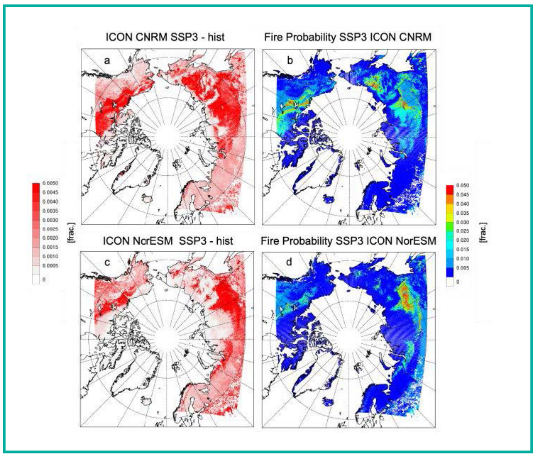
BOREAL WILDFIRES

HOW ARE WILDFIRES IN THE ARCTIC GOING TO DEVELOP UNDER DIFFERENT CLIMATE SCENARIOS AND STORYLINES?

RESEARCH

PolarRES conducted high-resolution simulations to assess how boreal wildfire in the Arctic will change by the end of the 21st century. The dynamic global vegetation model LPJ-GUESS and its fire-model SIMFIRE-BLAZE were applied. The models were driven by output from a regional climate model driven by two global climate models under the medium to high-risk greenhouse gas emissions scenario SSP3-7.0. This enabled detailed investigation of how changing climate and vegetation composition interact to shape the future fire regime across the Arctic regions.



RESULTS

The models show that the occurrence of wildfires will increase across the entire Arctic region, but will differ regionally, depending on the climate models applied. The main driver for changes in burned area are shifts in vegetation composition (fire biomes). An increase in biomass is the second driver dominating the increase of carbon emissions by fire in simulations with generally lower biomass.

Figure:. Increase in fire-probability [fract.] (average of the period 2070-2100 minus average 1985-2014): a) ICON-CNRM b) ICON-NorESM; and total fire probability averaged 2070-2100: c) ICON-CNRM d) ICON-NorESM.

POLICY ACTIONS NEEDED

To address the growing wildfire risk, **adaptation and mitigation planning are essential**. Measures may include more fire-fighting facilities or the application of fire-breaks, implementing early warning systems and strengthening international collaboration across Arctic nations to manage cross border fire hazards.

IMPORTANCE

These findings are important for both local and regional governments, infrastructure planners and national and global carbon accounting efforts.

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PERMAFROST THAW

HOW IS PERMAFROST THAW IN THE ARCTIC GOING TO DEVELOP UNDER DIFFERENT CLIMATE SCENARIOS AND STORYLINES?

RESEARCH

PolarRES conducted high-resolution simulations to assess how permafrost thaw and ground subsidence across the Arctic will change by the end of the 21st century. The CTSM-EXICE model was used and forced by outputs from two regional climate models driven by two global climate models under the medium to high-risk greenhouse gas emissions scenario SSP3-7.0. The analysis focused on permafrost extent, active layer thickness, and ground subsidence from 2015 to 2099, providing one of the most detailed regional assessments of Arctic permafrost future change.

RESULTS

All projections show a consistent and strong decline in Arctic permafrost throughout the 21st century. The most losses and associated ground subsidence exceeding one meter are projected in sub-Arctic regions between 60-70°N, where population and infrastructure are concentrated. As ground ice melts, surface subsidence is expected to accelerate after mid-century. The largest subsidence is projected in northern Canada and northeastern Russia, while even higher-latitude regions experience a gradual but persistent decline in near-surface permafrost. At the city scale, several major Arctic settlements are projected to face significant permafrost degradation, with implications for long-term urban development, transport systems, and safety.

