Shallow Coherent Structures Generated by Jets

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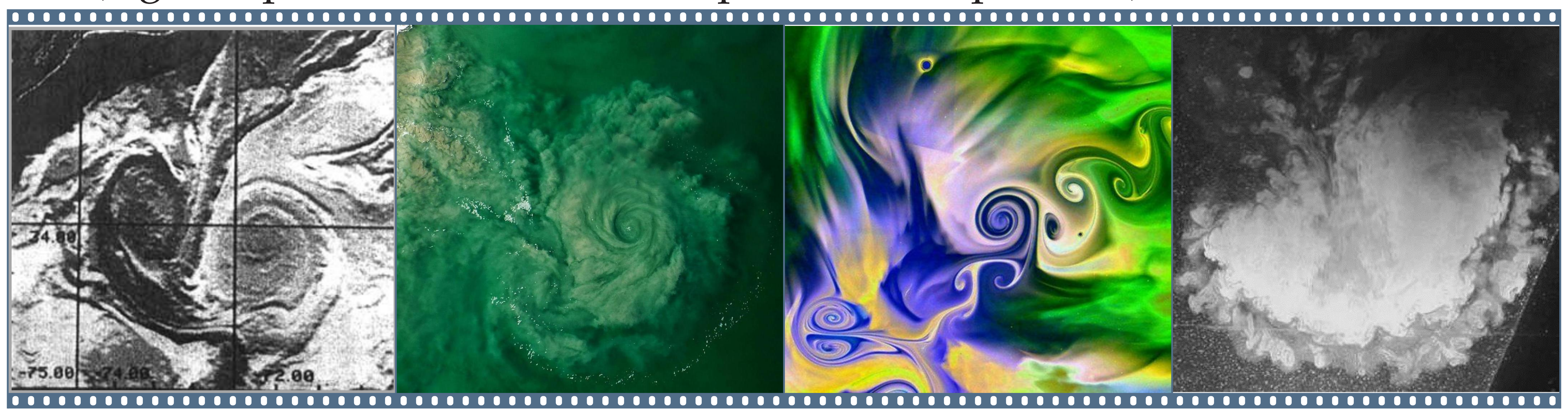
Background

Shallow coherent vortex structures are ubiquitous in nature and daily lives, having been frequently discovered in rives, estuaries, coastal regions, oceans, and atmosphere. The generation of such structures can be topographical forcing, the internal transverse shear instabilities, and base flow secondary instabilities. When the coherent structures occur, they may be felt on the water surface, and also play a crucial role in shaping the local environments due the the following reasons.

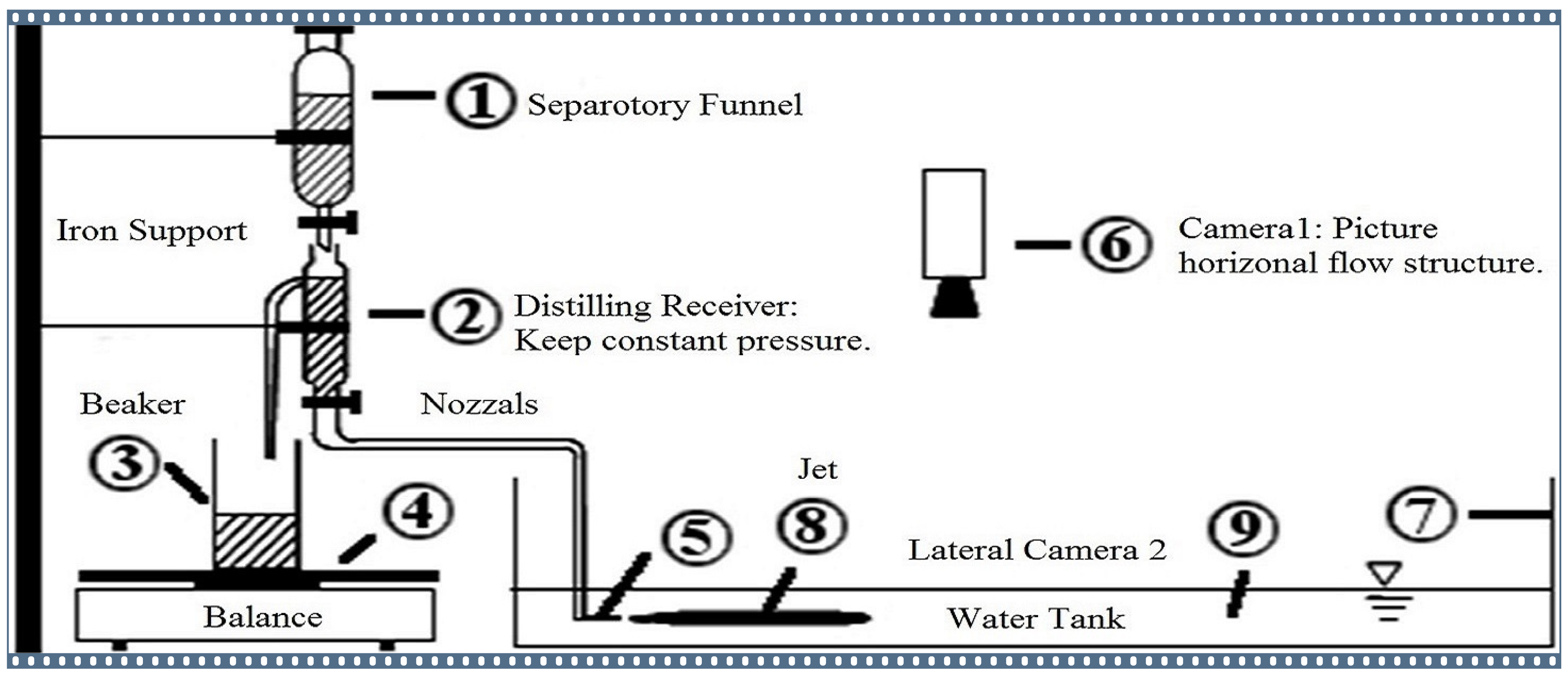
1. Having large horizontal and vertical scales, and long decaying time.
2. The coherent structures enhance the mixing and transport processes of momentum, mass, and energy in both horizontal and vertical directions.

