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Data science for Offshore Renewable Energies: Data availability and requirements for Metocean Analysis

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EMB Science webinar series
18/01/2024

EMB Future Science Brief main recommendations are to:

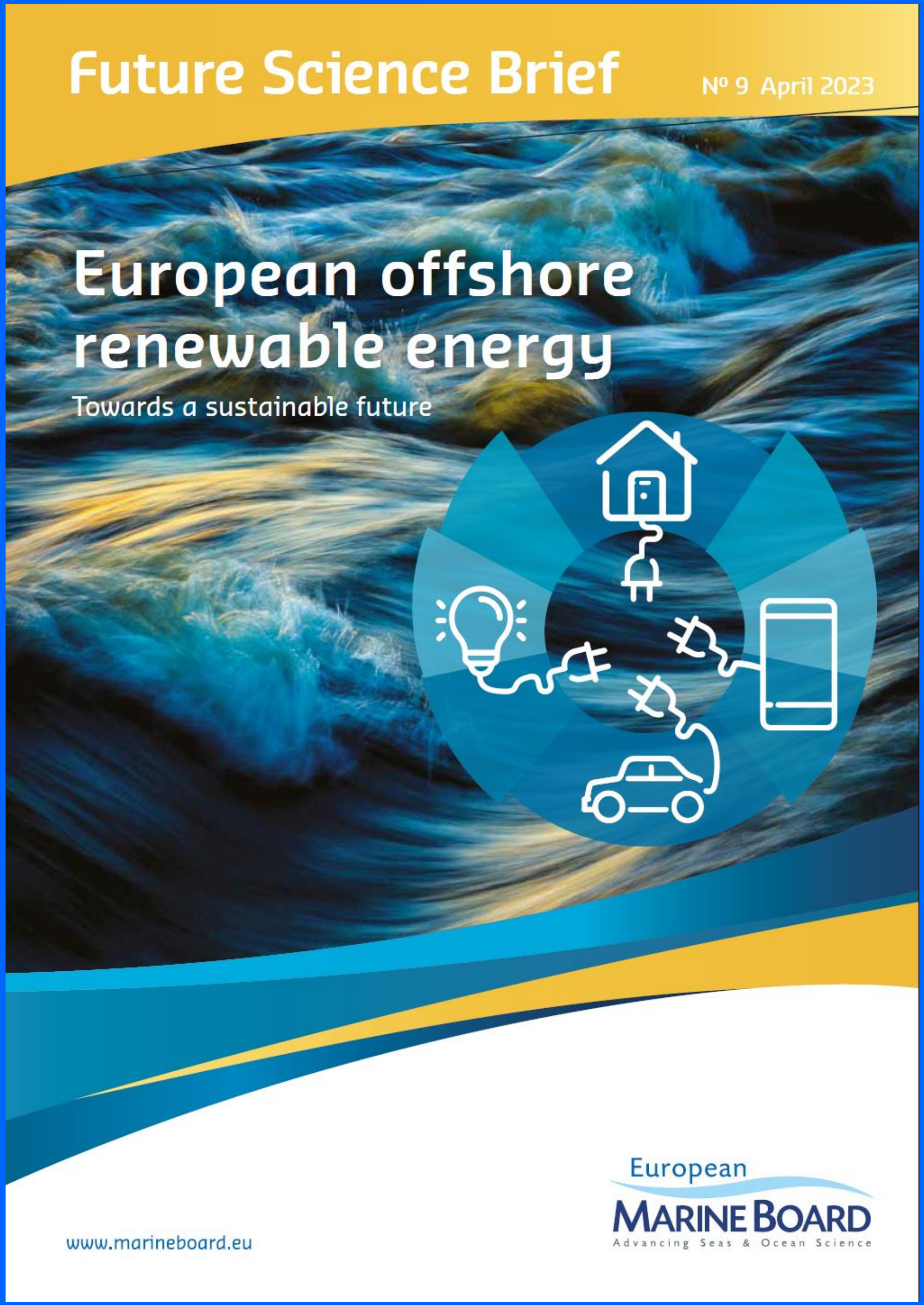
- Address misalignment in policy, and the approaches and practices used in different EU Member States that hinder efficient and sustainable ORE development and deployment;

- **Support measures to increase the availability of open and high-resolution data, to understand ORE resource availability, environmental impact, and the impact of climate change;**

- Further develop the research capability to holistically investigate the ecological and socioeconomic benefits and impacts of ORE;

- Conduct further research into the technical, environmental and socioeconomic aspects of ORE devices and their full lifetime from design to operation through to decommissioning, to improve sustainability and viability;

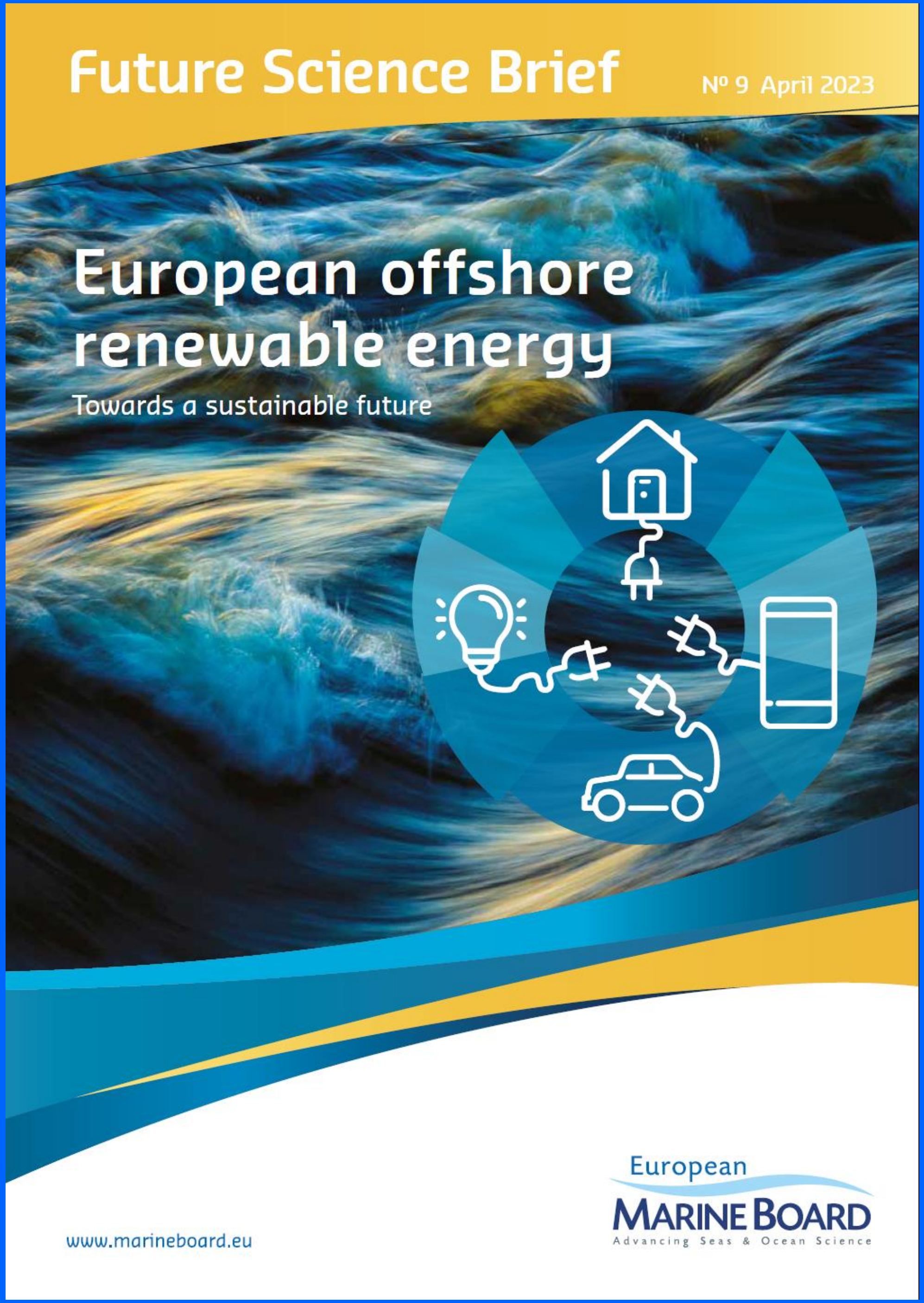
- Ensure that offers for training and skills development match industry requirements.



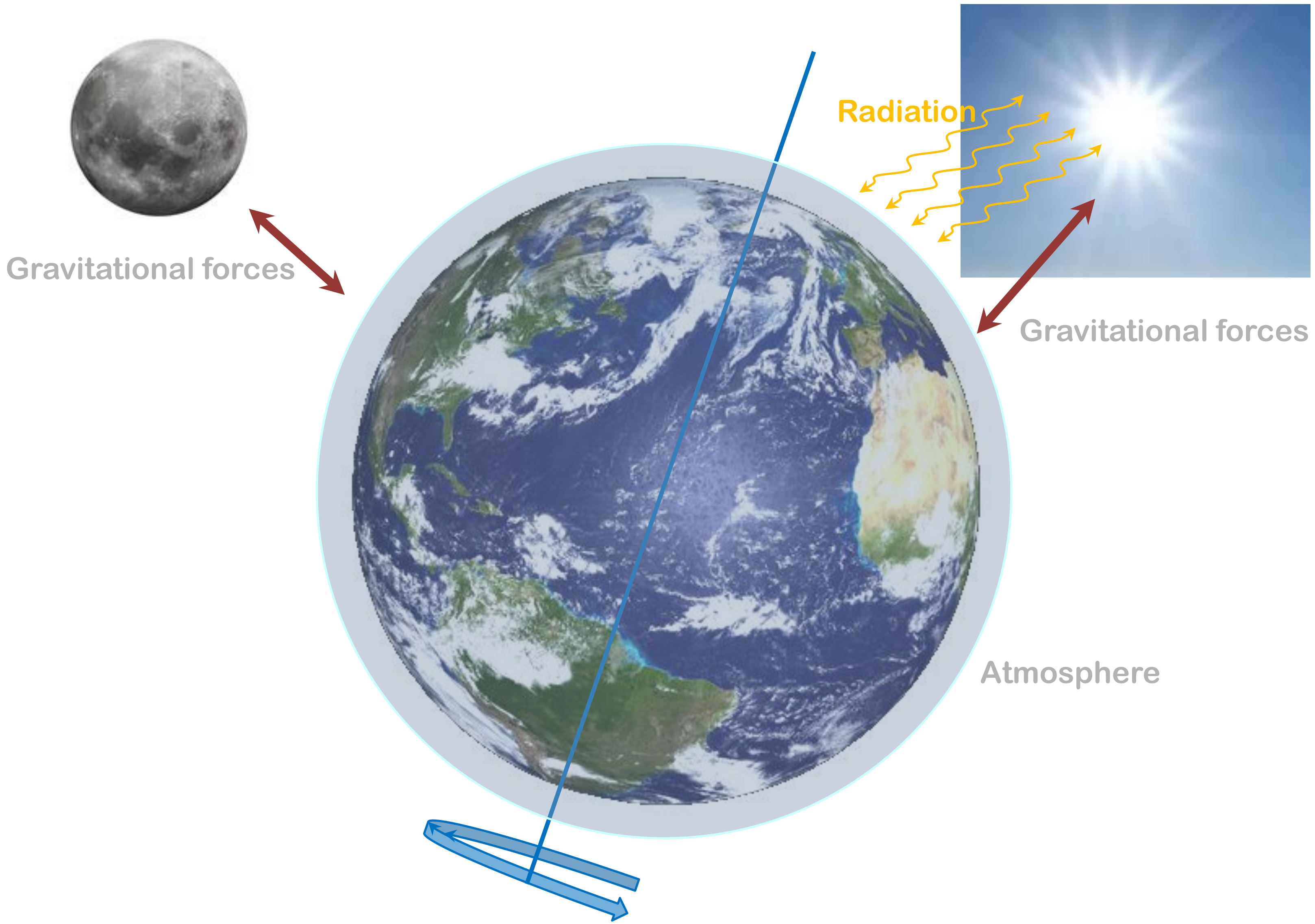
The use of ocean data in site assessment, resource characterisation and device design,

