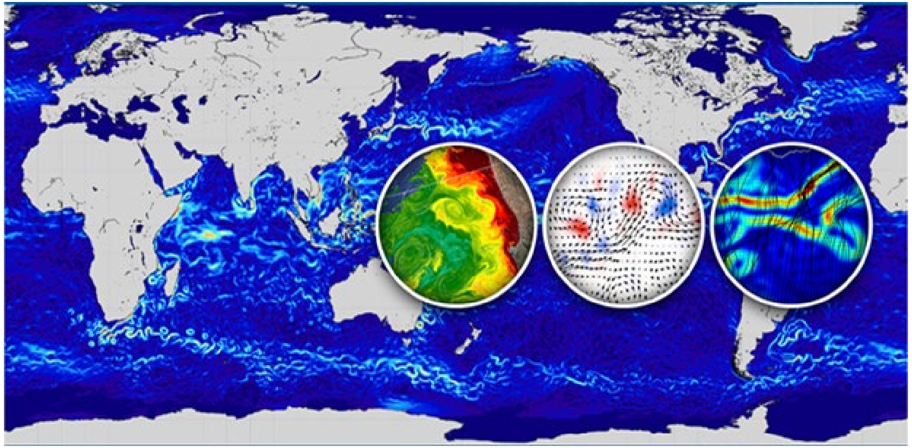
World Ocean Circulation Project

Main Achievements and Findings



Project presentation & main achievements

The consortium

&

our engaged Users

WOC Project Goal and Approach

Main goal:

"Advancing the retrieval of accurate upper-layer ocean circulation products responding to the needs of different key players engaged in the transition toward a Clean, Safe, Sustainable and Productive Marine Environment"

Specific objectives:

1- Test and implement innovative methods to generate and validate new products

2- Better understand upper layer ocean circulation

3- Involve key users

4- Promote and communicate project outcomes

Consortium motto

"At the right place at the rigth time"

The four themes

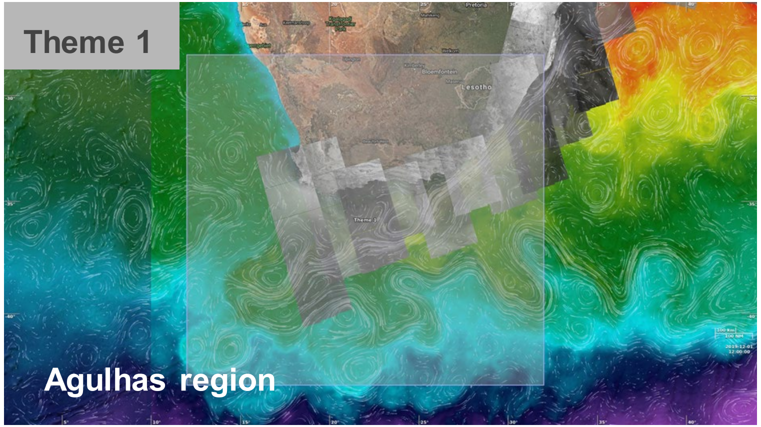
Theme 1: Sea-state current interactions for **Safe Navigation**

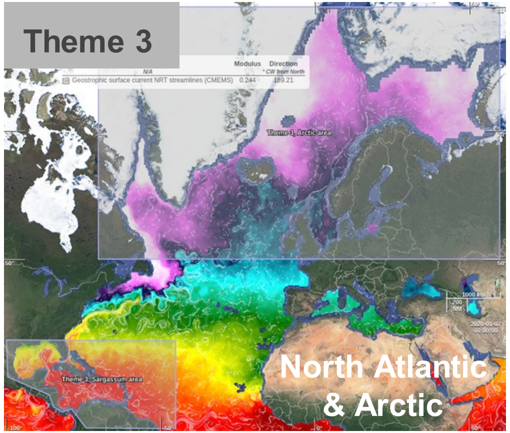
Theme 2: 3D currents and vertical motion for **Sustainable Fisheries**

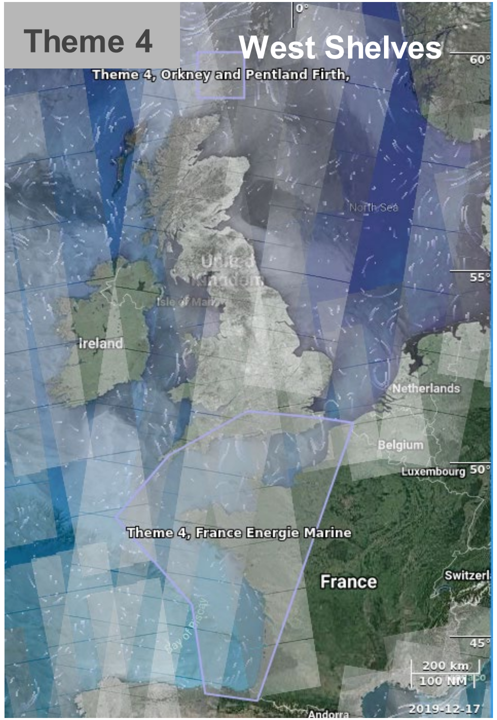
Theme 3: Surface Lagrangian drift for a **Clean Ocean**

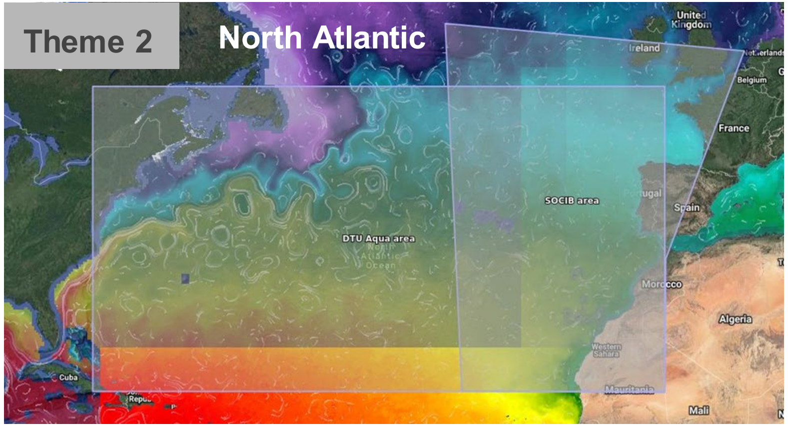
Theme 4: HR wave and current model assessment for a **Productive Ocean**

The pilot areas for each theme

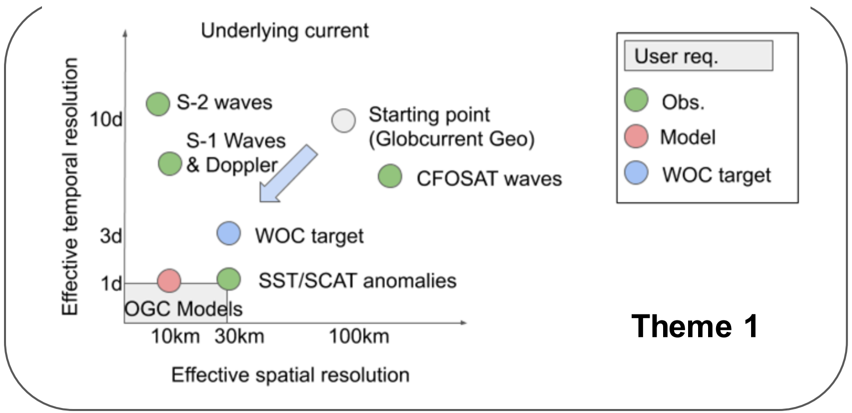


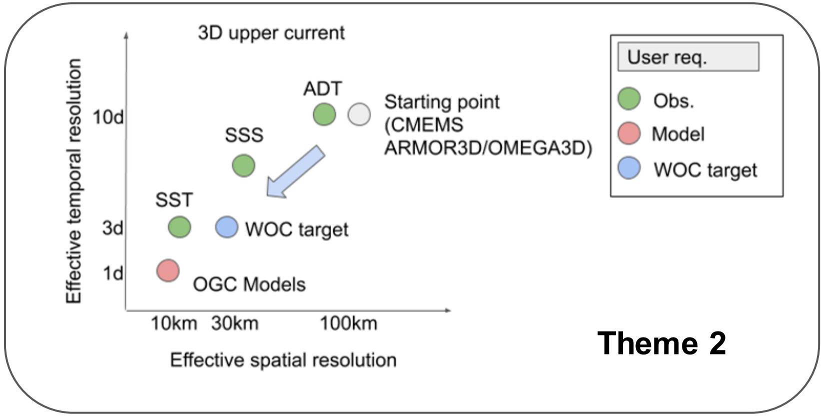


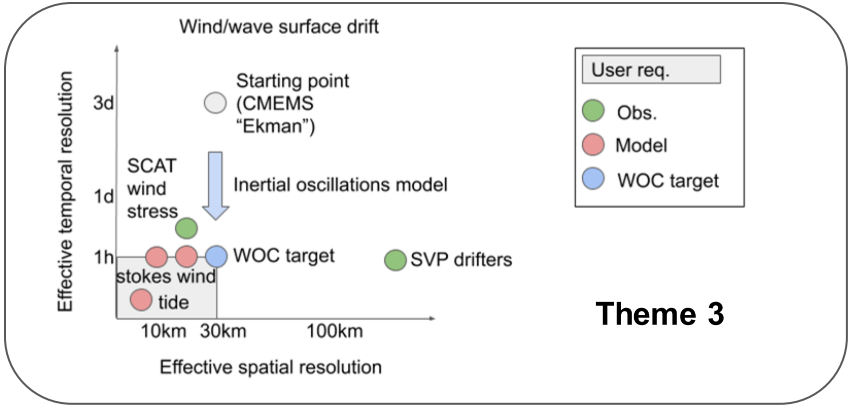


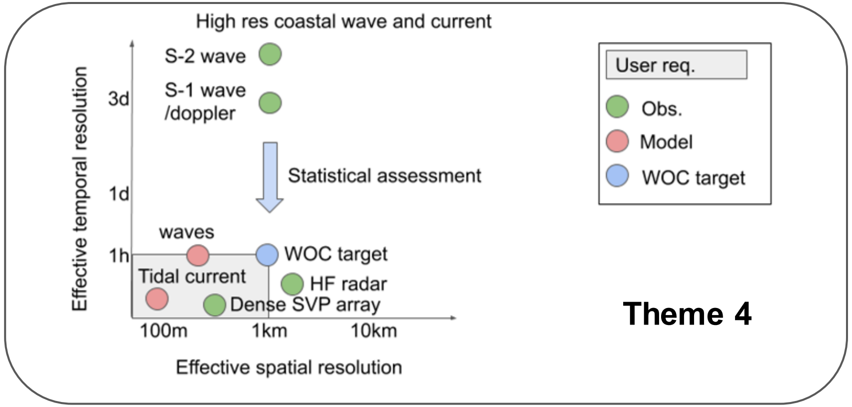


Challenges by theme







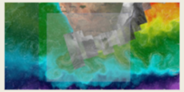


details of workplan by theme

Sea State current Interactions for Safe Navigation — Resp : OceanDataLab

User needs:
Better characterisation of the areas to be avoided and precautionary areas due to sea state increase by surface current gradients.

Pilot Area: Agulhas current



User involvement

- NAVTOR: Integrate Wave & Currents anomaly information within the navigation software
- CMA CGM: integrate spatio-temporal ranking criteria for current & wave forecast in routing software
- METEO FRANCE: Assess regionally improved surface current for extreme sea state index estimation

Technical and scientific challenges:
Direct qualification of the different surface current sources (both observed and modeled) used to force the sea state models

Indirect qualification (through the resulting observed sea state) will be performed from direct sea state variability estimates both from altimeters and spectral measurements (S-1/CFOSAT)

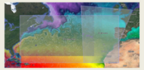
WOC partners developments and products:

- OceanDataLab: Sentinel1 and CFOSAT wavevector gradients estimations and surface current related cross seas indexes
- CSIC: Scatterometer wind stress-surface current analysis and altimeter sea-state-surface current interactions
- OceanNext: Gridded regional surface current product
- NERSC: Process Doppler from Sentinel1 to estimate ocean surface current radial velocities

3D currents & vertical motion for Sustainable Fisheries — Resp : CNR

User needs:
Knowledge-based fishery management requires the assessment of the impact of upper ocean currents and oceanographic features (e.g. fronts) on fish population dynamics/migration behaviour, on the dispersal of larvae, on the upwelling of nutrients needed for primary productivity

Pilot areas: North Atlantic & EBUS



User involvement

- SOCIB: Analyse how the mesoscale affects the migratory patterns of the Atlantic bluefin tuna in the North Atlantic EBUS during the displacements at the beginning and end of the reproductive season
- DTU: Investigate the influence of upper ocean dynamics on eels larvae distribution, dispersal and drift in the North Atlantic by 3D Lagrangian modelling

Technical and scientific challenges:
Improvement of space-time resolution for 3D upper ocean circulation including vertical motion and provision of frontal boundaries information

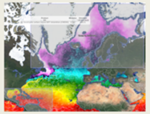
WOC partners developments:

- CNR: Combination of MW-IR SST, SMOS SSS , altimetry, in-situ [T,S] observations, atmospheric forcings (ERA5) to retrieve 2D & 3D HR ocean state fields including vertical velocity
- OceanDataLab: S3/VIIRS/MODIS OC/SST correlations, detection and tracking of ocean dynamical features using AI method
- Ifremer: Determination of upwelling indexes thanks to HR SST and SCAT winds

Surface Lagrangian Drift for a Clean Ocean — Resp : Utrecht Univ.

