*Regional Cooperation for Limited Area Modeling in Central Europe*

LACE
nwp central europe

# Forecasting surface currents (and wind waves) using neural networks

Martina Tudor on behalf of the NEURAL team

ZAMG DHMZ Czech Hydrometeorological Institute OMSZ IMGW METEO ROMANIA SHMU ARSO METEO Slovenia

# Introduction

- Interpreting and forecasting Adriatic surface currents by an artificial brain (NEURAL)
  - to research and to build an efficient and reliable prototype of ocean surface current forecasting system, based on neural network algorithms.
  - Unity Through Knowledge (UKF) Fund, www.ukf.hr
  - 15 October 2013 – 14 October 2015
- Built on measured data from HF ocean radars:
  - **Northern Adriatic**
  - **Central Adriatic**

# The Project Team

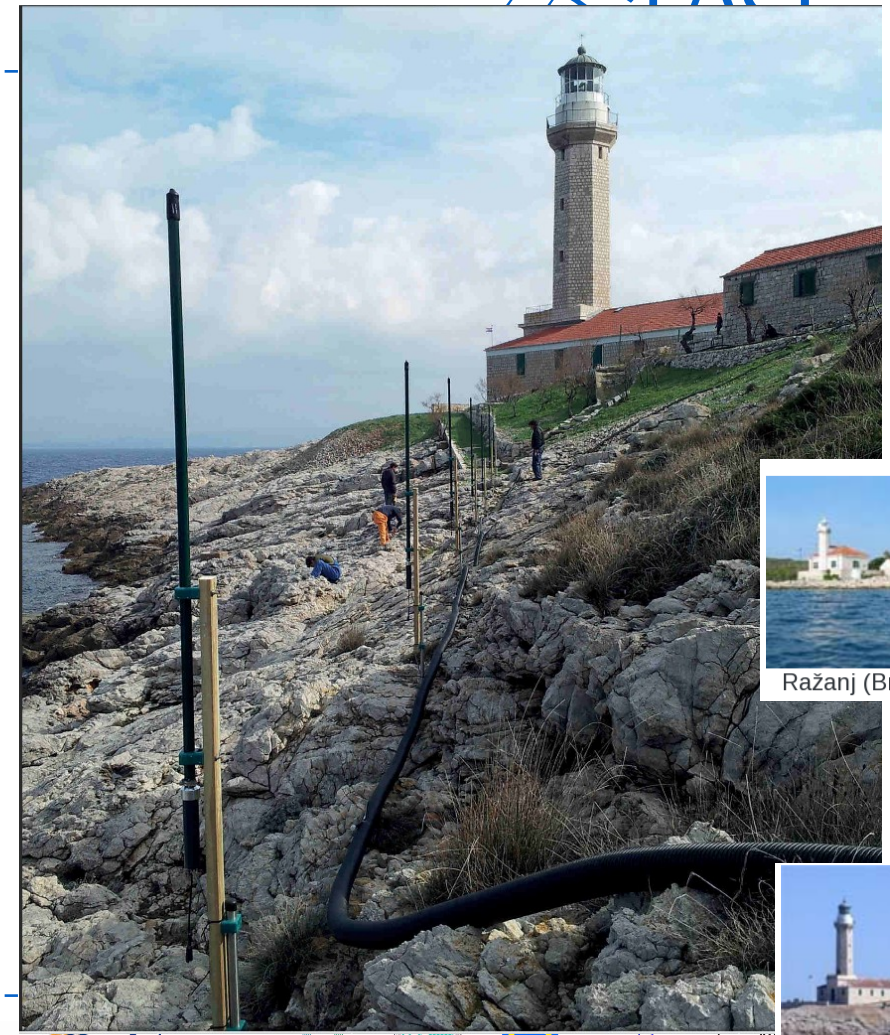
- Ivica Vilibić, Institute of Oceanography and Fisheries, Croatia, Principal Investigator
- Nedjeljka Žagar, University of Ljubljana, Slovenia, Co-Principal Investigator
- Vlado Dadić, Institute of Oceanography and Fisheries, Croatia, senior scientist
- Hrvoje Mihanović, Institute of Oceanography and Fisheries, Croatia, postdoctoral researcher
- Jadranka Šepić, Institute of Oceanography and Fisheries, Croatia, Ph.D. student
- Damir Ivanković, Institute of Oceanography and Fisheries, Croatia, programming and data management
- Martina Tudor, Meteorological and Hydrological Service, Croatia, research associate
- Simone Cosoli, National Institute of Oceanography and Experimental Geophysics, Trieste, Italy, senior scientist
- Blaž Jesenko, University of Ljubljana, Slovenia, research associate
- Hrvoje Kalinić, Institute of Oceanography and Fisheries, Croatia, postdoctoral researcher

# NEURAL main objectives:

- develop a hybrid ocean forecasting system based on the neural network approach and self-organizing maps algorithms using as input:
  - surface current fields measured by high-frequency oceanographic radars and
  - mesoscale surface winds simulated by the high-resolution numerical weather prediction (NWP) model
- learn about the wind effects on the ocean and to create characteristic circulation patterns in the Adriatic
  - **Self Organizing Maps (SOM) yield a finite number of characteristic sea surface current patterns that are related to specific wind field patterns**
- the ocean current patterns will be forecast by using outputs from the meteorological models only

# HF radars – Central Adriatic

- Two radars installed in HAZADR project
- The **High-frequency (HF) oceanographic radars** are remote sensing instruments that measure  surface currents in an area.
  - over a large region of the coastal ocean, from a few km offshore up to 200 km,
  - and surface waves and wind direction.
- The scattered radar electromagnetic waves emitted to all directions over the sea coherently return, resulting in a strong peak of energy at a very precise wavelength, known as **Bragg scattering frequency.**
- **https://www.hazadr.eu/**

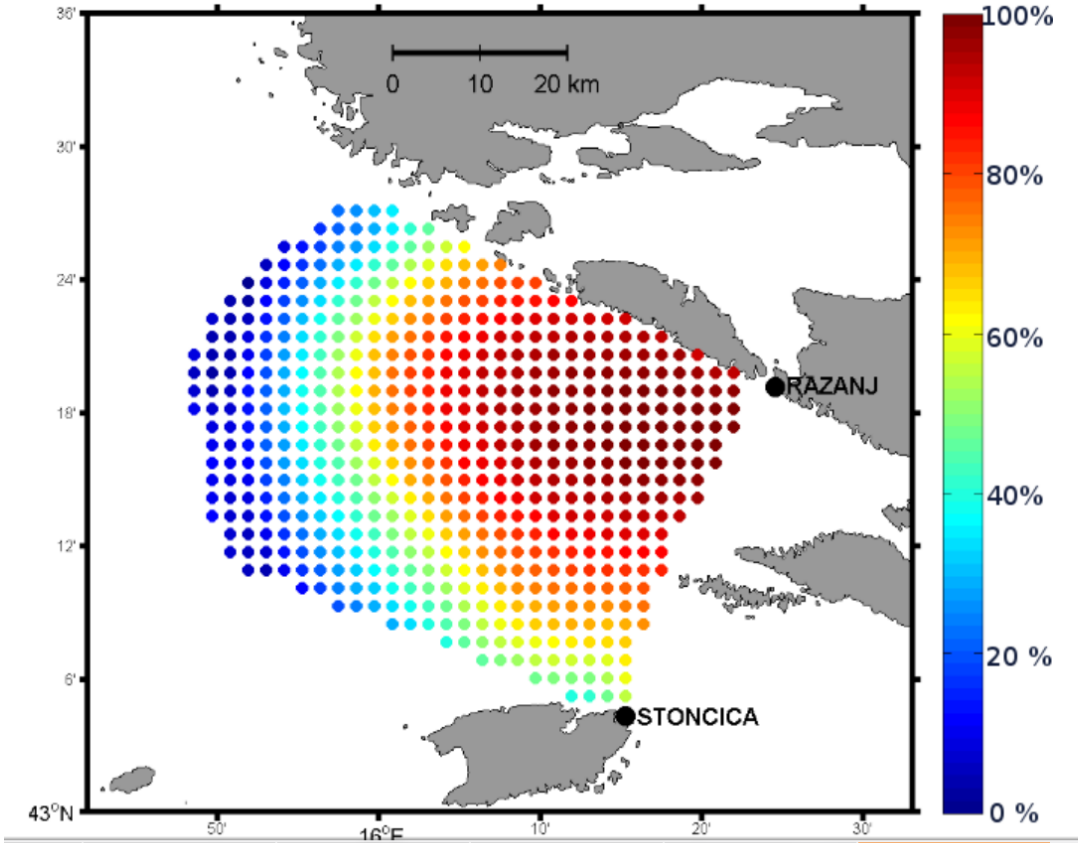


Ražanj (Brač)

Stončica (Vis)

# HF radars – Central Adriatic

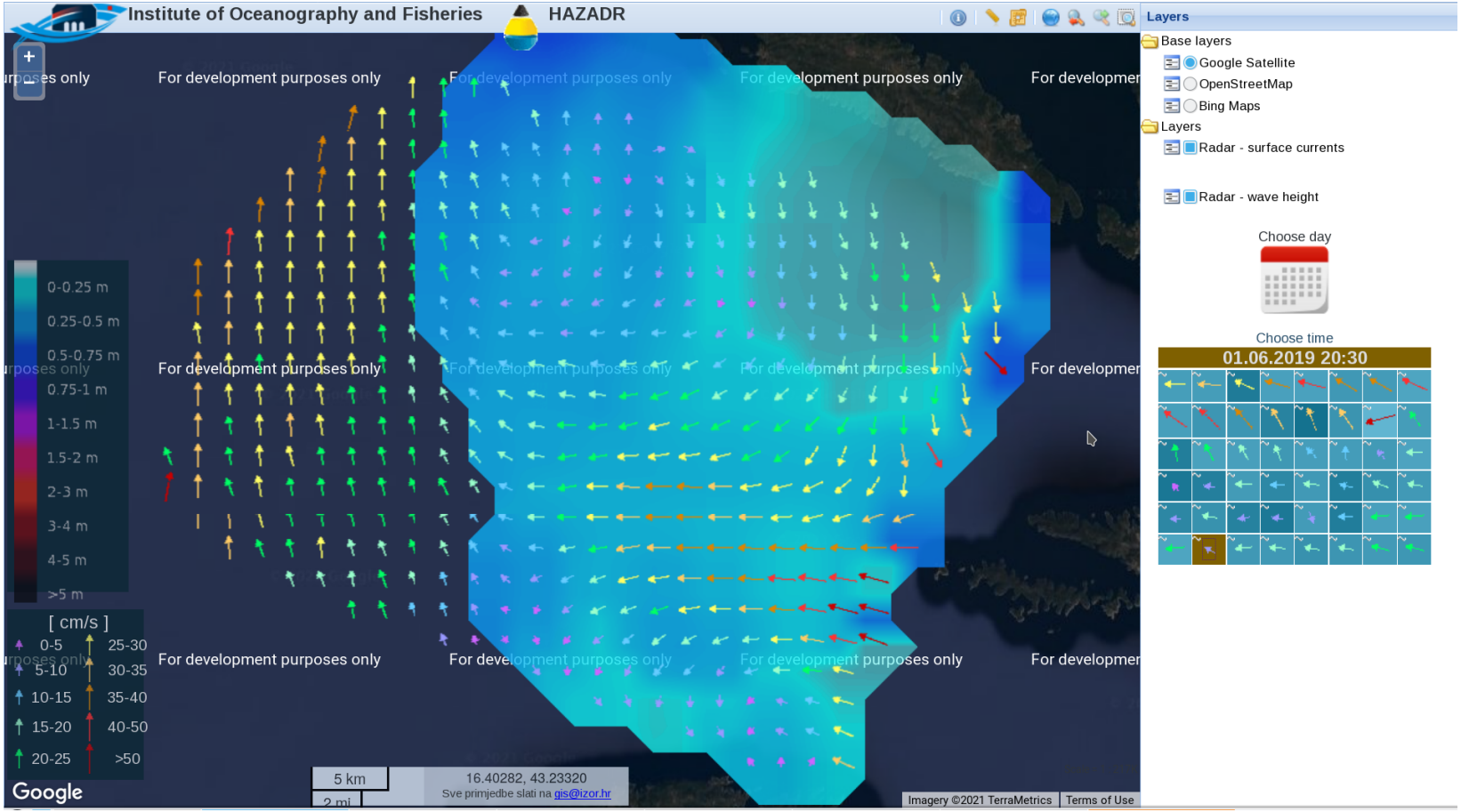
- The HF radars were of WERA type, manufactured by Helzel GmbH (http://www.helzel.com), operating on 26.200-26.350 MHz frequency and covering the area of about 50x50 km with spatial resolution set to 1.5 km. The installation was carried out during early months of 2014, when the Institute of Oceanography and Fisheries (IOF) team did the installation of the equipment at both sites, with the help of research vessel Bios Dva.
- http://jadran.izor.hr/hazadr/geoserver_en2.html



