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Snow

Developments and effects in South Tyrol and the Alps

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DOSSIER

Snow

Snow defines the winter landscape, provides vital water resources for ecosystems and agriculture and creates jobs. But climate change is threatening snow. How has snow changed in South Tyrol and the rest of the Alps? What is expected in the future and what will the consequences be?

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The intricate beauty of snow crystals is created as they travel through the atmosphere - environmental conditions determine their final shape. (Foto: Bresson Thomas)

What is snow?

Snow is the most common form of solid precipitation. It consists of ice crystals that are first formed in the atmosphere then grow further while falling. Their final size and shape depend on atmospheric conditions, especially temperature, humidity, and wind.
On the ground, snow accumulates to form the snow cover. The texture, size and shape of the snow grains change over time depending on surrounding conditions, such as temperature which causes melting and refreezing, wind transport or subsequent snowfall causing compression. Over the winter season, the snow cover accumulates a complex multi-layer structure, reflecting the weather conditions during and after each snowfall.

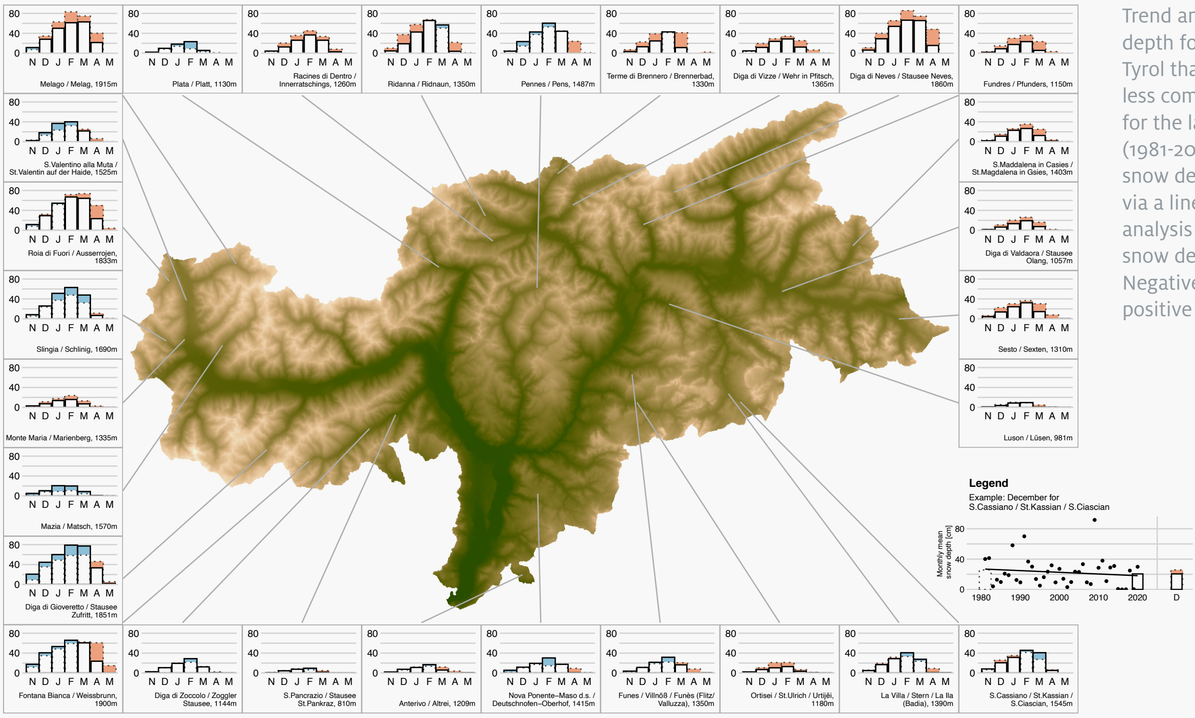
The snowpack is a complex structure, its layers tell the story of the winter from the first to the most recent snowfall. (Foto: David Newman)

When does it snow?

Snow feeds on moisture and cold temperatures in the atmosphere. Snow reaches the ground if surface temperatures are below 0°C. In a few specific cases snow can also reach the ground in temperatures of up to +5°C. Complex terrain, such as in South Tyrol, modulates the weather. Temperature generally decreases with altitude. The mountains influence the flow of air masses. The windward side receives more precipitation at higher altitudes. Leeward, air masses are drier resulting in those regions receiving less precipitation and consequently, less snow. This effect can lead to some regions, such as the Venosta valley, receiving very little moisture from the air masses. Altogether, this results in a complex spatiotemporal distribution of snow cover, where the main feature is more snow with increasing altitude.

