

Final report

1. Project details

Project title	EUDP 2020-I Globalt atlas over designparametre for hav- og kystnære vindmølleparker Global Atlas of Siting Parameters Ocean and Coasts (GASPOC)
File no.	J.nr. 64020-1043
Name of the funding scheme	Det Energiteknologiske Udviklings- og Demonstrationsprogram (EUDP)
Project managing company / institution	DHI A/S
CVR number (central business register)	36466871
Project partners	DTU Wind and Energy Systems, Vento Maritime Aps, DECK1 A/S
Submission date	28 February 2024

2. Summary

Project summary:

- The purpose of the project**

GASPOC set out to shorten the project development period for offshore wind farms getting new green energy faster into the energy mix, lower CAPEX and lower the OPEX once in production. This value has been brought through automated data driven downscaling techniques with high accuracy applied to meteorological and ocean modelling and services.

- Results, conclusions and perspective**

GASPOC has delivered new globally covering comprehensive and easily accessible state-of-the-art metocean datasets:

- Ensemble of meteorological siting data across the CFSR, ERA5 and MERRA2 datasets with 50-year wind and turbulence intensity. These are exposed in Global Wind Atlas.
- Global wave model dataset with improved performance in areas with offshore wind farms and its 50-year significant wave height. Accessible via DHI MetOcean On Demand data portal.

Modelling technologies were developed for these to be seamlessly used as input for new metocean downscaling models applied at offshore wind farms, cable corridors and near ports:

- MIKE Metocean Simulator based on a novel fast high-resolution wave model combining numerical modelling and machine learning techniques.
- Enhanced technical interface from PyWake and PyWAsP to Global Wind Atlas data, including interface and data transmission.

Equally important the free to use python ModelSkill library has been extended for validation against satellite and in-situ data.

Finally, GASPOC has developed two SME owned targeted services linking to above:

- The Vento MetOcean portal is a web service that provides metocean data analytics tailor-made for marine operation in connection with planning of installation and O&M of an offshore windfarm.
- DECK1 Weather Tool links metocean data to vessel and helicopter analytics and optimise wind turbine accessibility and compliance with sustainability goals and regulations.

Projekteresumé:

• Formålet med projektet

GASPOC har forkortet projektudviklingsperioden for havvindmølleparker og bringer dermed mere vindenergi ud til forbrugerne. Projektet har desuden bidraget til lavere CAPEX og OPEX omkostninger. Værdien skabes gennem automatiserede datadrevne nedskaleringsteknikker, der leverer nøjagtige data for havet og atmosfæren samt nye målrettede services.

• Resultater, konklusioner og perspektiv

GASPOC har leveret nye globalt dækkende og let tilgængelige state-of-the-art metocean-datasæt:

- Ensemble af meteorologiske siting data baseret på CFSR, ERA5 og MERRA2 datasæt med 50-års vind og turbulensintensitet. Disse er tilgængelige i Global Wind Atlas.
- Data fra global bølgemodel med forbedret nøjagtighed i områder med havvindmølleparker og tilhørende 50-års signifikant bølgehøjde. Tilgængelig via DHI MetOcean On Demand data portal.

Modelteknologier blev udviklet til let at bruge de globale data som input til nye lokale metocean modeller, der anvendes ved havvindmølleparker, kabelkorridorer og nær havne:

- MIKE Metocean Simulator er baseret på en ny hurtig bølgemodel i høj opløsning, der kombinerer numerisk modellering og maskinlæring.
- Forbedret teknisk interface fra PyWake og PyWASP til Global Wind Atlas data, inklusive interface og datatransmission.

Et andet vigtigt element er udvidelsen af det gratis python ModelSkill-bibliotek til validering mod satellit og in-situ data. Endelig har GASPOC udviklet to målrettede SMV-ejede tjenester, der knytter sig til ovenstående:

- Vento MetOcean portalen er en webtjeneste, der leverer metocean dataanalyse skræddersyet til marine operationer i forbindelse med planlægning af installation og O&M af en havvindmøllepark.
- DECK1 Weather Tool knytter metocean data til skibs- og helikopteranalyser og muliggør effektivitetsoptimering og overholdelse af bæredygtigheds mål og -regler.

3. Project objectives

The objective of GASPOC was to shorten the project development period for offshore wind farms getting new green energy plants faster into the energy mix, lower CAPEX and lower the OPEX once in production, thus lowering Levelized Cost of Energy.

To meet this objective the project set out to deliver easily accessible metocean siting data for design and planning anywhere offshore. Through a scalable quality/cost structure ranging from free general data analytics to more costly customized data services, the value of metocean data could be freed by anyone in the offshore wind energy value chain.

This purpose was achieved through automated, fast downscaling techniques with high resolution through improved observed data usage and applied to meteorological and ocean modelling and analytics tailored for seamless integration into both the engineering design, planning and operation of offshore wind parks developed and operated by the Danish offshore wind energy sector anywhere in the world.

GASPOC has delivered new globally covering comprehensive and easily accessible state-of-the-art metocean datasets:

- Ensemble of meteorological siting data across the CFSR, ERA5 and MERRA2 datasets with 50-year wind and turbulence intensity. These are exposed in Global Wind Atlas.
- Global wave model dataset with improved performance in areas with offshore wind farms and its 50-year significant wave height. Accessible via DHI MetOcean On Demand data portal.

Modelling technologies were developed for these to be seamlessly used as input for new metocean downscaling models applied at offshore wind farms, cable corridors and near ports:

- MIKE Metocean Simulator based on a novel fast high-resolution wave model combining numerical modelling and machine learning techniques.
- Enhanced technical interface from PyWake and PyWAsP to Global Wind Atlas data, including interface and data transmission.

Equally important the free to use python ModelSkill library has been extended for validation against satellite and in-situ data.

