COASTAL & MARINE RESEARCH LABORATORY
IACM - FORTH

MEEO
Meteorological Environmental Earth Observation

A near real-time oil spill detection and forecasting Ocean Twin

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ENVIRONMENTAL CRIMES WORKSHOP 2024

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esa

Iliad in a seashell

Iliad

Enabling an ecosystem of interoperable digital twins for the ocean trough:

- Connecting to *existing* ocean data infrastructures
- Enhance ocean data infrastructures with *additional* observation technologies and citizen science

Create an open marketplace accessible for all providers and users by:

- Development of *innovative methods* in open frameworks and platforms
- Enable model *evaluations* & *comparisons* for many Earth science applications from weather, energy, aquaculture to climate and more
- Facilitate the reuse of the knowledge and components

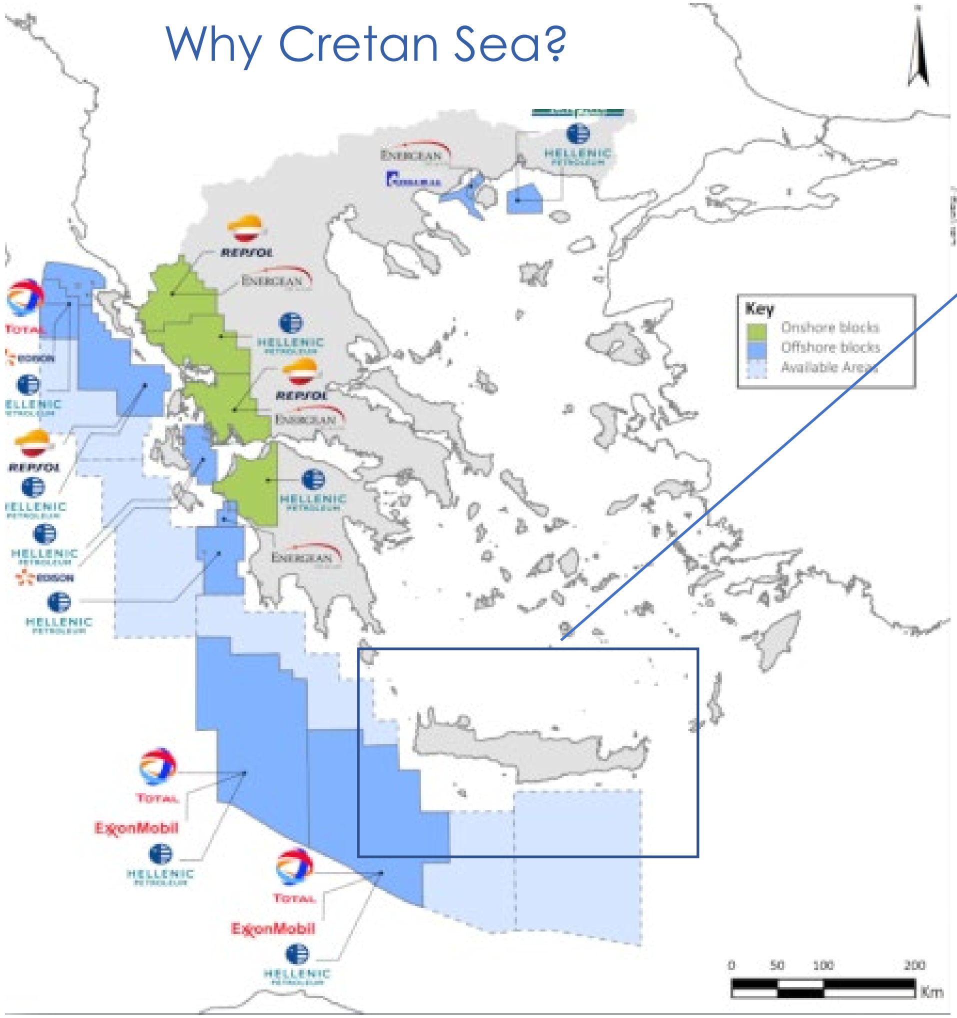
Provide solutions to address market needs by:

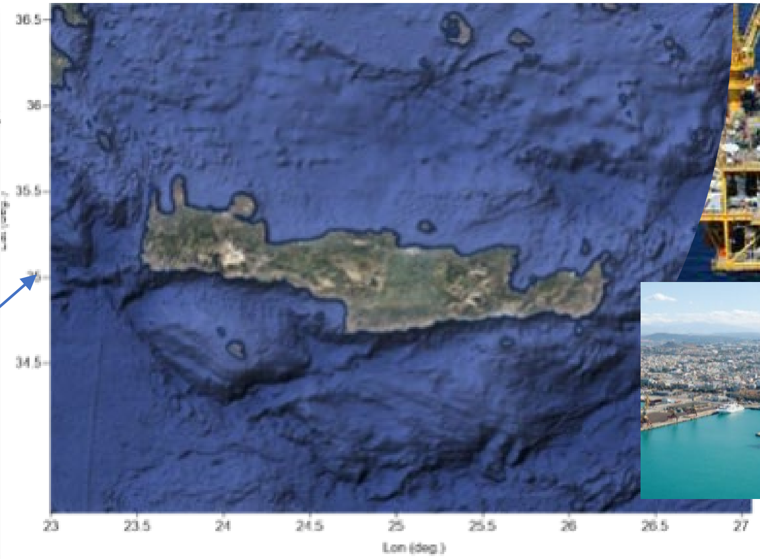
- Assembling a broad and diverse *user community* of existing and new users,
- Supporting the communities in testing and using the project's *innovative technological solutions*