Gaps and needs in data availability and measurement capability

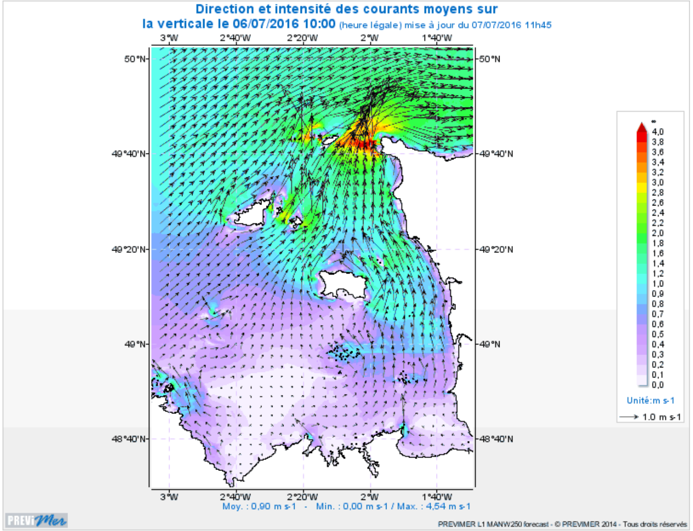
- Offshore Renewable Energy Resource Mapping
- Requirements for Design and Operations
- Data Availability & Measurement Capacity
- Data Access and Databases

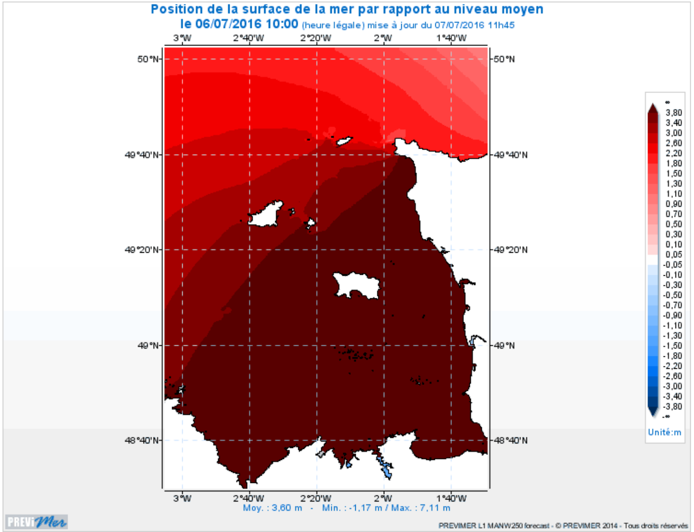


Offshore Renewable Energy Resource Mapping


Radiation
Gravitational forces
Gravitational forces
Atmosphere

Gravitational forces: Tides





Currents

Hydrokinetic Energy

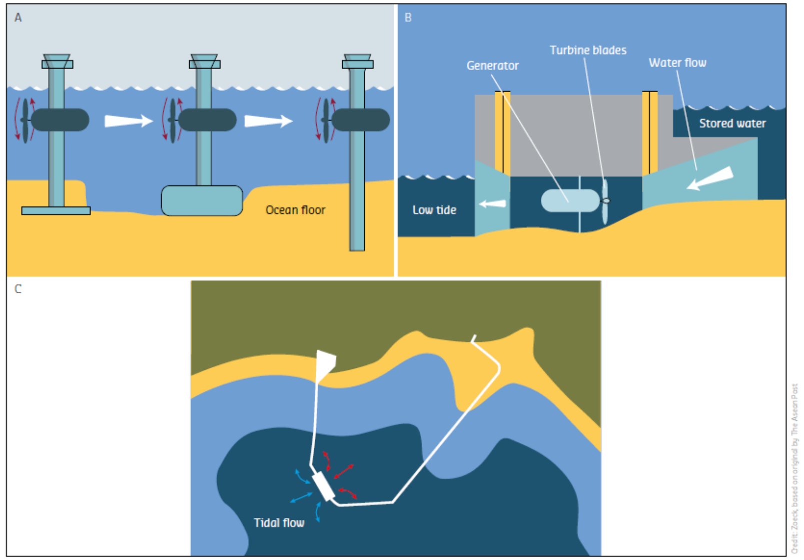
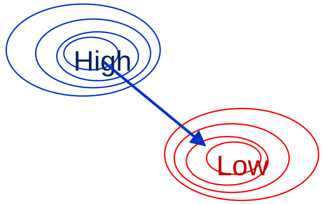


Figure 2.9 Methods for generating electricity from the tides: A: tidal current, B: tidal barrage, C: tidal lagoon.

