# Impact of 3D non-hydrostatic dynamics on tracer transport in the nearshore region

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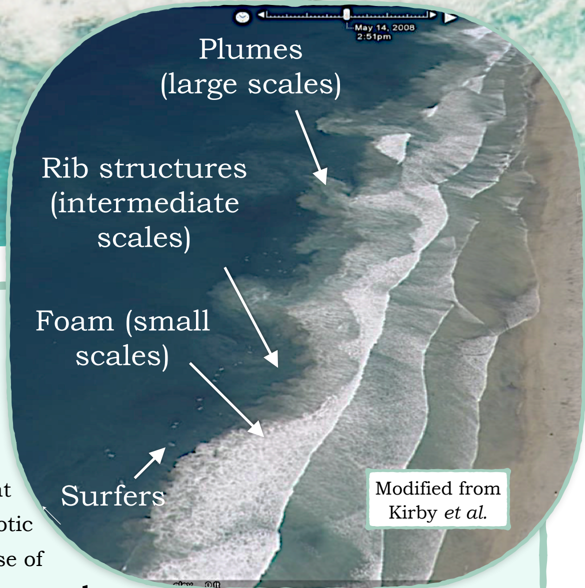



## 1 Context

✱ The nearshore region, consisting of the inner shelf (up to 20m depth) and the surfzone (from breaking point to shoreline), is a highly chaotic area difficult to study because of **very different spatial and temporal scales** coexisting and interacting with each other. Understanding transport and mixing in this area is of very importance to **predict the fate of tracers, such as pollutants, sediments, bacteria, or larvae**.

✱ Up to now, most of the models used for nearshore simulations are 2DH Boussinesq, resulting in a **poor understanding of 3D processes** in this area. In addition, 2DH models still have difficulties in accurately representing observations. In particular, they tend to **overestimate the offshore directed tracer propagation** while **underestimating surfzone mixing,** as shown for the IB09 experiment presented below (Hally-Rosendahl & Feddersen, 2016).

✱ New 3D wave-resolving models are now available to analyze full 3D dynamics while evaluating 2D model realism.

## 2 Dye release experiment


✱ IB09 is an experiment conducted in 2009 over one month to better understand the tracer transport in the Southern Californian Bight (Hally-Rosendahl & Feddersen, 2016)

✱ Data used: 6 hours **IB09 large-scale dye release**

✱ Alongshore-uniform bathymetry: **ideal for process study**

✱ Data already compared with the 2D wave-resolving *funwaveC* model (Hally-Rosendahl & Feddersen, 2016): **ideal for 3D processes identification**

✱ Domain of 400 m by 1000 m with 1 m resolution forced with southerly alongshore wind stress and JONSWAP wave spectrum with directional spreading ($H_s$=0.74 m, $T_p$=13 s, $\theta$=17°, $\sigma$=30°, $\gamma$=20)

✱ Inner shelf stratification representative of summer conditions in Southern California

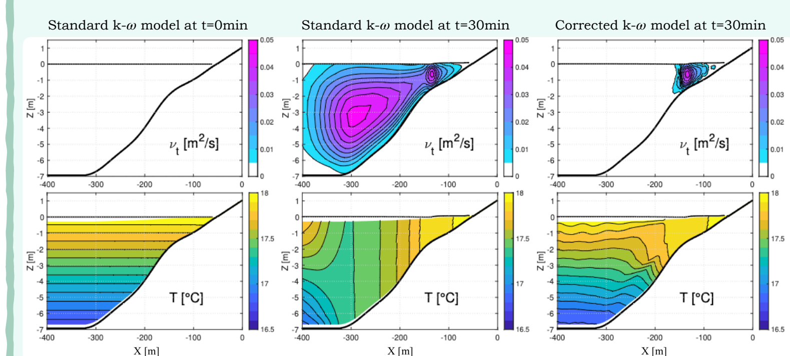
## 3 CROCO: a 3D non-hydrostatic wave-resolving model

✱ Free-surface **wave-resolving** model (like NHWAVES, SWASH) but with a **compressible** approach in the **non-hydrostatic** solver.

✱ Validated in hydrodynamics (Marchesiello *et al.*, 2021) and morphodynamics (Marchesiello *et al.*, 2022) studies.

✱ CROCO has recently been improved for nearshore studies by correcting several key issues (see below).

