Using a 1D boundary layer model to improve air-sea interactions, first tests in the North-East Atlantic

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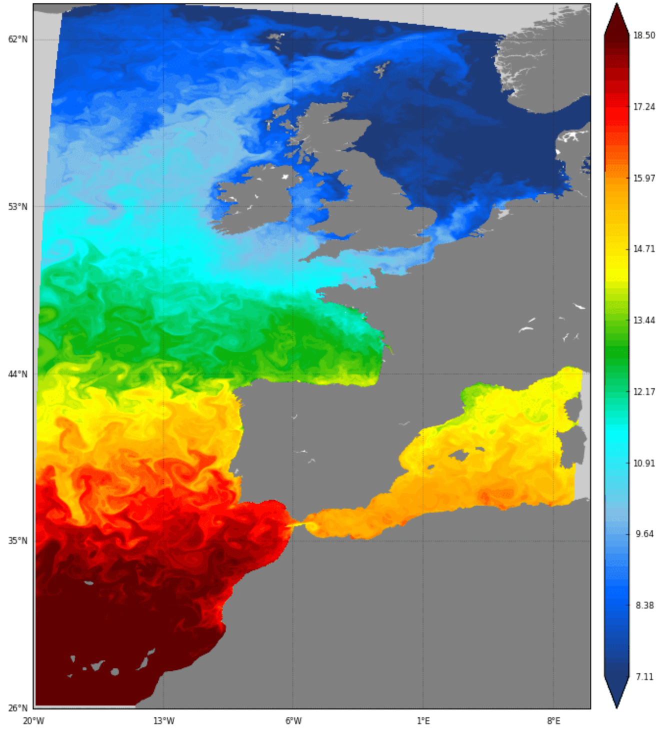
Mesoscale Air Sea interactions

- Iberian, Biscay, Ireland (IBI) area
  - Regional oceanic configuration devellopped by Mercator-ocean and Puertos del Estado (Maraldi et. al. 2012)
  - Oceanic reanalyses and forecasts produced at 1/12° and 1/36° resolution
  - Forced by ECMWF atmospheric forecasts / reanalyses
  - Test bed for future global high resolution configurations

- At such scales, currents and sea surface temperature have a significant impact on surface winds (Chelton et. al. 2007, Small et. al. 2008).

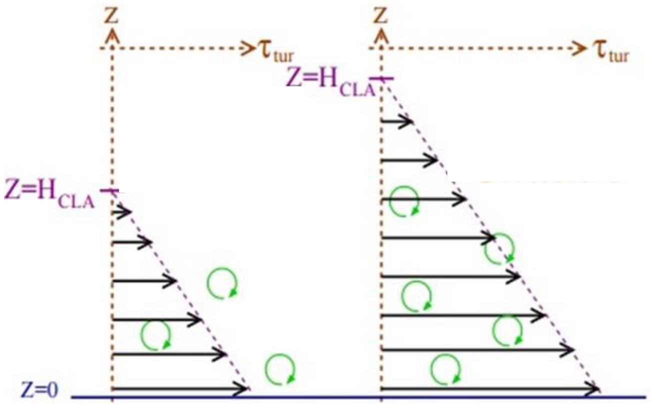
- Modulates the wind work input, and the ocean dynamics (Renault et. al. 2016).



A forecast of Sea Surface temperature in degrees (SST), from CMEMS product 1/36°

Thermal coupling

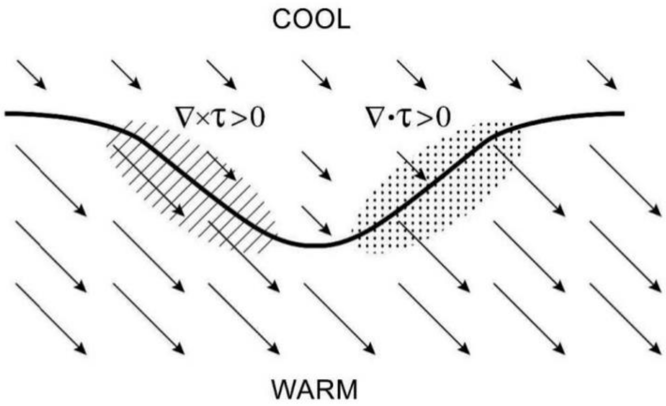
Changes in height and stability of the Atmospheric boundary layer (ABL)



