EMODnet Thematic Lot n°1 – Bathymetry

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Start date of the project: 20/12/2022 (24 months)

Centralisation Phase

Quarterly Progress Report 5

Reporting Period: 01/01/2024 – 31/03/2024

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1. Highlights in this quarter

Task 1 - Maintain and improve a common method of access to data held in repositories:

During the reporting period, the number of survey data sets has increased again from 42369 to 42837 CDI entries, while the number of Composite DTM entries increased from 279 to 282. New CDI entries for bathymetry survey data sets were contributed by 25 data providers, originating from 17 countries. There are still a few additional CDI entries expected from other data providers, which are currently under review in the CDI import service. Together with the new Composite DTM entries this implicates that nearly all data providers have populated new data sets to meet the deadline for data contributions for the planned 2024 DTM new releases for European seas and Caribbean Sea region.

As part of the Composite DTMs partner EOMAP has delivered and populated a large Satellite Derived Bathymetry DTM for the Danish Waters which is now being integrated by partner GST (Denmark) with single and multibeam surveys of GST for generating a new CDTM for the Danish waters on a 50 meters grid. This CDTM will serve GST as a national public product and will also be input for EMODnet Bathymetry.

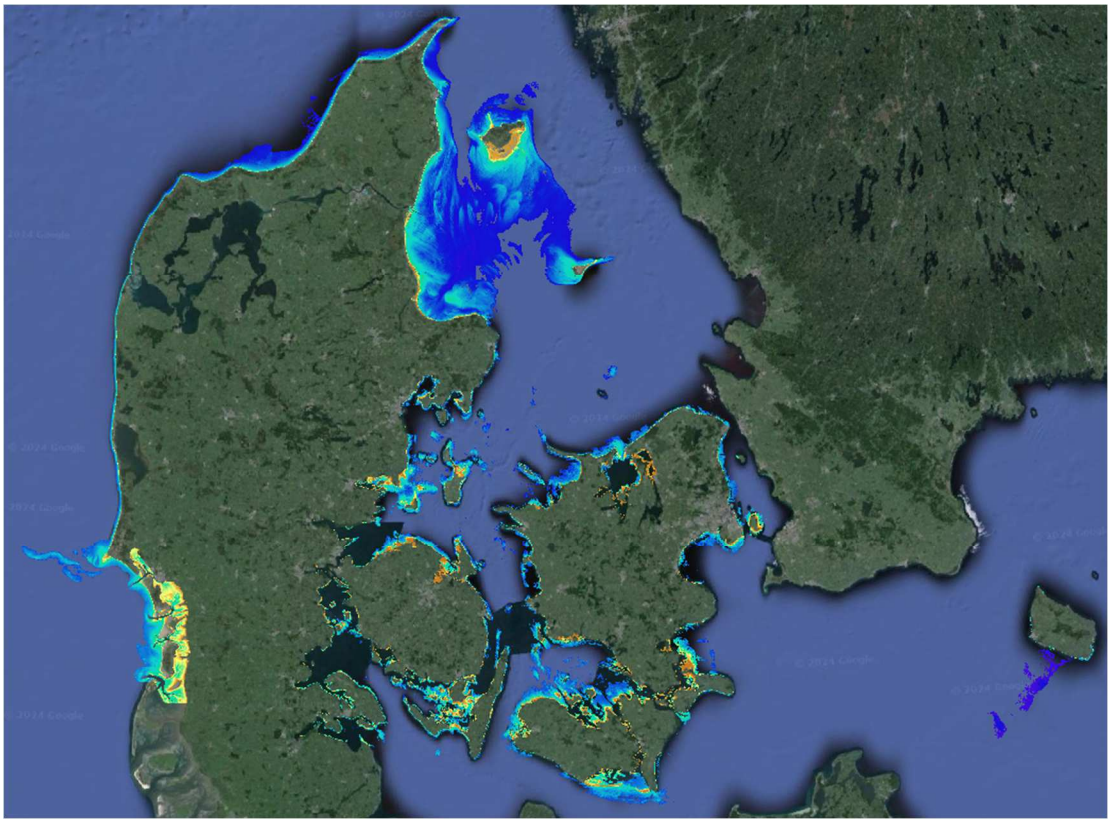


Image: Satellite Derived Bathymetry DTM as generated by EOMAP for Danish EEZ and integration with single and multibeam data in new 50 meters DTM being produced by GST (Denmark)

