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Computational 3-D fluid-dynamics model for sediment transport, erosion and deposition by turbidity currents

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INTRODUCTION

Turbidity currents are a variety of subaqueous density currents, in which the suspension of sediment by water turbulence produces a water-sediment mixture that is denser than the ambient water and hence flows due to gravity along a topographic gradient. This type of sediment gravity flow is the most important mechanism for the dispersal and deposition of sand on deep-sea floors, as well as on the underwater slopes of many deltas and in many lakes [1].

The dynamics of turbidity currents is difficult to study in the natural environments, whereas laboratory experiments are limited to small-scale flows, time-consuming and not necessarily easier when it comes to the measuring of flow properties and establishing of the relationships between the turbulent flow structure and the transport and deposition of sediment. Numerical simulations can be used to obviate these difficulties, and also to verify and upscale laboratory models and integrate the data from nature and experiments.

FLOW-3D MODEL

Computational Fluid Dynamics (CFD) is a relatively new numerical approach in this field of sedimentological research, though widely used in the engineering branches of fluid mechanics. The CFD refers to the numerical solution, by computational methods, of the governing equations describing fluid flow: the set of Navier-Stokes equations and the multi-phase fluid dynamics.

In the present study, a three-dimensional model has been constructed using the CFD software Flow-3D [2] to simulate the flow of turbidity currents, including erosion and deposition. The Flow-3D model employs a fixed Eulerian grid of rectangular finite volumes and the turbidity current being modelled by a drift-flux technique. The sediment is treated as a continuous phase whose spatial volumetric concentration is calculated. The scour, drifting and lifting of sediment particles are calculated in terms of physical components (fluid volumetric fraction, sharp-interface advection and free-surface boundary condition) superimposed on the sediment advection with the fluid. The size range (or mass) of particles and the fluid-particle interaction are accounted for, although the particles are assumed to have a zero volume for computational purposes. The model takes into account also the effect of static particles on the flow and their angle of repose. Flow regions where the sediment reaches a packing concentration are 'freezing', or regarded as consolidated sediment.

APPLICATIONS

An example of a relatively simple simulation, imitating a particular type of laboratory experiment [3], is shown in Fig. 1. Comparative simulations of this kind are used to assess and calibrate the numerical model on the bases of various experimental setups and laboratory datasets.

The model is presently elaborated and made adjustable to diverse topographic configurations, and will further be used to simulate various dynamic aspects of surge-type and sustained turbidity currents. One of the aims is to evaluate the turbidity current's sensitivity to changes in the individual flow parameters (e.g., bottom gradient, sediment grain size and concentration, initial suspension volume, internal pressure, frontal and internal velocity, mass-centre speed, net apparent viscosity, turbulent viscosity and kinetic energy), which will aid general understanding of the current's modes of behaviour.

The turbidity current's scour threshold (channelling capacity) and responses to topography (e.g., varied slope gradient, slope break, hydraulic-jump conditions, large obstacles, various channel geometries) can be evaluated for currents with different properties; the spatial pattern of sediment dispersal and mode of deposition under various flow conditions can be modelled; and the evolution of a turbiditic depositional system can be simulated.

The model can also be adopted to serve more specific objectives, such as to test the dynamic thresholds of turbidity current's 'high-density' behaviour [4], which means flow conditions causing nontractional deposition; or to verify the hypothesis of the so-called 'slurry flow' [5], which postulates that the joint settling of sand grains and mass-equivalent clay clots/lumps from turbulent flow leads to a rhythmic development of rapidly-freezing cohesive basal layers, instead of classic traction carpets.