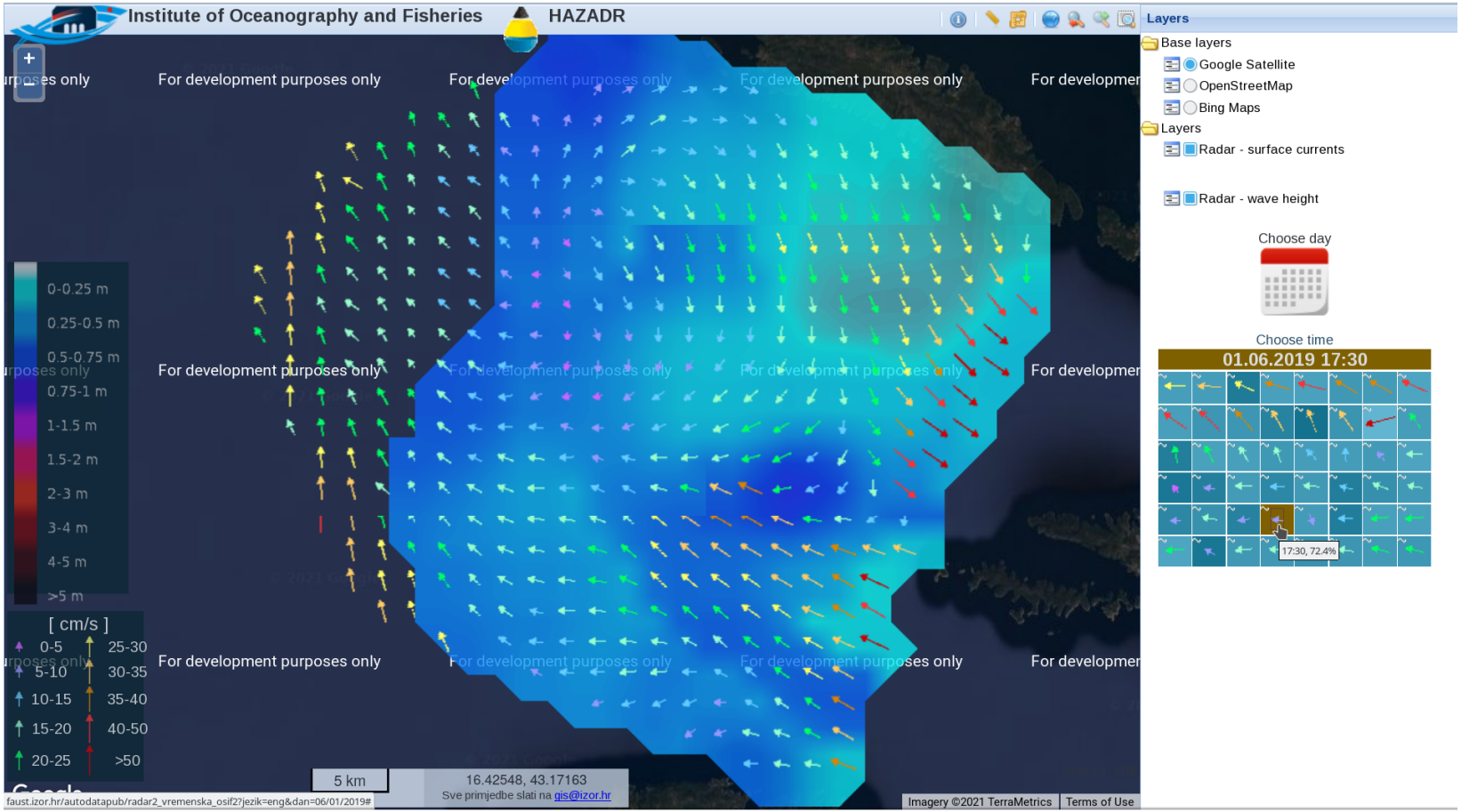


Stončica (Vis)

# HF radars – Central Adriatic



# HF radars – Central Adriatic



# Artificial Intelligence/Machine Learning

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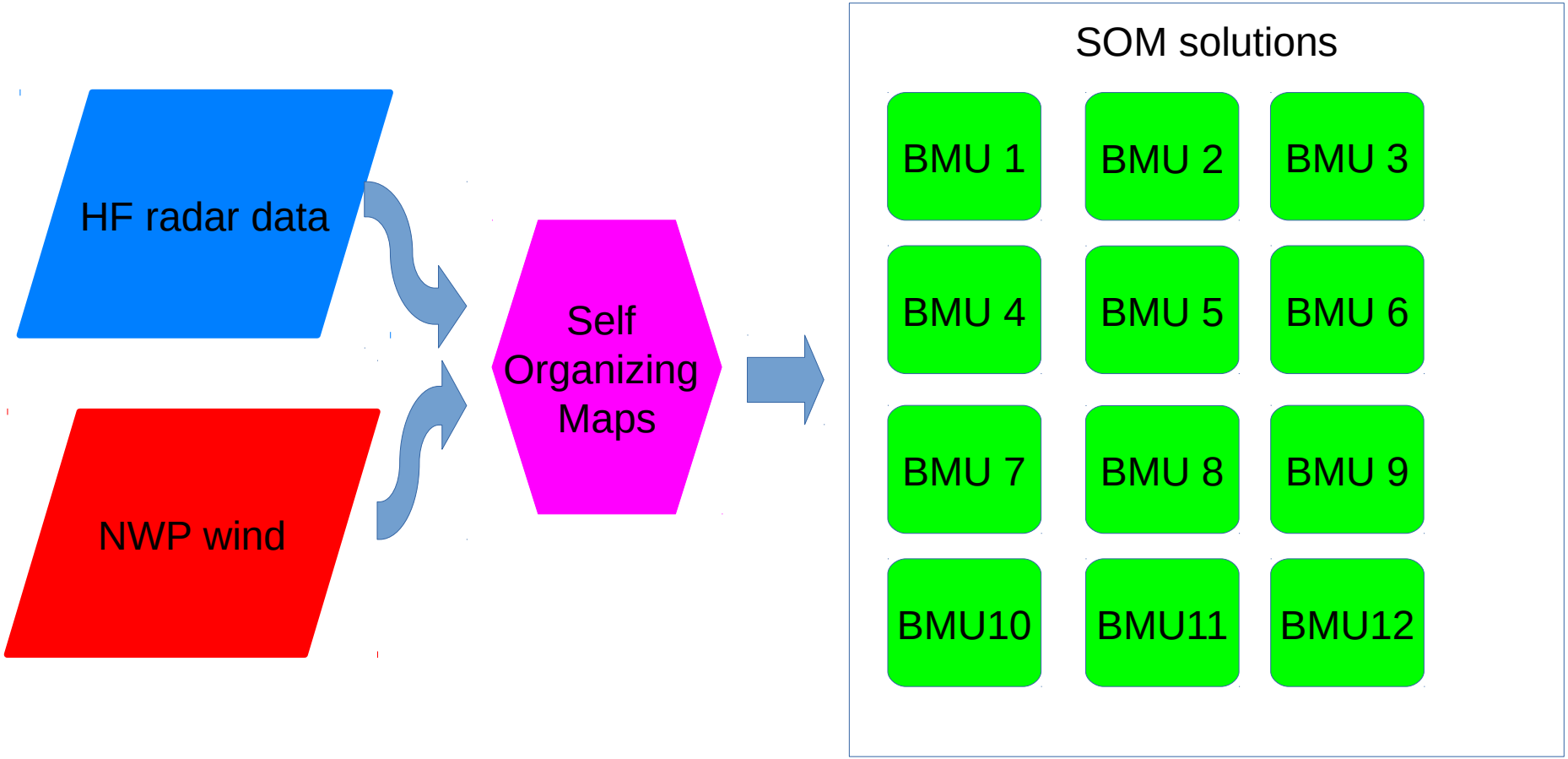
- AI/ML techniques need **a lot of input data** for training
  - hourly measured surface currents and model wind fields
  - (Northern Adriatic  training 1 Feb – 30 Oct 2008 – 273 days - 6552 hours)
  - Measurements quality checked, de-tided and interpolated (some gap filling)
  - Both currents and winds 33 hour low pass filtered
- (Teuvo) Kohonen neural networks – Self Organizing Maps
  - is one of clustering methods widely used in statistics, machine learning, bioinformatics, **forecasting within hybrid models** ...
  - Dimensionality reduction through unsupervised learning (from the number of input data fields)
  - high dimensional input data set to low(two)-dimensional output (map) BMU – Best Matching Unit
- Applied as:
  - **Introduce currents data to nxm SOM and get nxm characteristic fields**
  - **Joint set of current and wind data introduced to nxm SOM and another nxm joint patterns of wind and current fields were found**

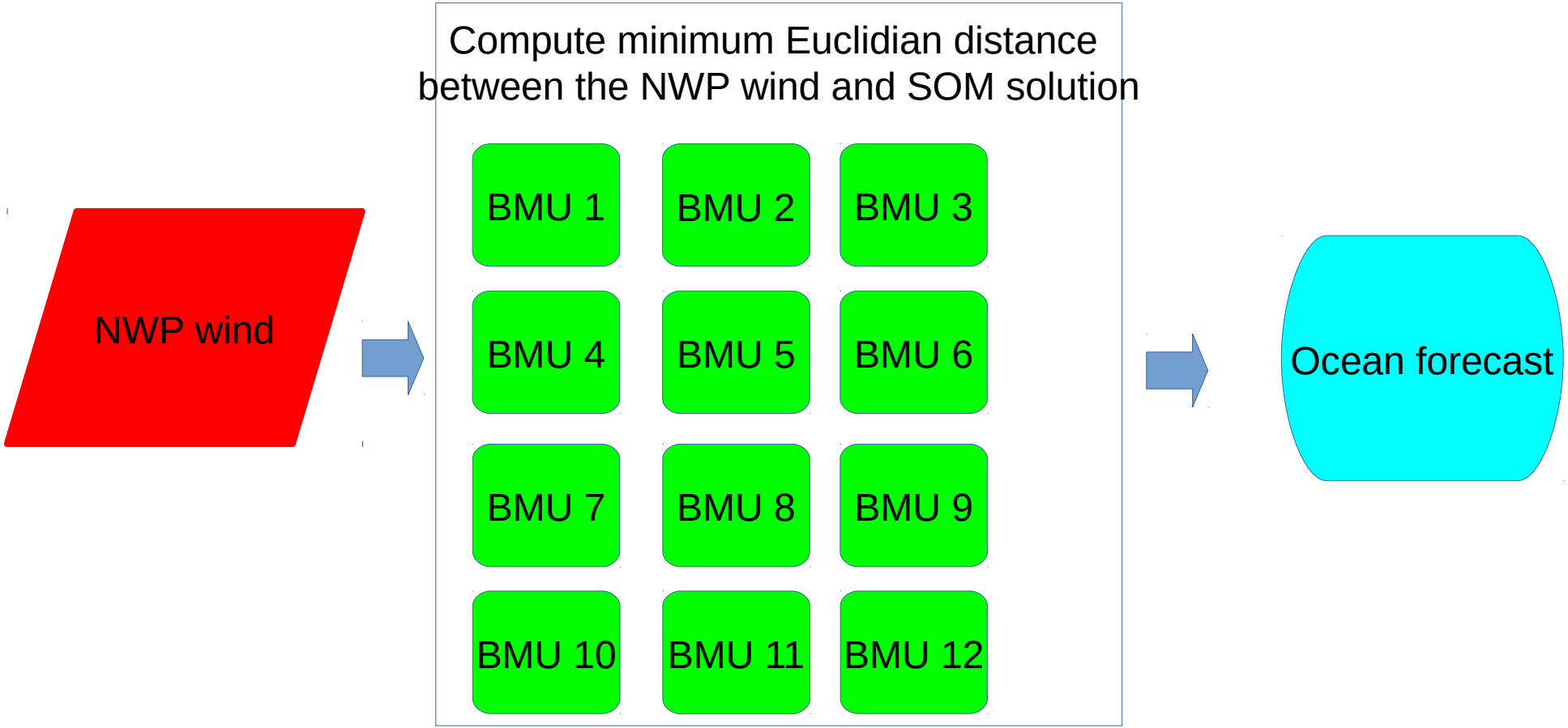
# Self Organizing Maps

- Assume local surface currents depend mostly on wind
- Find a robust link between the surface currents and wind fields
- Training phase:
  - surface currents in the area are measured using HF radars during a prolonged time interval;
  - sea-surface wind fields are obtained from a high-resolution mesoscale atmospheric model;
  - the characteristic surface current patterns are extracted from HF radar data using the SOM;
  - joint surface current and wind patterns are extracted from wind and surface currents using the SOM method;
  - optimal SOM parameters are estimated and the method applicability is tested on available data.
- The forecasting phase
  - forecasting surface winds with a high resolution mesoscale atmospheric model;
  - recognizing characteristic SOM patterns (as determined during the training phase) in the surface wind forecast by searching for the minimum Euclidian distance between characteristic patterns and the NWP-forecasted surface winds;
  - assign the corresponding surface current pattern as the surface current forecast.

# Self Organizing Maps forecast - training

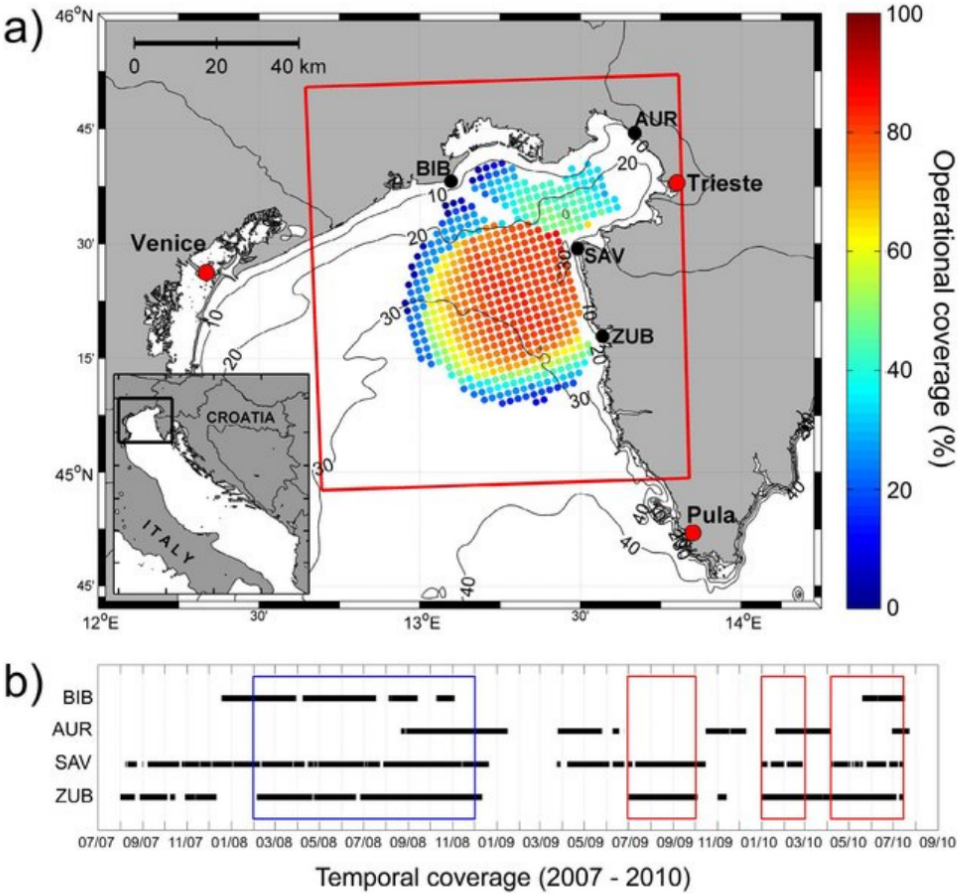


# Self Organizing Maps forecast



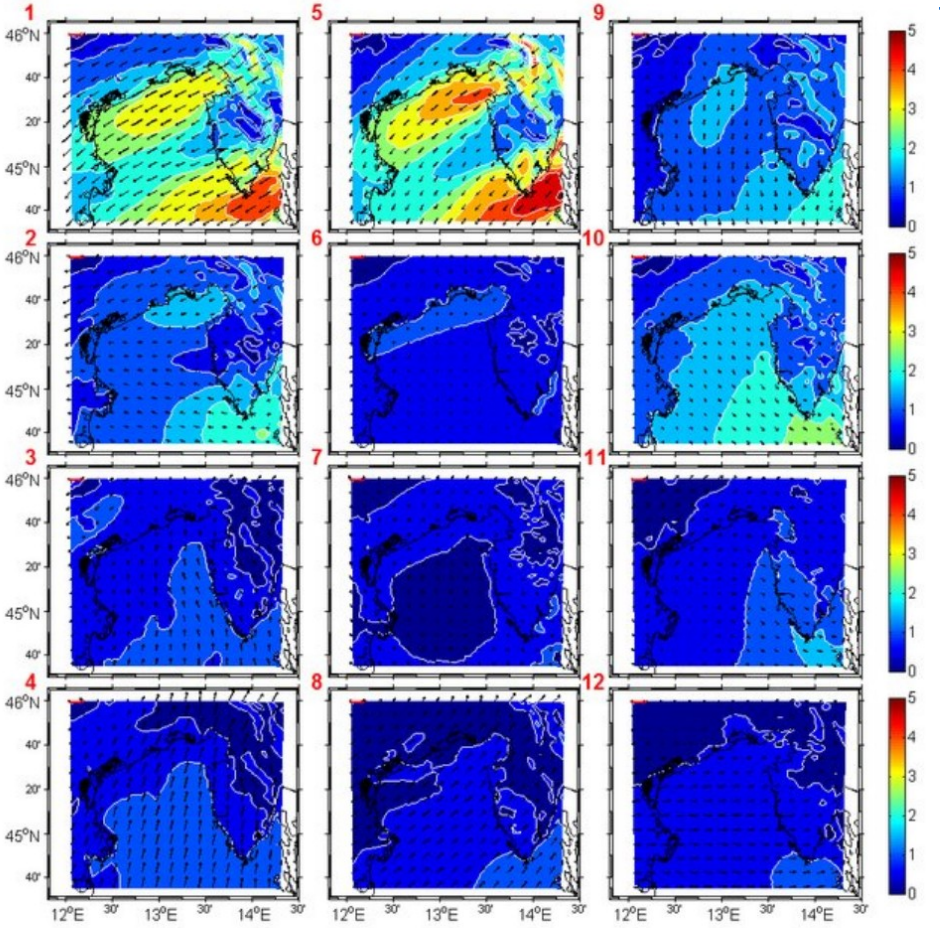
# Surface currents forecast – N Adriatic