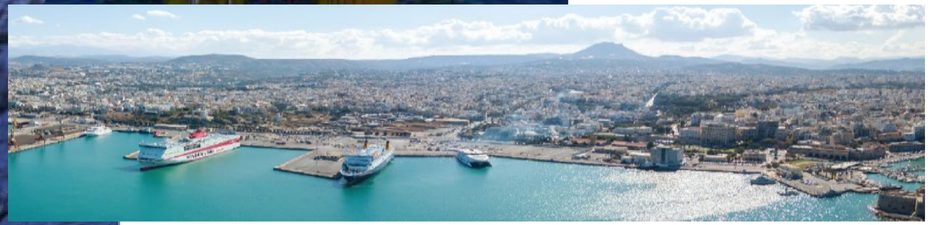
A Digital Ocean Twin for Response to oil spill events

Iliad

Why Cretan Sea?







- Area of high economic interest and human activity
- An important **ecosystem** – climate change hotspot
- The most **voluminous** and **deep** (2500 m) basin of the Aegean Sea
- Recent exploration and exploitation activities for offshore oil and gas
- **Port of Heraklion** - the third highest passenger traffic in Greece
- Main end users: Hellenic Coast Guard, Port of Heraklion, Shipping Industry, Shipping sector (e.g. Minoan lines)

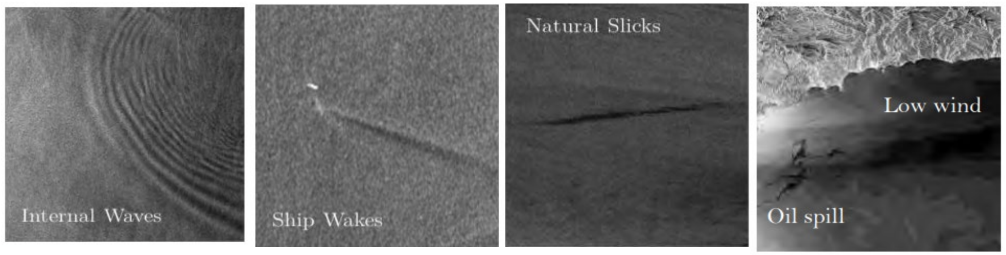
The Near-Real time Oil spill Detection system – Introduction and satellite monitoring

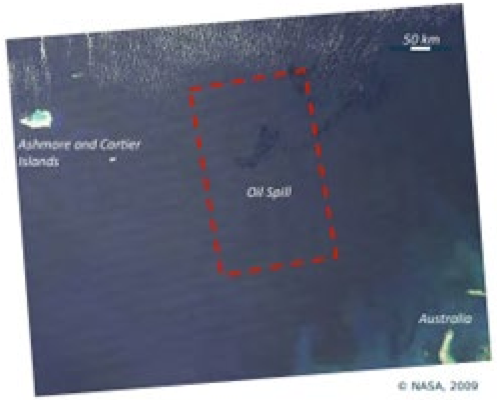
- **Oil Spills Definition**
  - Release of liquid hydrocarbons, primarily petroleum products.
  - Major threat to marine ecosystems globally.

- **Operations Polluting the Sea**
  - Ballast water
  - Tank washing residues
  - Engine room effluent discharges
  - Accidents: high in number, but not always large volumes.

AIS database helps link spills to sources, but some spills result from illegal oil dumping

- **Satellite Monitoring Challenges**
  - Look-alikes: difficult to distinguish spills from algae or wave patterns.
  - Revisit time: unpredictable events; satellite passes may miss spills.
  - Weather Conditions: cloud coverage and poor weather affect optical data.





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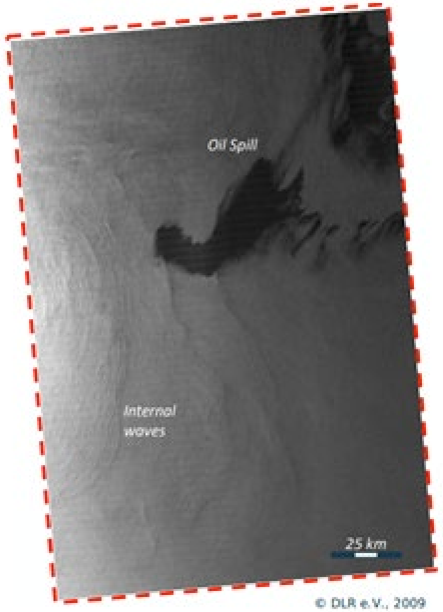

