GEM STRATEGIC STATUS

SYNTHESIS BY THEME (2022–2026)

GEM

Greenland Ecosystem Monitoring

DATASHEET

CONTENT

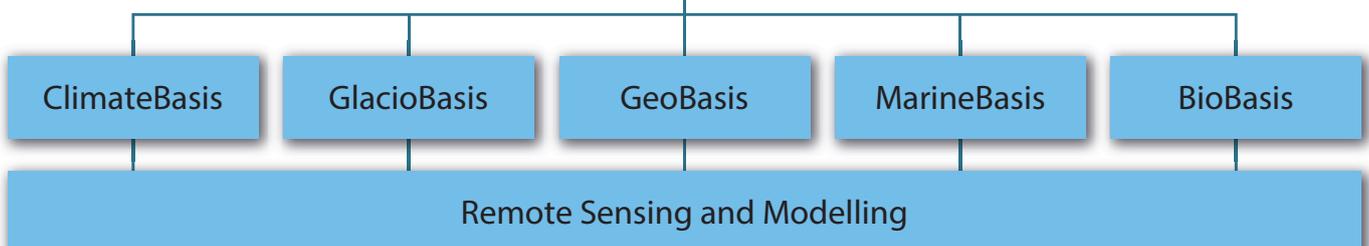# GEM STRATEGIC STATUS
– SYNTHESIS BY THEME (2022–2026)

In the Arctic, climate warming is amtplified, driving rapid and pronounced changes in ecosystem dynamics. To address concerns about these impacts, the Greenland Ecosystem Monitoring (GEM) programme was established in 1995 to provide early observations and baseline data on Arctic ecosystem functioning under a highly variable and rapidly changing climate. Initially implemented at Zackenberg in Northeast Greenland, GEM expanded with sites at Nuuk from 2005 and Disko from 2016, covering a climatic gradient from High to Low Arctic. Today, GEM is the only integrated long-term monitoring and research programme on ecosystem dynamics and climate change feedbacks in Greenland and a leading initiative in the Arctic. It applies internationally standardized methods and offers free access to data on over 2,000 variables, including Essential Climate Variables and Focal Ecosystem Components identified by international organisations.

GREENLAND ECOSYSTEM MONITORING – VISION, MISSION AND OBJECTIVES

Science themes

Climate and Cryosphere

Ecosystem feedbacks

Biodiversity and Populations

Operational structure

| ClimateBasis | GlacioBasis | GeoBasis | MarineBasis | BioBasis |

Remote Sensing and Modelling

INTRODUCTION

This synthesis consolidates contributions across GEM subprograms into the three themes identified in the GEM strategy 2022-2026 namely 1) Climate and cryosphere, 2) Ecosystem feedbacks and 3) Biodiversity and populations [link to strategy]. As such it follows the GEM Strategy to present narrative highlights, strategic contributions, collaborations, and representative publications from the 2022–2026 period.


PHOTO: ASIAQ

CLIMATE AND CRYOSPHERE

GEM is monitoring Greenland's climate and cryosphere, delivering long-term monitoring of weather, water, permafrost, glaciers, and snow. Climate stations are operated in partnerships with other monitoring (such as PROMICE) and data send to global networks in real time. This information helps scientists understand the energy exchange between land, water, ice and air. Ground-based snow measurements have been used to check the accuracy of major Arctic climate models, while glacier records, stretching back to 1957 for Disko and 1985 for Zackenberg, show a clear and steady retreat of ice over decades. Across all GEM sites, energy and carbon exchange, river flows, and snow and soil conditions are tracked continuously. Recent advances in river monitoring even improve our understanding of the impacts of extreme events and sudden glacial lake outbursts.

