Applications of SMC grid wave models in coupled systems
球面倍格元海浪模型在耦合系统中的应用

Jian-Guo Li

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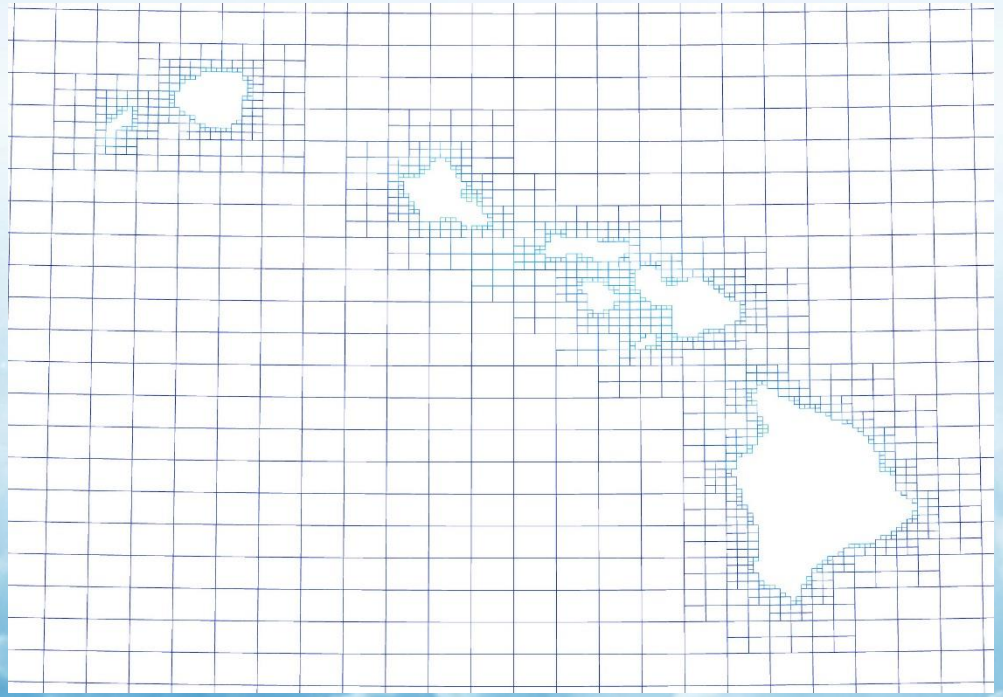
Jian-Guo.Li@metoffice.gov.uk



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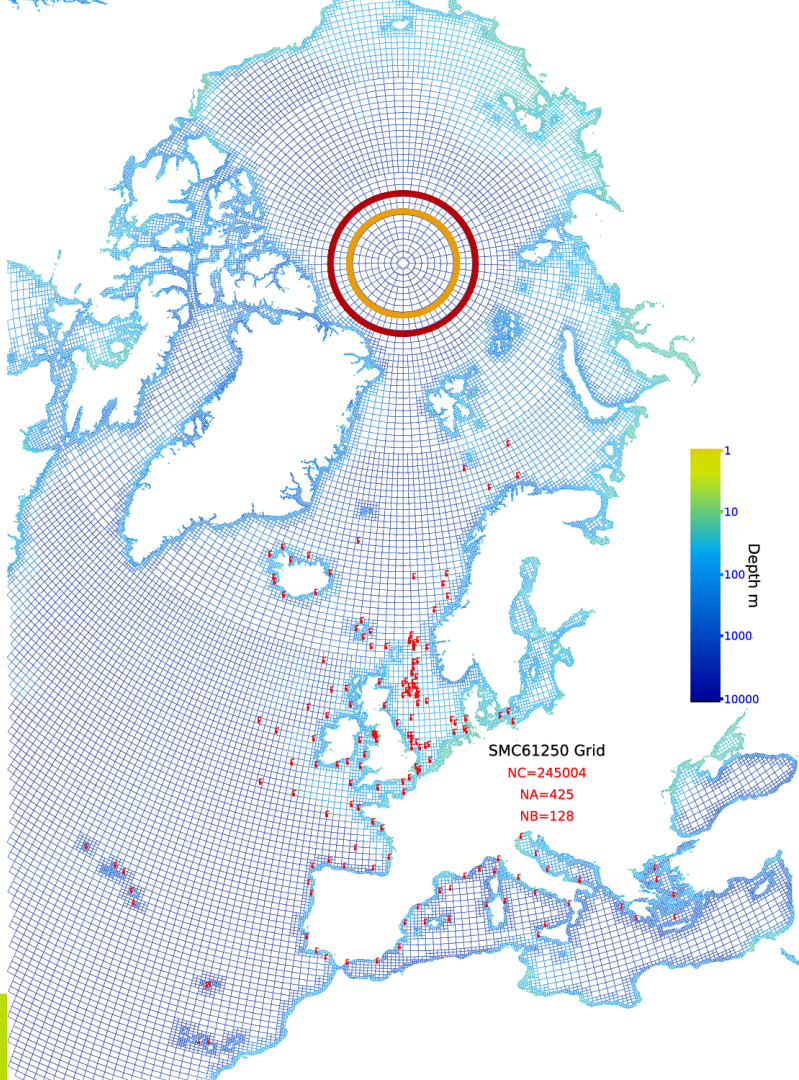
Three parts in this presentation

1. Spherical Multiple-Cell (SMC) grid --- a brief introduction.
2. Applications in global and regional wave forecasting.
3. Toolkits for generating and testing SMC grids.

Spherical Multiple-Cell grid

- Originally developed to solve the polar problems in latitude-longitude grid.
- Merged cells at high latitudes to relax CFL limit on timestep, like a reduced grid.
- Introduce round polar cell and fixed reference direction to include the whole Arctic Ocean in wave model domain.
- Flexible multi-resolutions by multiple sized cells to resolve small islands and detailed coastlines.

- Reference: Li, J.G. 2011: *Mon. Wea. Rev.*, **139**, 1536-1555.



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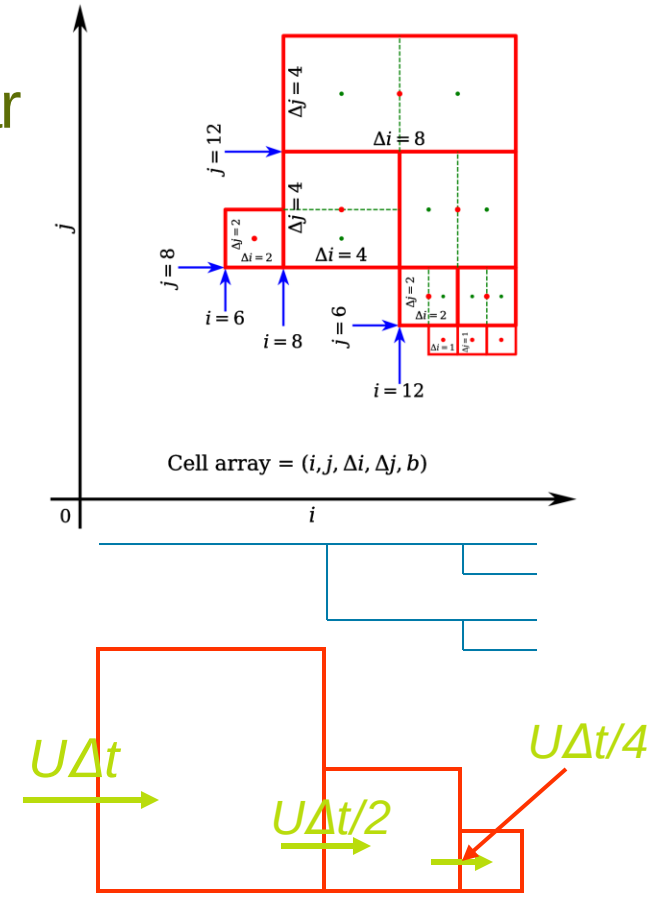
Unstructured SMC grid with rectangular cells and pointer-oriented loops

- Cells are defined by location and size indexes, convenient for mapping to lat-lon grid.
- Transport fluxes are calculated with face-array or pointer-oriented 1-D loops.
- Sub-timesteps are automatically used for refined cells in sub-loops for efficiency.
- Efficient hybrid (MPI+OpenMP) parallelization.

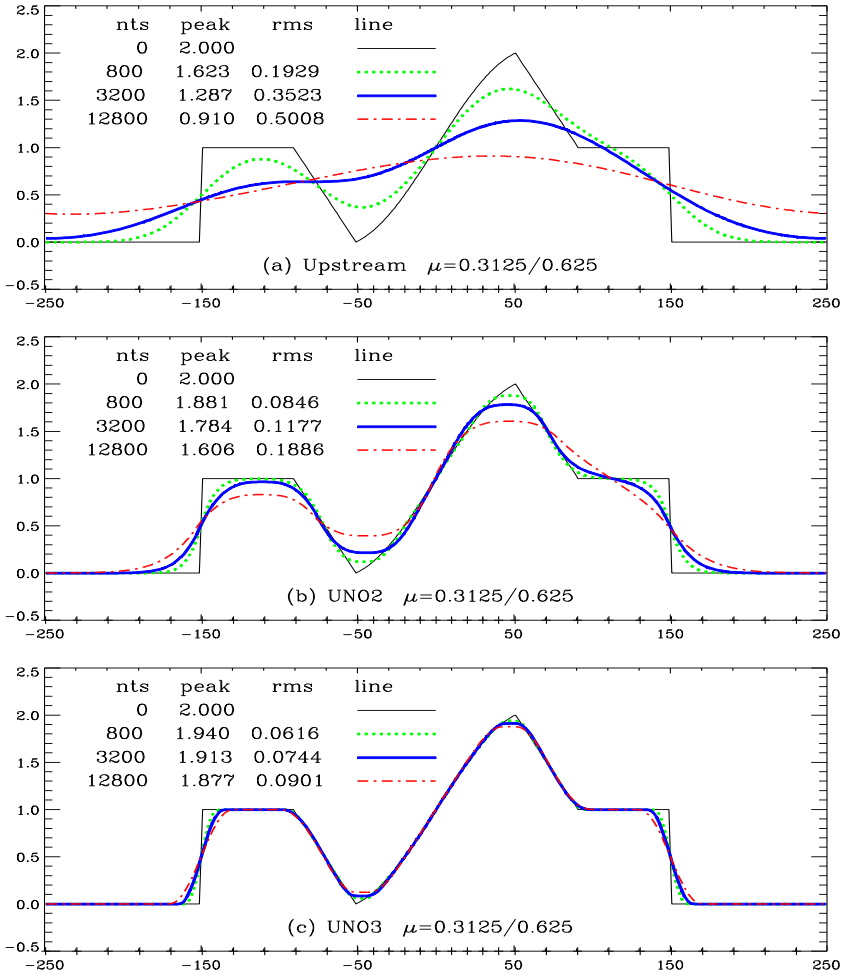


- Li, J.G. 2012: *J. Comput. Phys.* **231**, 8262-8277.

