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Deep-EDDIES: A Deep Learning Framework for Oceanic Eddy Detection

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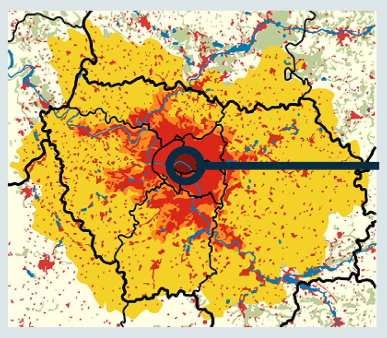
Background: What is an eddy?

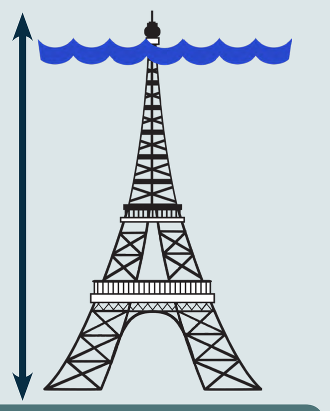
Mesoscale eddies are the "weather" of the ocean, with horizontal scales of tens of kilometers and timescales on the order of months. The mesoscale eddy field includes **coherent vortices**, as well as other structures such as filaments, squirts and spirals. It is is characterized by **temperature and salinity anomalies**, which extend to large depths, as well as **flow anomalies**. Eddies **carry large amounts of heat, salt, carbon and nutrients** around the ocean giving them a central role in ocean circulation and climate.

The increase of the spatial resolution in remote sensing observations revealed the prevalence of mesoscale eddies throughout the oceans. **Eddy Detection Algorithms** have been developed during the last ten years based on altimetry maps. They use geometrical and dynamical characteristics to detect and track vortex (eddy) contours *(Chelton et al., 2011, Mkhinini et al., 2014)*.

Eddies in the Mediterranean Sea...

