Modelling of oil spills

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October 2023

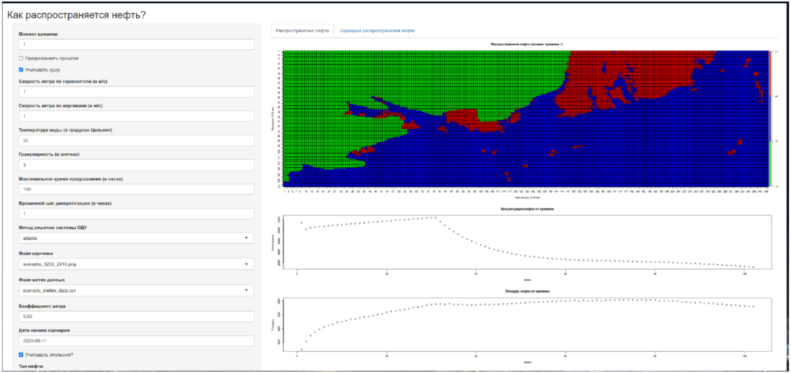
Statement of the problem

Examples of oil spills: Deepwater Horizon (2010), Wakashio Oil Spill (2020).
Given high precision satellite images, it is necessary to provide opportunities:

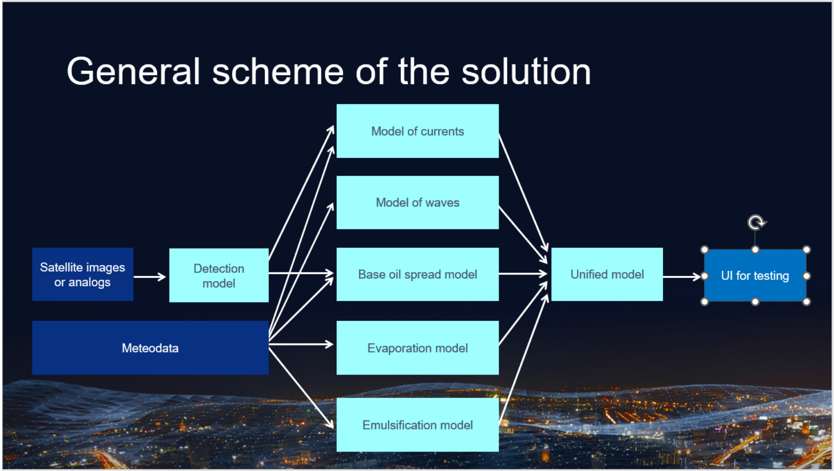
- to automatically detect oil spills,
- to forecast change of oil spill over time,
- to model influence of various parameters on an oil spill,
- to forecast past behaviour of the oil spill.

OilSync

- **OilSync** is a software for modelling oil spills that solves the problems stated above,
- it is registered in Reestr of Russian Software, register entry №19208 from 23.09.2023.



General scheme of the solution

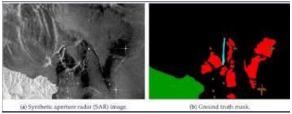


State of the art

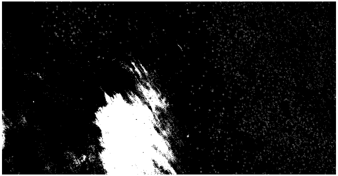
1. The detection problem is more or less solved.
2. The spread problem does not have a good solution due to presence of large number of factors.
    - There are open-source solutions (e. g., **gnome**, **HyosPy**), there are closed solutions,
    - **Euler formulation**, the spill is modelled as a whole,
    - Lagrange formulation, the spill is modelled as a set of particles.

