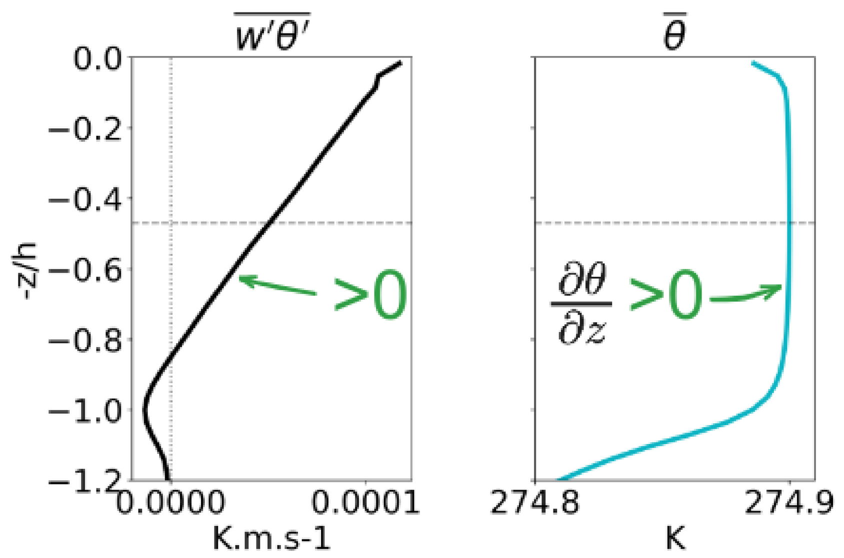
A Mass-Flux parameterization of Convection:
Energy Conservation and Uncertainty Quantification

Manolis Perrot [1] Florian Lemarié [1] Thomas Dubos [2] Benjamin Zanger [1] Olivier Zham [1]

[1]Inria, Univ. Grenoble Alpes, CNRS, Grenoble INP, LJK, Grenoble, France. [2]IPSL, Lab. Meteorologie Dynamique, Ecole Polytechnique, Palaiseau, France

1 – Eddy-Diffusivity fails for convection...

Diffusive closure $\overline{w'\theta'} \overset{\text{param}}{=} -K\partial_z\overline{\theta}$ not true on obs. and LES of convection:



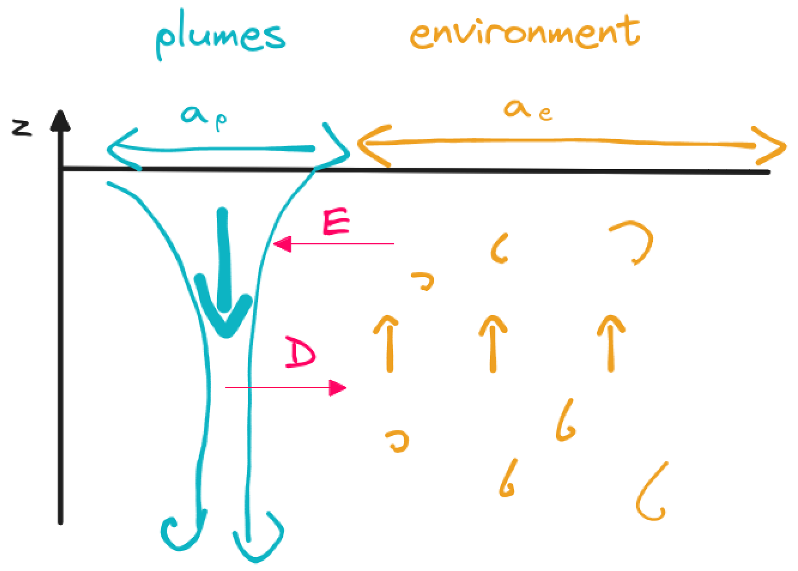
...because mixing is performed by convective plumes!

2 – Mass-Flux parameterization of plume mixing

For a generic tracer: $\partial_t\overline{\phi} = -\partial_z\overline{w'\phi'} + \text{sources} \qquad (\phi = u, v, \theta, S)$

Use a plume/environment averaging...