How is snow cover measured?

Recording scientific measurements of snow cover is rather straightforward and only requires a graduated stick or rod, which allows the depth of snowfall (fresh snow; height relative to empty surface) and snow depth (height relative to ground) to be measured. Such measurements date as far back as to 1787 in Torino and 1882 in Rovereto.
In South Tyrol, extensive manual observations started in 1980. Recently, automatic sensors were also deployed in higher elevations; however, their time series are not yet sufficient for longer climatological assessments. In recent decades, remote sensing has offered an alternative to accurately measure snow cover area, snow cover duration and snow type (wet/dry). The main benefit of remote sensing is that it covers the whole altitudinal gradient, although data relating to the past is available only for a short period. Hydrologically, the amount of water stored in the snow cover, the so-called snow water equivalent, is a key variable. However, its manual measurement is very labour intensive and the automatic measurement very costly, which is why it is not as widely observed as depth of snowfall or snow depth.



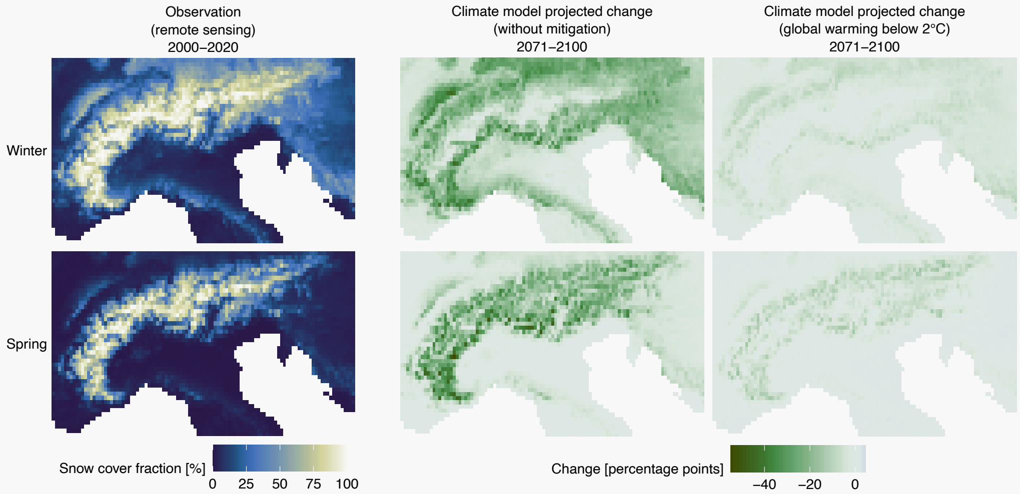
Trend analysis of snow depth for all sites in South Tyrol that have more or less complete records for the last four decades (1981-2020). The change in snow depth is determined via a linear regression analysis of monthly mean snow depth by year. Negative trends in red, positive trends in blue.

Have snow depths changed in South Tyrol?

Over the last 40 years snow depth has decreased at most sites in South Tyrol, but differences depending on month, elevation, and location have been recorded. For the 28 locations with more or less complete records from 1981 to 2020, decreases were observed in winter (December to March) at an altitude mainly below 1500m, while above that mark, increases and decreases were equally distributed. Moreover, there were spatial gradients, negative trends were observed mostly in the north and east, while positive trends were observed in the south and west. For example, in the western part of the province, Slingia/Schlinig, situated at an altitude of 1690m, had a mean snow depth for February which increased from 48cm to 63cm, while at 1860m, Diga di Neves/ Neves Stausee, in the north-east, the snow depth decreased from 86cm to 66cm. At the end of the season, that is April to May depending on elevation, no positive trends were observed. In fact, in most locations snow has been disappearing on average in the last month of the snow season. Today, April is on average snow-free below 1500m, while 40 years ago, 7 to 24cm of snow was not unusual, such as in Sesto/Sexten or Pennes/Pens. The main limitation of these results is that they are restricted to locations below 2000m, because above that altitude, no long-term observation records exist in South Tyrol.

What's the situation in the rest of the Alps?

The changes in South Tyrol are similar to what has been observed in the southern part of the Alps. The Alps are located in a transitional area influenced by three main climate forcing zones: the Atlantic Ocean, Mediterranean Sea, and European continent. The main climatic boundary is found along the central ridge which separates the north from the south, followed by an east-west-gradient. This affects temperature and precipitation especially in winter when the south receives on average 1/3 less precipitation than the north, which translates to approximately 20-30% less snow. An analysis of more than 800 stations throughout the Alps identified reductions in winter snow depth for most of the stations below 2000m in the period 1971-2019. Moreover, the decreases in the south were more prominent than in the north. Above 2000m, a high variability in trends was observed, from strong decreases in snow depth to strong increases. However, observations above 2000m over such long periods are sparse, so no alpine-wide statements are possible. In fall and spring, all stations in all regions showed the most pronounced decreases in snow depth.