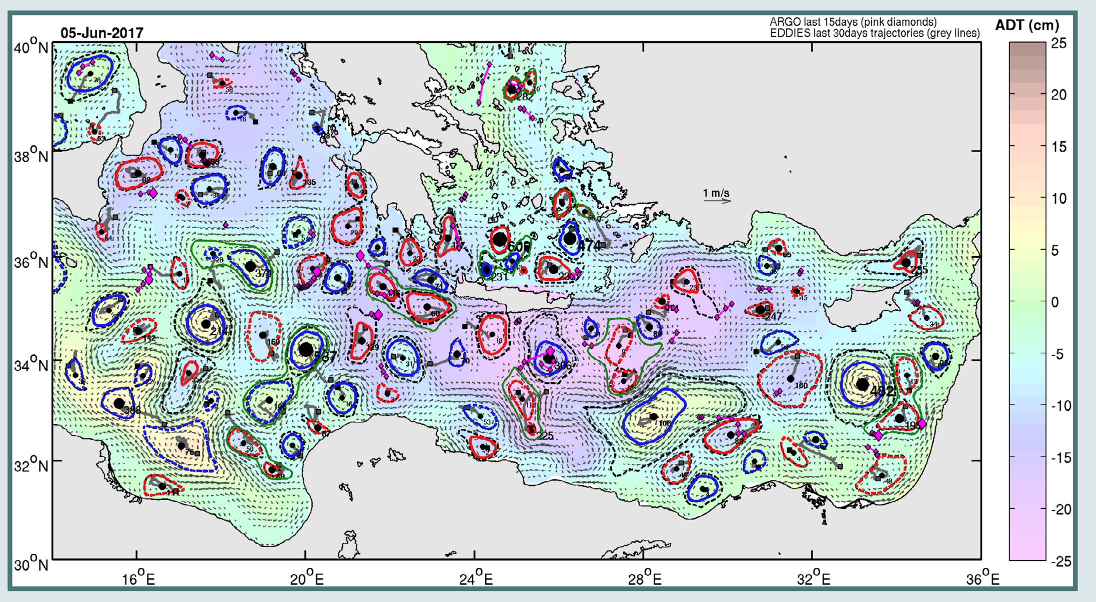


Can have a radius larger than that of the Paris Metropolitan area



Can go deeper than the Eiffel Tower sank

1 Eddy Detection from Satellite Altimetry: The DYNED-Atlas



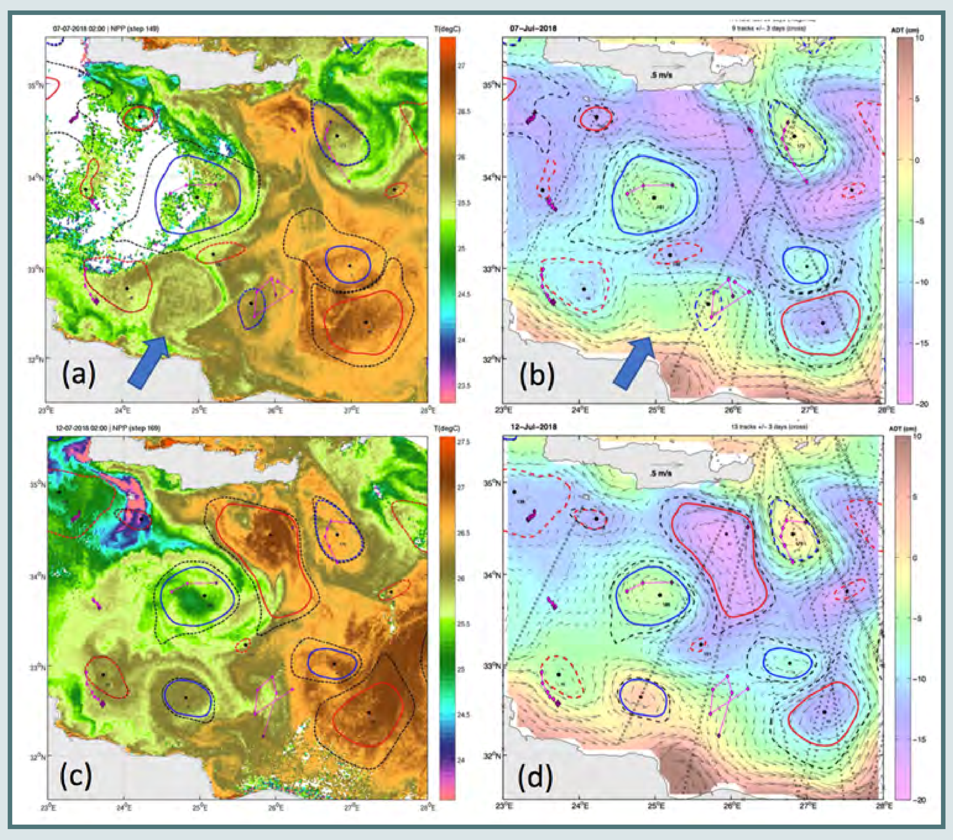
- **The AMEDA algorithm** *(Le Vu et al. 2018)* uses the Local Normalized Angular Momentum parameter to detect and track such closed contours, as well as their merging and splitting events.

- **The DYNED Atlas** consists of an unique database of surface intensified eddies for a 17 year period (2000-2017). Each detection provides **the center, the contour and the label of the eddy (cyclone/ anticyclone)**, along with other characteristics.

The Atlas is publicly available:
https://www1.lmd.polytechnique.fr/dyned/

Movie of eddy dynamical evolution:
https://vimeo.com/327967941

Sea Surface Height → Geostrophic Velocities → Cyclogeostrophic Surface Velocities *(Ioannou et al., 2019)*



Motivation

Mesoscale vortex structures, which have a signature on visible images, are not detected by standard eddy detection and tracking algorithms because their signature on AVISO / DUACS products is too low or disappears due to a local deficit of altimetry tracks.