Finally, GASPOC has developed two SME owned targeted services linking to above:

- The Vento MetOcean portal is a web service that provides metocean data analytics tailor-made for marine operation in connection with planning of installation and O&M of an offshore windfarm.
- DECK1 Weather Tool links metocean data to vessel and helicopter analytics and enable efficiency optimization, asset utilization maximization, and compliance with sustainability goals and regulations.

4. Project implementation

The GASPOC implementation plan set out to achieve the following:

- 1) A global database containing state-of-the-art metocean datasets that are easily accessible via cloud for both direct screening analysis and input for site specific downscaling
- 2) Accurate metocean model downscaling to local sites using:
 - a) Fast cloud scaled automated high-resolution numerical models and local scale data sources
 - b) statistical downscaling based on either a generalized approach or on machine learning using local scale observed data sources
- 3) Comprehensive model validation against satellite and in-situ data and an efficient human quality assurance tool set, with workflows optimised for the sector specific requirements
- 4) Automated metocean data analytics and applications that optimally support seamless application to
 - a) strategic planning of offshore wind energy development at national and regional level
 - b) offshore wind turbine, substructure, and farm design processes

- c) planning of installation, operation, maintenance and decommissioning
- 5) Data Service via user experience optimized web services
 - a) free global layers for global wind atlases
 - b) dedicated commercial web services for downscaling and use case specific application
 - c) API's, file transfer and web components
- 6) Demonstration and application

An early focus of the project was to conduct a substantial co-creation phase led by DHI's innovation, ideation and co-creation specialists. This was to concretize GASPOC while managing risks that the project developments misses the targeted application underpinning the value proposition. A series of interviews were conducted with relevant industry representatives, to map out the difficulties and challenges they meet in strategically planning, designing, installing and operating wind farms. Through interviews and workshops, we mapped out pain points and possible solutions, as seen from involved stakeholder's perspective.

There were three focuses of our investigation. First focus was on the pre-analysis of wind sites and the process before getting the data certified (design phase). For this focus, we conducted interviews and held a workshop with representatives from Ørsted and C2Wind. The second focus was on the process of operating and maintaining wind farms. To gain insights to this area we conducted interviews and held a workshop with representatives from DECK1, Vento Maritime from within the consortium and Vestas from outside. The third focus was on strategic planning at a national level which was addressed with a co-creation workshop with World Bank.

This early co-creation activities led to sharpening the emphasis of the various project tasks and services to what is now delivered as results. Some features remained as anticipated such as the addition of ensemble wind speed, turbulence intensity and significant wave height in Global Wind Atlas for strategic planning, while a clear steer from the design data part was to ease emphasis on speeding up gold-class design phase metocean data, but rather improve validation methods for on-demand metocean data. This led to focussing the fast wave modelling on very-fast, but silver-class modelling a factor 100-1000 times the speed for standard wave modelling, which has proven useful for installation planning, supplemented by an in situ data validation functionality in the DHI Metocean Data Portal.

The technical implementation of the global data sets and downscaling models followed the project plan, albeit with higher computational demands in calibration and data set production than anticipated for reaching the quality and resolution demanded. This success was also supported by two dedicated technical workshops with DHI and DTU. Regarding tying the data and service development back to use cases, the steps taken to engage the industrial partners continually during the project were insufficient in two accounts. 1) to cater for sharing the industry data input required by selected services and 2) bridging the gap from the presently established working methodologies to the novel ways of working with metocean data embedded in the project products. Reg. 1) Acquiring operational data from industry was deemed too challenging and resulted in establishing use cases without. Reg. 2) the project was extended by 6 months to allow 1:1 service provider to use case owner time to establish each use case.

Overall, the meeting structure and dissemination was initially affected in its shape by COVID-19. This has led to more online dissemination (e.g. via the establishment of a project home page), more frequent, but shorter meetings during the first half of the project, and fewer dissemination activities involving travelling. Also, the timing of final industrial dissemination workshop was moved until the very end to be able to include the outcomes of the use cases.

5. Project results

- *Was the original objective of the project obtained? If not, explain which obstacles that caused it and which changes that were made to project plan to mitigate the obstacles.*
- *Describe the obtained technological results. Did the project produce results not expected?*
- *Describe the obtained commercial results. Did the project produce results not expected?*
- *Target group and added value for users: Who should the solutions/technologies be sold to (target group)? Describe for each solutions/technology if several.*
- *Where and how have the project results been disseminated? Specify which conferences, journals, etc. where the project has been disseminated.*

Subject to the changes in the implementation described above, the project has obtained result in accordance with the original objectives. Technological results and commercial results are very interlinked since the commercial aspects of the project resides on attracting traffic for free services, selling subscriptions for the products and services developed as well as integrating them into advisory services.

Here we provide brief description of products and services that have been created or improved through the project GASPOC. For each service, we provide (1) a web link; (2) General description and value add for users; (3) Contribution from GASPOC; (4) Target group. For some, a figure is provided.

1. DHI Metocean Data Portal

<https://www.metocean-on-demand.com/>

Short description: MetOcean Data Portal: High-quality and reliable metocean data is fundamental to the success of any marine project. You can save time gathering, analysing and reporting metocean data with DHI's Metocean Data Portal. The global portal enables you to download and validate 40 years of wind, wave, water level and current data, as well as retrieve interactive analytics or download time series data through a user-friendly interface or API. With the subscription-based service, improved efficiency is experienced across all stages of your offshore or coastal project—from feasibility, planning and design to construction and operation.

GASPOC contribution: A new high resolution accurate Global Wave Model dataset covering 45 historical years 1979-2023. Automated access to your private MIKE Metocean Simulator results and in situ validation functionality.

Target group: Authorities dealing with strategic planning; developers and consultants working with pre-feed design and planning; downscaling services.

