High resolution tropical cyclones (TC) surface fields data challenge

Description of the task: The task is to estimate high resolution coupled ocean-atmosphere fields, such as wind and ocean parameters (waves, currents, sea surface height, salinity, temperature, colour) during the TC lifecycle by mobilising the variety of observations co-located with TC tracks in the MAXSS database. The objective is to better characterise and forecast the evolving structure of the cyclone (radii, intensity, inflow circulation), its interaction with the ocean during and after its passage (i.e. the TC wake signatures).

The solution can use the various available products as input (models, satellite and in situ observations) with objectives to provide wind and ocean parameter estimations. The evaluation will be performed on independent observations.

We propose different subtasks:

- **Filtering:** obs in [t - inf, t[and estimation at **t**
- **Smoothing:** obs in [t - inf, t+inf[and estimation at **t**
- **Forecasting:** obs in [t - inf, t-24h[and direct estimation at **t**

The variables to estimate are surface winds, waves, sea surface height (SSH), sea surface temperature (SST), sea surface salinity (SSS), ocean colour and upper ocean SST and SSS

Data Challenge Versioning Plan:

Version 1 By september 2025:

The first version will rely heavily on the existing MAXSS database going from 2010 to 2020.
The objective will be to estimate:

- surface winds in comparison with high-resolution O(km) satellite-derived wind product (i.e. Synthetic Aperture Radar (SAR))
- high resolution ocean surface waves, SSH, SST, SSS, ocean colour, in comparison with satellite observations and model re-analysis (ERA-5, Mercator-GLORYS)
- upper ocean salinity and temperature distributions in comparison with ARGO profile and model re-analysis (Mercator-GLORYS)

The estimation will be based on all available data described
The data challenge preparation will consist in

- facilitating the discovery and exploitation of different products.
- implementing and computing the metrics for the baseline method

New data sets will be integrated, especially to document particular cases

- Satellite SWOT altimeter (SSH, waves) measurements
- Satellite geostationary observations
- In situ drifters to analyze residual inertial upper ocean circulation

Version 2 By september 2026:

The MAXSS database is scheduled to be updated and extended in 2025-2026. This extension will contain a significantly improved high resolution SAR coverage of TC as well as additional surface products (SAR wind directions, SAR waves). This brings the possibility to improve the development and evaluation of the DC method.

The associated preparation will consist in integrating the additional data, selecting the evaluation cases, and computing the metrics for existing methods. Importantly, the TC wake signatures, to evaluate the ocean response to the passage of an extreme storm, will strongly benefit the present-day altimeter coverage (7 altimeters), including SWOT measurements.

Datasets:

1) **Data available to the algorithm as input for the estimation**

- Atlas of Multi-Source Earth Observations over Tropical Cyclones (2010-2020) from ESA MAXSS Project.
This dataset provides multivariate observations for a selection of storms. They are taken from more than 35 satellite, numerical models and in situ sources, providing the inner and surface ocean conditions for a comprehensive range of parameters (sea surface height, surface winds, waves, precipitation, surface and interior temperature, salinity, ocean colour, ...) before, during and after the storm passage. Different colocation radii and time windows are used depending on the parameter and observation datasets.

- IBTracks. It provides a re-analysis of the vortex characteristics by operational forecast experts in the TC meteorological centers.

- Atlas of Tropical Cyclone Induced Wakes (2010-2020) from ESA MAXSS Project
This dataset provides:
(1) pre-storm upper ocean conditions (e.g., SST, SSS, upper ocean vertical density, stratification strength, etc..)
(2) atmospheric forcing during the storm passage (maximum wind, accumulated rain and evaporation, wind power index, etc..)
(3) oceanic wakes left after the storm for an ensemble of variables (SST, SSS, sea level height, ocean color parameters).

