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# Extracting and Using Weather Time-Series Data for Offshore Renewable Energy Projects

## EXECUTIVE SUMMARY

Weather time-series data is vital for many analysis activities in the offshore renewable energy sector. This includes energy analysis to estimate expected revenue from a project, establishing design criteria, and weather downtime modelling to predict the impact of metocean conditions on constructing, operating and maintaining offshore assets. One publicly available source of weather time-series data is the ERA5 dataset, accessed through the European-funded Copernicus project. ORE Catapult has produced a Python script to enable the extraction of ERA5 weather time-series data from the Copernicus website. The script is freely available on the ORE Catapult website.<sup>1</sup> This paper supports the release of the script by highlighting how weather time-series data is valuable for offshore renewable energy projects and provides a reference for how to use the script to full effect.

<sup>1</sup> ORE Catapult web link: <https://ore.catapult.org.uk/analysisinsight/weather-time-series-data-in-offshore-renewables/>.

## INTRODUCTION

Offshore renewable energy (ORE), namely offshore wind (bottom-fixed and floating), wave energy and tidal stream energy, is expected to be a major contributor to the clean energy mix of global economies as many countries target 'Net Zero' emissions.<sup>i</sup> For example, the UK government has a target to reach 40GW of installed offshore wind capacity by 2030, as part of an effort to reach Net Zero by 2050.<sup>ii</sup> ORE technologies are dependent on metocean weather conditions to operate. The devices also need to be installed and accessed for maintenance, with periods of accessibility (due to operating thresholds) known as 'weather windows'. It is clear that the development and deployment of ORE technologies, particularly projects at a commercial scale, rely on a comprehensive understanding of metocean conditions at the offshore sites and associated locations, such as maintenance ports.

Weather time-series data is a vital resource for developers of ORE projects. For a given location, time-series data contains metocean parameters averaged (or as single samples/maximum/minimum) over a defined temporal resolution (see example in Table 1). This data is used in many different ways to assess the viability of an ORE project and, for example, support the Operations and Maintenance (O&M) phase.

Table 1: Example of weather time-series data

TIMESTAMP	SIGNIFICANT WAVE HEIGHT, HS (M)	PEAK WAVE PERIOD, TP (S)	WIND SPEED AT 100M HEIGHT, U <sub>100</sub> (KNOTS)
01/01/2020 00:00	2.34	6.79	15.67
01/01/2020 01:00	2.12	7.12	17.21
...	...	...	...
31/12/2020 23:00	2.57	7.29	22.43

Weather time-series data can be obtained through observed, real-time measurements (e.g. wave buoys, met masts, satellites) or through numerical modelling techniques (which are often informed by, and/or validated against, observed measurements). Common modelling approaches include atmospheric (and oceanographic) reanalysis<sup>iii</sup> and hindcasting<sup>iv</sup>. There are many different sources of modelled weather time-series data available in the public domain, such as CFSR<sup>v</sup>, MERRA-2<sup>vi</sup>, and ERA5<sup>vii</sup>. Some commercial services offer the opportunity to download weather time-series data easily using online portals, such as DHI's Metocean-on-Demand<sup>viii</sup>.

### What does this report aim to do?

ORE Catapult has produced a Python script<sup>2</sup> to allow users to extract weather time-series data from the ERA5 reanalysis dataset, via the Copernicus website, at no cost. The script is made freely available for public use through the ORE Catapult website. This report aims to raise awareness of the script and describe how weather time-series data, in general, can be accessed and used for supporting the development and deployment of ORE technologies.

<sup>2</sup> Based on work by JBA Consulting.

## Why ORE Catapult?

ORE Catapult acts as an independent, centralised, forward-thinking organisation at the heart of the offshore renewable energy industry, working closely with partners across industry and academia to develop new ways of working and prove, de-risk and develop promising new technologies. This publicly available report has been compiled by ORE Catapult and informed by related industry engagement.

## HOW IS THE DATA USED?

Weather time-series data is used in a number of ways in the ORE industry. For example, the Analysis and Insights team at ORE Catapult use the data to estimate the site-specific percentage increase of the duration of a particular operation involving a vessel (e.g. installing a wind turbine), due to inaccessible metocean conditions. Three case studies are highlighted below to demonstrate other examples of how weather time-series data is used for ORE projects.

