An atmospheric boundary layer model to represent mesoscale air-sea interactions in eddying ocean models

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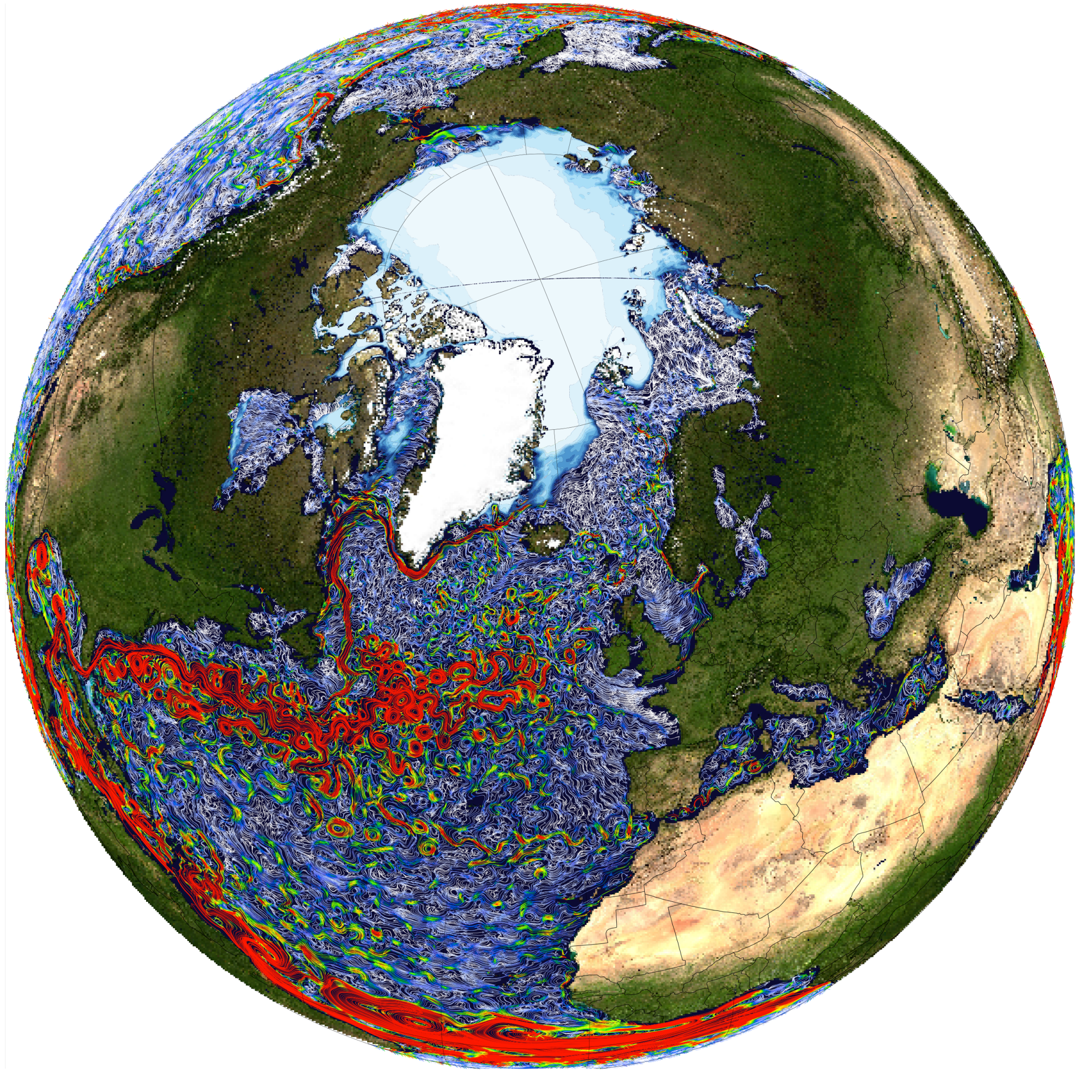
Context & Objectives



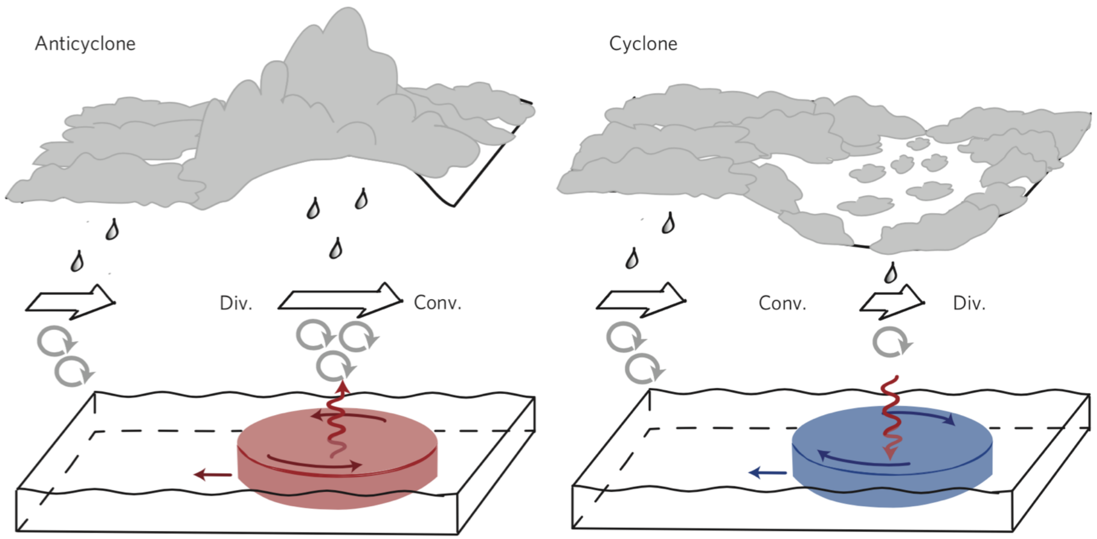
Sea surface current snapshot from ORCA12

- Mesoscale oceanic eddies well resolved at 1/12° resolution
- Mesoscale eddies influence the lower atmosphere (Chelton et. al. 2007, Small et. al. 2008)
- Energy transfers modulated by air-sea interactions at mesoscale (Renault et al. 2016)
- Coupled ocean-atmosphere models at high-resolution needed to represent it (Jullien et al. 2019)

