ASIF Data Challenge

Arctic Sea Ice Forecasting Data Challenge

Description of the Task

The overarching and fundamental goal of the ASIF data challenge is to improve our understanding of the hourly to seasonal response of the Arctic sea ice to external forcings (typically winds, currents and waves) in the context of the observed ongoing transition from a thick/multiyear ice cover to a thinner/mostly seasonal ice cover. More specifically, the data challenge will carry an environmental and operational safety dimension by assessing the proposed solutions on their ability to simulate and predict:

- ice edge position (key e.g. for the access to nutrient-rich fishing zones or for safe navigation),
- the timing of maritime route openings,
- the location and timing of extreme sea ice break-up events,
- the dispersion of pollutants (e.g. oil, plastic etc…) in ice-infested waters.

This data challenge is designed to evaluate and advance sea ice forecasting capabilities in the Arctic region by benchmarking state-of-the-art operational models (e.g., TOPAZ, NextSim-F) and promoting the development of innovative AI-based methods. Participants will focus on forecasting key sea ice parameters: sea ice extent, thickness, concentration and drift over short- to long-term horizons (1-10 days, seasonal).

Datasets

Participants will have access to a range of observational and model data to develop and test their forecasts:

1. Training Dataset

All datasets that are not used in the validation are allowed to train, test and tune the methods.

Among the identified potential useful data are:

- Historical satellite data of sea ice concentration, thickness, and drift from missions like Sentinel-1/2 (freely available at https://scihub.copernicus.eu/), CryoSat-2 (freely available at ftp://science-pds.cryosat.esa.int/), and SMOS (freely available at https://smos-diss.eo.esa.int/oads/access/).

- Historical satellite data of sea ice concentration and drift from missions like AMSR2 2002–2015 (described in Du et al., 2017, and available at http://files.ntsg.umt.edu/data/LPDR_v2).

- Reanalysis data from Copernicus Marine Service (CMEMS) and model outputs (e.g., TOPAZ), see for instance: https://data.marine.copernicus.eu/product/ARCTIC_MULTIYEAR_PHY_ICE_002_016/description

- High resolution sea ice simulations (e.g., NextSIM-F archives, available upon request).

- Meteorological forcing data (wind speed, temperature, precipitation) e.g., from ERA5 reanalysis (distributed by the ECMWF and available at https://cds.climate.copernicus.eu/datasets/reanalysis-era5-pressure-levels?tab=overview).

2. Validation/Test Dataset

The following data from 2016–2020 will be distributed to assess model performance on independent data:

- Satellite observations of sea ice concentration and drift (satellite AMSR2 brightness temperature data derived from passive microwave, from 10 to 60 km resolution): http://files.ntsg.umt.edu/data/LPDR_v2,

- Sea ice lead fraction from satellite MODIS, infra-red measurements gridded at 1 km resolution (available at https://doi.pangaea.de/10.1594/PANGAEA.955561 derived from MODIS according to Reiser et al, 2020).

- Ice embedded drifters of the International Arctic Buoy Program (IABP, https://iabp.apl.uw.edu/data.html).

The choice of evaluation period (2016-2020) could be extended if the non-stationarity of the system leads to a larger than expected variability in the methods' performance. However, as a starting point, this four year period seems like an adequate compromise to have a multiyear independent evaluation and a robust training dataset.

3. Preprocessing Steps

Algorithms should be made available to the participants in order to preprocess raw satellite data (e.g., spatial regridding, temporal aggregation…) and integrate meteorological data to their models.

Evaluation Metrics

Evaluation preprocessing: *Methods are not expected to produce a specific geometry. The only requirement is that the outputs can be assessed on the evaluation data geometry. Hence, either regridding and temporal alignment of model data onto gridded (Level 4) observations and drifter positions, or specific queries for implicit methods will be required. Algorithms for these preprocessing steps will be provided to the participants. However, the* *computational complexity of the preprocessings will vary depending on model architecture and grid structures.*

Models will be evaluated based on the following criteria:

1. Forecast Accuracy

- Sea Ice Extent: Root Mean Squared Error (RMSE) and Mean Absolute Error (MAE) comparing predicted vs. observed sea ice extent.
- Sea Ice Thickness: RMSE between predicted and observed thickness.
- Sea Ice Drift: Accuracy in forecasting ice drift speed and direction, evaluated using vector field comparison metrics.

2. Sea Ice Physics

- Statistics of sea ice deformation: shear, divergence, total deformation rates
- Ice texture: power spectrum density (PSD) of sea ice thickness fields
- Statistical representation of cracks and sea ice thickness along e.g. 1D transects
- Melt ponds characteristics: spatial coverage, timing and location

3. User-oriented metrics

- Prediction of ice presence on a specific shipping route (percentage of ice cover)
- Extreme sea ice break up events: representation of the timing and dynamic of propagation of ice cover debacle, e.g. in the Beaufort Sea
- Turbulent-like dispersion (e.g. oil or plastic dispersion forecast)

4. Computational Efficiency

The participants will be asked to provide information in terms of runtime and resource requirements (e.g., CPU/GPU time) for both traditional and AI-based methods.