- (a) The domain of the SOM-based operational forecasting system in the northern Adriatic with marked HF radar stations (BIB – Bibione, AUR – Aurisina, SAV – Savudrija, ZUB – Zub). Operational coverage of hourly surface currents over the predefined Cartesian grid during testing periods is given in percent, while spatial coverage of the Aladin/HR model used for training and forecasting is denoted by the red rectangle. Operational coverage at the same Cartesian grid during testing period was higher than 60%.
- (b) HF radar operability between 2007 and 2010 with marked training (blue rectangle) and testing (red rectangles) periods.



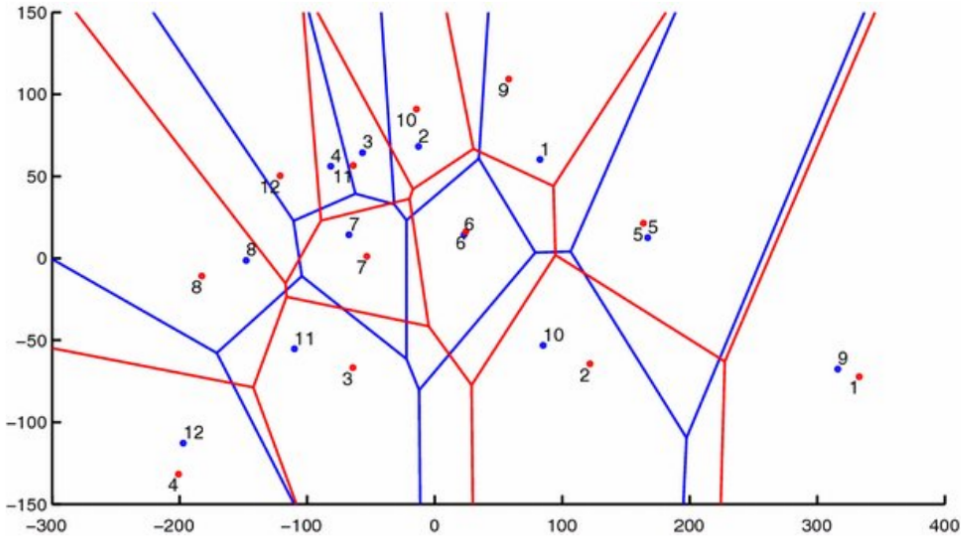
# Surface currents forecast

- 3x4 SOM patterns of ALADIN surface winds (arrows) and associated CBE (color, in m/s). Black line stands for the coastline. Red numbers stand for BMUs.



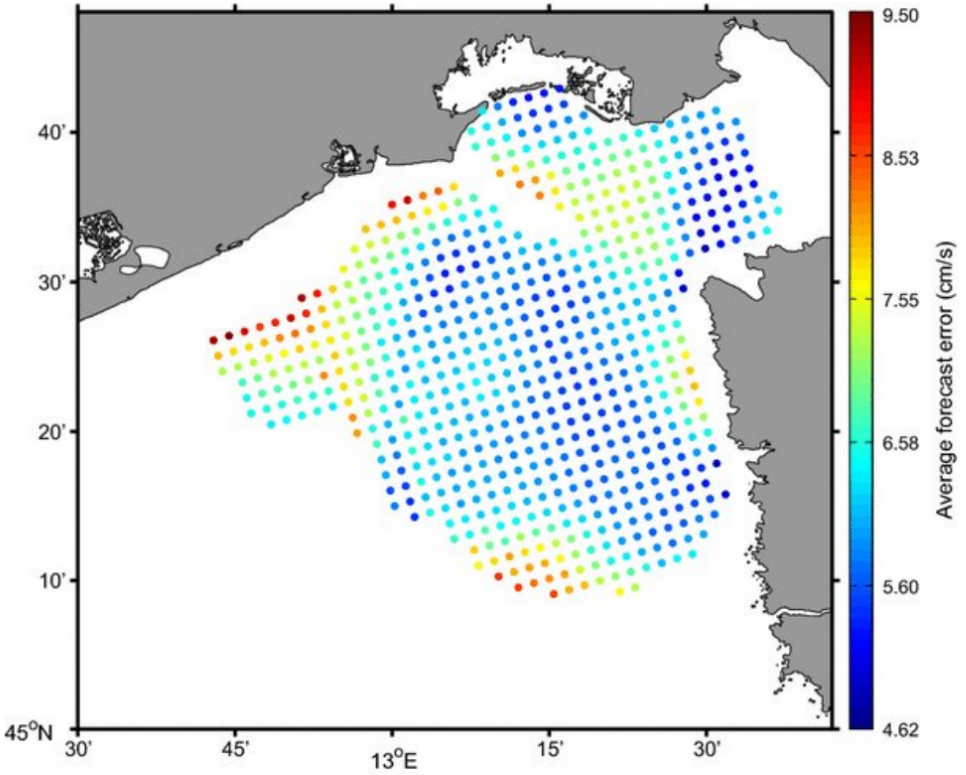
# Surface currents forecast

- Voronoi tessellation of SOM nodes (numbered dots) projected to 2D space using Isomap algorithm. Since SOM variables are normalized, and Isomap is nonlinear mapping algorithm, the axis is unitless. The tessellation is used to visualize the cluster borders (lines). Red indicates $CS^n$ (currents) and blue $CWS^n$ (currents and wind) characteristic patterns. Each cell contains vector that have a particular reference vector as their closest neighbour. The reference vector is characteristic pattern projected to 2D plane. All nodes are plotted with their labels, so cluster pairs can be easily established



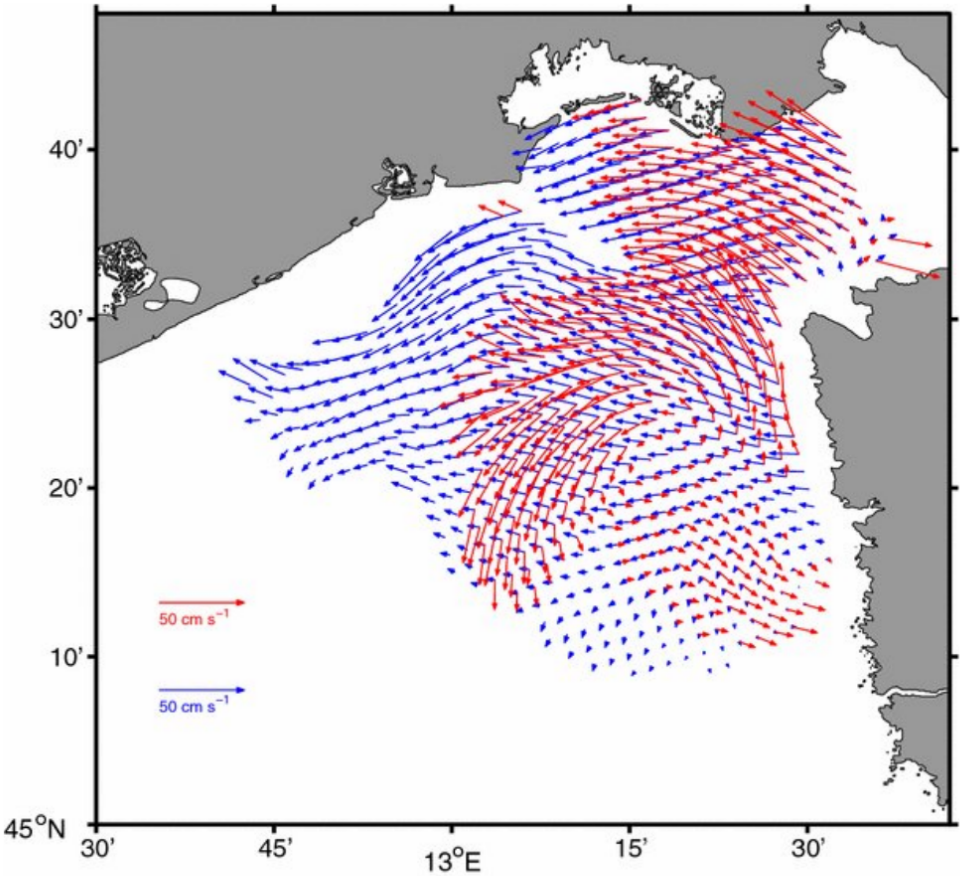
# Surface currents forecast

- Spatial distribution of the forecast error. Every grid point is colour coded showing the average error at specific location.
- The error is in cm/s
- The error is the largest at the edges of the range of the HF radars.



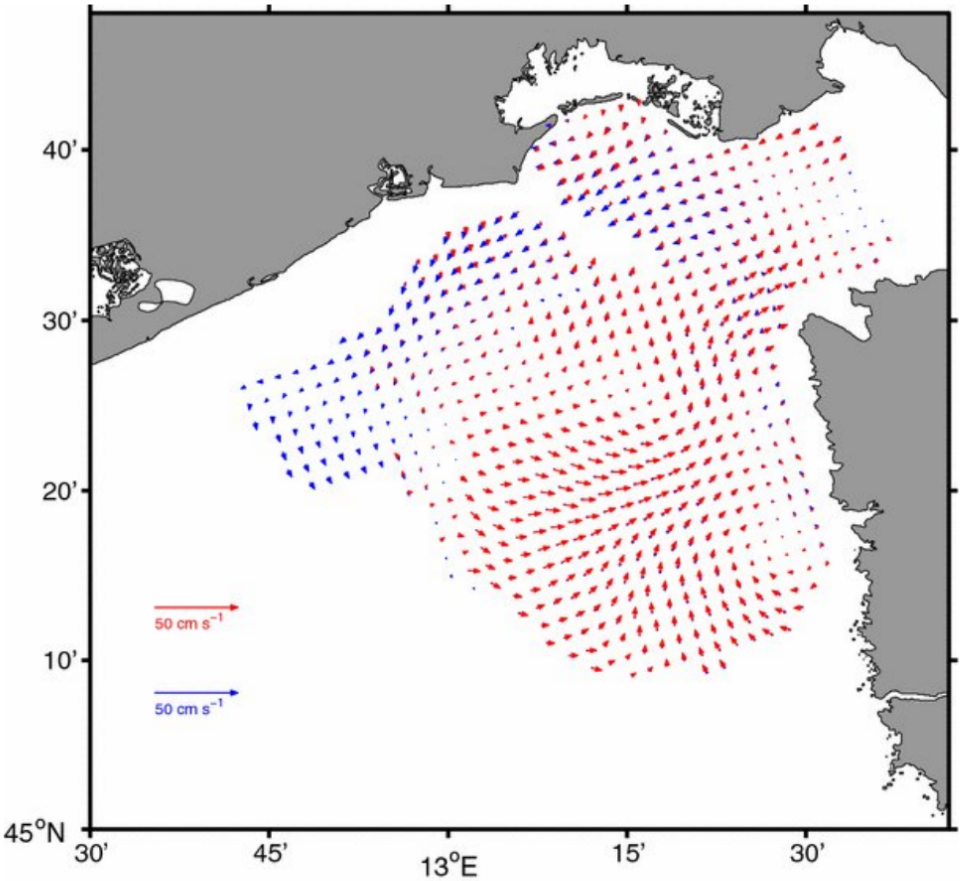
# Surface currents forecast

- Direct comparison between forecast and observed surface currents on September 14, 2008, at 20:00 (worst-case scenario)



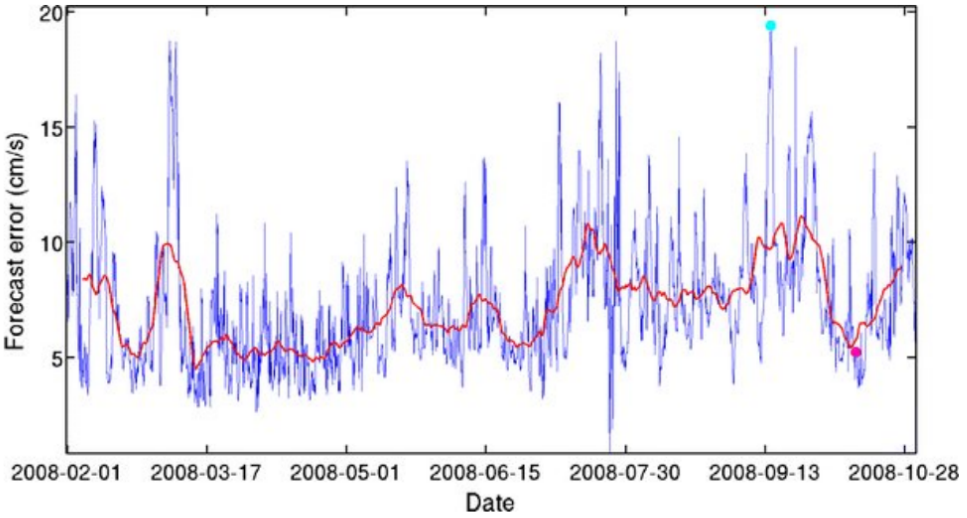
# Surface currents forecast

- Direct comparison between forecast and observed surface currents on October 12, 2008, at 6:00