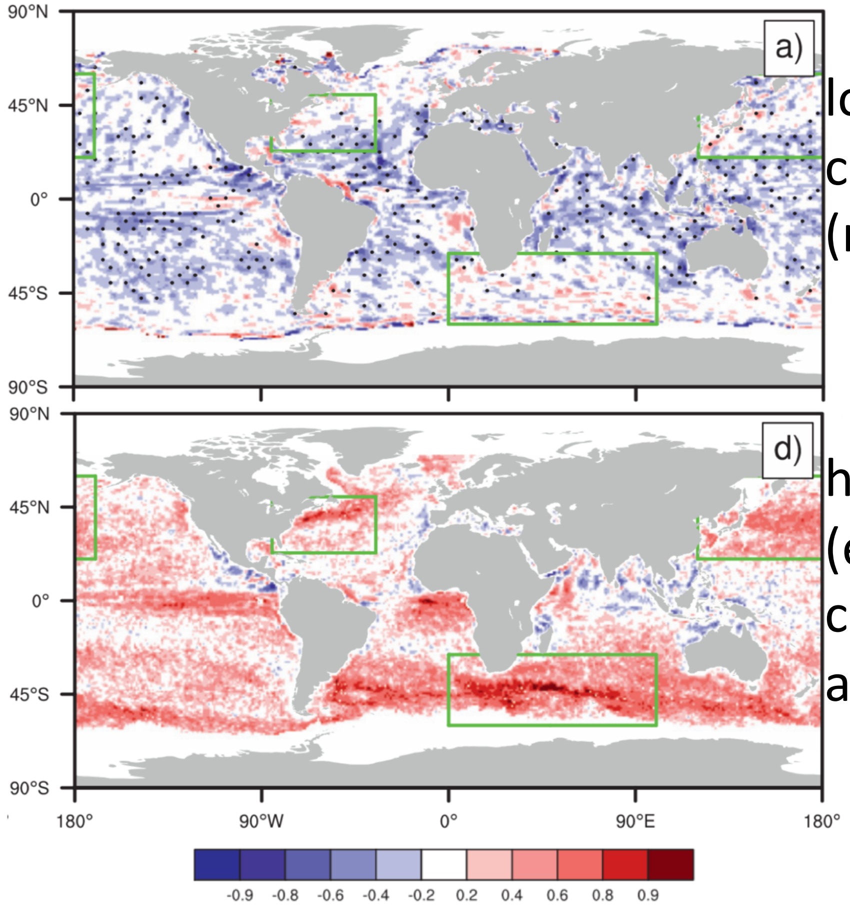
Context & Objectives

- Air-sea interactions at mesoscale = 2 mechanisms

  SST thermal feedback + current dynamical feedback



Relationship between SST anomalies and atmospheric turbulence, cloud cover and rainfall (Frenger 2013)



low-resolution (1°) coupled model (no mesoscale): **correlation < 0**

high-resolution (0.1°) (eddy resolving) coupled model and satellite data: **correlation > 0**

Correlation map of wind speed anomalies with SST anomalies (Bryan 2010)

Context & Objectives

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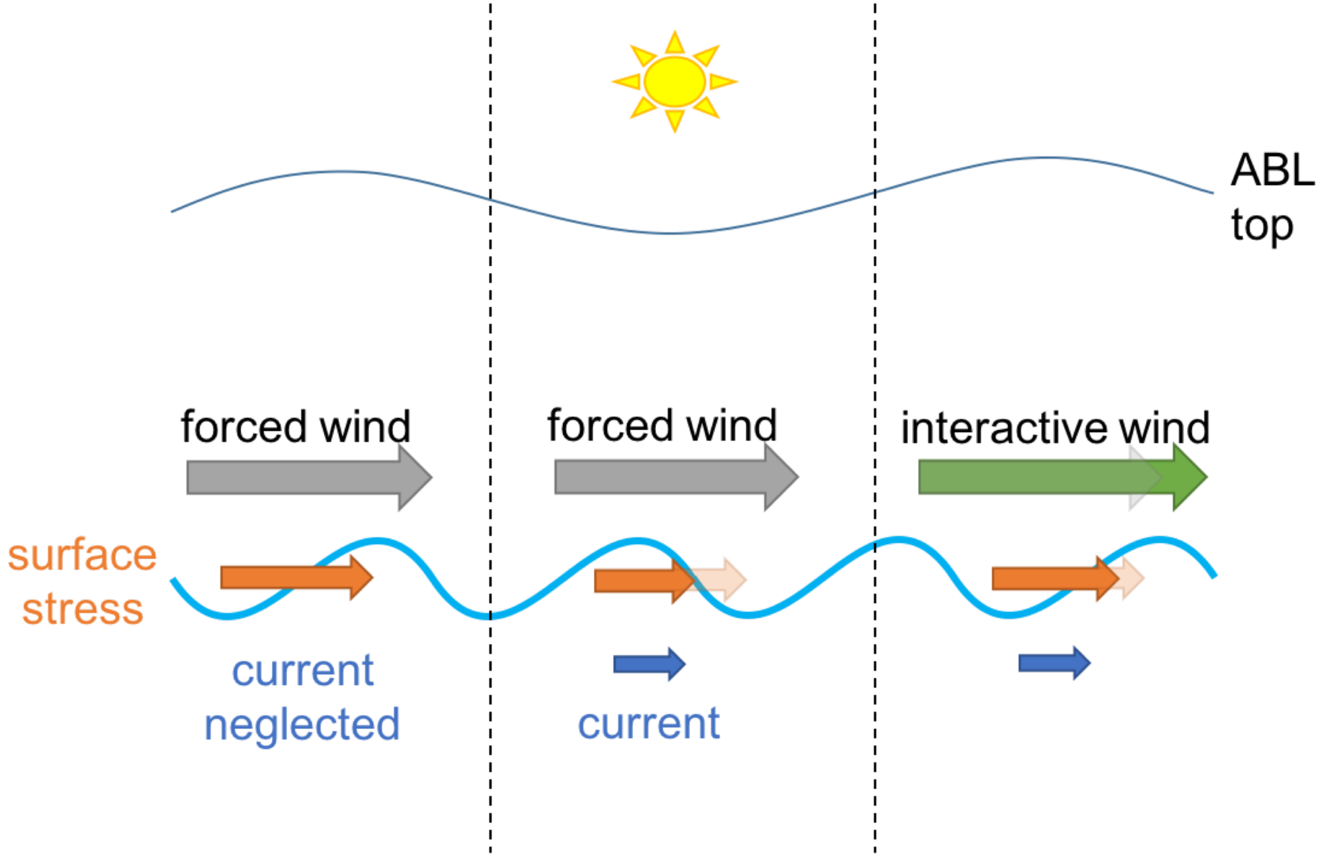
  SST thermal feedback + **current dynamical feedback**

3 ways to force an ocean model with wind:

- absolute wind ($U_{ATM\ FRC}$)
- relative wind ($U_{ATM\ FRC} - U_{OCE}$)
- coupled relative wind ($U_{ATM\ CPL} - U_{OCE}$)



