Greenland Ecosystem Monitoring

ANNUAL REPORT CARDS 2024

Title:	Greenland Ecosystem Monitoring Annual Report Cards 2024
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Publisher:	Aarhus University, DCE – Danish Centre for Environment and Energy URL: http://dce.au.dk
Year of publication:	2025
Citation:	Torben Røjle Christensen & Marie Frost Arndal (2025). GEM Annual report Card 2024. doi: 10.5281/zenodo.15463436. DCE – Danish Centre for Environment and Energy, Aarhus University, 48 pp. Reproduction permitted provided the source is explicitly acknowledged. Open Access under Creative Commons Attribution 4.0 International.
Layout and figures:	Tinna Christensen, Aarhus University
Front cover:	View of Zackenberg by Lydia Cornu.
Back cover photos:	Top to bottom: Jakob Abermann, Laura H. Rasmussen, Bula Larsen, Thomas Juul-Pedersen, Michele Citterio and Daniel Rudd (drone images)
ISBN: DOI:	978-87-7156-958-2 10.5281/zenodo.15463436
Number of pages:	48
Printed by:	Fællestrykkeriet, AU TRYK
Circulation:	250

The publication is available through www.g-e-m.dk.

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GREENLAND ECOSYSTEM MONITORING

ANNUAL REPORT CARDS 2024

GEM
Greenland Ecosystem Monitoring

GEM INTRODUCTION

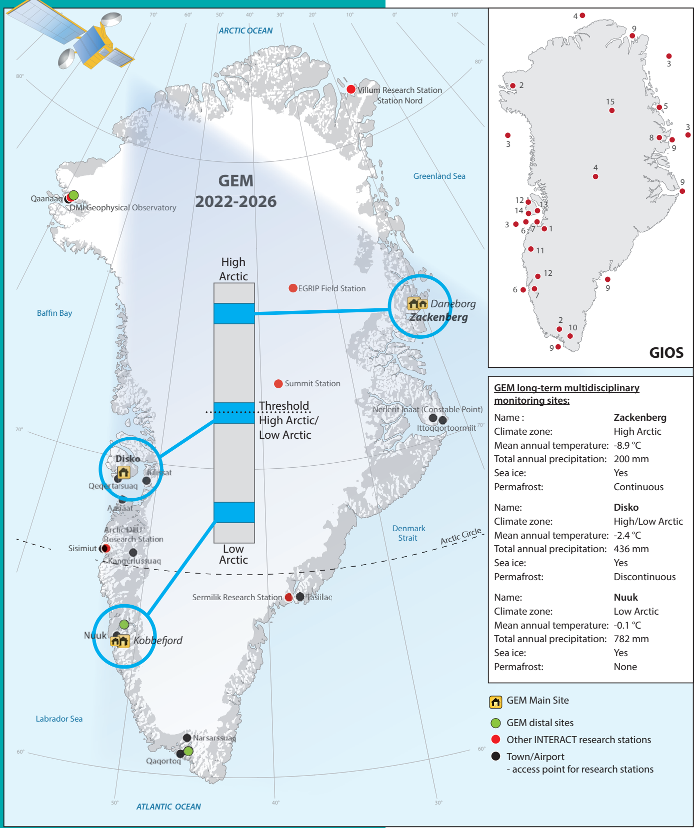

Figure 1. The GEM programme combines intensively studied ecosystems at three main sites (Disko, Nuuk and Zackenberg) with remote sensing and distal sites located along environmental and climatic gradients. The complementary study sites of Greenland Integrated Observing System (GIOS) are also shown.

About GEM

Greenland Ecosystem Monitoring (GEM) is an internationally recognized climate and ecosystem monitoring programme in Greenland, operated by research institutions in Denmark and Greenland. It was established in 1995 and has since then been monitoring essential climate and ecosystem variables. Throughout the years GEM has contributed to the working groups of the Arctic Council (AMAP and CAFF) and the long-term data has improved the scientific understanding of climate and ecosystem change in the Arctic. The programme has developed from a comprehensive climate change and ecosystem monitoring programme at a single site in the National Park in North-East Greenland, to also include two equally comprehensive programmes in West Greenland, supplemented with initiatives at other locations (Figure 1).

The three main sites are located at Zackenberg in High-Arctic Northeast Greenland, on Disko at the boundary between High-Arctic and Low-Arctic in West Greenland and at Nuuk in the Low-Arctic West Greenland.

The vision of GEM

"GEM will contribute substantially to the basic scientific understanding of arctic ecosystems and their responses to climatic changes and variability as well as their potential local, regional, and global implications."

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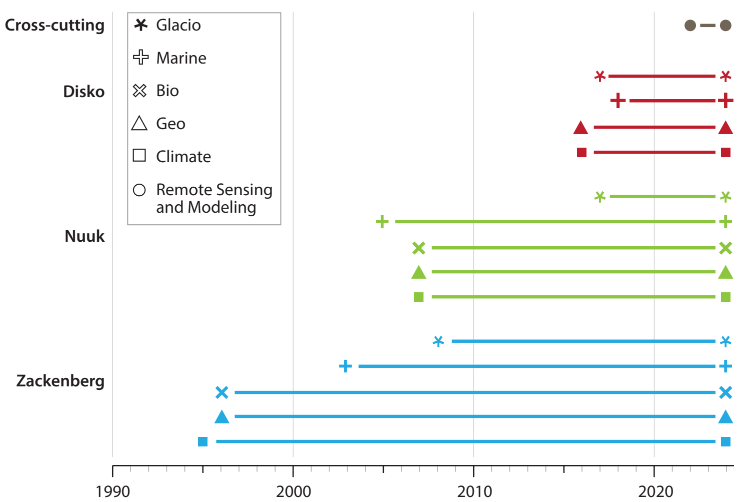
Figure 2. The GEM programme was initiated in 1995 as the Zackenberg Ecological Research Operations (ZERO). In the years 2005-2007 a new main site was established around Nuuk, and in 2016-2018 Disko area was included. All 5 Basisprogrammes are now funded at all three main sites, except for BioBasis at Disko. Remote sensing and Ecosystem modelling is the new cross cutting programme.



The GEM organisation consists of a Steering Group, a Secretariat, a Coordination Group and sub-programme leaders. The long-term monitoring efforts of the programme is funded by the Danish Ministry of Climate, Energy and Utilities (Klimastøtte til Arktis), the Danish Environmental Protection Agency (Miljøstøtte til Arktis), and by the Government of Greenland. Additional funding for programme development and improved process understanding is provided by the institutions behind the GEM programme and other external funding sources.

International cooperation

The GEM programme and scientists work closely with more than 30 international scientific networks to implement standard methodologies and share data for inter-comparisons and assessments. GEM scientists are involved in monitoring programmes of Arctic Council working groups (AMAP and CAFF) contributing with data and taking on leading roles in co-ordination, development and synthesis efforts. GEM scientists and data also contributes to regional and global intergovernmental assessments by IPCC and IPBES.

Education and Advice

GEM is making an active effort to help educate the next generation of scientists, with several university courses using GEM data, and associated Ph.Ds and Post Docs. GEM scientists work actively reaching out to students in schools and high schools through course and information materials based on GEM knowledge and data. This all combined with international cooperations reach a wide arctic audience. GEM work to create awareness and provide public insight into the changes that occurs in the Arctic climate and ecosystems.

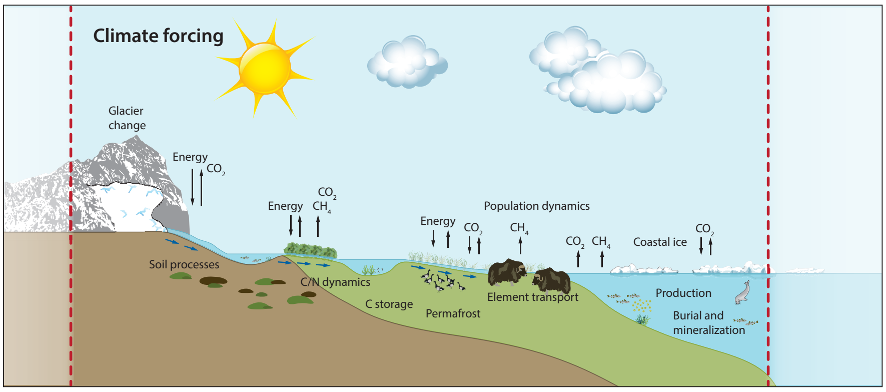


Figure 3. The GEM domain covers the glaciological, terrestrial, limnic and coastal marine compartments of the ecosystem.

Program aims

GEM aims to provide government advice on climate change and impacts, and where relevant GEM knowledge and data are used to address sustainability and adaptation efforts.

Free and open access to data

GEM provides free and open access to all data collected under the programme since the start in 1995. Data collection efforts have grown since the start of the programme and today includes more than 2000 parameters collected at the three main sites Zackenberg, Disko and Nuuk. Additional data are collected through remote sensing and supplementary transects and sites contributing to gradient studies and scaling efforts. All data are made available, quality assured and with DOI assigned to allow citation.

Explore GEM data on https://data.g-e-m.dk/

Read more about the GEM programme and its achievements on: **www.g-e-m.dk**

@GreenlandEcosystemMonitoring

Greenland Ecosystem Monitoring

Feel free to get in touch with the GEM Secretariat if you have questions or want to explore possibilities for collaboration at g-e-m@au.dk

Arctic Station – Disko

Zackenberg Research Station

Kobbefjord Station

ANNUAL REPORT

Results and achievements

News from GEM main sites and outreach

Kobbefjord

In June 2024 the station in Kobbefjord was used as the hub for the master's course Catchment2Coast. Twenty students collected data on nutrient transport from land via freshwater to the marine system during four days in the field. It was the first time the course was held, and plans are already laid for the continuation in 2025.

In August 2024 the station was visited by highschool students from Frederiksborg Gymnasium og HF, who did data collection according to the practical guidebook "Undersøgelser i felten" developed during the "Virtuel Rejse" project funded by Novo Nordisk Fonden.

In June 2024 Kobbefjord was visited by the head of Department from the Ministry for Agriculture, Self-Sufficiency, Energy and Environment together with department staff and four board members from Aage V Jensens Naturfond together with Josephine Nymand, director of the Greenland Institute of Natural Resources. Both groups were introduced to the GEM programme and the long-term monitoring taking place in Greenland.

Master's students visiting Kobbefjord during the Catchment2Coast course. Photo: Katrine Raundrup.

VIP visit in Kobbefjord. Photo: Katrine Raundrup.

Torben Røjle Christensen,
Scientific leader of GEM

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2024

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Disko

As part of the Danish Royal Family's visit to Greenland, Arctic Station had the honor of welcoming Their Majesties the King and Queen, along with their children, to Qeqertarsuaq. During their stay, Arctic station presented an update on current research activities at the station. The visit included a boat trip and a hike to the whale listening site, where the Royal Family learned about ongoing acoustic monitoring efforts. The GEM program was also here prominently featured.

The Royal family in Qeqertarsuaq. Photo: Kirsten Christoffersen.

Scientific leader of Arctic Station Kirsten Christoffersen is sharing insights with the Danish Royal Family during their visit to Qeqertarsuaq. A unique opportunity to present current research and highlight the importance of Arctic science. Photo: Kisser Thorsøe.

Zackenberg

In 2024, efforts continued to align with GEM's commitment to smarter, more energy-efficient, and sustainable operations. At Zackenberg, this first full season with all solar panels in operation resulted in a 70% reduction in diesel usage.

Additionally, construction work began on the new sustainable main building project at Zackenberg, which is scheduled for completion in 2027. A new boat garage at Daneborg, part of the donation from the Aage V. Jensen Foundations for new buildings at Zackenberg, was partially constructed and is expected to be completed in 2025.

The Greenland Institute of Natural Resources and MarinBasis operations at Daneborg received a new research vessel funded by the same foundations, which became operational in late August 2024. See the report card : Arfivik – A new vessel for marine monitoring in Greenland.

Solar Panels in Zackenberg. Three configurations are being tested: 15° east/west, 45° south, and vertical 90° panels - both bifacial and monofacial -to assess performance under Arctic conditions and the midnight sun. The PV (photovoltaic) system was finalized in 2024. Photo: Marie Arndal.

ANNUAL REPORT

The Board of the Aage V Jensen Charity Foundation visited the Zackenberg/Daneborg area on a three-day visit in August. This Board has been very instrumental for GEM in supporting the infrastructure that our operations are dependent on in both Kobbefjord and Zackenberg/Daneborg.

The Christening of the new vessel "Arfivik" in Daneborg. Photo: Torben R. Christensen.

Workshop for high school teachers in Aarhus, showcasing the newly developed GEM educational materials. Photo: Marie Arndal.

Education

The GEM-based educational project *"Virtuel rejse i arktiske økosystemer – dyk ned i klimaændringerne"* concluded in 2024. The project and the materials were introduced to high school teachers through workshops held in both Nuuk and Aarhus, as well as at the Biokonferencen for biology educators in Odense. The teaching materials are now being used in numerous high schools across Greenland and Denmark, which is expected to significantly increase the use of GEM data in education. See the report card: *Dive deep into the GEM database - teaching materials now available for high school students.*

2024

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Photo: 8 Workshop for high school teachers at Biokonferencen in Odense, with a presentation of the educational materials and distribution of the practical Field guidebook for students on how to collect data in nature. Photo: Marie Arndal/Katrine Raundrup.

International collaboration

GEM scientists have contributed extensively to a series of review papers that is forming part of a special issue of the journal Frontiers in Environmental Science. This in turn is part of an overall assessment process between AMAP and CAFF on ecosystem impacts and feedbacks in the Arctic. (Link to Frontiers | Climate Change Impacts on Arctic Ecosystems and Associated Climate Feedbacks)

A further AMAP related initiative towards making links with the US Permafrost Pathways project and developing joint plans for coupled monitoring in the Arctic was discussed at a workshop in Reykjavik in November 2024. In this workshop the GEM structure and protocols were discussed as a model that can be used elsewhere in the Arctic. (Link to workshop report: AMAP)

Overall 2024 was a succesful year for the GEM programme where the continued data gathering largely went as planned in all sub programmes.

GEM database

In 2024, the GEM database saw significant advancements and increased engagement. The GEM database recorded 3,712 total visits, with 1,448 dataset downloads by registered users for research and study purposes. The user base grew to 187 registered users following the launch of a new website in summer 2024. The database now offers 462 datasets, including 37 new additions. These datasets provide crucial timeseries data on ecosystem components at GEM research locations (Disko, Nuuk, and Zackenberg), supported by remote sensing products.

A completely renewed website was launched in 2024, improving data access, preview, and download performance. The new platform also supports API access and adheres to FAIR data principles. The use of GitHub for source control and software development has streamlined the process of implementing new features.

Efforts to integrate the Global Change Master Directory (GCMD) vocabularies have enhanced search functionality, making it easier for users to find relevant datasets. GEM has strengthened its international presence by integrating with the Data Observation Network for Earth (DataONE) and participating in the EU project POLARIN. These collaborations aim to increase the visibility and usage of GEM's quality-assured timeseries data.

GEM at a glance 2024

- Active Basis Programmes in 2024: 14+remote sensing
- Scientists in the field: 102
- Scientific publications: 51
- Conference with GEM representations: 11
- Conference presentations (poster): 15 (3)
- Courses using GEM data: 18

DIVE DEEP INTO THE

– TEACHING MATERIALS NOW AVAILABLE

How does photosynthesis respond to climate change in the Arctic? What does an earlier snow melt mean for flowers and insects in Greenland? How does muskoxen respond to more snow? With our new teaching materials, high school students can explore these questions, and many more, through real scientific data.

For the past years we have developed free teaching materials for high school students in Greenland and Denmark, using data and knowledge from GEM. The project, Virtuel rejse i arktiske økosystemer – dyk ned i klimaforandringerne, has resulted in products ready for students to use.

All materials are available on an online platform in either Greenlandic or Danish. The e-book covers 8 themes: Weather and Climate, Carbon cycle, Hydrological cycle, Arctic Ecosystems, Plants in the Arctic, Animals in the Arctic, Lake ecology, and finally a theme on how to get from data collection to climate models. Each theme includes different StoryMaps which present the theoretical content from the e-book in a more engaging and dynamic format. The StoryMaps combine text, images, videos, and maps to create an interactive storytelling experience. The StoryMaps also feature videos of GEM staff explaining, for example, how data is collected and why measuring specific parameters is important. At the end of each StoryMaps there are links to exercises with questions and data from GEM to highlight relevant examples from both the e-book themes as well as the text in the StoryMaps.

Authors:

Katrine Raundrup, Greenland Institute of Natural Resources

Marie Frost Arndal, Aarhus University

Data source:

The material is available at:

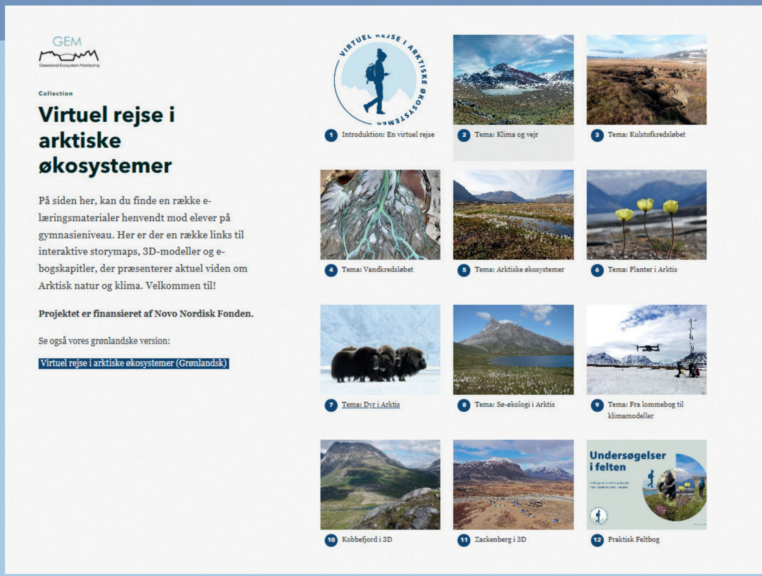
Danish: https://storymaps.arcgis.com/collections/670dd5803f0e49d19120e38798cfe068

Greenlandic: https://storymaps.arcgis.com/collections/f8c65635a8564176b444bbcff4238464

GEM DATABASE

FOR HIGH SCHOOL STUDENTS

Greenland Ecosystem Monitoring

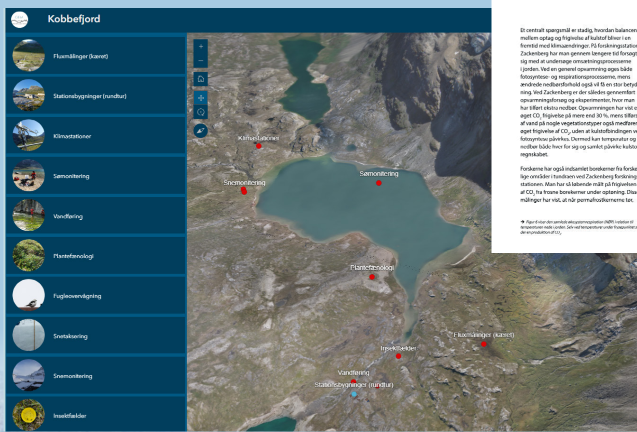


Furthermore, 3D-models from Zackenberg and Kobbefjord allow students to explore these locations virtually, giving them a sense of the local environment. The models also include videos explaining how, where and why data is collected.

