High resolution coupling with OpenIFS-FESOM2

Jan Streffing[1,2] 19.01.2023

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Overview

- AWI-CM1 CMIP6 model
- AWI-CM3
- Palo and DECK type simulations
- High resolution example case
- Stochastic coupling?
- Joined ESM development

Source: Brunner et al. 2020

Motivation

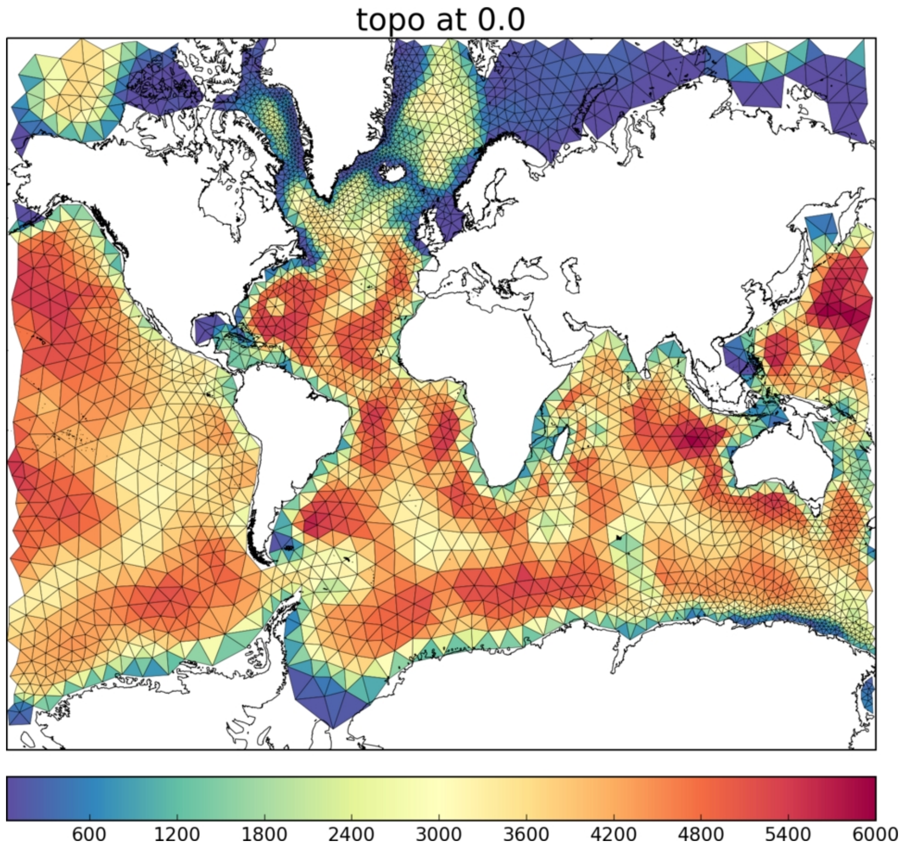
Major participating models for CMIP6:

ACCESS-CM2, **AWI-CM1-MR**, BCC-SM2-MR, CAMS-CSM1-0, CanESM5, CAS-ESM2-0, CESM2, CIESM, CMCC-CM2-SR5, CNRM-CM6-1-HR, E3SM-1-1, EC-Earth3, FGOALS-f3-L, FIO-ESM-2-0, GFDL-CM4, GISS-E2-1-G, HadGEM3MM, ICON-ESM-LR, IITM-ESM, INM-CM5-0, IPSL-CM6A-LR, KIOST-ESM, MCM-UA-1-0, MIROC6, MPI-ESM1-2-HR, MRI-ESM2-0, NESM3, NorESM2-MM, SAM0-UNICON, TaiESM1

Practical resolutions:

AWI-CM1

FESOM1: 100-10 km
ECHAM6: 200-100 km



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More details in:

Sidorenko, D., Rackow, T., Jung, T., Semmler, T., Barbi ,D., Danilov, S., Dethloff ,K., Dorn, W., Fieg, K., Goessling, H. F., Handorf, D., Harig, S., Hiller, W., Juricke, S., Losch, M., Schröter, J., Sein, D. V., Wang, Q. 2015. **Towards multi-resolution global climate modeling with ECHAM6–FESOM. Part I: model formulation and mean climate.** Climate Dynamics, 44(3-4), pp.757-780.

Rackow, T., Goessling, H.F., Jung, T., Sidorenko, D., Semmler, T., Barbi, D. and Handorf, D., 2016. **Towards multi-resolution global climate modeling with ECHAM6-FESOM. Part II: climate variability.** Climate Dynamics, pp.1-26.