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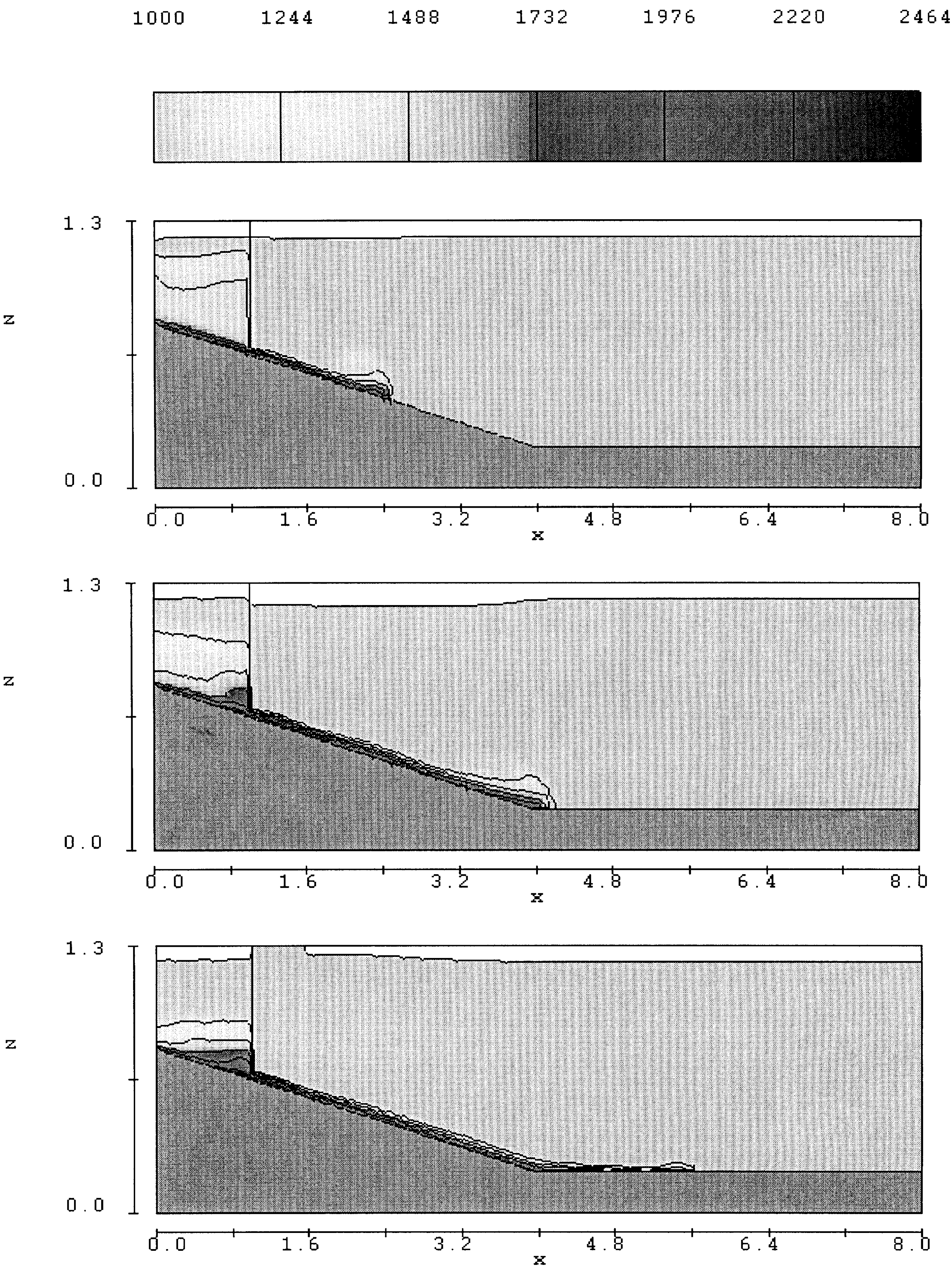

Fig. 1. Example of Flow-3D simulation: two-dimensional "snapshots" (longitudinal slices) of the density distribution in a high-density turbidity current flowing from a mixing tank through an inclined channel (8,6°) and expanding on horizontal flume floor. Snapshots after 2 sec (top), 4 sec (middle) and 6 sec (bottom). The vertical and horizontal scales are in metres and the density scale (top) is in gcm^{-3}.