The only printed product is a practical field book (but it is of course also found in an online version) where students are presented with studies that can be done in the field in either Greenland or Denmark. All 10 exercises have links to modified GEM datasets allowing students to compare their own collected data with real scientific data.

The materials are designed for high school students to teach and learn about the Arctic, climate change, and what GEM does to monitor the effects of the ecosystem changes. The goal is to engage students and inspire an interest in the natural sciences – ultimately sparking curiosity in the next generation of scientists.

The project is a collaboration between Aarhus University (Torben Røjle Christensen and Marie Frost Arndal), the Greenland Institute of Natural Resources (Katrine Raundrup) and Frederiksborg Gymnasium og HF (Svend Erik Nielsen) and is funded by Novo Nordisk Fonden.



ARFIVIK
– A NEW VESSEL FOR MARINE

Arfivik in Young Sound.
Photo: Mie Winding.

Arfivik – a new research vessel strengthening marine monitoring in Greenland! Built to withstand Arctic conditions, Arfivik ensures continued data collection on climate change impacts in Young Sound. A new era of Arctic research has begun!

The Arctic is changing rapidly, and long-term environmental monitoring is crucial to understanding these shifts. Since 2003, the MarinBasis Zackenberg program, part of Greenland Ecosystem Monitoring (GEM), has been collecting essential data on the physical and biological conditions in Young Sound, Northeast Greenland. Through year-round measurements of temperature, salinity, oxygen levels, and biological parameters, the program provides valuable insights into how climate change is reshaping Arctic marine ecosystems. This data is crucial for understanding not just local changes but also their global consequences.

To enhance these efforts, the Greenland Institute of Natural Resources has acquired a new research vessel, Arfivik, made possible through the support from the Vagn Forring's Foundation. This investment ensures that the MarinBasis Zackenberg monitoring, and research capabilities remain strong for years to come, allowing us to continue gathering critical data on Greenland's marine environment.

Arfivik in Young Sound.
Photo: Thomas Gjerluff Ager.

Authors:

Mie Winding, Greenland Climate Research Centre, Greenland Institute of Natural Resources

Mikael Sejr, Department of Ecoscience, Aarhus University

MONITORING IN GREENLAND

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The name Arfivik means bowhead whale in Greenlandic and represents resilience, endurance, and deep ties to the Arctic environment. The bowhead whale is a species uniquely adapted to the icy waters of the Arctic, much like our work requires a vessel capable of withstanding extreme conditions.

Replacing our old vessel, Aage V. Jensen, which has served the program well since 2003, Arfivik marks a new era for research in Young Sound. Arfivik is a 7.1-meter aluminum-hulled research vessel designed to withstand the harsh Arctic environment and support scientific operations in Greenland's coastal waters. Built with seawater-resistant aluminum, the boat features self-draining decks, and a reinforced hull to navigate icy and turbulent conditions.

Arfivik is equipped with two reliable and efficient Yamaha 250HP engines, ensuring excellent maneuverability for remote field operations, allowing us to cover a much larger survey area within limited Arctic field seasons. The fully enclosed steering cabin provides shelter for researchers, while the open front deck offers a flexible workspace. Built specifically for Arctic conditions, Arfivik offers improved safety through a reinforced hull, advanced navigation systems, and reliable performance in rough and icy waters.

With a maximum capacity of eight people, and advanced navigation and safety features such as radar, Arfivik is well-suited for research missions. Additionally, specialized storage compartments, anchoring systems, and lifting equipment make the vessel highly adaptable for scientific investigations.

Arfivik is built by MS BOAT and Sejs Marinecenter, and represents a significant upgrade for MarinBasis Zackenberg, ensuring continued data collection on climate change impacts in Greenland's marine ecosystems for years to come. Arfivik is designed to handle challenging conditions while improving safety, maneuverability, and research capabilities.

But Arfivik is more than just a research vessel, Arfivik is a symbol of scientific collaboration and dedication to understanding the Arctic environment. It will support both current and future scientists, helping us document the ongoing changes in Greenland's marine ecosystems and contributing to vital climate research.

Overall, Arfivik marks a significant step forward for marine monitoring in Northeast Greenland. The extended range, improved safety, and better working conditions allow for more consistent and wide-reaching data collection. This strengthens our ability to track changes in the Arctic marine environment and ensures that monitoring efforts can continue under even the most challenging conditions.

Ship naming ceremony and "kaffemik" in Daneborg. Photo: Karl Attard.


Climate
&

Cryos-phere

Photo: Thomas Juul-Pedersen.

THE FUTURE
OF THE MONITORED

Glaciers are disappearing all over the globe (The GlaMBIE Team, 2025). The glaciers at the three GEM sites are not an exception. Model results indicate that the monitored glacier at the Kobbefjord site, Qassinnguit Sermiat, could be gone already in 20 years, at the Disko site the Chamberlin glacier could be gone by 2080 and at the Zackenberg site the A.P. Olsen Ice Cap could be reduced to half the size by the end of the century.

Glaciers are freshwater reservoirs, releasing freshwater when melting in summer which ends up as stream flow independently of rain. In many areas of the world glacial meltwater is an important resource for hydropower, irrigation and drinking water. Ultimately, they are also freshwater reservoirs keeping water on land that would otherwise be in the ocean. Therefore, when they are melting more than they are being replenished, they are a source of global sea level rise.

Currently glaciers are melting much faster than they are being replenished due to the warming climate. In the Alps for example this has been observed as glaciers are disappearing completely, but also as a temporary higher rate of runoff as the glacier ice is melting more rapidly (The GLAMBIE team, 2025). The modelling of global glaciers volume is a community effort that GlacioBasis feeds into with in situ data via the World Glacier Monitoring Service (WGMS.ch).

Here we look at the model results from the global glacier projections done by Schuster et al. (2023) using the Open Global Glacier Model (OGGM) done as part of the Climate Model Intercomparison Project (CMIP6, Eyring et al., 2016) which was made as preparation for the sixth assessment report of the Intergovernmental Panel on Climate Change Assessment Report (IPCC AR6).

We show the projected future runoff from the glaciers based on two climate scenarios: SSP1-2.6 which is the sustainable pathway defined in the IPCC AR 6 and SSP5-8.5, which is the fossil fueled and worst case scenario for climate warming. By doing this we are addressing one of the key questions within the Climate and Cryosphere theme of how the observations and process-level understanding gained in the GEM monitoring can be used to understand longer term evolution of the cryosphere and hydrosphere.

Authors:

Signe Hillerup Larsen[1], Alexandra Messerli[2] & Michele Citterio[1]

[1]The Geological Survey of Denmark and Greenland GEUS

[2]Asiaq – Greenland Survey

Data source:

Data can be accessed on GEM database, https://data.g-e-m.dk

GlacioBasis – Surface mass balance monitoring

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(AS WE KNOW IT)
GLACIERS AT THE GEM SITES

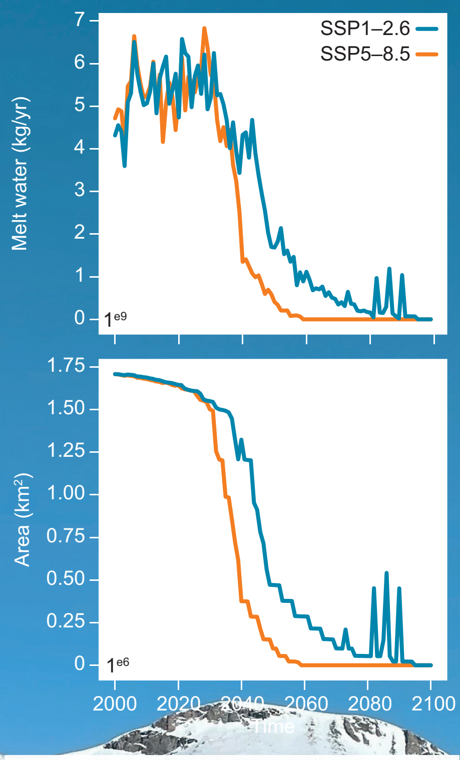

Figure 1. Qassinnguit Sermiat at the Kobbefjord site near Nuuk. Top panel shows projected melt from the glacier, bottom panel shows projected glacier area.

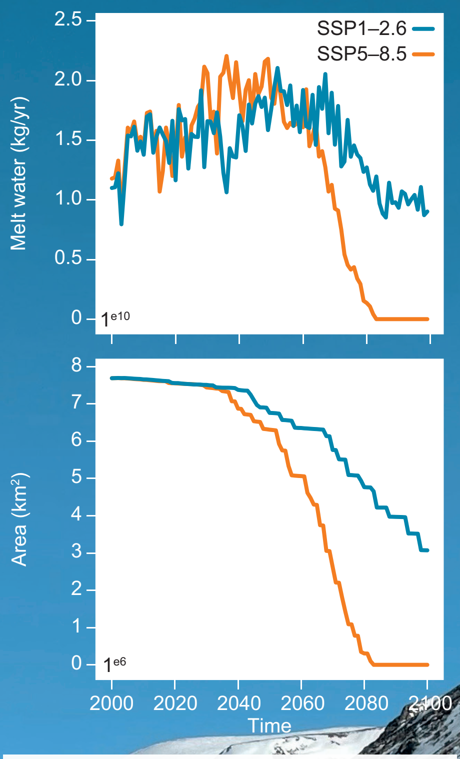

Figure 2. Chamberlin glacier on Lyngmarksbræen at the Disko site. Top panel side shows projected melt from the glacier, bottom panel shows projected glacier area.

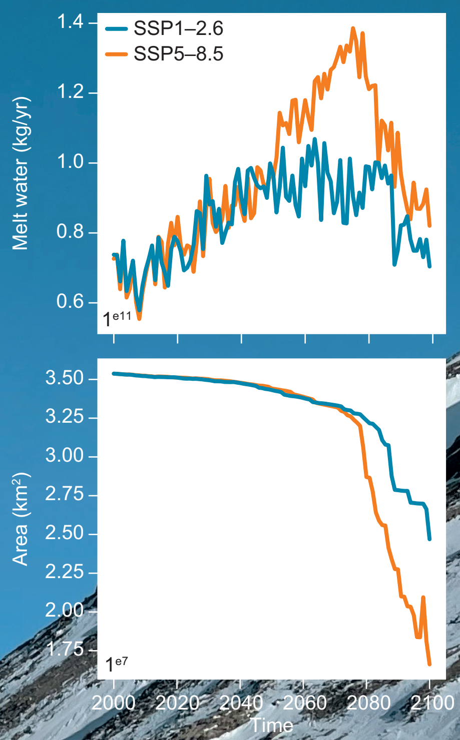

Figure 3. The monitored east flowing outlet of A.P. Olsen Ice Cap at the Zackenberg site. Top panel side shows projected melt from the glacier, bottom panel shows projected glacier area.

Unsurprisingly, the results show that the SSP5-8.5 scenario will lead to the demise of the two glaciers in the lower and mid arctic sites (Nuuk and Disko), and a reduction to half the size of the glacier at the high arctic site (Zackenberg) as can be seen in the right hand panel on Figure 1, 2 and 3 showing the evolution in area in the two different model scenarios. However, even in the best-case scenario SSP1-2.6 the Qassinnguit Sermiat at the Nuuk site will be more or less gone by 2080 (Fig. 1), while Chamberlin glacier at the Disko site will have lost half of the area (Fig. 2). As for projected runoff we can expect to see an increased amount of meltwater runoff from A.P. Olsen ice cap into the Zackenberg River for decades to come, peaking around 2060 to 2080 (Fig. 3). From Chamberlin glacier we can also expect to see an increased runoff peaking in 2060-2080 while runoff from Qassinnguit Sermiat will likely not be increasing much before it starts to drastically reduce from around 2035, which is only a decade from now.

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Ecosyst
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Photo: Charlotte Sigsgaard

SEASONAL PATTERNS IN SEDIMENT FROM A GLACIER

Arctic rivers provide a major link between land and sea by transport of freshwater, sediments and nutrients. Long-term monitoring of river parameters is part of the GEM programme and essential to quantify total fluxes from the terrestrial to the marine ecosystem. The runoff and the water quality are closely linked to climatic conditions and processes in the surrounding landscape.

Photo 1: Muddy brown and clear water corresponding to high and low turbidity in Røde Elv. Photo: Charlotte Sigsgaard.

The river Røde Elv (Kuussuaq) near Qeqertarsuaq on Disko Island drains an area of approximately 96 km^2 (Fig. 1). The drainage basin is characterized by a unique volcanic genesis with layered basalts, and a typical mountainous periglacial landscape. A detailed morphologic mapping of the drainage basin was carried out in 2023 (Richter et al., 2025). The basin consists of glaciated areas and block fields at elevations above 700 m, steep unvegetated upper talus slopes with active mass movements between 300 and 700 m, and vegetated lower talus slopes with riverbanks below 300 m elevation. The central part of the drainage basin has a braided river system with relatively flat slopes. The river narrows to a single channel before it enters the Disko Bay.

Figure 1. Outline of the river Røde Elv (Kuussuaq) drainage basin. The hydrometric gauging station is located near the outlet to the sea (yellow point) and the weather station AWS3 is located in Blæsedalen 90 m asl (blue point). The catchment varies in elevation from 0 to 900 m asl.

As part of the GEM monitoring at Arctic Station, we monitor hydrological parameters at a gauging station near the Røde Elv river outlet, by deploying a multi-parameter sensor in the river soon after river breakup. In addition to the unattended data sampling, manual water sampling and discharge measurements are carried out to validate the data and convert water level and turbidity to water discharge and suspended sediment concentrations.

Winter runoff is observed in the area but hard to quantify as water runs beneath ice- and snow cover, or as surface meltwater on the snow. Most discharge in the river Røde Elv occurs between June and October. Seasonal patterns in hydrological parameters from the 2024 season are shown in Figure 2. The discharge illustrates a typical Arctic runoff pattern with high snowmelt driven discharge rates in the early part of the season, and a gradual decline with depletion of snow in the landscape (Fig. 2). This pattern is overlaid by event-peaks induced by either rain or extraordinary warm periods that increase melt water input from glaciers. The peak discharge of the 2024 season happened at the end of July as a response to several days of rain.

The mid-summer rain event also triggered the highest turbidity of the season (Fig. 2). Turbidity is a measure of water clarity and often adopted as a proxy for the suspended sediment concentration in the water (Photo 1). The turbidity in 2024 closely follows the fluctuations in discharge. During the rain event, particles from surrounding land was washed into the river giving it a muddy reddish-brown color, which can be tracked as a visible plume reaching out in the marine near coastal zone (Photo 2). During high discharges, the water velocities are high and so is the potential for erosion along the riverbed and banks. The peak-event clearly illustrates a characteristic hysteresis loop with higher turbidity values during rising discharge and lower values during the falling discharge as sediment availability depletes (Fig. 3). The effect of rain events on the total export of sediment and nutrients is highly linked to intensity and seasonal timing. Late summer rain events, when the active layer is deepest, has potential for higher sediment loads, as thawed soils are more erodible, and a larger part of the drainage basin can deliver sediments and nutrients to the streams.

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Data source:

GEM GeoBasisDisko/ Hydrology/ Discharge

GEM GeoBasisDisko/ Hydrology/ Multisonde

GEM GeoBasisDisko/Meteorology/ AWS3-Meteorology

Data can be accessed on GEM database, https://data.g-e-m.dk

RIVER WATER AND SUSPENDED
FED CATCHMENT DURING SUMMER 2024

GEM
Greenland Ecosystem Monitoring

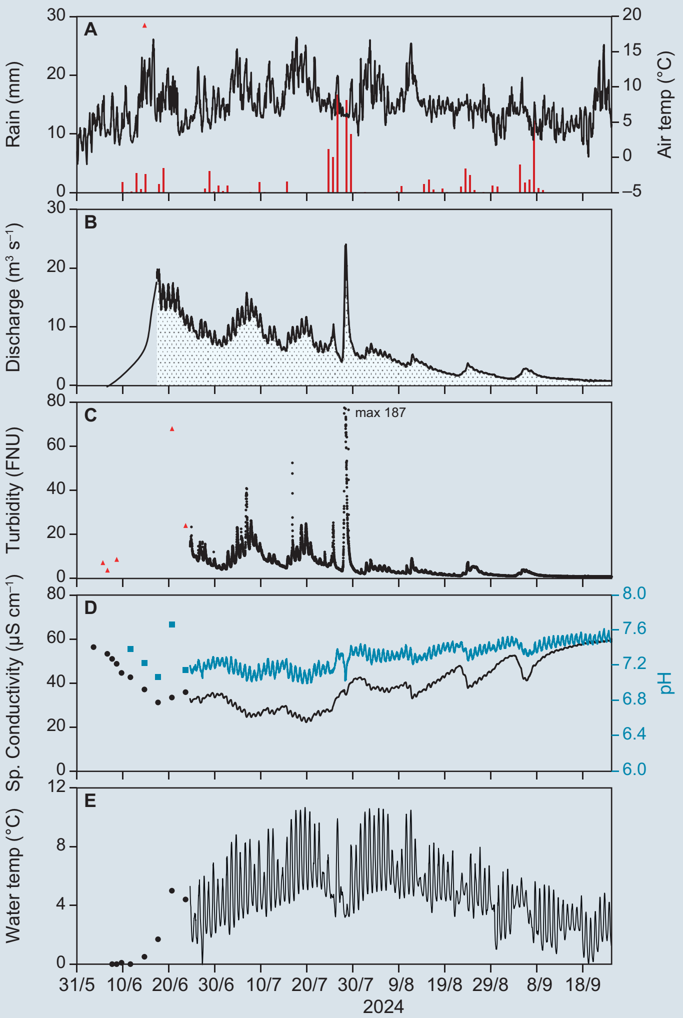


Figure 2. Seasonal variation in parameters measured at the hydrometric station during the main part of the runoff season in 2024 (Panel B to E). The upper panel (A) shows air temperature and daily sum of rain measured at the automatic weather station AWS3. The discharge (B) is estimated in the period from river breakup 7 June until 18 June due to snow and ice in the riverbed. In situ spot measurements of turbidity (C), pH (D), conductivity (D) and water temperature (E) cover the period until continuous measurements are available.