PHOTO: MARIE FROST ARNDAL

ECOSYSTEM FEEDBACKS

Field observations, satellite data and computer models now work hand in hand to give a clearer picture of ecosystems in Greenland. GEM produces regular updates on vegetation conditions including greenness and density (NDVI), land-surface temperatures, and snow depth, along with detailed land surface temperature maps for the three monitoring super-sites. Models built for Young Sound and Disko Bay – based on GEM's long-term data – simulate how coastal marine ecosystems respond to shrinking sea ice and increased glacial runoff. Vegetation maps link small-scale plots to entire landscapes, while new marine products track chlorophyll a (i.e. phytoplankton biomass proxy), sea ice, and water temperature to connect what happens on land with changes in fjords. Carbon fluxes are continuously monitored at all sites providing a basis for validation of models. By combining ground stations, cameras, and satellites, we improve forecasts and reduce uncertainties in climate, ecosystem and carbon flux models.
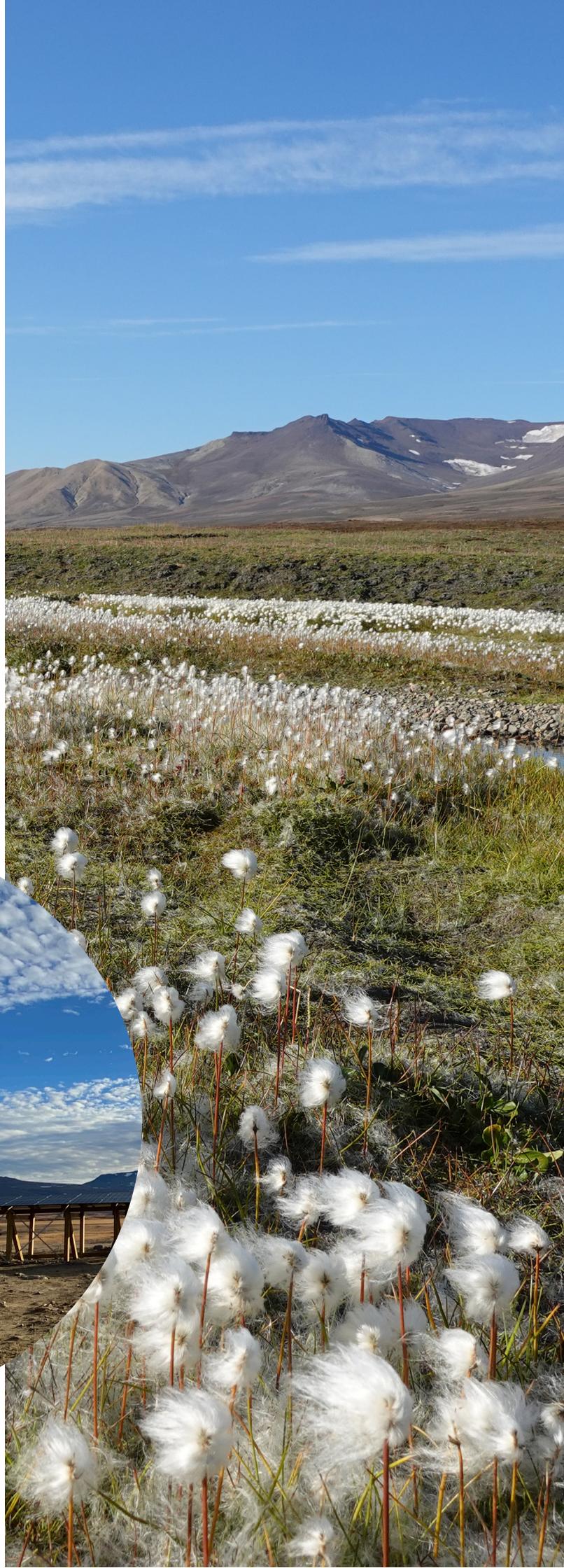
BIODIVERSITY AND POPULATIONS

Monitoring of land, lakes, and seas in Greenland has not only continued, but it has also expanded. GEM uses dense networks of sensors, drones, and cameras to capture changes in population dynamics of birds, mammals and plant growth, alongside year-round marine sampling and autonomous monitoring. Biodiversity baselines have been strengthened with DNA analysis of land animals, insects, marine plankton and fish, and multi-year records of harmful algae reveal emerging risks. GEM has provided new knowledge on depth limits of kelp as well as macroalgal reproduction at the northern edge of their range. GEM data also supports education and training programs and underpins the first cross-ecosystem study of carbon and nutrient flows from land to fjords, helping us understand how ecosystems in Greenland are connected from mountains to the sea.