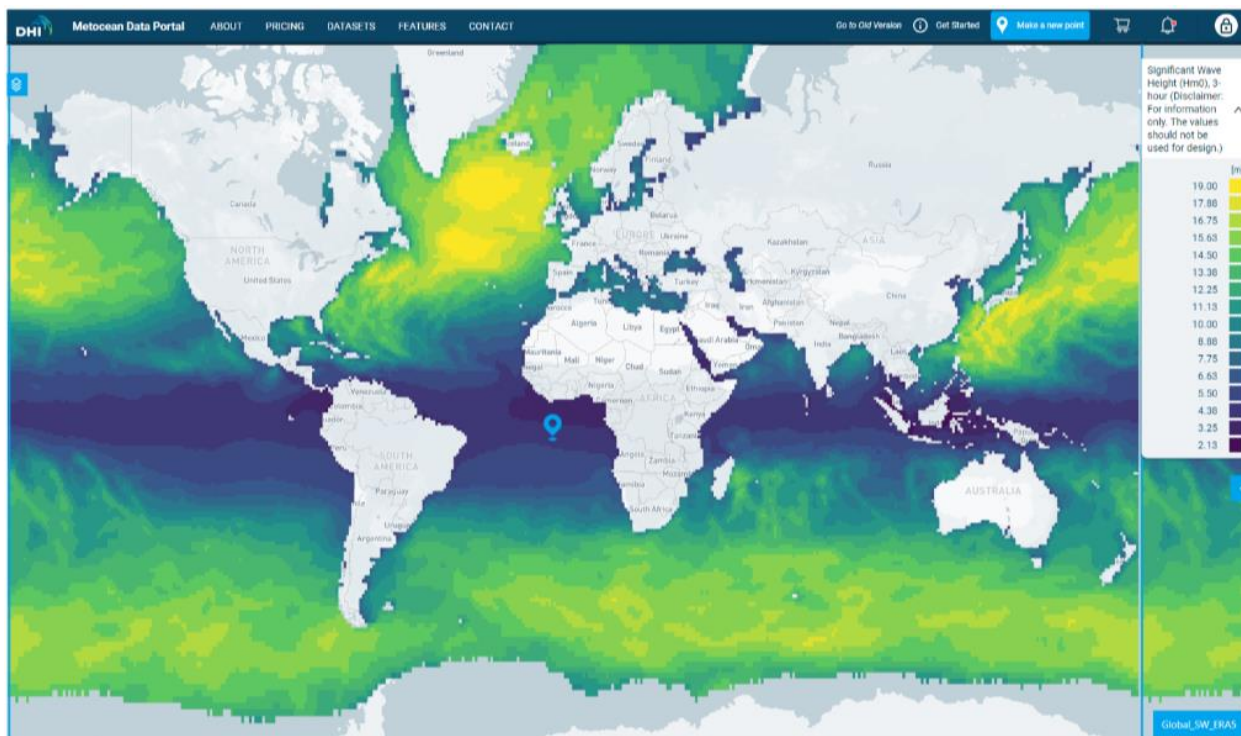


Figure 1 Significant wave height, Hm0, with 50-year return period as available via MOOD

2. DHI MIKE 21 SW

link: [MIKE 21 Spectral Waves \(mikepoweredbydhi.com\)](https://mikepoweredbydhi.com/)

Short description: With MIKE 21 Spectral Waves, you can calculate wind-waves in all seas - easily and accurately. The numerical model can calculate the size of wind-generated waves and swell to produce metocean data as a solid and cost-effective foundation for a multitude of offshore or nearshore wave sensitive engineering activities, e.g. Offshore Wind Energy activities. This advanced 3rd generation wind-wave modelling software offers a pioneering flexible mesh approach and highly efficient engine parallelisation. MIKE 21 Spectral Waves enables you to properly resolve the physical environment and governing wave processes by calculating wave climates at the regional and local scale when high spatial resolution is required.

GASPOC contribution: Released 24 November 2021: Research based new Source term formulations as well as input correction to neutral wind speed included in Release 2022. These are a prerequisite for the accurate new long term Global Wave Model data sets and the wave siting data in the Global Wind Atlas.

Target group: Developers, contractors, operators and consultants working with design and planning.

3. DHI Marine Observation Data

link: [Marine Observation Data \(dhigroup.com\)](https://dhigroup.com/)

Short description: Convenient near real-time marine altimetry satellite data for modelers
Near real-time global sea surface height, wave height and wind speed data, conveniently packaged for hydrodynamic modeling.

GASPOC contribution: validate against in situ data, expose for validation in MOOD, add the Sentinel 6a satellite and link to model calibration/validation using ModelSkill as well as data assimilation using MIKE 21 SW.

Target group: Developers, contractors, operators and consultants working with design and planning.

4. DHI MIKE Metocean Simulator

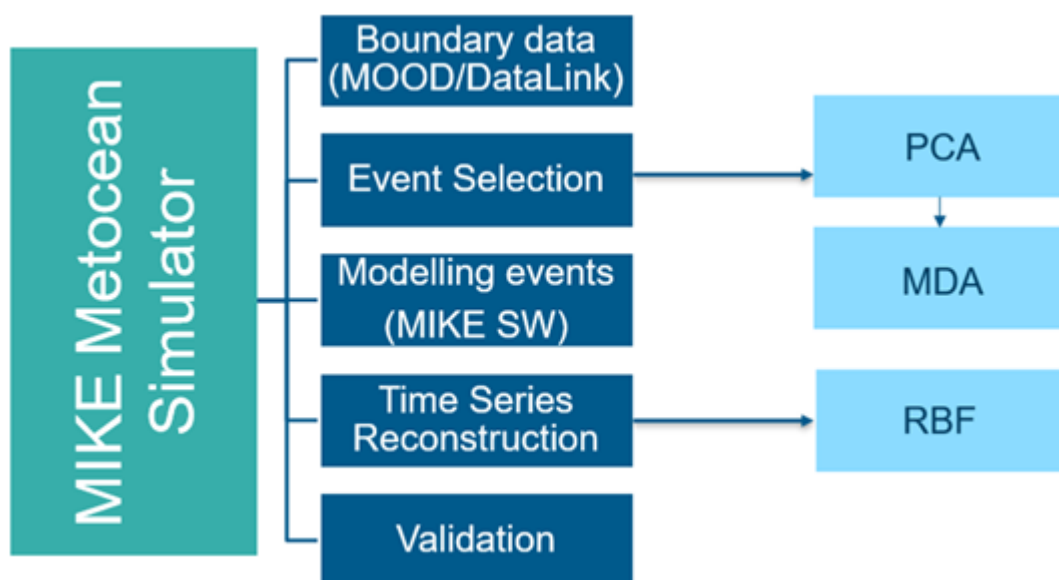
link: [MIKE Metocean Simulator \(mikepoweredbydhi.com\)](https://mikepoweredbydhi.com), Released 5 December 2024