Upstream Non-Oscillatory advection schemes

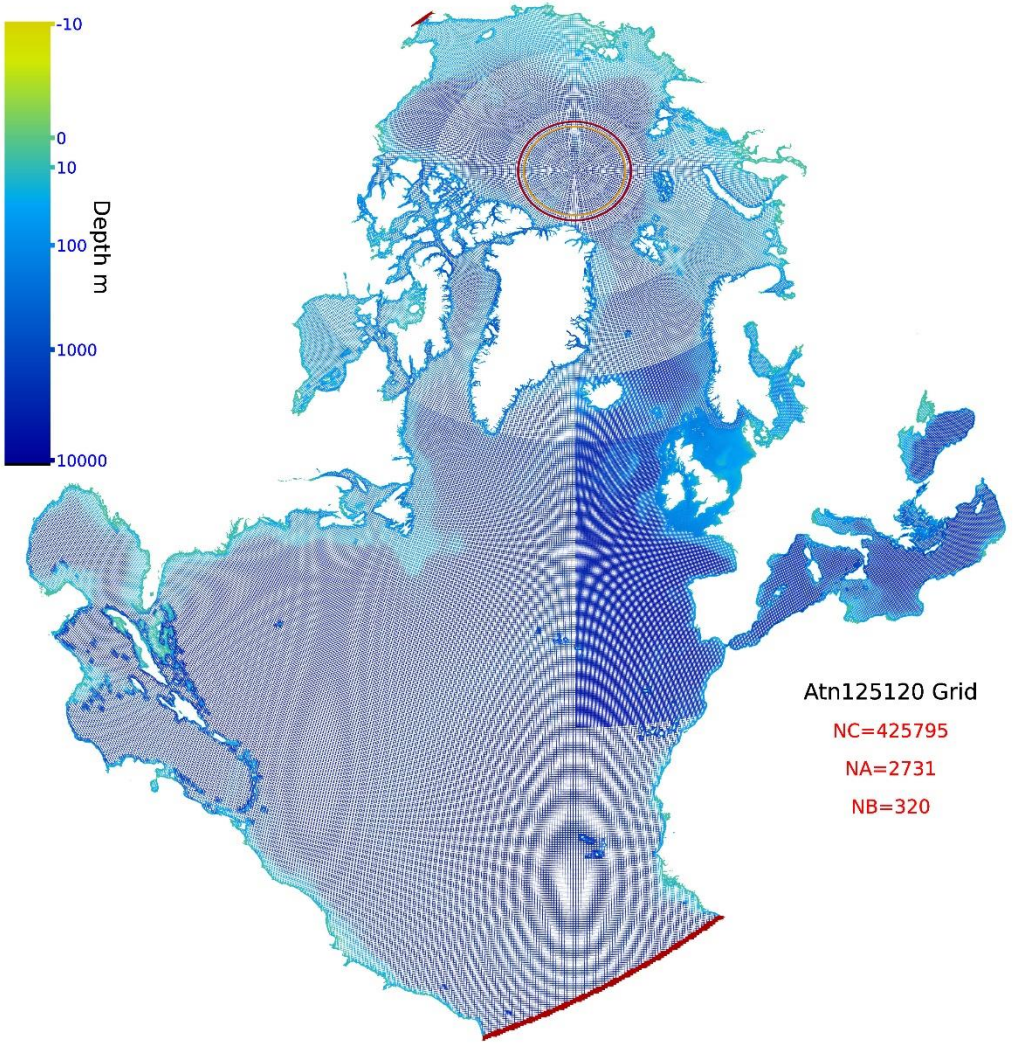
- Choice of 2nd and 3rd order UNO advection schemes are available on SMC grid.
- Recommend the 2nd order UNO2 scheme for wave models, fast and accurate enough, saving 30% computing time than the 3rd order scheme.

Reference: Li, J.G. 2008: *Mon. Wea. Rev.*, **136**, 4709-4729.



Recent update: Multi-grid and hybrid parallelization

- Hyprid (MPI+OpenMP) parallelization is enabled for SMC grid in WW3 and it could halve model runtime.
- SMC sub-grids are now included in WW3 multi-grid option for further parallelization, which create room for higher resolutions and are more convenient regional forecast than single-grid model.



Li, J.G. 2022: *J. Parallel Distrib. Comput.*, **167C**, 187-198. doi: 10.1016/j.jpdc.2022.05.002

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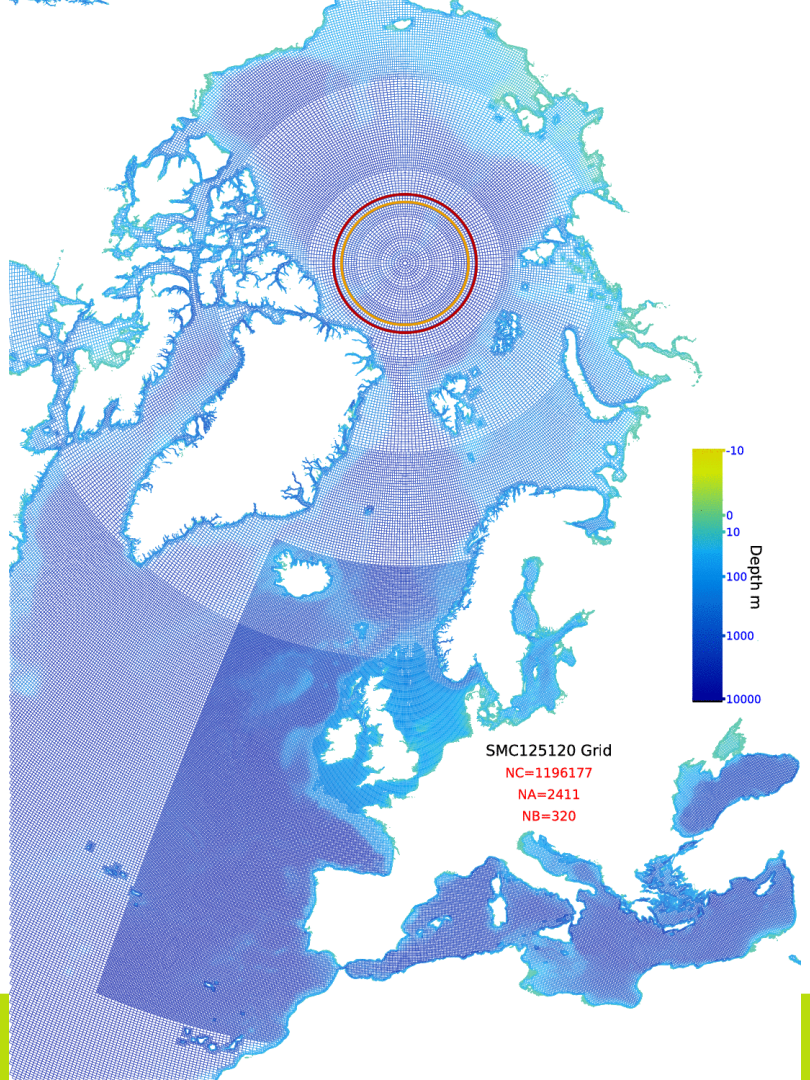
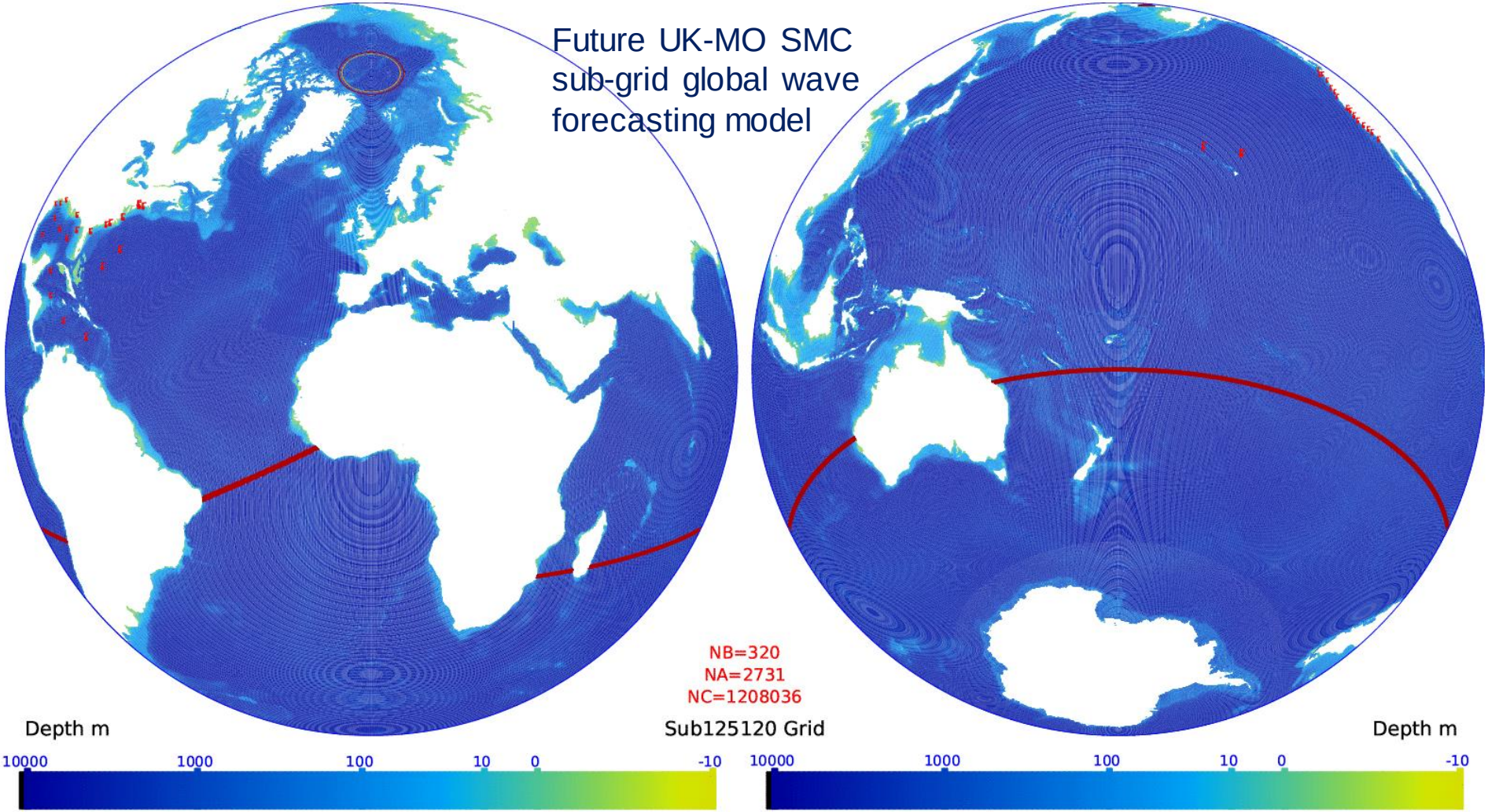
Planned UK Met Office update SMC 1.25-2.5-5-10-20 km grid

