Climate science

Snow loss pinned to human-induced emissions

Jouni Pulliainen

Analysis of a large, varied data set reveals that snow cover in the Northern Hemisphere has undergone marked changes in the past four decades. Evidence that humans caused the shift suggests that snow loss will accelerate in the future. See p.293

Predicting how anthropogenic climate change will affect the future availability of fresh water requires an understanding of variations in Earth's seasonal snow cover – and how human-induced changes differ from natural fluctuations. But obtaining such information is no easy feat. On page 293, Gottlieb and Mankin[1] introduce a promising approach to the problem, which combines historical observations of snow mass in the Northern Hemisphere with spatially unified records of snow-cover evolution and climate-model predictions. The study reveals a surprising nonlinear relationship between snow mass and temperature, which has complex ramifications.

Satellite data have previously identified considerable shrinkage in the extent of Earth's seasonal snow cover during the past four decades[2,3]. The water that flows through rivers in the Northern Hemisphere is mainly melted snow, which underlines the importance of understanding snow loss and the role that humans have in inducing it[4]. Snow mass is a more complicated indicator to analyse than is the extent of snow, because trends in snow mass depend heavily on regional changes in precipitation during the winter months. Indeed, although the general pattern across the Northern Hemisphere indicates that snow mass has decreased since 1980, some cold regions that have historically had low amounts of seasonal snow have experienced substantial increases in snow mass[5,6].

The most likely reason for this anomaly is that, despite rising global temperatures, cold regions remain well below freezing during winter. For example, marked increases in March snow masses were observed[6] in the second half of the 2010s in eastern Siberia, Russia, and these were a result of an increase in snowfall – a phenomenon that might have been caused by the diminishing sea-ice cover in nearby areas. By measuring the composition of chemical isotopes in water vapour, scientists have found evidence to suggest that a reduction in Arctic sea ice has also induced heavy snowfall events across continental Europe[7].

Gottlieb and Mankin have further teased out the complex relationship between snow mass and temperature.

The authors analysed an ensemble of 'gridded' observations (measurements that are interpolated over a spatially uniform grid) of March snow mass across the Northern Hemisphere. Snow mass is characterized using a common measure known as snow water equivalent – the depth of water released by instantaneous snow melt. Gottlieb and Mankin focused on March because it is the month of maximum snow mass in the Northern Hemisphere. As well as gridded snow data, temperature and precipitation information, their analysis included an ensemble of climate-model predictions of these variables. The authors modelled the historical change in snow water equivalent on the basis of observations, and estimated the impact of humans on snow loss by combining the data-based model with climate-model predictions.

In general, climate-model simulations do not capture the spatio-temporal behaviour of snow water equivalent accurately enough to register changes at the scale of river basins. Gottlieb and Mankin overcame this problem by assessing the relationship between snow mass and the two driving variables – precipitation and temperature – through analysis of an extensive data set of observations in the Northern Hemisphere.

The analysis revealed that anthropogenic influence had a decreasing effect on March snow mass between 1981 and 2020 in river-drainage basins south of the latitude 60° N. However, Gottlieb and Mankin also showed that human-induced changes increased snow mass modestly over the same period in several high-latitude cold basins that drain into the Arctic Ocean. This varied response is explained by their revelation that historical temperature increases have had little effect on snow's response to warming when average winter temperatures have stayed below −8 °C. But losses accelerate in a nonlinear manner above this threshold temperature.

Gottlieb and Mankin compared spatial patterns of March snow-mass trends with

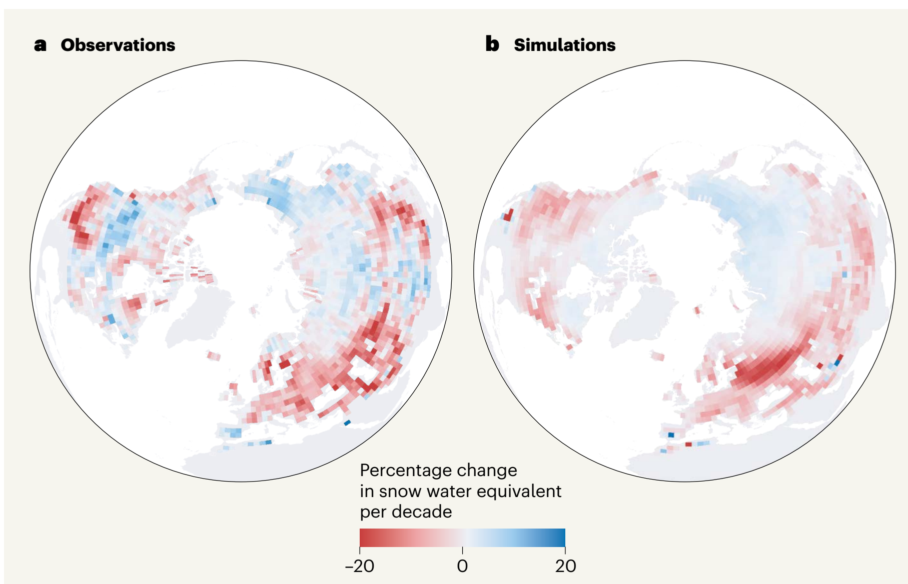

Figure 1 | Mapping human-induced snow loss. Gottlieb and Mankin[1] assembled data from various sources to reveal the temperature dependence of a measure of snow mass known as snow water equivalent. **a**, They showed that March snow mass generally decreased between 1981 and 2020 at low latitudes in the Northern Hemisphere. Shown here is an ensemble of 'gridded' snow data, which are interpolated over a spatially uniform grid. **b**, Climate-model simulations that include both natural and anthropogenic drivers correlate with the observations shown in **a** more closely than do simulations that include only natural drivers (not shown). However, simulations alone are not sufficient to reproduce river-basin-scale trends. This disagreement highlights the need for Gottlieb and Mankin's innovative fusion of data and modelling to predict the impact of humans on the future availability of fresh water. (Adapted from Fig. 2 in ref. 1.)