River water parameters like pH, conductivity and water temperature are indicators for the chemical composition of the water (Fig. 2, D and E). *In situ* measurements of pH indicate that the water in Røde Elv was slightly alkaline (7.0 to 7.6). Conductivity provides information about the concentration of dissolved ions/nutrient status in the water. The seasonal variation indicates shift in the relative dominance from various sources of water. Melt water from the glacier has a relatively low conductivity compared to soil water and therefore the conductivity shows a steady increase towards the end of the season, as input from the glaciers decreases.

Altered precipitation patterns, rising temperatures and permafrost degradation all have implications for the river systems and thereby the total transport of freshwater, nutrients and sediments from land to sea. Knowledge of the annual and inter annual variations in the river parameters is an important baseline for these quantifications. Daily mean runoff data from Røde Elv, along with those from Zackenberg and Kobbefjord (Nuuk) are reported to the Global Runoff Data Centre (GRDC) as the three sites representing Greenland.

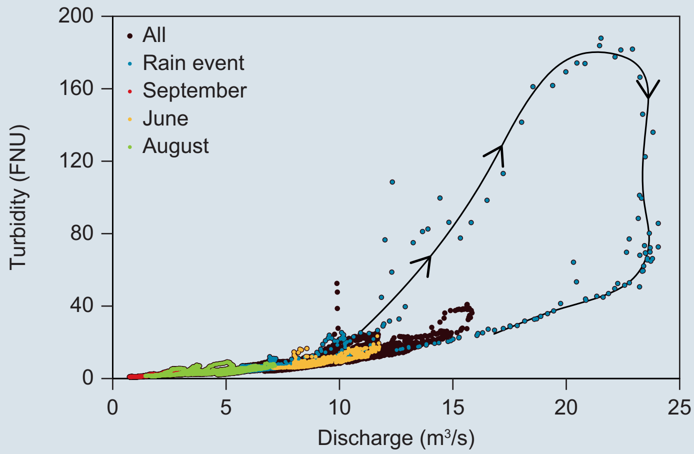
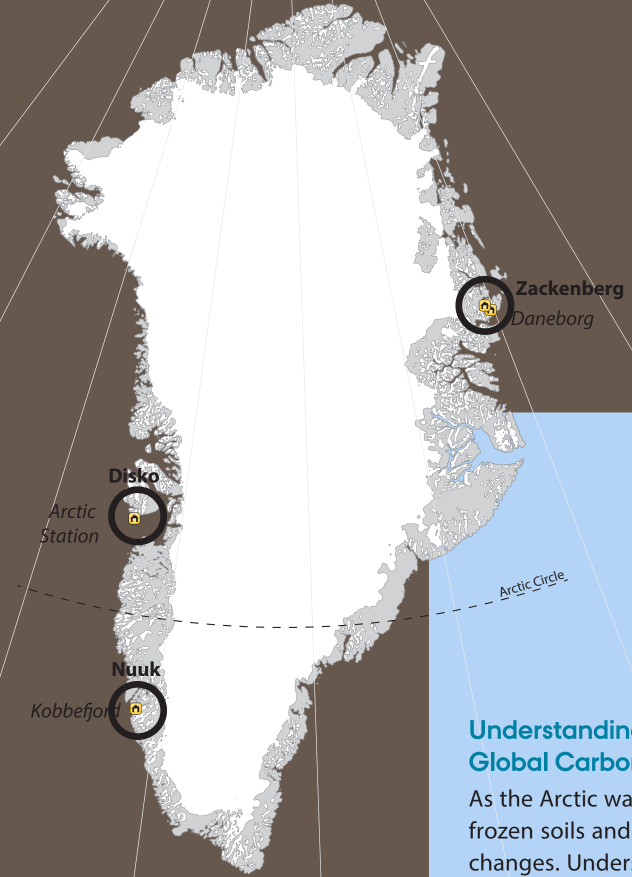


Figure 3. Turbidity versus discharge rates 2024. The line and arrow show the progress during the rain event. Turbidity increases during rising discharge and drops before the discharge drops as available sediments depletes.

Photo 2: The outlet of the river Røde Elv with a small plume of suspended sediment. The river gauging station is marked by the yellow dot. Photo: Gregor Luetzenburg.

References

Richter, U., Sigsgaard, C., Kroon, A. (2025): Geomorphological map for the watershed of the Røde Elv, Disko Island, CW Greenland (QGis Map Package) [dataset]. PANGAEA. (https://doi.pangaea.de/10.1594/PANGAEA.974723)



Annual Report Card 2024

TOWARD A ROBUST
BUDGET FOR ARCTIC

The Arctic is warming faster than any other region on Earth, driving ecosystem changes that have global consequences. New research[1] reviews how different contributors to the carbon (C) balance in Arctic catchments can be measured and modeled holistically while addressing the uncertainties that make predicting these changes a critical challenge for the planet's future.

Understanding Greenland's Role in the Global Carbon Cycle

As the Arctic warms, vast carbon reserves stored in frozen soils and tundra are undergoing significant changes. Understanding how carbon moves vertically and laterally across the land-freshwater-fjord continuum is essential to assessing the role of Northern latitudes in global carbon dynamics. Greenland, with its unique and heterogeneous landscapes, plays a crucial role in answering these questions. Researchers are working to better understand how these environments are responding to rapid climate change and to reduce the substantial uncertainties in current carbon budget assessments.

At the heart of this framework is the Net Ecosystem Carbon Balance (NECB) – a comprehensive measure of all carbon fluxes in and out of an ecosystem. NECB accounts for processes such as plant CO_2 uptake through photosynthesis, soil respiration, methane emissions from wetlands, the transport of dissolved carbon through rivers and streams, interaction with large herbivores, and episodic extreme events and disturbances (Fig. 1). By applying this holistic approach, researchers aim to determine whether Greenland's ecosystems are net carbon sinks – helping to mitigate climate change – or sources of greenhouse gases that accelerate warming. The Greenland Ecosystem Monitoring (GEM) programme plays a pivotal role in NECB research by providing long-term, high-resolution data from Arctic sites such as Zackenberg, Kobbefjord and Disko. GEM's datasets enable precise measurement of CO_2 exchange through eddy covariance towers, methane emissions via automated chambers, and lateral carbon transport monitored through river discharge analyses (Fig. 1). These data are integral to modeling NECB components and understanding how Greenland's ecosystems respond to environmental changes.

Why Does This Matter?

The Arctic is warming three to four times faster than the global average. This rapid shift is destabilizing permafrost –frozen ground that has locked away vast amounts of carbon for centuries. As permafrost thaws, stored carbon is released into the atmosphere as CO_2 and methane, intensifying global warming. Greenland's ecosystems are a critical part of this equation, acting as both carbon sinks (absorbing C) and sources (releasing C and other greenhouse gases) depending on the location and time of year.

The balance between these roles is, however, constantly shifting. For instance, longer growing seasons can enhance CO_2 uptake by Arctic vegetation, but warmer temperatures also accelerate soil decomposition, increasing CO_2 release. Methane emissions from thawing wetlands add further complexity to the equation.

All NECB components can be measured in Greenland

Understanding the NECB helps us see how Arctic ecosystems work and respond to change. It includes CO_2 exchange, methane emissions, carbon transport through water, herbivore impacts, and disturbances. Let's break down each of these key pieces and how they shape the bigger picture.

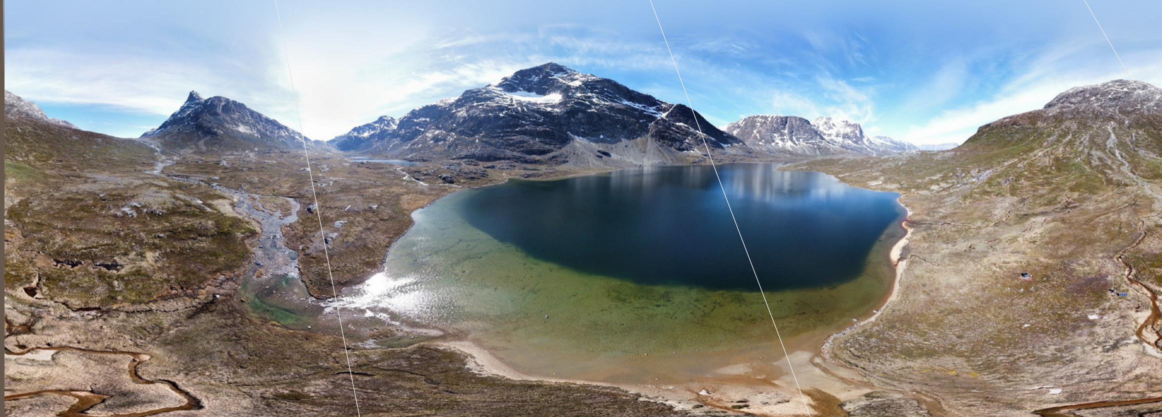
Authors:

Efrén López-Blanco, Niels Martin Schmidt, Torben Røjle Christensen

Aarhus University, Department of Ecoscience

Data source:

Data can be accessed on GEM database, https://data.g-e-m.dk



INTEGRATED CARBON
CATCHMENTS

GEM
Greenland Ecosystem Monitoring

- Carbon Tug-of-War: While plant growth is increasing CO_2 absorption during extended summers, warming soils are also emitting more carbon. Methane emissions from Arctic wetlands –though relatively small in volume –have a disproportionately high warming potential.
- Rivers as Carbon Highways: Carbon doesn't remain trapped in soil or the atmosphere –it also moves through rivers and streams as dissolved organic matter. Some of this carbon is buried in sediments, while much is released as CO_2 and CH_4 into the atmosphere.
- The Role of Herbivores: Large herbivores such as reindeer and muskoxen significantly influence Greenland's carbon balance. By grazing on shrubs, they alter surface reflectivity (albedo), which in turn affects local climate conditions. Their activities also move nutrients around and impacts soil structure and greenhouse gas fluxes.
- Extreme Events & Disturbances: Warming temperatures are increasing the frequency of wildfires, rapid permafrost erosion, and extreme weather events in Arctic regions. These disturbances release stored carbon and disrupt ecosystem stability, creating cascading effects that extend far beyond the Arctic.

Changes in Greenland's carbon balance don't stay in Greenland –they have global repercussions. Data collected by Greenland Ecosystem Monitoring (GEM) feeds into international climate assessments, including those conducted by AMAP (Arctic Monitoring and Assessment Programme) and CAFF (Conservation of Arctic Flora and Fauna).

For Arctic communities, understanding NECB is also about adaptation and survival. Shifts in vegetation, wildlife populations, and greenhouse gas emissions directly impact traditional ways of life. On a global scale, this research informs policymakers and decision-makers, informing initiatives for climate mitigation and ecosystem conservation.

Looking Ahead

The research focused on Greenland isn't just about tracking today's climate –it's about preparing for the future, and Greenland's landscapes serve as an early-warning system in a changing climate. Through integrating jointly NECB measurements on the basis of sustained long-term monitoring works (such as GEM), scientists can better predict how Arctic ecosystems will respond to continued warming.

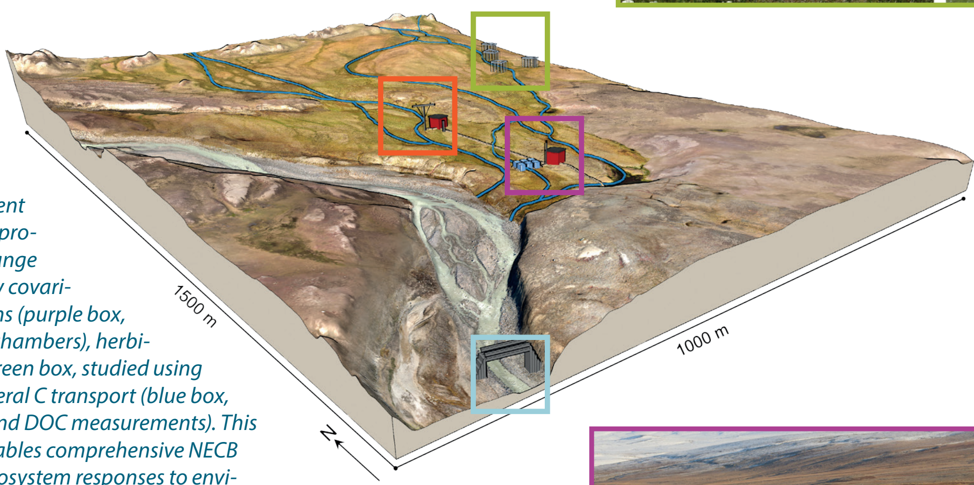
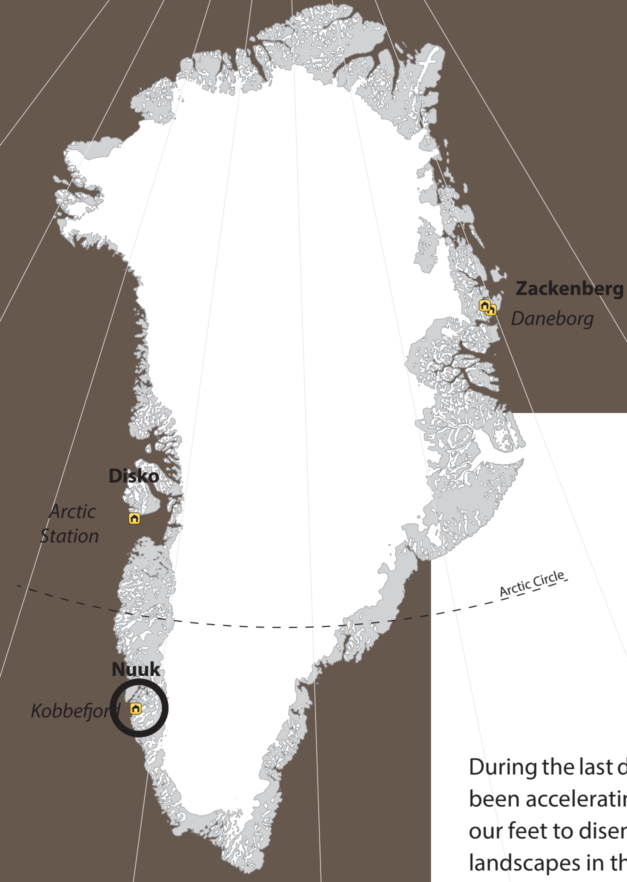


Figure 1. Integrated assessment of Net Ecosystem Carbon Balance (NECB) components in the Rylekærene fen, Zackenberg, East Greenland. The 3D terrain representation illustrates the spatial distribution and measurement approaches for key carbon flux processes: net ecosystem CO_2 exchange (orange box, measured via eddy covariance towers), methane emissions (purple box, quantified through automatic chambers), herbivore-vegetation interactions (green box, studied using exclosure experiments), and lateral C transport (blue box, monitored via river discharge and DOC measurements). This landscape-scale integration enables comprehensive NECB modeling and assessment of ecosystem responses to environmental changes.

Reference

1. López-Blanco, E., et al., The net ecosystem carbon balance (NECB) at catchment scales in the Arctic. Frontiers in Environmental Science, 2025. 13.



Annual Report Card 2024

MONITORING

NEW EDDY COVARIANCE DATA

Methane (CH_4) is a potent greenhouse gas, with a warming potential of 20-30 times that of CO_2 on a 100-year time horizon. Therefore, the monitoring of CH_4 fluxes has been an integral part of the GeoBasis programme for more than two decades, providing a unique insight into (inter)annual dynamics in Arctic methane flux processes.

During the last decade, atmospheric CH_4 concentrations have been accelerating (Nisbet et al., 2023) and in GEM we are on our feet to disentangle the role of climate feedback in Arctic landscapes in this acceleration.

In Kobbefjord, we installed a new methane analyzer in 2024 as part of the eddy covariance setup that previously only measured CO_2 exchange in a small wetland. As a result of a parallel investment in power-infrastructure, we can now present a sneak peek on the first season of preliminary wetland CH_4 fluxes from eddy covariance in Kobbefjord (Fig. 1). The temporal resolution of ½ hour allows us to explore links between the CH_4 flux and other meteorological variables measured alongside the greenhouse gas flux.

The magnitude of the preliminary (a median of ~0.02 µmol/m²/s from mid-June through August) is comparable to previously reported CH_4 fluxes from Kobbefjord (Fig. 2), although the seasonal pattern was stronger in the chamber-data from 2010 (Fig. 2). This is highly promising as the eddy covariance system represents a landscape-integrated flux as opposed to the automatic chambers reported in fig. 2 which are distributed point measurements. The seasonal pattern and diurnal dynamics are similarly promising with a general pattern of higher mid-day fluxes and lower night fluxes.

