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

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1. **Thermal coupling**

   - Downward mixing (e.g. Chelton, 2013; Frenger et al., 2013)
     \[
     \begin{align*}
     \nabla \times \tau &= c_1 \nabla \text{SST} \times \hat{\tau} \\
     \nabla \cdot \tau &= c_2 \nabla \text{SST} \cdot \hat{\tau}
     \end{align*}
     \]

   - Back pressure effect (e.g. Minobe, 2008; Lambaerts et al., 2013)
     \[
     \nabla \cdot \tau \propto -\| \nabla^2 \text{SST} \|
     \]

2. **Dynamical coupling**

   \[
   \tau = \rho_a C_D \| \mathbf{u}_a - \mathbf{u}_o \| (\mathbf{u}_a - \mathbf{u}_o)
   \]

   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. $\Delta x_{\text{oce}} = \Delta x_{\text{atm}}$)
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

**Usual practice**

- 10m ECMWF IFS / ERAi
- Surface module
  - BULK formulation
  - LIM sea-ice
- OCEAN

**Task 1**

- 3D ECMWF IFS / ERAi
- Surface module
  - Simplified Atmospheric Boundary layer model
  - BULK formulation
  - LIM sea-ice
- OCEAN

**Task 2**

- 3D ECMWF IFS / ERAi
- Surface module
  - Simplified Atmospheric Boundary layer model
  - BULK formulation
  - LIM sea-ice
- WW3

**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 $u$, potential temperature $\theta$ and specific humidity $q$

\[
\begin{align*}
\frac{\partial}{\partial t} u &= f k \times (u - u_G) + \partial_z (K_m \partial_z u) \\
\frac{\partial}{\partial t} \theta &= \partial_z (K_s \partial_z \theta) + \lambda_s (\theta - \theta_{LS}) \\
\frac{\partial}{\partial t} q &= \partial_z (K_s \partial_z q) + \lambda_s (q - q_{LS})
\end{align*}
\]

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 $K_m \partial_z u|_{z=0}$, $K_s \partial_z \theta|_{z=0}$, $K_s \partial_z q|_{z=0}$

→ 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 $45^0$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)

![SIMBAD1D](image1)

![MESO-NH LES](image2)

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 ($\frac{1}{12^0}$) & 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)