Short description and GASPOC contribution: MIKE Metocean Simulator is a GASPOC initiated new data and application driven metocean downscaled wave modelling workflow. It transfers regional scale modelling results from the Metocean Data Portal (MOOD) to the local scale of offshore wind farms, access and cable corridors as well as ports and thus generates new project specific data sets in the data portal.

MIKE Metocean Simulator is a MIKE Cloud application for modelling high-resolution nearshore and offshore wave conditions. MIKE Metocean Simulator applies statistical methods to get radically faster results than traditional modeling. It applies high-quality data from the new global wave model. MIKE Metocean Simulator leverages cloud infrastructure to remove hardware investment, increasing cost-effectiveness. It is powered by recognized MIKE 21 SW.

The diagram below shows the sequence of obtaining boundary conditions and selecting a subset of the events by using principal component analysis (PCA) and maximum dissimilarity analysis (MDA). At completion of the modelling of the selected events the full timeseries is reconstructed using a radial basis function (RBF).

Target group: Developers, contractors, operators and consultants working with design and planning.



5. DHI ModelSkill

link: [GitHub - DHI/modelskill: Compare results from MIKE and other simulations with measurements](https://github.com/DHI/modelskill)

Short description: ModelSkill is designed to be your modelling validation assistant. It should be useful enough to use every time you do a metocean simulation. Modelskill will make it easy to assess the skill of a metocean model by comparing model results with measurements also when result is split on several files (2d, 3d, yearly, ...), to compare the skill of different calibration runs, to compare your model with other models, to use a wide range of common evaluation metrics, to create common plots such as time series, scatter and taylor diagrams, to do aggregations. And it should be difficult to make mistakes by verifying input, trustworthy by having >95% test coverage and easy to install.

GASPOC contribution: During 2021 and H1 2022: Support for efficient comparison against satellite altimetry data via aggregation in spatial bins and improved scatter plot including data density visualization.

Target group: Authorities dealing with strategic planning; Developers, contractors, operators and consultants working with design and planning.

6. DTU PyWake

Link: <https://gitlab.windenergy.dtu.dk/TOPFARM/PyWake>)

Short description: PyWake is an open-sourced and Python-based wind farm simulation tool developed at DTU capable of computing flow fields, power production of individual turbines as well as the Annual Energy Production (AEP) of a wind farm. The software solution provides an interface to both a selection different engineering models as well as CDF RANS (PyWakeEllipSys). It is highly efficient in calculating how the wake propagates within a wind farm and can quantify the interaction between turbines. The main objective of PyWake is to calculate the wake interaction in a wind farm in a computationally inexpensive way for a range of steady state conditions. It is very useful for computing the power production of a wind farm while considering the wake losses for a specific wind farm layout configuration.

GASPOC contribution: GASPOC enhanced the technical merge of PyWake function and GWA data, including the interface, data transmission from GWA to PyWake, test PyWake function with the new input. The input data include wind speed and turbulence intensity at given heights.

Target group: Offshore wind energy industry, wind turbine manufacturers, Authorities dealing with strategic, energy planning; developers and consultants working with pre-feed design and planning; downscaling services; the consortium's current customers.

7. DTU PyWASP

link: [WASP / PyWASP Examples · GitLab \(dtu.dk\)](#), and [WASP - PyWASP](#)

Short description: PyWASP is a powerful software tool that allows users to easily access the functionality of WASP, the leading tool for predicting wind resources of wind turbines in different terrain. With PyWASP, users can easily integrate WASP's powerful wind resource prediction capabilities into their own Python-based applications and projects. This allows users to take advantage of the advanced wind resource prediction capabilities of WASP without needing to learn the intricacies of the WASP tool itself. So, whether you are a professional wind energy consultant, a researcher in the field of renewable energy, or simply someone interested in wind resource prediction, PyWASP has something to offer. With its intuitive Python-based API and comprehensive documentation, PyWASP makes it easy for users to get up and running quickly and start using WASP's powerful capabilities to their full potential.

GASPOC contribution: GASPOC enhances the PyWASP function in receiving data from Global Wind Atlas (GWA), including siting parameters. GASPOC enriches the GWA with global ensemble data for the extreme winds and turbulence data in the coastal and offshore area, at 10 m, 50 m, 100 m, 150 m and 200 m.

Target group: Offshore wind energy industry, wind turbine manufacturers, Authorities dealing with strategic, energy planning; developers and consultants working with pre-feed design and planning; downscaling services; the consortium's current customers.

