Regional Cooperation for Limited Area Modeling in Central Europe



Forecasting surface currents using neural networks

OMSZ

Martina Tudor on behalf of the NEURAL team















- 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 (installed temporarily)
 - Central Adriatic









- Ivica Vilibić, Institute of Oceanography and Fisheries, Croatia, Principal Investigator
- Nedjeljka Žagar, University of Ljubljana, Slovenia, Co-Principal Investigator
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- Blaž Jesenko, University of Ljubljana, Slovenia, research associate
- Hrvoje Kalinić, Institute of Oceanography and Fisheries, Croatia, postdoctoral researcher









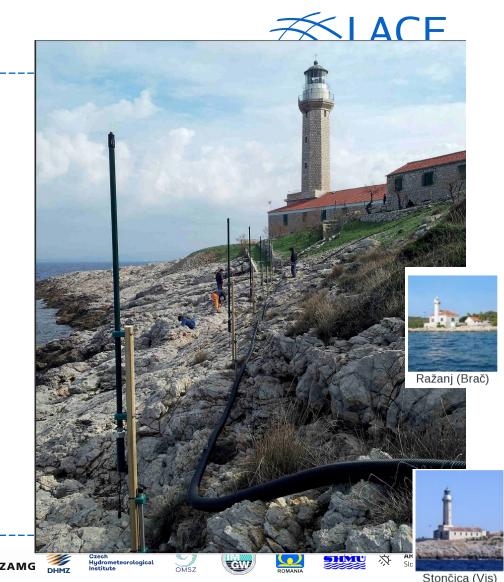


- develop a hybrid ocean forecasting system based on the neural network approach and self-organizing maps algorithms using as input:
 - surface current fields measured by high-frequency oceanographic radars and
 - mesoscale surface winds simulated by the high-resolution numerical weather prediction (NWP) model
- Iearn 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

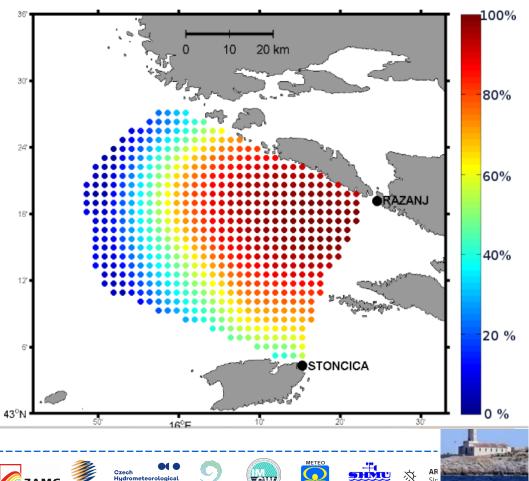


HF radars – Central Adriatic

- Example of 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/



- 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_e n2.html



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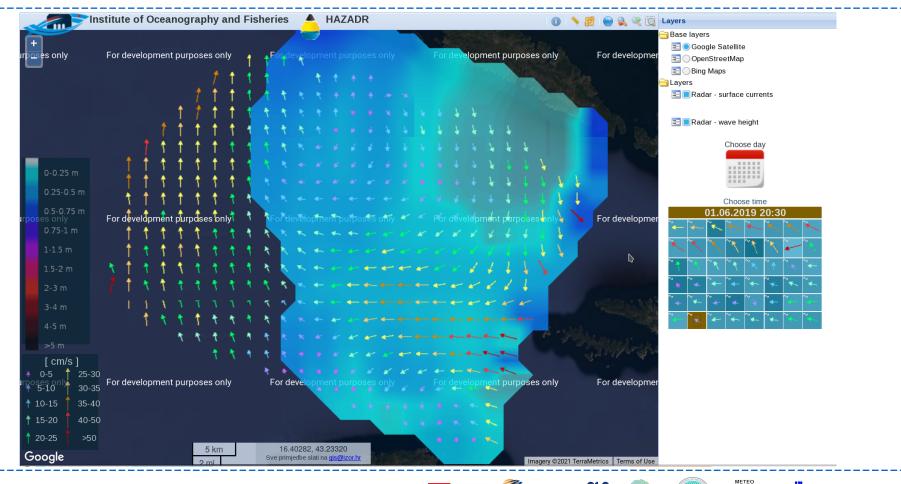
HF radars – Central Adriatic data coverage *KLACE*

HF radars – Central Adriatic



ARSO METEO

Slovenia





Czech

Institute

Hydrometeorological

GW

OMS7

Artificial Intelligence/Machine Learning



- 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.

