Time persistence of floating-particle clusters in free-surface turbulence

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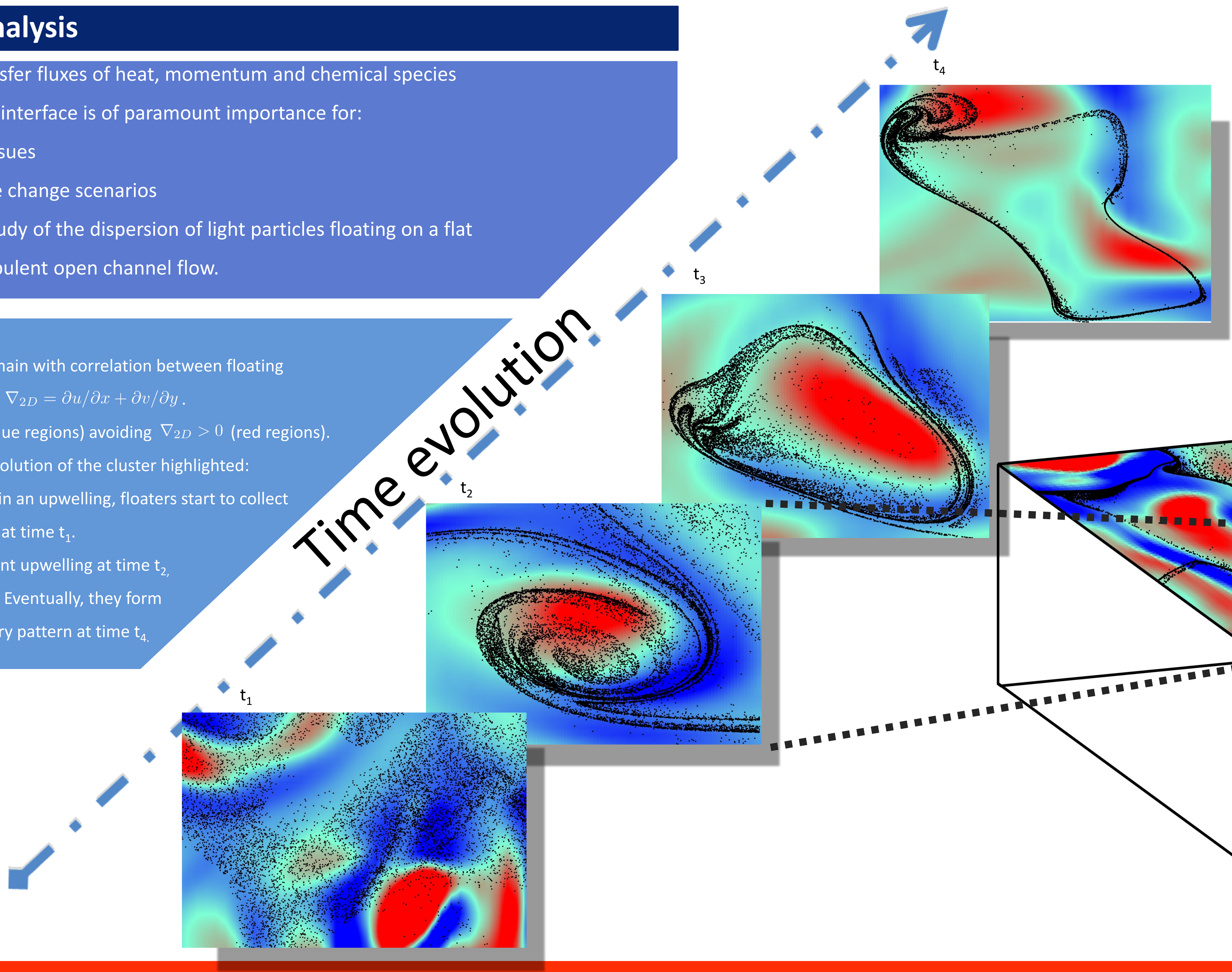
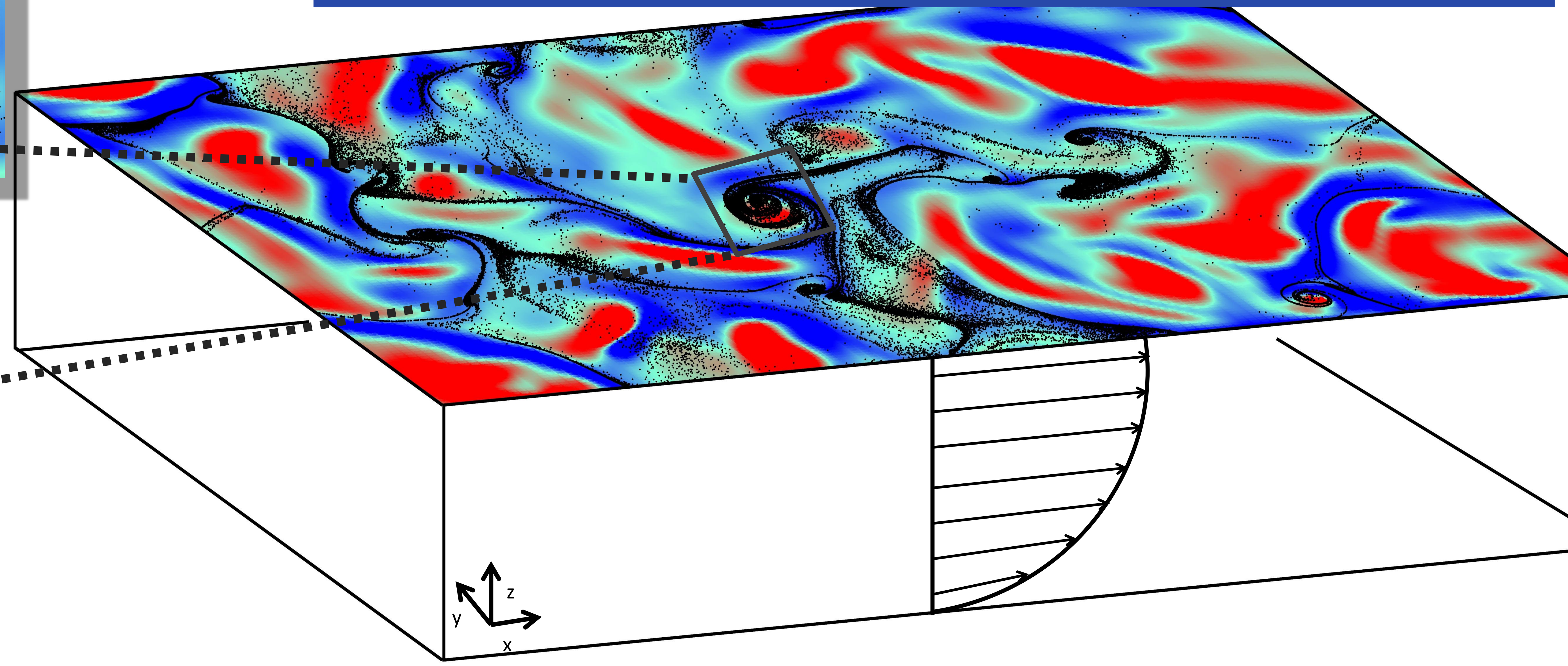
Problem under analysis