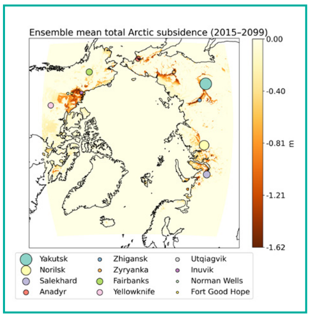

Figure: CTSM-EXICE ensemble mean total Arctic subsidence (2015–2099) at the city scale. The size of the circles on the map denotes the population of the considered Arctic cities.

POLICY ACTIONS NEEDED

To prepare for the impacts of thawing ground, **risk-informed infrastructure planning is essential**. Measures include integrating permafrost hazard mapping into construction standards, strengthening monitoring systems, and promoting cross-border collaboration among Arctic nations to share data, expertise, and adaptation strategies.

IMPORTANCE

Permafrost thaw releases greenhouse gases that accelerate global warming and destabilize the ground, threatening infrastructure and ecosystems. It also reshapes Arctic landscapes by altering the distribution of wet and dry areas, vegetation, and water quality—posing major challenges for local and regional governments, planners, and climate agencies.

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RADIONUCLIDES

IN RECENT DECADES, RADIOACTIVE CONTAMINATION OF THE ARCTIC OCEAN FROM DUMPED MATERIALS AND SUNKEN SUBMARINES HAS RAISED MAJOR CONCERNS. CLIMATE CHANGE MAY INFLUENCE THE SOURCES AND TRANSFER OF THIS RADIOACTIVITY. NUCLEAR TESTS ON NOVAYA ZEMLYA (1957–1963) DEPOSITED LONG-LIVED RADIONUCLIDES ON GLACIERS - THE MELTING OF WHICH COULD RELEASE THESE SUBSTANCES INTO THE SEA, ENDANGERING HUMAN AND ENVIRONMENTAL HEALTH.

RESEARCH

Under PolarRES, 3D Lagrangian radionuclide particle tracking model was used to simulate radionuclide transport in the Arctic Ocean based on high resolution simulations of the ocean with NEMO. A novel probabilistic approach for transforming particles' states, including radioactive decay, adsorption-desorption in bed and suspended sediments, erosion, and deposition was developed. We considered 4 scenarios based on historical and projection storylines. In these scenarios, potential contamination of water and sediments due to releases of Caesium-137 (137Cs) in 4 locations of sunken submarines K-159 and "Komsomolets", dumped K-27, and Novaya Zemlya coast are considered.

RESULTS

- The transport pathways of 137Cs in the Arctic Ocean was highly influenced by the depth of the radioactive outflow; Other factors influencing the pathway included the source locations and changes in ocean circulation.
- The portion of 137Cs ending up in the bottom sediments is less than 1% for the submarine in deep water while it was more than 85% for the shallow water submarine fjord of Abrosimov in the Kara Sea.
- Under future climate projections, the transport pathways change little but amount of radioactivity ending up in the bottom sediment change by more than 50%.

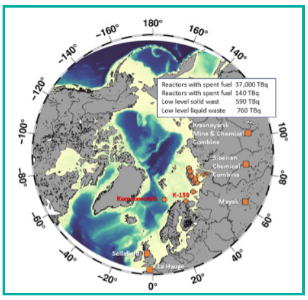

Figure: Locations of sunk submarines and dumped wastes (crosses), and reprocessing plants (squares

POLICY ACTIONS NEEDED

Currently, no significant radioactive leaks from locations of dumped materials and sunk submarines have been detected in the Arctic Ocean. However, such sources may emerge in the future, particularly as a result of melting coastal glaciers on Novaya Zemlya. Therefore, **monitoring of these locations, including bottom sediments, is necessary in the next decades**.

IMPORTANCE

Melting glaciers due to global warming could release long-lived radionuclides into the sea, posing risks to human health and the environment. The greatest threat to fisheries arises from shallow releases of radionuclides in the Barents Sea, such as the scenario involving the K-159 sunken submarine.

