EMODnet Bathymetry

D3.12: Tidal bathymetry for Venice Lagoon

Technical Report

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1 Introduction

With every release of the EMODnet Bathymetry DTM more and more surveys are collected and incorporated into the database. However, at the coast where the seas and oceans meet river deltas and estuaries, the coverage is still relatively low. This seems to be caused by several interacting effects. Firstly, the coastline that we use in EMODnet to mask the land from the datasets is not always accurate. It may shortcut river-mouths and estuaries, or it may be too coarse to capture the small channels and creeks that are present in the intertidal zone. This may be in line with our human perception of the coastline, but it cuts away potentially relevant data. Note that we can not just remove the step where we cut away the cells in the grid marked as land, since this plays an important part in the impolation of the bathymetry. Secondly, the institutes involved in obtaining the surveys are often different ones than those that perform the survays at sea.

One example that illustrates this, is Venice lagoon. Until now the EMODnet gridded bathymetry did not include the lagoon. This is caused by a lack of data and the fact that the current land-sea mask does not include the lagoon. In this project we add Venice lagoon based on a bathymetry dataset from ISMAR (Sarretta et al., 2015) and satellite derived intertidal bathymetry. In addition, we develop a regional hydrodynamic model for the Adriatic Sea, that includes the lagoon. This model is then used to study the effect of including Venice lagoon in the EMODnet bathymetry on the distribution of tidal dissipation. It is expected that the inclusion of the lagoon will increase the tidal dissipation in the northern Adriatic Sea and have an effect on a much wider area than the lagoon itself. If this is true, then this has important implications for the hydrodynamic modelling of the northern Adriatic Sea and perhaps also for modeling tides near other estuaries and lagoons around Europe.

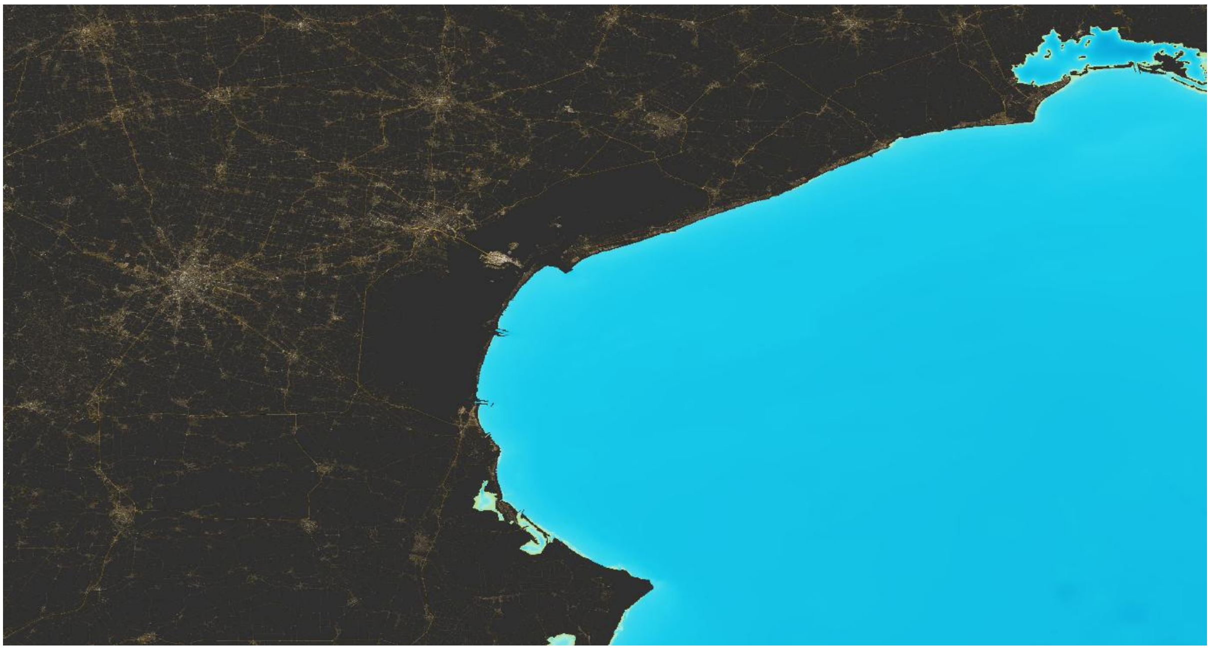

Figure 1 Emodnet gridded bathymetry (tile E5) around Venice lagoon

2 Disclaimer

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3 Satellite derived inter-tidal bathymetry

3.1 Context

The EMODnet Bathymetry DTM releases so far do not include the lagoon of Venice. This is caused mainly by the fact that the current land-sea mask does not include the lagoon and in part by a lack of data. Here we attempt to include the lagoon based on a bathymetry dataset from ISMAR and satellite derived intertidal bathymetry.

3.2 Existing bathymetry

We found a few bathymetric datasets that cover the lagoon of Venice. The most complete one is from ISMAR (Saretta et al., 2015). The most recent survey was performed in 2002 and made available. The dataset is available in the EPSG:3004 projection. According to a dataset description in Saretta et al. (2010), the vertical reference should be very close to mean sea level (MSL).

Using this dataset, we first remapped to WGS84 (EPSG:4326) coordinates. We also mapped to the grid of the E5 tile of EMODnet DTM and to the grid of the satellite derived inter-tidal bathymetry that is described below. For conversion between MSL and LAT, we extended the LAT interpolation to include Venice lagoon. The difference between LAT and MSL in Venice lagoon is around 85cm (computed with GTSM).