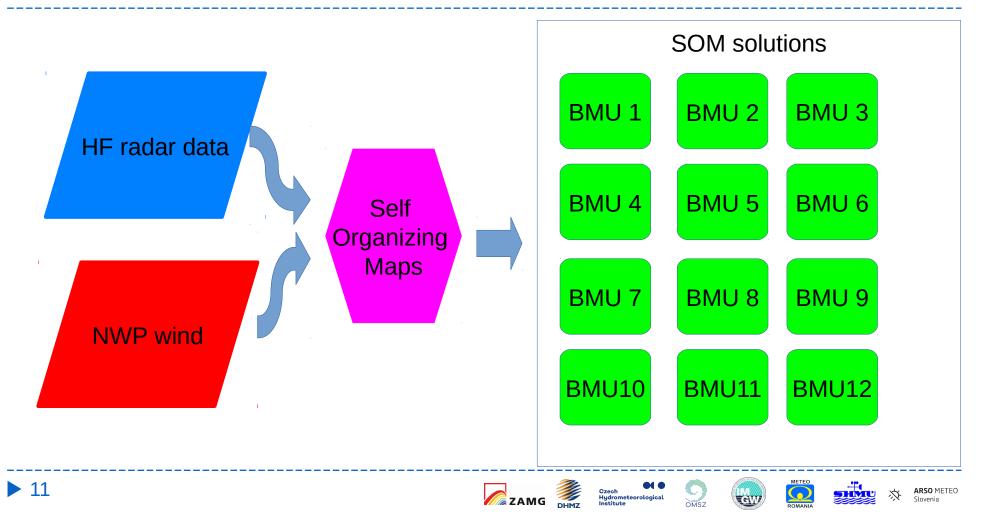






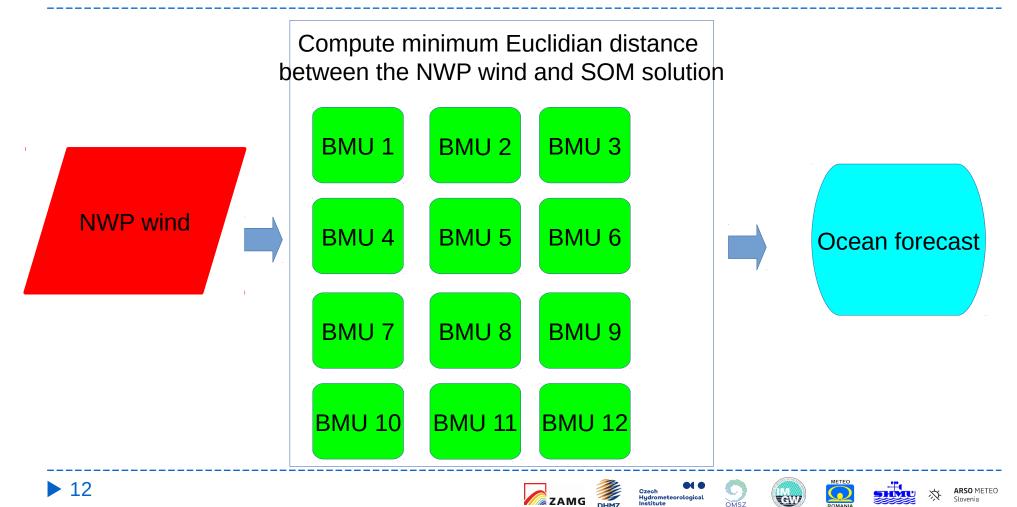
Self Organizing Maps forecast - training





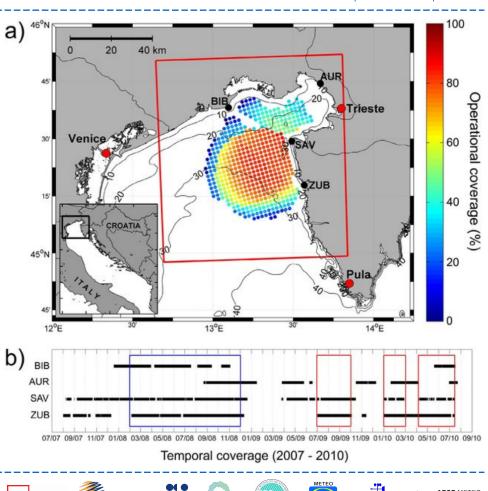
Self Organizing Maps forecast





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.





associated CBE (color, in m/s). Black line stands for the coastline.

Red numbers stand for BMUs.

