



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

Florian Lemarié, Guillaume Samson, Jean-Luc Redelsperger, Hervé Giordani, Gurvan Madec

► To cite this version:

Florian Lemarié, Guillaume Samson, Jean-Luc Redelsperger, Hervé Giordani, Gurvan Madec. Toward an improved representation of air-sea interactions in high-resolution global ocean forecasting systems. EGU 2017 - European Geosciences Union General Assembly, Apr 2017, Vienna, Austria. pp.1-19. hal-01660799

HAL Id: hal-01660799

<https://inria.hal.science/hal-01660799>

Submitted on 15 Jan 2018

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

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

F. Lemarié¹, G. Samson², J.L. Redelsperger³, H. Giordani⁴, G. Madec⁵

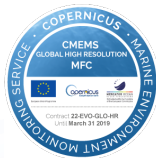
¹ Inria, Université Grenoble Alpes, LJK, Grenoble, France

² Mercator Océan, Toulouse, France

³ Laboratory for Ocean Physics and Satellite remote sensing, Brest, France

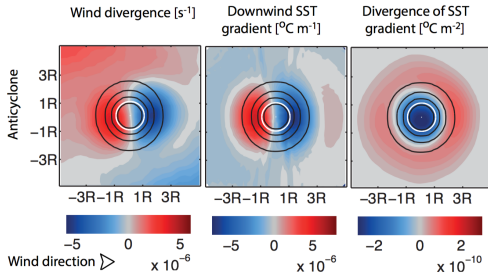
⁴ Météo-France, Toulouse, France

⁵ Sorbonne Universités-CNRS-IRD-MNHN, LOCEAN Laboratory, Paris, France



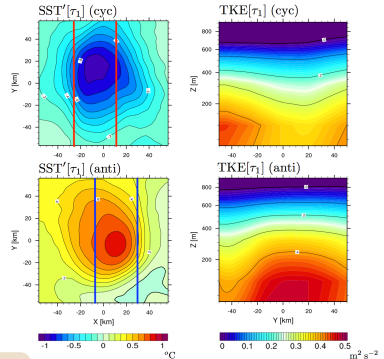
General context – Composite averaging in an eddy-centric coordinate

Eddy composites for the southern ocean from obs.



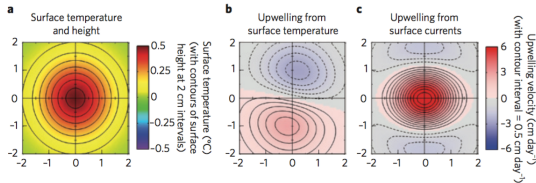
[Frenger et al., 2013]

TKE in MABL from coupled model



[Lemarié et al.]

Eddy-induced vertical velocities from obs. [Chelton, 2013]

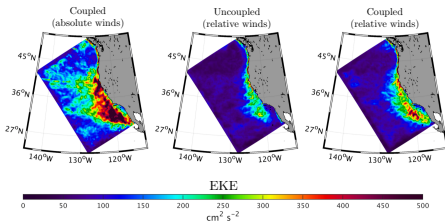


Strong thermal and dynamical coupling at the characteristic scales of the oceanic mesoscale

Limitation 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)



[Renault et al., 2016]

→ CheapAML [Deremble et al., 2013]

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

→ Full-coupling

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

What are the alternatives to force an eddying global operational model (?)

- 1 Proposed methodology
- 2 Simbad1d : a simplified marine atmospheric boundary layer model
- 3 Atmosphere-only numerical tests
- 4 Coupling with an OGCM and preliminary tests

⇒ **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)

Momentum equation

$$\partial_t \mathbf{u} + \underbrace{\mathbf{u} \cdot \nabla \mathbf{u}}_{\text{advection}} = \underbrace{-f \mathbf{k} \times \mathbf{u}}_{\text{coriolis}} - \underbrace{\frac{1}{\rho} \nabla p}_{\text{hpg}} + \underbrace{\partial_z (K_M(z) \partial_z \mathbf{u})}_{\text{turbulent mixing}}$$

- ▷ Radiative forcing is kept as it is
- ▷ Which term should be recomputed at the resolution of the ocean ?