Task 2 - Construct products from one or more data sources that provide users with information about the distribution and quality of parameters in time and space:

As follow-up to the data gathering and population of the CDI and Sextant catalogue services, most data providers have also undertaken pre-processing of the associated data, using GLOBE and following EMODnet methodology, to 1/32 * 1/32 gridded data sets which are transferred to the Regional Coordinators for use in the updating of the Regional DTMs. A workshop with Regional Coordinators together with core partners will

take place 16 – 17 April 2024, hosted by GGSgc in France, for monitoring and discussing the RDTM generation process. At the meeting, Regional Coordinators will also share their experiences and annotations made with the Collaborative Virtual Environment (CVE) that was made available by Ifremer to all Regional Coordinators after the Full Meeting in September 2023. In the meantime, Ifremer has developed new functionality facilitating to export the annotations made in CVE and to read these into the Globe software. It is now available in the latest Globe version 2.5.1, that will be released at the coming meeting. Moreover, CORONIS made further progress with optimizing interpolation methods and upgrading 3D viewing software, while Deltares made further progress with developing other EMODnet Bathymetry products such as new releases of the Satellite Derived Coastlines for LAT, MSL, and MHW, and the inventory of national coastlines and baselines. These progresses are reported in Annex 1 of this report.

Task 3 - Develop procedures for machine-to-machine connections to data and data products:

EMODnet Bathymetry continued to operate and maintain several catalogue services and web services, which are being harvested and/or directly feeding the Central Portal services. The services are following INSPIRE principles and their operations are being monitored from the Central Portal with good results. EMODnet Bathymetry is regularly testing the functionality of the Central Portal and following up feedback from users. This is aimed at spotting possible bugs in the back-office systems of EMODnet Bathymetry or at the front-office interfaces of the Central Portal. Any identified bugs are reported to JIRA for further action. Also, shortcomings or requests for improved functionality are being gathered from internal consortium testing and following user feedback and these are submitted to the CP team through JIRA and/or at TWG meetings as wishes for future developments. Most will be directed towards optimisation of functionalities, while also additional functionalities might come forward.

Task 4 - Contribute data, data products and content to a central portal that allows users to find, view and download data and data products:

New EMODnet Bathymetry products are planned near the end of 2024 and these will be then be added and published at the Central Portal following the methodology that was earlier developed and successfully applied for the 2022 product releases.

Task 5 - Contributing content to dedicated spaces in Central Portal:

Each thematic has its own dedicated space at the Central Portal where it publishes its so-called 'narrative'. The maintenance is done by sending an updated document to JIRA which is then processed by the EMODnet Secretariate. On short term, EMODnet Bathymetry will prepare an update of the narrative. While for posting Deliverables, such as Technical Reports, in the CP reports catalogue EMODnet Bathymetry has an account at the Drupal CMS which was successfully used for adding a few reports.

Task 6 - Ensure the involvement of regional sea conventions:

Secretariats of the Regional Sea Conventions are kept up-to-date of the EMODnet Bathymetry services, inter alia through regional partners. The 2024 EMODnet bathymetry products, planned for release by end 2024, will again provide a good opportunity to reinforce the good relationships with the secretariats of the Regional Sea Conventions who are kept up-to-date of the EMODnet Bathymetry services and products, and where possible, engaged in wider promotion and contributing to mobilising more potential data providers and product users. Note that during this period, a presentation was provided to the CIESM (Mediterranean Science Commission).

Task 7: Contribute to the implementation of EU legislation and broader initiatives for open data:

On a global scale, good synergy is continued with GEBCO and the Seabed 2030 project. In practice, the EMODnet DTM is considered as the European contribution to Seabed 2030 and as such fully integrated into the GEBCO DTM. This is strengthened by the fact that George Spoelstra (GGSgc) and Federica Foglini (CNR),

both members of the EMODnet Bathymetry consortium, act as Chair and Vice-Chair of the GEBCO subcommittee TSCOM (Technical Subcommittee on Ocean Mapping). As a follow-up to the meeting held at the EMODnet Jamboree between SeaBed 2030 and EMODnet Bathymetry full group, GEBCO has requested support from the EMODnet Bathymetry team to perform QA/QC activities on the draft GEBCO 2024 grid. This will be discussed at the coming EMODnet Bathymetry meeting of Regional Coordinators.

