



Applications of the SMC Grid in Ocean Surface Wave Models

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This presentation covers the following areas

- Introduction of SMC grid
- Propagation on a SMC grid
- Application in wave models
- Summary and conclusions



STD Grid 128x64 Projection Pole -60.0°E 45.0°N

Transportation equation in spherical system, 1 of 900:

$$\frac{\partial \psi}{\partial t} + \frac{\partial (u\psi)}{\partial x} + \frac{\partial (\upsilon\psi\cos\varphi)}{\cos\varphi\partial y} = 0$$

Eulerian advection time step at high latitudes. Hence wave models stop at

The Pole is a singular point Flow has to go around it,



 ψ

- Merged cells at high latitudes to relax CFL limit on time step.
- Introduce round polar cells with integral equation to avoid polar blocking and singularity.

$$\frac{\partial}{\partial t} \iint_{A} \psi \, dA = - \prod_{C_A} \psi \, \mathbf{v} \cdot d\mathbf{s}$$

$$\boldsymbol{\psi}_{P}^{n+1} - \boldsymbol{\psi}_{P}^{n} = \pm \frac{\Delta t}{A_{P}} \sum_{i=1}^{m} \boldsymbol{\psi}_{i}^{*} \boldsymbol{\upsilon}_{i} \Delta s_{i}$$

More details please see: Li, J.G. 2011: Mon. Wea. Rev., 139, 1536-1555.

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Map-east reference direction



- SMC grid uses merged cells at high latitudes to relax CFL limit on time step.
- Introduce a round polar cell to avoid polar blocking and singularity.
- Define wave spectral component with fixed reference direction --- the map-east, instead of the rapidly changing local east at high latitudes.
- Keep map-east system in *Arctic part* from the local east in *global part*.





Refined 6-12-25 km SMC grid

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- Refined resolution up to 6km near coastlines, resolving small islands.
- Number of cells (520615) still smaller than lat-lon grid (1024x768=786 432) 66%.
- Could make regional models redundant.
- Sub-time-steps to handle refined cells.



Creating a multi-resolution SMC grid



Each cell is assigned a 5-element array, giving its SW corner x, y index i, j, and sizes or number of increment in unit of size-1 dx, dy.

X and Y sizes may be different for different resolutions or high latitude merged cells.

For more details see: WAVEWATCH III V5.16: smc_docs/SMC_grid_guide



• Ocean surface wave spectral energy balance equation in spherical coordinate system:

$$\frac{\partial \psi}{\partial t} + \frac{\partial F_x}{\partial x} + \frac{\partial (F_y \cos \varphi)}{\cos \varphi \partial y} + \frac{\partial (\dot{k}\psi)}{\partial k} + \frac{\partial (\dot{\theta}\psi)}{\partial \theta} = S$$
$$F_x \equiv (u+U)\psi - D_x \partial \psi / \partial x$$
$$F_y \equiv (\upsilon+V)\psi - D_y \partial \psi / \partial y$$

Advection and diffusion terms are merged. Great-circle turning is added to refraction. Details see: Li, J.G. (2012) *J. Comput. Phys.*, 231, 8286-77.



Upstream Non-Oscillatory 2nd Order (UNO2) Advection Scheme

see:

$$\begin{split} \psi_{j}^{n+1} &= \psi_{j}^{n} + \left(u_{j-1/2}\psi_{j-1/2}^{MF} - u_{j+1/2}\psi_{j+1/2}^{MF}\right)\Delta t / \Delta x_{j} \\ \psi_{j+1/2}^{MF} &= \psi_{C}^{n} + \left(x_{MF} - x_{C}\right)G_{C} \\ \mathbf{UNO2} \\ \mathbf{VONC2} \\ \mathbf{VOUKNOW TOO} \\ \begin{aligned} & K_{MF} - x_{C} &= 0.5sign\left(u_{j+1/2}\right)\left(\Delta x_{C} - \left|u_{j+1/2}\right|\Delta t\right) \\ G_{C} &= Sign(G_{DC})\min\left(|G_{DC}|,|G_{CU}|\right) \\ G_{AB} &= \left(\psi_{A} - \psi_{B}\right) / \left(x_{A} - x_{B}\right) \\ \end{aligned}$$

Upstream, Central and Downstream cells relative to velocity *u*.





- Internal and boundary faces are treated alike in 1-D array. No boundary for global model.
- Single point island is extended by 0-cells, allowing singleisland blocking.
- Two-D spherical surface advection is done by 4 loops: uand v-face flux loops and 2 cell update loops.









Multi-Resolution SMC grid

- Sub-flux loop for refined faces with sub-timestep.
- Temporary net flux variable to hold flux into each cell between space and sub-time levels.
- Sub-cell loop to update refined cells and reset net flux variable.
- Number of refined levels defined by user.













- 1. Global wave model SMC36125 grid, replaced 35 km lat-lon grid model in August 2016. The European regional wave model on rotated latlon 8km grid will retire as the global SMC36125 model has a refined area over European.
- 2. Climate wave model on SMC50km grid.
- 3. Ensemble N Atlantic wave model 3-6-12-25 km SMC grid.
- 4. UK regional wave model on rotated lat-lon 4km grid, will be replaced with a SMC1.5-3 km grid.



Comparison SMC36125 Arctic and European SWH with/out Ice

LI, JG 2016: Ocean Dynamics, 66, 899-1004.









Along satellite tracks in Atlantic



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Along satellite tracks in Pacific



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Comparison with spectral buoys

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Global 25km orography from Glob25km.pp and selected buoys



Comparison SMC36125-ST4 via Buoy SWH 201209-12



WW3 V4.18 retuned ST4 source term

32 spectral buoys from NDBC.



