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Toward an improved representation of air-sea interactions in high-resolution global oceanic forecasting systems

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General context : air-sea interactions in eddying models

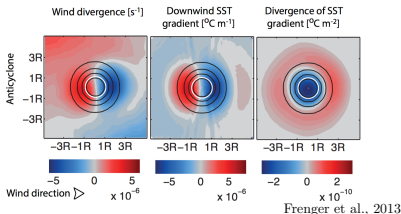
Thermal coupling

- Downward mixing (e.g. Chelton, 2013; Frenger et al., 2013)

$$\begin{cases} \nabla \times \boldsymbol{\tau} = c_1 \nabla \text{SST} \times \hat{\boldsymbol{\tau}} \\ \nabla \cdot \boldsymbol{\tau} = c_2 \nabla \text{SST} \cdot \hat{\boldsymbol{\tau}} \end{cases}$$

- Back pressure effect (e.g. Minobe, 2008; Lambaerts et al., 2013)

$$\nabla \cdot \boldsymbol{\tau} \propto -\|\nabla^2 \text{SST}\|$$

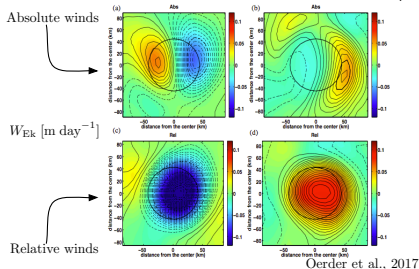


Dynamical coupling

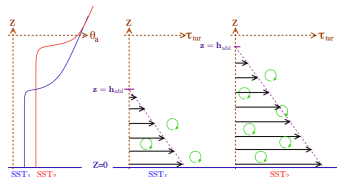
$$\boldsymbol{\tau} = \rho_a C_D \|\mathbf{u}_a - \mathbf{u}_o\| (\mathbf{u}_a - \mathbf{u}_o)$$

Acts as a "top drag" (e.g. Dewar & Flierl, 1987)

- Strongly reduced mesoscale activity (intensified eddy damping) (e.g. Renault et al., 2016)
- Strongly increases vertical velocity anomalies associated to eddies (e.g. Oerder et al., 2017)

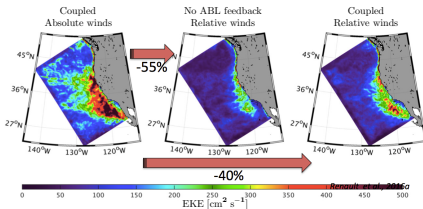


Important processes



Downward mixing
(Source: Oerder, 2016)

Dynamical coupling
(Source: Renault et al., 2016)



Strong interactions at the characteristic scales of the ocean meso-scale

- ▷ Proper representation of those interactions requires an interactive ABL
- ▷ Atmospheric resolution must be "eddy-resolving" (i.e. $\Delta x_{oce} = \Delta x_{atm}$)

Limitations of current practices in global models

→ **Bulk forcing** (i.e. via an atmospheric surface-layer parameterization)

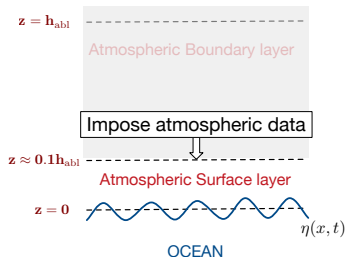
- effect of thermal coupling is under-estimated (no downward mixing)
- effect of dynamical coupling is over-estimated (wrong energy transfers)

→ **CheapAML** (Deremble et al., 2013)

- Designed for large scales (no thermal or dynamical coupling)

→ **Full-coupling**

- computationally unaffordable when $\Delta x_{oce} = \Delta x_{atm}$
- hard to find a good "set" of parameterizations
- Initialization issues

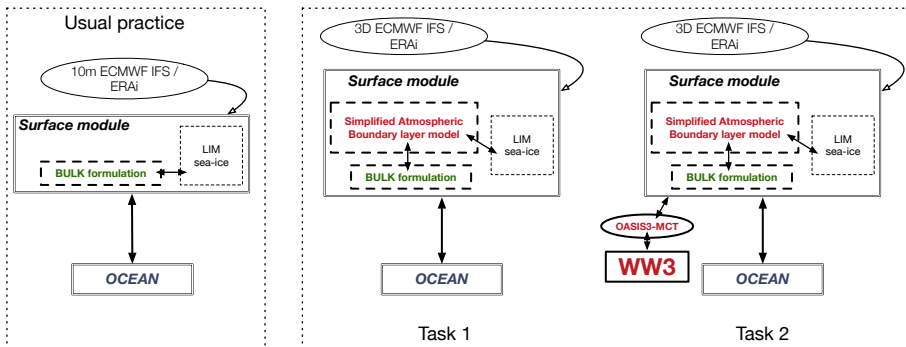


Objective: find an alternative to force an eddying global operational model

The ALBATROSS Project



- High-resolution ocean, waves, atmosphere interaction



General approach : dynamical downscaling of atmospheric data to the oceanic resolution via a simplified MABL model (called SIMBAD) guided by operational weather forecasts or reanalysis (e.g. ERAi, operational IFS)

Current status of the project (1/2)

1. Define a single-column model (SIMBAD1d)

Integrate winds \mathbf{u} , potential temperature θ and specific humidity q

$$\begin{cases} \partial_t \mathbf{u} &= f \mathbf{k} \times (\mathbf{u} - \mathbf{u}_G) + \partial_z (\mathbf{K}_m \partial_z \mathbf{u}) \\ \partial_t \theta &= \partial_z (\mathbf{K}_s \partial_z \theta) + \lambda_s (\theta - \theta_{LS}) \\ \partial_t q &= \partial_z (\mathbf{K}_s \partial_z q) + \lambda_s (q - q_{LS}) \end{cases}$$

