Multi-grid parallelization on SMC grids in WW3 model

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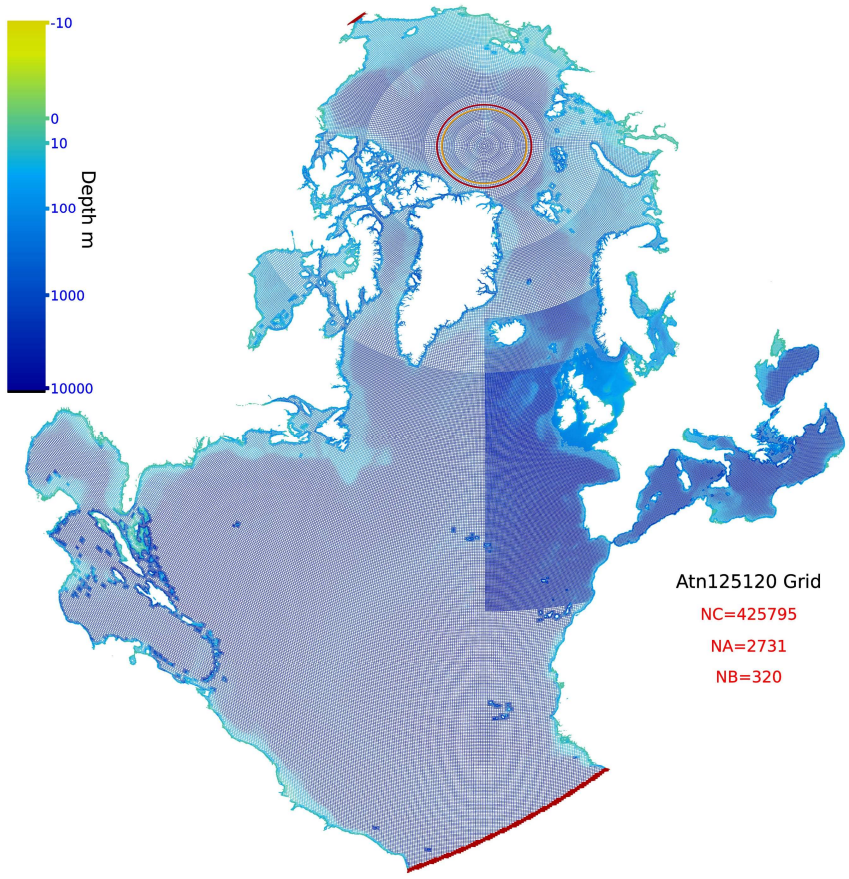
Abstract: Spherical Multiple-Cell (SMC) grid (Li, 2012) is an unstructured grid, supporting flexible domain shapes and multi-resolutions. It retains the quadrilateral cells as in the latitude-longitude (lat-lon) grid so that simple finite-difference schemes can be used. Sub-timesteps are applied on refined cells and grid cells are merged at high latitudes to relax the CFL restriction. A fixed reference direction is used in polar regions to solve vector polar problems. The SMC grid was implemented in the WAVEWATCH III (WW3) wave model in 2012 as an alternative for the lat-lon grid and updated in the latest WW3 Version 7. The WW3 model is parallelised by wave spectral component decomposition (CD) in MPI mode, which has a limit on number of MPI ranks. Hybrid MPI-OpenMP parallelisation may extend the node usage, but the OpenMP scalability flattens out beyond a few threads. The multi-grid option in WW3 provided another parallelisation method that combines CD with domain decomposition (DD), which is used in atmospheric and ocean models. This combined CD-DD parallelisation is initially applied only to the standard lat-lon grid. Although the curvilinear grid and the unstructured triangle cell grid are later added into the multi-grid option, they are limited to run in series mode with a parent lat-lon grid model, which may be split into sub-grids and run in the multi-grid parallel mode.

The SMC grid module in WW3 is recently extended to use this multi-grid option to expand node usage in hybrid parallel mode (Li, 2022). The flexible domain shape of the SMC grid allows optimised domain splitting and minimised boundary exchanges. It also allows the sub-grid setup to be pre-calculated and tuned to save model run time. A new subroutine is added into WW3 to set up the one-to-one spectral boundary exchanges among SMC sub-grids without any interpolation, thanks to the unstructured feature of the SMC grid, which allows boundary cells for one sub-grid to be duplicated in its donor sub-grids. In addition, mixed resolution SMC sub-grids can be used in the multi-grid mode, which eases the computation load balance. The combined CD-DD parallelisation is tested on mixed resolution SMC sub-grids with various hybrid node-thread combinations. Results indicate that switching from MPI to hybrid MPI-OpenMP mode can halve the run time of our present SMC 3-6-12-25 km global wave forecasting model. Using the hybrid CD-DD method on 3 SMC sub-grids may reduce the elapsed time further by 30%. The elapsed time for one model day run is reduced from about 3 min on 12 nodes in single grid MPI mode to less than 1 min on 180 nodes in hybrid multi-grid mode. Besides, the hybrid multi-grid method reduces memory demand on one computing node and allows future model updates for higher resolutions.