Data for detection

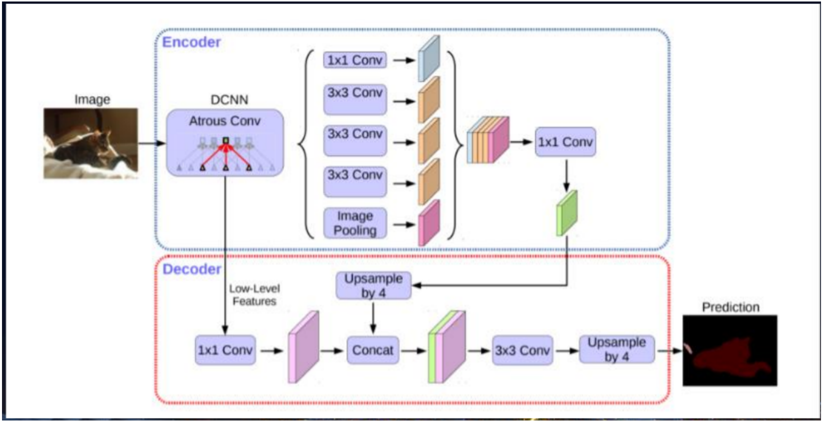
- A dataset for research institutions (https://m4d.iti.gr/oil-spill-detection-dataset/)



- A dataset of Syncretis: weak labelling (euristics and clustering on data by Maxar)



DeepLabV3+

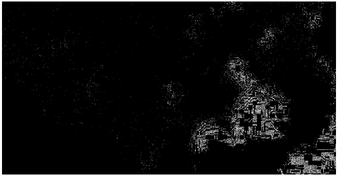

Encoder
Image
DCNN
Atrous Conv
1x1 Conv
3x3 Conv
3x3 Conv
3x3 Conv
Image Pooling
1x1 Conv
Decoder
Low-Level Features
Upsample by 4
1x1 Conv
Concat
3x3 Conv
Upsample by 4
Prediction

Detection model

- Best models from papers by **Krestenitis et al**:
  1. DeepLabV3+ with ResNet101,
  2. DeepLabV3+ with MobileNetV2,
  3. UNet.
- Detection model by Syncretis: DeepLabV3+ with ResNet50,
- In all cases mean IoU is around 0.65.

Model name.	**Mean IoU.**
DeepLabV3+ with ResNet50	66.49%
DeepLabV3+ with MobileNetV2	62.81%
UNet	65.32%
Baseline.	38.72%

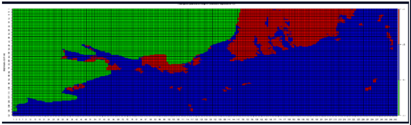
Examples of results

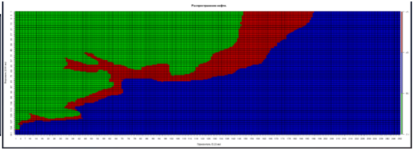


Input data

- Wind velocity (vector).
- Water temperature (for coefficient of diffusion).
- Data on the spill and on the land.
- Data on time.

Dynamical system.





Base model

- Advection-diffusion reaction on concentration:

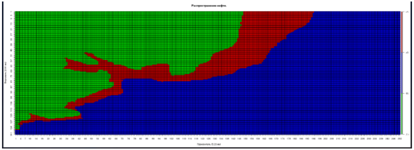
$$\frac{\partial C}{\partial t} + u \cdot \nabla C = \nabla(k \nabla C),$$

$$k = 0.002 \left(\frac{T}{22}\right)^{1.53}.$$

- Boundary conditions correspond to the detected spill.
- Discretization and reduction to a system of ODEs.
- Solution of ODE system by method of Adams.
- The model is taken from **Duran et al**.

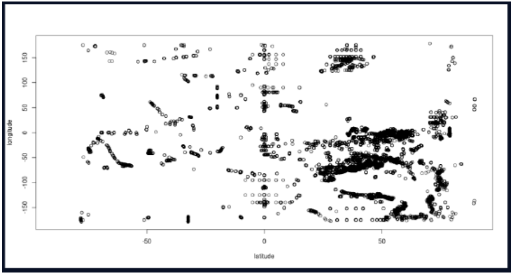
Features of the base model

- Wind velocity may depend on time and on coordinates.
- The land is taken into account via a separate script.
- The inverse problem for the model is not solvable, but it is solvable for the approximation.