Blue terms are specified via large-scale data

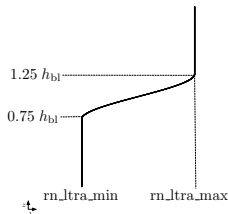
Red terms are given by turbulent closure

- ▷ **Radiative forcing** is kept as it is
- ▷ **Surface boundary conditions** for $K_m \partial_z \mathbf{u}|_{z=0}$, $K_s \partial_z \theta|_{z=0}$, $K_s \partial_z q|_{z=0}$

→ IFS bulk formulation

- ▷ used operationally at ECMWF
- ▷ consistent with large-scale data
- ▷ include sea-state and convective limit

- ▷ **Relaxation term** scales with PBL height



Current status of the project (2/2)

2. Turbulent closure scheme : TKE-based scheme of Cuxart et al. (2000)

- ▷ used operationally at Meteo-France (e.g. in Arome and Meso-NH models)
- ▷ recoded from scratch to allow more flexibility and better performances

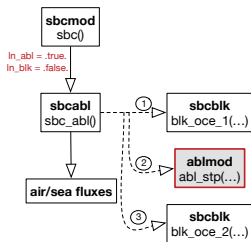
3. Development of preprocessing tools to handle 3D IFS data and extract geostrophic winds

4. Implementation in NEMO surface (SAS) module in a generic way

- Online interpolation of external 3D data
- Option to split NEMO and SAS on separate nodes
- Standalone mode
- MPI capability

→ **Computational cost** considering the default Mercator settings & 50 vertical levels in the ABL :

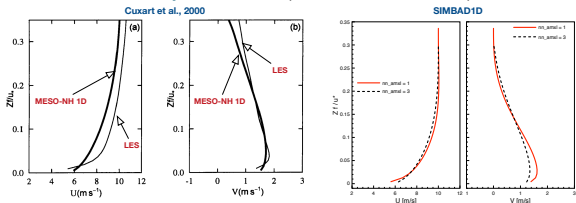
- + 12% in memory size
- + 7 - 12 % in elapsed time depending on namelist options



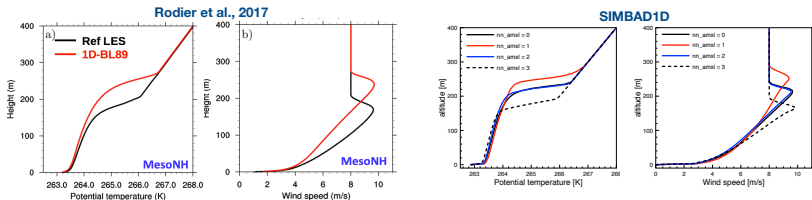
Current status of the validation strategy (1/2)

1. Validation of Simbad1d using standardized test-cases from the ABL community (see GABLS initiative)

→ Neutral turbulent Ekman layer at 45°N (Cuxart et al., 2000)

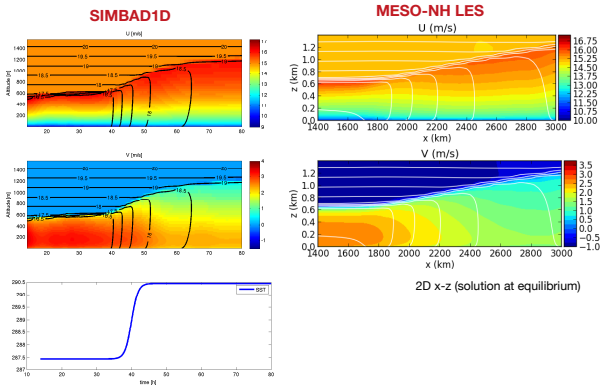


→ Stably stratified boundary layer (typical situation over sea-ice)



Current status of the validation strategy (2/2)

2. Winds across a Midlatitude SST Front (Kilpatrick et al., 2014)



3. NEMO1D / SIMBAD1D coupling at the PAPA station (50.1°N , 144.9°W)

→ MSc of Théo Brivoal

- Extension of the work of Reffray et al. (2015) with NEMO to the coupled case

Expected benefits for CMEMS services

Expected benefits of added feedback loops :

- Consistent integration of each media (**proper energy transfers**)
- Impact on **mixed layer extent** and surface currents in ocean forecasting
- Better forcing of the **dynamics in the tropics** (improved seasonal forecasts?)
- Account for the effect of **tropical cyclones** in oceanic reanalysis
- Wind-SST and Wind-current interactions have strong **impact on biogeochemistry**

Perspectives & ongoing work

- **R. & D.**

- Increased level of complexity in the MABL reduced model (add horizontal/vertical advection and fine-scale pressure gradient)
→ Simbad2d, Simbad3d
- SIMBAD over sea-ice (multi-surface option) + waves
- Initialization of the NEMO/SIMBAD coupled system (in collaboration with Arthur Vidard, Inria)

- **Validation strategy**

- Global standalone simulation of SIMBAD relaxed toward ERAi & comparison with ERAi fluxes + sensitivity to oceanic data resolution
- North-East Atlantic realistic simulation ($1/12^0$) & comparison with fully coupled MESONH/NEMO simulations (PhD T. Brivoal)

Ongoing work & perspectives

- Initialization of the NEMO/SIMBAD coupled system
(in collaboration with Arthur Vidard, Inria)

Objectives :

- Avoid initialization shocks (e.g. Mulholland et al. 2015) and more generally inconsistencies at the interface
→ consistency of air-sea fluxes in the analyzed state
- Account for cross-correlations in the error covariance matrices
→ ensemble method
- Enforce good regularity in time
→ iterative ensemble Kalman smoother (IEnKS)