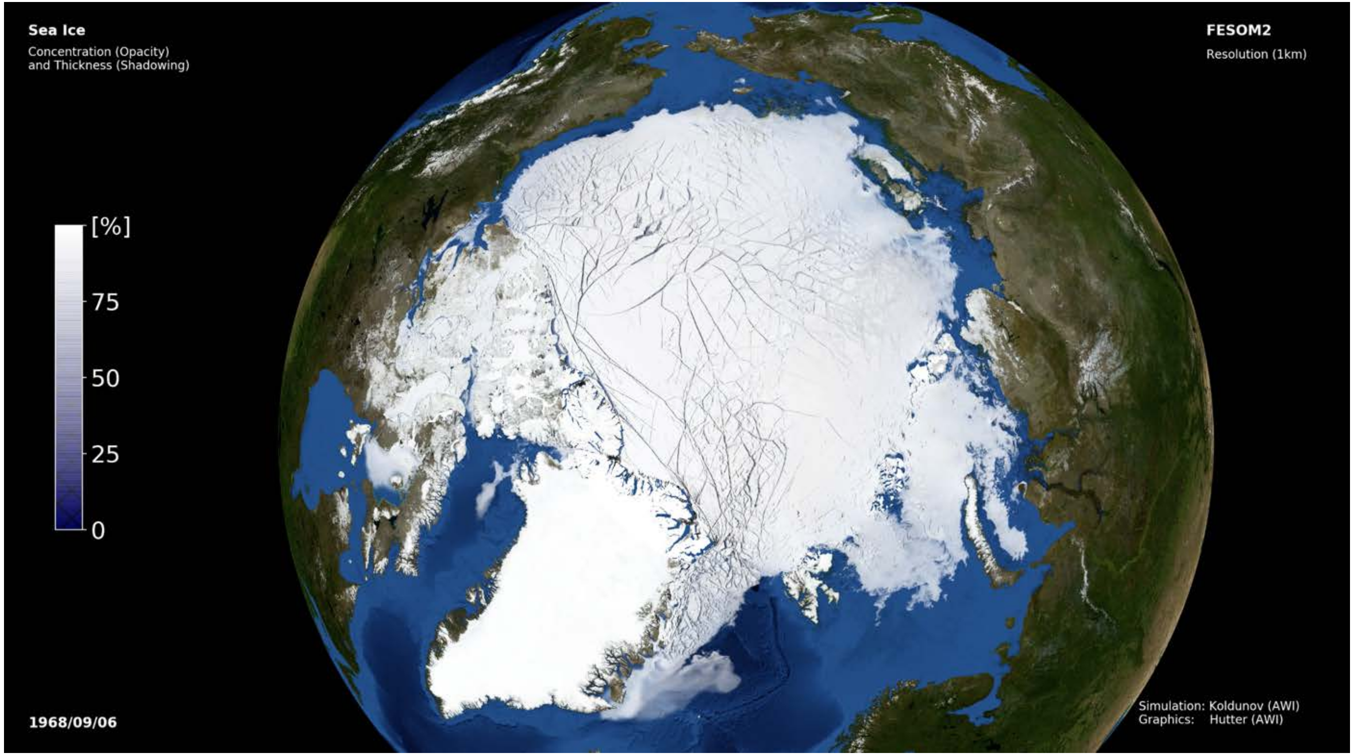
Very high resolution modelling with unstructured mesh global ocean model (FESOM2)



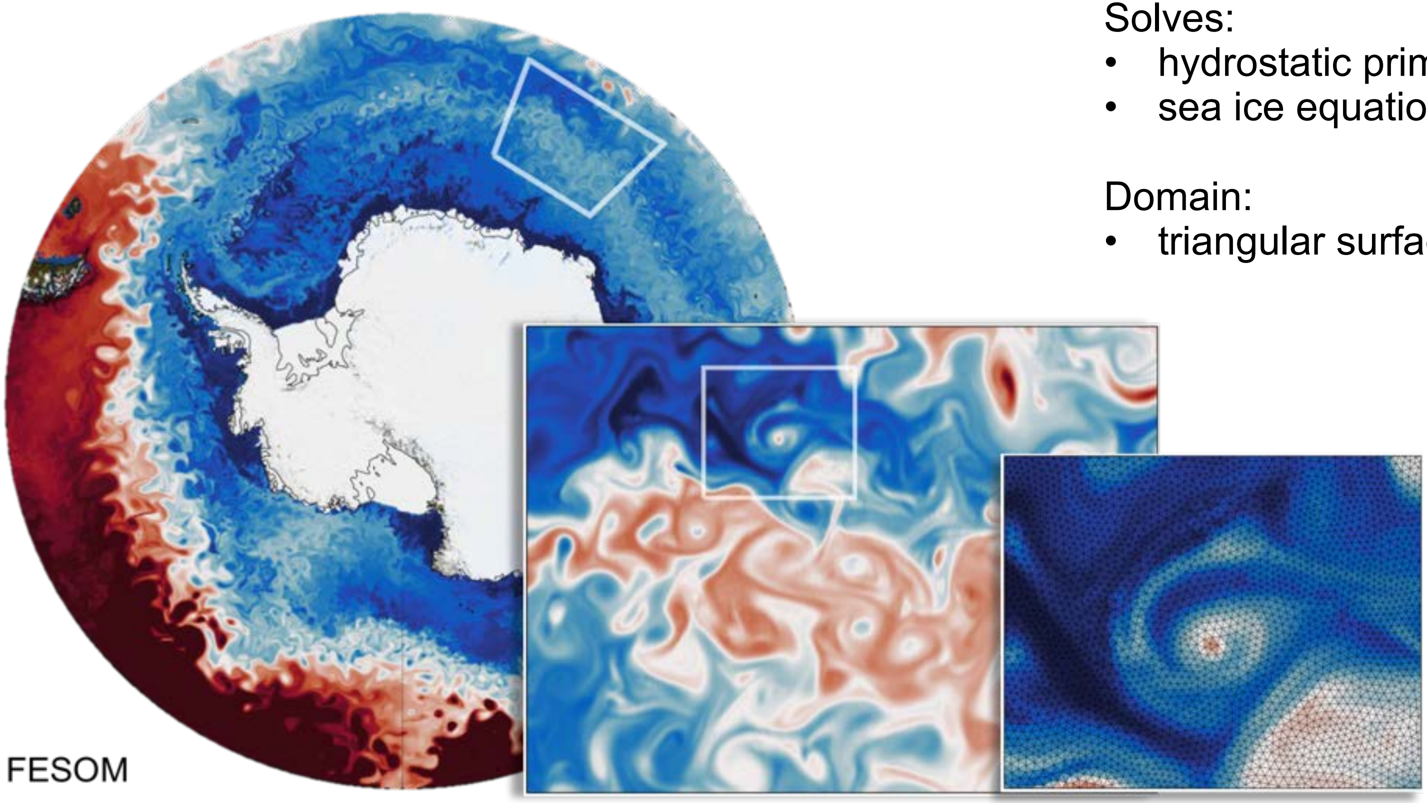
Nikolay Koldunov, Sergey Danilov, Dmitry Sein, Dmitry Sidorenko, Patrick Scholz, Qiang Wang, Vadym Aizinger, Natalja Rakowsky, Claudia Wekerle, William Cabos, Thomas Jung