User needs:
Resolve a large fraction of the small scale dispersion of the floating material

Pilot areas: Arctic corner of north atlantic
Tropical Atlantic



User involvement

- ITOPF: Improve the selection of current & wave forecast by validating the best models for oil spill pollution in arctic
- METEO FRANCE
- CICESE: Improved 2D current for sargassum pollution monitoring & forecast

Technical and scientific challenges:
Improvement the space/time resolution of input 2D currents as well as the lagrangian advection schemes

WOC partners developments:

- OceanNext: Combination of drifters, HF wind (SCAT corrected wind stress), alti, SLAB model to retrieve HF surface current
- Universiteit Utrecht: Lagrangian advection and validation of surface drift
- Ifremer: Enhanced stokes drift estimates from sea state model

High Resolution wave and current model assessment for a Productive Ocean — Resp : OceandataLab

User needs:
Better assessment of high-resolution coastal models for wave and currents for site studies and energy production estimates

Pilot Area: Orkney and french coast

User involvement

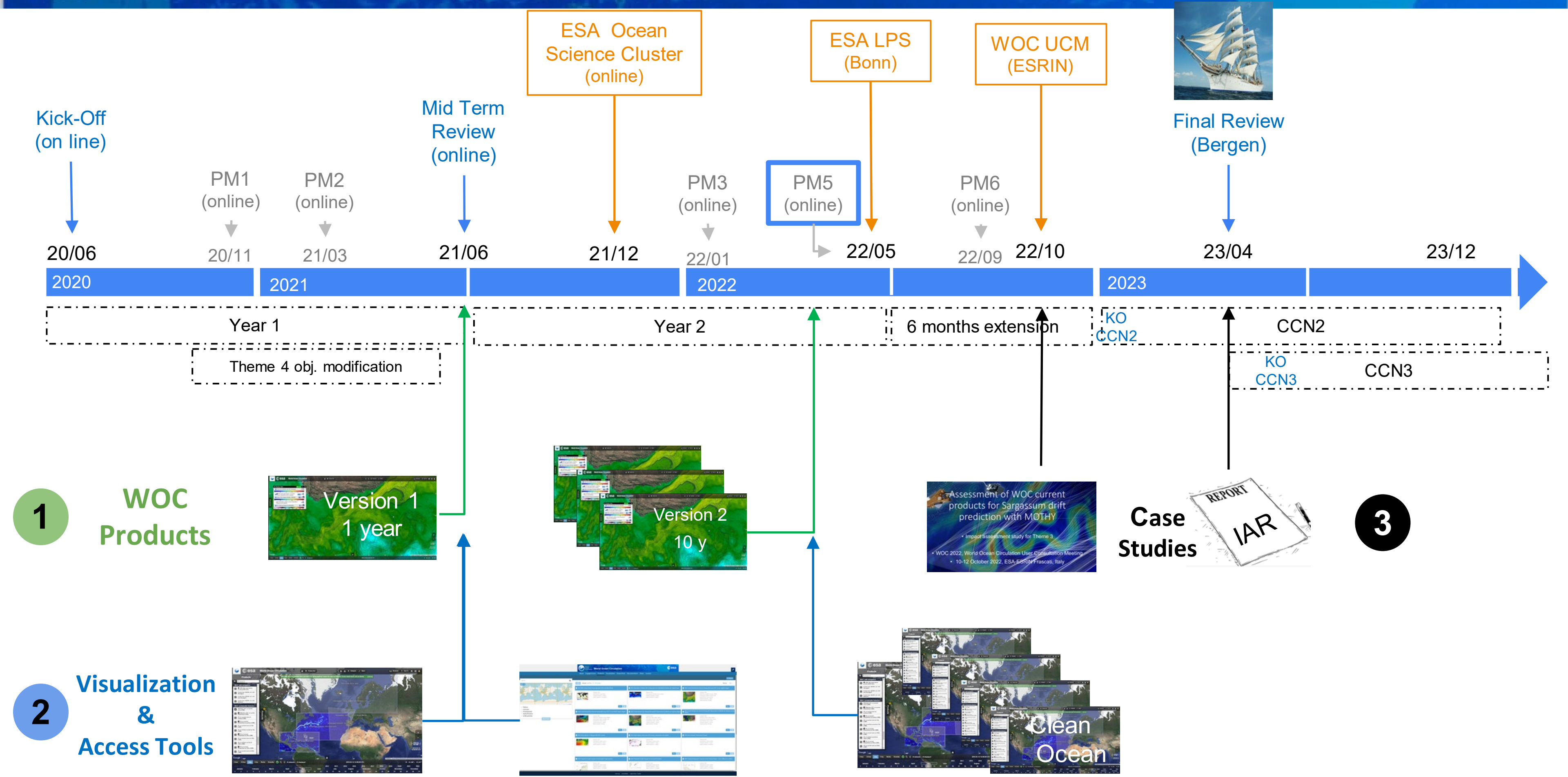
- HERIOT WATT University: Evaluation and validation of productible potential estimates based on qualified coastal models.
- FRANCE ENERGIES MARINES: Evaluation and validation of design conditions (probability over threshold) based on qualified coastal models.

Technical and scientific challenges:
Better understand and possibly anticipate the occurrence of power ramps, associated to peak-over-threshold sea state statistics, and characterized as sudden large changes in the power distributions

WOC partners developments:

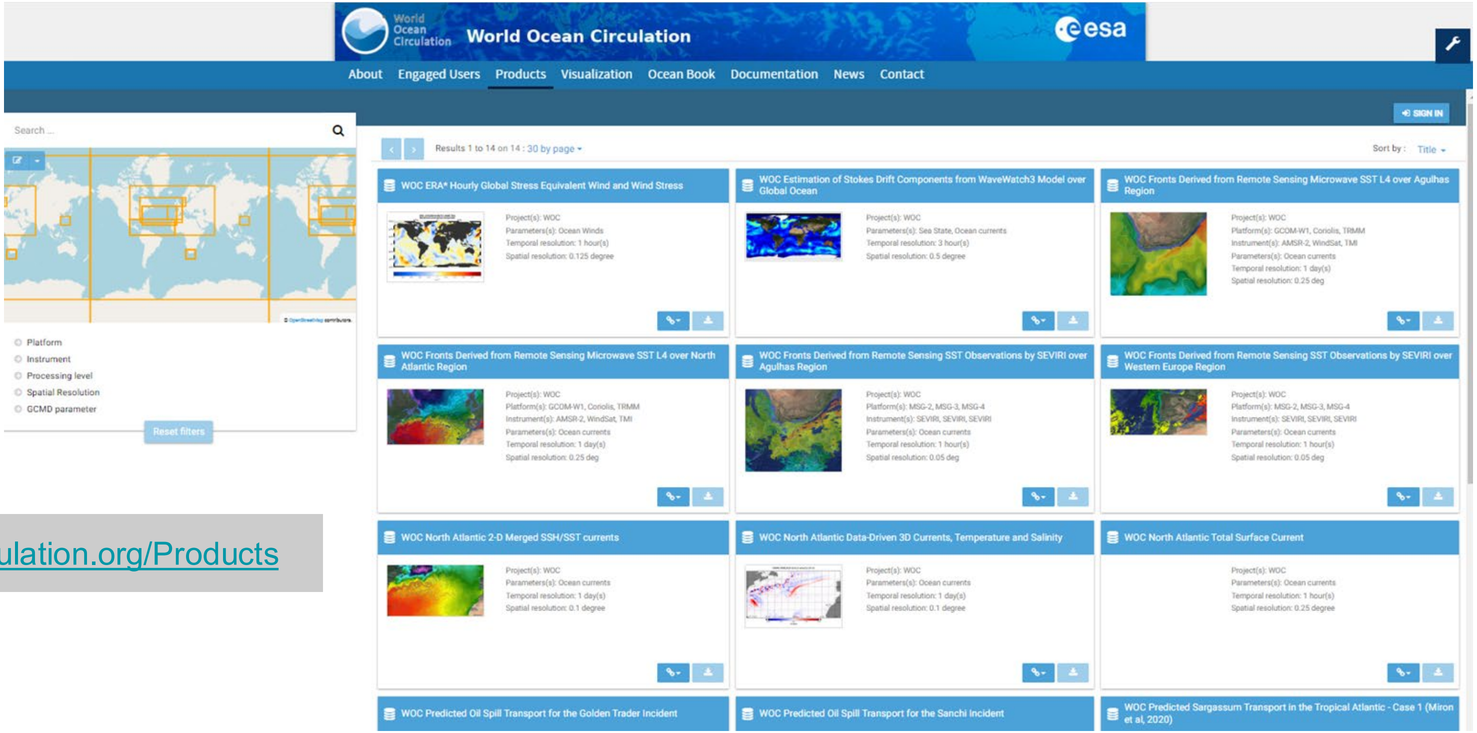
- OceanDataLab: Aggregation and Classification of high-resolution satellite observations
- Ifremer: Improved wave ray-tracing methods

Project achievements in one slide



WOC Datasets Available

All data accessible on FTP and HTTPS - free and open access, no registration :



https://www.worldoceancirculation.org/Products

Access issues: contact CERSAT Help Desk (cersat@ifremer.fr)

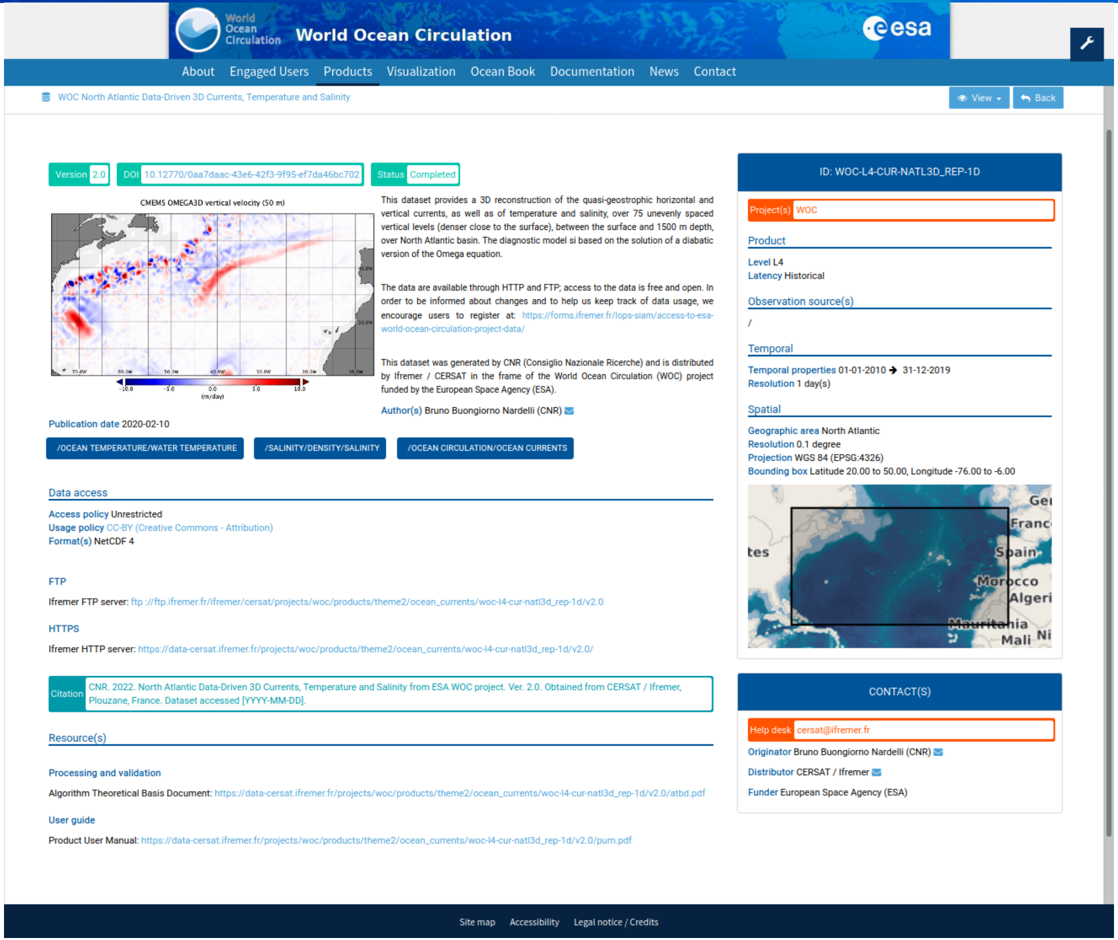
WOC Datasets Available

Theme 1	WOC ERA* Hourly Global Stress Equivalent Wind and Wind Stress	ICM/CSIC	2010-2020
	Sentinel-1 IW Ocean Surface Current Radial Velocity over Agulhas Region	NERSC	2019-2020
	Fronts Derived from Remote Sensing Microwave SST L4 over Agulhas Region	ODL	2010-2021
	Fronts Derived from Remote Sensing SST Observations by SEVIRI over Agulhas Region	ODL	2011-2021
Theme 2	North Atlantic Data-Driven 3D Currents, Temperature and Salinity	CNR	2010-2019
	North Atlantic 2-D Merged SSH/SST currents	CNR	2010-2019
	Canary upwelling indexes	Ifremer	1982-2020
	Fronts Derived from Remote Sensing Microwave SST L4 over North Atlantic Region	ODL	2010-2021
	Fronts Derived from Remote Sensing SST Observations by SEVIRI over Western Europe Region	ODL	2011-2021
Theme 3	North Atlantic Total Surface Current	DATLAS	2010-2019
	Predicted Oil Spill Transport for the Golden Trader Incident	Utrecht University	Sept 2011
	Predicted Oil Spill Transport for the Sanchi Incident	Utrecht University	Jan 2018
	Predicted Sargassum Transport in the Tropical Atlantic - Case 1 (Miron et al, 2020)	Utrecht University	2018
	Predicted Sargassum Transport in the Tropical Atlantic - Case 2	Utrecht University	May 2019
	Estimation of Stokes Drift Components from WaveWatch3 Model over Global Ocean	Ifremer	2010-2020

WOC Datasets Available

each dataset has a factsheet with:

- Main characteristics description
- Access to documentation:
  Product User Manual,
  Algorithm Theorical Baseline Document
- A specific DOI



