Assessment of great ocean currents as a source of renewable energy using recent OGCM simulations of the global ocean

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Acknowledgments

OUTLINES

1 – Introduction

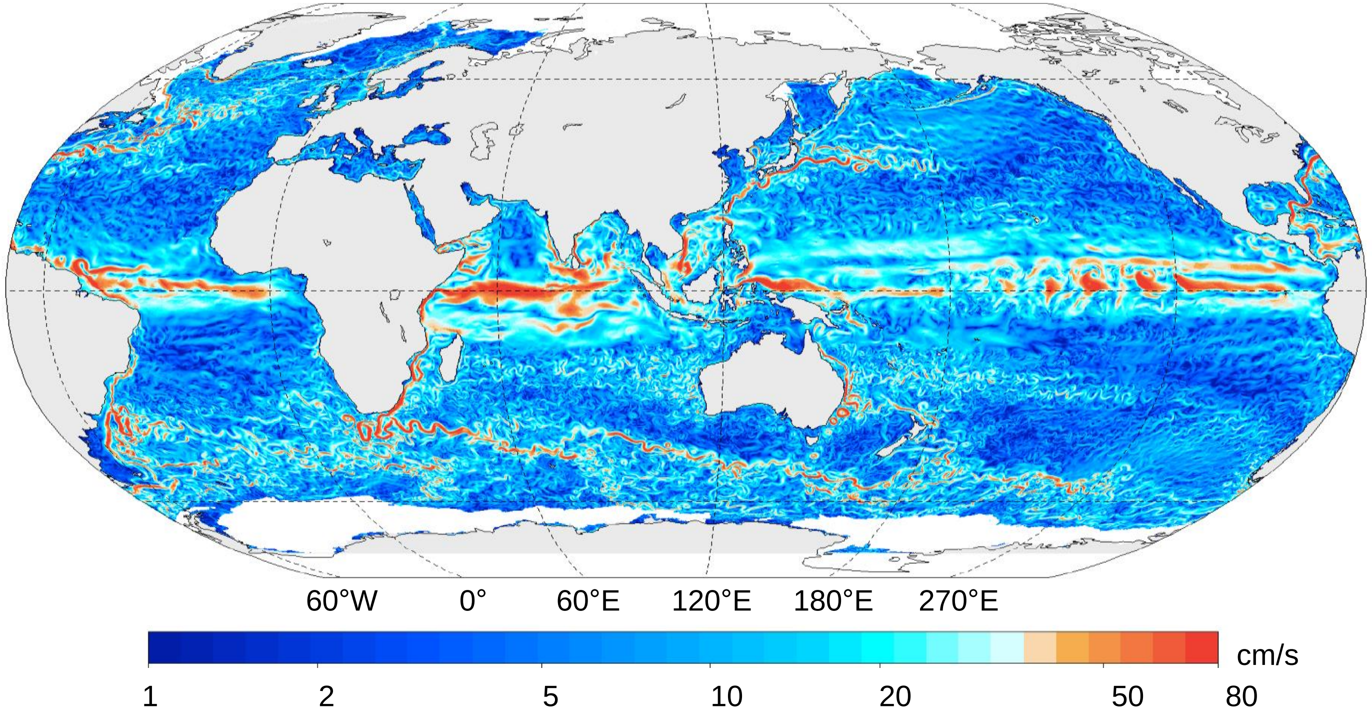
2 - Modelling approach

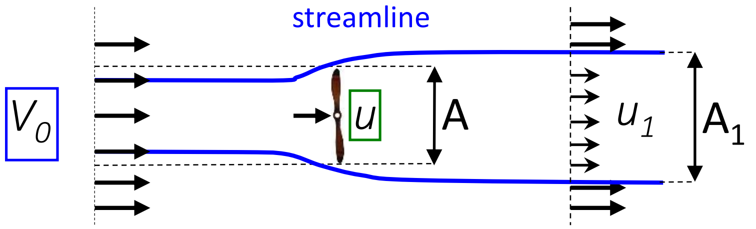
3 - Results

4 - Perspectives

Large variety of approaches to estimate the potential of ocean currents as source of electrical power

Current speed at 18 m depth from a high resolution (< 10 km) model





Theoretical Available Power

$$TAP = \frac{1}{2}\rho \cdot A \cdot V_0^3$$

Harnessable Power

$$HP = \frac{1}{2}\rho \cdot A \cdot u^3$$

Practical Harnessable Power

$$PHP = E_{ff} \cdot A_T \cdot HP$$

V_0	: Current speed from observations or models with no turbine in the flow
u	: Current speed flowing through in the presence of a turbine
E_{ff}	: Turbine efficiency (< 0.59 - Betz limit).
A_T	: Effective Power Plant Ratio (%) (related to internal power plant design).

Hasen (2008), McGowan et al., 2002)

Large variety of approaches to estimate the potential of o

EPU = Energy Production Unit (i.e. a power plant made of a large number of organized turbines)"

Current speed at 18 m depth from a high resolution (< 10 km) model

Present work: the focus in on ***U*** and ***HP***

Question addressed:

If one places an **EPU** "Energy Production Unit" at a given depth in a current :

- How will it modify the upstream flow ?
- Which power reduction can be expected?

V_0	: Current speed from observations or models with no turbine in the flow
u	: Current speed flowing through in the presence of a turbine
E_{ff}	: Turbine efficiency (< 0.59 - Betz limit).
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Practical Harnessable Power

$$PHP = E_{ff} \cdot A_T \cdot HP$$

Hasen (2008), McGowan et al., 2002)

Previous work of that nature (far for exhaustive papers published in the last 3 years)

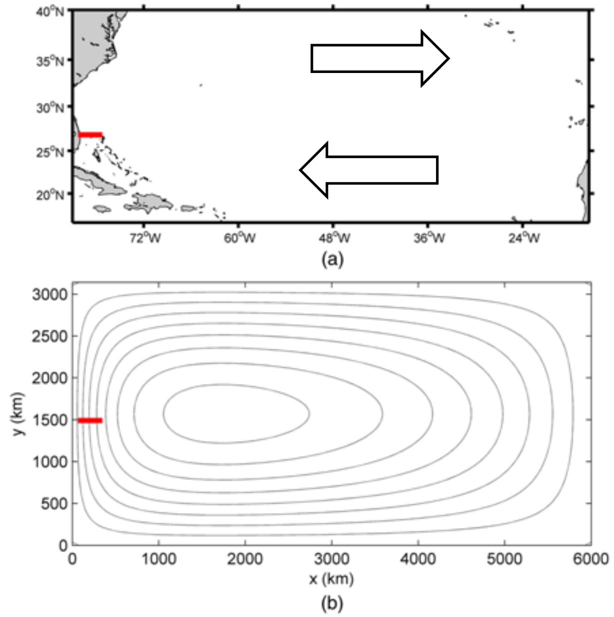
Assessment of the total energy that can extracted from a large portion of the current.