Task 8 - Monitor quality / performance and deal with user feedback:

The overall performance of the portal and its services is continuously measured and its results are reported in the separate indicators spreadsheet. It demonstrates that Bathymetry and its services and products continue to be quite popular. The number of visits and downloads of the full DTM products are again high in the reporting period. User feedback is on the quality of the DTM product and the usability of the portal. Answers are directly provided to the users.

Task 9 - Maintain the existing thematic web portal for a maximum of six months from the start of the project:
EMODnet Bathymetry is maintaining the operation and maintenance of the various Bathymetry catalogues and web services that feed into the Central Portal, which provides the one-stop-shop.

Project management:

Shom and MARIS prepared the Q4-2023 progress report as well as the Interim Annual Report which were reviewed and accepted by the EU CINEA.

Milestone/Deliverable in numerical order	WP	Date due	Status (To do/ Delivered/ Delayed)	Date delivered	If Delayed: reason for delay and expected delivery date
D1.1: Quarterly concise progress reports	WP1	M4, M7, M10, M13, M16, M19, M24,	Delivered D1.1a,b,c,d,e	M4, M7, M10, M13, M16	
D1.2: Annual Interim report	WP1	M12	Delivered	M14	
D1.3: Final report	WP1	M24			
D1.4: Plan for service continuity, incl. docs and sources	WP1	M24			
D2.1: Upgraded guidelines for data pre-processing and population of metadata	WP2	M6	Delivered	M6	Annexed to D1.2
D2.2i: Training Workshop for data pre-processing and metadata population	WP2	M9	Delivered as part of meeting 25-26 Sept 2023 in Brest - France	M9	

D2.3: Pre-processed survey data sets and included in CDI Service	WP2	M12	Delivered	M15	Few more entries underway
D2.4: Pre-processed composite DTMs and included in Sextant service	WP2	M12	Delivered	M15	Few more entries underway
D2.5: Satellite Derived Bathymetry data sets and included in Sextant Service	WP2	M12	Delivered	M15	Included in Sextant service
D3.1: Upgraded guideline of EMODnet methodology for DTM production, including using prototype CVE	WP3	M9	Delivered	M10	Annexed to D1.2
D3.2i: Upgraded Globe software	WP3	M9	Delivered and presented at meeting 25-26 Sept 2023 in Brest - France	M9	Note that Globe is regularly updated upon request and made available publicly
D3.3i: Training and intercalibration Workshop	WP3	M11	Has been re-scheduled to better fit the latest planning for production of DTM	M16	Workshop of Regional Coordinators and Integrator at M16
D3.4i: Processed and pre-gridded data sets as input for RDTMs	WP3	M14	Well underway		Status will be checked at meeting of Regional Coordinators in April 2024
D3.5i: Regional DTMs with common resolution of 1/16 arc minutes grid	WP3	M17			
D3.6i: Best version HR DTMs for coastal waters and hotspots	WP3	M20			
D3.7: New EMODnet DTM incl Quality Index and loaded in EMODnet web services for viewing and downloading	WP3	M23			

D3.8: HR-DTMs loaded as separate layer in EMODnet web services for viewing and downloading	WP3	M23			
D3.9: Source reference layer in EMODnet web services to link to CDI and Sextant Catalogue services	WP3	M23			
D3.10: Refined best-estimate European digital coastlines in EMODnet web services for a range of vertical levels	WP3	M22	Well underway		See Annex 1
D3.11: Updated Inventory of existing and ratified baselines and registered claims / disputes under UNCLOS, for European countries at the portal	WP3	M22	Well underway		Sea Annex 1
D3.12: Methodology for assessing bathymetry between coastline and foreshore	WP3	M23	Well underway		See Annex 1
D4.1: Standard machine- to-machine services delivered for common functionalities	WP4	M3	Delivered	Operational since M0	
D4.2: Dedicated machine- to-machine services adapted / delivered for special functionalities	WP4	M6	Delivered	Operational since M0	
D4.3i: CVE optimised for reginal coordinators	WP4	M14	Delivered	M15	Status will be demonstrated at meeting of Regional Coordinators in April 2024
D4.4i: Globe software + GGSGC workbench upgraded with extra functionality	WP4	When required	Following requests and suggestions		