Cold SST **Warm SST**

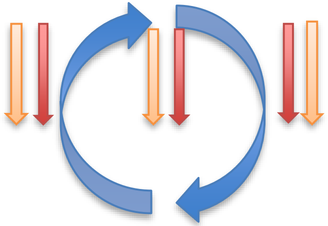
Vertical profile of Wind stress over a warm/cold SST, from Oerder (2016)

SST-induced changes in wind stress



Wind stress over a SST front, Chelton et. al. (2007)

Dynamical coupling on ocean modelling



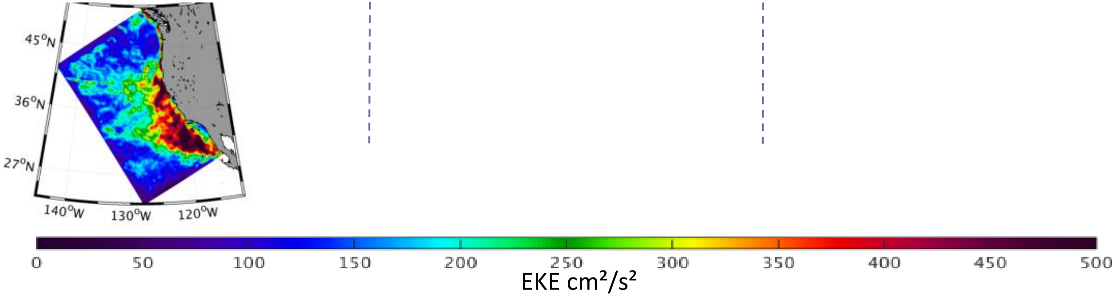
Curl(U’) < 0

Curl(τ’) = 0

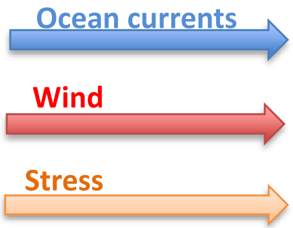
Curl(Wind’) = 0

Forced,
Absolute winds
U = Uatm

- Absolute winds : Strong EKE



Mean Surface Eddy Kinetic energy (EKE) from Renault et al. 2016



Mesoscale Air Sea interactions

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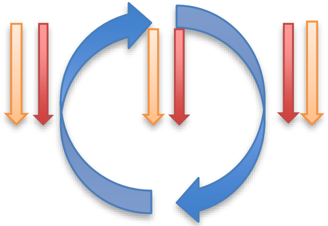

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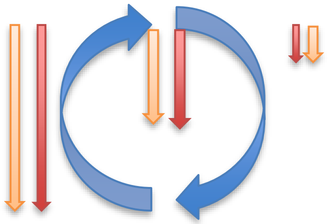


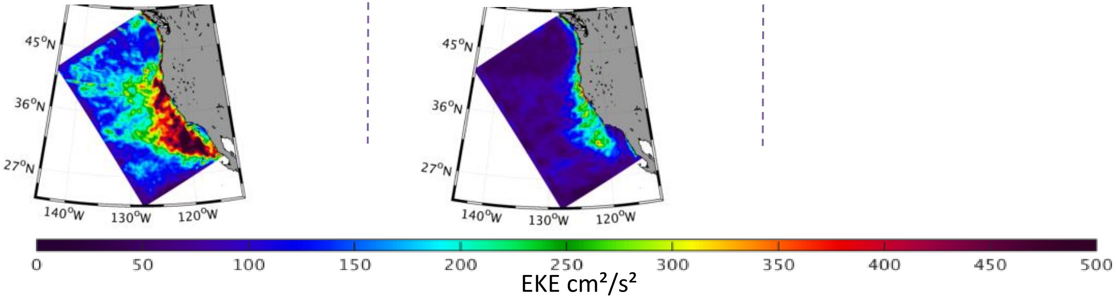
Curl(U’) < 0

Curl(τ’) > 0

Curl(Wind’) > 0

Forced,
Relative winds
U = Uatm - Uoce

- Absolute winds : Strong EKE
- Relative winds winds: « Eddy killing » by Current Feedback (CFB) mechanism