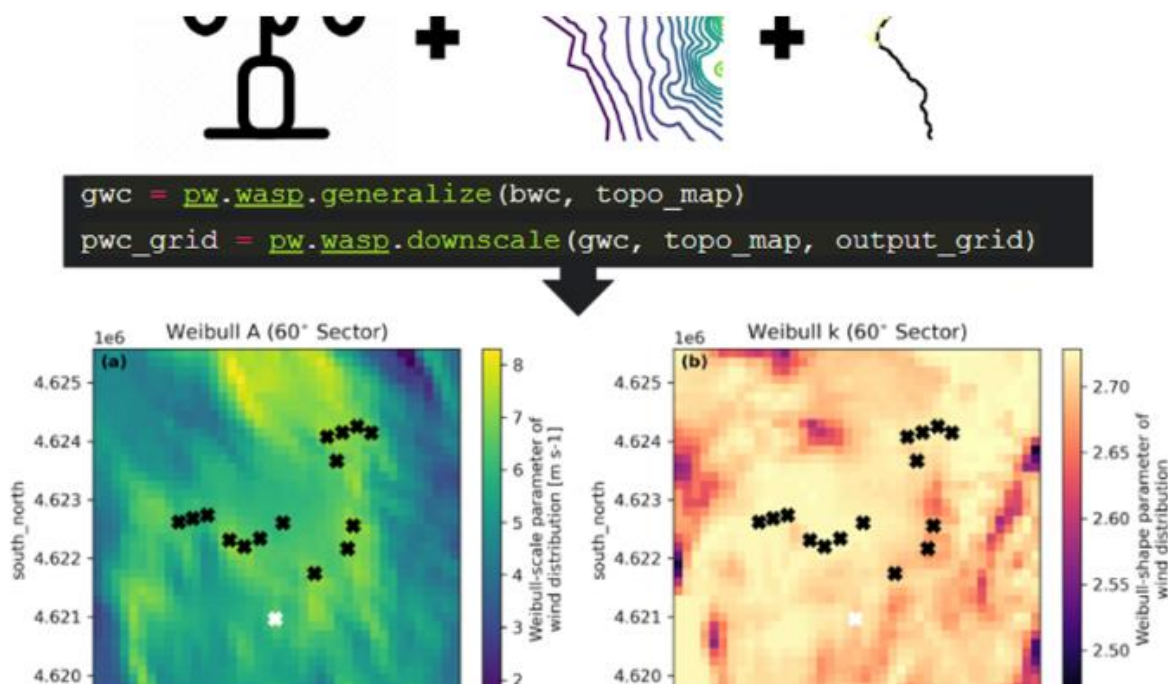


Figure 2 PyWASP: Python-based API for running WAsP and WAsP Engineering models.

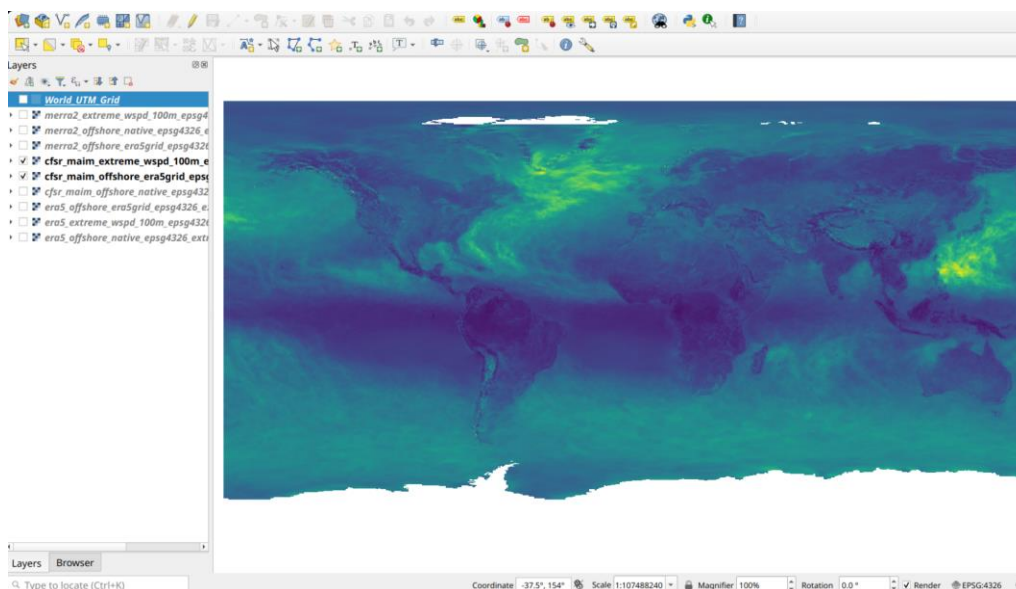
8. DTU Global Wind Atlas

link: [Global Wind Atlas](#)

Brief description: This portal hosts many global data layers for wind energy applications, including wind resource data and siting parameters at several heights relevant for modern wind turbines. Before GASPOC, the data cover all land area and coastal zones (200 km offshore from shoreline), at a spatial resolution of 275 m.

GASPOC contribution: GASPOC adds data layers over all water area, including particularly the 50-year wind and turbulence intensity. The 50-year winds are calculated using the spectral correction method based on several reanalysis products: CFSR, MERRA2 and ERA5. Within GASPOC, the spectral correction method for TC-affected areas has been further developed by generalizing the calibration methodology to MERRA2 and ERA5 as well as a spatial expansion of the TC-affected zones based on long-term best track data. See the figure-(b) below. The turbulence intensity is calculated using ERA5 data with turbulence considering 2D turbulence, sea state and stability effect. Also, a global map of 50-year significant wave height is added.

Target group: Offshore wind energy industry, wind turbine manufacturers, Authorities dealing with strategic, energy planning; developers and consultants working with pre-feed design and planning; downscaling services; the consortium's current customers.