PHOTO: CHARLOTTE SIGSGAARD

PHOTO: LARS H HANSEN

CONTRIBUTION TO KEY SCIENCE QUESTIONS

Decades of integrated observations show clear evidence of climate-driven change across Greenland. Glacier retreat is well-documented, while precipitation and snow-depth studies reveal how wind redistributes snow – improving climate models. Energy and carbon measurements help us understand ecosystem feedbacks, and advances in hydrology improve predictions of floods and extreme events. Scalable remote-sensing products allow us to assess changes across regions and forecast carbon, water, and energy cycles. Ecosystem models predict future conditions on land and in the fjords under scenarios of less snow and sea ice as well as more runoff. Long-term biodiversity records document shifts in timing and food webs, while DNA and algae monitoring highlight new ecological risks (e.g. expansion of harmful algae). Finally, studies of carbon and nutrient flows from land to fjords reveal how these couplings shape coastal ecosystems and their potential for storing "blue carbon".
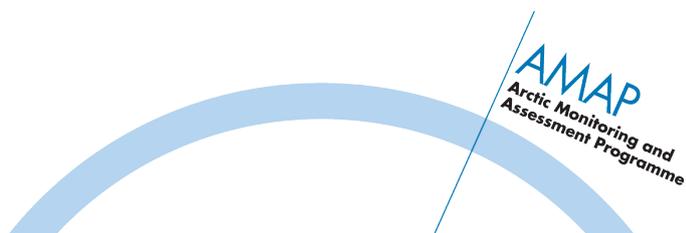
Key collaborations

WGMS – World Glacier Monitoring Service | PROMICE – Programme for Monitoring of the Greenland Ice Sheet | GC-Net – Greenland Climate Network | WMO OSCAR – WMO Observing Systems Capability Analysis and Review Tool | GIOS – Greenland Integrated Observing System | ICOS – Integrated Carbon Observation System | FLUXNET – Global Eddy-Covariance Flux Network | AMAP – Arctic Monitoring and Assessment Programme | CBMP – Circumpolar Biodiversity Monitoring Program | CAFF – Conservation of Arctic Flora and Fauna | ARC-BON – Arctic Biodiversity Observation Network | CARRA – Copernicus Arctic Regional Reanalysis | PATHS – Pan-Arctic Terrestrial Hydrology Synthesis (project) | LOGS | ICELINK – Advancing Knowledge of North Atlantic Land Ice | FACE-IT – Arctic Biodiversity & Livelihoods | POMP – Polar Ocean Mitigation Potential | GreenFeedBack Project | DSOS – Davis Strait Observing System | GreenHAB – Greenland Harmful Algal Blooms | DANCEA – Danish Cooperation for Environment in the Arctic | BlueCea – BlueCea Initiative | BlueARC – Blue Arctic Research Cluster | INTERACT – International Network for Terrestrial Research and Monitoring in the Arctic | POLARIN – Polar Research Infrastructure Network |

TEN RECENT CHOSEN PUBLICATIONS FROM ACROSS THE GEM PROGRAM

1 See, C.R., Virkkala, A.M., Natali, S.M. *et al.* (2024). Decadal increases in carbon uptake offset by respiratory losses across northern permafrost ecosystems. Nature Climate Change, 14, 853–862. https://doi.org/10.1038/s41558-024-02057-4

2 Schmidt, N. M., *et al.* (2023). Little directional change in the timing of Arctic spring phenology over the past 25 years. Current Biology, 33(15), 3244–3249. https://doi.org/10.1016/j.cub.2023.06.038

3 Desforges, J.-P., *et al.* (2021). Environment and physiology shape Arctic ungulate population dynamics. Global Change Biology, 27(9), 1755–1771. https://doi.org/10.1111/gcb.15484

4 Vonnahme, T.R., Chitkara, C., Krawczyk, D., Meire, L., Skogseth, R., Vader, A. & Juul-Pedersen, T. (2025). Abrupt decline of microplankton species richness linked to coastal inflow in an Arctic fjord. Limnology and Oceanography. https://doi.org/10.1002/lno.70159

