

Presentation

Highly non-linear eddies emerging from wide-swath altimetry

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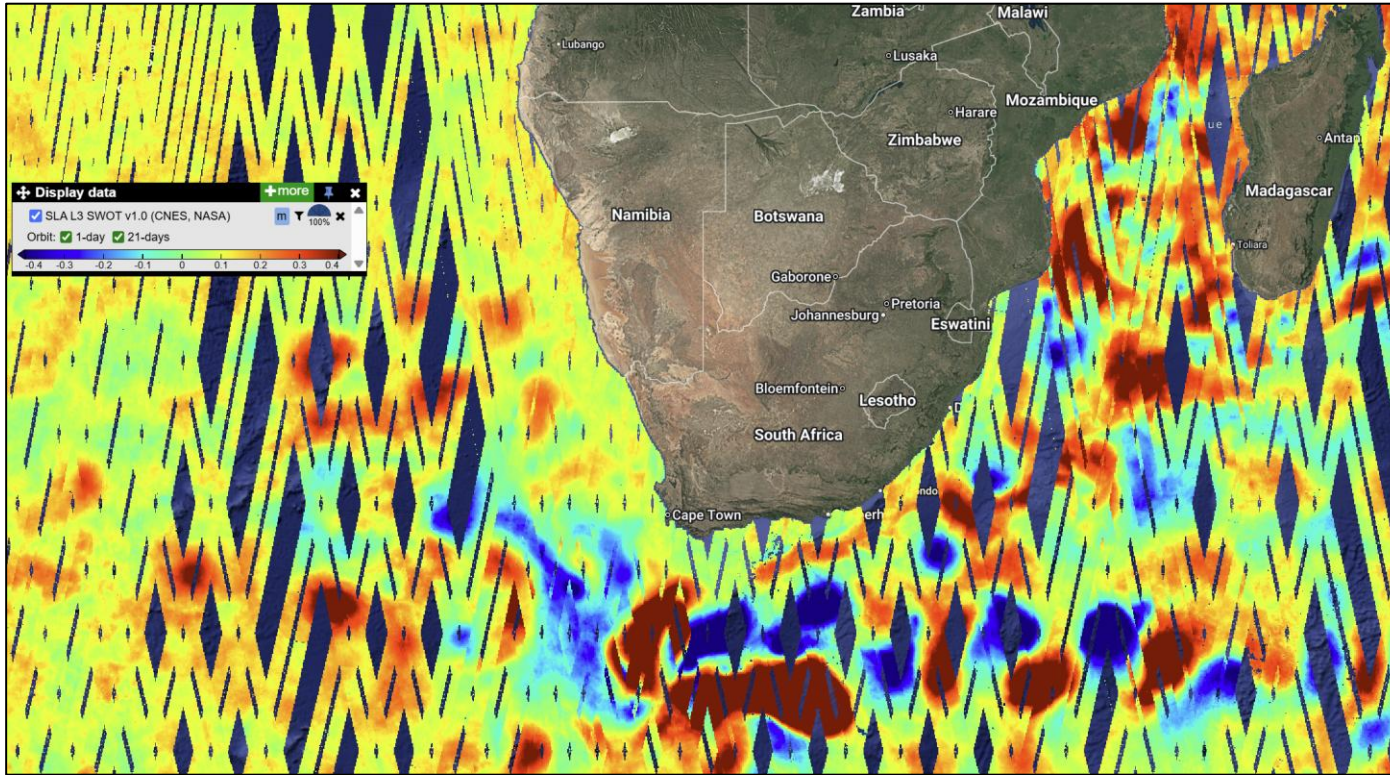
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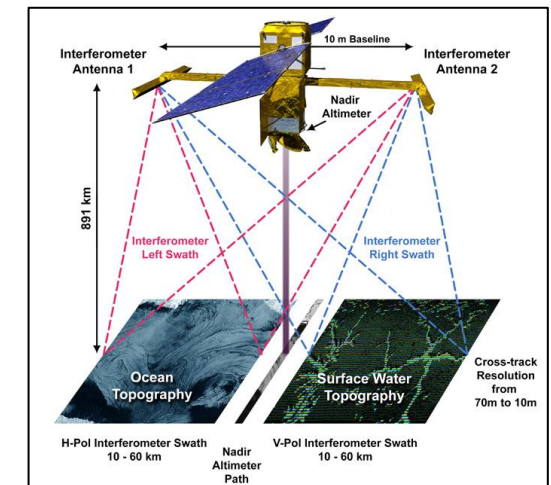
Wide-swath Altimetry



Source: <https://aviso-calval.oceandatalab.com/>

- SWOT Sea-level Anomalies (SLA)
- SWOT SLA L3 products
- Coverage during 2 weeks in September 2024.
- 21-day repeat

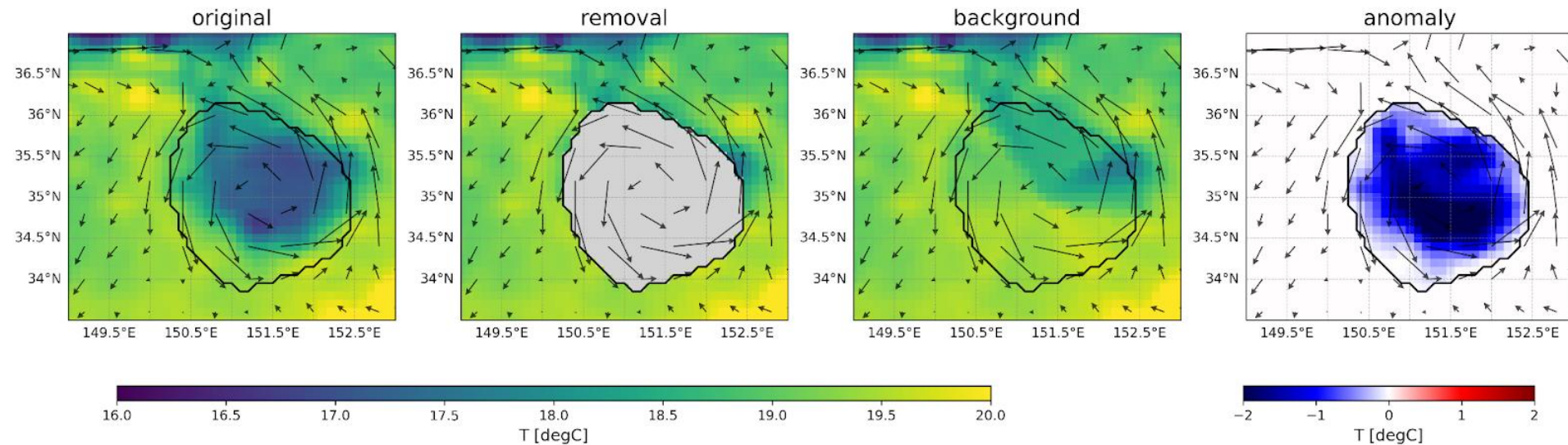
Key-message: SWOT sample the ocean surface at unprecedented resolution, $< O(100 \text{ km})$, but temporal sampling is sub-optimal for resolving the temporal evolution of small-scale features of the ocean circulation