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Practical resolutions:

AWI-CM1

FESOM1: 100-10 km
ECHAM6: 200-100 km

AWI-CM2

FESOM2: 100-1 km
ECHAM6: 200-100 km

More details in:

Sidorenko, D., Goessling, H. F., Koldunov, N. V., Scholz, P., Danilov, S., Barbi, D., et al (2019).
Evaluation of FESOM2.0 coupled to ECHAM6.3: Pre-industrial and HighResMIP simulations.
Journal of Advances in Modeling Earth Systems, 11.
https://doi.org/10.1029/2019MS001696

Motivation

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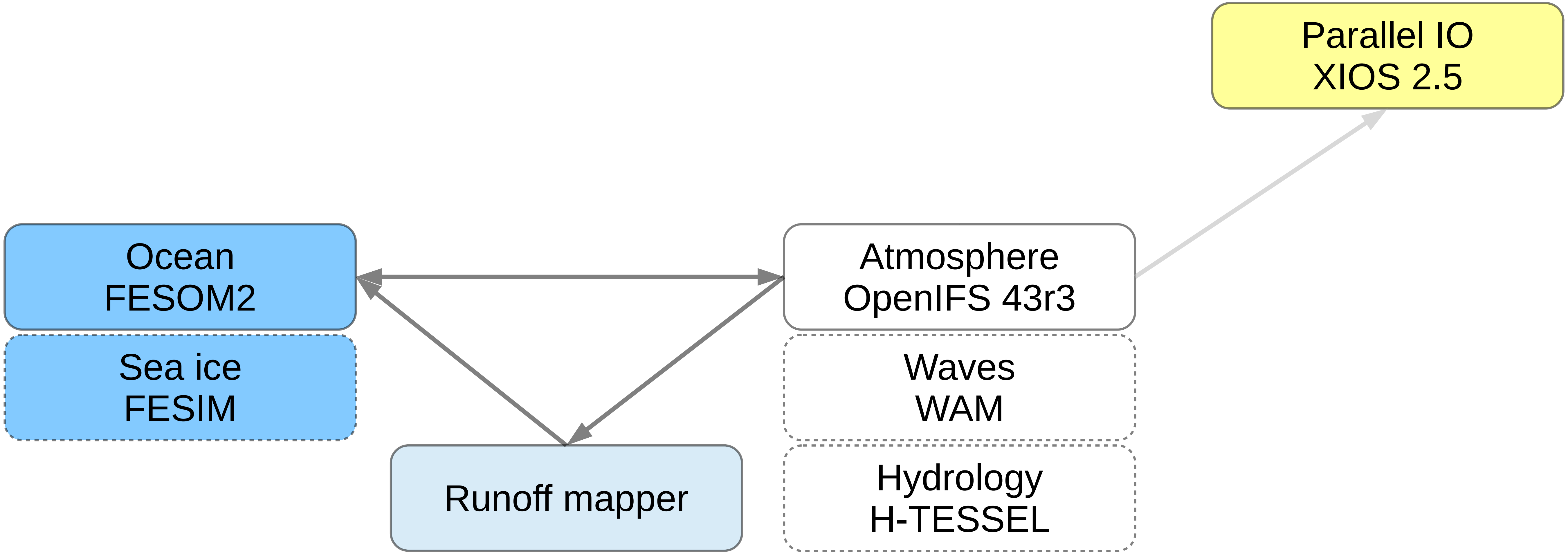
Practical resolutions:

AWI-CM1	FESOM1: 100-10 km ECHAM6: 200-100 km
AWI-CM2	FESOM2: 100-1 km ECHAM6: 200-100 km
AWI-CM3	FESOM2: 100-1 km OpenIFS: 120-4.5km

More details in:

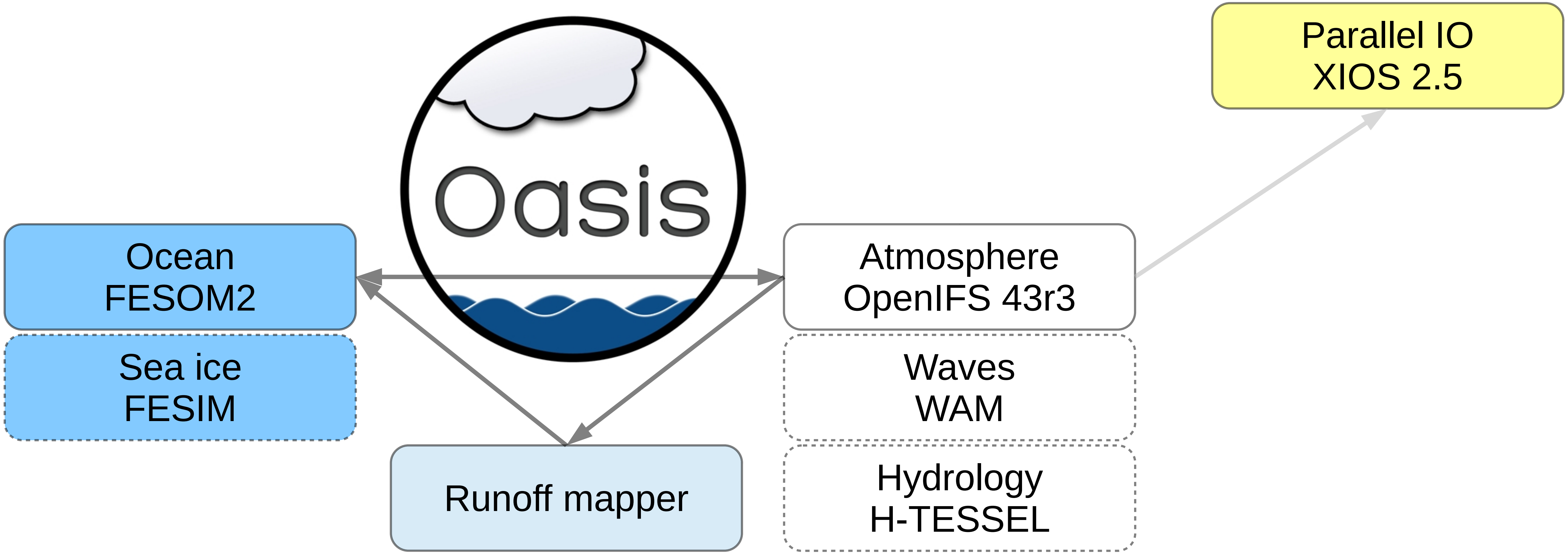
Streffing, J., Sidorenko, D., Semmler, T., Zampieri, L., Scholz, P., Andrés-Martínez, M., ... & Jung, T. (2022).
AWI-CM3 coupled climate model: description and evaluation experiments for a prototype post-CMIP6 model.
Geoscientific Model Development, 15(16), 6399-6427.
https://doi.org/10.5194/gmd-15-6399-2022

Coupling schematic



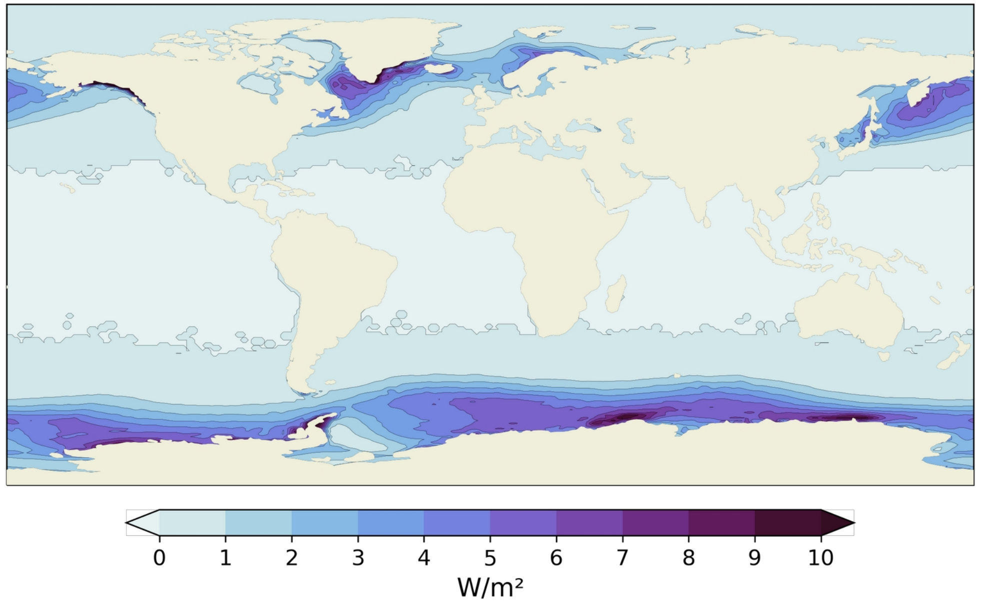
Coupling schematic

Currently GAUSWGT + CONSERV postprocessing for fluxes
GAUSWGT / BICUBIC for non-fluxes