$\tau = \varphi_a C_D U_{ATM}$

$\tau = \varphi_a C_D (U_{ATM} - U_{OCE})$

Context & Objectives

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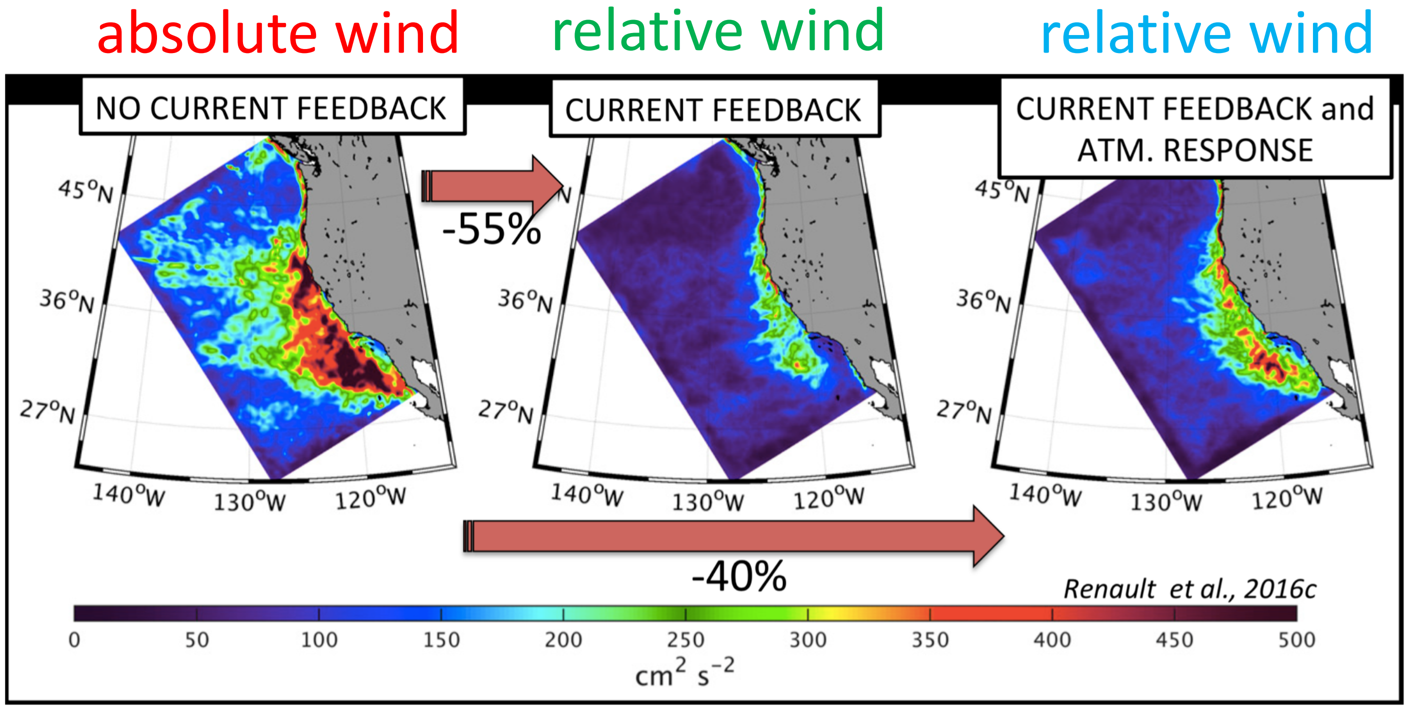
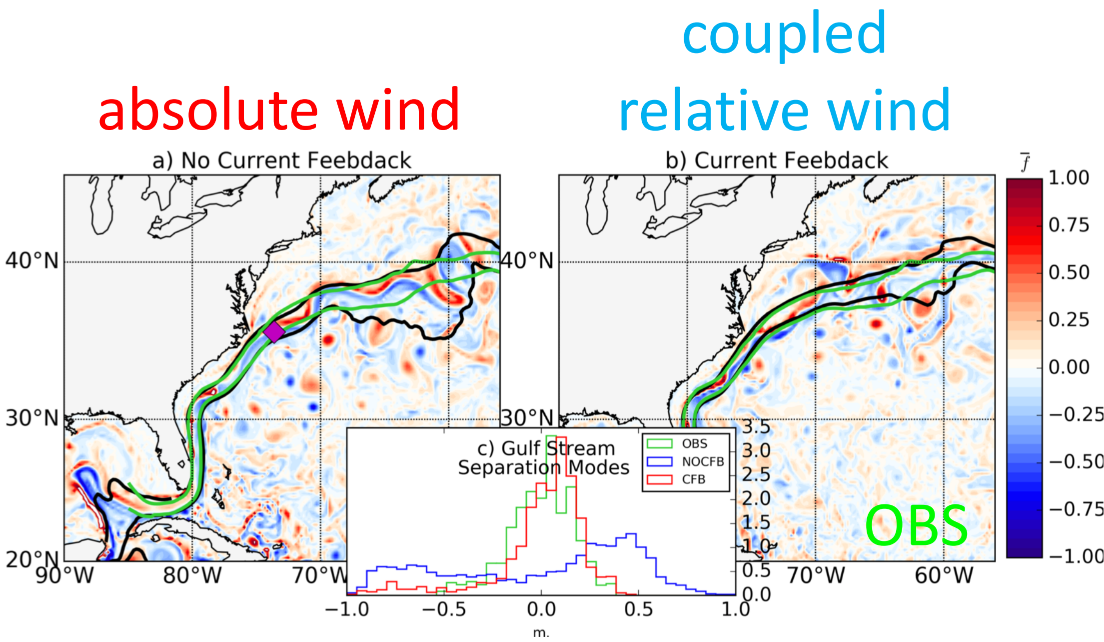
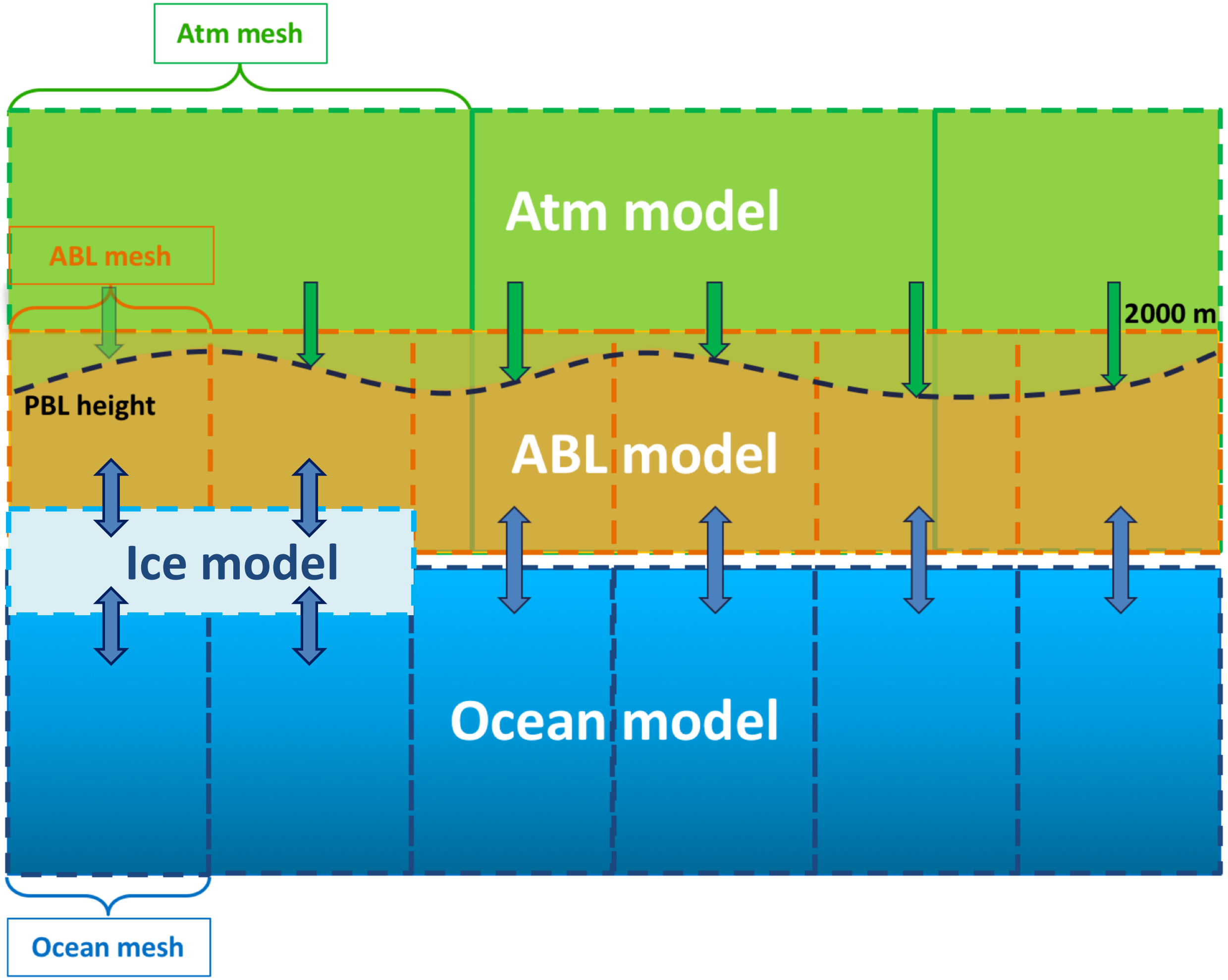