What is the appropriate level of complexity ...

⇒ **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)

Momentum equation

$$\partial_t \mathbf{u} + \underbrace{\mathbf{u} \cdot \nabla \mathbf{u}}_{\text{advection}} = \underbrace{-f \mathbf{k} \times \mathbf{u}}_{\text{coriolis}} - \underbrace{\frac{1}{\rho} \nabla p}_{\text{hpg}} + \underbrace{\partial_z (K_M(z) \partial_z \mathbf{u})}_{\text{turbulent mixing}}$$

- ▷ Radiative forcing is kept as it is
 - ▷ Which term should be recomputed at the resolution of the ocean ?
- ① **Derive a single-column model (SCM) (Coriolis + turbulent mixing)**
 - ② Define a coupling between SCMs [e.g. giordani, 2006]
 - ③ Define an integral "shallow-water like" version with slab model

Continuous formulation of single-column MABL model

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

$$\begin{cases} \partial_t \mathbf{u} &= f \mathbf{k} \times \mathbf{u} + \partial_z (K_m \partial_z \mathbf{u}) + R_{LS} \\ \partial_t \theta &= \partial_z (K_s \partial_z \theta) + \lambda_s (\theta - \theta_{LS}) \\ \partial_t q &= \partial_z (K_s \partial_z q) + \lambda_s (q - q_{LS}) \end{cases}$$

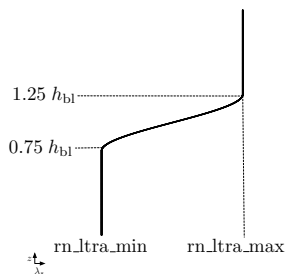
R_{LS} represents a geostrophic "guide" and/or a Newtonian relaxation

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



Continuous formulation of single-column MABL model

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

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

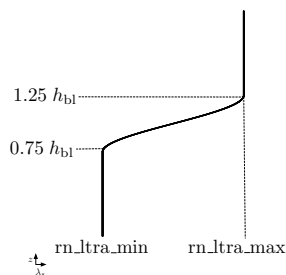
R_{LS} represents a geostrophic "guide" and/or a Newtonian relaxation

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



Closure scheme

TKE-based scheme following [Cuxart, Bougeault, Redelsperger, 2000]

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

$$\begin{cases} \partial_t \mathbf{e} &= K_m \left[(\partial_z \langle u \rangle)^2 + (\partial_z \langle v \rangle)^2 \right] - K_s N^2 + \partial_z (K_e \partial_z \mathbf{e}) - \frac{C_\varepsilon}{L} \mathbf{e}^{3/2} \\ \mathbf{e}(z=0) &= 4.63 u_\star^2 + 0.2 w_\star^2 \end{cases}$$

$$\mathbf{K}_s = \frac{L}{6} \phi_z \sqrt{\mathbf{e}}, \quad K_e = \frac{4L}{10} \sqrt{\mathbf{e}}, \quad \mathbf{K}_m = \frac{L}{15} \sqrt{\mathbf{e}}, \quad \phi_z(z) = f(L, N^2, \mathbf{e})$$

Computation of the diagnostic mixing length L

At a discrete level we ensure consistency with

- MO theory in surface layer [Redelsperger et al. 2001] (i.e. $L = 2.8z$)
- [Deardorff, 1980] scale for $N^2 = \text{cste}$ (i.e. $L = \sqrt{2e/N^2}$)
- [Bougeault & Lacarrere, 1989] length scale with shear-dependent term of [Rodier et al., 2017]

- Validation methodology along the lines of the GABLS (GEWEX Atmospheric Boundary Layer Study) initiative
- Definition of standardized test-cases
 - Model inter-comparisons between LES and SCMs