The eddy covariance fetch, i.e., the surface area that the measured signal is representing, should have an impact on the measured fluxes, given the heterogeneous surfaces we see in Kobbefjord. Windspeed affects the boundary layer and thus the size and direction of the fetch. We see a relationship between windspeed and CH_4 flux (Fig. 2A), which may support this relationship, but further modelling of the size and location of the fetch is needed to confirm this. The decomposition of organic material in the fen results in a release of CH_4 following the anoxic conditions in the soil. This microbial decomposition is partly temperature-regulated which can be seen from the significant link to air temperature (Fig. 2B).

The new eddy covariance based CH_4 data provides a new baseline for both the monitoring of greenhouse gas emissions from Kobbefjord, as well as a critical validation dataset for modelling of and remote sensing of greenhouse gases.

Authors:

Andreas Westergaard-Nielsen[1], Karoline Nilsson[2], Daniel Rudd[3], Thomas Friborg[1] & Mikhail Mastepanov[3]

[1]University of Copenhagen

[2]Asiaq – Greenland Survey

[3]Aarhus University

Data source:

Data can be accessed on GEM database, https://data.g-e-m.dk

METHANE:
FROM KOBBEFJORD WETLAND

GEM
Greenland Ecosystem Monitoring

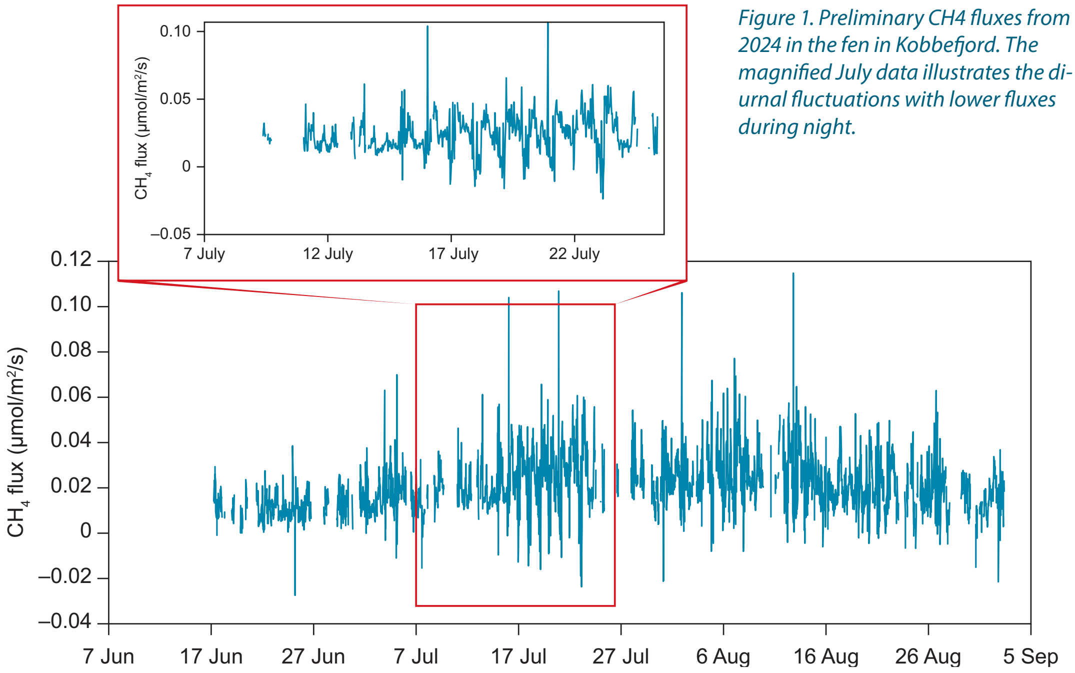


Figure 1. Preliminary CH4 fluxes from 2024 in the fen in Kobbefjord. The magnified July data illustrates the diurnal fluctuations with lower fluxes during night.

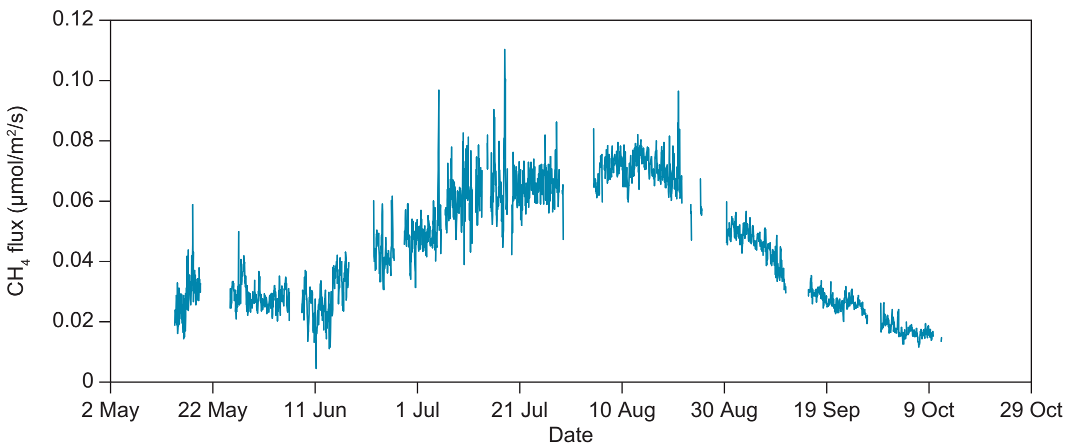


Figure 2. Previously reported CH_4 fluxes from the Kobbefjord fen measured with automatic chambers in 2010.

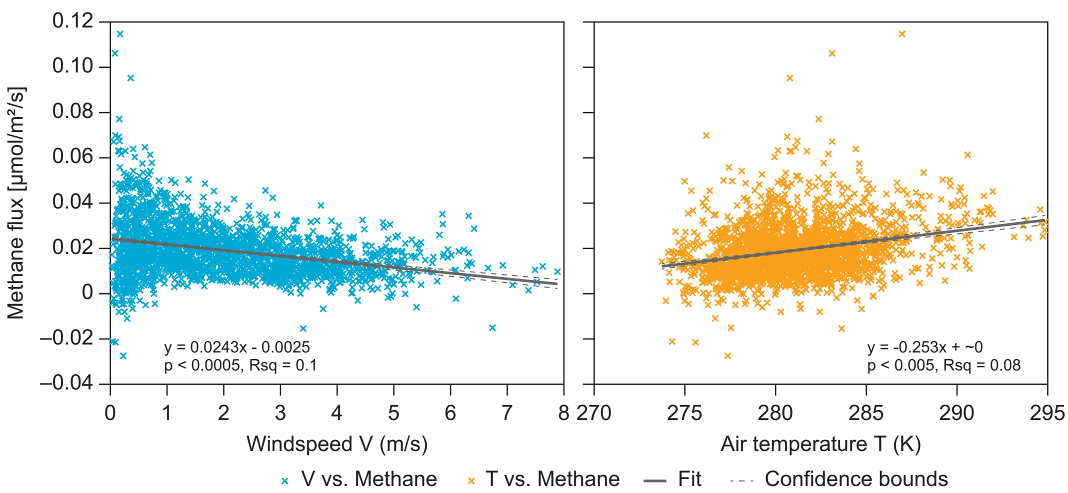


Figure 3. Both the windspeed V (A) and air temperature T (B) are significantly correlated to the methane fluxes, although with a limited degree of explanation of the variation in the fluxes.

Reference

Nisbet, E.G., Manning, M.R., Dlugokencky, E.J., Michel, S.E., Lan, X., Röckmann, T. & Bromley, T. (2023). Atmospheric methane: Comparison between methane's record in 2006–2022 and during glacial terminations. *Global Biogeochemical Cycles*, *37*(8), e2023GB007875.

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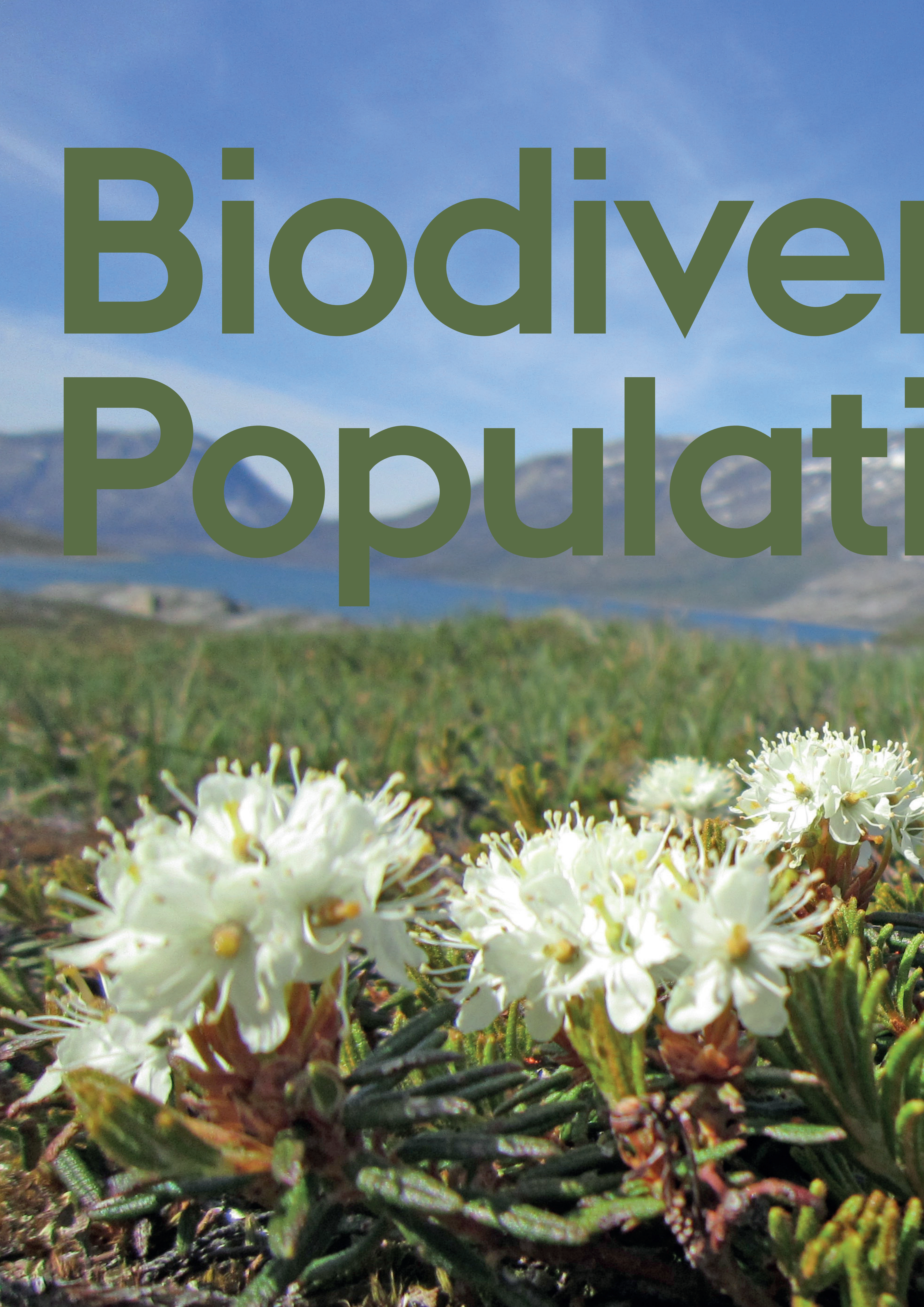

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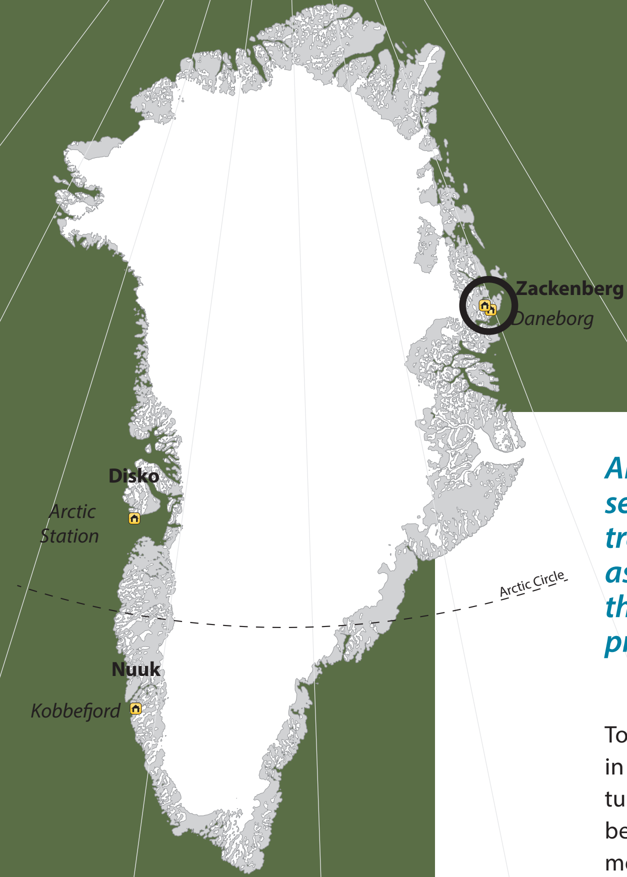
Photo: Katrine Raundrup.



RELIABLE ESTIMATES

BIOMASS MATTER FOR

Arthropods are a fundamental component of terrestrial ecosystems, serving as key prey for many predators and playing vital roles in energy transfer. Understanding their abundance and availability is crucial for assessing ecosystem processes, but how abundance is measured – as the number of individuals or as their biomass – affects ecological interpretations.

To understand the role that arthropods play in ecosystems, such as the arctic terrestrial tundra, their variation in abundance needs to be monitored. Arthropod abundance can be measured in different units, for example the number of individuals or their biomass. The choice between either may depend on the context of the study or be based on practical reasons. For example, biomass is a more ecologically meaningful metric when considering energy fluxes, while individual counts may be more relevant in population studies. Many studies rely on arthropod counts because measuring individual biomass is labour-intensive. However, we show that using numbers instead of biomass can lead to significantly different conclusions, particularly in studies of trophic interactions and phenological mismatches.

To improve biomass estimation, we developed length-biomass regressions for 27 Arctic arthropod families from two High Arctic sites: Zackenberg (northeast Greenland) and Knipovich Bay (Siberian Russia). Our results show that biomass estimates vary substantially depending on which regression equations are used (Fig. 1). For example, applying previously published and often used order-level regressions to arthropods at Zackenberg led to biomass overestimations of 69.7% to 130% compared to site-specific regressions (Fig. 1). This underlines the importance of using locally derived relationships for accurate biomass estimates.

Sticky trap with many flies.
Photo: Jeroen Reneerkens.

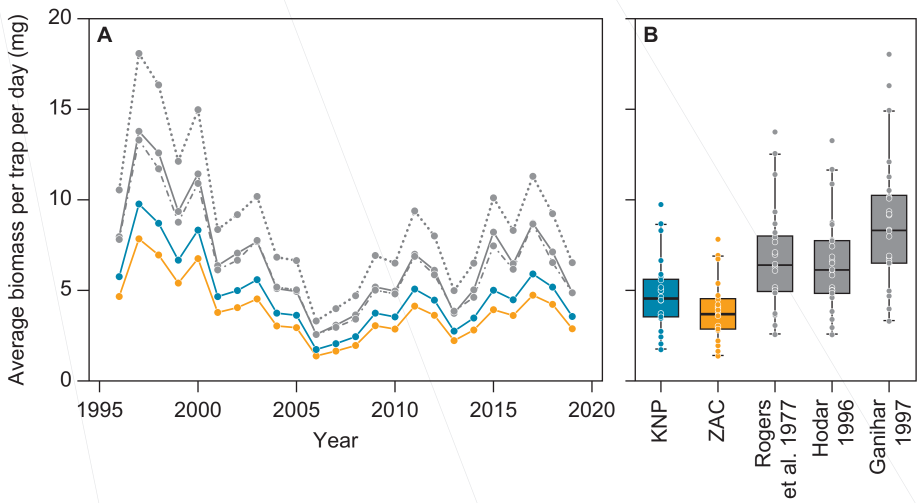


Figure 1. Estimates of average biomass per pitfall trap per day at Zackenberg (1996 –2019), calculated based on regressions from five different sources. Data depicted in blue are calculated using family-level length-biomass regressions for Knipovich (KNP) and data in orange using family-level regressions for Zackenberg (ZAC). Data depicted in grey are calculated using order-level regressions extracted from literature, where the solid grey line is based on regressions from Rogers et al. (1977; Ann. Entomol. Soc. Am. 70: 51–53), the dashed grey lines on regressions from Hódar (1997; Misc. Zool. 20: 1–10) and the dotted grey line on regressions from Ganihar (1997; J. Biosci. 22: 219–224). Boxplots summarize the spread in the data, where horizontal white bars indicate the median, the box depicts the interquartile range and whiskers represent 1.5 times the interquartile range from the upper/lower quartile.

Authors:

Jeroen Reneerkens[1], Tom Versluijs[2] & Niels Martin Schmidt[1]

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[2]Netherlands Institute for Sea Research

Data source:

BioBasis Zackenberg

Data can be accessed on GEM database, https://data.g-e-m.dk

We also examined how the choice of metric – biomass or numbers – affects our understanding of the temporal overlap between arthropods and their predators. Using data from an Arctic-breeding shorebird, Sanderling (*Calidris alba*), we found that the median peak of arthropod biomass occurred, on average, 6.9 days later than the median peak in arthropod numbers, with some years showing discrepancies of up to 21 days (Fig. 2). This can be explained by a later emergence of larger arthropod specimens as compared to smaller specimens. Over a 23-year period, Sanderling hatch dates became less synchronized with the peak in arthropod numbers but remained more in synchrony with peak biomass.

Our findings emphasize that biomass-based estimates are essential for accurately assessing ecological interactions, particularly in studies of predator-prey interactions. We recommend that length-biomass regressions be developed for specific study regions to ensure reliable biomass estimates and that biomass, rather than numbers, are used when examining phenological mismatches between arthropods and their predators.

