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Key Findings from the AMAP Arctic Climate Change Update 2024

The 2024 report provides status updates on key indicators of climate change in the Arctic along with updated findings for recurring topics such as extreme events (including wildfires) and Arctic/mid-latitude linkages. It also provides new information on landscape hydrology and ocean acidification in the Arctic, which were not discussed in the 2019 or 2021 reports. The cryosphere chapter provides an extensive discussion of permafrost, which is an issue of growing concern for Arctic Indigenous Peoples and other Arctic communities and policymakers.

The AMAP climate update series is intended to provide shorter scientific reports on key climate issues, identified as of immediate importance by AMAP experts and national delegates. The aim is to produce climate update reports on a biennial basis, but the 2024 report was delayed by one year owing to the pause in Arctic Council activities. A summary for policymakers with recommendations based on the scientific report will be delivered to the Arctic Council ministerial meeting in May 2025.

Chapter 2 - Overview of multiple Arctic climate change indicators

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- The Arctic climate system, as a cold-pole of the Earth's planetary heat engine, has undergone profound physical changes since the mid-1980s.

- The Arctic has warmed about three times as fast as that of the global average since 1979 owing to amplifying feedbacks in the climate system, but the exact estimate depends on the period chosen and is influenced by pronounced natural year-to-year variations.

- The greatest Arctic warming trends occur in the October-through-May 'cold season' that sets the stage for the June-through-September 'heating season' via thermal depletion of cold content in the ground and cryosphere (sea ice, snow cover, land ice, ground ice), meaning less heat input is required for melting to ensue.

- Observation data showcase evidence of widespread loss of the Arctic cryosphere in all its forms (spring snow-cover extent, land ice, sea ice) as well as warming and thawing of permafrost.

- The Arctic is becoming wetter, with more precipitation falling as rainfall rather than snowfall with an overall increase in precipitation totals.

- The Arctic Ocean is acidifying in response to CO_2 uptake, loss of sea-ice cover, ocean freshening and warming, and contributions of organic carbon from terrestrial sources.

- The Arctic is responding to changes in the climate system much more rapidly than any other region on Earth, and the changes in the far north are being felt far beyond the Arctic.

- The latest future Arctic climate projections suggest a more rapid Arctic warming and sea-ice loss by 2100 than previous projections, and consequently, greater and faster changes in the hydrological cycle, including Arctic glacier reduction.

Chapter 3 - Arctic climate extremes

Lead author: James Overland

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- Recent increases in extreme events, especially those near and beyond previous records, are a major new index for Arctic and global climate change. These record shattering, unprecedented events often have no known historical analogues and suggest that other climate surprises may be in store. Storms, heatwaves, wildfires, rain, sea-ice minima, ecosystem reorganizations, and different seasonal timing are examples noted both by weather services and by Indigenous local reports. Impacts are felt by many coastal communities. The diverse type, location and timing of recent (past five years) extreme events, taken together, allow a consilience interpretation (i.e., a strong conclusion based on multiple reasons) for a new Arctic climate.
- The interdependence and interaction of climate change, Arctic amplification, and natural variability is producing new extremes. Global warming leads to temperature increases, permafrost thaw, and sea-ice loss /open water. These factors combine with the natural range of atmospheric and oceanic dynamics, such as jet stream meanders, blocking weather patterns, storms, and upper ocean heat content. This interdependence produces new physical and ecological extremes, characterized by different types, locations, seasonality, and duration of events. The interaction of these processes, referred to as emergence, can now be said to be the cause of unprecedented impacts.

Chapter 4 – Arctic and high-latitude wildfires

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- Increased numbers of wildfires have been observed in the Arctic region in recent decades due to the fast rate of change in the climate at high northern latitudes driving changes in fuel availability (e.g., poleward expansion of vegetation and permafrost thaw), fire danger (i.e., drier vegetation and fuels, and warmer conditions), and fire behavior following ignition.

- Fire occurrence in the Arctic, and more generally at high northern latitudes (north of 60°N) is a common feature each summer but with a high degree of year-to-year variability reflecting human, biogeographical, and hydrometeorological influences. In general, the majority of observed fires occur in regions with human activities and where soil moisture and precipitation levels are below the climatological mean.

- Knowledge of ignition sources for Arctic wildfires has improved in recent years, with better understanding and observational evidence of human-caused and natural ignitions. Improved capabilities for detecting holdover fires and lightning ignitions, and incorporation of Indigenous knowledge are both essential to understanding wildfires in the Arctic under a changing climate.

- Emerging research and novel monitoring technologies (e.g., new satellites and developments using artificial intelligence) are providing further insight into the relative roles of human and non-human ignition sources, available fuel types (including peat and high carbon soil) and fuel conditions, as well as into fire behavior across the region which is essential to monitoring/modeling current/future vulnerability of the Arctic and high northern latitudes to wildfires.

Chapter 5 – Cryosphere

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- Since 1980, the Arctic cryosphere has diminished both on land (permafrost and snow) and over the ocean (sea ice). The melt season has lengthened while the freeze season has shortened.

- Permafrost has warmed and thawed over the past four decades which has led to landscape change especially where permafrost is ice-rich. Permafrost degradation is expected to continue in response to increasing air temperature but there is less certainty regarding the magnitude and timing of the response.

- Snow-cover extent has declined substantially in spring and autumn based on a combination of multiple snow products, which is consistent with earlier assessments. A larger declining trend was found in Eurasia than in North America. Seasonal maximum snow water-equivalent is projected to decrease across much of the Arctic but regional increases are expected in eastern Siberia and the Canadian Arctic Archipelago. Projected spring snow extent and snow mass both show a nearly linear response to the increase in global mean near-surface temperature regardless of the emission scenarios employed in the climate model (CMIP6) simulations.

