Hydrodynamic and biogeochemical estuarine modelling with FlexSem

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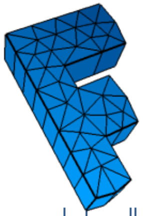
Small model group funded by research grants and governmental advice



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FlexSem - history

Model nutrient retention in Danish fjord for the Baltic Nest Institute

3D unstructured + simplified physics -> fast box model

Separate programming from ecological modelling

Precompiled program, user inputs equations in text file

Interpolate 3D velocities from structured model (HBM/BSHcmod)

Use 3D pelagic- 3D benthic biogeochemical model in open water areas

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3D semi-implicit, finite difference-finite volume, hydrostatic and nonhydrostatic solution to the Navier-Stokes equations on an unstructured computational mesh

Casulli and Zanolli 2002 Semi-implicit numerical modeling of nonhydrostatic free-surface flows for environmental problems

Horizontal and vertical advection and diffusion of momentum is discretized using an eulerian second order Adam-Bashford approach

Fringer et al. 2006 An unstructured-grid, finite-volume, nonhydrostatic, parallel coastal ocean simulator

Semi-implicit advection diffusion scheme. Smagorinsky turbulent viscosity. Surface heat budget. Open boundaries. Bottom, vertical wall and surface drag. Coriolis. Sources.

Implemented in standard c++, windows, parallelized with openMP

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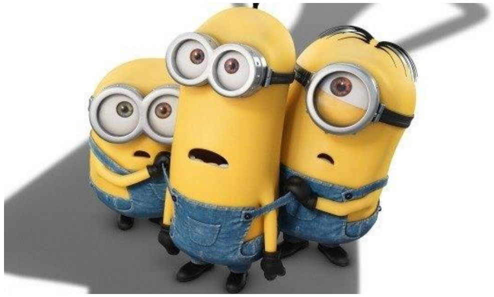
3D semi-implicit, finite difference-finite volume, hydrostatic and nonhydrostatic solution to the **Navier-Stokes equations** on an unstructured computational mesh

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} - fv = -\frac{\partial p}{\partial x} + \nu^h\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) + \frac{\partial}{\partial z}\left(\nu^v\frac{\partial u}{\partial z}\right),$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} + fu = -\frac{\partial p}{\partial y} + \nu^h\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) + \frac{\partial}{\partial z}\left(\nu^v\frac{\partial v}{\partial z}\right),$$

$$\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} = -\frac{\partial p}{\partial z} + \nu^h\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2}\right) + \frac{\partial}{\partial z}\left(\nu^v\frac{\partial w}{\partial z}\right) - \frac{\rho}{\rho_0}g,$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0.$$



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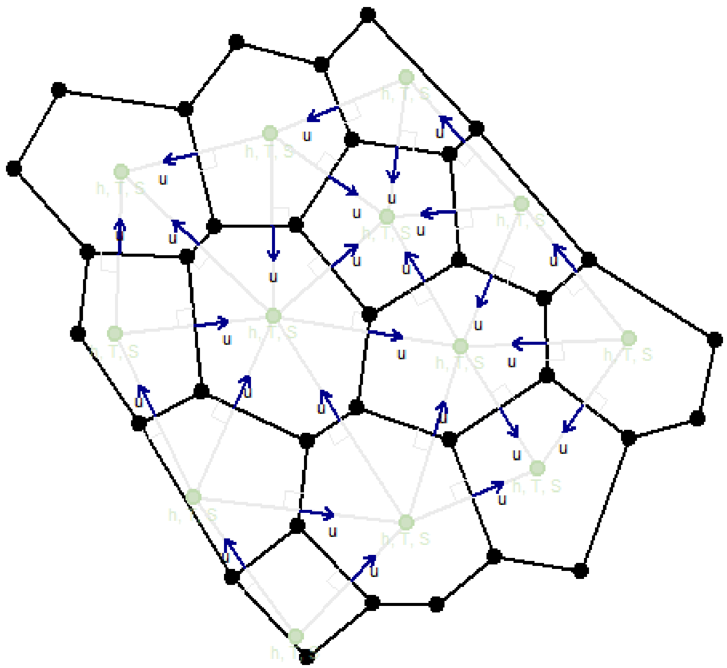
3D semi-implicit, **finite difference-finite volume**, hydrostatic and nonhydrostatic solution to the Navier-Stokes equations on an **unstructured computational mesh**