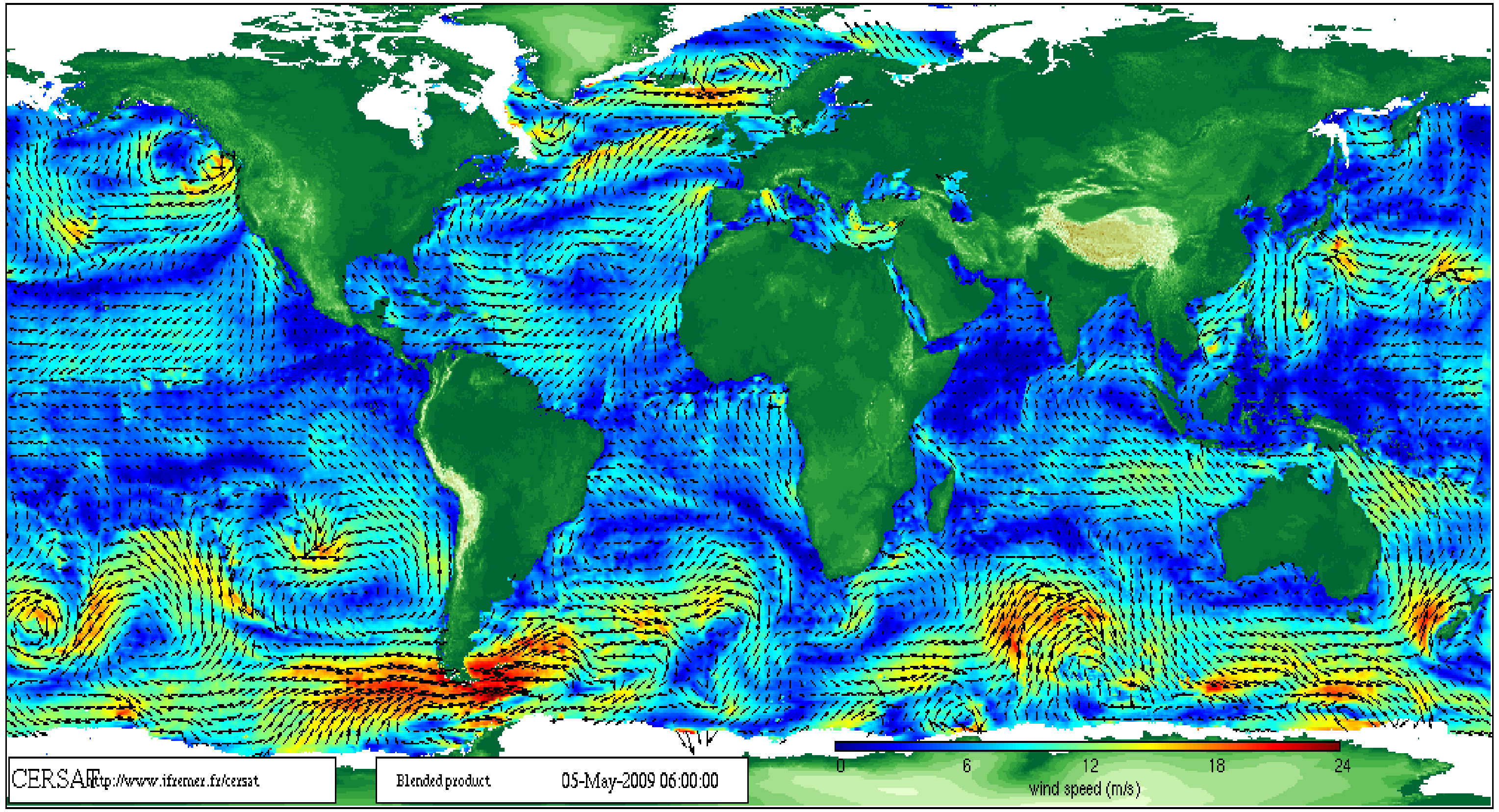
Sea level variation

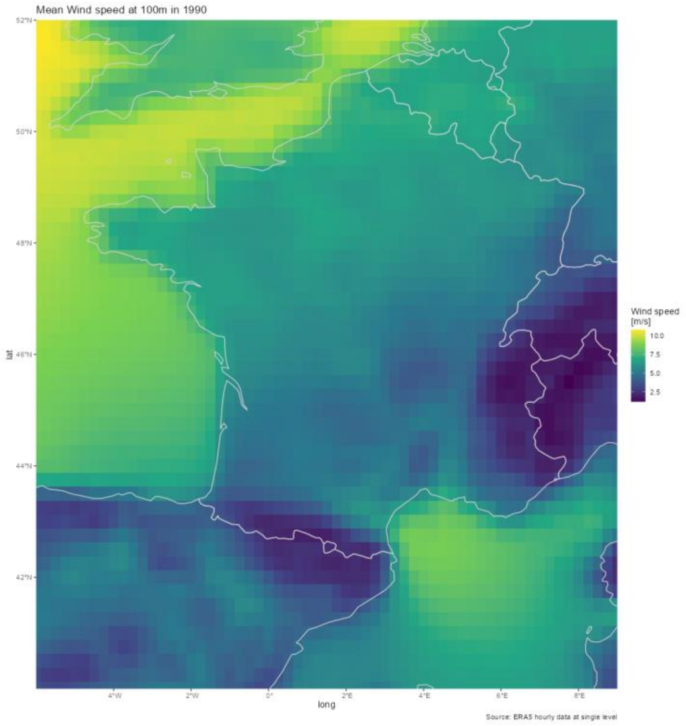
Potential Energy

Solar radiation: driver of ocean-atmosphere exchanges



Wind





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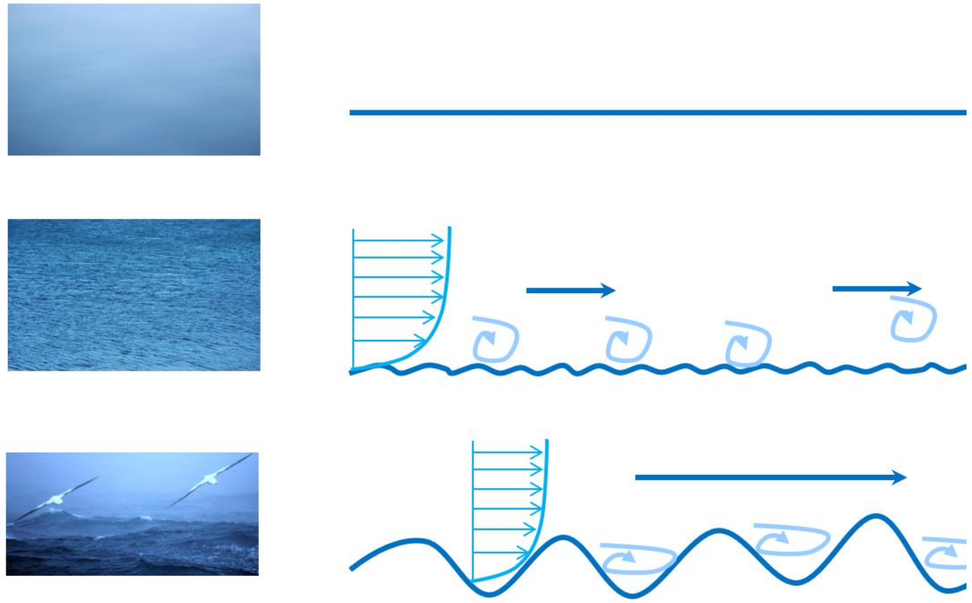
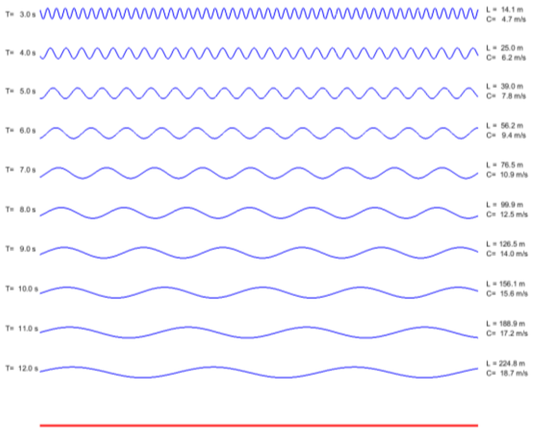
Compared to onshore wind, offshore wind is stronger and less turbulent, and thus more energetic and stable.

Solar radiation: driver of ocean-atmosphere exchanges

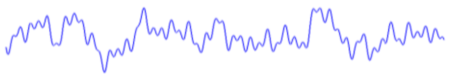
Waves

Wind energy transfer to the oceans surface

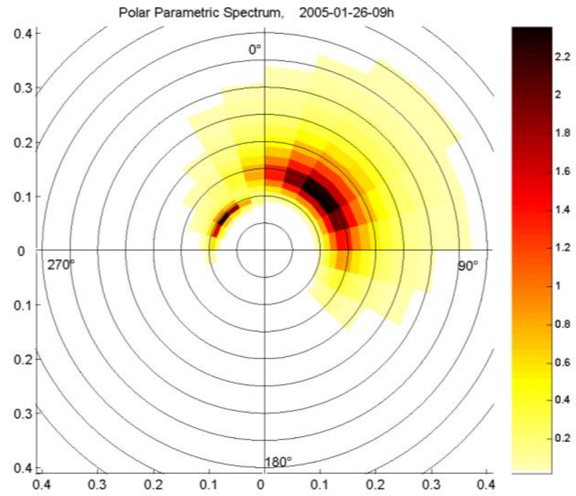




Random process



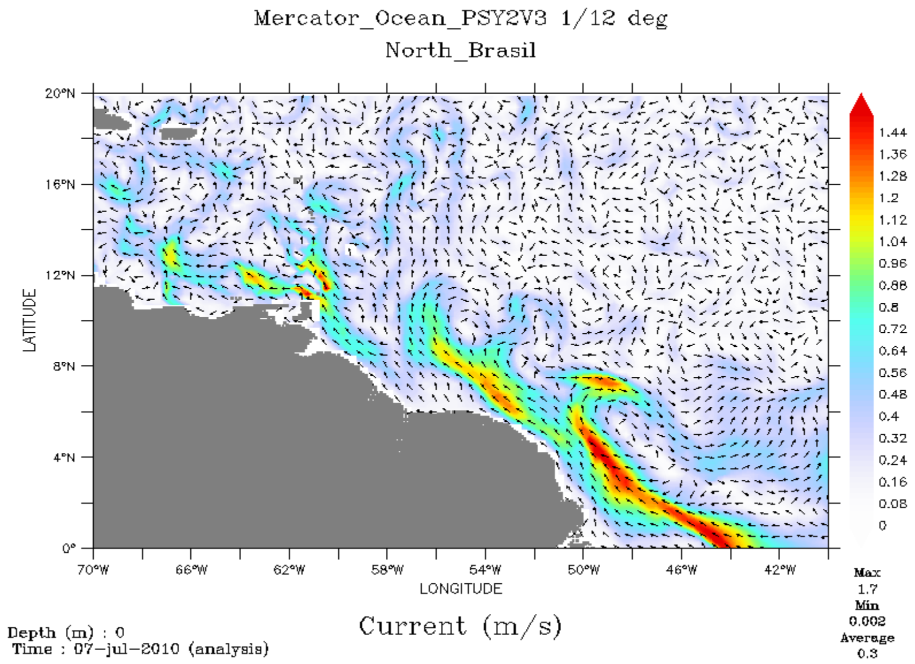
Wave energy distributed in frequency and direction



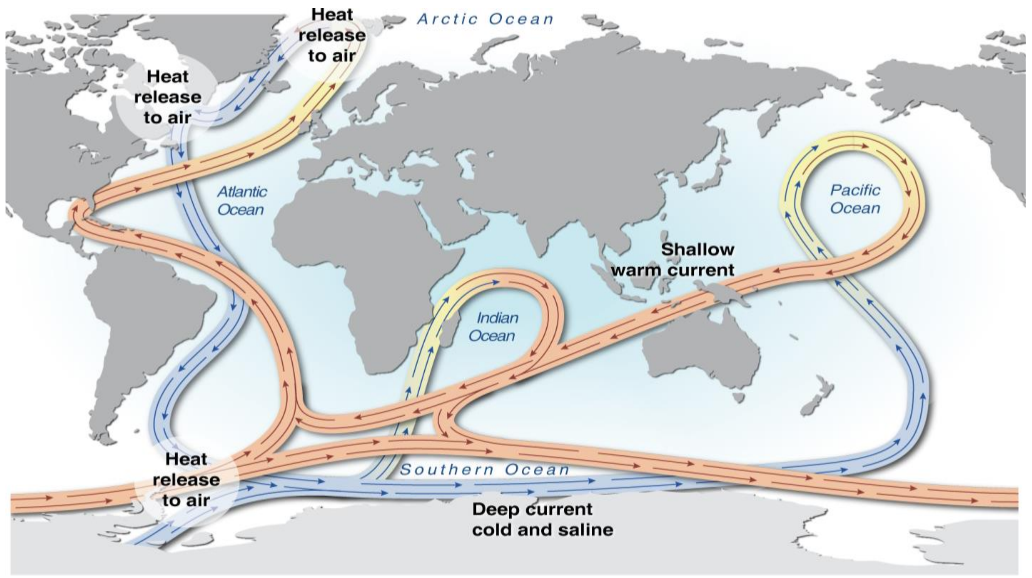
Solar radiation: driver of ocean-atmosphere exchanges

Ocean circulation

Wind driven inertial currents



Thermohaline circulation



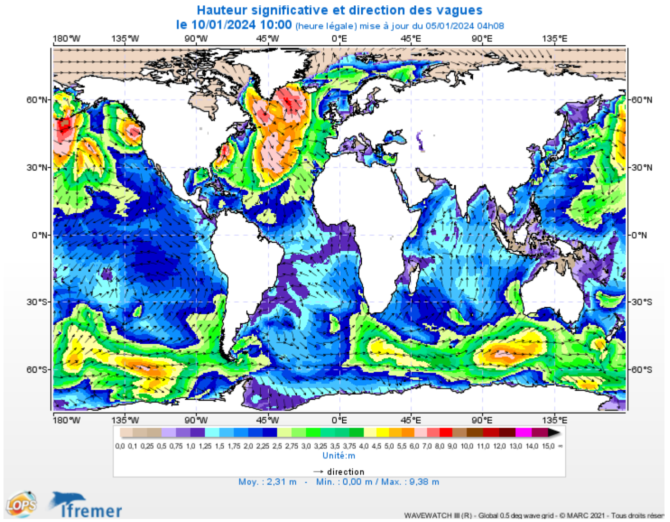
Gulf Stream, Kuroshio, …

Resource Assessment

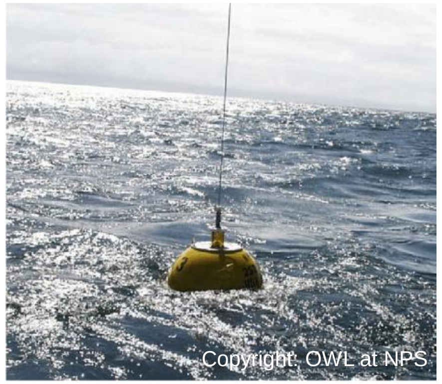
Characterisation of the available power and its distribution

Resource mapping is built combining different sources of data :

Numerical modelling (hindcast)



In-situ measurement



Remote sensing

Resource Assessment

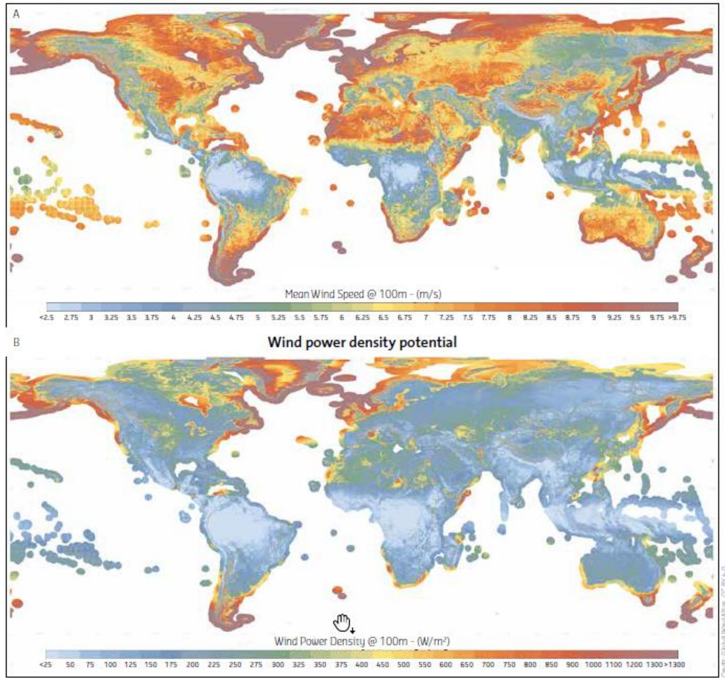


Figure 2.1 A. Global distribution of mean wind speed, and **B.** wind power density potential at a reference height of 100m for offshore areas up to 200km offshore. Source: Maps obtained from the Global Wind Atlas 3.0, a free, web-based application developed, owned, and operated by the Technical University of Denmark (DTU). The Global Wind Atlas 3.0 is released in partnership with the World Bank Group, utilising data provided by Vortex, using funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalwindatlas.info.