3x4 SOM patterns of ALADIN

surface winds (arrows) and

Surface currents forecast

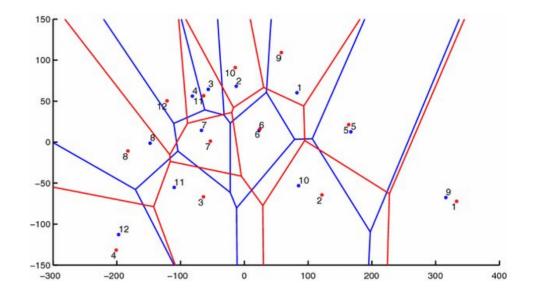
45°N 45°N 45°N 45°N 12°E 30' 13°E 30' 14°E 30' 13ºE 30' 14ºE 30' 12°E 30 13ºE 12°E 14°E





-Indrometeorological

Voronoi tessellation of SOM nodes (numbered dots) projected to 2D space using Isomap algorithm for 12 nodes. 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 CSⁿ (currents) and blue CWSⁿ (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

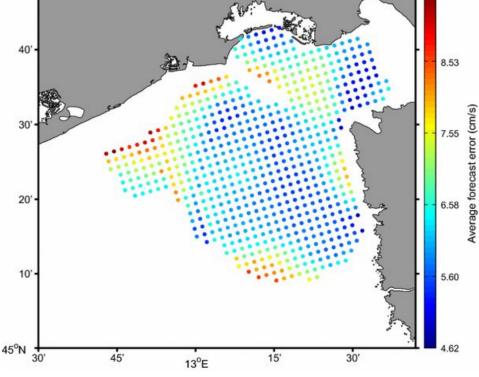




coded showing the average error at specific location.

- The error is in cm/s
- The error is the largest at the edges of the range of the HF radars.

Spatial distribution of the forecast error. Every grid point is colour





9.50





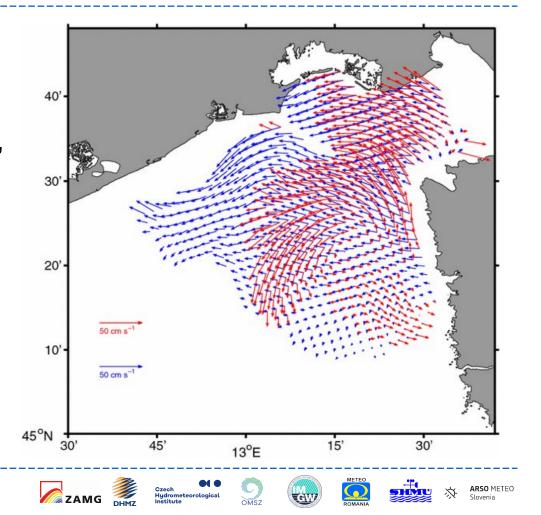






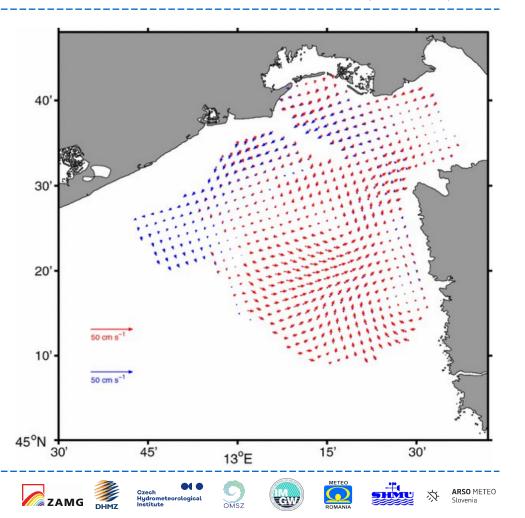
► 17

- Direct comparison between forecast (blue arrows) and observed (red arrows) surface currents on 14th September, 2008, at 20:00 UTC (worst-case scenario)
- Measurements are not always available on the whole grid!





- Direct comparison between forecast (blue arrows) and observed (red arrows) surface currents on 12th October, 2008, at 6:00 UTC
- Measurements are not always available on the whole grid!



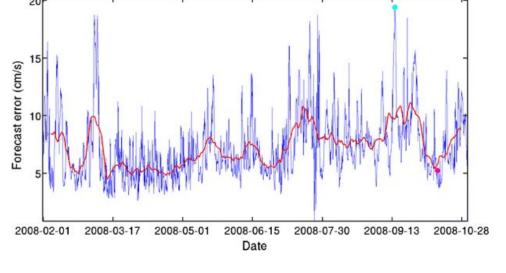


for 10-day average forecast error.

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

Time series of the forecast error. Blue line stands for hourly and red 20

Surface currents forecast











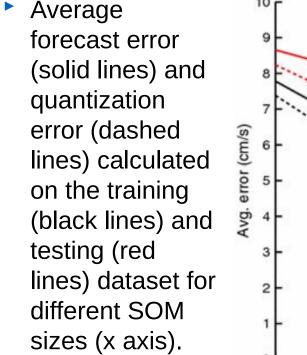


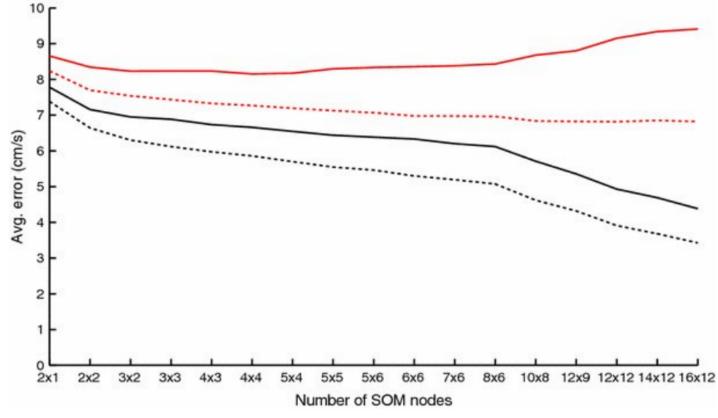


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Surface currents forecast error