- The largest sea-level rise contributions are glacier melt from Greenland, Alaska, and Arctic Canada, resulting from amplified Arctic warming and increasing atmospheric rivers reaching Greenland. The rates of Arctic glacier ice loss have increased for all regions in each successive decade since the 1970s.

- Over the 43-year record (1980–2023), the decline in sea-ice extent is greater in September (month of the annual minimum extent) than March (month of the annual maximum extent). Decadal variability is also more pronounced in September than March. The largest decline in these months occurred in the period 1993–2006.

- Sea-ice thickness shows large regional variability based on satellite data for 2011–2022. A sea ice-free Arctic summer is projected by mid-century based on CMIP6 models under the moderate to high greenhouse gases emissions scenarios, consistent with previous climate model projections

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Chapter 6 – Terrestrial hydrology

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- Precipitation has increased over recent decades, especially in cold seasons, and is associated with an increase in rainfall in all seasons and a decrease in snowfall. in summer with spatially varying trends in winter.. This century, precipitation events presently regarded as extremes are expected to become routine. Snow mass has decreased across northern North America but in Eurasia the trend has been negligible and snow depth has increased in parts of Eurasia

- Permafrost thaw is likely to drive changes in the water balance in Arctic areas, but the relevant subsurface processes are difficult to observe directly at the catchment scale. However, observed changes in streamflow dynamics and water chemistry indicate that permafrost thaw is influencing hydrological connectivity by creating deeper and longer waterflow pathways through catchments across the Arctic.
- Increasing trends in annual river discharge to the Arctic Ocean from both continents are continued, providing compelling evidence of intensification of the Arctic water cycle. A significant increase in base streamflow during the cold season is observed across most regions of the pan-Arctic drainage basin. The magnitude of maximum river discharge has not changed significantly; however, the timing of snowmelt freshet has become earlier almost everywhere across the pan-Arctic.

- Lake area is declining across the discontinuous permafrost zone. In the continuous permafrost zone, however, the number of sites with decreasing lake area is similar to the number with increasing lake area. Stronger lake area declines in the discontinuous permafrost zone is consistent with permafrost thaw being further advanced here than in the continuous permafrost zone.

- Ice-cover duration on rivers has declined significantly in cold regions over the past several decades due to later freeze-up and earlier breakup. The observed decline in river ice is likely to continue in the future due to the projected increase in air temperature. Maximum river ice thickness has decreased significantly on most pan-Arctic rivers over the last 50 to 60 years, with the greatest decrease observed before 2000.

- Lakes are rapidly losing ice across the Northern Hemisphere, with later ice-on dates, earlier ice-off dates, and in some years, some lakes not freezing at all.

- Freshwater delivery from Arctic land ice is roughly equivalent to that from North American rivers. Eurasian river discharge is roughly three times higher. However, the increase in Arctic river discharge was 1.6 times smaller than the increase in freshwater flux from Arctic land ice. Most of the increased land ice freshwater discharge originated from Greenland and Arctic Canada

- A further increase in freshwater flux from land ice reduction is likely to continue with the projected future increase in Arctic warming.

- Changes in the terrestrial hydrological system have important impacts on ecosystems and Arctic livelihoods. Declining snow cover, permafrost, lake areas and lake ice have implications for ecosystems, as well as hunting, fishing, reindeer herding, transportation and drinking water availability. Impacts also include feedbacks to the climate and ocean circulation through increased freshwater fluxes to the Arctic Ocean and changes in lake areas and ice cover.

Chapter 7 – Arctic ocean acidification

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- The Arctic Ocean is continuing to acidify and is already witnessing environments that are deleterious to marine life, negatively impacting the activities, well-being, and rights of Arctic Indigenous Peoples.
- Globally, the greatest declines in pH continue to be projected for the Arctic Ocean and reflect impacts from surface ocean warming, loss of sea ice and atmospheric CO_2 uptake.
- The upper 1000 m of the Arctic Ocean is projected to be undersaturated with respect to aragonite by 2100 for all emission pathways.
- Fjord systems are currently undergoing rapid transitions due to the accelerated melting and retreat of glaciers. The freshwater input from glacial meltwaters enhances ocean acidification.
- Methane may act as an additional climate change driven ocean acidification accelerator, further increasing uncertainties in Arctic ecosystems.
- Polar cod (*Boreogadus saida*) eggs and larvae are vulnerable to ocean acidification.
- Owing to their high ocean acidification sensitivities, pteropods in the high latitudinal regions are already severely compromised.
- All model projection evaluations demonstrate that emission reductions can drastically slow the pace at which multiple drivers emerge or critical thresholds will be crossed.
- Community-based monitoring led by Arctic Indigenous Peoples would fill a gap in local and regional observational data, and can be paired with climate model downscaling to assist in policy decision-making.

Chapter 8 – Arctic/midlatitude weather connectivity

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- Arctic climate change can influence midlatitude weather and climate, impacting millions of people.
- Understanding the meteorological processes for this connection remains controversial: the physics includes both local Arctic forcing such as sea-ice loss and temperature increases (Arctic amplification), and internal atmospheric variability such as tropospheric jet stream and stratospheric polar vortex dynamics.
- The movement of the stratospheric polar vortex over continents can help explain some of the location, timing and duration of Arctic/midlatitude weather connections, such as cold-air outbreaks over the eastern parts of Asia and North America.