Eddy Detection



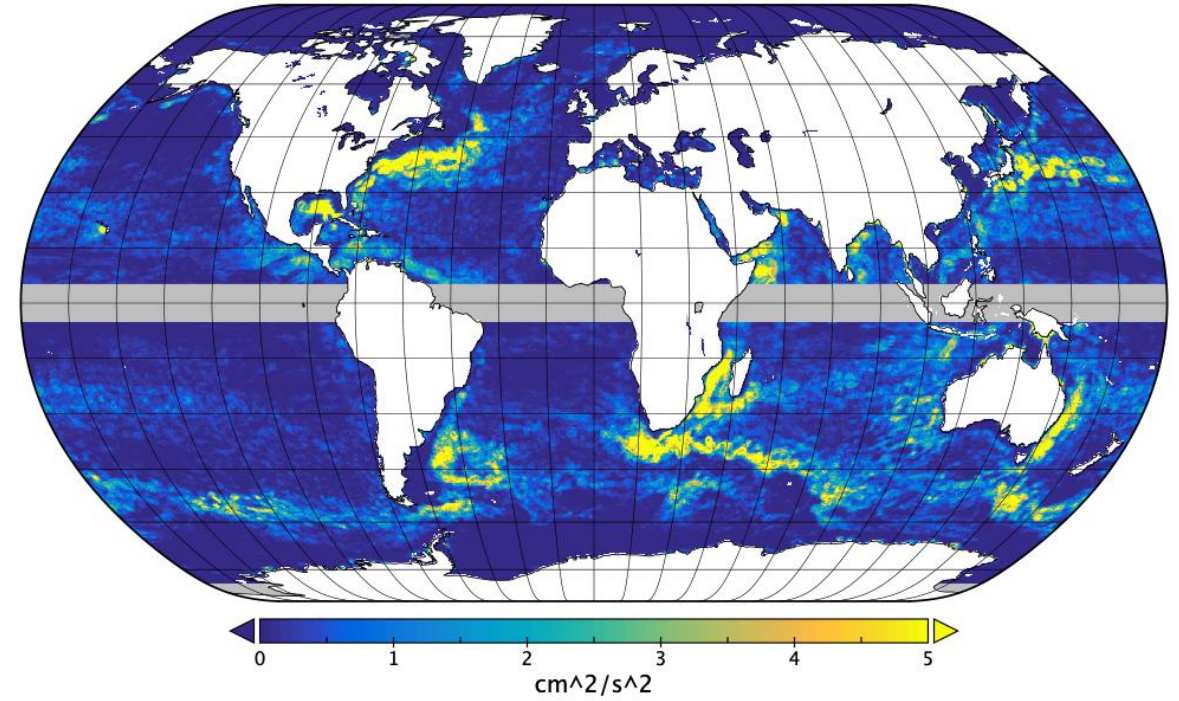
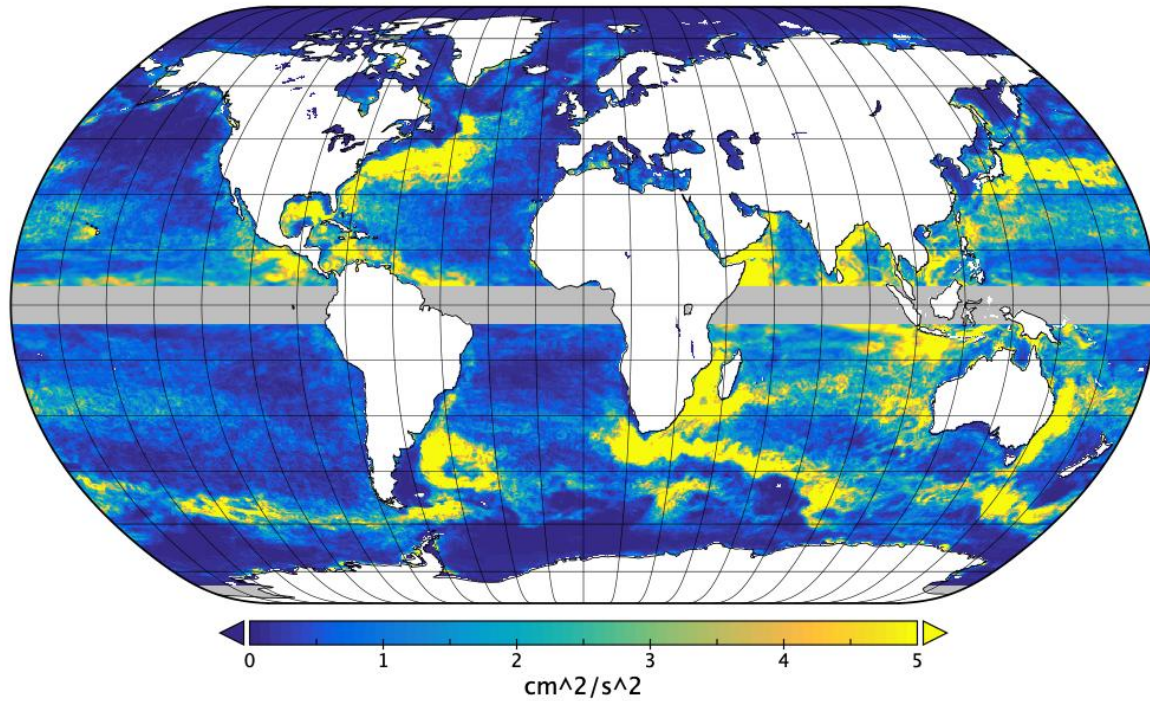
- Geometrical constraint - coherent surface elevation anomaly (SWOT L4 MIOST)
- Dynamical constraint - existence of a rotation within
- Eddy-active population → considering SST (ESA CCI) anomalies