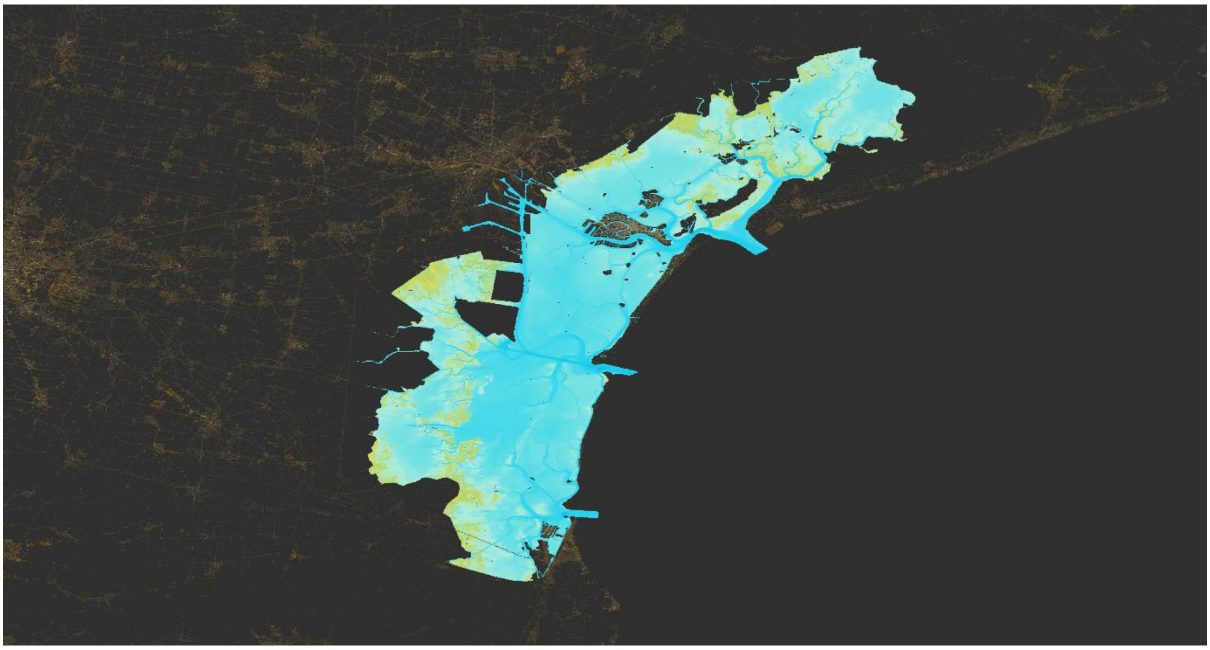

Figure 2 Bathymetry (2002) for Venice lagoon as published by Saretta et al 2010

To provide a preview of the data integrated into the EMODnet gridded bathymetry, we averaged the data onto the common grid and corrected for the LAT-MSL difference. For this step, it was necessary to adapt the land-sea mask, which we based on the Saretta et al. (2015) dataset. We did not perform any manual editing, nor the standard quality checks. By visual inspection in QGIS, it was noted that the common resolution is quite coarse for Venice lagoon. In addition, there are some artefacts such as the channel by Lido that is closed off, probably by a remnant of the coastline. Looking at maps and satellite images for the area, more adjacent waters can be found. It is difficult to see from these data if those waters are connected to the tidal part of the lagoon.

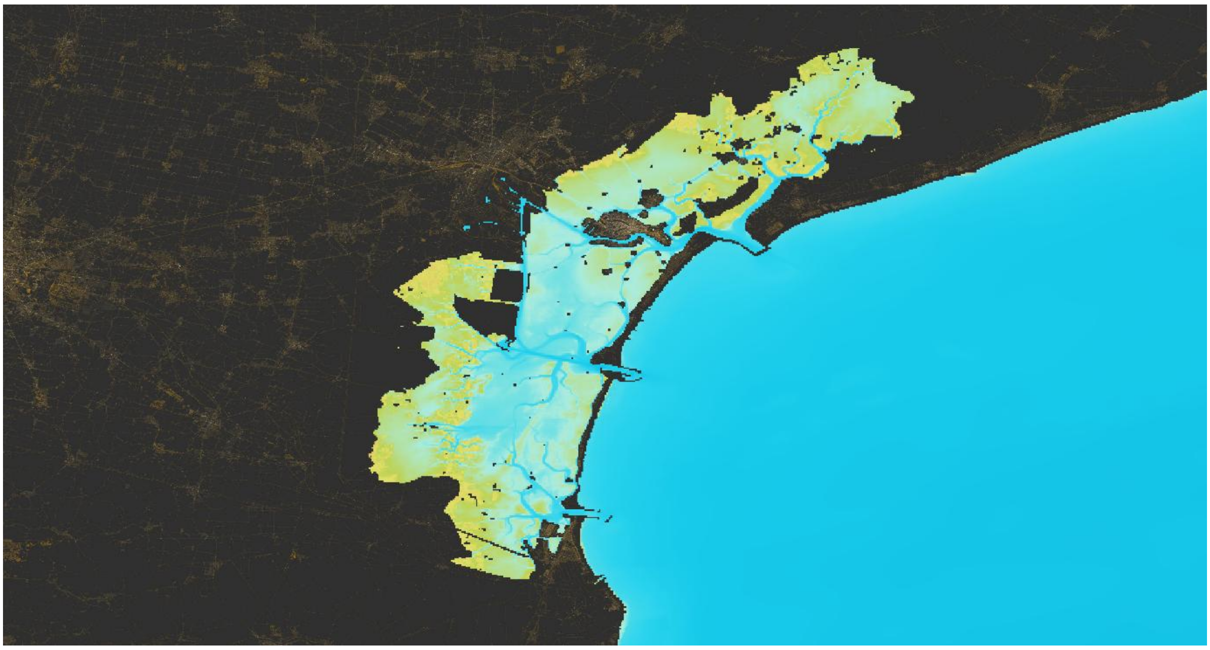

Figure 3 EMODnet gridded bathymetry E5 tile extended with Venice lagoon

3.3 Satellite derived inter-tidal bathymetry

There are several techniques available to derive bathymetry from optical satellite imagery. Here, we will focus on the detection of land versus water using the Normalized Difference Water Index (NDWI), an index based on the different reflection of near-infrared and green light between water and land. We combine a large number of images, filtering eg for cloud cover, resulting in a water index that represents the fraction of time that a grid-cell is covered by water. These percentages are combined with sea-level time-series from a tide-gauge or model to infer the inter-tidal bathymetry. The processing chain is based on the work of Donchyts et al. (2017) and Luijendijk et al. (2018).

In this studie images were collected from Sentinel-2 and Landsat-8. Figure 4 shows the coverage over time and gives an indication of the number of images that was used. Note that the coverage was limited to that area covered by the Sarretta dataset. Even though the water is quite shallow in much of the Venice lagoon, the inter-tidal area is still quite limited.

The sealevel statistics were computed using the GTSMv4.1 model (Wang et al 2020, 2022) and combined with the water index. Figure 6 shows the resulting inter-tidal bathymetry. At first it is difficult to assess the quality of this results. Next, we compare to the Sarretta (2015) dataset by computing the difference. Most of the differences are less than 20cm, but some larger changes can be observed. For example, the channel next to Lido shows some new constructions, that are probably part of the new Mose storm-surge barrier. This may have led to some erosion of the nearby tidal flat, while some other tidal flats have become higher since 2002.

The inter-tidal bathymetry described here has been made available to EMODnet bathtymetry.