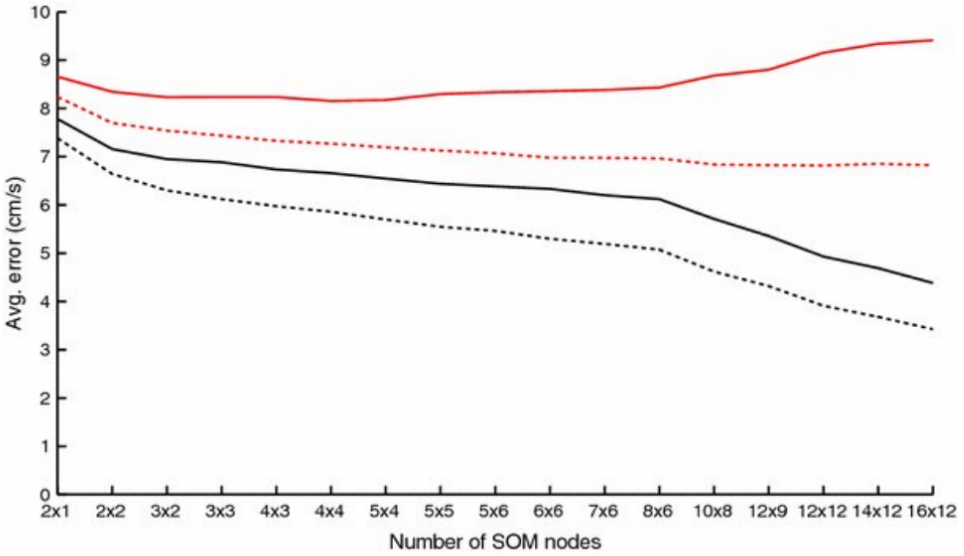
# Surface currents forecast

- Time series of the forecast error. Blue line stands for hourly and red for 10-day average forecast error. Cyan dot indicates time at which Fig. Two slides ago is taken, and magenta dot indicates time at which Fig. one slides ago is taken



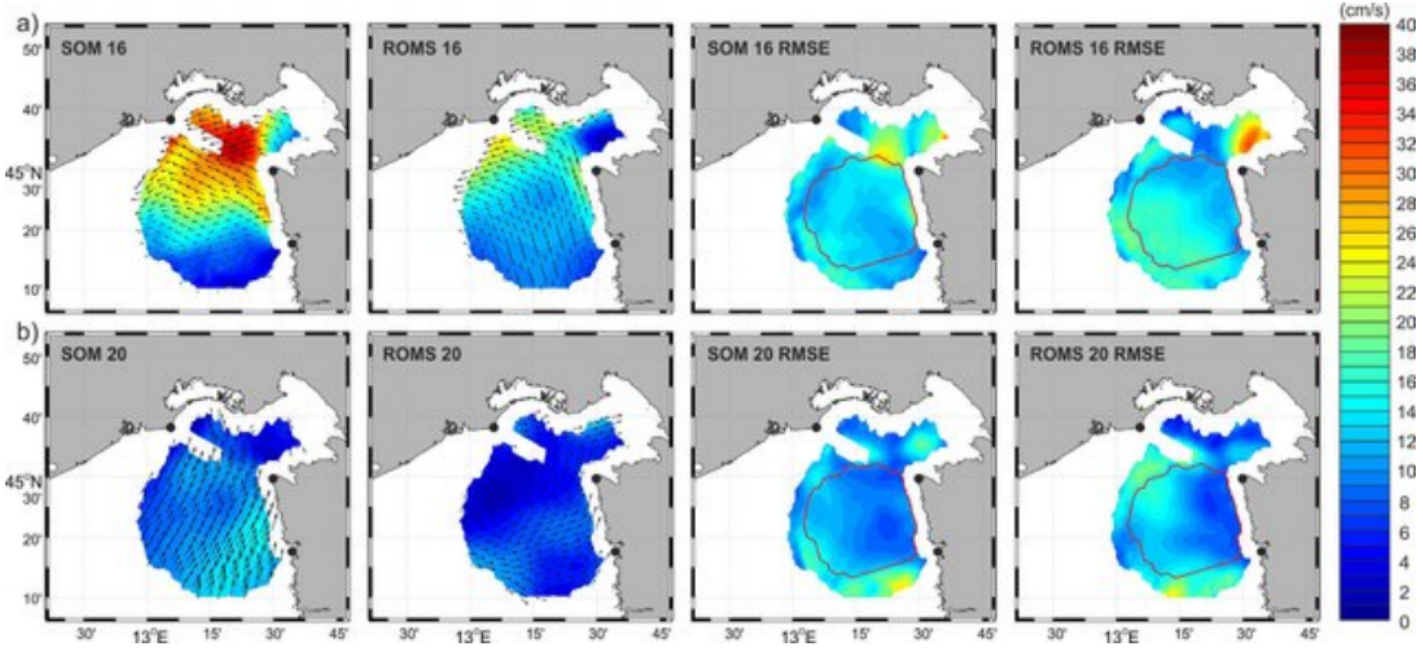
# Surface currents forecast

- Average forecast error (solid lines) and quantization error (dashed lines) calculated on the training (black lines) and testing (red lines) dataset for different SOM sizes



# Surface currents forecast - ROMS

- Surface currents obtained by the SOM-based forecasting system, the respective average surface currents obtained by ROMS forecasting system, and the RMSE between SOM-based and ROMS-based forecast of surface currents and the measurements, computed for




- (a) BMU16 (associated with strong bora wind), and
- (b) BMU20 (associated with sirocco wind). Encircled area includes grid points with at least 60% operational coverage during the testing period.

# Surface currents forecast

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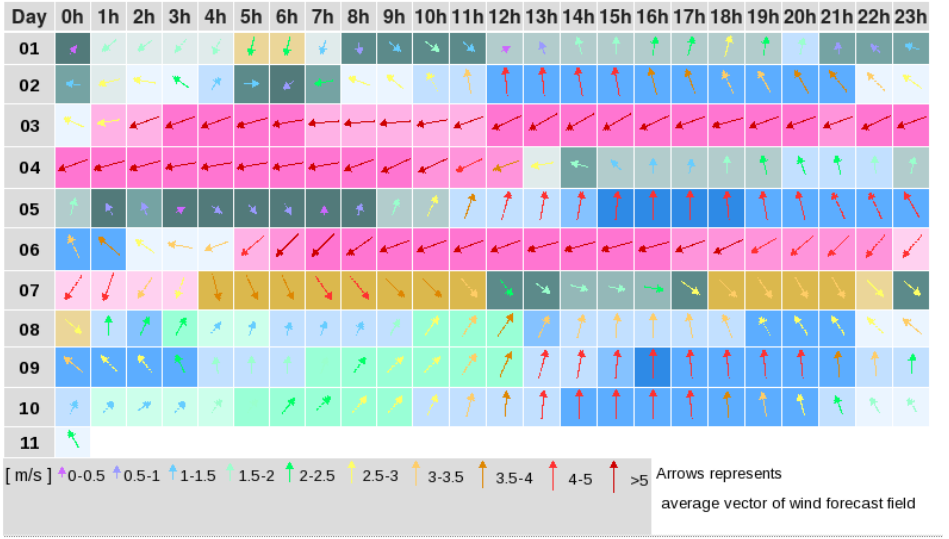
Scene (forecast types) table with appearance percentage

| | | | |
|---|---|---|---|
| 1 3.49% | 6 6.45% | 11 7.38% | 16 6.45% |
| 2 8.05% | 7 7.2% | 12 6.23% | 17 5.6% |
| 3 5.4% | 8 6.04% | 13 5.93% | 18 4.55% |
| 4 4.72% | 9 5.78% | 14 4.78% | 19 2.99% |
| 5 2.69% | 10 1.99% | 15 2.12% | 20 2.16% |

Color codes with explanations

| | | | |
|---|---|---|---|
| Very strong Bora (Bura) | Very strong Sirocco (Jugo) | Strong Tramontane | Very very Calm |
| Strong Bora (Bura) | Strong Sirocco (Jugo) | Weak Tramontane | Very Calm |
| Medium Bora (Bura) | Medium Sirocco (Jugo) | Strong Libeccio | Calm |
| Weak Bora (Bura) | Weak Sirocco (Jugo) | Weak Libeccio | Calm with weak wind |
| Very weak Bora (Bura) | Very weak Sirocco (Jugo) | | Calm with some wind |
| | | | Calm with wind |




- Indices Best Matching Unit in 4x4 SOM with associated frequency in percent (left top table) with associated weather types (left bottom table)
- Top right table: overview of forecasts for March 2021. Colour indicates which ‘type’ of field is forecast (subsequent forecasts can be identical if they belong to the same type)



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- Hourly forecast fields in ‘radar’ grid points (only in points with sufficient data quality for that current pattern)
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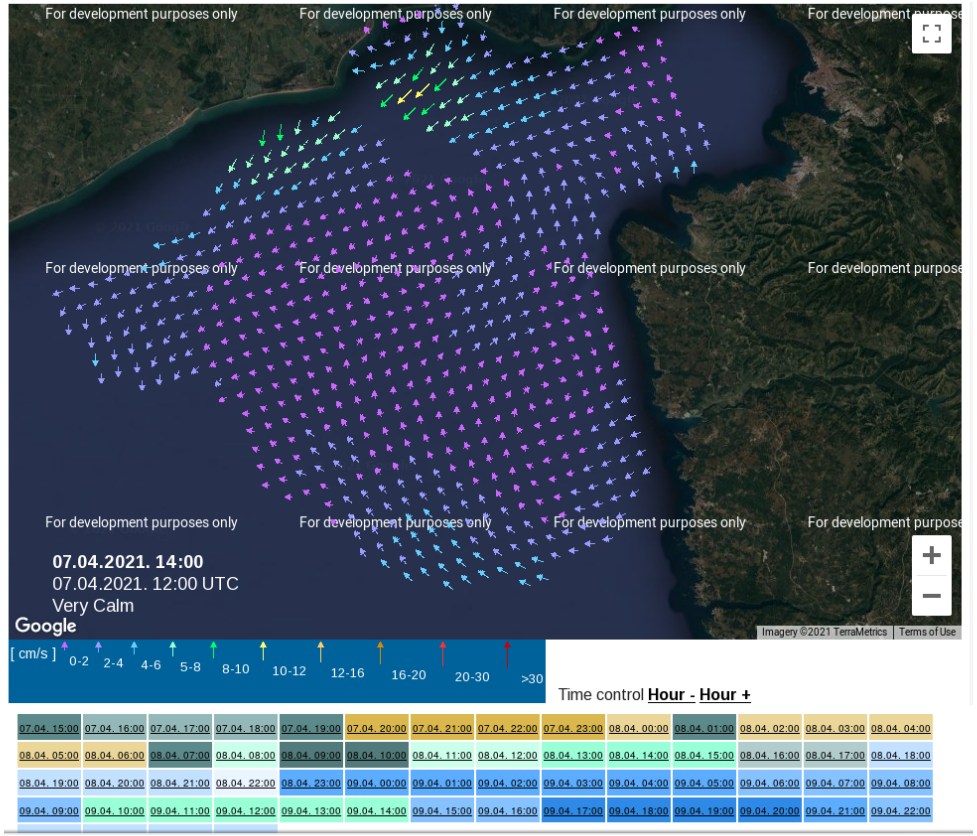

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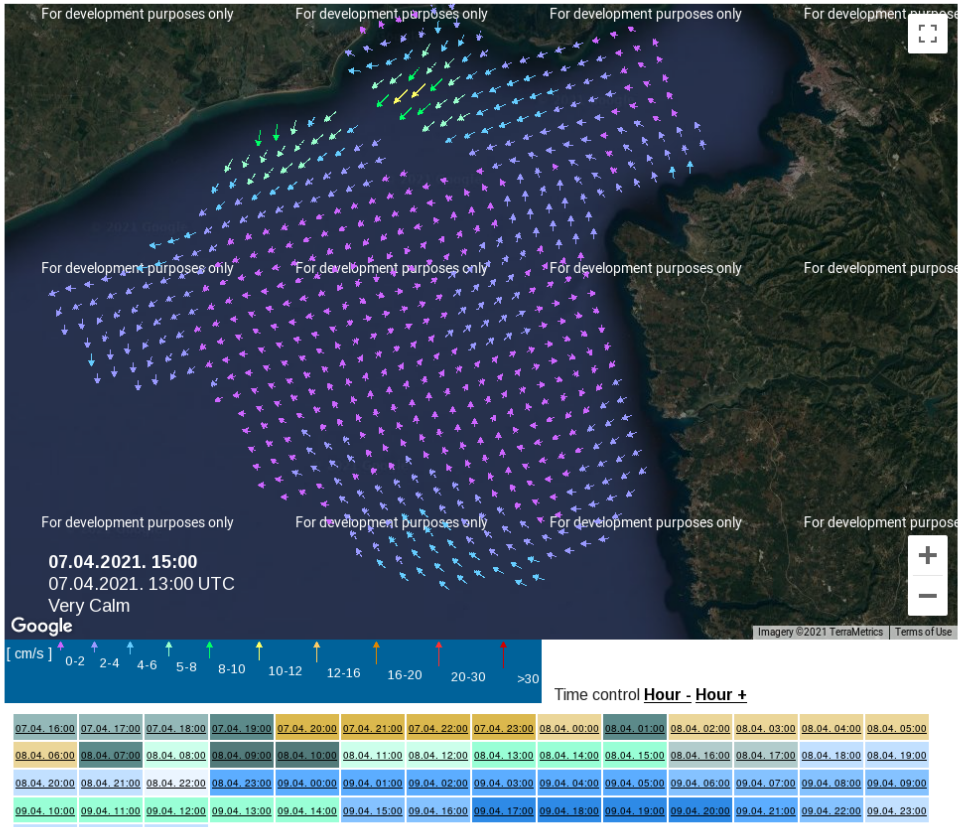