The first two figures illustrate several large-scale coherent structures discovered in nature environments (e.g., the Gulf Stream[1], an Australian beach[2]), while the last two figures show large-scale coherent structures in laboratories (e.g., a rip current [3], and multiple vortex dipoles [4]).

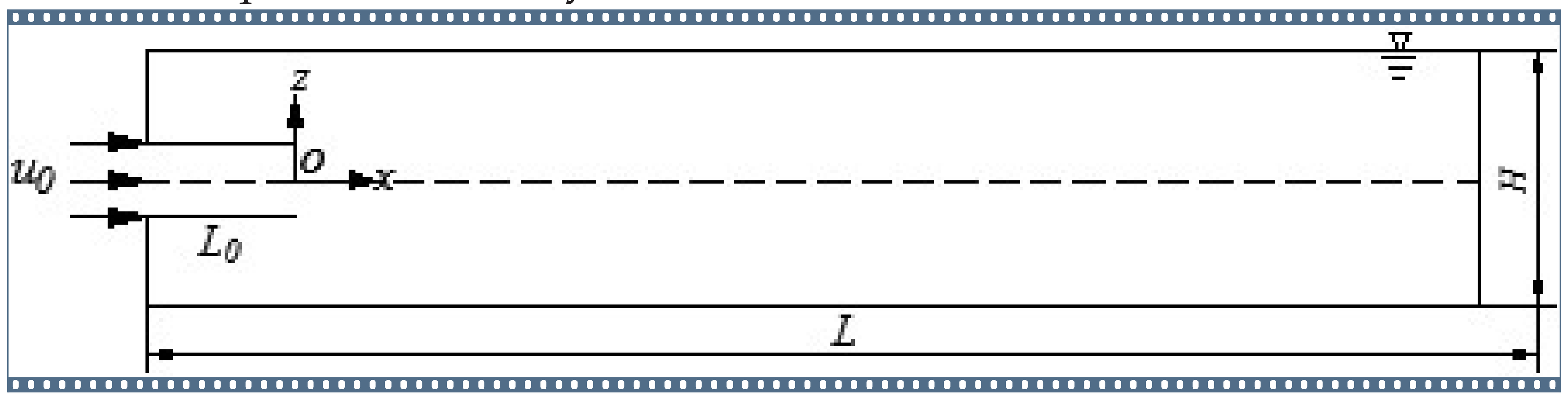


the Gulf Stream | Australian beach | a rip current | vortex dipoles

Methods

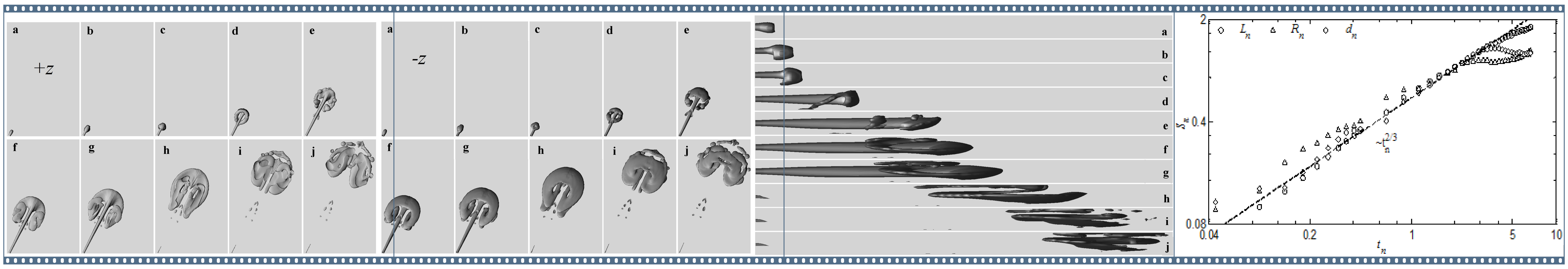


The experimental system generates a constant momentum source, and records the dyed fluid evolution. The shallow water effects on the jet motion is captured, and quantitative analyses of the data is conducted.



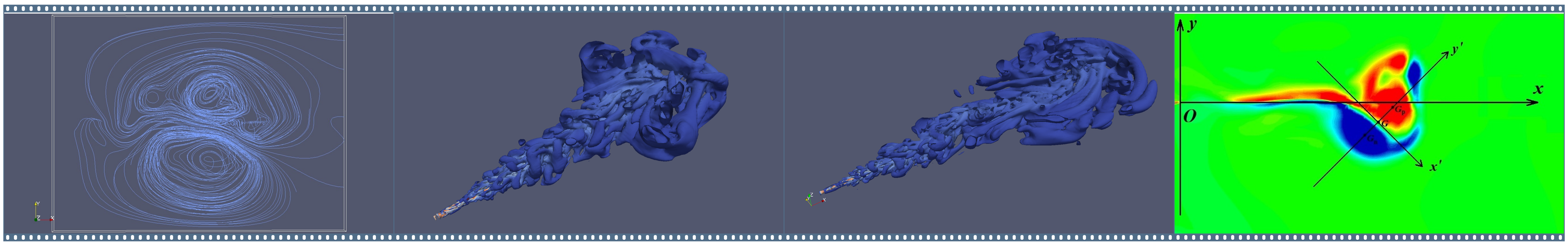
The domain and meshing is designed as above. The nozzle inlet has a uniform velocity while the bottom and top are wall and free surface.

Results: Laminar jets and Turbulent jets



Top view | Bottom view | Front view | Geometry parameters

1. The motion of the coherent structure in shallow water is composed of two simultaneous motions, namely, the horizontal mushroom-like current and the vertical spiral motion.
2. The flow pattern shows both pure 2D and 3D flow features which is characterized by the relationships of $t^{2/3}$ and $t^{1/2}$, respectively.
3. For lower Reynolds numbers, the flow features are more dominated by 3D features, while dominated by 2D features for large Reynolds numbers.
4. The vertical flow structure is much smaller than that in the horizontal direction, but plays an indispensable role in transporting momentum from lower water layers to upper water layers.



Streamline | $\lambda_2, t = 3s$ | $\lambda_2, t = 5s$ | ω_z