Eddy Kinetic Energy



- Eddy-induced EKE (Jul. '23 - May '24) - **SWOT MIOST**



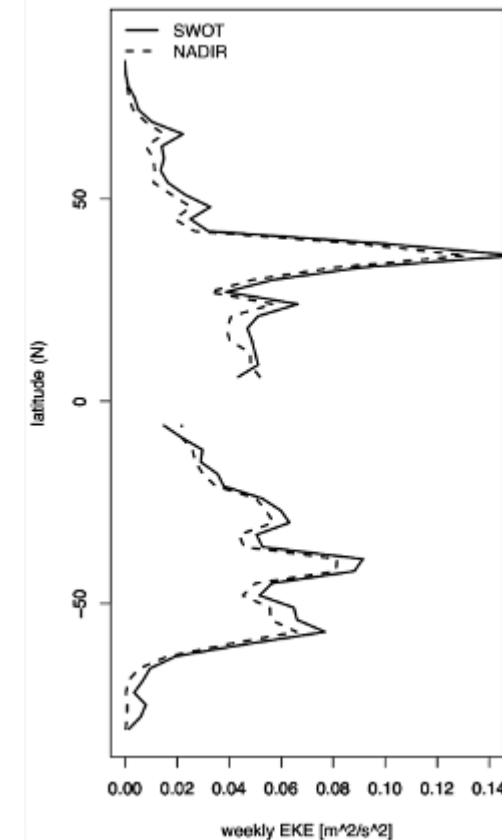
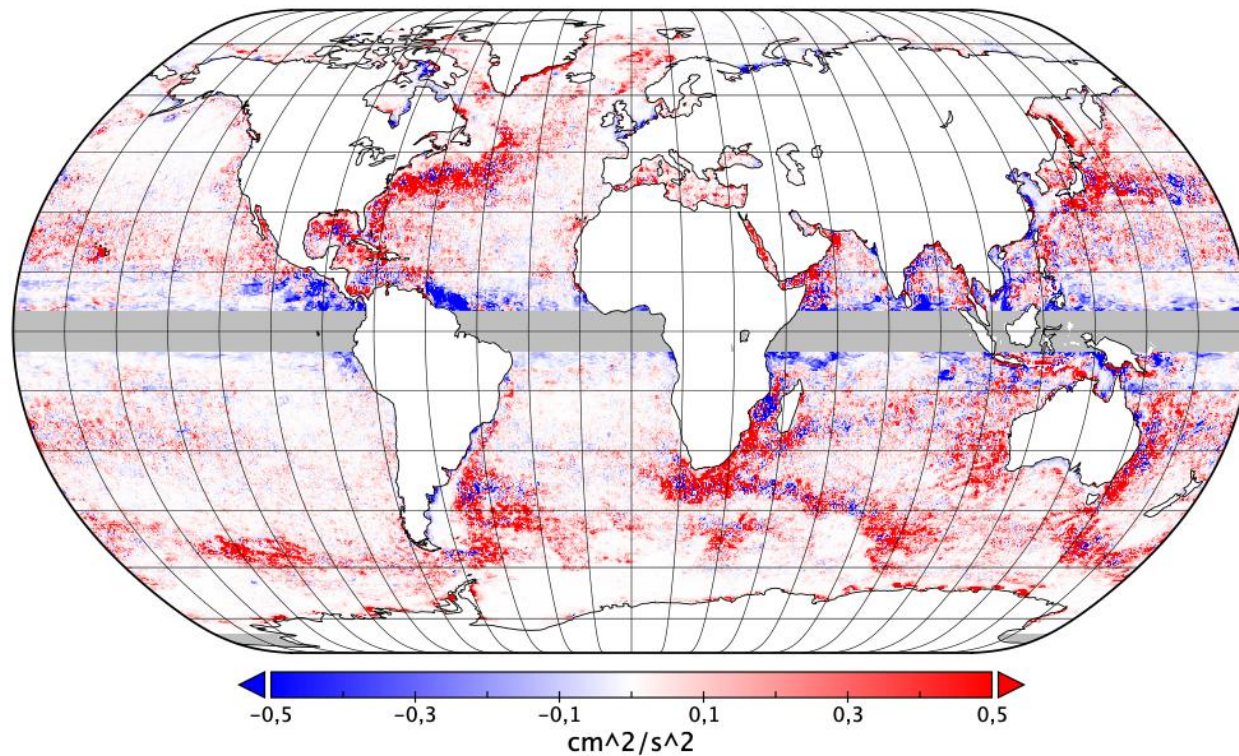
- Total Eddy kinetic energy (left)
- Eddy kinetic energy induced by eddy lifetime > 7 days (right).



Eddy Kinetic Energy



- Eddy-induced EKE (Jul. '23 - May '24): differences between **SWOT** experimental and **conventional** altimetry maps considering eddy lifetime > 7 days averaged weekly



- Eddy-induced EKE (Jul. '23 - May '24) in SWOT MIOST larger than in conventional altimetry



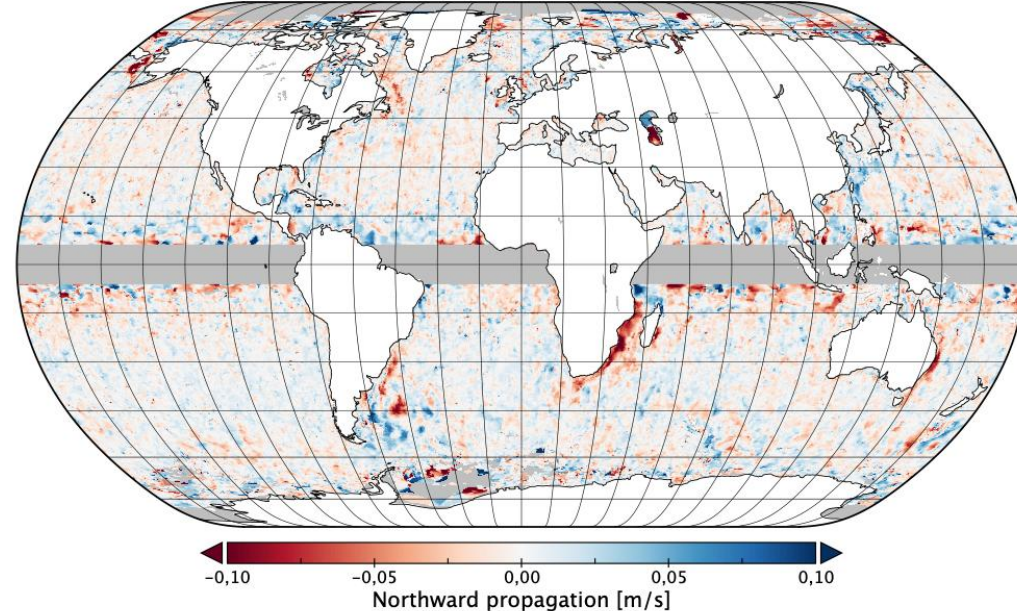
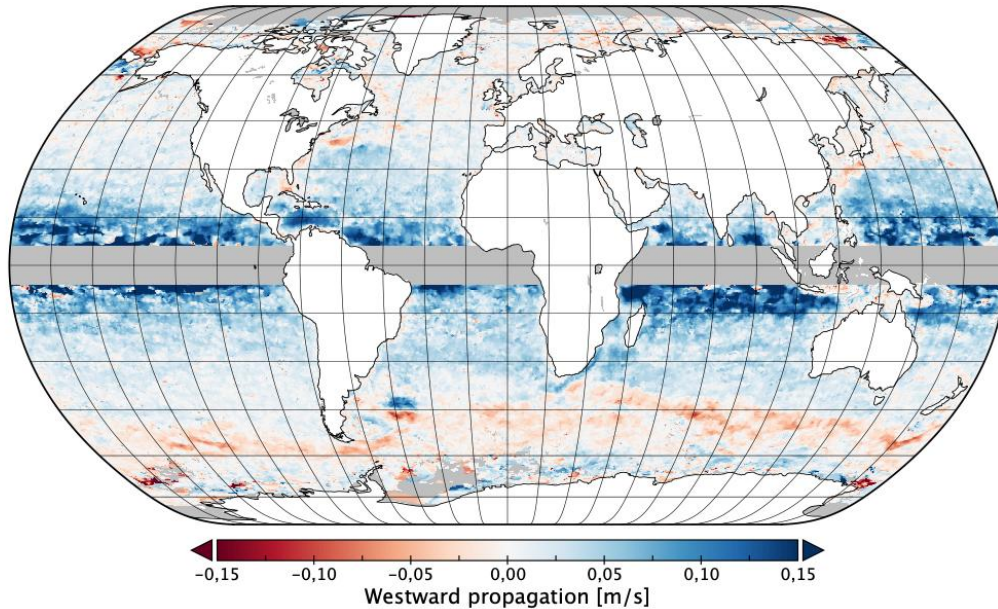
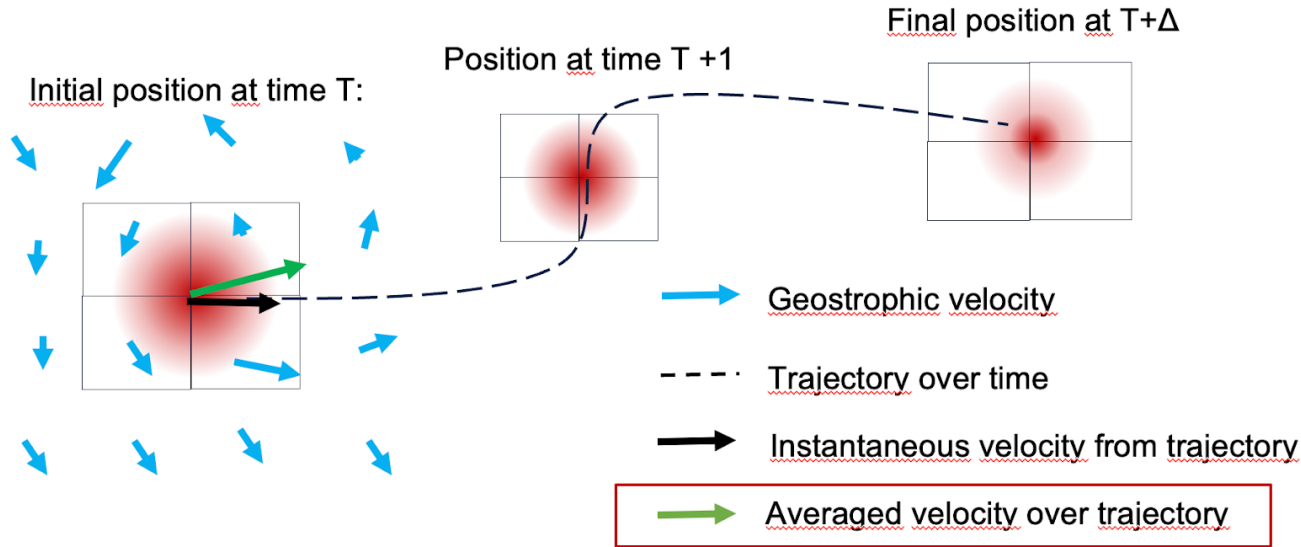
Eddy Trajectories and Velocities