EKE in California eastern boundary upwelling system (Renault et al. 2016)



Gulfstream path stabilization (Renault et al. 2019)

Modelling strategy: OCEAN-ABL1D coupled model



- single column (1D) version
- 1.5-order TKE closure (Cuxart et al. 2000) with 3 possible mixing lengths
- same Δx and Δt as the ocean model
- compatible with sea-ice
- weak numerical cost (+10%)
- prognostic wind (u_h), temperature (θ) and humidity (q)
- driven by large-scale data from atmospheric model (forecast, reanalysis,…)
- precipitation and radiative fluxes not modified

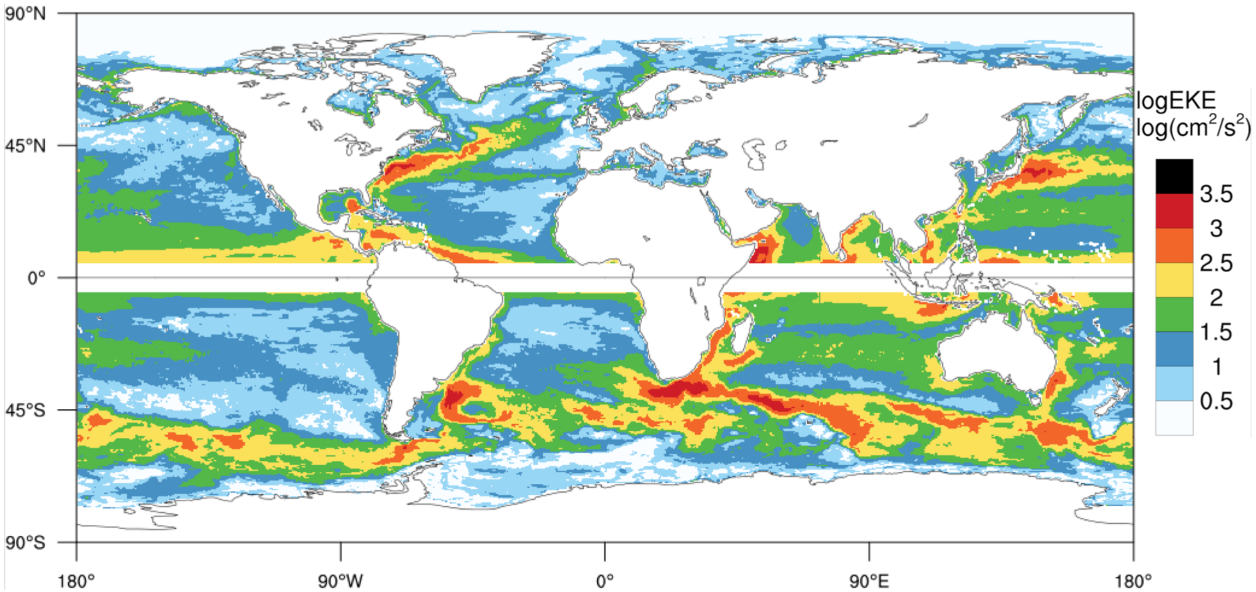
Experimental Setup

NEMO setup:

- NEMO ocean & SI^3 sea-ice models (v4.0)
- ORCA (tripolar) 0.25° grid with 75 vertical z-levels
- Atmospheric forcing: ECMWF Era-Interim (6h at 0.75°)
- Period: 2014-2018
  (after one-year spinup started from Mercator reanalysis)

ABL setup:

- 50 vertical levels (from 10m to 2000m)
- Deardorff (1980) turbulent mixing length
- Tracers relaxation time: 0.5h above PBL, 1.5h inside
- Horizontal pressure gradient (from ERAI) dynamical forcing
  (geostrophic guide)



Simulated mean surface geostrophic EKE for the 2014-2018 period

4 global ¼° ocean simulations:

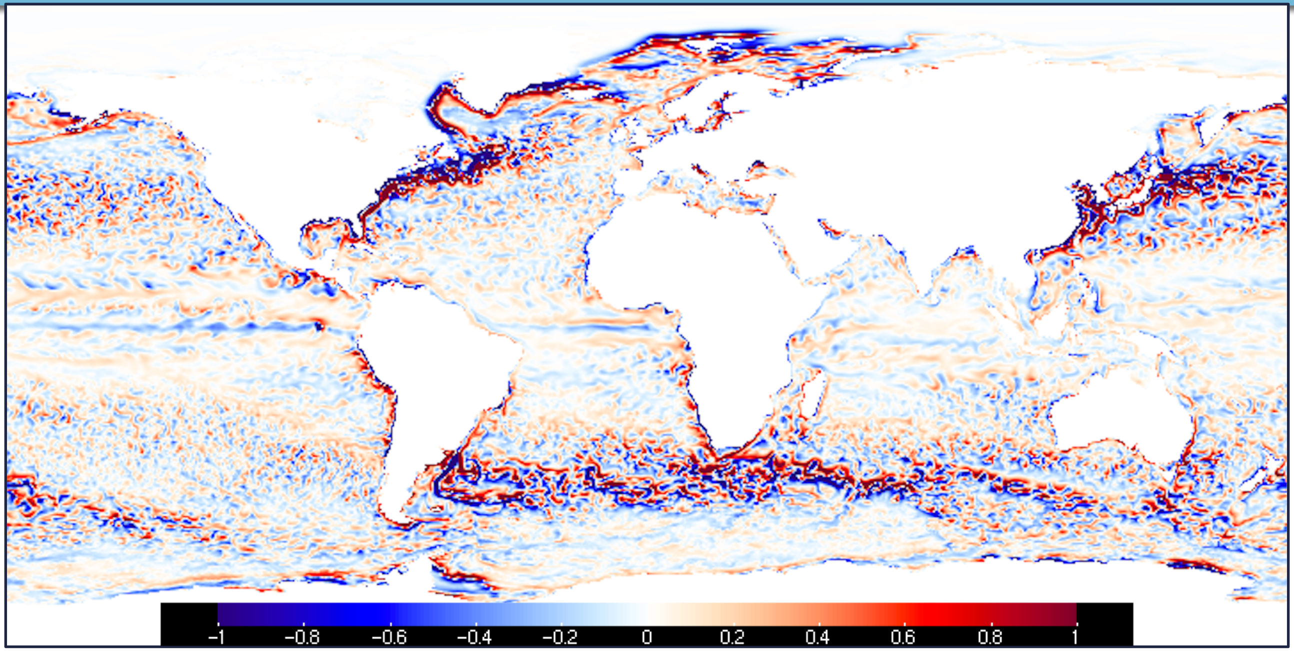
- Forced with absolute winds (U = Uatm) : **FRC_ABS**
- Forced with relative winds (U = Uatm – Uoce) : **FRC_REL**
- Coupled NEMO-ABL with absolute winds : **ABL_ABS**
- Coupled NEMO-ABL with relative winds : **ABL_REL**

Analysis:

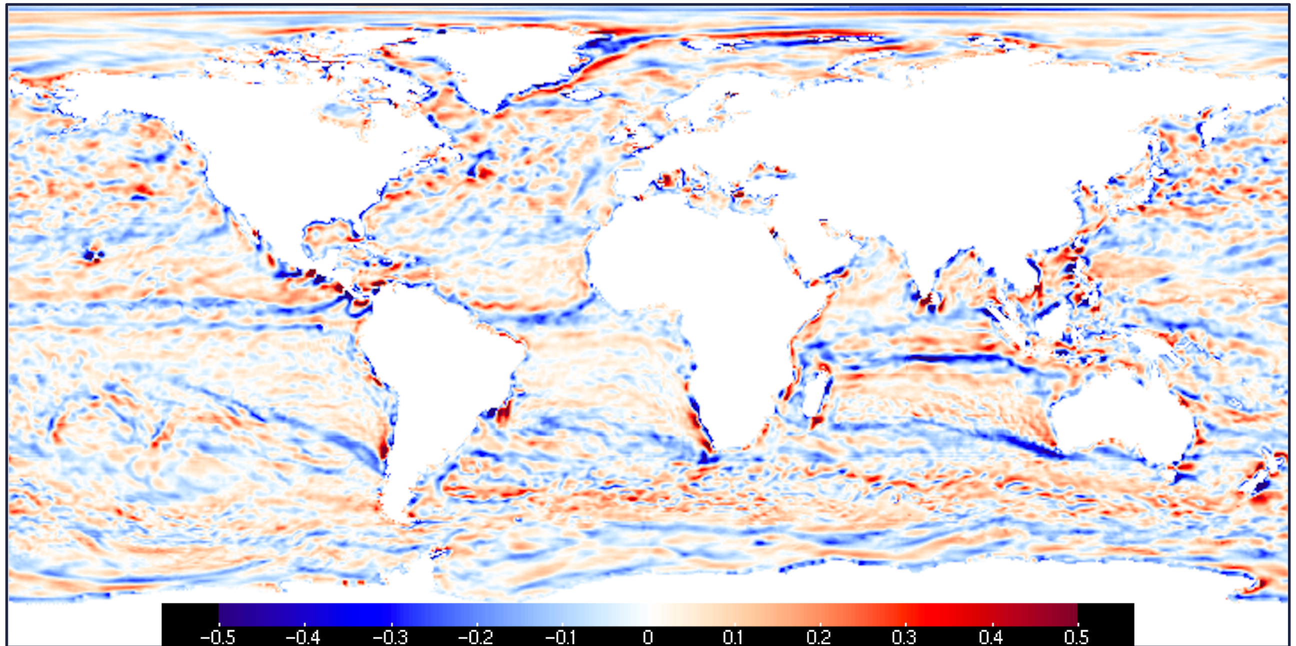
- Gaussian spatial filter (~250 km cutoff) to extract mesoscale anomalies from daily averaged outputs

Mesoscale filtering (< 250 km)

SST anomaly (°C)



10m wind anomaly (m/s)



Gaussian spatial filter
to extract mesoscale anomalies
from daily averaged outputs

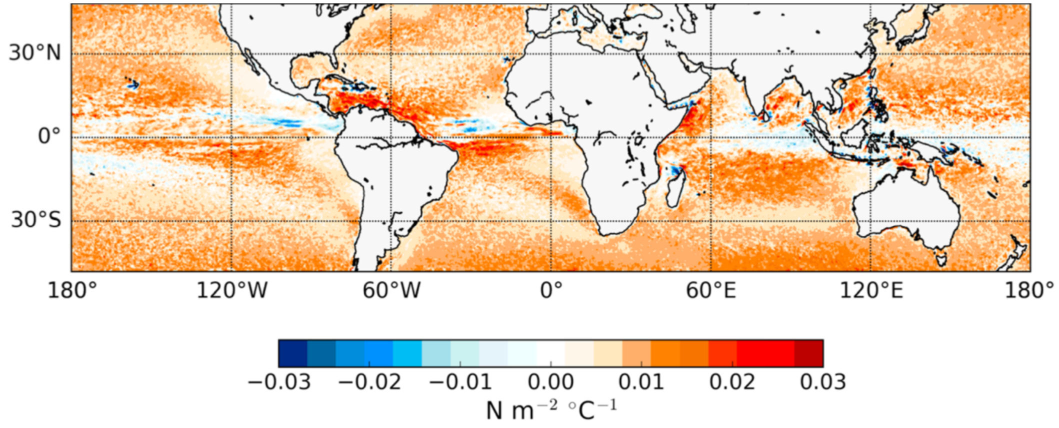
Applied to:

- SST
- STRESS
- WIND

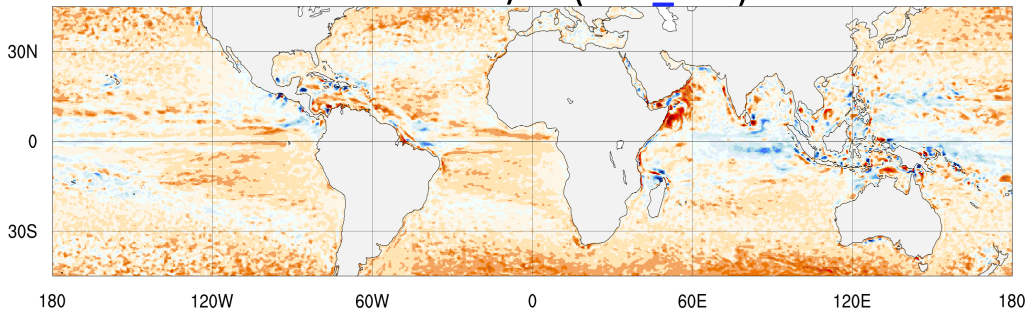
- CURRENT CURL
- STRESS CURL
- WIND CURL

SST thermal feedback

NEMO-WRF 1/12° (*Renault et al. 2019*)

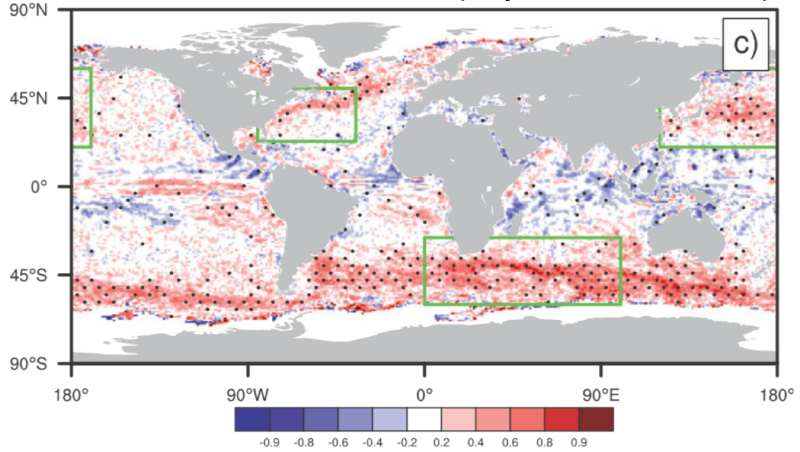


NEMO-ABL 1/4° (**ABL_REL**)

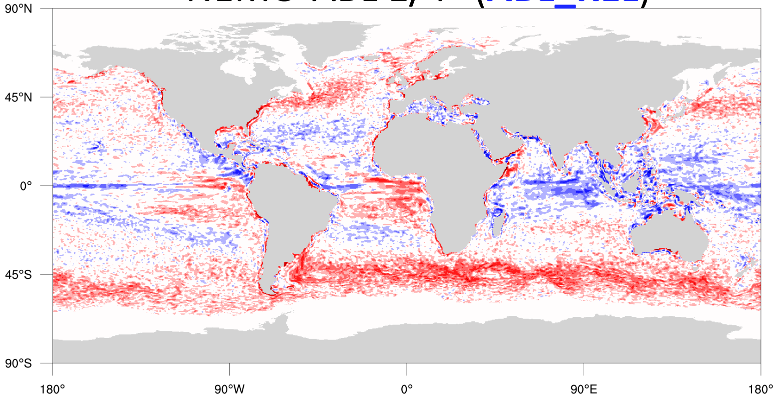


Linear regression coefficient map
between SST and stress mesoscale anomalies

OCE 0.1° - CAM 0.25° (*Bryan et al. 2010*)



NEMO-ABL 1/4° (**ABL_REL**)

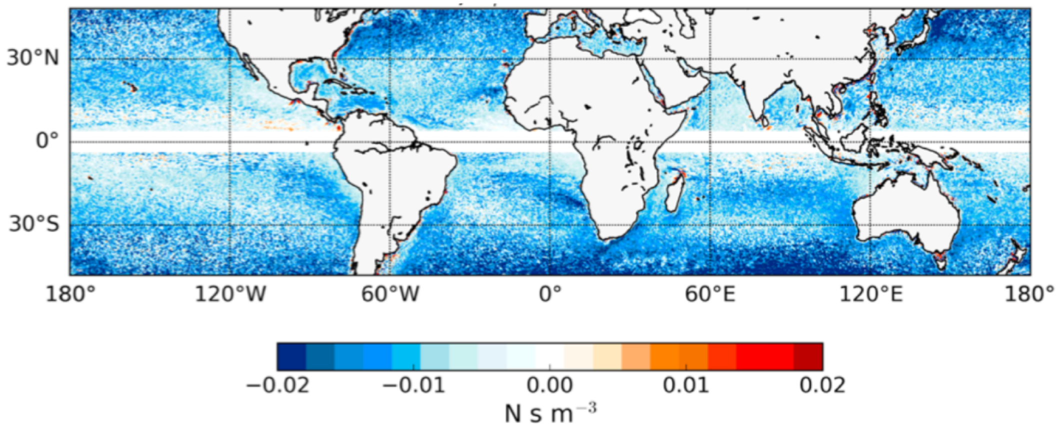


Time correlation coefficient map
between SST and 10m wind mesoscale anomalies

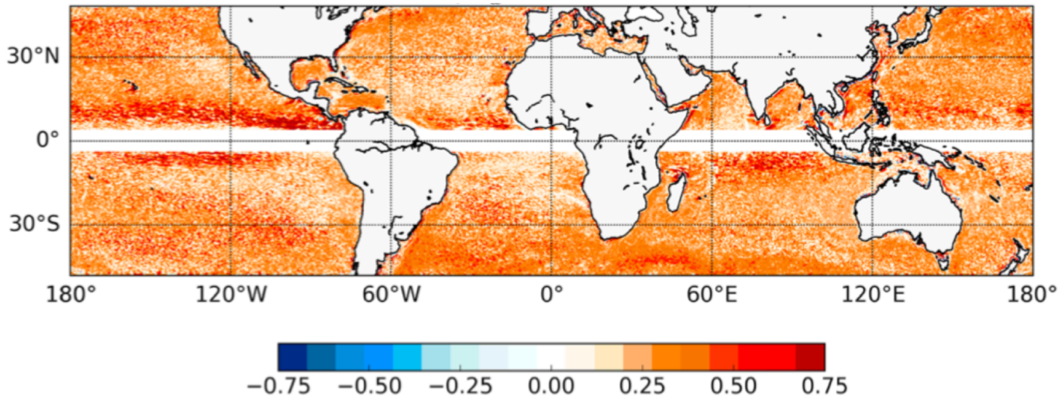
- Comparison between classic ocean-atmosphere coupled models and NEMO-ABL
- Mesoscale coupling between SST, stress and wind similar to fully coupled models (strength, pattern, relationship)
- SST-stress coupling underestimated due to model resolution ? relaxation time toward atmospheric reanalysis ?