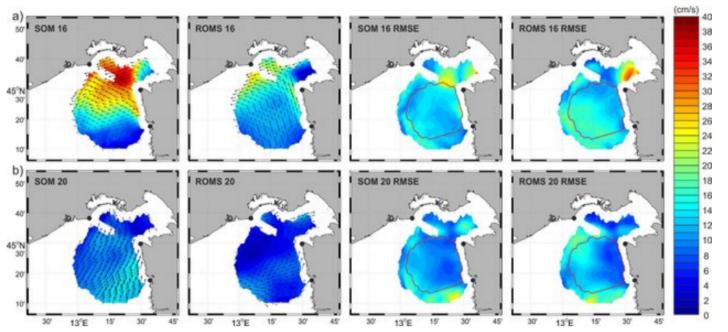




Surface currents forecast - ROMS



Surface currents obtained by the SOMbased forecasting system, the respective average surface currents obtained by ROMS forecasting system, and the **RMSE** between SOMbased and ROMSbased 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.









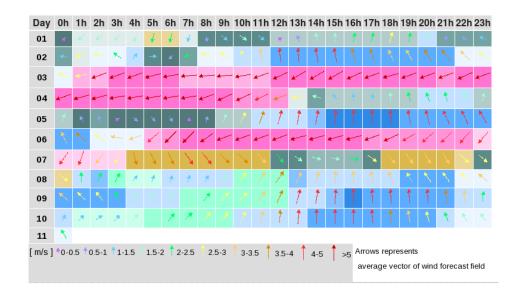
ARSO METEO

Scene (forecast types) table with appearance percentage

<u>1</u>	<u>6</u>	<u>11</u>	<u>16</u>
<u>3.49%</u>	6.45%	<u>7.38%</u>	6.45%
<u>2</u>	<u>7</u>	<u>12</u>	<u>17</u>
<u>8.05%</u>	<u>7.2%</u>	6.23%	<u>5.6%</u>
<u>3</u>	<u>8</u>	<u>13</u>	<u>18</u>
5.4%	6.04%	5.93%	<u>4.55%</u>
<u>4</u>	<u>9</u>	<u>14</u>	<u>19</u>
<u>4.72%</u>	<u>5.78%</u>	<u>4.78%</u>	2.99%

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)

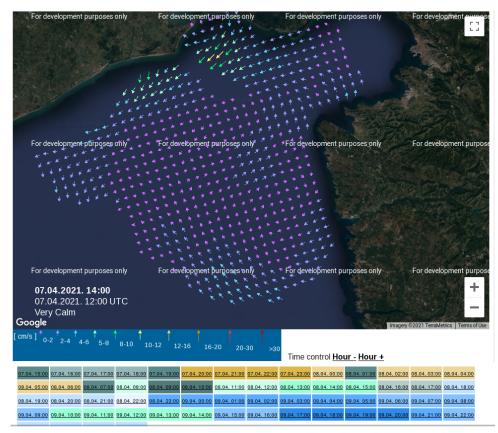






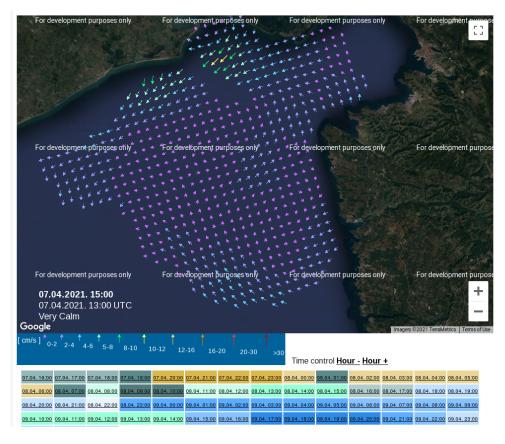


- Surface currents forecast available operationally at http://faust.izor.hr/autodatapub/n eural_som_karta?jezik=eng
- Hourly forecast fields in 'radar' grid points (only in points with sufficient data quality for that current pattern)
- Vector length and colour in cm/s
- Colour indicates which 'type' of field is forecast (subsequent forecasts can be identical if they belong to the same type)