WOC Visualization tool

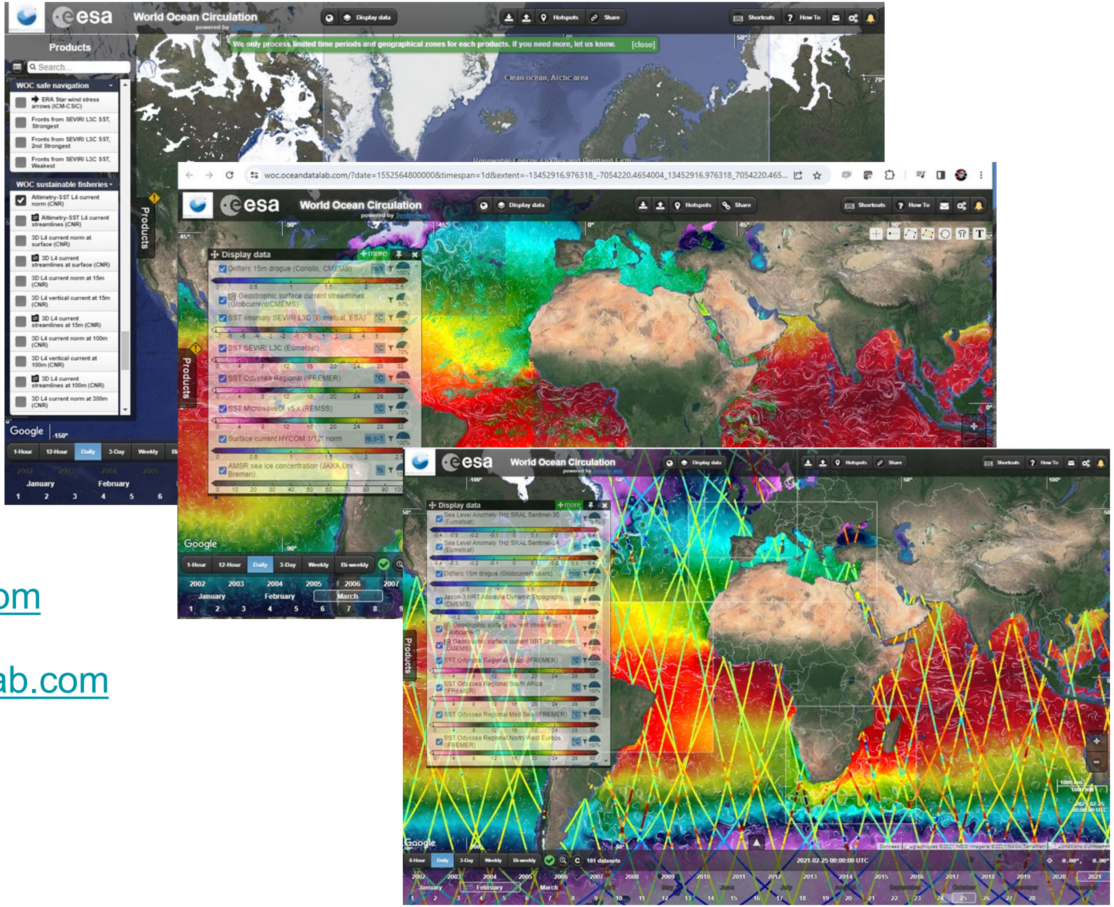
- One generic portal to access and play with WOC products
  Visualization tool

- Dedicated portal by theme:

https://woc-safe-navigation.oceandatalab.com

http://woc-sustainable-fisheries.oceandatalab.com

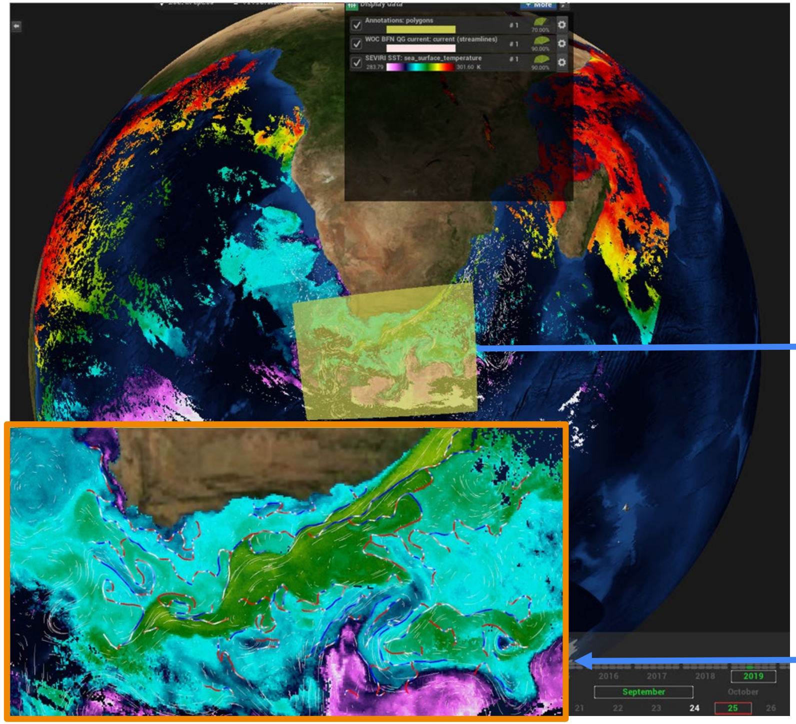
http://woc-clean-ocean.oceandatalab.com



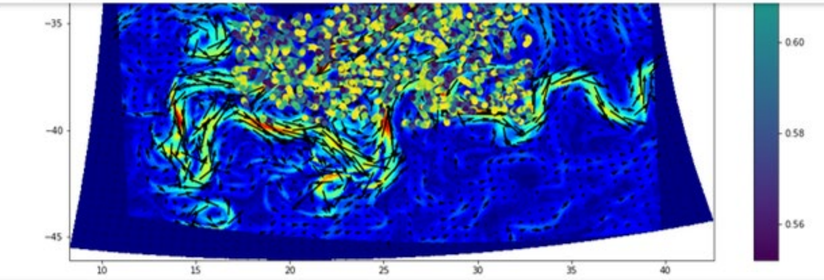
WOC Visualization tool

SEAScope visualisation and analysis tool is a stand alone application that enables to collocate easily in time and space WOC and other products

Using two ways communication with Jupyter notebooks, one can easily perform cross analysis of a wide variety of products



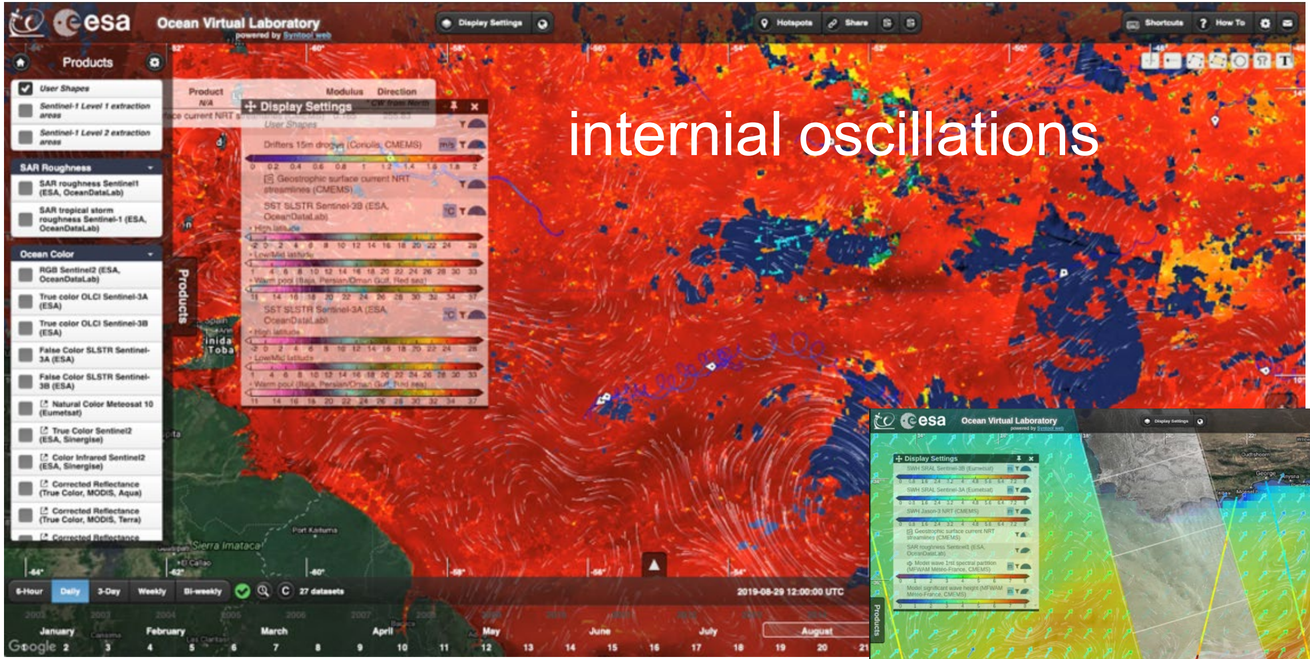

```
flows = result['flows']

fig = plt.figure(figsize=(16,10))
plt.pcolormesh(velocity['lon'], velocity['lat'],
               numpy.sqrt(velocity['u']**2 + velocity['v']**2),
               cmap='jet', vmin=0, vmax=2)

X, Y = numpy.meshgrid(numpy.arange(0, velocity['u'].shape[1]),
                      numpy.arange(0, velocity['u'].shape[0]))
ss = 15
Q = plt.quiver(velocity['lon'][::ss, ::ss], velocity['lat'][::ss, ::ss],
               numpy.clip(velocity['u'][::ss,::ss],-2,2),
               numpy.clip(velocity['v'][::ss,::ss],-2,2))
qk = plt.quiverkey(Q, 0.5, 0.98, 2, r'$2 \frac{m}{s}$', labelpos='W',
                   fontproperties={'weight': 'bold'})
for flow in flows:
    front = flow['front']
    flux_across = flow['flux_across']
    plt.scatter(front['lon'], front['lat'], c=flux_across)

cbar=plt.colorbar()
```

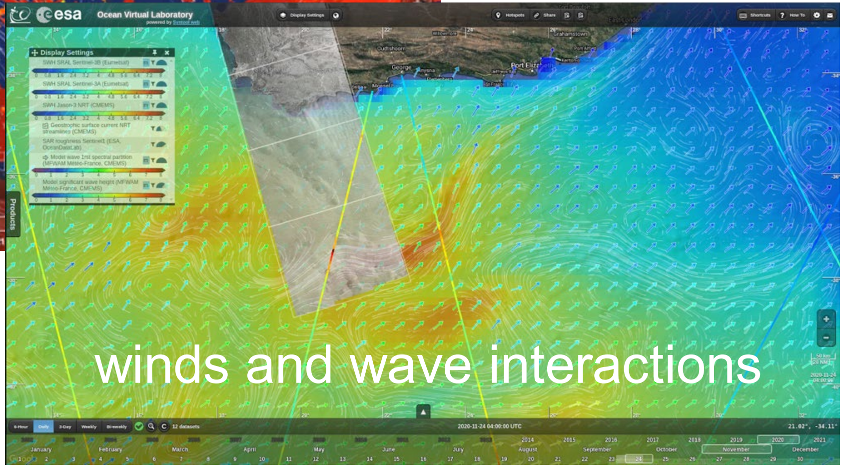


6. Export flows back to SEAScope

```
from SEAScope.lib.utils import create_collection, create_variable
from SEAScope.lib.utils import create_granule, set_field
```

WOC ocean e-book





Illustrations describing the upper layer ocean circulation processes for the pilot areas

https://www.worldoceancirculation.org/Ocean-Book

Dissemination of the WOC Project and Products

- **ESA Ocean Science Cluster 2021 (online)**

  December 2021; https://eo4society.esa.int/communities/scientists/esa-ocean-science-cluster/ Theme 5 Upper-Ocean Dynamics (Chair: F. Collard, D. Ciani)

- **ESA Living Planet Symposium (Bonn, Germany)**

  May 2022 (https://lps22.eu/)

  Numerous presentations by project's partners

  Training/Outreach with Syntool

- **ESA WOC User Consultation Meeting (Frascati, Italy)**

  Octocber 2022 (https://woc2022.esa.int/)

  Key WOC achievement by all the teams including products description and impact assessment results

  Summary to feed the scientific roadmap

- **One Ocean Expedition (online and at sea from Maputo to Cape Town)**

  Advanced Ocean Synergy Training Course (OTC-2023)

- **Seasar2023 workshop (Longyearbyen, Svalbard, Norway)**

  May 2023 (https://seasar2023.esa.int)

  Key results related to the SAR and Doppler shift retrievals

WOC based Publications

Buongiorno Nardelli, Bruno. (2020). A Deep Learning Network to Retrieve Ocean Hydrographic Profiles from Combined Satellite and In Situ Measurements. *Remote Sensing. 12. 3151. 10.3390/rs12193151*.

Van Sebille, E., Zettler, E., Wienders, N., Amaral-Zettler, L., Elipot, S., & Lumpkin, R. (2021). Dispersion of surface drifters in the Tropical Atlantic. *Frontiers in Marine Science, 7, 1243*.

Resseguier V., B. Chapron, E Memin, (2022), Effects of Smooth Divergence-Free Flows on Tracer Gradients and Spectra: Eulerian Prognosis Description *DOI: 10.1175/JPO-D-21-0014.1*

Moiseev, A., Johannessen, J. A., and Johnsen, H. (2022). Towards Retrieving Reliable Ocean Surface Currents in the Coastal Zone from the Sentinel-1 Doppler Shift Observations. *Journal of Geophysical Research: Oceans, 127, e2021JC018201, https://doi.org/10.1029/2021JC018201*

Gomez-Navarro, Laura and Van Sebille, Erik and MORALES MÁRQUEZ, Verónica and Hernandez-Carrasco, Ismael and Albert, Aurelie and Ubelmann, Clement and Le Sommer, Julien and Molines, Jean-Marc and Brodeau, Laurent (2022), The effect of model tidal forcing on virtual particle dispersion and accumulation at the ocean surface, *Earth and Space Science Open Archive*.