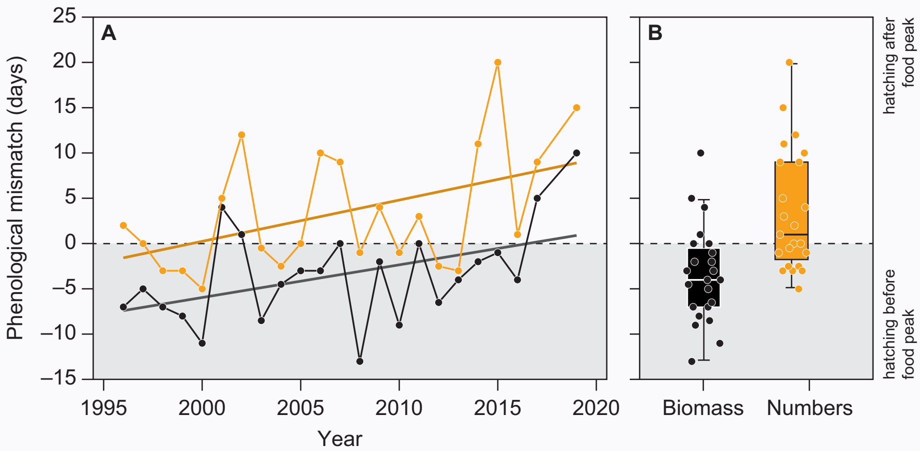

Figure 2. Mismatch between Sanderling median hatch dates and the date when 50% of cumulative arthropod abundance (orange) or cumulative arthropod biomass (black) was sampled in pitfalls in Zackenberg (1996–2019, excluding 2018). Positive values indicate that the median hatch date occurred after the 50% date in arthropod abundance or biomass. Fitted linear models are shown as solid straight lines. Boxplots summarize the spread in the data, where horizontal white bars indicate the median, the box depicts the interquartile range and whiskers represent 1.5 times the interquartile range from the upper/lower quartile. For visual clarity we applied a horizontal jitter to the raw data depicted in the boxplots.

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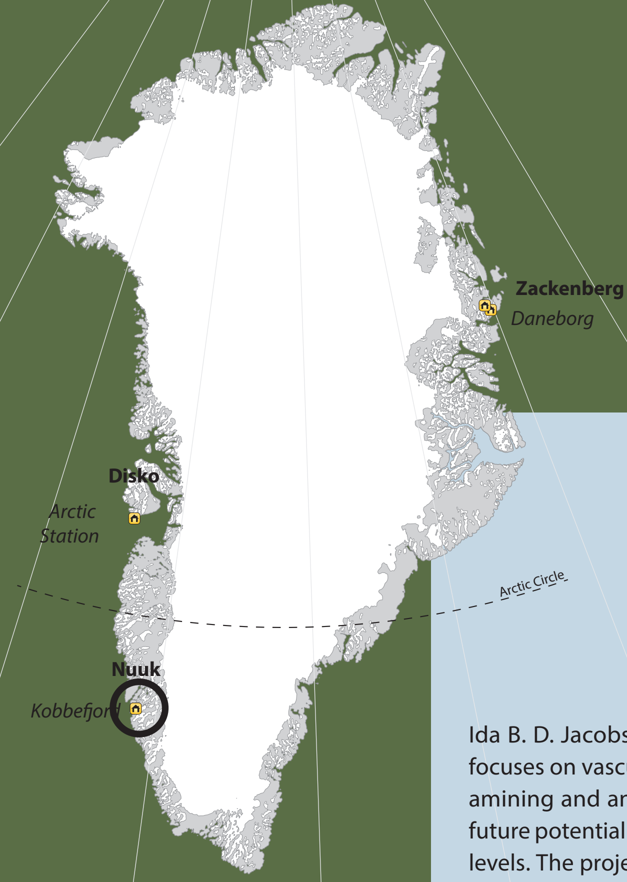
Versluijs, T.S.L., Zhemchuzhnikov, M.K., Kutcherov, D., Roslin, T., Schmidt, N.M., van Gils, J.A. & Reneerkens, J. 2024. Different currencies for calculating resource phenology result in opposite inferences about trophic mismatches. - Proc. R. Soc. B Biol. Sci. 291: 20231785.

Photo: Misha Zhemchuzhnikov.

Photo: Tom Versluijs.



MAXIMIZING MINIMIZING

In 2024, 1536 BioBasis plot coordinates in Kobbefjord were updated using RTK GPS through a collaboration between BioBasis, a PhD project, and Asiaq. This significantly improved spatial accuracy, enabling better integration with remote sensing and drone-based NDVI monitoring, reestablishment of lost plots, and more robust long-term ecological analyses.

Ida B. D. Jacobsen's PhD project, MappingPlants, focuses on vascular plant vegetation dynamics, examining and analysing past shifts and modelling future potential changes at community and species levels. The project utilises both new data collected during the project and BioBasis Nuuk data. Specifically, the project will analyse vegetation data from the NERO line. The NERO line is a permanent transect established in 2007 with the purpose of track climate change impacts on Arctic plant communities.

The NERO line consists of 83 segments assigned to one of six vegetation types with up to 10 plots in each segment. This totals 654 plots where all vascular plant species are recorded every five years (last in 2022). However, the NERO lines original georeferencing was conducted only at the segment level using average-precision GPS, limiting its potential for integrating external datasets such as remote sensing or drone imagery.

To address this, Ida used high-accuracy Real Time Kinetic (RTK) GPS equipment borrowed from colleagues at Asiaq. Asiaq have already established the reference point needed for the RTK GPS measuresments and have all necessary equipment. This setup allowed for georeferencing all 460 excisting NERO line plots with centimeter-level precision. Leveraging this opportunity and taking full advantage of already allocated field days, she also measured almost all markers of BioBasis monitoring plots.

A totalt of 1536 points were mesaured during 7 field days in 2024. This included all permanent markers of 4 arthropods plots, 8 micro-arthropod plots, 20 phenology plots, 23 TMS-4 loggers and 420 plots and 83 segment dividers for the NERO line.

The measurement itself of an individual point takes no more than a few seconds. Therefor, locating the plots and hiking between plots is the temporal bot-

Figure 1. Previous coordinates of 4 BioBasis plots; SAL2, Art3, Mart3 and Loi2. Background image from Bing Aerial.

Figure 2. Updated georeferenced of the same plots. White dots are the points measured with RTK. Background image from Bing Aerial.

Authors:

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[2]Aarhus University, Roskilde, Denmark

Data source:

Data can be accessed on GEM database, https://data.g-e-m.dk

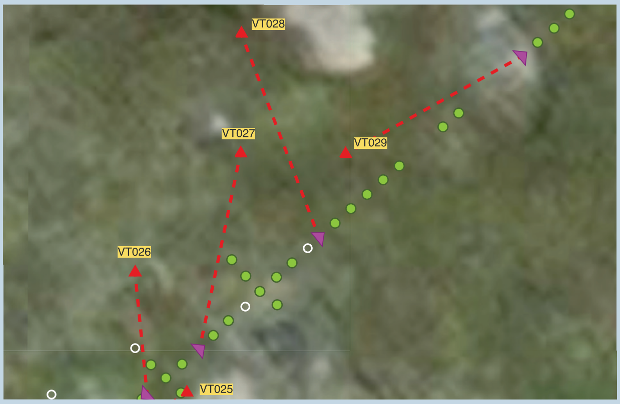


Figure 3. Section of the NERO line with both old and updated coordinates. Red triangles are old coordinates of segment dividers. Dashed lines indicate error distance. Purple triangles mark RTK measures segment dividers. Light green dots indicate plots (not previously georeferenced). White circles indicate lost plots that have been georeferenced via QGIS. Background image from Bing Aerial..

tleneck of these measurements. There is additionally temporal limitation due to the equipment battery capacity, and a spatial limitimation in the connection range of the base and rover unit. This became an issue only at the furthest corners of the monitoring area.

It is the intention that the remaining BioBasis plots (30 carbon-flux plots and 16 TMS-4 loggers) will be measured during the 2025 field season.

The technical requirements of the RTK system, e.g., a calibrated reference point and the physical bulkiness of the instruments, including the base unit (stationed at the reference fix point) and the rover GPS unit (the portable instrument for actual measurement) in the form of a 2 m long rod, makes the set up unsuitable for opportunistic or ad hoc surveys. On the other hand, for long-term monitoring of permanent plots it is a very valuable investment in minimizing uncertainty related to georeferencing and spatial analysis.

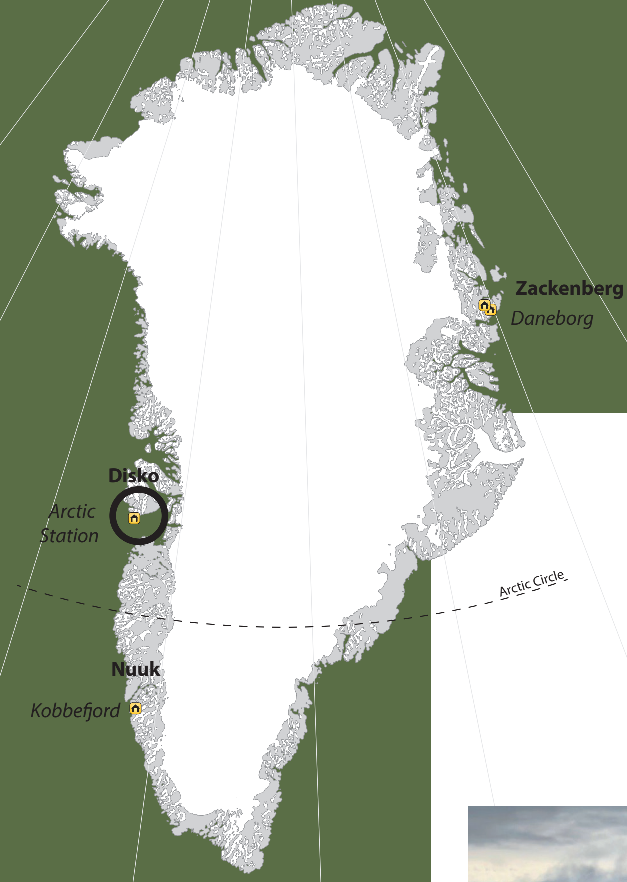
The improved georeferencing of all these plots minimizes uncertainties in plot locations, enabling more robust spatial analyses and enhancing opportunities to integrate monitoring data with external datasets.

The accurate coordinates will additionally be central in new drone-based initiatives to measure NDVI and image-based monitoring in Kobbefjord which are planned to be initiated in 2025. Integration of ground truthed plots with remote sensing and drone imagery is already integral to much ecological research. Integrating these practices with minimised uncertainty regarding the georeferencing of the plots will ensure quality and robustness in future use of the BioBasis data.

The accurate georefering of all excisting plots also allow for reestablishment of lost plots of the NERO line. The NERO line originally consisted of 454 plots but over the course of 19 years a number of plots have been lost to e.g. human acitivies, frost/thaw and general soil dynamics, fox acitivies and rock falls. Knowing precisely where the current plots are and principal design of the lay out of plot now allows for reestablishments of the lost plots.

The updated coordinates of plots and corresponding measurements will be available with updated datasets in the GEM database and in the next revised BioBasis Nuuk manual. This will allow data users to make accurate spatial connections to other data sets and remote sensing products. The highly accurate georeferencing of the NERO line will allow for analysis taking spatial aspects in to account in a way not otherwise possible.

Figure 5. Based unit of the RTK GPS with antenna. Photo Ida Bomholt Dyrholm Jacobsen.



Annual Report Card 2024

TRANSITION FROM A

PROTIST COMMUNITY DURING THE DARK COMMUNITY IN SURFACE WATERS OF

The GEM Marine monitoring programme at Disko Bay explores the seasonal changes in biodiversity of phototrophic and heterotrophic plankton organisms using e-DNA, allowing for documentation of climate driven changes in the food web structure.

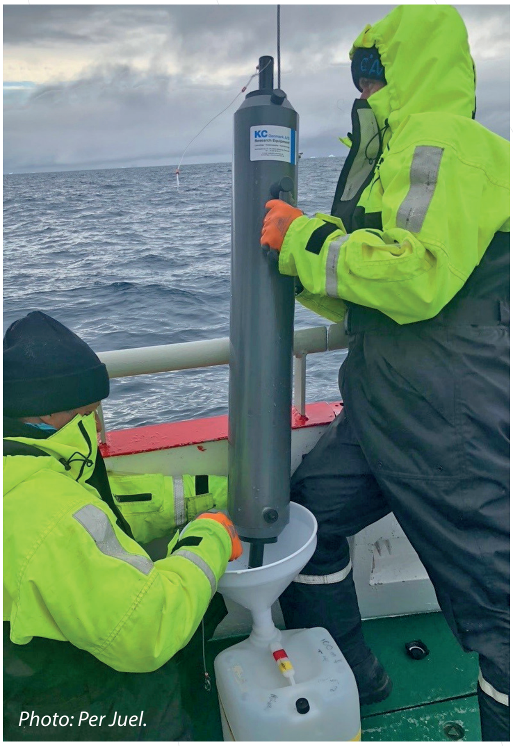


Photo: Per Juel.

Due to climate change, the Arctic is one of the fastest changing environments in the world. This has already affected the Arctic biosphere and will lead to further changes in the future. The base of the complex marine pelagic food web consists of unicellular organisms, such as bacteria and eukaryotic unicellular plankton (protists) occupying different ecological niches and providing food for higher trophic levels. Unicellular eukaryotic plankton communities (protists) are the major basis of the marine food web.

Plankton communities have traditionally been described and quantified using microscopical techniques in monitoring programmes. These techniques allow for quantification in terms of carbon biomass in functional groups in most cases. However, such an approach does not give enough resolution for several reasons. Typically, small water volumes are used for the description of the plankton communities, and especially for the smaller size fraction of organisms (< 15 µm), the organisms cannot be identified to genus and species level, in some cases not even to class level.

Photo: Per Juel.

Photo: Per Juel.

Authors:

Claudia Sabine Bruhn[1,2], Nina Lundholm[3], Per Juel Hansen[4], Sylke Wohlrab[1] & Uwe John[1]

[1]Alfred Wegener Institute, Germany

[2]GFZ Helmholtz Centre for Geosciences

3Natural History Museum of Denmark, University of Copenhagen, DK

[4]Department of Biology, University of Copenhagen, DK

Data source:

MarinBasis Disko, DOI: https://doi.org/10.17897/KGV0-N239

Data can be accessed on GEM database: https://data.g-e-m.dk

MIXOTROPHIC/HETEROTROPHIC

WINTER TO A PHOTOAUTOTROPHIC SPRING DISKO BAY, GREENLAND

GEM

Greenland Ecosystem Monitoring

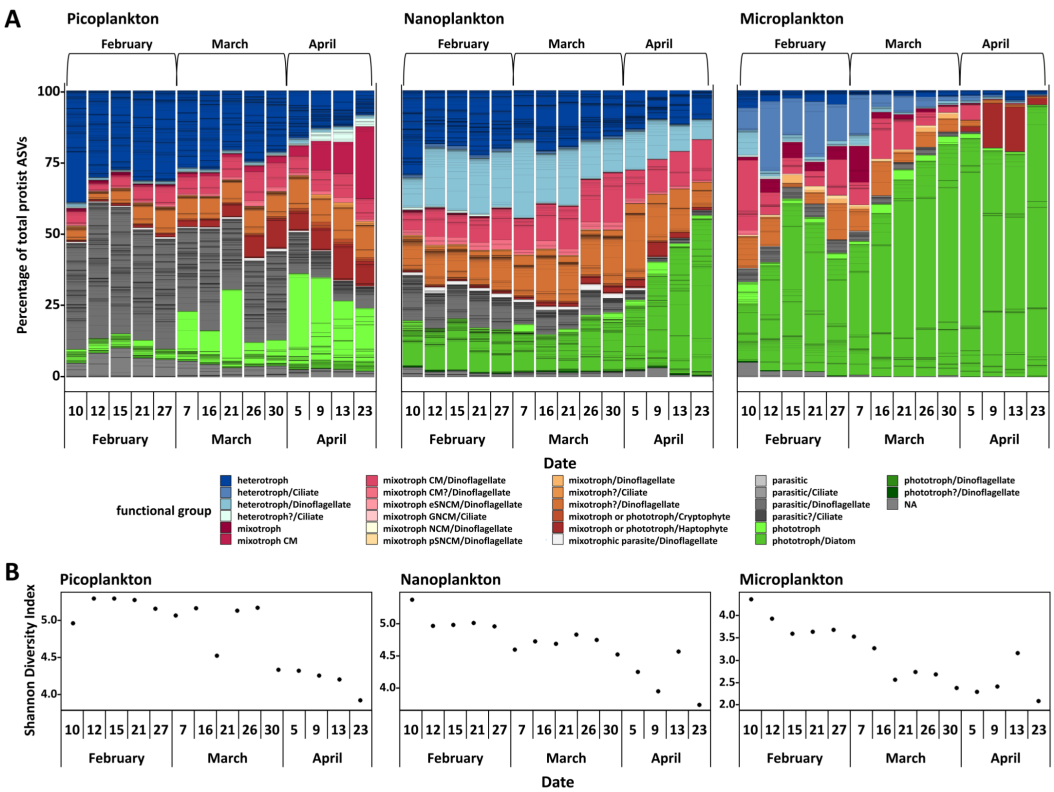


Figure 1. Protist community analyses. Water samples have been size-fractionated (picoplankton 0.2-3 µm, nanoplankton 3-20 µm and >20 µm). Normalized protist ASVs, divided by functional group and size fraction and additionally divided into three calendar months (A). CM, constitutive mixotroph; eSNCM, endo-symbiotic specialist non-constitutive mixotrophs; GNCM, generalist non-constitutive mixotrophs; NCM, non-constitutive mixotroph; pSNCM, plastidic specialist non-constitutive mixotrophs. It was not possible to assign the definite trophic mode to each ASV, hence a putative trophic mode (indicated with a question mark or NA) is displayed. The Shannon Diversity Index (B) is also displayed.