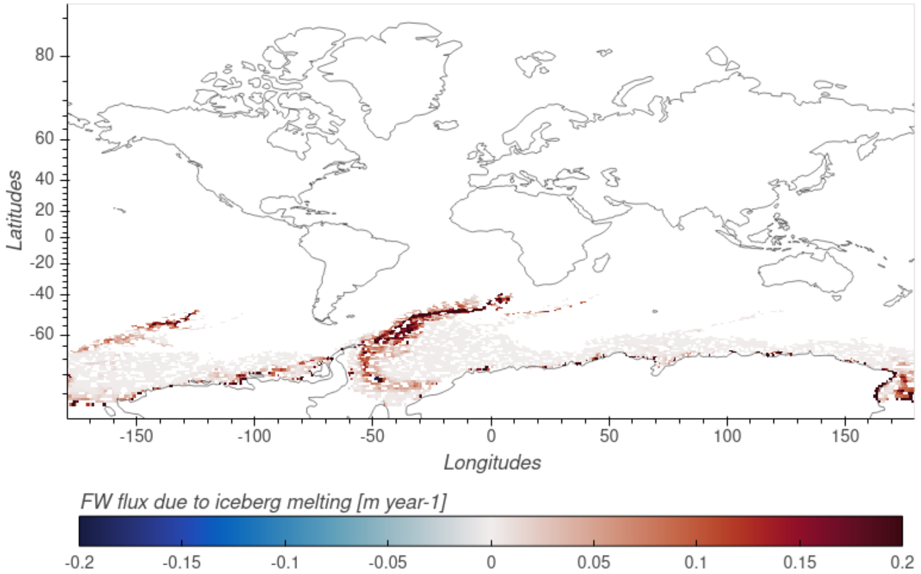


Energetically consistent coupling

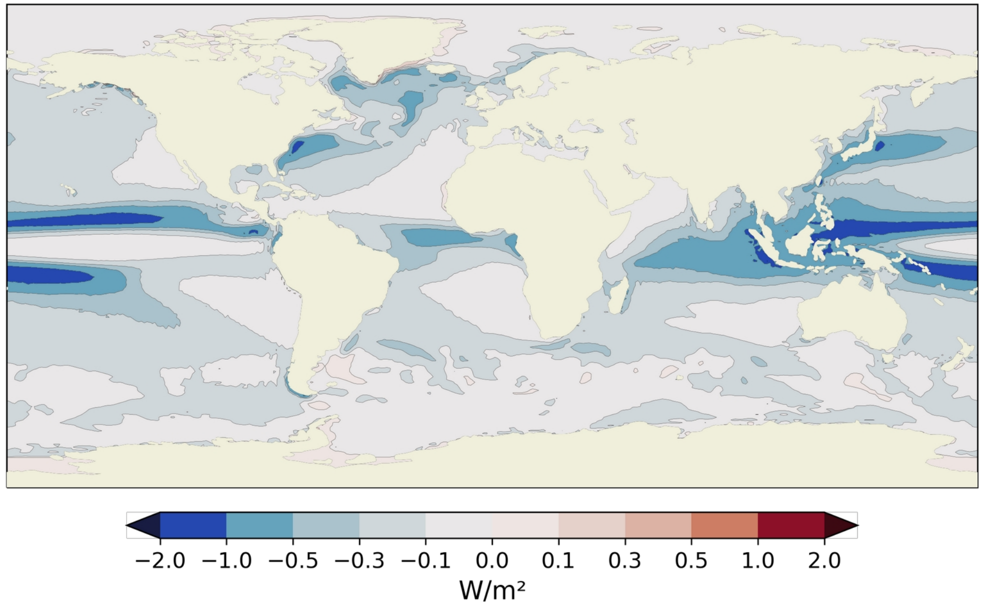
Enthalpy of fusion of snow falling into ocean