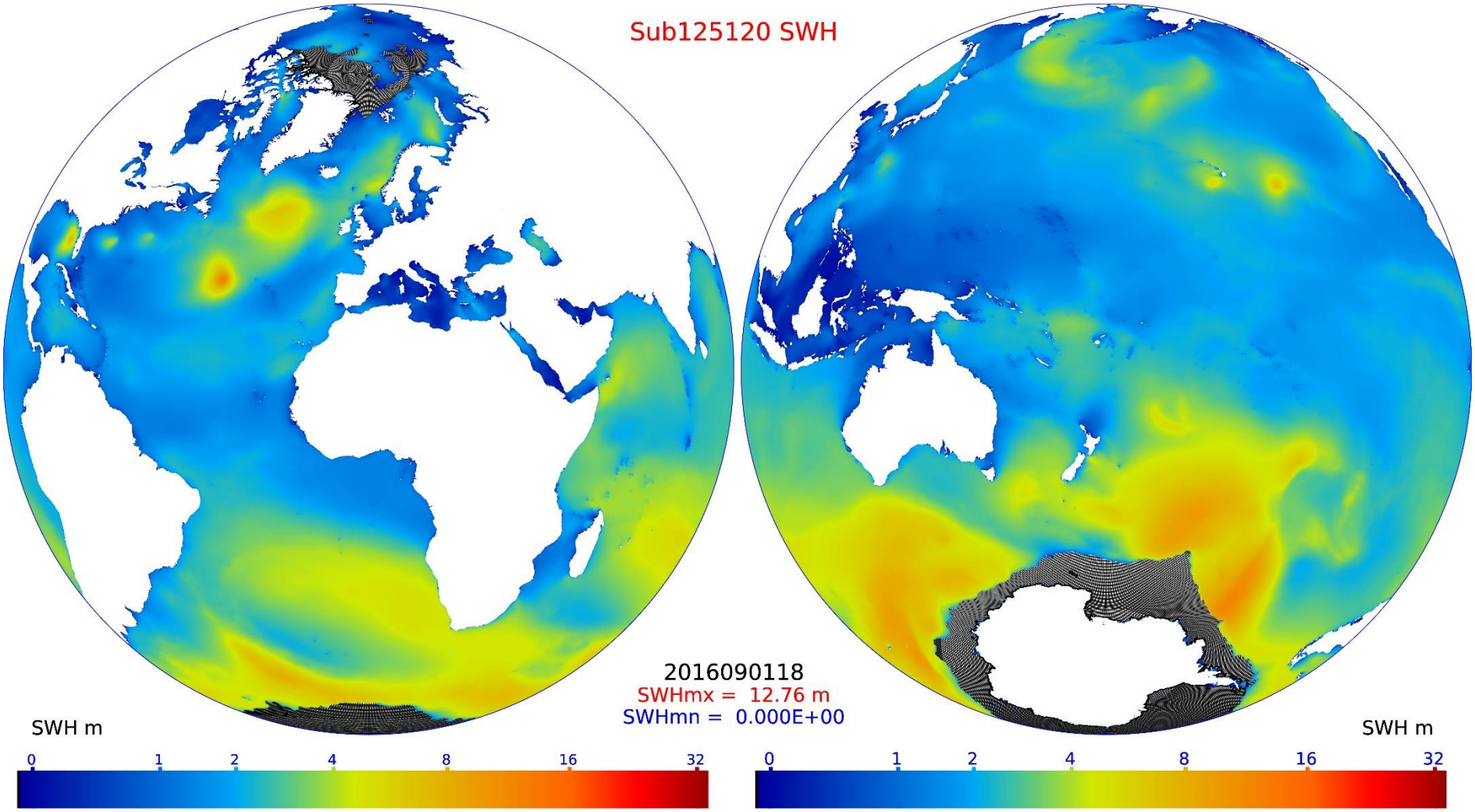
European regions is refined to 10 km and shallow waters around UK is refined to 5 km, in addition to coastal refinement to 1.25 km.

The rest of world oceans are resolved with 2.5-5-10-20 km.

Sub125120 multi-grid will be created by splitting this global grid into 3 sub-grids.




Future UK-MO SMC sub-grid global wave forecasting model
NB=320
NA=2731
NC=1208036
Sub125120 Grid
Depth m
10000
1000
100
10
0
-10
Depth m
10000
1000
100
10
0
-10

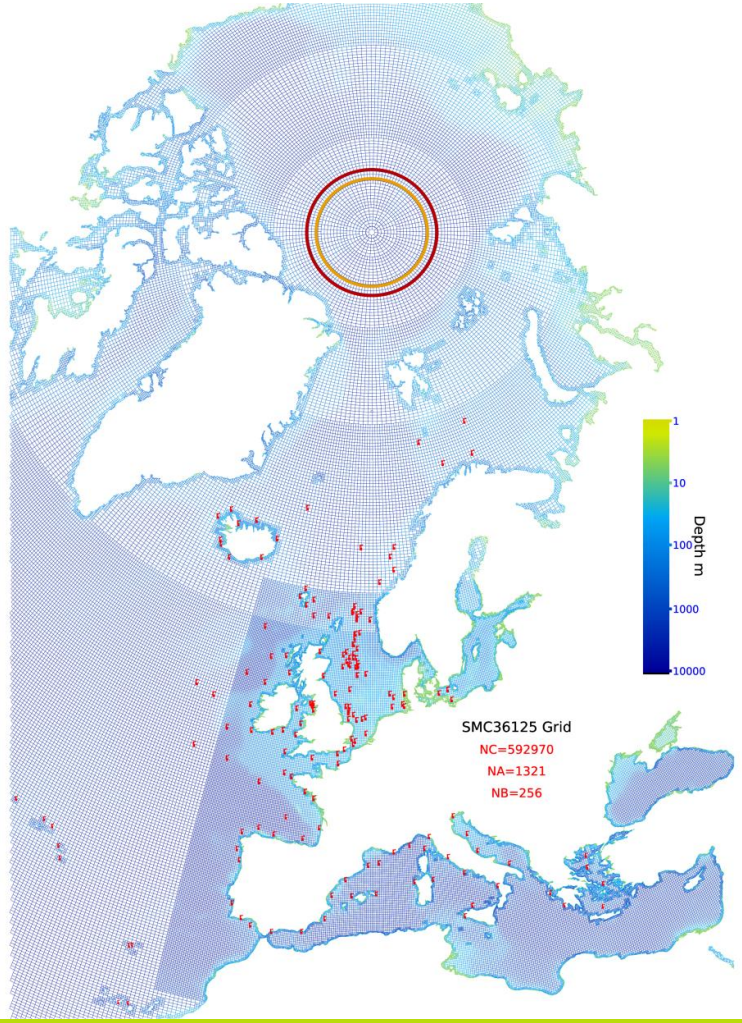

Sub125120 SWH
2016090118
SWHmx = 12.76 m
SWHmn = 0.000E+00
SWH m
0
1
2
4
8
16
32
SWH m
0
1
2
4
8
16
32

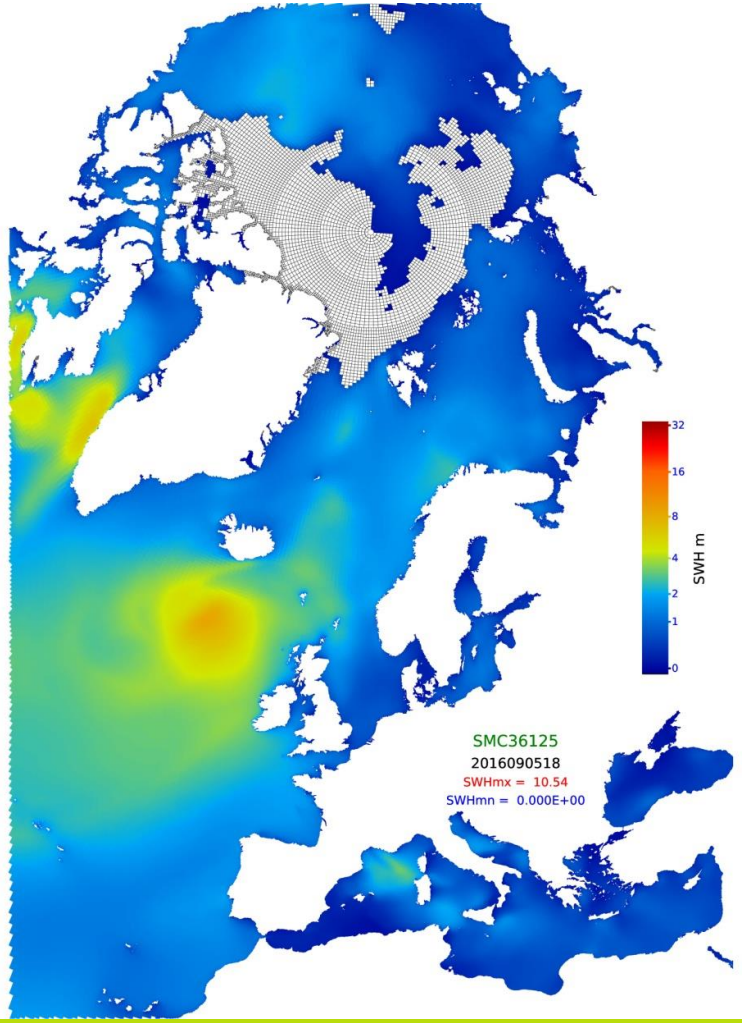
UK Met Office global wave forecast model

Implemented in WW3 wave model in 2012 and use for global wave forecasting in UK Met Office since 2016.

Faster and better than regular lat-lon grid model.

Li, J. G., A. Saulter 2014:. *Ocean Dynamics*, **64**, 1657-1670.





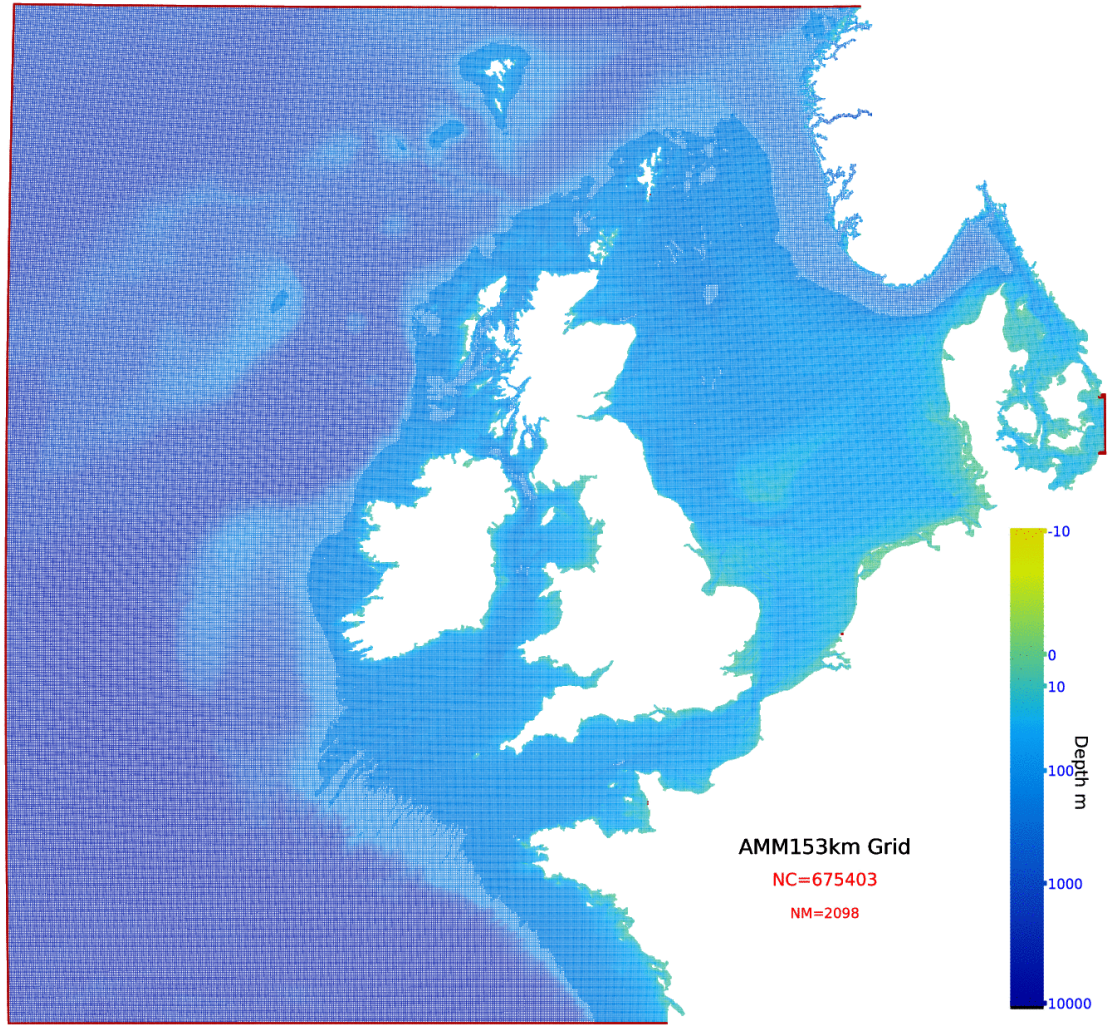
UK Met Office regional wave forecast model

Rotated SMC grid at 1.5-3 km resolutions, matching with ocean model grid for coupled system.

