An interactive tool for stratigraphic visualization applied to turbulence-resolved numerical simulations of turbidity currents

Felipe Schuch[1], Filipi Vianna[1], Marcio Pinho[1], and Jorge Silvestrini[1]

[1]Pontifícia Universidade Católica do Rio Grande do Sul

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Abstract

Hyperpycnal flows are produced when the density of a fluid flowing in a relatively quiescent basin is greater than the density of the fluid in the basin. The density differences can be due to the difference in temperatures, salinity, turbidity, concentration, or a combination of them. Turbulence-resolved numerical simulations of such flows, in particular DNS (Direct Numerical Simulations), generate vasts amounts of resulting data. In the case of poli-disperse particle laden gravity currents simulations, where several sediments diameters are considered, very detailed data of the concentration field is available near bed. It can be post processed and analysed as a deposition map of one geological event. Traditional visualization tools lack the geological visual metaphor, and a new visual and interactive tool is proposed in this work. The aim of this new tool is to provide a better way to visualize numerical simulation results of particle laden gravity currents, plotting the results with the visual resemblance of a stratigraphic image. Since numerical simulation results usually have better spatio-temporal resolution compared to traditional stratigraphy, as the resolution depends exclusively on the amount of computing power available and it gets higher each day, the proposed interactive tool let the user visualize how the deposition map evolves in time and space. This tool can be employed to analyse the link between the deposition map and the turbulent flow that produced it, and the influence of all governing parameters. Numerical data was provided by Incompact3d, a code based on a Boussinesq system for incompressible fluids, designed for supercomputers. However this particular approach is a data driven post processing tool, thus it should be compatible with any numerical solver.

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Felipe N. Schuch, Filipi D. Vianna, Marcio S. Pinho and Jorge H. Silvestrini

School of Technology, Pontifical Catholic University of Rio Grande do Sul, Porto Alegre, Brazil

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Objectives

This work aims to provide a new visual and interactive tool that:

- Handles the vast amount of data resulting from turbulence-resolved numerical simulations (DNS or LES) of turbidity currents;
- Translates the information to a geological visual metaphor;
- Is compatible with any numerical solver or even experimental data;
- Can be employed to analyse the link between the deposition map and the turbulent flow that produced it.

Flow Configuration

- High-order solver of the incompressible Navier-Stokes equations simplified by the Boussinesq approximation `Incompact3d` [1, 2], designed for supercomputers, in addition to $N = 7$ transport equations for scalar transport:

$$\frac{\partial u_j}{\partial x_j} = 0, \tag{1a}$$

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{1}{Re}\frac{\partial^2 u_i}{\partial x_j \partial x_j} - Ri\,\delta_{i2}\sum_{\ell=1}^{N} \varphi_\ell, \tag{1b}$$

$$\frac{\partial \varphi_\ell}{\partial t} + (u_j - u_{s,\ell}\delta_{2j})\frac{\partial \varphi_\ell}{\partial x_j} = \frac{1}{ReSc}\frac{\partial^2 \varphi_\ell}{\partial x_j \partial x_j} \qquad \ell = 1,\ldots,N, \tag{1c}$$

being u_i the velocity field, p the pressure, φ the scalar concentration, δ the Kronecker delta, u_s the settling velocity, $Re = 15{,}000$ the Reynolds, $Sc = 1$ the Schmidt and $Ri = 0.5$ the Richardson numbers.

- LES modelling using Implicit Spectral Vanishing Viscosity (ISVV) [3].
- The computational set-up is based on the lock-release configuration [4]:

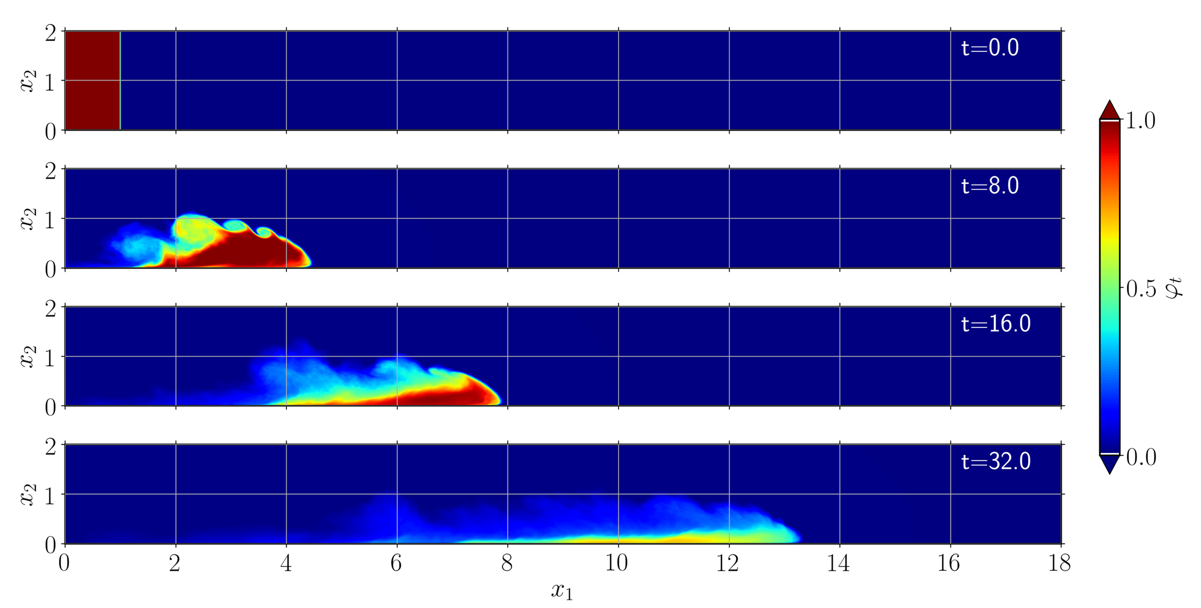

Figure 1:Flow evolution, represented by the spanwise-averaged total concentration field. Spanwise extension is $L_3 = 2$. The computational domain is discretized in $1153 \times 257 \times 121$ mesh nodes, and a time step of 1.2×10^{-3} is used for a total of 8×10^4 iterations.

Deposition layers

Deposit thickness as a function of time and the position at the bed

$$D_\ell(x_1,x_3,t) = \int_0^t u_{s,\ell}\varphi_\ell(x_1,x_2=0,x_3,\tau)d\tau \quad \text{and} \quad D_t = \sum_{\ell=1}^{N} D_\ell \tag{2}$$

Grain size proportion is the ratio between individual and total deposit

$$P_\ell = \frac{D_\ell}{D_t}, \qquad \ell = 1,\ldots,N \tag{3}$$

Averaged sediment diameter and its standard deviation

$$\bar{d}_s = \sum_{\ell=1}^{N} P_\ell \tilde{d}_{s,\ell} \quad \text{and} \quad \sigma = \sqrt{\sum_{\ell=1}^{N} P_\ell(\tilde{d}_{s,\ell} - \bar{d}_s)^2} \tag{4}$$