Accurate prediction of transfer fluxes of heat, momentum and chemical species at the ocean-atmosphere interface is of paramount importance for:

- sizing environmental issues
- depicting future climate change scenarios

Focus of this work is the study of the dispersion of light particles floating on a flat shear-free surface of a turbulent open channel flow.





Main Figure:
Sketch of the computational domain with correlation between floating clusters and surface divergence $\nabla_{2D} = \partial u/\partial x + \partial v/\partial y$.
Floaters segregate in $\nabla_{2D} < 0$ (blue regions) avoiding $\nabla_{2D} > 0$ (red regions).
On the left is shown the time evolution of the cluster highlighted: upon reaching the surface within an upwelling, floaters start to collect into a neighboring downwelling at time t_1.
Then, they are hit by a subsequent upwelling at time t_2, and scattered around at time t_3. Eventually, they form a highly concentrated filamentary pattern at time t_4.

Governing equations & Simulation details

The system under analysis is described using Direct Numerical Simulation of the coupled Navier-Stokes equation of incompressible flow (1) and Lagrangian Particle Tracking for the evolution of particles by solving equations (2).
The simulations are performed by means of pseudo-spectral algorithm on a channel geometry. Boundary conditions are: periodic in the stream-wise and span-wise directions, no-slip velocity at the bottom wall, free-slip velocity at the surface.

$$\frac{\partial \mathbf{u}}{\partial t} = -\mathbf{u}\cdot\nabla\mathbf{u} + \frac{1}{Re_\tau}\nabla^2\mathbf{u} - \nabla P \qquad (1)$$

$$\frac{\partial \mathbf{x}_p}{\partial t} = \mathbf{v}_p\ ,\ \frac{\partial \mathbf{v}_p}{\partial t} = \frac{(\rho_p - \rho_f)}{\rho_p}\mathbf{g} + \frac{(\mathbf{u}_{@p} - \mathbf{v}_p)}{\tau_p}(1 + 0.15\, Re_p^{0.68}) \qquad (2)$$

RESULTS

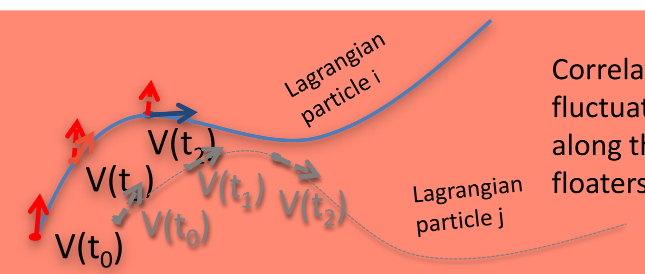
Lagrangian integral time scale

The lagrangian integral time scale is equal to: $T_{\mathcal{L},ij} = \int_0^\infty R_{f,ij}[t, \mathbf{x}_f(t)]dt$

where

$$R_{f,ij}[t, \mathbf{x}_f(t)] = \frac{\langle \mathbf{u'}_{f,i}[t, \mathbf{x}_f(t)] \cdot \mathbf{u'}_{f,j}[t_0, \mathbf{x}_f(t_0)]\rangle}{\langle \mathbf{u'}_{f,i}[t_0, \mathbf{x}_f(t_0)] \cdot \mathbf{u'}_{f,j}[t_0, \mathbf{x}_f(t_0)]\rangle}$$

is the correlation coefficient of velocity fluctuations.



Correlation of velocity fluctuations computed along the lagrangian floaters trajectories

Time scaling of floaters clustering

- Floaters are scattered by upwellings and form highly-concentrated intermittent filamentary pattern
- Intermittency is connected to the formation of sources and sinks of fluid velocity generated by subsurface upwelling and downwelling motions
- Clusters over-lives the surface turbulent structures which produced them for several Lagrangian integral fuid time scales.