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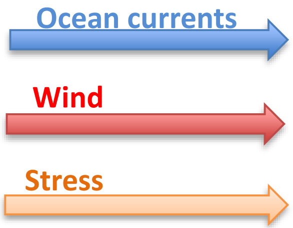
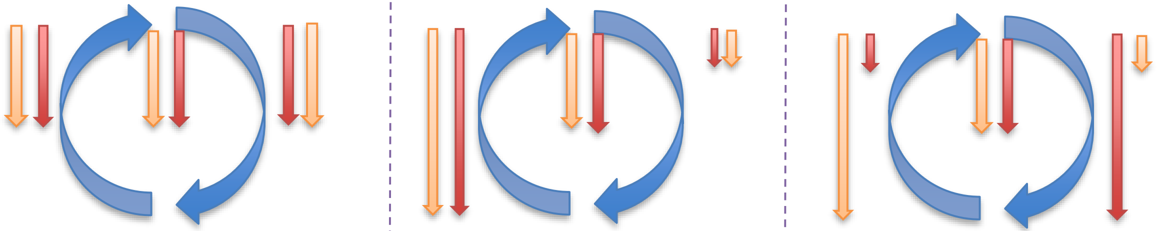


Dynamical coupling on ocean modelling



Forced, Absolute winds	Forced, Relative winds	Coupled, Relative winds
Curl(U') < 0	Curl(U') < 0	Curl(U') < 0
Curl(τ') = 0	Curl(τ') > 0	Curl(τ') > 0
Curl(Wind') = 0	Curl(Wind') > 0	Curl(Wind') < 0

Forced,
Absolute winds
U = Uatm

Forced,
Relative winds
U = Uatm - Uoce

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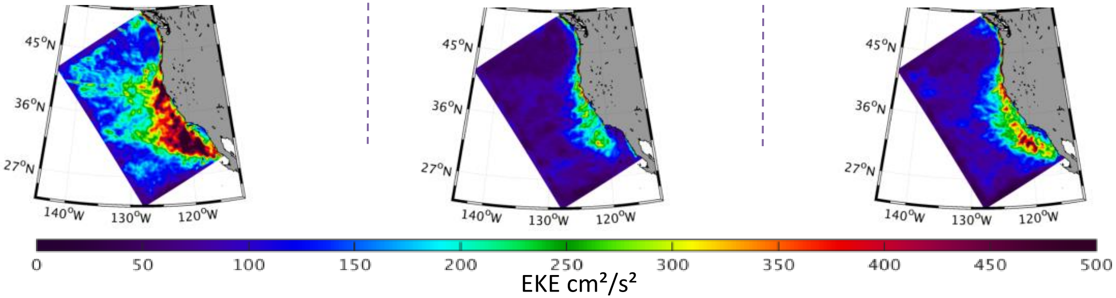
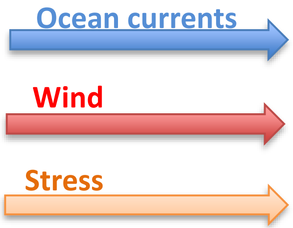


Mean Surface Eddy Kinetic energy (EKE) from Renault et al. 2016

- Absolute winds : Strong EKE
- Relative winds: « Eddy killing » by Current Feedback (CFB) mechanism
- Partial re-energisation of the ocean by coupling



The ABL1D model

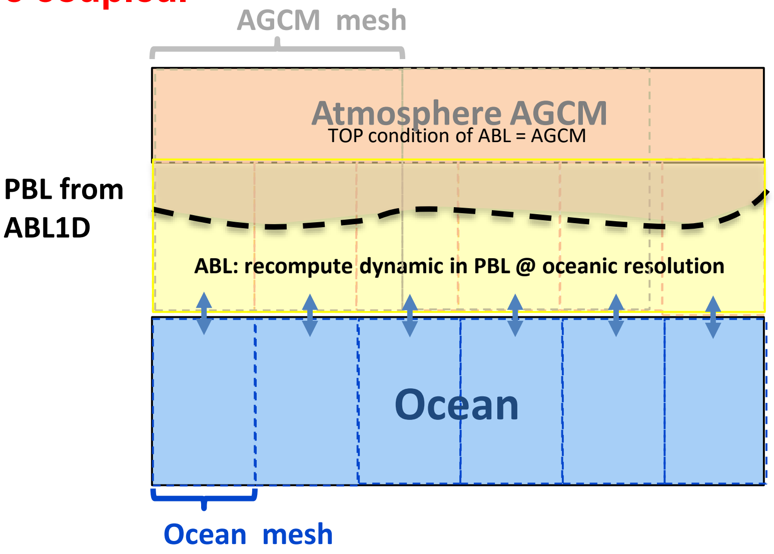
At mesoscales, ocean and atmosphere models have to be coupled.