Use of idealized models (1 or 2 layer, rectangular geometry, constant zonal wind)
EPU's are represented by a drag applied to a portion of the current (100 km)

Yang et al (2013) : **44 GW** for the Gulf Stream system

Yang et al. (2014) : **4 to 6 GW** in Florida Current increased to **18 GW** if the entire portion of the GS along the US coast.

San (2016) : **10 GW** by turbines distributed over a length scale of 100 km along WBC.



What is the value of these estimates as the electrical power output could be significantly reduced by engineering and technical constraints?

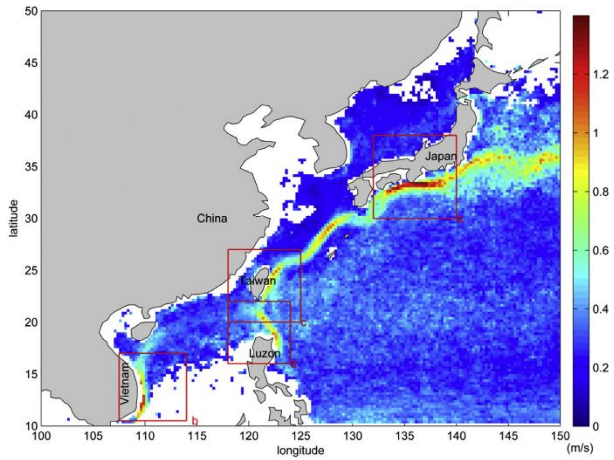
Previous work of that nature (far for exhaustive papers published in the last 3 years)

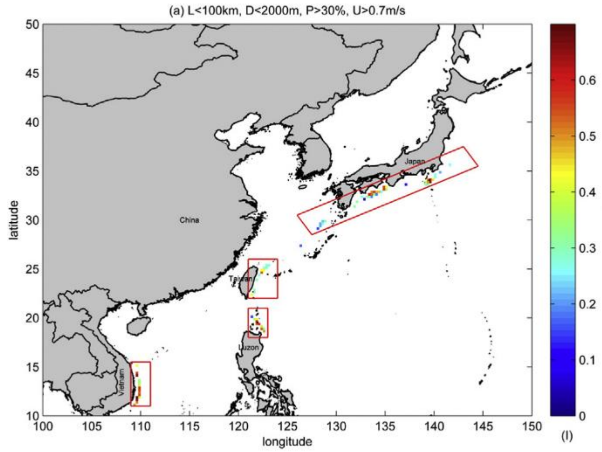
Theoretical calculations based on <u>observed</u> current estimates

Chang et al., (2015) use 6-hourly 15 m depth currents derived from surface drifters.

- Define an index that identifies "favourable locations".

- Identify possible sites along the Kuroshio.





Limitation:

- upstream effects of a large EPU on the current must be considered

<u>Our Study:</u>

Attempt to go one step forward and include Current/EPU interactions in identifying most favorable locations and assessing the Harnessable Power

2 - Modelling approach: twin model simulations

2.1 - Simulate the great ocean currents for a long period (1979-2011)

- with a state of the art realistic numerical ocean circulation model

→ No-Turbine simulation

2.2 - Use 5 years of model current statistics (2007-2011) to:

- identify regions of maximum TAP based on a criterion → TAP
- select precise location for EPU implementation.

2.3 – Implement virtual EPUs

- 16 EPUs implemented at selected locations
- run the model again for a full year (2008) → Turbine simulation → HP

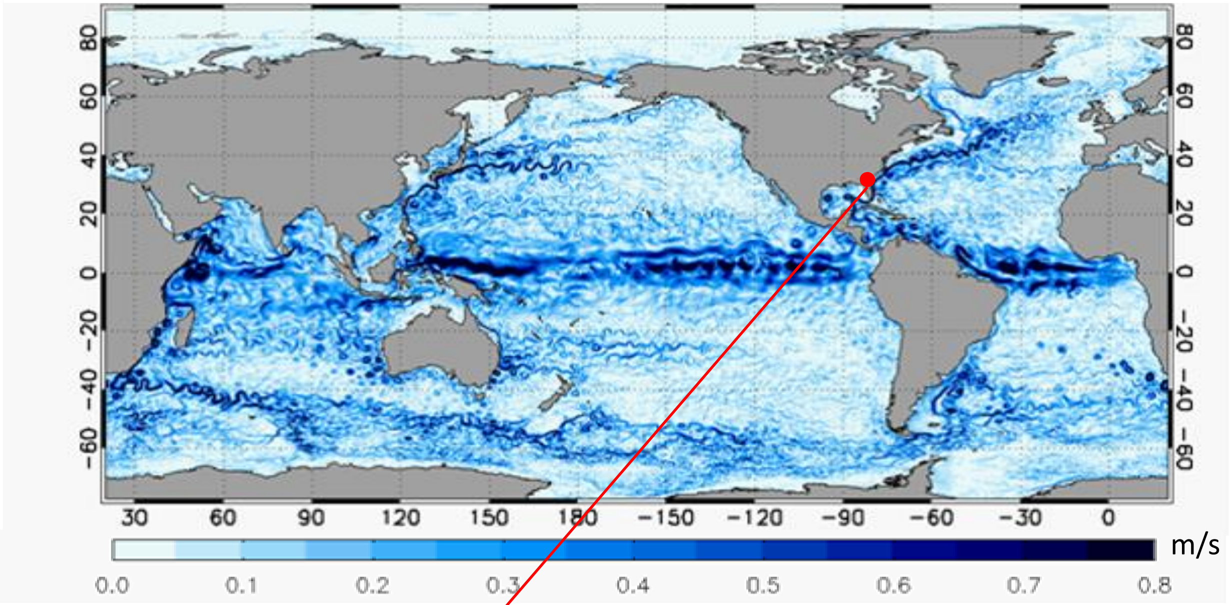
Assess impact of EPUs by comparing the Turbine and No-Turbine simulations

2.1 - Simulate the great ocean currents for a long period (1979-2011)

→ **No-Turbine simulation**

- with a state of the art realistic numerical ocean circulation model (NO TIDES).