Boundary conditions generated with our global wave model.

Hybrid parallelization mode runtime less than 2 min per model day on 90 nodes (3240 cores, Cray XC40).

Larger than our global 3-6-12-25 km wave model with 592,970 cells (675,403 for AMM153 model).

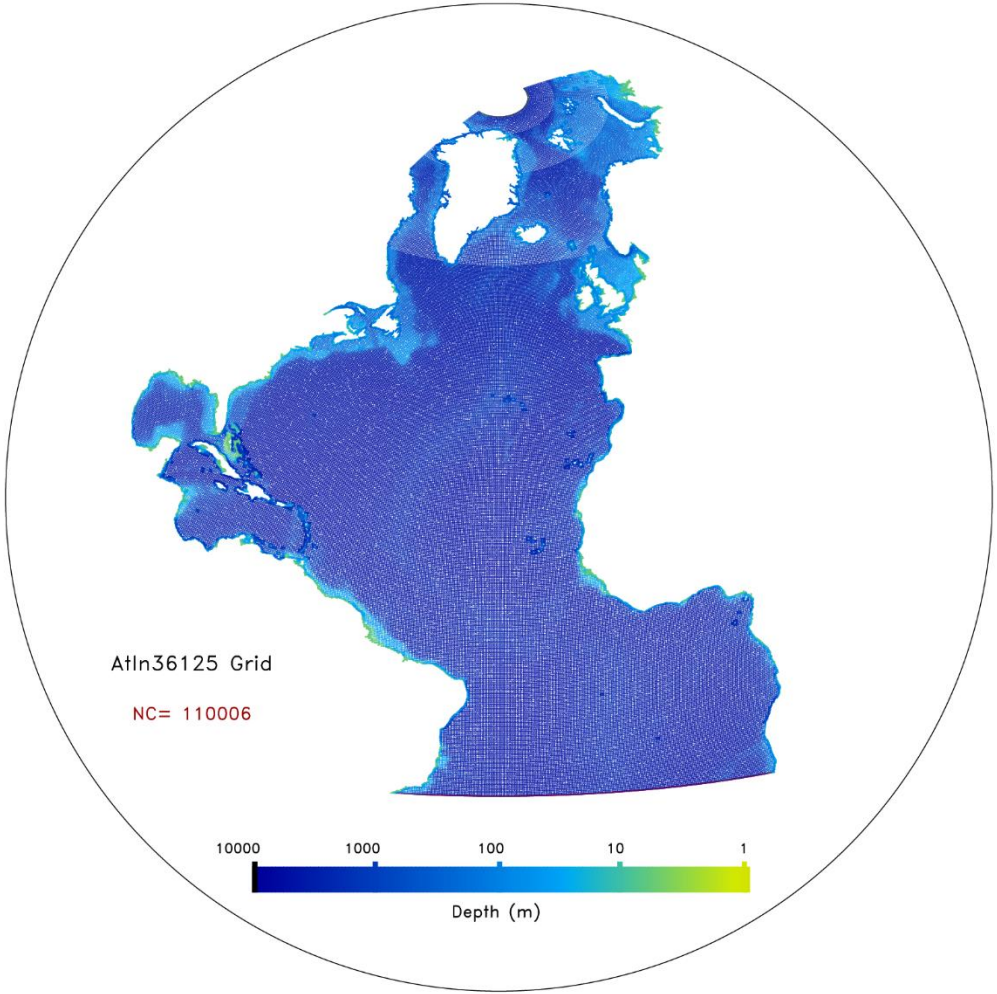


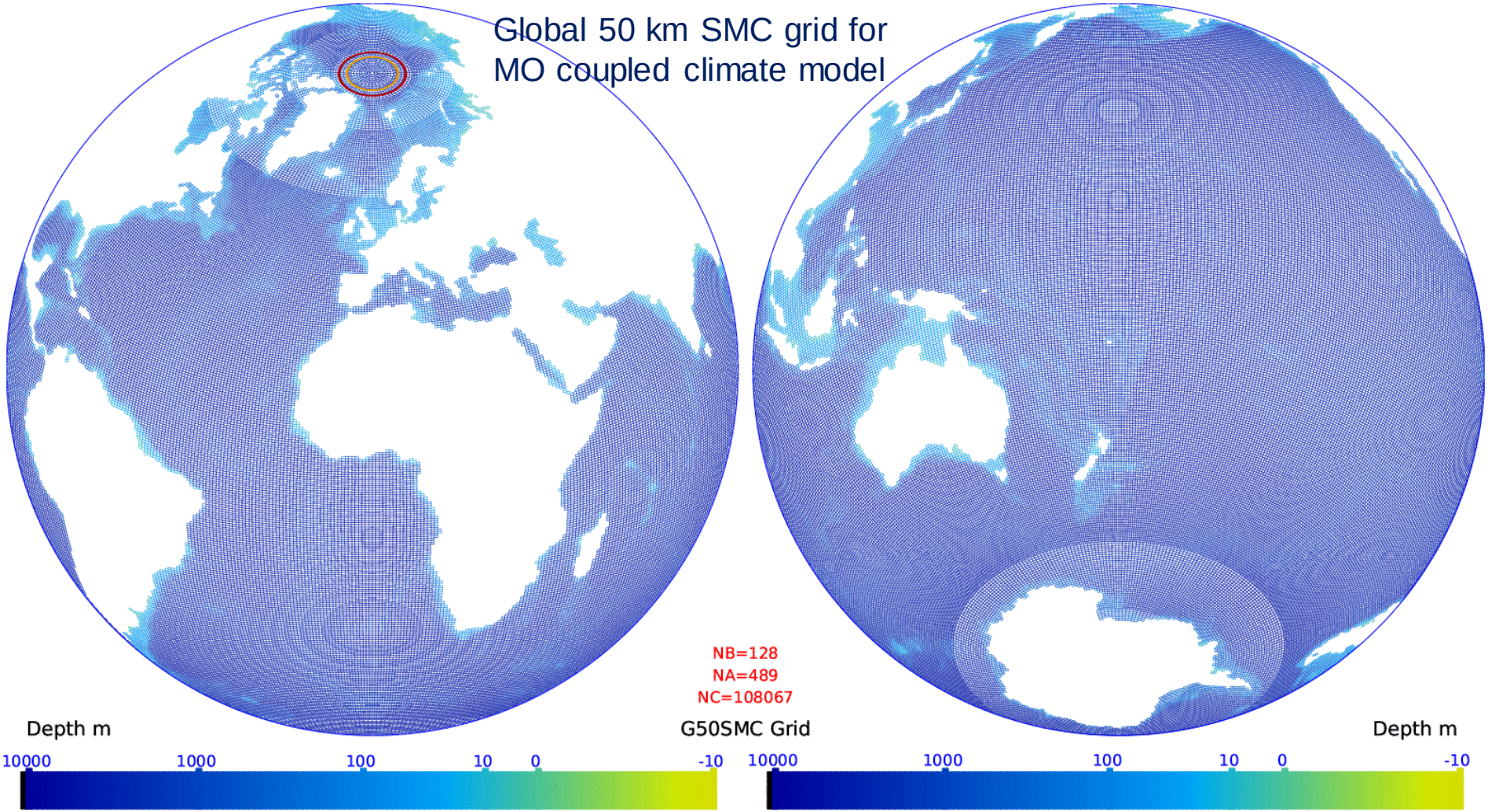
UK Met Office Atlantic Short–Range Wave Ensemble Prediction System

SMC grid at 3-6-12-25 km resolutions, covering essential ocean waters related to the British Isles.

Boundary conditions generated with our global wave model.

Perturbated with MOGREPS-Global atmospheric wind forcing.




Global 50 km SMC grid for
MO coupled climate model
NB=128
NA=489
NC=108067
Depth m
10000
1000
100
10
0
-10
G50SMC Grid
Depth m
10000
1000
100
10
0
-10

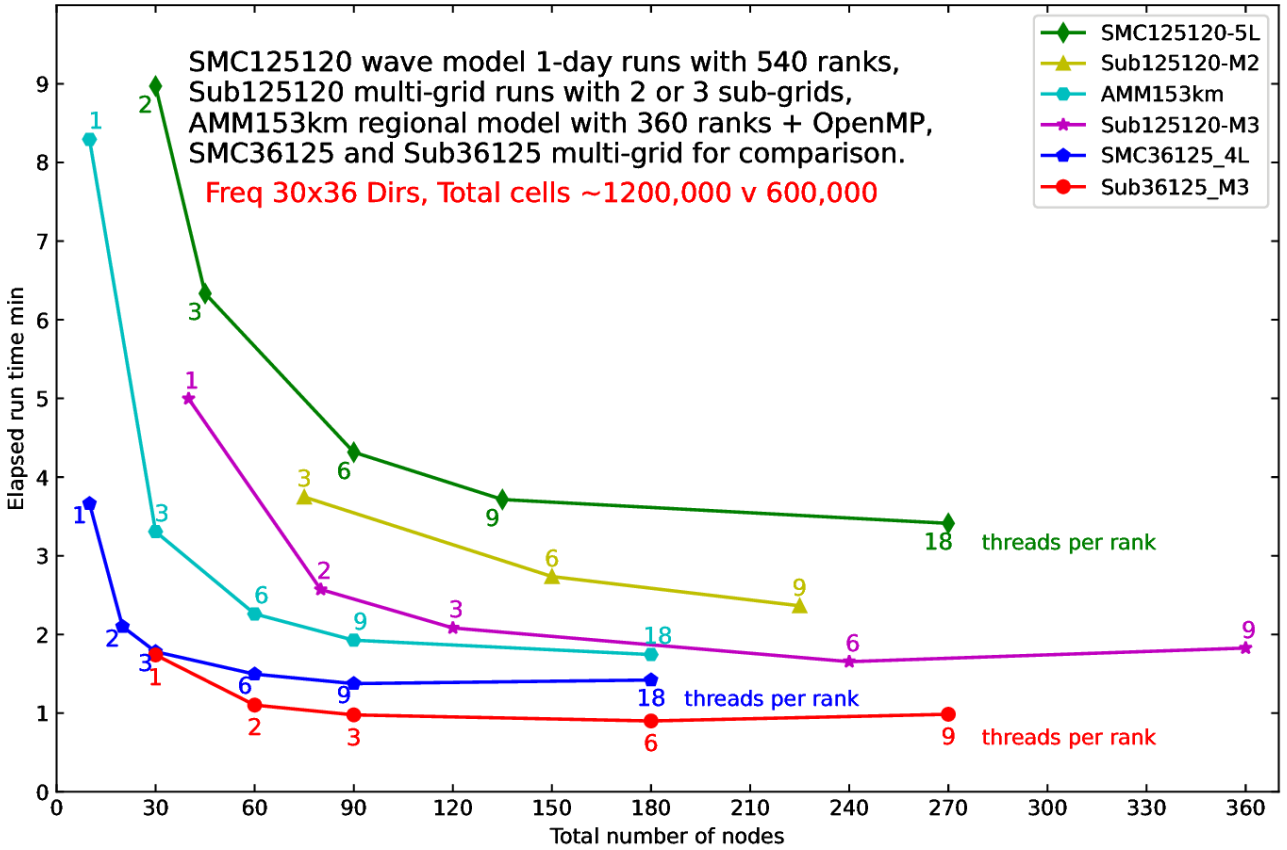
Global / regional model runtimes

SMC36125 model best runtime is 83 s (90 nodes)

AMM153 model runtime is 116 s on 90 nodes.

