Parallel 2D and 3D numerical simulations of melting with convection

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The coupling between thermal convection and melting is a key phenomenon in many applications, ranging from geophysical flows (Earth's mantle formation, magma oceans) to the energy storage or passive temperature control devices using phase-change materials (PCMs). We present numerical simulations of a heated cavity filled with a pure PCM and consider both lateral (Fig. 1a) and basal heating (Fig. 1b). We also simulate a water freezing case (Fig. 1c). The first case is well documented in the literature, while the second one (equivalent to the Rayleigh-Bénard convection with melting) was less studied for confined geometries [1].
High accuracy numerical simulations are performed using the numerical system described in [3] and implemented as a toolbox of the free software FreeFem++ [2]. We use finite elements (P_2 for the velocity and P_1 for the pressure and temperature) to discretize a single-domain model based on the Navier-Stokes-Boussinesq equations. An enthalpy transformation model is used for the energy equation and a Carman-Kozeny penalty model to bring the velocity to zero inside the solid region. The mesh is dynamically adapted to accurately capture the interface between solid and liquid phases. We use the recent library `ffddm` [4] that makes available in FreeFem++ state-of-the-art scalable Schwarz DD-methods enhanced by coarse space corrections.

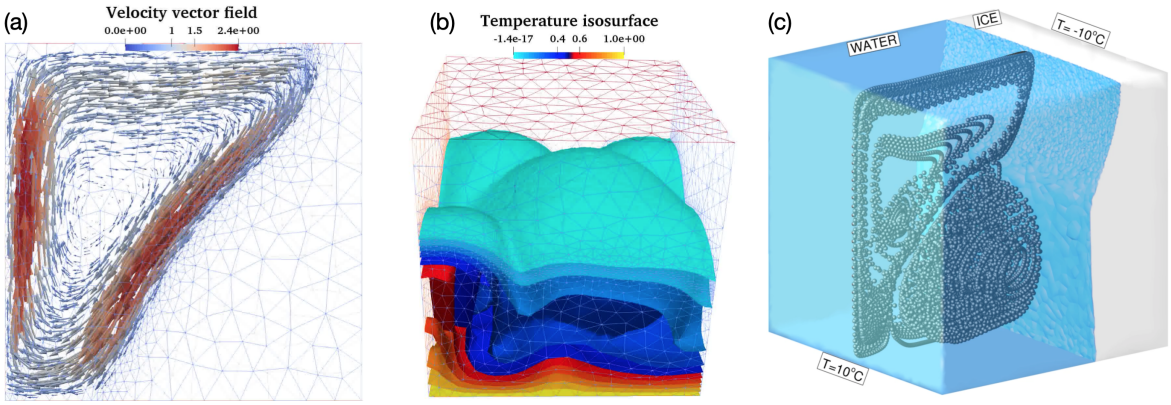

FIGURE 1 – Melting of a phase change material using lateral (a) and basal (b) heating. Water freezing (c). We show in the liquid phase the vector velocity field (a), temperature contours (b) and velocity stream tracers (c).

[1] B. Favier, J. Purseed, L. Duchemin. *Rayleigh bénard convection with a melting boundary.* J. of Fluid Mechanics, **858(437–473)**, 2019.

[2] F. Hecht. *New developments in freefem++.* Journal of Numerical Mathematics, **20(251–266)**, 2012.

[3] G. Sadaka, A. Rakotondrandisa, P.-H. Tournier, F. Luddens, C. Lothodé, I. Danaila. *Parallel finite-element codes for the simulation of two-dimensional and three-dimensional solid-liquid phase-change systems with natural convection.* Computer Physics Communications, **257(107492)**, 2019.

[4] P.-H. Tournier, P. Jolivet, F. Nataf. *ffddm : Freefem++ domain decomposition methods.* (doc.freefem.org/documentation/ffddm/ffddm/), 2018.

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