-> Very high computational cost !

Alternative approach:

-> Atmospheric boundary layer (ABL1D) model

- Simplified
- Lower computational cost
- Same temporal and horizontal resolution as ocean model
- Facilitates physical processus analyses



The model (ABL1D):

- 1D on the vertical dimension, top at 2000m
- Computes T, Q and Winds
- Reproducing turbulent transport within the ABL
- Nudged towards geostrophic winds or pressure gradients for the dynamics.
- **Implemented in NEMO 3.6 ocean model**

$$\begin{cases} \partial_t u = fk * u + \partial_z(K_m \partial_z u) + R_{LS} \\ \partial_t \theta = \partial_z(K_s \partial_z \theta) + \lambda_s(\theta - \theta_{LS}) \\ \partial_t q = \partial_z(K_s \partial_z q) + \lambda_s(q - q_{LS}) \end{cases}$$

The ABL1D model

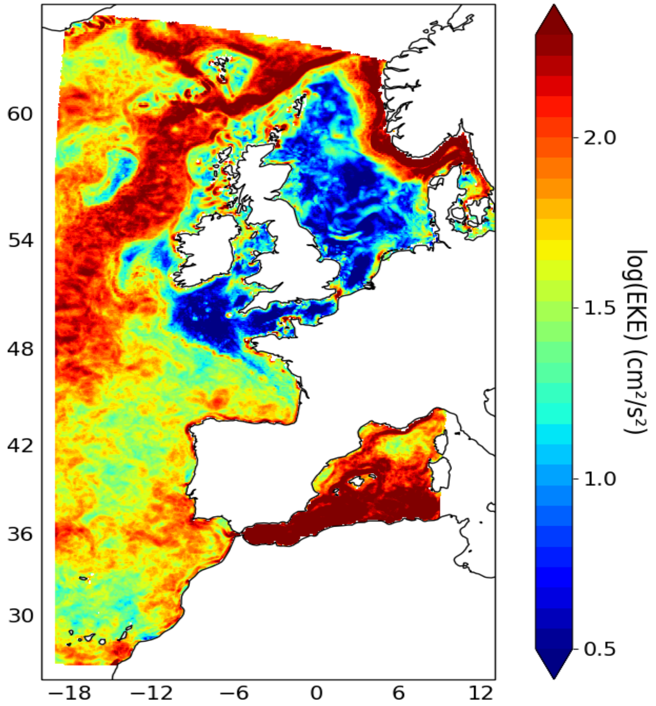
Two main questions:

- Does ABL1D is able to reproduce the air-sea coupling mecanisms ?
- What is the impact of the ABL1D on the ocean dynamics ?

Experimental setup

- 3 simulations of 2,5 years (01/2015 – 06/2017), IBI area:
  - Forced with absolute winds ($U = U_{atm}$) (FORCED ABS)
  - Forced with relative winds ($U = U_{atm} - U_{oce}$) (FORCED REL)
  - Coupled ocean – ABL (COUPLED ABL), with relative winds

- Setup:
  - NEMO 3.6, IBI 1/36° configuration (~3km),
  - 1093 * 1894 points, 75 vertical levels
  - Initial Condition: IBI CMEMS product (1/36°)
  - Atmospheric forcings: Erai Interim reanalysis (0,75°)
  - Boundary condition: Global CMEMS product (1/12°), TPXO tidal model