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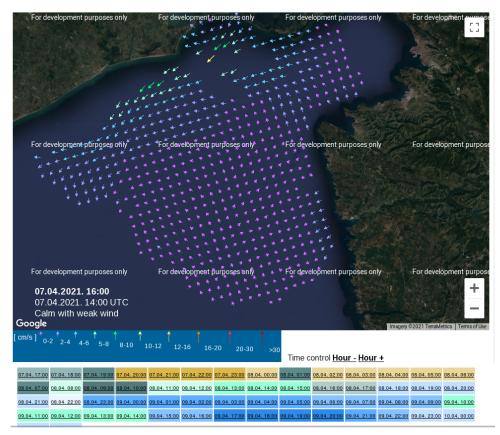






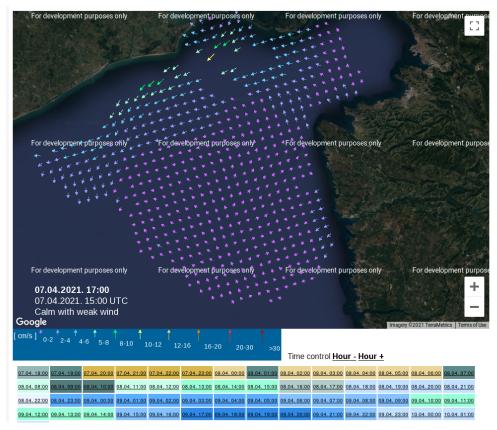


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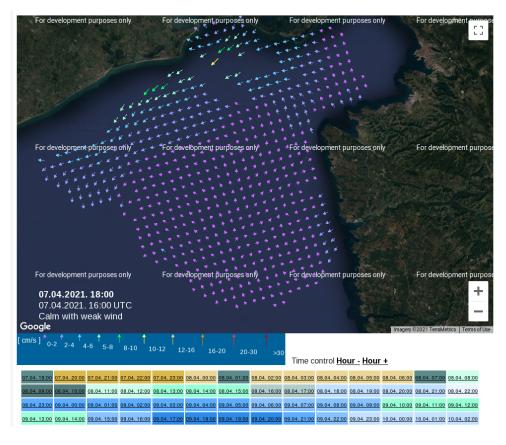


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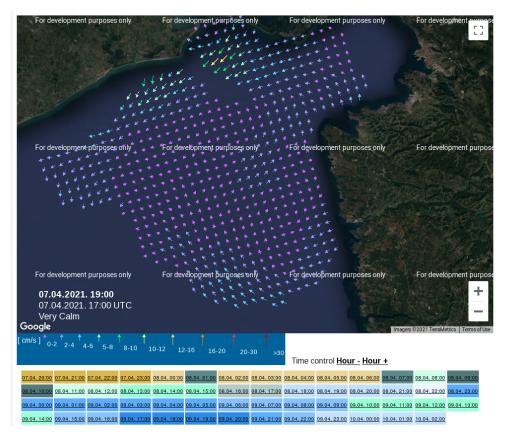






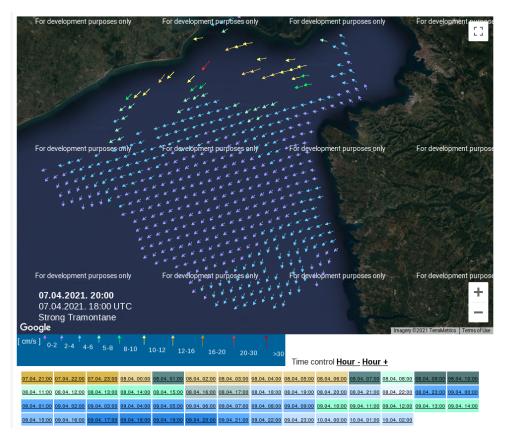


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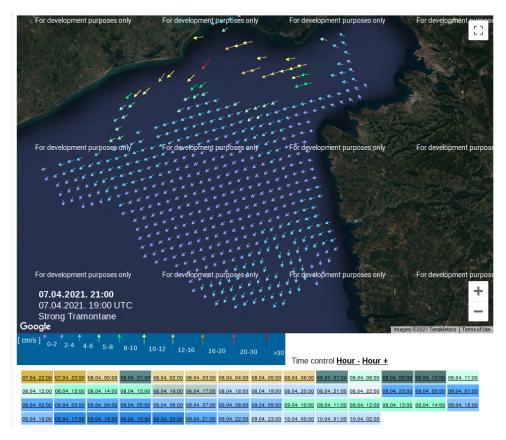


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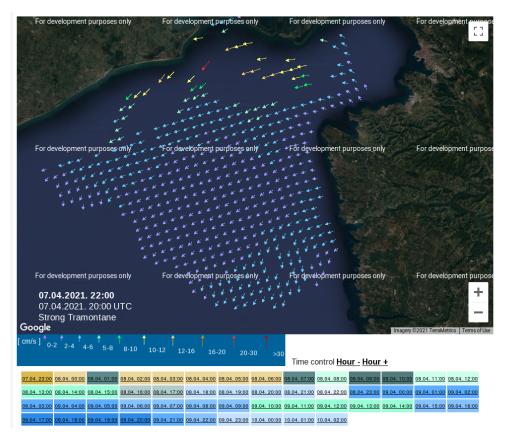