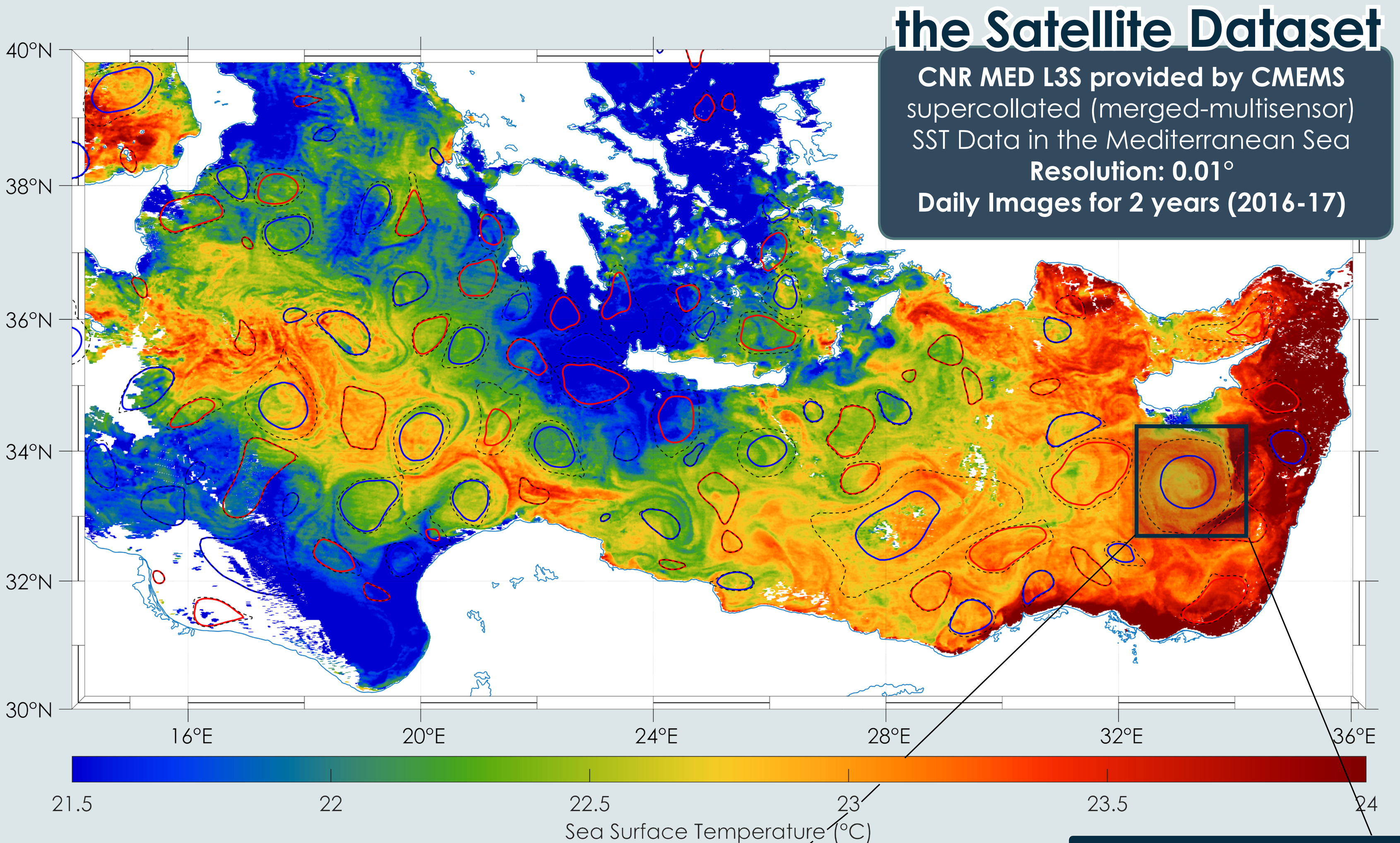
Using an OSSE study, *Le Vu et al (2019)*, estimated that the percentage of mesoscale eddies (R>18km) which are missed could reach 25-30% on the regional AVISO / DUACS products (1/8°) for the Mediterranean Sea.

Comparison between SST (a,c) NPP VIIRS (resolution 1/50°) and the altimetry maps provided by AVISO/DUAC at 1/8° (b, d). The 7th of july 2018 an eddy signature is visible on the SST image (a) while according to the surface geostrophic velocity (b) there is no closed streamlines (cf blue contours). Five days later, the 12th of July 2018, the anticyclone which still have an SST signature (c), can be detected on the AVISO/DUACS product (d) thanks to an altimetry tracks (dashed line) crossing its diameter. Red (blue) contours correspond to cyclonic (anticyclonic) eddies detected by the AMEDA algorithm.