### CASE STUDY 1

## ForeCoast® Marine – Operations Modelling

JBA Consulting offer their ForeCoast Marine software services to project developers for modelling capital and operational expenditure (CAPEX and OPEX), including the explicit representation of metocean effects on construction and O&M.<sup>ix</sup> The software does this by simulating how the operations would have “played out” if it they been undertaken last year, or the year before, or over many historical years. These simulations are done by using historical metocean data (from hindcast models or observations) and algorithms to represent the operations, their logistics and costs, and their dependencies on weather and sea-state conditions. ForeCoast Marine has been used by a wide range of project developers and contractors for various purposes, including optimising construction and O&M strategies based on key performance indicators such as turbine availability and operational expenditure, as well as exploring the impacts of climate change on O&M.<sup>x, xi</sup>

*“Detailed, accurate metocean data is an absolute essential when it comes to robust OPEX and CAPEX modelling. The costs associated with metocean delays are immense and often underestimated. The traditional “back-of-the-envelope” approaches typically used to account for metocean effects are simply no longer fit for purpose, and much greater due diligence is required. High quality metocean data, such as the freely available data from the Copernicus Climate Data Store, are readily available, and should form an essential component of any development project.”*

Mark Lawless, Director, JBA Consulting

## CASE STUDY 2

## SSE – Wind Energy Analysis

Offshore wind turbines are designed primarily to generate electricity for supply into the national grid. The amount of electricity they generate dictates the amount of revenue that is earned, which is one of the dominant metrics that a developer, such as SSE, will use to assess the financial viability of a project. Weather time-series data is used to predict how much electricity will be generated by an offshore wind turbine by matching the wind speed (at hub height) to the manufacturer's power curve. SSE is one of the market leading project developers of offshore wind energy, and their technical analysis team use weather time-series data extensively.

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*"Weather time-series data is a critical part of our energy analysis process – primarily this is in relation to wind data, which we measure to accurately estimate the energy output of a wind farm, but we also measure other aspects of climate on a site specific level such as metocean and environmental data. This allows us to ensure our windfarms are designed as accurately and safely as possible so we can operate them to their maximum potential."*

David McCracken, Technical Analysis Team Leader, SSE

## CASE STUDY 3

## ABPmer – Downtime Modelling

Marine operations for all forms of ORE are subject to a risk of delay when operational metocean limits are exceeded. Weather time-series data can be used to estimate the increased duration of a marine operation, known as weather downtime (WDT). In a report on the feasibility of towing floating wind turbines to port for major repairs<sup>xii</sup>, the Offshore Wind Innovation Hub (OWIH) utilised ABPmer's Weather Downtime Express (WDTX) service<sup>xiii</sup>. The WDTX package was used to identify the weather downtime of each stage of the operational programme for a tow-to-port event. WDTX uses hindcast data to inform the analysis, sourced from the ABPmer SEASTATES databases, which includes wind data from the CFSR database. The WDTX service was used to great extent in the OWIH report to identify that towing a floating wind turbine to a sheltered port for major repairs was a more cost-effective option, in most cases, than attempting offshore repairs in harsher metocean conditions.

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*"In terms of our Weather Downtime Express (WDTX) service, winds are from the NOAA CFSR reanalysis dataset. Wave data on the European continental shelf are from ABPmer's in-house spectral wave model hindcast. This is forced using the NOAA CFSR reanalysis winds. Outside of the European shelf, waves are from the NOAA WaveWatch III hindcast. Some of this data is accessible through our Data Explorer<sup>xiv</sup>"*

Robin Stephens, Lead Metocean Consultant, ABPmer

## CASE STUDY 4

## DHI Metocean-on-demand (MOOD) – Design conditions

Meteorological and oceanographic (metocean) time-series data serve as crucial input to the safe and cost-efficient design, installation, and maintenance of offshore wind turbines and their support structures (towers, sub-structures, and foundations). Design metocean conditions, including normal sea states and extreme sea states, are typically established from long-term model hindcasts of wind conditions, water levels, current speeds, and wave conditions. Regional metocean hindcast model databases can offer a valuable repository of metocean time-series data for offshore wind projects during Preliminary Front End Engineering Design (pre-FEED). RWE recently utilised data from DHI's North Europe database (available from the metocean-on-demand data portal) to establish preliminary design information at the Five Estuaries Offshore Wind Farm located in the southern North Sea, approximately 40 km from the coast of Suffolk.<sup>xv</sup> The North Europe model provides over 40-years of high quality atmospheric conditions, water levels and depth-averaged currents, as well as ocean surface wave parameters and 2D wave spectra.