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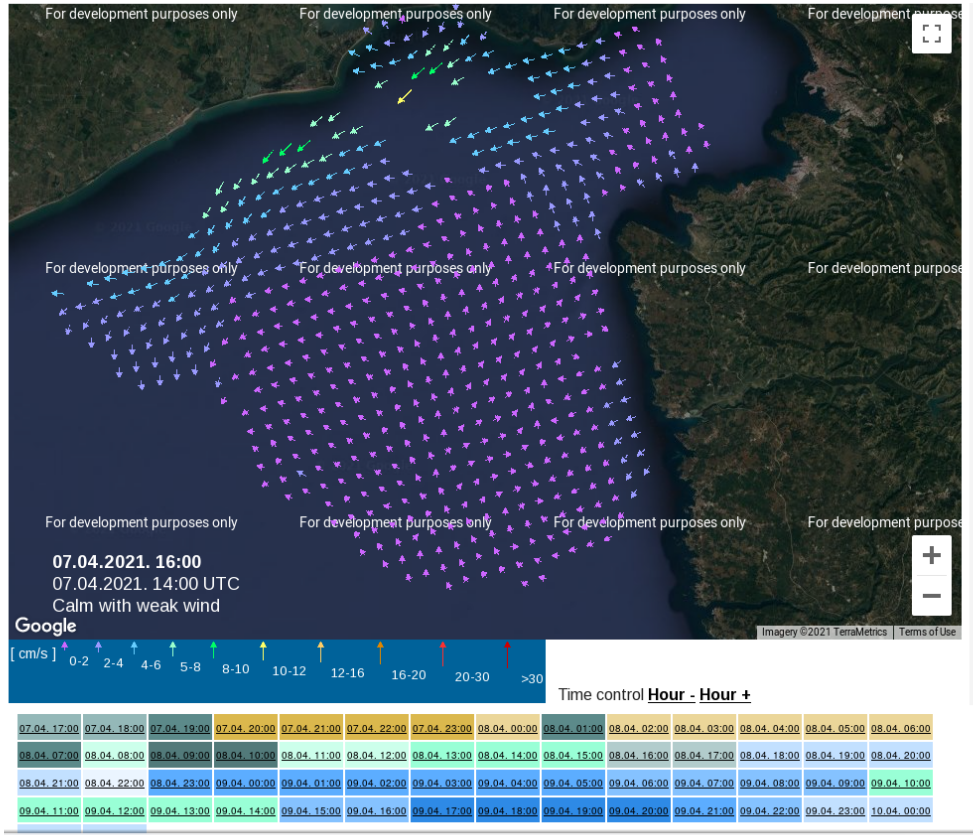

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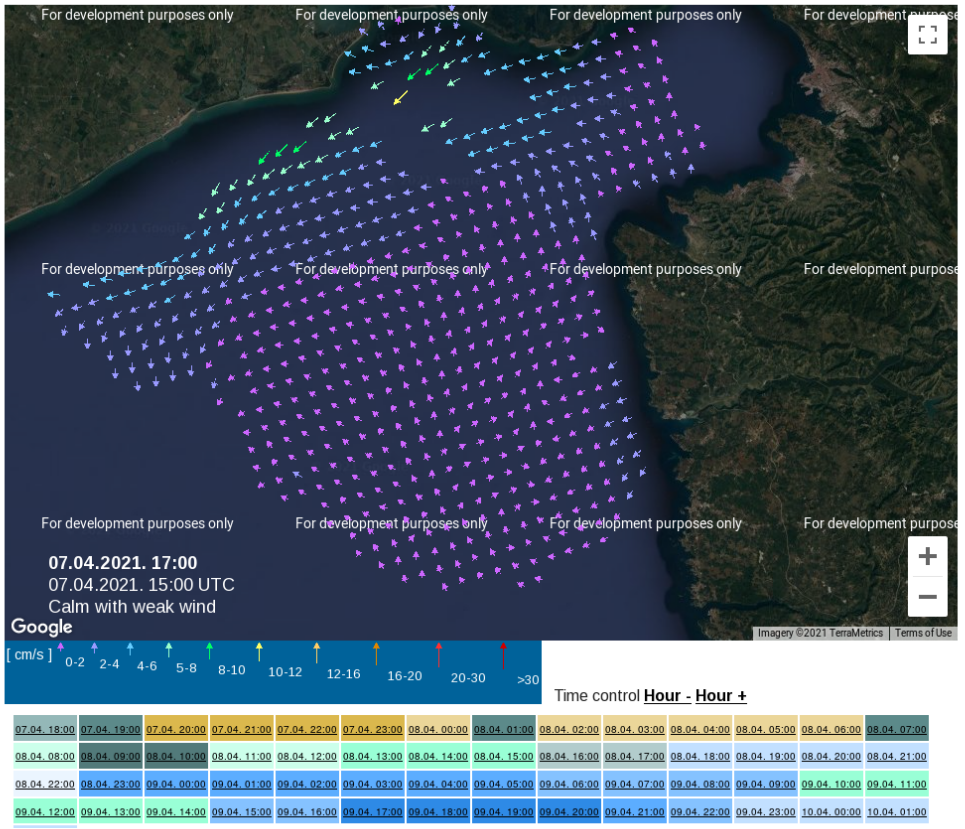

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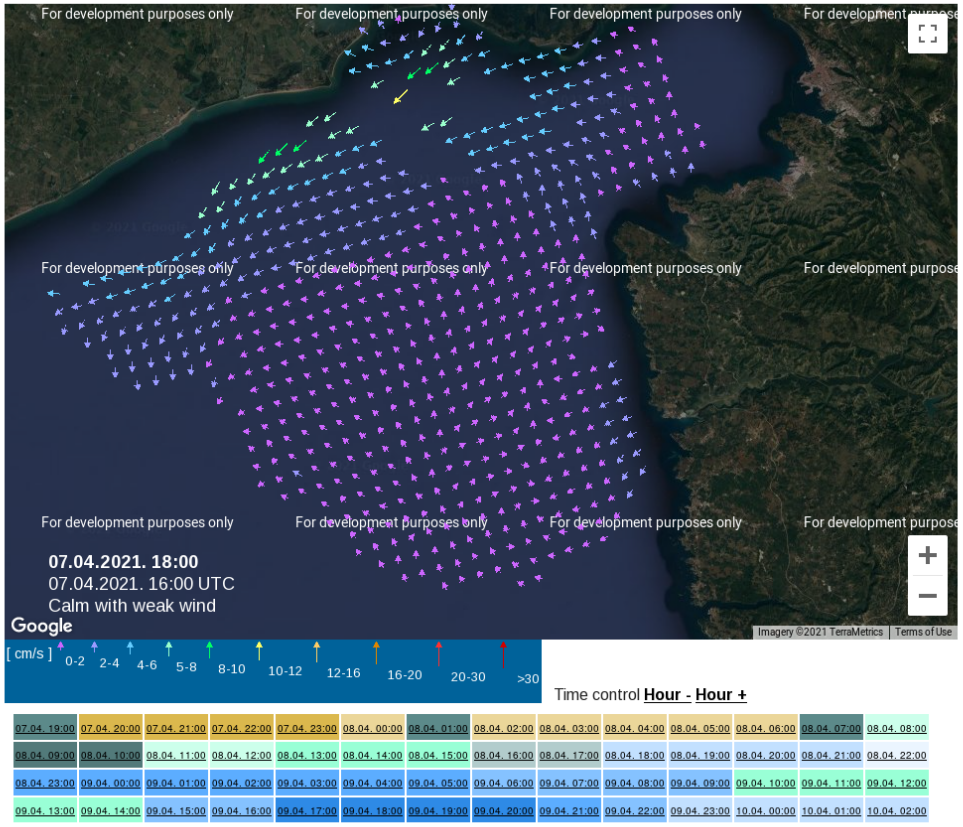

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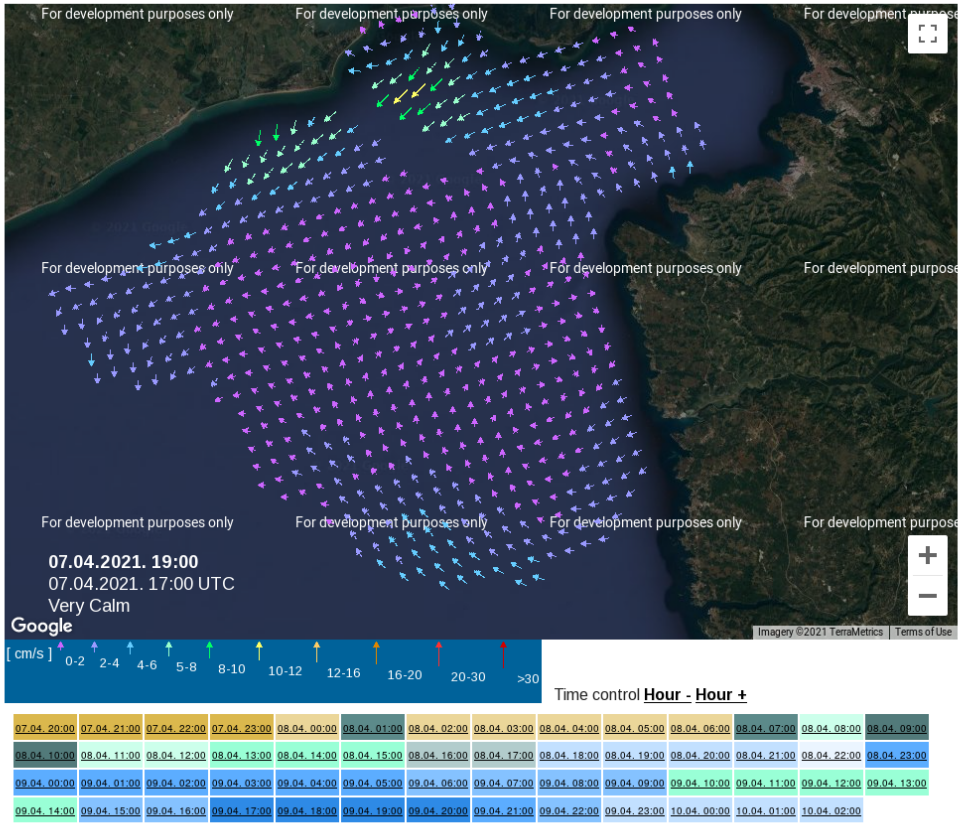

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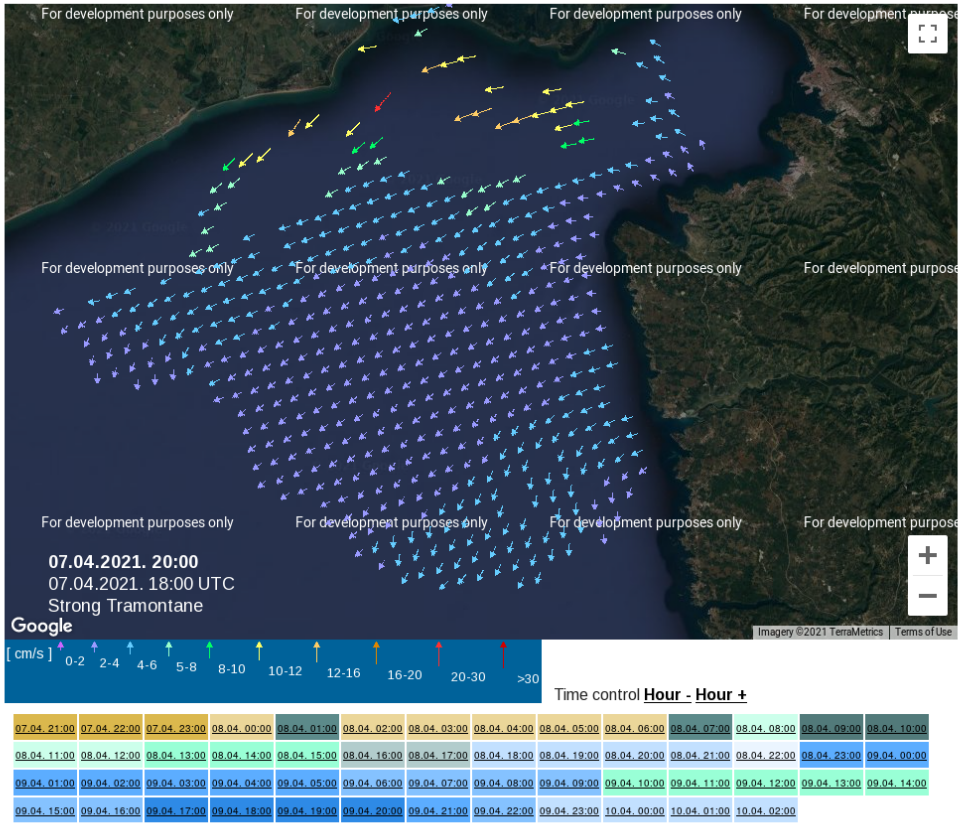

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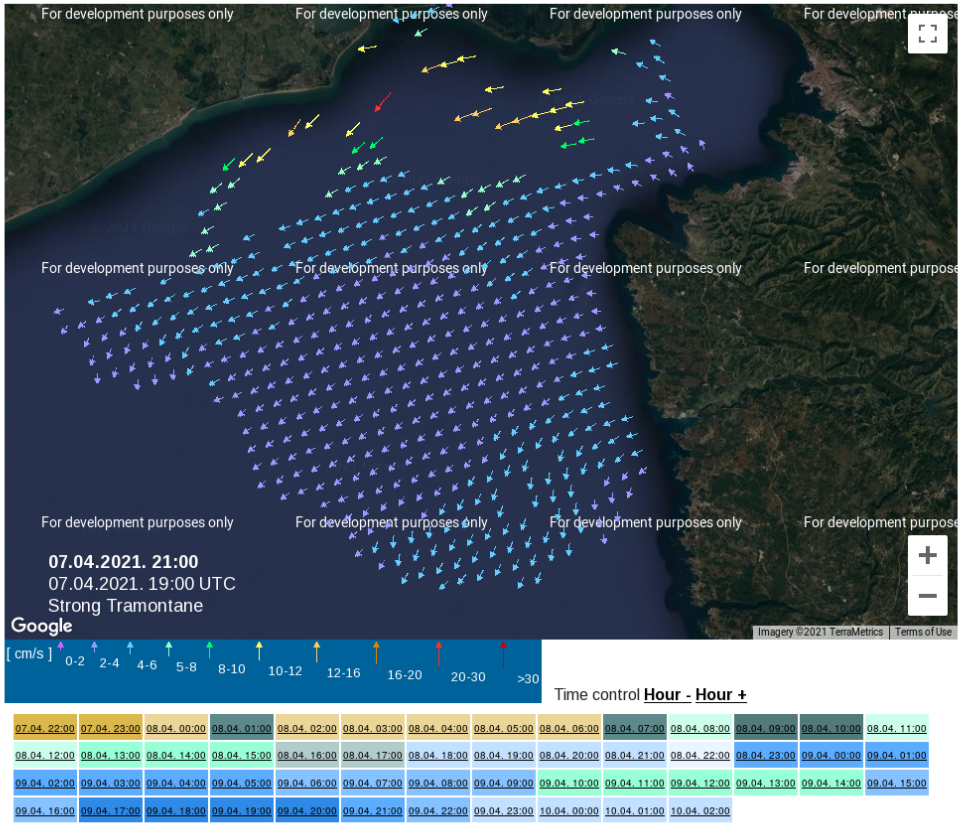