Current dynamical feedback

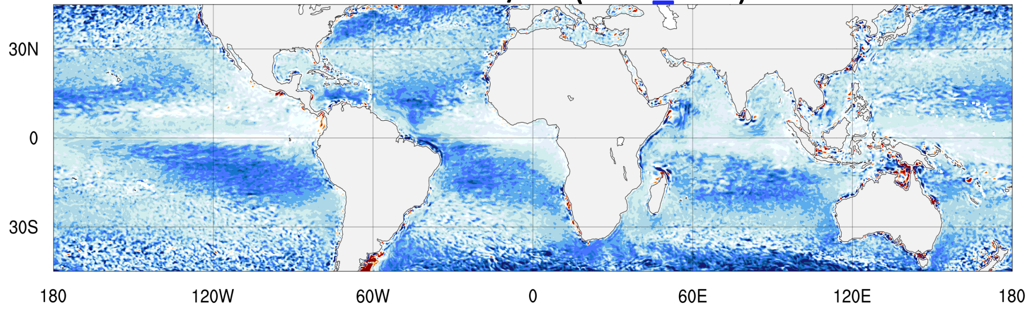
NEMO-WRF 1/12° (*Renault et al. 2019*)



NEMO-WRF 1/12° (*Renault et al. 2019*)

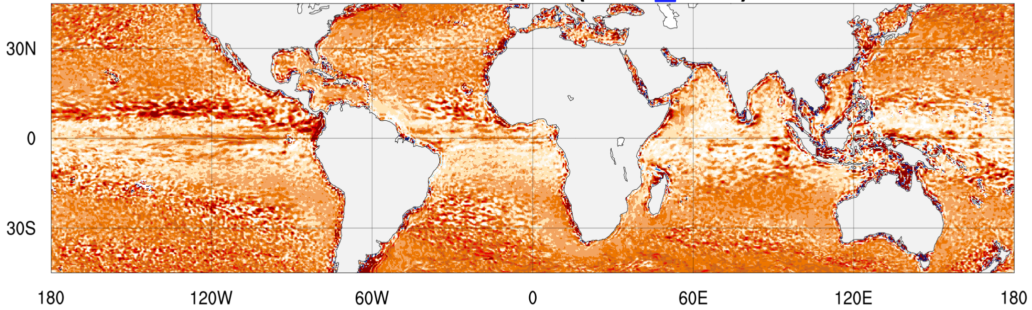


NEMO-ABL 1/4° (**ABL_REL**)



Linear regression coefficient map
between current curl and stress curl anomalies

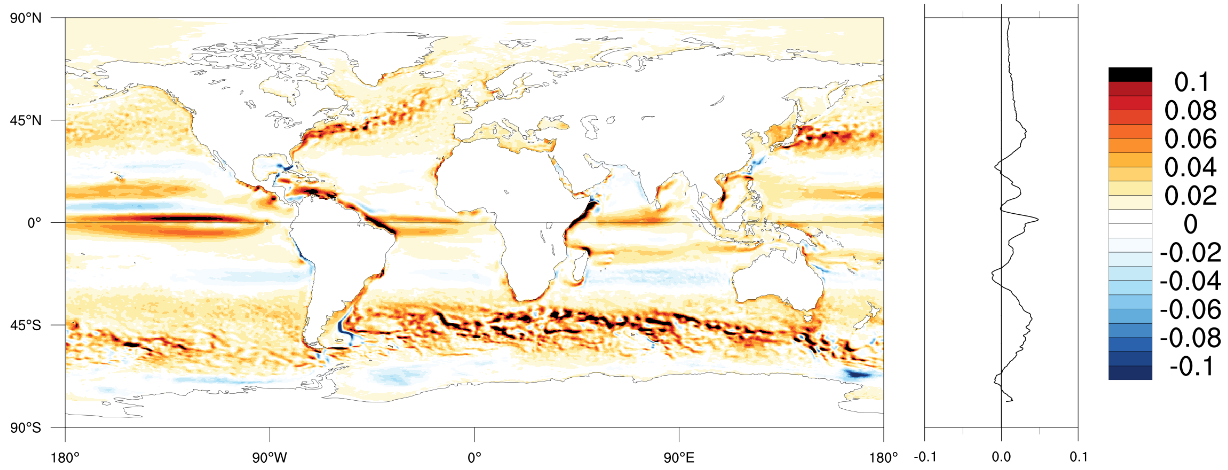
NEMO-ABL 1/4° (**ABL_REL**)



Linear regression coefficient map
between current curl and 10m wind curl anomalies

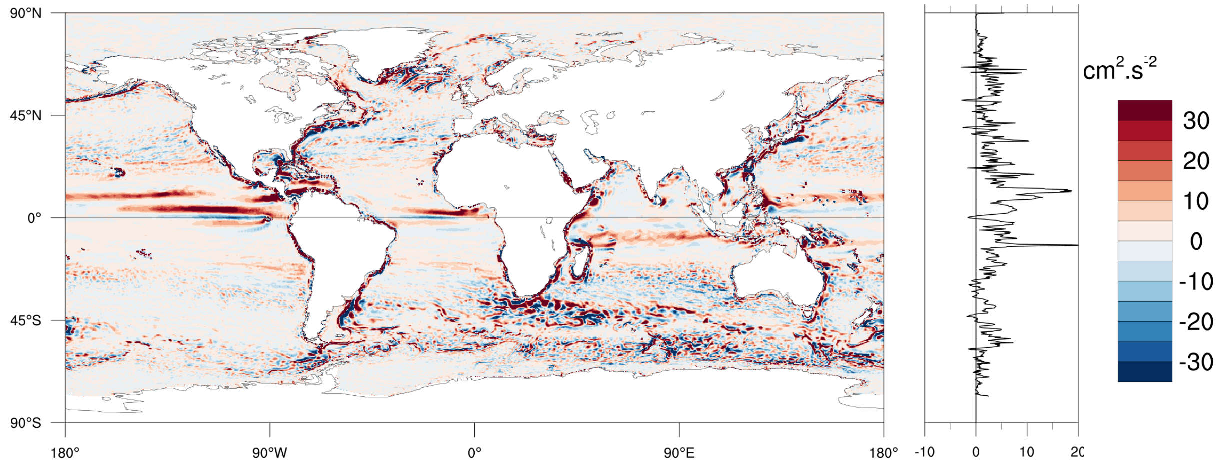
- Comparison between classic ocean-atmosphere coupled model and NEMO-ABL
- Realistic negative mesoscale coupling between current curl and stress curl ("eddy killing" effect)
- Positive mesoscale coupling between current curl and wind curl in good agreement with NEMO-WRF coupled model

ABL-current feedback effect on ABL wind



5-year averaged 10m **wind speed** ABL_REL - ABL_ABS difference (m/s)

