Danish Meteorological Institute

# Student Research Projects
# MSc and BSc Project Ideas

## Danish Meteorological Institute

### National Centre for Climate Research

### Weather Research Department

2024

Danish Meteorological Institute

# Student Research Projects

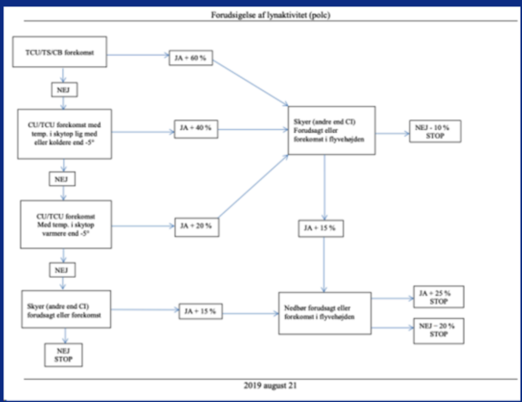
This catalogue is the result of an effort to present collectively the ideas that researchers at the National Center for Climate Research (NCKF) and the Weather Research Department (VF) at DMI have for potential MSc and BSc projects.

Best wishes

DMI

## AUTOMATED LIGHTNING RISK PREDICTION

The project aims at replacing existing flowchart diagram with learnt decision trees to support lightning risk in aviation and military services. The flowchart in the figure is used to quantify probability of lightning conditions. DMI have data about lightning events covering approximately 10 years. This dataset can be used to train a model, taking NWP forecasts as input to predict a probability of lightning conditions





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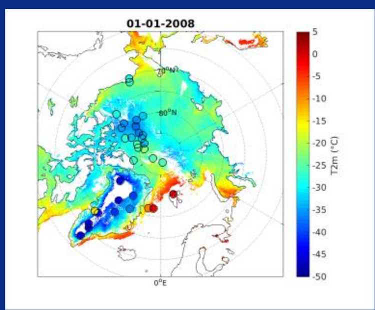
## MACHINE LEARNING FOR ESTIMATING ARCTIC AND ANTARCTIC AIR TEMPERATURES OVER SEA ICE

The Arctic and Antarctic regions regions are heavily under-sampled when it comes to in situ observations, especially over sea ice, causing large uncertainties and differences among the existing temperature records in these very sensitive regions. Satellite observations provide a much better spatial coverage, but provide the surface temperature, which at most times differ from the near-surface air temperatures. Using machine learning models to covert satellite surface temperature observations into air temperatures over sea ice is a promising approach which can provide a much better coverage compared to the sparse in situ observations. The detailed information brings a new possibility of estimating the high latitude warming and Arctic amplification, which may still be underestimated. Sounds interesting?

Requirements: Msc student with machine learning experience

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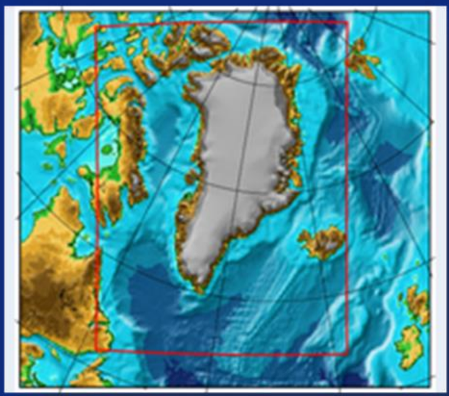
# CLIMATE CHANGES IN THE SEA AROUND GREENLAND AND IN THE ARCTIC

DMI is conducting an analysis of the physical conditions in the sea around Greenland and in the Arctic. The oceanographic data can, for example, be used to study the significant changes in the extent of Arctic sea ice that have occurred in the last 10-20 years or to examine the major hydrographic changes observed in the southeast and western Greenlandic waters during the same period. The oceanographic data can also serve as a background for studies of the Greenlandic marine environment. These data can thus be used to drive, for instance, marine biological, chemical, or other models that depend on the physical parameters



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# TOWARDS IMPROVED ARCTIC SEA ICE THICKNESS ESTIMATES

This project aims at evaluating modeled freeboard estimates to be used in sea ice thickness assimilation products. To derive Arctic wide sea ice thickness, satellite freeboard observations are crucial. These observations are associated with a range of uncertainties. In a recently developed framework an error based assimilation technique has been presented, which uses freeboard assimilation to derive Arctic wide sea ice thickness in contrast to the classically used sea ice thickness. For this technique, freeboard from numerical sea ice model output is used. After a successful pilot study new and improved freeboard estimates have been calculated. The proposed project aims at evaluating this freeboard simulations and at investigating how well know observation uncertainties can be addressed with model simulations.

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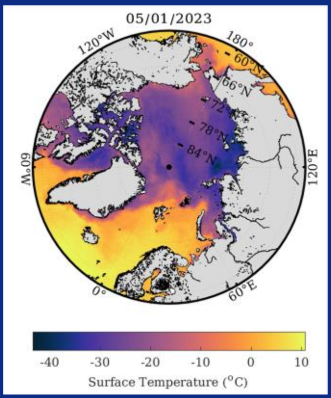
# SEA AND ICE TEMPERATURES IN THE ARCTIC

The Arctic is one of the regions on Earth where climate changes have the most significant impact. Would you like to help determine where and how temperature changes have occurred? As something new, DMI has developed methods and algorithms for determining the temperature of the sea ice surface. Together with the sea surface temperature, this allows us to know the surface temperature throughout the Arctic. DMI has conducted a reprocessing of satellite Sea Surface Temperature (SST) and Sea-Ice Surface Temperature (IST) data from 1982 to the 2023. This dataset can be used to assess climate changes in the Arctic over the past 30 years in the Arctic ocean. These products need to be validated against in-situ observations, after which they can be used to determine temperature changes in the Arctic with much greater detail than before. The aim of the project is to update and extend the validation of this Multi-Year dataset up to 2024 and to assess the impact of increasing its spatial resolution.

