The Effects of Near-Surface Turbulence on Ocean Alkalinity Enhancement

Josiane Ostiguy[1], Ruth Musgrave[1], Graig Sutherland[2], Douglas Wallace[1], and Anneke ten Doeschate[3]
[1]Dalhousie University, [2]Environment and Climate Change Canada, [3]Rockland Scientific

Surface Turbulence and OAE

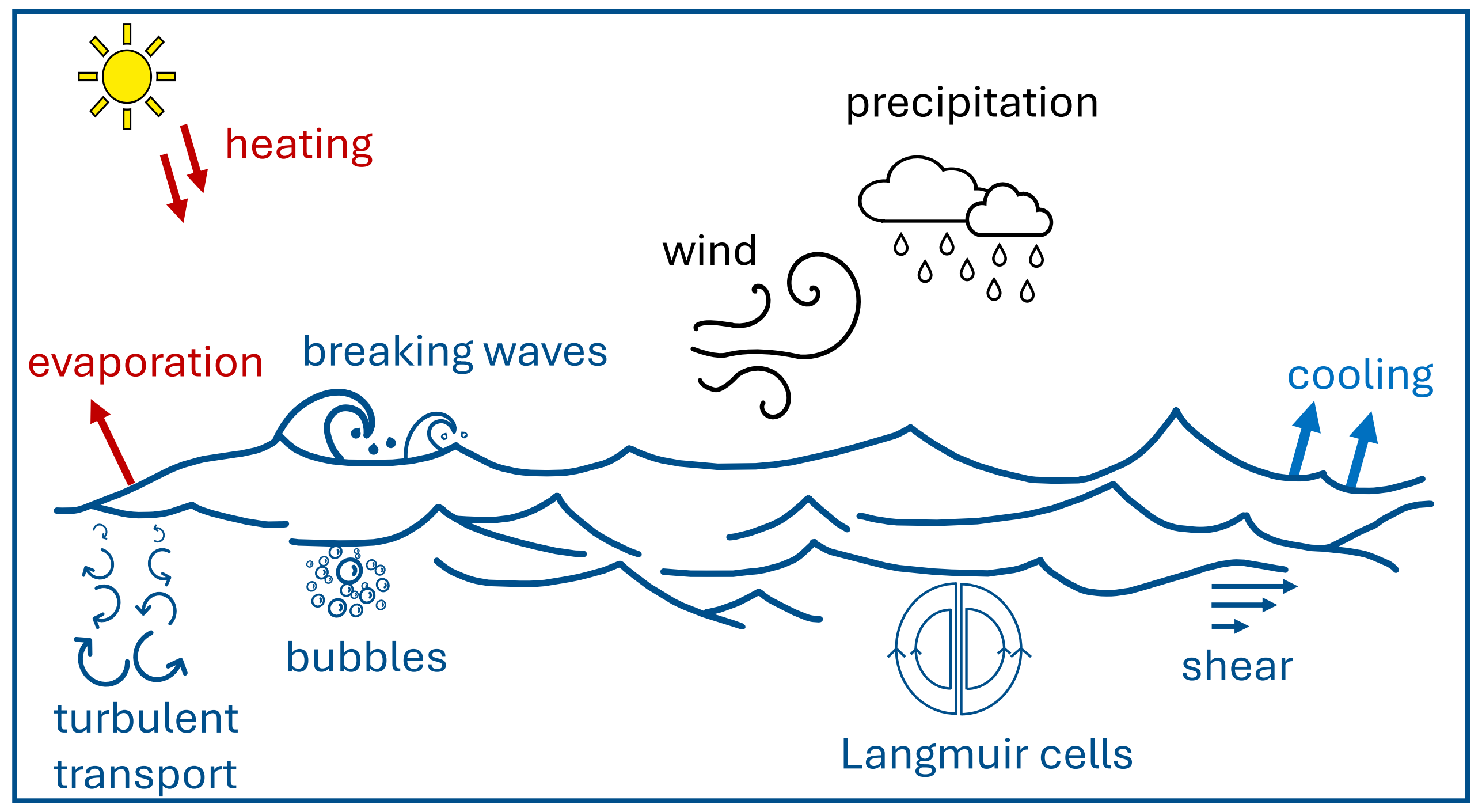


Figure 1: Processes driving surface turbulence in the ocean.

Estimates of CO_2 uptake by the ocean from ocean alkalinity enhancement (OAE) rely on parameterizations of turbulent mixing and gas exchange, as these small scale processes (Fig 1) cannot be resolved in regional or global scale numerical models.