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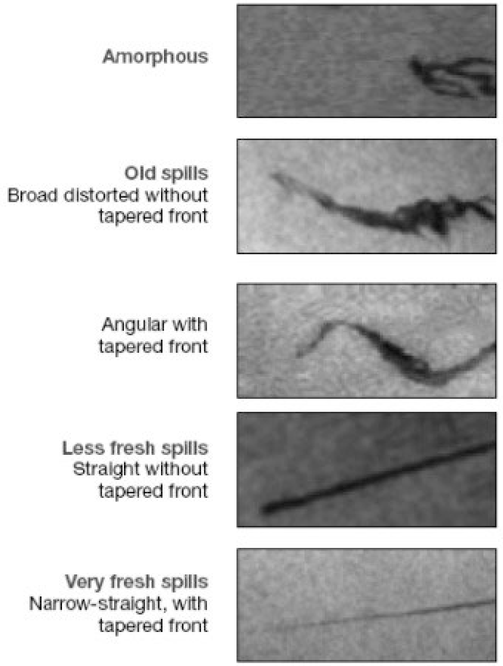
The Near-Real time Oil spill Detection system – The project

- **Spill Evolution and Prediction**
  - Spills vary in size and are influenced by currents and winds, making trajectories prediction difficult.
  - Example: Syrian oil spill in August 2021 showed signal overestimation near the coast.

- **Innovative Solutions with Iliad**
  - New methods to detect and forecast oil spills using wind and ocean current and wave data.



Cretan Sea Digital Twin components & novelties

Data download & Preprocessing

- **ASF database search API**
  - Historical Search → Specific Images downloaded
  - Monitoring → Bounding Box as parameter

Image Manipulation

- SNAPpy → speckle filtering ---> linear to dB

Object Detection

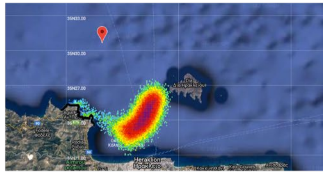
- **FCOS Neural Network** → Previously-trained model FCOS, fine-tuned with a dataset of +1000 SAR images, including 4 different classes (oil spill, look-alike, ship, land) → Bounding Boxes (CSV)

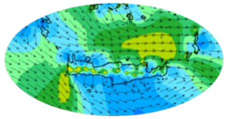
Signal Extraction

- Semantic Segmentation → U-Net
- SNAPpy based → Adaptive Thresholding Algorithm

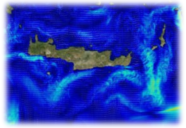
OIL SPILL MODELS

- **Trajectories**
- **Oil weathering**
- **Vertical dispersion**
- **Wave entrainment**

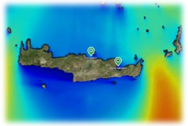




WRF (~ 3 X 3 km)



NEMO (~ 1 X 1 km)



WW3 (~ 1 X 1 km)

Twin overview:

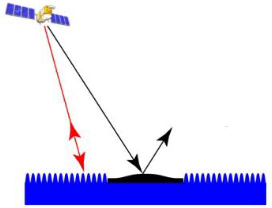
1) Detection
2) Forecasting

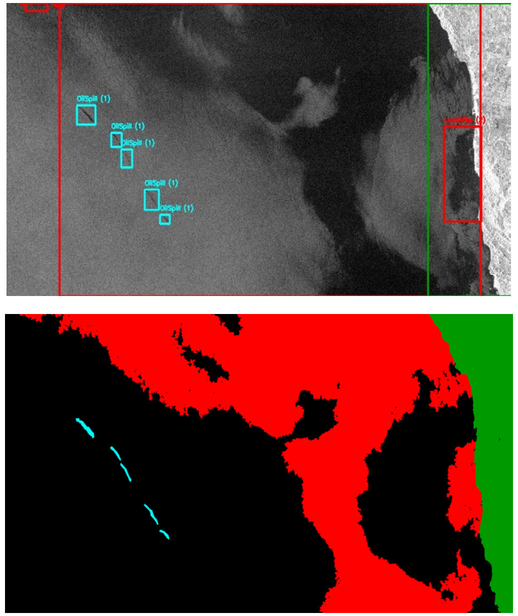
The Near-Real time Oil spill Detection & Forecasting system – AI Detection

Part 1: Detection

Since performing segmentation of oil spills on a big SAR image in an automatic way is nearly impossible, the basic idea is to perform object detection to locate the oil spill, crop the interested portion of the image (with a padding) and then perform segmentation.

- **Data Download and Input**
  - Sentinel-1 SAR data downloaded from the ASF search API, applied speckle filtering to VV polarization and converted to decibels (dB).
- **Image Enhancement**
  - Contrast function to enhance the oil spill signal.
- **AI Detection Workflow**
  - Object detection and semantic segmentation using AI.
  - Pre-trained models fine-tuned with 1000+ SAR images (oil spills, land, look-alikes, ships).
  - **Object Detection**: Generates bounding boxes for oil spill signals. → **FCOS Model**
  - **Semantic Segmentation**: Segments oil spills within each bounding box. → **UNet Model**
  - Combination of **FCOS** and **UNet** improves accuracy by reducing noise.
- **Traditional Methods**
  - Statistical approaches included in segmentation step of the pipeline.
- **Output**
  - Binary GeoTIFF mask feeded to the forecasting oil spill model.



