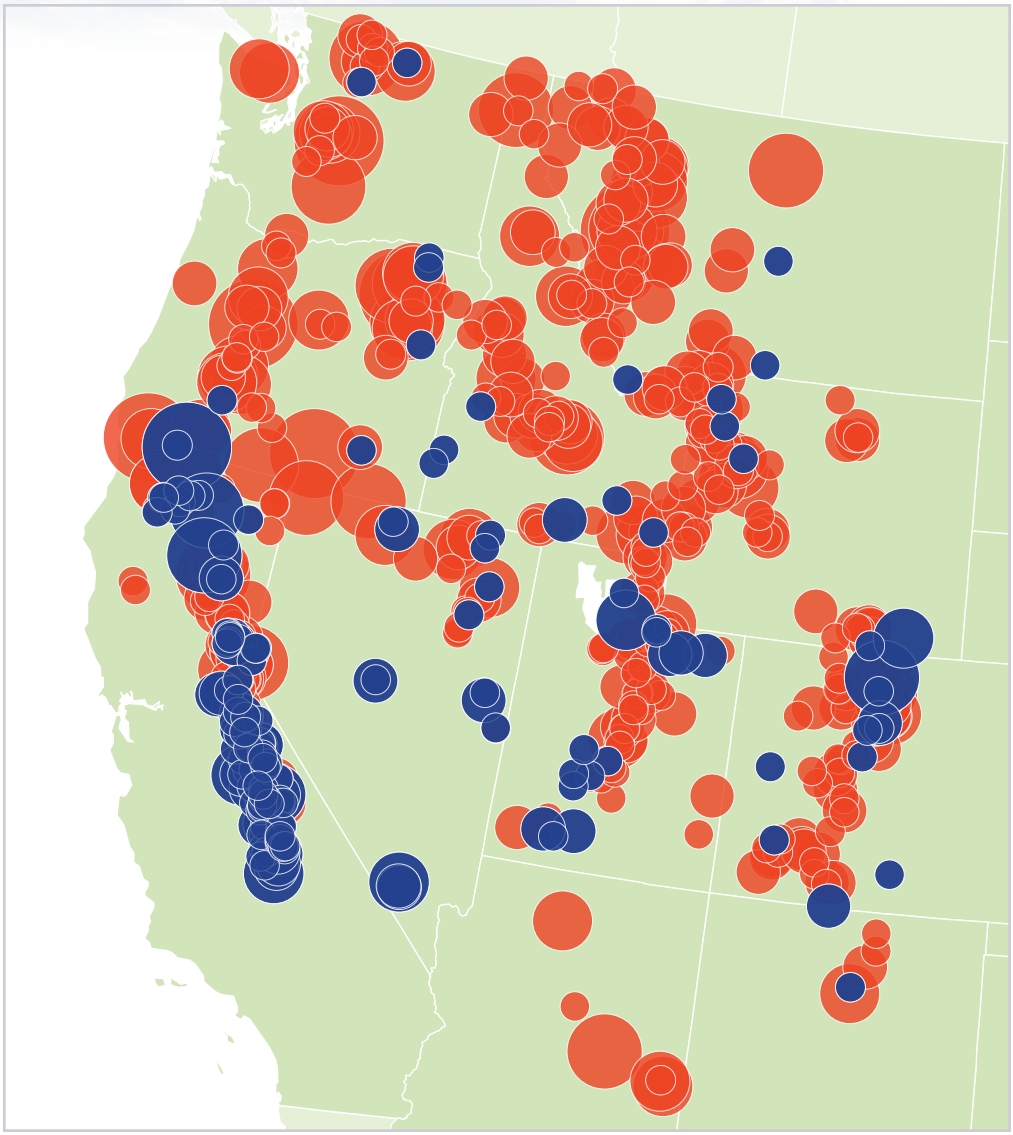
Changes in mountain snowpack can affect agriculture, winter recreation, and tourism in some areas, as well as plants and wildlife. For example, certain types of trees rely on snow for insulation from freezing temperatures, as do some animal species. In addition, fish spawning could be disrupted if changes in snowpack or snowmelt alter the timing and abundance of streamflows.

ABOUT THE INDICATOR

This indicator uses a measurement called snow water equivalent to determine trends in snowpack. Snow water equivalent is the amount of water contained within the snowpack at a particular location. It can be thought of as the depth of water that would result if the entire snowpack were to melt.

The U.S. Department of Agriculture and other collaborators have measured snowpack since the early 1900s. In the early years of data collection, researchers measured snow water equivalent manually, but since 1980, measurements at some locations have been collected with automated instruments. This indicator is based on data from approximately 700 permanent measurement sites in the western United States. The indicator shows long-term rates of change for the month of April, which could reflect changes in winter snowfall as well as the timing of spring snowmelt.

Figure 1. Trends in April Snowpack in the Western United States, 1955–2013



Percent change:

< -80 | -60 to -80 | -40 to -60 | -20 to -40 | 0 to -20 | 0 to 20 | 20 to 40 | 40 to 60 | 60 to 80 | > 80

This map shows trends in April snowpack in the western United States, measured in terms of snow water equivalent. Blue circles represent increased snowpack; red circles represent a decrease.

Data source: Mote and Sharp, 2014[33]

INDICATOR NOTES

EPA selected 1955 as a starting point for this analysis because many measurement sites in the Southwest were established in the early 1950s. Natural variability in the Earth's climate means that snowpack trends may vary slightly when measured over different time periods. For example, the period from 1945 to 1955 was unusually snowy in the Northwest, so if this indicator were to start in 1945 or 1950, the Northwest would appear to show larger decreases over time. However, the general direction of the trend is the same regardless of the start date.

Although most parts of the West have seen reductions in snowpack—consistent with overall warming trends shown in the U.S. and Global Temperature indicator (p. 28)—snowfall trends may be partially influenced by non-climatic factors such as observation methods, land-use changes, and forest canopy changes.

DATA SOURCES

Data for this indicator came from the U.S. Department of Agriculture's Natural Resources Conservation Service Water and Climate Center and the California Department of Water Resources. The map was constructed using methods described by Mote et al. (2005).[34] The U.S. Department of Agriculture data are available at: www.wcc.nrcs.usda.gov. The California Department of Water Resources data are available at: http://cdec.water.ca.gov/snow/current/snow/index.html.