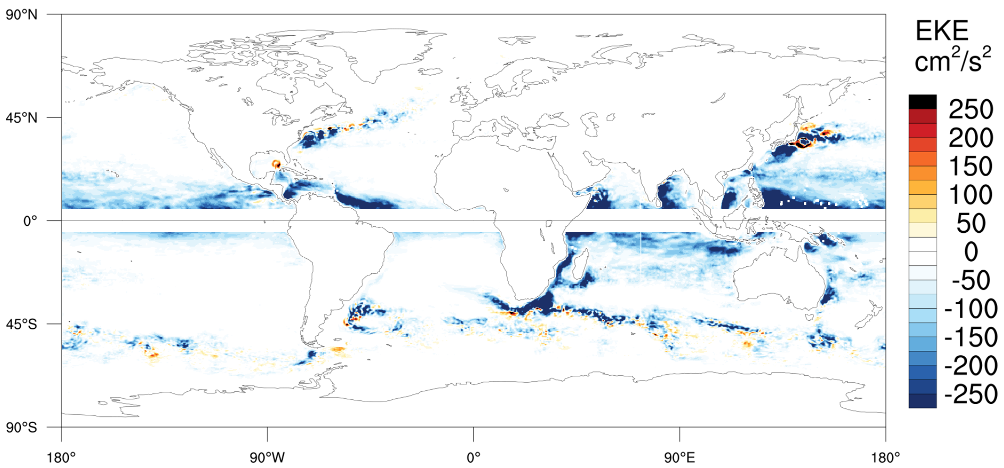
- Global wind speed adjustment to CFB
- Small global wind speed increase (+5%)
- Local significant wind change (> 0.2 m/s) over WBC, ACC, Somali Current and Eq. Current



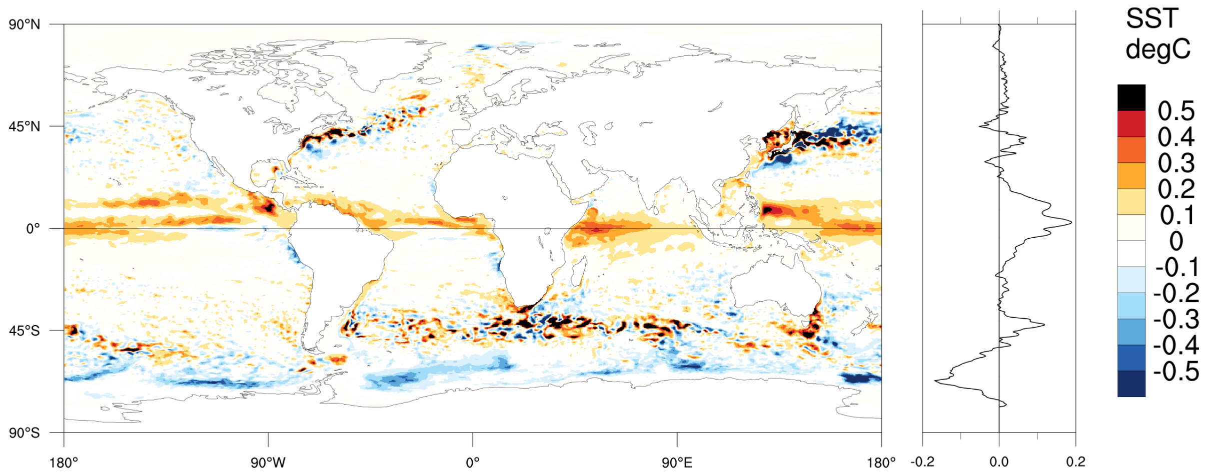
5-year averaged 10m **wind curl^2** ABL_REL - ABL_ABS difference (cm^2/s^2)

- curl^2 ≈ energy (cm^2/s^2)
- Global wind curl increase due to CFB
- Poleward shift in WBC regions
- Strong signature along coasts
- Wind curl increase along the equatorial band

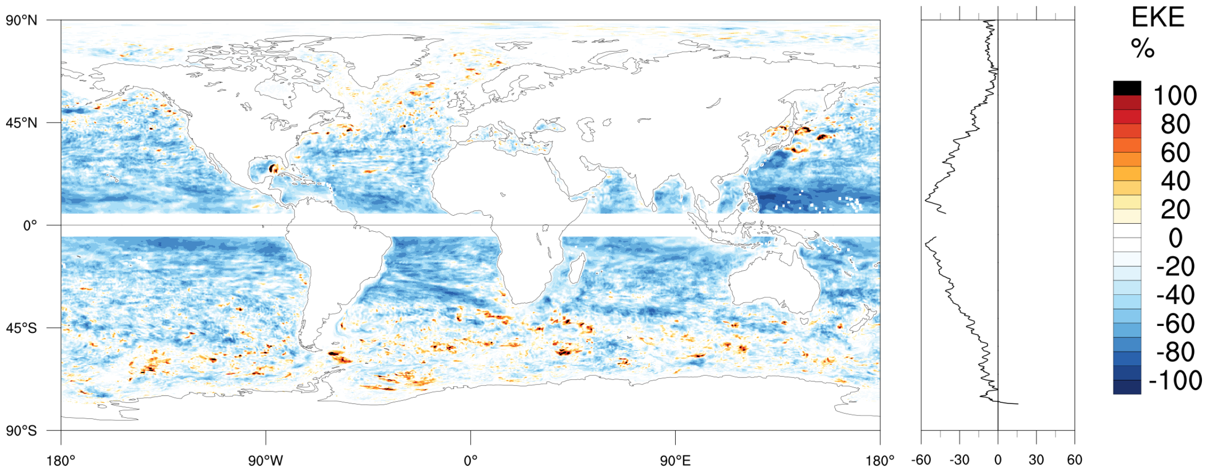
ABL-current feedback effect on ocean



5-year averaged geostrophic **EKE**
ABL_REL - **ABL_ABS** difference (cm²/s²)



5-year averaged **SST** **ABL_REL** - **ABL_ABS** difference (degC)



5-year averaged geostrophic **EKE**
ABL_REL - **ABL_ABS** relative difference (%)

- Strong EKE decrease in energetic regions
- Relatively homogenous global EKE decrease (-25%)
- From -15% at high-latitudes to -50% in eq. regions

- Global SST increase with +0.1°C zonal-mean at ±45° and +0.2°C zonal-mean along the equator
- Local strong SST shift in WBC and Agulhas current
- SST decrease in Antarctic region due sea-ice cover increase in **ABL_REL**

Conclusions & Perspectives

Conclusions

Our ABL model is able to accurately represent mesoscale air-sea interactions (SST thermal and Current dynamical feedbacks) and their effect on near-surface atmosphere (wind speed and curl increase) and upper ocean (EKE decrease, SST increase)

It can be used in replacement of a full atmospheric model in ocean-oriented studies :

- with a marginal numerical cost (ocean model + 10%)
- at the same resolution as the ocean model (dynamical downscaling of the large-scale atmospheric forcing)
- with a near-surface atmosphere coherent with ocean and sea-ice surface conditions
- with the same consistency and chronology as the large-scale atmospheric forcing

Perspectives

- **Available in next NEMO release (v4.2)**
- 2 publications to be submitted on ABL model implementation and application in a regional 1/36° configuration
- Application to Mercator-Ocean future reanalysis products (GLORYS)
- Longer term: 1D -> 3D version

Thank you

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