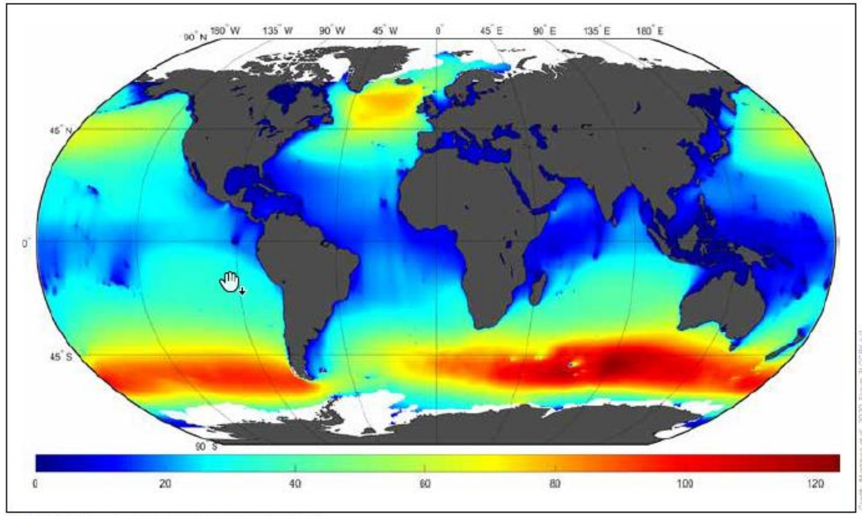


Figure 2.2 Global mean value of wave power, P (kW/m).

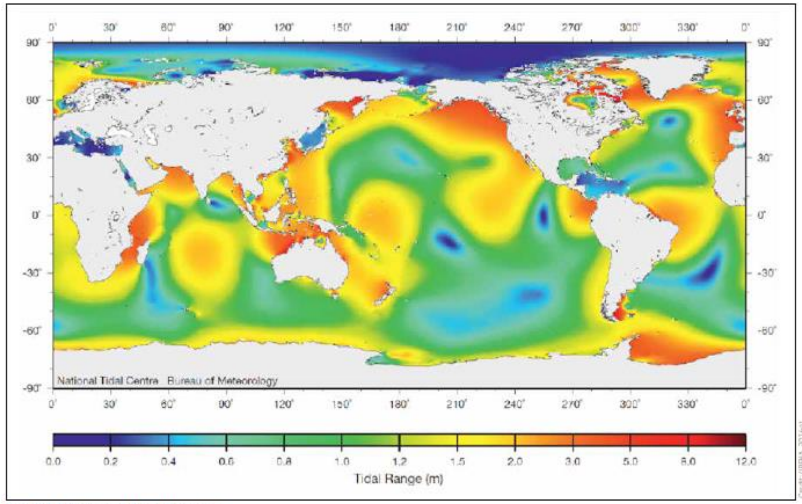


Figure 2.3 Global tidal range distribution.

Wind

Waves

Tides & currents

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The estimated global energy demand in 2019 was 65,000 Terawatt Hours (TWh), while onshore and offshore wind energy could, in an ideal/theoretical situation, provide 900,000 TWh per year.

The theoretical potential annual global wave energy production is estimated to be 29,500TWh.

The number of coastal locations with strong enough tidal currents or high enough tidal ranges to make energy extraction economically viable is limited. In highly energetic sites where current velocities can regularly reach values higher than 2.5m/s (or 9km/h) the flow is invariably turbulent, which creates high resource variability in space and time.

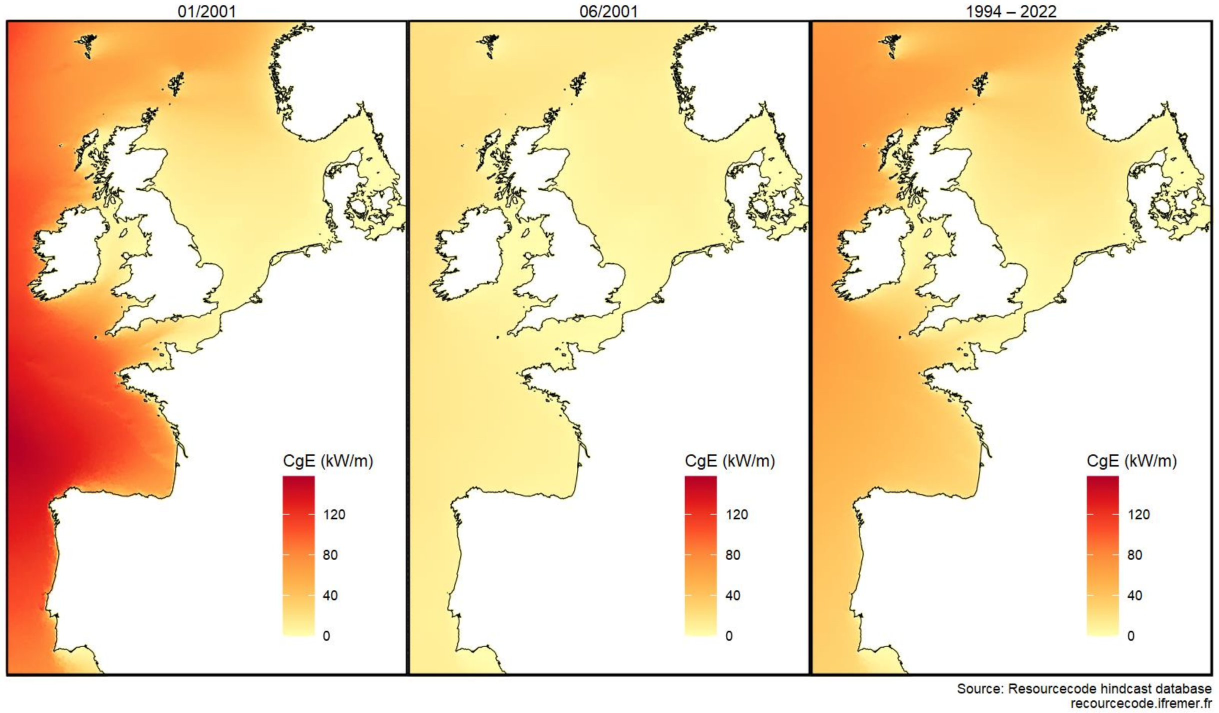
Resource Assessment

Variability in time and space

- Regional distribution
- Seasonal and Internanual variability

- Random processes
- Pseudo-periodic processes

Wave Energy flux



January June Yearly average

➢ Long time series are necessary to conduct proper statistical assessment and build climatologies

➢ Spatial discretisation must be refined enough to catch the physics of the phenomena

Requirements for Design and Operations

Structures design, deployment and operation

Offshore Wind Turbines

Tidal turbines

Wave Energy converters

- Complex marine environment (wind, waves, current)

- Long life span
- Efficiency
- Reliability (fatigue ageing, Extremes)
- Marine Operations (Deployment, maintenance, …)

→ Reduction of the LCoE

- Environmental Impact

EMB FUTURE SCIENCE BRIEF

ORE technologies have reached different stages in their development:

- Offshore wind energy is mature and in commercial operation (TRL 9), with floating wind in a pre-commercial phase (TRL 8);
- Wave energy is at full-scale prototype phase (TRL 7);
- Tidal current energy is in the demonstration phase with pilot projects (TRL 6);
- Tidal range energy is mature and in commercial operation (TRL 9);
- Offshore or floating solar energy is in early demonstration phase (TRL 5).

Structures design, deployment and operation

Wind speed long term variability

Power Spectral Density functions provide information on the time scales of variability of the wind speed

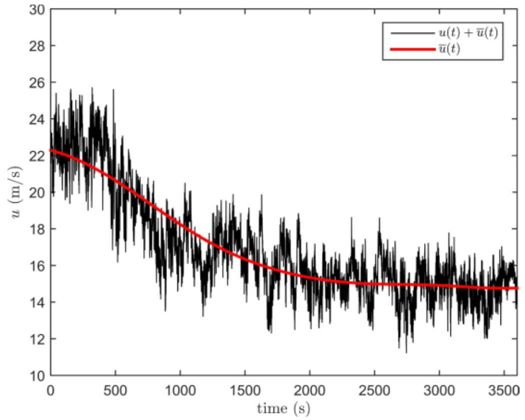
Band	Origin	Period From	Period To
Interannual	Internal	11 years	1.1 years
Annual	Astronomical	1 year only	
Multimonth	Internal	11 months	1.1 months
Storm	Internal	1 month	18 h
Diurnal	Astronomical	24 h only	
Semidiurnal	Astronomical	12 h only	

Wind speed short term variability

Variations within the Minute

Associated with turbulence or transient events:

- Impact on turbine efficiency.
- impact on fatigue ageing of the turbine



Variations within the Hour

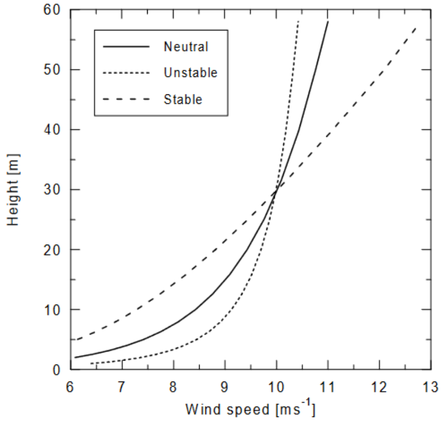
Associated with the passage of storm fronts

- Influence on production when close to cut-out speed

Variations over a few Hours

No real influence on production as long as forecast is accurate enough at the scale of a wind farm

Wind speed profile in the atmospheric boundary layer



Offshore Wind Turbines

Requirements

- Long duration time series of wind velocity
- High frequency sampling
-
- ~200m above sea surface

Structures design, deployment and operation

Offshore Wind Turbines

Wind Turbines and farms wake

- Turbines efficiency downstream
- Layout optimisation
- Ageing
- Environmental impact

Joint assessment of wind, waves and current conditions

- Floating structure dynamics
- Moorings ageing and extreme loading
- Export dynamic cables ageing and extreme loading

Requirements

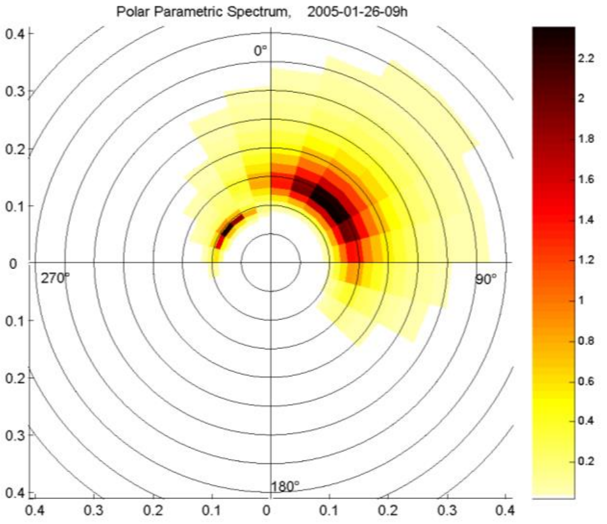
- Refined spatial grids at the regional/site scale
- Joint parameters databases
- Long duration time series

Structures design, deployment and operation

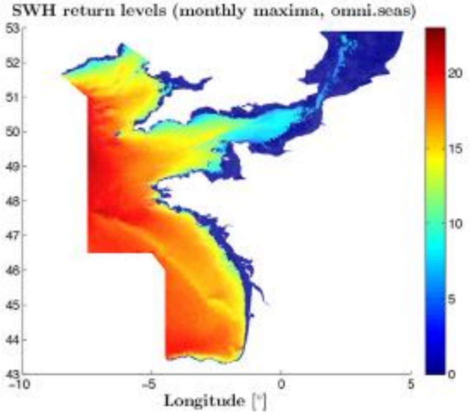
Wave Energy converters

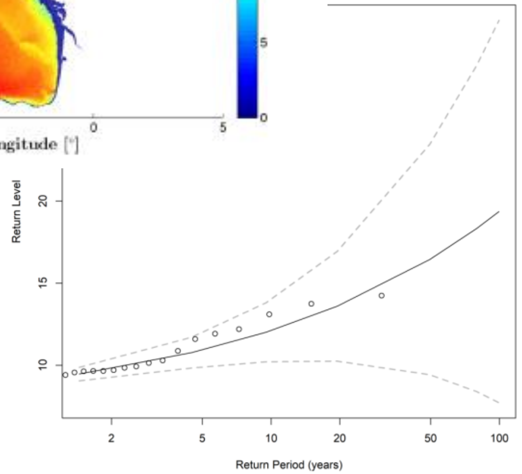
Sea-states characterisation for Wave energy converters

