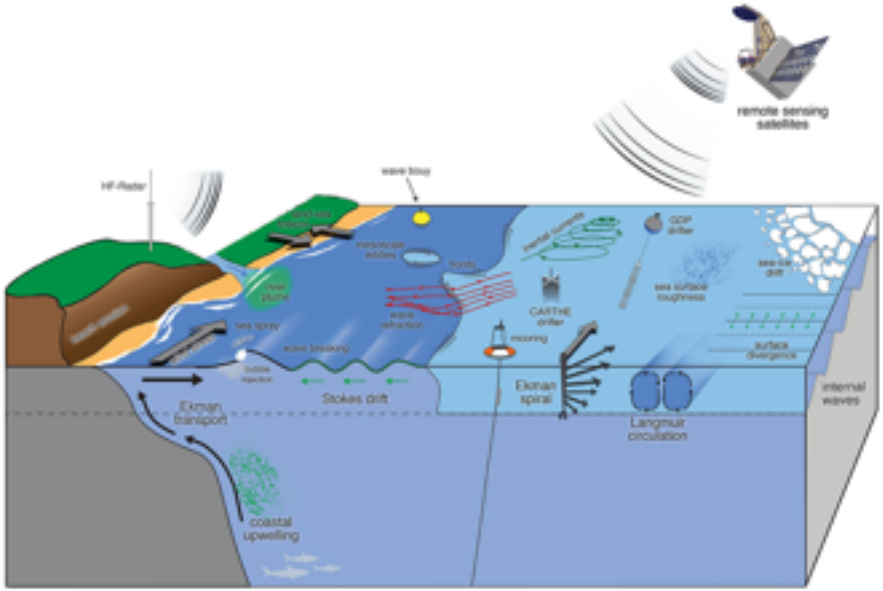
# World Ocean Circulation Project

## Retrieve the ocean velocities at the right place at the right time



# WOC Themes

## 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**

Integrate Wave & Currents anomaly information within the navigation software

integrate spatio-temporal ranking criteria for current & wave forecast in routing software

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:**

Sentinel1 and CFOSAT wavevector gradients estimations and surface current related cross seas indexes

Scatterometer wind stress-surface current analysis and altimeter sea-state-surface current interactions

Gridded regional surface current product

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**

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

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:**

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

S3/VIIRS/MODIS OC/SST correlations, detection and tracking of ocean dynamical features using AI method

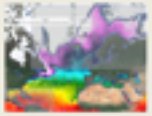
Determination of upwelling indexes thanks to HR SST and SCAT winds

## 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**

Improve the selection of current & wave forecast by validating the best models for oil spill pollution in arctic

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:**

Combination of drifters, HF wind (SCAT corrected wind stress), alti, SLAB model to retrieve HF surface current

Lagrangian advection and validation of surface drift

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**

Evaluation and validation of productible potential estimates based on qualified coastal models.

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:**

Aggregation and Classification of high-resolution satellite observations

Improved wave ray-tracing methods

# Products available for Use Cases

| | | |
|---|---|---|
| Theme 1 | Cross-seas indexes | event |
| | Location of dangerous seas | event |
| | Surface current sources ranking | 2010-2020 |
| | Wind stress vector (& anomalies) | 2010-2020 |
| | Surface current from Sentinel-1 Doppler | april 2019-may 2020 |
| | Gridded Surface Current | 2010-2020 |
| Theme 2 | Daily 3D ocean currents | 2010-2019 |
| | 2D ocean currents | 2010-2019 |
| | Upwelling indexes | 2010-2020 |
| | Oceanic/current fronts | 2010-2021 |
| Theme 3 | North Atlantic Total Surface Current | 2010-2020 |
| | Tropical Total Surface Current | 2010-2020 |
| | Predicted oil spill transport in the North Atlantic | event |
| | Predicted sargassum transport in the Tropical Atlantic | event |
| | Stokes Drift estimation | 2010-2020 |
| Theme 4 | Aggregation & Classification of HR observations | april 2019-may 2020 |

Website https://www.worldoceancirculation.org/Products

Visualization tool

# Use Cases Description

| | | |
|---|---|---|
| Theme 1 | Cross-seas indexes | event |
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# Publications

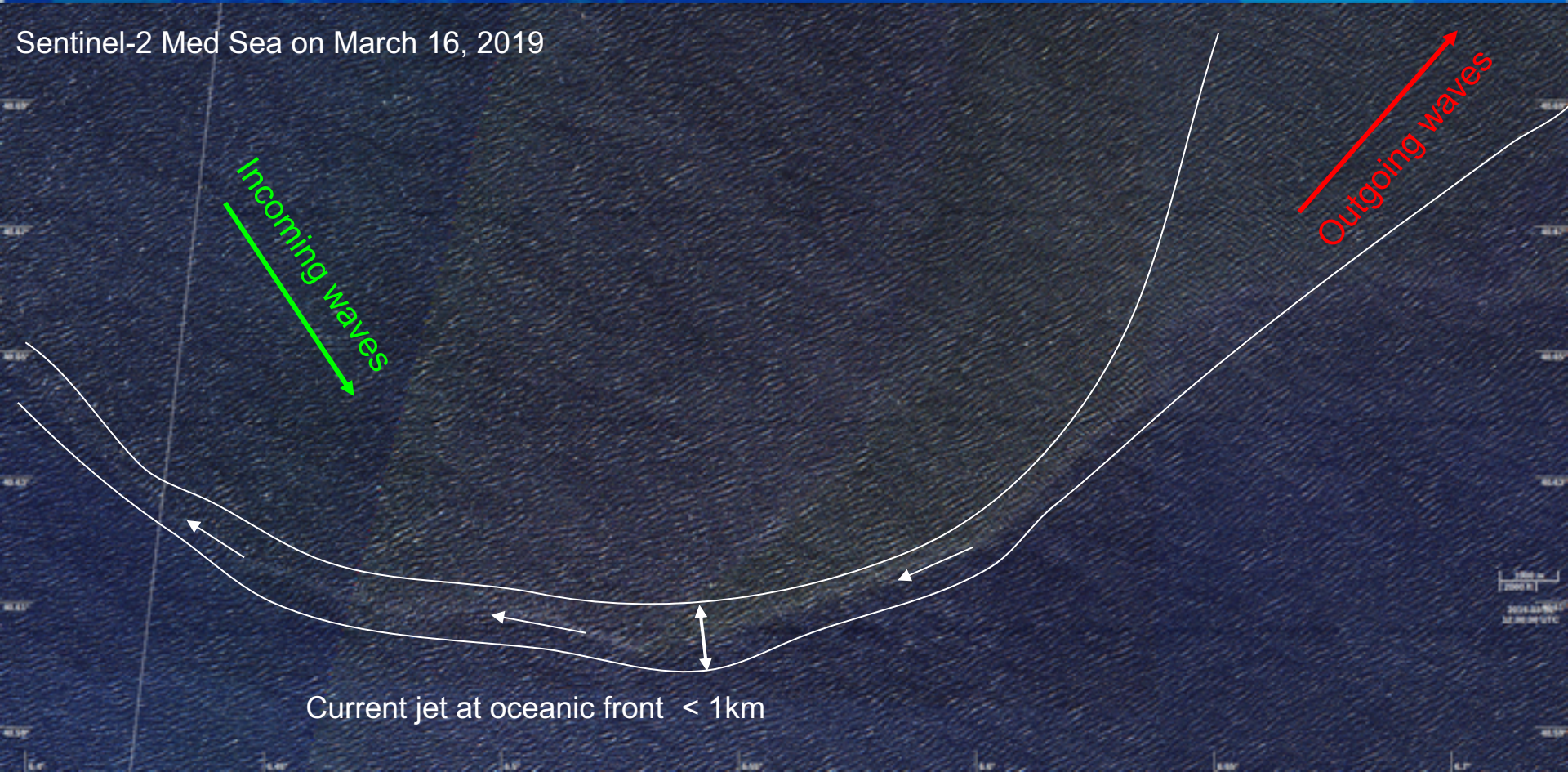
## Published papers

- 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., & 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.