Average area that is snow covered (snow cover fraction) in winter (December to February) and spring (March to May) for the present (2000-2020) and projected changes for the future (2071-2100). Present observations are based on 20 years of satellite observations, and future conditions based on an ensemble of regional climate models, which have been bias corrected using observations. The maps have a horizontal resolution of 12km, which corresponds to the resolution of the current generation of regional climate models.

How will climate change affect snow?

If climate change is not mitigated, temperatures will increase and precipitation patterns might change, with possibly more winter precipitation in store for the Alps. Because of the higher temperatures there will be less snow in fall and spring. For lower elevations this will also occur in winter, since precipitation will fall as rain instead of snow because of the higher temperatures. For higher altitudes, an increase in precipitation might lead to more snowfall in the central winter period, but the season will be shorter because of rising temperatures: snow will accumulate later in fall and melt earlier and faster in spring. At the regional scale, the amount of snow will be significantly lower across all seasons, especially in spring. By the end of this century, snow cover could experience an elevation shift of 500-1000m, that is, the snow conditions in the year 2100 at an elevation of 2000m will be as they are today at 1000-1500m. If climate targets are achieved, that is, global warming held below 2°C, this elevation shift could be confined to 250-500m.

Huge snow masses will continue to occur in the future, despite overall decreasing snow amounts and because of climate change, heavy snowfalls could even become more extreme.
(Foto: Adobe Stock/Andreas Buchwald)

How do extreme snow events fit into this picture?

In South Tyrol, extreme snowfalls occur under very specific weather conditions, bringing moist air originating from the Mediterranean. This was the case, for example, in November 2019 and December 2020. With climate change, not only air temperatures increase, but also sea temperatures, which facilitate atmospheric moisture uptake. Consequently, precipitation intensifies, both for rain and snowfall events. The November 2019 event was exacerbated because of atmospheric blocking, which inhibits change in large-scale weather patterns. The consequence: multiple extreme snowfalls one after the other. With climate change, atmospheric blocking is expected to occur more often – in addition to the rise in air and sea temperatures. So, it is likely that because of climate change these events have become more extreme. In the future, there will be less snow on average, but extreme snow events will still occur. However, no confident assessments can be made on the likelihood and severity of future snow extremes, because for complex terrain such as that of South Tyrol, the current generation of climate models only allow predictions of the mean climate. Therefore, it is not clear if associated risks, such as tree falls, black-outs, landslides, and avalanches, will be reduced in the future. Decreasing snowfalls do not necessarily imply a reduction of avalanche risk, because the processes triggering avalanches are complex and higher temperatures could even accelerate snow destabilisation processes.

How important is natural snow for winter tourism and the ski industry?

Winter tourism depends on snow for skiing. In South Tyrol this is independent of natural snow because snow making coverage spans up to 90% of the skiing areas. However, suitable weather conditions for making technical snow are required, which come with a great demand on water and energy. In the winter seasons of 2007 to 2016, snow cannons in South Tyrol consumed 5 to 10 billion litres of water per season and, together with ski lifts, 90 to 170 million kWh of electricity, which corresponds to 6 to 12% of the total annual drinking water consumption and 2.9 to 5.4% of the total annual energy consumption of South Tyrol. If snow becomes scarcer, these demands will increase. As a consequence, the already heated debate on winter tourism is likely to intensify, citing on the one hand the negative environmental impacts and on the other, the positive impacts on economy and for rural populations in remote valleys.

If snow doesn't fall from the sky, it comes from a snow gun: 90% of the slopes in South Tyrol can be covered with snow in this way. However, the water and energy consumption is high. (Foto: Adobe Stock/Sonja Birkelbach)

What are the consequences of climate change for ski areas?

The most important period for winter tourism is the central winter period, especially Christmas. If insufficient natural snow is present, the question is whether enough snow can be produced before Christmas. This depends on suitable weather conditions, which will become less likely with global warming, the performance of the snow plants, which will likely increase with technological advancements, and, finally, on the availability of water and energy.