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Comparison SMC36125-ST4 with Buoy 4-bin SRWH



First two bins for swell, model is slightly higher than buoy;

Last two bins for windsea, model is slightly lower;

So retuned ST4 source term is balanced over the full spectral range.

Comparison with other centres - all





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Comparison with other centres - Hawaii

SMC36125 refined coastlines lead to improved swell propagation as small island effect is resolved better than old single resolution model.

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Total cell 108,067 ~ 58% of the lat-lon grid 512x368



SMC36125 Atlantic model

Regional grid for the N. Atlantic Ocean.

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Boundary condition is minimised by extending to coastlines. Only the southern boundary (red) along the Tropic of Capricorn requires input.

Isolated or weakly linked waters, like the Hudson Bay, Baltic and Mediterranean Sea are removed to speed up the ensemble model.





SWH in SMC36125 Atlantic model

North boundary sealed by Arctic sea-ice;

Southern boundary is defined by input from our global SMC36125 wave model;

Sheltered waters (Gulf of Mexico, Hudson Bay, Baltic and Mediterranean Sea) are negligible to N Atlantic.





SMC36125 Atlantic model UK area







Rotated SMC1.5-3 km UK grid



Multi-resolution 1.5-3 km grid.

Rotated N' at 177.5°E,37.5°N, grid for evenly spaced cells around UK.

Boundary conditions provided by SMC36125 global model.

Inpputs include current and tidal effects.



SMC1.5-3 km UK model SWH



Wind and current effects included.

Note the high waves off the Brittany coast or around the Isle of Ushant. It is caused by an unknown interaction between the ocean current gradient induced k-shift (part of wave refraction) and the nonlinear wave interaction term.



SMC6125 km rotated Arctic grid

Rotated pole at (135°E, 10°N) so the Arctic region is near the rotated Equator with an evenly spaced mesh.

Boundaries are set across Atlantic and Bering Strait.





SWH in SMC6125 km Arctic model

SWH from an ice-free case of the rotated grid Arctic model.

Boundary condition is provided by our global SMČ36125 wave model.





Applications outside Met Office

- 1. NCEP Great Lakes 0.5 1 2 km SMC grid.
- 2. Environment Canada wave climate model on 12-25 km SMC Arctic grid, nested in global 50-100 km SMC grid.
- Australia Hurricane wave research 4-8-16 km Gulf of 3. Mexico SMC grid.
- Mediterranean Sea 3-6-12-25 km SMC grid for UPC, 4. Spain and CNR – ISMAR, Italia.
- West Pacific regional wave forecast model for 5. NMEFC, China
- 6. West Pacific wave model ensemble system for Industrial Technology Institute, Hsinchu, Taiwan.





SWH of SMC0512 GtLakes model

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SMC36125 Mediterranean Model

10000 1000 100 10 Depth (m) Med36125 Grid NC= 26205 4632 Hm=



SWH in Mediterranean model

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SMC12-25 km EC Arctic model

Courtesy of

Dr Mercè Casas-Prat

Environment Canada





SMC12-25 km EC Arctic SWH

Courtesy of

Dr Mercè Casas-Prat

Environment Canada





SMC2-4-8 Gulf of Mexico model

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SMC36125 SWH Asia Pacific 20 5 10 SWH (m) SMC36125 SWH 201409150000 $Hs_{max} = 12.94 m$ $Hs_{min} = 0.000E + 00$



SMC4-8-16 km Pacific model

波浪系集預報系統

Courtesy of

Dr Hengwen Chang

Industrial Technology **Research Institute**,

Hsinchu, Taiwan



佔用計算資源: 32 CPU × 20 ensembles 32 CPU \times 2 deterministics

計算時間(包括風場前置處理、系集計算、後處理): 3 hours



SMC50 Global wave model NMEFC

Courtesy of Dr CAI, Qiongqiong NMEFC of

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- SMC grid relaxes CFL limit on time step by merging cells at high latitudes and reduces curvature error by switching from the local east to a fixed (map-east) direction system in the Arctic.
- Multi-resolution is achieved for coastal regions with refined cells and sub-time-steps are used to reduce computation cost. This makes it possible to merge global and regional wave models and include the Arctic if necessary.
- Four processes (advection, diffusion, refraction and great-circle turning) related to ocean surface wave propagation are formulated on the SMC grid and coded into the WW3 model V4.18 and V5.16.
- There are 4 SMC grid models currently in use the Met Office, including SMC36125 km global wave forecast model and N Atlantic ensemble model, SMC50km global wave model for coupled system and rotated SMC grid UK1.5-3 km wave model.
- International collaborations involve 6 SMC grid models so far, including the 0.5-1-2 km Great Lakes, Mediterranean 3-25 km, EC12-25 km Arctic, Gulf of Mexico 2-4-8 km, West Pacific forecast and ensemble models on multi-resolution SMC grids.



Thank you! Questions?

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SMC1-2-4 km UK rotated grid



Multi-resolution 1-2-4 km SMC grid

Rotated N' at 177.5°E,37.5°N, grid for evenly spaced cells around UK.

Boundary conditions provided by SMC36125 global model.

Will include current and tidal effects.



SMC1-2-4 km UK model SWH



Multi-resolution 1-2-4 km SMC grid

Using rotated grid for evenly sized cells in whole domain.

Boundary conditions provided by SMC36125 global model.

Will include current and tidal effects.



SMC36125 wave model NMEFC

Courtesy of Dr CAI, Qiongqiong, NMEFC of China





Nested grids could be replaced by a single SMC grid.

Courtesy of **Dr. Tom Durrant** MetOcean Solutions Ltd., Raglan, New Zealand



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SRWH 4-bin output SMC25