- Structure dynamics
- PTO optimisation
- Control methods
- Moorings and cables ageing
- Extreme loading
- Survivability



Extremes and return values assessment





Requirements

- Long time series of 2D wave spectra
- Long time series of integral parameters
- Refined spatial grids at the regional/site scale
- Wave-by-wave information (control, wave breaking, impact)

Structures design, deployment and operation

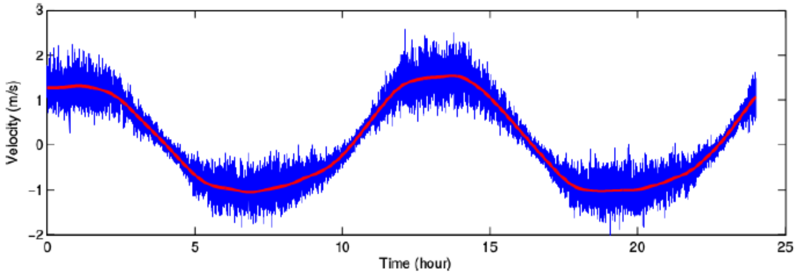
Tidal turbines

Tidal turbines

- Turbine optimisation
- Control methods
- Extreme loading
- Fatigue ageing
- Wake characterisation

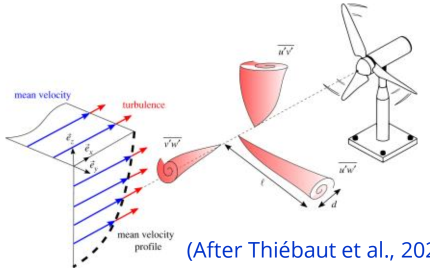
(Layout optimisation, Environmental impact)

Flow variability & Turbulence



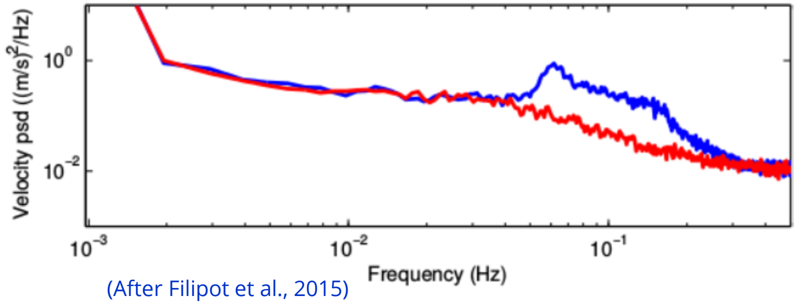
(After Filipot et al., 2015)

Fig. 4. 24h time series of east-west current velocities (blue curve). Low frequency tidal part (red curve).



(After Thiébaut et al., 2020)

Wave kinematics



(After Filipot et al., 2015)

Fig. 3. Spectral density of current velocities measurements. In red without waves(April 7), in blue with waves (April 10).

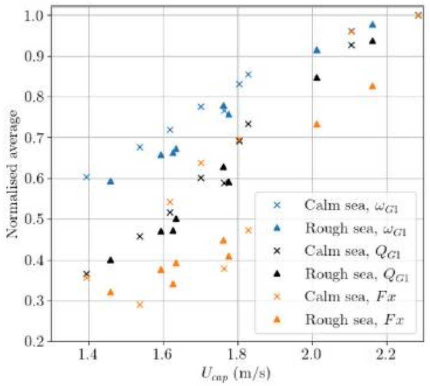


Fig. 15. Normalised average over the hour centred on the tidal velocity peak of the torque (C_{G1}) and the rotational speed (ω_{G1}) of the generator 1, and of the axial load (Fx) with regard to U_{cap}. Each quantity is normalised by its maximal value.

(After Moreau et al., 2020)

Requirements

- High frequency current velocity time series
- Water levels time series
- Refined bathymetry
- Sea-states parameters and spectra time series

Structures design, deployment and operation

Marine Operations

Weather windows

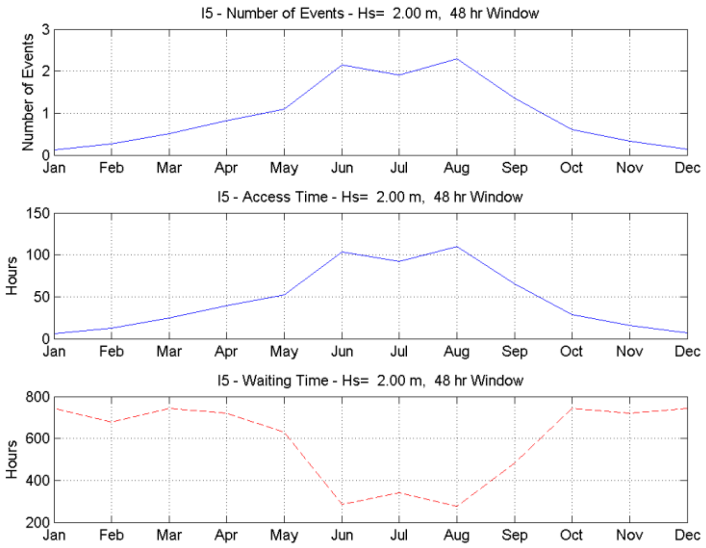
- Established from joint statistics combining wave, wind and current data
- Regional scale

Short term forecast

- Operation planning (go, no-go, safety)

Real-time information on site

- Wave detection
- Current velocity
- Wind velocity



weather windows

Requirements

- Long time series of joint parameters (wind, wave, currents)
- Forecast data
- In-situ measurement

Ifremer

Structures design, deployment and operation

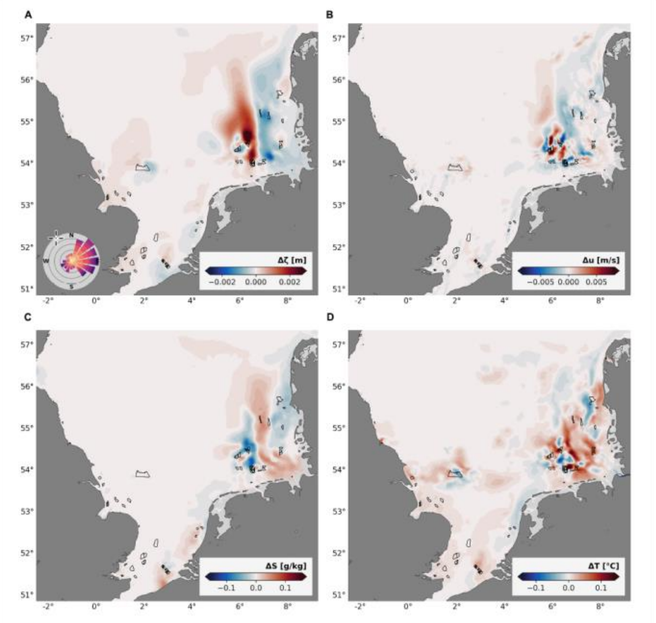


FIGURE 7 | Mean changes in sea surface elevation ζ **(A)**, depth-averaged velocity *u* **(B)**, sea surface salinity *S* **(C)**, and sea surface temperature *T* **(D)** for the month of August 2013. Black polygons indicate offshore wind farms. The wind rose indicates the direction in which the wind blew (color range between 1 and 12 m/s).

After Christiansen 2022, doi: 10.3389/fmars.2022.818501

Environmental Impact

Assessment of the evolution of the physical parameters locally and in the wake of the farm (wind speed, wave height, current velocity, temperature, salinity, sediment transport …)

- Influence of machines and moorings
- Wake of the farms

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The Environmental Impact Assessments (EIA) Directive (see Section 4.5) already requires that likely significant effects *"should cover the direct effects and any indirect, secondary cumulative, transboundary, short-term, medium-term and longterm, permanent and temporary, positive and negative effects of the project".* However, more work is needed to assess cumulative effects as these occur at a large scale, the ecological processes at work are complex and environmental baseline information is inadequate.

Requirements

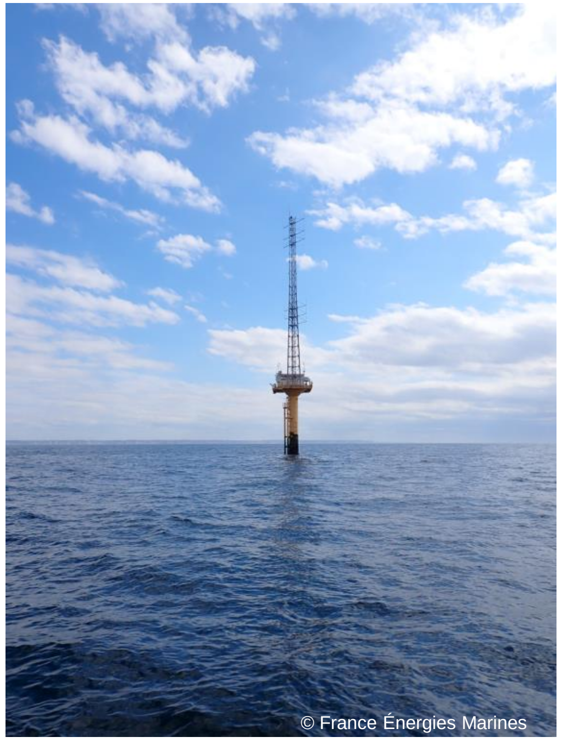
- Model data at regional scale (refined grid)
- In-situ monitoring (wind, wave, currents)
- Remote sensing for local and regional assessment (wake)

Data availability & measurement capacity

In-situ measurement
Wind

Met Mast

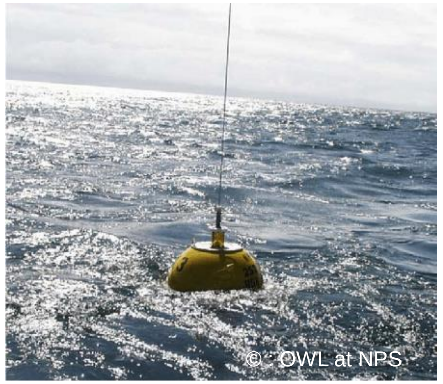
- Considered as the reference
- Multi-sensor
- Very expensive
- Restricted to shallow/intermediate depths areas



Lidar - *laser imaging detection and ranging*

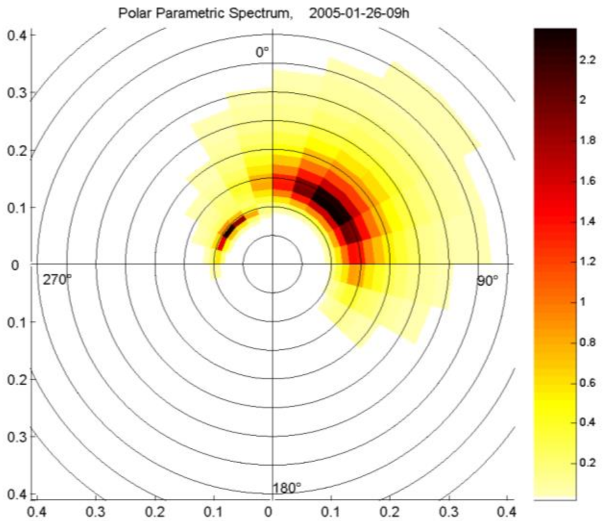
- Provides information on wind profiles up to ~200m height
- Large amount of data, processing,
- Theoretical assumptions for wind profile recompositions
- Requires compensation/correction of the platform motion when mounted on floating platform