FESOM HELMHOLTZ ASSOCIATION

Finite volumE Sea Ice Ocean Model FESOM2

Solves:
- hydrostatic primitive equations
- sea ice equations

Domain:
- triangular surface meshes



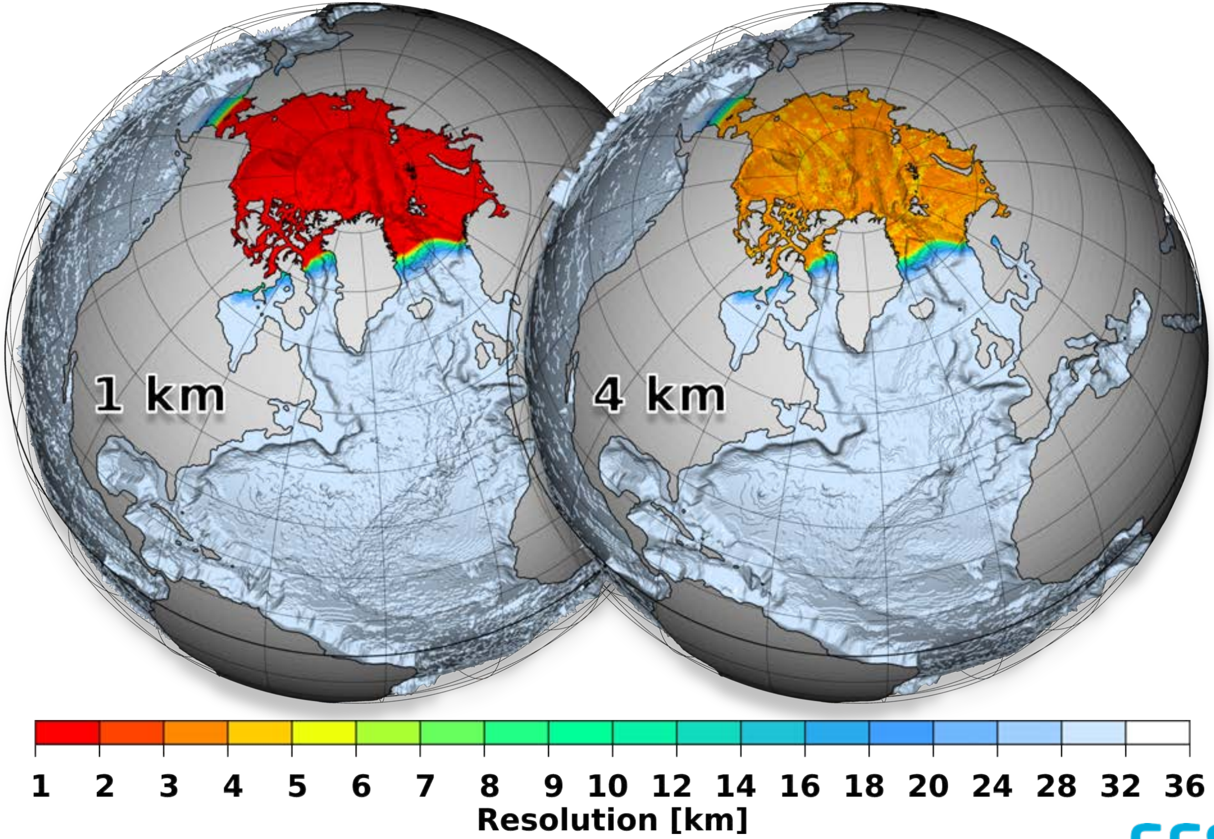
How to benefit from unstructured meshes?

- Refine mesh in chosen regions and/or narrow straits: the same as traditional nesting. Regional ocean modelling in a global framework.

- Vary mesh resolution smoothly in the global ocean according to specified functions (for example, of Rossby radius or eddy variability)

- The combination of the two

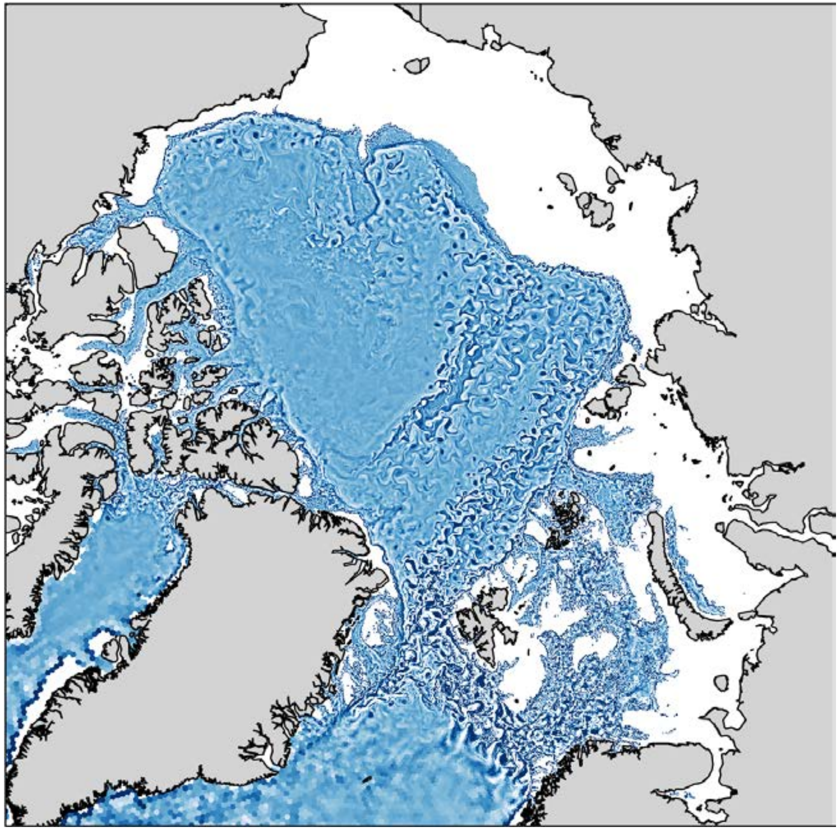
Eddy resolving Arctic Ocean (1km) in global model