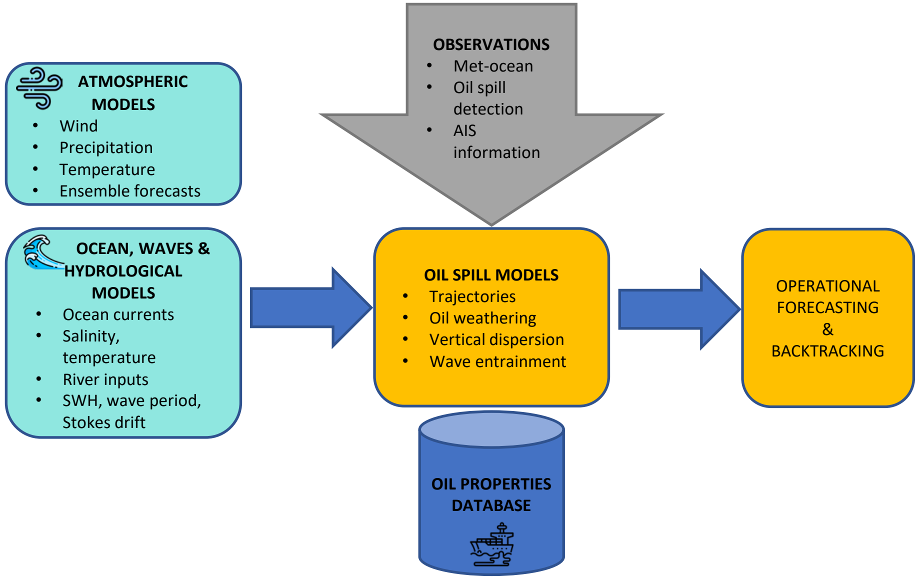


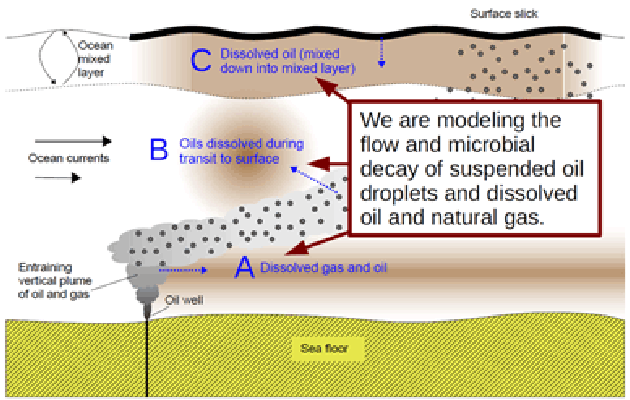
Object detection (above) and semantic segmentation (below) dataset images

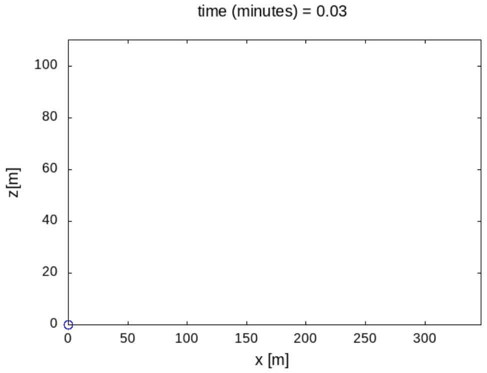
The Near-Real time Oil spill Detection & Forecasting system – Forecasting oil spill fate & transport

Part 2: Forecasting of spill trajectories

- Utilize wind and ocean current data to predict oil spill evolution, in-situ met-ocean data from existing sensors and novel sensors deployed in the frame of Iliad
- Multi-model approach - for predicting the spill trajectories:
    - **MEDSLIK-II** and **OpenDrift** oil spill models coupled to operational high-resolution weather (WRF), hydrodynamic (NEMO) and sea state (WAVEWATCH III) models for Cretan Sea
- Improved **oil weathering algorithms,** as well as vertical dispersion and wave entrainment, define the physicochemical state of the oil as it reaches the coasts
- **Deep-Sea** oil spill jet/Plume model, including microbial decay of oil droplets, dissolved oil and natural gas, defines the oil fate until it reaches the surface; crucial for minimizing environmental impact of offshore deep-sea oil spill incidents