As part of the GEM marine monitoring programme at the Arctic Station in Qeqertarsuaq, we have therefore included e-DNA sampling to improve description of species diversity that also allows for a better resolution of the different functional groups. Here, we report on the use of e-DNA to describe the winter - spring transition in the protist community (Fig. 1; Bruhn et al 2024).

The spring bloom is especially important, because of its high biomass. However, it is poorly described how the protist community composition in Arctic surface waters develops from winter to spring. We show that mixotrophic and parasitic organisms are prominent in the dark winter period (Figure 1). Especially, the distribution of parasitic organisms is largely unstudied in Arctic waters, because they cannot be quantified using traditional techniques. The transition period toward the spring bloom event was characterized by a high relative abundance of mixotrophic dinoflagellates, while centric diatoms and the haptophyte *Phaeocystis pouchetii* dominated the successive phototrophic spring bloom event during the study. The data shows a continuous community shift from winter to spring, and not just a dormant spring community waiting for the right environmental conditions.

The spring bloom initiation commenced while sea ice was still scattering and absorbing the sunlight, inhibiting its penetration into the water column. The initial increase in fluorescence was detected relatively deep in the water column at ~55 m depth at the halocline, at which the photosynthetic cells accumulated, while a thick layer of snow and sea ice was still obstructing sunlight penetration of the surface water. This suggests that water column stratification and a complex interplay of abiotic factors eventually promote the spring bloom initiation.

References

Bruhn, C.S., Lundholm, N., Hansen, P.J., Wohlrab, S. & John, U. (2024). Transition from a mixotrophic/heterotrophic protist community during the dark winter to a photoautotrophic spring community in surface waters of Disko Bay, Greenland. Frontiers in Microbiology. 15. doi: 10.3389/fmicb.2024.1407888

Photo: Per Juel.

PROGR
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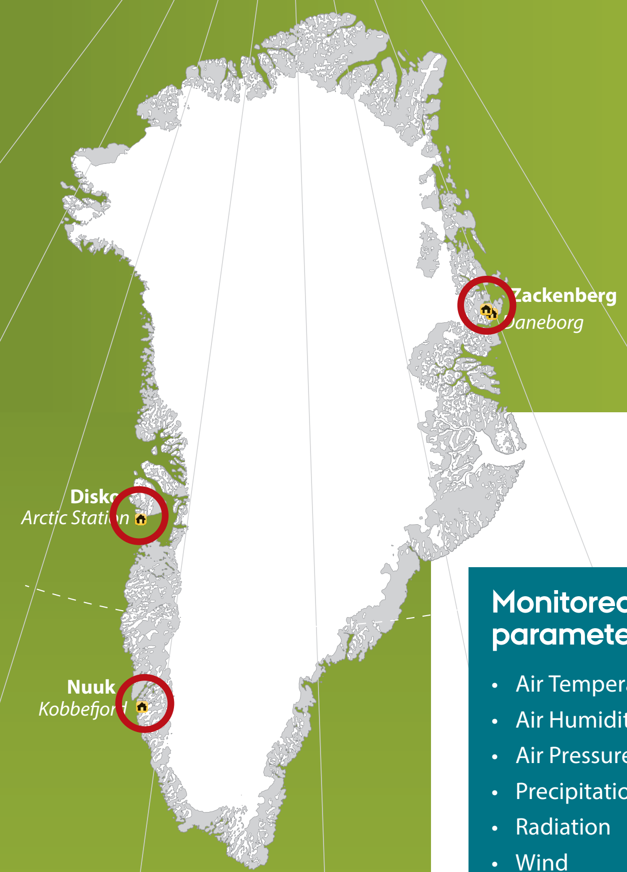
The program descriptions are restricted to the five data-gathering observational programmes. In addition the Remote Sensing and Modelling programme is now using the observational data from these five programmes for integration.



Annual Report Card 2022

GEM CLIMATEBASIS

Monitored parameter groups

- Air Temperature
- Air Humidity
- Air Pressure
- Precipitation
- Radiation
- Wind
- River hydrology
- Snow properties
- Fractional cloud cover
- Column-integrated water vapour

Discharge measurement using salt dilution in Chamberlin Stream, a tributary to Røde Elv in Disko, which carries meltwater and sediment from Chambelin glacier. Photo: Asiaq.

The ClimateBasis programme monitors climate and hydrology in Zackenberg, Kobbefjord and Disko and is run by Asiaq - Greenland Survey. The collected data build base-line information on climate variability and trends for all the other sub-programmes within GEM and serve as a trustworthy foundation for adaptation strategies for Greenlandic society. The stations are embedded in Asiaq's extensive climate and hydrology monitoring network. Furthermore, the runoff data is delivered to the World Hydrological Cycle Observing System (WHYCOS) and the Global Runoff Data Centre (GRDC) networks. Atmospheric parameters are collected redundantly at each location on two separated masts with individual energy supplies in order to be able to treat data gaps and sensor biases consistently. Hydrometric parameters are monitored on various automated stations. Emphasis is placed on the establishment of reliable stage-discharge relations, a challenging task since their temporal stability depends on the river bed. At the river Zackenberg for instance, repeated glacier outburst floods require an updated stage-discharge relation every year, where the related field work is performed together with the GeoBasis sub-programme.

All three GEM stations registered mean annual temperatures close to the longer-term means in 2024, with the west coast stations Disko and Kobbefjord experiencing a year slightly cooler than the 2008-2024 mean (-0.8°C and -0.5°C, respectively), and Zackenberg ever so slightly warmer (0.1°C). If the mean for the complete timeseries available at Zackenberg is used (1996-2024), the difference rises to 0.3°C. In Figure 1, one may discern by eye a warming trend for the temperatures at Zackenberg, while at the other stations, no obvious trend is visible among much higher year-to-year variability. Temperatures are close to or above zero degrees Celsius more frequently at Kobbefjord and Disko,

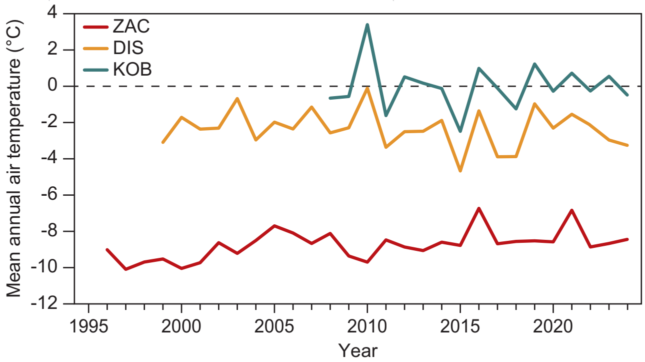


Figure 1. Mean annual air temperature at the three GEM sites Zackenberg (ZAC), Disko (DIS) and Kobbefjord (KOB).

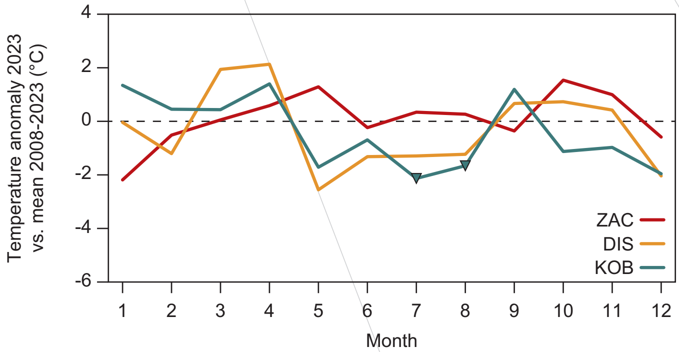


Figure 2. Monthly air temperature anomaly for 2023 compared to the common reference period 2008-2023 for Zackenberg (ZAC), Disko (DIS) and Kobbefjord (KOB). A triangle marks a month whose mean temperature has been more extreme than those of the corresponding month in any other year from 2008-2023. The downward pointing triangle indicates that the month has been the coldest in this period.

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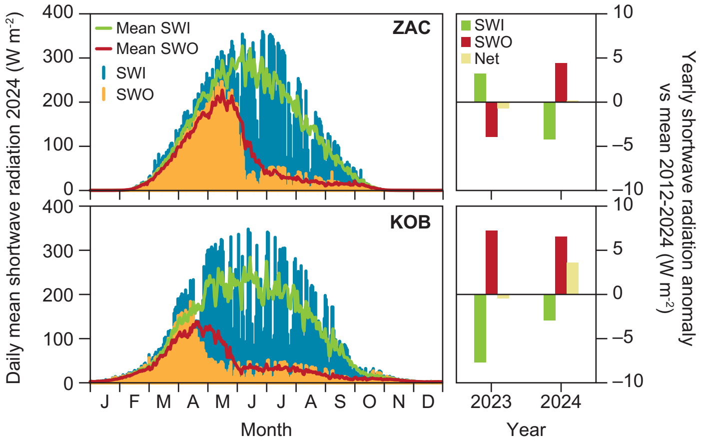

Figure 3. Main plots: Daily mean shortwave incoming radiation (SWI) and shortwave outgoing radiation (SWO) in 2023 with their respective daily means for the period 2012 to 2023 (SWI mean and SWO mean) for Zackenberg (ZAC) and Kobbefjord (KOB). Bar plots (right columns) show yearly mean anomalies for the two most recent years, with outgoing radiation (SWO) taken to be negative, so that the net radiation is simply the sum of SWI and SWO.

Measuring discharge at Kobbefjord. Photo: Marie Arndal.

and much of the energy available in the climate system is preferentially consumed by the melting of ice and snow rather than by raising the air temperature. At Zackenberg, however, temperatures are generally lower but rising since less melting takes place and more of the energy added to the climate system by human activities is available for heating the atmosphere.

Monthly temperatures also stayed closer to the longer-term means than in past years (Fig. 2). Zackenberg was colder in the winter but mostly slightly warmer for the rest of the year, whereas Disko and Kobbefjord had a colder summer but a warmer spring and autumn. Kobbefjord, in fact, experienced the coldest July and August since 2008. Figure 3 hints at one contributing factor: a large number of cloudy days during the summer at Kobbefjord, characterized by low levels of incoming solar radiation. Outgoing shortwave radiation is an indicator of the reflectivity of the ground surface, which is higher when it is covered by snow. Outgoing radiation dropped to lower levels earlier during 2024 at Kobbefjord compared to the long-term mean, indicating that snow melt occurred earlier. This coincides with the higher spring temperatures apparent in Figure 1. By comparison, the snow melt at Zackenberg occurred close to its average timing. Despite the cloudy summer at Kobbefjord, the annual radiation receipt there was higher than the average, owing to the lower total of reflected radiation.

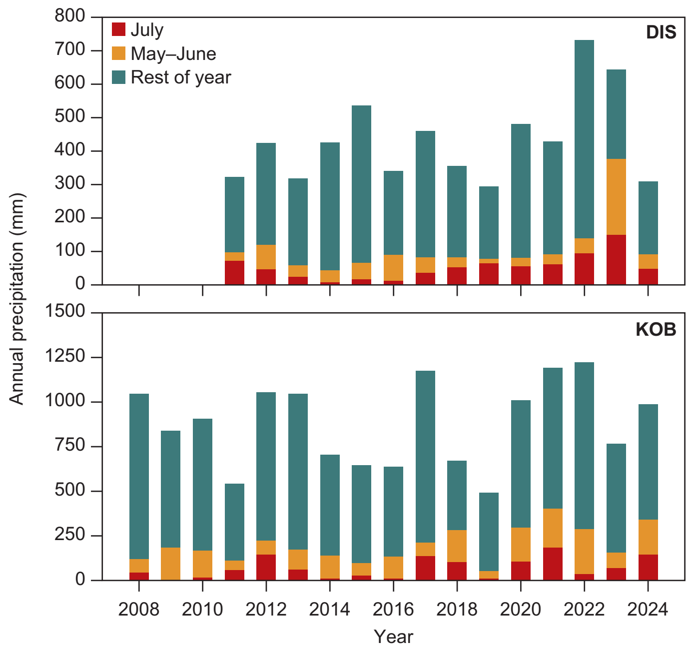

Figure 4. Annual Precipitation for Disko (DIS) and Kobbefjord (KOB) showing contribution for July (blue), May+June (orange) and the rest of the year (green) separately.

The last two years, 2022 and 2023, have brought exceptional precipitation to Qeqertarsuaq, particularly in summer and fall, while 2024 sees a return to dryer conditions (Fig. 4). Interestingly, these same two years have not been as exceptional at Kobbefjord, which lies further south on the west coast; nonetheless, the last 5 years appear comparatively wet in the context of the full GEM record at Kobbefjord, too.

Photo: Marie Arndal.

Discharge measurement using salt dilution, Kobbefjord. Photo: Asiaq.

Annual Report Card 2024

GEM GEOBASIS

The GEM GeoBasis Programme

The GEM GeoBasis programme focuses on selected abiotic characteristics describing the state of Greenlandic terrestrial environments and their potential feedback effects in a changing climate (e.g. effects of permafrost thaw, energy fluxes and greenhouse gases). Monitored plot data provides a basis for up-scaling to a landscape level and improvements of ecosystem models to be able to quantify interactions in relation to the atmosphere and also the adjacent marine environment. The GeoBasis programme provides an active response to recommendations in international assessments such as ACIA and SWIPA with due respect to maintenance of long time series; and a continuous development based on AMAP and other international recommendations.

The four GEM eddy covariance stations are operated as Integrated Carbon Observation System (ICOS) labeled ecosystem stations. The stations have been standardized to be aligned with ICOS standards, which must be regarded as the eddy covariance community state-of-the-art standards. Zackenberg Fen is labelled as a Class 2 station, which sets some strict requirements on how the station operates. The other three stations are labelled as Associated Stations, which has a less strict protocol.

The onset of the growing season is closely linked to the timing of snow-melt. At all stations, the growing season (net CO_2 sink) typically begins in late June to early July when snow has disappeared from the ground (Fig. 1).

New chambers for methane and CO_2 flux monitoring installed at the fen in Zackenberg. Photo: Mikhail Mastepanov.

Monitored parameters

Snow properties
- Snow cover
- Snow depth
- Snow density

Soil properties
- Thaw depth/Active layer development
- Soil/ground temperature
- Soil moisture
- Soil water chemistry

Meteorology
- Air temperature and relative humidity
- Wind speed and direction
- Incoming and outgoing long- and shortwave radiation

Flux monitoring
- Eddy covariance measurements of CO_2, water vapor and energy
- Automatic chamber measurements of CH_4 and CO_2

Hydrology
- River water discharge
- River water chemistry and transport of suspended sediment and organic matter

Geomorphology
- Shore line mapping
- Mapping of landscape dynamics and erosional features

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Preparing the deployment of sensors in the river Røde Elv (Kuussuaq). Photo Charlotte Sigsgaard.

PROGRAMME DESCRIPTION

GEM
Greenland Ecosystem Monitoring

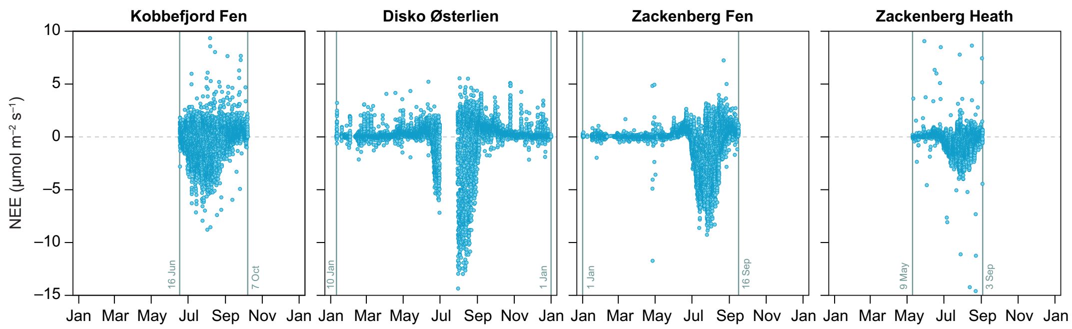


Figure 1. The Half-hourly Net Ecosystem CO_2 Exchange (NEE) is measured at the GEM/ICOS eddy covariance (EC) stations located at Kobbefjord Fen, Disko Østerlien, Zackenberg Fen, and Zackenberg Heath. Negative values indicate a net ecosystem sink of CO_2, while positive values indicate a CO_2 source. Disko Østerlien is the only station connected to grid power, enabling year-round operation. Due to a logging failure in the anemometer no fluxes are presented from the Disko site in July. Zackenberg Fen operates on a reliable autonomous off-grid power system during the winter, currently undergoing testing. Kobbefjord Fen and Zackenberg Heath are restricted to operation only when the stations are accessible, affecting data coverage throughout the year (refer to the figure for start and end dates of operation). The range of fluxes varies considerably among ecosystems, with the smallest net CO_2 sink observed at the dry Zackenberg Heath.

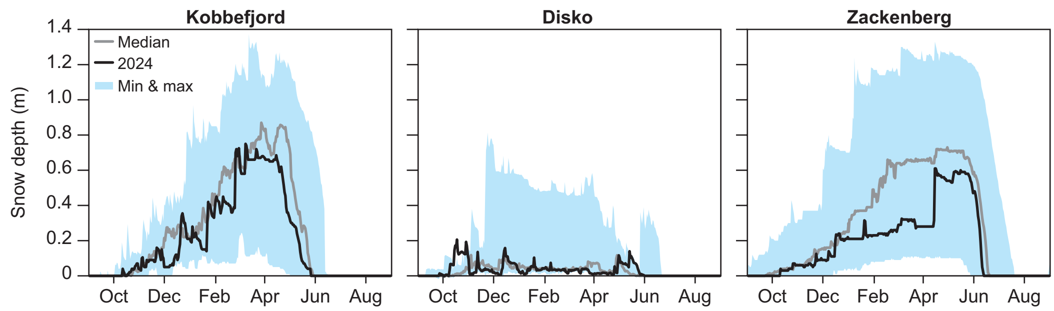


Figure 2. Snow depth measurements in 2024 (black lines) compared to min and max for the historical record (shaded area) and the median (grey line). Snow is a key parameter in Arctic ecosystem functioning. Several different methods are in use to get information on spatial distribution and temporal patterns in snow cover, across the three GEM sites. Methods include time-lapse photography, transect surveys, snow density measurements and, as shown here, long-term point-based monitoring of snow depth. Data used in the figure: Kobbefjord: 2008-2024, Disko: 2012-2024 and Zackenberg: 1997-2024.