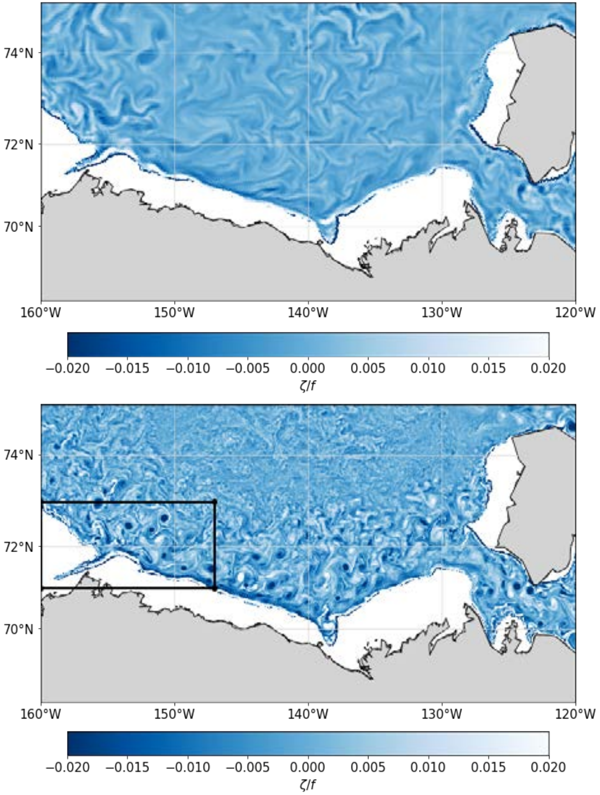


FESOM HELMHOLTZ ASSOCIATION

Eddy resolving Arctic Ocean (1km) in global model

Potential vorticity at 250 m





4km

1km

Wang et al., subm. GRL

FESOM HELMHOLTZ ASSOCIATION

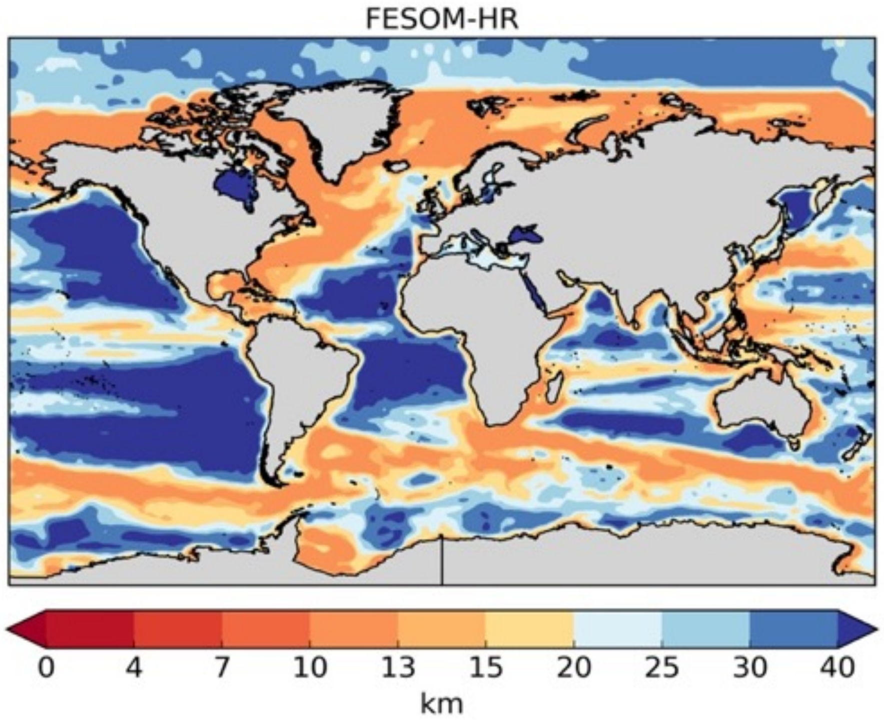
Eddy resolving for the price of eddy permitting

Refinement according to SSH var.

Resolution: 1/4°-1/10°

Wet points: 1.3M

Number of points is similar to structured 1/4° resolution grid.

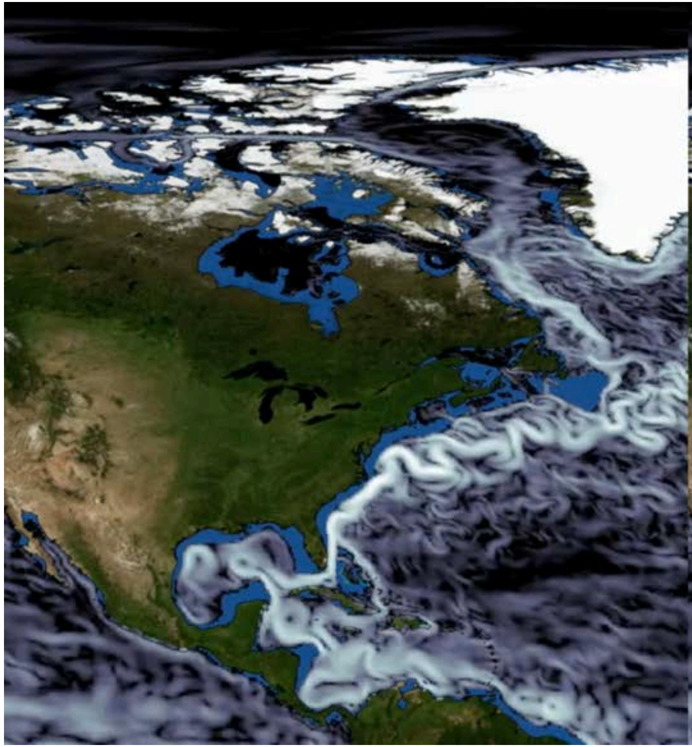


Sein et al., 2017

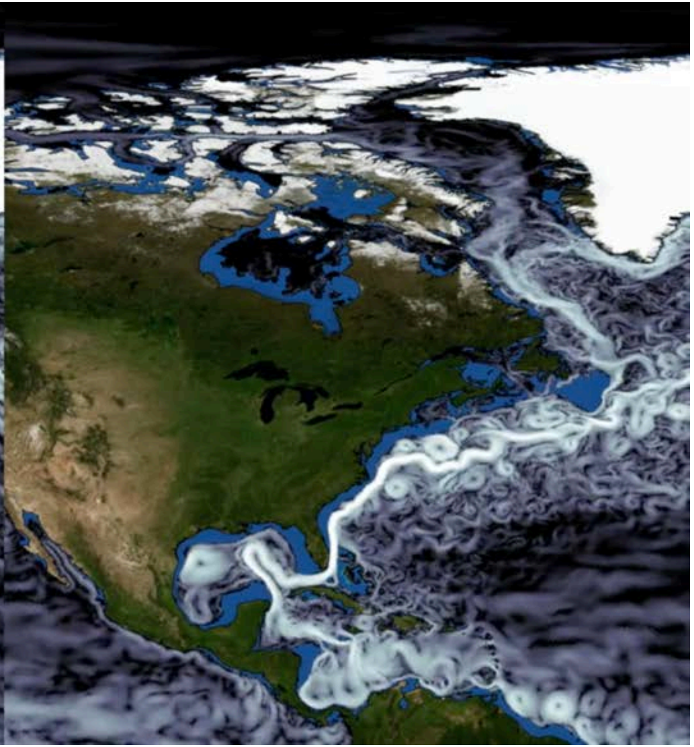
VIDEO: https://www.youtube.com/watch?v=HINcizEIM4Q