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3D semi-implicit, finite difference-finite volume, hydrostatisk og ikke hydrostatisk løsning til Navier-Stokes ligningerne på et ustruktureret beregningsnet

$$\mathbf{A}_j^n \tilde{\mathbf{U}}_j^{n+1} = \mathbf{G}_j^n - \theta g \frac{\Delta t}{\delta_j} \left[\tilde{\eta}_{i(j,2)}^{n+1} - \tilde{\eta}_{i(j,1)}^{n+1} \right] \mathbf{\Delta Z}_j^n,$$

$$P_i \tilde{\eta}_i^{n+1} = P_i \eta_i^n - \theta \Delta t \sum_{l=1}^{S_i} s_{i,l} \lambda_{j(i,l)} \left[\mathbf{\Delta Z}_{j(i,l)}^n \right]^{\mathsf{T}} \tilde{\mathbf{U}}_{j(i,l)}^{n+1} - (1-\theta) \Delta t \sum_{l=1}^{S_i} s_{i,l} \lambda_{j(i,l)} \left[\mathbf{\Delta Z}_{j(i,l)}^n \right]^{\mathsf{T}} \mathbf{U}_{j(i,l)}^n,$$

$$\tilde{\mathbf{U}}_j^{n+1} = \begin{bmatrix} \tilde{u}_{j,M}^{n+1} \\ \tilde{u}_{j,M-1}^{n+1} \\ \vdots \\ \tilde{u}_{j,m}^{n+1} \end{bmatrix}, \qquad \mathbf{\Delta Z}_j^n = \begin{bmatrix} \Delta z_{j,M}^n \\ \Delta z_{j,M-1}^n \\ \vdots \\ \Delta z_{j,m}^n \end{bmatrix},$$

$$\mathbf{G}_j^n = \begin{bmatrix} \Delta z_{j,M}^n \left\{ F u_{j,M}^n - \frac{\Delta t}{\delta_j}(1-\theta) \times \left[g\left(\eta_{i(j,2)}^n - \eta_{i(j,1)}^n\right) + q_{i(j,2),M}^n - q_{i(j,1),M}^n \right] \right\} + \Delta t \gamma_{T,j}^{n+1} u_{a,j}^{n+1} \\ \Delta z_{j,M-1}^n \left\{ F u_{j,M-1}^n - \frac{\Delta t}{\delta_j}(1-\theta) \left[g\left(\eta_{i(j,2)}^n - \eta_{i(j,1)}^n\right) + q_{i(j,2),M-1}^n - q_{i(j,1),M-1}^n \right] \right\} \\ \vdots \\ \Delta z_{j,m}^n \left\{ F u_{j,m}^n - \frac{\Delta t}{\delta_j}(1-\theta) \left[g\left(\eta_{i(j,2)}^n - \eta_{i(j,1)}^n\right) + q_{i(j,2),m}^n - q_{i(j,1),m}^n \right] \right\} \end{bmatrix},$$

$$\mathbf{A}_j^n = \begin{bmatrix} \Delta z_{j,M}^n + a_{j,M-1/2}^n + \gamma_{T,j}^{n+1} \Delta t - a_{j,M-1/2}^n 0 \\ -a_{j,M-1/2}^n \Delta z_{j,M-1}^n + a_{j,M-1/2}^n + a_{j,M-3/2}^n - a_{j,M-3/2}^n \\ \cdots \\ \cdots \\ 0 - a_{j,m+1/2}^n \Delta z_{j,m}^n + a_{j,m+1/2}^n + \gamma_{B,j}^{n+1} \Delta t \end{bmatrix},$$

with $a_{j,k\pm 1/2}^n = \nu_{j,k\pm 1/2}^v \Delta t / \Delta z_{j,k\pm 1/2}^n$.