## Foreseen papers

- Valentin Resseguier, Erwan Hascoet, Bertrand Chapron, B. (Submitted). "Random ocean swell-rays: a stochastic framework". STUOD Proceedings
- Data driven models for Ekman and inertial currents from high-frequency winds (C. Ubelmann et al.) → submission by the end of summer
- Lyapunov exponents toolbox. L. Gomez-Navarro, V. Morales-Marquez, I Hernandez-Carrasco (in prep. for The Journal of Open Source Software)

# Wave current interactions : Model vs. Observed current

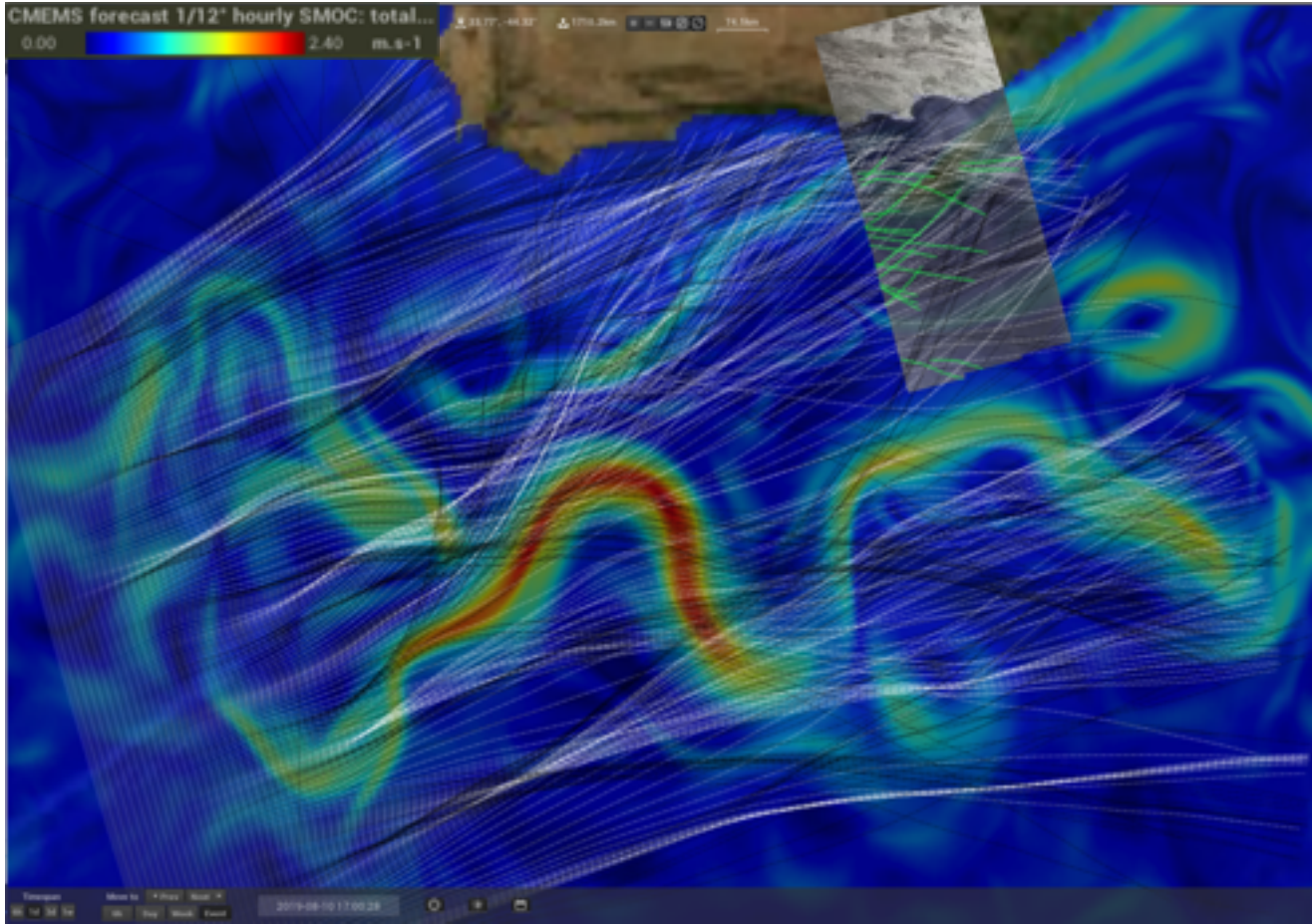


# Wave current interactions : Model vs. Observed current

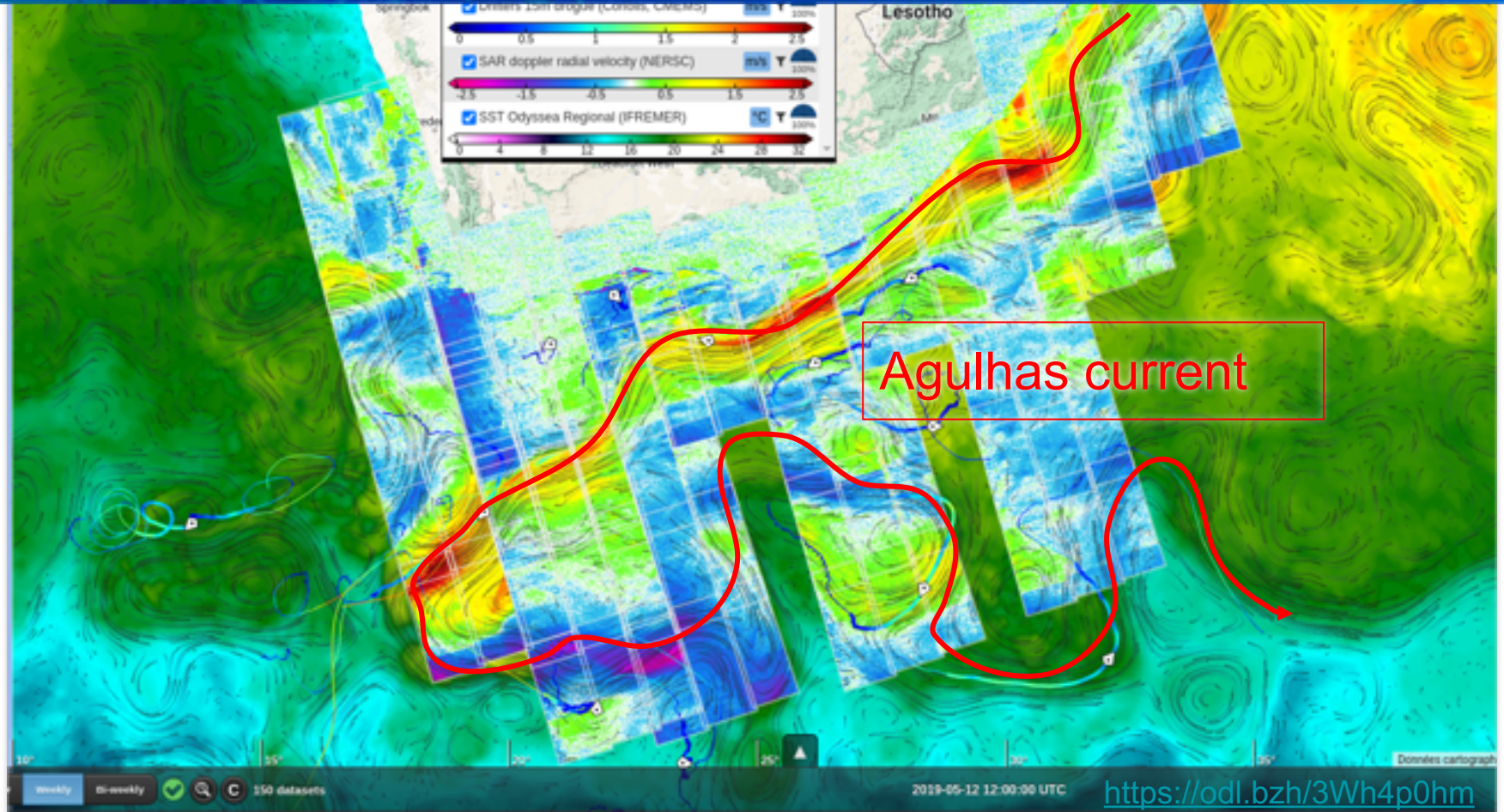
**Sentinel 1 Observations**

**Geostrophic + random small scales**

**Mercator Model 1/12°**



# SAR Doppler velocities vs Altimeter surface currents



# Back-and-Forth Nudging Geostrophic Current

## Algorithm :

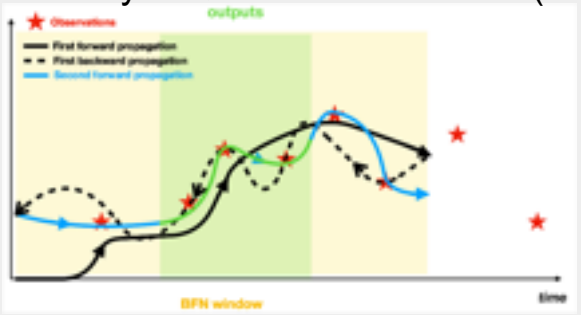
Dynamic interpolation : Nudging SSH in a 1-layer QG model advection (Le Guillou et al., 2021)