In-situ measurement
Waves



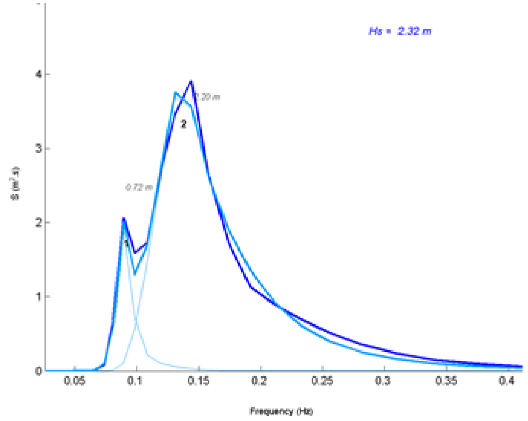
Wave buoys

- Considered as the reference
- Provides wave-by-wave and spectro-directional information
- Methods for identification of the direction and directional spreading require improvement
- Multi-modal spectra characterisation



Acoustic Doppler Current Profilers (ADCP)

- To be combined with current measurement
- Reliable in intermediate waters



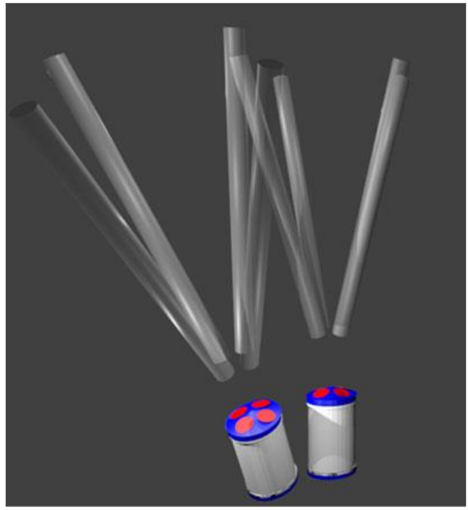
Pressure sensors

- Limited to shallow water, surf zone

In-situ measurement
Currents

Acoustic Doppler Current Profilers (ADCP)

- Adapted to mean velocity profile measurement
- Improvement required for turbulence and variability assessment (Technical, methodology, assumptions)
- Large amount of data, processing



(After Thiébaut et al., 2020)

Acoustic Doppler Velocimeter (ADV)

- Local measurement

HF Radar

- Spatial coverage
- Near Real time

Remote sensing

Altimeters

Scatterometers

Synthetic Apperture Radar

Advantages :

- Global coverage
- Widespread measurement zones
- Long time series

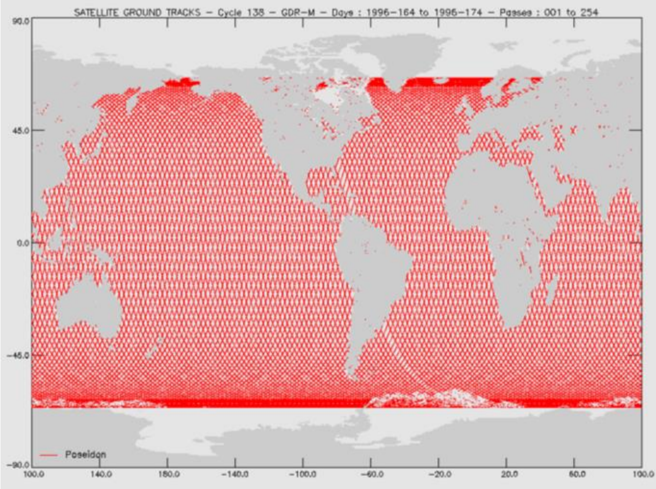
Limitations :

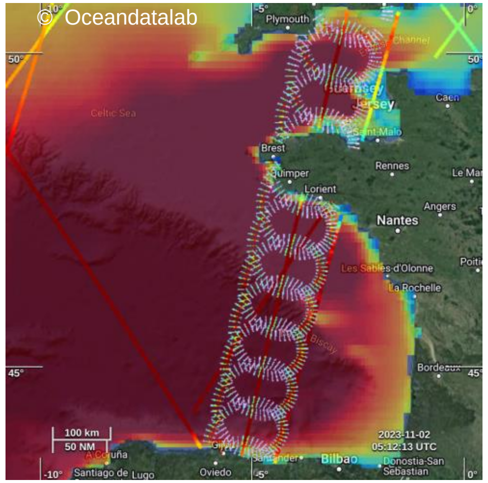
- Time and space discretisation
- Complex indirect processing methods
- Cal/Val (in-situ, other sensors)
- Quality of the measurements in extreme conditions (strong wind, harsh seas)

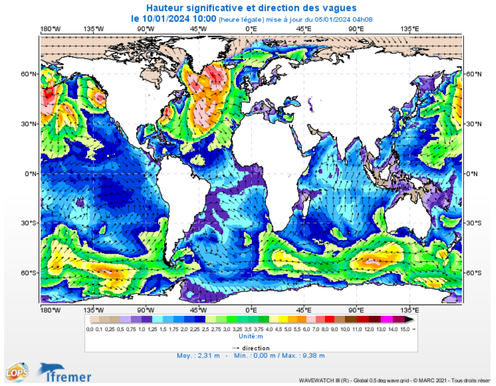
Valuable for :

- Enhancing knowledge
- Calibration/validation of numerical models
- Characterisation at site scale

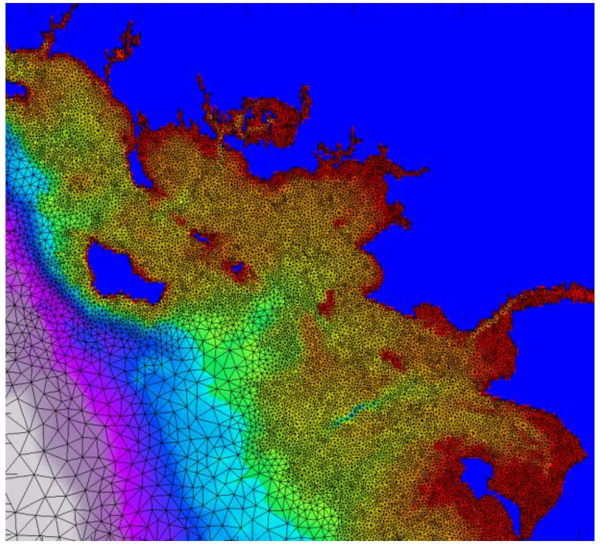
Wind
Wave
Current







Numerical modelling



Source terms

$$\frac{\partial N}{\partial t}+\frac{\partial}{\partial x}\dot{x}N+\frac{\partial}{\partial y}\dot{y}N+\frac{\partial}{\partial k}\dot{k}N+\frac{\partial}{\partial \theta}\dot{\theta}N=\frac{S}{\sigma}$$

Local rate of change of action density in time

Propagation of action in geographical space

Shifting of the relative frequency due to variations in depths and currents

Depth-induced and current-induced refraction

Spectral action density balance equation

Advantages :

- Global to local coverage
- Long time series
- Refined grids

Limitations :

- Parametric models
- Data storage and handling

Valuable for :

- Building climatologies (statistics)
- Knowledge enhancement

Input:

- Bathymetry
- Seabed roughness
- Coastlines contour
- Wind fields
- Current fields & water levels
- River flows
- Ice mask

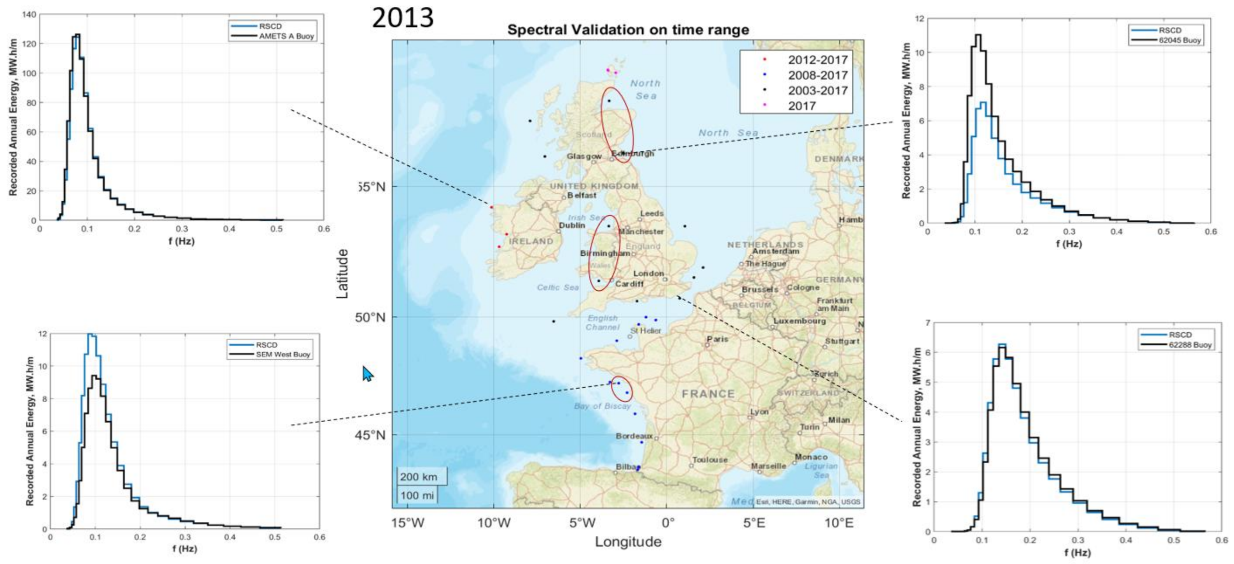
Physics described using parametric models (Source terms):

- Wind-Wave energy transfer
- Wave-wave non linear interaction
- Dissipation (whitecapping, turbulence)
- Bottom induced dissipation
- …

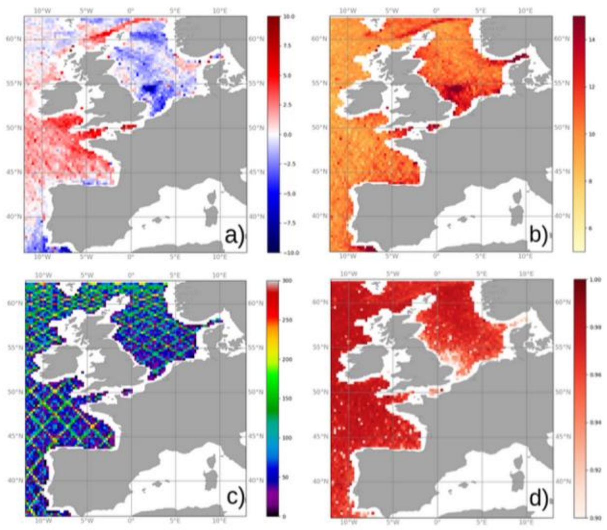
Numerical modelling

Calibration / Validation

In-situ data



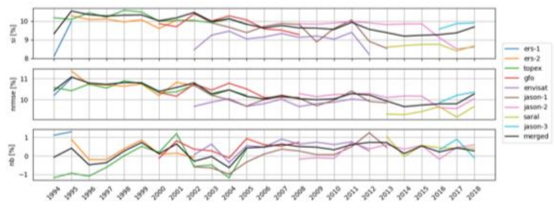
Remote sensing data



Yearly validation criteria averaged over 1994-2018.
a) NB; b) NRMSE; c) matches-up; d) R