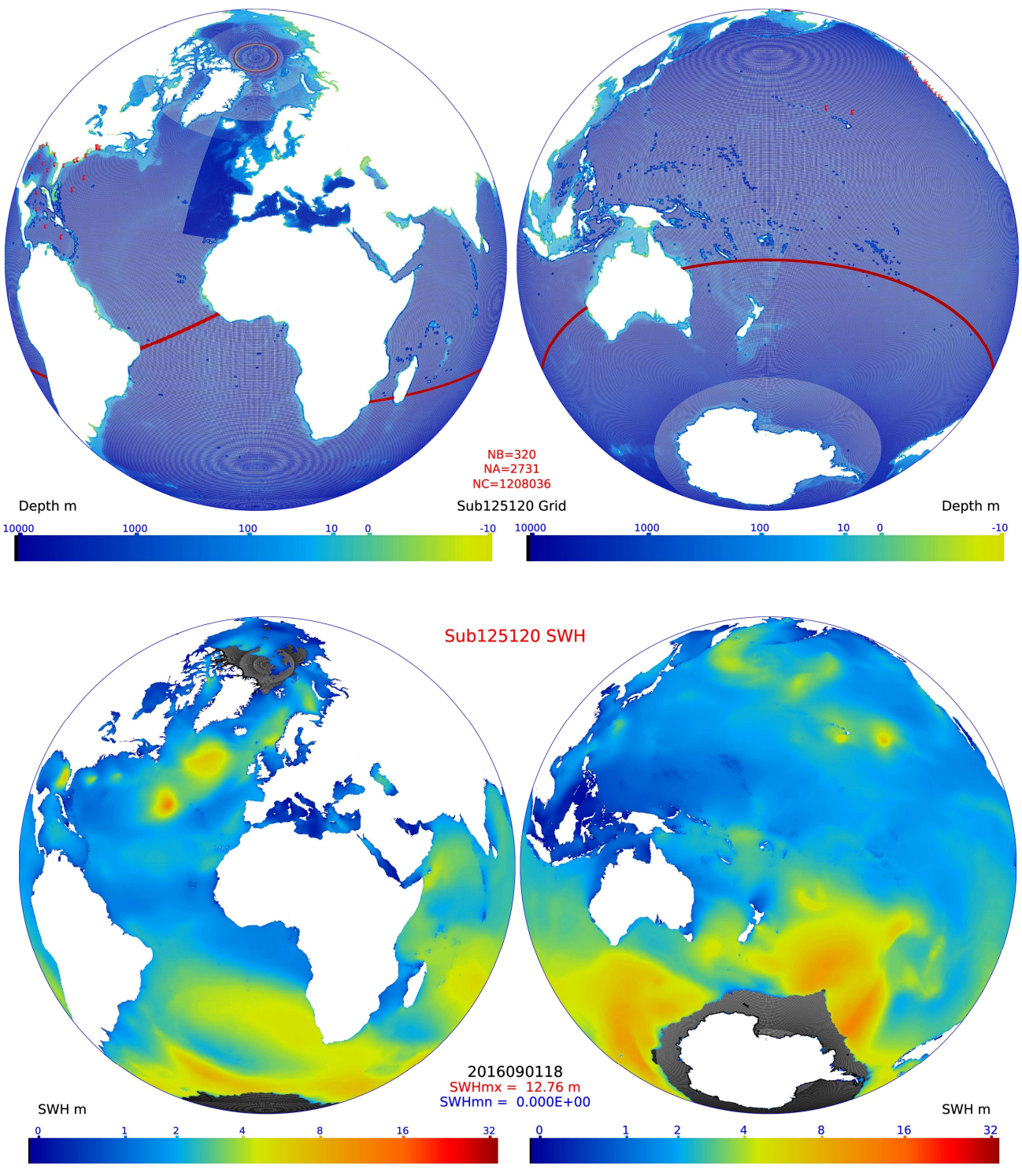
Li, J.G. 2012: Propagation of ocean surface waves on a spherical multiple-cell grid. *J. Comput. Phys.*, **231**, 8262-8277.
Li, J.G. 2022: Hybrid multi-grid parallelisation of WAVEWATCH III model on spherical multiple-cell grids. *J. Parallel Distrib. Comput.*, **167C**, 187-198.