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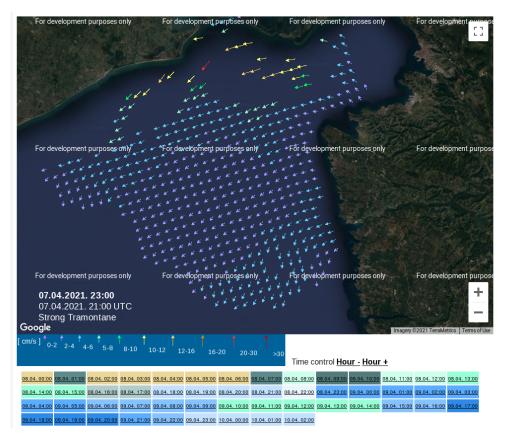


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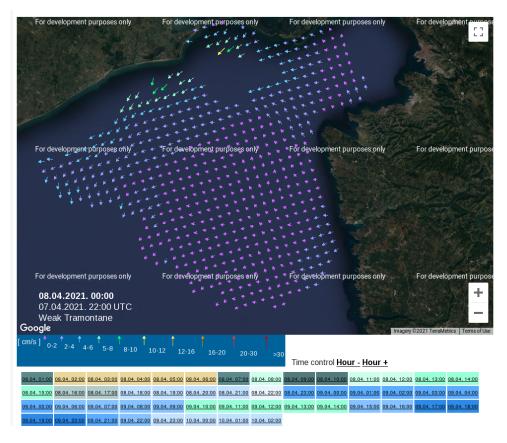


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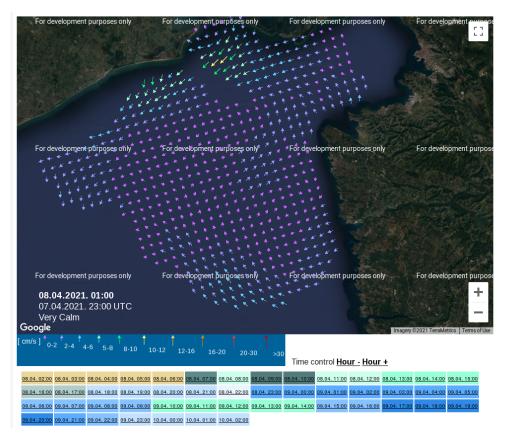


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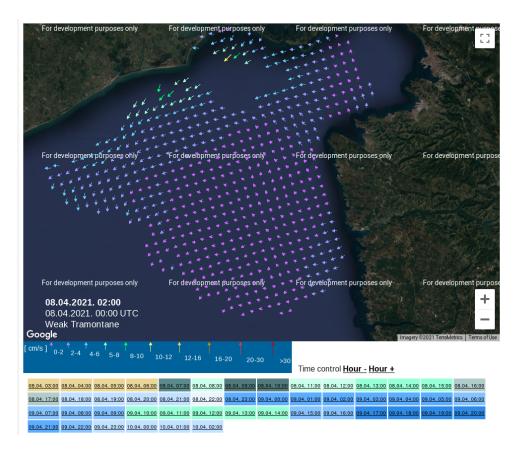


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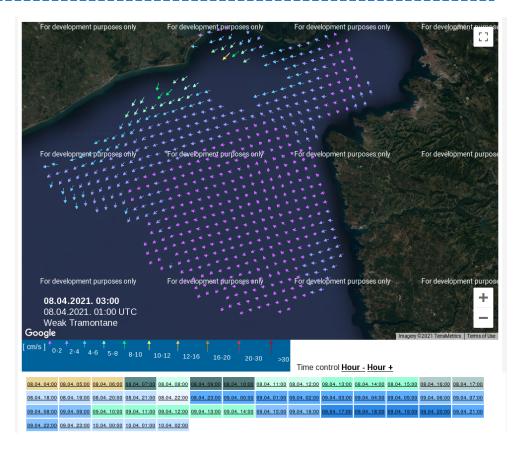