OVERALL STATISTICS PER ALTIMETER

Satellite	Covered period	B (m)	NB (%)	RMSE (m)	NRMSE (%)	SI (%)	R (%)
ERS-1	1994-1995	0.021	1.20	0.300	10.61	9.05	93.87
TOPEX	1994-2005	-0.013	-0.32	0.325	10.52	10.16	97.11
ERS-2	1995-2002	0.004	0.23	0.308	10.73	10.03	96.08
GFO	2000-2008	0.008	0.44	0.315	10.37	9.85	96.96
JASON-1	2002-2013	0.001	0.04	0.307	10.06	9.56	96.90
ENVISAT	2002-2012	0.011	0.47	0.292	9.86	9.06	96.11
JASON-2	2008-2018	0.011	0.28	0.308	10.08	9.56	96.92
SARAL	2013-2018	0.015	0.47	0.279	9.42	8.64	97.03
JASON-3	2016-2018	0.014	0.37	0.292	10.14	9.78	97.16
MERGED	1994-2018	0.007	0.26	0.307	10.30	9.82	96.80



Overall timeseries of SI, NRMSE and NB

Monitoring

Production sites are monitored for

- Production management and optimisation
- Operations management
- Structures ageing
- Environmental impact assessment

Requirements

- Local In-situ measurement
- Low sampling frequency
- Joint parameters (wind, waves, current)
- Remote sensing (events, EIA)

Laboratory measurement

Important complementary data

- Contribution to knowledge enhancement on physical phenomena
- Validation of theoretical/parametric models to be implemented in numerical models

Requires adapted similitude laws (scaling effects)

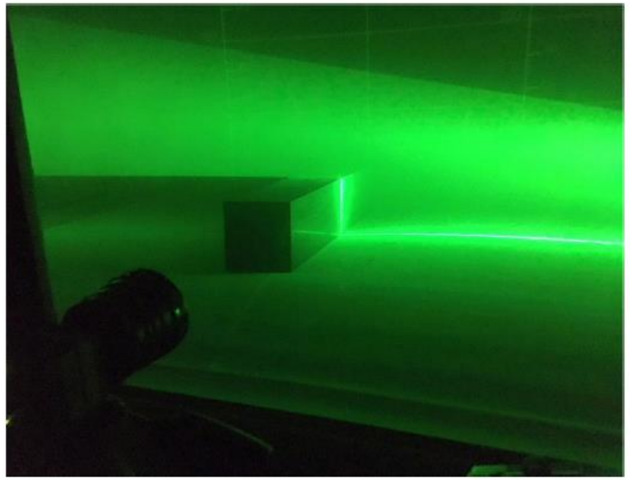


Fig. 2. Cylinder during PIV measurements.

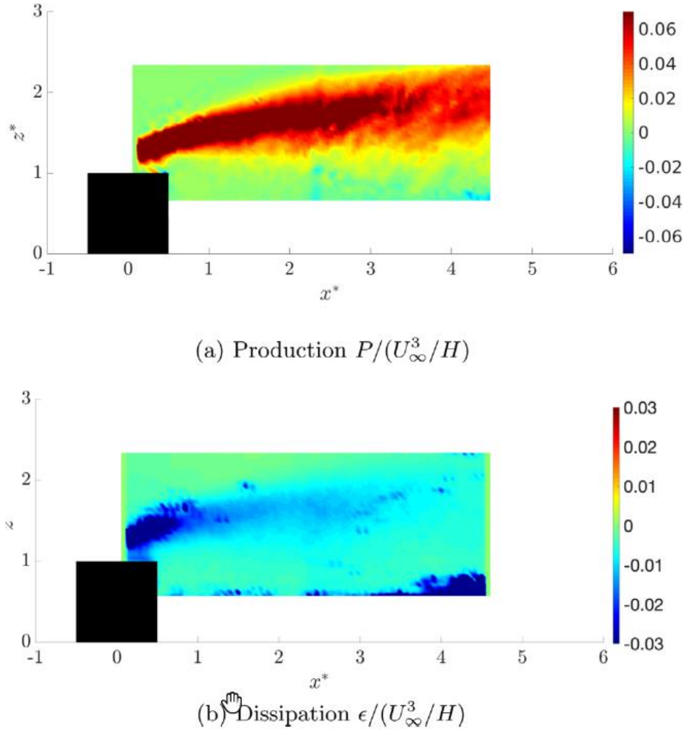


Fig. 10. Maps of production P and dissipation ϵ in the near wake.

After Ikhennicheu 2020, https://doi.org/10.1016/j.oceaneng.2020.107582

Data access and data bases

Requirements for ocean data

Combined use of the 3 available sources of information

- Numerical Model (global coverage, long duration hindcast)
- In-situ (local reference, short duration, high sampling fequency)
- Remote Sensing (global coverage, validation, physics knowledge)

Cross-validation is necessary prior to any statistical climatology assessment

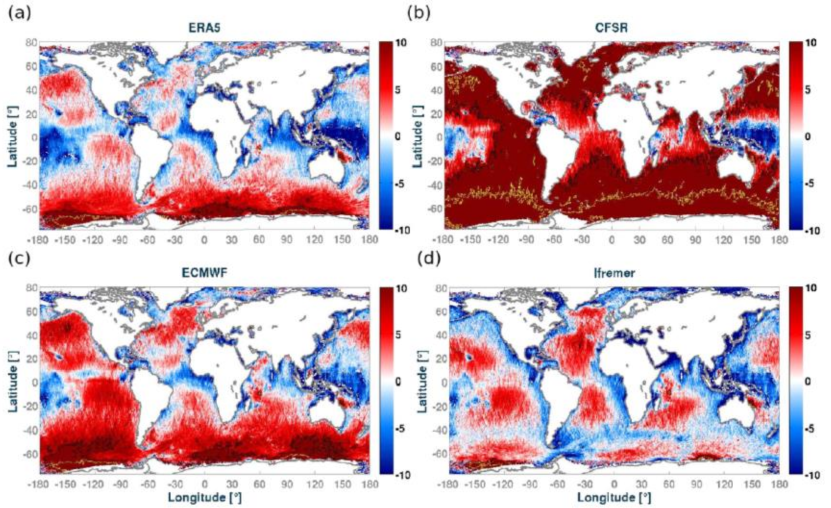


Fig. 10. Normalized Mean Difference of modeled H_s minus Sea State CCI Altimeter data, averaged over the year 2011, using (a) ERA5, (b) CFSR, (c) ECMWF operational deterministic products and (d) Ifremer winds. The model was run with the set of parameters T475 as given in Table 2. Colorbar indicates NMD in percent. Black and yellow lines mark the +10 and +20% contours.

Requirements for ocean data

Hindcast data bases (numerical models)

- Long duration time series: statistics, extrêmes assessment, climatologies
- Refined grids at the regional/site scale (downscaling)
- Co-localisation of information (wind, waves, current)
- Spectro-directional information for structures design

- Improve parametric models
- Consolidate the quality/validation of the forcing fields
- Take advantage of numerical and IT improvements to increase resolution

Requirements for ocean data

In-situ measurement

- Pluriannual time series (site characterisation, models validation,…)
- Co-localisation of the information (wind, waves, current)
- Spectral information (high sampling frequency) for structures design

- Sensors with adapted processing methods, based on verified assumptions
  - Wind: improve lidar capacity and accuracy, especially for floating lidars
  - Waves: improve wave direction and directional spreading assessment methods
  - Currents: improve ADCPs/develop new tools so as to efficiently capture turbulence and flow variability in energetic currents (technical, methodology, assumptions)

Requirements for ocean data

Remote sensing

- Long duration time series (site characterisation, models validation,…)
- Co-localisation of the information (wind, waves, current)
- Enhancing Knowledge

- Time and space discretization
- Measurement in harsh wheather
- Spectral bandwidth

Data access

- Co-localisation of the information (wind, waves, current)
- Definition of a common nomenclature
- Relevant parameters also adapted to the needs of the engineers
- Properly informed Meta-data
- Standard data format (NetCDF,…)

- Advanced tools and environment for easy access and extraction (maps, time series)
- Open access licenses
- Reference repositories
- Digital Object Identifier

Data bases

Reference datasets

Global coverage

ERA5

Fifth generation ECMWF reanalysis for the global climate and weather from 1959 onwards - 3-hourly - WAM

- Reanalysis: 0.25° x 0.25° (atmosphere), 0.5° x 0.5° (ocean waves)
- Mean, spread and members: 0.5° x 0.5° (atmosphere), 1° x 1° (ocean waves)

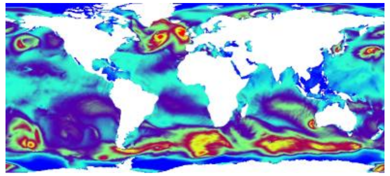
https://www.ecmwf.int/

GLOBMULTI_ERA5_GLOBCUR_01

Wave hindcast based on WAVEWATCH-III® with parameterization from Alday et al 2021. Forced by ERA5 winds, CMEMS-GLOBCURRENT currents, SSMI ice mask and ALTIBERG iceberg mask on a global grid nested with regional subgrids at higher resolution - 1993- 2021 – 3-hourly

Global grid at 30-min spatial resolution on a rectilinear grid

Regional 10-min and 3-mn nested grids



https://sextant.ifremer.fr/geonetwork/srv/api/records/857a3337-f59a-481a-bf98-5561e8b61e7b

NOAA

WAVEWATCH III® Hindcast and Reanalysis Archives

- A 30-year hindcast generated from the NCEP Climate Forecast System Reanalysis and Reforecast (CFSRR) dataset of hourly high-resolution winds. (1979 - 2009). True hindcast generated with a single version of the model and a statistically consistent forcing wind field, and is suitable for use in climate studies.
- A data set produced by rerunning the model from the operational wind fields to produce best-estimate nowcast datasets for the time period of Feb 2005 through May 2019. This is a statistically inhomogeneous hindcast data set, because the underlying models are periodically updated. Therefore this data set should not be used for climate studies.

https://polar.ncep.noaa.gov/waves/hindcasts/

Data bases

Reference datasets

https://marine.copernicus.eu/

Copernicus Marine Service

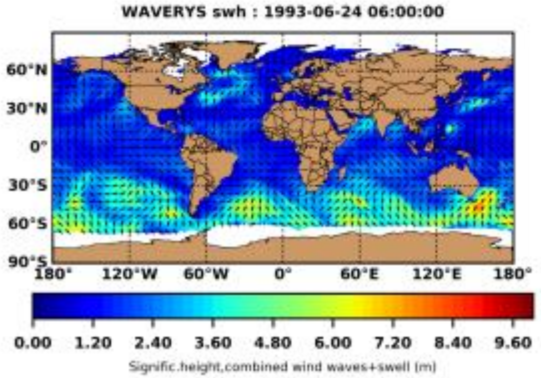
Global Ocean Waves Reanalysis WAVERYS

https://doi.org/10.48670/moi-00022

Global wave reanalysis 1993-2020 – 3-hourly.

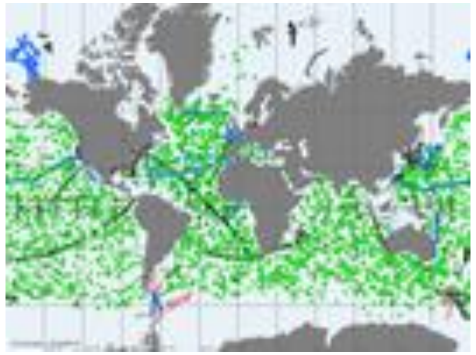
based on the MFWAM model providing wave spectra on a 1/5° irregular grid. Global parameters are delivered on a regular 1/5° grid with a 3h time step.