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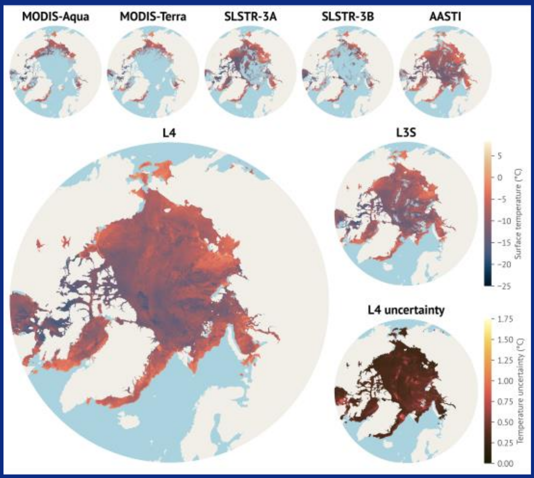
# IMPROVING SEA ICE SURFACE TEMPERATURES IN THE ARCTIC

A gap-free (L4) climate data record (CDR) of Arctic Sea Surface Temperature (SST) and Sea-Ice Surface Temperature (IST) for the period 1982-2023 is produced at DMI as a part of the Copernicus Marine Service. This project will investigate the impact of including new IST products (ESA LST_cci) from MODIS and VIIRS in the processing of the Arctic SST and IST product. The assessment will focus on the stability and relative performance of the ESA LST_cci products, compared to the existing infrared IST products from, e.g. the AVHRR satellite series. Also, the consistency will be examined in the Marginal Ice Zone, towards the open ocean. Selected in situ reference observations will used to assess the improvements in the final product and recommendations will be made for the applications of the ESA LST_cci products for future use.

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## INTEGRATION OF REMOTE SENSING DATA INTO OCEAN AND SEA ICE MODELS

Integration of remote sensing data into ocean and sea ice models is used for both validation and assimilation. With the right combination of supervisor from DTU and DMI a wide range of studies can be setup.

One example of the more challenging fields is to measure sea ice thickness based on altimetry. The satellite measures the freeboard, which includes some assumptions about the snow cover. The ocean and sea ice model has knowledge about both sea ice thickness and snow thickness, therefore a study of how the freeboard is represented in the remotely sensed observations and the coupled model system is interesting.

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## ADVANCING COASTAL PREDICTIONS WITH AI/ML TOOLS

This research proposal aims to harness Artificial Intelligence and Machine Learning (AI/ML) to improve coastal predictions and projections in marine science. At the DMI, we have access to high-resolution atmosphere-ocean reanalysis and projection datasets, which will serve as valuable training data for AI/ML models. AI/ML technologies offer the potential to enhance existing forecasting methods and enable purely data-driven predictions, ultimately contributing to more accurate coastal predictions for management and climate change assessment. The project will involve data preparation, AI/ML model development, integration with existing systems, and comparative evaluation.

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# IMPROVED SATELLITE BASED ICE SURFACE TEMPERATURE (IST) OBSERVATIONS OVER GREENLAND ICE SHEET

The increasing focus on Earth's surface temperature, particularly due to global warming, highlights the importance of accurate Ice Surface Temperature (IST) measurements, especially as Arctic temperatures rise up to four times faster than the global average. Current satellite-based IST measurements rely on outdated 40-year-old algorithms. This project aims to develop advanced Machine Learning (ML) techniques to improve IST accuracy through two main objectives:

- Create an ML-based algorithm to outperform existing IST estimation methods.
- Develop a statistical/ML approach to identify and handle atmospheric disturbances—such as clouds and ice crystals—that affect IST estimates.

We will use a one-year match-up dataset, including advanced weather station observations, polar satellite radiances, and Numerical Weather Prediction (NWP) model data. The findings will enhance real-time IST monitoring and support future Climate Data Records (CDR) for EUMETSAT and Copernicus Climate Change Service, optimizing satellite-based climate analysis.

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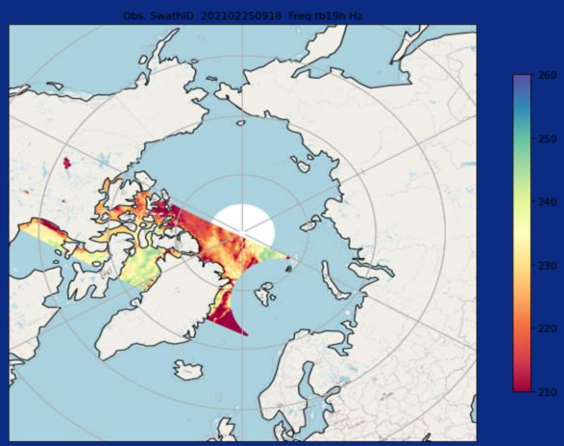
# ASSESSMENT OF SIMULATED MICROWAVE BRIGHTNESS TEMPERATURES OVER SNOW AND SEA ICE

Due to the very dynamic nature of sea ice, in the Polar regions, the sea ice surface properties are complex to simulate. Therefore, it is challenging to build a model capable of generating accurate simulations of brightness temperatures over the sea ice. Such simulations would be useful for sea ice model validation, data assimilation and atmospheric sounding. We are planning sensitivity studies to have a better understanding of snow and ice properties. We use an in-house ocean sea ice coupled model to simulate brightness temperature through SMRT model (https://github.com/smrt-model). After simulation of brightness temperatures, we will do a comparison with observed brightness temperatures from AMSR2

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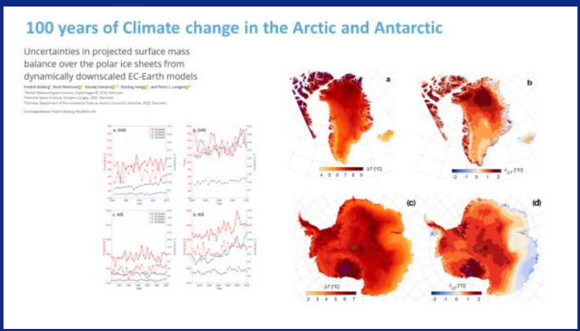
## WHAT WILL THE CLOUDS DO? A HUNDRED YEARS OF CLIMATE CHANGE IN GREENLAND AND ANTARCTICA

Future climate simulations show that the type, height and ice contemt of clouds in the polar regions have an outsize importance when it comes to controlling surface snow and ice melt rates. Thi sproject will use model outputs from a large ensemble of simulations to assess the uncertainty in ice sheet melt produced by different cloud parameterisations. The project would suit someone with experience in processing large datasets and those interested in cloud physics and the development of new parameterisations using machine learning methods. Python and linux experience are a requirement.

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## THE ROLE OF GREENLAND ICE SHEET ON THE CLIMATE SYSTEM

Recent observation and model studies have shown that Greenland and Antarctic ice sheets can respond to atmospheric and ocean warming on relatively short time scales of a decade or less. Understanding and quantifying the response of the ice sheets to climate change and the ice sheet feedbacks to the climate system requires a climate model system that are dynamically coupled with an ice sheet model. One of such a model, the EC-EARTH – PISM coupled model, has recently been developed which incorporate the dynamical interaction of the Greenland ice sheets (GrIS). A number of control and 4xCO2 simulations of more than 350 years have already performed using the coupled (EC-EARTH – PISM ) and uncoupled (EC-EARTH) model.