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

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

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

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




Spatial resolution : 1/10 degree

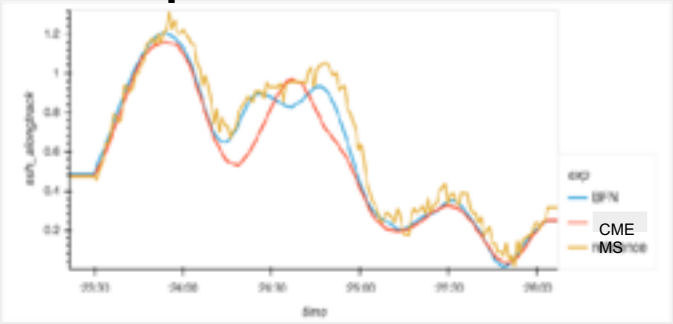
Temporal resolution : 3-hourly

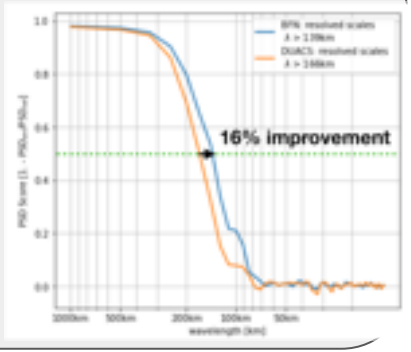
## Input Data : All Altimeter missionsCMEMS

## Improvements regarding CMEMS Geostrophic current ?

Successful validation against standard CMEMS mapping algorithm (based on independent Altimetry data: Le Guillou et al., in prep.)

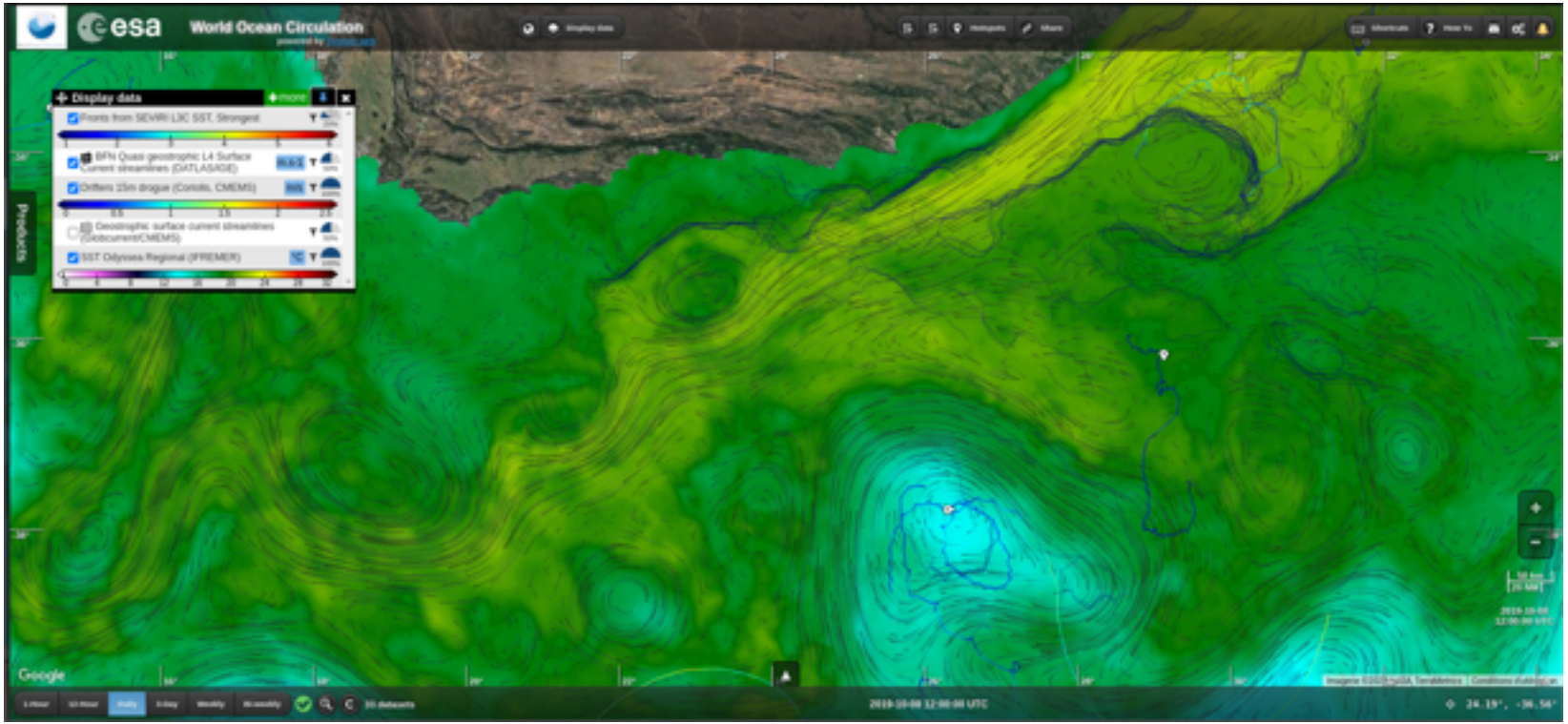
Ongoing validation with Drifters



# Back-and-Forth Nudging Geostrophic Current

Florian Le Guillou, Sammy Metref, Emmanuel Cosme, Clément Ubelmann, Maxime Ballarotta, et al.. Mapping altimetry in the forthcoming SWOT era by back-and-forth nudging a one-layer quasi-geostrophic model. 2020. ⟨hal-03084218⟩