Figure 4 Times of L8 and s2 satellite images

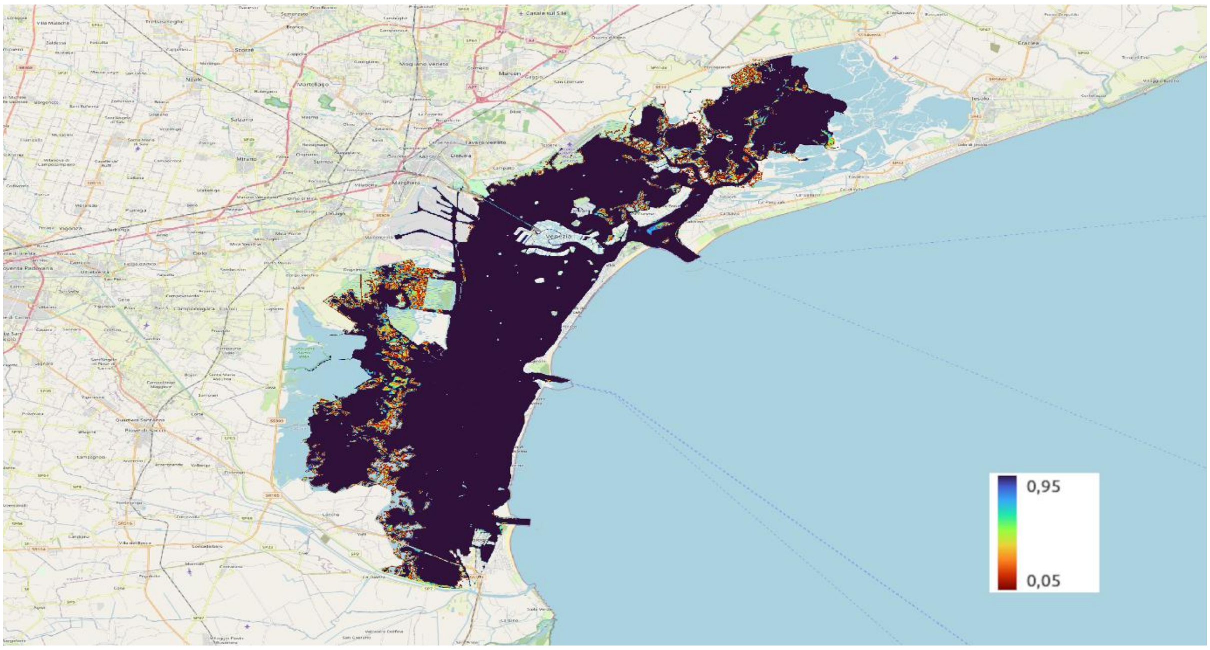

Figure 5 Water index

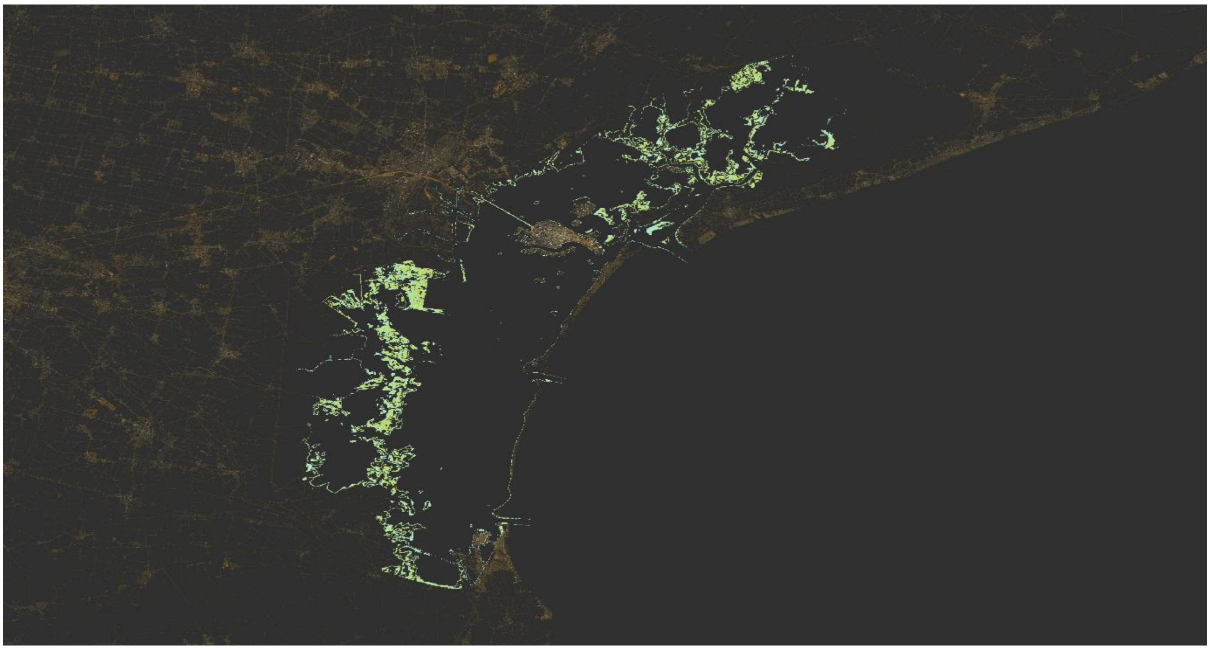

Figure 6 Satellite derived inter-tidal bathymetry

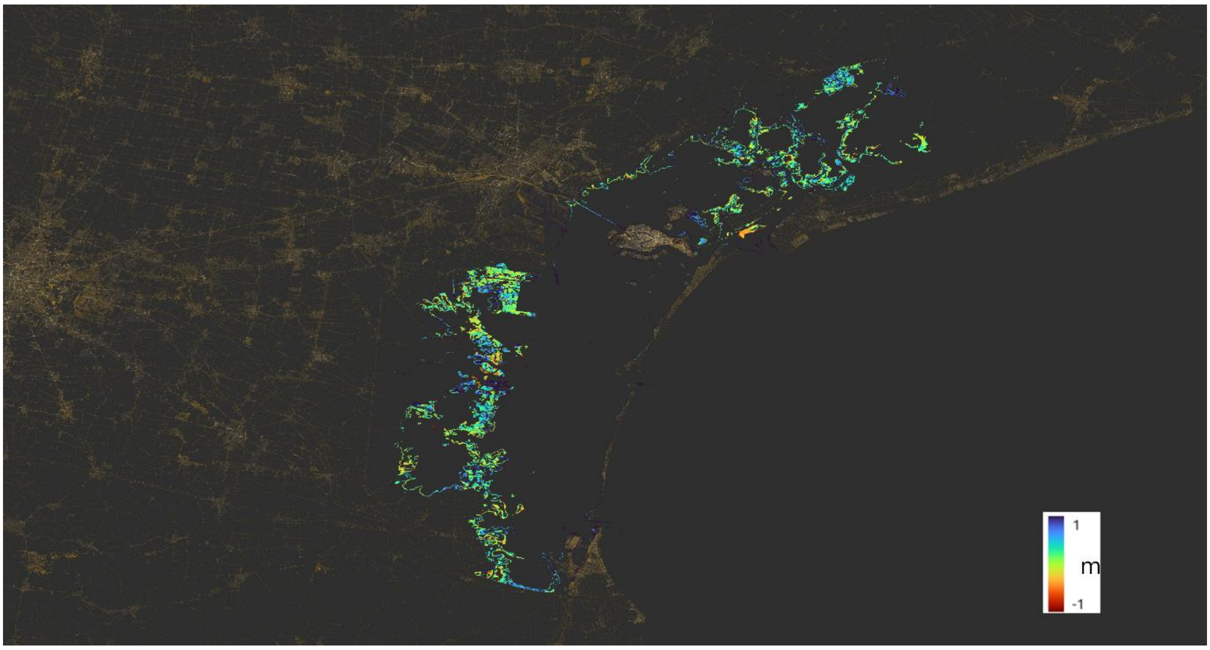

Figure 7 Satellite inter-tidal bathymetry minus Sarretta survey

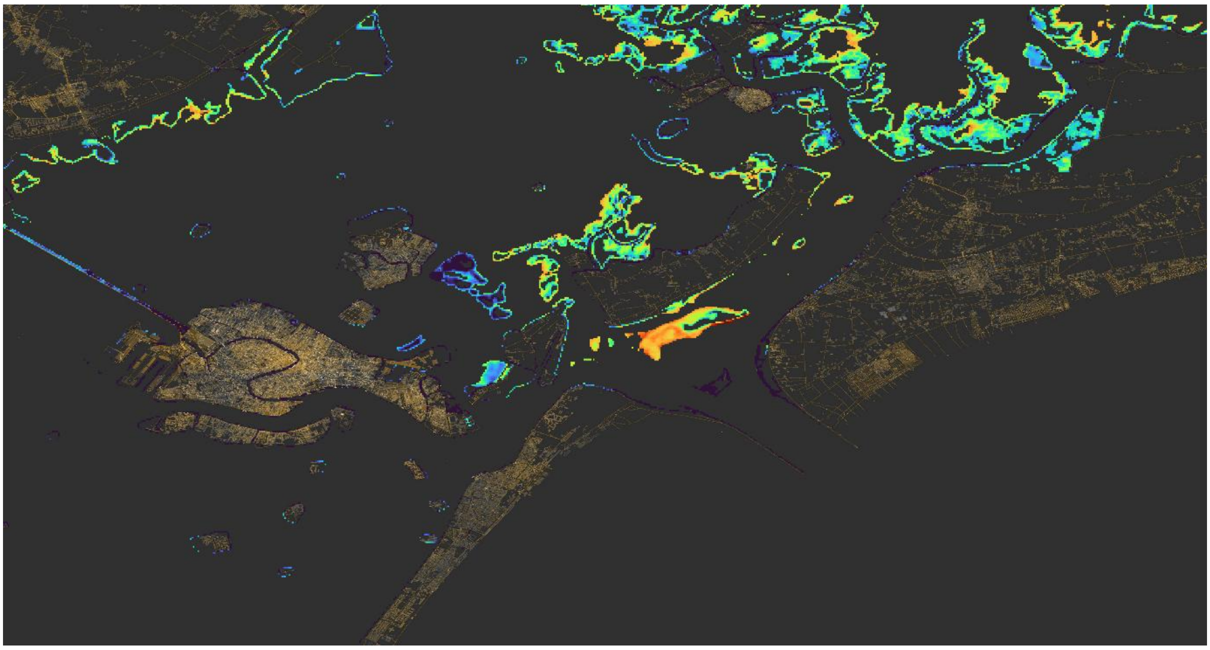

Figure 8 Detail from previous figure

3.4 Satellite derived sub-tidal bathymetry

Another technique to derive bathymetry uses the differences in attenuation of light in water for different colors. In general the water in Venice lagoon contains a significant amount of silt, so that the sunlight hardly reaches the sea-bed, except in very shallow parts.

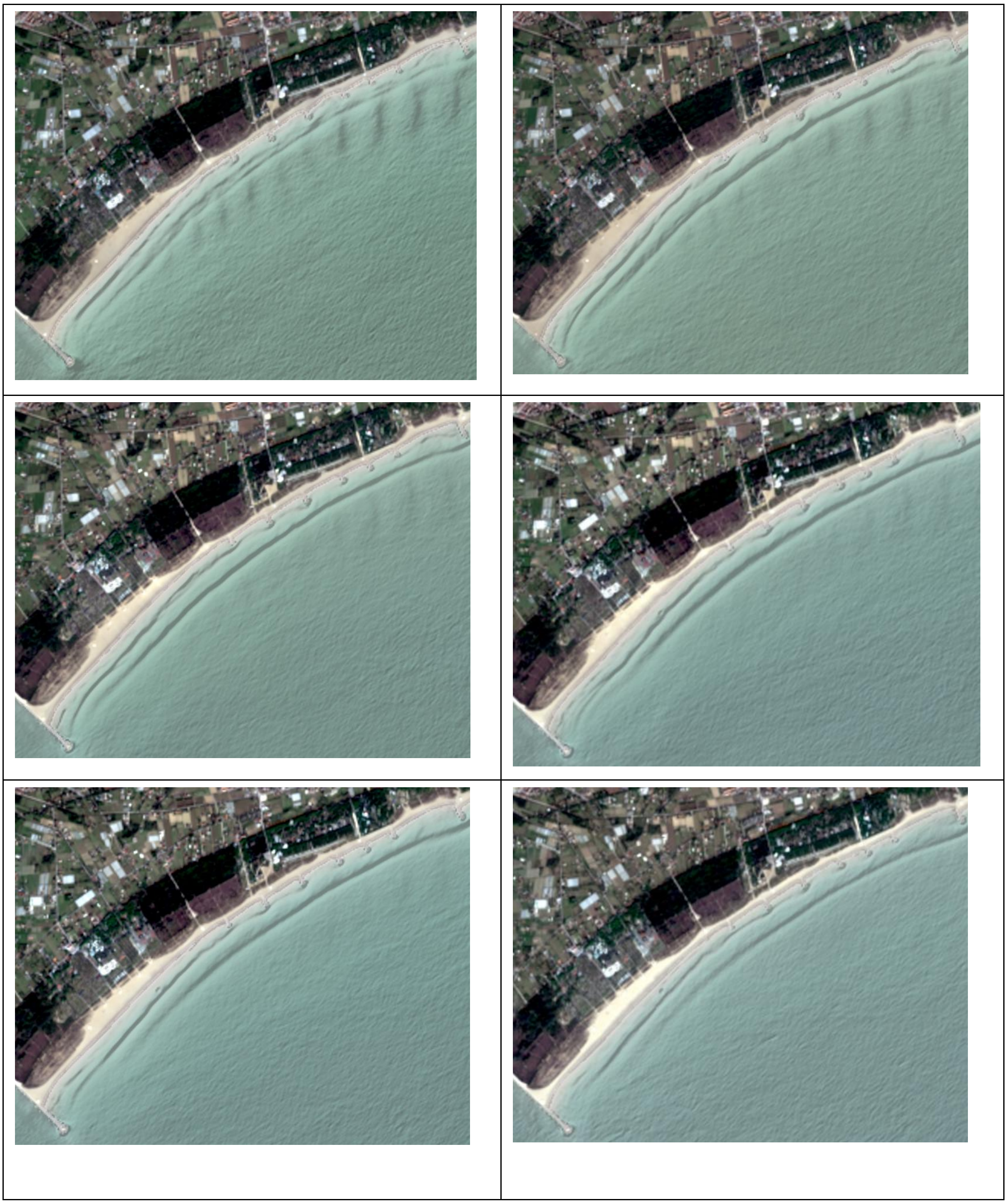

Figure 9 Bathymetry for years 2016 to 2021

Dissipation of tidal energy in Venice lagoon

3.5 Development of a regional mode for the Adriatic including Venice lagoon

In order to quantify the effect of the inclusion of bathymetry for Venice Lagoon, a D-FlowFM hydrodynamic model was set up for the Adriatic Sea. The model grid is refined up to 100 meters towards shallow/coastal regions (Figure 10 and Figure 11). Tidal constituents from FES2014 (Florent and Lyard, 2021) are used as forcing on the southern boundary of the model. This tide-only model is used to assess the impact of adding bathymetry in Venice Lagoon, by analysing the energy dissipation in the model domain. Two scenarios are assessed, one with only EMODNET2020 bathymetry (where Venice Lagoon is not included) and one with a combination of EMODNET2020 and the Saretta (2015) dataset, supplemented by the 145_DTM_CNR-ISMAR-124 channel bathymetry dataset (Madricardo et al., 2017) to bridge the missing values (Figure 12). The Chezy roughness is 62.5 in the entire domain. The tidal model is run for the period of January 2014, therefore covering one complete spring-neap cycle.

