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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**

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

\[
\begin{align*}
\nabla \times \tau &= c_1 \nabla \text{SST} \times \hat{\tau} \\
\nabla \cdot \tau &= c_2 \nabla \text{SST} \cdot \hat{\tau}
\end{align*}
\]

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

\[\nabla \cdot \tau \propto -\| \nabla^2 \text{SST} \|\]

**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)

---

Absolute winds

Relative winds

\[W_{Ek} \text{ [m day}^{-1}\text{]}\]

Frenger et al., 2013

Oerder et al., 2017
Important processes

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)

→ **CheapAMLM** (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**

**OCEAN**

**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 \( q \)

\[
\begin{align*}
\partial_t u &= f_k \times (u - u_G) + \partial_z (K_m \partial_z u) \\
\partial_t \theta &= \partial_z (K_s \partial_z \theta) + \lambda_s (\theta - \theta_{LS}) \\
\partial_t q &= \partial_z (K_s \partial_z q) + \lambda_s (q - q_{LS})
\end{align*}
\]

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
\[K_m \partial_z u \big|_{z=0}, \ K_s \partial_z \theta \big|_{z=0}, \ K_s \partial_z q \big|_{z=0}\]

→ 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

\[ \text{sbcmod} \]
\[ \text{sbc()} \]
\[ \text{sbcabl} \]
\[ \text{sbc_abl()} \]
\[ \text{sbcblk} \]
\[ \text{blk_oce_1(…)} \]
\[ \text{sbcblk} \]
\[ \text{blk_oce_2(…)} \]
\[ \text{air/sea fluxes} \]
\[ \text{ablmod} \]
\[ \text{abl_stp(…)} \]
\[ \text{ln_abl} = \text{.true.} \]
\[ \text{ln_blk} = \text{.false.} \]
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 $45^0\text{N}$ (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**
- **MESO-NH LES**

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°) & 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)