*"The availability of accurate and reliable metocean time-series data are essential for the various phases of any offshore wind farm development. This is particularly important during the design phase (pre-FEED, FEED, or detailed design), where access to validated long-term weather time-series data is crucial for establishing design criteria. This information contributes to a solid business case for developers and de-risks the project. Our Metocean-on-demand data portal efficiently supports that process, either by using data directly from the portal (pre-FEED/FEED), or as input to further data down-scaling using high-resolution numerical models where required (detailed design)."*

Dr Matthew Easton, Engineering Project Manager, DHI Water Environments (UK) Ltd

## ACCESSING DATA

The main objective of this report is to inform readers about the ERA5 reanalysis dataset and the purpose-built Python script, made freely available by ORE Catapult, to extract the weather time-series data, via the Copernicus website. The instructions for using the script are shown in the Appendices, and the script itself can be accessed through the ORE Catapult website. The Python script utilises an application programming interface (API) to extract the ERA5 data, so an internet connection is required. There are several pre-requisites, including creating an account on the Copernicus website and having Python installed on your computer, which are explained in the instructions. With the ERA5 dataset, the user can select any offshore point with a spatial resolution of 0.5 decimal degrees (although wind data is available at 0.25 degrees resolution) and obtain metocean parameters at one-hour time steps for any period of time since 1979. Available metocean parameters include wind speed and direction (calculated from the U and V components of wind) at 10m and 100m height, significant wave height and peak wave period. ERA5 does not include hydrodynamic data, such as current speeds and water levels. There is extensive documentation for

ERA5 which can be used to modify the ORE Catapult script if required, for example, to extract different parameters.<sup>xvi</sup>

Of course, ERA5 is not the only source of weather time-series data. Table 2 highlights ERA5 alongside some other widely used options for accessing data. There are several advantages to utilising a payment-based service, such as DHI’s Metocean-On-Demand or ABPmer’s SEASTATES, as discussed in the next section.

Table 2: Selected sources of weather time-series data

DATASET	ORGANISATION	APPROACH	PAYMENT-BASED SERVICE?	WEBLINK
CFSR	NCEP	Reanalysis	No	<a href="https://rda.ucar.edu/datasets/ds093.1/">https://rda.ucar.edu/datasets/ds093.1/</a>
ERA5	ECMWF	Reanalysis	No	<a href="https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels?tab=overview">https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels?tab=overview</a>
MERRA-2	NASA	Reanalysis	No	<a href="https://disc.sci.gsfc.nasa.gov/datasets?page=1&amp;keywords=MERRA-2">https://disc.sci.gsfc.nasa.gov/datasets?page=1&amp;keywords=MERRA-2</a>
Metocean View (various datasets)	MetOcean Solutions	Hindcast	No	<a href="https://app.metoceanview.com/hindcast/">https://app.metoceanview.com/hindcast/</a>
MOOD MetOcean On Demand (various datasets)	DHI A/S	Reanalysis and Hindcast	Yes (free for some parameters)	<a href="https://www.metocean-on-demand.com/">https://www.metocean-on-demand.com/</a>
SEASTATES	ABPmer	Hindcast	Yes	<a href="https://www.seastates.net/explore-data/">https://www.seastates.net/explore-data/</a>

## CHALLENGES AND SOLUTIONS

Despite the many advances in recent years in making weather time-series data available through numerous sources (some stated previously), there are still some challenges that exist with accessing and using such data for ORE projects.