Mean surface EKE for the 2015-2016 period, IBI area

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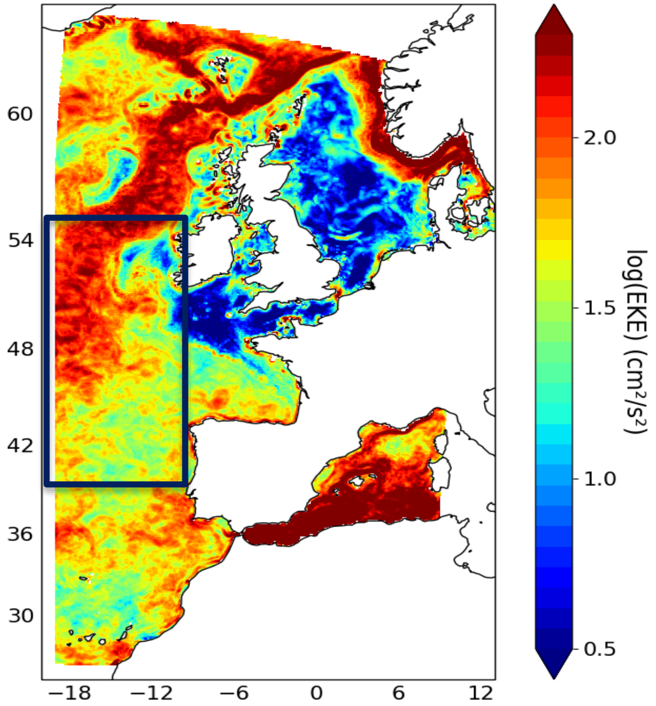
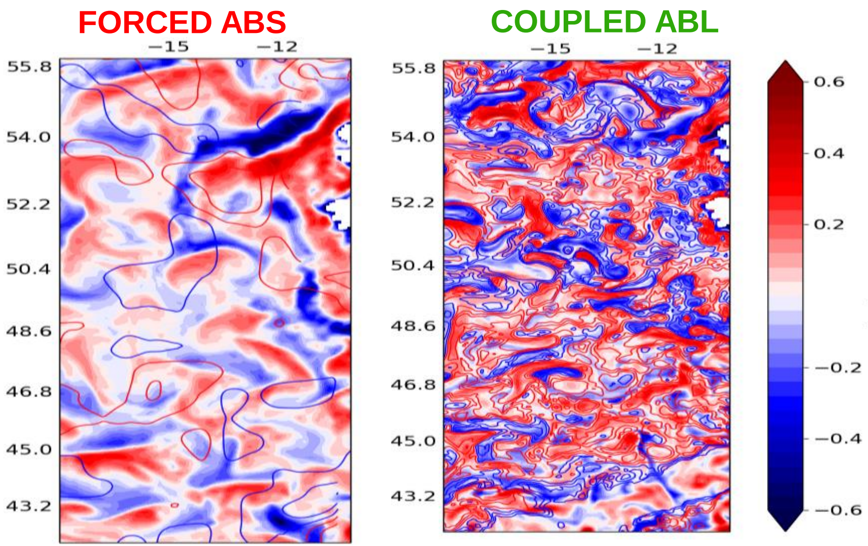


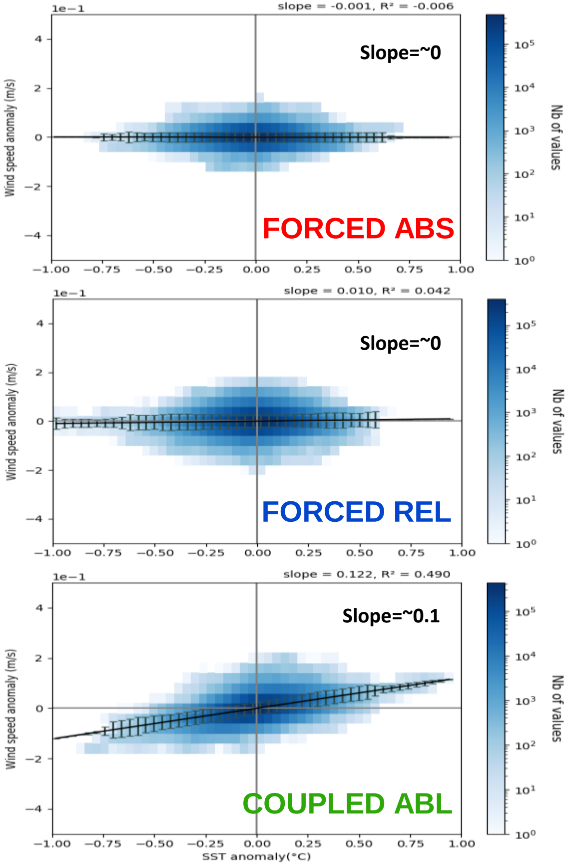
Mean surface EKE for the 2015-2016 period, IBI area