We employ turbulence-resolving numerical simulations that include dissolved inorganic carbon (DIC) and total alkalinity (TA) as tracers to try to develop a physically consistent model of gas exchange and interior mixing for OAE.

Model Setup

We run a series of large eddy simulations (LES) using Oceananigans (Ramadhan et al. 2020), with the Smagorinsky closure and horizontally periodic boundary conditions. We prescribe initial conditions as in Fig 2, and apply wind stress, heating/cooling and CO_2 flux at the surface (Table 1).

Wind speed	0 – 20 m/s
Momentum flux	- $C_d(u_{10})\, u_{10}^2$ (Edson et al. 2013)
Heat flux	200 W/m²

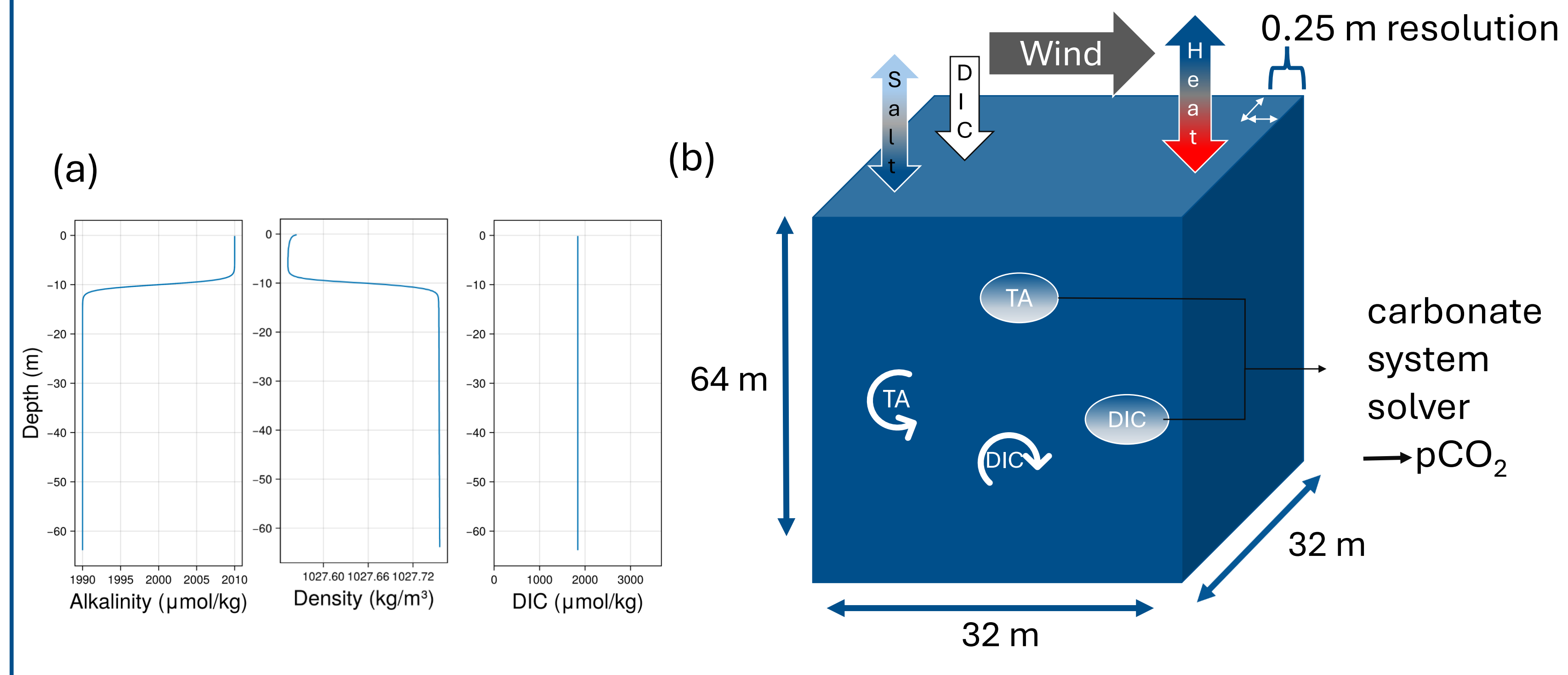
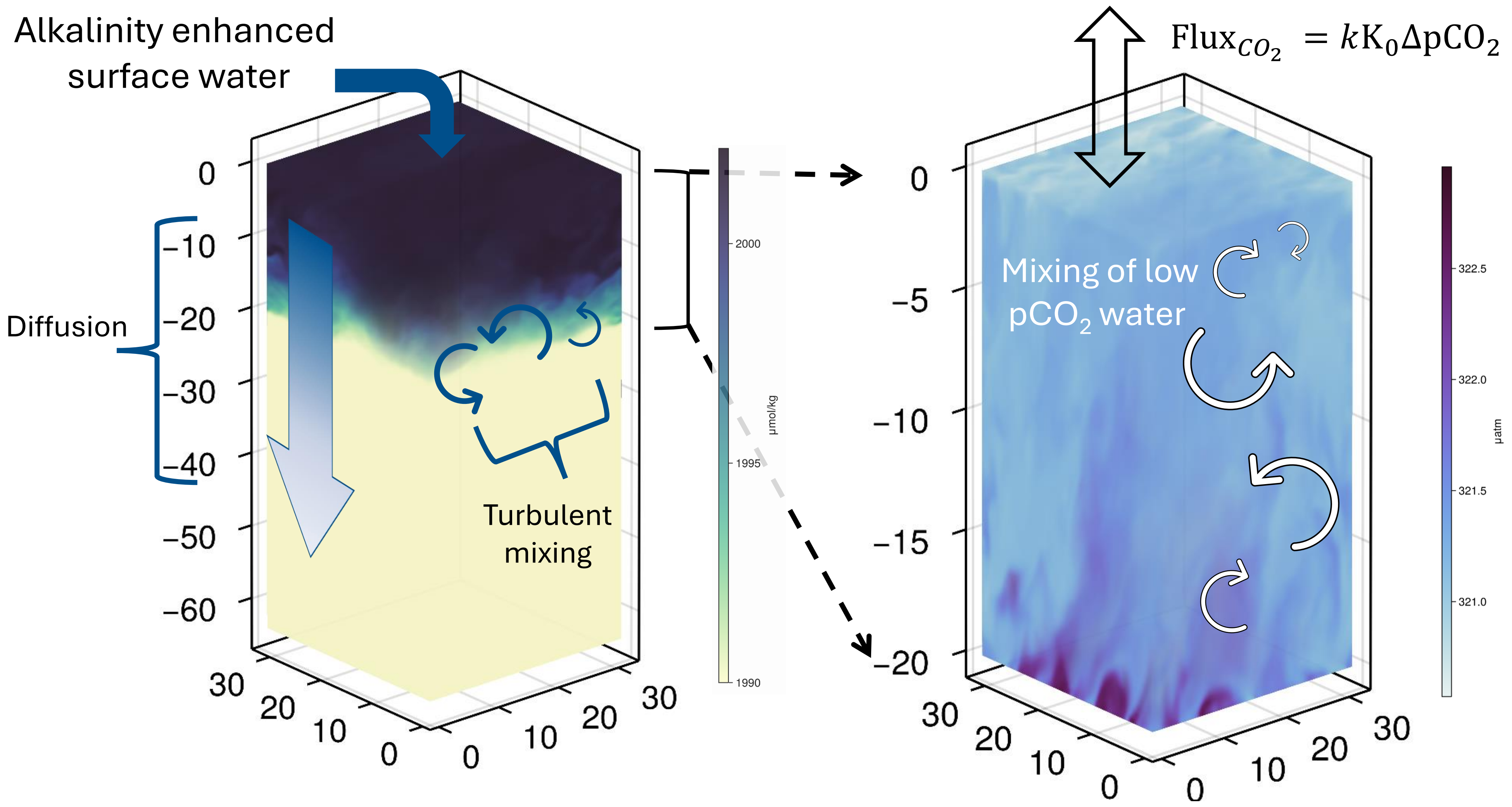