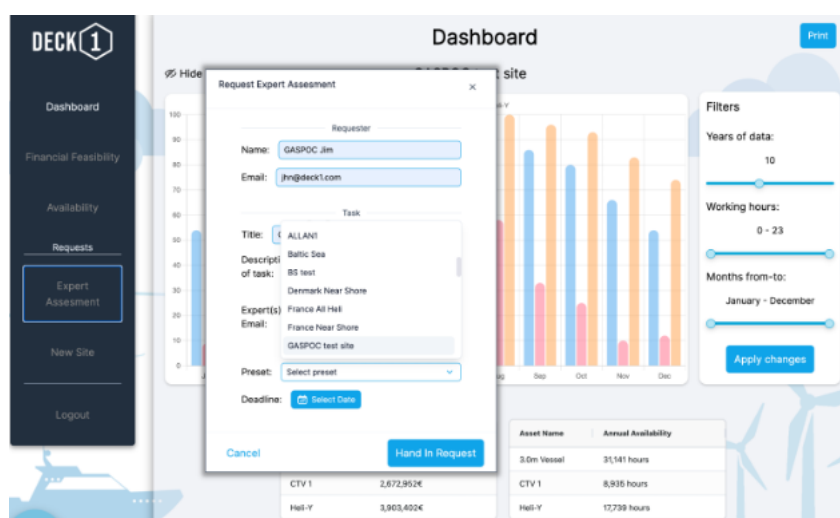


9. DECK1 Weather Tool

Link: [Site WX comparing tool](#)

User: JHH@deck1.com / Code: 12345678

Short Description: D1 Site WX tool compile information for a quick overview of cost, CO2 and accessibility (ability to plan activities) for windfarm operators. It is possible in minutes to get a weather validated 1st view of offshore logistic strategy, compare assets and more. As standard it includes ERA5 weather data, but there is the option to get more precise calculations with weather data from GASPOC, proprietary weather data from customers own databases, or due diligence reports via a link to specialist such as Vento Maritime.



GASPOC contribution: The tool is based on ERA5 weather data that lags accuracy in detail to support FID (Final Investment Decision). The FID often have multi-million € consequences both in contract cost and in

project execution. For that the customers often need more detailed data or evaluations which the GASPOC project can provide.

Target group: *Contractors, subcontractors and operators dealing with strategic planning concerning off-shore operations.*

10. Vento Maritime Offshore Weather Service

Link: [Offshore Weather Service | Vento Maritime](#))

Short Description: The Vento Maritime Offshore Weather Service is a web service that provides metocean data analytics that tailor-made for planning any marine operation in connection with planning of installation, operation, and maintenance of an offshore windfarm. The standard setup make use of global ERA5 hindcast data and HYCOM surface current reanalysis data. However, if the customer prefers metocean hindcast from even higher quality regional or local model setups this can be included. Furthermore, if the customer has measurement data this can be included to make a validation of the hindcast data and therefore provide vital quality measure of the hindcast data and the analytics calculated. Additionally, a ramp up / ramp down analysis will be carried out to validate the calculated weather windows. This analysis will also provide a quality assessment of how well the hindcast model will perform when forecasting during project execution.

GASPOC contribution: GASPOC provides access to spectrally corrected, global hindcast data for even higher accuracy in the calculated metocean statistics. Furthermore, it provides the possibility to utilize downscaled very high-resolution local wave model setup. This is crucial for customers planning near-shore marine operations, where coarser global hindcast models will not suffice.

Target group: *Contractors, subcontractors and operators dealing with strategic planning concerning off-shore operations.*

GASPOC results have been actively disseminated as follows:

Conferences, workshops & meetings:

Participation in Wind Energy Science Conference, 26 May 2021, Hannover, Germany

WindEurope Electric City, 23-25 November 2021, Copenhagen, Denmark

Wind Energy Science Conference (WESC), 2021, May, online

WindEurope Annual Event 2022, April Bilbao, Spain

Seminar on Offshore Wind collaboration between Norway and Denmark 9th March 2022, Copenhagen, Denmark
Wind Denmark Annual Meeting 23rd March 2022, Vejle, Denmark

Green Power Denmark Topmøde, 2nd June 2022, Copenhagen, Denmark

WindEurope Technology Workshop 2022 June Brussels

WindEurope WindEnergy Hamburg, 27-30 September 2022, Hamburg, Germany

Wind Energy Denmark 2nd November 2022, Risø, Denmark

WESC 2023, 6-8 September 2023, Glasgow, UK

RWE Renewables Danmark opening reception, 3rd March 2023, Copenhagen, Denmark

Green Power Denmark housewarming and 1st anniversary, 30th March 2023, Copenhagen, Denmark

WindEurope Annual Event 2023, April, Copenhagen, Denmark

EGU 2023, 23-28 April 2023, Vienna

Green Power Denmark Topmøde, 1st June 2023, Copenhagen, Denmark

Green Energy Export Day 2023, 29th August 2023, Copenhagen, Denmark

Presentation of a demo version of Offshore Weather Service, November 2023.

Green Power Denmark event, 30th November 2023, Horsens, Denmark

EGU 2024, 13-19 April Vienna

MOOD 2022 Webinar with GASPOC global wave model, 13 December 2022

MOOD 2024 Webinar with GASPOC new validation tools, 7 February 2024

MIKE Metocean Simulator Webinar, 17 January 2024

News stories, SoMe and web:

<https://www.gaspoc.com/landing-page/>

[DTU offers new open data for more safe and efficient wind industry - DTU](#)

<https://energiforskning.dk/en/node/15996>

<https://worldwide.dhigroup.com/global/news/2020/06/sustaining-the-acceleration-of-global-offshore-wind-energy>

https://www.linkedin.com/feed/update/urn:li:activity:6686227464882065408/?updateEntityUrn=urn%3Ali%3Afs_feedUpdate%3A%28V2%2Curn%3Ali%3Aactivity%3A6686227464882065408%29

[Hurtigere vej til nye vindmølleparker med automatiseret modelleringsværktøj - GTS \(gts-net.dk\)](#)

DHI is writing a GTS news story based in the industrial dissemination workshop, which is published after the deadline for the final report.

Publications, posters:

J. Tornfeldt Sørensen, "Global Atlas of Siting Parameters Ocean and Coast (GASPOC)", Wind Energy Science Conference, 26 May 2021, Hannover, Germany

Imberger M., Larsén X. and Davis N. (2024): Global Atlas for Siting Parameters Ocean and Coast – Ensemble calculation of 50-year return winds, DTU Wind report E-0244, ISBN: 978-87-87335-72-0

Imberger M. and Larsén X. (2022) Sensitivity and quality assessment of the global 50-year return winds using reanalysis products and measurements. WindEurope Annual Event 2022, April Bilbao, Spain.