## 4 Correction of turbulent closure for stratified nearshore studies

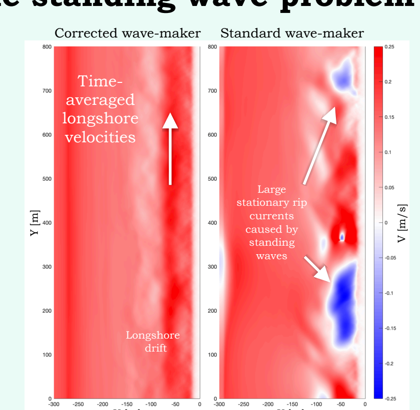



✱ Instability of two-equation turbulence closures (*e.g.* k-ω, k-ϵ) leads to **overmixing in near-potential (irrotational) flows** under non-breaking waves and results in destruction of the inner shelf stratification.

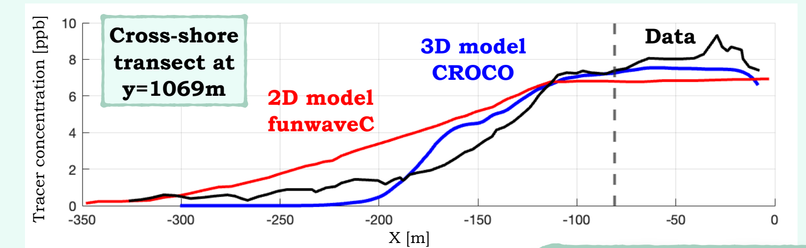
✱ This problem is corrected in CROCO (Marchesiello & Treillou, *in revision*), allowing 3D studies with stratification.

## 5 Correction of the standing wave problem

✱ Simulating realistic random sea state with a deterministic wave-maker can lead to **phase-locking** (interference between two waves of the same frequency but different directions) and to **spurious standing waves**. This problem is addressed and corrected in CROCO by adding random frequencies.

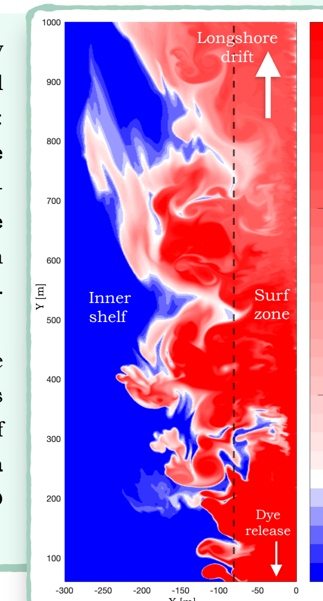



## 6 RESULT: Attenuated surf-shelf exchanges




✱ In our 3D non-hydrostatic framework, new processes are taken into account. Vertical shear affects the whole spectrum of dynamics: 1) it creates rib structures at **intermediate scales** of about 5 meters from 3D Kelvin-Helmholtz instabilities **increasing surfzone mixing;** 2) it weakens large-scale flash rips in the surfzone, **significantly attenuating cross-shore exchange with the shelf**.

✱ The 3D processes drastically change the kinetic energy cascade. While 2D simulations only exhibit a strong inverse cascade typical of 2D turbulence, 3D simulations have **both inverse and direct cascades** typical of 3D turbulence (but the inverse cascade is weaker).




## 7 Conclusions and perspectives

✱ Our results so far demonstrate the importance of 3D processes on tracer transport. Shear-driven processes that weaken the inverse cascade appear to play an important role in the observed intensity of surf-shelf exchange. Their absence in 2D models may explain why they **overestimate tracer mass in the inner shelf**. On the other hand, 3D instabilities at intermediate scale increase surfzone mixing and their absence in 2D models would explain why they **underestimate mixing in the surf zone**.

✱ Future work will focus on a more detailed analysis of surfzone mixing diagnostics and diffusivity estimation. More attention will also be given to parameter sensitivity analysis (*i.e.*, the effect of bathymetry or wave spectrum on currents and mixing). The **effect of stratification** and Earth rotation will also be studied in this configuration.

**KEY MESSAGE: 3D non-hydrostatic processes can significantly reduce cross-shore exchange between surf zone and inner shelf**

• Hally-Rosendahl, K. & Feddersen, F. Modeling surfzone to inner-shelf tracer exchange: MODELING SURFZONE INNER-SHELF EXCHANGE. *J. Geophys. Res. Oceans* **121**, 4007–4025 (2016).
• Marchesiello, P. *et al.* Tridimensional nonhydrostatic transient rip currents in a wave-resolving model. *Ocean Modelling* **163**, 101816 (2021).
• Marchesiello, P. & Treillou, S. Correction of GLS turbulence closure for wave-resolving models with stratification. *In revision.*
• Treillou, S. & Marchesiello, P. Impact of 3D non-hydrostatic dynamics on tracer transport in the nearshore region. in vol. 17 (191-200) (Paralia, 2022).