- a_p, a_e: plume and environment fractions of the grid cell
- E, D: lateral Entrainment and Detrainment



...to get vertical fluxes:

$$\overline{w'\phi'} \simeq \underbrace{-K_\phi\partial_z\overline{\phi}}_{\text{ED}} + \underbrace{a_p(w_p - \overline{w})(\phi_p - \overline{\phi})}_{\text{MF}}$$

(environment flux is assumed isotropic and closed with diffusion)

...to get plume dynamics:

$$\begin{aligned} \underbrace{\partial_z(a_p w_p)}_{\text{vert. convergence}} &= \underbrace{E - D}_{\text{lateral Entrainment/Detrainment}} \\ \underbrace{\partial_z(a_p w_p \phi_p)}_{\text{vert. advection}} &= \underbrace{E\overline{\phi} - E\phi_p}_{\text{hor. "advection"}} + \text{sources} \end{aligned}$$

(area conservation)

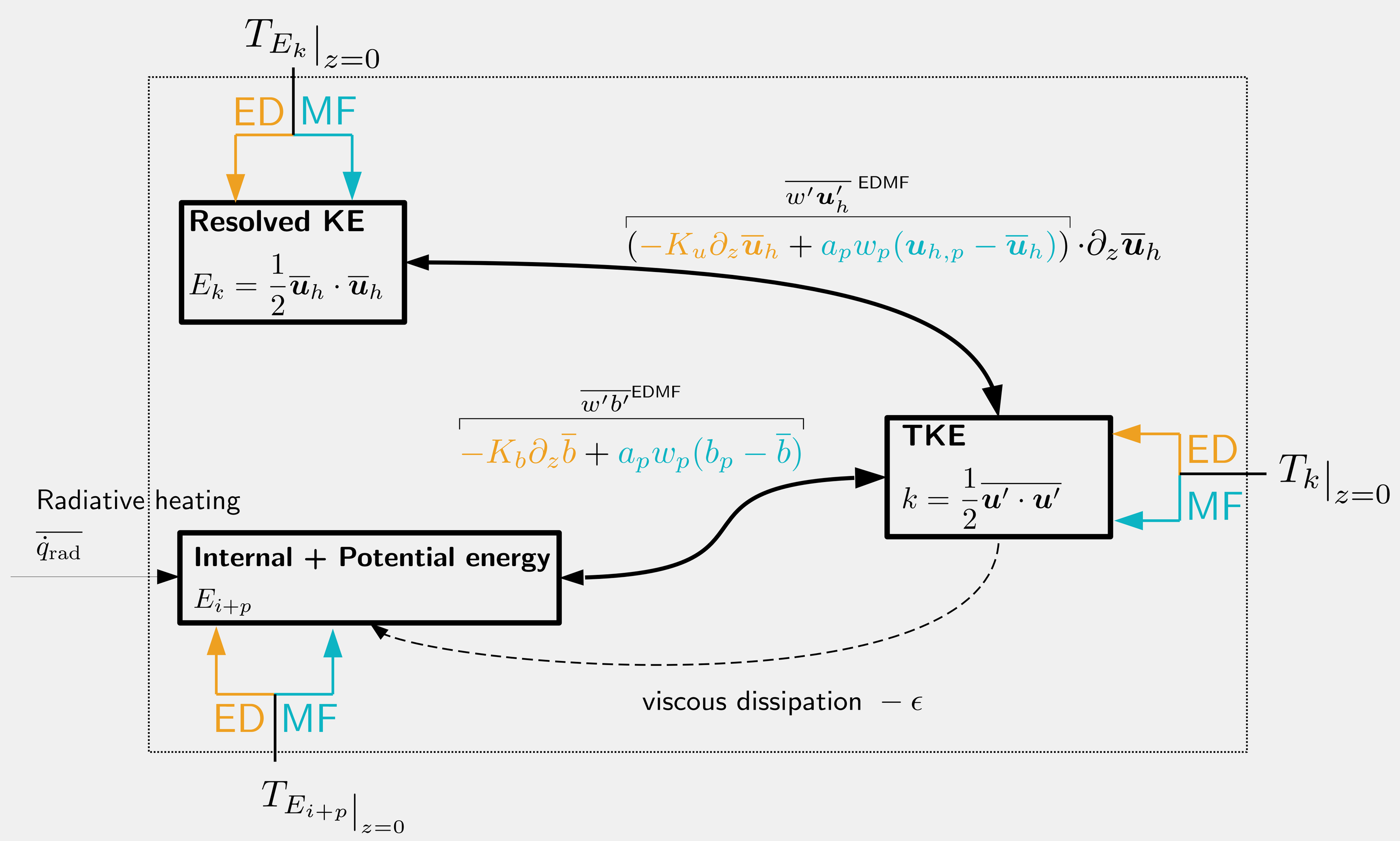
$(\phi = w, u, v, \theta, S)$

(with assumption of stationarity)

3 – To close the parameterization energy budgets, we derived:

Theoretical energy budgets

which include ED and MF terms in bulk and boundary energy transfers



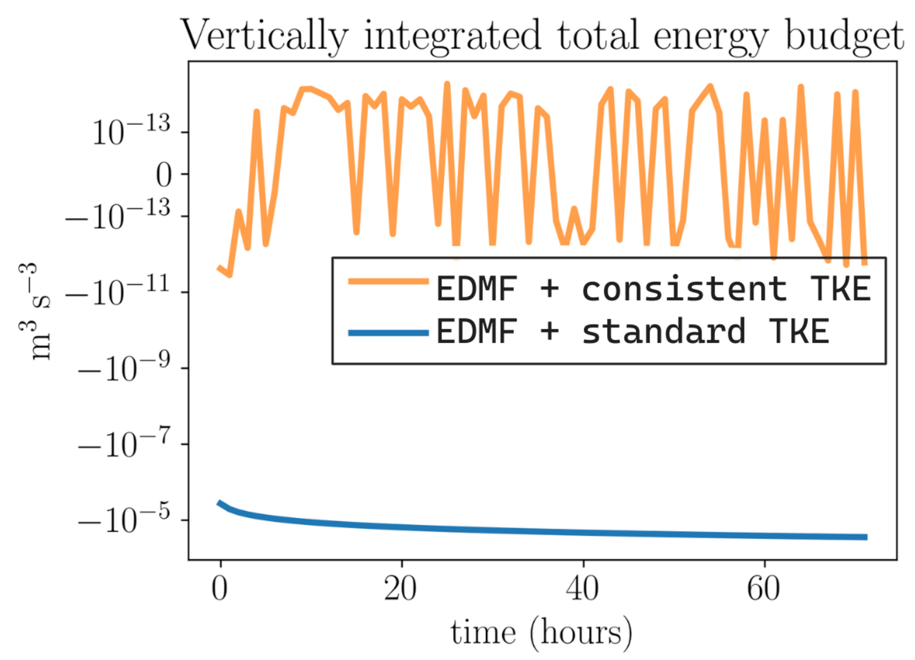