- Eddies propagate eastward in the ACC both for cyclonic and anticyclonic and in the eastern boundary currents.

- The rest of the basin shows a prominent western propagation that increases with latitude

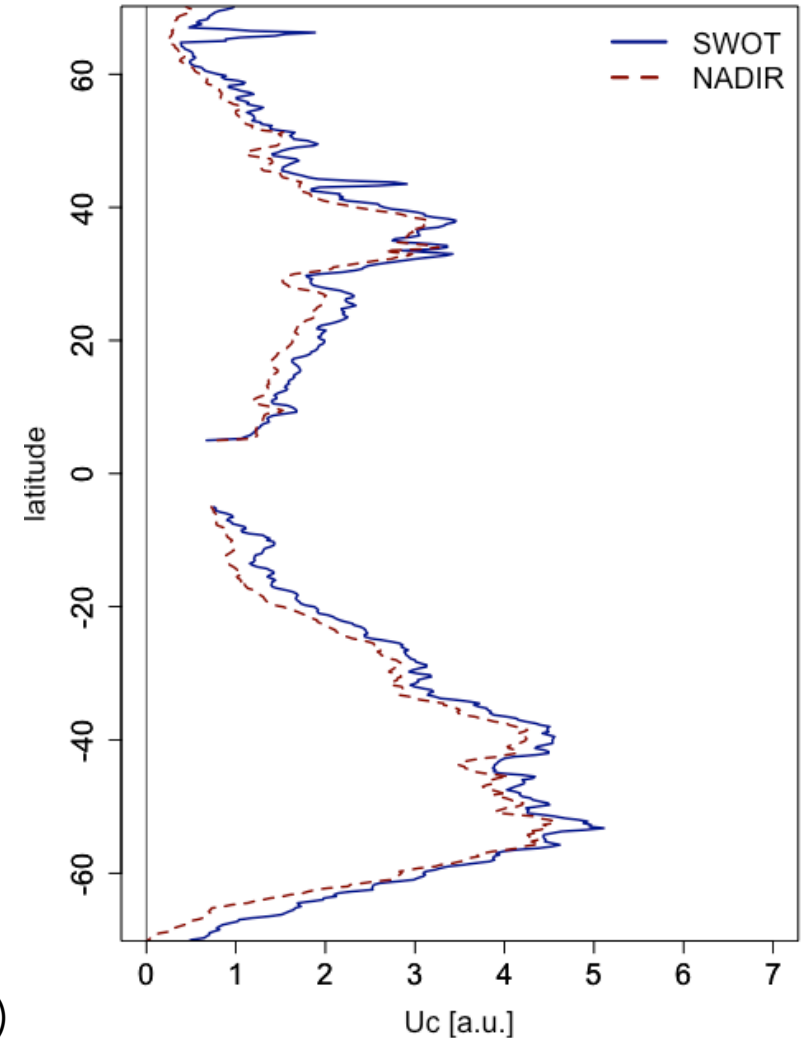
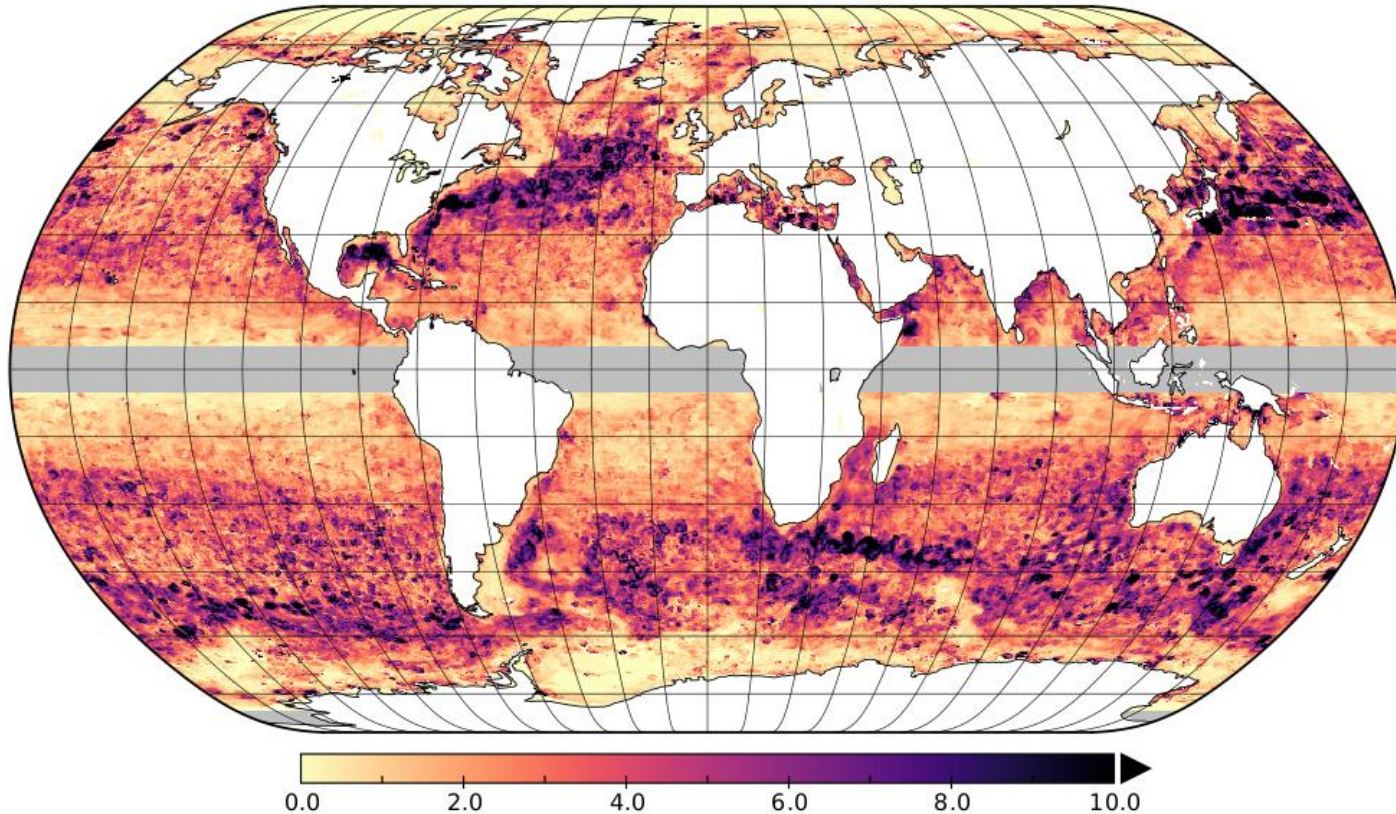
- Cyclonic eddies tend to have an equatorial-ward direction around 50S while anticyclonic eddies are mainly polarward around 60S