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# RESOLUTION EFFECTS IN ICE SHEET MODELING

When running an ice sheet model, a set of input data is needed to drive the model. These corresponding records of temperature and surface mass balance or precipitation are usually taken from a climate model. The resolution of the climate model is much coarser than the resolution of the ice sheet model and various interpolation schemes transform the data from one grid to another. But how dependent is the response of the ice sheet on the resolution of the initial climate model? When increasing the climate model's resolution, more features caused by e.g. local topography become apparent, but how will the ice sheet model respond to this? As an example, a better representation of the coastal orography of Greenland may shift precipitation patterns, thereby affecting the forcing fields for the ice sheet. This study will be comprised of running the ice sheet model PISM over Greenland forced by a number of climate model (HIRHAM) runs at various resolutions and comparing the various outcomes in order to identify any effects of resolution of the driving model.

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# PROCESSING AND QUALITY CONTROL SYSTEM FOR THERMAL MAPPING MEASUREMENTS

The road weather forecasts with a focus on prediction of the slippery road conditions are performed by the Road Weather Modelling System (RWMS), and it is an important operational product produced by DMI in collaboration with the Danish Road Directorate (DRD). Recently the RWMS extended its applicability with focus on detailed road stretch forecasting at distances of 1 km and even down to 250 meters along the driving lanes, and hence, information about spatial variability of observed icing conditions on roads or situations leading to such danger became needed. Ice on road surfaces is one of the most serious and dangerous meteorological hazardous phenomenon, and it is well known that annually it causes serious injuries and even deaths in road accidents.

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# HUMAN INFLUENCE ON THE VARIABILITY OF CLIMATE (IN EUROPE/NH) AND CIRCULATION PATTERNS

A possible consequence of global warming is the change of the distribution of the climate variability, hence the return of the extreme events. This study is to investigate whether the anthropogenic warming can lead to changes in the variability of (1) surface climate (i.e., patterns and frequencies in extremes); (2) atmospheric circulation patterns such as North Atlantic Oscillation (NAO) and the multi-decadal Atlantic Oscillation (MAO); and (3) the deep ocean circulation, i.e., Atlantic meridional overturning circulation (AMOC). The interconnections between the climate and these circulation patterns under different forcing conditions will also be investigated.

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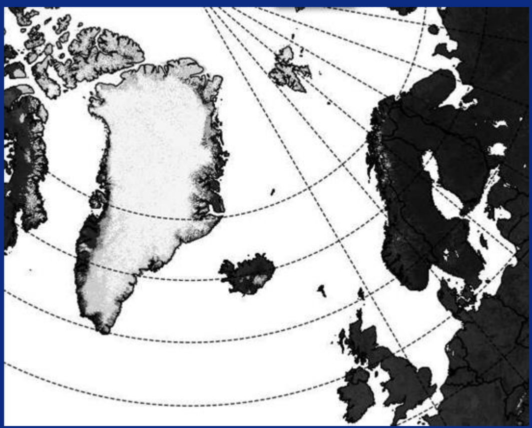
# ADVANCED ALBEDO MODELLING WITH THE HARMONIE GREENLAND WEATHER MODEL

The albedos of snow and ice are of great importance for the surface energy balance in the Arctic. They are often considered to be a number ranging from 0 to 1 that gives the reflectance of shortwave (solar) irradiances. A more elaborate description of albedos includes their dependences on the angular distribution of spectral radiances. This description can be used in the framework of the HARMONIE Greenland weather model



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## USING DRONE OBSERVATIONS TO ASSESS THE SPATIAL SURFACE TEMPERATURE VARIABILITY

The Arctic is warming faster than any other region of the world leading to rapid and widespread changes. Despite much attention, there are large uncertainties in Arctic surface temperature estimates. DMI routinely flies a drone mounted with a thermal infrared camera over the sea ice in Qaanaaq, Greenland. An enormously amount of data has been collected on a weekly basis and is waiting to be processed and analysed. The drone observations have a large potential to improve our understanding of the spatial scales of the surface temperature variability over sea ice, allowing a better representation of the uncertainties when considering averaged surface temperature products.

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## USING ADVANCED TECHNIQUES TO VERIFY ENSEMBLE BASED DISPERSION PREDICTIONS

Accounting for meteorological uncertainties in atmospheric dispersion modelling can be achieved by using data from DMI's NWP ensemble prediction system. For a given release scenario, this approach generates a number of concentration plumes that, combined with statistical post-processing, provide a probabilistic dispersion prediction. However, how accurately does the ensemble spread reflect the uncertainties of the predicted concentration fields? In other words, how can we quantify the extent to which the ensemble prediction aligns with the measurement data? This remains an unresolved question in modern emergency management, where ensemble techniques are increasingly being adopted. By applying advanced model verification techniques, we aim to validate the ensemble based probabilistic dispersion predictions, thereby enhancing our understanding of the dispersion model uncertainties and, in turn, improving our interpretation of the ensemble predictions. We will assess selected cases such as the European Tracer Experiment (ETEX), where the release is accurately known, and quality-controlled measurements are available to represent the plume (msc project)

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# ENSEMBLE FORECASTING OF THE ATMOSPHERIC DISPERSION OF VIRUS PARTICLES FOR ANIMAL DISEASES (MSC PROJECT)

In the event of an outbreak of an airborne animal disease, e.g. foot-and-mouth disease, with consequences for the Danish veterinary preparedness and disease management, DMI predicts the dispersion of the released virus particles with the Danish Emergency Response Model of the Atmosphere (DERM A) using in-house Numerical Weather Prediction (NWP) model data. In the project, the potential use of ensemble techniques to assess the meteorological uncertainty of the predicted virus concentration in the air will be studied.

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# ICE DRIFT MODEL FORECAST SKILL

Sea ice in the arctic ocean is constantly moving, driven by wind and ocean forcing. We observe ice drift by gps equipped buoys and by tracking the ice using daily satellite radar images. In addition, we try to estimate the ice drift by applying ice drift prediction models. Buoy locations are transmitted via satellite communication link (typically iridium) every 1-2 hours while satellite observations are typically available ever 1-2 days. From the satellite observations, it is thus possible to determine ice drift over a period of 24-48 hrs.

We have ice drift predictions from DMI’s own ice/ocean models as well as from the Copernicus marine core service global and regional operational forecast models. The DMI model delivers ice drift forecasts for every hour, whereas only daily average ice drift is available from the Copernicus models. Predictions typically reach 5-10 days into the future and are periodiced 1-2 times per day.

