

TKE budget equation terms of a gravity current approaching a vertical obstacle

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ABSTRACT

The terms of the TKE budget equation of a gravity current approaching a vertical cylinder are analyzed experimentally through PIV measurements. The presence of an increasing pressure adverse gradient interferes with the redistribution of TKE in the head of the current, suppressing the transport of TKE from the major production source located at the interface of the two fluids to the rest of the current.

1. Introduction

Flows driven by a density gradient, called gravity currents, are present throughout the planet, often spreading pollutants and modifying the environment in which they propagate. Given their impact, it is necessary to understand how gravity currents modify - and are modified by - the different morphologies they may encounter during their path, such as different roughnesses (Maggi et al., 2022) or industrial installations on the seabed (De Falco et al., 2021). The present work aims to interpret the effects that an adverse pressure gradient generated by an obstacle induces on an approaching gravity current, thus providing a first characterization of how the presence of vegetation or human obstacles influences the production and diffusion of turbulent kinetic energy (hereinafter TKE) of these flows, an aspect still little investigated.

2. Experimental apparatus

Full lock-released gravity currents are reproduced in a smooth horizontal rectangular channel with a length, height and width of 3 m, 0.4 m and 0.175 m, respectively. An emergent cylinder, mounted vertical at half width of the channel, is placed at $3x_0$ from the left side of the channel, with $x_0=0.3$ m is the position of the lock. Given the ratio between the length of the channel and the position of the lock, the current propagates in the slumping phase, even before the impact with the obstacle (Simpson, 1999). Instantaneous longitudinal u and vertical w velocity components are measured with a 2D classical P.I.V. along the centerline of the channel, in the refractive index condition. A digital camera with acquisition frequency of 15 Hz records a section upstream the cylinder (Fig.1). The measurements start with the removal of the gate, causing the collapse of the dense fluid (consisting in salt diluted in fresh water) into a mixture of alcohol and fresh water filling the rest of the tank. The height of water column $h_0=0.2$ m is equal for both the volumes. A total of 20 repetitions are performed and analyzed, 10 with the cylinder and 10 without it, to have a base of comparison. All the repetitions have been performed with a constant density gradient $\Delta\rho=6$ kg/m³. The analyses focus on the head of the current, identified as the leading steady part of the current showing the phase during its propagation. The head is followed before the impact with the cylinder, or until the end of section recorded in the undisturbed configuration.

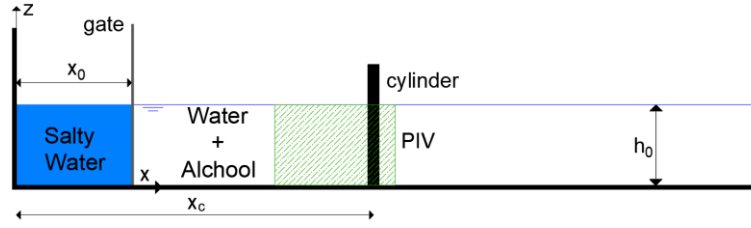


Fig 1. Geometry of the channel

3. Results

The TKE budget equation is defined as in Dai et al (2023):

$$\frac{\partial \langle k \rangle}{\partial t} + \underbrace{\langle u_j \rangle \frac{\partial \langle k \rangle}{\partial x_j}}_C = - \underbrace{\langle \rho' u'_{3'} \rangle}_B - \underbrace{\langle u'_i u'_j \rangle \frac{\partial \langle u_j \rangle}{\partial x_j}}_P - \frac{\partial}{\partial x_j} \left(\underbrace{\frac{1}{2} \langle u'_i u'_i u'_j \rangle}_T + \underbrace{\langle p' u'_j \rangle}_{TP} - \underbrace{\frac{2}{RE} \langle \frac{\partial u'_i}{\partial x_j} u'_i \rangle}_V \right) - \langle \varepsilon \rangle \quad (1)$$

where t – time [s], $k = \langle u'_i u'_i \rangle$ – turbulent kinetic energy [$\text{m}^2 \text{s}^{-2}$], x_i – i^{th} Cartesian coordinate [m], u_i – j^{th} velocity components [m s^{-1}], Re – Reynolds number, p – pressure [Pa], ρ – density [kg m^{-3}]. The symbology $\langle \blacksquare \rangle$ indicates the application of the ensemble average while variables marked with ' are fluctuations on the averaged ones. K_t is TKE variation in time. C, P T, V and ε are the convective rate of change, the production, the diffusion due to Reynolds and viscous stresses and the dissipation of TKE, respectively. B is the buoyancy turbulent fluxes while TP is the diffusion due to pressure. All the terms show a reduction of their intensity inside the head section, except for the sum B+DP. Figure 2 shows the maps of TKE production term, with overlapped vectors of TKE fluxes. The current interacting with the cylinder is characterized by almost zero values of P inside the section. At the interface P has higher intensity compared to the undisturbed configuration. The TKE fluxes, in the case of the cylinder, are localized only along the interface layer, the major source of TKE production. Previous study on turbulent flows shown that diffusion due to pressure is generally opposite to turbulent diffusion. In shear layers, however, the two diffusions act in concert, increasing the total diffusion of TKE (Lumley, 1975). This explains the interruption of TKE flows from the interface. Consequently, the failure to redistribute TKE from the major production source causes a reduction in the same in the rest of the current.

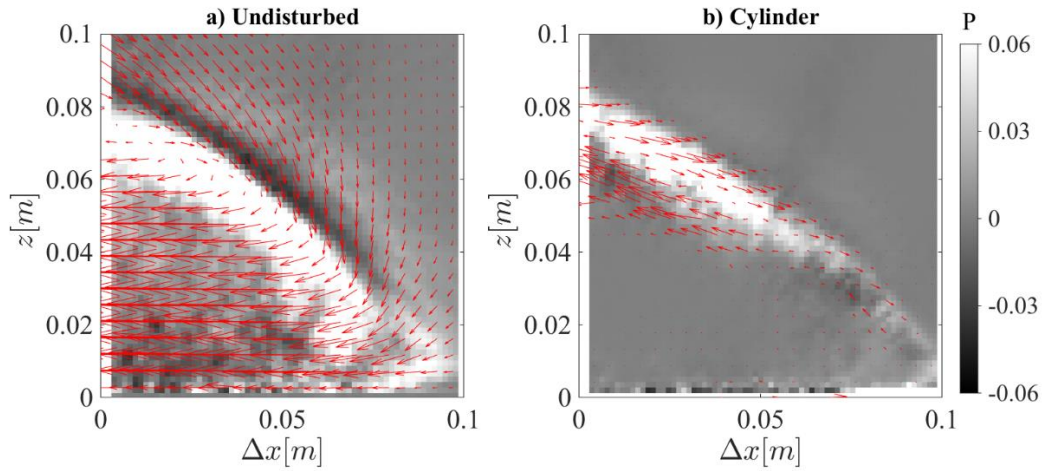


Fig 2. Maps of production term for a) undisturbed current and b) current approaching the cylinder. The vectors indicate the TKE fluxes.

Acknowledgements

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