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Towards petascale simulation of atmospheric circulations with soundproof equations

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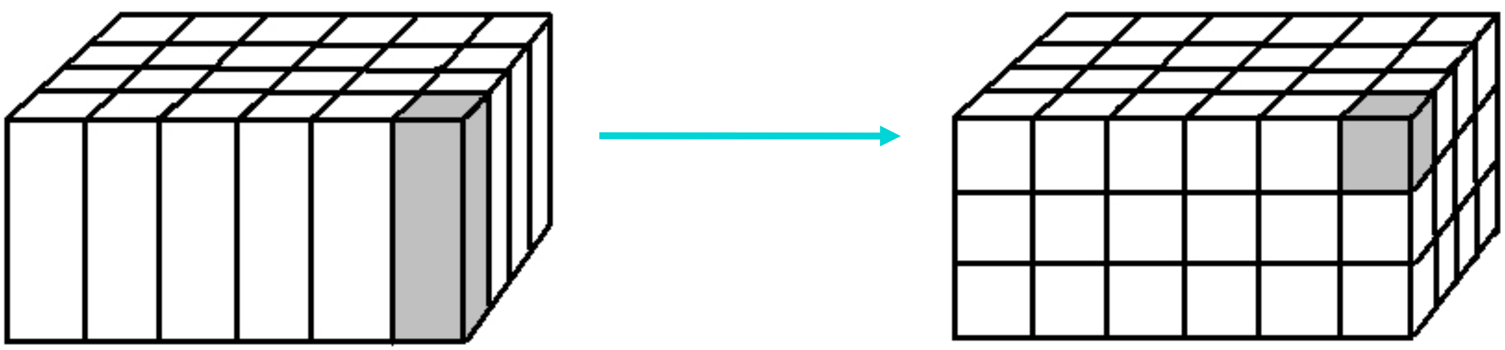
Extending MPI parallel formulation of multiscale anelastic model Eulag for geophysical flows

Traditional 2D decomposition

Newly developed 3D decomposition



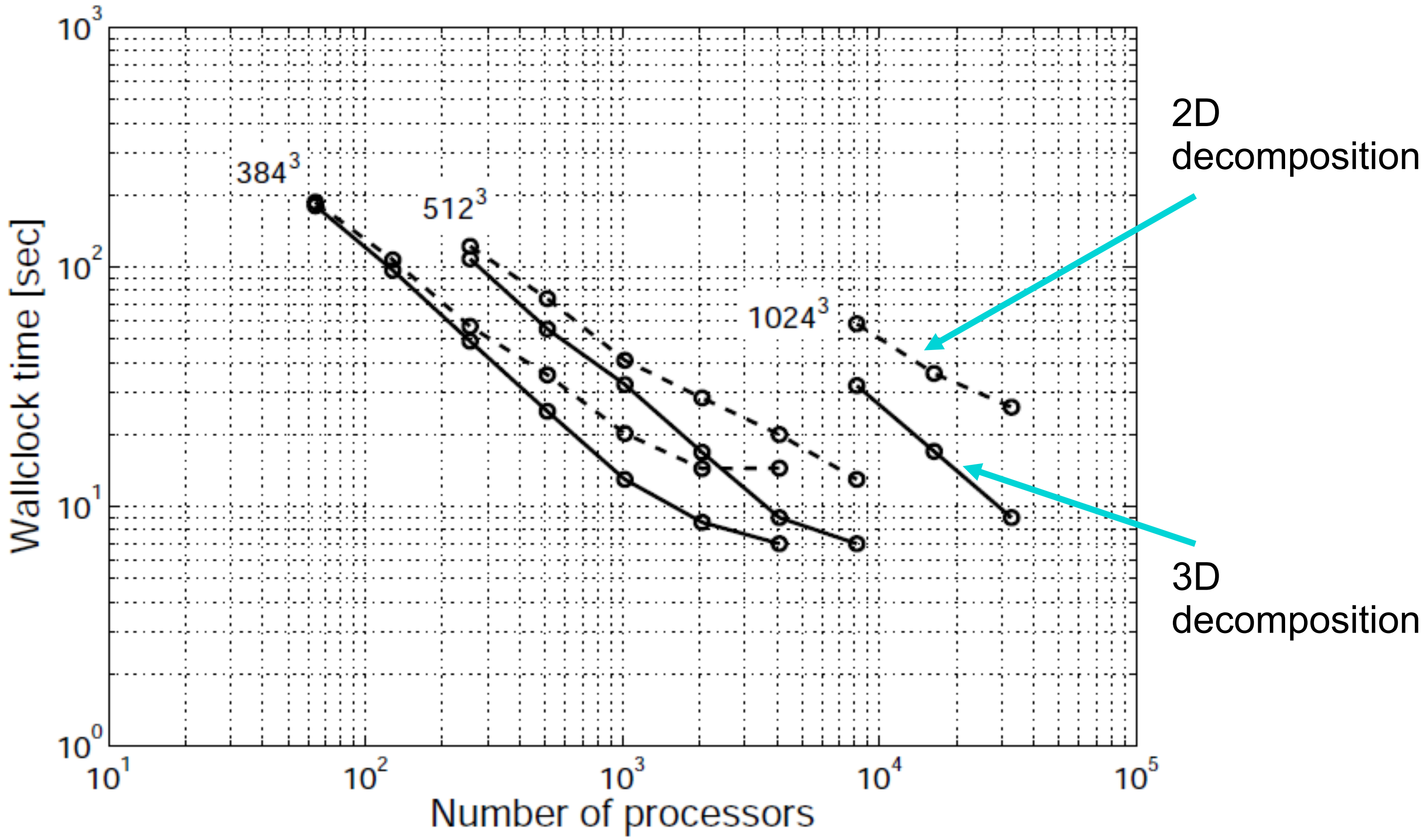
Test experiments in the range of scales from micro to planetary