Fischereit J., Imberger M. and Larsén X. (2022): Cost-effective mesoscale modeling methods for offshore wind resource assessment with farm wake effect. WindEurope Technology Workshop 2022 June Brussels.

Larsén X. (2022) Calculating Turbulence Intensity from mesoscale modeled Turbulence Kinetic Energy. DTU Wind Energy. DTU Wind Energy E No. E-0233

Larsén X.G., Imberger M. and Hannesdóttir Á. (2023). The Impact of Climate Change on Extreme Winds over Northern Europe According to CMIP6, Wind Energy Science, <https://doi.org/10.5194/wes-2022-102>

Larsén X. G. and Ott S. (2022): Adjusted Spectral Correction Method for Extreme Wind in Tropical Cyclone Affected Water Areas. Wind Energy Science, 7(6), 2457-2468, <https://doi.org/10.5194/wes-2022-64>.

Larsén X.G., Rutgersson A., Karimi F. et al. (2023): Climate Change and Offshore Wind Energy in the Baltic Sea. Oxford Research Encyclopedia of Climate Science. Accepted with minor revision.

Larsén X., Fischereit J., Hamzeloo S., Bärfuss K. and Lampert A. (2024): Do offshore wind farms weaken or enhance surface wind and wave fields? EGU24-9862, 18 April, 2024, Vienna.

Larsén X., Imberger M., David N., Sørensen J., Kofoed C., Olsen B., Fischereit J. and Badger J. (2023): The GASPOC project and the global offshore atlases of siting parameters. <https://doi.org/10.5194/egusphere-egu23-5382>

Larsén X., Imberger M. and Floors R. (2024): Modelling offshore turbulence intensity including large-scale turbulence, stability and wave state. To be submitted to Wind Energy.

Olsen B. et al. (2023): Integration of PyWake in PyWASP for calculating AEP with wind farm effects, WESC, 2023 Sep, Glasgow.

Pierre Swiegers (2024). Harnessing technology to refine and share accurate long-term metocean conditions, accepted for publication, Sea Technology Magazine.

Vieira de Vieira de Carvalho G., Kaji A., Swiegers P.B.; Andersson J.H. ; Tornfeldt Sørensen J., Overcoming stationary assumption in efficient coastal wave modelling for climate change studies. Submitted to Ocean Engineering 31 January 2024.

6. Utilisation of project results

The rather broad suite of GASPOC technologies, their commercial integration into new or improved products and services and the target group is described the previous section.

In three years, the expectation for resulting accumulated GASPOC impact has been estimated to be: turnover 12,000,000 kr.; exports 9,000,000 kr.; employment 8 FTE's; additional private investments 3,000,000 kr.

The outcome of GASPOC supports a chain of offshore activities related to wind energy: better data for designing offshore wind farms, better wind and ocean data as well as targeted services for planning operation and maintenance. These will help avoid damages and downtime caused by e.g. wrong turbines, wrong time (dangerous wind and wave conditions) or sub-optimal assets (vessels, helicopters) available for the trip to the wind farms. GASPOC will contribute to a more secure operation and maintenance of wind turbines and farms for their lifetime and accordingly safer supply of wind energy. Overall, GASPOC will increase efficiency and reduce risks for the offshore wind industry and hence stable production of renewable energy. GASPOC further prepares key data for global offshore wind energy applications, thus making it possible for global offshore profiling of site conditions, suitable turbines, optimal farm locations and displacement, thus accelerate offshore energy planning, thereby promoting wind energy, supporting sustainable integration of renewable energy and increasing cost efficiency. This is done not only on a national but also international scale, a significant contribution to

our independence of fossil fuels, not only promoting Denmark, but also other countries. All together this support Danish, European and global energy policy objectives.

The general market for metocean data, analysis, service and application to the offshore wind energy sector is heterogeneous as are the GASPOC products and services, which is reflected in below analysis.

Strategic planning

There is no direct competitor offering an open global metocean siting analytics for strategic planning of offshore wind energy development with the transparency of methodology and applicability provided by Global Wind Atlas (appr. 50,000 users per month), which already is the de-facto go-to offering for resourcing during the strategic phase and now with GASPOC uses this recognized position to also support the siting parameters in coastal and offshore areas. The open access to global validated GASPOC data layers will help establishing early cost calculations and thereby remove barriers hidden within spatial planning and tendering processes leading to the accelerated wind energy roll-out.

Design data

A relatively large and well-established service industry exists supplying wind energy resource assessment and metocean data for design parameters and planning due to the corresponding value harvested for project developers on these two aspects. DHI is a globally leading supplier of metocean design studies and, in MOOD, have an established metocean data subscription service, thus already supporting the digitalisation of the offshore wind energy industry from a metocean data perspective. GASPOC services have added an improved MIKE 21 SW wave modelling engine, an accurate and higher resolution global wave modelling dataset for analysis and boundary conditions of site-specific models, improved MOOD validation data access and functionality as well as MIKE Metocean Simulator results visualization in MOOD. This has led to more reliable data more places in the world and as has already been contributed to a faster or less risky development of more than 20 wind farms worldwide. For metocean design studies, a number of competitors exist, such as Deltares, DNVGL, Rambøll, COWI, Fugro, Metocean consult and CDR. The Danish competitors already use DHI's desktop software with access to the GASPOC datasets and modelling techniques. It is expected that project owners increasingly will benefit from generating their project specific metocean data using the new more automated generation of metocean data building further onto the work started in GASPOC. In a different perspective, this is the natural next step of MOOD and its competitors, <http://www.openocean.fr/en/> and www.waveclimate.com as well as public met-office services and the EU funded Copernicus services. You get low cost or cheap data anywhere, but if you need more accuracy, you can enrich it with project proprietary data of e.g. bathymetry and in-situ observations and generate locally validated metocean results in an assisted workflow.