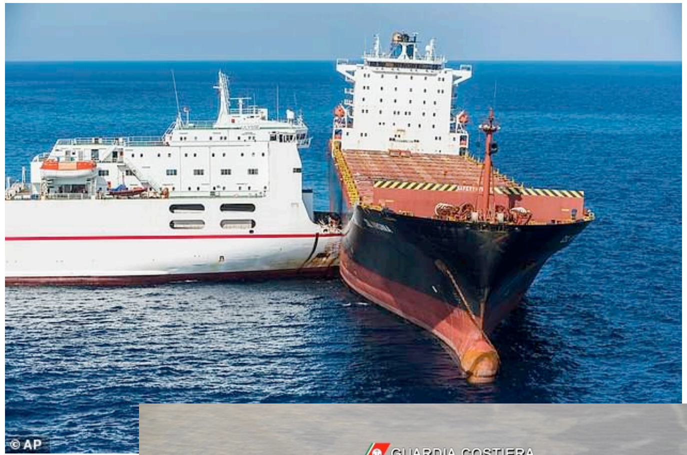


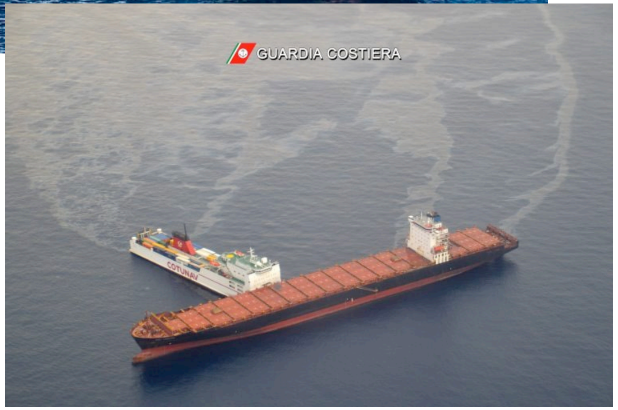
Reconstruction of SINTEF deep sea experiment

- Where will the oil spill move to?
- How soon will it get there?
- What will its state be when it arrives?
- What resources are threatened?

Evaluation of the oil spill detection & forecasting system-The 2018 Corsica oil spill

The near-real time oil spill detection and forecasting system has been evaluated by reconstructing the oil spill caused by the collision between the Ro-Ro ship Ulysse and CSL Virginia on October 7th, 2018, off the coast of Corsica.



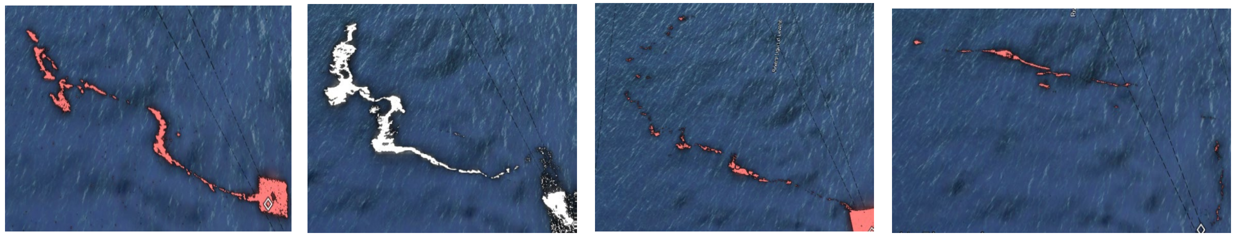


Accident timeline

- **October 7th**, 6:30 am, UTC: the Tunisian vessel Ulysse collides with the Cypriot container ship CSL Virginia around 28 km north of Cap Corse;
- The collision caused the leak of **530 m^3** of Bunker fuel. That day the spill spread over **25 km** and formed **7 distinct slicks.**
- Between **October 8th and October 14th**, Sentinel-1 images detected the oil spill location
- Spill monitoring and cleanup were performed as a part of international efforts to address pollution accidents in the Mediterranean – involvement of REMPEC
- Ulysse separated from the hull of Virginia on October 11th
- On **October 16th** tar balls were spotted on Saint Tropez beaches (CEDRE, 2018)
- Reached the Spanish coastline by September 19th (CEDRE, 2018)

Data and methods

- **<u>Observational Data:</u>** input data for the oil spill detection algorithms consist of 10m-resolution dual-polarization Sentinel-1 images acquired with the Interferometric Wide Swath (IW) Ground Range Detected mode at high resolution (GRD-HD)
- **<u>Oil Spill Detection</u>:** oil detected between 8th and 14th October. FCOS model employed of Object Detection, **SNAPpy-based** adaptive thresholding algorithm and **Semantic Segmentation** for oil spill delineation.