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## STUDY OF NON-HYDROSTATIC EFFECTS WITH HARMONIE MODEL

Hydrostatic balance is an approximation used extensively in meteorology. Under this assumption, pressure gradient in the vertical is balanced by gravity and vertical acceleration can be neglected in the vertical component of the momentum equation, resulting in great convenience in numerical weather prediction and in observation technique for measuring atmospheric profiles. Hydrostatic balance, however, breaks down when aspect ratio of meteorological phenomena, i.e., the ratio between vertical and horizontal scales of the motion, approaches 1. This corresponds to situation with significant vertical acceleration, often seen in strong convection, and orographic induced flow associated with steep orography.


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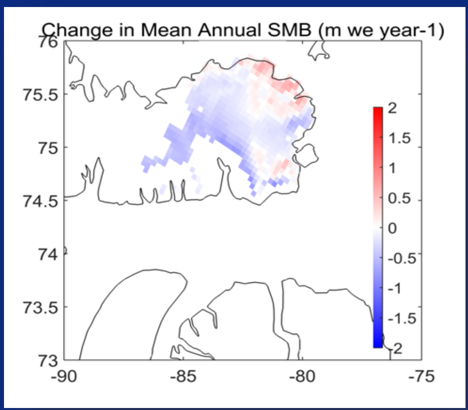
## ASSESSING THE HEALTH OF SMALL GLACIERS AND ICE CAPS IN THE ARCTIC

Small glaciers and ice caps are disproportionally important in Greenland as they receive large amounts of snow and experience large amount of melting. Around the Arctic, some of the best mass balance records are found on the smaller glaciers and ice caps, giving good possibilities to validate records. However, the small size of these ice caps makes them tricky to resolve in most regional climate models and innovative techniques to statistically compare modelled and observed meteorological and glaciological variables are required. In this project, the output from very high resolution (~5km) simulations by the RCM HIRHAM5 covering Greenland, Svalbard and Eastern Arctic Canada will be made available to the student to analyse and compare with observations for key ice caps and glaciers including for example, but not limited to: Devon Ice cap, Renland Ice cap (Greenland), Mittivakat ice cap (Greenland), Midre Lovenbreen ((Svalbard).





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## BALTIC-NORTH SEA-NORTH ATLANTIC WATER EXCHANGE IN A CHANGING CLIMATE

Water exchange between Baltic Sea, North Sea and North Atlantic provides a background of the marine dynamics for ecosystem in this region. Due to demanding computation power for running regional ocean climate models in the wide North Atlantic-North Sea-North Atlantic region, previous regional ocean climate study either use a Baltic-North Sea domain, or North Sea-North Atlantic domain or covering the entire domain but with a lower resolution, which leads to weaknesses on resolving the water mass exchange. This study will use a seamless, two-way nested Danish coastal-shelf sea model HBM to investigate climate change of Baltic-North Sea-North Atlantic water exchange. This study requires some experiences on ocean modelling and data post-processing, and some pre-knowledge on Fortran and/or python.

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## ANTARCTIC ICE SHELF STABILITY IN CMIP6 MODELS

How well do the global climate models represent present day climate over Antarctic ice shelfs? What is the prognosis for the future? This project will use the Melt-Index and apply it to the global climate model and/or new high resolution regional climate models to assess the present and future stability of Antarctic ice shelves.

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# ASSIMILATION OF GPS RADIO OCCULTATION PROFILES IN THE HARMONIE MODEL

Radio Occultation (RO) measurements utilizing the Global Positioning System (GPS) is an emerging technique which probes the atmosphere horizontally, as opposed to conventional satellites that views the atmosphere from above.

GPS RO measurements complement conventional satellite retrievals have proven very valuable for initializing global numerical weather prediction (NWP) models. The assimilation of GPS-RO data in NWP can be done without bias correction as opposed to all other assimilated data, and therefore they serve as a unique tool for anchoring the models.

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# NEIGHBOURHOOD FORECAST IN POST-PROCESSING OF HARMONIE

HARMONIE is the mesoscale Numerical Weather Forecast (NWP) model used at the Danish Meteorological Institute for routine short range weather prediction, which has shown great potential in prediction of high impact weather. As a convection-permitting model, HARMONIE resolves directly deep convection, resulting in more realistic description for small scale, strongly convective weather situation.

In this study, we explore and evaluate use of neighborhood method to post-process HARMONIE model output for individual points to provide forecast with additional probabilistic information. Such forecast takes into account spatial scales with predictive skills, the uncertainty in model prediction on temporal and spatial phases. The proposed work is inspired by the research at UK Met Office on verification of mesoscale model with in-situ measurement (Mittermaier, 2014).

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## USING AI IN RETRIEVAL OF HUMIDITY AND TEMPERATURE FROM GNSS RADIO OCCULTATION

Global Navigation Satellite Systems (GNSS), such as GPS are being used in weather forecasting and climate research in many ways. One of the more exotic ways, the Radio Occultation (RO) technique, exploits the signals emitted from navigation satellites by observing the atmospheric refraction of the emitted radio waves, passing horizontally through the atmosphere. The receiver is mounted on another satellite, traveling in a low orbit (see illustration). Due to vertical density and humidity gradients the path of the radio signal is bended by the atmosphere.

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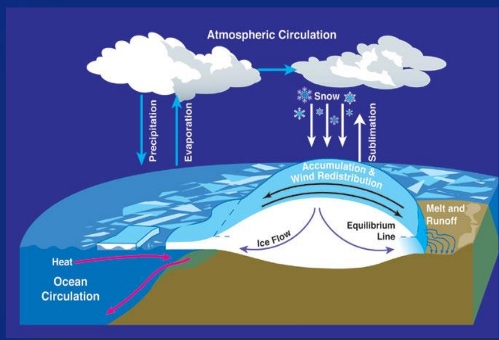
## ATTRIBUTING CHANGES IN SURFACE MASS BALANCE IN GREENLAND TO CLIMATE CHANGE

Surface mass balance (SMB) is defined as the sum of snowfall (positive) and ablation (negative) where ablation includes melt water that runs off the ice sheet and evaporative fluxes from the surface. Recent analysis has shown that the total mass balance of the ice sheet is dominated by the surface mass balance and it is therefore crucial to understand what the controls on SMB are in order to both make accurate projections of sea level rise and to be able to attribute recent changes in SMB trends to natural or anthropogenic changes.