For the wind data offshore that are provided in GASPOC, DTU does not see many direct competitors as they are among the leading the research and development of the most relevant key issues regarding design and farm planning in the world, though Fraunhofer and SINTEF are examples of institutes with some overlap in competencies. GASPOC has enhanced the functionality of existing tools such as PyWASP and PyWASP. This means that GASPOC utilizes well-established channels to deliver its new functions through WASP customers with its more than 1500 active users per month, and through courses and DTU's Global Wind Atlas websites. In GASPOC, DTU have been in close collaboration with DHI providing support on ocean wave topics, making the Danish position an even stronger player in this field. Collaboration with DECK1 and Vento Maritime brings the data in this project to direct application targeted solutions with feedback for prompt improvement. Large actors in the wind industry such as Vestas and Ørsted may have inhouse competences on these aspects and their participation as user advisory board members shows the prospects they continually see in GASPOC's activities.

Planning and execution of operations

Application of metocean data for planning and execution of operations during installation, operation and maintenance constitutes a quite different market. This is characterised by more versatile applications, workflows and cultures that does not always allow exploitation of the added value of accurate data over free general-purpose weather data or lower-quality alternatives. Also, the commercial structure and contracts make it necessary to have low setup costs and to be able to supply studies or forecasts in areas new to the service provider within hours to days. Consequently, players accept lower accuracy and some information loss. This market has therefore been provided with a different service in GASPOC that is fast to set up, has scalable costs and can be integrated into the workflows of dedicated service providers on this market.

DECK1 and Vento Maritime are two such active players that have built their business embracing a combination of new digital services and specialist knowledge to increase market shares exploiting a mix of free data sources and GASPOC's globally standardized approach to support entering new geographical markets. A wide range of service providers are delivering planning and execution support to operations in the offshore wind industry. Prominent examples are StormGeo, WNI, DTN, Shoreline and JBA. However, through GASPOC development and core technology, DECK1 has improved its service to the end users on several parameters particularly for helicopter and vessel planning and operation. From long term strategic planning of contracts to seasonal detailed operations with current assets as well as references on day-to-day operations for safe operations. Beyond above potential competitors from the maritime domain, companies like iAIMS from the airline industry could still be a threat and many offshore wind farm operators also have in-house experts and tools performing similar calculation. GASPOC has helped DECK1 sharpen its offering to establish themselves with a demonstrated value proposition in planning and management of helicopter transports to offshore wind farms.

Modelling software

DHI further develops and sells proprietary ocean modelling software as part of MIKE Powered by DHI. DHI's ocean hydrodynamic and wave modelling software products are used by many competitors delivering metocean design studies and operational forecast systems. The MIKE Powered by DHI Software is the world's leading commercial software package of its type for offshore and coastal engineering but is continually in competition with e.g. Delft3D, SWAN, ROMS, FVCOM, Adcirc. The automated and assisted downscaling techniques in GASPOC blending machine learning and numerical modelling for wave and flow modelling are at the heart of the ongoing competition.

DTU has for decades developed and maintained desktop software WAsP and WAsP Engineering. While there are software competitors for some of the general resource calculation function in WAsP, DTU has now and with contribution from GASPOC developed a completely new product called PyWAsP. PyWAsP gives new capabilities for users to run WAsP and WAsP Engineering models in custom specific works-flows using a flexible Python coding environment. This has become a unique product in the sector and addressing industrial partners with inhouse software development capabilities. PyWake is similarly a flexible workflow modelling package, which now integrates Global Wind Atlas siting data directly with the calculation of wake effects.

7. Project conclusion and perspective

GASPOC has contributed with major strides to present and future metocean data and modelling services. Based on a set of comprehensive co-creation events, targeted requirements were formulated based on input from Danish industrial users as well as the broad industry and scientific knowledge of the consortium.

The move towards more automation has embedded resistance and market adoption of these is expected to be increase as 'automation' more correctly is experienced as 'assistance' and the resulting new modelling

tools start building a respectable track record. This was supported by GASPOC's use case approach, which from day one was the aim of the project to deliver.

The project delivery via a broad set of products and services has been a robust approach as this allowed the necessary flexibility and reprioritization of efforts to aim to deliver the sought impact with the end users. In the nature of this, each technology has been sharpened and their next steps of development vary among them accordingly.

For strategic siting and planning applications, the DTU driven Global Wind Atlas is the unchallenged platform providing free data, and this has been consolidated GASPOC data layers offshore from DTU and DHI. The GASPOC partnership has led to an agreement that as new ocean layers are requested in Global Wind Atlas, DHI will provide these as achievable at global scale, while DTU will be improving atmospheric data sets. A step that would require a major new development project would be to advance a global near-surface ocean current data set optimized for offshore wind energy application, which would be of value to the development of floating wind energy.

For the two services in the operational planning space, the Vento Maritime Offshore Weather Service and the DECK1 Weather Tool will both focus future development on services which combine the special competence of each company with the digital capabilities and services developed within GASPOC. The link to GASPOC quality data is an option but not always worthwhile in the operational space.

The value of linking the new global data sets to downscaled models via input to PyWASP, PyWake and MIKE models for individual offshore wind farms has been delivered by GASPOC. For the MIKE Metocean Simulator, the idea was weighted to strong that it has already been released as a brand-new cloud product in the MIKE Cloud family of services. It also gave rise to the birth of a first of its kind innovative similar concept for modelling of water level and ocean currents, which was proven in principle as part of GASPOC and is expected to attract additional investment to develop as a new branch of the MIKE Metocean Simulator product.

In addition, at a final project meeting, more than 10 other new ideas spawned both from known needs and the realm of the possible, proving the value of the partnership created during the 3 ½ years of GASPOC.

8. Appendices

- Add link to relevant documents, publications, home pages etc.

Project references are kept up to date for at least one year in: <https://www.gaspoc.com/>