WAVERYS takes into account oceanic currents from the GLORYS12 physical ocean reanalysis and assimilates significant wave height observed from historical altimetry missions and directional wave spectra from Sentinel 1 SAR from 2017 onwards.



Global Ocean- In-Situ Near-Real-Time Observations
https://doi.org/10.48670/moi-00036
Global Ocean - near real-time (NRT) in situ quality controlled observations, hourly updated - Since 15 Jan 2010

- Significant wave height
- Mean Period
- Mean direction



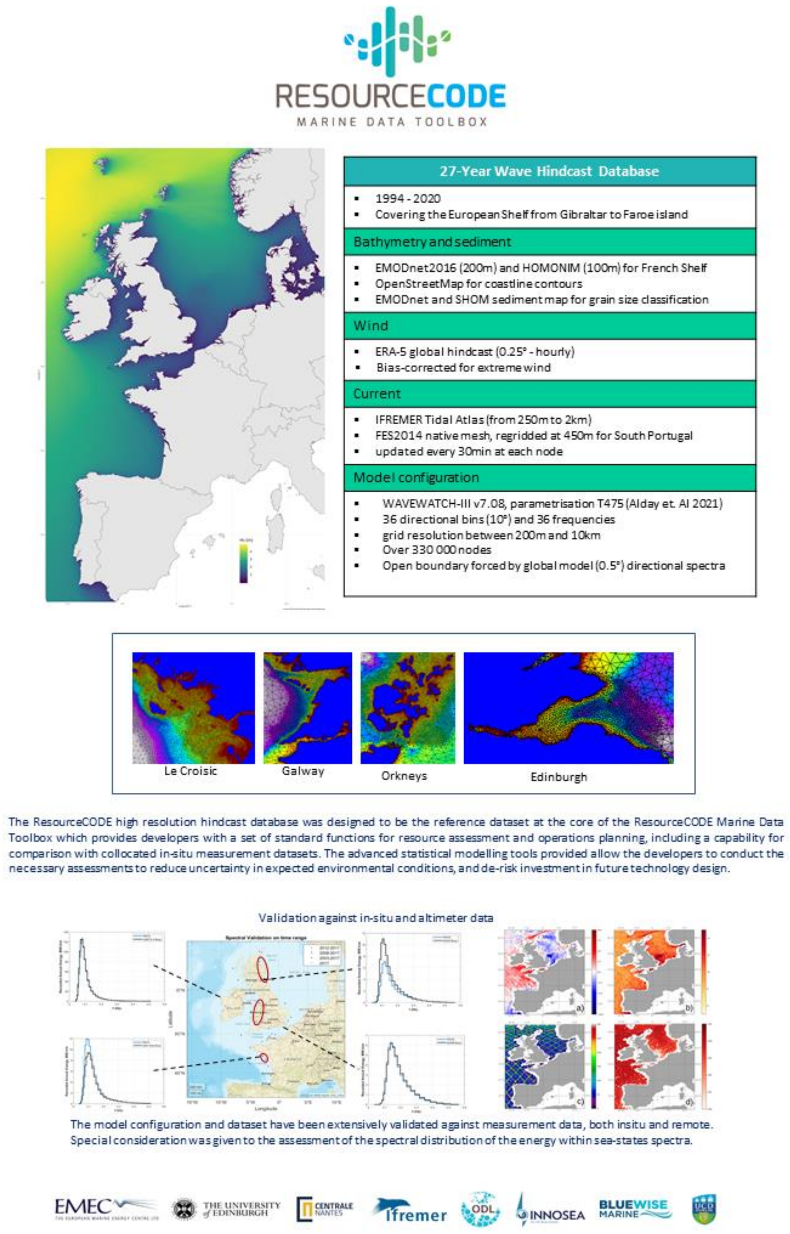
Data bases

Reference datasets

Regional high resolution

ResourceCODE

https://resourcecode.ifremer.fr/



Data bases

Reference datasets

European Commission

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Energy, Climate change, Environment

European Marine Observation and Data Network (EMODnet)

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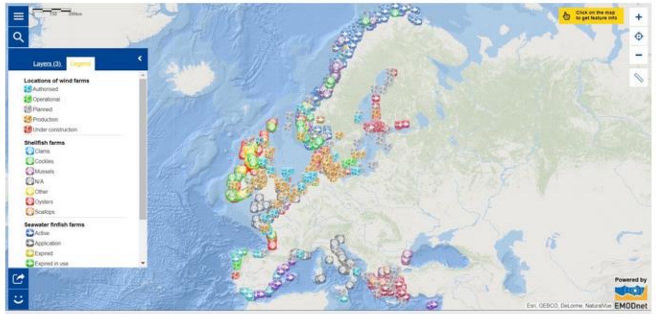
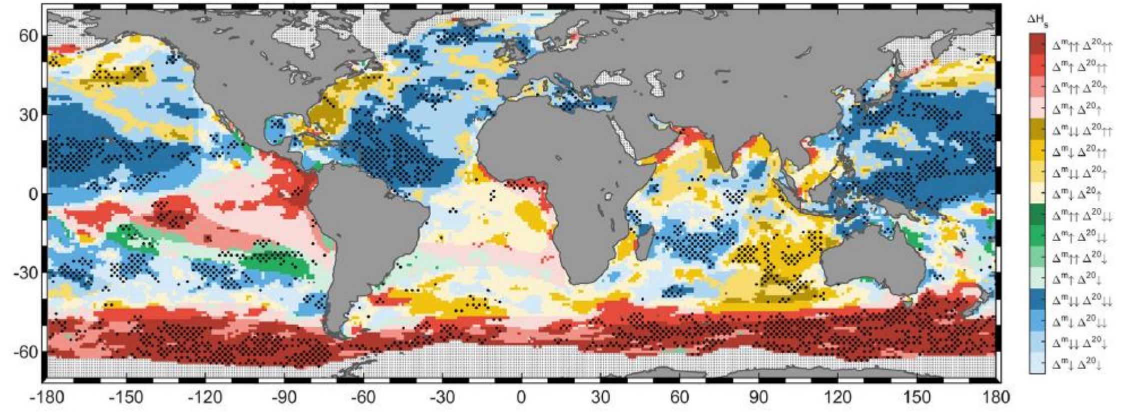
Human Activities

EMODnet Human Activities aims to facilitate access to existing marine data on activities carried out in EU waters, by building a single entry point for geographic information on 20 different themes.
Data on marine and maritime human activities are essential for effectively managing our seas and oceans in a sustainable way. This is becoming increasingly necessary due to growing population size and greater demand for resources, combined with advances in technology, resulting in a huge increase in the number and extent of marine and maritime human activities. These range from established activities such as fisheries and shipping to more recent activity such as construction of offshore energy facilities. Whilst there is considerable data available on these activities it is often only available on a per country, regional or sector-by-sector basis.



EMODnet Human Activities - Aquaculture and Wind farms Map

Climate change



Numerical modelling

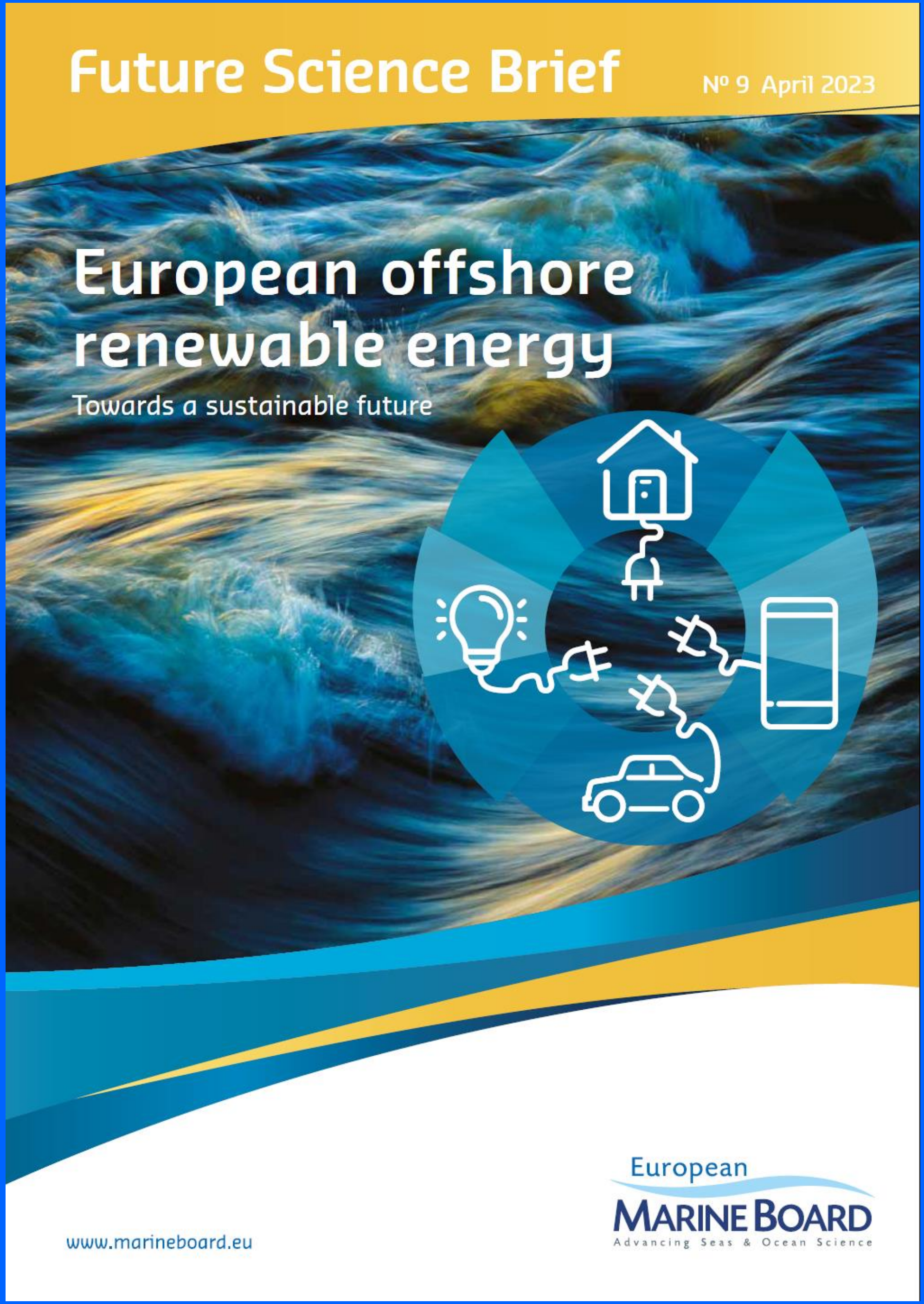
- Common reference forcing fields (IPCC scenarios)
- Downscaling at the regional/site scale

- Reduction of the uncertainties
  - Common statistical models and metrics
  - Agreement on physics implemented in the models and assumptions

EMB FUTURE SCIENCE BRIEF

As highlighted in Section 1.3, climate change and climate variability are likely to affect the offshore renewable energy (ORE) sector by altering resource availability, and have knock-on effects on the design, operation, maintenance and survivability of devices.
Climate change effects on the ORE sector could be assessed by using climate models to simulate future conditions associated with different emission scenarios e.g. those provided in the Intergovernmental Panel on Climate Change (IPCC)'s interactive Atlas, where a regional synthesis is presented regarding climatic impact drivers and anticipated future changes. More research is needed on downscaling the climate models to understand the impacts of different climate change scenarios on ORE resource availability. The spatial and temporal variability of meteorological and oceanographic parameters imply that this will need to be done on a case-by-case basis for the specific region of interest.

Thank You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Nº 9 April 2023
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