Multi-grid hybrid option with 3 sub-grids for global Sub36125 model could save 30% runtime, about 58 s on 90 nodes and 54 s on 180 nodes (6480 cores)

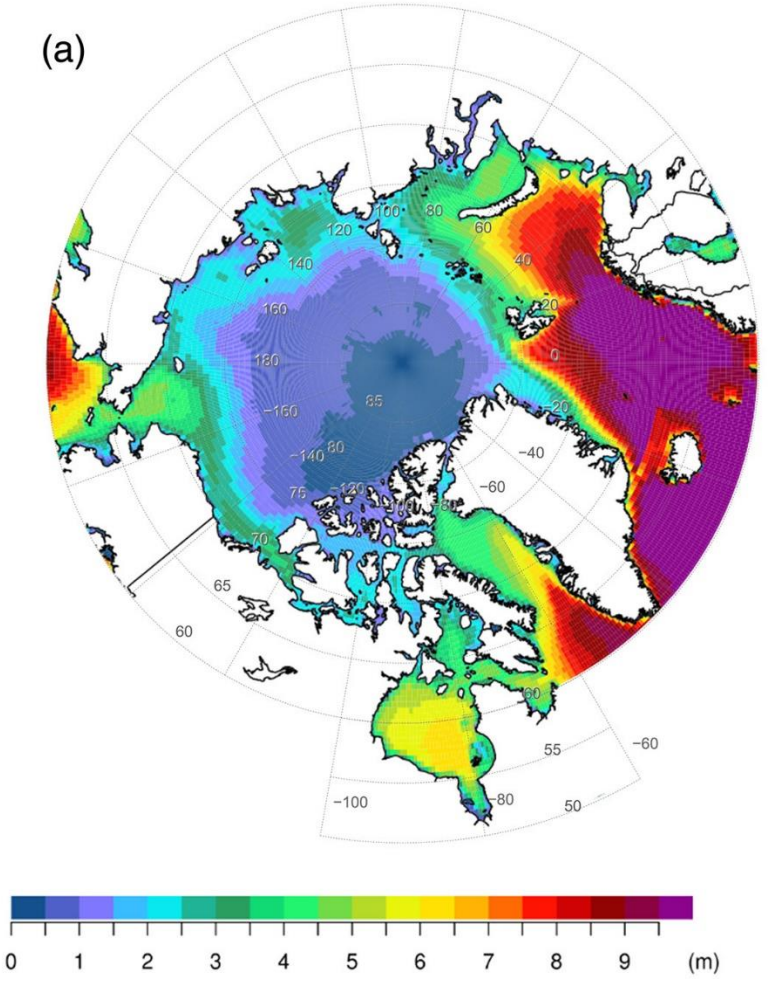
Future multi-grid Sub125120 model best time ~ 100 s on 240 nodes (8640 cores). Single grid best time ~ 205 s on 270 nodes (9720 cores).



Environ. Canada Arctic models and Ocean Univ. China climatic studies.

- Courtesy of **Dr Mercè Casas-Prat** Environment Canada and **Dr LI, Jinkai**, Ocean University of China

- Casas-Prat et al 2018: *Ocean Modelling*, **123**, 66-85.
- Li, J., Y. Ma, Q. Liu, W. Zhang, C. Guan, 2019: *Cold Regions Sci. Techn.* **164**, 102790.



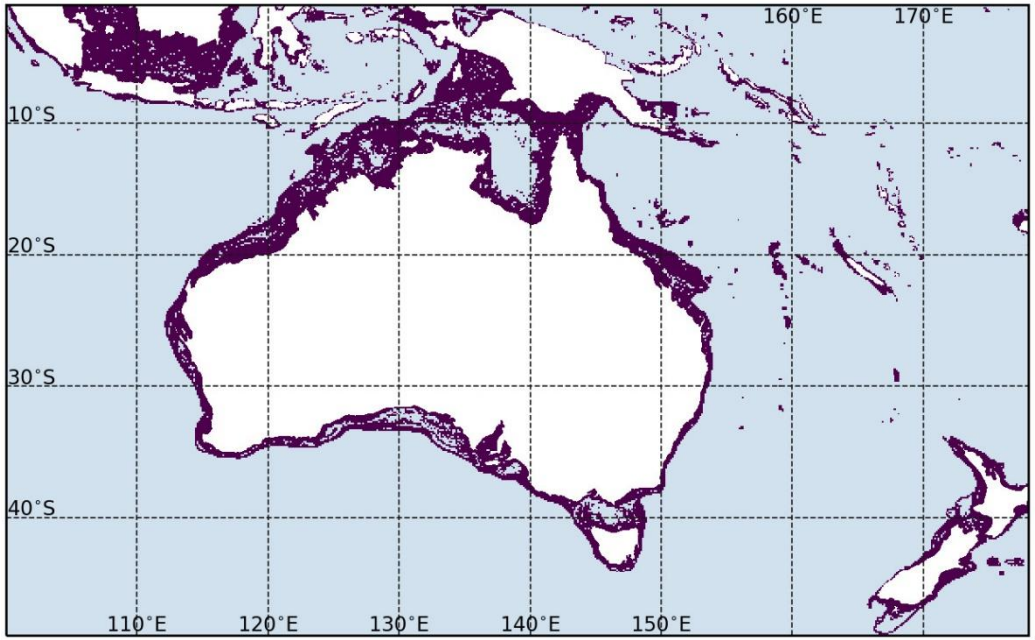
Australia BoM wave forecasting model

- Courtesy of **Dr Stefan Zieger, Bureau of Meteorology, Australia**

Base resolution of 1/8°,

Increase to 1/16° around islands or in shallow waters (< 350 m)

Zieger, S., D.J.M. Greenslade, 2021: AUSWAVE-G3. *Bureau Res. Report* **51**. 74pp.



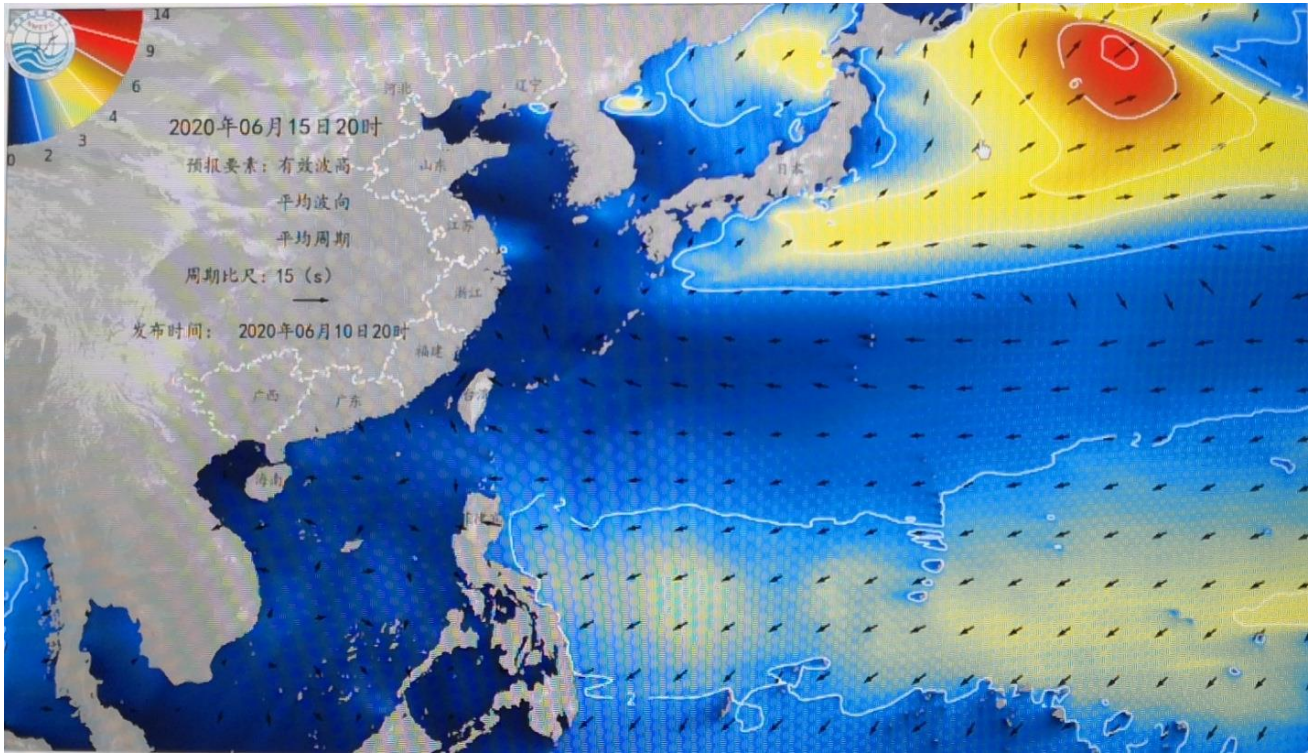
China NMEFC wave forecasting model

Courtesy of

Dr GAO, Zhiyi
NMEFC, China

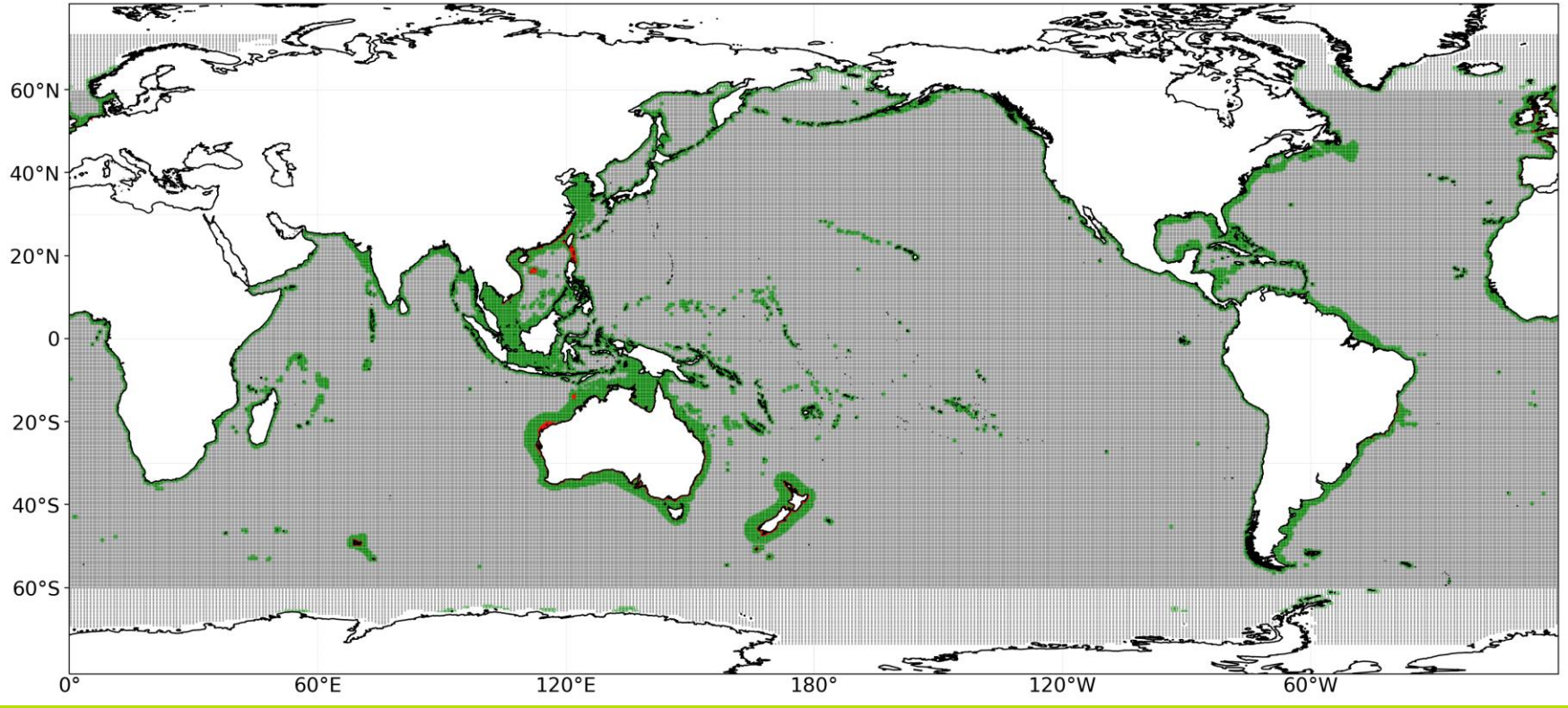
6-level SMC grid from 50 km down to about 1.5 km.