Firstly, although many of the data sources are free-of-charge, they can be difficult to access for users inexperienced with particular IT systems. The Python script accompanying this report aims to make it easier to access the ERA5 data from the Copernicus website, however, that may still be challenging for some users and does take a considerable amount of time to extract long periods of data with multiple metocean parameters (although the program can be run in the background whilst users get on with other tasks). Lautec’s ESOX service (free of charge) allow users to quickly and easily download ERA5 data covering 1990 to 2019, although this only includes wind speed, significant wave height and peak wave period.<sup>xvii</sup> Payment-based services, such as DHI’s Metocean-On-Demand, offer an easy-to-use portal for extracting data and can be significantly quicker than other services.

Some datasets do not contain all metocean parameters that users may need. For example, ERA5 does not contain tidal current speed data, which can be useful in ORE projects, particularly for

analysing operability and accessibility of devices (e.g. installing or inspecting mooring lines). This means that combining many different metocean parameters into a single time-series can be time consuming when extracting from multiple data sources. In addition, the spatial resolution of ERA5 data is quite coarse (i.e. 0.5 decimal degrees is approximately 50km, although wind data is available at 0.25 degrees), making it challenging to access data for specific locations (particularly metocean conditions at or close to a port). Again, these are both areas where payment-based services are useful, as much of the work to combine different models/datasets and improve spatial resolution has already been carried out for customers. It is also important that users of weather time-series data ensure that it is fit for their purposes as, for example, not all marine physical processes are captured or well characterised in numerical model hindcasts.

Another common issue with weather time-series data is that wind speeds are often provided at a height of either 10m or 100m. Analysts of wind farms often want to know the wind speed at the hub height of a wind turbine, as this enables energy assessments to be made, as well as allowing for construction and O&M weather window calculations. Fortunately, there are two well established methods for estimating wind speed at a specific height, based on wind speeds obtained at a different height. These are i) the wind profile power law, and ii) the log wind profile, both of which are discussed further in the Appendices.

Finally, a common challenge with weather time-series data is ensuring that the data is calibrated, validated and comprehensively quality checked. The best way to calibrate and validate modelled data is by comparing to observed measurements over a suitable period of time. This can be costly but is vital to ensure accuracy of the modelled data. Project developers typically deploy wave buoys and met masts at their sites in order to gain a holistic view of the area and validate any modelled data they obtain. Satellite data is also often used to validate hindcast and reanalysis weather time-series data. Datasets can be cross verified against other models, although validation against real-world measurements is preferred. Datasets which are regularly monitored and updated, which includes ERA5, are quality checked by analysts prior to public release. A high level of quality checking is undertaken for payment-based services as well as 'on-the-fly' validation (i.e. before data purchase).

# Appendices

## ERA5 DATA EXTRACTION INSTRUCTIONS

1. Re-save the script in a folder as .py file
2. Download Python 3 via Anaconda
  - a. Link: <https://www.anaconda.com/products/individual>
  - b. Go to the Anaconda website and download Python 3 (whichever version is most recent)
  - c. Stick with any recommended settings throughout the installation
  - d. Remember where you've installed it because you need that 'path' in the next step
  - e. e.g. mine is 'C:/Users/anthony.gray/AppData/Local/Continuum/anaconda3' (use back slashes, not forward slashes like the example)
3. Register with Copernicus and add the CDS configuration
  - a. Register an account: <https://cds.climate.copernicus.eu/cdsapp#!/home>
  - b. then need to follow the Step-by-step guide on this page:  
<https://confluence.ecmwf.int/display/CKB/How+to+install+and+use+CDS+API+on+Windows>
  - c. On prerequisites, you've done point 1, and just ignore points 2 and 3
  - d. To complete prerequisites point 4, open Anaconda Prompt (you can find it by typing into your toolbar) [\*]
  - e. Then type in 'conda config --add channels conda-forge' and press enter
  - f. When that is done, type in 'conda install cdsapi' and press enter, when prompted press 'y' and enter
  - g. Now on the Step-by-step guide, follow the points. Some info which may help:
    - i. You'll need to create the '.cdsapirc' file:  
<https://confluence.ecmwf.int/pages/viewpage.action?pagelId=139068264>
    - ii. Put the '.cdsapirc' file in your C drive – e.g. mine is in 'C:/Users/anthony.gray' – and copy in the two-line code (back slashes)
    - iii. For point 4, remember you may need to change directory [\*] in the Anaconda prompt before attempting the pip commands – 'pip3 install cdsapi' or 'pip3 install --user cdsapi'
    - iv. On point 5, you may need to accept the Copernicus terms and conditions if not already done  
(<https://cds.climate.copernicus.eu/cdsapp#!/terms/licence-to-use-copernicus-products>)