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# CLIMATOLOGY IN DANRA: THE HIGH-RESOLUTION REANALYSIS DATASET FOR DENMARK

Description: DANRA is a new Danish reanalysis product. We would like to investigate how it performs with respect to climatological indicators, through comparison to coarser reanalysis products and through comparison directly to observations. As an example, rainfall is not assimilate into DANRA, and it is of great interest to validate to which degree the model is able to simulate rainfall extremes in the right physical places compared to observations from radar. As a perfect match is not expected, the project will be to develop metrics that describes how the DANRA product performs "reasonable well" in producing the right extreme precipitation event in time and space. Other topics could be related to heat waves or droughts where the higher resolution of data could have impact on the results.

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# FAST DOWNSCALING OF CLIMATE OVER GREENLAND AND/OR ANTARCTIC ICE SHEET

In this project, the new CISSEMBEL model, developed at DMI will be used to produce ice sheet surface mass budget directly from global climate models without first using an intermediate regional climate model. The output will then be compared with output from a regional climate model to see what are the likely biases in this approach and if we can improve them.

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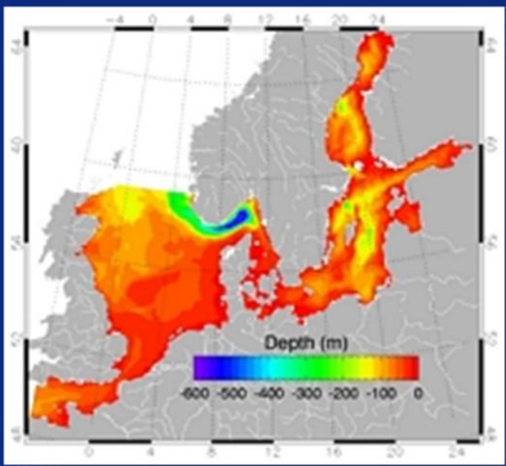
# SIMULERING AF VANDMASSERNE OMKRING DANMARK

DMI's operationelle havmodel HBM beregner strøm, salinitet og temperatur i Nordsø – Østersøområdet. Ved hjælp af en kunstig tracer er det muligt at følge vandmasser med forskellig oprindelse, fx hvordan vand fra Tyske Bugt bevæger sig langs den jyske vestkyst og ind i Skagerrak og Kattegat.

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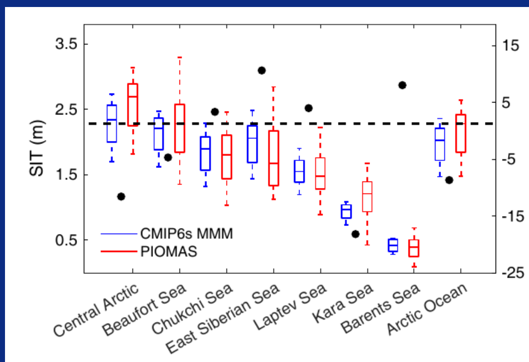
# REGIONAL ASSESSMENT OF SEA ICE THICKNESS IN CMIP6 SIMULATIONS

The interplay between the sea ice cover and the ocean is vital in regulating atmosphere-ocean fluxes, with the ocean influencing the ice cover through fracturing, divergence, and melting. Compared to sea ice cover, regional assessments of sea ice thickness and error source identification in coupled models remain limited. This research aims to bridge this gap by focusing on regional comparisons between different sea ice models. The outcome of this research are essential for reducing uncertainties in sea ice simulations for CMIP7 and enhancing our understanding of the role of sea ice in the climate system, addressing critical challenges posed by climate change.

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## ULTRA-HIGH RESOLUTION REGIONAL CLIMATE MODELLING IN NW GREENLAND

Another ambitious project suited to an MSc student with experience in running complex code. This project will use the state-of-the-art regional climate model HCLIM at km scale resolutions to examine the effect of winds on the regional fjord scale climate of the Inglefield Bredning in NW Greenland. This project will analyse effects of winds on sea ice and if changes in ice sheet topography are likely to change local wind fields.

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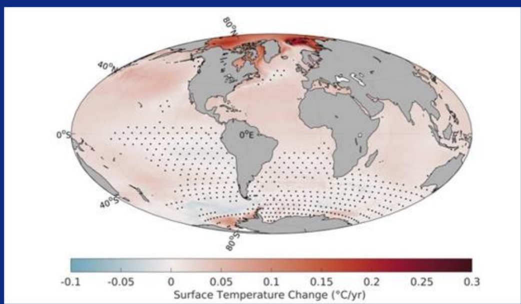
## GLOBAL SEA AND SEA-ICE TEMPERATURES

Global surface temperatures are rising, with the highest warming rates in regions where the sea ice cover has declined the most. DMI has recently produced the first global combined sea and sea-ice surface temperature climate data record (1982-2024) within Copernicus Climate Change Service (C3S). This dataset can be used to assess climate changes globally over the past ~40 years in the open ocean and (as something new) in sea ice covered regions as well. This new product needs to be validated against in situ observations after which it can be used to determine temperature changes in the high latitudes with much greater consistency and detail than before. The derived surface temperatures and corresponding trends will be compared to existing observational based datasets and model reanalyses to evaluate the performance and the most likely surface temperature trends regionally as well as globally.

Sounds interesting?

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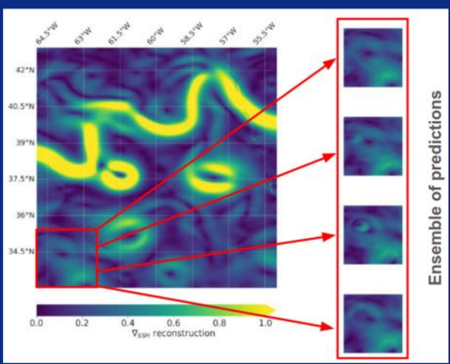
## EMBEDDING GENERATIVE MODELS IN DATA ASSIMILATION FOR UNCERTAINTY QUANTIFICATION OF SEA ICE SHORT-TERM FORECASTS

Over the last years, the raise of deep learning based methods in Geosciences enabled to tackle the traditional data assimilation (DA) problems with neural formulations. Among these methods, Fablet et al. (2021) proposed 4DVarNet, a neural variational scheme to reconstruct and forecast gappy states from partial and noisy observations: Many developments have been proposed to apply these scheme on real geophysical datasets (4DVarNet-SSH, Beauchamp et al. 2023a). In the core version of the method, the prior, typically provided by numerical models in data assimilation, is replaced by a projection operator inspired by UNet architectures. In this work, we propose to leverage generative AI models and replace the prior term by random realizations of a trainable prior distribution. We target as application to build a demonstrator for the reconstruction and short-term forecast of sea ice concentration fields in the Arctic (msc project)