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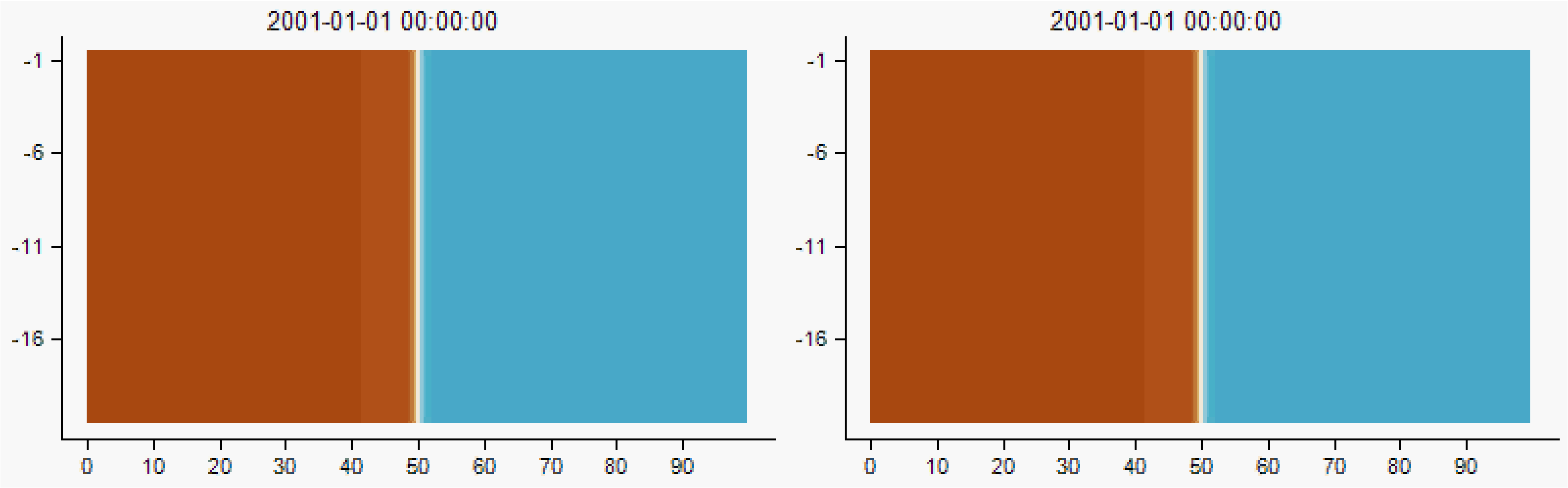

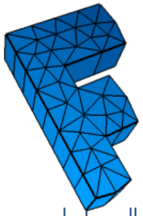

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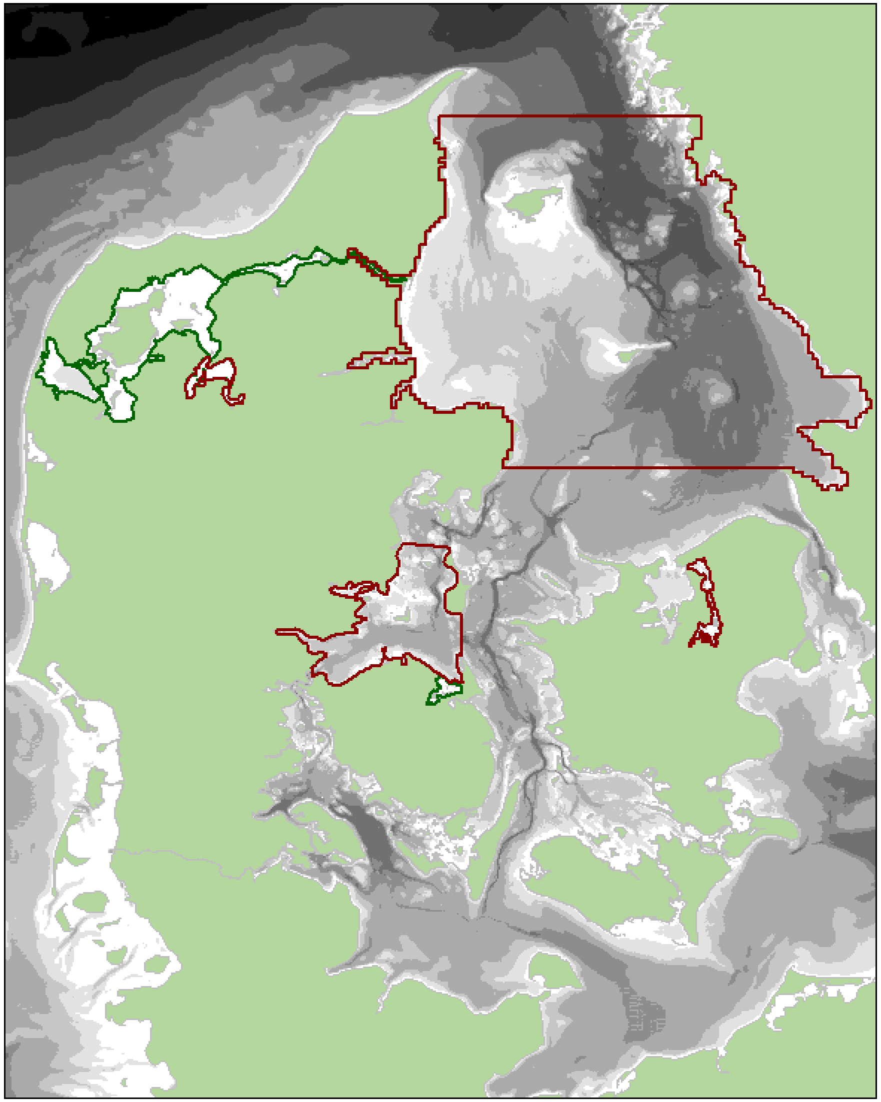
FlexSem Setups