Peter Munk, Patrizio Mariani, Bruno Buongiorno Nardelli and Jorgen Bendtsen (2023), Mesoscale driven dispersion of early life stages of European eel (2023), *Front. Mar. Sci. - Marine Ecosystem Ecology*

WOC Based Publications (in preparation/submitted)

L. Gomez-Navarro, V. Morales-Marquez, I Hernandez-Carrasco (2023), Lyapunov exponents toolbox. *(to be submitted to the Journal of Open Source Software)*

Clément Ubelmann, Bertrand Chapron, Lucile Gaultier, Laura Gomez-Navarro, Pierre Brasseur and Luz-Andrea Silva-Torres (2023), A data-driven wind-to-current transfer function for the unsteady-Ekman component and application to surface current estimates, *(to be submitted to Ocean Science Discussions by the end of summer*)

S. Asdar, D. Ciani, B. Buongiorno Nardelli (2023), 3D reconstruction of horizontal and vertical quasi-geostrophic currents in the North Atlantic Ocean, *(to be submitted to ESSD)*

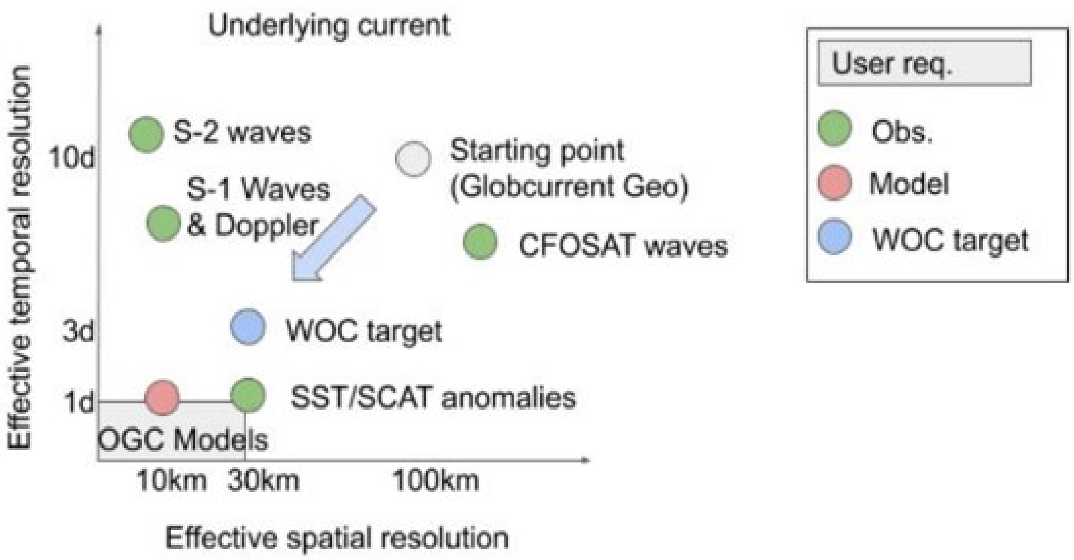
Valentin Resseguier, Erwan Hascoet, Bertrand Chapron, B. (2023) Random ocean swell-rays: a stochastic framework. *Submitted to STUOD Proceedings*

Summary of scientifics achievements by theme

WOC Lesson learned and Perspectives - Theme 1

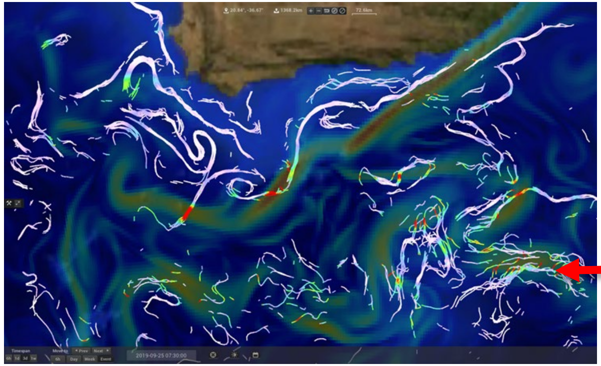
Theme 1 : Sea-state interactions for Safe Navigation

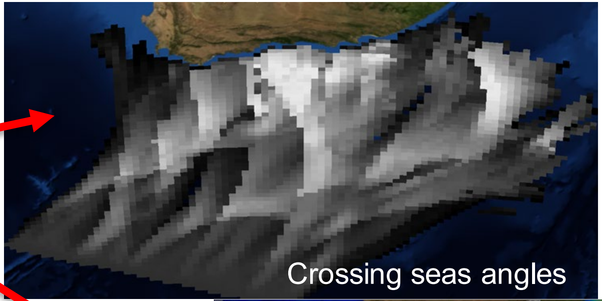
- Dangerous seas/crossing waves index
- Scatterometer based wind-stress in presence of surface current, sea state and surface current interactions
- Sentinel-1 Doppler
- Validation diagnostics



- Improved currents derived (meeting the WOC project target)
- Sentinel-1 Doppler promising for validation of surface current snapshots
- Validation diagnostics based on SST fronts clearly valuable for surface current ranking (intermediate user)
- Little involvement of ends users

WOC Theme 1 Products



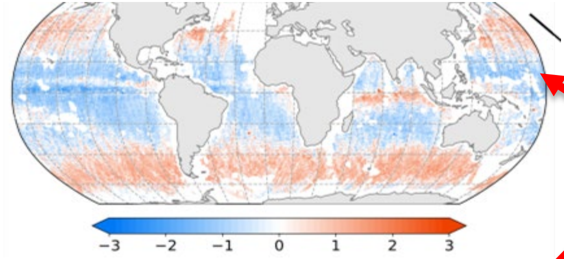


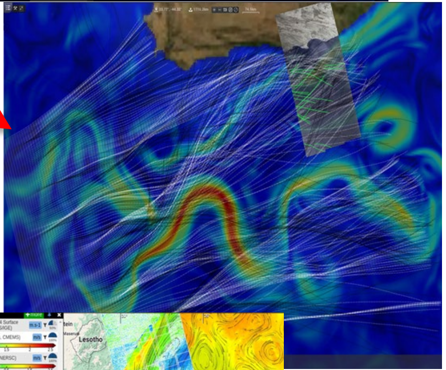
Cross-seas indexes
Location of dangerous seas
Surface current sources ranking

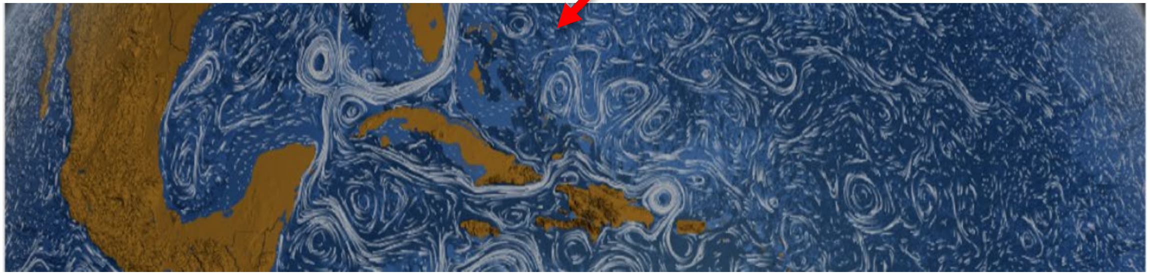
Wind stress vector

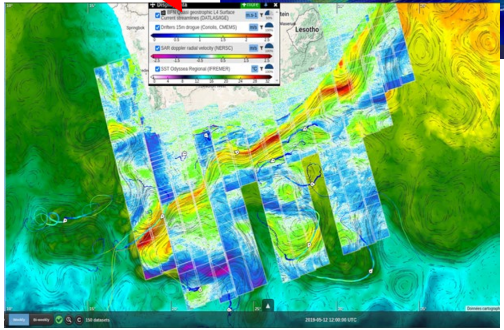
Surface current from S-1 doppler

Improved geostrophic surface current









High-Frequency Total Surface Current : a new step forward

World Ocean Circulation

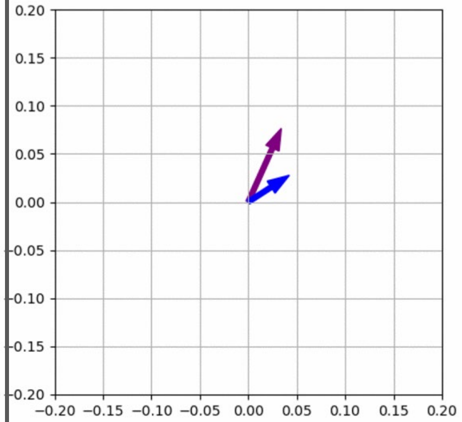
esa

This is a step forward beyond the CMEMS total current product :
based on a **convolution to account for wind history in the Ocean response for the unsteady-Ekman component**

Ekman/CMEMS

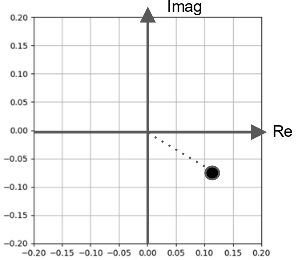
$$\boldsymbol{u} = Ae^{i\theta}\boldsymbol{\tau} = G\boldsymbol{\tau}$$

Stress-to-Ekman-current



Single scalar multiplication

G :

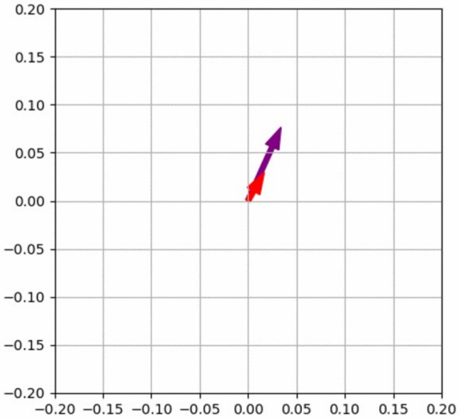


A single scalar relation is used in the CMEMS data

Unsteady-Ekman WOC

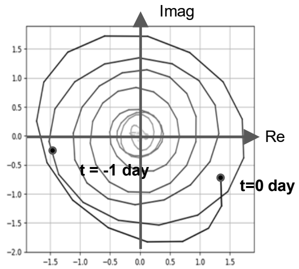
$$\boldsymbol{u} = \int_{-T}^{0} A(t')e^{i\theta(t')}\boldsymbol{\tau}(t+t')dt' = \int_{-T}^{0} \boldsymbol{G}(t')\boldsymbol{\tau}(t+t')dt'$$

Stress-to-Unsteady-Ekman-current



Time convolution

G(t) :

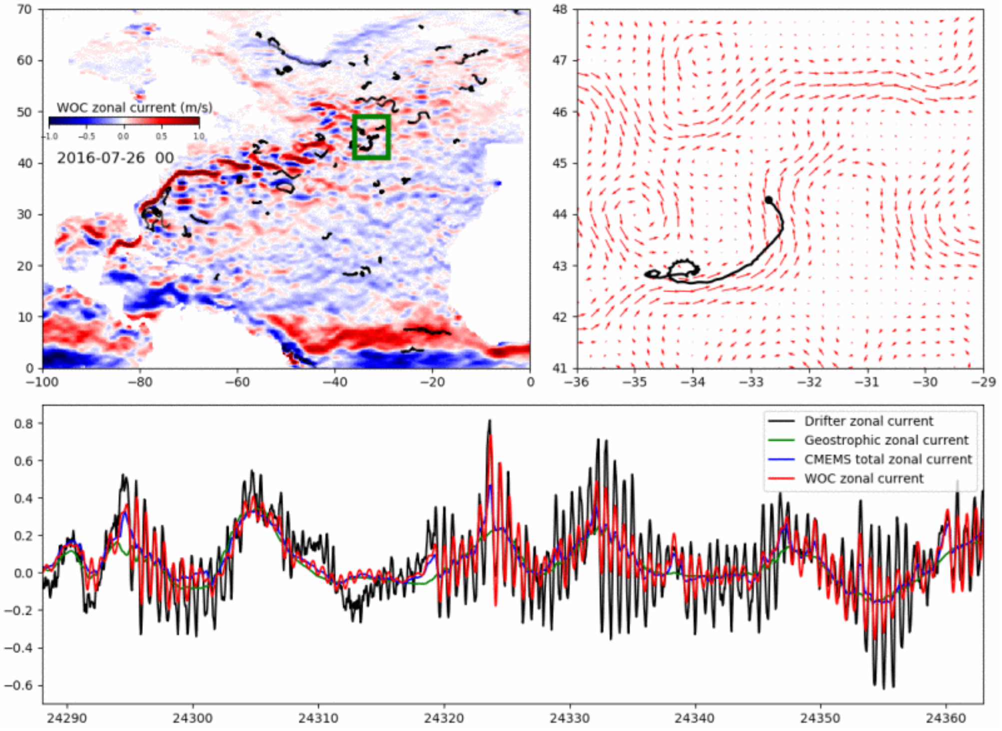


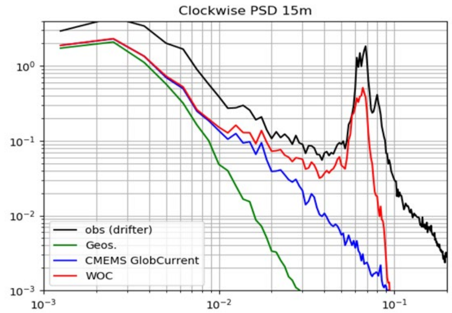
G(t) is solved with a data-driven inverse problem :

$$u_{drifter} - u_{alti} = \int_{-T}^{0} \boldsymbol{G}(t')\boldsymbol{\tau}_{era5}(t+t')dt' + \epsilon$$