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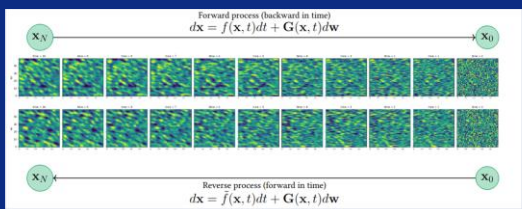
## DIFFUSION MODELS FOR ENSEMBLE-BASED OCEAN FORECASTING

With recent progress have been made in deep generative modeling to approximate the pdf of high-dimensional pictures, a growing interest appears to uptake this family of stochastic neural networks to physical and time-dependent state spaces, see e.g. Høivang (2023), Brajard et al (2024). Among these approaches, diffusion models proposed an appealing framework in which the denoising process relates to stochastic differential equations (SDE), see Song et al. (2021), thus raising some potential for building physically sounded  diffusion models. Here, we propose to explore how diffusion-based strategies are relevant for the generation of large oceanic predictions ensembles. We may also consider how to interprete the backward diffusion step as a forward time-integrator  of a surrogate SDE model along a time window. Targeted applications are short-term or seasonal predictions of ocean surface variables. DL tools may investigate the use of PyTorch or JAX for SDE speed up frameworks (msc project)

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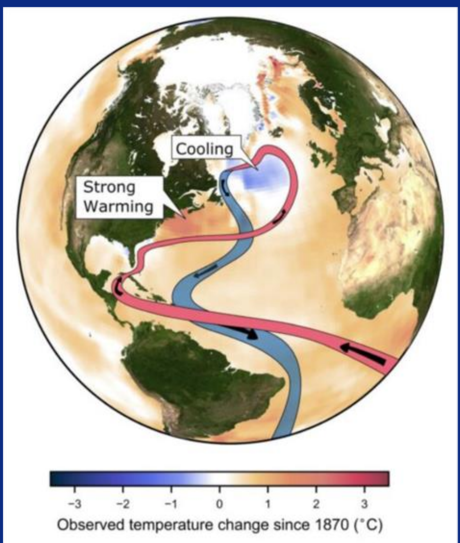
# COMPRESSION OF CMIP6 CLIMATE MODEL OUTPUTS FOR AMOC TIPPING IDENTIFICATION

Classical early warning indicators suggest that the present-day AMOC approaches a tipping point before the end of this century but the uncertainty remains very high [Boers et al., 2021 ; Van Westen et al, 2024 ; Ben-Yami et al 2024]. AI can be used to detect subtle signals of AMOC changes in observational and simulated data. By identifying these signals early, AI-driven models could provide advance warning of shifts in the AMOC, allowing for timely mitigation and adaptation strategies. This work package aims to encode climate models output into a low-dimensional latent space to identify early warning signals of AMOC tipping points. By reducing the complex climate data to a few hundred key latent variables, the project seeks to detect subtle temporal shifts in this latent space that may indicate an impending AMOC tipping event (msc project)





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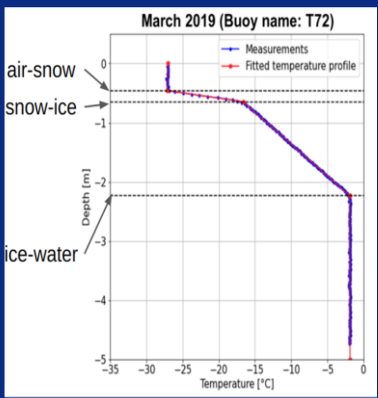
# UNDERSTANDING THE VERTICAL STRUCTURE OF THE ARCTIC SEA ICE

The rapid change in Arctic sea ice is one of the most vivid evidence of global climate change, and satellite observations have contributed significantly to understanding climate change. However, compared to the sea ice area, there are still challenges to obtaining vertical information (e.g., sea ice thickness and snow depth on sea ice) from satellites. Understanding the vertical structure of the Arctic sea ice system is the essential first step in obtaining such information.

This project will analyse in situ temperature profile measurements of the snow-ice system, focusing on:

- To do the quality assessment of the temperature profile measurements
- To detect the air-snow, snow-ice, and ice-water interfaces from the temperature profile
- To find the relationship between the variability of physical variables at the three interfaces
- To develop parameterization that can improve satellite observation





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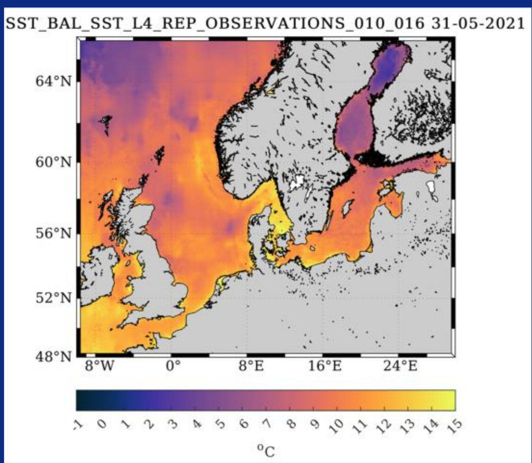
# MULTI-YEAR SST MONITORING IN THE BALTIC SEA

As part of the Copernicus Marine Service (https://marine.copernicus.eu/), DMI is providing Sea Surface Temperature products from satellite observations for the Baltic Sea and North Sea as Multi-Year datasets (1982-2024). These consist of daily, gap-free SST fields with a 0.02 degrees resolution covering the surface temperature of the sea water. In early 2025, a new version of the MY dataset will be available, using the most up-to-date SST input data and we are looking for someone to help us validate it using in situ observations and analyse it for climate trends and other long-term features.

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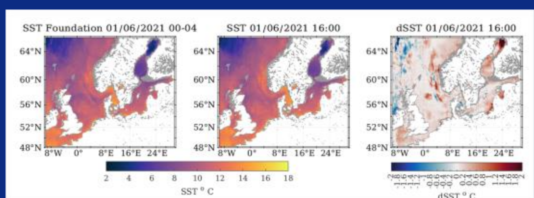
# MONITORING DIURNAL VARIABILITY OF SST IN THE BALTIC SEA

As part of the Copernicus Marine Service (https://marine.copernicus.eu/), DMI is providing Sea Surface Temperature products from satellite observations for the Baltic Sea and North Sea at Near-Real-Time, i.e. the same or next day. Since 2022, a new hourly product for SST has been made available consisting of hourly, spatially complete (no gaps due to missing data) fields at a 0.02 degrees resolution covering the North Sea and the Baltic Sea. The hourly temporal resolution of this product allows for monitoring of the diurnal variability of SST, i.e. how it changes during a day because of solar hearing and low winds; it can be as high as 2.5 degrees or more with direct impact on the exhchange of heat between the ocean and the atmosphere. Diurnal variability is not well captured by ocean models and coupled atmosphere-ocean models and it can also complicate the retrieval of SST from space. We are looking for someone to help us compare the hourly SST product with in situ observations from drifting buoys and to examine its potential for capturing the diurnal variability of SST.