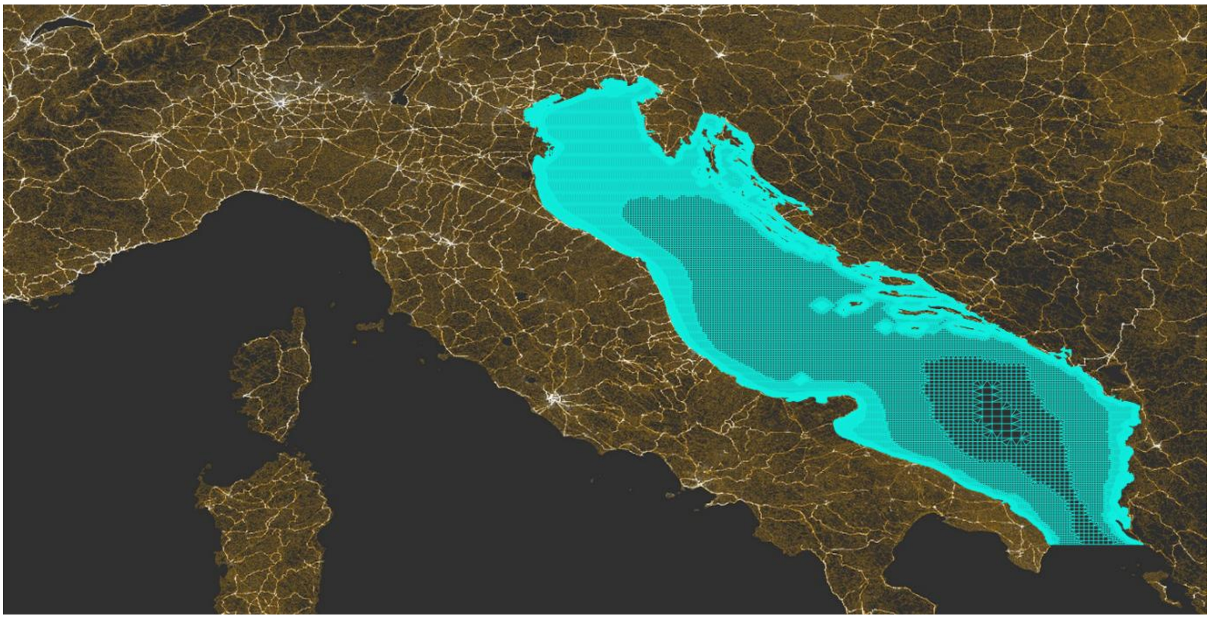

Figure 10 Adriatic Sea model grid

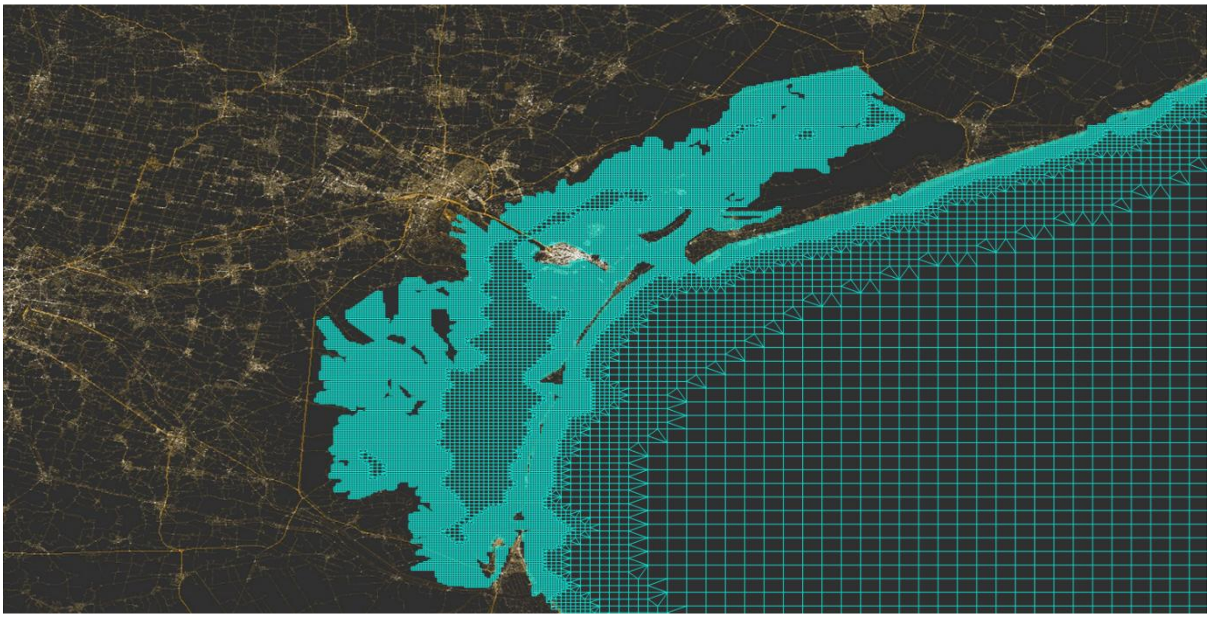

Figure 11 Adriatic Sea model grid, Venice Lagoon zoom in

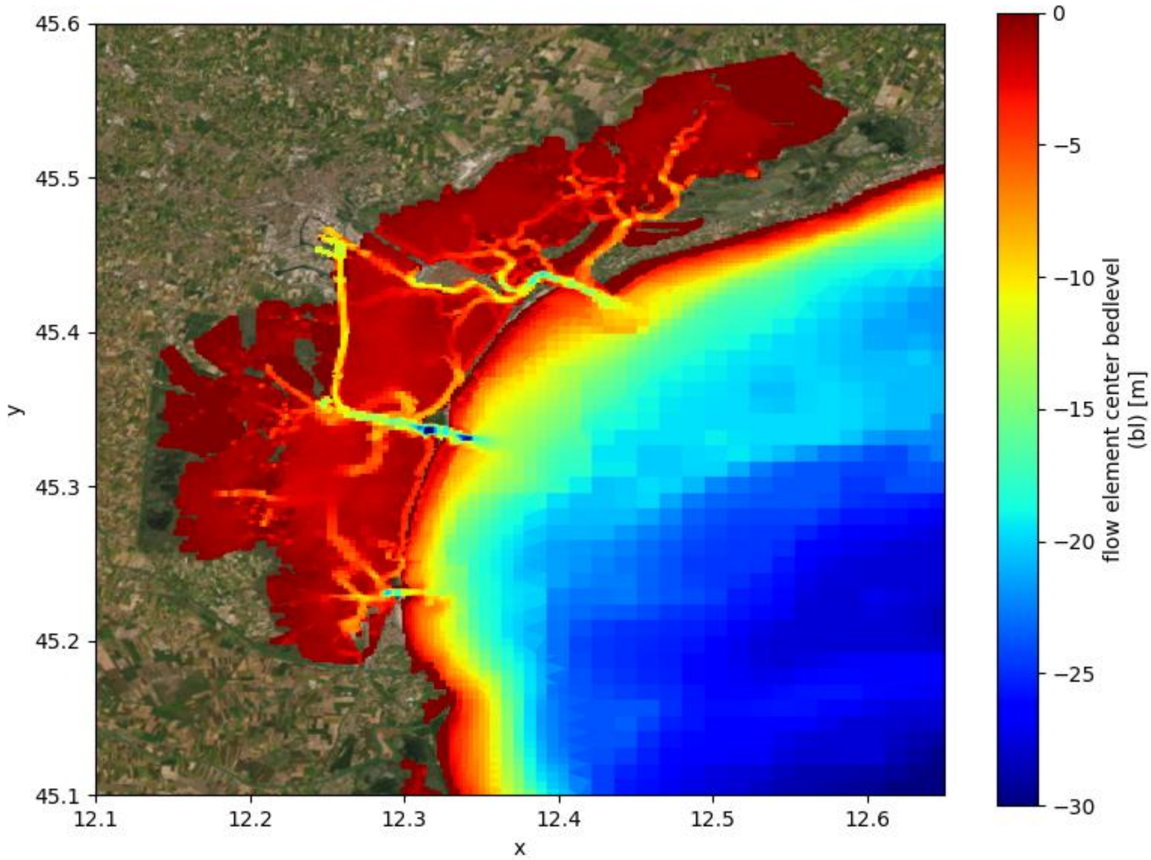

Figure 12 Adriatic Sea model bathymetry, for the scenario including Venice Lagoon bathymetry

3.6 Model validation

The modelled water level timeseries are compared to tidal waterlevels. These tidal water levels are predicted with tidal components derived from water level measurements of multiple years. The measurements are retrieved from GESLA3 (Haigh et al., 2022) and IOC (VLIZ, 2023). These sources provide tidal water levels troughout the domain (Figure 13).