Skive-Lovns, Limfjord
Limfjord
Kattegat
Roskilde Fjord
Odense Fjord
Horsens Fjord

Disko Bay, Greenland
Clarion-Clipperton zone, Pacific
Hove, Roskilde Fjord,
Samsø, Great Belt



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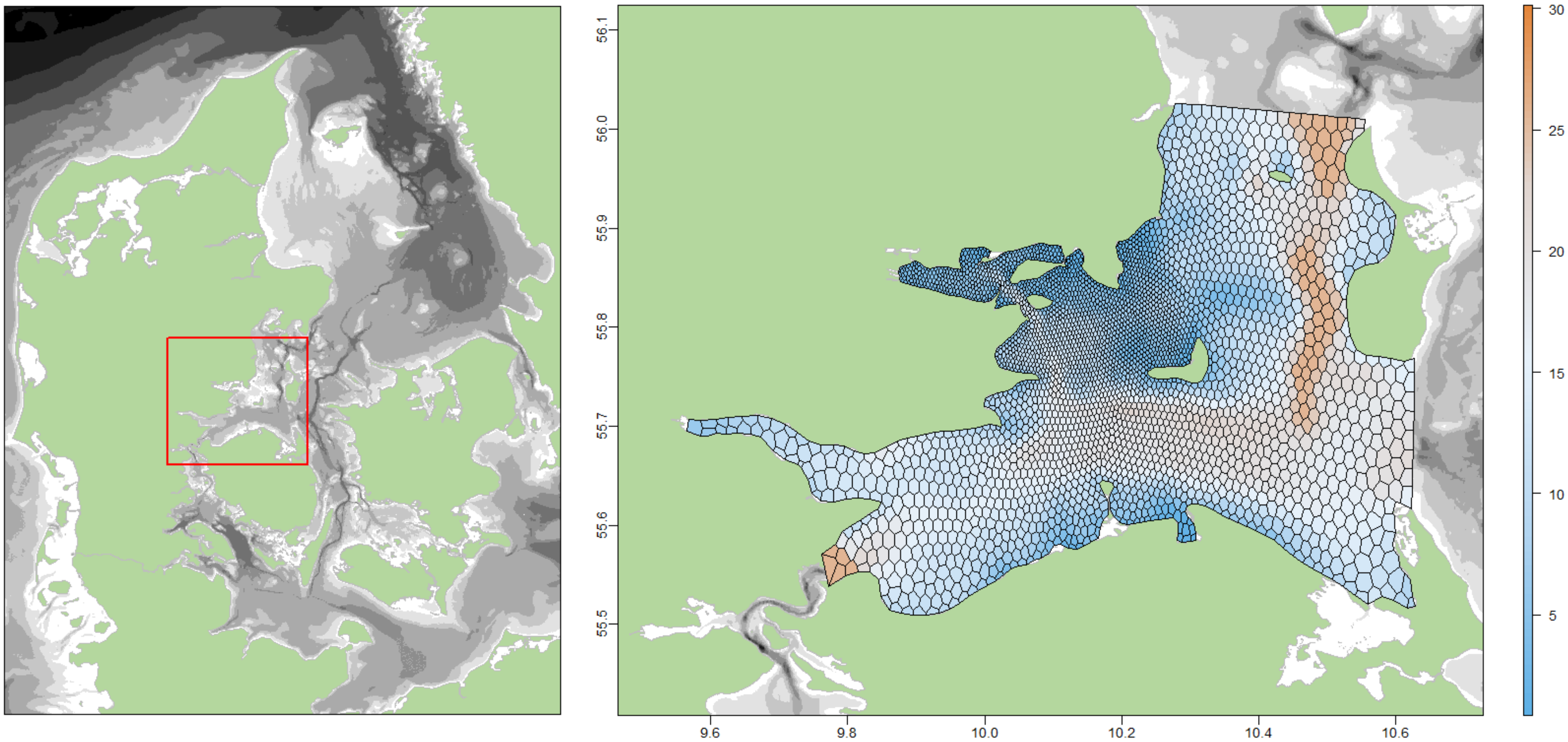
Horsens Fjord