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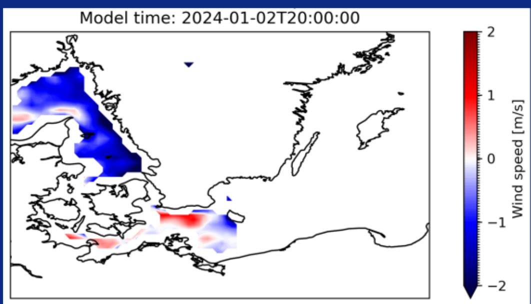
## VERIFICATION OF MODELLED WINDS UNDER STORM CASES IN DENMARK USING SCATTEROMETER WINDS FROM SATELLITES

Flooding from a storm case on January 3rd 2024 in Køge bay was under-predicted partially due to a mismatch between the modelled winds from the operational HARMONIE NEA model used to drive the storm surge forecast model and the real winds. In this project, we aim to use satellite observations for the ocean surface winds from the ASCAT scatterometer on board the MetOP-B/C platforms to assess if any differences were indeed found between modelled and satellite-observed surface winds. In situ observations from meteorological masts offshore, e.g. FINO-2 in the Baltic Sea, can also be included to compare to the satellite and model winds.

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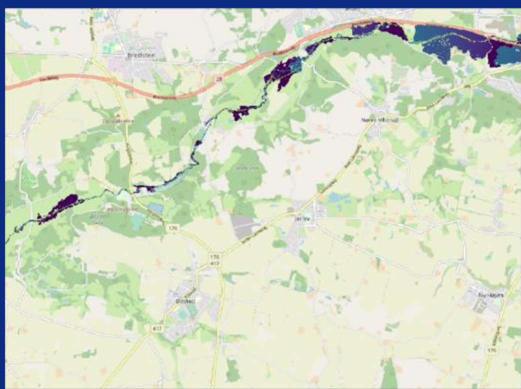
## FLOOD MAPPING OF RIVERS BY REMOTE SENSING

Mapping of flood extent is important tool for flood mitigation, planning and climate adaptation. it defines the areas at risk for emergency services, including critical infrastructure. to estimate the current and future flood risks, flood models are required. however, there is often only limited information available to evaluate and improve these models. the application of satellite remote sensing, including radar platforms, together with dmi's knowledge of historical flood events provides a powerful source of data for understanding the flood processes and evaluating the models used to predict future flood risk. when combined with other sources of data from drones, photographs and flood marks, dmi can benchmark flood models for both short-term flood warning and future flooding under climate change. by developing workflows for satellite, mapping there is also an opportunity to provide near-real time flood maps for flood forecasting and warning. (msc project)



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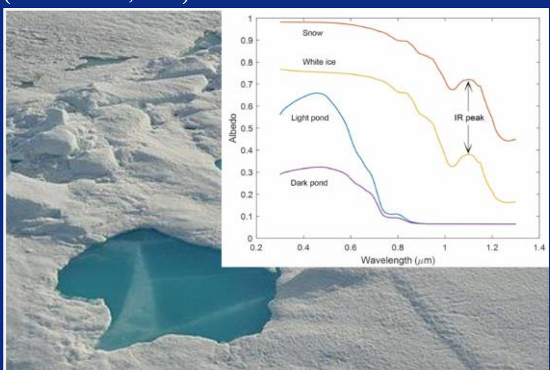
## INTEGRATING HIGH RESOLUTION SATELLITE-OBSERVED MELT POND CHARACTERISTICS TO REFINE ALBEDO CALCULATIONS USING MACHINE LEARNING

Linking melt pond depth and fraction is essential for accurately modeling sea ice albedo, which significantly impacts climate change feedback mechanisms. Shallow melt ponds absorb more sunlight than deeper ponds due to their darker surface, leading to decreased albedo as pond fraction increases. This study will employ machine learning to integrate melt pond characteristics into albedo calculations. By establishing empirical relationships between pond depth, fraction, and sea ice types using high-resolution satellite imagery, we aim to refine albedo estimates. This research will provide valuable insights to sea ice dynamics in climate models.

Proficiency in Python and Linux is required, with experience in satellite data processing (ENVISAT, Sentinel-2, Sentinel-3, ICESat-2) and knowledge of CNNs and U-Net preferred. Suitable for master’s-level candidates.

Photo by Hannah Niehaus, IUP: melt pond on relatively thick sea ice. embedded figure: albedo values for various ice types (Malinka et al., 2016).

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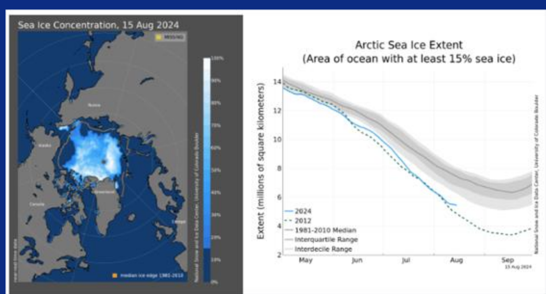
## IMPROVING CMIP6 PROJECTIONS OF AN ICE-FREE ARCTIC USING SATELLITE-BASED SEA ICE METRICS AND MACHINE LEARNING

This project utilizes integrated time series from CMIP6 simulations, from 1850 to 2100, to improve projections of an ice-free Arctic by incorporating observational constraints from satellite-based sea ice metrics. Leveraging machine learning techniques, the project aims to detect and correct model biases, resulting in more reliable projections of future sea ice conditions.

This study will provide some insights into evaluating and attributing model biases in Arctic sea ice representation within climate models. A Master’s student will gain hands-on experience in climate data analysis, machine learning, and model evaluation, contributing to our understanding of Arctic climate dynamics.

Proficiency in Python and Linux is essential, along with experience in statistical analysis. Suitable for master's-level candidates.

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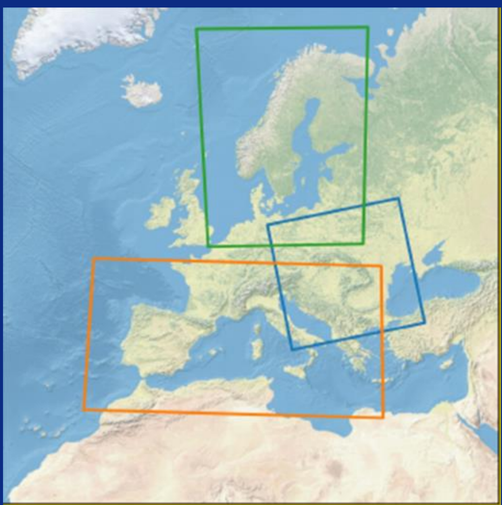
## DOWNSCALING EUROPEAN HEATWAVES USING MACHINE LEARNING

We compiled a dataset of near-surface air temperature from the global reanalysis ERA5 (1985–2020) at 0.25-degree resolution, supplemented by the regional CERRA reanalysis for Europe at 0.05-degree resolution.