1. The flow pattern is different from that in laminar cases, but the vertical confinements caused by the bottom and the free surface still exist, making the flow structure a quasi-2D flow structure.
2. Big coherent structures can be easily recognized from the streamlines, the λ_2, and the vorticity contours.
3. There exits momentum exchange between horizontal Q2D structure and the small 3D structure in the front region of the Q2D structure.
4. The small 3D structure is a kind of secondary flow, caused by the bottom friction, and can convert to large Q2D structures under a certain conditions.

References

[1] Mied R. P., Lindemann G. J., and McWilliams J. C., 1991. The generation and evolution of mushroom-like vorticies. Journal of Physics Oceanography, 21(4): 489-510.
[2] http://beachsafe.org.au/surf-ed/ripcurrents.
[3] http://www.bbc.co.uk/news/10108401.
[4] Sous D., Bonneton N., and Sommeria J., 2004. Turbulent vortex dipoles in a shallow water layer. Physics of Fluids, 16(8): 2886-2898.

Future Directions

1. Further analyses on the force balance, the bottom shear stress, and energy balance processes are necessary in order to fully understand the formation and evolution mechanisms.
2. Proposing a theoretical model to predict the dominant vortex scales, kinetic energy, and bottom shear stress.
3. Considering the buoyant effect (e.g., the density different between the injection and ambient fluids, stratified ambient fluid).
4. Introducing sediments into the jets, and studying the influences of turbulence and shallow effects on the local sediments motion, concentration distribution, and bottom deposition distribution.