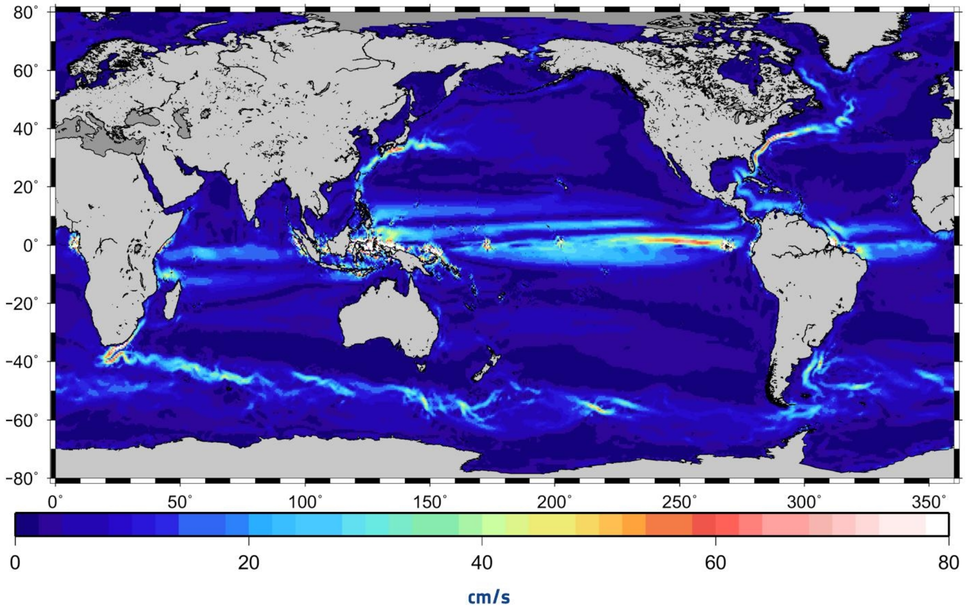
Mass + Enthalpy of iceberg melting



Heatflux of rain falling into ocean with temperature ≠ SST



Current feedback



AWI-CM3 Performance

AWI-CM3.1_SPP CMPI: 0.895

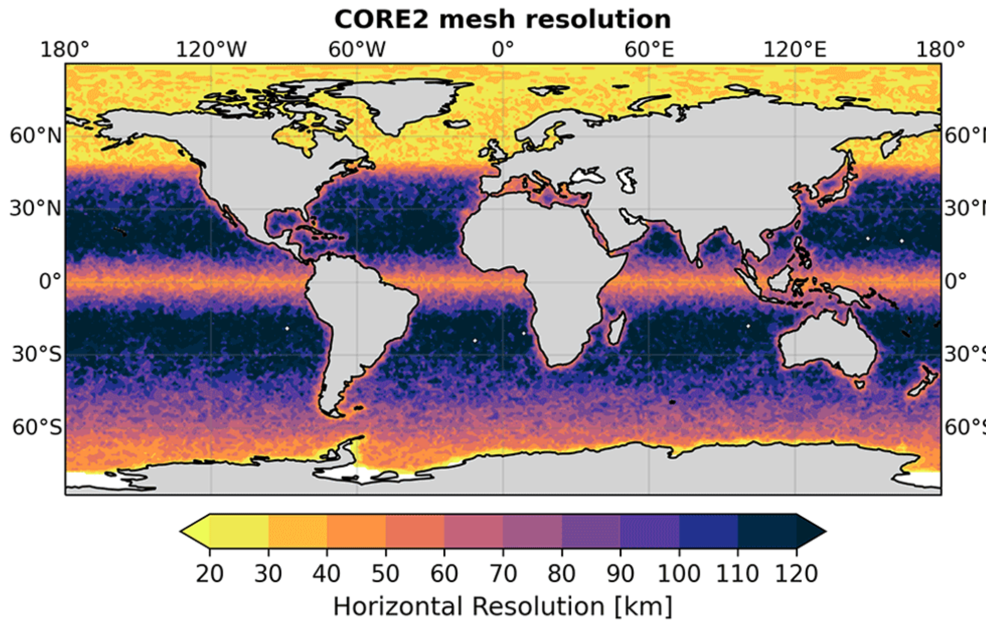
	arctic MAM	arctic JJA	arctic SON	arctic DJF	northmid MAM	northmid JJA	northmid SON	northmid DJF	tropics MAM	tropics JJA	tropics SON	tropics DJF	nino34 MAM	nino34 JJA	nino34 SON	nino34 DJF	southmid MAM	southmid JJA	southmid SON	southmid DJF	antarctic MAM	antarctic JJA	antarctic SON	antarctic DJF
siconc	1.40	0.68	0.48	1.26	0.81	1.09	1.00	0.80									0.85	1.08	0.88	0.98	0.90	0.49	0.52	0.79
tas	1.62	0.64	0.76	1.27	0.91	0.71	0.74	0.90	0.94	0.98	0.89	0.95	1.36	2.47	1.69	1.03	0.81	0.71	0.70	0.85	0.70	0.35	0.52	0.43
clt	1.01	1.20	1.24	1.17	0.69	0.79	0.67	0.76	0.81	0.78	0.63	0.68	0.81	0.44	0.66	0.67	0.82	0.79	0.72	0.87	1.01	1.00	0.82	0.81
pr	0.68	0.68	0.88	1.00	0.81	1.21	1.07	0.99	1.05	1.00	0.86	0.82	1.47	0.97	1.01	1.11	1.35	0.77	1.10	1.31	0.80	0.82	0.86	0.81
rlut	1.48	1.19	1.12	1.22	1.10	0.66	0.68	1.01	1.13	1.08	0.93	0.87	1.55	0.91	0.85	1.10	0.58	0.96	0.87	0.45	0.70	1.00	0.84	1.08
uas	0.60	0.80	0.57	0.81	0.63	0.77	0.41	0.56	1.04	0.86	0.82	0.87	1.45	1.37	0.54	1.05	0.83	0.76	0.82	0.54	0.53	0.47	0.50	0.48
vas	0.68	0.70	0.63	0.73	0.61	0.68	0.54	0.62	0.95	0.87	0.78	0.78	1.21	1.64	0.86	0.70	0.67	0.81	0.65	0.52	0.56	0.53	0.50	0.51