ORCA12: snapshot of ocean current speed forecasted by Mercator-Ocean (CMEMS)



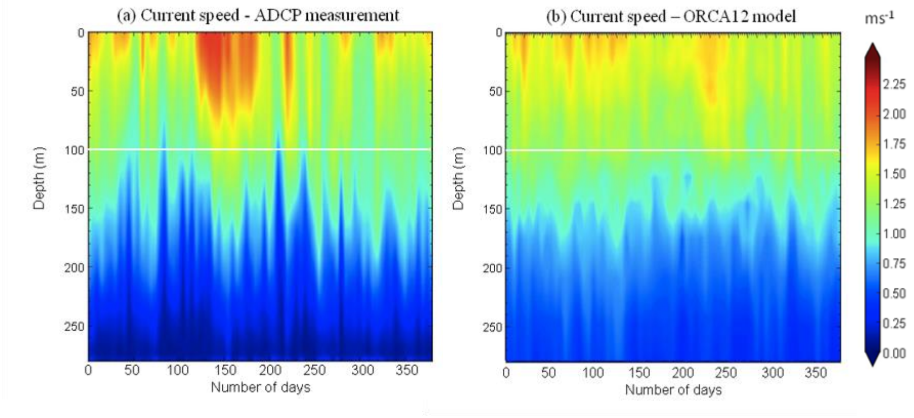
ORCA12 Model

Jointly developed and used by

- DRAKKAR consortium (CNRS, IFREMER, NOCS, UKMO, GEOMAR)
- COPERNICUS Marine Services (CMEMS)

Code: NEMO

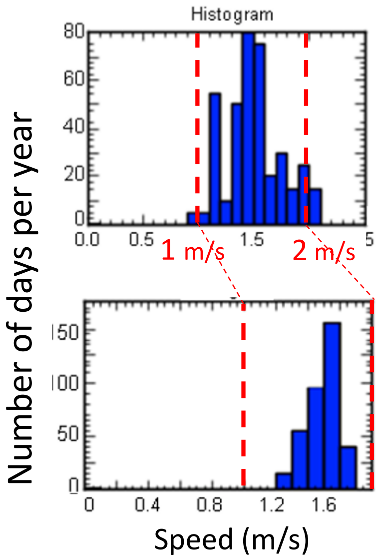
- 1/12° resolution (10 km to 4 km)
- Driven by DFS5 forcing (based on ERAinterim reanalysis)

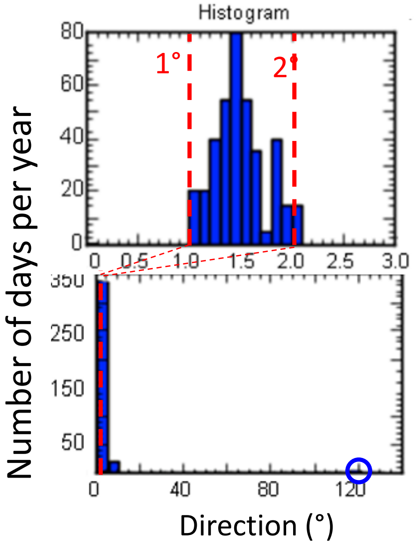


20-40 m depth range

ADCP Speed	
Mean:	1.51 m/s
Min :	0.99 m/s
Max :	2.08 m/s
Std :	0.25 m/s

ORCA12 Speed	
Mean:	1.50 m/s
Min :	1.23 m/s
Max :	1.71 m/s
Std :	0.10 m/s





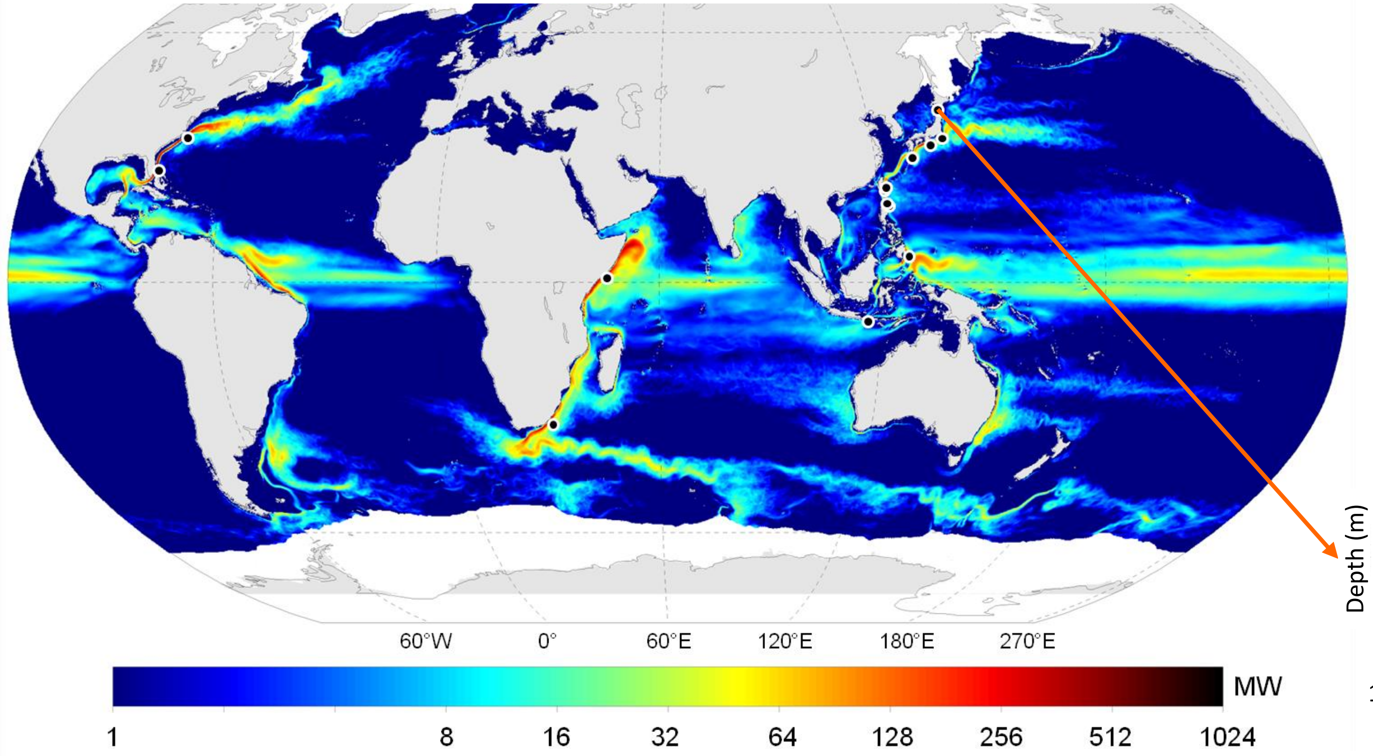
2.2 - Use 5 years (2007-2011) of the No-Turbine simulation to:

- Calculate TAP and identify regions of maximum TAP based on a criterion
- select precise location of EPUs.