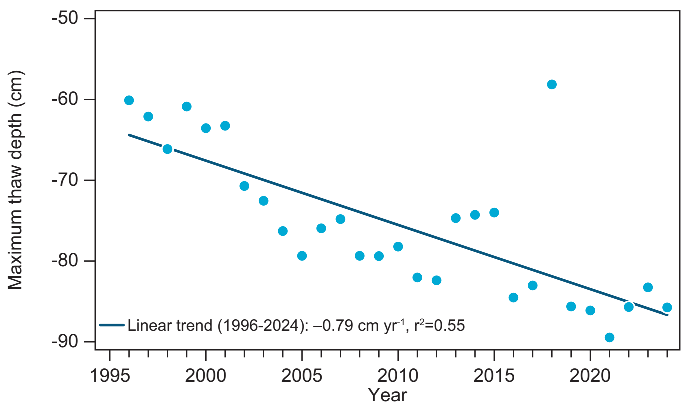


Figure 3. Long-term trend in annual maximum soil thaw depth in Zackenberg Circumpolar Active Layer Monitoring grid # 1 (ZEROCALM-1). Soil thaw and active layer depth are studied under different vegetation types. Monitoring methods include manual probing, as the one shown here, and borehole temperature recordings.

The registered snow depths during the winter 2023-2024 are shown in Figure 2. Kobbefjord showed a close to median snow accumulation. The snow depth is usually low at the site in Disko and warm spells or even rain during winter are not uncommon. In April, the site was snow free for a period during a warm spell with temperatures up to 10 degrees. Zackenberg shows a slower-than-usual snow accumulation through the winter, with the snow depth remaining well below the long-term median. In April, a large snowfall event almost doubles the existing snow depth but still does not reach the median values. Finally, the station becomes snow free earlier than in typical years.

The mean maximum thaw depth of the 110 grid nodes in ZEROCALM-1 reached 86 cm at the end of the summer (Fig. 3).

As the Arctic snow thins, an orange marker emerges – part of the CALM grid in Zackenberg, where the active layer is measured as it begins to thaw. Photo: Daniel Alexander Rudd.

GEM BIOBASIS

The GEM BioBasis programme is the biodiversity component of the GEM programme. The programme studies key species and key processes across plant and animal populations and their interactions within the terrestrial and limnic ecosystem compartments in Kobbefjord/Nuuk (low Arctic) and Zackenberg (high Arctic). The main focus of BioBasis is on biodiversity in general, and abundance and community composition in particular, of the most important flora and fauna components in the tundra biome. Central to the programme is the monitoring of status and trends of selected focal species, phenology of their life history events and rates of reproduction and predation. Through these monitoring activities, BioBasis documents the intra- and inter-annual variation in central biotic parameters, their resilience towards biotic and abiotic perturbations, as well as their long-term trends. The long time series and the interdisciplinary approach of GEM provides in-depth knowledge of ecosystem structure and function, and the status of key biodiversity elements in a changing Arctic. BioBasis has strong linkages to Arctic Council's Circumpolar Biodiversity Monitoring Program (CBMP) and play a leading role in the development and implementation of their monitoring plans.

Monitored parameters

Vegetation
- Flowering phenology
- Plant community composition
- Plant community distribution and zonation
- ITEX and effect monitoring

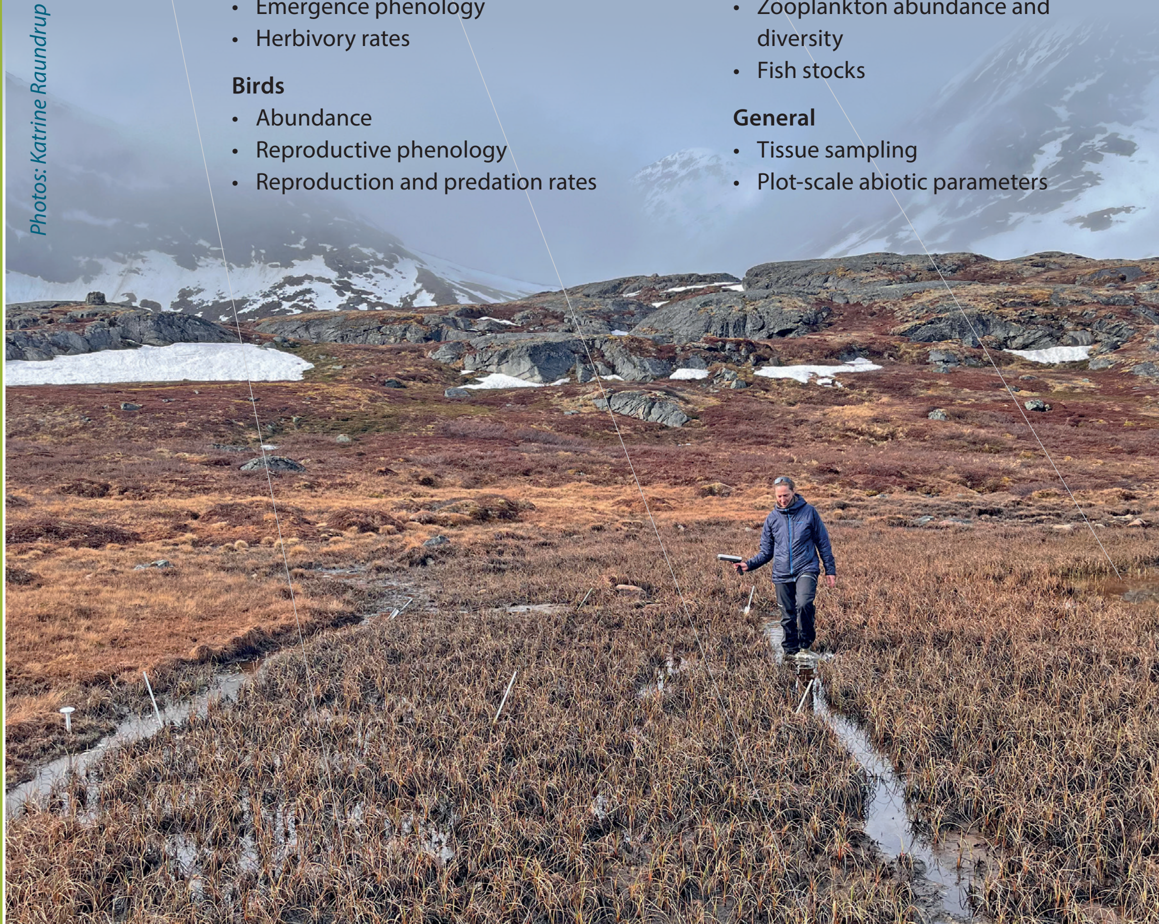
Arthropods and microarthropods
- Abundance
- Emergence phenology
- Herbivory rates

Birds
- Abundance
- Reproductive phenology
- Reproduction and predation rates

Mammals
- Abundance
- Spatial distribution
- Reproduction and predation rates

Lake flora and fauna
- Phytoplankton abundance and diversity
- Zooplankton abundance and diversity
- Fish stocks

General
- Tissue sampling
- Plot-scale abiotic parameters



Photos: Katrine Raundrup

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GEM
Greenland Ecosystem Monitoring

PROGRAMME DESCRIPTION

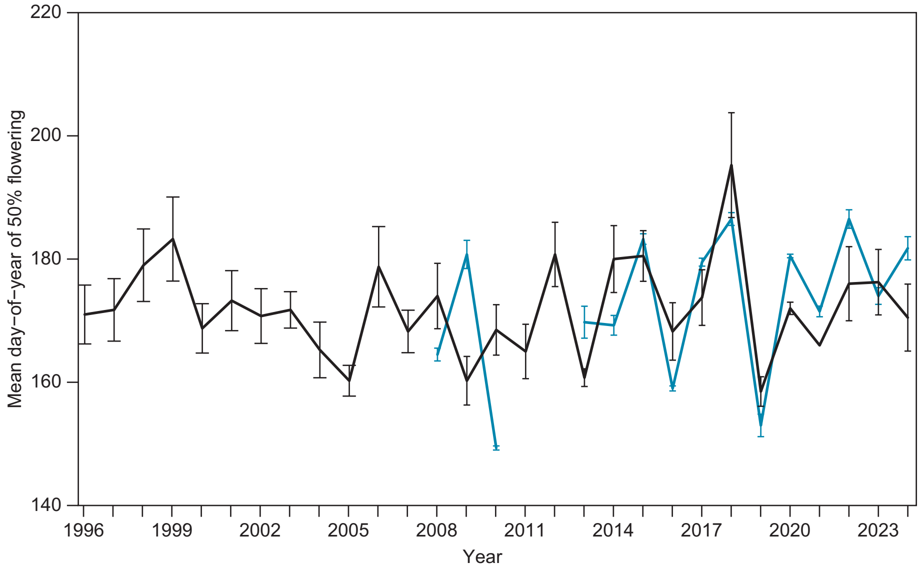

Figure 1. Day of 50% flowering is indicative of the effect of climate variability on the timing of flowering. The timing of plant growth and flowering is important for e.g. insects and herbivorous animals. The graph shows inter-annual variation in mean Salix flowering phenology during the period 1996 to 2024 in selected permanent plots in Kobbefjord (blue) and Zackenberg (black). Note that no flowering was observed in Kobbefjord in the years 2011 and 2012 due to insect outbreak, and due to the covid-19-induced late arrival to Zackenberg in 2020 and 2021, two out of four plots in 2020 and three out of four in 2021 had reached 50% flowering prior to arrival.

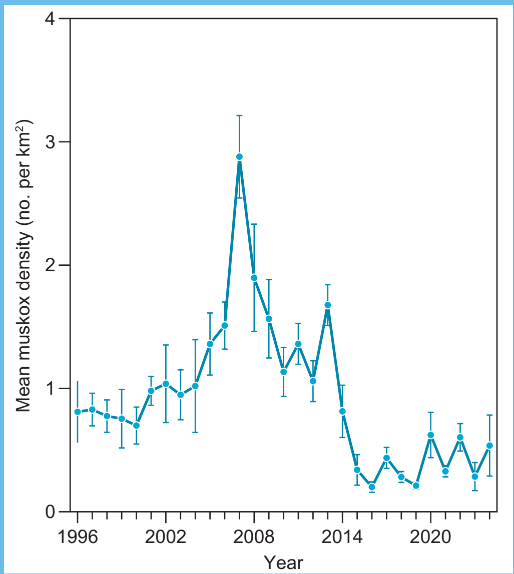

Figure 3. Inter-annual variation in muskox population dynamics (July and August) at Zackenberg 1996-2024.

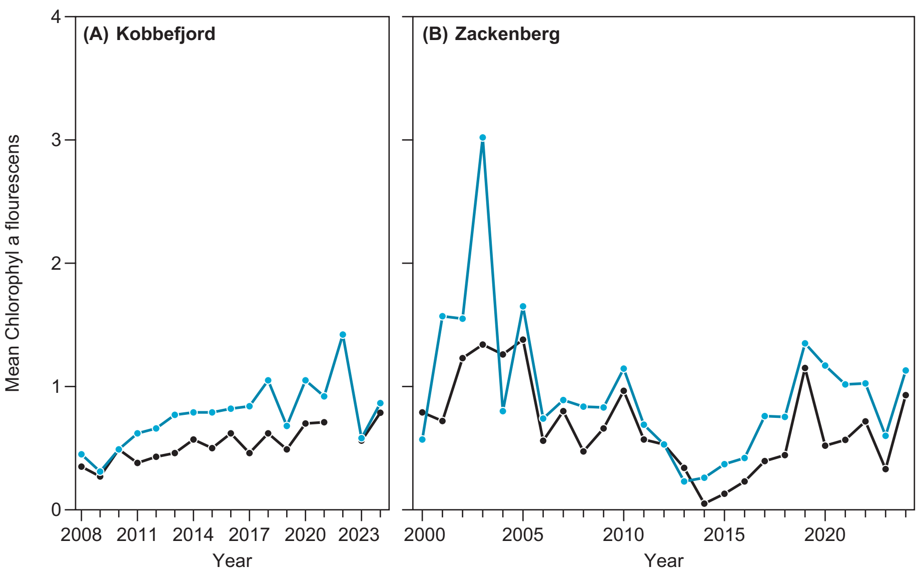

Figure 2. Chlorophyll fluorescence is a measure of productivity in the limnic ecosystem. The graphs show inter-annual variation in chlorophyll fluorescence in lakes at Kobbefjord and Zackenberg 1996-2024. Blue lines indicate lakes with fish, black lines lakes without fish. Note that due to the late onset of the 2020 season at Zackenberg dictated by the covid-situation, only one measurement was conducted in July. In 2022, one lake in Kobbefjord could not be sampled due to logistical constraints.

Annual Report Card 2024

GEM MARINEBASIS

Photo: Christian Klindt Sølbeck.

The GEM MarineBasis programme collects physical, chemical and biological data from the Greenland coastal zone. Work is focused in three fjord systems (Godthåbsfjord, Disko Bay and Young Sound) all influenced by glaciers from the Greenland Ice Sheet. The programme provides long-term data for identification of trends and improved understanding of ecosystem function, both of the physical environment (such as sea ice cover, water temperature, salinity and nutrient concentrations) and of the biotic environment (such as primary production and marine biodiversity). Data from the program feed into several working groups under the Arctic Council, i.e. the Circumpolar Biodiversity Monitoring Programme (CBMP) under the Conservation of Arctic Flora and Fauna (CAFF) and the Arctic Monitoring and Assessment Programme (AMAP).

Monitored parameters:

- Sea Ice and Snow Conditions
- CTD Measurement
- *p*CO_2
- DIC
- TA
- Nutrients
- Chlorophyll a Concentration
- Phaeopigments Concentration
- Particulate Pelagic Primary Production
- Particulate Sinking Flux
- Plankton
- Fish Larvae
- Benthic Vegetation
- Marine Mammals
- Sea Birds

Photo: Christian Klindt Sølbeck.

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PROGRAMME DESCRIPTION

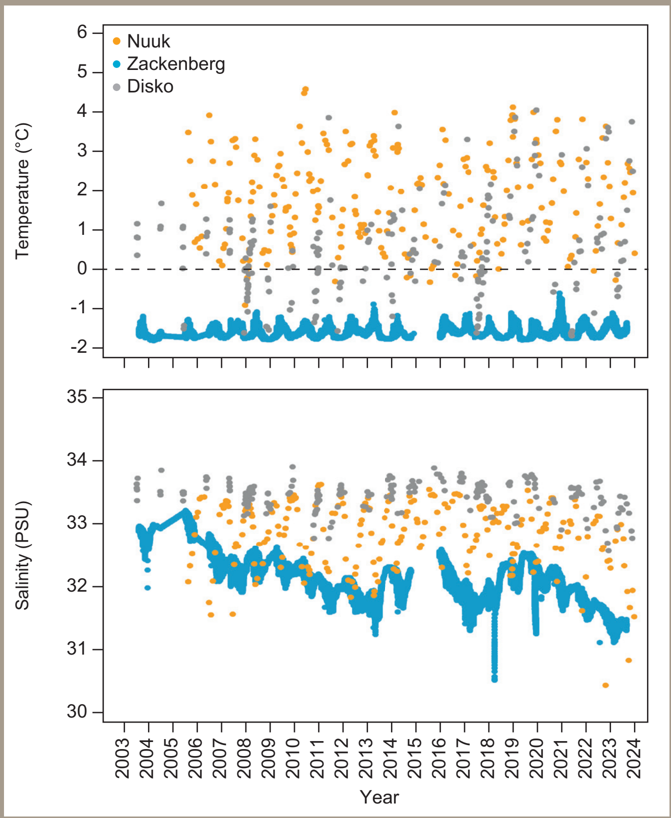
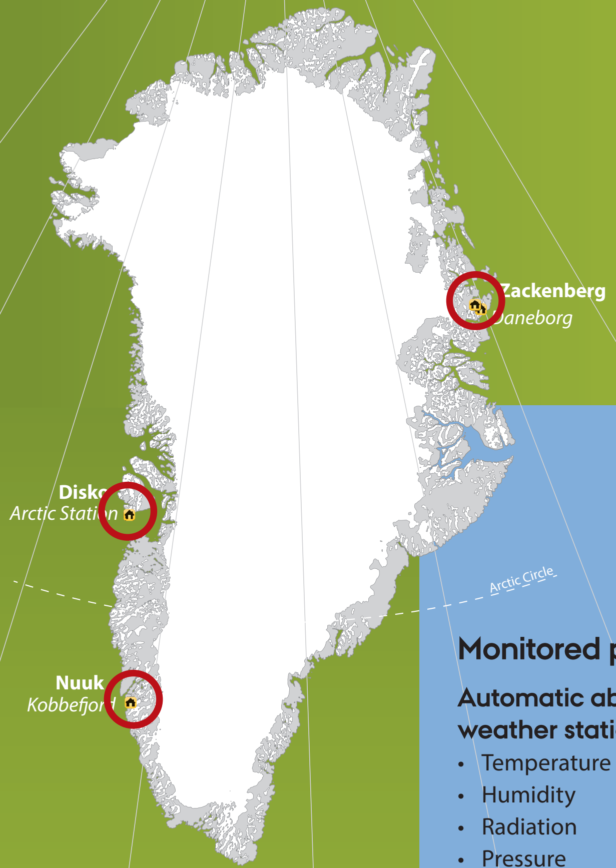


Figure 1. Water temperature and salinity at the permanent monitoring stations in Nuuk, Disko and Zackenberg. The time series from Nuuk and Disko represents one depth (63 m) selected from a monthly profile covering the entire water column. The time series from Zackenberg represents an autonomous mooring deployed at an average depth of 63 m.

Photo: Christian Klindt Sølbeck.

Photo: Thomas Juul-Pedersen.