D5.1: Operational Help-desk	WP5	continuously			
D5.2: Monitoring data about visits and usage	WP5	continuously			
D5.3: Promotional material and up-to-date thematic space at central portal	WP5	continuously			
D5.4: Presentations at relevant conferences	WP5	Regularly			

2. Identified issues: status and actions taken

A. Priority issue(s) identified and communicated by CINEA/ DG MARE/ SECRETARIAT				
Priority issue	Status (Pending/ Resolved)	Action(s) taken/ remaining actions planned	Date due	Date resolved

B. Issues / challenges identified by the thematic assembly group itself				
Priority issue / challenge	Status (Pending/ Resolved)	Action(s) taken / remaining actions planned	Date due	Date resolved
EM-806 Increase zoom level for coastline	pending	Action to be undertaken by CP to increase the zoom level. Pre-tiled level already existing	30/04/2024	
EM-703 Bathymetry narrative update	pending	One series of update in the narrative done. Ticket left opened as a new series should come shortly	30/04/2024	

3. Communication assets

[In Table A, list peer reviewed publications directly (co-)authored by consortium and project partners in the reporting period. In Table B, list all non-peer reviewed publications (co-)authored. In all cases, indicate the type of publication, provide the full reference incl. title, volume and issue etc., and whether the publication is open or closed access.]

A. (Co-)Authored peer-reviewed publications in the quarter					
Date of publication	**Type of publication**	**Full reference**	**ISBN**	**DOI**	**Is it open access? Yes/No**

B. Other/non-peer reviewed types of publications (co-)authored in the quarter					
Date of publication	**Type of publication**	**Full reference**	**ISBN**	**DOI**	**Is it open access? Yes/No**

B. Other/non-peer reviewed types of publications (co-)authored in the quarter					
Date of publication	**Type of publication**	**Full reference**	**ISBN**	**DOI**	**Is it open access? Yes/No**

For a comprehensive overview of publications referring to/making use of EMODnet data and/or data products, please consult Google Scholar.

4. Monitoring indicators

[Refer to the standardised monitoring tool, i.e. Europa Analytics, to complete the indicators excel template, and provide a short explanation in the table below on the numbers and trends for each indicator when possible/applicable. Indicate clearly if monitoring was carried out using tools other than Europa Analytics.]

Comments on the progress indicators in the indicators spreadsheet		
Progress indicator	**Means of collecting figures**	**Comment**
1. Current status and coverage of total available thematic data A) Volume and coverage of available data	CDI catalogue service	There is a steady increase of CDIs with several data providers contributing CDI data sets for the production of the new 2024 EMODnet DTM.
What is your opinion on the data coverage within EMODnet for your thematic?	Considering population of CDI and Sextant catalogues	Overall, EMODnet Bathymetry has brought together an excellent data collection (CDIs and Composite DTMs), covering all European sea regions and compiled by 66 data providers.
B) Usage of data in this quarter	CDI RSM shopping ledger service	The number of downloaded CDIs is 20% lower than previous quarter, but still in the normal order.
2. Current status and coverage of total number of data products A) Volume and coverage of available data products	Statistics from downloading at the Bathymetry system	The 2022 DTMs (Europe and Caribbean) and new HR-DTMs have been released in the first quarter of 2023. The number of these products is then frozen till the new release of the 2024 DTM and HR-DTMs which is planned for end 2024.
B) Usage of data products in this quarter	Analysing download statistics	The number of product downloads has decreased compared to the previous quarter. But that quarter was extraordinary. However, the dowlods in this quarter are still large and demonstrate the continuing interest of users in these EMODnet products. This concerns not only the HRDTMs and DTM tiles, but also of the Satellite Derived Coastlines package. Also, the number of WMS - WFS requests is again very high.
3. Internal and external organisations supplying/approached to supply data and data products within this quarter	CDI catalogue service	Twenty five data providers have submitted new entries as part of meeting the deadlines of the contract
4) Online 'Web' interfaces to access or view data	N.A.	No changes
5.1 Daily number of page views of EMODnet Thematic entry page	Europa Analytics	Daily number of page views of the Bathymetry narrative is quite steady and around 150. This is the static content. Unfortunately, we cannot see how the bathymetry map layers and products are visited
5.2 Quarterly total number of visitors, page views, unique page	Europa Analytics	The quartely numbers are reasonable as the bathymety narrative is a static story. See the earlier remark under

Comments on the progress indicators in the indicators spreadsheet		
Progress indicator	**Means of collecting figures**	**Comment**
views and percentage of returning visitors		5.1.This quarter the numbers are circa 6% higher than the previous quarter.