Non-linear eddies

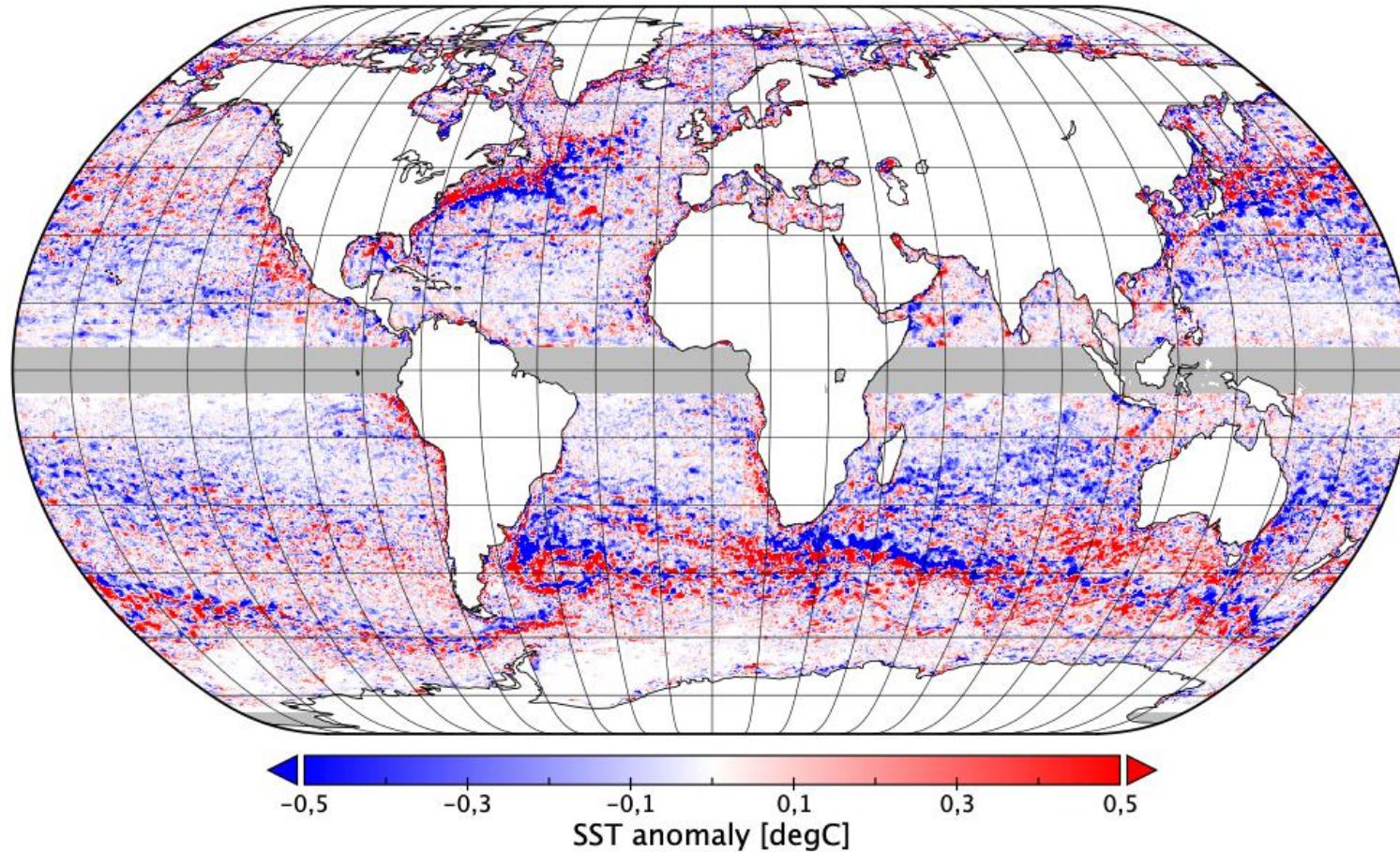
Advective non-linear parameter defined as the ratio between rotational speed (**U**) and the translational speed (**c**)

$U/c > 1$ eddies trap and advect fluid parcels as it propagates, preventing significant leakage of energy or tracers across its boundary.



Advective non-linear parameter in SWOT MIOST (eddy lifetime > 7 days)

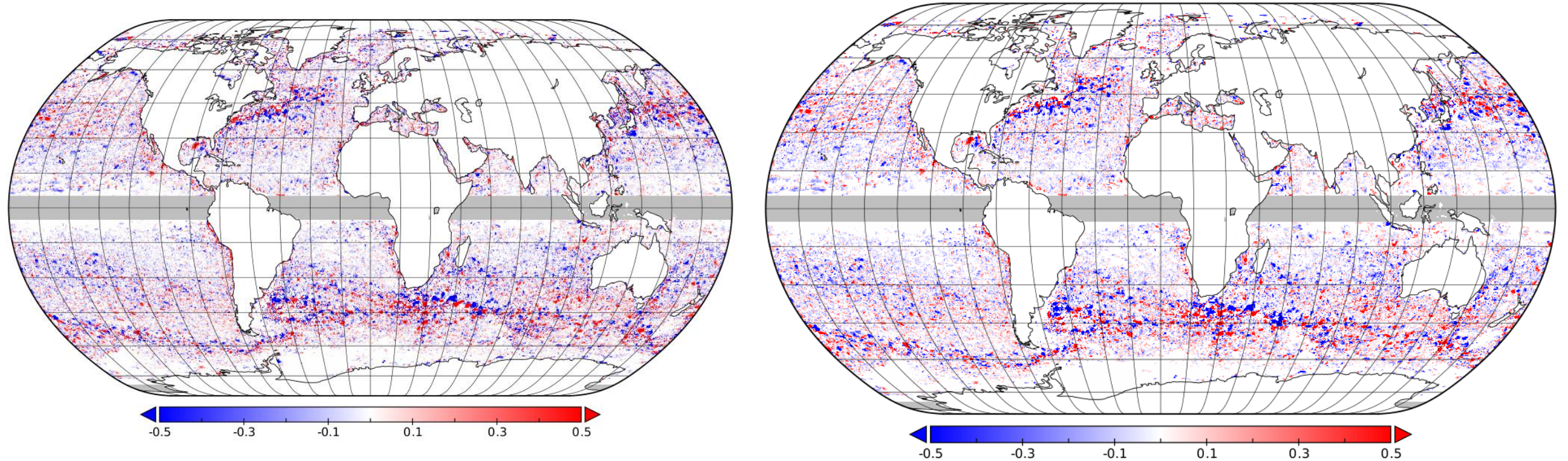
Eddie-induced SST anomalies



- **SST anomalies induced by non-linear eddies** ($U/c > 1$) detected from SWOT MIOST altimetry maps (lifetime > 7 days).