Energetically Consistent TKE equation

$$\begin{aligned} \partial_t k + \partial_z \overline{w'\frac{\boldsymbol{u}'\cdot\boldsymbol{u}'}{2}} = &-K_\phi\partial_z\overline{b} + a_p w_p(b_p - \overline{b}) \\ &+K_u(\partial_z\overline{\boldsymbol{u}}_h)^2 - a_p w_p(\boldsymbol{u}_{h,p} - \overline{\boldsymbol{u}}_h)\cdot\partial_z\overline{\boldsymbol{u}}_h \\ &-\epsilon_\nu \end{aligned}$$

Energetically Consistent Discretizations

$$\begin{cases} \mathrm{Sh}_{j+1/2} &= \dfrac{(\delta_z\overline{u})^{n+1/2}_{j+1/2}}{\Delta z_{j+1/2}}\left(K_{j+1/2}\dfrac{(\delta_z\overline{u})^{n+1,\star}_{j+1/2}}{\Delta z_{j+1/2}} - (a_p w_p)_{j+1/2}\left(u^p_{j+1/2} - \overline{u}^{n+1,\star}_j\right)\right) \\ \mathcal{B}_{j+1/2} &= -K^b_{j+1/2}\left(N^2\right)^{n+1,\star}_{j+1/2} + (a_p w_p)_{j+1/2}\left(b_{\mathrm{eos}}(\overline{\phi}^p_{j+1/2}) - b_{\mathrm{eos}}(\overline{\phi}^{n+1,\star}_j)\right) \\ \epsilon_j &= \dfrac{\Delta z_{j+1/2}\epsilon_{j+1/2} + \Delta z_{j-1/2}\epsilon_{j-1/2}}{2\Delta z_j} \end{cases}$$