The question on the consequences of climate change for ski areas cannot be answered using simple temperature indices, because of the high variability of climate and snow in complex terrain at high elevations. More insight could be gained using dedicated snow modelling studies, which consider local climate and topography. However, such studies do not yet exist for South Tyrol. The current body of knowledge suggests that the full ski season as it exists today, might not be guaranteed anymore. The viability of low elevation ski areas is endangered, in part because of rising energy and water demands, as has been shown by studies in Austria and Switzerland. Determining the future viability of winter tourism and the ski industry under climate change will require an integrated approach and a cost-benefit-analysis, and will need to extend beyond pure monetary income to include ecological implications, energy and water issues, and non-monetary value for the rural livelihood (such as better infrastructure, more shops and bars with longer opening hours). Facing decisions for or against investments, scientific support is necessary, as is the participation of the local population.

What are the implications of the changes in snowfall and snow cover for the water cycle?

Snow acts as a water storage, which accumulates in winter, when vegetation does not require water, and is released in spring and summer, when vegetation and agriculture have the highest water demands. If there is less snow which also melts earlier, then spring and summer will face drier conditions, here in South Tyrol and further downstream. Drought conditions could further be exacerbated because evaporation increases with higher temperatures, dry soils heat up intensively, thus making it even warmer. This feedback loop is further strengthened by water shortage induced by the increasing water demands of natural vegetation and irrigation. Water managers will need to cope with the reduced water availability in spring and summer, and should strive for an integrated approach considering all involved parties in the entire catchment. For the Adige, for example, this covers the area from the Passo Resia/Reschenpass to the Adriatic Sea, and includes balancing the needs of household drinking water, agriculture, ecology, and energy production in order to prevent water use conflicts.

What is the role of snow and climatic changes for glaciers?

Glaciers are persistent bodies of dense ice, which originate from snow. They form, often over centuries, when snow accumulation exceeds ablation, that is, when more snow is accumulated than gets lost through melt, evaporation, sublimation (direct phase change from solid to gas), wind erosion, and ice calving. Presently, glaciers are shrinking rapidly because ablation exceeds accumulation. This imbalance is largely driven by high summer temperatures which cause a strong melting rate; the reduced total snowfall during the rest of the year has little impact. Glaciers act as reservoirs of fresh water and contribute significantly to the water cycle and river runoffs in many parts of the world. In South Tyrol, however, the water from snowmelt is more important, and glacial water only impacts a few specific catchments, such as Solda/Sulden, Martello/Martell, or Valle Aurina/Ahrntal. Even if global warming is confined to 2°C, only a quarter of the glacier mass in South Tyrol will remain until 2100, because glaciers only react slowly to climatic changes. If climate targets are not achieved, all the South Tyrolean glaciers will likely have disappeared by 2100.

What can be done to mitigate these changes?

The most important task is to reduce greenhouse gas emissions in order to prevent climatic changes as much as possible. Simultaneously, preparations to adapt to the new reality must be put into place. Like climate change, which needs a coordinated global response, snow and water do not adhere to artificial human-made boundaries. Coordinated action of all involved parties, across regions and sectors will provide farsighted decisions and improve individual and societal wellbeing, more sustainably and more efficiently than solo efforts.

Less snow, changes in the hydrological cycle: adaptation measures

Measure	⊕ Advantages	⊖ Disadvantages	Improvement potential
Technical snow	⊕ Winter sport is independent of natural snowfall	⊖ High energy demand	(*) Use water more efficiently (*) Use weather and snow-model forecasts to allocate resources more efficiently. The EU-project PROSNOW developed a tool for this (http://prosnow.org)
Snowfarming (snow depots, which store snow from the previous season)	⊕ Snow is available in time for the start of the ski season ⊕ Less technical snow-making required in the fall	⊖ Requires suitable storage infrastructures ⊖ Remaining amount of snow is sometimes insufficient ⊖ Since it is often technical snow that is stored, the energy and water demands are high ⊖ Distribution of the stored snow is very labour intensive	
Water reservoirs and dams	⊕ Water is available when needed ⊕ It's not necessary to take water from rivers in winter, when they carry little anyway ⊕ Enables green energy production ⊕ Increases the drought resilience of agriculture and enables the capture of earlier melting water	⊖ Impacts river and landscape ecology, plant and fish species change in the catchment ⊖ Long-term consequences are unpredictable ⊖ It's difficult to find suitable locations in alpine terrain ⊖ Building dams invade in natural alpine landscape ⊖ Building new dams in South Tyrol is geologically and politically impossible to realise. ⊖ Regional or national solo-efforts can lead to conflict. ⊖ Large dams have a big CO_2 footprint, both for their construction as well as when the flooded organic material is decomposed.	(*) Increasing water-use-efficiency in agriculture. Large margins of improvements exist for irrigation. (*) Diversifying the usage of dams: not only to produce electricity, but also to manage floods and droughts.

Editors:
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This project received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 795310.