5 How, P., Petersen, D., Kjeldsen, K.K., Raundrup, K., Karlsson, N.B., Messerli, A., Rutishauser, A., Andersen, S.B. (2025). The Greenland Ice-Marginal Lake Inventory Series from 2016 to 2023. Earth System Science Data, 17, 6331–6351. https://doi.org/10.5194/essd-17-6331-2025

6 Hynek, B., Binder, D., Citterio, M., Larsen, S.H., Abermann, J., Verhoeven, G., Ludewig, E. & Schöner, W. (2024). Accumulation by avalanches as a significant contributor to the mass balance of a peripheral glacier of Greenland. The Cryosphere, 18, 5481–5494. https://doi.org/10.5194/tc-18-5481-2024

7 Christensen, T.R., Lund, M., Skov, K., Abermann, J., López-Blanco, E., Scheller, J., Scheel, M., Jackowicz-Korczynski, M., Langley, K., Murphy, M.J. & Mastepanov, M. (2021). Multiple ecosystem effects of extreme weather events in the Arctic. Ecosystems, 24(1), 122–136. https://doi.org/10.1007/s10021-020-00507-6

8 Hermesdorf, L., Mortensen, L.H., Blitz, S.B., Jepsen, M.S., Westergaard-Nielsen, A., Michelsen, A., Blok, D., Sigsgaard, C., Christiansen, C.T., Hansen, B.U. & Elberling, B. (2024). Changes in soil and plant carbon pools after 9 years of experimental summer warming and increased snow depth. Science of The Total Environment, 951, 175648. https://doi.org/10.1016/j.scitotenv.2024.175648

9 Oehri, J., Schaepman-Strub, G. & Chambers, S.D. (2022). Vegetation type is an important predictor of the Arctic summer land surface energy budget. Nature Communications, 13(1), 6379. https://doi.org/10.1038/s41467-022-34049-3

10 Chitkara, C., Juul-Pedersen, T., Krawczyk, D., Søreide, J.E., Vader, A., Gradinger, R., Winding, M.H.S.,& Vonnahme, T.R. (2024). Seasonality in phytoplankton communities and production in three Arctic fjords across a climate gradient. Progress in Oceanography, 227, 103317. https://doi.org/10.1016/j.pocean.2024.103317

From 2022 to mid 2025, 138 GEM papers have been published and are available at: https://g-e-m.dk/gem-publications-and-reports

GEM DATABASE

The GEM database is a cornerstone of Arctic research, providing open access to high-quality, harmonized data from key monitoring sites in Greenland – Zackenberg, Nuuk, and Disko – alongside satellite-based products. Built on FAIR principles (Findable, Accessible, Interoperable, Reusable), the platform offers search tools, API access, and connected to global networks like DataONE. GEM data and metadata are shared through the GEM portal and partner platforms such as ICOS, POLARIN, INTERACT, WGMS, and WMO OSCAR, making it easy for scientists to reuse data across disciplines and regions. Standardized formats and rigorous quality checks ensure compatibility with pan-Arctic initiatives and Earth-system models. By boosting visibility and interoperability, the GEM database accelerates collaboration and deepens our understanding of climate change impacts on Arctic ecosystems. Selected data is also accessible via map-based platforms (Google Earth Engine), allowing for visual interpretation and quick analyses online. Continued efforts to increase the use and visibility of the GEM data will be part of the coming strategy period.

TRAINING AND EDUCATION

GEM supports the next generation of Arctic researchers through MSc and PhD training, leveraging its logistics, long-term datasets, and innovative methods like eDNA, drones, and automated sensors. Educational materials for high schools (available in Greenlandic and Danish) bring Arctic science and GEM data into classrooms. Student theses and postdoctoral projects expand analytical capacity and strengthen research networks connected to GEM sites. GEM subprogrammes have also provided time series data and contributed to teaching within the Arctic Science Study Programme (ASSP) in Nuuk, which has educated more than 500 international graduate students in natural sciences since 2015

PHOTOS: KATRINE RAUNDRUP

INFRASTRUCTURE AND OUTREACH

Upgrades to stations, new sustainable buildings, and improved energy systems have been granted by private foundations in support of the monitoring efforts. These have increased resilience and safety for year-round monitoring. The commissioning of a new research vessel enhances access to remote areas and boosts data collection. Public engagement is growing through short videos and broadcasts (e.g., KNR, DR, BBC), helping people understand why long-term monitoring matters. Collaboration with local and national rightholders and stakeholders ensures GEM's work remains relevant to society and supports sustained monitoring efforts.