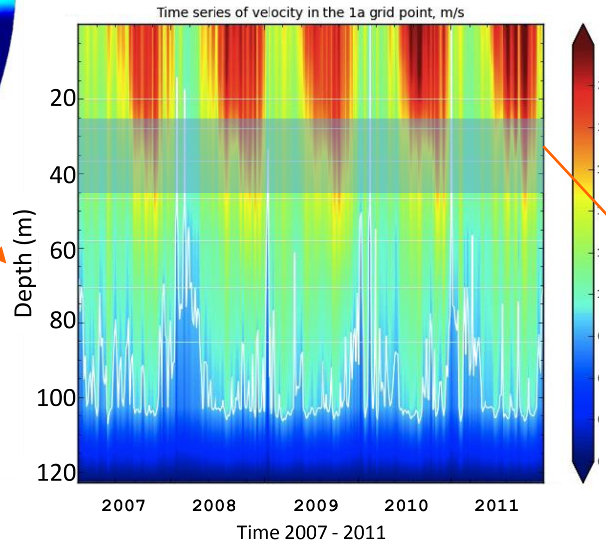
Criterion for EPU location

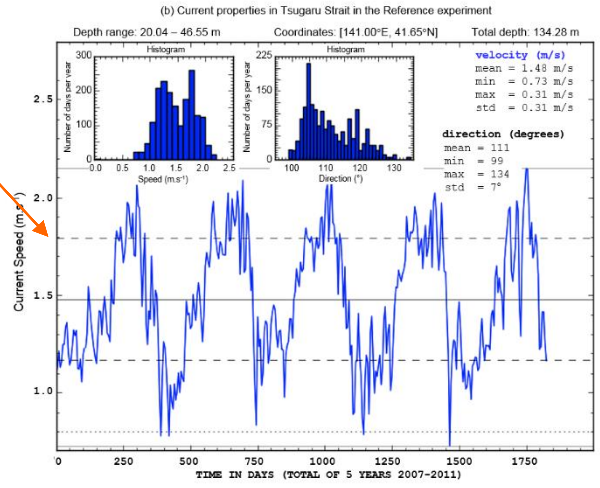
- Distance to coast < 50 km
- In the depth range 20 – 50 m:
  - 5 year mean current speed U > 0.8 m/s
  - Steadiness of speed and direction

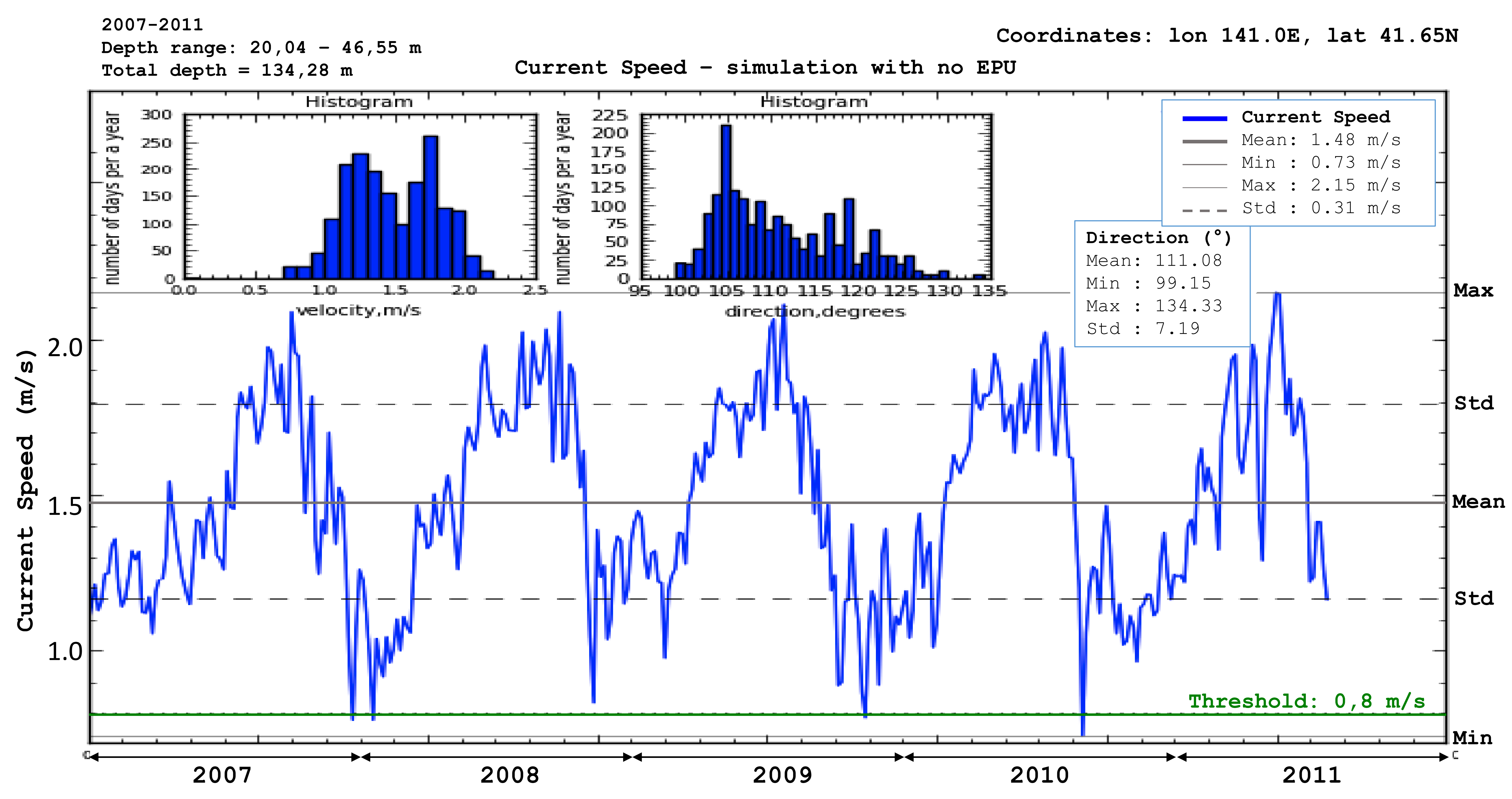
Mean TAP from the No-Turbine simulation (2007-2011)