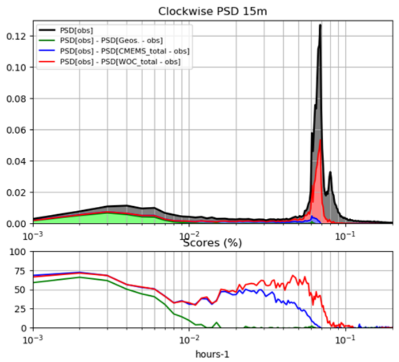
High-Frequency Total Surface Current : results

Time Period: June 2020 – December 2022





The WOC HF product resolves some energy in the Near Inertial band



The signal phase matches quite well the independent observations

BFNQG : a step beyond the Altimetry CMEMS Optimal Interpolation

Dynamic interpolation : Nudging SSH in a 1-layer QG model advection (Le Guillou et al., 2021)

- Use of prior dynamics :

$$\frac{\partial ssh}{\partial t} = M(ssh,t) \qquad ssh(0) = ssh_0$$

$$\frac{\partial ssh}{\partial t} = M(ssh,t) + K(ssh^{obs} - ssh)$$

$$\frac{\partial ssh}{\partial t} = M(ssh,t) \qquad ssh(T) = ssh_T$$

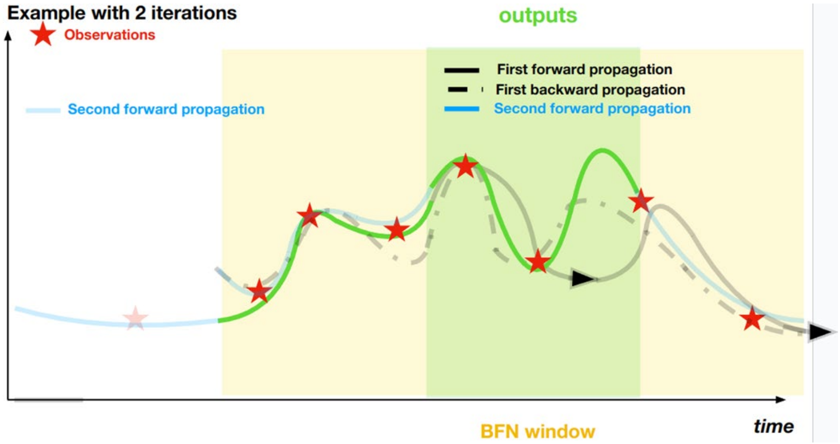
$$\frac{\partial ssh}{\partial t} = M(ssh,t) - K(ssh^{obs} - ssh)$$

BFN algorithm: combination of the **forward nudging** and the **backward nudging**

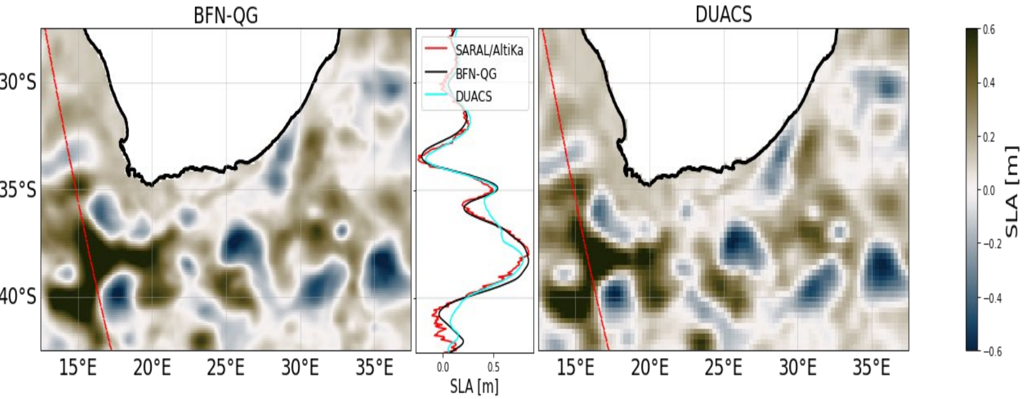
iterative process over a temporal window

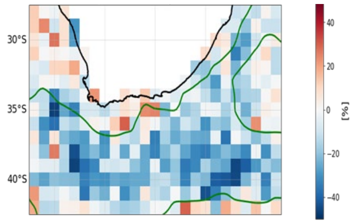
- Input Data : All Altimeter missionsCMEMS

With the following inversion scheme :

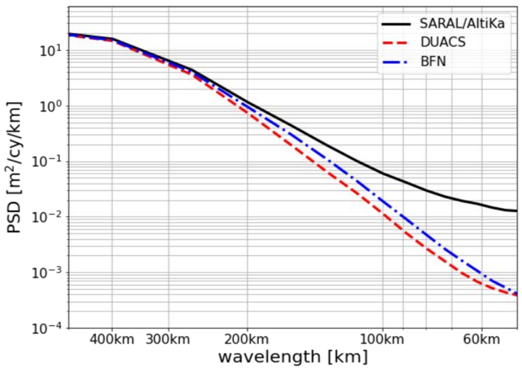


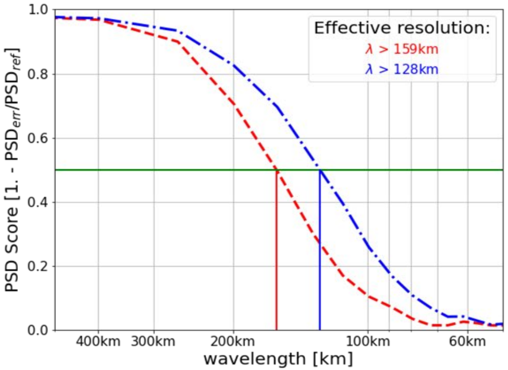
BFNQG : results





The spatial resolution of BFNQG is visually improved





Confirmed from diagnostics with independent data

SAR Doppler derived radial surface current

One year of radial surface current has been produced using Re-Calibrated Sentinel1 Doppler and a new Sea State Doppler GMF CDOPSiX, taking into account wind and wave parameters.

Sentinel-1 Doppler centroid anomaly

$$f_{dca} = \underbrace{f_{bias} + f_{att} + f_{sca}}_{\text{Non-geophysical}} + \underbrace{(f_{ss} + f_{osc})}_{\text{Geophysical}}$$

Sentinel-1A/B IW Ocean Surface Current Radial Velocity retrieval algorithm:

- Step #1: Remove all non-geophysical contributions
- Step #2: Estimate sea-state-induced contributions to the signal (wave bias)
- Step #3: Generate & evaluate Sentinel-1 IW OSC RVL products

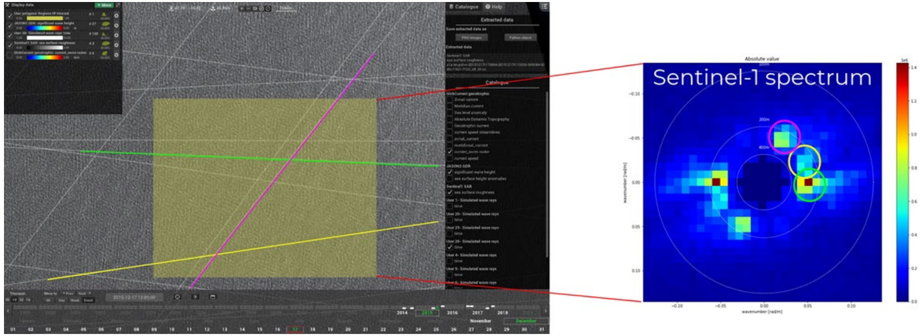
Residual Doppler shift after calibration is about 4 Hz corresponding to 0.15 - 0.25 m/s radial velocity
2 times better than the previous version

Dangerous seas index

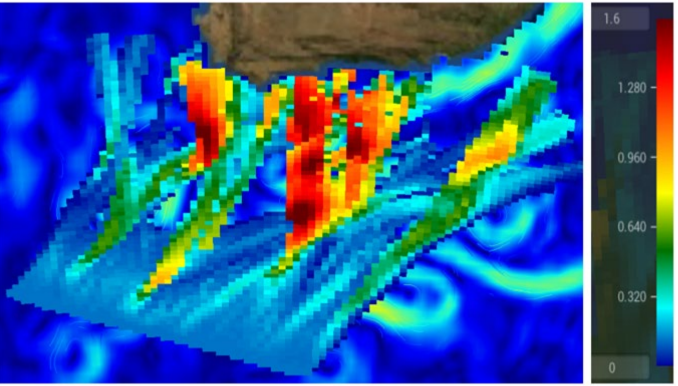
Wave-current interaction analysis with ray tracing for the calculation of cross-seas indexes and location of Dangerous Seas for navigation.

Dangerous seas index is complemented with satellite observations of significant wave height in excess of sea state model hindcast.

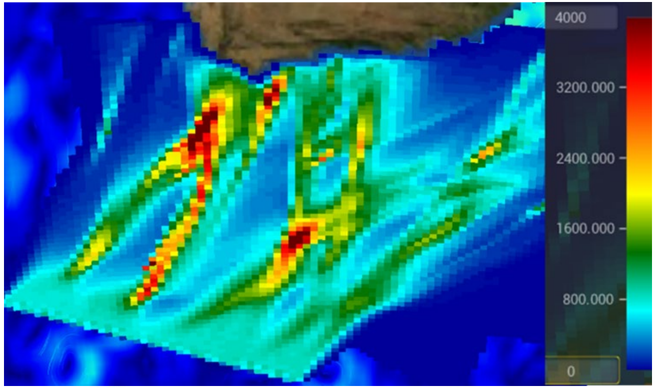
Validation using SAR detected waves



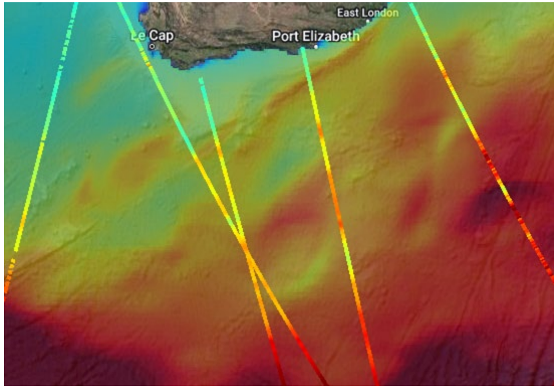
Crossing seas angle



Crossing seas wave energy focussing



Observed wave height vs. model hindcast



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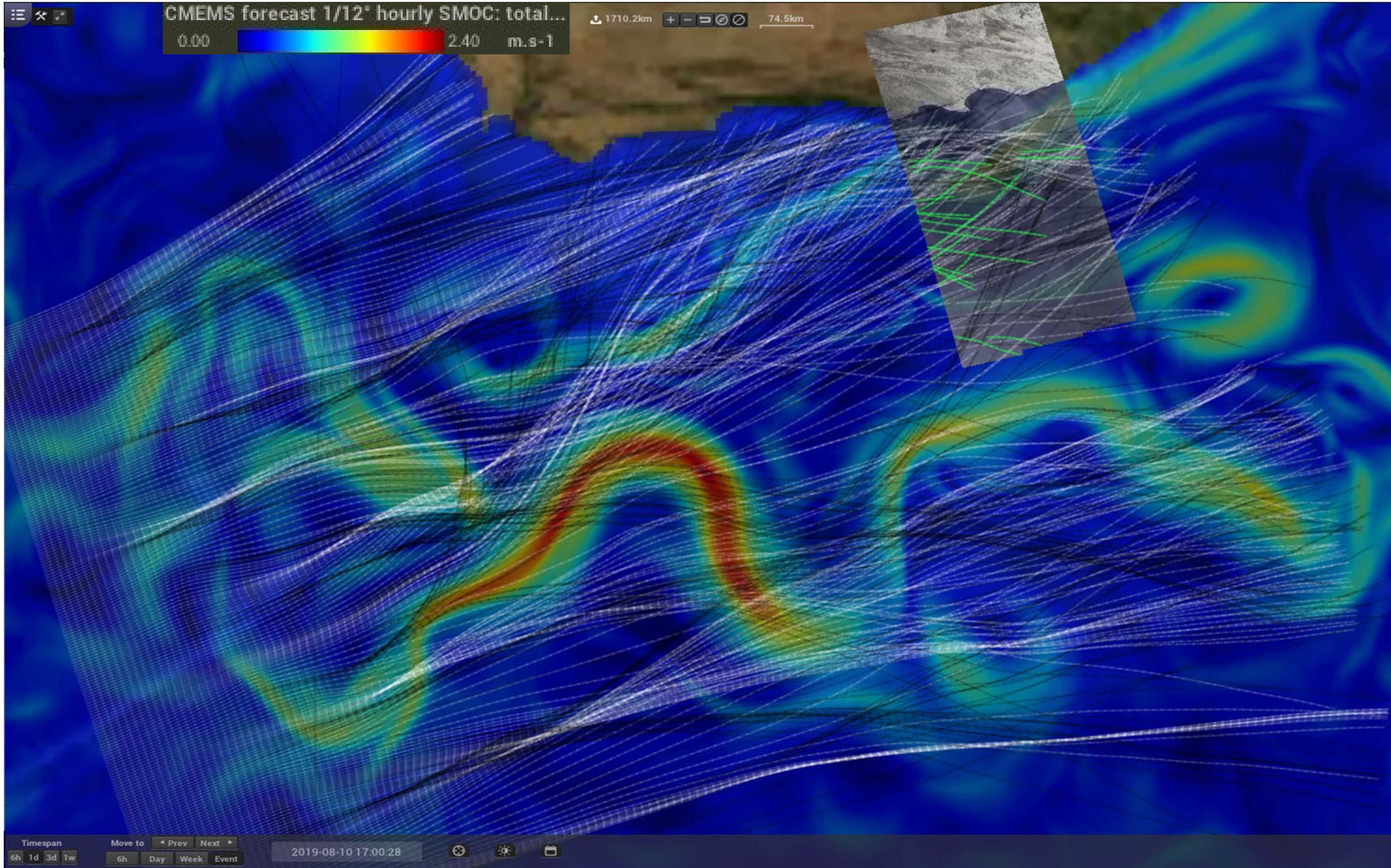
Crossing waves: Model vs. Observed current