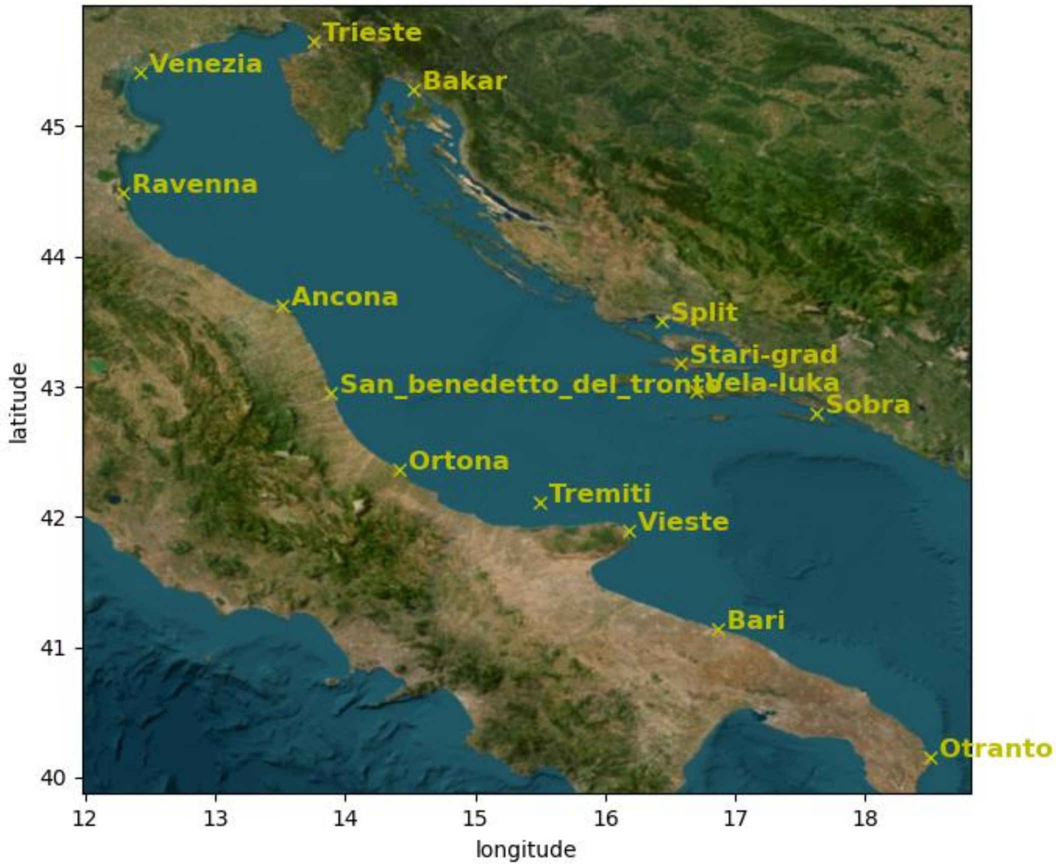

Figure 13 Water level stations in the Adriatic Sea model

Figure 14 shows the statistical performance of the model in terms of standard deviation and time error. The standard deviation increases slightly towards the North, but is low altogether. The time error is low in the entire domain except for Bakar, an area with lots of islands which is probably not represented well. Figure 15 shows that the amplitude, timing and shape of the tidal water level in the stations Ancona, Ravenna and Venezia is represented quite well.