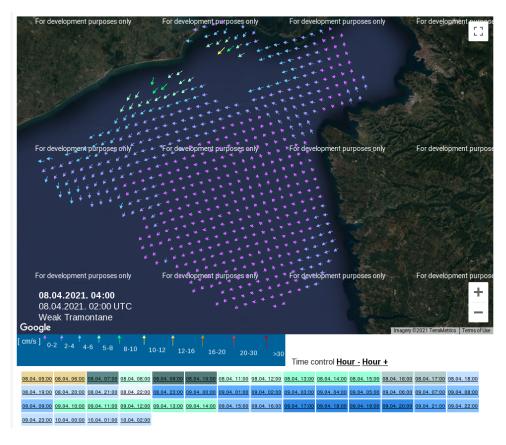


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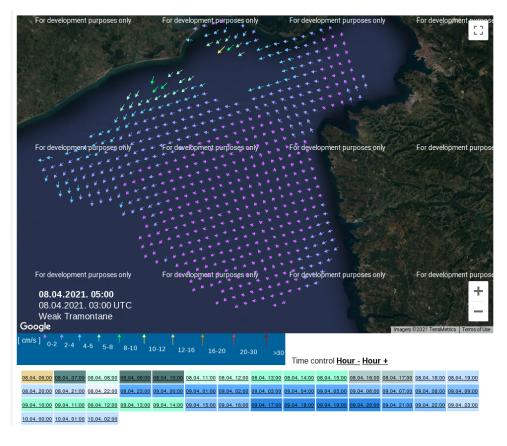






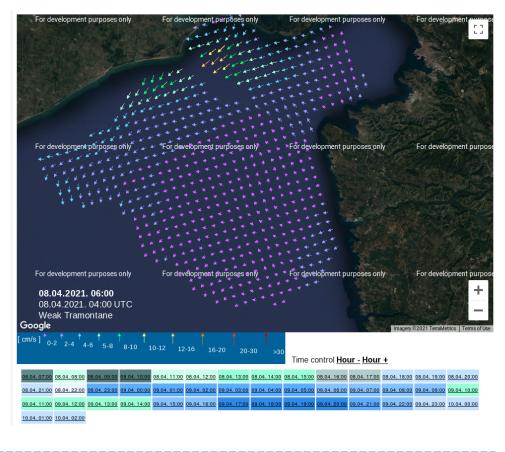


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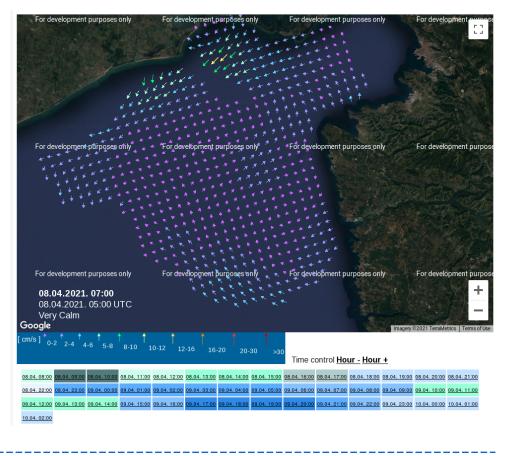


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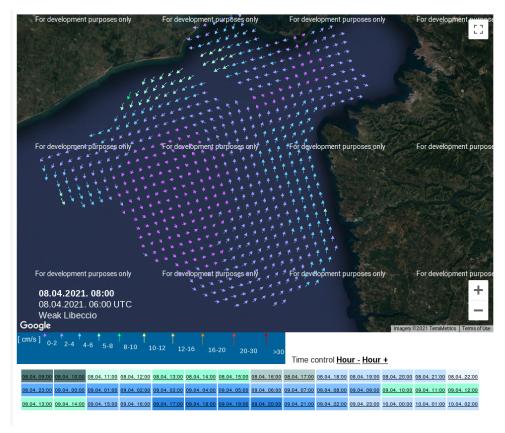


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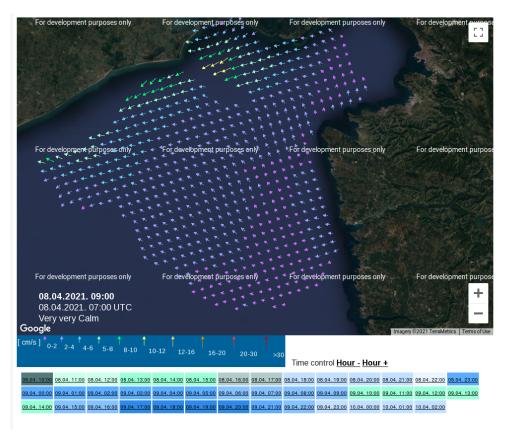


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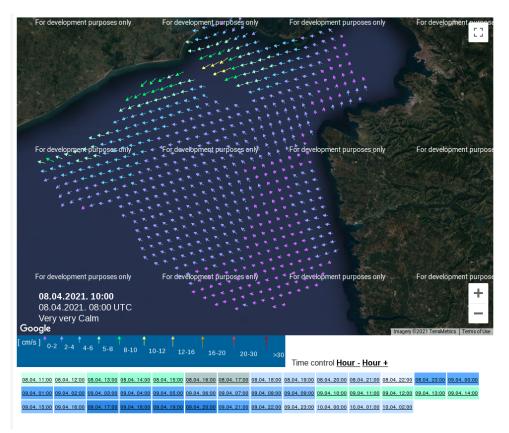