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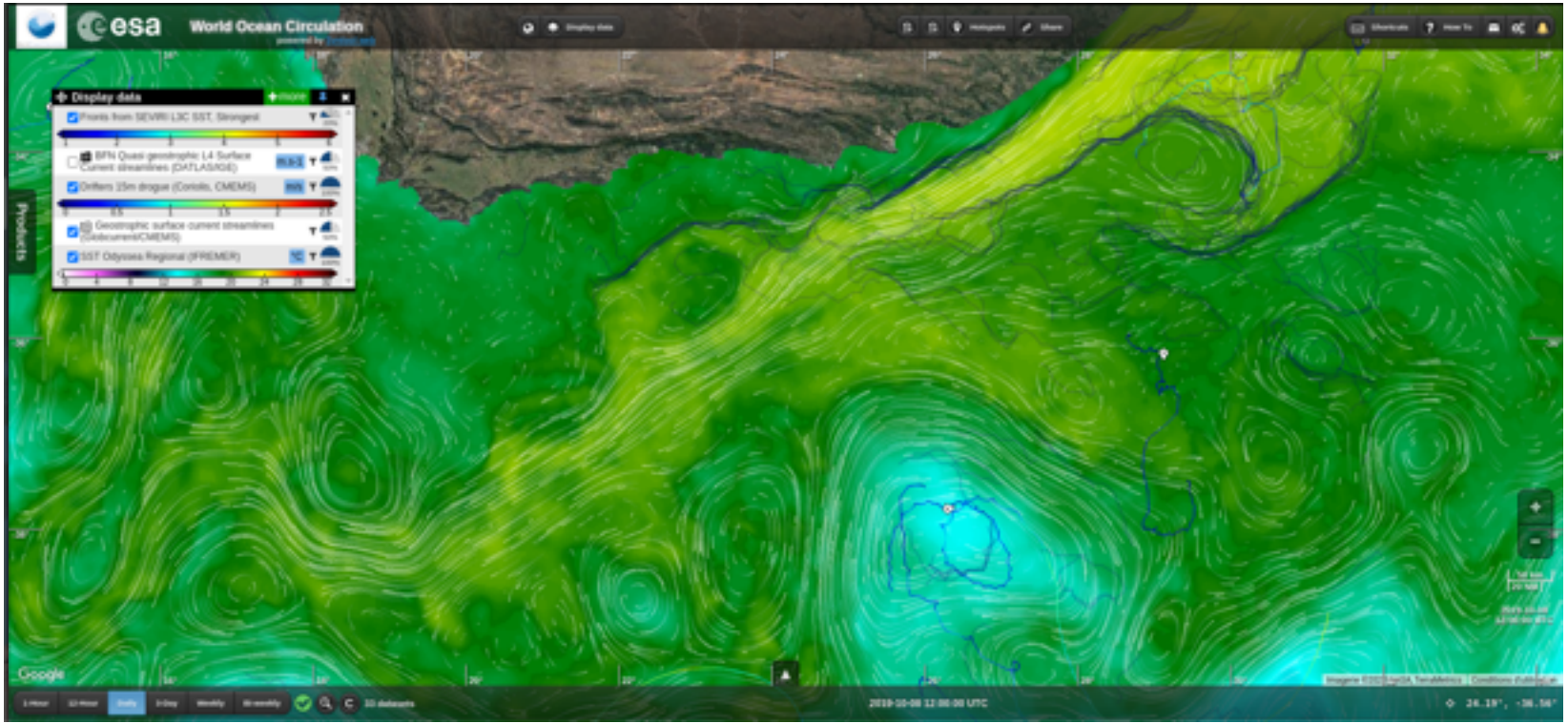
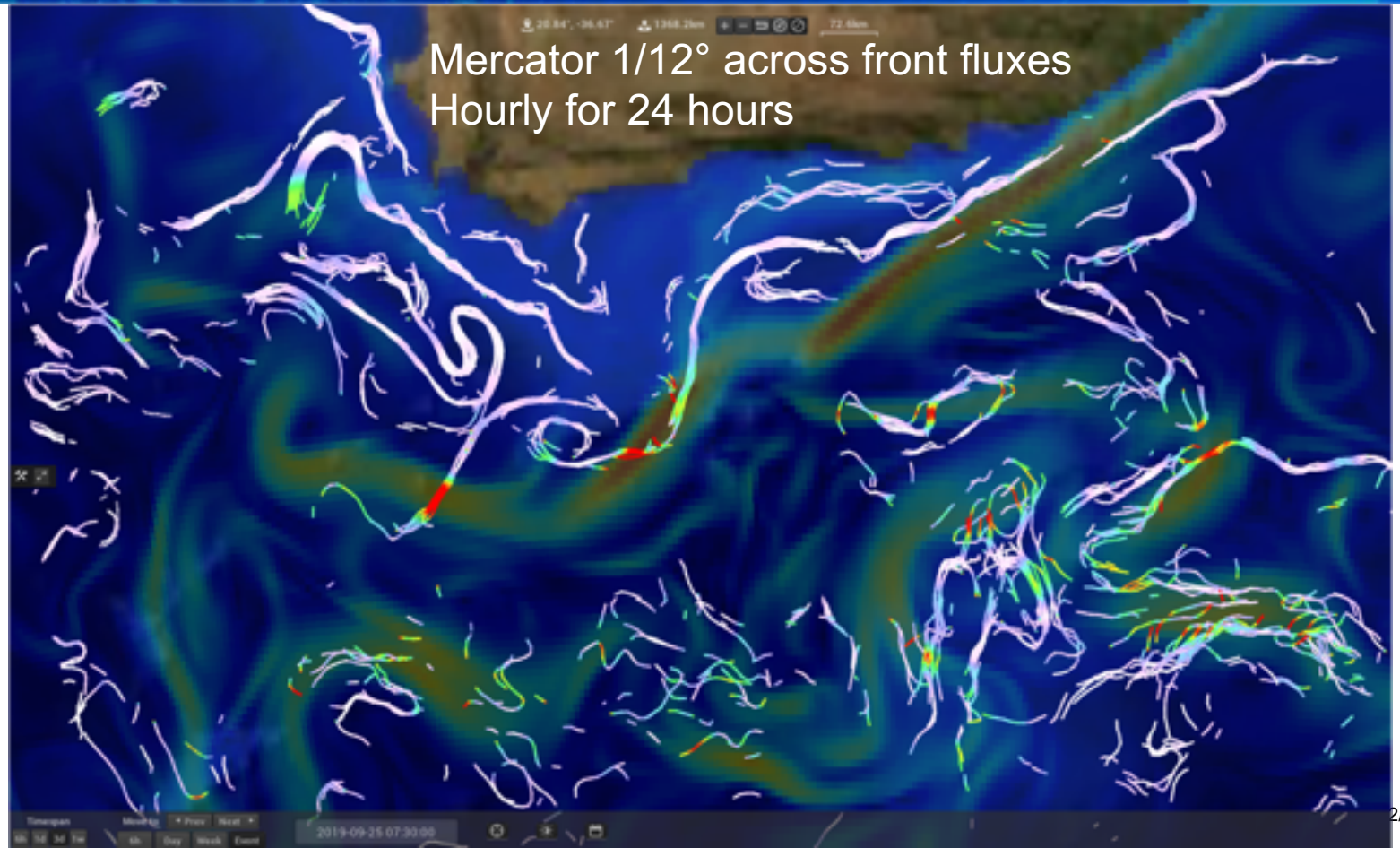
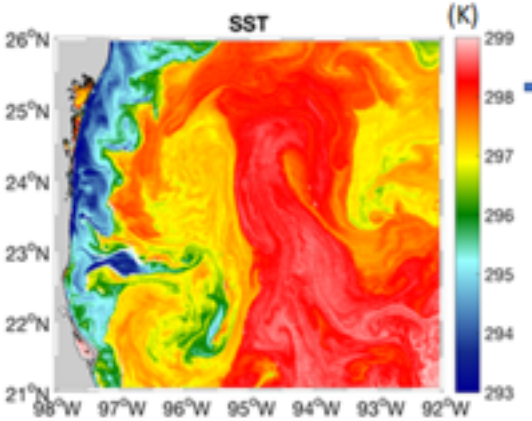