Eddy resolving for the price of eddy permitting

Equivalent of ORCA25 (1/4°)

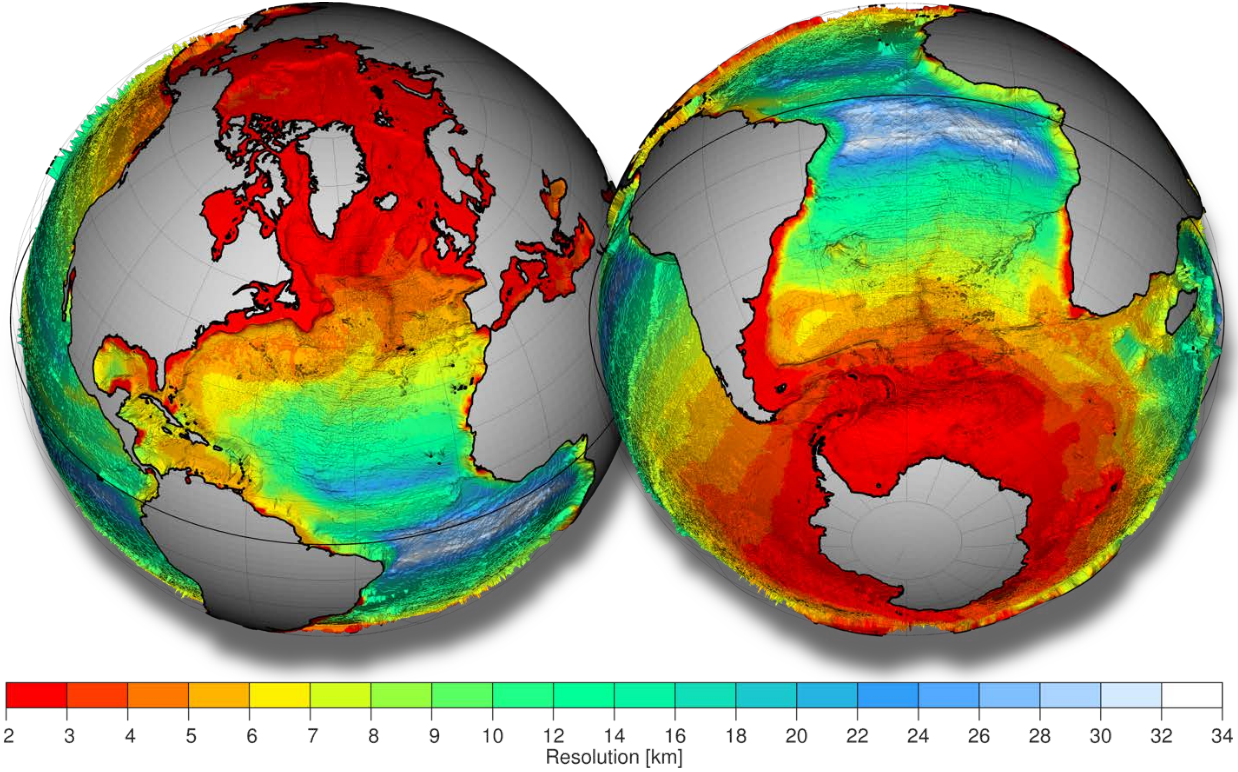


HR mesh (10-60 km)



FESOM HELMHOLTZ ASSOCIATION

ROSSBY4.2 mesh



23M points
(1/24° equivalent)
80 vertical levels
1.85-25 km
resolution

VIDEO: https://www.youtube.com/watch?v=a3XnJ9wG9Zc&t=5s

FESOM2 family

AWI-ESM
FESOM2/REcoM/PISM/ECHAM6/JSBACH/VILMA

FESIM
Sea ice model

AWI-CM2
FESOM2/ECHAM6

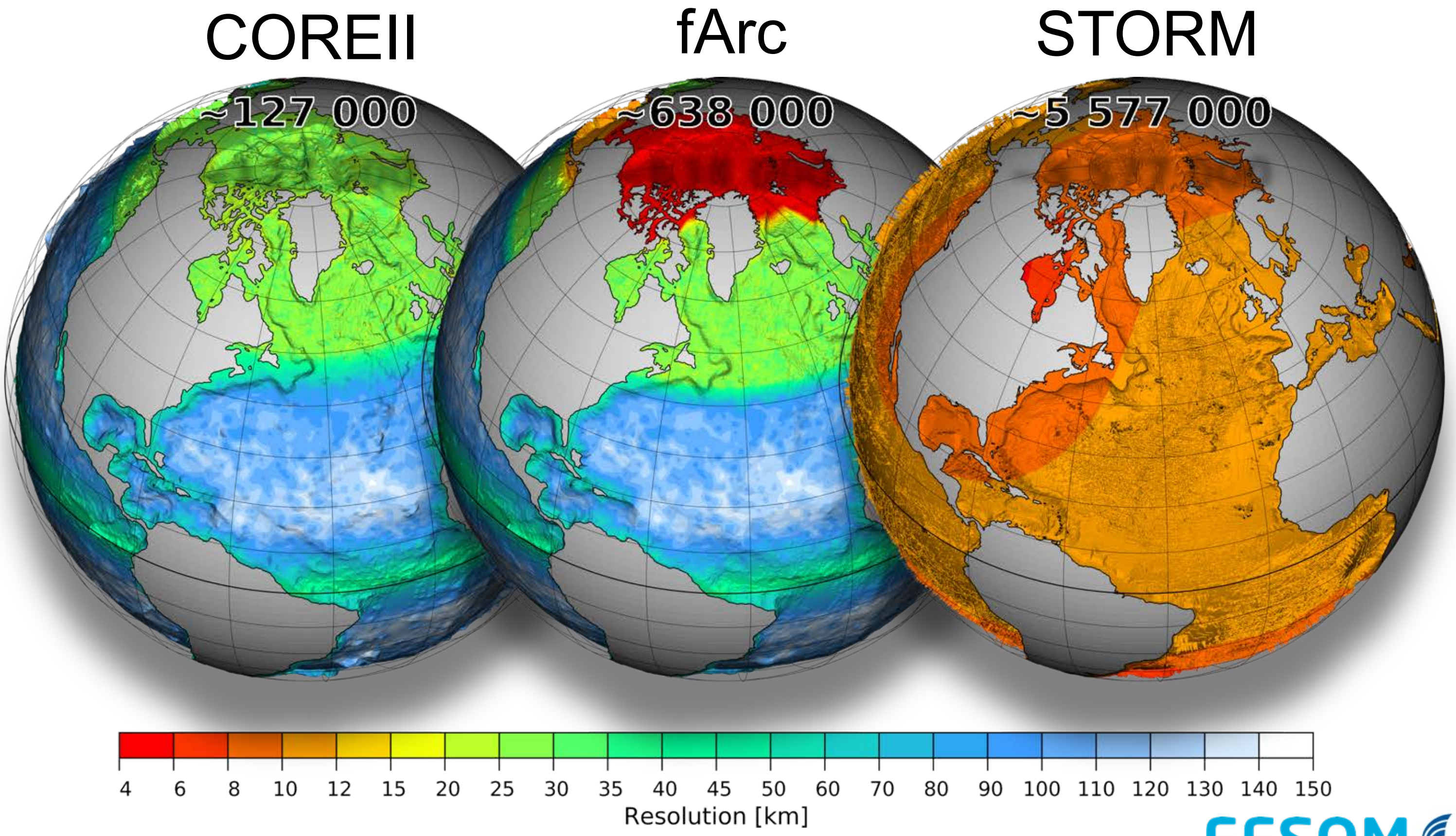
FESOM2
Finite volumE
Sea ice-Ocean Model