Baselines

1. Short term forecast

- The Lagrangian sea ice model: NextSIM-F (Williams et al., 2021) ***[Operational Baseline]***

- The IceCastNet model (developed in the IceCastNet CMEMS Service Evolution 2024 project) ***[AI-based baseline]***

- Sea ice emulator (Durand et al., 2024) trained on a coupled NEMO-NextSIM simulation (Boutin et al., 2023) ***[AI-based baseline]***

2. Seasonal forecast

- Ocean-ice coupled model and assimilation system, TOPAZ (Sakov et al., 2012), the operational system developed at NERSC (Norway) for the CMEMS ARC-MFC. ***[Operational Baseline]***

- Sea ice emulator (Durand et al., 2024) trained on a coupled NEMO-NextSIM simulation (Boutin et al., 2023) ***[AI-based baseline]***

Related Scientific References

- Williams, T., Korosov, A., Rampal, P., and Ólason, E.: Presentation and evaluation of the Arctic sea ice forecasting system neXtSIM-F, The Cryosphere, 15, 3207–3227, https://doi.org/10.5194/tc-15-3207-2021, 2021.

- Sakov, P., Counillon, F., Bertino, L., Lisæter, K. A., Oke, P. R., and Korablev, A.: TOPAZ4: an ocean-sea ice data assimilation system for the North Atlantic and Arctic, Ocean Sci., 8, 633–656, https://doi.org/10.5194/os-8-633-2012, 2012.

- Durand, C., Finn, T. S., Farchi, A., Bocquet, M., Boutin, G., and Ólason, E.: Data-driven surrogate modeling of high-resolution sea-ice thickness in the Arctic, The Cryosphere, 18, 1791–1815, https://doi.org/10.5194/tc-18-1791-2024, 2024.

- Boutin, G., Ólason, E., Rampal, P., Regan, H., Lique, C., Talandier, C., Brodeau, L., and Ricker, R.: Arctic sea ice mass balance in a new coupled ice–ocean model using a brittle rheology framework, The Cryosphere, 17, 617–638, https://doi.org/10.5194/tc-17-617-2023, 2023.

- Du, J., Kimball, J. S., Jones, L. A., Kim, Y., Glassy, J., & Watts, J. D. (2017). A global satellite environmental data record derived from AMSR-E and AMSR2 microwave Earth observations. *Earth System Science Data*, *9*(2), 791-808.

- Reiser, F., Willmes, S., & Heinemann, G. (2020). A new algorithm for daily sea ice lead identification in the Arctic and Antarctic winter from thermal-infrared satellite imagery. *Remote Sensing*, *12*(12), 1957.

Relevance of the Proposal in terms of AI-Native Solutions for the Digital Twin of the Ocean (DTO)

The ASIF challenge will directly support the DTO initiative by fostering AI-native approaches to sea ice forecasting, moving beyond traditional physics-based models. AI-driven solutions developed and inter-compared through this data challenge will likely offer more accurate, efficient, and scalable forecasts, which is a pressing need for both the scientific polar and user communities in the context of the rapidly changing Arctic and its amplified warming. The forecasting methods proposed through this challenge will be designed for seamless integration into the DTO framework, becoming part of a global, real-time numerical ocean representation. This will provide end-users—such as policymakers and Arctic operators—with reliable, data-driven insights for informed decision-making and geostrategic planning.

Relevance of the Proposal in terms of Topical Demonstrations

This proposal addresses key challenges in Arctic sea ice forecasting, with direct implications for polar operations such as shipping, fisheries, and resource exploitation at large. While encouraging AI-based solutions, the data challenge aims to better understand and improve the prediction of critical sea ice processes, including seasonal sea ice extent, ice edge position (crucial e.g. for delineating nutrient-rich fishing zones), or the opening of maritime routes at the onset of the summer for instance. Additionally, the data challenge shall i) contribute to better forecast rare but not insignificant extreme events such as large sea ice breakup in the Canadian Basin of the Arctic Ocean, ii) support environmental monitoring and strategic decision-making of stakeholders.

DC Versioning plan

- **Version 1 (September 2025):**
  The initial version will focus on **forecast accuracy** and **computational efficiency**. The evaluation will rely on satellite observations of sea ice concentration and drift, prioritizing short-term prediction capabilities (1–10 days). This straightforward approach aims to benchmark existing models and test AI-based methods against reliable, widely documented references. By focusing on these core metrics, Version 1 establishes a robust foundation for assessing the basic performance of forecasting approaches.
- **Version 2 (September 2026):**
  Building on the insights from Version 1, the second version will dive deeper into **Sea Ice Physics** and **user-oriented metrics** to increase the scientific and operational impact of the challenge. It will incorporate:
  - **Sea Ice Physics Metrics:** Evaluation of sea ice deformation, texture, and representation of cracks and melting ponds.
  - **User-Oriented Metrics:** Metrics tailored for operational purposes, such as ice presence in shipping routes, indicators relevant for extreme events (e.g., rapid ice breakup or ridging) and turbulent-like dispersion.

