Equations primitives *Reynolds averaged* $\quad X = \langle X \rangle + X'$

$$
\begin{aligned}
\frac{D\langle \mathbf{u}_h \rangle}{Dt} + f\mathbf{k}\times\langle \mathbf{u}_h \rangle &= \frac{\boldsymbol{\nabla}_h p}{\rho_0} - \boldsymbol{\nabla}\cdot\langle \mathbf{u}'_h \mathbf{u}'_h \rangle - \partial_z \langle w' \mathbf{u}'_h \rangle \\
\partial_z p &= -g\rho' \\
\boldsymbol{\nabla}\cdot\langle \mathbf{u} \rangle &= 0 \\
\frac{D\langle T \rangle}{Dt} &= -\frac{\partial_z Q_s}{\rho_0 C_{p,o}} - \boldsymbol{\nabla}_h\cdot\langle \mathbf{u}'_h T' \rangle - \partial_z \langle w' T' \rangle \\
\frac{D\langle S \rangle}{Dt} &= -\boldsymbol{\nabla}_h\cdot\langle \mathbf{u}'_h S' \rangle - \partial_z \langle w' S' \rangle \\
\rho &= \rho_{\mathrm{eos}}(\langle T \rangle, \langle S \rangle, z)
\end{aligned}
$$

Text

Turbulence assimilée à du mélange

$$
\langle X' w' \rangle = -K_X(z)\partial_z \langle X \rangle, \qquad X = u, v, T, S
$$

Comment sont calculés $K_X(z)$, $\langle X'w' \rangle_{\mathrm{sfc}}$ et $\langle X'w' \rangle_{\mathrm{bot}}$?

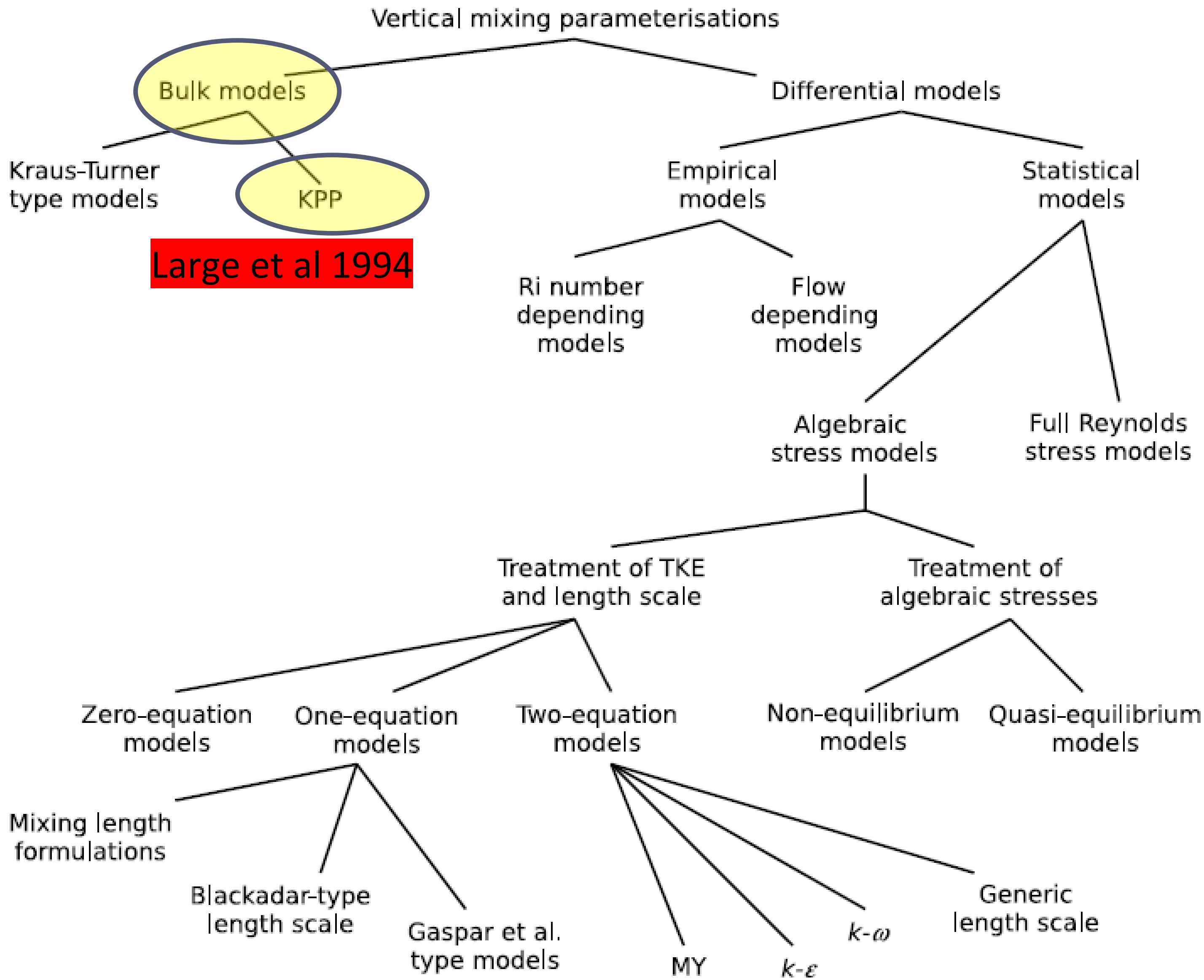
Calcul de $< X'w' >$

$$
\begin{aligned}
-\langle \mathbf{u}'_h w' \rangle_{\mathrm{sfc}} &= \boldsymbol{\tau}/\rho_o & \qquad -\langle \mathbf{u}'_h w' \rangle_{\mathrm{bot}} &= \boldsymbol{\tau}_b/\rho_o \\
-\langle T' w' \rangle_{\mathrm{sfc}} &= Q_H/(\rho_o C_{p,o}) & \qquad -\langle T' w' \rangle_{\mathrm{bot}} &= 0
\end{aligned}
$$