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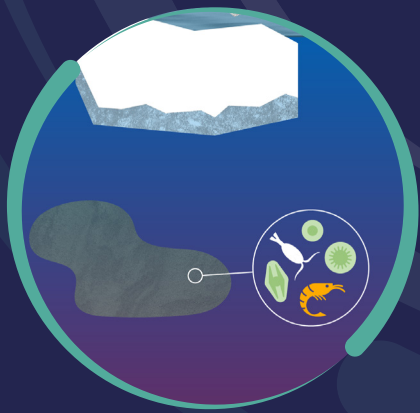
MARINE ECOSYSTEMS

CLIMATE CHANGE IS INCREASINGLY THREATENING LIFE IN THE SOUTHERN OCEAN, ONE OF EARTH'S MOST REMOTE AND FRAGILE ECOSYSTEMS. THIS STUDY ASKED HOW FUTURE CONDITIONS MIGHT AFFECT TINY BUT VITAL CREATURES CALLED COPEPODS - ZOOPLANKTON THAT PLAY A HUGE ROLE IN THE OCEAN'S FOOD WEB.



RESEARCH

PolarRES focused on four dominant Antarctic copepod species. These species dominate the zooplankton biomass and rely on carbon-rich fat reserves to support them during winter diapause in deep waters. Using decades of copepod data and hindcast high-resolution regional ocean climate models (MetROMS and HCLIM) we developed Ecological Niche Models (ENMs) to map habitat suitability and environmental conditions for copepod survival. We then applied future climate projections to simulate how these might change under potential future climate regimes.

RESULTS

This study was the first to map copepod populations across the Southern Ocean over different seasons and years. ENMs showed strong variability in range limits, hot spots, and life cycle events like maturation and diapause timing. Historical simulations showed declining biomass and habitat area, driven by warming and fewer phytoplankton (a critical food source). Future projections, representing two scenarios differing in extent of ocean temperature rise, predicted that copepods might shift further south and, unexpectedly, habitat suitability and biomass might increase. However, the increases should be interpreted cautiously as current models lack full integration of phytoplankton.

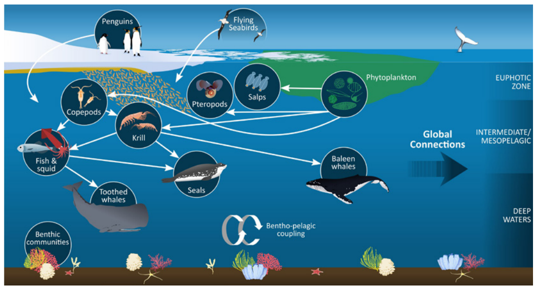


Figure: Copepod's role in the food web, credit: Nadine Johnston, BAS & Johnston et al 2022.

POLICY ACTIONS NEEDED

- Improve models by including copepods food sources
- Use results to guide future ecosystem assessments and research programmes
- Establish long-term monitoring programmes that include copepods
- Including copepods in Earth System Models and conservation and management plans
- Promote public awareness of copepods' global ecological importance

IMPORTANCE

Copepods are an essential ecosystem component. They help move nutrients through the ocean, support fisheries, wildlife and tourism, and store carbon - helping regulate Earth's climate. Understanding how they will respond to future change will help educators, scientists, and policymakers protect ocean life and plan for the future. This research supports global efforts by groups like BIOPOLE, SCAR, CCAMLR, IPCC, and MEASO.

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TRANS-ARCTIC NAVIGATION

CLIMATE CHANGE AND THE WITHDRAWAL OF ARCTIC ICE COVERAGE ARE EXPECTED TO EXPAND THE SAILING SEASON AND THEREFORE THE UTILISATION OF THE NORTHERN SEA ROUTE. THE KEY QUESTION ADDRESSED WAS WHAT IS THE CAPACITY OF THE NORTHERN SEA ROUTE UNTIL 2050 CONSIDERING THE CHANGING ICE CONDITIONS AND THE CHARACTERISTICS OF THE SHIPPING FLEET.

RESEARCH

To estimate the future transit capacity, a capacity model was built, based on two CMIP6 climate model simulations, the technical characteristics, including cargo carrying capacity and ice-class of the world commercial fleet and the available icebreaking capacity.