Eddie-induced SST anomalies



- SST anomalies induced by non-linear eddies detected from SWOT MIOST altimetry maps.
- Distribution SST anomalies induced by eddy lifetime > 7 (left) and > 28 days (right), when $U/c > 1$ in SWOT MIOST and $U/c < 1$ in NADIR



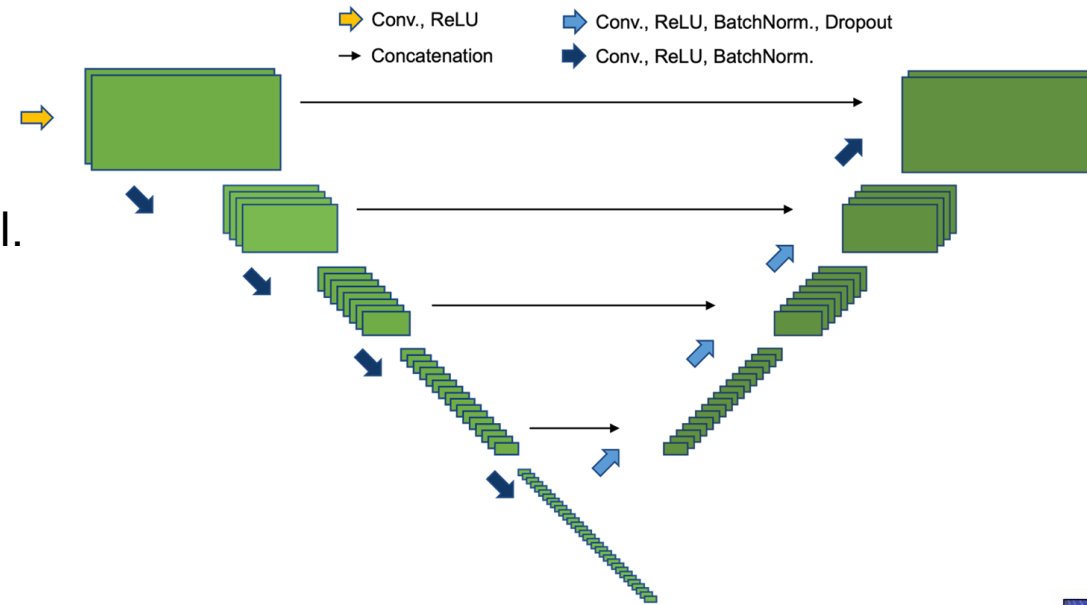
ML-based eddy Detection



nadir
or
SWOT

- SLA
- ugosa, vgosa
- surface phase vel.
- SST

ESA CCI



- eddy detection mask
- spatial SST anomaly

Loss function

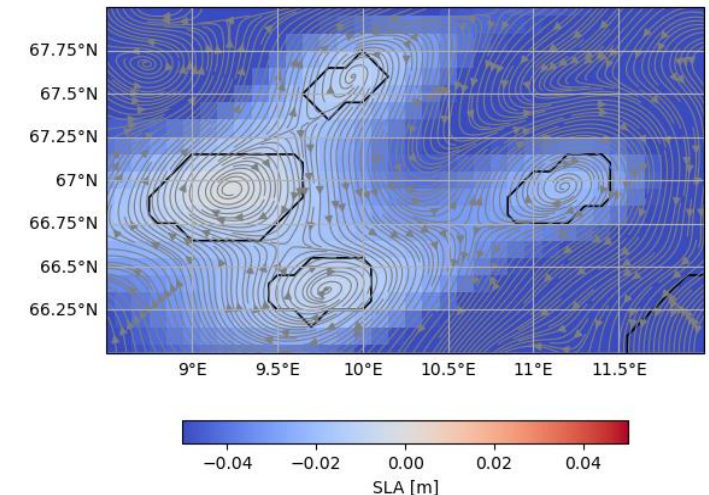
- Binary crossentropy
- Mean squared error
- 'coupling' terms
 - border
 - gradient

Training data:

- Global L4 altimetry maps (0.10°)
- Detections of the dynamical algorithm as target
- timeseries:
 - Jan '22 - May '24 conventional altimetry
 - Jul '23 - May '24 SWOT-enriched altimetry

Results:

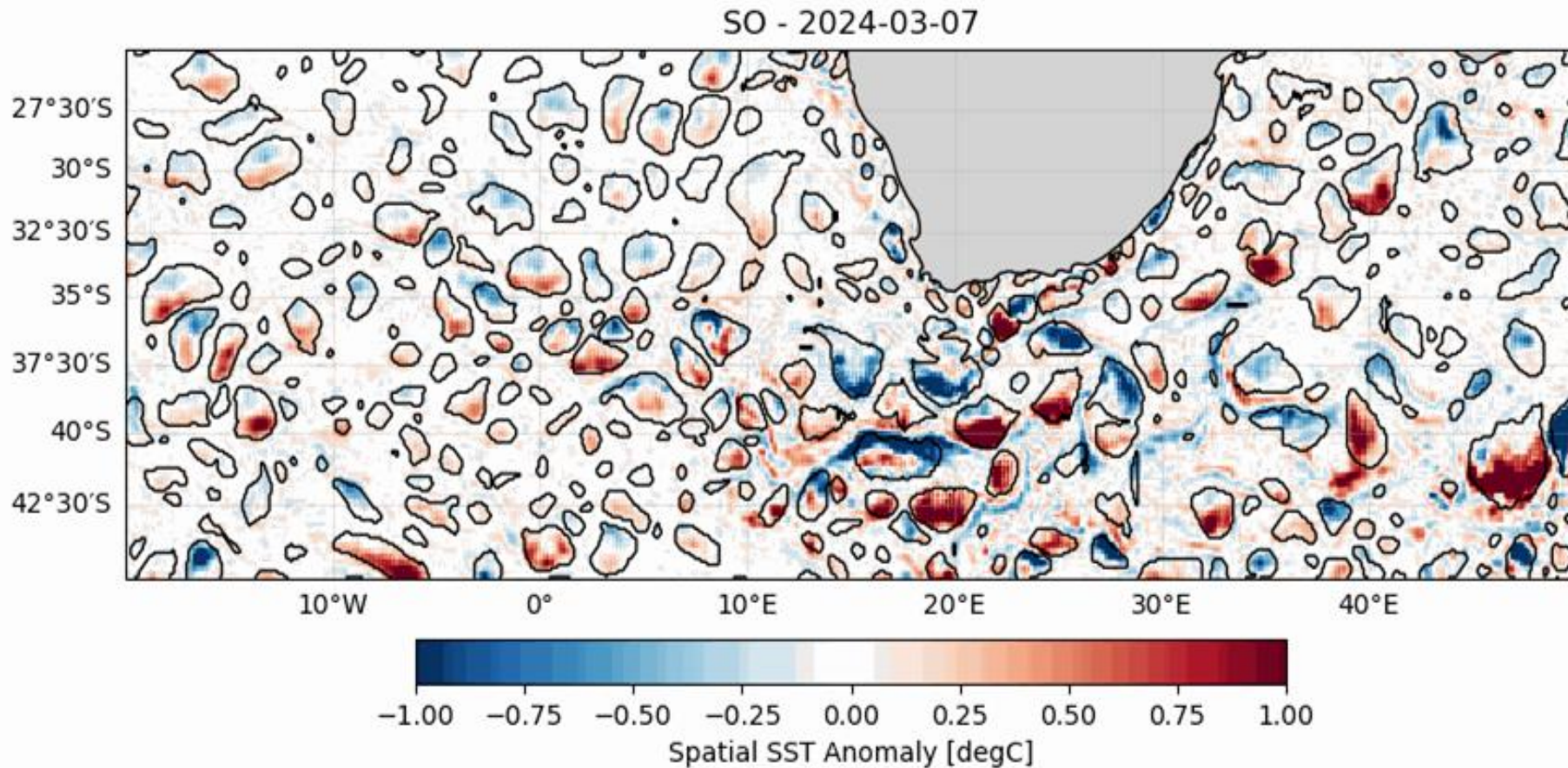
- multimodal input/output can improve detection compared to dynamical algorithm
- 30% more eddies even when applied to nadir data