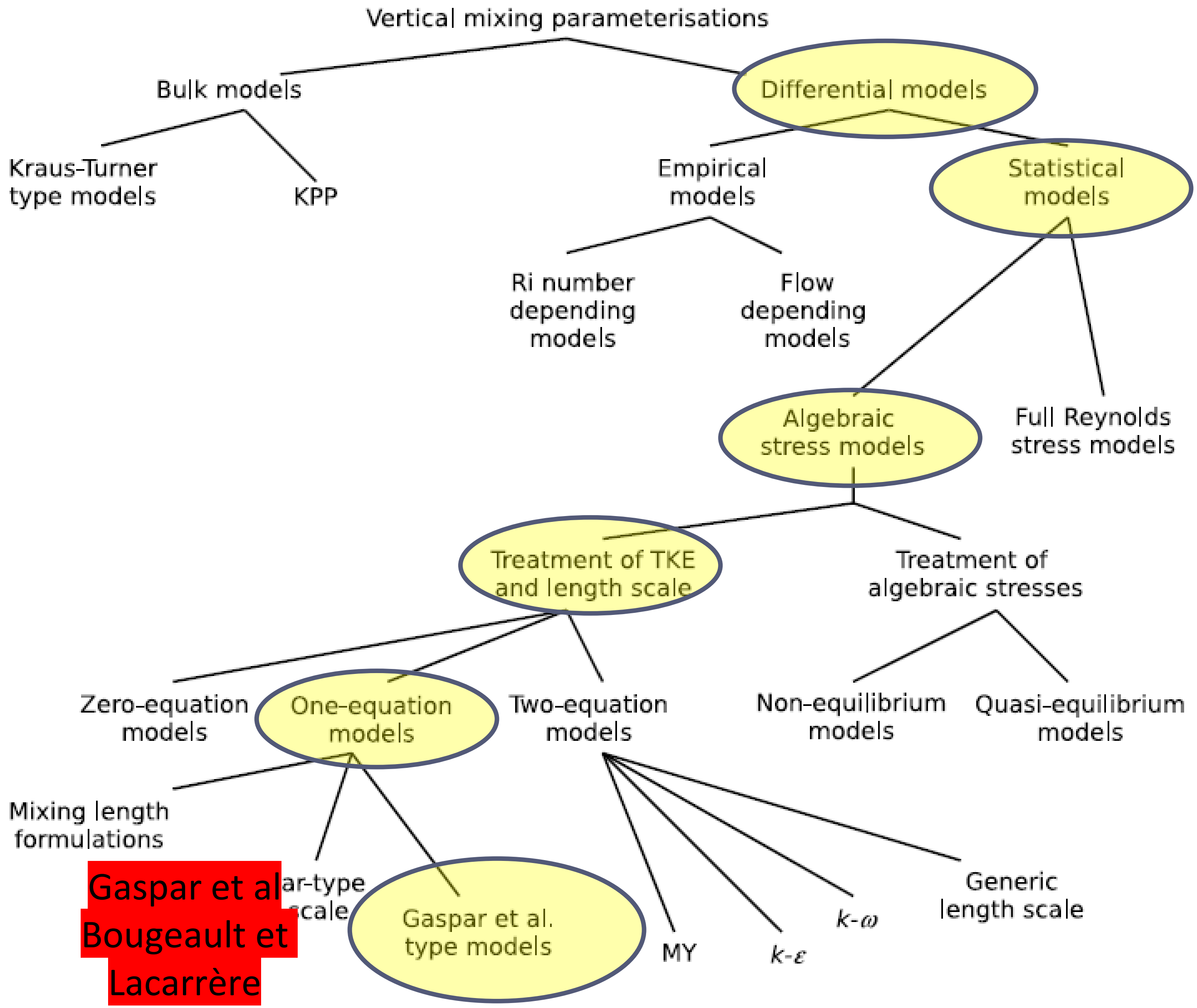
$$
\begin{aligned}
-\left\langle \mathbf{u}'_h w' \right\rangle(z) &= K_m(z)\partial_z \left\langle \mathbf{u}_h \right\rangle \\
-\left\langle T' w' \right\rangle(z) &= K_s(z)\partial_z \left\langle T \right\rangle
\end{aligned}
$$

Nom	Variable	unités
sustr	τ_x/ρ_0	$\mathrm{m}^2\ \mathrm{s}^{-2}$
svstr	τ_y/ρ_0	$\mathrm{m}^2\ \mathrm{s}^{-2}$
stflx(itemp)	net heat flux	$\mathrm{K\ m\ s}^{-1}$
srflx	$Q_s/(\rho_0 C_{p,o})$	$\mathrm{K\ m\ s}^{-1}$
bustr	$\tau_{b,x}/\rho_0$	$\mathrm{m}^2\ \mathrm{s}^{-2}$
bvstr	$\tau_{b,y}/\rho_0$	$\mathrm{m}^2\ \mathrm{s}^{-2}$
Akv	K_m	$\mathrm{m}^2\ \mathrm{s}^{-1}$
Akt	K_s	$\mathrm{m}^2\ \mathrm{s}^{-1}$