The monitoring numbers reported as part of the progress monitoring of EMODnet performance are collected through Europa Analytics, unless reported otherwise.

5. Annex 1: Progress of Coronis and Deltares activities on interpolation, visualization, deep-learning, and best estimate coastlines

Coronis – Activities for improving interpolation techniques and 3D viewer

Based on the comments of the users of the interpolation package collected in previous EMODnet Bathymetry iterations, during this period Coronis focused on trying to improve the runtime of some of the interpolation methods [1]. In this sense, Coronis took advantage of the high level of parallelization of GPU architectures for matrix-based operations, which are a recurrent operation in the inpainting-based methods of implemented in the package. At the time of writing this document, the *Harmonic* and *CCST* [2] interpolation methods of the package have been implemented to allow the execution of their most computationally-intensive steps on the GPU. The user can now request for such methods to execute on the GPU, if available on the running system. If the GPU architecture is not found, it will automatically fall back to its CPU implementation, letting the user know about this issue.

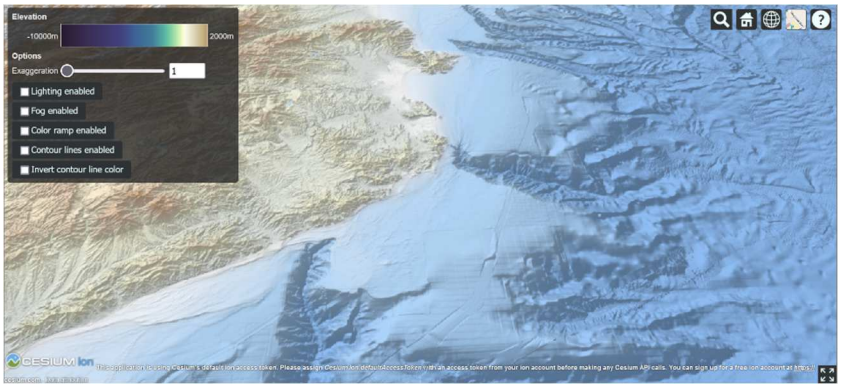
Coronis also implemented a new command line application for interpolating scattered data input. The original command line application in the interpolation package only accepts DTMs in NetCDF4 format as input, while this new application allows for non-gridded data in longitude/latitute/elevation format. This new application can apply the same set of interpolation methods as the original command to this new input type, and outputs a raster DTM in NetCDF4 format. The cell size of such raster is set by the user, and its limits can also be set by the user or automatically derived from the range of values in the input points. Depending on the type of interpolation method requested, the app behaves a bit different:

- For **scattered data** interpolators, the input data points are used to create an interpolant, which is then evaluated at each cell of the output raster grid.
- For **PDE-based inpainting** methods, since they require the input data to be gridded, we pre-grid the input points before executing the method. We thus create the output raster grid and, for each point, we put its elevation value in the cell closest to the point's longitude/latitude, and if more than a point falls within the same cell we compute the mean of the corresponding elevation values.

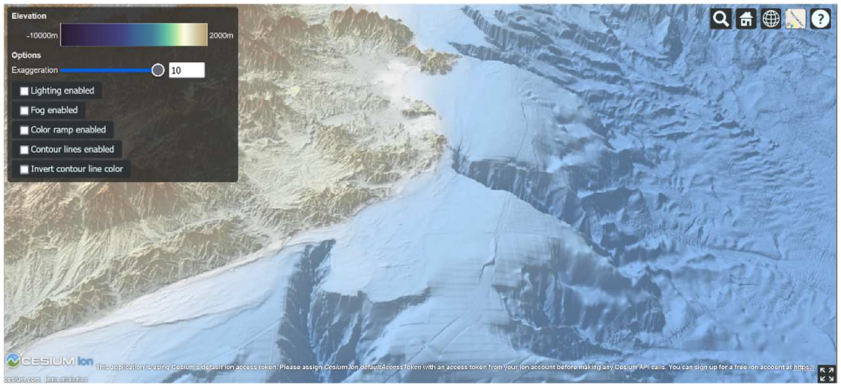
Coronis also deployed the interpolation Python package in the public Pipy repository. PyPI is a software repository of the Python language and is used by most developers to both share their packages with the

community as well as to obtain third party package dependencies on their projects. We believe this can widespread adoption of this package, as PyPI is the de-facto standard for Python package management. In the same way, this also eases the integration of new developments inside Globe, as now updating the package can also be done via PyPI, while before there was the need to resort to the sources of the package for its integration.