This study applies state-of-the-art deep learning techniques (UNet, Transformers, Diffusion) to downscale temperature fields, improving the detection and characterization of European heatwaves. By refining ERA5's resolution to match CERRA, we aim to enhance the accuracy of extreme temperature events. We will compare results from DeepR and Deep Neural Networks, evaluating their pros and cons in capturing both general patterns and extreme events. This research provides insights into ranking machine learning techniques for climate downscaling. Proficiency in Python and familiarity with Linux are required. Some knowledge regarding Deep-Learning framework (PyTorch) would be appreciated. Suitable for master's-level candidates.



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## FLOOD MAPPING OF RIVERS BY REMOTE SENSING

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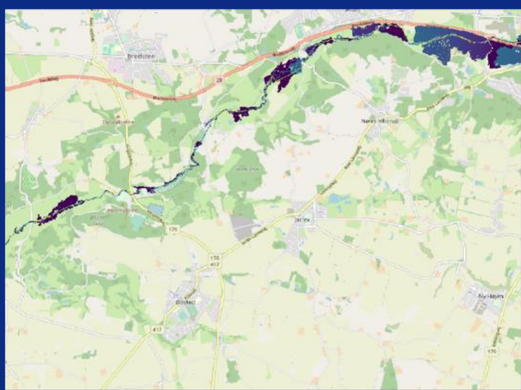

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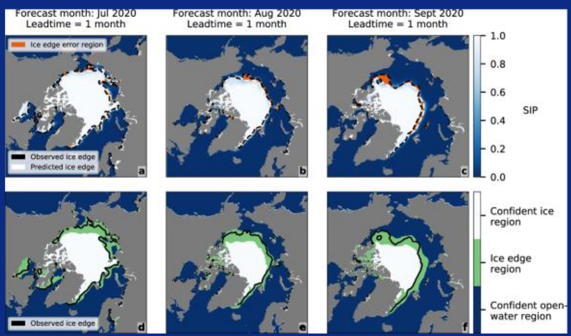
## SEASONAL SEA ICE CONCENTRATION FORECASTING WITH MACHINE LEARNING

Recent studies have examined forecasting sea ice concentrations using a machine learning model of a U-NET type and reanalysis data from ERA5.

At DMI we have been a part of producing an Arctic higher resolution reanalysis dataset (CARRA) and we hope to be able to obtain an improved sea ice concentration forecasts by using this data to train a UNET model.

In this master student project you will use data from CARRA, along with sea ice concentration from OSISAF to train a neural network to predict future sea ice concentration values. You will compare your results to those obtained in the reference paper (see below) and asses if using this dataset provide improved possibilities for SIC forecasting.

Reference paper: *Seasonal Arctic sea ice forecasting with probabilistic deep learning*

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## STUDYING PHYSICAL PROCESSES THROUGH THE EMBEDDING SPACE OF A TRAINED DEEP LEARNING WEATHER FORECASTING MODEL

This project will investigate how deep learning models utilise their embedding space to represent the physical processes they are aiming to simulate. doing this will enable us to build better data-driven models by improving on how these models utilise the embedding space and offers the opportunity to improve traditional equation-based numerical modelling by exploiting relationships found by deep learning models in the embedding space. Specifically, the project will explore embedding information from physical principles in data-driven models for weather forecasting to

1) make them physically consistent and increase their reliability in simulating key atmospheric features and

2) discover physical relationships learnt by deep learning models

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## ACHIEVING KM-SCALE SKILL AT PRECIPITATION FORECASTING

Achieving km-scale skill at precipitation forecasting. Existing graph-based neural-network atmospheric circulation models have not yet achieved high predictive skill on km-resolution precipitation, although some diffusion-based downscaling models are pushing the frontier. This may be a particularly difficult task for current graph-based architectures as the fully three-dimensional state of the atmosphere is collapsed into a single feature vector representing the entire atmospheric column at a given geographical location. This project will investigate effects of architecture and training on the predictive skill of precipitation (especially intense rain, cloudbursts) in the Graph Neural

Network data-driven model being developed at DMI with particular emphasis on the models ability to capture precipitation from convective clouds.

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## CALIBRATION OF KM-SCALE NOWCASTS FOR RAIN AND SOLAR ENERGY

Providing skillful near real-time forecasts of precipitation (particularly cloudbursts) and surface radiation have recently become a possibility due to the development of deep learning based nowcasting models that forecast directly from observations (radar and satellite), however the generalisability of these models to new domains has not yet been established.

This project will investigate effects of diffusion process parameters and training data in probabilistic nowcasting forecasts by utilising high-resolution observations covering Denmark.

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# ADAPTIVE MESH-BASED ATMOSPHERIC MODELS

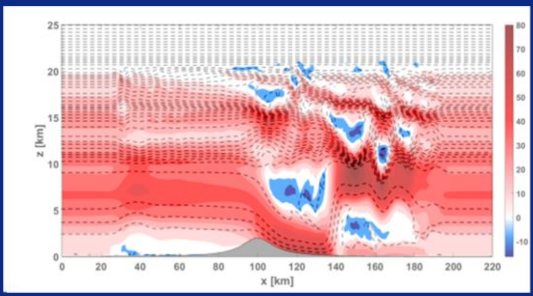
A recently developed IMEX-DG atmospheric model uses discontinuous finite elements and a semi-implicit time discretization that efficiently deals with sound waves based restrictions and simulates atmospheric dynamics in Cartesian geometry. Implemented within the C++-based deal.II open-source library (https://www.dealii.org/), the model includes advanced adaptive mesh refinement capabilities that enable the use of variable-resolution meshes, enhancing accuracy over orographic features while reliably and efficiently simulating larger-scale dynamics.MSc projects with DMI co-supervision related to this development include:

Exploring the extension of the scheme's functionality to simulate flows in spherical geometry, moist dynamics, and non-ideal gases;

The impact of advanced preconditioning techniques on the efficiency of the numerical scheme;

The three-dimensional implementation of a novel scheme for absorbing boundary conditions at the model top.

Prerequisites: fundamentals of C++ programming, computational fluid dynamics, numerical linear algebra

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