FESOM2/OpenIFS

FESOM-C
Coastal model

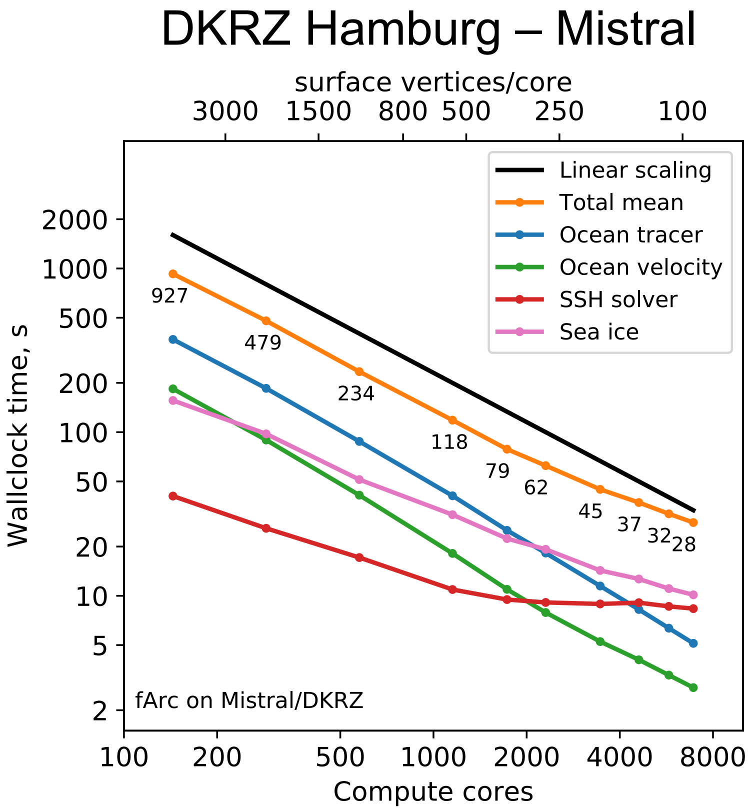
FESOM2/IFS
Numerical weather prediction

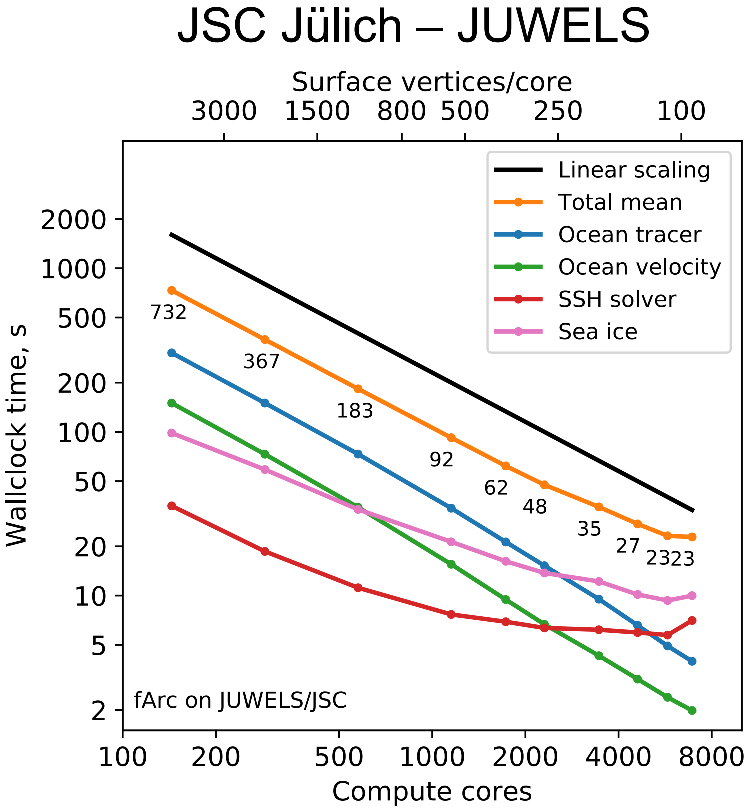
Meshes used for scalability study



FESOM

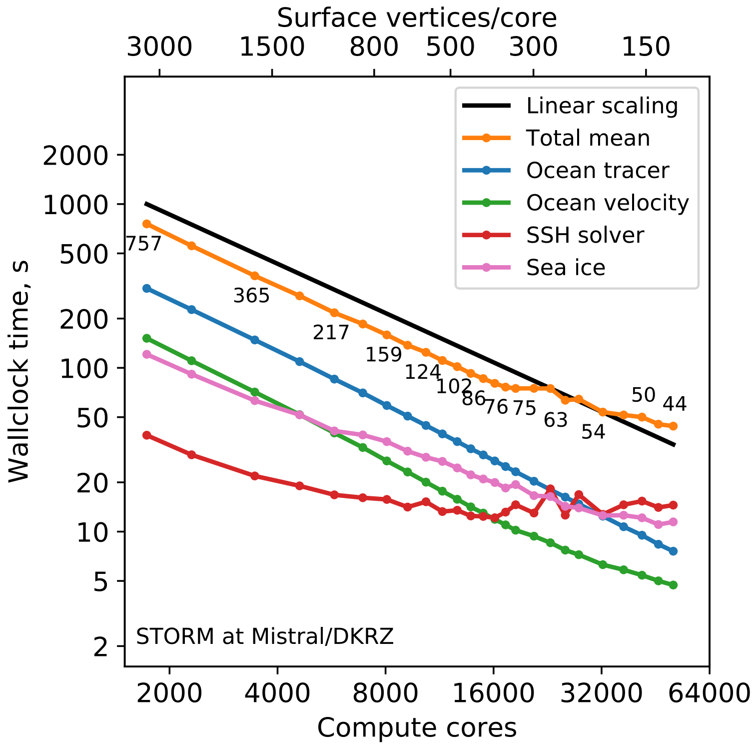
0.6Mio surface vertices (4.5 km Arctic) scaling



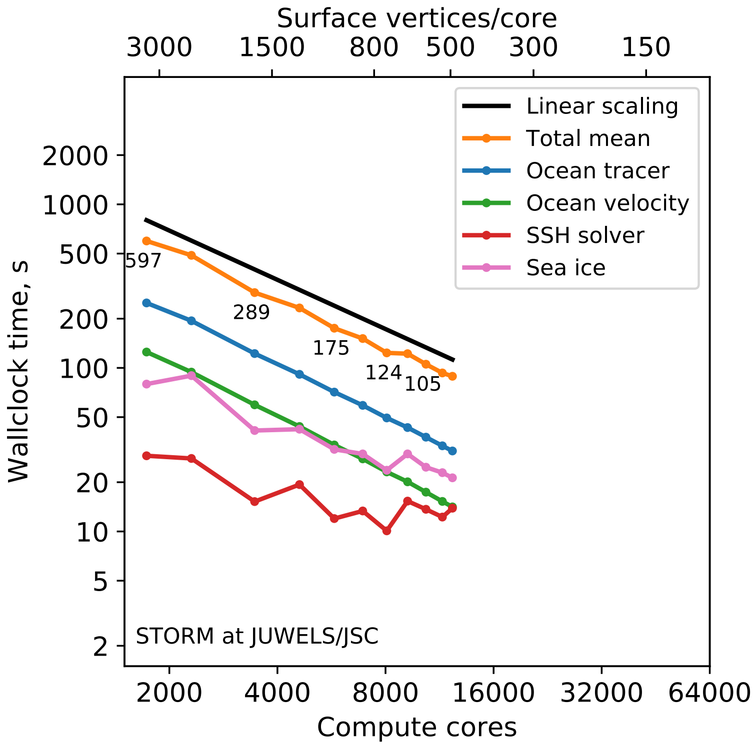


5.5Mio surface vertices (1/10°) scaling

DKRZ Hamburg – Mistral

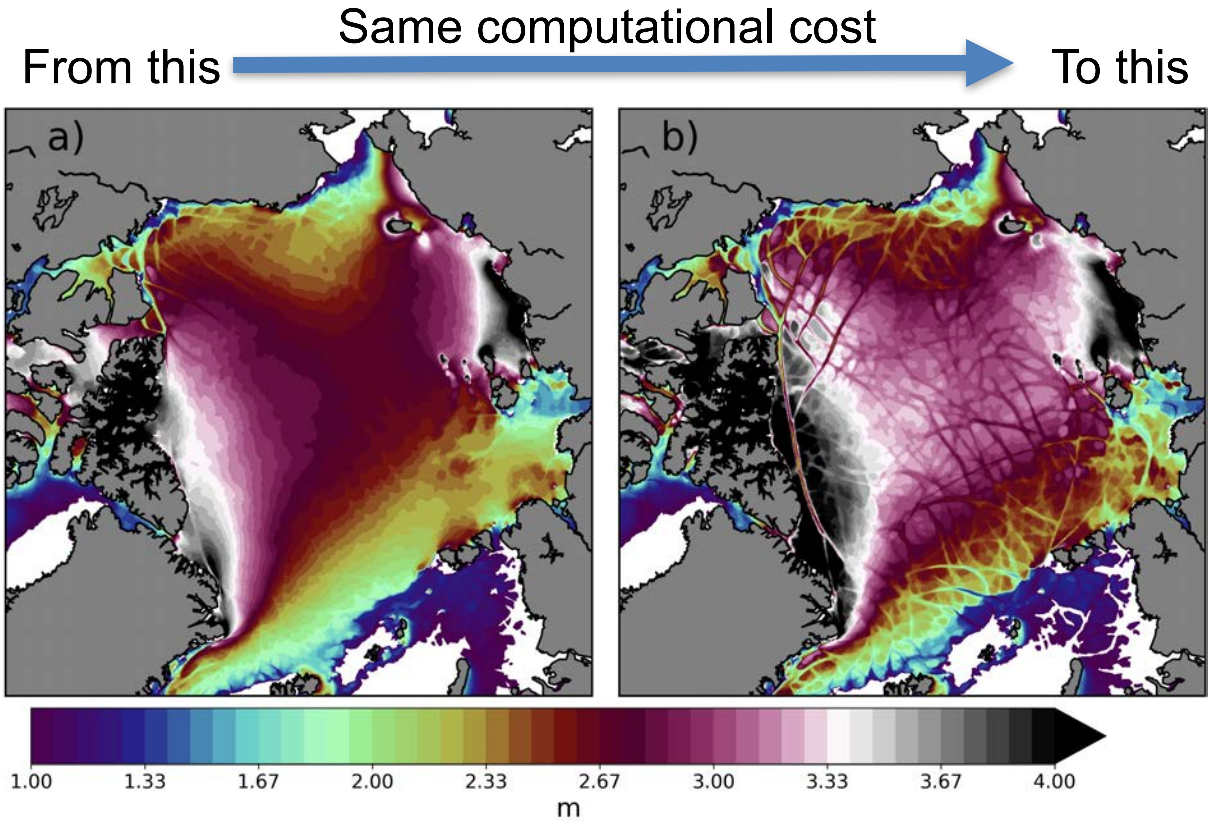


JSC Jülich – JUWELS



FESOM HELMHOLTZ ASSOCIATION

Sea ice



Koldunov et al., JAMES 2019

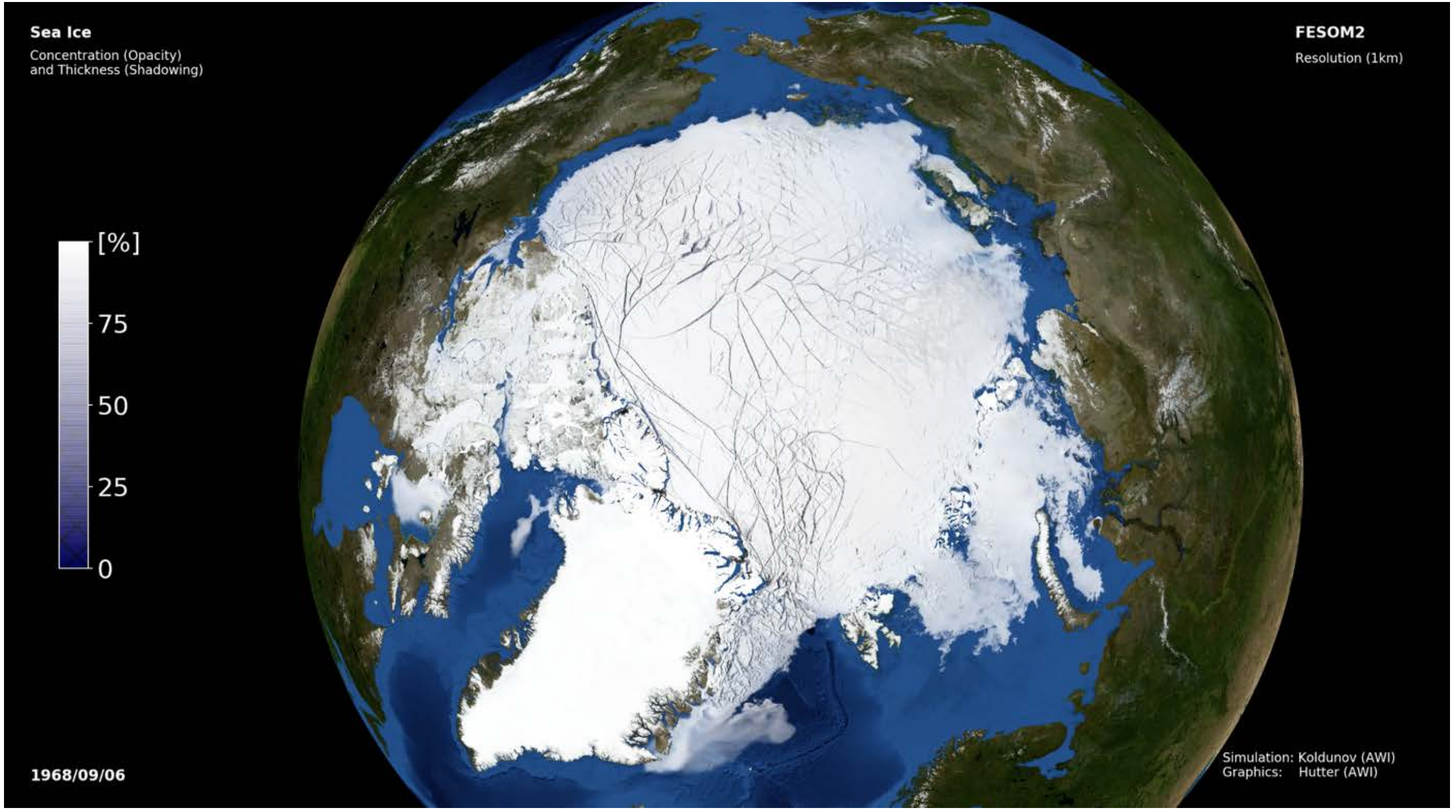
Implement modified sea ice dynamics that converges faster (x6).

Planned:

- Couple every other time step
- Run on dedicated CPUs in parallel
- Run on GPUs in parallel.