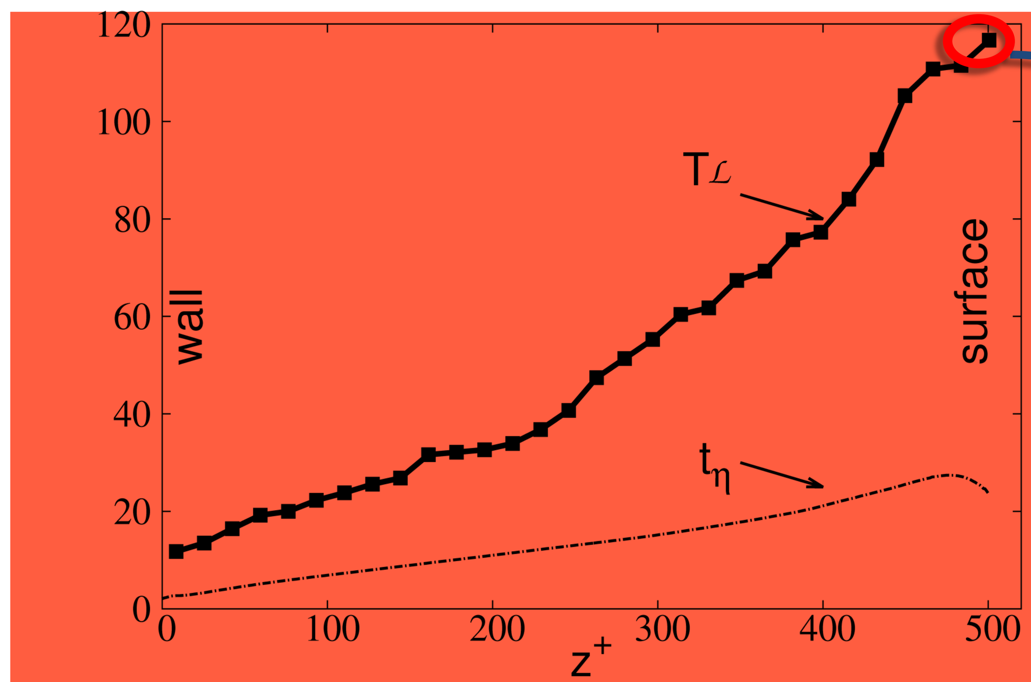


Figure1:. Lagrangian integral fluid time scale and Kolmogorov time scale as function of the wall -normal coordinate

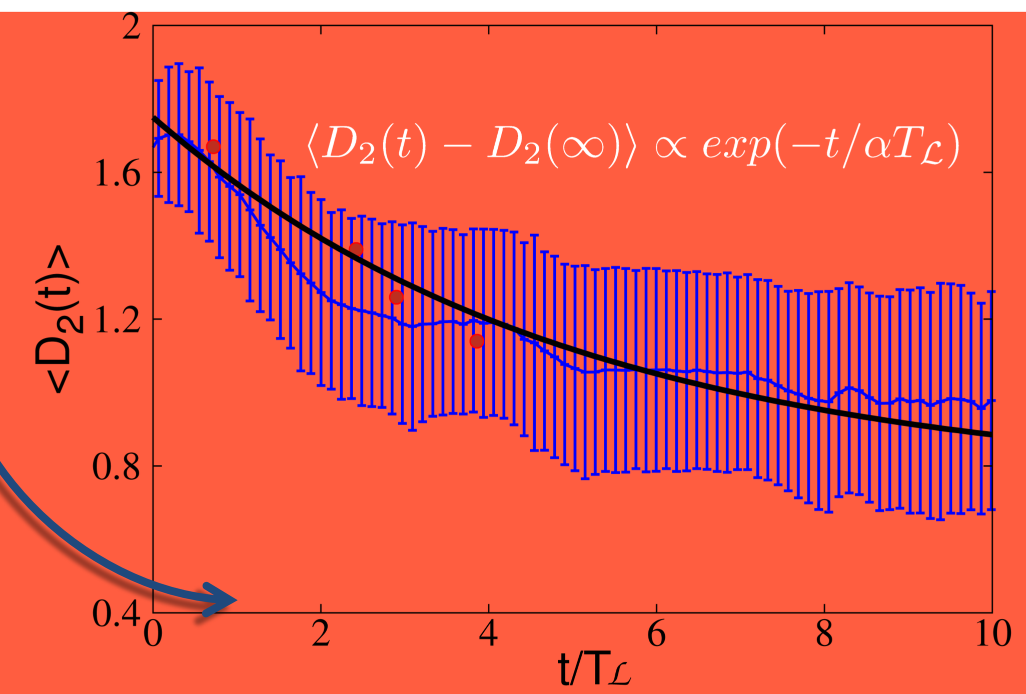


Figure2: Time evolution of correlation dimension $\langle D_2(t)\rangle$.
Circles in panel represent the istantaneous values of $\langle D_2(t)\rangle$ for the floater cluster shown in the main figure. The black line is the estimate of $\langle D_2(t)\rangle$ obtained assuming an exponential decay rate.

Reference:
S. Lovecchio, C. Marchioli, A. Soldati, Phys. Rev. E 88,0033003 (2013)