Thermal coupling



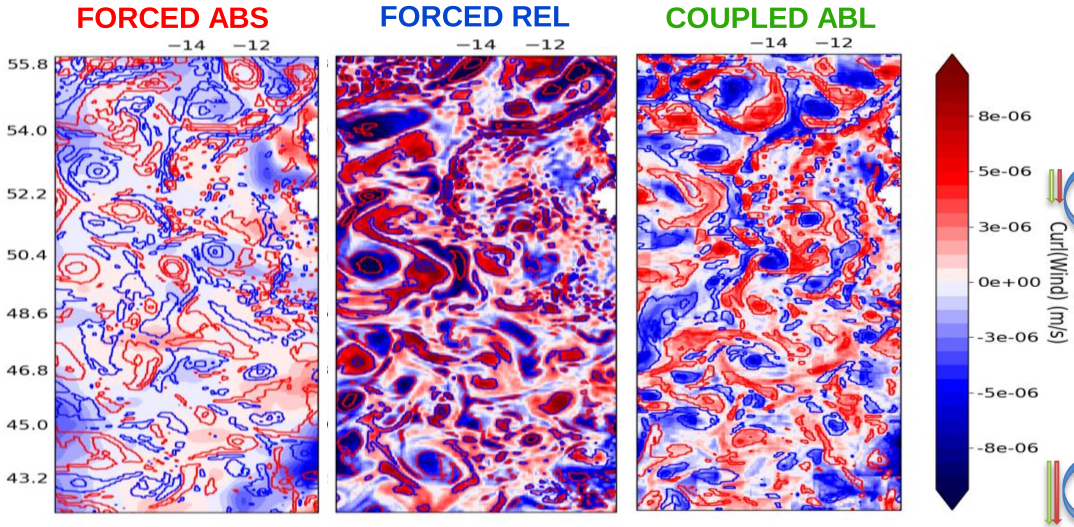
Sea Surface temperature (colours) and wind speed anomalies (contours)