climate-model simulations to show (using further analysis) that human-induced greenhouse-gas emissions almost certainly contributed to these trends (Fig. 1). Their findings suggest that this human-caused loss of snow mass will accelerate in the coming decades. Perhaps more importantly, they note that many basins in populated areas in the Northern Hemisphere will approach an average winter temperature of −8 °C, causing a major decay of snow mass that will lead to drastic decreases in river discharges, especially in the heavily populated drainage basins of North America and Europe.

The authors' use of ensemble data necessarily combines sources with varying spatial resolution and uncertainties. There are substantial spatio-temporal differences in gridded snow-cover data and, for this reason, the trends suggested by different types of data are inconsistent with each other for some regions. In complex mountainous terrain, for example, these problems are amplified owing to the spatial variability of snow water equivalent on scales much smaller than those of the authors' gridded data, which have spatial resolutions of several to dozens of kilometres. These factors affect Gottlieb and Mankin's calculation of confidence in the trends identified in their analysis.

Owing to observational uncertainties, it is unclear how well ensemble approaches can represent spatial details on the scale of basins in the Northern Hemisphere. Thus, observational uncertainties limit the accuracy of climate reconstructions and predictions. One way to mitigate these issues could involve collating snow-cover data from satellite, ground-based and model-based information. This would in turn require new observational systems, such as satellite sensors with a high spatial resolution. Satellite missions that are currently being planned include radar sensors with a spatial resolution ranging from tens to hundreds of metres[8–10]. Such sensors also have the potential to improve calculations of the uncertainty associated with historical observations.

Gottlieb and Mankin's study underlines the impact that humans have had — and will continue to have — on heavily populated drainage basins in the Northern Hemisphere. However, the relevance of the authors' analysis extends beyond these regions to the Arctic and other sparsely populated high-latitude and mountainous regions. This is because Arctic temperatures, for example, are increasing four times more rapidly than is global mean temperature[11]. And, as well as affecting water availability for people, changes in seasonal snow cover directly affect ecosystems, both those in seasonal snow regions and those in snow-free downstream areas. Such changes, in turn, influence the efficacy of carbon sinks, and increase the likelihood of extreme events, such as wildfires or droughts.

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Ancient DNA

Multiple sclerosis rooted in European prehistory

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An exploration of more than 1,600 ancient Eurasian genomes suggests that genetic changes that increase autoimmune-disease risk in modern Europeans could have protected ancient Europeans from pathogens. **See p.301, 312, 321 & 329**

Multiple sclerosis is an autoimmune disease that can affect all human populations, but its prevalence is the highest in white people, particularly northern Europeans. On page 321, Barrie *et al.*[1] examine the prehistoric origins of the genetic changes that might hold the key to understanding Europeans' elevated risk of multiple sclerosis. The researchers' work builds on three accompanying papers from members of the same team[2–4], presenting a deep dive into the genomic history of ancient Eurasian populations using data gathered from ancient DNA.

Multiple sclerosis is a complex disease, which is contributed to by environmental and heritable factors. Understanding the role of heritable factors in multiple sclerosis can help to predict an individual's risk of developing the disease and can even point to potential drug targets for its treatment[5]. So far, scientists have identified more than 230 genetic changes that can increase the likelihood of developing the disease (risk variants)[6]. For example, a genetic variant on chromosome 6 called HLA-DRB1*15:01 is present in up to one-fifth of northern Europeans, and individuals with this variant have a threefold higher risk of developing multiple sclerosis compared with those who do not have the variant[6]. The HLA-DRB1*15:01 variant is much less common in southern European populations and populations with non-European ancestry[6].

In the latest study, Barrie *et al.* sought to explore the origins of multiple sclerosis risk in northern Europeans. The researchers show that genetic risk is correlated with the proportion of ancestry from ancient pastoralists who introduced domesticated animals to Europe around 5,000 years ago. Moreover, they show that the proportion of ancient pastoralist ancestry is higher in northern Europeans than in southern Europeans, bringing answers to the debate about the origins of the north–south gradient in multiple sclerosis burden in Europe. Finally, they show that some risk variants have risen in frequency in Europeans over time, suggesting that these variants could have provided an evolutionary advantage in the context of the lifestyle of ancient Europeans (Fig. 1).

To reach these conclusions, the authors first had to step back and examine the genomes of individuals who lived several thousands of years before the arrival of pastoralists in Europe. Researchers in the same team as Barrie and colleagues (Allentoft *et al.*[2], on page 301, and Allentoft *et al.*[3], on page 329) generated a genomic data set using bones and teeth from the remains of 317 ancient inhabitants of Europe and western Asia. Combined with existing genetic data from more than 1,300 ancient Europeans, this data set is a unique resource that captures Europe's population history over the past 10,000 years.

This period encompasses major events in recent human evolution. Chief among these is the shift from hunting and gathering to farming and pastoralism. Although most of Europe's inhabitants were hunter-gatherers 15,000 years ago, by 5,000 years ago they had almost entirely shifted to farming domesticated crops that had been brought by Middle Eastern farmers. Around this time, pastoralists from the northern shores of the Black Sea and Caspian Sea (situated between Europe and Asia) introduced domesticated animals.

Major changes in the lifestyles of people in a population are often accompanied by changes