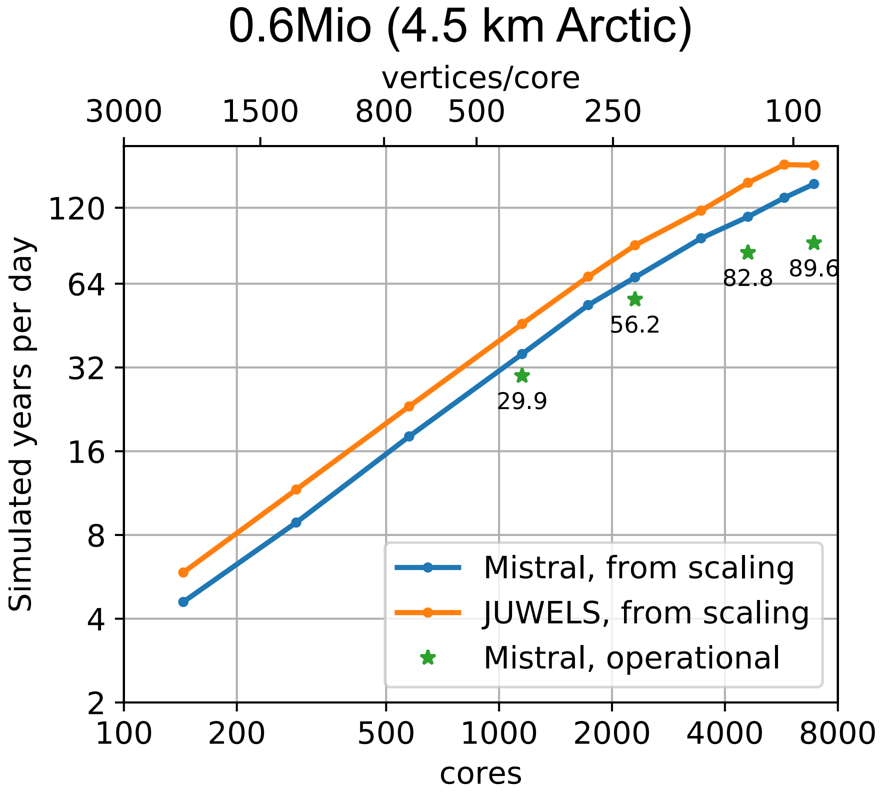
FESOM HELMHOLTZ ASSOCIATION

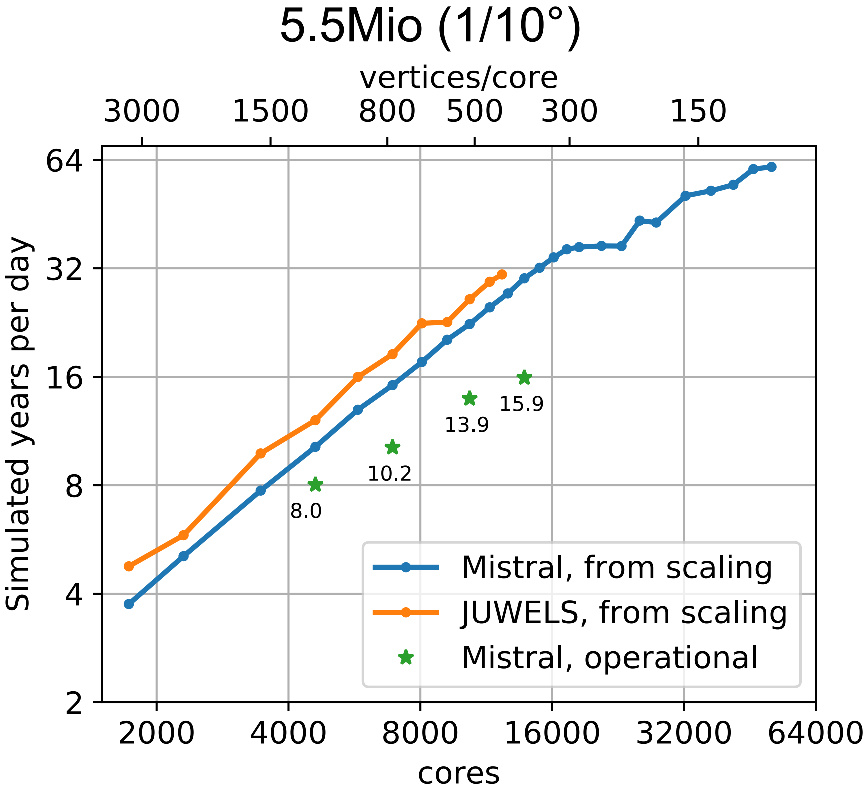
Sea ice in 1km Arctic Ocean simulations



VIDEO: https://www.youtube.com/watch?v=HKdaheQR9kM

FESOM2 throughput





FESOM

HELMHOLTZ ASSOCIATION

Comparing performance to other models (POP, NEMO, MOM)

$$Simulatted\ year\ per\ day\ (SYPD) = c_{SYPD}\frac{timer\ step\ *Number\ of\ cores}{Degrees\ of\ freedom}$$

Model/mesh	Resolution	Vertices (ocean)	Cores	Time step, s	Levels	SYPD	c_{SYPD}3-D	c_{SYPD}2-D	Citation
POP	1/10°	5.8 million	16 875	173	60	10.5	1252	20	Huang et al. (2016)
ACCESS-OM2-01	1/10°	5.8 million	6138	450	75	1.2	188	3	Kiss et al. (2019)
FESOM2/STORM	1/10°	5.6 million	13 828	600	47	15.9	505	11	
NEMO/ORCA25	1/4°	0.9 million	2048	3600	75	5–10	92	1	Prims et al. (2018)
MOM5.1/CM2.5	1/4°	0.9 million	960	1800	50	11	286	6	Ward and Zhang (2015)
MOM6	1/4°	0.9 million	1920	1200	75	8.9	260	3	Ward (2016)
ACCESS-OM2-025	1/4°	0.8 million	1816	1800	50	9	110	5	Kiss et al. (2019)
FESOM2/fArc	1/3°	0.6 million	2304	900	47	56.2	764	16	
ACCESS-OM2	1°	0.065 million	240	5400	50	63	158	3	Kiss et al. (2019)
FESOM2/CORE2	1°	0.13 million	288	2700	47	120	921	20	

Koldunov et al., 2019

Some recent numbers on 10800 cores

	Points/Rossby radius	High/low	Throughput	Nodes
D3	1-0.5	5-25 km	20 SYPD	3.1M
Next	0.5-0.25	2-25 km	3.5 SYPD	12.9M
ROSSBY4.2	0.25	1.85-25 km	1.5 SYPD	23.2M

100 years of simulations already done

FESOM HELMHOLTZ ASSOCIATION

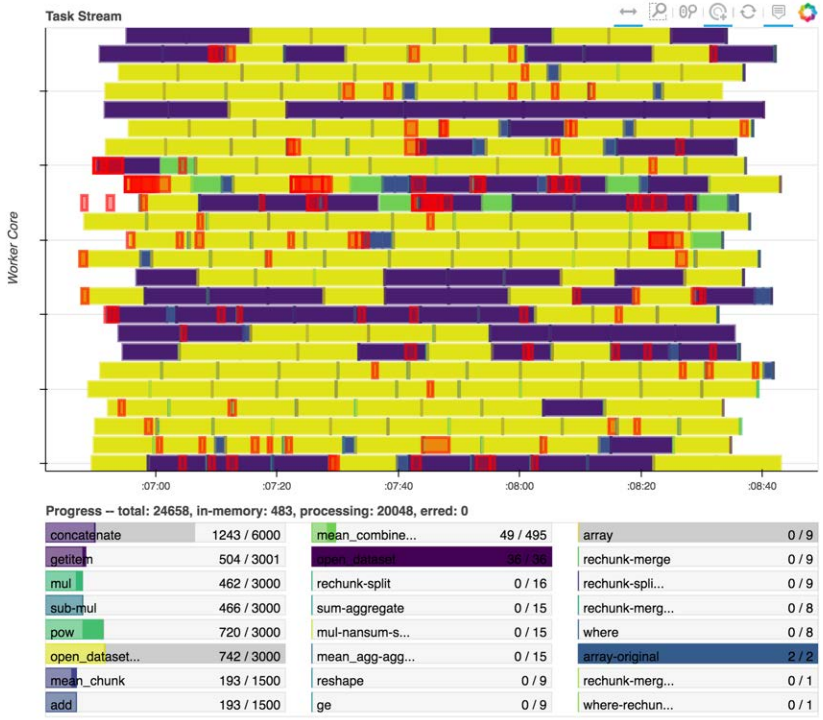
Additional bottlenecks

- Data storage
  - Do more inside the model code itself
  - New file formats (e.g. zarr) for faster parallel access

- Post-processing and visualization
  - Only parallel after some number of points is possible.
  - Should be interactive (exploratory), otherwise it is hard to do science.

Python saves the day

Interactive data processing on local cluster pre/post processing node (24 cores, 1T of memory)



Take home messages

- Unstructured mesh ocean models allow to put resolution where it is needed – this saves computing time.
- For the same number of points Global unstructured mesh models can be as fast as classical regular grid ocean models.
- Main scalability bottle necks are SSH solver and sea ice model, they have to be optimized first.

GMDD paper:

Scalability and some optimization of the Finite-volumE Sea ice-Ocean Model, Version 2.0 (FESOM2)

Nikolay V. Koldunov[1,2], Vadym Aizinger[2,3], Natalja Rakowsky[2], Patrick Scholz[2], Dmitry Sidorenko[2], Sergey Danilov[2,4], and Thomas Jung[2]

FESOM HELMHOLTZ ASSOCIATION