# SST derived fronts and surface current model assessment



# NATL_2D: synergistic Altimeter/SST currents

## NATL2D product: Method




**Exploit sequences of SST satellite observations to correct background altimeter-derived currents ($u_{geo}$, $v_{geo}$) and obtain an optimized merged velocity: OPTimal Currents - OPT ($u_{opt}$, $v_{opt}$)**

METHODOLOGY:
Require the velocity field (u,v) to obey to the tracer (□) evolution equation:

$$\frac{\partial \square}{\partial t} + u\frac{\partial \square}{\partial x} + v\frac{\partial \square}{\partial y} = F$$

F= source and sink terms

$$u_{opt} - u_{geo} - \frac{A(Au_{geo} + Bv_{geo} + E)}{A^2 - B^2} - u_{geo} + u_{CORR}$$

$$v_{opt} - v_{geo} - \frac{B(Au_{geo} - Bv_{geo} + E)}{A^2 + B^2} - v_{geo} - v_{CORR}$$

$A = \frac{\partial}{\partial x}\square$ $B = \frac{\partial}{\partial y}\square$ $E = \frac{\partial}{\partial t}\square - F$

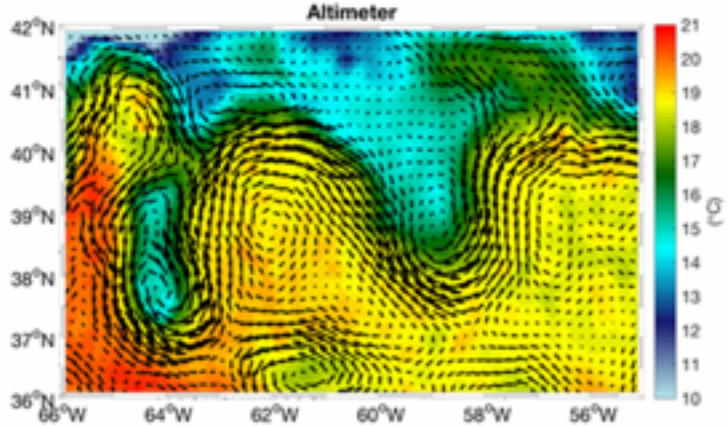
- CMEMS DUACS-18 Altimeter Geostrophic Velocities (1/4°, daily) - MULTISENSOR

+

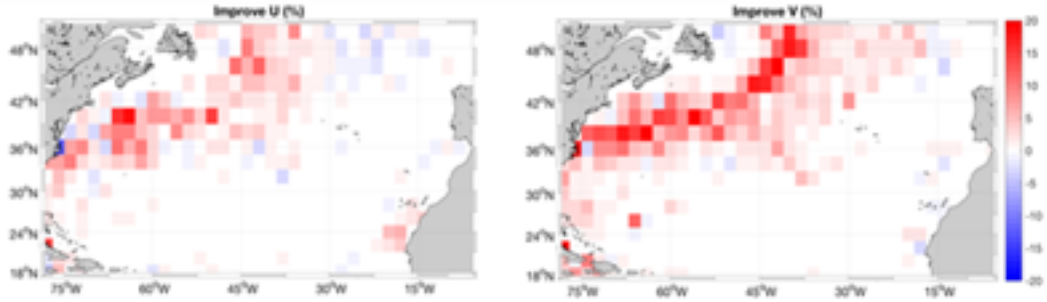
- CMEMS OSTIA SST (remapped to 1/10°, daily) MULTISENSOR

Ciani, D., et al.: Improving the altimeter-derived surface currents..., Rem. Sens., 1–16, 2020.
Rio and Santoleri.: Improved global surface currents..., RSE, 216, 2018

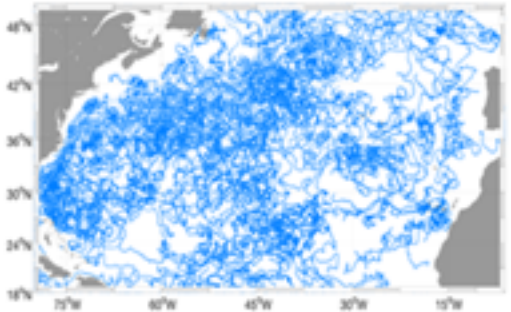
# NATL_2D: synergistic Altimeter/SST currents




HR SST gradients provide a constraint for the Altimeter geostrophic currents, yielding corrections mainly in large SST gradient areas




Percentage of improvement (PI), evaluated via comparison with in-situ measured currents in 2014-2016



$$\mathrm{PI} = 100 \cdot \left(1 - \frac{\mathrm{RMS_{OPT}}}{\mathrm{RMS_{GEO}}}\right)^2$$

# NATL_3D

**WOC-NATL3D product**
daily 3D (0-1500 m) ocean currents (u,v,**w**), at mesoscale-resolving spatial resolution (1/10°x1/10°), over a wide section of the central/North Atlantic Ocean (20°N-50°N, 76°W-6°W)

## Three-step algorithm:

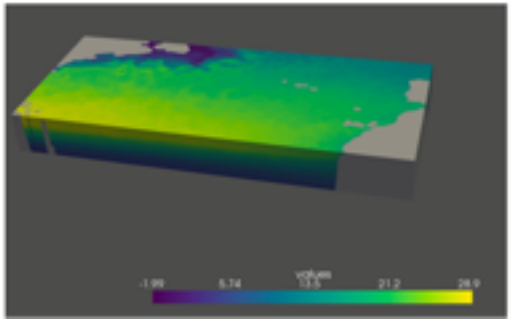
**1. Collect/develop high resolution surface data**:
Sea Surface Temperature (SST)→**CMEMS-OSTIA**
Sea Surface Salinity (SSS)→**WOC internal product**
Absolute Dynamic Topography (ADT) →**WOC-NATL2D**


**2. Retrieve ocean 3D hydrographic structure** from combined surface data and in situ vertical profiles

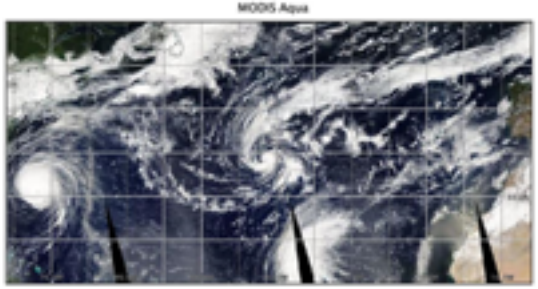
→Long-Short Term Memory Network

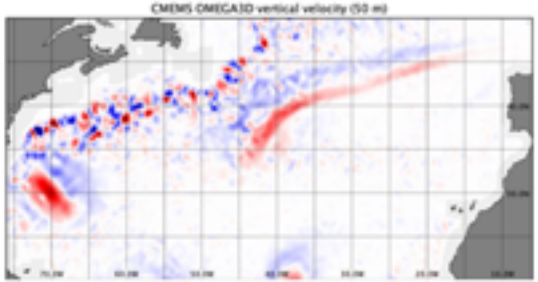
**3. Solve diabatic Quasi-Geostrophic Omega equation including surface forcings**

**high resolution WOC-NATL3D processing chain** adapted from CMEMS-OMEGA3D
**improved diabatic forcing term** estimation including empirical Ekman shear estimates