● Regions where TAP > 500 MW

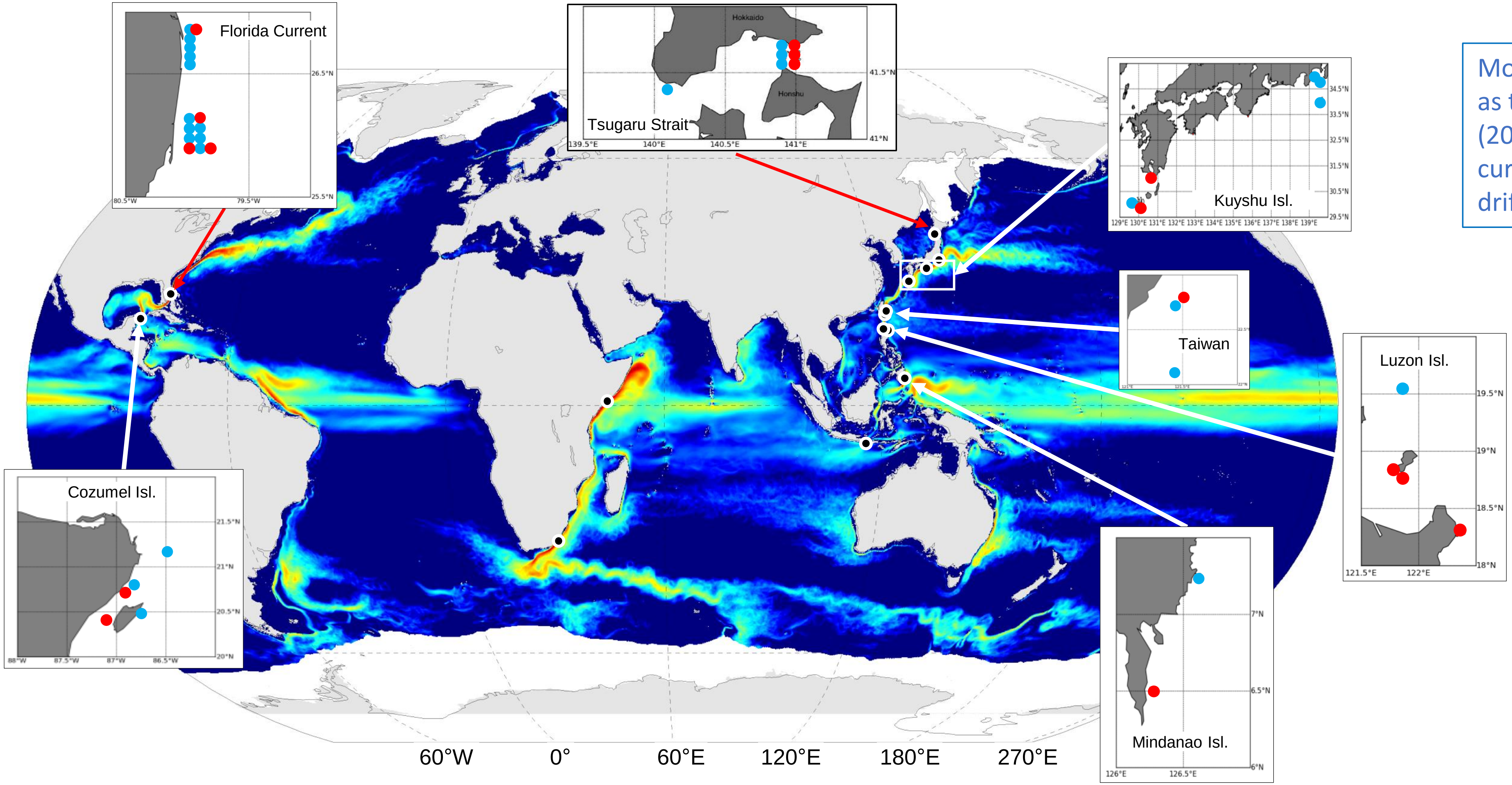






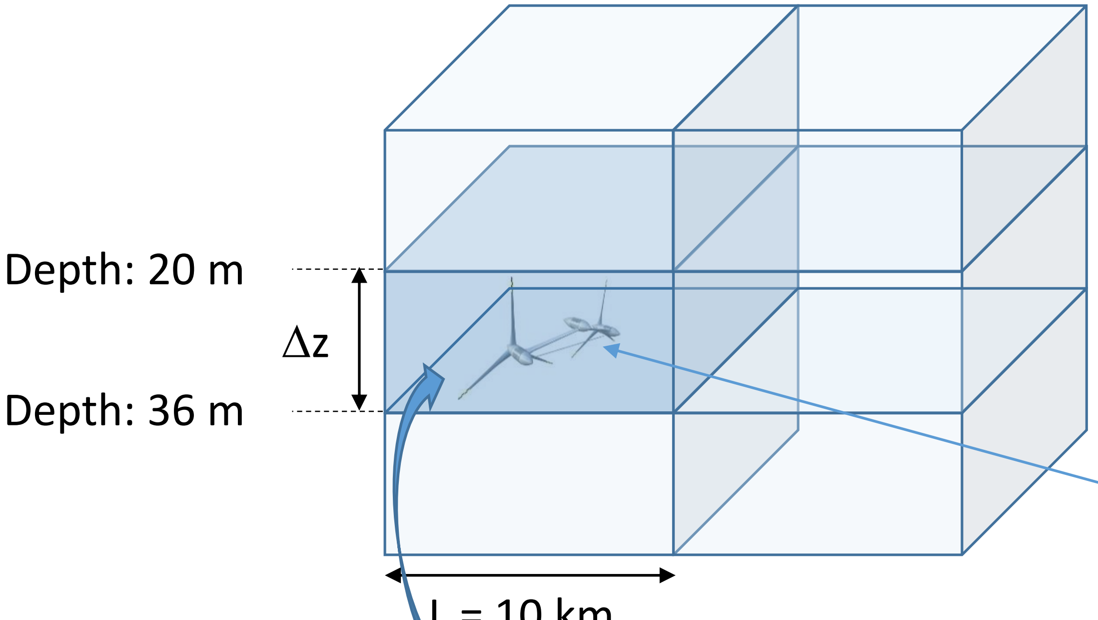
2007-2011
Depth range: 20,04 - 46,55 m
Total depth = 134,28 m
Coordinates: lon 141.0E, lat 41.65N
Current Speed - simulation with no EPU
Histogram
number of days per a year
velocity,m/s
Histogram
number of days per a year
direction,degrees
Current Speed
Mean: 1.48 m/s
Min : 0.73 m/s
Max : 2.15 m/s
Std : 0.31 m/s
Direction (°)
Mean: 111.08
Min : 99.15
Max : 134.33
Std : 7.19
Current Speed (m/s)
Max
Std
Mean
Std
Min
Threshold: 0,8 m/s
2007
2008
2009
2010
2011

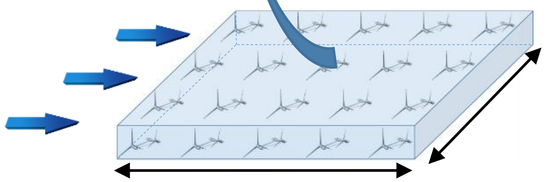
- 42 locations favourable to implement virtual EPUs are identified : +
- 16 retained where **EPUs** has been implemented

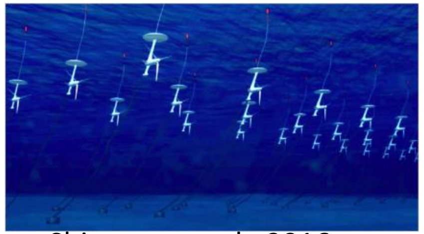


Model locations are the same as those found by Chang et al (2015) using "observed" currents (derived from surface drifters).