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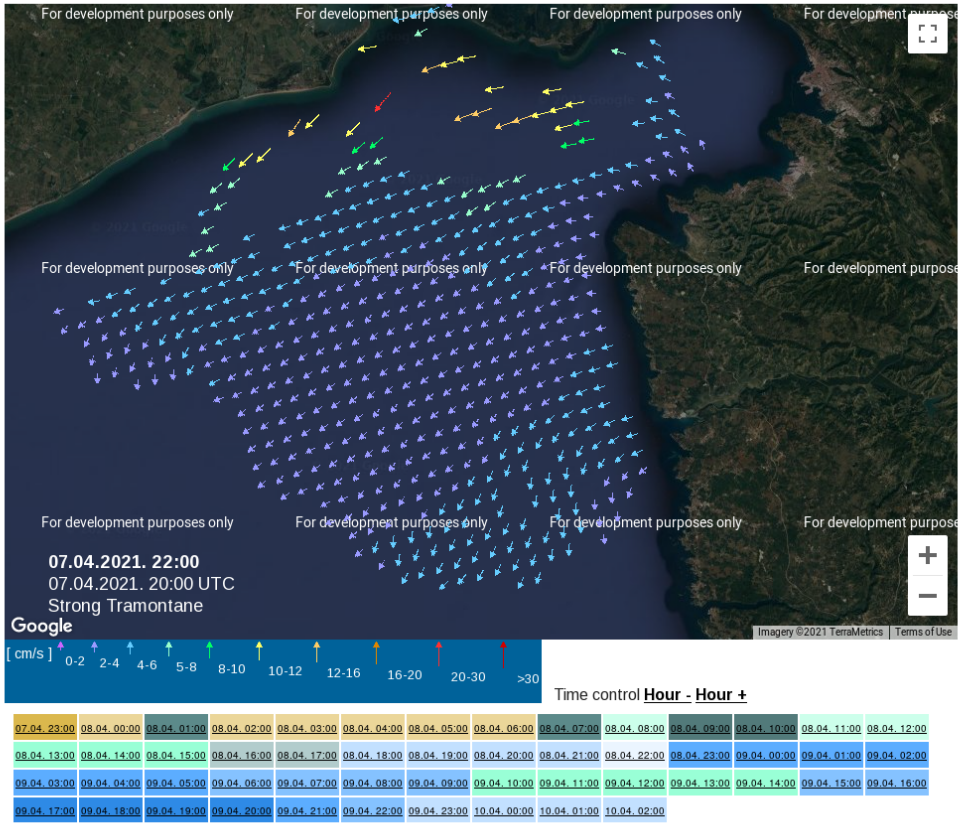

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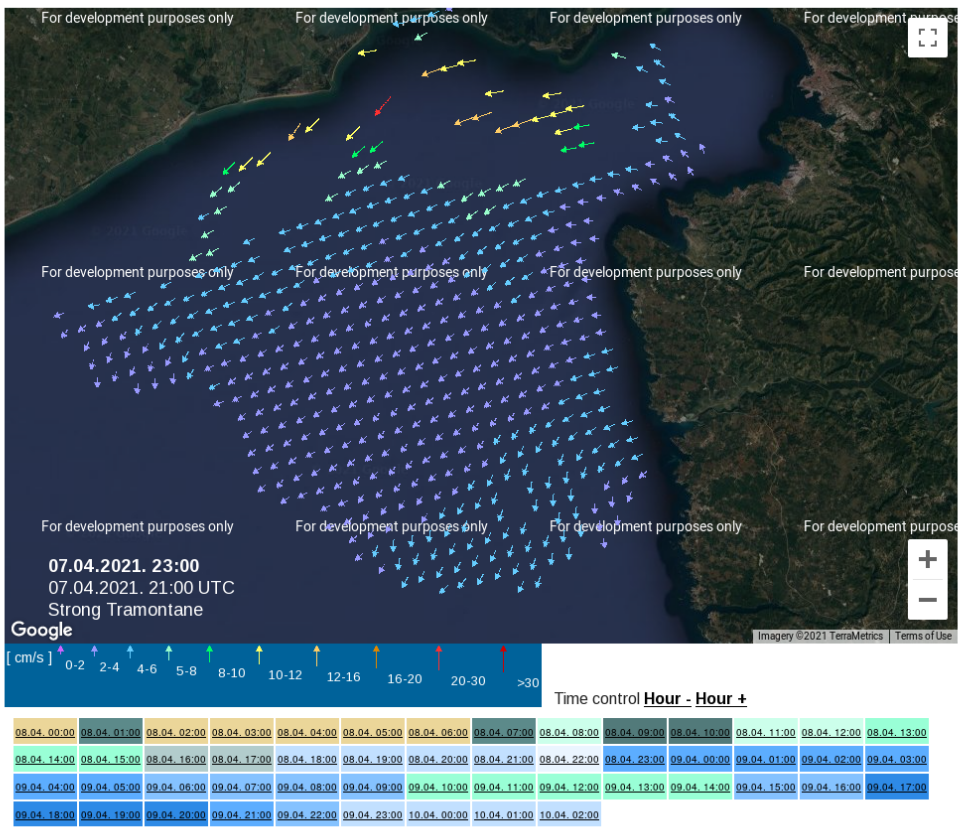

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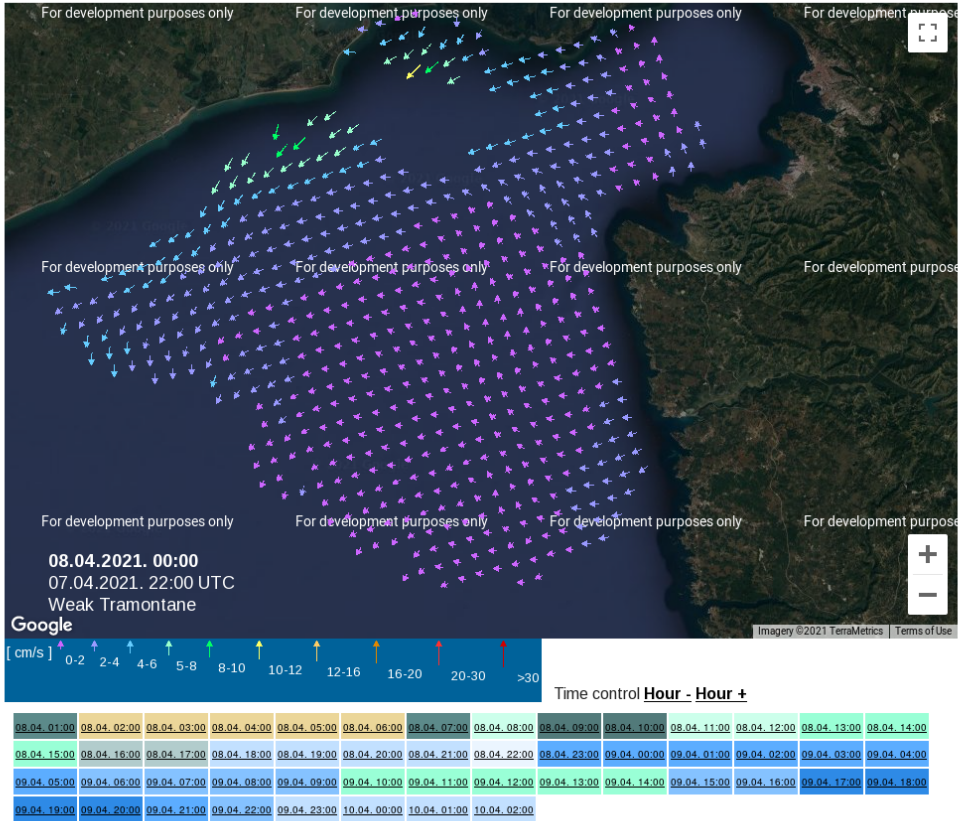

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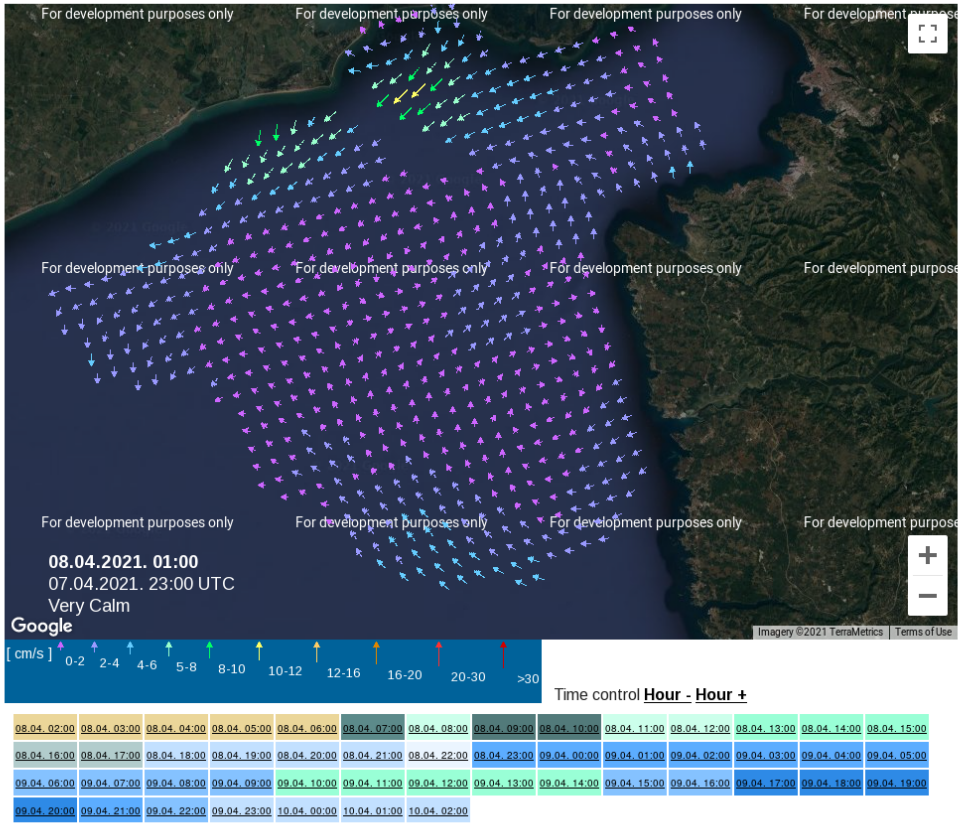

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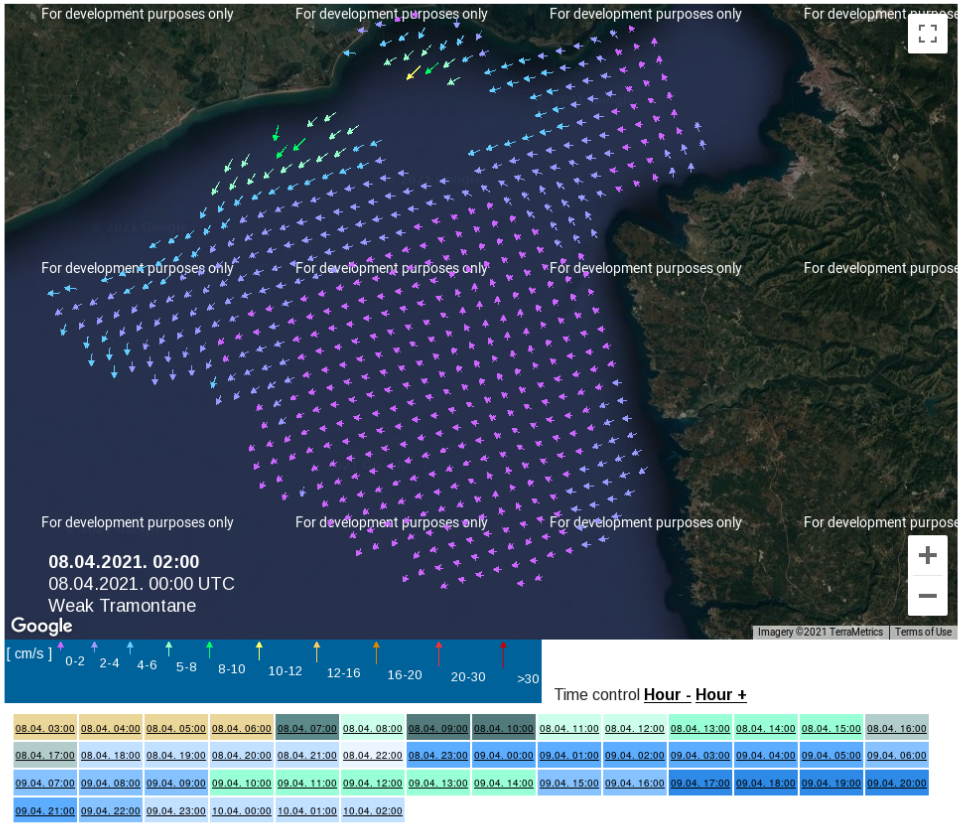

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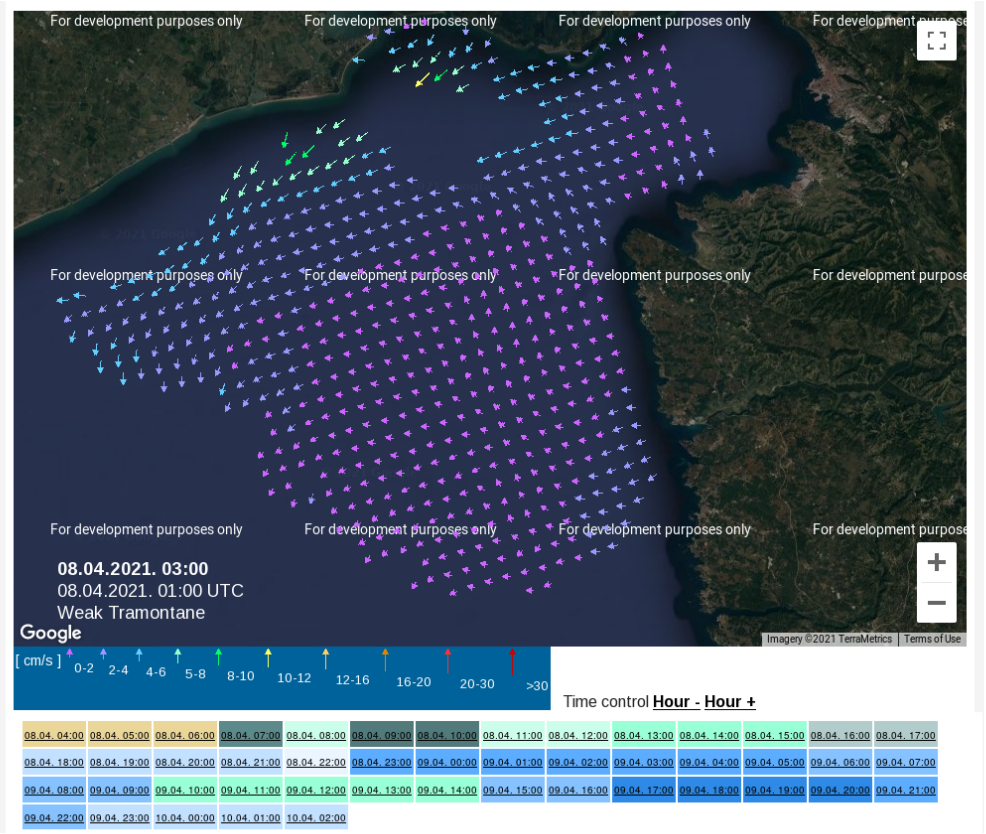