Hou F., Gao Z., Li J., Yu F. 2022: *Acta Oceano. Sinica*, 41(5), 41-50.



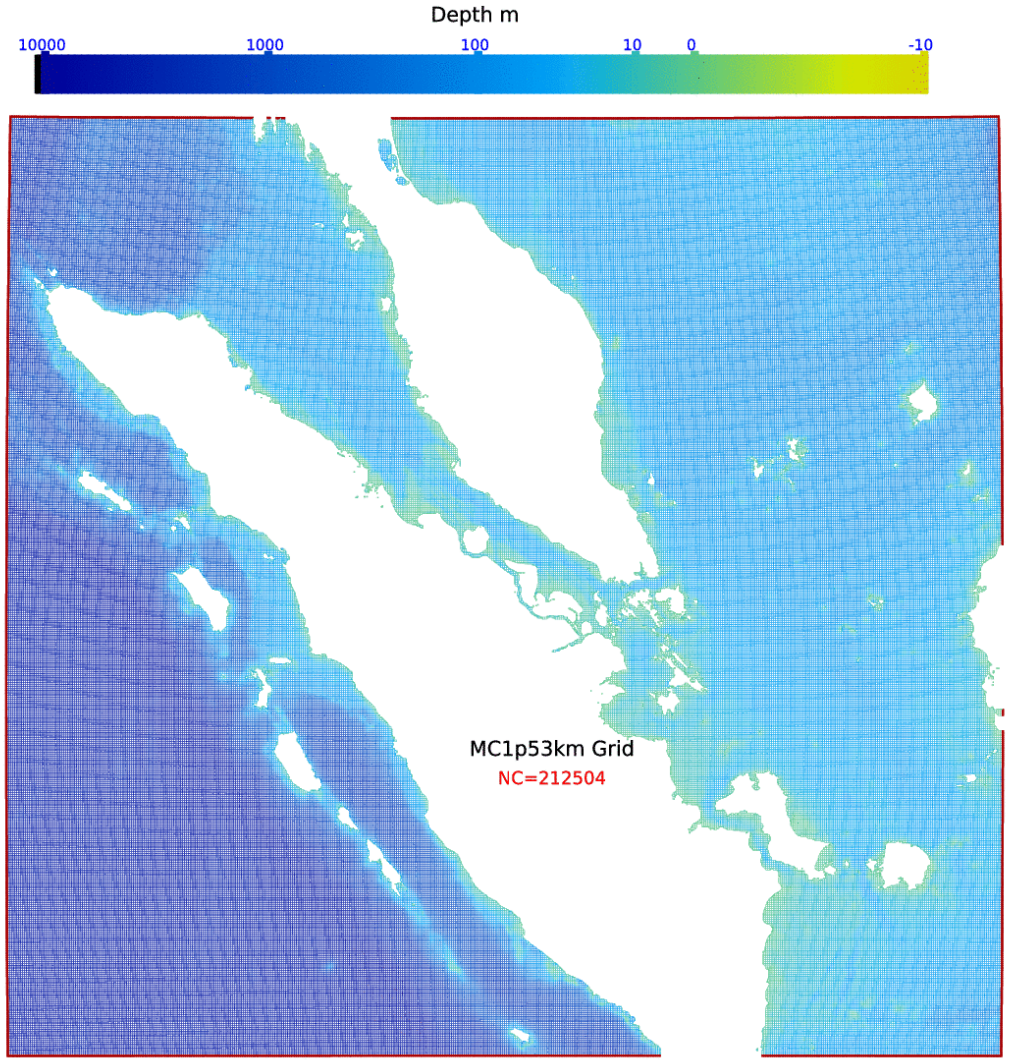
MetOcean Solutions (NZ) wave forecasting model

- Courtesy of **Dr Emilio Echevarria, MetOcean Solutions, New Zealand** **40-20-10 km**



Meteorological Service Singapore coupled climatic model

- Courtesy of **Dr Rajesh Kumar**
  CCRS, Meteorological Service Singapore (MSS)
  National Environment Agency Singapore (NEAS)
- SMC 1.5-3 km wave model coupled with NEMO and the Unified atmospheric model.



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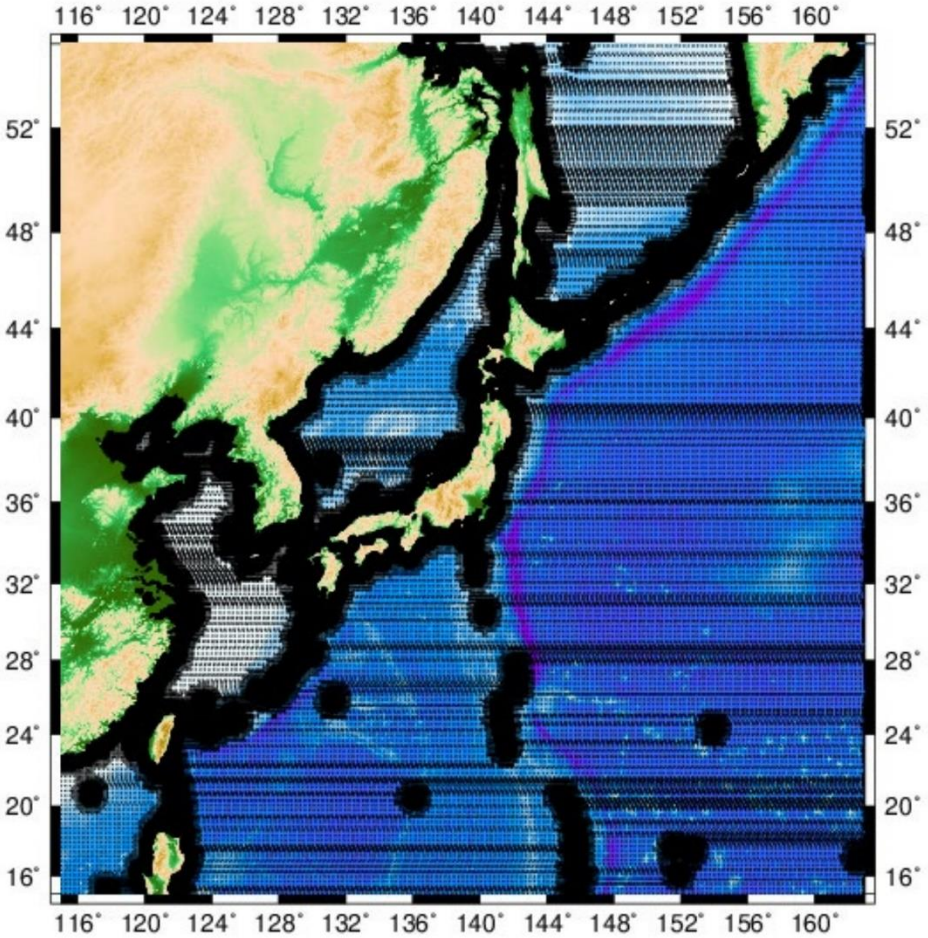
Japan Meteorological Agency coupled wave climate model

- Courtesy of **Dr Nadao Kohno** MRI, Japan Meteorological Agency (JMA)
- West Pacific 5-level (1-2-4-8-16 minutes) SMC grid by distance from Japan coastlines (1 min ~ 1.5 km for first 20 miles and 16 min ~ 25 km beyond 60 miles).



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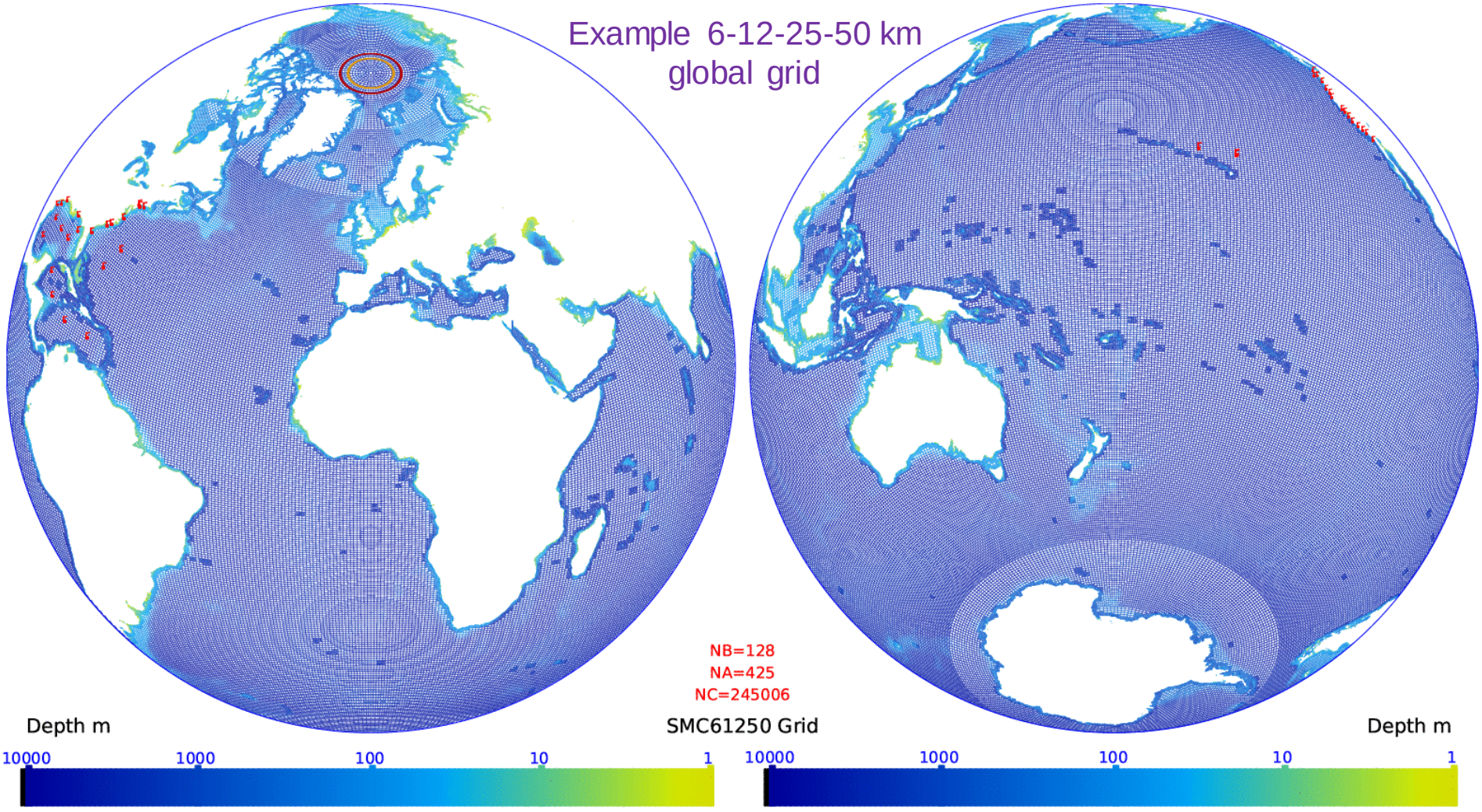
SMC Grid Toolkits on Github