RESULTS

The results indicate that the overall cargo throughput of the Northern Sea Route would increase from 50 to 120 million tons p.a. in the slower ice melting simulation or from 350 to 460 million tons p.a. in the faster ice melting simulation. Individual navigation is expected to remain limited also in the coming decades. The navigation is expected to remain seasonal with high yearly fluctuations defined by the changing ice conditions. Due to this, the route is likely to be utilized mainly for tramp shipping, whereas conditions for liner shipping will remain challenging.

POLICY ACTIONS NEEDED

Enabling the growth of traffic flows requires considerable investments into supporting infrastructure along the route, including terminal facilities, icebreaking capacity and safety and rescue equipment among others. At the same time, increasing commercial traffic in sensitive Arctic areas is deemed to create additional negative externalities. **Stricter regulation is required to minimize the negative impacts.**

IMPORTANCE

The results assist shipping companies to make long term investment decisions. Local authorities are provided with improved estimates on the future demand and requirements of supporting infrastructure. Finally, as with other trade routes, **the results have a geopolitical dimension and contribute to the understanding of international politics.**

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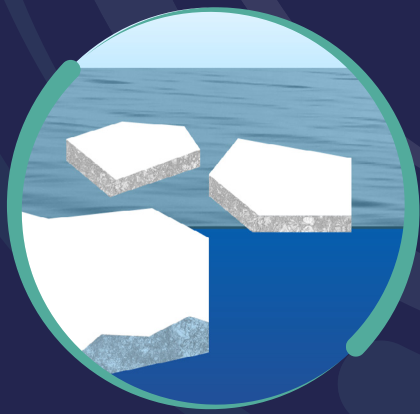
EXTREME WEATHER AND CLIMATE EVENTS IN THE ARCTIC



HOW ARE EXTREME WEATHER AND CLIMATE EVENTS IN THE ARCTIC CHANGING? WHAT DRIVES THESE CHANGES, HOW WELL ARE THEY REPRESENTED IN CLIMATE MODELS, AND WHAT ARE THEIR SOCIETAL AND ENVIRONMENTAL IMPACTS?

RESEARCH

The research done under PolarRES reviewed current knowledge of Arctic extremes, combining observations with process-based and modelling analyses. It identified key knowledge gaps in drivers, predictability, and risks related to temperature, precipitation, and compound events. A case study was conducted on the record-warm summer of 2024 in Svalbard, showing that persistent atmospheric circulation and anomalously warm sea surfaces drove the extreme heat. Advanced climate modelling was carried out using global atmospheric models, both with and without enhanced regional resolution over the polar regions, to analyse present and future Arctic extremes under different "storylines" of climate change.

POLICY ACTIONS NEEDED

- Strengthening monitoring and early-warning systems for Arctic extremes.
- Investing in resilient infrastructure and enhancing emergency response capacity.
- Broadening communication with indigenous communities and integrating local knowledge into adaptation strategies.
- Enhancing international collaboration and linking scientific insight with policy and investment.

Coordinated, science-based action will reduce risks, protect livelihoods, and enable sustainable development in an Arctic increasingly shaped by extreme weather and climate events.

RESULTS

- Arctic warming amplifies extremes: Rising temperatures are increasing the frequency and intensity of extreme events, reshaping ecosystems and challenging community resilience.
- Complex drivers: Extremes result from interactions between background global warming and natural variability, with persistent uncertainties in their future evolution.
- Future projections: Simulations show strong, storyline-dependent increases in temperature and precipitation extremes, especially in minimum temperatures and heavy precipitation.
- Added value of high resolution: Regional refinement improves the representation of precipitation extremes, capturing enhanced moisture transport, convergence, and the influence of orography and jet-stream shifts.

IMPORTANCE

Local communities need reliable information to ensure safety and adapt livelihoods. Emergency services and policy-makers depend on accurate forecasts for planning and disaster response. The industry, infrastructure operators, and insurers require robust projections to manage risk, while scientists and international bodies use this knowledge to strengthen preparedness and cooperation across the Arctic.

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