Let it snow

Global snow coverage has declined substantially with anthropogenic warming, impacting biological, socio-economic and physical systems. This issue includes a suite of Comments, Reviews, Perspectives and original research documenting the importance of snow in the climate system, and how this may change with continued warming.

As *Game of Thrones* character Jon Snow forewarns, "Winter is coming", and for many (including those in the fictitious land of Westeros) this means snow. Images of snowball fights, snowmen, skiing and the festive season (at least in the Northern Hemisphere) are synonymous with winter. But snow is far more important than providing opportunities for winter recreation or *Game of Thrones* memes. Snow is a key component of the global climate system, influencing surface energy budgets, regulating temperatures, driving atmospheric teleconnections and governing hydrological systems. As we explore in this issue and in an accompanying online collection — www.nature.com/collections/snow — the role of snow is being impacted by anthropogenic climate change, with potentially severe implications.

Snow is created when sufficiently moist air is exposed to temperatures below 2 °C, forming ice crystals that agglomerate and fall under their own weight. Therefore, with warmer temperatures, it has long been recognized that global snow cover will decline. Naturally, warming prevents snow formation (causing it to instead fall as rain) and accelerates the melt of existing snowpacks[1]. Surface darkening associated with light-absorbing particles (such as dust and black carbon) is further known to have driven contemporary melt of the cryosphere via perturbations to surface albedo. In their Review in this issue, McKenzie Skiles and co-workers suggest this effect may be enhanced in the future due to greater dust deposition associated with aridification, as well as increasing black carbon emissions in industrializing nations.

As reported by Kat Bormann and colleagues, snow coverage is now one month shorter across large swathes of the Northern Hemisphere compared to 40 years ago. Where feedback potential is strongest, these changes are most notable, including across Eurasia. Synthesizing 30 years of research, Gina Henderson and co-authors illustrate that snow variability in this region can force shifts in the North Atlantic Oscillation (or Northern Annular Mode), perturbing the atmospheric circulation, and therefore temperature and precipitation patterns, across much of the Northern Hemisphere.

Credit: Ivan Kmit/Alamy Stock Photo

Eurasian snow cover also plays a strong role in determining the timing and strength of the Asian summer monsoons[2], which millions rely on for fresh water. Snow–atmosphere coupling therefore has the potential to extend the climatic impacts of snow variability far beyond the regions of anomalous snow.

Changes in snow cover, however, are not confined to such continental scales. As Bormann et al. document, marked snow loss has also been observed in several mountain locations such as the Sierra Nevada and High Mountain Asia, where melt is integral for society. A Snapshot in this issue, for example, emphasizes how changing snow melt characteristics — earlier melt and decreased flow[3] — imperil water security in heavily populated regions including the western United States, India and China. Such shifts in snowmelt further threaten hydropower production, a key energy source in these locations.

Although shifts in snow may have broader consequences beyond the regions of direct snow cover, their effects can also be more local. In mountain regions, for example, snow supports economies through winter tourism and recreation. With deteriorating snow conditions, it is clear that snow tourism has begun, and will continue, to suffer: most global ski resorts report shorter ski seasons, increased artificial snow-making and lower tourist numbers[4]. Indeed, ski resorts from the United States[5] to Australia[6] are projected to become less economically viable in the near future. In addition, these resorts may face further risks from avalanches, as warmer temperatures and increased rain-on-snow events act to destabilize the snow pack (see the Feature by Olive Heffernan in this issue).

Snow is also an important determinant of biological communities and ecosystem function[7], acting as a protective insulating layer against extreme atmospheric cold, a refuge for hibernation and a control on plant phenology. Any change in snow characteristics influences these functions. For example, increases in rain-on-snow events raise the likelihood of ice-layers forming in the snowpack, threatening plants, herbivores (such as lemmings and reindeer) and their corresponding predators[8]. In this issue, Pekka Niittynen and colleagues further demonstrate that reductions in snow-cover duration accelerate rates of local moss, lichen and vascular plant extinction in Fennoscandia.

The changing nature of snow under anthropogenic warming — including coverage, duration and melt characteristics — stands to exert substantial impacts across physical, biological and socio-economic systems. However, our understanding of these impacts is often constrained by inadequate snow observations, limited in both spatial and temporal resolution. Indeed, a common theme across many pieces in this snow issue is the need for further observations, be it to constrain models, validate remote sensing products or quantify current snow melt rates. As suggested in a Snapshot, citizen science projects may offer some hope for increasing the number of field measurements. Nevertheless, it is clear that further efforts are needed to adapt to present-day and projected declines in snow cover. ❐

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