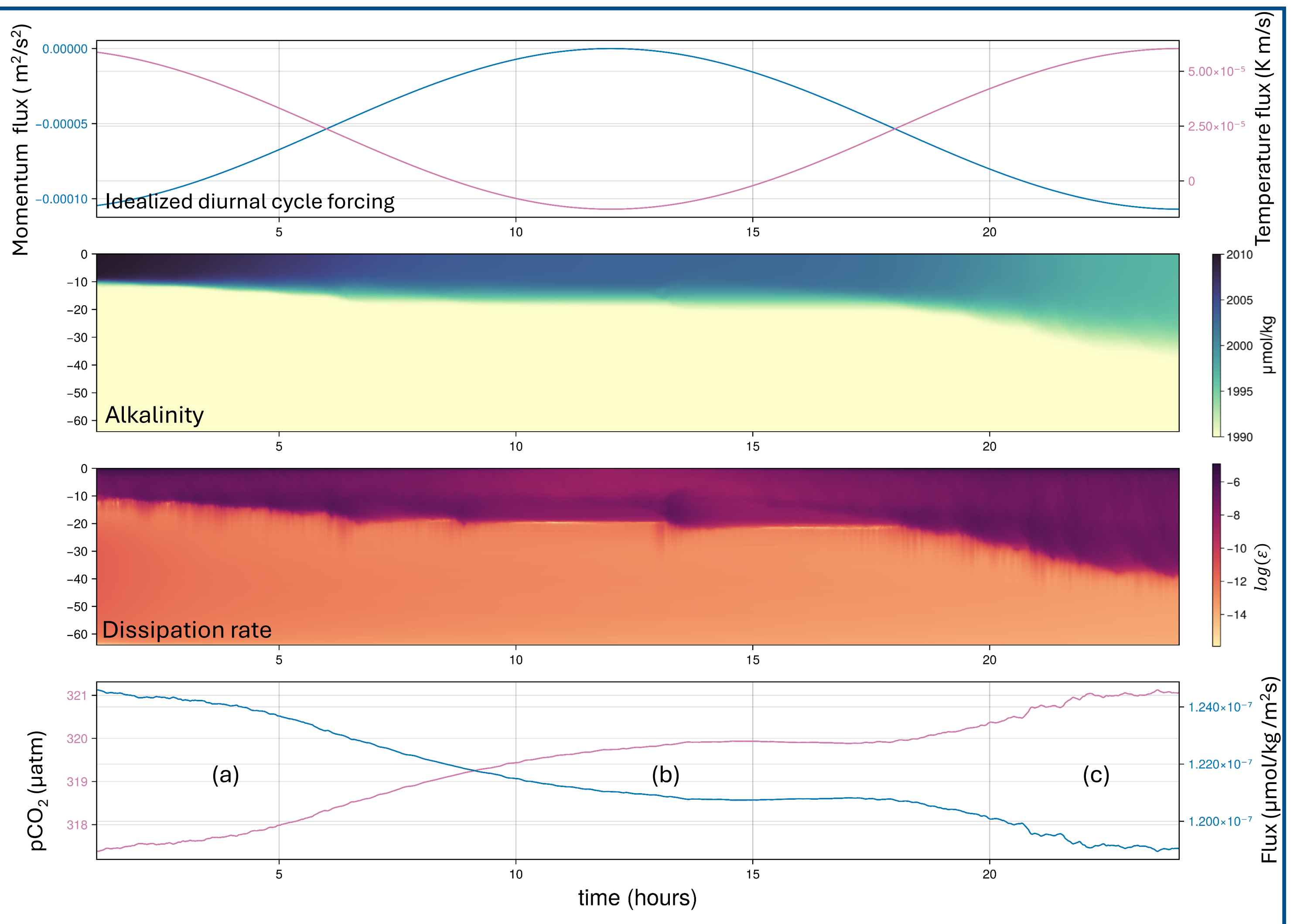
Figure 2. Initial conditions profiles (a) and schematic of LES set-up (b)