Annual Report Card 2024

GEM GLACIOBASIS

The GlacioBasis programme focuses on monitoring the mass and energy balance of Arctic glaciers at the three Greenland Ecosystem Monitoring (GEM) sites. The program provides in situ observations of essential climate variables, as identified by AMAP, IPCC, WMO-GCW, and WGMS. These observations help quantify the processes governing glacier mass balance and assess the impacts of Arctic glacier melt on future sea-level rise, freshwater inputs into fjord systems, and fjord ecosystems.

By addressing glacier and glacial meltwater runoff components, GlacioBasis contributes to the hydrological monitoring within GEM sites, enhancing understanding of the interactions between glaciated, freshwater, terrestrial, and marine ecosystems. The collected data supports the calibration and validation of modeling and remote sensing products, such as downscaled temperatures from regional climate models, snow extent analyses, and discharge modeling.

Globally, glacier ice loss contributes significantly to sea-level rise, accounting for 25-30% of the observed increase (Zemp et al., 2019). Greenland glaciers are the second-largest contributors to this global loss. The three GlacioBasis monitoring sites represent half of Greenland's existing glacier monitoring locations, highlighting their critical role in addressing the sparse distribution of such data.

GlacioBasis monitors three key glaciers: Qassinnguit Sermiat at the Kobbefjord, Nuuk site, Chamberlin Glacier, an outlet of Lyngmarksbræen at the Disko site and the east-flowing outlet of A.P. Olsen Ice Cap at the Zackenberg site.

The monitoring programme employs a combination of permanent installations, including automatic ablation and weather stations that transmit data hourly, a stake network, a time-lapse camera, and field surveys. As an example ice ablation, measured as surface lowering, is illustrated in Figure 1. Notably, ice ablation data were not recorded at Qassinnguit Sermiat in 2024 due to instrument failure, likely influenced by prolonged snow cover, as observed by the time-lapse camera (Fig. 2).

Monitored parameters:

Automatic ablation and weather stations:

- Temperature
- Humidity
- Radiation
- Pressure
- Wind speed and direction
- Ice temperature down to 10 m
- Ice surface lowering/ice ablation

Field surveys and permanent installations

- Snow depth surveys using UAVs, probes and snow radar.
- Snow water equivalent
- Surface elevation change (UAV)
- Winter, Summer, Annual net surface mass balance (stake method)
- Timelapse camera

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The terminus of Chamberlin glacier. Photo: Michele Citterio.

Checking mass balance stakes on Qassinnguit Sermiat, Kobbefjord. Photo: Asiaq.

PROGRAMME DESCRIPTION

GEM
Greenland Ecosystem Monitoring

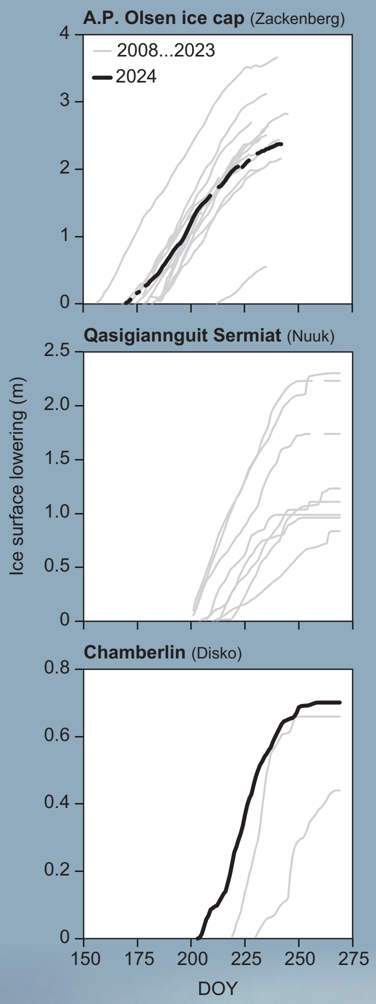


Figure 1. Ice surface lowering, directly convertible to ice melt, from GlacioBasis automatic ablation and weather stations in the ablation zone of the monitored glaciers at the three GEM sites in 2024 (black) vs. earlier years (gray).

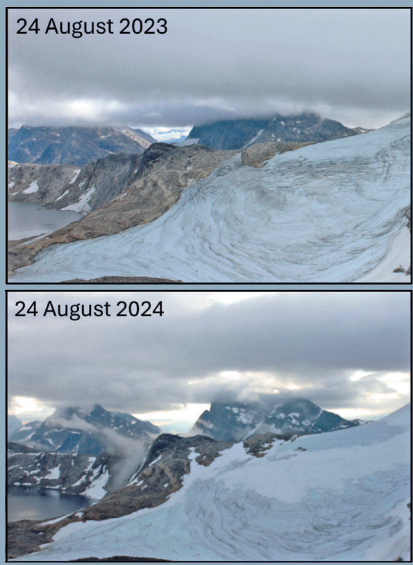
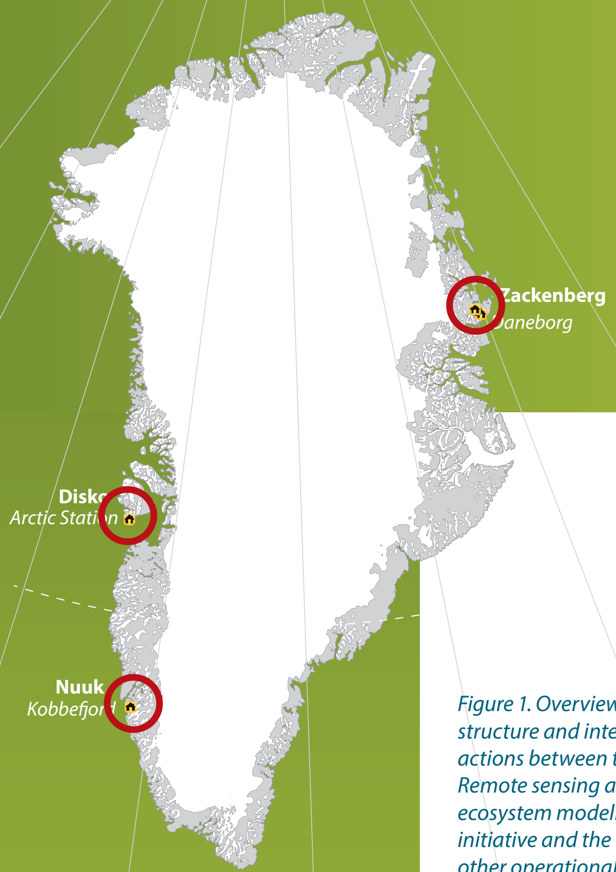


Figure 2. Timelapse camera showing the snow cover in August 2024 was much higher than the same time in 2023.

A stake upon arrival at A.P. Olsen Ice Cap. Photo: Signe Hillerup Larsen.

The automtic ablation and weather station at the summit of A. P. Olsen. Photo: Signe Hillerup Larsen.



GEM
REMOTE SENSING PROGRAMME

Increased accessibility of select GEM remote sensing products

Ecosystem modelling and remote sensing are key tools for understanding changes and making forecasts for remote and highly heterogeneous arctic landscapes. Since 2022, GEM has implemented several remote sensing and modelling products across the three science thematic structures aligned with the GEM 2022-2026 strategy (see Fig. 1) for use by national/international stakeholders and researchers.

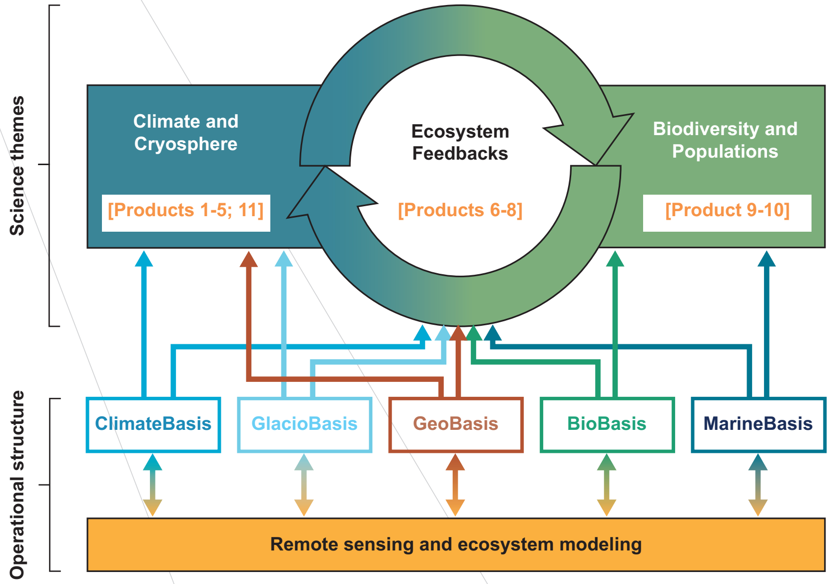


Figure 1. Overview of structure and interactions between the Remote sensing and ecosystem modeling initiative and the other operational Basis-programs.

The GEM initiative of providing specifically developed and calibrated remotely sensed products and model runs for Arctic Greenland is moving into a new phase aiming at increased user accessibility. This is an important step towards the remote sensing and modelling initiative being able to bridge across both the established Basis-programs and the three thematic themes from the current GEM strategy.

The GEM database has been expanded to better include the spatial datasets, and web applications are being developed to spark explorations of select datasets. Users can extract time series of e.g.Normalized Difference Vegetation Index (NDVI) and land- and near-shore water surface temperature (LST) data by clicking on the map. The map viewer allows users to visualize the surface temperature image at given dates.

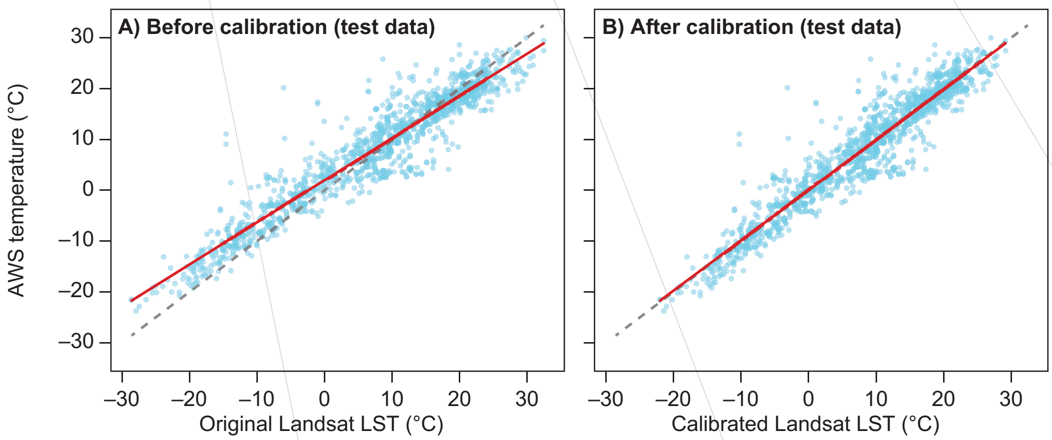


Figure 2. Comparison of original Landsat Surface Temperature (a) and the calibrated Landsat Surface Temperature (b) against ground truth GEM automatic weather station measurements.

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AND MODELING DESCRIPTION

GEM
Greenland Ecosystem Monitoring

Starting with LST, we generate MODIS and Landsat-based land surface temperature products for Greenland by calibrating and combining satellite and reanalysis data. Two versions are now available to explore on our recently developed GEMLST-viewer.

Daily Greenland-wide dataset at 1km resolution: https://ku-gem.projects.earthengine.app/view/gemlst-viewer.

Site-specific (GEM sites) dataset, up to biweekly at 100m resolution: https://ku-gem.projects.earthengine.app/view/gemestlandsat.

Moreover, we can present two NDVI products available for exploration in the web-application:

A daily NDVI product at 250m resolution for the entire Greenland: https://ku-gem.projects.earthengine.app/view/gemndvimodis.

A high-resolution NDVI product (10 m resolution), from the GEM sites: https://ku-gem.projects.earthengine.app/view/gemndvisentinel2.

In the future we will work towards implementing more products into the Google Earth Engine web-application format for easy user access, and inspiration on how the products can be used to support a broad range of studies in Arctic Greenland.

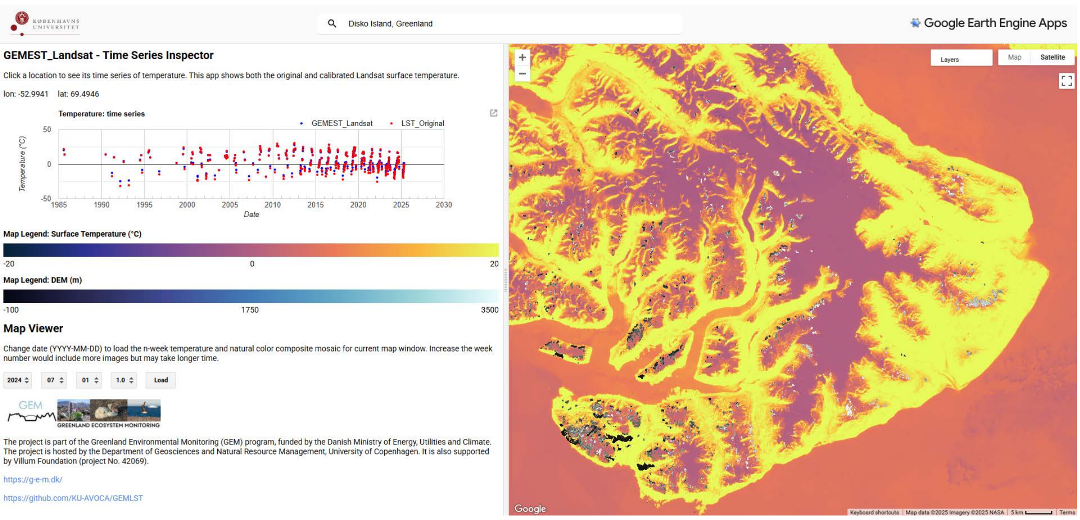


Figure 3. Web application of Landsat-generated LST. Users can extract time series of surface temperature data by clicking on the map. The map viewer allows users to visualize the surface temperature image at given dates.

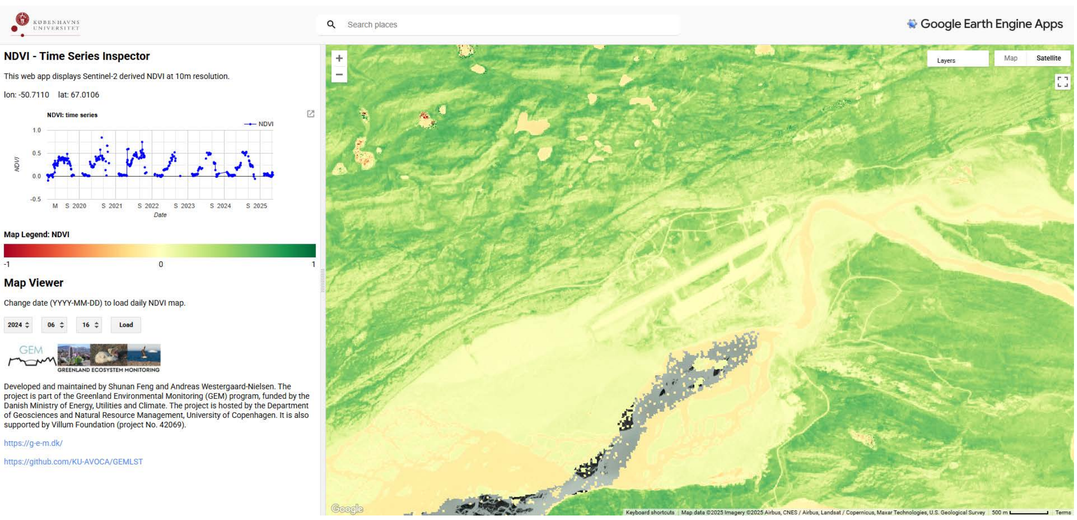


Figure 4. Example of GEMNDVI_Sentinel2 web application. Users can click on the map to extract NDVI time series and visualize NDVI images for selected dates.

Greenland Ecosystem Monitoring

Greenland Ecosystem Monitoring (GEM) is an integrated monitoring and long-term research programme on ecosystem dynamics and climate change effects and feedbacks in Greenland.

www.g-e-m.dk

AARHUS UNIVERSITY

GEUS

ASIAQ

Greenland Institute of Natural Resources

DTU Technical University of Denmark

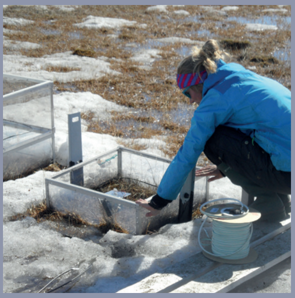
UNIVERSITY OF COPENHAGEN

ClimateBasis Programme

The GEM ClimateBasis Programme studies climate and hydrology providing fundamental background data for the other GEM programmes.

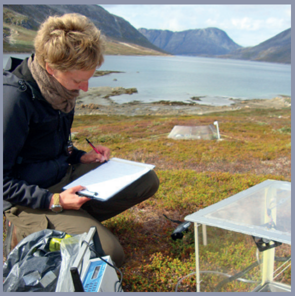
GeoBasis Programme

The GEM GeoBasis Programme studies abiotic characteristics of the terrestrial environment and their potential feedbacks in a changing climate.



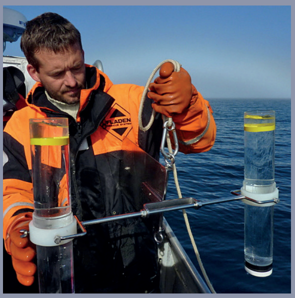
BioBasis Programme

The GEM BioBasis Programme studies key species and processes across plant and animal populations and their interactions within terrestrial and limnic ecosystems.



MarineBasis Programme

The GEM MarineBasis Programme studies key physical, chemical and biological parameters in marine environments.



GlacioBasis Programme

The GEM GlacioBasis Programme studies the response to climate of Greenland's glaciers and ice caps independent from the ice sheet.

The GEM Remote Sensing and Ecosystem Modeling programme supports the the identification of extreme events, potential tipping points and quantifies processes across a full spatial domain from site to landscape and regional scale.