2.3 – Implement Virtual EPUs and Run the "Turbine" simulation for one year (2008).






Shirasawa et al., 2016

Virtual EPUs are represented by a
Quadratic Drag Force
added to the model momentum equation
at the location (lon, lat, depth)
that the EPU is assumed to occupy.

Drag Force F = Thrust T

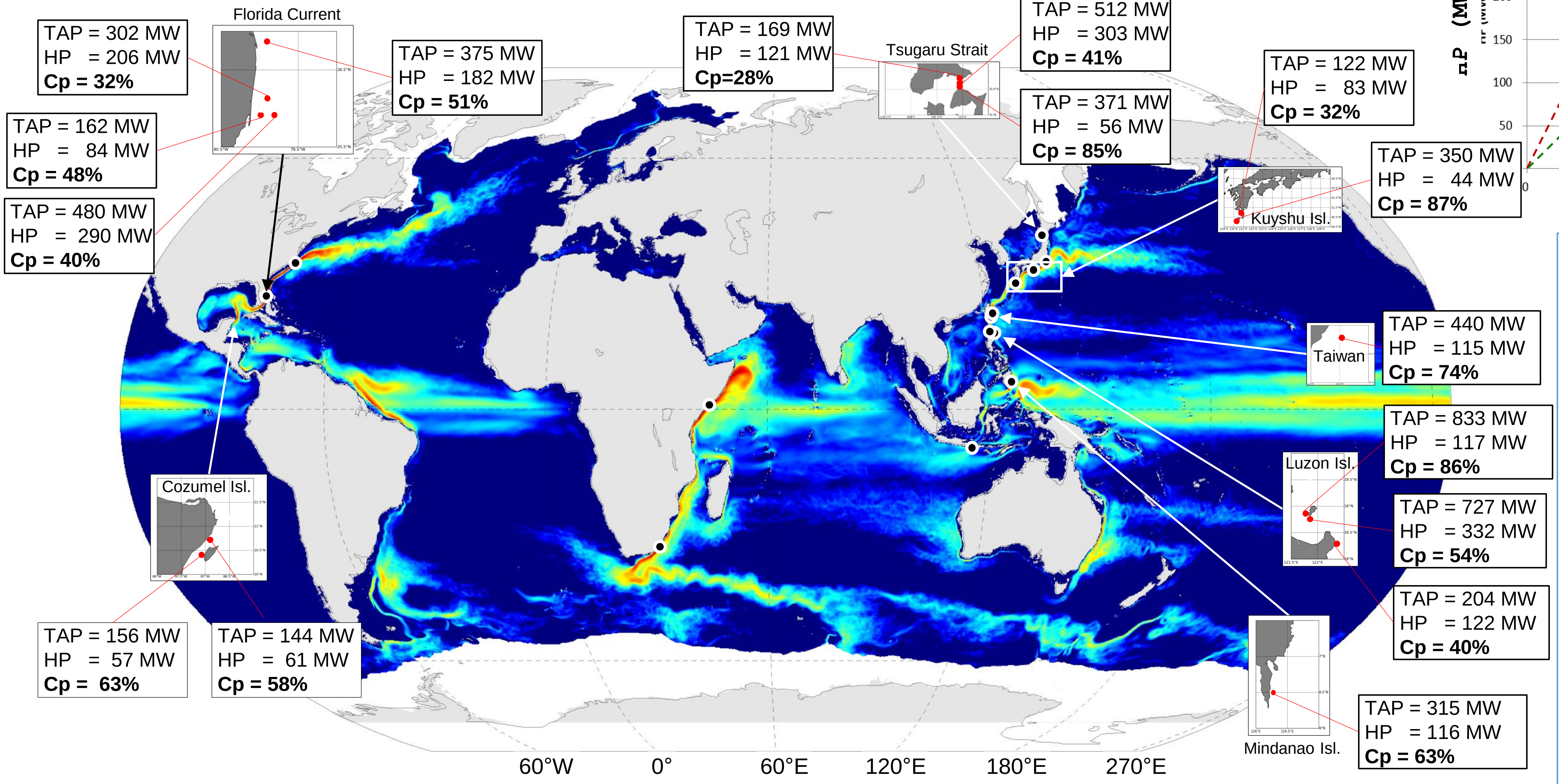
$$F = \rho C_D L^2 u^2 = T = \rho A u^2$$

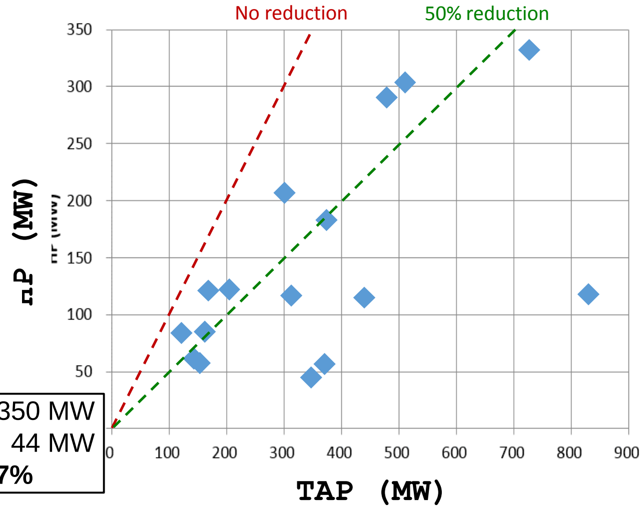
$$A = L \cdot \Delta z$$

$$C_D = \frac{\Delta z}{L} \qquad C_D = 2.6\times10^{-3}$$

The model is re-run for one year (2008) with the drag force acting at the selected grid-points

3. Compare Turbine (HP) and No-Turbine (TAP) simulations to assess the impact of EPUs on recoverable power





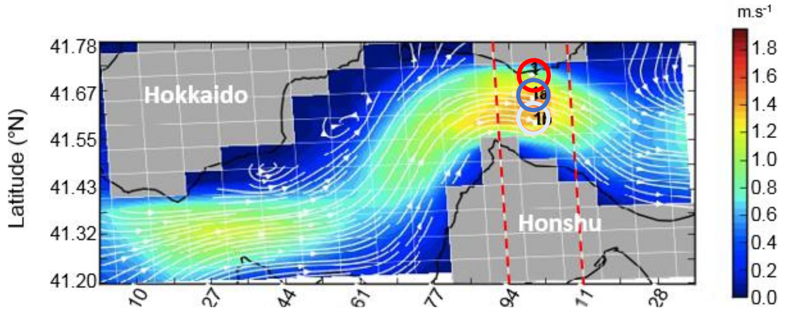
Harnessable Power **HP** is **28% to 87% Smaller** than **TAP** Theoretical Available Power

Case of small reduction - Tsugaru Strait (North Japan)