- Triply periodic decaying turbulence in the box (Taylor – Green vortex) – perfect candidate for three-dimensional parallelization

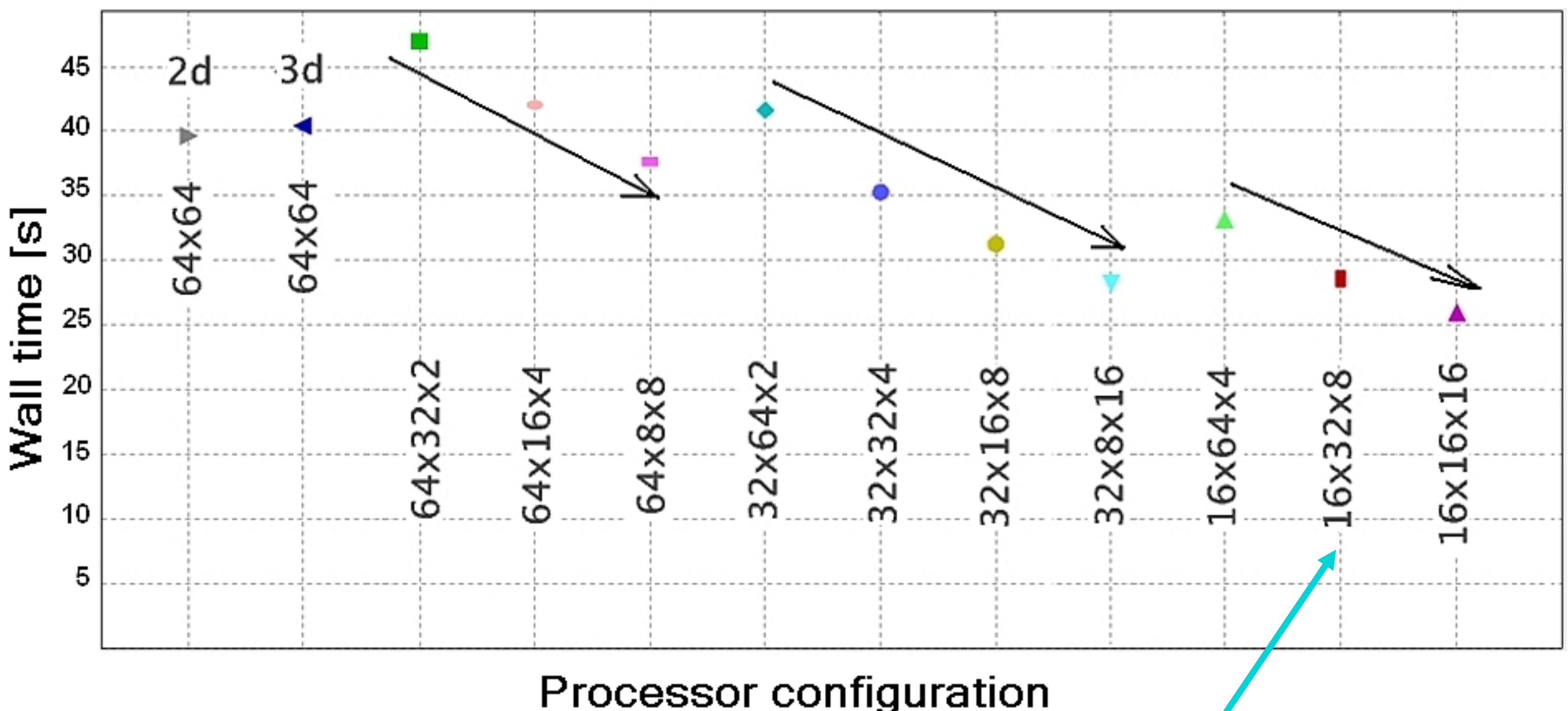
- Idealized climate simulations

  (after Held-Suarez 1994) – traditionally decomposed in two dimensions

Strong scaling - triply periodic decaying turbulence on Cray XT4



512^3 gridpoints decaying turbulence - dependence of performance on the processor configuration on Bluegene/L



Longest innermost loop