ESA Water Project



ML-based eddy detection of active eddies



Spatial SST reconstruction of the U-Net with detected-eddies contours from SWOT data



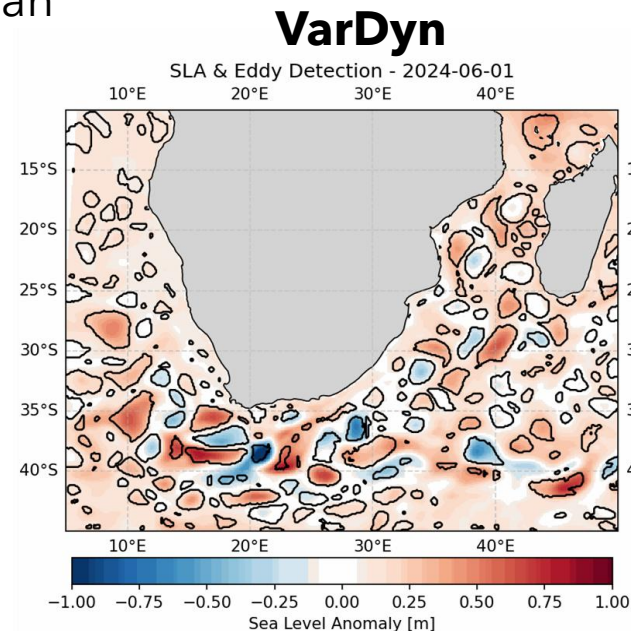
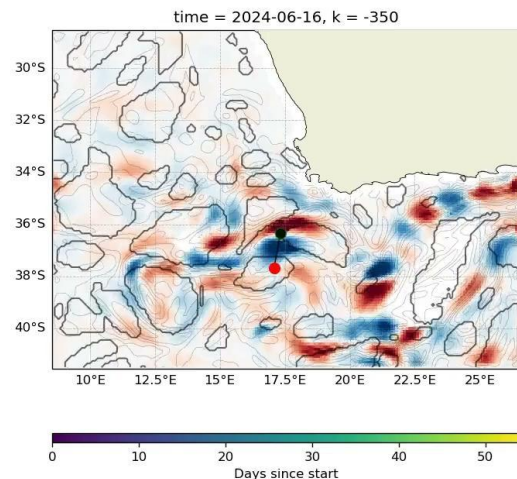
Take-home messages



- SWOT allows resolving more energetic mesoscale features (EKE) compared to conventional altimetry
- Highly non-linear eddies emerges for SWOT MIOST compared to conventional altimetry maps
- SST eddy-induced anomalies by non-linear eddies clearly emerge in the global ocean
- ML-based methods allows for the reconstruction of the mesoscale field and induced anomalies in the global ocean in a fraction of time compared to conventional methods

Perspectives

- Include other SWOT L4 products which also consider SST and SSS → **VarDyn** (LeGuillou et., 2025)
- Support the Field campaign planned in 2026 by the **ERC - WHIRLS Project**
- Contribute to **SWOT-NOR** and **SmartAgulhas Projects** – SWOT and OSTST Science Teams
- Contribute to Sentinel-1 / SWOT validation activities



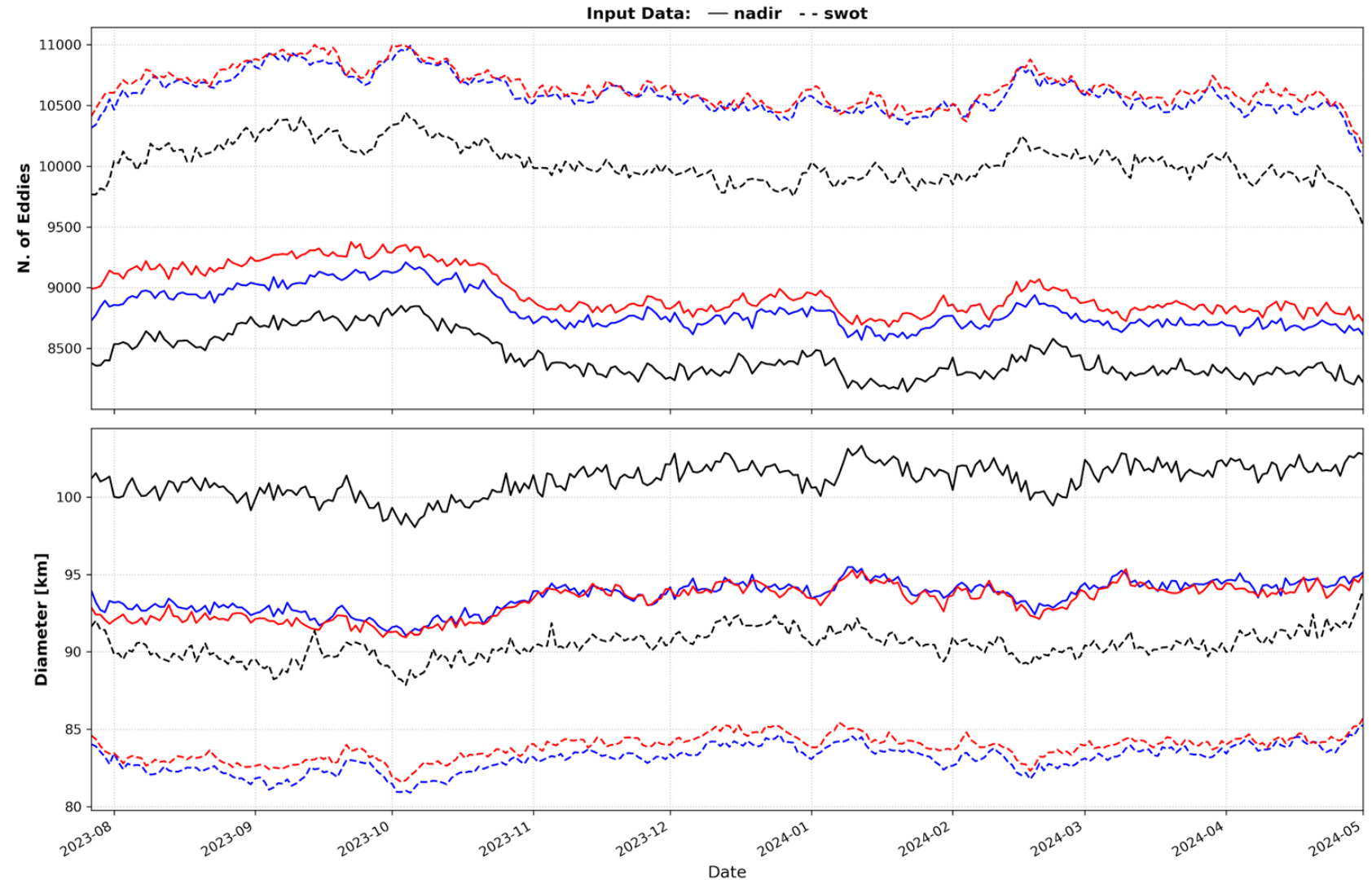
Discussion Slides

ML-based eddy detection improvements



Active and inactive eddies

- Nadir U-Net
 - SWOT U-Net
 - Dynamical algorithm
- larger population with smaller structures detected by U-Net
- little sensitivity to training data
- 30% more eddies detected by **SWOT U-Net** when applied to nadir data w.r.t. dynamical algorithm