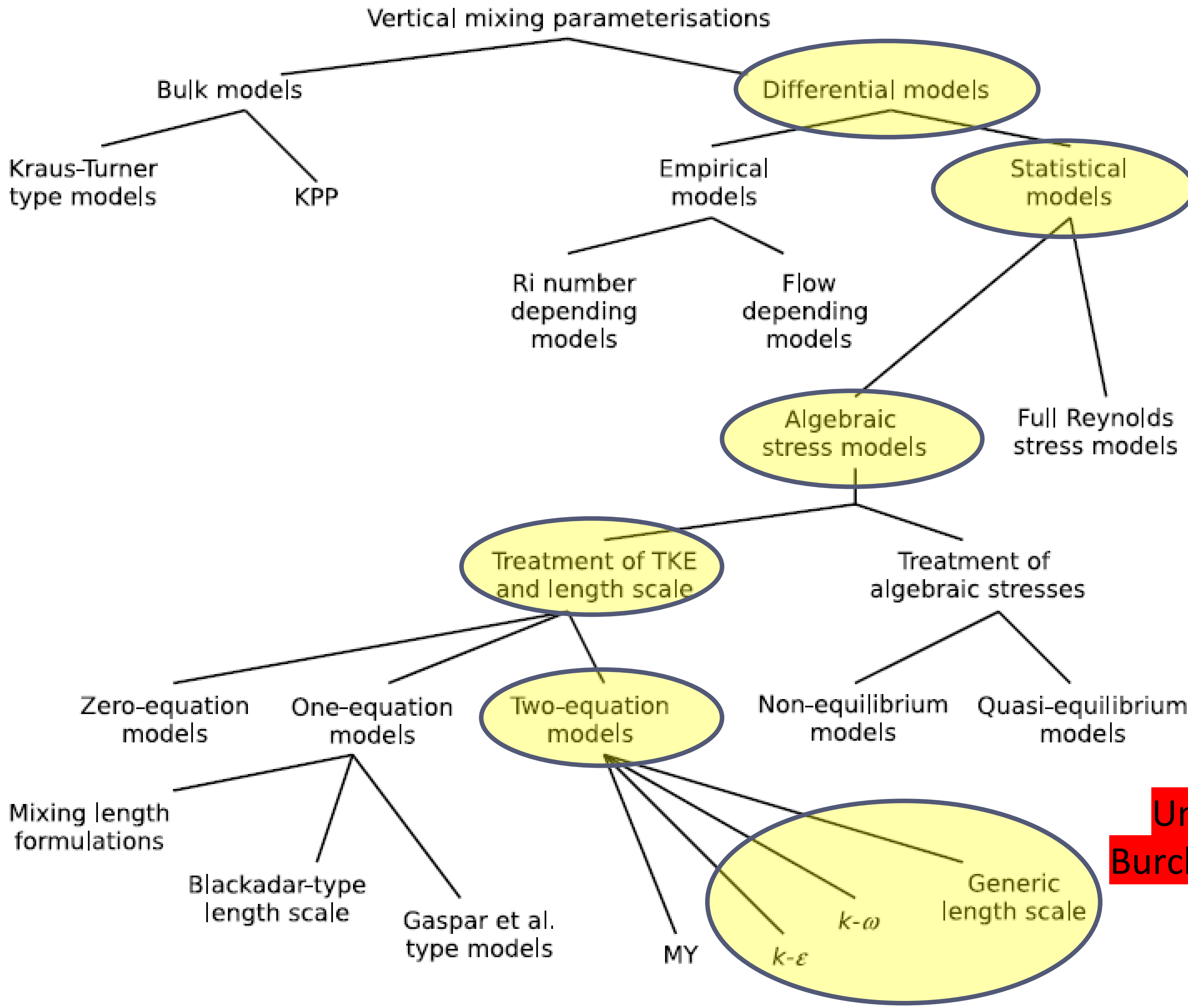
Overview of closure turbulence model in marine applied turbulence



Overview of closure turbulence models in marine applied turbulence



Overview of closure turbulence models in marine applied turbulence



Umlauf & Burchard 2003

Principe

[GLS_MIXING]

$$\begin{aligned} \partial_t e &= \partial_z \left(K_e \partial_z e\right) + P + B - \varepsilon, & K_e &= K_M/\mathrm{Sc}_e \\ \partial_t \psi &= \partial_z \left(K_\psi \partial_z \psi\right) + \psi e^{-1}\left(\beta_1 P + \beta_3^{\pm} B - \beta_2 \varepsilon\right), & K_\psi &= K_M/\mathrm{Sc}_\psi \end{aligned}$$

avec

$$\psi = \left(c_\mu^0\right)^p e^m l^n, \qquad P = K_m\left[(\partial_z u)^2 + (\partial_z v)^2\right], \qquad B = -K_s N^2$$

et

$$\varepsilon = \left(c_\mu^0\right)^{3+p/n} e^{3/2+m/n} \psi^{-1/n}, \qquad l = \left(c_\mu^0\right)^3 e^{3/2} \varepsilon^{-1}$$

$$K_m = \boldsymbol{c_\mu}\left(e^2/\varepsilon\right), \qquad K_s = \boldsymbol{c_\mu}'\left(e^2/\varepsilon\right)$$

Une instance de GLS se caractérise par :

- Un choix pour les exposants m, n et p (e.g. $k-\varepsilon$, $k-\omega$, $k-kl$, gen)
- Une valeur pour les coefficients β_1, β_2 et $\beta_3^{\pm}$
- Une valeur pour les nombres de Schmidt Sc_e et Sc_ψ

Wijezekera et al, 2003 -> Differences in regional domains tend to be limited: diffusion/viscosity is a second-order process