Sentinel - 1 Observations

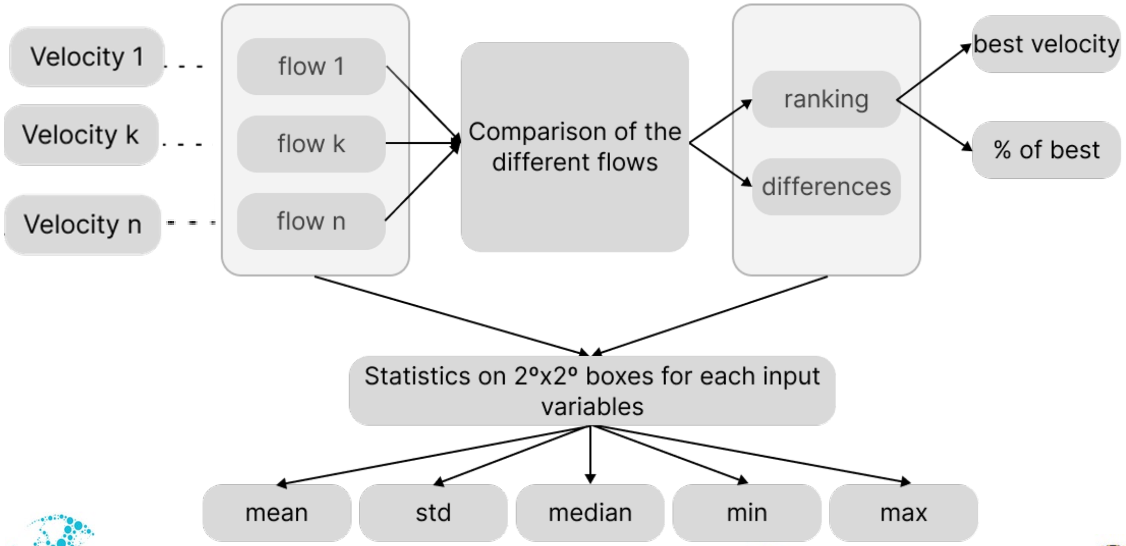
Observed Geostrophic + random small scales

Mercator Model 1/12°

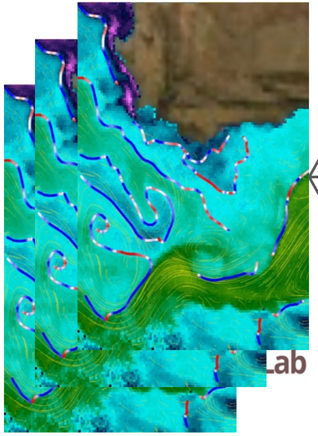


Velocity ranking

Different velocity products (from model and observation) are assessed using WOC fronts.
Statistics are derived on spatio temporal boxes where there are a significant number of point.



Computation of flows for all velocities for all WOC fronts



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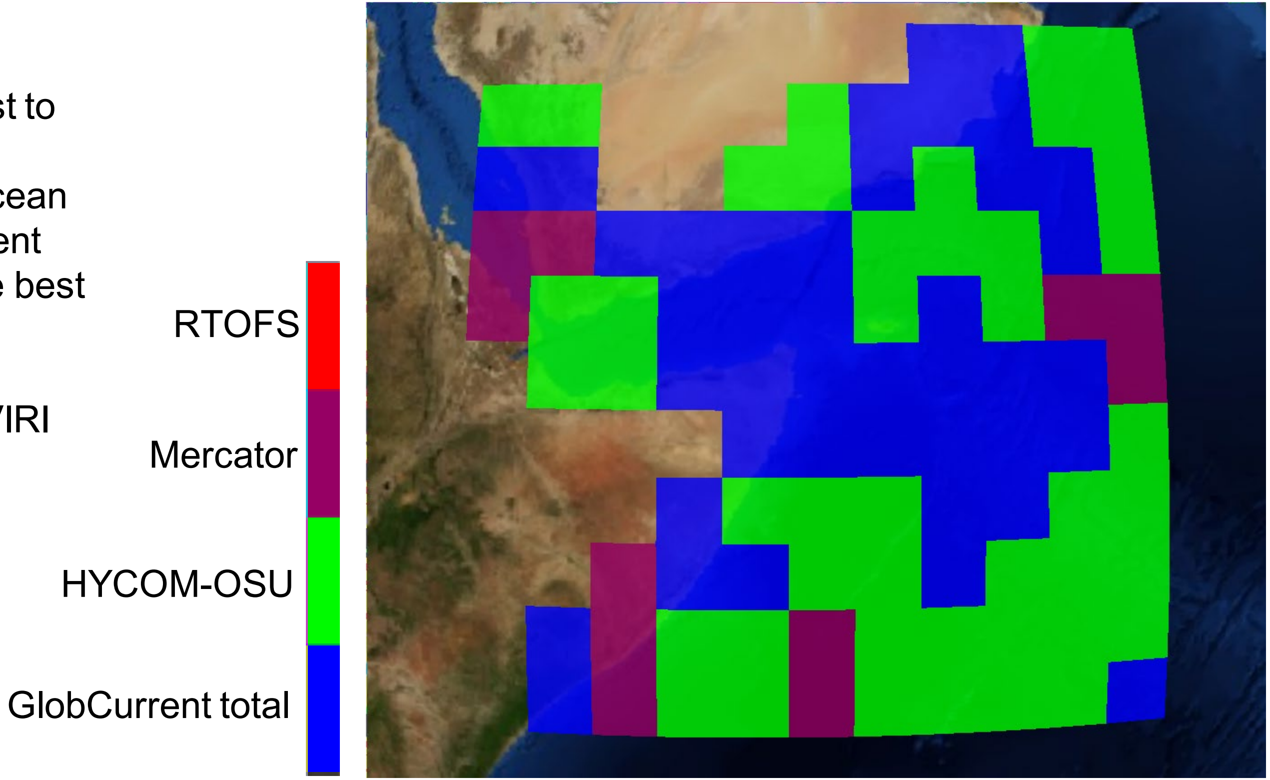
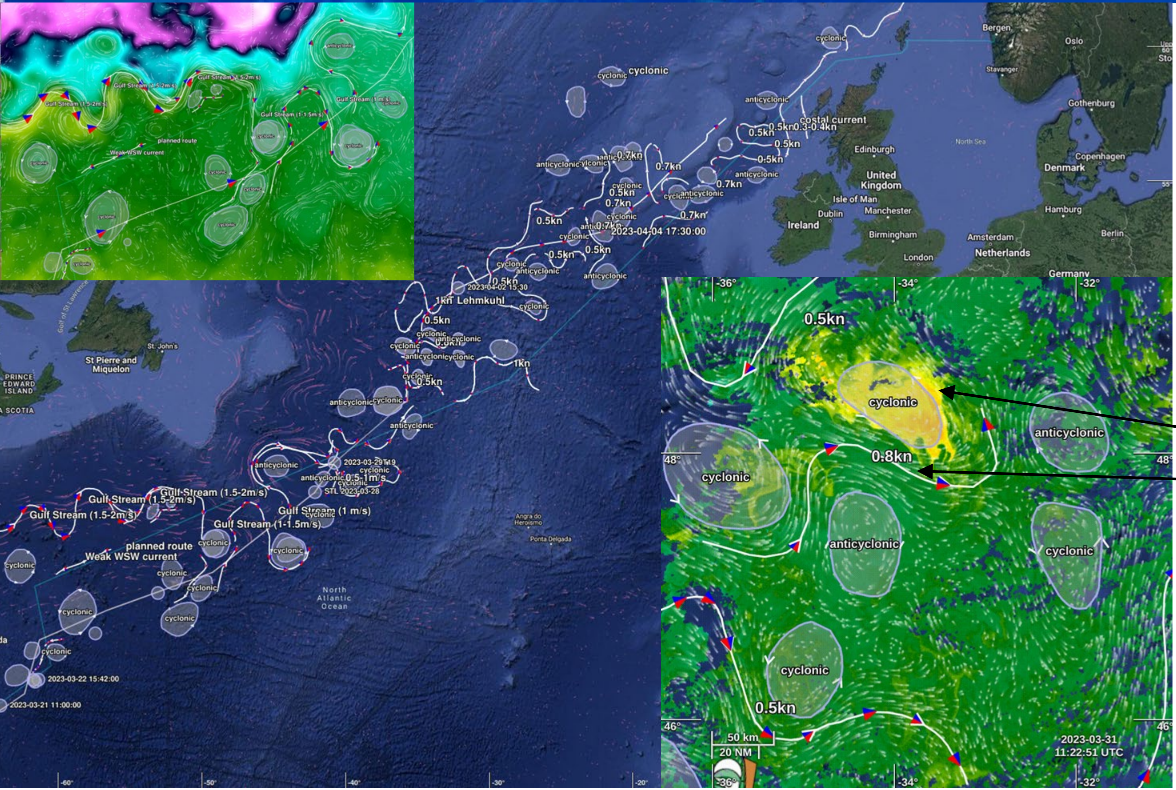
Regional ranking to provide optimized current to CMA-CGM

CMA-CGM shipping needs the best surface current analysis and forecast to optimize their ship routing.
An NRT experiment in the Indian Ocean was set up where velocity assessment and ranking was used to provide the best current (ranked first)
Analysis of surface current velocity products were performed using SEVIRI SST fronts over a spatio-temporal window of 7 days and 2°x2° lat/lon.



Color indicates which surface current source is ranked first

Synoptic analyses for routing purposes

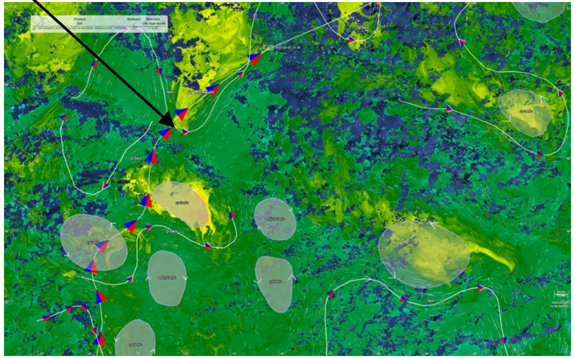


Synoptic analyses performed in NRT using remote sensing observations (SST, Chlorophyll, CMEMS current).

Voyage of the St. Lehmkuhl: Puerto Rico - Shetland 2023-03-16 - 2023-04-09

One synoptic map with analysis provided every 2/3 days to the St. Lehmkuhl:

- eddies, fronts
- current direction and strength
- recommendation on path



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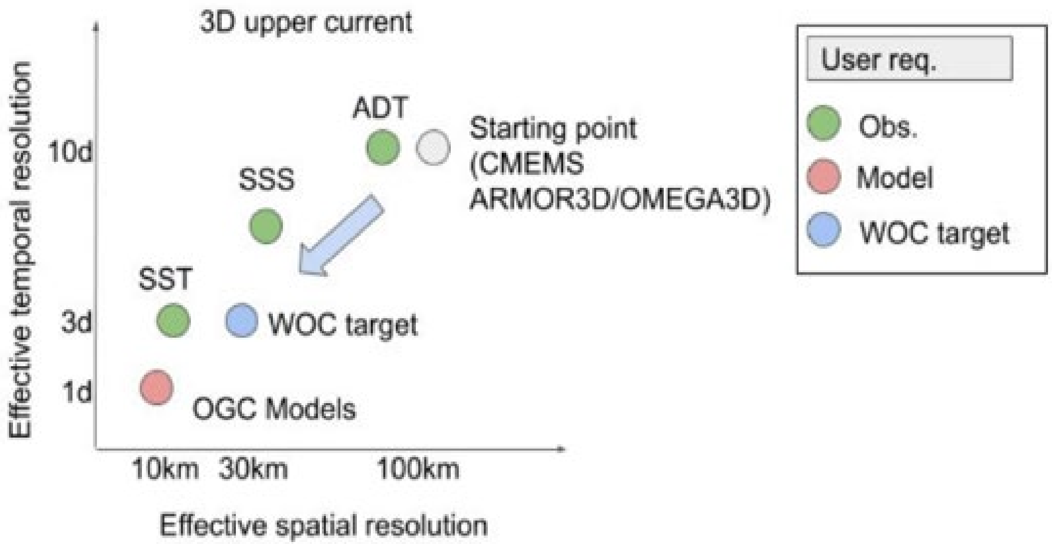
WOC Lesson learned and Perspectives - Theme 2

Theme 2: 3D currents and vertical motion for sustainable fisheries

- 3D upper ocean circulation
- Upwelling indexes
- Validation diagnostics development



- Improved spatial resolution of geostrophic current for 3D upper ocean circulation retrievals
- Successful Involvement of intermediate (expert) users

2D currents from SSH/SST synergy

World Ocean Circulation (2020-2023)

Development of upper ocean circulation 2D products from the synergy of satellite observations: sea surface height (SSH) and sea surface temperature (SST) data

- The Copernicus marine service altimeter-derived geostrophic currents are improved by means of Higher Resolution SST fields:

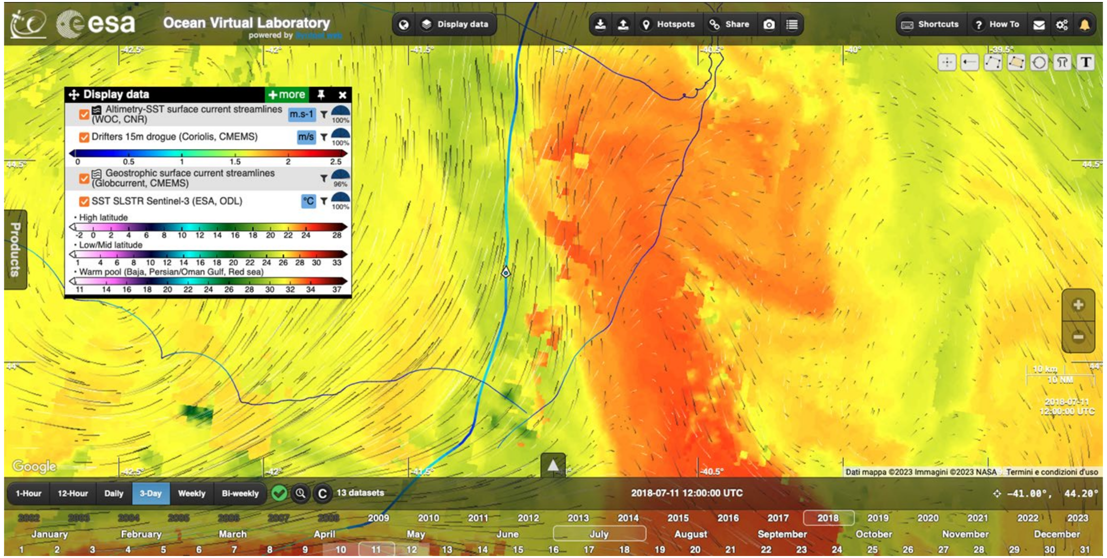
WOC-L4-CUR-NATL2D : OVERVIEW

- **Copernicus DUACS-18 Altimeter** Geostrophic Velocities (1/4°, daily)

+

- **Copernicus OSTIA SST** (remapped to 1/10°,daily)

WOC-L4-CUR-NATL2D – CASE STUDY ON 11 JULY 2018



The black streamlines depict the circulation pattern according to the WOC Altimetry-SST product, while the white streamlines illustrate the Copernicus GlobCurrent geostrophic currents. The background field displays the ODL Sentinel-3 SLSTR SST. To validate the surface currents direction, a SVP drifter situated at a depth of 15 meters is employed. This analysis highlights how the SST data can enhance the reconstruction of upper ocean currents.

https://odl.bzh/Qr3TCwiX

3D quasi-geostrophic currents

World Ocean Circulation

World Ocean Circulation (2020-2023)

- 3D reconstruction of quasi-geostrophic horizontal and vertical currents based on the solution of the diabatic quasi-geostrophic **Omega equation**.
- Developed from satellite and in situ observations, reanalysis and modelled data and reconstructed 3D density fields (based on a deep learning technique).
- Improvement with respect to OMEGA3D (product developed in the frame of MOB-TAC)

WOC_L4_CUR_NATL3D_REP_1D : OVERVIEW

- Spatial resolution: 1/10°
- Temporal resolution: daily
- Spatial coverage: North Atlantic basin 20°N-50°N, 76°W-6°W
- Temporal coverage: 2010-2019
- Vertical extension : 75 levels, from 0 to 1500 m

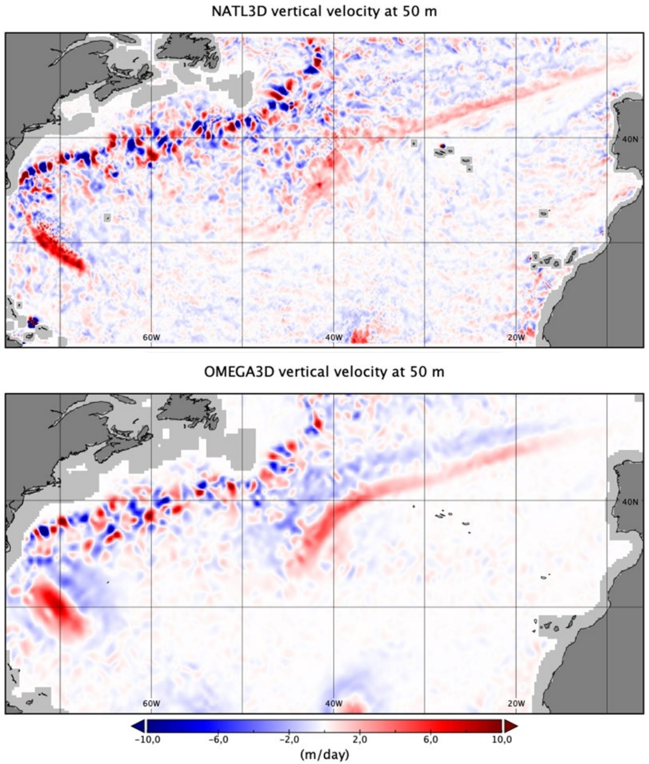


Figure: Snapshots (12/09/2018) of the vertical velocity for (top) NATL3D and (bottom) OMEGA3D

NATL3D

- High spatial resolution.
- More accurate surface Ekman currents.
- Optimized reconstruction of density fields obtained with LSTM network.

OMEGA3D

- Lower spatial resolution
- Inaccurate surface Ekman currents

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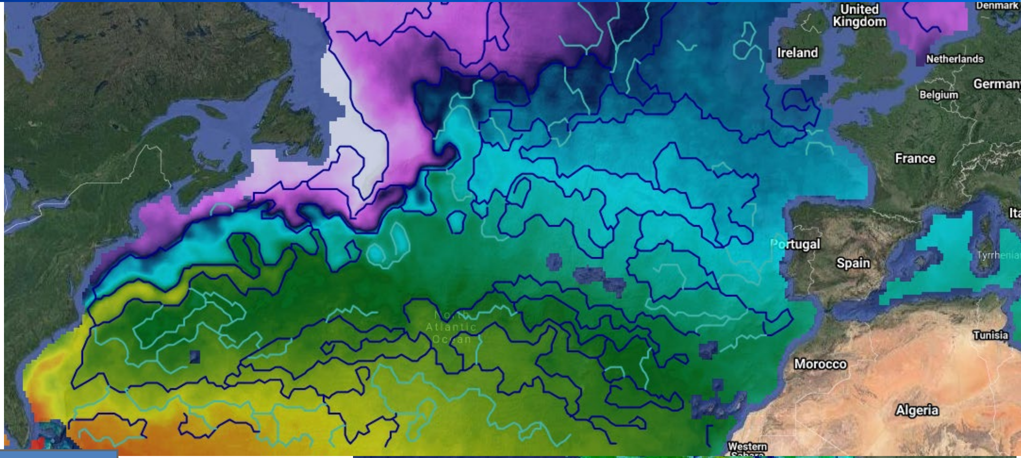
SST fronts detection



Population detection algorithms have been implement to automatically retrieve frontal structures from SST satellite observation. ~10 years of SST fronts are available for SEVIRI and Microwave sensors on two areas.

Algorithms are open source and available on git: https://github.com/oceandatalab/fronts_detection

Products	Resolution	Time range	Domain
fronts_t1_seviri	5 km / 1 h	2011 -> 2021	Agulhas
fronts_t1_mw_oi	25 km / 1 d	2010 ->2021	Agulhas
fronts_t2_seviri	5 km / 1 h	2011 -> 2021	North Atlantic
fronts_t2_mw_oi	25 km / 1 d	2010 -> 2021	Western Europe

Velocity comparison using SST fronts

The WOC SST front database has been used to perform current validation:

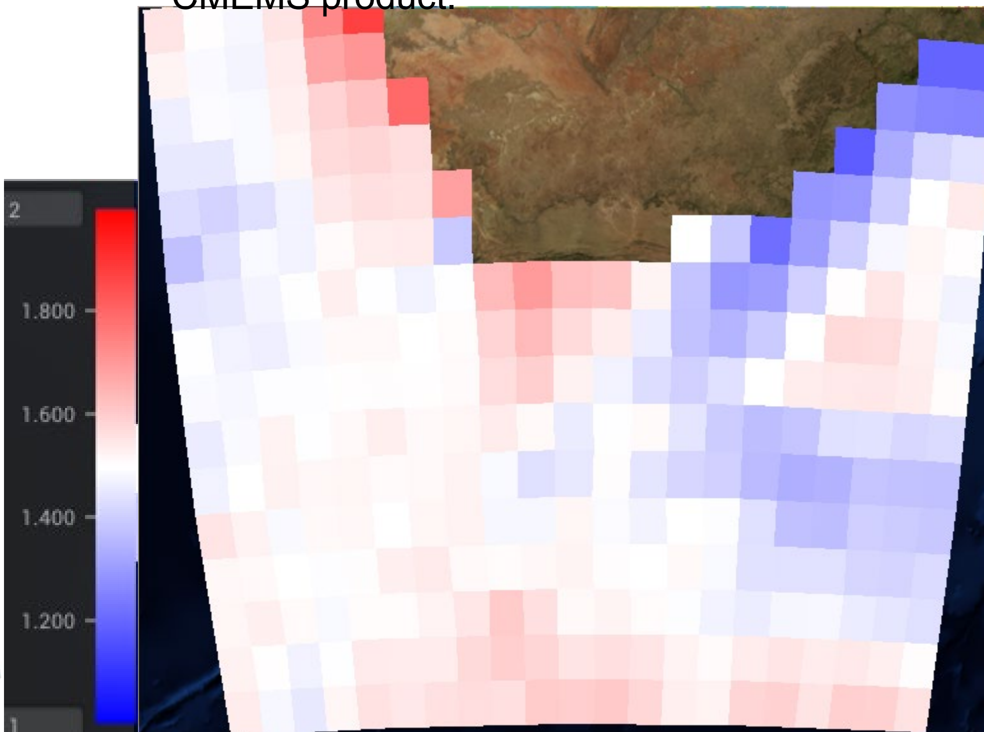
- Compute the normalized flow that is crossing a front for each point $P_i \begin{bmatrix} lon_i \\ lat_i \end{bmatrix}$ that belongs to a front

$$Flow[P_i] = \frac{\left|\vec{v}[P_i] \cdot \vec{\delta}_i\right|}{\left|\vec{v}[P_i]\right| \left|\vec{\delta}_i\right|} \quad \text{with} \quad \vec{\delta}_i = \begin{bmatrix} lat_{i+1} - lat_{i-1} \\ (lon_{i-1} - lon_{i+1})cos(lat_i) \end{bmatrix}$$

- Compute statistics on defined spatio-temporal boxes (e.g 3days / 1ºx1º) (mean and std for each product, mean ranking, difference comparing different products)

Method has been applied to improve WOC BFN product and compare it with CMEMS geostrophic current

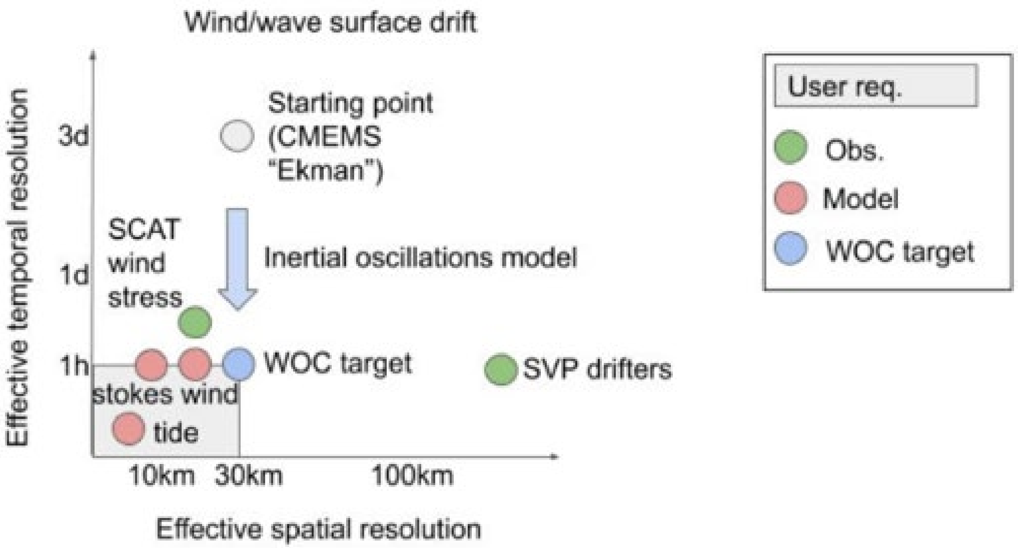
Mean ranking comparing WOC BFN with CMEMS geostrophic current. Values close to 1 (Blue) show were the BFN current direction is more consistent with SST fronts than the CMEMS product.



WOC Lesson learned and Perspectives - Theme 3

Theme 3: Surface lagrangian drift for a Clean Ocean

- Lagrangian advection and validation of surface drift
- Combination of drifters, high-frequency winds and altimetry to reconstruct high-frequency surface current



Lagrangian advection and validation of drift

Lagrangian simulations:

OceanParcels.org

- Step 1 — **Ingestion of hydrodynamic data**
- Step 2 — **Adding particle behaviour**
- Step 3 — **Executing the simulation**

- WOC new currents product
- Wind data (ERA5, GFS)
- WOC Stokes drift product

4 test cases:

Oil spills

<u>Case 1</u>

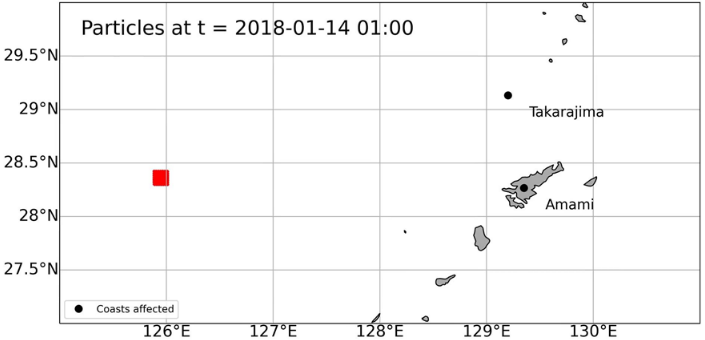
Golden Trader (NATL, Sep. 2011)

❌ too coastal!

<u>Case 2</u>

Sanchi (Kuroshio region, Jan. 2018)

✅ Better oil landing predictions than with previous products!