Performance model for halo communication bandwidth usage

Examine $R=r_{3d}/r_{2d}$, where:

r3d = [(np3d + 2h) × (mp3d + 2h) × (lp3d + 2h) − V3d]/V3d
r2d = [(np2d + 2h) × (mp2d + 2h) × lp2d − V2d]/V2d .

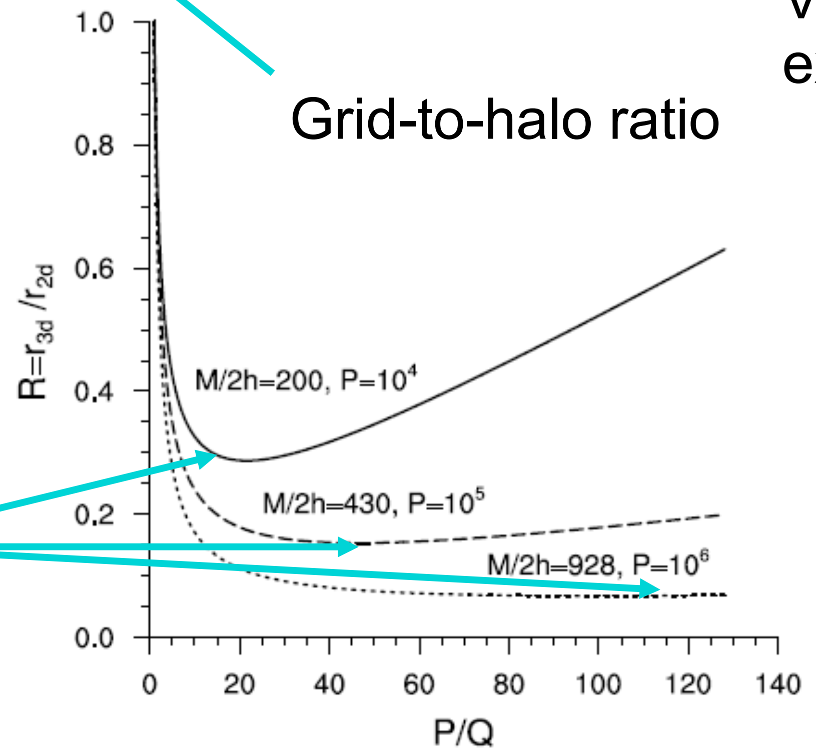
$$R\left(\frac{P}{bQ};\, P,\, \widetilde{M}\right) = \frac{\left(1+\frac{\sqrt{P/b}}{\widetilde{M}}\sqrt{\frac{bQ}{P}}\right)^2\left(1+\frac{a}{\widetilde{M}}\frac{P}{bQ}\right)-1}{\left(1+\frac{\sqrt{P/b}}{\widetilde{M}}\right)^2-1},$$