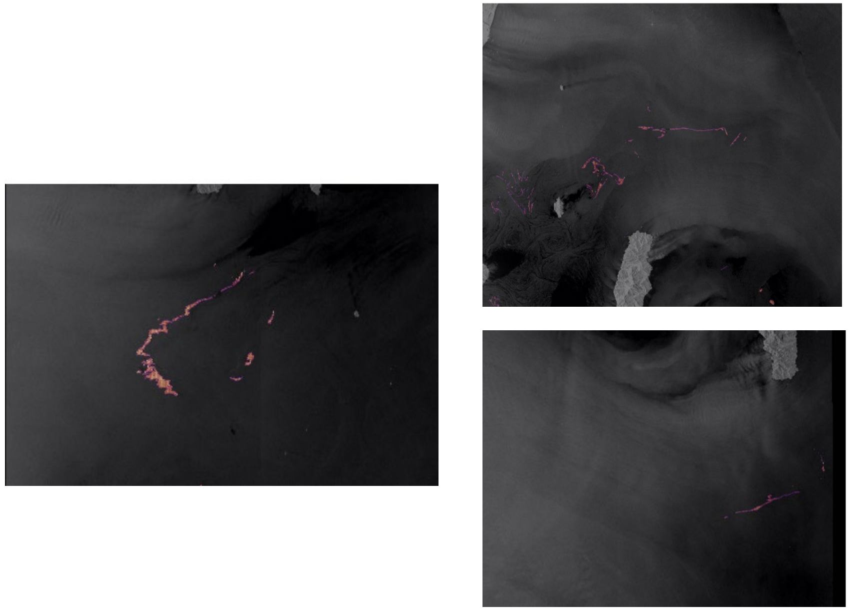
8-10, 05:28 UTC~25 km long

8-10, 17:21 UTC~35 km

9-10, 17:14 UTC~60 km

14-10, 05:27 UTC

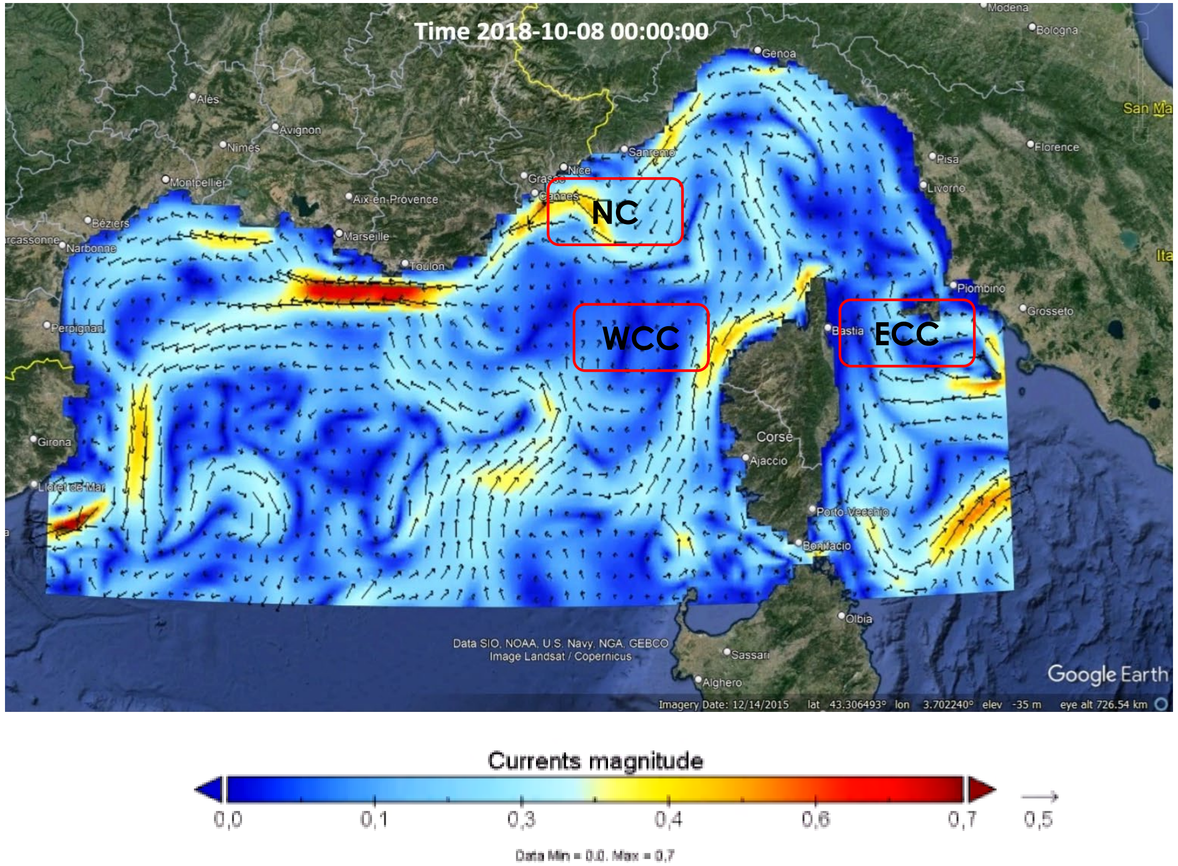
Examples of segmentation masks using SNAPpy thresholding algorithm



Examples of segmentation masks using Sentinel-1 images 9-10 17:14 UTC, 14-10 05:27 UTC, 14-1017:22 UTC

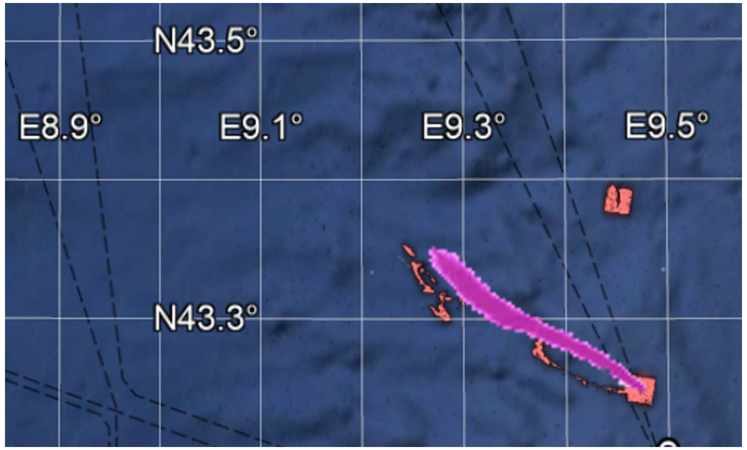
Data and methods

- **Model:** Medslik-II oil spill model is used to simulate the oil spill fate and transport between 7th October-18th October.
- **Forcing data:** The model is forced with hourly CMEMS ocean (currents & waves) reanalysis data and ECMWF 6hr analysis atmospheric fields