\*if Anaconda prompt gives an error at this point then you will likely need to change the 'path':

- Type in 'cd ` followed by the path where your Python executable is – e.g. I would type 'cd C:/Users/anthony.gray/AppData/Local/Continuum/anaconda3' (back slashes)



4. Install xarray
  - a. You need the xarray package to make the code work
  - b. Open your Anaconda Prompt again, change directory like before, then type in `'conda install -c anaconda xarray'` and press enter, when prompted press 'y' and enter
  - c. I've had issues when doing this on my personal laptop – I had to `'conda uninstall numpy'` twice before being able to run my code – but hopefully the above points will suffice for you.
5. Open the script in an Integrated Development Environments (IDE)
  - a. If you are a new user of Python then I recommend you use Spyder as your IDE (already installed through Anaconda)
  - b. Open Spyder by searching for it in your toolbar
  - c. Open the Python script in your IDE
6. Define your user settings in the script
  - a. You only need to change variables in the USER DEFINED INPUTS - HIGH PRIORITY section near the top of the script
  - b. I recommend you keep the 'site\_name' quite short as the script will add the coordinates and years to the output filename
  - c. The 'site\_coordinates' (latitude, longitude) need to be in decimal degrees and 0.5 degree resolution is required.
  - d. Set the 'start\_year' and 'end\_year' – remember that it is inclusive (so 2000 to 2001 will get two years of data)
  - e. Selecting your parameters should be self-explanatory - you can select multiple parameters
  - f. If extracting wind speed, remember to set `'wind_speed_in_knots'` to False if you want wind speed in m/s. Otherwise, leave as True if you want knots.
7. Run the script.
  - a. Press F5 or the green 'play' button on the top toolbar (if using Spyder)
  - b. Remember that it takes a while to run, but you can do other things (e.g. Excel, Word etc.) whilst it is running
  - c. The output CSV file will be stored in the 'Output\_CSVs' folder (a subfolder of where you've stored the script)
  - d. I suggest you run the script in one go, so leave your computer on overnight if needs be – it is possible to stop and re-start but I wouldn't recommend it as it would involve fiddling with settings. Connection to the API is lost occasionally which delays the script, but it will complete in time.

## EXTRAPOLATE WIND SPEED AT DIFFERENT HEIGHTS

Two methods for estimating wind speed at a specific height, based on wind speeds obtained at a different height, are i) the wind profile power law, and ii) the log wind profile. Both of these methods have advantages and disadvantages, which are well described in literature (see references).<sup>xviii</sup> Further analysis would be required to incorporate the impact of turbulence between turbines in an offshore wind farm.

### Wind Profile Power Law

$$U_z = U_r \left(\frac{z}{r}\right)^\alpha$$

The equation above defines the wind profile power law, where  $U_z$  is the wind speed (metres per second) at the desired height  $z$  (in metres),  $U_r$  is the known wind speed at the height  $r$ , and  $\alpha$  is a coefficient, usually taken to be 0.11 for offshore wind farms.<sup>xix</sup>

### Log Wind Profile

$$U_z = U_r \left(\frac{\ln((z - d)/z_0)}{\ln((r - d)/z_0)}\right)$$

The equation above defines the log wind profile, where  $U_z$  is the wind speed (metres per second) at the desired height  $z$  (in metres),  $U_r$  is the known wind speed at the height  $r$ ,  $d$  is the zero plane displacement (in metres), and  $z_0$  is the surface roughness (in metres).<sup>xx</sup> The zero plane displacement ( $d$ ) can be omitted for offshore wind farm analysis. Surface roughness ( $z_0$ ) has been estimated to be between 0.001m and 0.005m for the offshore environment, although this is site dependent.<sup>xxi</sup>

## RECOMMENDED READING

IMarEST (2018). Metocean Procedures Guide for Offshore Renewables. Available from: <https://www.imarest.org/reports/650-metocean-procedures-guide>.

## AUTHOR PROFILE



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