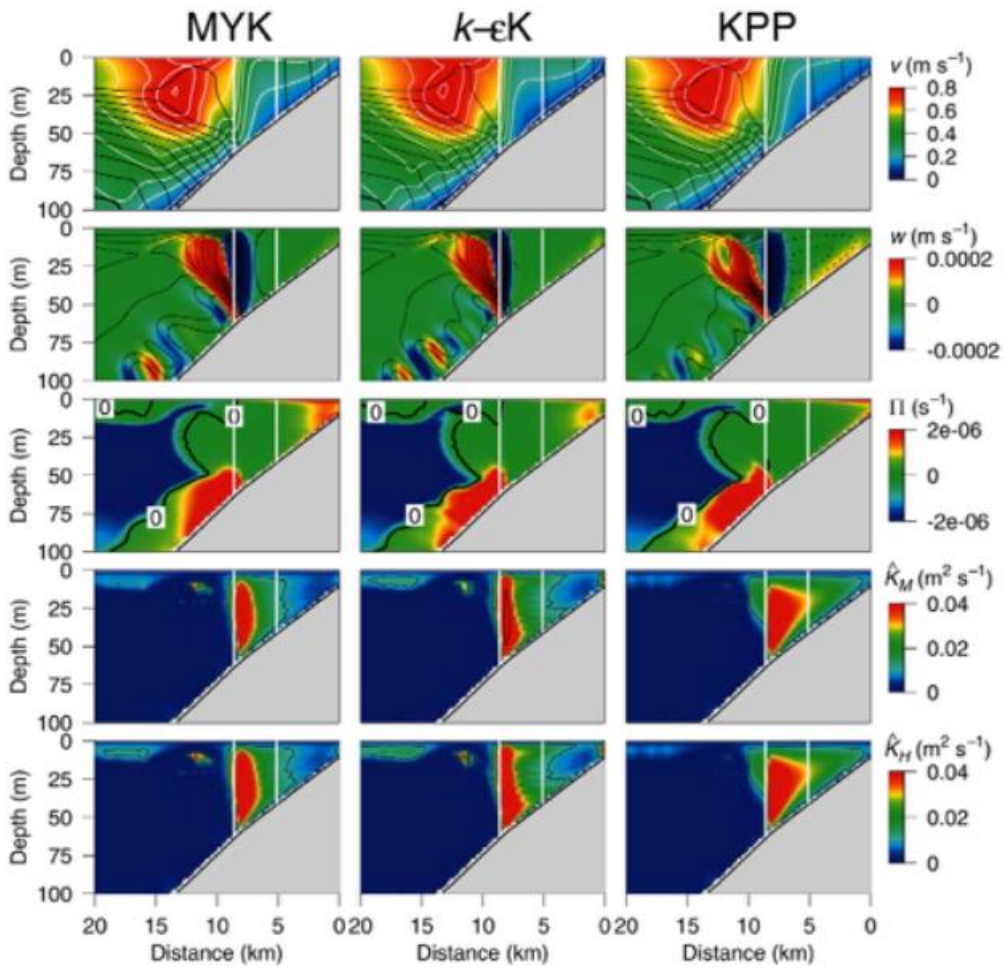


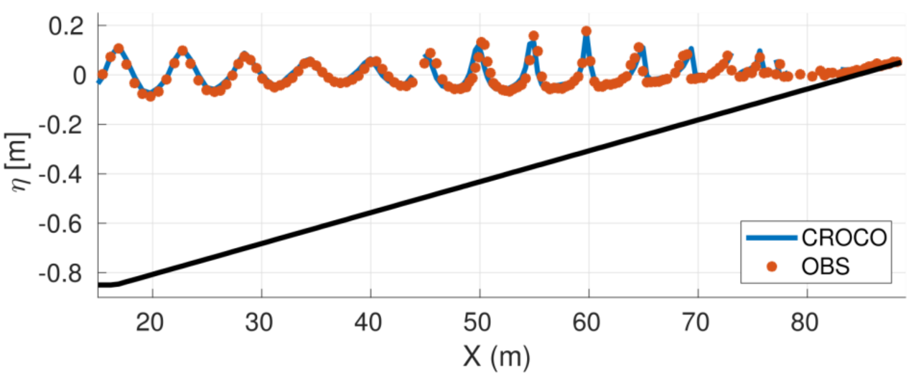
Figure 12. Fields of alongshore velocity v (color contours and white contour lines) together with density σ_θ (black contour lines), vertical velocity w (color contours) together with stream function for the across-shelf flow Ψ (black contours), potential vorticity Π, eddy viscosity $\hat{K}_M$ and eddy diffusivity $\hat{K}_H$ for the MYK, k-ϵK and KPP mixing schemes at $t = 24$ IP ($\approx$ day 17) for the downwelling experiments. The contour intervals are $\Delta\sigma_\theta = 0.2$ kg m^{-3}, where $\sigma_\theta = 26$ kg m^{-3} is marked by a heavy line; $\Delta v = 0.1$ m s^{-1}; $\Delta\Psi = 0.1$ m^2 s^{-1}, where $\Psi = 0$ is marked with a heavy line and $\Psi > 0$ is dashed. The vertical white lines mark the locations of profiles to be discussed in detail.