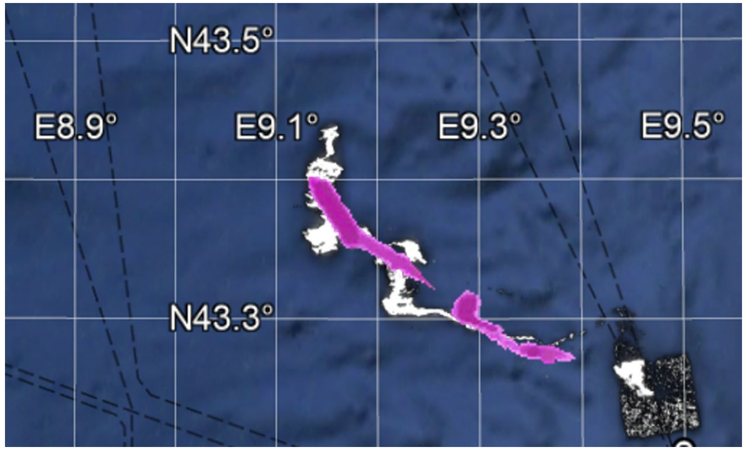


- **Oil spill simulation scenario:** Following CEDRE data, around 525 tons of oil, with density of 974 kg/ m^3 were spilled. A continuous point spill is assumed, at the point of the collision, of 64 hours duration.
- **Model parameters**, and windage applied to the motion of the oil, were adjusted to have a good agreement between model output and observations
- **Modelling methodology:** As oil spill modelling results tend to accumulate errors, due to the intrinsic simplification of the oil behaviour, Medslik-II had been reinitialized with updated observation patterns (4 times).
- **Forecasting performance:** evaluated by comparing modelled trajectories with Sentinel-1 images. Different Metrics are used to assess model's skills.

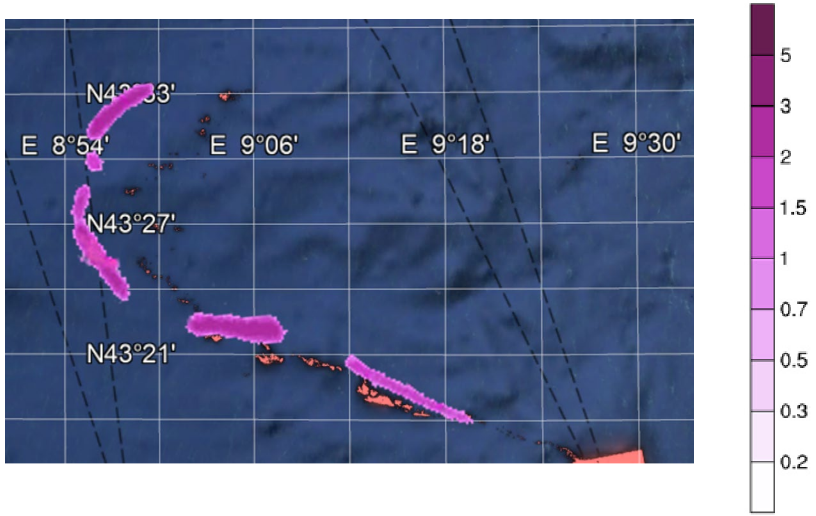
Model-based oil spill reconstruction – Results & Discussion



8-10, 05:28



8-10, 17:21



9-10, 17:14

tons/ m^2

Forecasting skills metrics

Lagrangian Separation Distance (LSD)

$$d_c(x_c^{mod}(t_i), x_c^{obs}(t_i))$$

Centroid Skill Score (CSS)