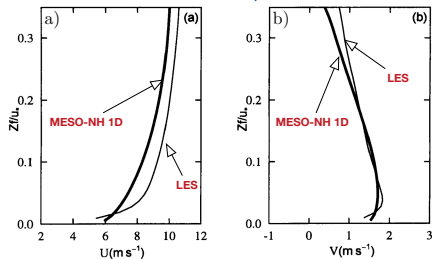
Testcases for the validation of Simbad1D

- ① Neutrally stratified testcase [Andren et al., 1994]
- ② GABLS1 : Stably stratified ABL [Cuxart et al., 2006] (typical situation over sea-ice)
- ③ Winds across a Midlatitude SST Front [Kilpatrick et al., 2014]

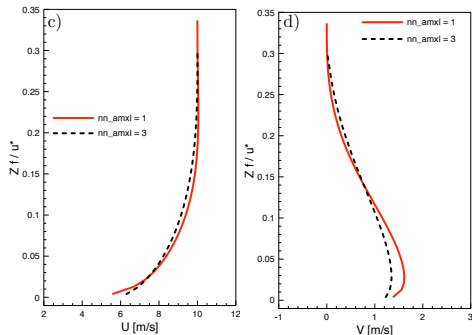
Simulations of reference obtained thanks to MESO-NH in LES mode

Neutrally stratified boundary layer

Cuxart et al., 2000



SIMBAD1D



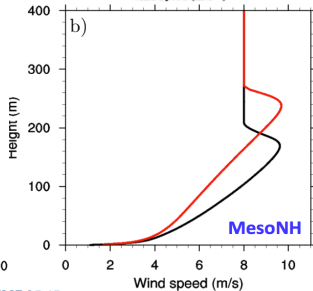
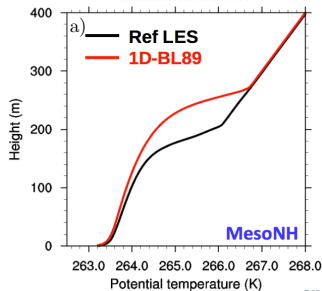
A neutral turbulent Ekman layer at 45°N

- $(u_G, v_G) = (10, 0) \text{ m s}^{-1}$
- Roughness length of $z_o = 0.1 \text{ m}$
- Simulation of 28 hours

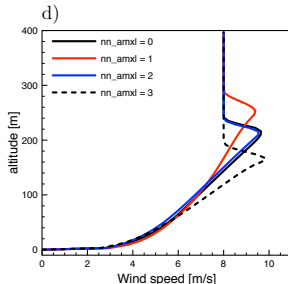
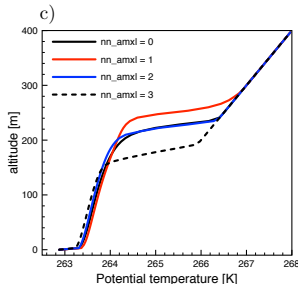
→ Improved results thanks to the discrete consistency with MO theory in surface-layer

Stably stratified boundary layer (GABLS1)

Rodier et al., 2017



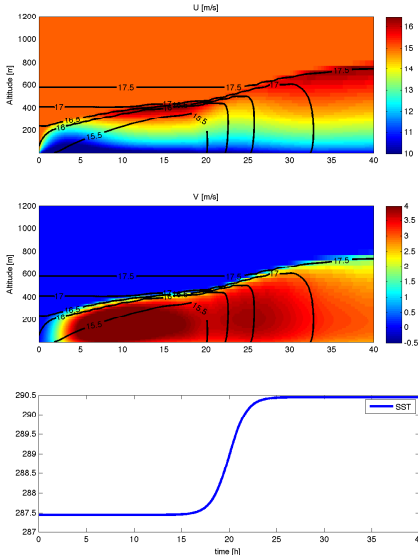
SIMBAD1D



- $(u_G, v_G) = (8, 0)$ m/s
- Simulation of 9 hours
- $\theta_s(t) = -10^\circ\text{C} - t/4$
- $\Delta\theta_{\text{ini}} = 2^\circ\text{C}$