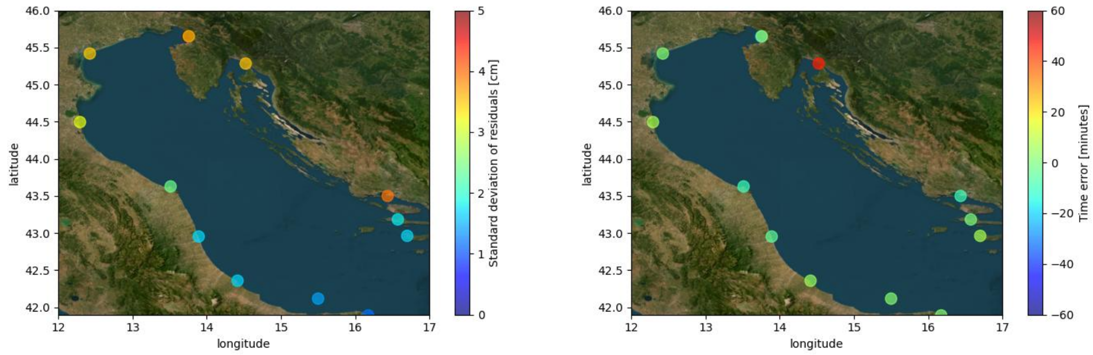

Figure 14 standard deviation and time error of tidal residuals

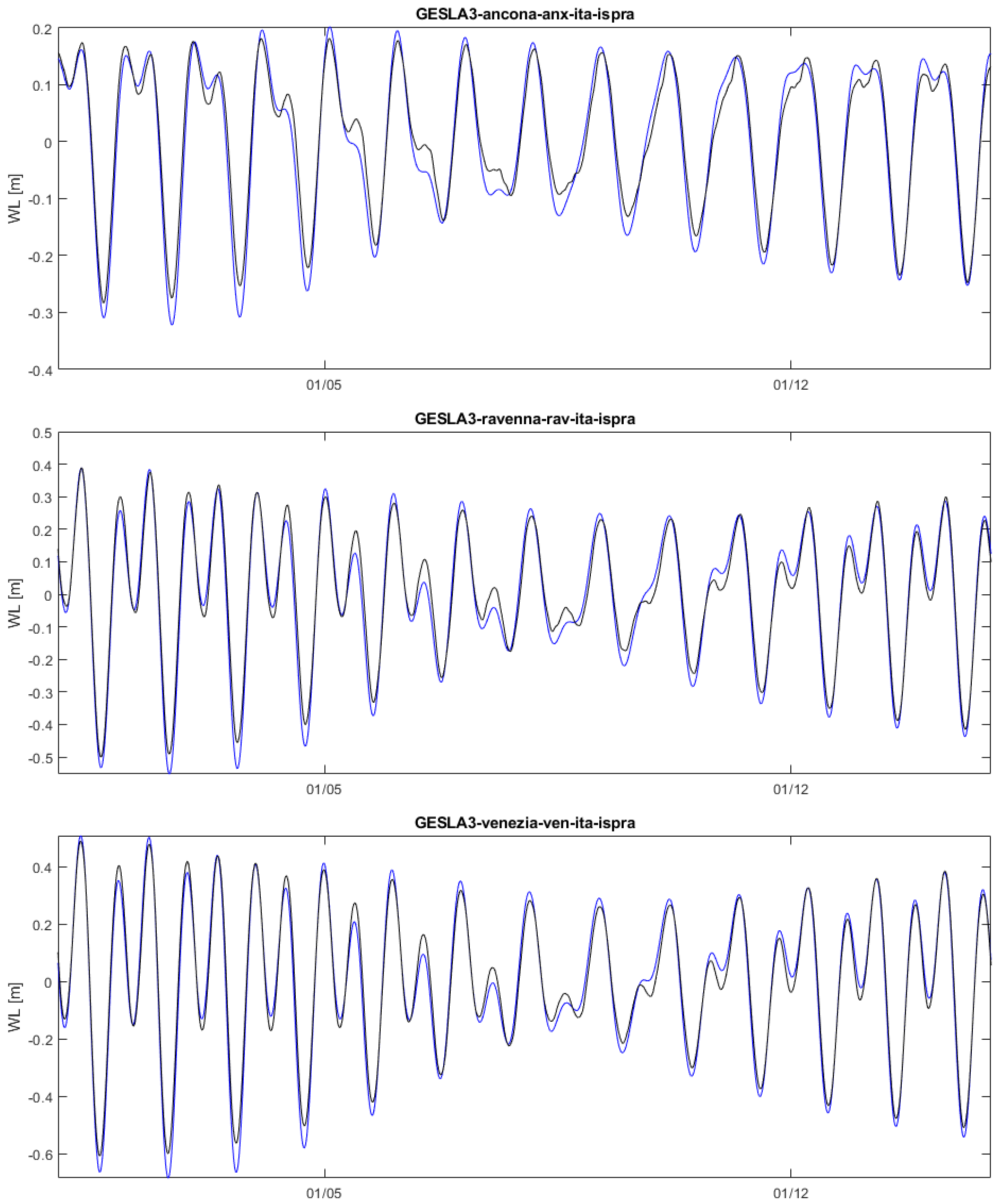

Figure 15 Tidal timeseries for the Adriatic Sea model for stations Ancona, Ravena and Venezia (blue shows the model and black shows the tidal water level derived from measurements)

3.7 Analysis of tidal dissipation in the northern Adriatic

The two scenarios differ only in the exclusion or inclusion of (bathymetry in) Venice Lagoon. The impact is analysed by comparing the energy dissipation in the Adriatic Sea model. The time-mean energy dissipation for both scenarios (Figure 16), shows not only extra dissipation inside the Venice Lagoon, but also slightly higher values in the rest of the Adriatic Sea. This is more clearly visible when looking at the difference in between the two scenarios (Figure 17). The area-total time-mean energy dissipation in the scenario without Venice Lagoon is 53.6 MW and 65.2 MW in the scenario with (of which 4.6 MW is dissipated inside the lagoon itself).

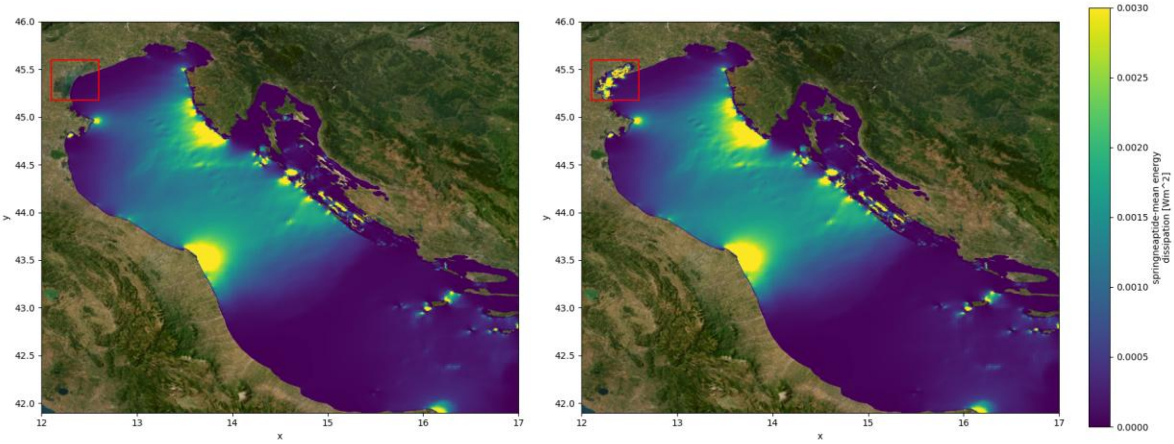

Figure 16 Mean energy dissipation in the Adriatic Sea for the scenario without and with bathymetry in Venice Lagoon

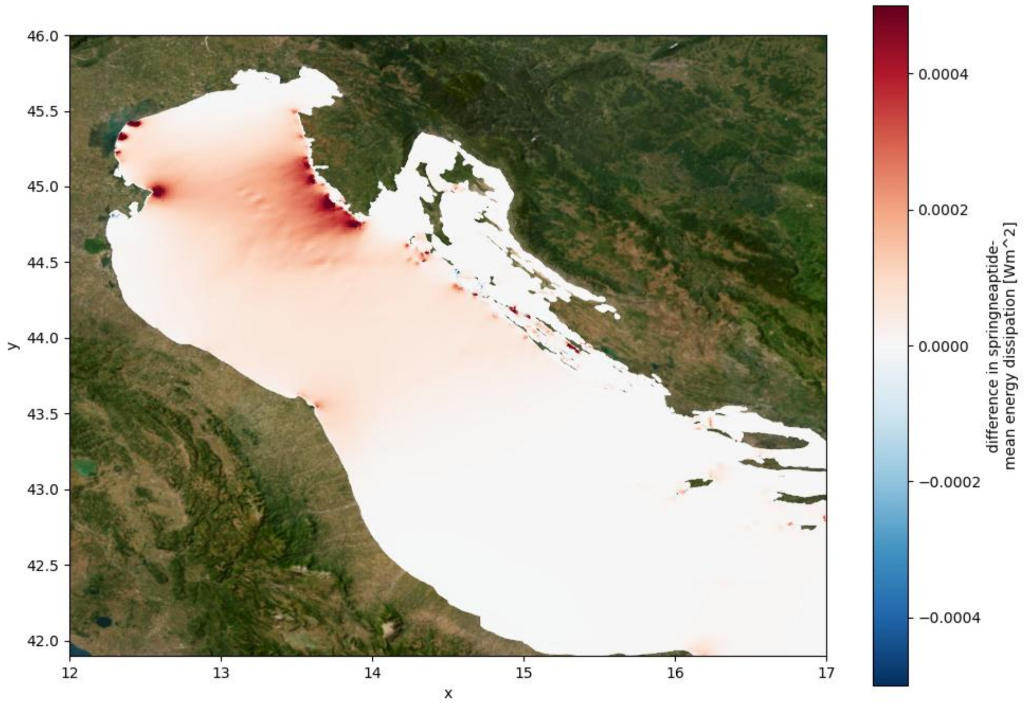

Figure 17 Difference of the mean energy dissipation between the two scenarios

Since the energy dissipation differs significantly throughout the spring-neap cycle, Figure 18 shows the area-total energy dissipation over time.