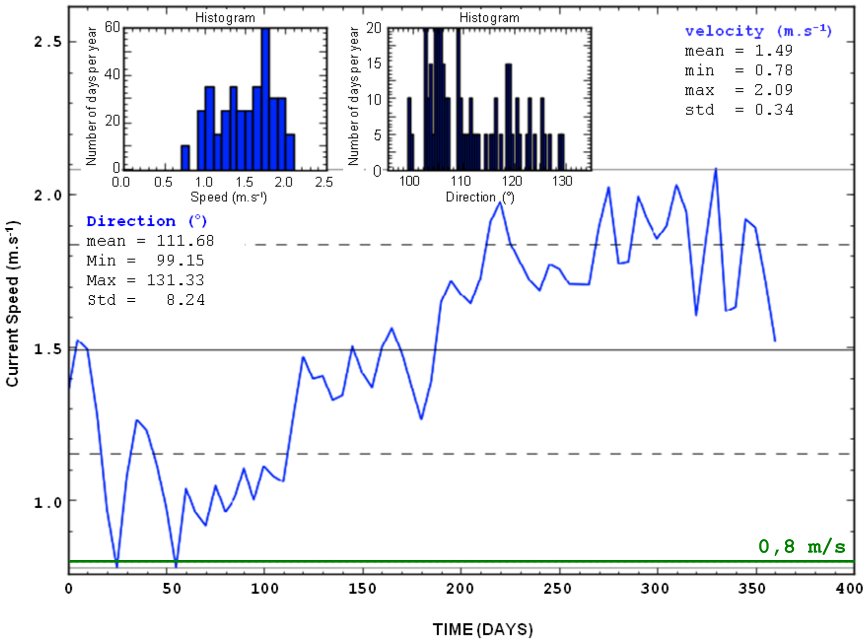
NO-TURBINE

Large energy potential: **TAP = 169 MW**

TAP = 512 MW



(a) ORCA12 Reference simulation



Mean Current

1.49 m/s → 1.26 m/s

Current below 0,8 m/s

0 day → 10 days

Direction STD

8.2° → 4.7°

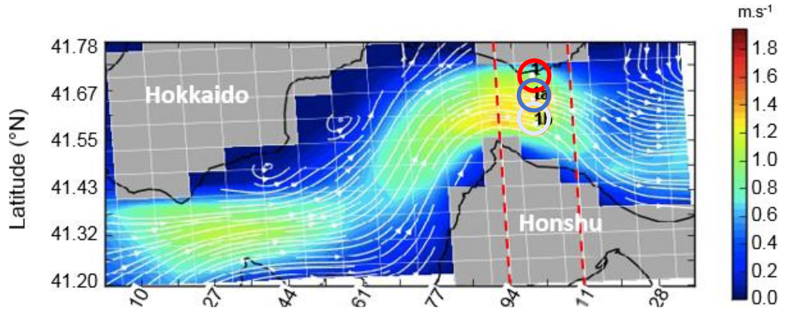
The *reduction* of the *current spe*ed by the EPU drag is responsible for the power *reduction*

Power ~ V^3

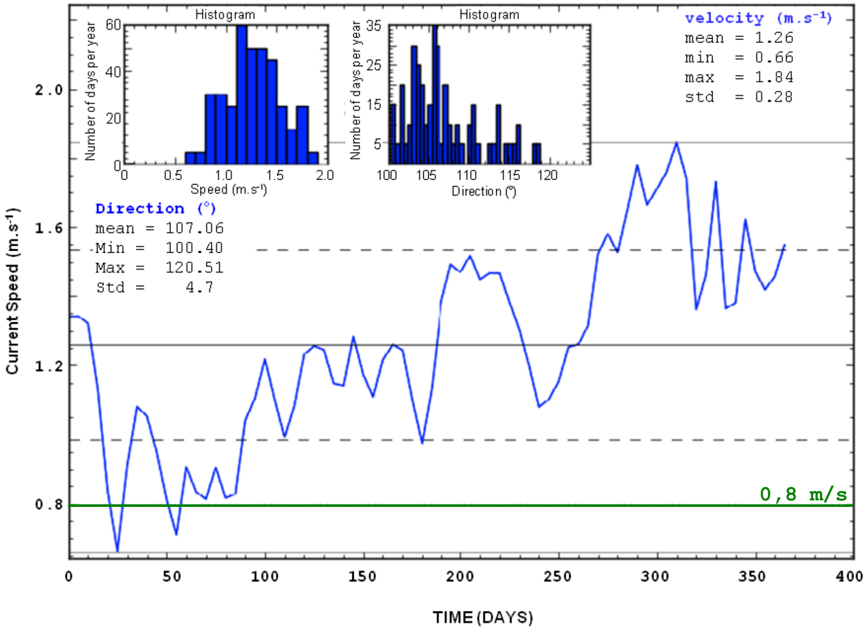
TURBINE

Moderate Reduction 28%: **HP = 121 MW**

41%: **HP = 303 MW**



(b) ORCA12 Turbine simulation



Case of large reduction - North Luzon Island (Philippines)