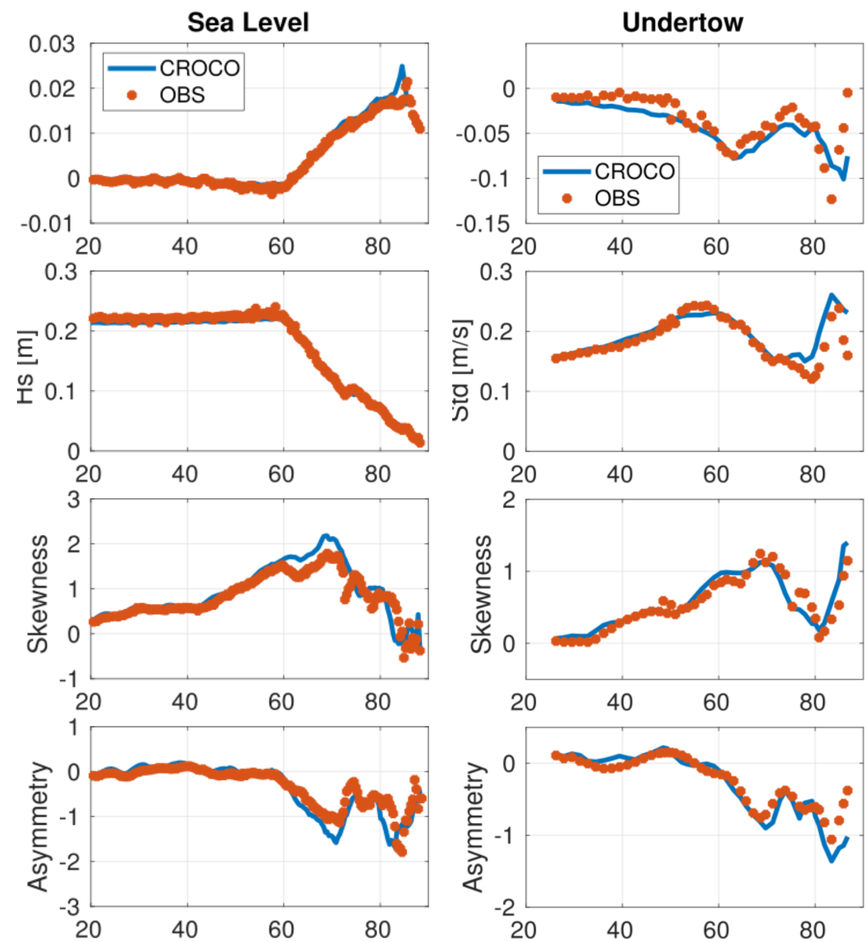
Scheldt Wave Flume (Deltares)

Validation with flume experiments

GLOBEX (B2) - Michalet et al. (2014)

Resolution: 12 cm, 10 sigma levels
Breaking-induced turbulence:
WENO5 + k-ω





Large-scale flume

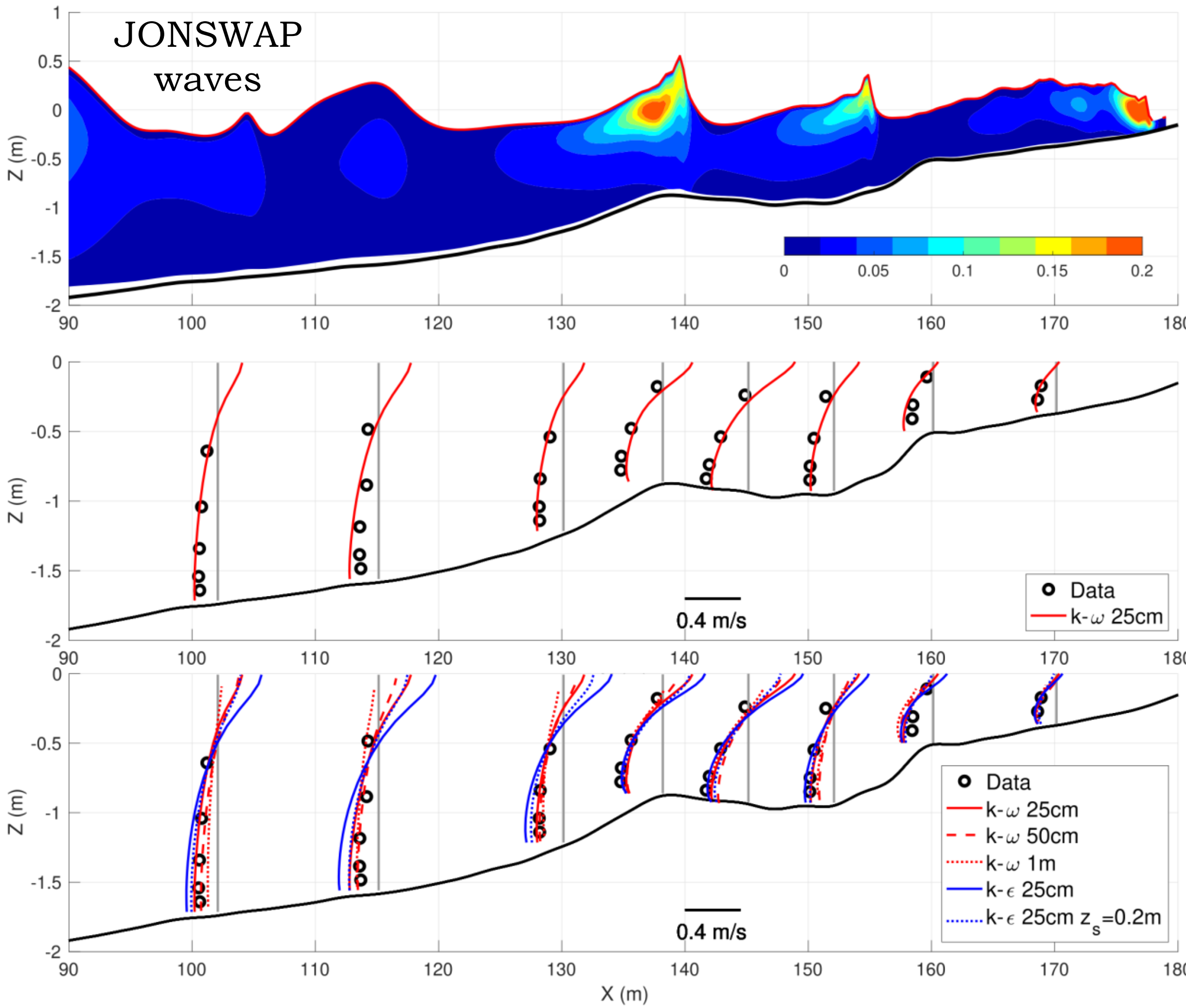
LIP-11D (1B) - Roelvink & Reniers (1995)

Delta Flume (Deltares)

TKE

Mean U

Test of resolution and turbulence closure



- Revisite du GLS en tridimensionnel (i.e. sans hypothèse d'homogénéité horizontale et sans négliger l'advection verticale)

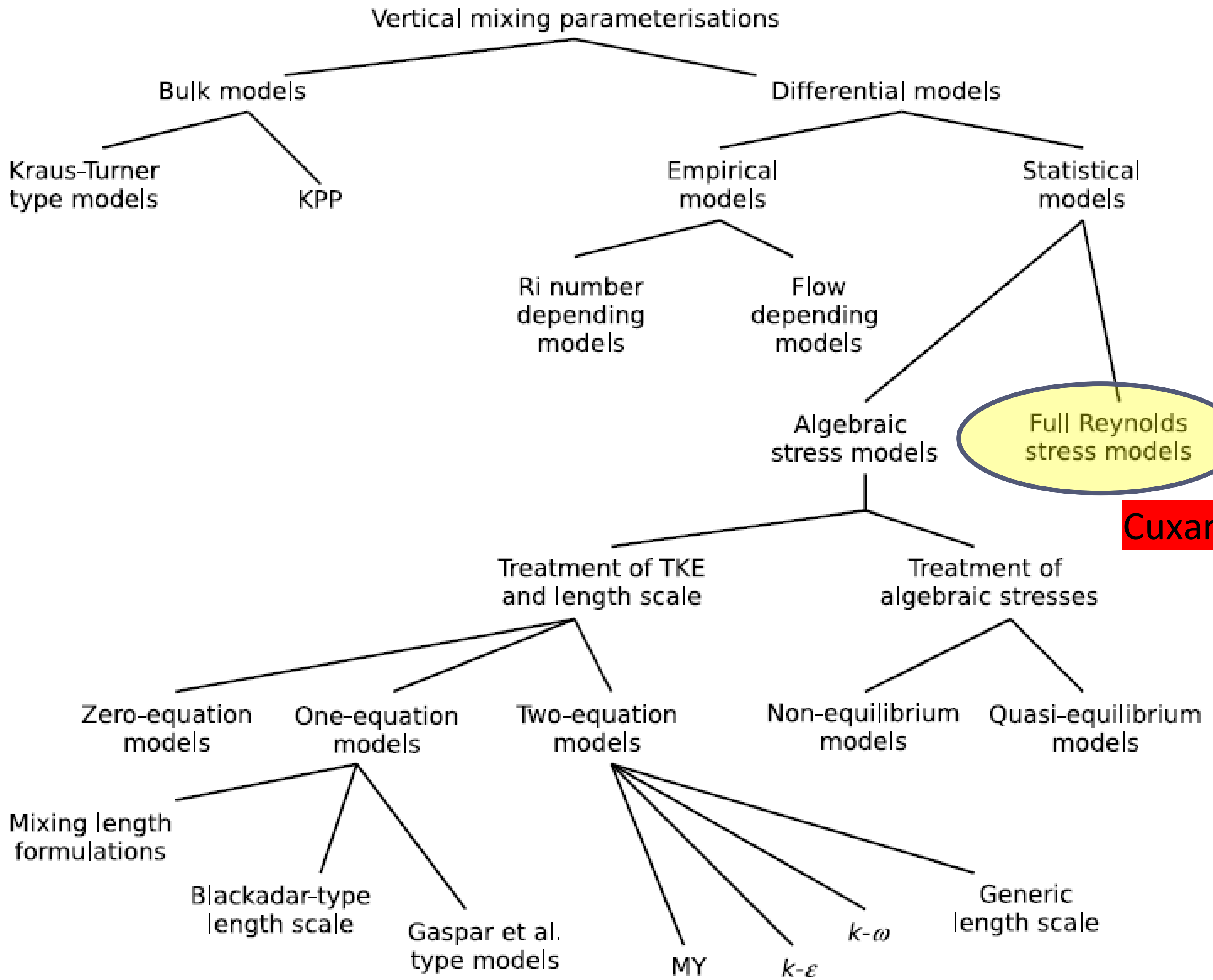
  Difficultés :

  - Vitesse 3D non-divergente aux points w
  - Stabilité pour l'advection verticale
  - e et ψ sont définis positifs

- Evolution vers l'utilisation de GLS dans le cadre LES (e.g. Ilicak et al., 2008)

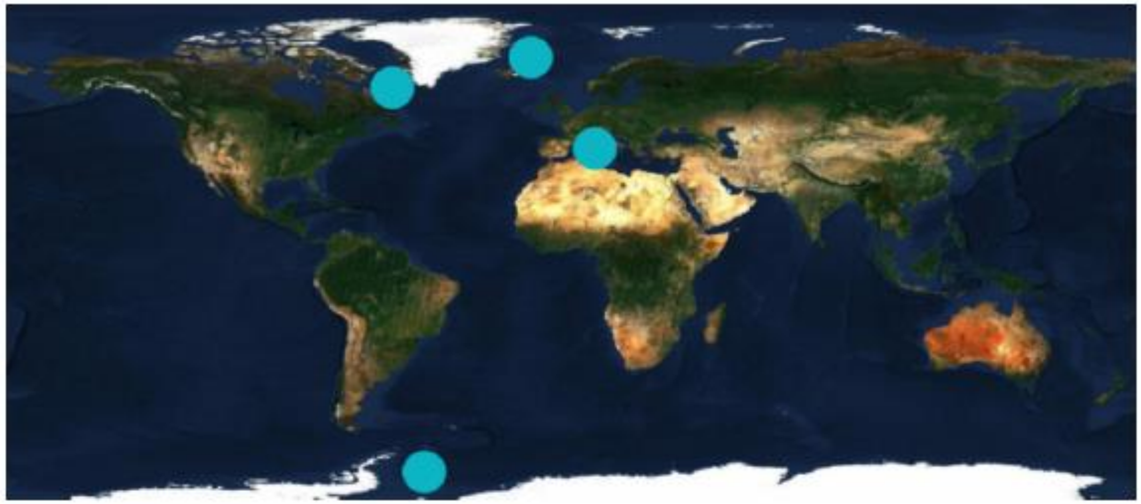
  - Technique *very large eddy simulation* (VLES) pour permettre l'utilisation de $k - \varepsilon$ dans les modèles non-hydrostatiques
  - Pont vers les travaux réalisés autour de Meso-NH sur les schémas de turbulence pour le LES (e.g. Cuxart et al., 2000)