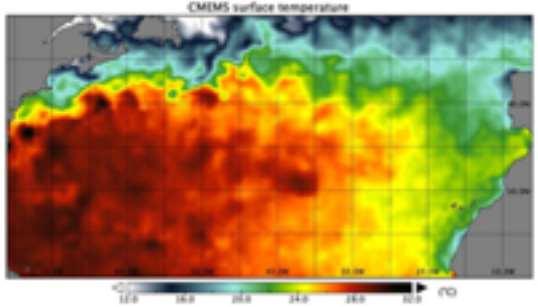


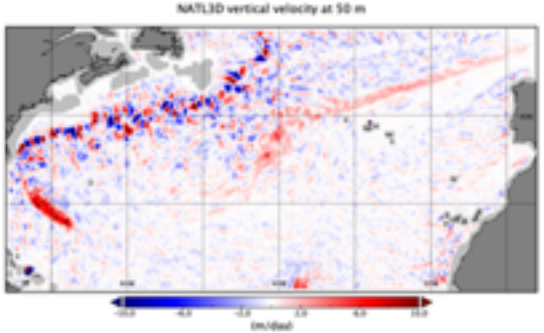
# NATL_3D




**CMEMS-OMEGA:**
-mesoscale "permitting" resolution
-inaccurate surface Ekman currents




**WOC-NATL3D:**
-mesoscale "resolving" resolution
-more accurate surface Ekman currents

**12 September 2018**

MODIS true colour image (top-left), CMEMS OMEGA3D vertical velocities at 50 m depth (top-right),
CMEMS SST (bottom-left), WOC_NATL3D vertical velocities at 50 m depth (bottom-right).
Vertical velocities are modulated at different scales by hurricane Florence, visible in the left part of the domain, and by the mesoscale meanders and eddies along the Gulf Stream

# High-Frequency Total Surface Current

## Algorithm :

Parameter vector **K**

ERA5 winds

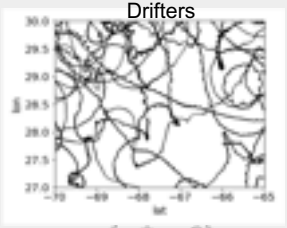
Direct model M(K)

$$(U(K,x,y,t), V(K,x,y,t))$$

Colocalisation

$$(u(K), v(K))$$

**Training Data base :**
0m and 15m-drogued GPS Drifters



$$(u^o, v^o)$$

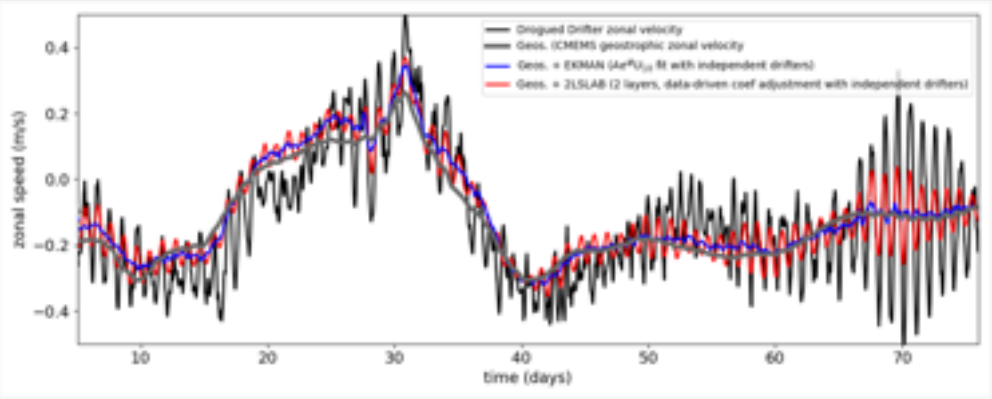
Cost function

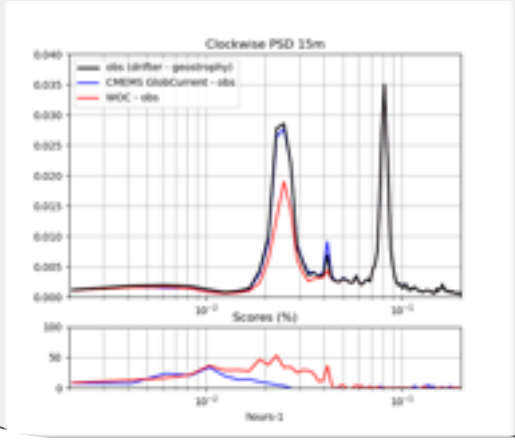
$$J(K) = (u(K) - u^o)^2 + (v(K) - v^o)^2$$

1/10 resolution, hourly.
Content : Ekman + near-inertial motions
CMEMS geostrophy added separately

**Input Data :** ERA5 hourly wind stress and Drifter database (drogued and undrogued)

## Improvements regarding CMEMS Total current ?

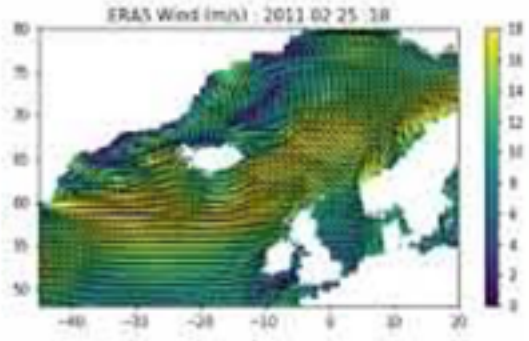


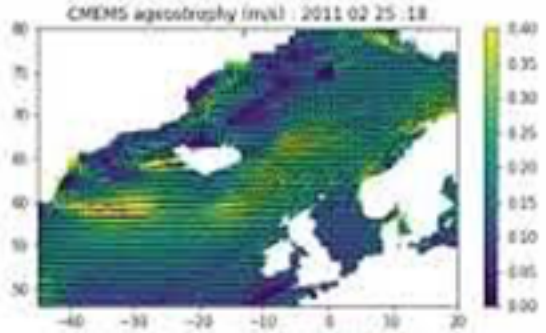



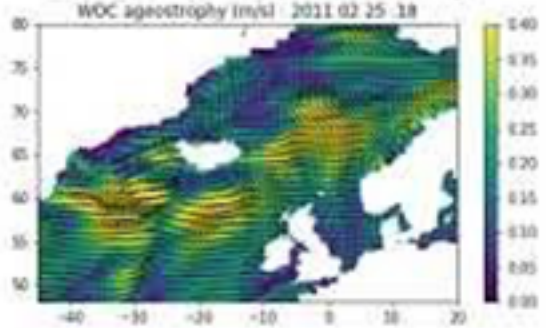

Near-Inertial Motions quite in phase with those measured by **independent observations**

Reconstruction scores suggest nearly 50% reconstruction at high-frequency

# High-Frequency Total Surface Current



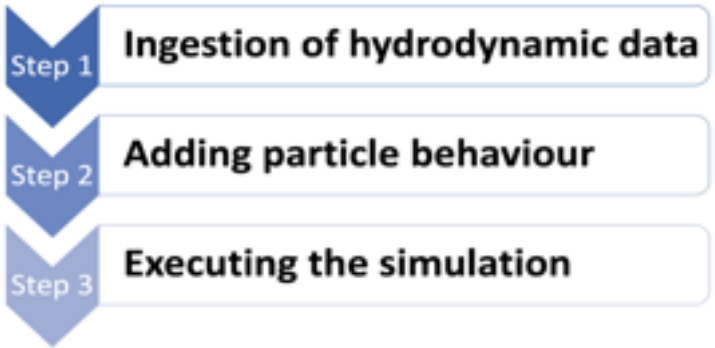



# Lagrangian Advection of surface drift

Product characteristics:

- Trajectories simulated using: The Parcels code (**P**robably **A** **R**eally **C**omputationally **E**fficient **L**agrangian **S**imulator), version 2.2.2 (Delandmeter & van Sebille, 2019; https://github.com/OceanParcels/parcels/releases)

- The algorithm used for the runs works as:




- Velocity fields include geostrophic currents, inertial oscillations, Ekman and Stokes as a total component and are a **combination of satellite and drifter data** (data product developed by C. Ubelmann)

- **Oil spill:** North Atlantic region during 2011. 14 days run reproducing the Golden Trader (Denmark) incident.
- ***Sargassum:*** Tropical Atlantic region during 2018. 180 days run reproducing the Miron *et al* (2020) study.