NO-TURBINE

Large energy potential: **TAP = 833 MW**

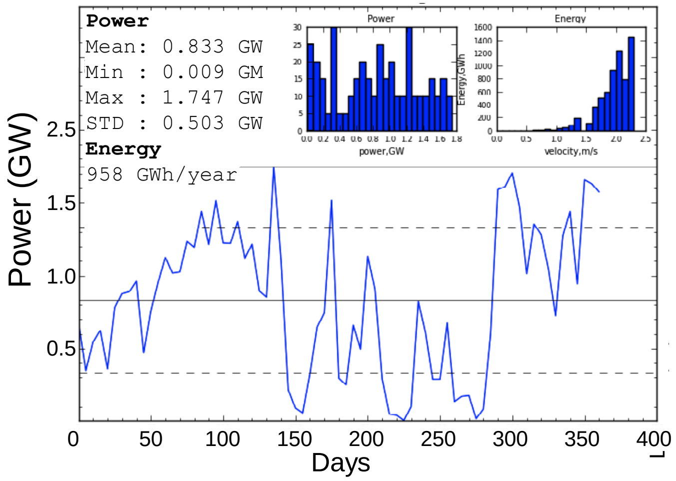
TAP = 727 MW

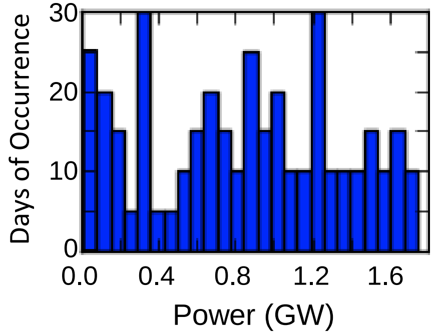
TURBINE

Large Reduction 86%: **HP = 117 MW**

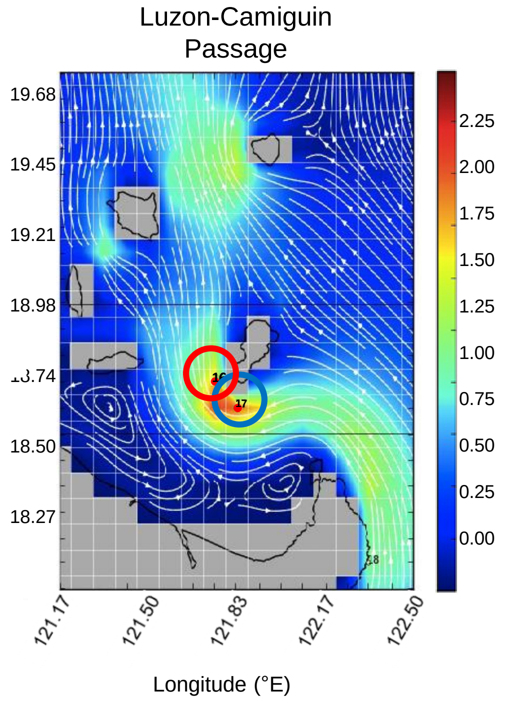
54%: **HP = 332 MW**

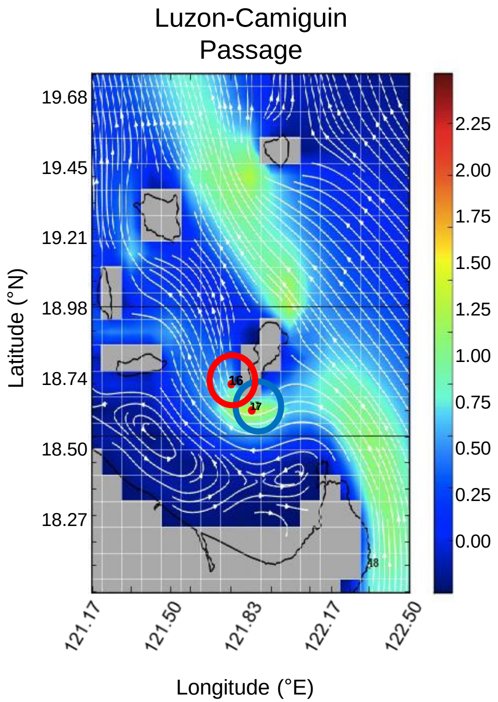
Theoretical Available Power (TAP) in the No-Turbine simulation



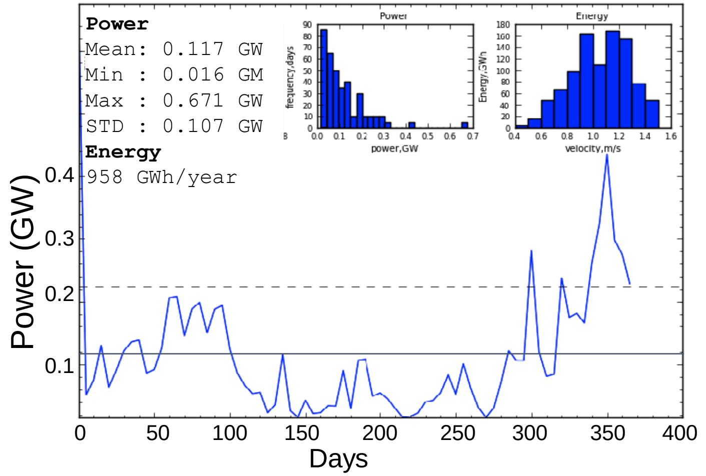


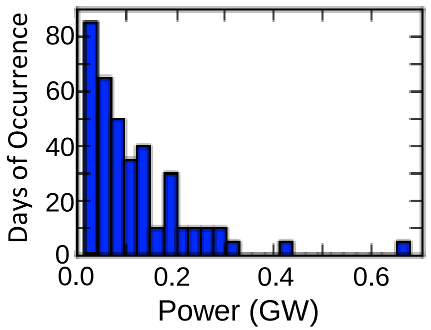
Depth range	Total depth	Distance from Coast
20-46 m	855 m	<5 km





Harnessable Power (HP) in the Turbine simulation





Upstream effect of the EPUs: **shift of the main path of the current from the west side to the east** side of the *Caminguin Island*

4 – Conclusions

- Ocean models used for operational forecast can be used to simulate the feedback of EPUs on the flow.
- Upstream effect of an EPU could be very important, changing the path of the current.
- Every “spot” with a large potential (TAP) is a particular case.
- Long time series are necessary (1 y or more).
- **Large uncertainty of the drag force mimicking the effect of the “virtual EPU”**

Perspectives

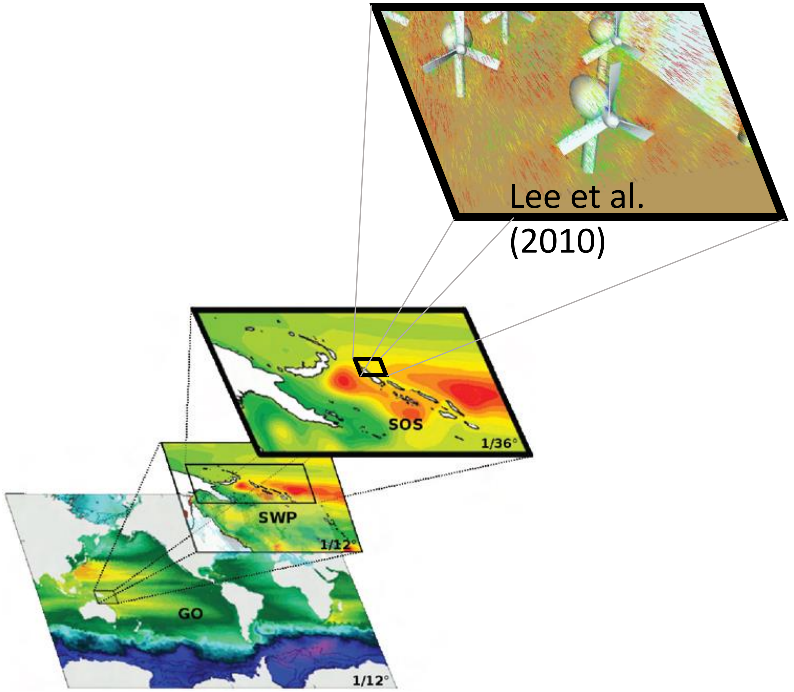
- **Ocean modelling tools are ready to go forward**

  - Global operational models (CMEMS) can provide realistic boundary conditions to large scale regional models.

  - Grid refinement techniques allow to get down to very high resolution (2km → 400 m → 80 m)

  - EPU models should be “embedded” into the domain of finest resolution

- **Operational forecasts would allow real time management of resources**



Djath et al. (2014)