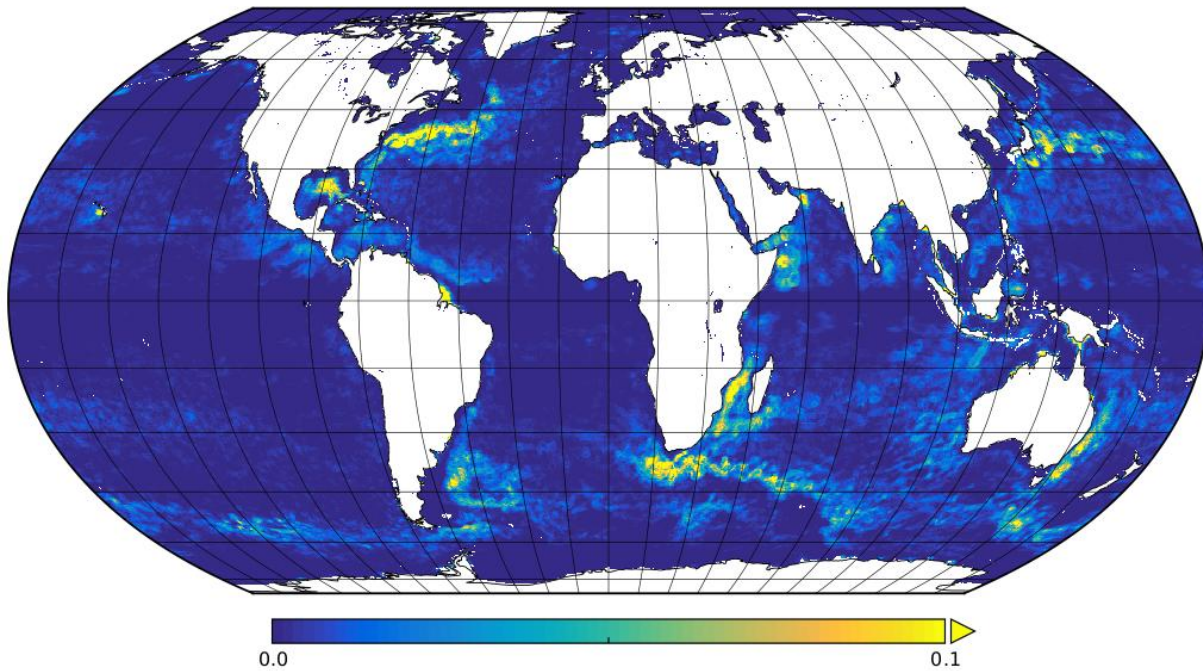


ML-based eddy detection: reconstruction of mesoscale field

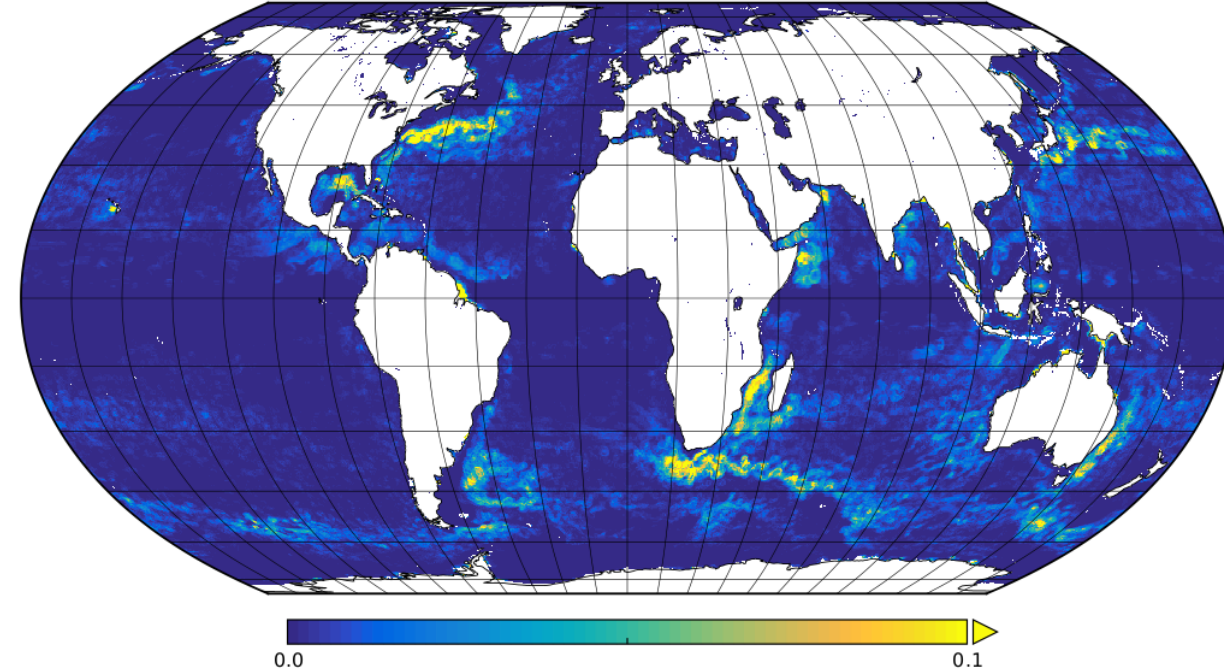


- Eddy-induced EKE (**Nov. `23 - May `24**) emerging from **SWOT** and **SWOT UNET** (eddy lifetime > 7 days)

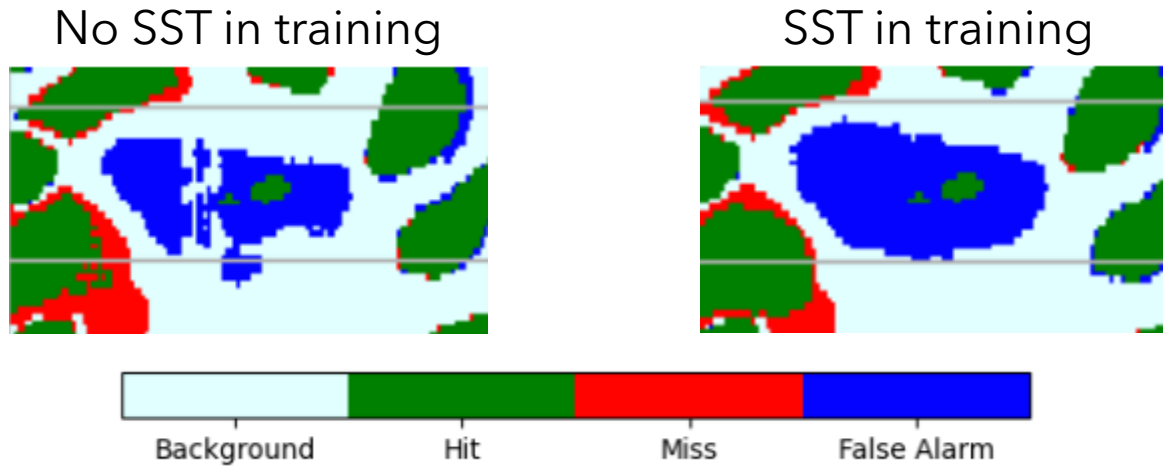
EKE - SWOT



EKE - SWOT UNET



Back-up: Impact of the SST



And these are arguably two different eddies:

