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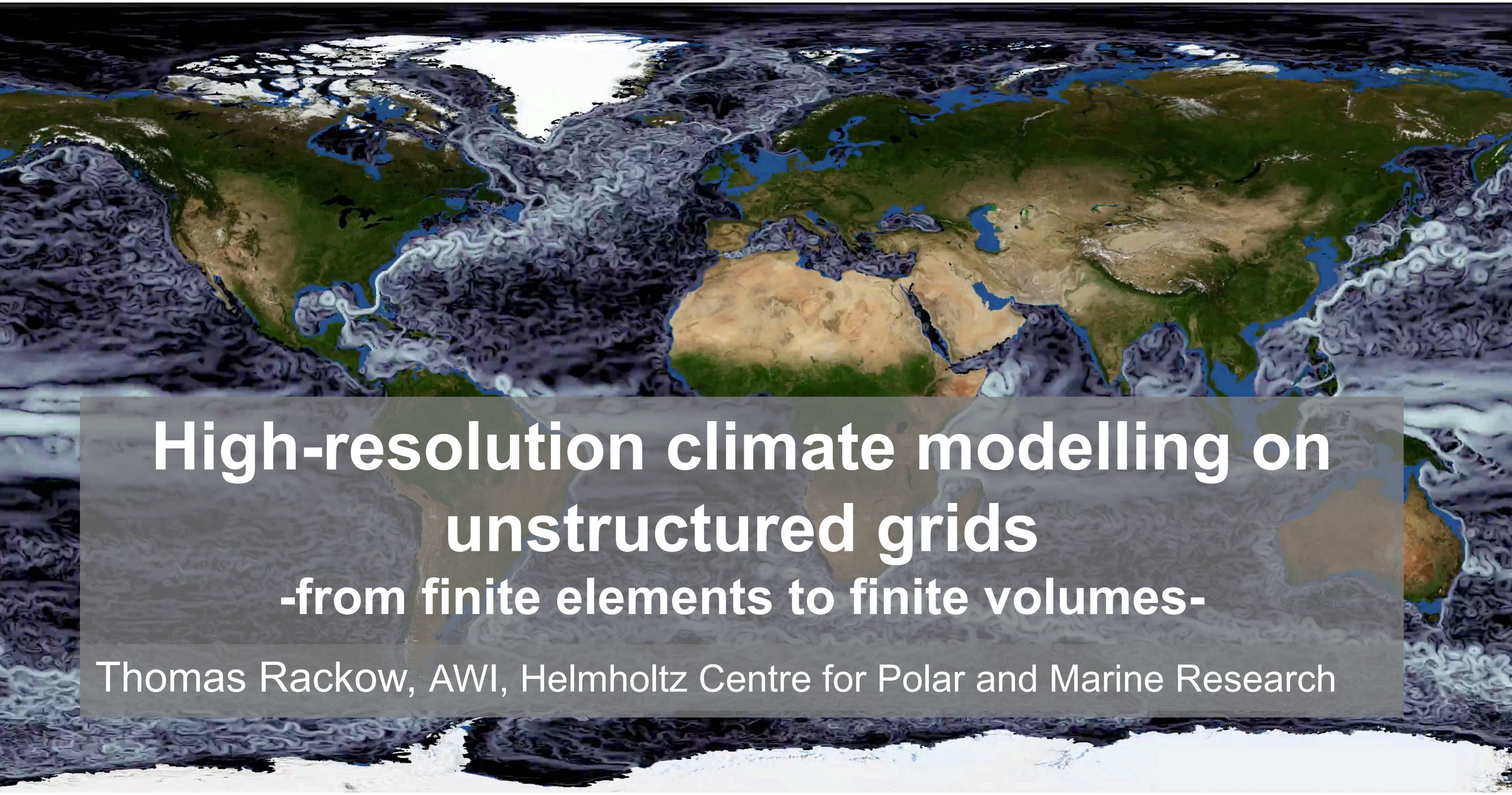


# High-resolution climate modelling on unstructured grids

## -from finite elements to finite volumes-

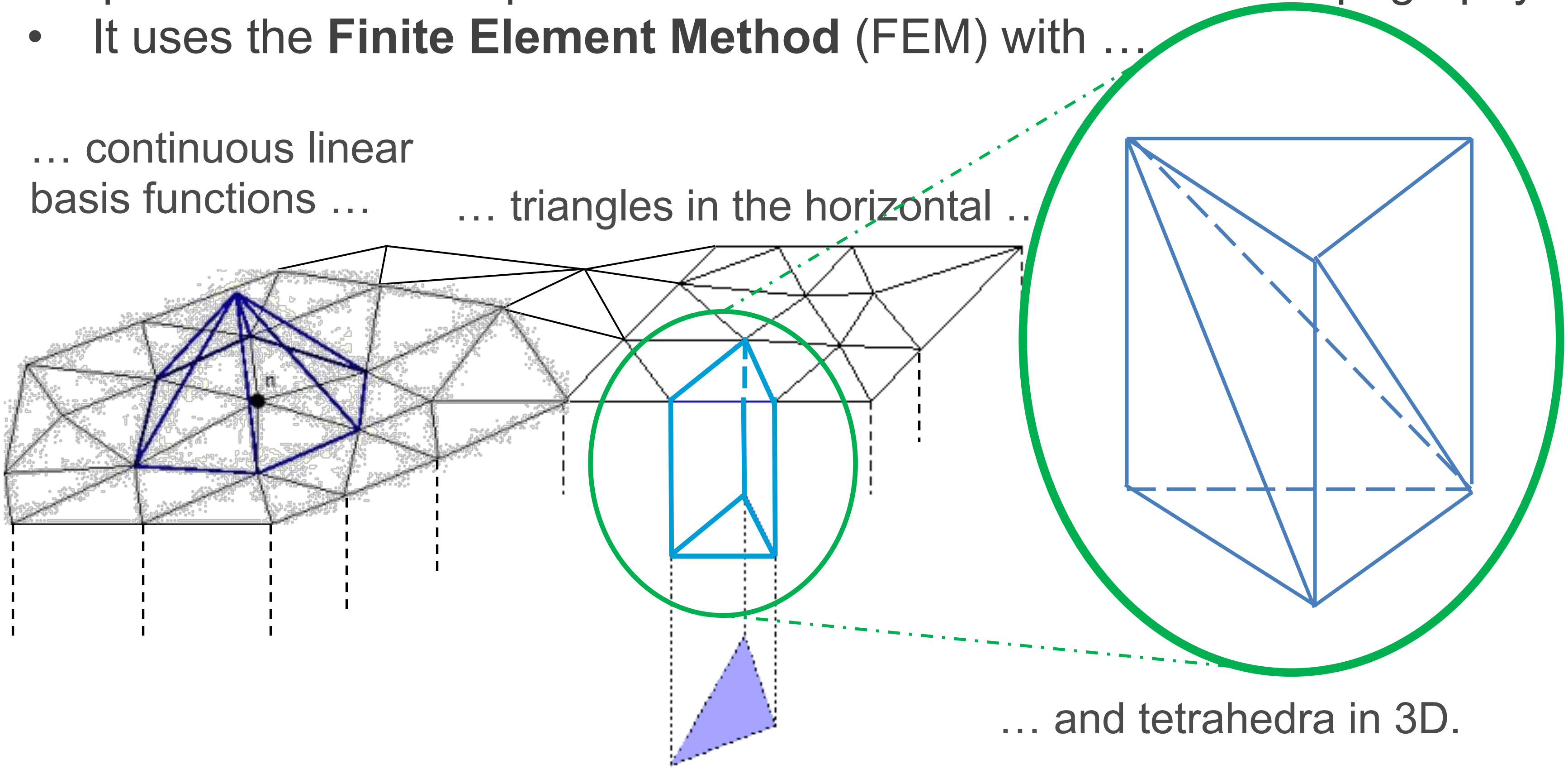
Thomas Rackow, AWI, Helmholtz Centre for Polar and Marine Research

# FESOM1.4: finite elements

- FESOM1.4 is a hydrostatic, primitive-equation global ocean (and sea-ice) model
- A-grid, all prognostic variables are co-located
- ‘pressure mode’ requires stabilisation in case of realistic topography
- It uses the **Finite Element Method** (FEM) with …

… continuous linear basis functions …

… triangles in the horizontal …

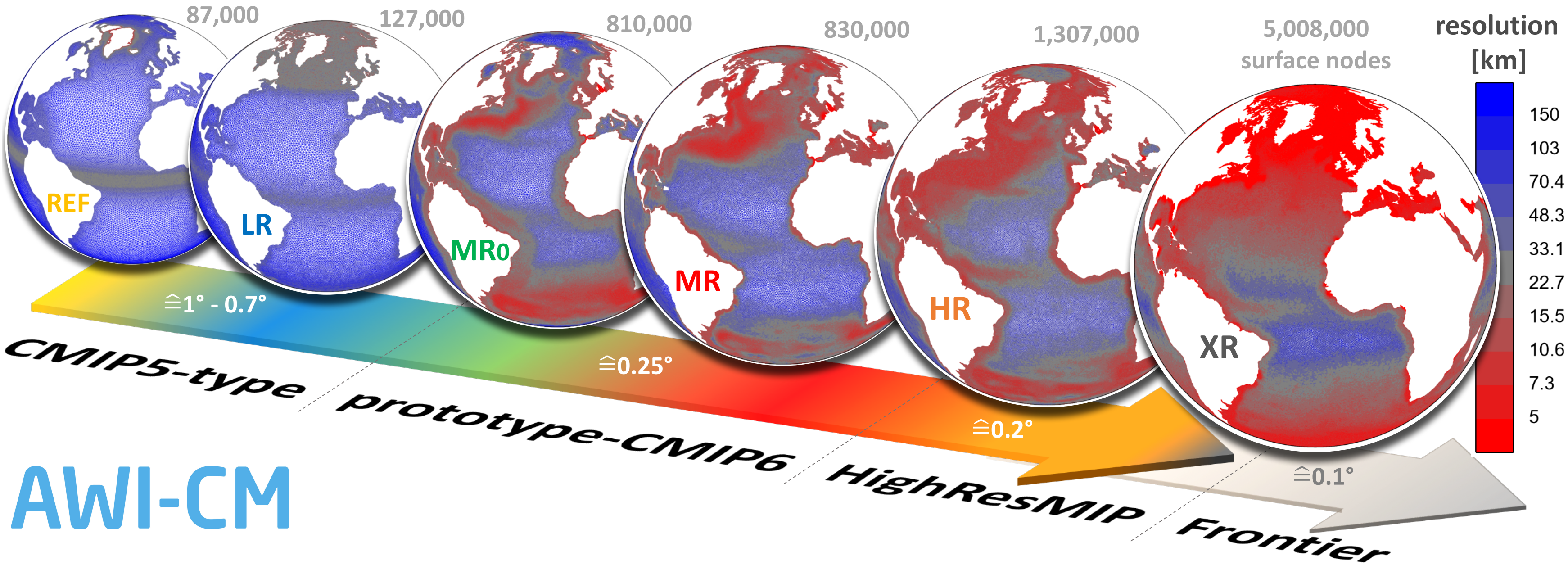



… and tetrahedra in 3D.

# The AWI Climate Model (AWI-CM)

- Coupled configuration of **FESOM1.4** and **ECHAM6**, using **OASIS-MCT** coupler *(Sidorenko et al. 2015; Rackow et al. 2016, Clim.Dyn)*

- Hierarchy of different FESOM meshes for different projects:

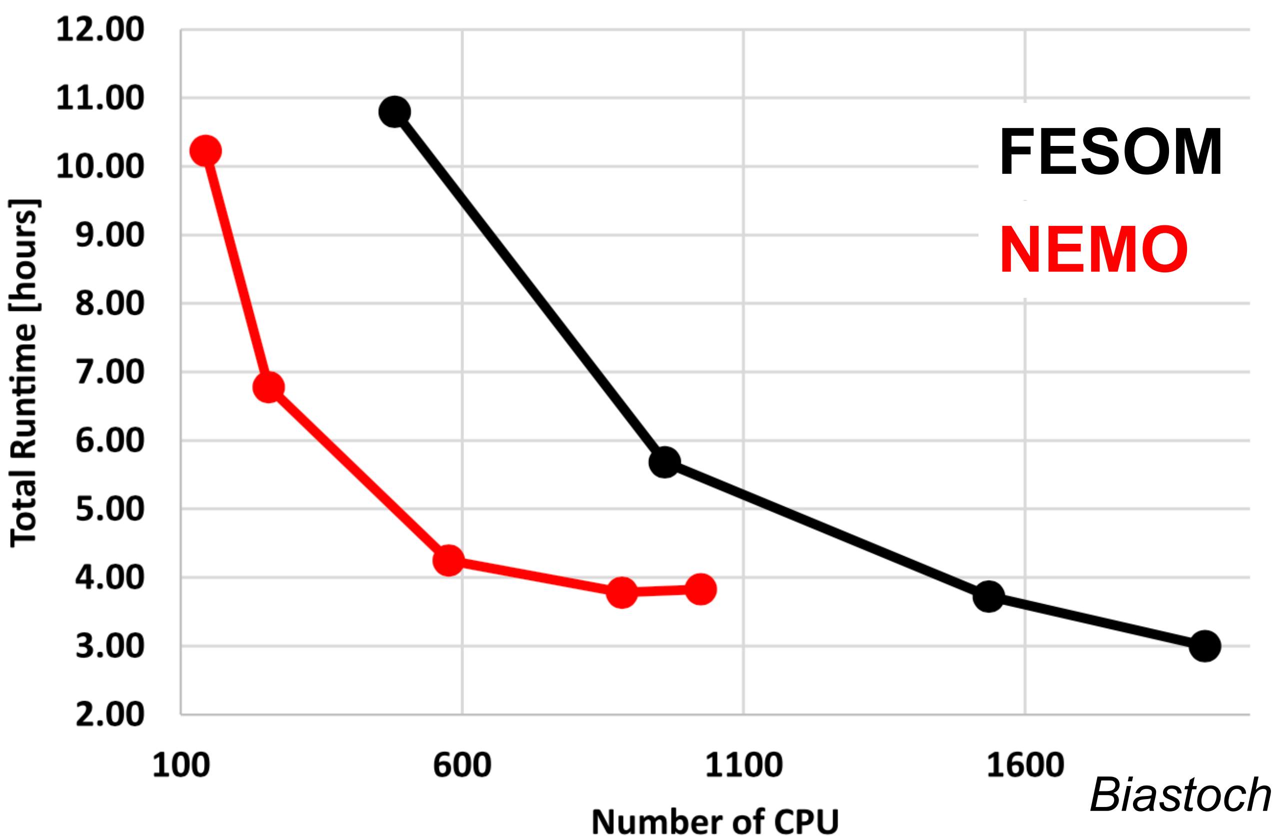



*Rackow et al.* (in prep. for GMD)

- ‘**XR**’ frontier configuration (*Sein et al. 2017*, JAMES), following the local Rossby radius
- **FESOM2** will replace FESOM1.4; ECHAM6→**OpenIFS** (**started**)

# FESOM1.4: scalability tests

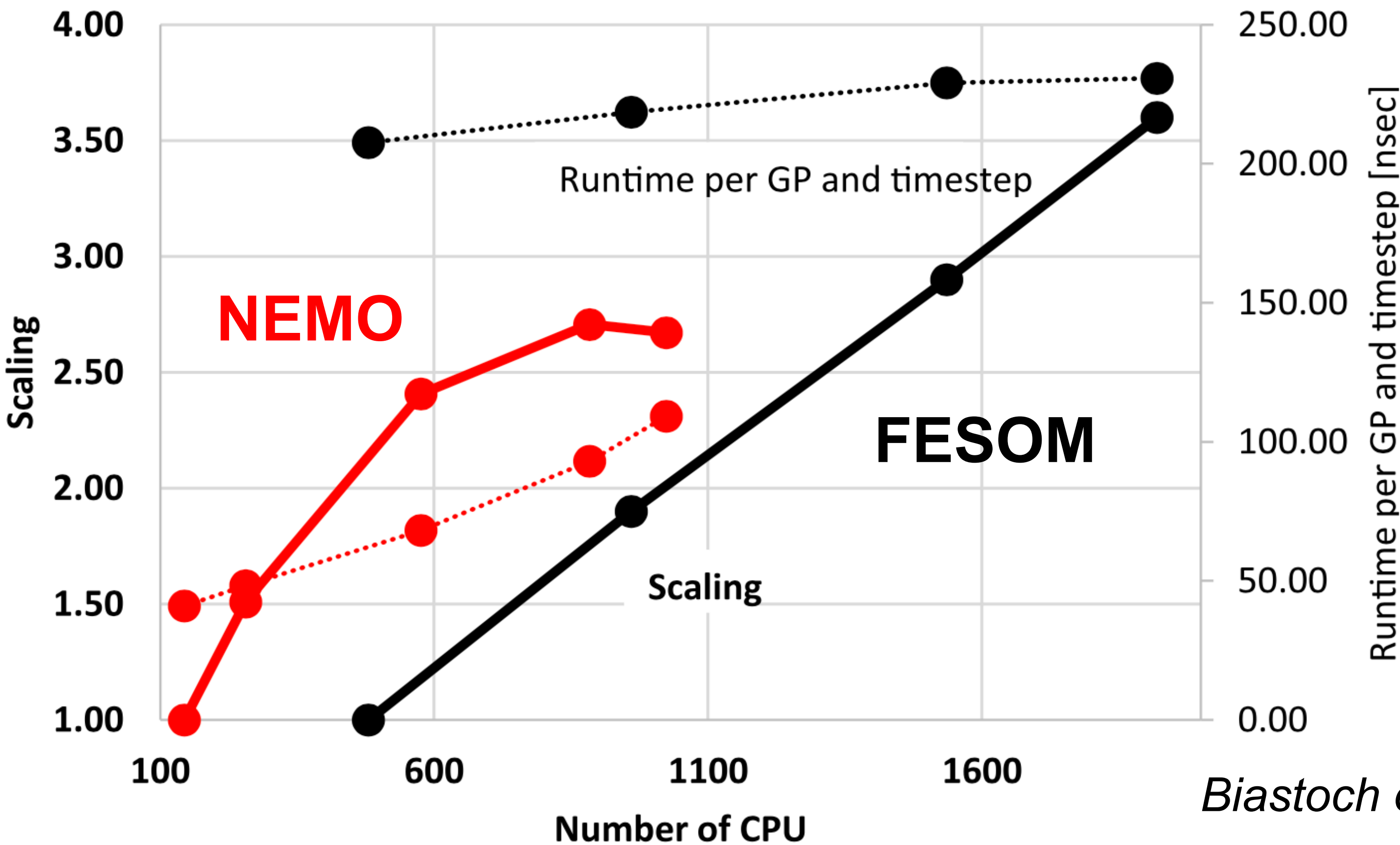
- Experiments with **NEMO3.6** (INALT01 setup) and **FESOM1.4** (Agulhas zoom) on Cray XC40, with Intel Xeon Haswell CPUs
- **NEMO uses 2-3 times lower CPU time for the same runtime**




*Biastoch et al. (2018)*

# FESOM1.4: scalability tests

- Experiments with NEMO3.6 (INALT01 setup) and FESOM1.4 (Agulhas zoom) on Cray XC40, with Intel Xeon Haswell CPUs
- **Nearly linear scaling for FESOM! (personally run on 14K CPUs)**




*Biastoch et al. (2018)*

# FESOM2: why finite volumes?

- Much higher computational efficiency when compared to **FESOM1.4**
  - efficient data structure: #levels x #2Dnodes
- Switch from tetrahedral elements to **prisms**
  - less bookkeeping, no need for 3D lookup data tables; neighbour connectivity pattern is preserved in the vertical dimension
- **Fluxes are defined in a clean way**

# FESOM2: why finite volumes?

- Similar **scalability** characteristics
- possibility to choose from a **set of transport algorithms** (with flux-corrected-transport, FCT)
- vertical coordinate: **ALE coordinate** newly implemented (Arbitrary Lagrangian-Eulerian)
- Changed placement of variables → **higher effective resolution?**

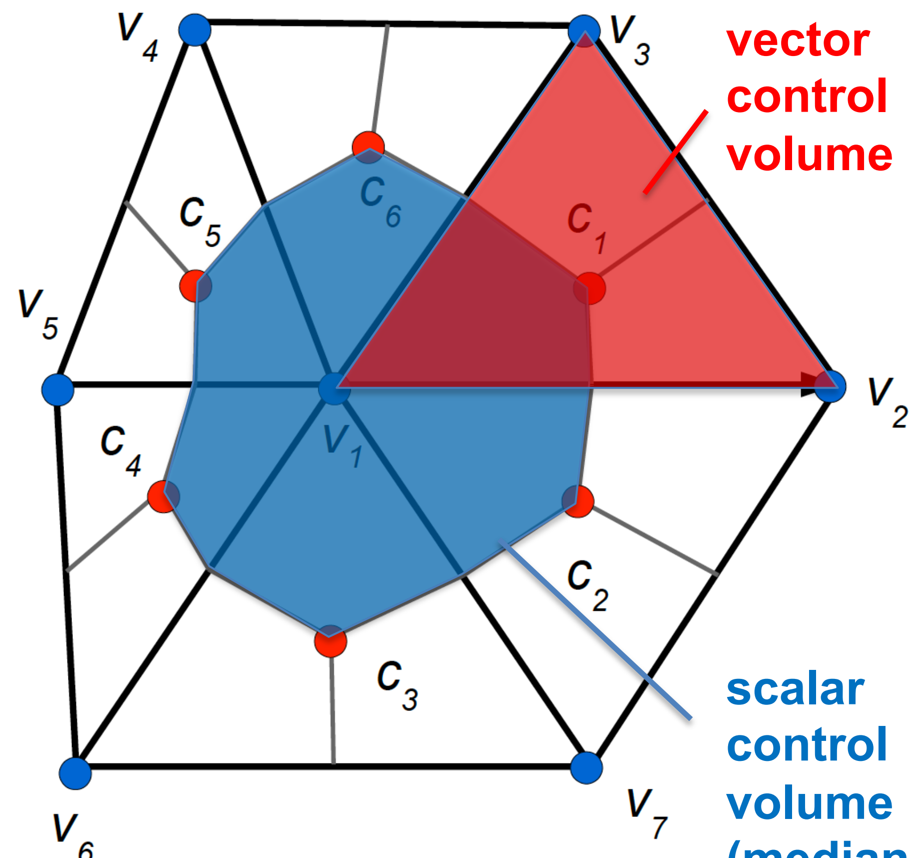
# FESOM2.0: placement of variables

- **Cell-vertex discretisation**

- **Horizontal velocities** at cell centres $c_i$
- Scalar quantities (**elevation, pressure, temperature, and salinity**) are at vertices $v_i$

- **'Quasi-B-grid'**

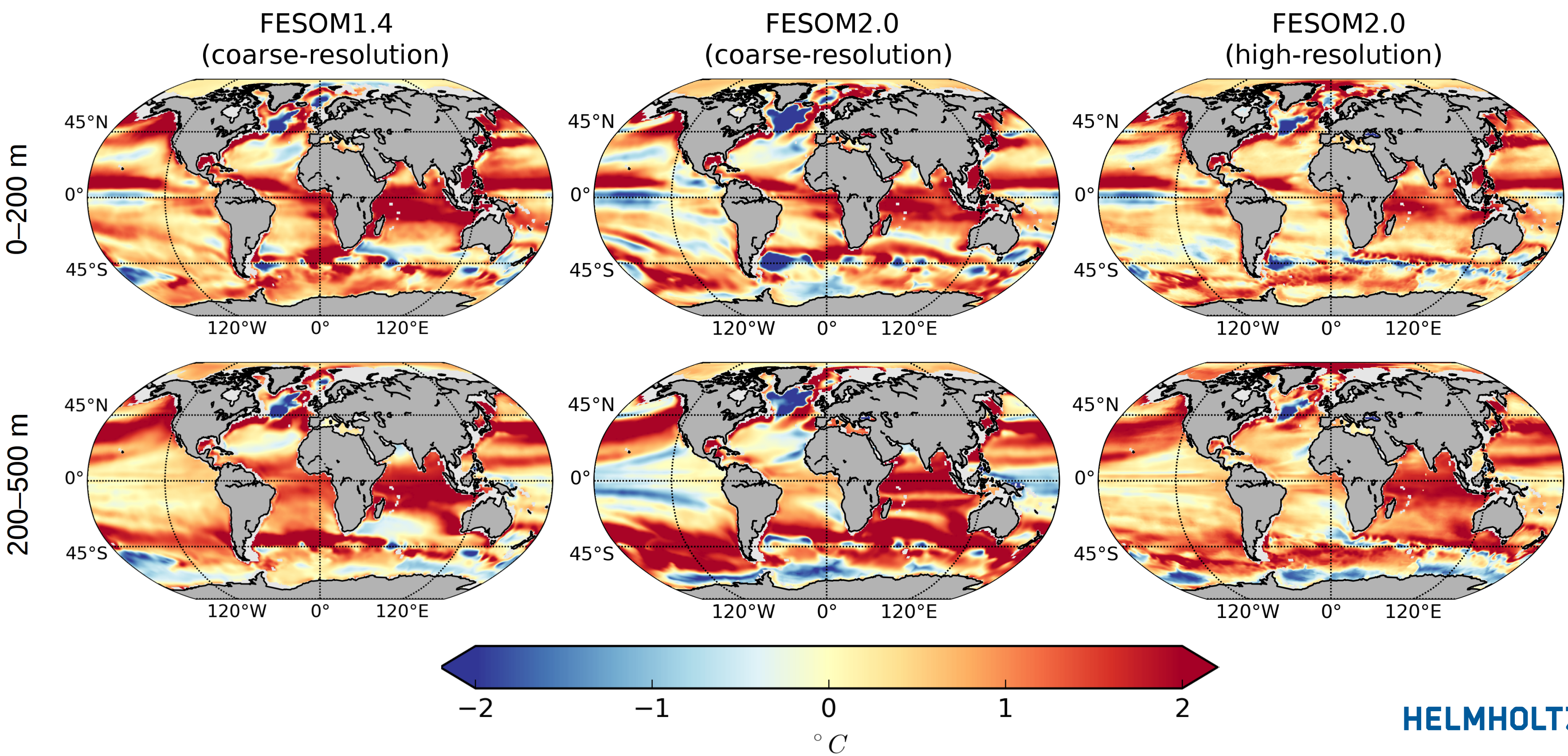
- **Advantages**:
  no 'pressure modes' known for A-grid (e.g. FESOM1.4)
- **Disadvantage**: *too many velocities* (2N compared to N vertices)




- 3D structure: a collection of prisms, defined by the surface mesh and a system of horizontal levels

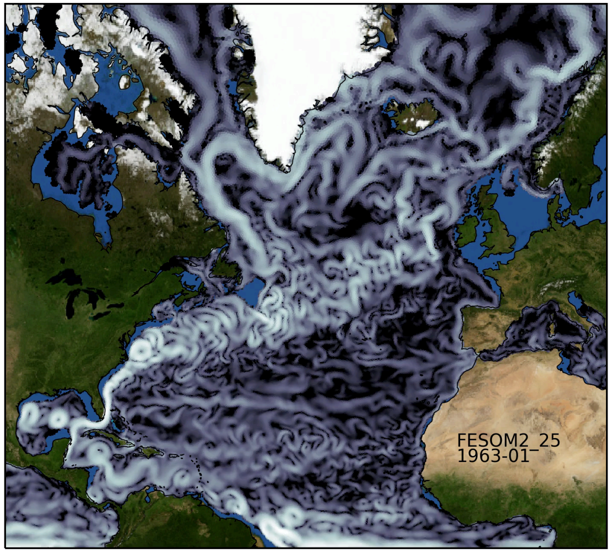
# FESOM1.4 vs. FESOM2.0: T biases

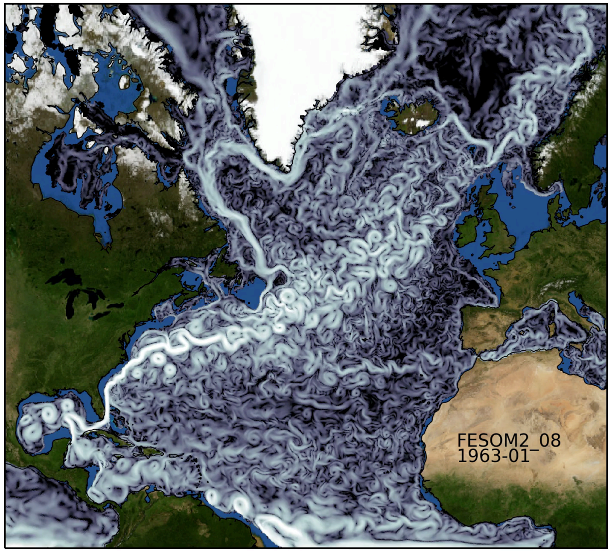
- Similar performance on coarse-resolution grid (**‘LR‘**), and on global **15km** high-resolution grid
- Fully functional and highly competitive general ocean circulation model *(Danilov et al., 2017, GMD)*

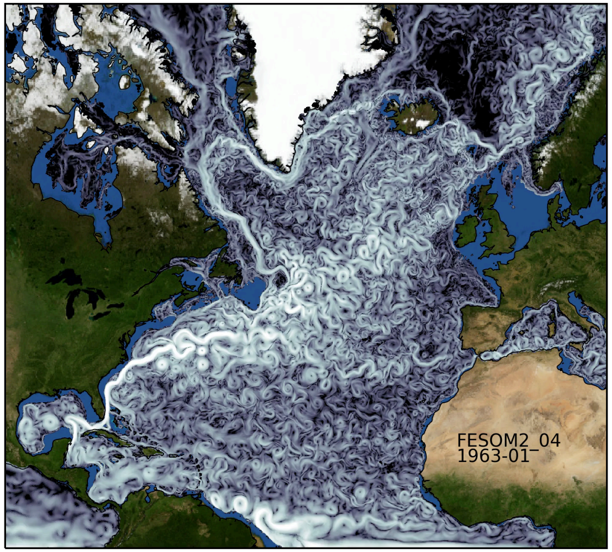


# FESOM2.0: uniform resolution tests

- **North Atl./Arctic at 25 km, 8 km, and 4 km resolution, 1728 cores**








*www.fesom.de*

- **Simulated years per day (SYPD):**

| | | |
|---|---|---|
| 25 km | ~ | **15** years/day |
| 8 km (**2M** 2D nodes, 47 levels) | ~ | **10** years/day |
| 4 km (**6M*** 2D nodes, 47 levels) | ~ | **2** years/day |

***6M** is the number of wet points on a 1/10 quasi-Mercator structured mesh.

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# Summary/Outlook

- **FESOM2** is a fully functional and highly competitive general ocean circulation model
- FESOM2 is about **3x** faster than **FESOM1.4;** will become the new ocean model of AWI-CM (and AWI-ESM)
- **OpenIFS** is going to be tested in the AWI-CM framework

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- **NEMO** is coupled to **IFS-spectral**: How could **FESOM2** perform in comparison?
  - Scalability at high resolutions compared to NEMO?
  - Mimic IFS‘ data structures in the discretisation, e.g. identical surface grid? (Reducing systematic errors in air-sea fluxes when coupling grids of different geometry); GFDL approach with exchange grid?

- **IFS-FVM** and **FESOM2**: compare weaknesses and strengths of the dynamical cores?

**Thank you!**

# Appendix: Agulhas intercomparison

- Agulhas system
- horizontal resolution in (top) **FESOM** and (bottom) **NEMO**