2 Sea Surface Temperature Imagery

the Satellite Dataset

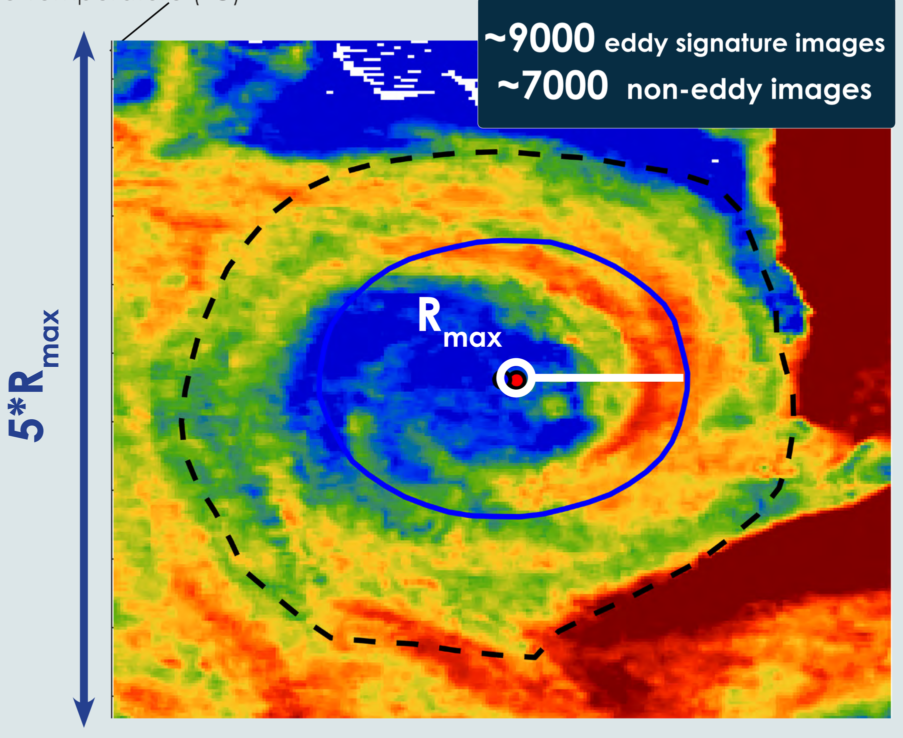
CNR MED L3S provided by CMEMS
supercollated (merged-multisensor)
SST Data in the Mediterranean Sea
Resolution: 0.01°
Daily Images for 2 years (2016-17)



Vortex signatures are visible even by eye on the Sea Surface Temperature imagery: fronts, gradients and swirls are located everywhere in this picture of the SST in the Mediterranean the 5th of June of 2017.

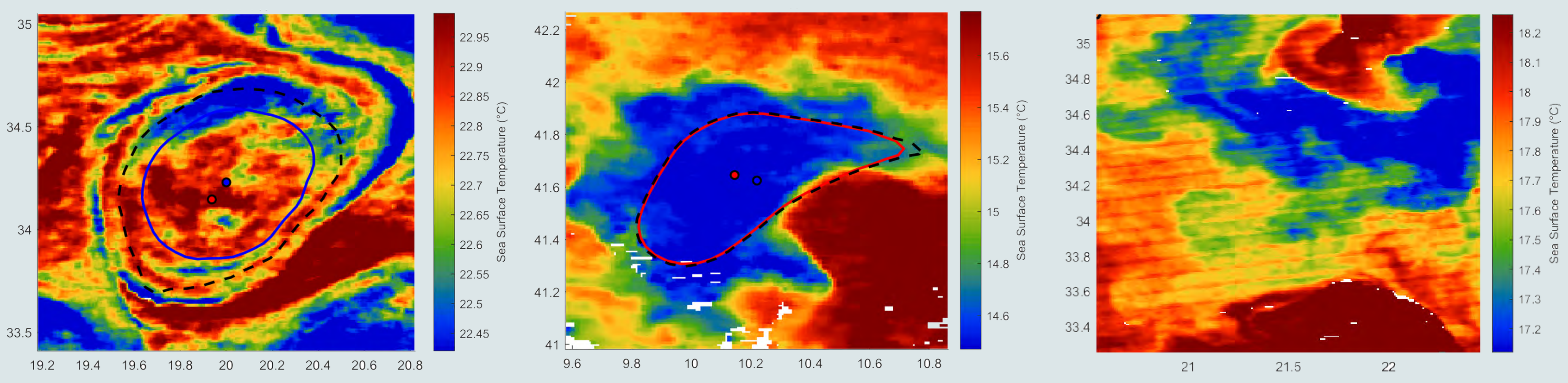
To receive images containing an eddy signature:
-**Eddy locations are identified** through the AMEDA.
-**A reliability index** allows us to separate regions with high satellite track density.
-**A box is cropped** based on the radius of an equivalent circle to the maximum eddy velocity contour.
-**The image is interpolated** (nearest-neighbor) to a constant size of 230x230 pixels (2.3x2.3 °).

To receive images without an eddy signature, we search for boxes of a variety of sizes which do not contain eddy any eddy contours in a central area of interest, and no eddy centers in the cropped box.