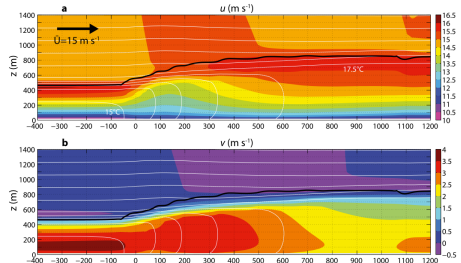
Lagrangian advection of an air column over a SST front (dry case)

SIMBAD 1D



- $(u_G, v_G) = (15, 0)$ m/s
- Cold side : SST = 14.3°C
- Warm side : SST = 17.3°C
- $N_v^2 = 10^{-4} \text{s}^{-2}$, $\theta(z=0) = 15.8^\circ\text{C}$
- $q(z) = 0$

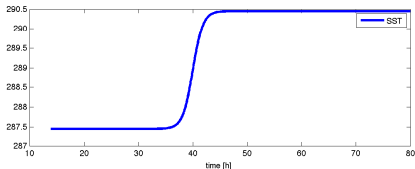
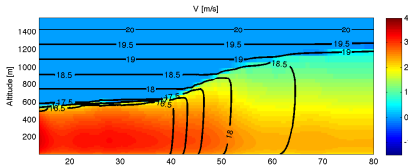
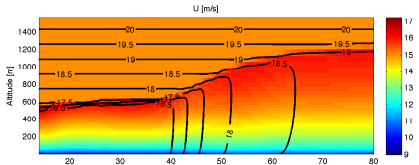
WRF [Kilpatrick et al., 2014]



2D x-z (solution at equilibrium)

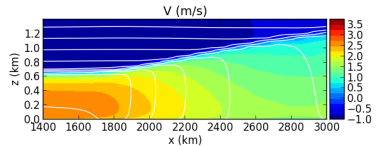
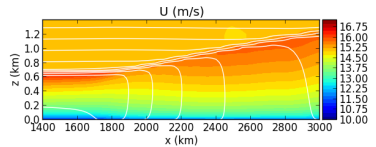
Langrangian advection of an air column over a SST front (moist case)

SIMBAD 1D



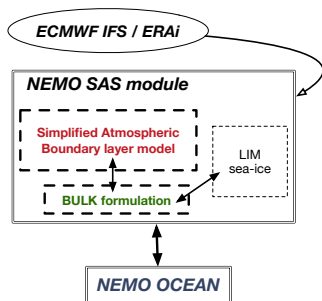
- $(u_G, v_G) = (15, 0)$ m/s
- Cold side : SST = 14.3°C
- Warm side : SST = 17.3°C
- $N_v^2 = 10^{-4} \text{s}^{-2}$, $\theta(z = 0) = 14^\circ\text{C}$
- $q(z) = 10^{-2} \text{kg kg}^{-1}$

MESO-NH LES



2D x-z (solution at equilibrium)

Implementation in NEMO surface module

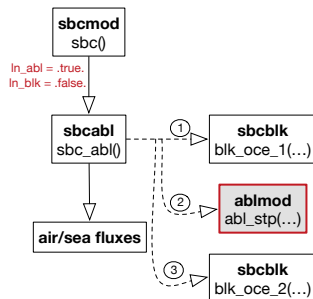


Main developments

- Preprocessing tool to handle 3D IFS data
 - Plug Simbad1D with a generic interface with the NEMO bulk routines
 - Handle 3D atmospheric data instead of 2D
- relatively minor modifications overall

Take advantage of existing features

- Online interpolation of external data & I/Os
- Split NEMO and SAS on separate nodes
- Bulk formulae from Aerobulk (Brodeau et al.)