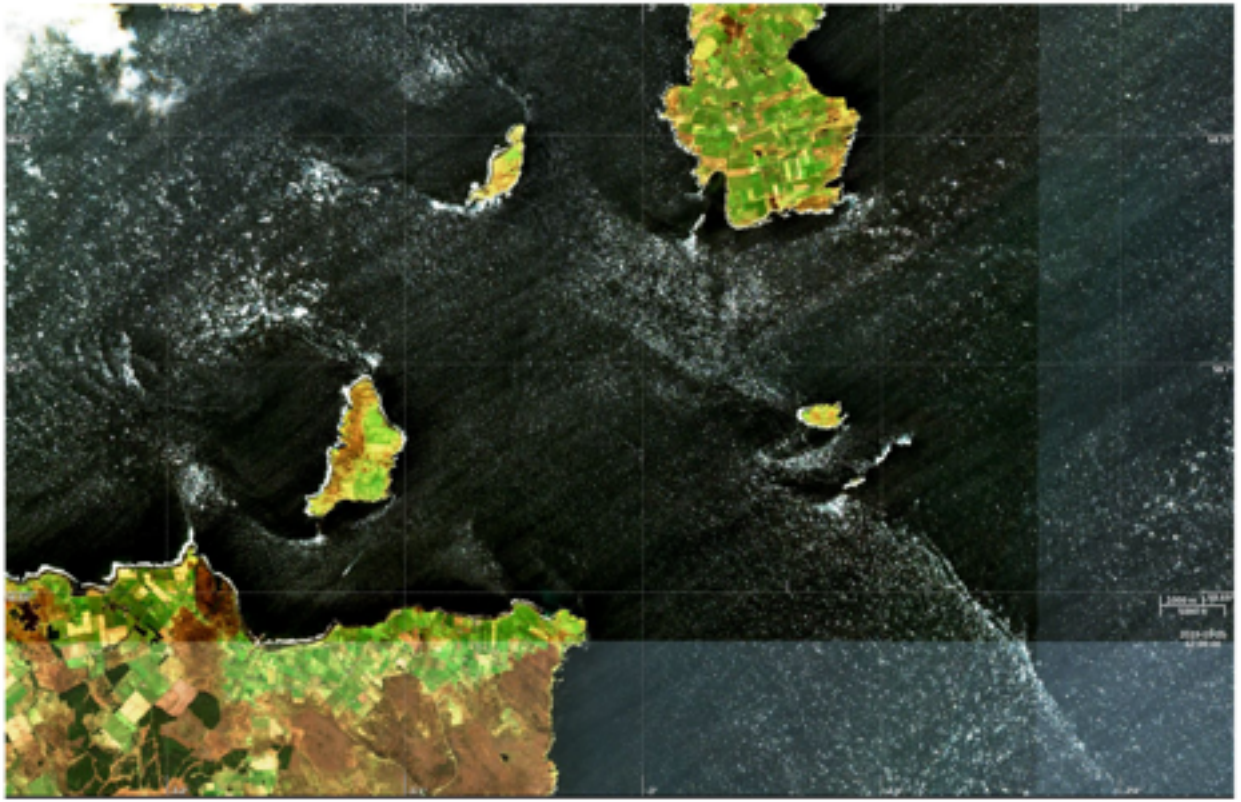
What is the improvement regarding state of the art products (CMEMS) ?

*Sargassum* and oil spills are simulated including more ocean dynamics, namely **high frequency motions**, which impact their trajectories and where they end-up on the coast.

