The Eddy Hunter System:

a data mining system for high-resolution eddy signals, leveraging spatio-temporal similarities in the SWOT satellite data

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Get in touch!

1 - SSH, Satellite Altimetry and the SWOT Mission

Sea Surface Height (SSH) is essential to understand the **ocean dynamics** [4]. Since 1980s, many **satellites** constantly survey the ocean surface, providing real-time, global SSH measurements.

On December 16, 2022, satellite altimetry entered a new chapter with the launch of the ***Surface Water and Ocean Topography*** **(SWOT)** mission: the satellite's ***Ka-band Radar Interferometer*** **(KaRIn)** enables previously unattainable **SSH resolution**, unlocking new possibilities for ocean scientists.

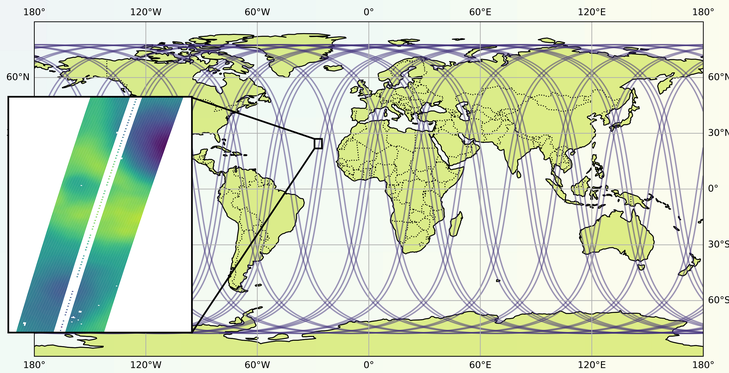


Figure 1. Ground track of the first 100 passages of SWOT's Scientific orbit (approx. 4.5 days).

2 - The Role of Mesoscale Eddies

Mesoscale eddies are defined by signals between **50 and 500 km**, evolving over periods of **10 to 100 days** [3].

They are relevant both for scientist and society, playing an **important role** in ocean's **food-chain** and **climate**, by transporting **heat, nutrients and salt**, vertically and horizontally [5, 1].

3 - Integrating SWOT and traditional satellite altimetry

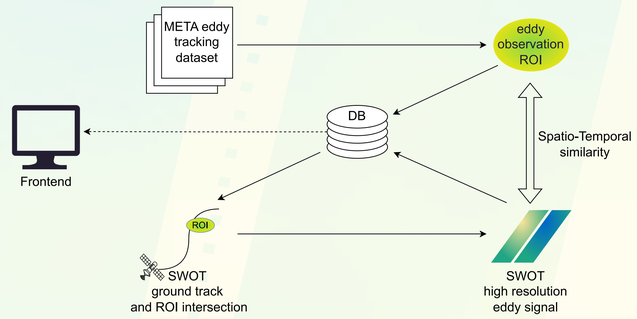
Eddy **detection** and **tracking** with SWOT are particularly **challenging** due to its **orbit characteristics** [2]: the narrow KaRIn swath often covers signals partially, moreover, the sensing cycle's orbit makes eddy tracking almost impossible.

We aim to overcome these limitations by **integrating SWOT** with **traditional satellite** altimetry and identify **high-resolution eddy signals** similar to a low resolution counterpart. In particular, our system combines the **Mesoscale Eddy Trajectory Atlas (META)** and **SWOT Level 3 KaRIn Nadir**.

4 - The Eddy Hunter System (EHS)

The **EHS** uses **spatio-temporal similarity** to find eddy signals in SWOT data:

1. For every observation in the META, a **Region Of Interest (ROI)** is computed:
$$ROI(x) = (c_u,\ c_v,\ t,\ \rho,\ \Delta t) \quad x \in META$$
2. SWOT's **ground track** inside the temporal window $[t - \Delta t,\ t + \Delta t]$ is computed.
3. Obtained ground track is **intersected** with the ROI.
4. If the intersection is not empty, reference is stored in the database.



5 - Use Case and Impact

SWOT has proven his revolutionary scientific value and is object of intense research, especially around **sub-mesoscale features** [4]. The EHS can enhance scientific research with SWOT in two distinct applications:

- As **Data Mining tool** to retrieve useful signals, fostering new discoveries in mesoscale and sub-mesoscale **physical oceanography**.
- Building a **high-resolution eddy signal repository**, allowing for advancements in applied **AI and ML in oceanography**, like eddy clustering or generative-AI SWOT interpolation.

6 - Conclusion and Future Research

The EHS could **improve usability** of SWOT data, fostering new sub-mesoscale and marine-applied AI research:

- Eddy detection **inside** SWOT data.
- Apply new methods within the **sub-mesoscale** scope (e.g. **feature extraction**, **similarity** measures and **clustering**).
- **Standardize** the access to **eddy signals in SWOT** data and create a new altimetry product.

7 - References

[1] R. Czeschel et al. "Transport, properties, and life cycles of mesoscale eddies in the eastern tropical South Pacific". In: *Ocean Science* (2018).

[2] C. Ma et al. "An Investigation of the Influences of SWOT Sampling and Errors on Ocean Eddy Observation". In: *Remote Sensing* (2020).

[3] R. Morrow and P.-Y. Le Traon. "Recent advances in observing mesoscale ocean dynamics with satellite altimetry". In: *Advances in Space Research*. Oceanography, Cryosphere and Freshwater Flux to the Ocean (2012).

[4] Y. Wang, S. Zhang, and Y. Jia. "Enhanced resolution capability of SWOT sea surface height measurements and their application in monitoring ocean dynamics variability". In: *Ocean Science* (2025).

[5] Z. Zhang, W. Wang, and B. Qiu. "Oceanic mass transport by mesoscale eddies". In: *Science* (2014).

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Background: eddy signal from Copernicus' SSH L4 products overlaid with correspondent SWOT data found with the Eddy Hunter System.