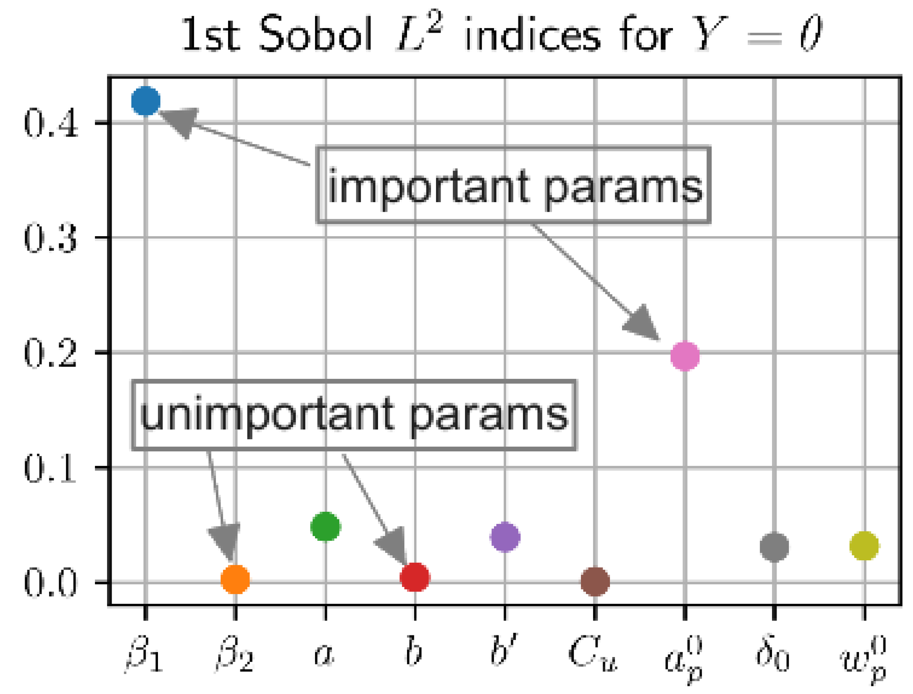
4 – Results



$\longrightarrow$ significant energy biases for inconsistent formulation

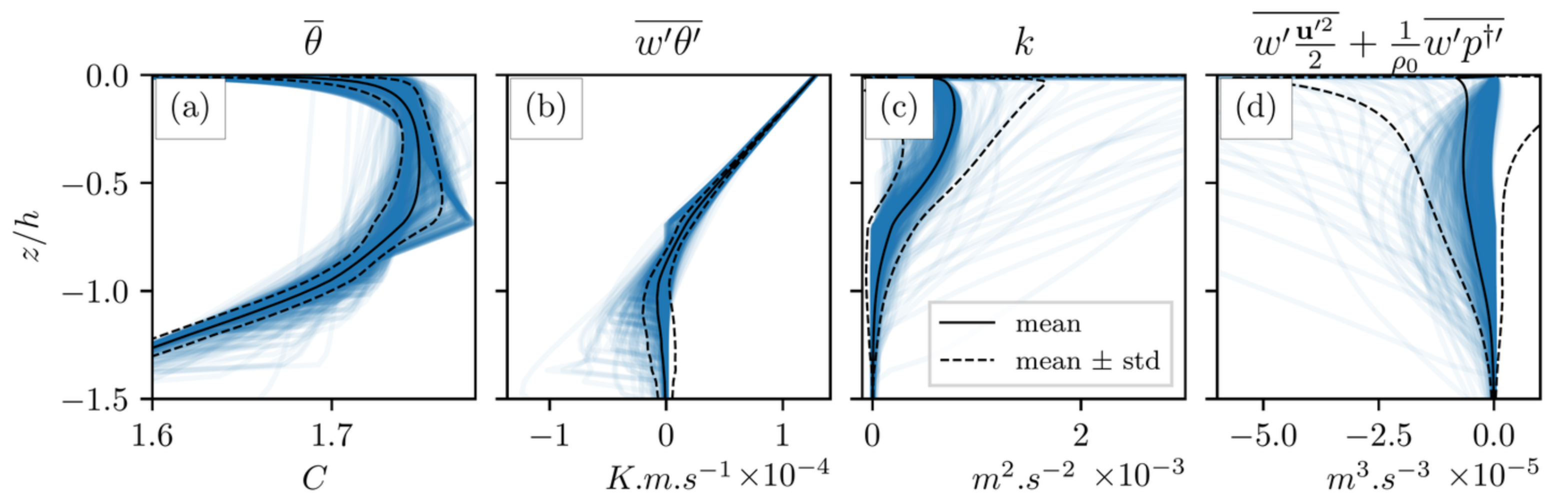
4 – Quantify Uncertainty due to "free" parameters