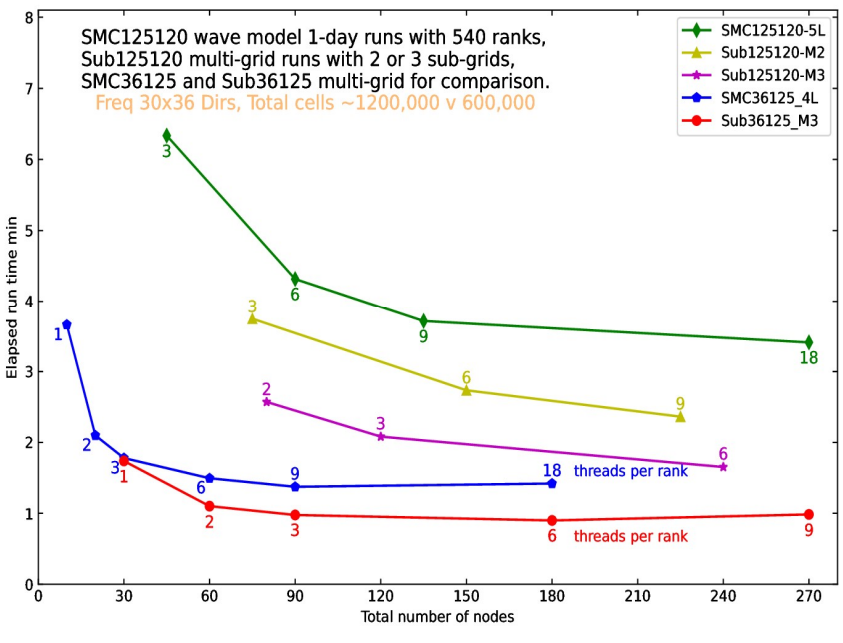


Met Office future multi-grid 1.25-2.5-5-10-20 km global wave model

The UK Met Office is planning to update its global wave forecasting model with 3 SMC sub-grids at 1.25-2.5-5-10-20 km resolutions (Sub125120). The main sub-grid convers the North Atlantic and Arctic regions with European and UK areas at base resolution of 10 km and refined up to 1.25 km (Atn125120), as shown in the top figure. Shallow area below 150 m deep in the UK waters are resolved at 5 km minimum resolution. This sub-grid output will be used for most of our forecast products, without handling the whole global output in postprocessing. The other two sub-grids cover the Southern Ocean and the rest global domain area as shown in the middle figure. These two sub-grids will have 4-level resolutions at 2.5-5-10-20 km. The 3 sub-grids could be merged into a global grid as shown in the middle figure. The boundary line across the Indican and Pacific can be adjusted so that the three sub-grids have balanced computing loads. Model results have been compared with observations of spectral buoys, which are shown by the red marks in the middle figure. The multi-grid output is slight better than the our present 3-6-12-25 km global SMC36125 grid model, One significant wave height global output from this sub-grid model is shown in the bottom right figure, which is almost identical to the output from the single grid SMC125120 model.

Timing results of this new global model are shown in the bottom left figure. For comparison, the present SMC36125 global model runtimes are also shown here. The SMC36125 global model runtime has been reduced from over 3 min on 10 nodes in pure MPI mode to less than 1.5 min in hybrid mode on 90 nodes 9 OpenMP threads per rank, as indicated by the blue lines in the figure. So, switching from MPI mode to hybrid mode alone could halve the model runtime. Splitting the SMC36125 global grid into 3 sub-grids for multi-grid run could reduce the elapsed time by another 30% as shown by the red line. Node usage is extended from 10 nodes (360 MPI ranks) for our global SMC36125 model to over 200 nodes in multi-grid mode. The fastest runtime for one model day is less than 1 min on 180 nodes with 360 MPI ranks 6 OpenMP threads for each of the 3 sub-grids. The green line shows the new SMC125120 model runtime as a single global grid in hybrid mode. This model runtime is optimised when it is configured in 540 MPI ranks. The fastest runtime is about 205 s on 270 nodes with 18 OpenMP threads. The hybrid multi-grid runtime of the Sub125120 model is given by the pink line and its fastest time is about 99 s on 240 nodes with 6 threads, which is over 50% reduction in comparison with the single grid runtime (205 s). The SMC125120 model also shows better scalability with OpenMP threads than the SMC36125 model, most likely due to the increased spatial resolution as the new grid has doubled the number of sea points of the present SMC36125 model. The yellow line in the bottom left figure shows the runtime of a 2-grid configuration of the new SMC125120 model, in which the Atn125120 grid is kept the same but the other two sub-grids are merged into one sub-grid. Its runtime is still shorter than the single grid case but longer than the 3 sub-grids one.





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