Overview of closure turbulence model in marine applied turbulence



Cuxart et al 2000

Oceanic deep convection



Wintertime cold winds generate important surface cooling $(500 - 1000\,\mathrm{W\,m}^2)$

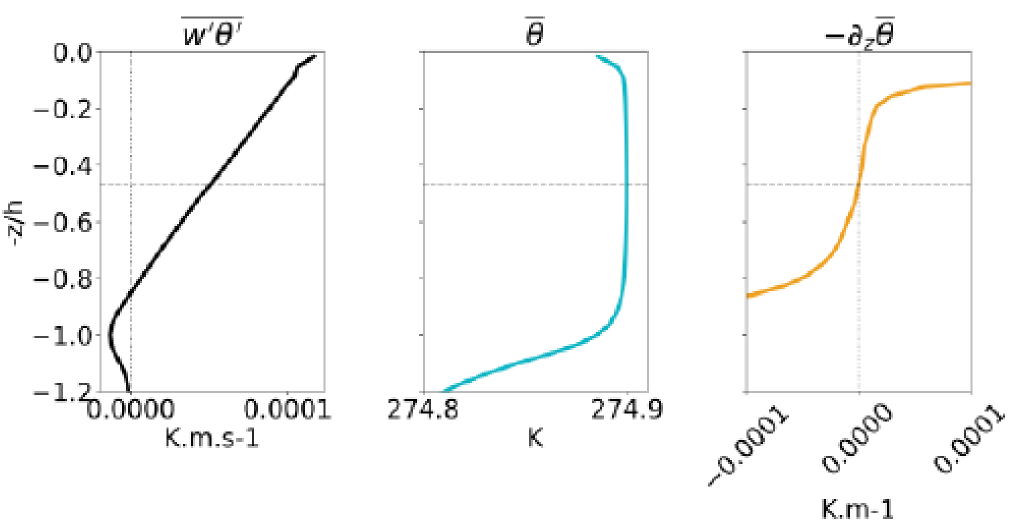
- Dense plumes overturn and mix the water column
- Intermediate and bottom water formation (500 - 2000m)
- Influence thermohaline circulation [Marshall & Schott 1999, Lazier 2012...]

Parameterization of oceanic deep convection

Beyond the downgradient flux assumption

$$\overline{w'\Theta'} = \underbrace{\overline{w'\Theta'}_{\text{local}}}_{\text{local turbulence}} + \underbrace{\overline{w'\Theta'}_{\text{non-local}}}_{\text{coherent convection}}$$

In convective conditions, turbulent fluxes are dominated by processes unrelated to local gradients (strong fluxes exist even when $\partial_z \overline{\Theta} = 0$)



Parameterization of oceanic deep convection

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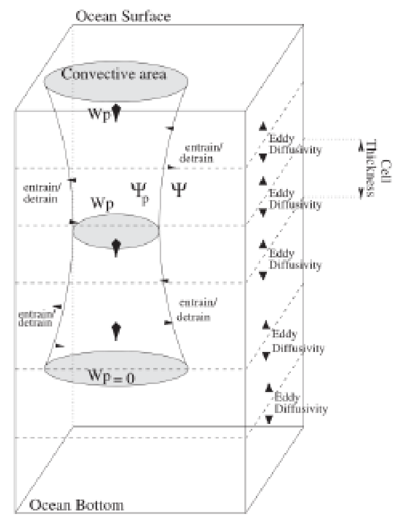


Usual approaches :

- Increase vertical diffusion to 'mix' unstable density profiles [LMD_CONVEC]
- Non-local term inspired from atmospheric parameterization (e.g. Troen & Mahrt 86) [NON_LOCAL] ⚠Implemented with wrong sign for 2 decades in ROMS

⇒ **Mass flux convection scheme**

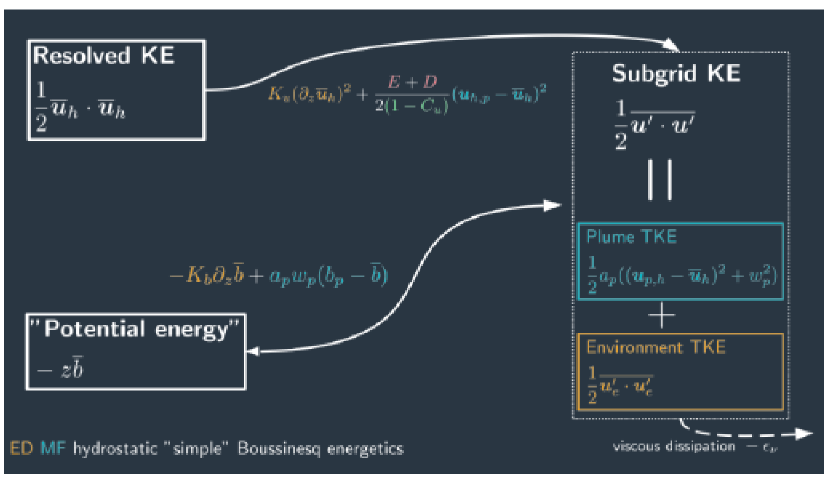
$$\overline{w'\Theta'}_{\mathrm{non-local}} = M(\Theta_p - \overline{\Theta}), \qquad M = -\underbrace{a_p}_{\text{area fraction}}\underbrace{w_p}_{\text{plume velocity}}$$