The Effects of Turbulence on Vertical Gradients of Alkalinity and DIC



Turbulence mixes alkalinity down into the water column, reducing the rate of draw down of atmospheric CO_2 associated with the addition.

Air-sea gas exchange creates a near surface gradient in DIC, which is eroded by turbulence in the interior. Higher levels of turbulence renews low pCO_2 water at the surface, and may increase the rate of atmospheric CO_2 draw down.



(a) Flux decreases as pCO_2 near the surface increases and the alkalinity is diffused downwards under high winds.
(b) Flux stabilizes as the turbulence weakens under light winds and heating conditions.
(c) Flux continues to decrease as the alkalinity is further diffused downwards, and surface pCO_2 increases.

→ Mixing down dominates over increased gas transfer velocity from high winds

Towards a Physically Derived Gas Exchange Parameterization

The modelled turbulent structure:

- evolves alkalinity and DIC tracers by advection and diffusion, and
- can be used to calculate the gas exchange rate.

Empirical gas exchange parameterizations are based on wind speed, under the assumption that wind speed is the only driver of turbulence. Most commonly, the gas transfer coefficient, k, is a calculated as a function of the 10 meter wind speed,

$$k \propto Sc^{-n} u_{10}^{2} \qquad (1)$$

(Wanninkhof 2014). Physically derived parameterization seek to include other drivers of turbulence (Fig 1). These are based on the turbulence kinetic energy dissipation rate, ε_0, where,

$$k \propto Sc^{-n} (\varepsilon_0 \nu)^{1/4} \qquad (2)$$

(Lamont & Scott 1970). If the dissipation rate, ε, is consistent with the Law of the Wall then,

$$k \propto Sc^{-n} u_* \qquad (3)$$

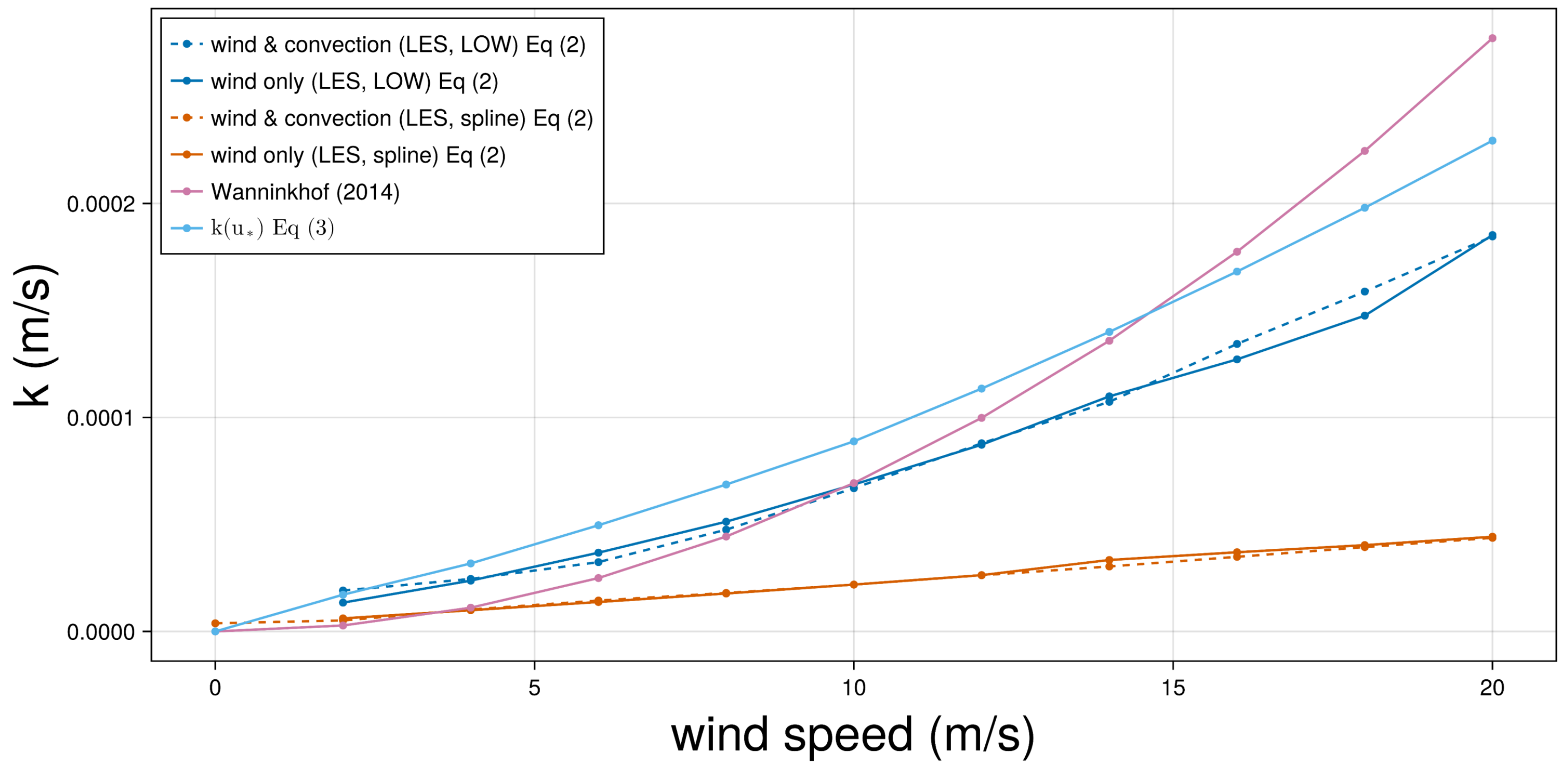


Figure 3. Gas exchange velocity calculated by (1) , (2) and (3) with and without convection

Results show that gas exchange calculated by (2) and (3) resemble those predicted for LOW turbulence. The surface dissipation ε_0 is sensitive to the fit (e.g. LOW, spline) and leads to a different result. Future work will seek to improve on estimates of ε_0 in our simulations, and additionally include other turbulent producing processes (e.g. wave breaking), to more closely represent ocean conditions.

Contact: josiane.ostiguy@dal.ca