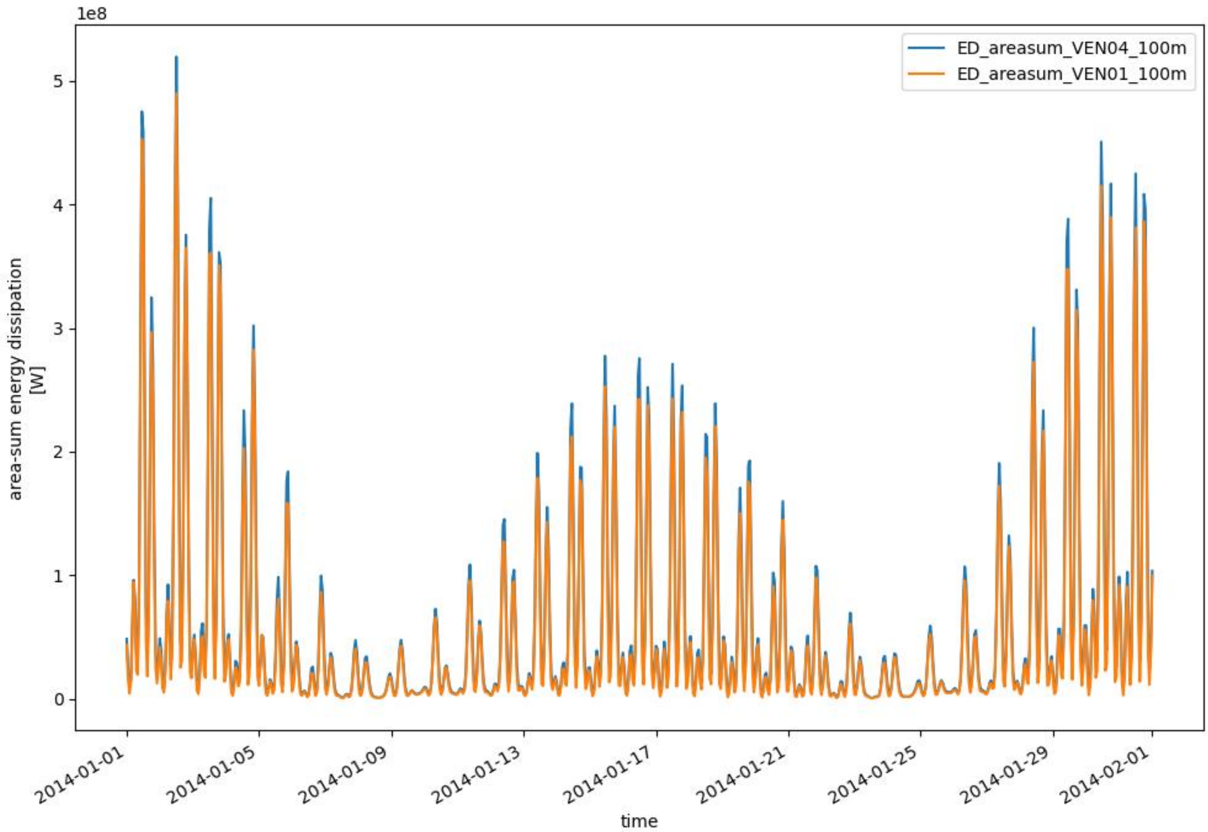

Figure 18 Total energy dissipation in the Adriatic Sea model over time

4 Conclusions and recommendations

This report describes the successful addition of Venice lagoon to the EMODnet gridded bathymetry. Most of the data was provided through a study by Sarretta et al (ISMAR). One of the obstacles for inclusion of the area was the land-sea mask, which now cuts-off potentially very useful contributions. We recommend to revisit the land-sea mask to allow for a more streamlined inclusion of coastal data into the EMODnet gridded bathymetry. One potential way forward is the use of a satellite derived coastline or land-sea mask.

The inclusion of more coastal waters into the EMODnet gridded bathymetry will require input from more data-holders in Europe, since in many countries different institutes are responsible for surveying coastal and inland waters. Satellite derived bathymetry can often contribute to collect additional bathymetry in shallow water. In this report, we mainly considered intertidal bathymetry, which is based on tracking the land-sea contrast on a stack of many satellite images. It was possible to apply this technique to Venice lagoon. However the total area of the inter-tidal zone is relatively limited in this region. Still, the data produced seems accurate in the order of 10cm. If we interprete the difference with the Sarretta (2015) dataset from 2002 as changes over time, then we can observe many interesting features. We also computed changes over the period 2016-2021, which shows some features that can be linked to morphodynamics. We recommend to extend the period to include also older satellite data, to also gain insight in slower changes in the area. We also applied a second method, that is based on penetration of the light through water. This resulted in some nice features, but the applicability is limited here, since the water is not that clear because it contains silt. In summary, we can conclude that Venice lagoon is a challenging case for Satellite Derived Bathymetry (SDB), but we could identify some interesting features. SBD can potentially contribute much in the coastal zone, but especially in clear waters and in the inter-tidal zone.

In the second part of the report a hydrodynamic model for the Adriatic was developed to study the impact of Venice lagoon on tides. Clearly this is crucial for studying tides in the lagoon itself, but we also found that the shallow tidal waters of the lagoon contribute significantly to the tidal dissipation on a much larger scale. The impact is thus much larger than the relative size of the area because the lagoon is a large sink of tidal energy. Our hypothesis is that this is important for many more areas around Europe. And it would help modellers with hydrodynamic models much if the coverage of EMODnet bathymetry in coastal waters would further improve. This can be achieved, at least partially, by contacting additional data-providers and by including satellite derived bathymetry. It may be worthwhile to also invertigate the possibilities of using machine learning to ‘interpolate’ the missing parts to at least achieve a realistic bathymetry that may for example provide modellers with a realistic tidal dissipation.

5 References

- Apecechea, M. I., Verlaan, M., Zijl, F., Le Coz, C., & Kernkamp, H. (2017). Effects of self-attraction and loading at a regional scale: a test case for the Northwest European Shelf. Ocean Dynamics, 67(6), 729-749. https://doi.org/10.1007/s10236-017-1102-z
- Donchyts, G., Baart, F., Winsemius, H., Gorelick, N., Kwadijk, J., & Van de Giesen, N. (2017). The Deltares aqua monitor.
- Flanders Marine Institute (VLIZ); Intergovernmental Oceanographic Commission (IOC) (2023): Sea level station monitoring facility. Accessed at http://www.ioc-sealevelmonitoring.org on 2023-01-20 at VLIZ. DOI: 10.14284/482
- Florent H. Lyard et al. (2021). FES2014 global ocean tide atlas: design and performance. Ocean Sci., 17, 615–649, 2021. https://doi.org/10.5194/os-17-615-2021
- Ivan D. Haigh, Marta Marcos, Stefan A. Talke, Philip L. Woodworth, John R. Hunter, Ben S. Hague, Arne Arns, Elizabeth Bradshaw, Philip Thompson (2022). GESLA Version 3: A major update to the global higher-frequency sea-level dataset. Geoscience Data Journal, 8 September 2022. https://doi.org/10.1002/gdj3.174
- Luijendijk, A., Hagenaars, G., Ranasinghe, R., Baart, F., Donchyts, G., & Aarninkhof, S. (2018). The state of the world's beaches. Scientific reports, 8(1), 1-11.
- Madricardo, F. et al. High resolution multibeam and hydrodynamic datasets of tidal channels and inlets of the Venice Lagoon. Sci. Data 4:170121 doi: 10.1038/sdata.2017.121 (2017).
- Sarretta, A., Pillon, S., Molinaroli, E., Guerzoni, S., & Fontolan, G. (2010). Sediment budget in the Lagoon of Venice, Italy. Continental Shelf Research, 30(8), 934-949.
- Sarretta, Alessandro; Pillon, Simone; Molinaroli, Emanuela; Guerzoni, Stefano; Fontolan, Giorgio (2015): Bathymetry of Lagoon of Venice, 2002. figshare. Dataset. https://doi.org/10.6084/m9.figshare.1293558.v3
- Wang, X., Verlaan, M., Veenstra, J., and Lin, H. X. (2022). Data-assimilation-based parameter estimation of bathymetry and bottom friction coefficient to improve coastal accuracy in a global tide model. Ocean Sci., 18, 881–904, 2022. https://doi.org/10.5194/os-18-881-2022
- Wang, X., Verlaan, M., Apecechea, M. I., & Lin, H. X. (2021). Computation-Efficient Parameter Estimation for a High-Resolution Global Tide and Surge Model. Journal of Geophysical Research: Oceans, 126(3), e2020JC016917. https://doi.org/10.1029/2020JC016917