No. of cores in vertical

Total no. of cores

Grid-to-halo ratio

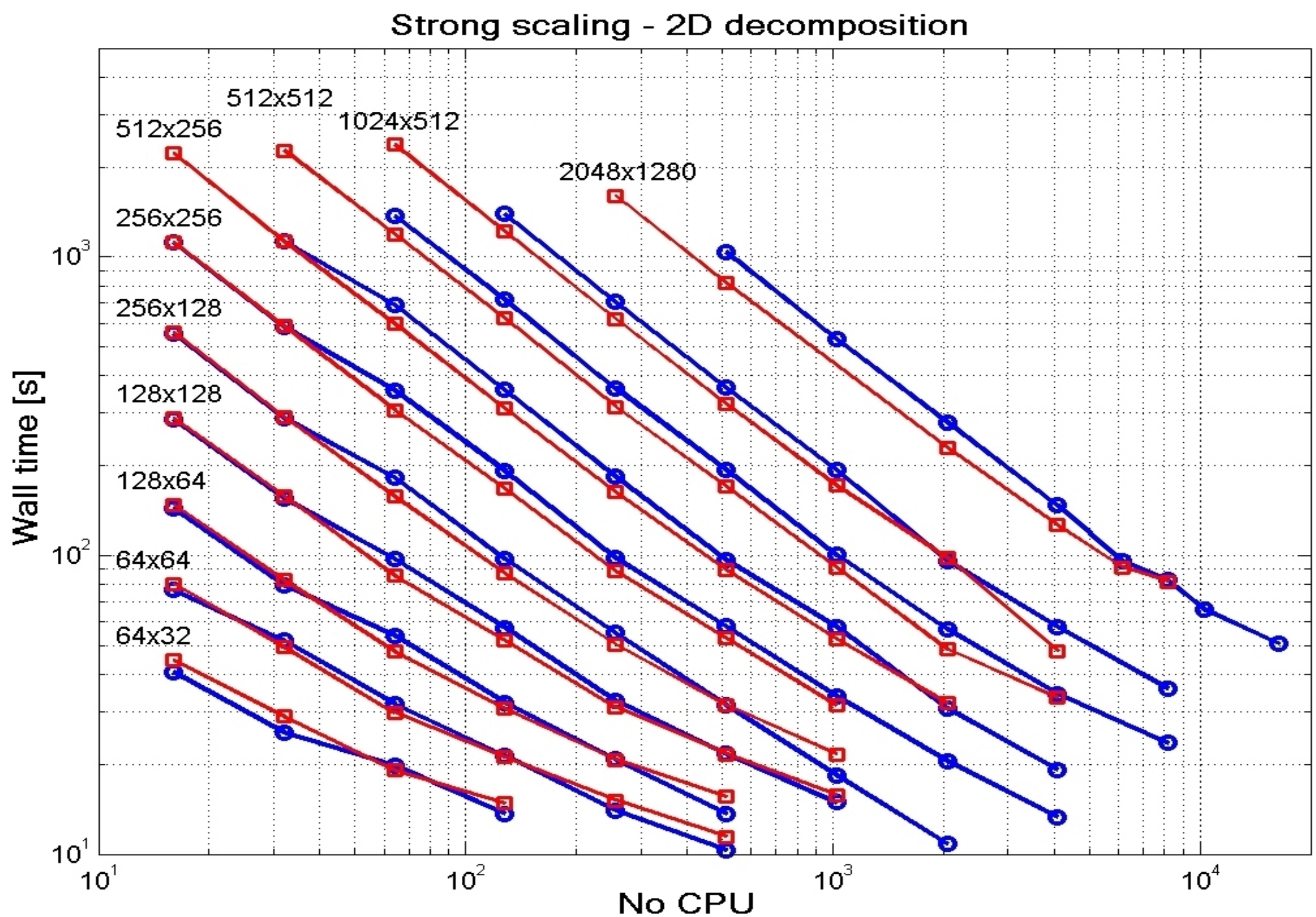
Vertical/horizontal extent



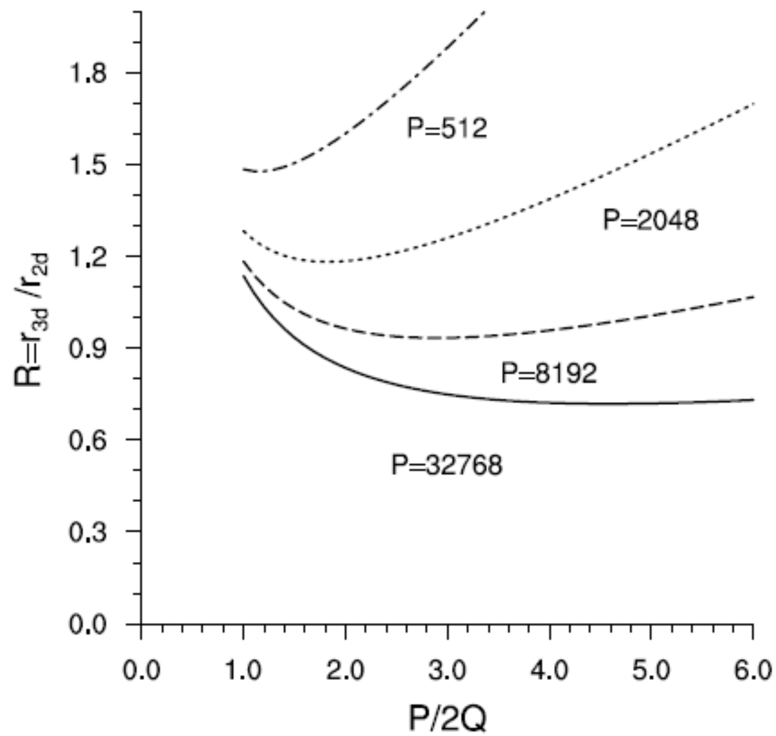
Optimal no. of cores in the vertical

$$P/bQ = \sqrt[3]{P/ba^2}.$$

Scaling for idealized climate simulations – 2D decomposition



Performance model 1024 × 512 × 41 idealized climate simulation



Not always a performance gain from the 3D decomposition !

... but we can always use more cores to decrease time-to-solution !

Table 1: Strong scaling of idealized climate simulation on a $256 \times 128 \times 64$ grid, using 512 processors in the horizontal with increasing number of processors in the vertical.

Total processor number	512	1024	2048	4096
Processor configuration	$32 \times 16 \times 1$	$32 \times 16 \times 2$	$32 \times 16 \times 4$	$32 \times 16 \times 8$
Wallclock time [sec]	52	30	20	15

Vertical algorithms

- Tridiagonal solver (Thomas algorithm)
  - For small (16 ?) number of cores in vertical, parallelization still scales
  - Approach used is the recurrence doubling (precomputation of a_n^{core} parts independent of a_1^{core}, then single Gather/Scatter in the vertical.
- Rainfall (1D vertical advection).
  - Additional communication for vertical parallelization.
  - Processing for the whole domain rather than point by point
- Radiation (employs tridiagonal solvers)

Conclusions

Three dimensional MPI parallel formulation, for symmetric (cubical) problems, can decrease time to solution for given number of cores used by factor of ~ 0.5.

For thin-shell applications, it allows for decreasing time-to-solution by admitting much larger number of computing cores.