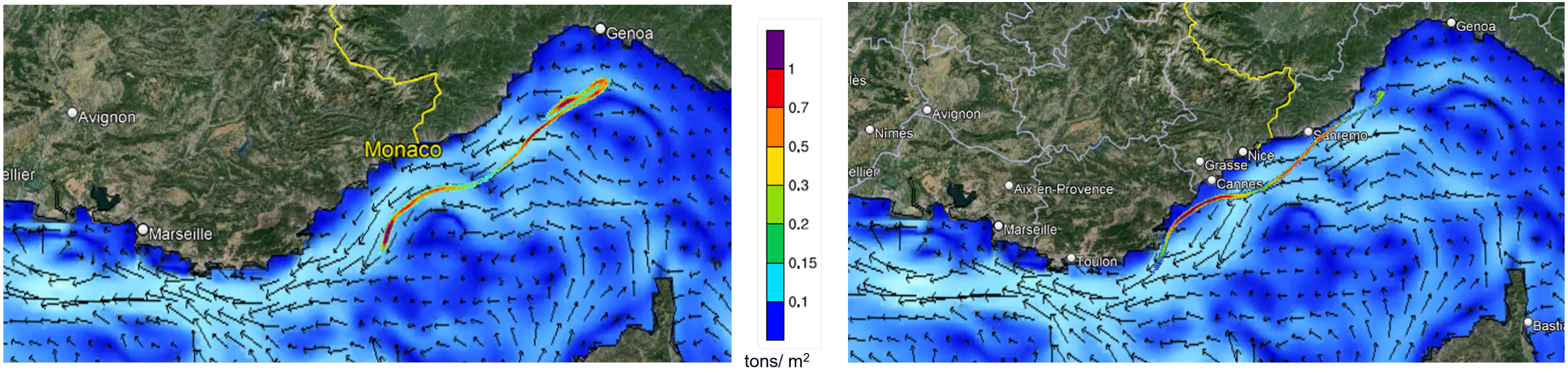
$$\text{CSS} = 1 - \frac{C_I}{C_{\text{thr}}}, \quad \text{for } C_I < C_{\text{thr}} \qquad C_I = \Delta x / L_{\text{OBS}}$$

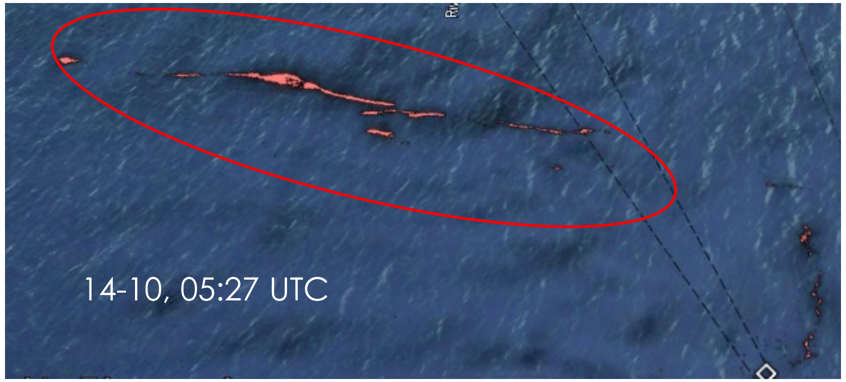
$$\text{CSS} = 0, \quad \text{for } C_I > C_{\text{thr}}$$

Observations	LSD (km)	Observed Length (km)	CSS
8-10, 05:28	3,5	11,2	0,81
8-10, 17:21	4,6	19,8	0,75
9-10, 17:14	9.4	28,8	0,85

Model-based oil spill reconstruction – Results & Discussion

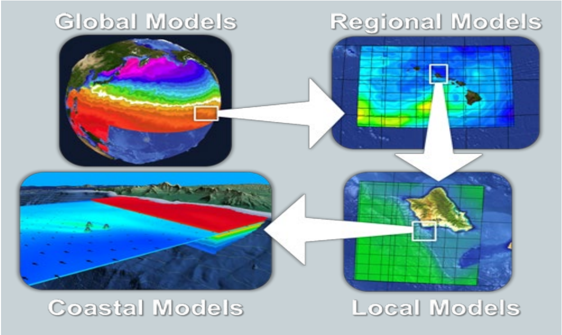
Modelled oil concentration on October 18th, 12:30 pm

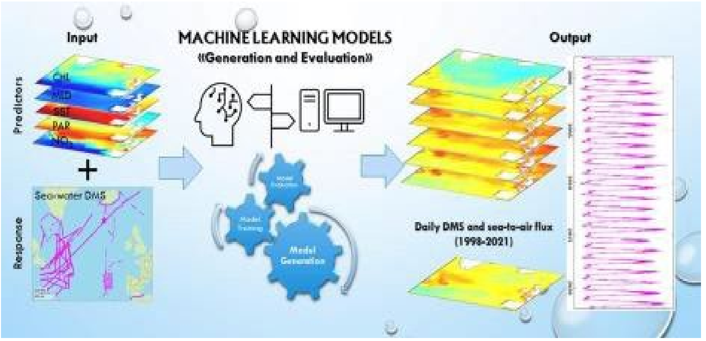




Next steps, Conclusions & Outlook

- A natural next step for the spill detection is to improve the pipeline to include **optical data** (with some limitations), which will help filling the gaps between SAR detection and therefore allow for a better result from the forecasting model, which is **re-initialized** every time there is a new signal to improve the prediction of the spill trajectories.
- Sensitivity analysis of the physical parameters of the forecasting Lagrangian model for assessing their impact on model results
- Including uncertainty assessment on trajectories forecasting (uncertainty of initial conditions of the spill, wind ensembles)
- Testing the performance (accuracy, speed) of the full pipeline for Cretan Sea
- High-resolution ocean currents and winds are expected to enhance the accuracy of forecasts for Cretan Sea.
- Multi-model approach also contributes to reducing uncertainty of forecasts






Thank you