Wind speed vs SST

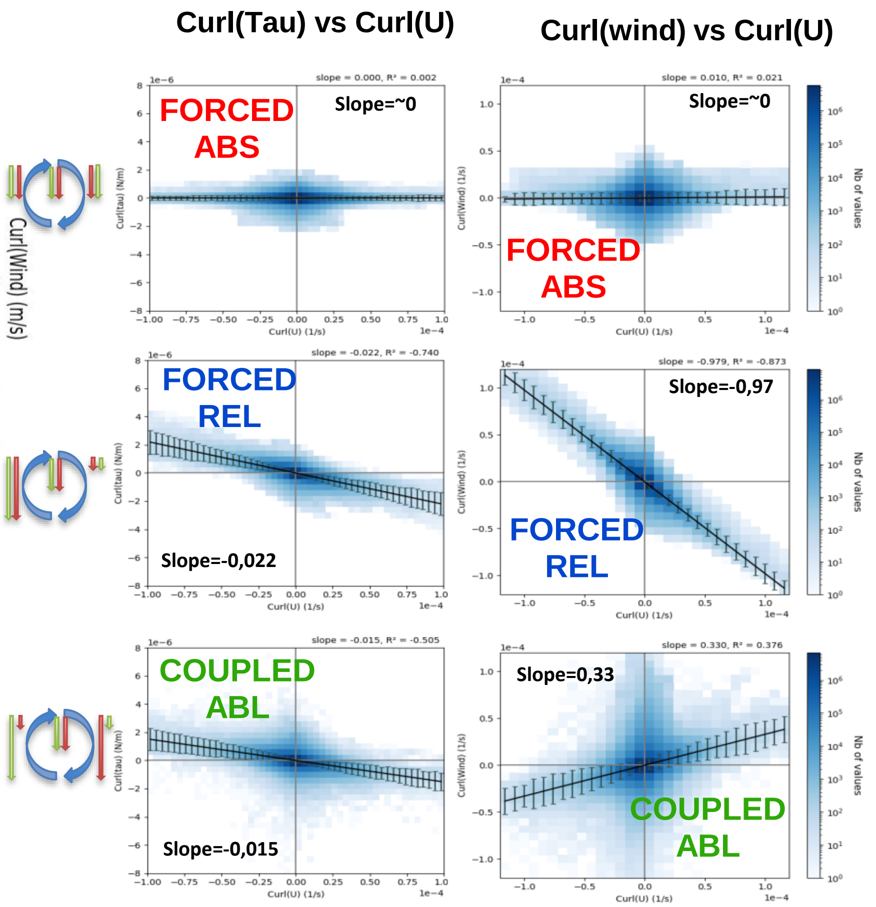


- Mesoscale anomalies: Filtered with a 150km wide gaussian filter
- No correlation between winds and SST anomalies for forced simulations
- Positive correlation between winds and SST anomalies in ABL

Dynamical coupling

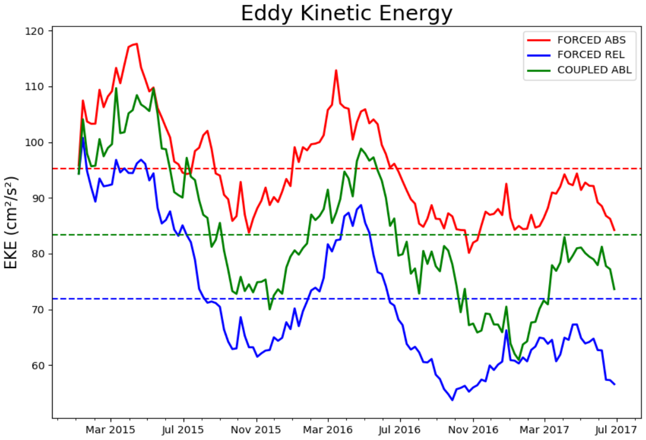


Surface wind curl (colours) and surface currents vorticity (contours)

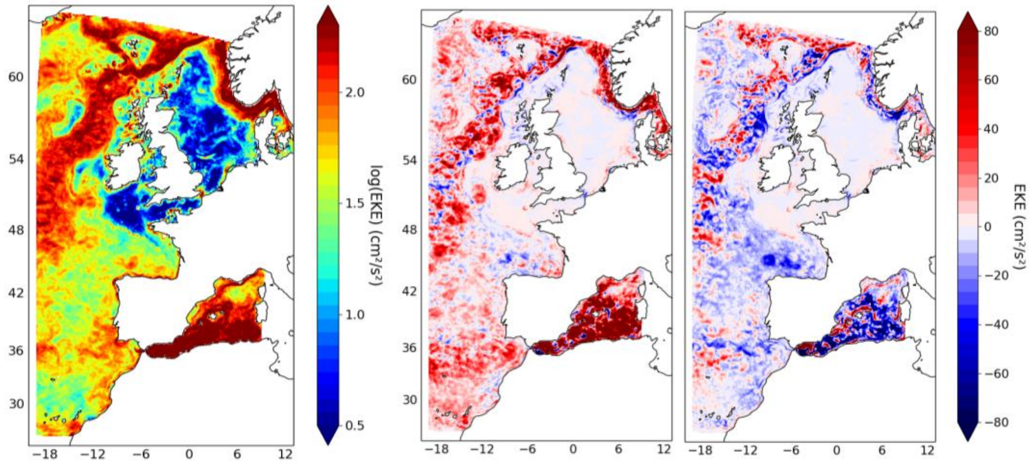


- BULK ABS: No correlation
- BULK REL: “Eddy killing”, Curl(Wind) (& Curl(τ)) opposed to Curl(U) -> Loss of EKE
- ABL: Curl(Wind) adapts to Curl(τ), partial re-energisation of the ocean
- **ABL1D is able to reproduce dynamical and thermal feedback**

ABL1D impact on ocean dynamics



Ocean Eddy kinetic energy (mean over IBI area) time series



EKE(COUPLED ABL)