Global Sensitivity analysis

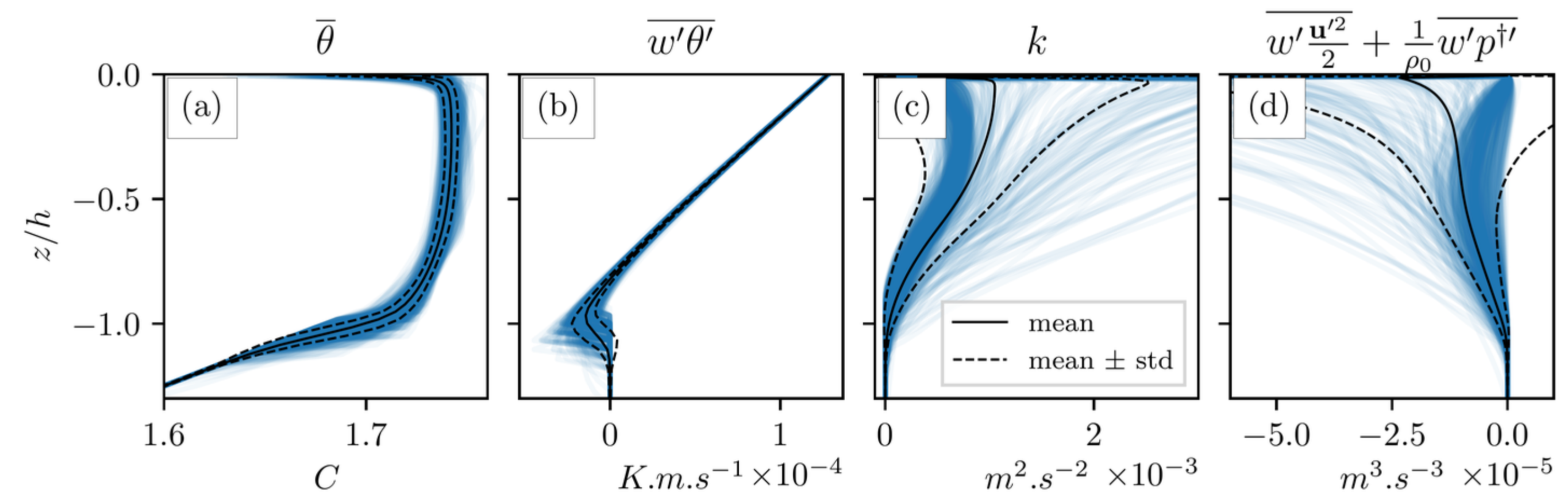


MCMC Bayesian Estimation, conditionned on LES data

Uncertainty BEFORE parameter calibration



Uncertainty AFTER parameter calibration



Temperature and temperature flux uncertainties are reduced.
Question: Why TKE and TKE uncertainties are not reduced?

Giordani, Bourdallé-Badie, Madec. *An Eddy-Diffusivity Mass-Flux Parameterization for Modeling Oceanic Convection. JAMES, 2020*

Perrot, Lemarié, Dubos. *Energetically consistent EDMF schemes for Atmospheric and Oceanic Convection, Part I (JAMES, in press); Part II (under review for JAMES)*