300hPa ua	0.59	0.96	0.59	0.66	0.69	1.08	0.51	0.66	0.83	0.70	0.65	0.71	0.54	0.77	0.48	0.61	0.64	0.77	0.96	0.56	0.74	0.58	0.61	0.71
500hPa zg	0.43	0.47	0.56	0.35	0.64	0.35	0.26	0.63	0.50	0.56	0.27	0.60	0.67	0.61	0.30	0.66	0.46	1.30	1.26	0.32	0.24	0.64	0.40	0.19
st. dev. zos	0.64	0.45	0.63	0.62	0.90	0.96	0.92	0.90	1.08	1.05	1.09	1.11	1.43	1.57	1.80	1.86	0.95	0.98	0.99	0.98	0.90	0.81	0.97	0.97
st. dev. tos	1.25	1.10	1.13	1.23	1.20	1.94	1.63	1.38	1.30	1.27	1.08	1.46	0.28	0.32	0.26	0.39	1.85	1.12	0.98	1.99	1.82	0.82	0.97	1.83
mlotst	0.93	0.45	0.59	0.94	2.93	0.55	0.77	2.48	1.41	1.06	1.66	1.05	0.54	0.72	0.79	0.64	0.58	2.30	3.18	1.13	1.00	2.57	1.34	0.36
10m thetao	1.09	1.00	0.83	1.06	0.91	0.81	0.72	0.90	1.09	1.18	1.03	0.93	1.57	2.08	1.45	1.26	1.00	0.93	0.92	1.00	1.29	0.77	0.82	1.43
100m thetao	0.89	0.87	0.86	0.84	1.05	1.04	1.00	1.04	1.13	1.14	1.11	1.12	0.83	0.74	1.19	1.07	0.96	1.00	1.01	0.96	1.16	1.40	1.65	1.44
1000m thetao	1.31	1.31	1.31	1.31	0.47	0.47	0.48	0.48	0.45	0.45	0.45	0.45	0.07	0.07	0.08	0.06	0.52	0.52	0.52	0.52	0.60	0.63	0.61	0.59
10m so	0.98	0.85	0.77	0.94	0.96	0.95	0.95	0.96	0.98	0.95	0.95	0.95	0.63	0.62	0.67	0.81	0.73	0.70	0.73	0.72	0.63	0.97	0.88	0.68
100m so	0.41	0.43	0.45	0.42	1.16	1.18	1.15	1.16	0.94	0.95	0.94	0.95	1.11	1.06	1.07	1.08	0.78	0.75	0.75	0.77	1.42	1.42	1.40	1.44
1000m so	0.46	0.50	0.50	0.44	1.16	1.16	1.16	1.16	0.97	0.97	0.97	0.97	1.03	1.04	1.05	1.04	0.52	0.52	0.51	0.52	0.65	0.65	0.64	0.64

Paleo setup:

Atm: 100km

Oce: 120-25km

SYPD: 130



Green = better than CMIP6 average

Magenta = worse than CMIP6 average

Number = Factor by how much

https://github.com/JanStreffing/cmpi-tool/

AWI-CM3 Performance

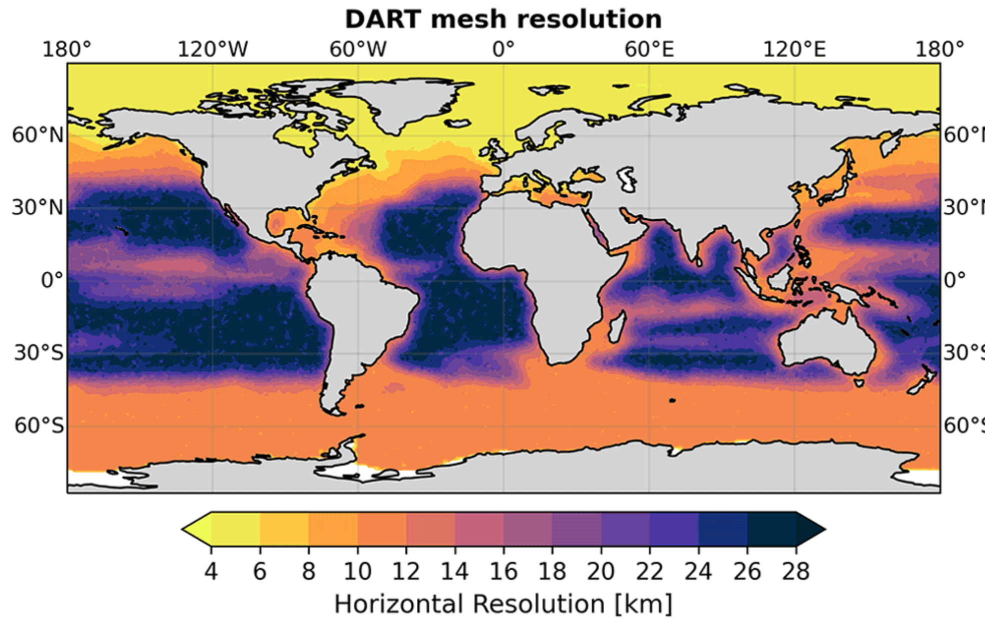
AWI-CM3-1950c CMPI: 0.752

	glob MAM	glob JJA	glob SON	glob DJF	arctic MAM	arctic JJA	arctic SON	arctic DJF	northmid MAM	northmid JJA	northmid SON	northmid DJF	tropics MAM	tropics JJA
siconc	0.89	1.24	1.27	0.72	1.18	1.76	1.81	0.64	0.64	1.15	1.53	0.64		
tas	0.62	0.57	0.72	0.64	0.51	0.41	0.82	0.61	0.82	0.51	0.51	0.77	0.89	0.87
clt	0.89	0.84	0.78	0.81	1.23	1.01	1.05	1.01	0.73	0.76	0.73	0.90	0.74	0.70
pr	0.89	0.81	0.83	0.78	1.39	0.86	1.06	1.04	0.75	1.21	0.99	0.84	0.81	0.74
rlut	0.73	0.70	0.62	0.64	0.65	0.78	0.46	0.46	0.68	0.56	0.45	0.51	0.84	0.73
uas	0.45	0.49	0.48	0.39	0.42	0.40	0.37	0.41	0.41	0.73	0.36	0.35	0.63	0.54
vas	0.44	0.42	0.41	0.40	0.43	0.38	0.35	0.34	0.36	0.51	0.39	0.36	0.60	0.51
300hPa ua	0.63	0.66	0.74	0.53	0.67	0.57	0.59	0.47	0.51	1.02	0.62	0.48	0.68	0.44
500hPa zg	0.53	0.49	0.57	0.51	0.44	0.22	0.88	0.13	0.71	0.32	0.33	0.65	0.79	0.71
st. dev. zos	0.57	0.57	0.60	0.58	0.59	0.45	0.59	0.54	0.56	0.55	0.56	0.60	0.63	0.67
st. dev. tos	0.90	1.27	0.98	0.91	0.93	1.43	1.04	0.83	0.79	1.53	1.06	1.07	0.98	0.96
mlotst	1.12	1.01	1.09	1.27	0.44	0.79	0.74	0.40	0.87	2.00	1.09	0.69	2.86	2.31
10m thetao	0.82	0.94	0.91	0.78	0.93	0.77	0.75	0.95	0.62	0.64	0.52	0.60	0.96	1.09
100m thetao	1.00	1.00	0.97	1.00	1.36	1.38	1.44	1.46	0.65	0.64	0.61	0.66	1.05	1.04
1000m thetao	0.33	0.33	0.33	0.33	0.56	0.57	0.56	0.55	0.17	0.18	0.18	0.18	0.15	0.15
10m so	0.69	0.70	0.66	0.66	0.91	0.92	0.81	0.85	0.53	0.53	0.52	0.53	0.57	0.53
100m so	0.50	0.49	0.49	0.50	0.39	0.39	0.41	0.41	0.56	0.58	0.56	0.58	0.51	0.50
1000m so	0.30	0.30	0.30	0.29	0.26	0.30	0.30	0.25	0.19	0.19	0.19	0.19	0.16	0.16