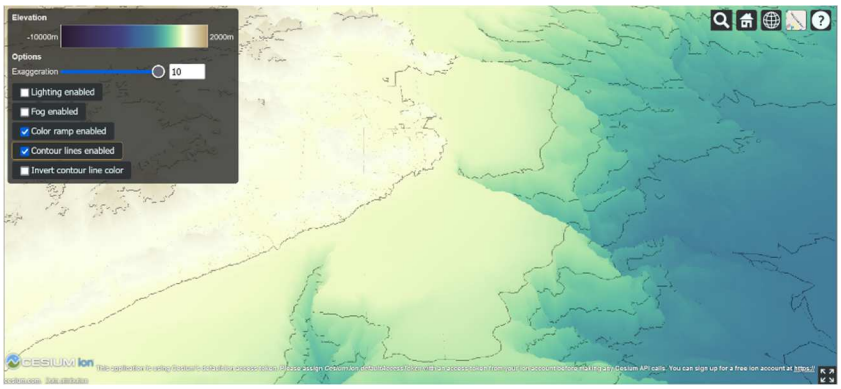
Regarding the web-based visualization of the EMODnet DTM, Coronis is currently developing a demo 3D viewer using CesiumJS showcasing how the new visualization options of the newer versions of this library can be included in the current version of the EMODnet Map Viewer in the web portal to improve usability. These new additions include the ability to change the exaggeration factor of the elevation in real time or drawing user-defined color ramps and contour lines, among others (see Figures below). The developed demo viewer is just a showcase of what can be done, and a discussion with the actual users is needed to define which of these new features will really improve their experience and should be finally implemented in the EMODnet Map viewer.



(a)



(b)



(c)

Figures 5.1: Demo viewer showcasing the new 3D terrain visualization options available in CesiumJS. The screenshot in (a) shows the terrain with no exaggeration, while in (b) we have the exaggeration factor set to 10 (the change is performed in real-time via the slider on the top-left corner). In (c) the original imagery map has been replaced by a user-defined color ramp, and contour lines are also displayed.

References:

[1] EMODnet Bathymetry Heightmap Interpolation Package. url: https://github.com/coronis-computing/heightmap_interpolation

[2] Smith, W. H. F, and P. Wessel, 1990, Gridding with continuous curvature splines in tension, Geophysics, 55, 293-305.

Deltares – Extrapolation of missing bathymetry with deep-learning

During the previous release, the EMODnet gridded bathymetry was extended to Venice lagoon. This included several new datasets both from bathymetric surveys and from satellite derived bathymetry. It also became clear that even though a larger and larger fraction of the coastal waters is covered with every new release of the EMODnet gridded bathymetry, there are still numerous coastal regions where no high-quality data is available and where the water is not clear enough for satellite derived bathymetry. To fill these gaps, we proposed to develop a generative deep learning approach to fill the gaps, at least until these can be replaced by survey data.