This two-phase approach ensures that Version 1 delivers benchmarkable, high-impact results for immediate scientific and operational use while Version 2 expands the challenge's reach, proposing innovative ways of measuring the performance of forecasting methods more in sync with scientist' and users' expectations.

Requested Engineer Resources

- **Requested Engineer Resources (PPR):**
  We anticipate needing **4–6 person-months (p.m.)** of dedicated effort to create the

data challenge. This includes tasks such as curating and preprocessing datasets,, setting up evaluation metrics, and implementing the challenge infrastructure.

- **Support from the Proposing Team:**
The proposing team includes a recently recruited postdoctoral fellow with expertise in AI-based sea ice forecasting methods. Their contribution will significantly streamline the challenge's development, and they are expected to cover a substantial portion of the workload. Additional support will come from other team members providing guidance on scientific and operational relevance, as well as validation of the challenge setup. Specifically, members well versed in the exercise of setting up data challenges will be able to track and guide the PPR engineer's progress.

Scientific and Technical Staff Involved

Related projects: SASIP (Schmidt science), IceCastNet (CMEMS service evolution), ARC-MFC (CMEMS MFC), Arctic-BLISS (CMEMS service evolution)

In alphabetical order

Name	Institute	Position	Expertise
Julien Brajard	NERSC	Senior scientist	Machine learning for sea ice
Charlotte Durand	IGE	Postdoctoral fellow	Machine learning for sea ice
Stéphanie Leroux	Daltas	IR	Sea ice modelling
Julien Le Sommer	IGE	DR CNRS	Machine learning, Oceanography
Sammy Metref	Daltas	IR	Data challenges, Inverse methods
Pierre Rampal	IGE	CR CNRS	Sea ice physics and modelling

- *Julien Brajard is a senior scientist at the NERSC (Bergen, Norway). To improve the accuracy of climate forecasts, JB develops innovative approaches that combine data assimilation and machine learning. Using data, particularly from satellites, he works with the correction of errors in climate models to achieve more reliable predictions of key climate variables. The research has the potential to improve the understanding of climate change in vulnerable areas such as marine ecosystems and the Arctic sea ice. The effects of these changes will then also be easier to predict.*

- *Charlotte Durand was a PhD candidate at Ecole Nationale des Ponts et Chaussées-CEREA under the supervision of Marc Bocquet. Her work focused on* *developing and combining deep learning models and data assimilation methods to represent sea-ice dynamics. This work was conducted in the framework of the SASIP project. She is now postdoc at IGE within the same SASIP project and under the supervision of Pierre Rampal.*

- *Stéphanie Leroux is a research scientist and cofounder of the Datlas company. In Datlas, she is in charge of the research & development activities based on probabilistic ensemble approaches for ocean and sea-ice numerical modeling and forecast applications. Her experience builds on 15 years of working with numerical models and realistic ensemble simulations of the ocean-sea-ice on regional and global scales. She is currently leading the CMEMS-Service-Evolution project Arctic-BLISS (2024-2026) focusing on the short-term predictability of sea ice drift in a modeling system that incorporates three innovative features of future operational systems: a brittle/fracture rheology, a coupling with an interactive 1D atmospheric boundary layer, and an ensemble modeling framework.*

- *Julien Le Sommer, is a CNRS senior researcher at IGE (Grenoble, France). He is an expert in computational oceanography (numerical modeling, data assimilation, inverse problems and machine learning). He is co-chairing NEMO working group on Machine Learning and Model Uncertainties.*

- *Sammy Metref is a research engineer and cofounder of the Datlas company. He has specialized in data assimilation and inverse methods for oceanographic applications. In particular, he previously worked on the BOOST-SWOT ANR project to update the DUACS optimal interpolation method in anticipation of the SWOT satellite data. More recently, he has acquired an expertise in the formulation of data challenges with, amongst others, the creation of the ocean-data-challenges (Ballarotta et al., 2020a ; Ballarotta et al., 2020b).*

- *Pierre Rampal is a CNRS Researcher at IGE (Grenoble, France). He has about 15 years experience in sea ice modeling and observations. His main interests are sea ice physics, variability and forecast. He has worked extensively on better understanding the physics controlling sea ice drift and its source of predictability. He initiated and led the development of the Lagrangian next generation sea ice model neXtSIM until 2021, and has been the instigator of the neXtSIM-F forecasting platform that distributes since 2021 near real-time sea ice products for the Arctic through the CMEMS. He has led a significant number of research projects, including the ongoing SASIP project (https://sasip-climate.github.io/), on polar regions funded by both public and private entities.*