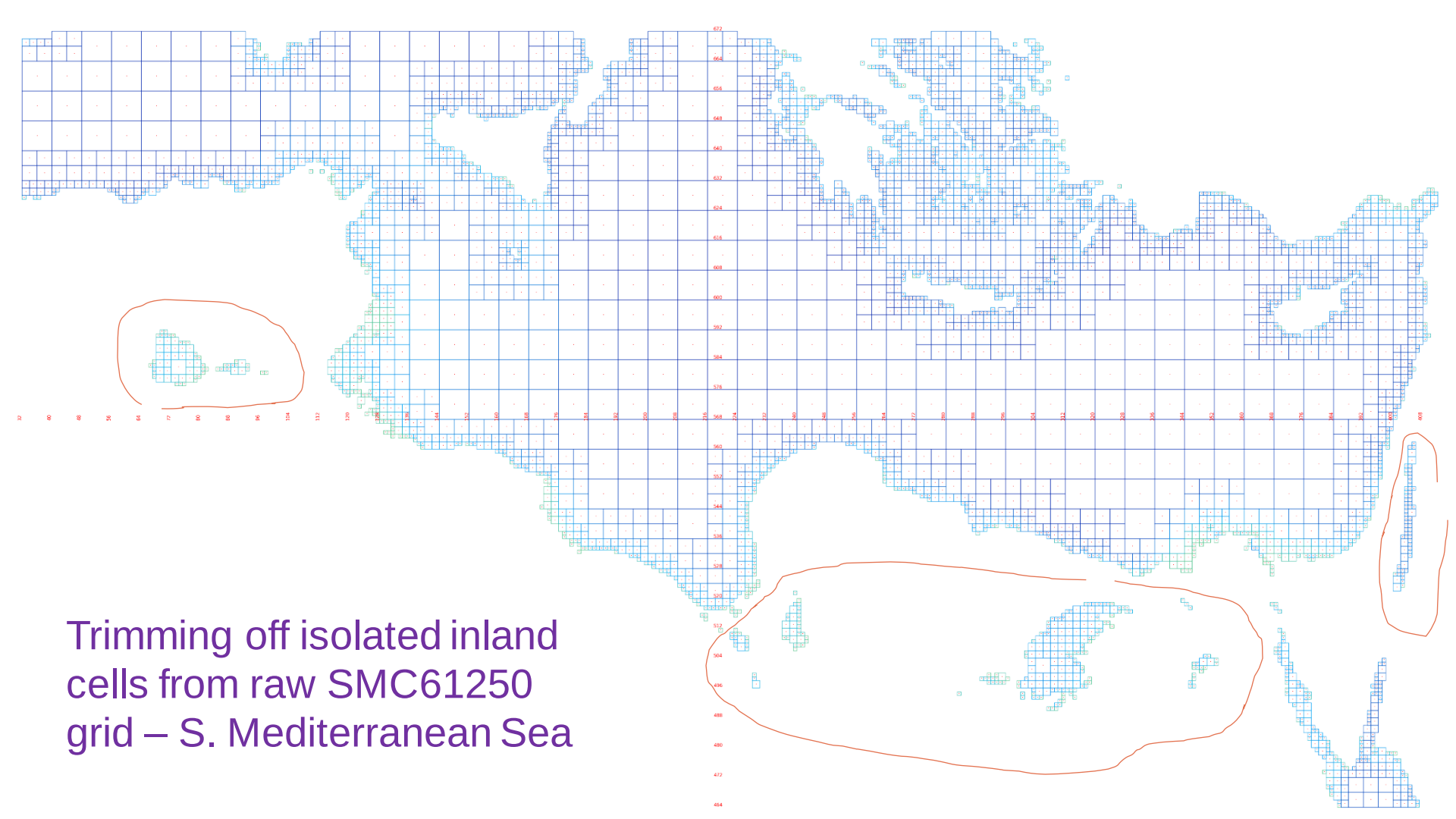
Some SMC grid generating and testing tools have been developed and uploaded on Github for public use. The package can be downloaded from the web site:

https://github.com/ww3-opentools/SMCGTools

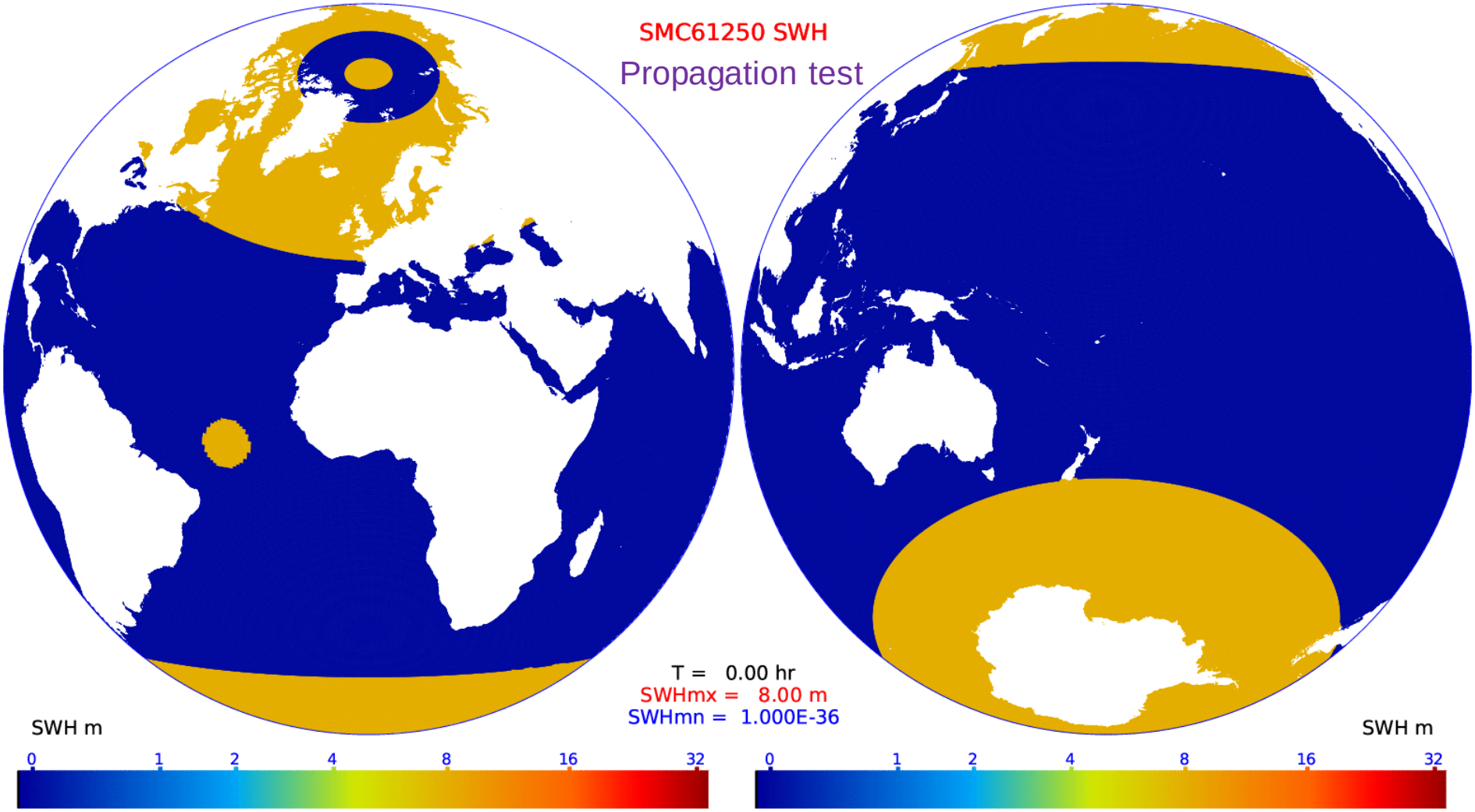
There is a document, *SMC_Grid_Guide2023.pdf*, for introduction and another document, *SMCGToolsGuide2023.pdf*, for use of the toolkits.

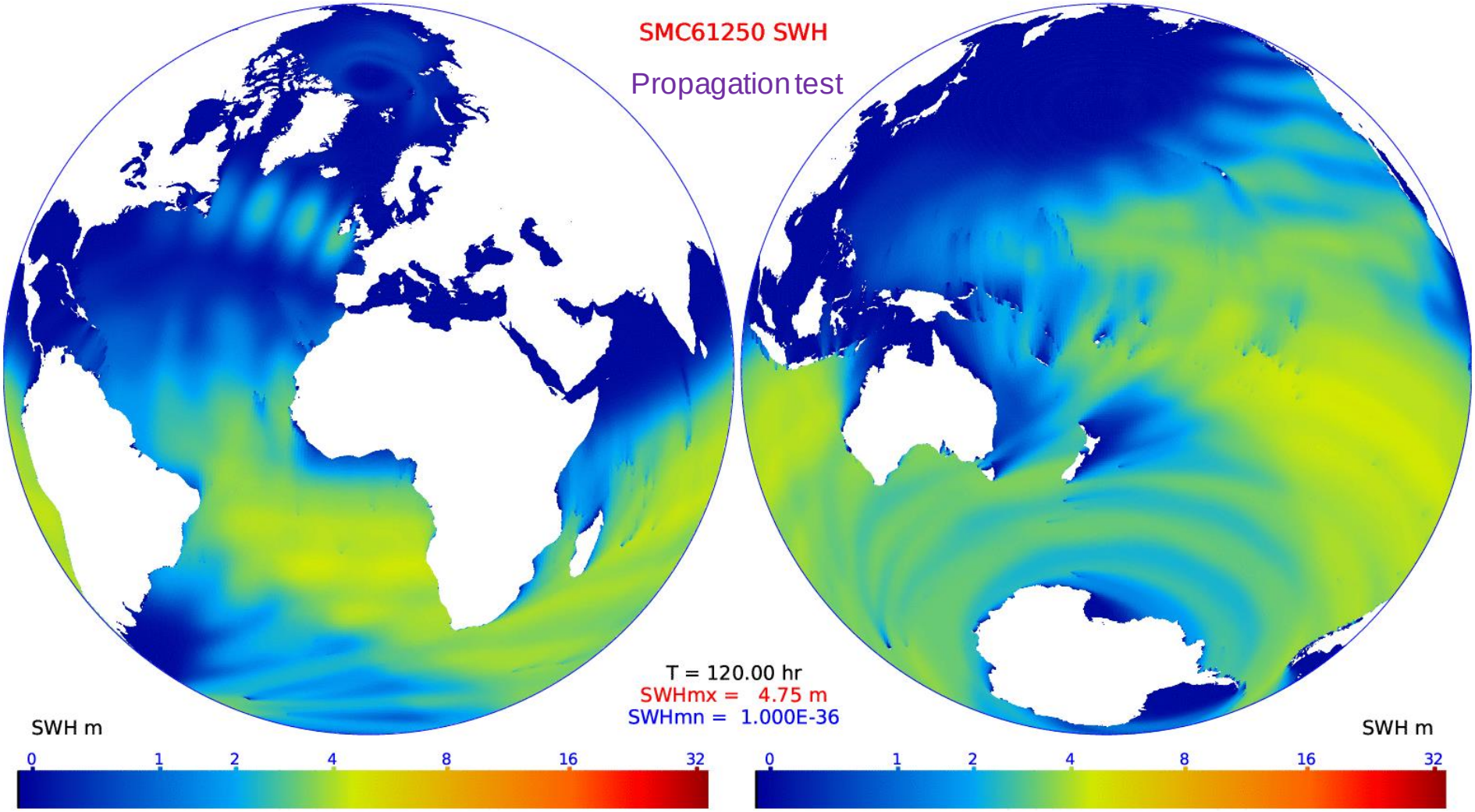
- The package includes bathymetry preparation from the GEBCO_2022 raw data.
- SMC grid generating and visualisation programs in Python and Linux scripts.
- SMC face array generating and propagation test programs in FORTRAN 90.
- Unwanted cell trimming scripts and grid splitting program in Python and Linux.
- WW3 model input preparation and model results visualisation programs.