Results

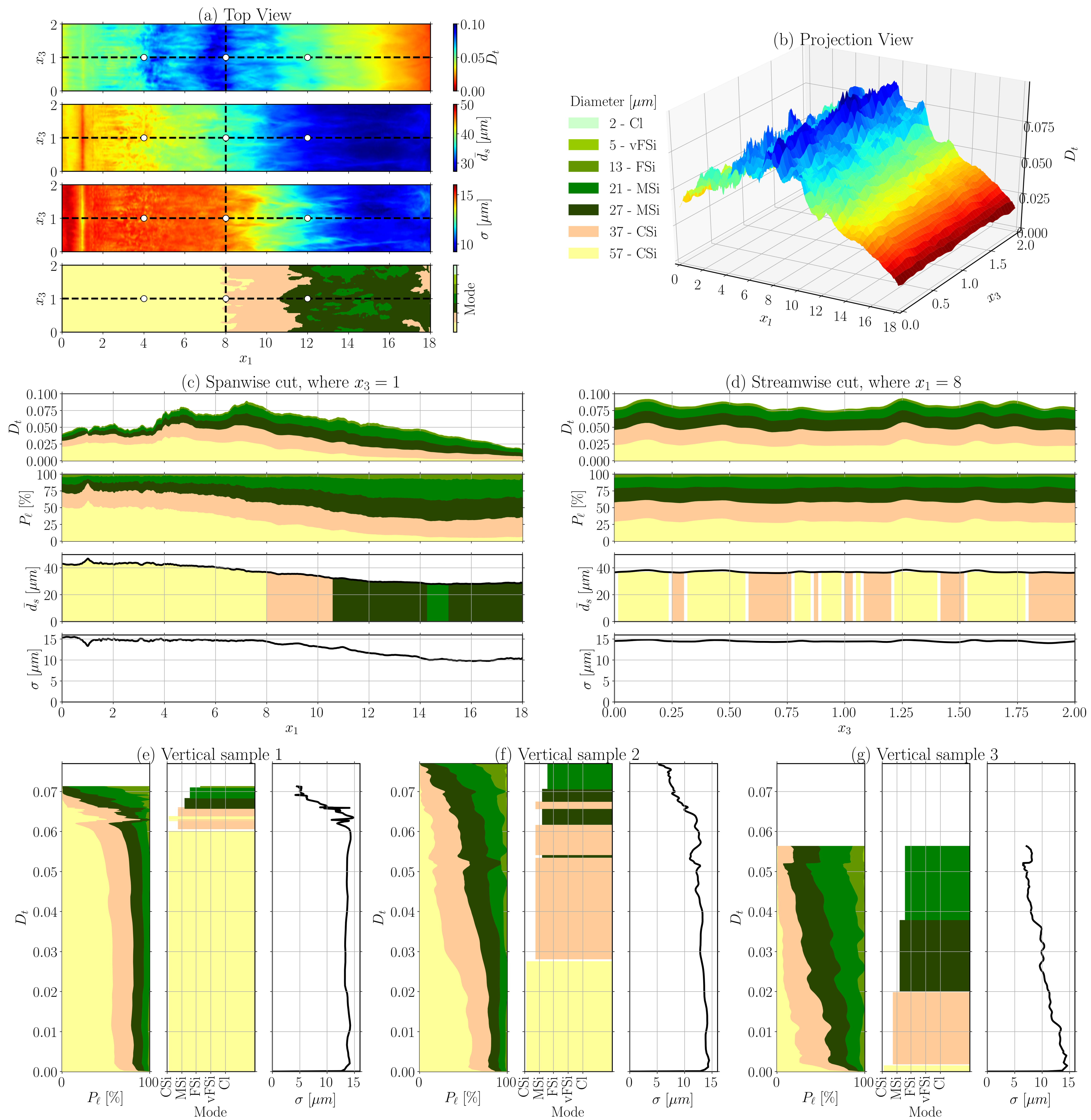

Figure 2:(a) Top visualization of the deposit thickness D_t, averaged sediment diameter $\bar{d}_s$, standard deviation σ and mode (fraction with the higher proportion); (b) Projection visualization of the deposit thickness D_t; (c) and (d) represent spanwise and streamwise cut, respectively, the positions are indicated in (a) as dashed lines; (e to g) Vertical samples, the positions are indicated by the dots in (a), vertical axis represents deposit thickness D_t and horizontal axes the grain size proportion P_ℓ, mode and standard deviation σ.

Summary and Conclusions

Turbulence-resolved numerical simulations of poli-disperse particle-laden gravity currents produce a considerable volume of data with high spatio-temporal resolution. In this work, we presented how to stack the near-bed concentration field and convert it to deposit thickness in addition to vertical detailing (Eqs. 2 to 4). This information can be presented with the visual resemblance of a stratigraphic image, showing how the deposition map evolves in time and space. Figure 2 presents a prototype produced by Matplotlib, a Python plotting library. Results show a noticeable variation in deposit thickness and the other properties, besides, a normally graded bed was formed from the lock-release flow configuration. However, due to the large amount of data from rendering all the visualization into static images, this prototype is expensive in terms of storage. An optimized strategy is to store pre-calculated data using a relational database and dynamically generate the visualizations using javascript. This approach will also enable improvements in user interaction, besides, it will be released together with [5]. Moreover, additional flow configurations might be investigated in this context, for instance, the plunging of an hyperpicnal flow in a tilted bed [6], or the finite-release in a basin configuration [7].

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Contact Information

felipe.schuch@edu.pucrs.br
politecnica.pucrs.br/laboratorios/laset
fschuch
fschuch