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High-Order Compact scheme for High-Performance Computing of stratified rotating flows

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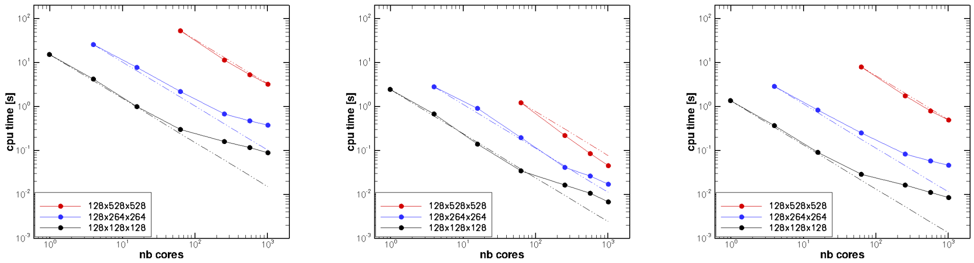
To take advantage of modern generation computing hardware, a scalable numerical method, based on high-order compact scheme, was developed to solve rotating stratified flows in cylindrical annular domains.

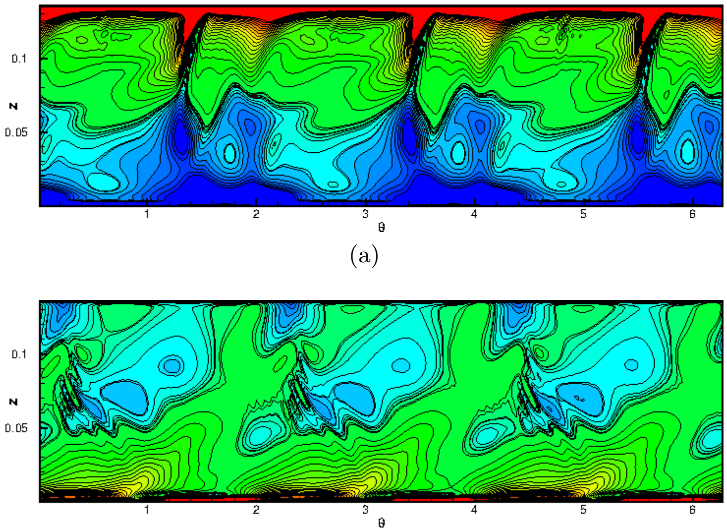
The azimuthal direction has been discretized using Fourier series expansion to benefit from the natural periodicity of the cylindrical geometry, and the favorable complexity algorithms for computing Fast Fourier Transforms. The space discretization in the two wall-bounded directions relies on the fourth-order compact scheme approximations. The code parallelization strategy combines two approaches. The first one is the $2d$-pencil decomposition to address the parallel solution of the implicit viscous terms and the pressure-like equations based on the diagonalization method. The second strategy of parallelization consists in the calculation of the compact derivatives/interpolations, using the approximate tridiagonal solver named reduced Partial Diagonal Dominant (rPDD) algorithm [1].The developed technique is validated with respect to analytical solutions, using the method of manufactured solutions, and available data for two specific configurations of rotating stratified flows : the Taylor-Couette setup under an axial thermal stratification and the baroclinic cavity. The purpose is to demonstrate its ability to correctly capture the flow characteristics in strato-rotational instability and in baroclinic instability with associated small-scale features. Moreover, this code is found to drastically reduce the huge execution times that often prevent detailed numerical investigations of these complex phenomena.

Figure 1 shows a strong scaling test carried out to assess the performance for up to 1024 cores using grid up to $128 \times 568 \times 568$ in radial, axial and azimuthal directions. Figure 2 shows instantaneous isocontours in the (θ, z) plane of the horizontal velocity divergence $\nabla_h.\mathbf{u}$ along the inner cold wall and along the outer hot cylinder in the baroclinic configuration. This variable is introduced to exhibit the occurrence of small-scale features simultaneously with the large-scale baroclinic waves. In the first plot, the small-scale structures, developing towards the bottom wall, have been identified as inertia gravity waves (IGWs) by different authors in similar water-filled cavities. The present observed features recall such IGWs reported by these authors. Recently, for the same present configuration, [2] mentioned the presence of ripples resulting from hydrodynamical instability along the outer hot cylinder. We also capture the same phenomenon, as illustrated by the isocontours of the horizontal divergence.



(a) (b) (c)

Figure 1: Baroclinic configuration - Strong scaling test a) temporal iteration b) solution of Poisson equation c) convective terms.



(a)

(b)

Figure 2: Baroclinic configuration - Instantaneous isocontours in (θ, z) plane of the horizontal divergence of the velocity: at radius close to inner wall (a), at radius close to outer wall (b).

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