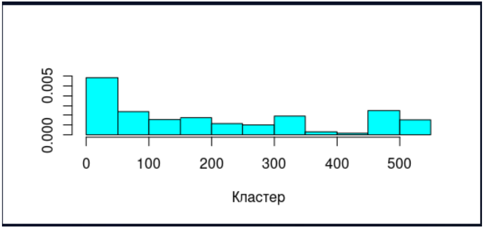
Data for the model of currents

- Data on currents by **Woods Hole Oceanographic Institution**.
- Short time series.
- Dependency on geographical coordinates.
- Annual data.



Forecast of the model of currents

- Solution components: euristics, HDBSCAN, SMA, EMA, Catboost, VAR.
- The model: blending of models basing on HDBSCAN, EMA, VAR.
- MAPE is around 0.45.
- Approximation of a point by cluster average during the forecast.



Choice of model of currents

Name.	SMAPE.
Baseline.	51.17%
Catboost + HDBSCAN + SMA	55.41%
Catboost + HDBSCAN + SMA + correlation	53.28%
Blending of baseline and HDBSCAN.	49.17%
EMA	49.38%
Euristics.	50.46%
SMA	50.37%
Blending of baseline, HDBSCAN, EMA.	47.99%
VAR	51.29%
Blending of baseline, HDBSCAN, EMA, Catboost	47.91%
Blending of baseline, HDBSCAN, EMA, VAR.	46.21%

Model of waves

- The model by Sverdrup, Munk, Bretschneider.
- Empirical model basing on wind velocity and fetch length:

$$H = 0.283\alpha \frac{W^2}{g} \tanh\left(\frac{0.0125}{\alpha}\left(\frac{gF}{W^2}\right)^{0.42}\right),$$

$$T = 7.54\beta \frac{W}{g} \tanh\left(\frac{0.077}{\beta}\left(\frac{gF}{W^2}\right)^{0.25}\right),$$

$$\alpha = \tanh\left(0.53\left(\frac{gH}{W^2}\right)^{0.75}\right), \quad \beta = \tanh\left(0.833\left(\frac{gH}{W^2}\right)^{0.375}\right),$$

where H is wave length, T is wave period, W is wind speed, F is fetch length.

Evaporation model

The model is taken from *Fingas*:

$$E = KCU^{7/9}d^{-1/9}\mathrm{Sc}^{-r},$$

- K is mass transfer rate,
- C is concentration of oil,
- U is wind speed,
- d is area of the poll,
- Sc is Schmidt number,
- r is an empirical constant.

Emulsification model

Emulsification is a process of mixing of oil and water.
The model is taken from *Aghajanloo et al*:

$$\frac{\partial D}{\partial t} = K\,(1+U)^2\left(\frac{1-F}{OC}\right),$$

- K is emulsification coefficient,
- U is wind speed,
- OC is a constant that characterizes type of oil.

Vertical transport model

- The oil goes down, and then it goes up.
- Three-dimensional generalization of the base model.
- The model is taken from *Aghajanloo et al.*
- There is a problem with initial conditions.

$$\frac{\partial C}{\partial t} + \frac{\partial uC}{\partial x} + \frac{\partial vC}{\partial y} - \frac{\partial wC}{\partial z} = \frac{\partial}{\partial x} D_x \frac{\partial C}{\partial x} + \frac{\partial}{\partial y} D_y \frac{\partial C}{\partial y} + \frac{\partial}{\partial z} D_z \frac{\partial C}{\partial z},$$

where C is concentration, u, v are velocities, w is buoyancy speed, D_x, D_y, D_z are coefficients of diffusion.

Features

- There are two regimes of work: an individual regime and a scenario regime with possibility of validation on historical events.
- There are models of oil detection and oil spread.
- The model is quite complicated and quite flexible, it can include extra factors.
- The oil spread model is based on Euler formulation unlike Lagrange formulation in most other solutions.

Thank you very much for your attention!

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