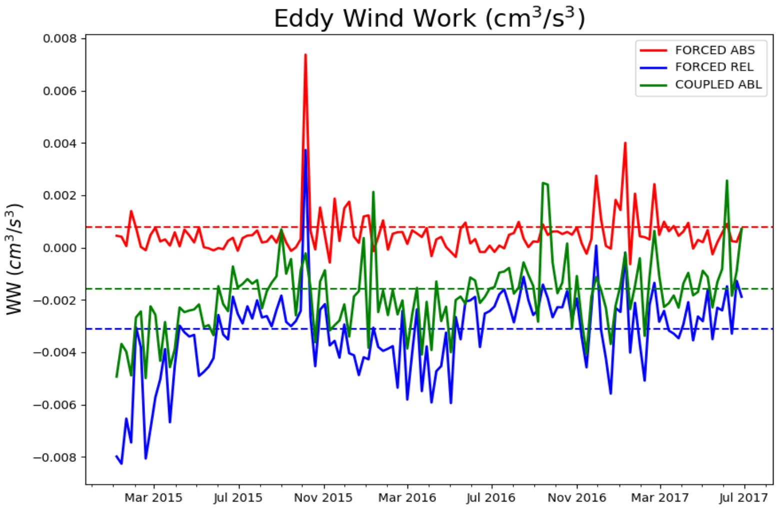
EKE(FORCED ABS) – EKE(COUPLED ABL)

EKE(FORCED REL) – EKE(COUPLED ABL)

- Reduction of ocean EKE by relative winds, reduction of ~ -25% of EKE and ~ -10% of total KE
- Ocean partial re-energisation when coupling with ABL -> ~ + 13% of EKE and ~ + 5% of total KE

- > What are the main mechanisms that modify EKE ?

ABL1D impact on wind work



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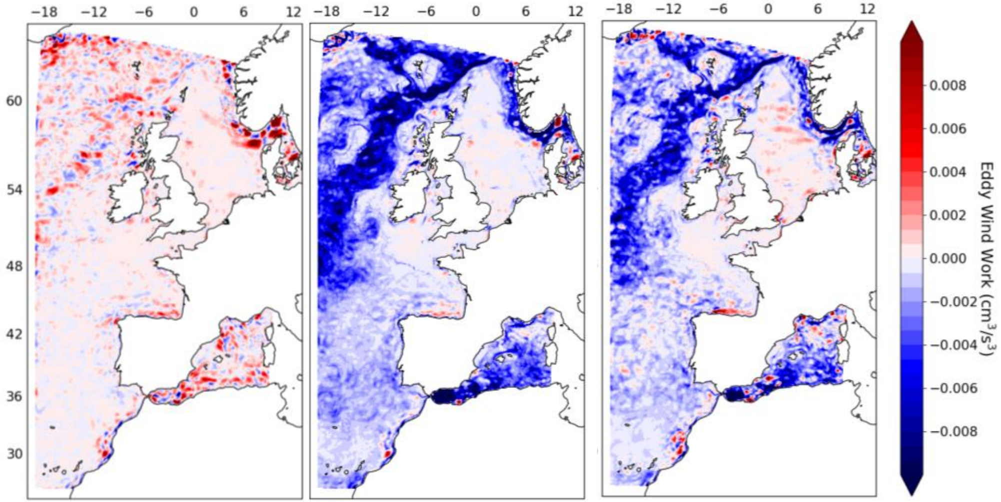

FORCED ABS FORCED REL COUPLED ABL

Mean eddy wind work over the period 2015 - 2016

- BULK REL and ABL1D small scale current feedback induce negative Eddy Wind Work
  -> Loss of energy at mesoscales

- ABL1D dynamical feedback: Wind adapts to change in surface stress
  -> Wind work less negative for ABL

Conclusion

- ABL1D model reproduce key mechanisms of Air-sea interactions at mesoscales
- Reproduce the current feedback mechanism and partial re-energisation of the ocean.
- Reproduce wind adaptation to SST from turbulent processes
- Reduced computational cost (+10% only)
- ABL1D reduces EKE by 13%, FORCED REL by 25%
- Perspectives:
  - Validation with in-situ and satellite data
  - Comparison with a fully coupled ocean-atmosphere model