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Horsens setup

- 3497 elements, 11 layers and a total of 24365 computational cells (JigSaw by Darren Engwirda)
- Spatial resolution between 250 and 1500 meters
- Forced on open boundaries by surface height, velocities, temperature and salinity from Copernicus
- Meteorological forcings of wind speed and temperature
- 2 fresh water sources (to be updated)
- Hydrostatic solution with timestep of 5 minutes, simulates 1 yr in 40 minutes on my desktop pc

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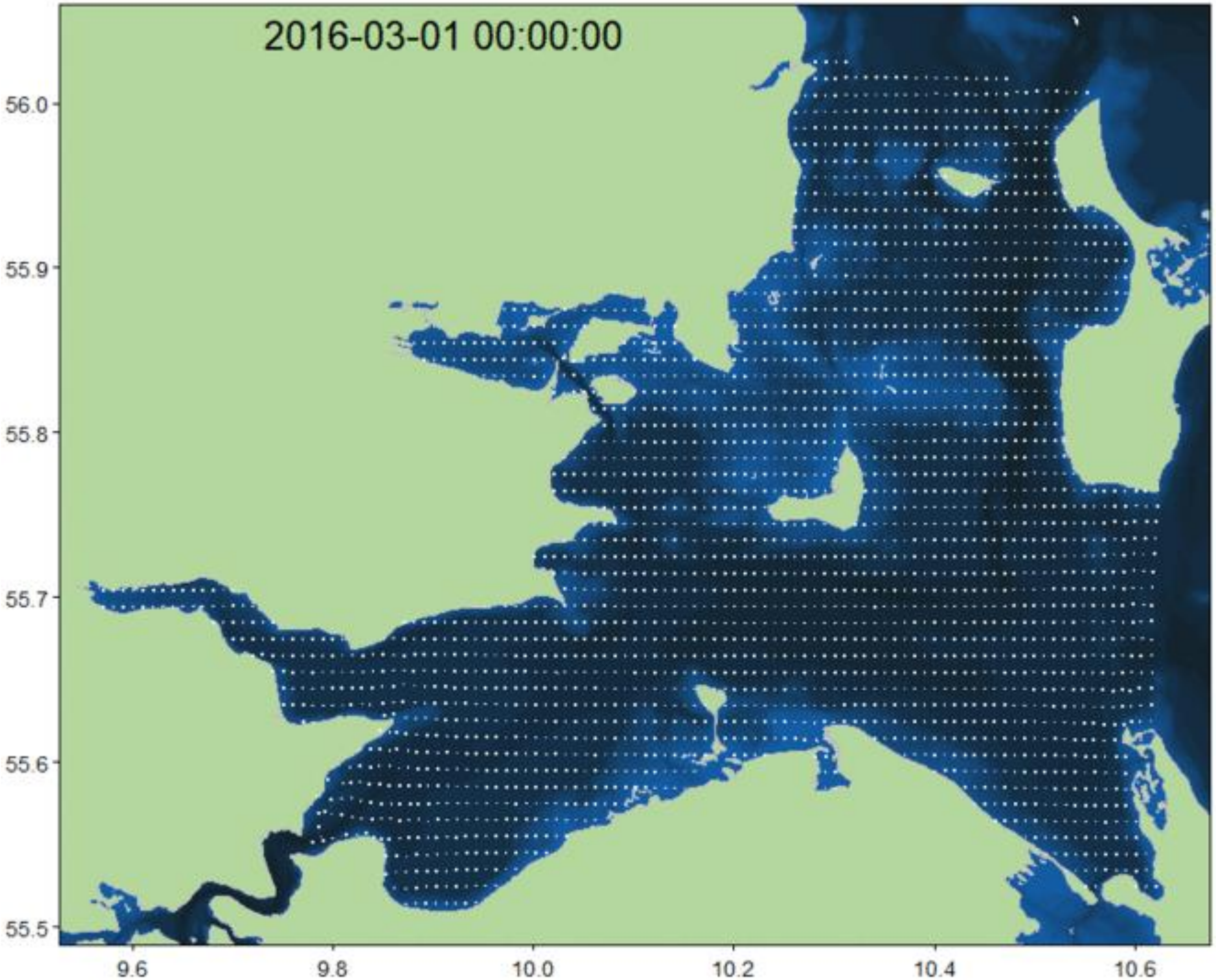

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FlexSem is free software (GNU General Public License) **http://marweb.dmu.dk/flexsem**

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