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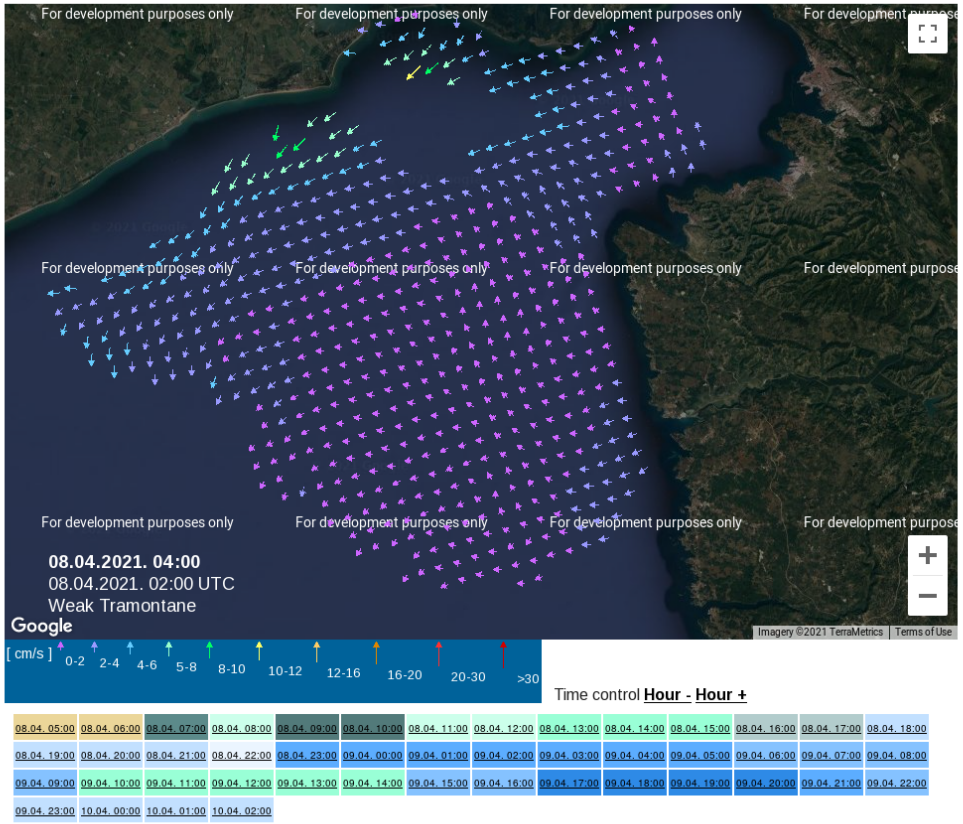

# Surface currents forecast

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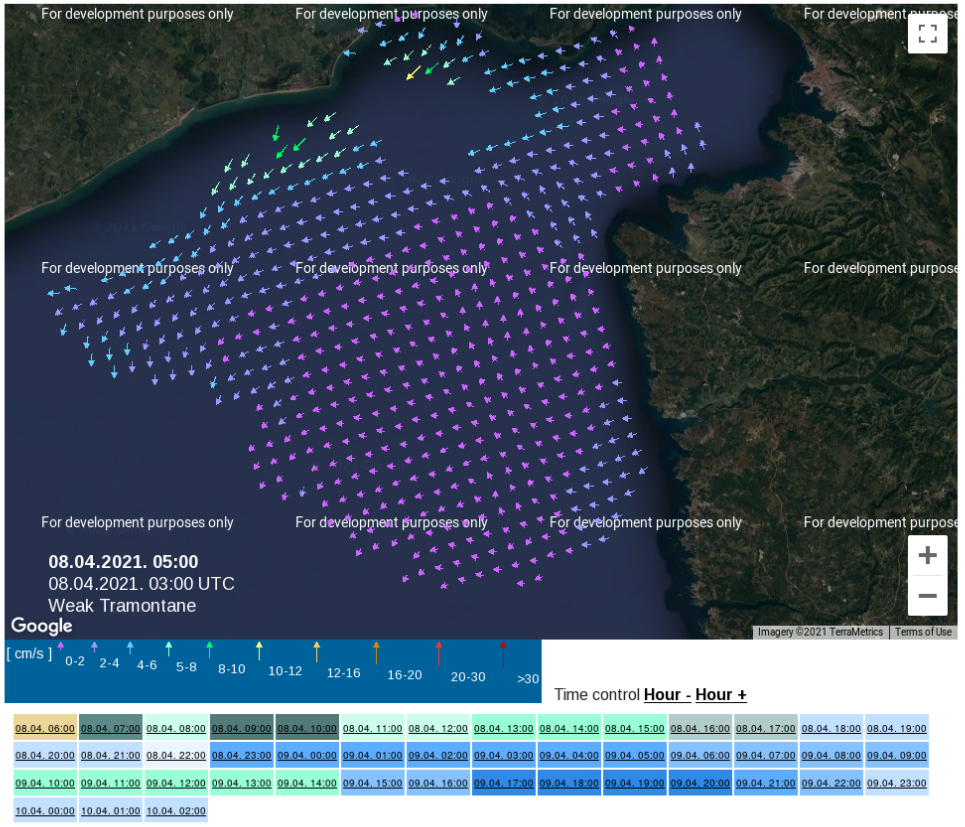

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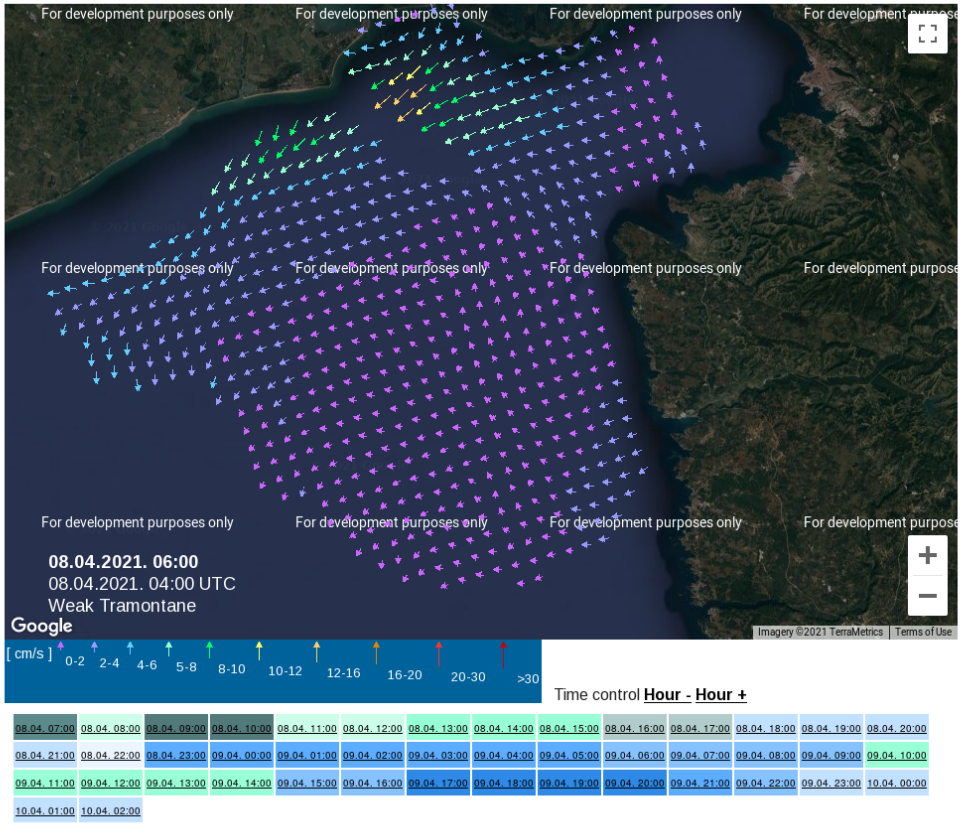

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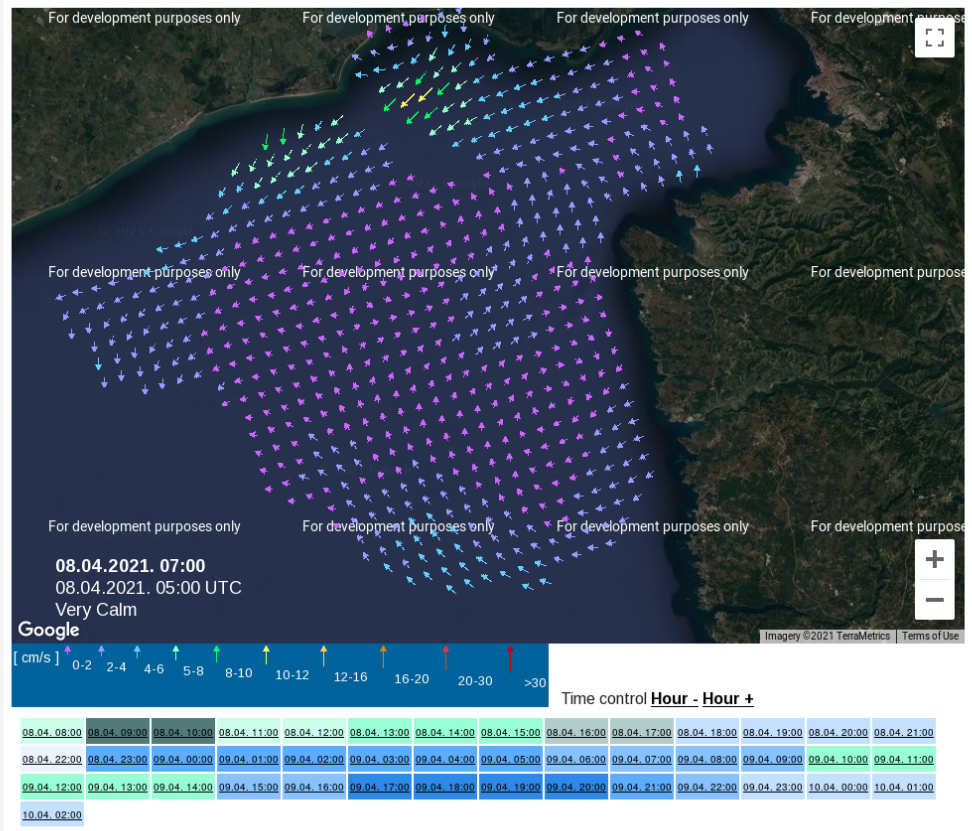

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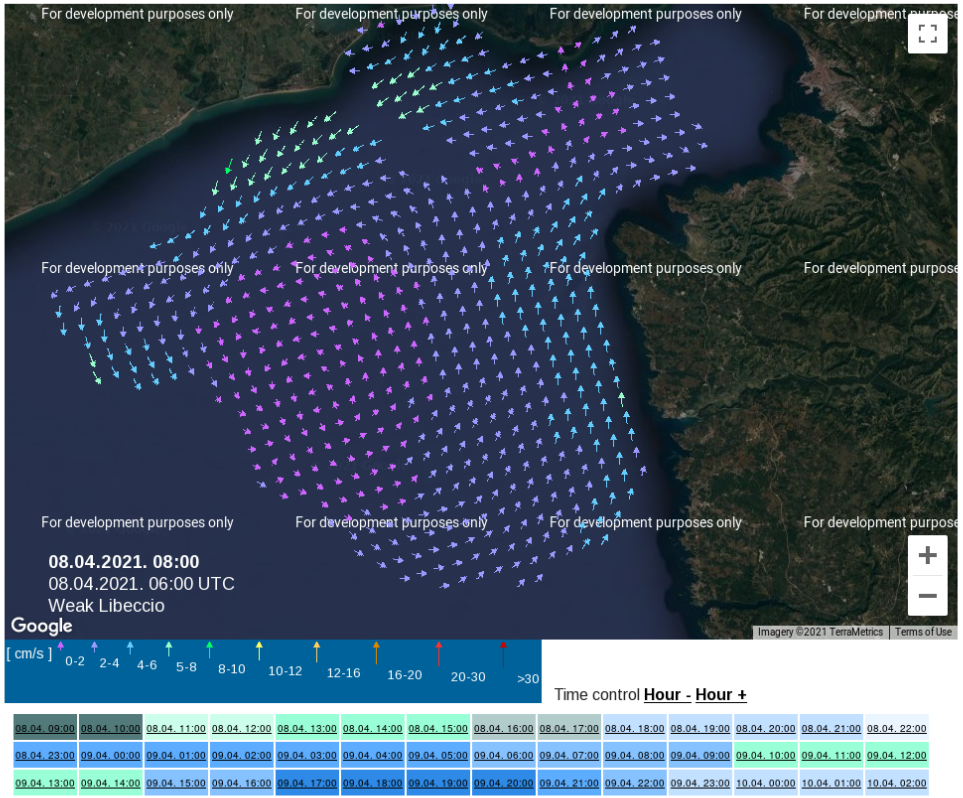

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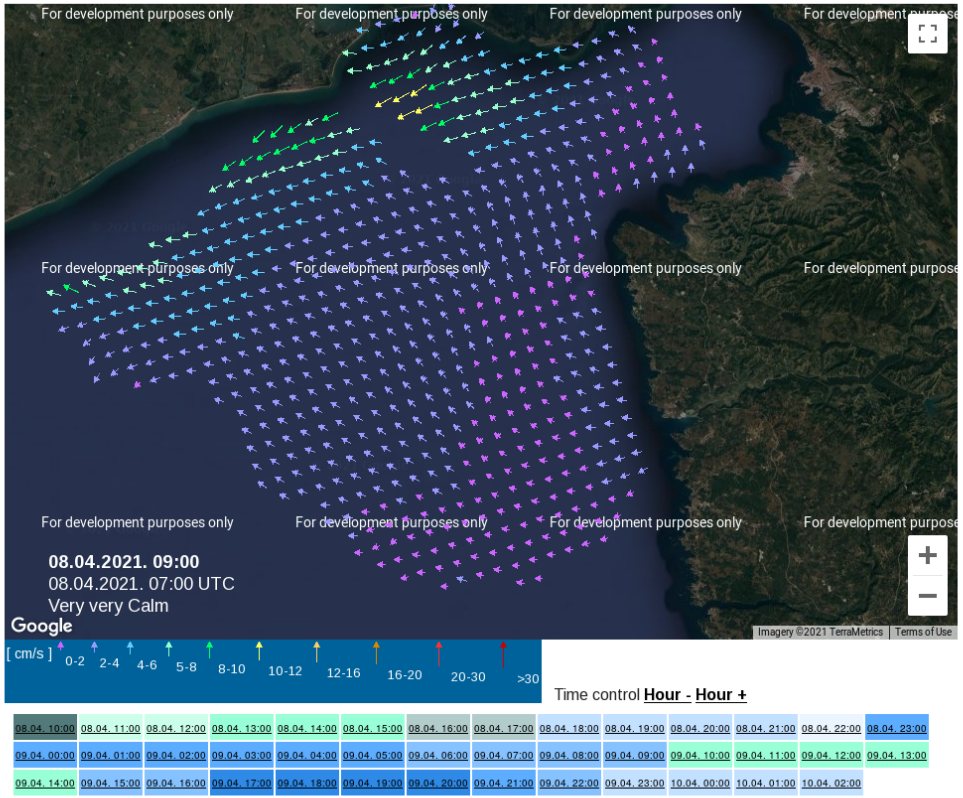