- ERA5 atmosphere re-analysis
- Mercato-GLORYS ocean re-analysis

Reference data used to train and evaluate the model (The evaluation split will be selected by choosing representative events with relevant collocated data. Remaining data can be used for training.**) :**

- High Resolution Tropical Cyclone Vortex and Wind Structure from SAR Imagery for ESA MAXSS Project

- CyclObs SAR database (v0 scheduled for end of year 2024, with more missions and upcoming auxiliary fields like wind direction)
- Altimeters and SWOT (SSH, ocean waves)
- SMAP + SMOS (surface salinity, and medium to low resolution surface winds)
- passive microwave instrumentsq + infrared SST

- ARGO profiles for upper ocean temperature and salinity profiles

Baseline Wind:

- Global Merged Multi-Mission Hourly Gridded Wind Level 4 Dataset (2010-2020) for ESA MAXSS Project
- ERA5
- ECMWF forecasts

Baseline Ocean:

- SST, SSS, ocean colour merged L4 products
- SSH merged AVISO products
- Interior ocean ARGO profiles and ISAS products
- Mercator-GLORYS re-analysis products

Other:

- HWRF forecasts

Since 2021, the number of high resolution ocean surface wind measurements has significantly increased. The use of this data to build the solution may be beneficial but requires specific work to update the existing database (to be done during the data challenge preparation or when developing the solution).

Evaluation metrics:

- Wind metrics :intensity spectral score, radius errors, wind profiles, … RMSE, wrt SAR, wind direction error wrt scatterometer and SAR,

- Ocean metrics: scaling laws, RMSE and spectral score for surface waves, surface currents, SSH, SST and SSS signatures in the TC wakes, Brunt-Vaisala parameter and mixed layer depth changes.

Related technical and scientific references:

https://doi.org/10.12770/35002607-3546-412b-8c5d-9c182a16ffea
https://doi.org/10.12770/447aa88f-0c0b-4607-afe2-9c77e95a14b8
https://doi.org/10.12770/6c56bcde-050f-42eb-92b8-8e882e1f4db9
https://doi.org/10.12770/cc0577e4-55d6-4aa9-a938-b4965be121ab
https://doi.org/10.1029/2024GL110637
https://doi.org/10.1029/2020GL091478
https://doi.org/10.1029/2024GL108327

Relevance of the proposal in terms of AI-native solutions for the DTO (digital twin ocean): (5-10 lines)
The MAXSS data set provides a great opportunity to develop AI methods that are able to leverage data from different instruments with different sampling, resolutions and noise in order to extract relevant signals to describe coupled ocean-atmosphere processes under extreme conditions. The development of solutions for this task will unlock methodological aspects to enforce the DTO construction and evaluation targeting ocean-atmosphere extremes.

Relevance of the proposal in terms of topical demonstrations: (5-10 lines)
Better characterisation of extreme marine-atmosphere events, especially a more precise description of their often unknown evolving dynamics, is archetypical of the uniqueness of remote sensing data to provide key information about complex ocean-atmosphere interactions. Advancing AI-guided data-driven representations will have great scientific values to better explore the driving conditions controlling the dynamics of these extremes, and to help identify expected changes under environmental condition changes.

Scientific and technical staff involved: Description of the key personnel for the proposal. For each member, provide a short (<5 lines) CV and describe the key ocean and/or AI expertise for the proposal.

B. Chapron (Ifremer/LOPS-Odyssey): Senior scientist, first class research director, at Ifremer ; he has multi-year experience on the combined use of space-borne ocean remote sensing active and passive measurements. Chapron holds the ERC Synergy grant (Stochastic Transport in Upper Ocean Dynamics, STUOD 2020-2026, with E. Mémin (Inria, France), D. Crisan and D. Holm (Imperial College, Great-Britain).

A. Mouche (Ifremer/LOPS-Odyssey): Alexis Mouche is a research scientist. His research interests include the interaction of electromagnetic and oceanic waves for ocean remote sensing applications. His recent work has focused on observing TC from space. He led the development of algorithms to derive ocean surface wind forcing at very high resolution, culminating in the creation of the CyclObs multi-SAR observation database, which compiles high-resolution Tropical Cyclone observations.

Q. Febvre (Ifremer/LOPS-Odyssey): Quentin Febvre is currently a research scientist with LOPS at IFREMER, France, since 2024. He received his PhD IMT-A on Deep-Learning for ocean satellite altimetry, and is a co-developer of OceanBench, a framework for co-designing machine-learning-driven high-level experiments from ocean observations. At Ifremer, he works with high resolution SAR image analysis for wave and wind inversion using deep learning methods.

Requested Engineer Resources:
An assessment of the engineer person-month (p.m.) resources requested from the PPR to design and implement the proposed DC, as well as an estimate of p.m. support from the proposing team.

Request of 9 p.m. of an engineer + 3 pm proposing team