Performances : a first evaluation

TOY Configuration :

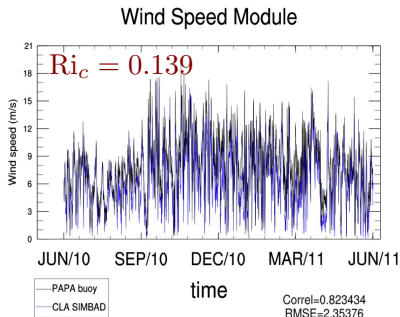
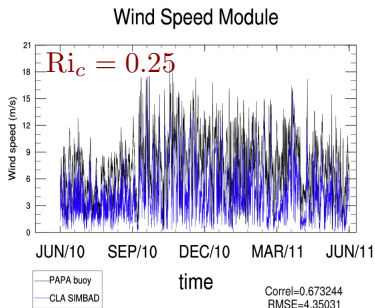
- 50 x 50 points, 75 vertical levels with the default Mercator settings
- 50 vertical levels in SIMBAD1D

→ ifort with optimization options on Intel Xeon CPU E5-1650 @ 3.20GHz

		Bulk mode		ABL mode	
module	subroutine	elapsed time	% time	elapsed time	% time
zdfgls	zdf_gls	287.52 s	19.44	287.23 s	18.06
dynspg_ts	dyn_spg_ts	166.50 s	11.26	166.67 s	10.48
traadv_tvd	nonosc	117.66 s	7.95	114.96 s	7.23
traadv_tvd	tra_adv_tvd	54.32 s	3.67	54.26 s	3.41
dynzdf_imp	dyn_zdf_imp	49.21 s	3.33	49.66 s	3.12
ablmod	abl_stp	-	-	49.08 s	3.09
dynldf_bilap	dyn_ldf_bilap	47.44 s	3.21	47.92 s	3.01
domvvl	dom_vvl_interpol	47.34 s	3.20	47.66 s	3.00
eosbn2	rab_3d	42.74 s	2.89	42.57 s	2.68
ablmod	abl_zdf_tke	-	-	49.59 s	2.49
trazdf_imp	tra_zdf_imp	28.42 s	1.92	28.13 s	1.77
...
fldread	fld_read	5.00 s	0.34	10.10 s	0.64
Increase of memory size $\approx 12\%$		24m39		26m30	

Ongoing work

- ▷ NEMO1D / SIMBAD1D coupling at the PAPA station (50.1°N, 144.9°W)
 - Extension of the study [Reffray et al., 2015] with NEMO1d to the coupled case
 - Work done by T. Brivoal & G. Samson (Mercator-Ocean)

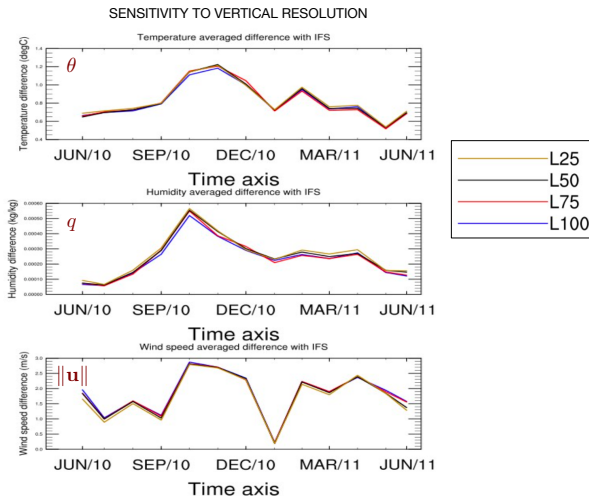


Large-scale data from operational IFS product

Ongoing work

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

- Extension of the study [Reffray et al., 2015] with NEMO1d to the coupled case
- Work done by T. Brivoal & G. Samson (Mercator-Ocean)



- Sensitivity tests and comparison with IFS surface fluxes at global scale
- Increased level of complexity (add horizontal/vertical advection and fine-scale pressure gradient)
- Shallow-water like 2D x - y integral layer version
- SIMBAD over sea-ice
- Initialization of the NEMO/SIMBAD coupled system (in collaboration with Arthur Vidard, Inria)