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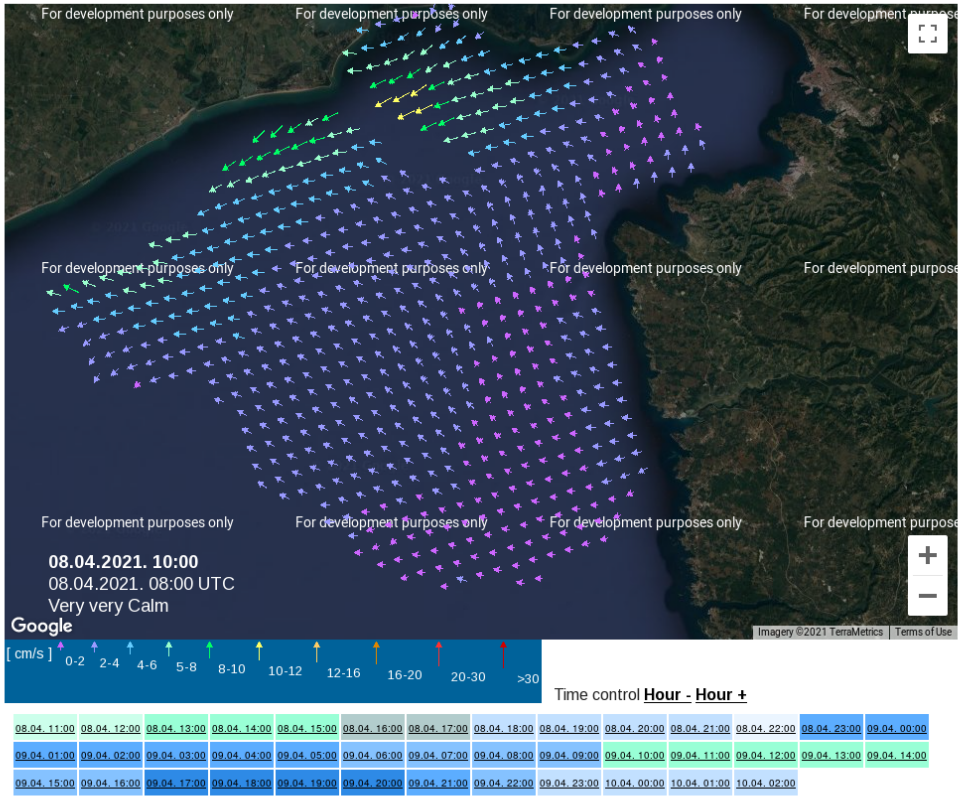

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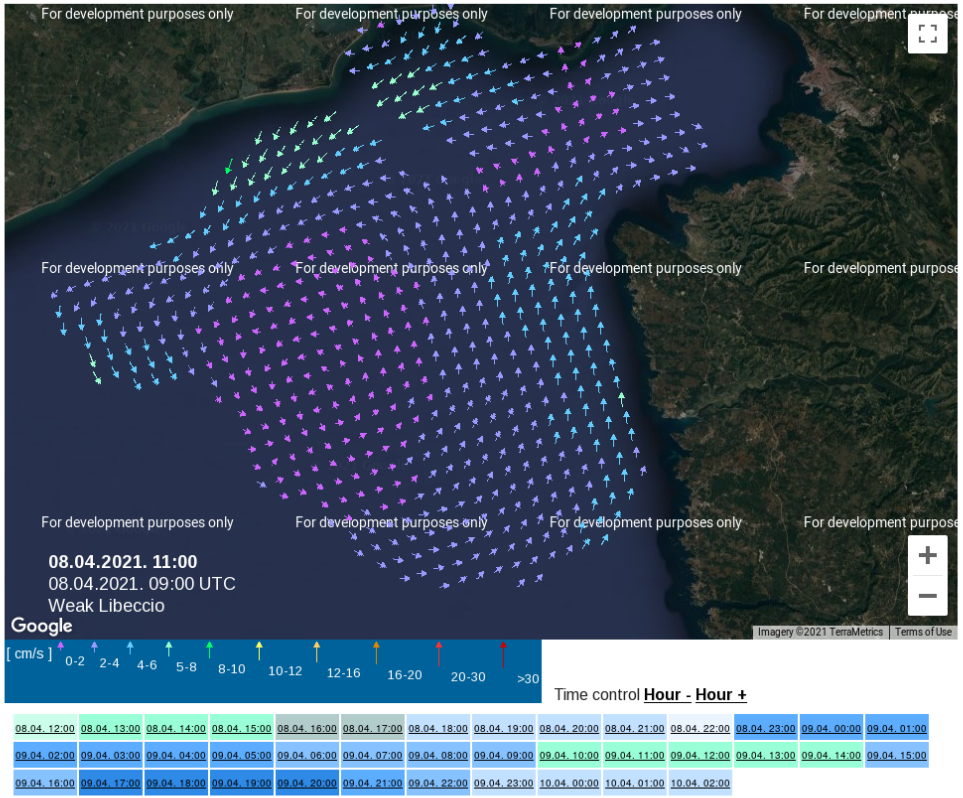

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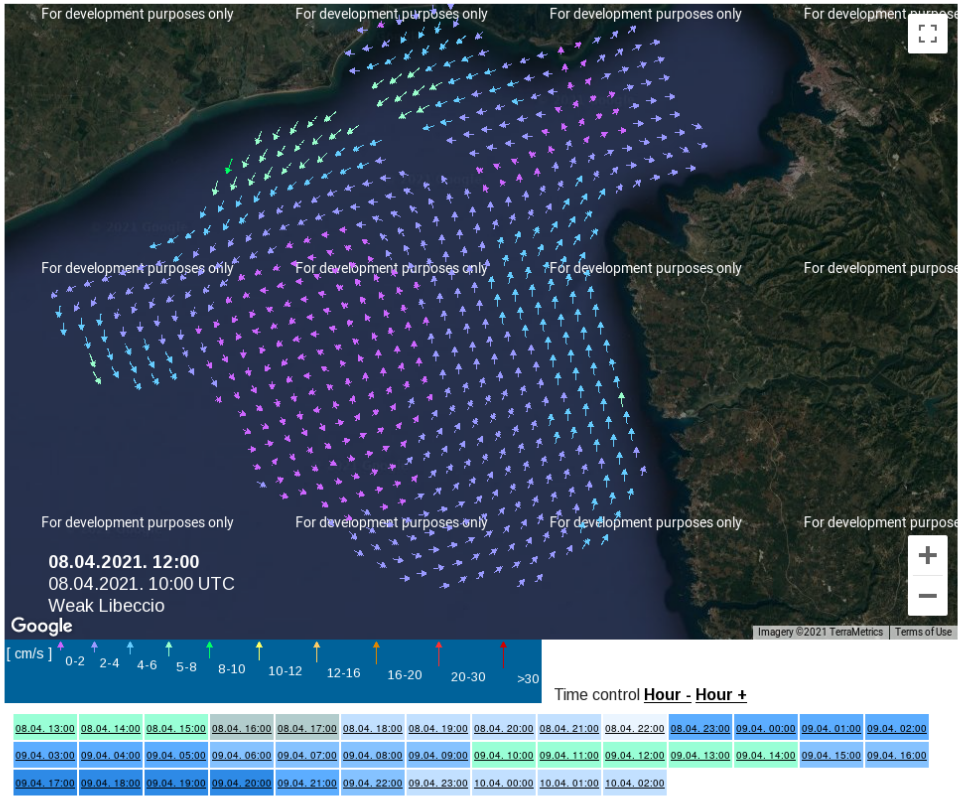
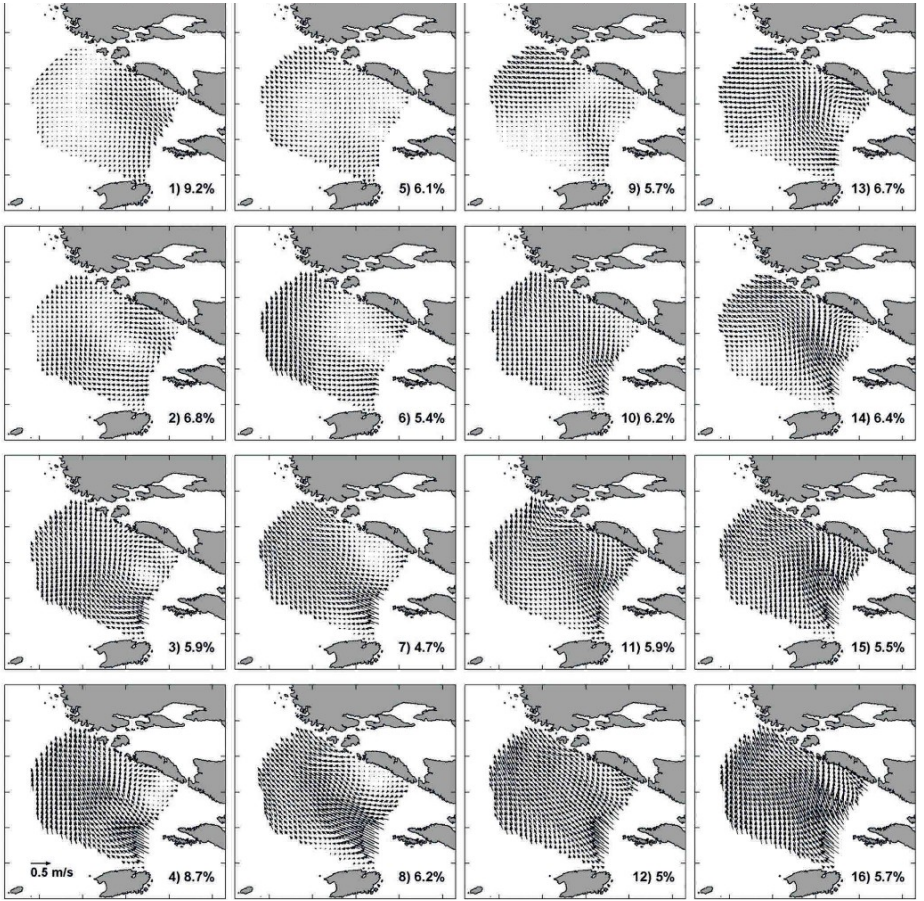
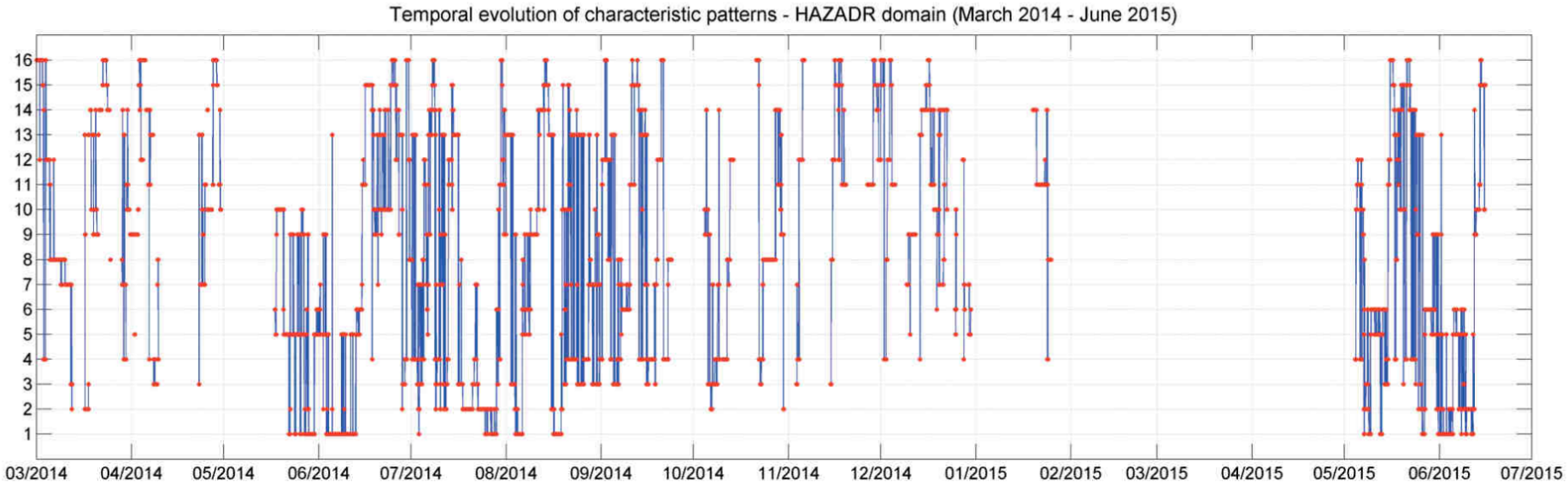


# Surface current SOMs – Central Adriatic

- Sixteen characteristic patterns extracted by the SOM using low-pass filtered current data from 1 March 2014 to 15 June 2015.



# Surface current SOMs – Central Adriatic




- Temporal evolution of characteristic SOM patterns. Temporal coverage of the radar measurements till 15 June 2015 is also visible here, with the largest gap between January and April 2015.

# Conclusions

- Having quality input data is essential for AL/ML so for NN/SOM too.
- SOM can provide reliable forecast of surface currents based on wind field forecast if the currents are primarily driven by wind
- Can be applied to other wind driven ocean fields such as wave height and direction (and much more)
- The variability of the ocean current forecast field is substantially reduced to nxm BMUs, constant then jumpy when changing patterns
- Applicable only where extensive measurements are done (alternatively, one could train SOM on an ocean or wave model)
- Useful on limited areas due to limited number of patterns (Adriatic would have to be divided to use satellite data)

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# Thank you for your attention.

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