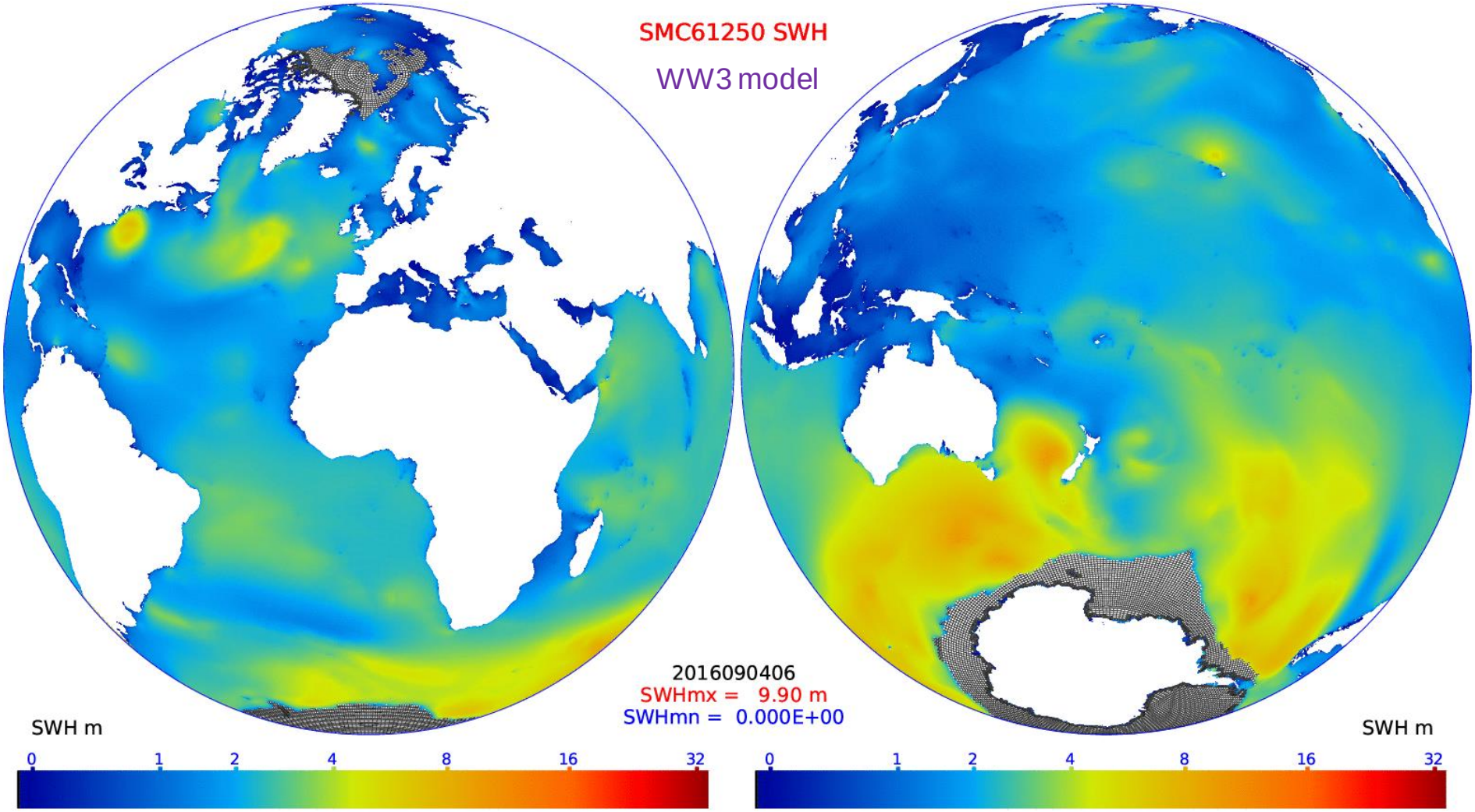

Example 6-12-25-50 km
global grid
NB=128
NA=425
NC=245006
Depth m
10000
1000
100
10
1
SMC61250 Grid
Depth m
10000
1000
100
10
1



Trimming off isolated inland cells from raw SMC61250 grid – S. Mediterranean Sea


SMC61250 SWH
Propagation test
T = 0.00 hr
SWHmx = 8.00 m
SWHmn = 1.000E-36
SWH m
0
1
2
4
8
16
32
SWH m
0
1
2
4
8
16
32


SMC61250 SWH
Propagation test
T = 120.00 hr
SWHmx = 4.75 m
SWHmn = 1.000E-36
SWH m
0
1
2
4
8
16
32
SWH m
0
1
2
4
8
16
32


SMC61250 SWH
WW3 model
2016090406
SWHmx = 9.90 m
SWHmn = 0.000E+00
SWH m
0
1
2
4
8
16
32
SWH m
0
1
2
4
8
16
32

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Summary and conclusions

- SMC grid is an unstructured grid but retains the lat-lon grid rectangular cells with efficient finite-difference schemes. It allows multi-resolutions with mesh-refinement and includes the whole Arctic after solving the polar problems in traditional lat-lon grid. The SMC grid is implemented in WAVEWATCH III® and has been updated with hybrid parallelization and multi-grid option.
- SMC grid wave model is suitable for coupled systems, thanks to its straightforward mapping to lat-lon grid, its multi-resolution to resolve small islands and efficient hybrid parallelization for short runtime. The SMC grid wave model has been used in several weather centres in the world for wave forecasting and climate studied.
- SMC grid tool package is available on Github. It contains Python, FORTRAN and Linux scripts for generating and testing SMC grid. Several users have used the toolkits to generate their own SMC grids.

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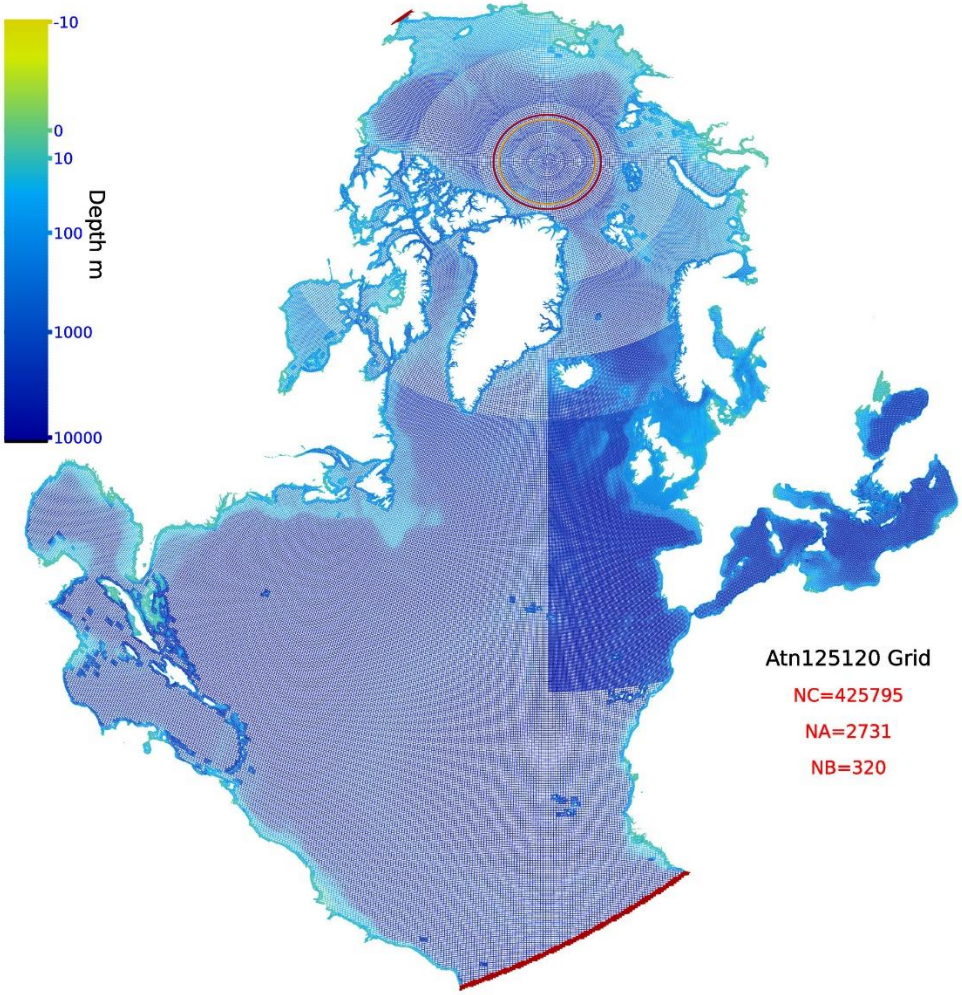
Thanks! Questions?


-10
0
10
100
1000
10000
Depth m
Atn125120 Grid
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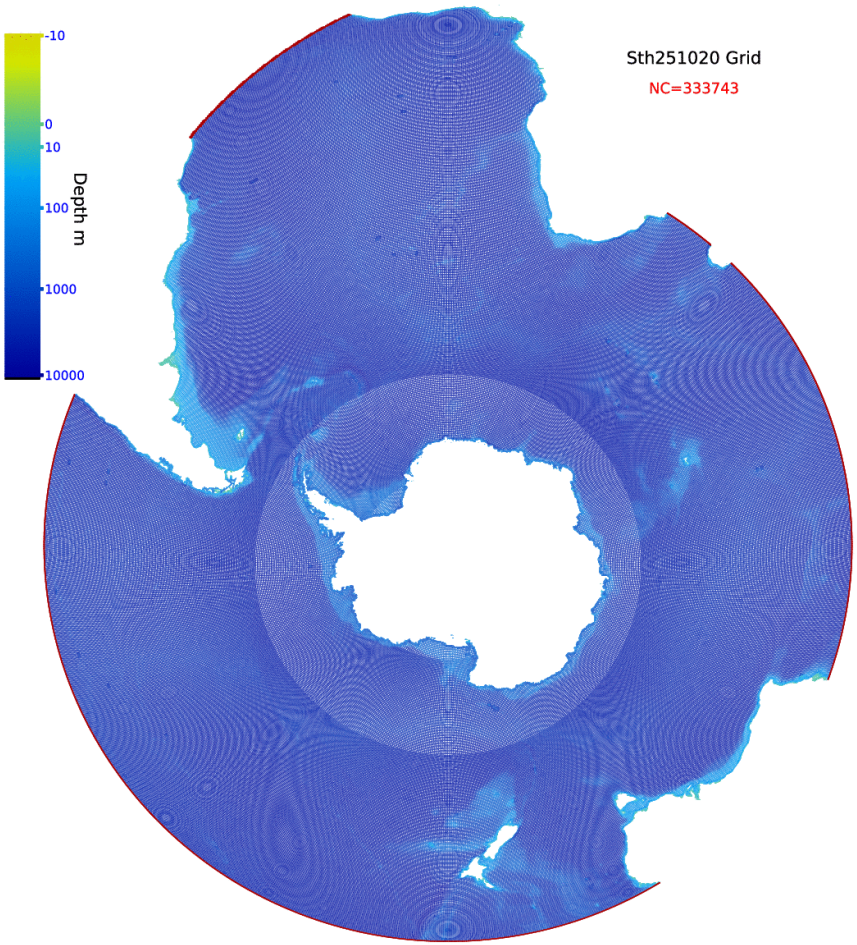
NA=2731
NB=320


-10
0
10
100
1000
10000
Depth m
Sth251020 Grid
NC=333743