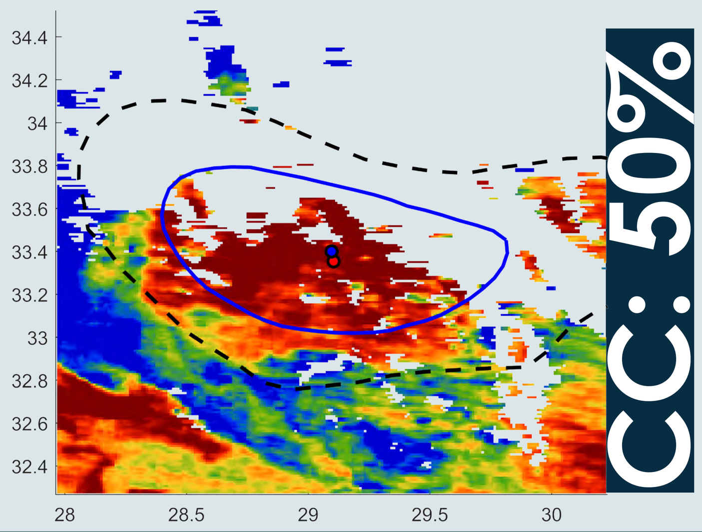


3 The Dataset: Labeled SST Images

Eddy and Non-Eddy signature Images with three labels:



Cloud Coverage (CC) can create missing data in eddy imagery:

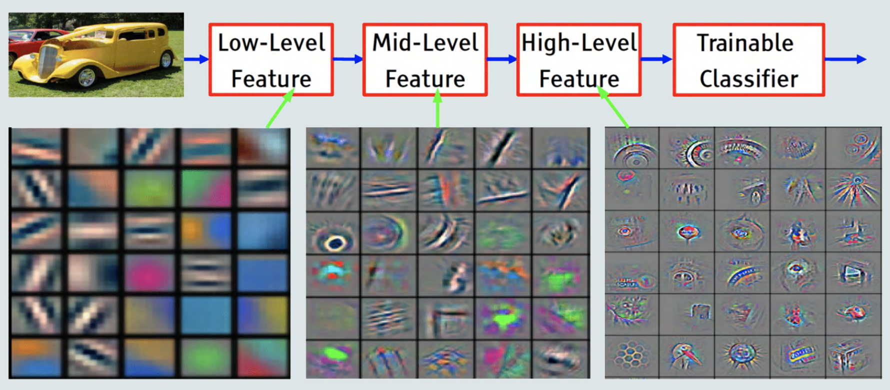


Images with CC>50% are excluded.

Seasonal Variabillity

- Cloud coverage higher in winter
- Different SST patterns between seasons due to mixed layer

4 Transfer Learning with a ResNet



- **Transfer learned features from a ResNet18 petrained on Imagenet**
- **Finetuning: All layers are unfrozen**
- **One Channel Input**
- **Train 75% / Test 25%**
Train Incl. 10% Validation

5 Learning: Tasks and First Results

1 Eddy Detection

random sampling on the Dataset

SST IMAGE → EDDY SIGNARURE / NO EDDY SIGNATURE

Score: 91%

2 Binary Classification

on eddy images

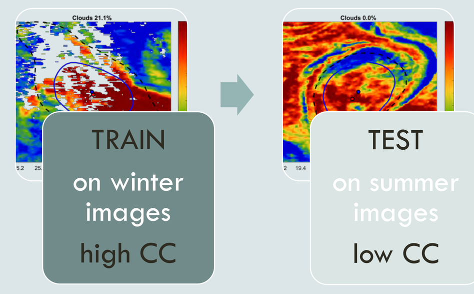
SST IMAGE → ANTICYCLONE / CYCLONE

Score: 94%

3 Domain Adaptation

due to Seasonal variability

Score: 86%



6 Improvements and Potentials

Improve accuracy of detection on individual images:
- **Multi-modal input** through other satellite imagery (SAR, Ocean Color)
- **Learning methods for missing data** (Pajot et al., 2018)

Improve accuracy of localization on a wider domain:
- **Tracking of eddies** with a recurrent network
- **Increasing sensitivity** to eddy detection, by reducing specificity

Potentials of the trained detector on a larger domain

- Validating the reiliability of the physical detector (AMEDA).
- Eddy localization and segmentation in the Mediterranean Sea.

References

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