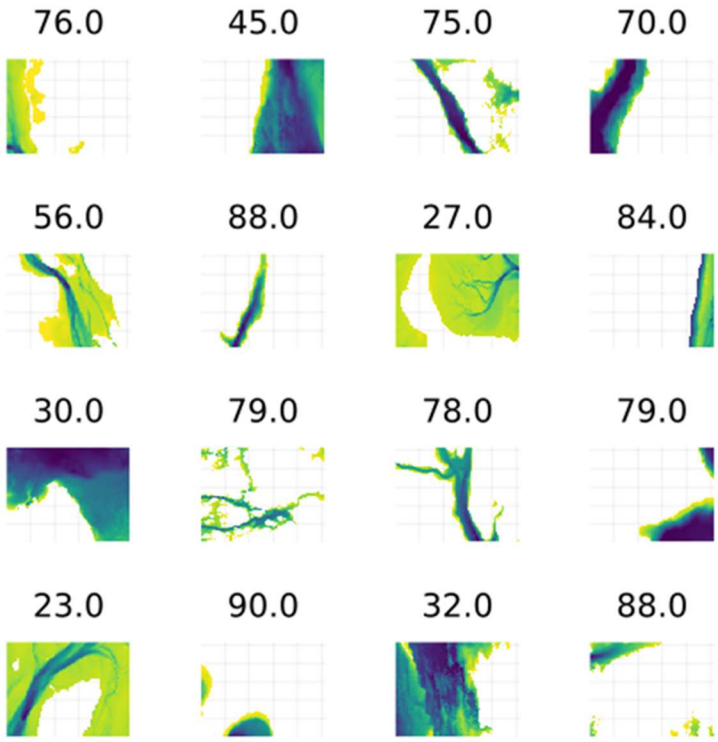


Figure 5.2: Sample of generated tiles meant for training and testing the neural network.

In recent months, Deltares has continued its work on extrapolating bathymetry data using generative AI. To generate new samples, we need to consider two challenges: learning the underlying probability distribution of which the data are samples, and, having learned the distribution, how to sample from it. We tackle these challenges using techniques from diffusion learning [1]. Learning the distribution, the first challenge, is done by deforming the data in a stepwise process to samples of a known distribution and training the network to learn the marginal distributions of each step. Generating new samples, the second challenge, is then achieved by sampling from the known distribution, and using the learned marginal distributions to reverse the stepwise process. A particular convenient choice for the stepwise process is to add a small amount of white noise at each step. This way the final, known distribution is simply a Gaussian distribution (easy and fast to sample from) and all the marginal distribution are also Gaussian [2]

The process of adding noise can be treated at face value, as a discrete process with a finite number of steps, or as a discretized version of a continuous process characterized by a stochastic differential equation (SDE). Finally, each SDE has an ordinary differential equation (ODE) associated with it. These different viewpoints offer different sampling schemes, either using the discrete process or using SDE or ODE solvers. The choice of sampling scheme is determined by a tradeoff between sampling speed and sample quality, with the SDE/ODE solvers typically being slower but better quality [2]

Having previously tested this technique and getting ourselves acquainted with this technique using the MNIST dataset, we have now made a first attempt at learning bathymetry data, using the D5 tile of the EMODnet bathymetry split into 128x128 pixel images. Since we are primarily interested in coastal regions, we filter the images based on percentage land present, and generate land masks for each image. We use a UNET network architecture with 4 convolutional blocks, a common choice in image processing [3]. The loss function is adapted so that it is only calculated on pixels not on land. Various approaches to data normalization were tested, with log normalization being the most successful so far. More commonly used normalization

approaches, such as normalizing to the [0,1] range and normalizing by the mean and standard deviation, are less successful as they poorly represent the distribution of depth values present in the images.

By way of testing our approach we mask part of the image and use our network to generate new data for the masked region using the rest of the image as context, a task known as image inpainting. To make this work, we adapt the sampling process so that the known parts of the image are inserted into the generated sample at each step in the sampling process. An example of (normalized) input image, masked image and output image is shown below in figure 5.3.

With the current pipeline in place to do inpainting for bathymetry data, we can focus on improving our approach over the next months. Some points that need attention: 1) the quality of the in painted bathymetry data leaves room for improvement. Even without knowledge of which area was masked, it is still apparent in figure 1c which parts were generated. One of the issues is that our model output still retains some of the noise from the sampling process. We think this can be remedied by a combination of proper data normalization and noise scale in the learning process, and changes to the sampling process. 2) generating samples is not very efficient, especially when scaling beyond a small number of test samples. To address this, we will first review and optimize our GPU code. A new sampling algorithm can also improve the efficiency but requires a more substantial review of the code. 3) a thorough comparison of different sampling approaches (discrete approaches vs SDE/ODE solvers) and an exploration of the model hyperparameter space.

Once these issues are addressed, we can expand the amount of EMODnet bathymetry data used in training, the number of images generated, and sampling areas consisting of multiple images. Finally, we see opportunities to incorporate other data sources, for the generation of the land masks of unknown areas for which the bathymetry is to be generated.