INTEGRATED APPROACHES

GEM is a unique platform for linking glaciers, land, lakes, and fjords with climatic conditions – supporting catchment-to-coast studies and improving remote-sensing and model upscaling. Cross-program quality checks connect atmospheric, cryosphere, terrestrial, freshwater, and marine processes, giving us system-level insights. The Land2Fjord project shows how carbon and nutrients move across these compartments and informs evaluations of "blue carbon" storage in coastal ecosystems.

PHOTO: LARS H HANSEN

FUTURE OUTLOOK

Looking ahead to 2027–2031, GEM will focus on making data streams even more interoperable across sites and ecosystems. GEM plans to expand monitoring of snow, permafrost, and hydrology, and turn remote-sensing and model products into near-real-time tools for decision-making. Priorities include mapping carbon budgets across fjords, developing hazard-ready hydrological indicators, and strengthening biodiversity monitoring networks using eDNA, harmful algae tracking, and macroalgae studies. GEM aims to refine early-warning systems aligned with Arctic Council programs (e.g. CAFF/CBMP and AMAP) and combine process-based and machine-learning models for better forecasting. Improved calibration between satellites and field data – including coastal color – will enhance accuracy, while open-science workflows will support pan-Arctic synthesis and policy assessments.
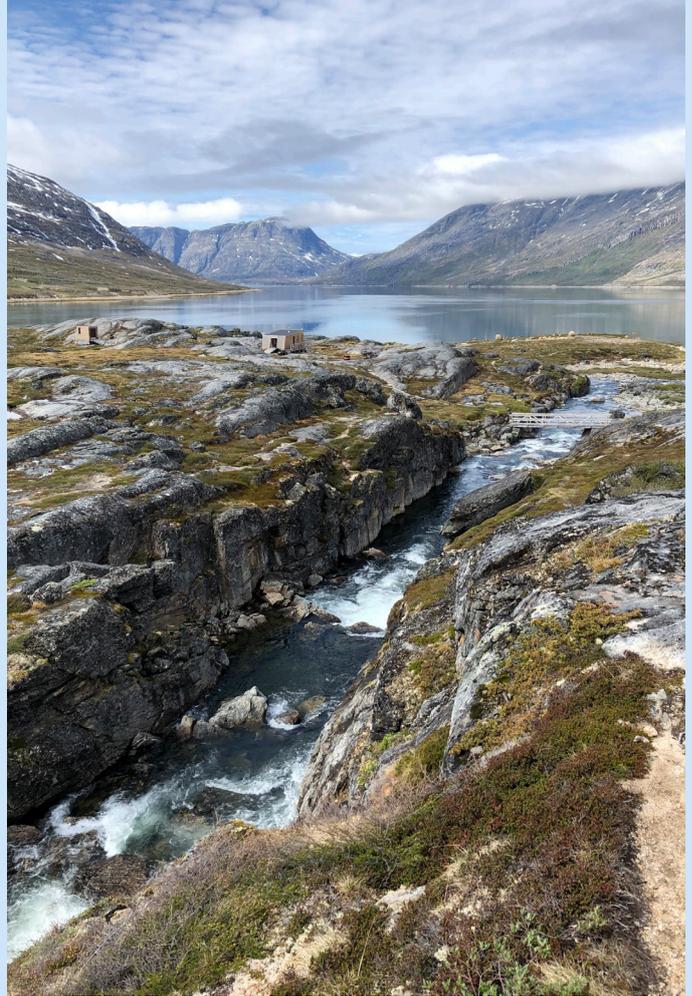
PHOTO: CHARLOTTE SIGSGAARD

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