Sargassum

<u>Case 1</u>

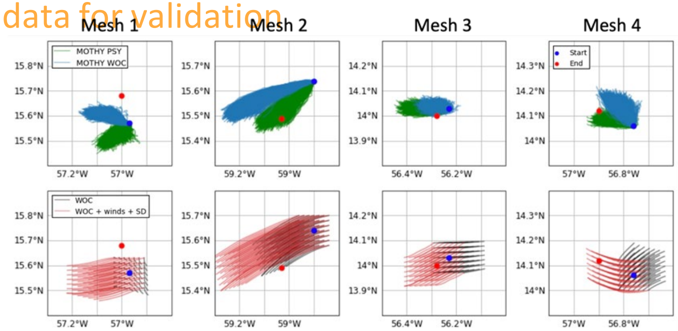
Drifters in Tropical Atlantic (Miron *et al.*, 2020)

✅ More inertial oscillations than with previous products!

<u>Case 2</u>

Satellite images where *Sargassum* mats identified (TATL, May 2019)

~ some improvements, but not enough data for validation



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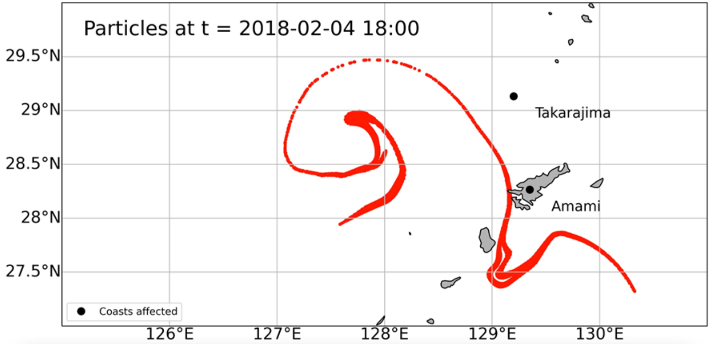

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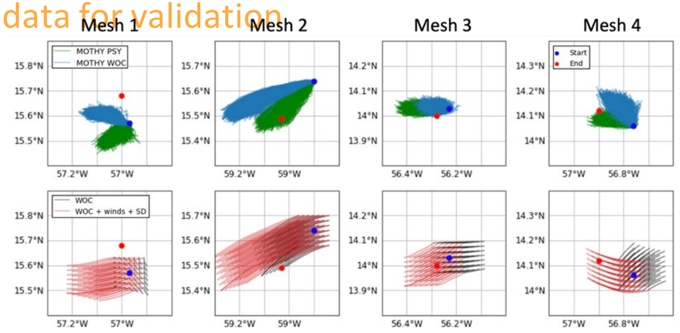

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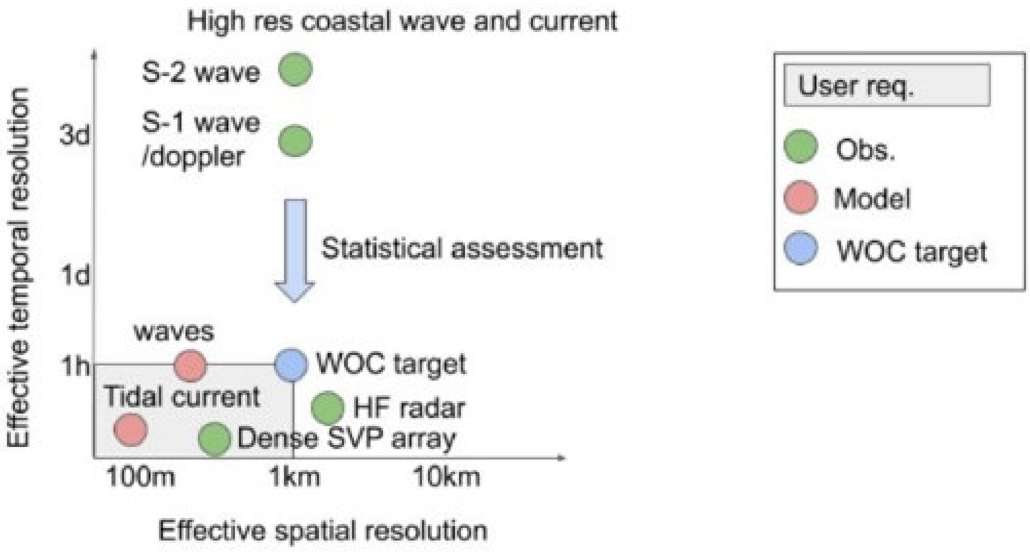
WOC Lesson learned and Perspectives - Theme 4

Theme 4 : High Resolution wave and current model assessment for a Productive Ocean

- Sentinel-1 Doppler in coastal zone
- Sentinel-1/2 estimates of waves transformations by surface currents (coastal strong tidal current revealed on Sentinel-1 SSR to be deployed anywhere with sufficient Sentinel-1 coverage when no other measurements available)

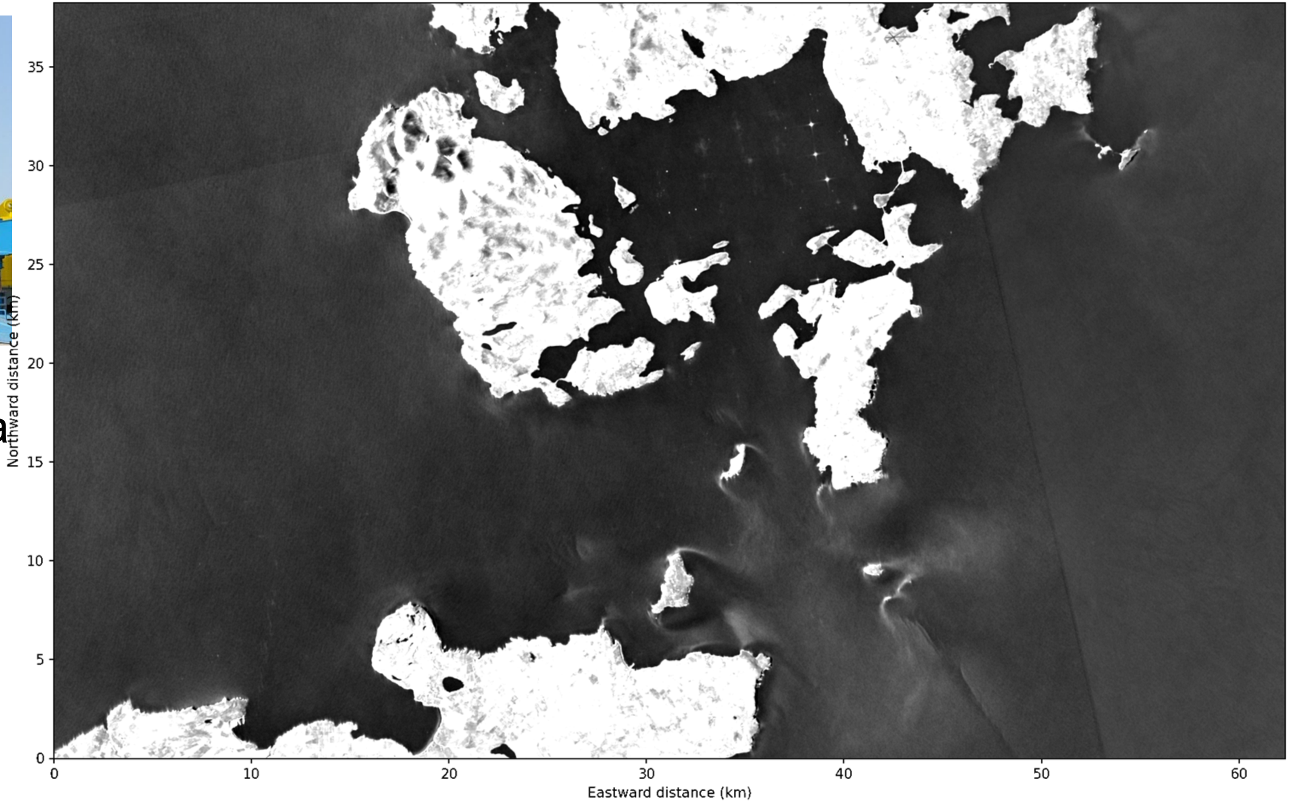


- Coastal Sentinel-1 Doppler-based Range Velocity estimates promising
- Wave - tidal current interaction documented by accumulation of radar-cross section vs tidal phase
- Promising technique but too few satellite observations for learning systematic wave transformation to implement related HR-Data Driven Physical Constrained Method

Sentinel-1 based Tidal current induced wave breaking

Marine Renewable Energy

Orkneys : Mean sea surface roughness vs. M2 tidal phase.



Need for wave breaking area identification for safe installation and operation

Wave breaking areas correspond to brighter areas on mean sea surface roughness map.

Futur steps - roadmap

WOC Roadmap 1

upper ocean high resolution circulation for targeted applications

- Analysis of frontal structures and eddies for surface current field evaluation and benchmark,
  - further develop metrics on direction difference statistics vs scales.
  - metrics for comparison of lagrangian LR advections with HR snapshots (both data driven and CMEMS model)
- Improved temporal resolution of geostrophy using microwave SST/SSS with dynamical SSH interpolation -> target 1 to 5 days.
  - Link the back and forth nudging with lagrangian advection.
  - Segmentation of regions with deep or shallow mixed layer.
  - Link anomalous Lagrangian diagnostics with Eulerian observations (frontal localization, eSQG deviations, …)
- Pursue the analysis of waves transformations by surface current and related vorticity (from Sentinel-1 TOPS, SCAT, Alti, glitter using S2 L1b). Develop automated processing capabilities for wave ray tracing in Sentinel1 TOPS mode.
- Further improve snapshot validation dataset based on
  - SAR Doppler by using cross spectra for wave Doppler and apply it to Sentinel-1 IW mode, benefiting from SARWAVE project.
  - Sentinel 2 L1-b processing to provide reference data sets for quantitative validation.
- Continue interaction with shipping but targeting intermediate users, instead of end users.
  - provide routing applications support, synthetic synergetic view, short term forecast based on previous observed situation
  - provide assessment of surface current models.
- Further support analysis of Sargassum drift based on combined Sentinel-1 and Sentinel-2 HR observations
- Tidal-conditional Sentinel-1 IW mode analysis, and also altimeter products, over coastal dedicated regions

WOC Roadmap 2

Mixed layer depth

- estimate anomalies of the depth of the mixed layer (diurnal regional seasonal) using combined in-situ and satellite at better spatial and temporal resolution than ARGO climatology.
- decomposition of drifter trajectories into surface current components. may require specific low cost drifter deployment
- Continue and improve NIO and Stokes-Ekman for surface drift.
  - improved forcing and assess the role of interior ocean properties (MLD, surface and internal waves…).
  - Better exploit argo float surface drift to estimate the G transfer function
  - Use of satellite together with in-situ (drifter/sat obs snapshots collocation).
  - drifter trajectory analysis (decomposition/classification/short term forecasting)
  - interaction of inertial motion and geostrophy
  - MAXSS storm atlas and very intense upper ocean currents associated to high wind conditions
- Provide higher resolution upwelling index based on improved scatterometry, Doppler and SAR winds, also using HR SST. Link to MAXSS improved wind temporal resolution.
- To consider analogue diagnostics and recurrence analysis to be more systematically implemented, to further help creating AI-ready datasets for model training and validation.

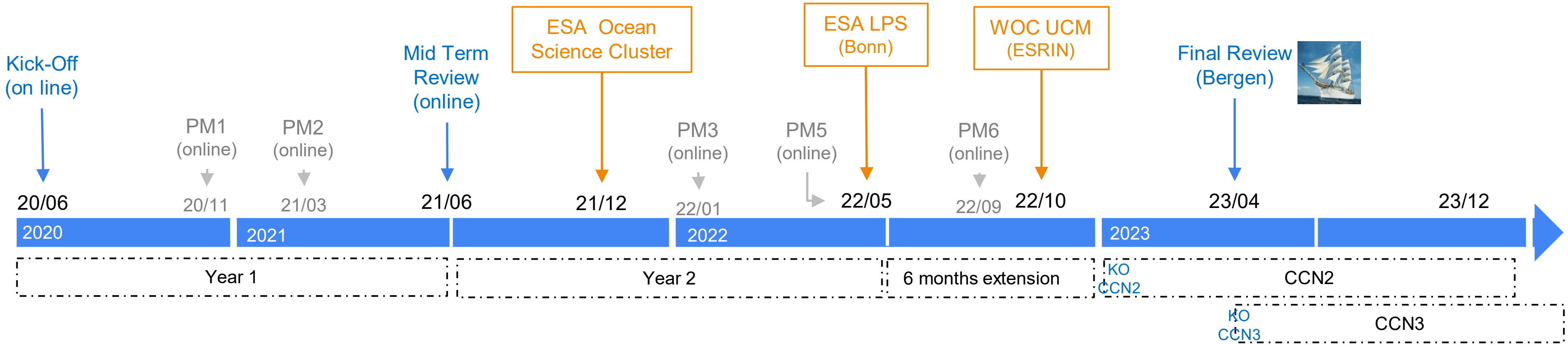
WOC Roadmap 3

Ocean heat content, and eddy fluxes

- Better assess variability of western boundary current instabilities influencing the separation when leaving the shelf and subsequent eddies. interannual variability of eddy fluxes using SST/SSS satellite observations
- Analysis of impact on Arctic ocean heating
- To actively perform synthesis and curation of reference data (including in situ, satellite, and numerical simulations)
- Develop regional focus on climate relevant processes
    - Circulation in Arctic and high latitude
    - tropical ocean, tropical instability waves
    - closed basin dedicated area (4DMed…)

Backup slides

Project presentation & main achievements



Theme 1: Sea-state current interactions for Safe Navigation

Theme 2: 3D currents and vertical motion for Sustainable Fisheries

Theme 3: Surface Lagrangian drift for a Clean Ocean

Theme 4: HR wave and current model assessment for a Productive Ocean