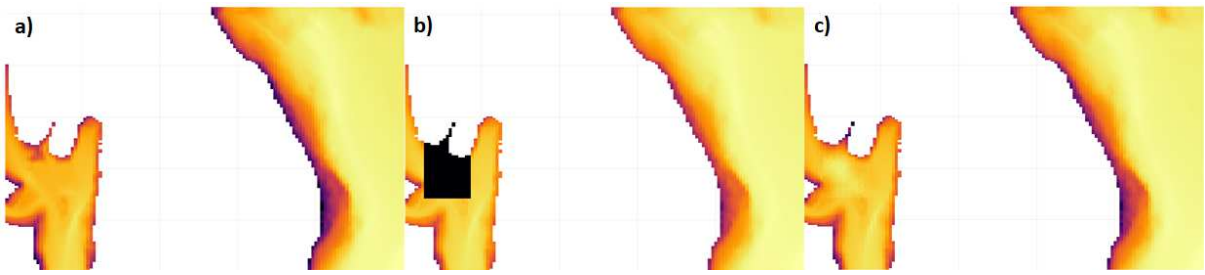


Figure 5.3: Example of first attempt at generating bathymetry data a) A 128x128 pixel cut out of the D5 tile, normalized with log normalization. Land areas are shown in white. b) A mask, shown in black, is applied to the image in a) where the data is set to 0. This indicate to the sampling process in which area a new sample is to be generated. c) The output image where the black area in b) has been inpainted. The place where new data was generated is still noticeable.

References

1. Sohl-Dickstein et al., *PMLR 37:2256-2265*, (2015), https://proceedings.mlr.press/v37/sohl-dickstein15.html
2. Song et al., *arxiv:2011.13456,* (2021), *https://doi.org/10.48550/arXiv.2011.13456*
3. Ronneberger et al., *MICCAI 9351*, (2015), https://doi.org/10.1007/978-3-319-24574-4_28

Deltares: To update and refine best-estimate European digital coastlines for a range of vertical levels

In the past few months, we reorganized the software pipeline for the processing of optical satellite imagery. Based on the now much more broad experience with the methods, we're revisiting many steps in the process, aiming to replace heuristics where possible with solid statistical methods. A second topic of interest is the efficiency and ease of deployment on different computers. An example of a topic that we're revisiting is a

potential bias caused by the orbit of Sentinel-2. It is well known that Sentinel-2 has a sun-synchronous orbit, which means that it passes over at a similar time of day everywhere. In the processing of the satellite statistics, we have used in previous releases the assumption that the sea-level distribution would be random, but a part of the tide is linked to the orbit of the sun and this may cause a bias. We're now testing how much that bias is and how complex it would be to account for it.

Deltares: To update and further complete the overview of legal baselines

Replies for the request for (updates of) legal baselines and official coastlines are still coming in. There is some discussion on specific datasets. Progress is good in general. The list of questions from MarineRegions is being considered step-by-step and there is good progress. A careful step-by-step approach will resolve most of the issues.

No	Country	Baseline	Coastline
1	Albania	Available	N/A
2	Belgium	Available	Available
3	Bosnia and Herzegovina	N/A	N/A
4	Bulgaria	N/A	Available
5	**Croatia**	**Available**	N/A
6	**Cyprus**	**Available**	N/A
7	Denmark	Available	Available
8	**Estonia**	Available	**Available**
9	Finland	Available	N/A
10	France	Available	Available
11	Georgia	N/A	N/A
12	Germany	Available	Available
13	Greece	Available	Available
14	**Iceland**	Available	**Available**
15	Ireland	Available	Available
16	**Israel**	**Available**	Available
17	Italy	Available	Available
18	Latvia	Available	Available
19	Lithuania	Available	N/A
20	Malta	Available	Available
21	Monaco	N/A	N/A
22	Montenegro	N/A	N/A
23	Netherlands	Available	Available
24	Norway	Available	Available
25	**Poland**	Available	**Available**
26	Portugal	Available	Available
27	Romania	Available	Available
28	Russian Federation	N/A	N/A
29	Slovenia	Available	Available
30	Spain	Available	Available
31	**Sweden**	**Available**	Available
32	Turkey	N/A	N/A
33	Ukraine	N/A	N/A
34	United Kingdom	Available	Available

Figure 5.4: Status for baselines and coastlines (per feb 2024)