# Sentinel1 based Tidal current induced wave breaking

## Marine Renewable Energy

Need for wave breaking area identification for safe installation and operation



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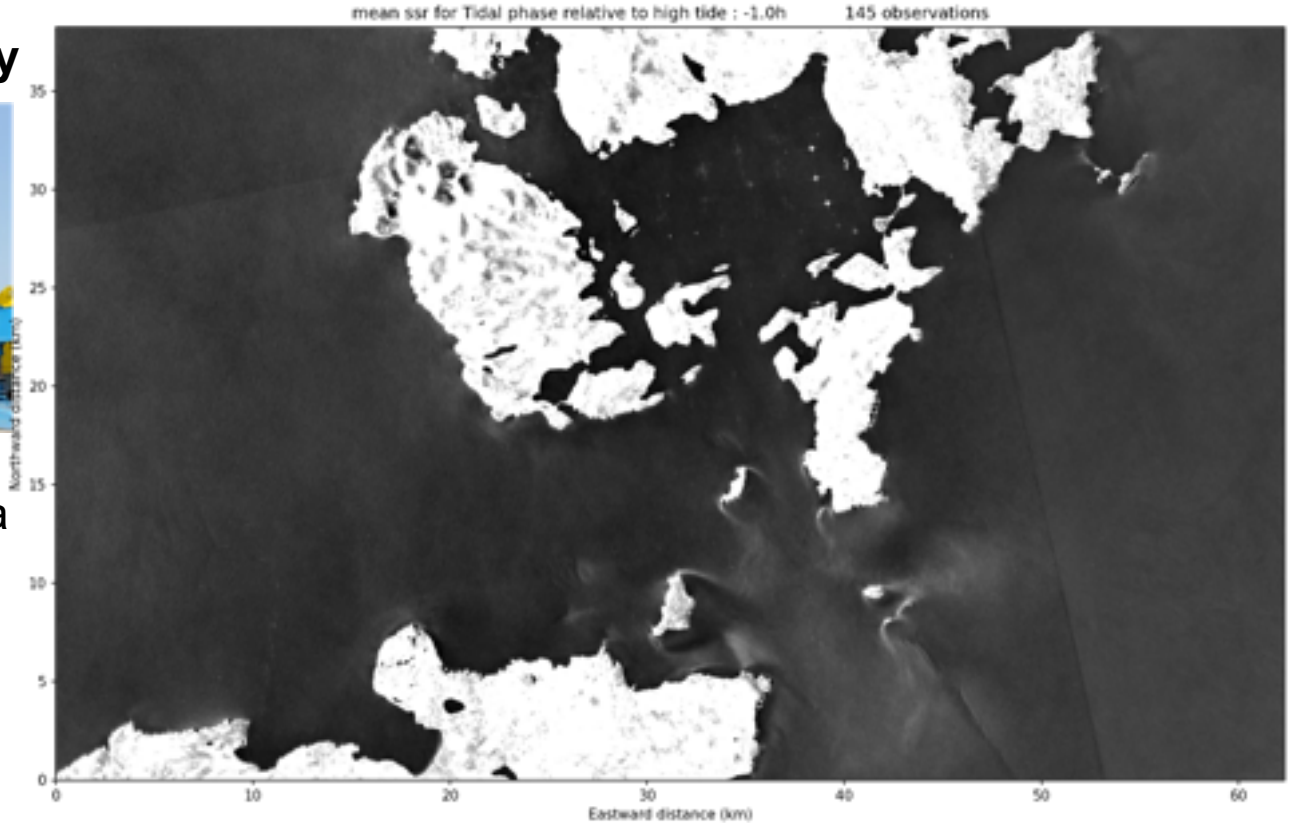
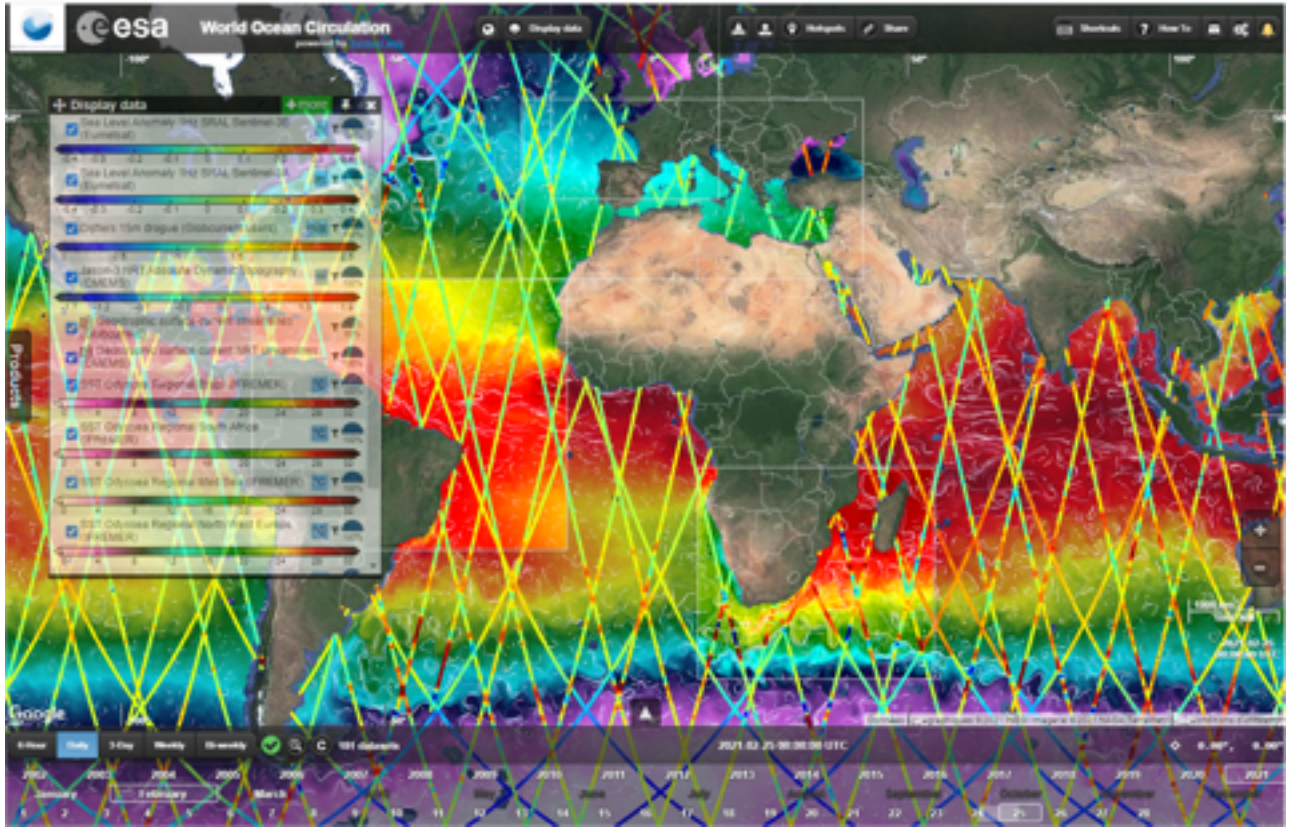


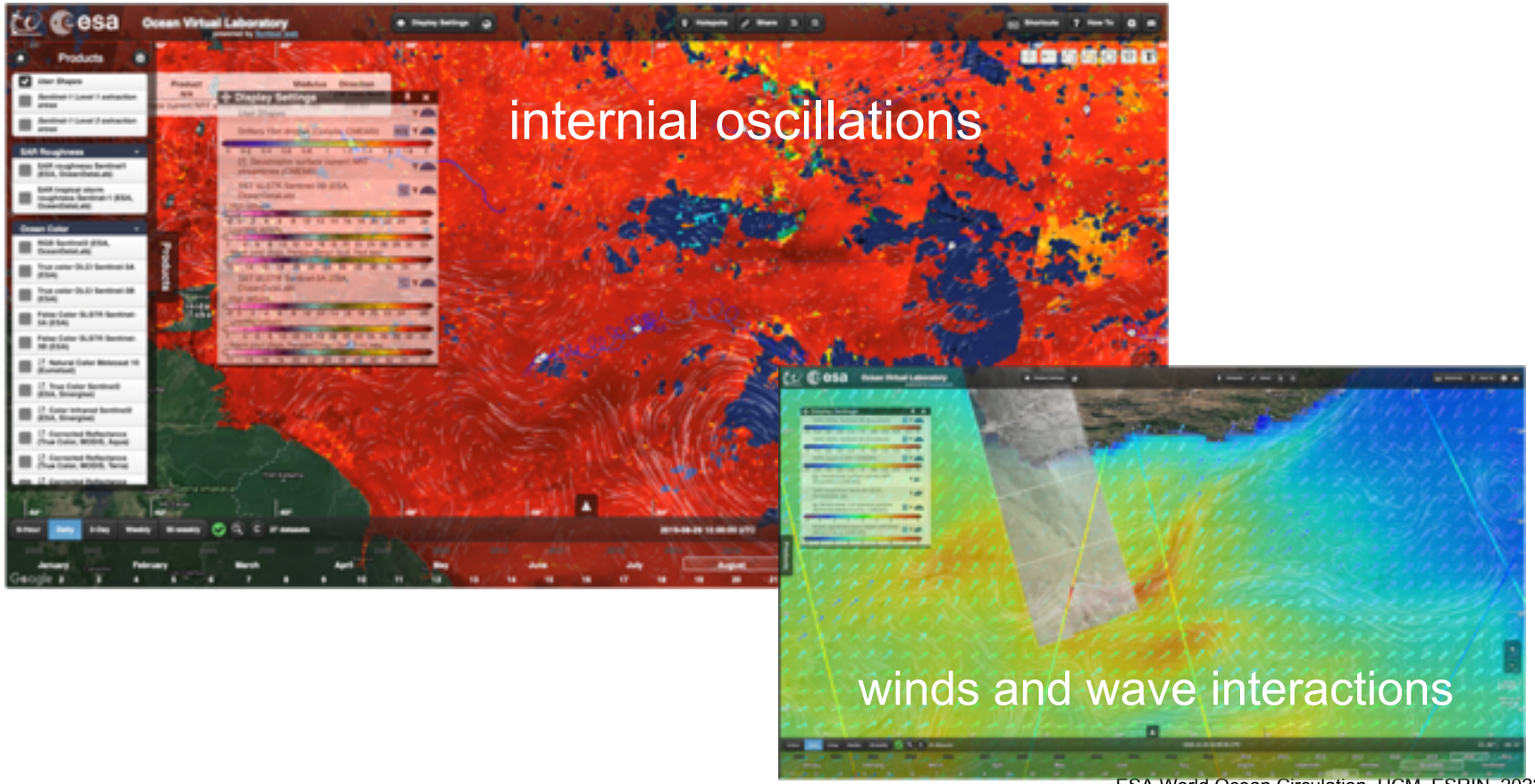
# Backup slides

# Visualize and play with the products




Link: [Syntool for WOC]

# First version of our ocean e-book



# The consortium







**&**

**our engaged Users**