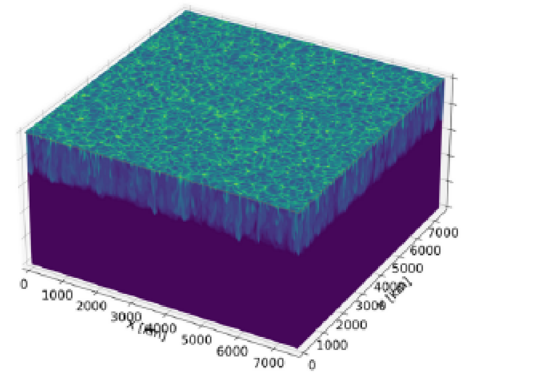
Mass-flux scheme = ODEs on a_p, w_p, Θ_p controlled by entrainment/detrainment rates (e.g. Giordani et al., 2020)

Work in progress on adapting mass flux schemes to the ocean

Objectives:

- Re-derive rigorously a mass flux scheme from a multi-fluid approach to identify underlying assumptions
- Use LES simulations (Croco/Meso-NH/Basilisk) to calibrate the parameterization (Bayesian inversion)
- Energetic consistency in a continuous & discrete sense (extension of Burchard, 2002 paper to the ED+MF context)

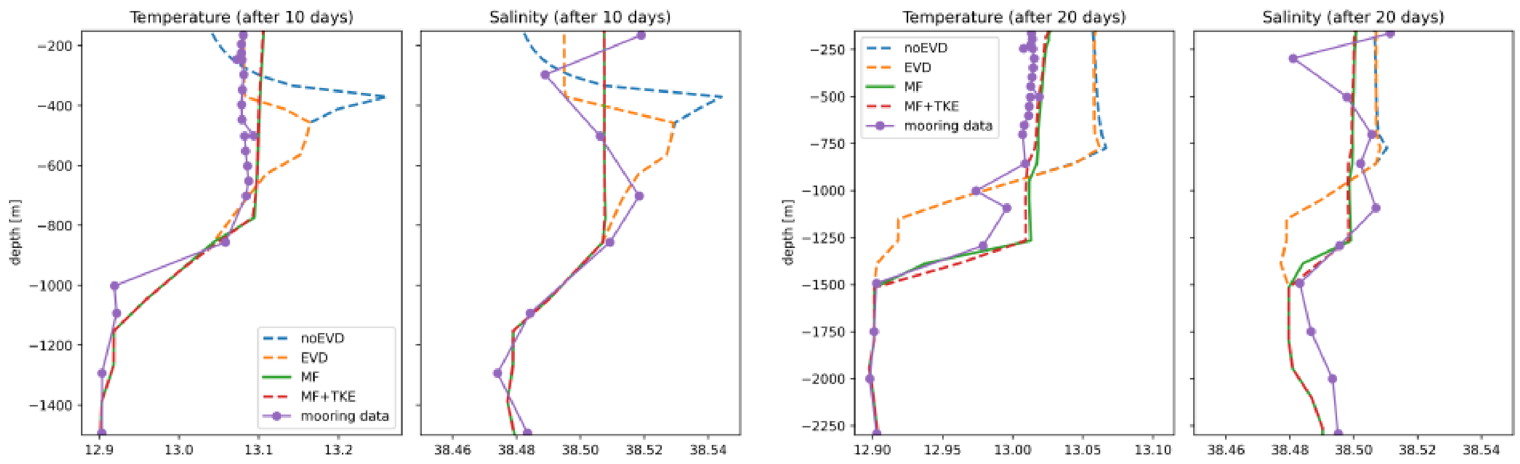




⇒ Manolis Perrot's thesis

First results in a single-column framework

→ HyMeX/ASICS-MED experiment at the LION buoy



Approximate schedule

- Creation of a "deep convection parameterization" branch in summer 2023
- Objectives :
  - dusting off the NON_LOCAL option
  - implement mass flux scheme
  - incorporate work by A. Legay (IGE) for convection with GLS

Relevant LES with CROCO

Objective : simulate LES flows in the presence of surface/bottom turbulent boundary layers with a mixed implicit- explicit subgrid-scale modelling approach :

- **Away from the boundaries :** rely on implicit dissipation from advection schemes
- **Close to the boundaries :** need for an explicit 3D closure scheme to represent anisotropic turbulence motions near boundaries ⇒ rely on a 3D prognostic TKE equation

+ take advantage of the performance boost from NH_INT option relevant for most LES cases.

Opportunity : collaboration with E. Lamballais (Pprime, Poitiers) within MOTIONS project

Strategy :

- 3D extension of GLS : relevance of the stability functions (?) and stability and realisability of the model in 3D (?).
- "Simple" one-equation 3D TKE scheme with diagnostic mixing lengths (e.g. Sullivan et al., 1994; Cuxart et al., 2000).
- Alternative for well established LES codes (e.g. XCompact3d)

Relevant LES with CROCO

- Creation of a "3D turbulence" branch in late 2023 / early 2024 with a focus on convection for the testing

+ Use this opportunity to revise the discretization of GLS following the energetic consistency principles proposed by Burchard, 2002 and Marsaleix et al., 2008

⇒ could allow to get rid of the numerous smoothing procedures

Opportunité MEDIATION

Financement postdoc (22 mois) : évaluation des paramétrisations fines échelles (instabilité de couche de couche de mélange, symétrique,,, cf Dong et al 2021)

Autres aspects paramétrisations non discutés ici discutés ailleurs ?

- Bulk, Current feed back
- Pénalisation
- Obstacles végétations
- ,,,,