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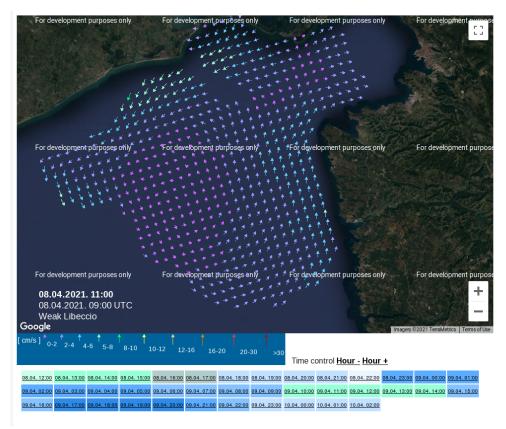


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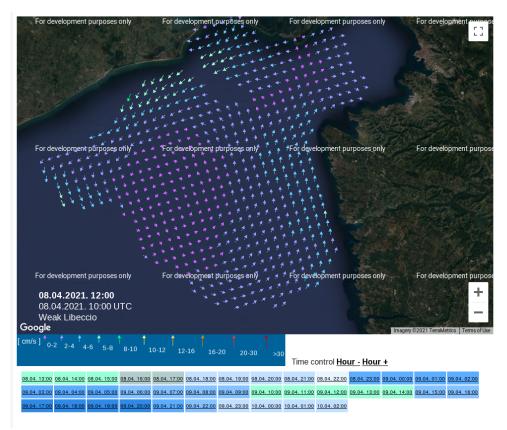


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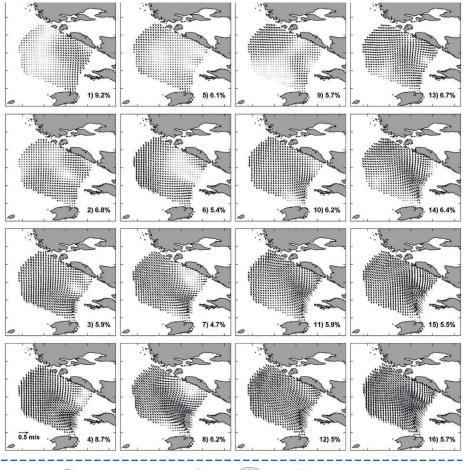


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Surface current SOMs – Central Adriatic

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











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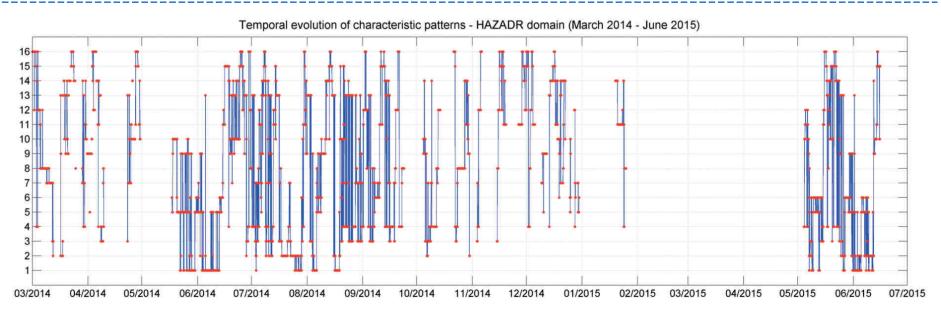
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Surface current SOMs – Central Adriatic





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.





lydrometeorological





- Having quality input data is essential for AL/ML so for NN/SOM too.
- SOM gives an organized spatial pattern and 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)









References and published papers

- Voronoi G (1908) Nouvelles applications des paramètres continus à la théorie des formes quadratiques. Journal für die Reine und Angewandte Mathematik 133:97–178
- Kohonen T (2001) Self-organizing maps, 3rd edn. Springer, New York
- Mihanović H, Cosoli S, Vilibić I, Ivanković D, Dadić V, Gačić M (2011) Surface current patterns in the northern Adriatic extracted from high-frequency radar data using self-organizing map analysis. J Geophys Res 116:C08033

- Kalinić H, Mihanović H, Cosoli S, Vilibić I (2015) Sensitivity of self-organizing map surface current patterns to the use of radial versus Cartesian input vectors measured by high-frequency radars. Comput Geosci 84:29–36
- Kalinić H, Mihanović H, Cosoli S, Tudor M, Vilibić I (2017) Predicting ocean surface currents using numerical weather prediction model and Kohonen neural network: a northern Adriatic study. Neural Comput & Applic (2017) 28 (Suppl 1):S611–S620
- Vilibić, I. et al. Self-Organizing Maps-based ocean currents forecasting system. Sci. Rep. 6, 22924; doi: 10.1038/srep22924 (2016).





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Thank you for your attention.