	tropics SON	tropics DJF	nino34 MAM	nino34 JJA	nino34 SON	nino34 DJF	southmid MAM	southmid JJA	southmid SON	southmid DJF	antarctic MAM	antarctic JJA	antarctic SON	antarctic DJF
siconc							0.96	0.82	0.88	1.02	0.81	0.75	0.72	0.75
tas	0.89	0.96	1.44	1.22	1.70	1.29	0.62	0.86	0.96	0.70	0.38	0.39	0.50	0.32
clt	0.68	0.74	0.88	0.43	0.31	0.84	0.81	1.01	0.83	0.79	0.91	0.90	0.73	0.69
pr	0.70	0.64	1.17	0.81	0.96	1.01	1.27	0.66	1.02	1.25	0.84	0.90	0.99	1.02
rlut	0.77	0.68	1.14	0.66	0.68	0.96	0.46	0.54	0.53	0.44	0.61	0.92	0.50	1.06
uas	0.55	0.47	0.63	0.51	0.24	0.44	0.37	0.45	0.57	0.38	0.30	0.34	0.41	0.31
vas	0.53	0.49	0.82	0.84	1.03	0.60	0.52	0.53	0.50	0.53	0.28	0.24	0.27	0.28
300hPa ua	0.61	0.54	0.43	0.44	0.33	0.36	0.62	0.85	1.01	0.54	0.67	0.73	0.97	0.64
500hPa zg	0.69	0.93	0.90	0.76	0.80	0.92	0.52	1.22	1.14	0.50	0.24	0.16	0.18	0.30
st. dev. zos	0.69	0.62	1.22	1.40	1.36	0.97	0.49	0.52	0.50	0.50	0.79	0.69	0.83	0.83
st. dev. tos	0.81	0.99	0.45	0.20	0.24	0.39	1.14	1.39	1.15	1.13	0.50	0.81	0.98	0.52
mlotst	3.07	2.63	5.91	4.68	6.67	6.69	1.07	1.07	1.31	1.74	1.28	0.39	0.34	3.63
10m thetao	1.02	0.93	1.39	1.01	1.29	1.33	0.79	1.08	1.11	0.77	0.67	0.86	0.91	0.45
100m thetao	1.00	1.04	0.64	0.44	0.72	0.58	0.93	0.90	0.89	0.92	1.14	1.26	1.37	1.21
1000m thetao	0.15	0.15	0.12	0.13	0.13	0.08	0.63	0.63	0.63	0.62	0.48	0.51	0.52	0.50
10m so	0.54	0.54	0.25	0.27	0.29	0.21	0.50	0.48	0.49	0.50	0.67	0.85	0.87	0.58
100m so	0.51	0.51	0.54	0.48	0.51	0.49	0.51	0.49	0.47	0.49	0.78	0.76	0.73	0.74
1000m so	0.16	0.16	0.04	0.05	0.05	0.04	0.62	0.61	0.61	0.61	0.49	0.50	0.49	0.47

DECK setup:

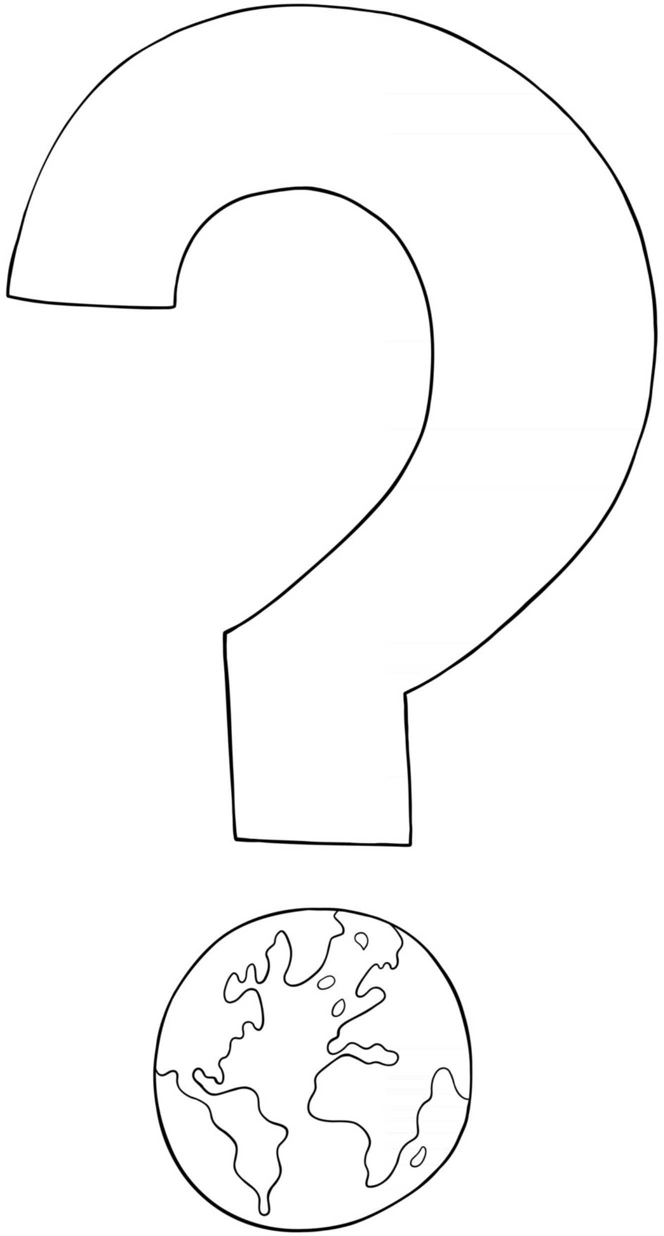
Atm: 31km
Oce: 30-6km
SYPD: 8



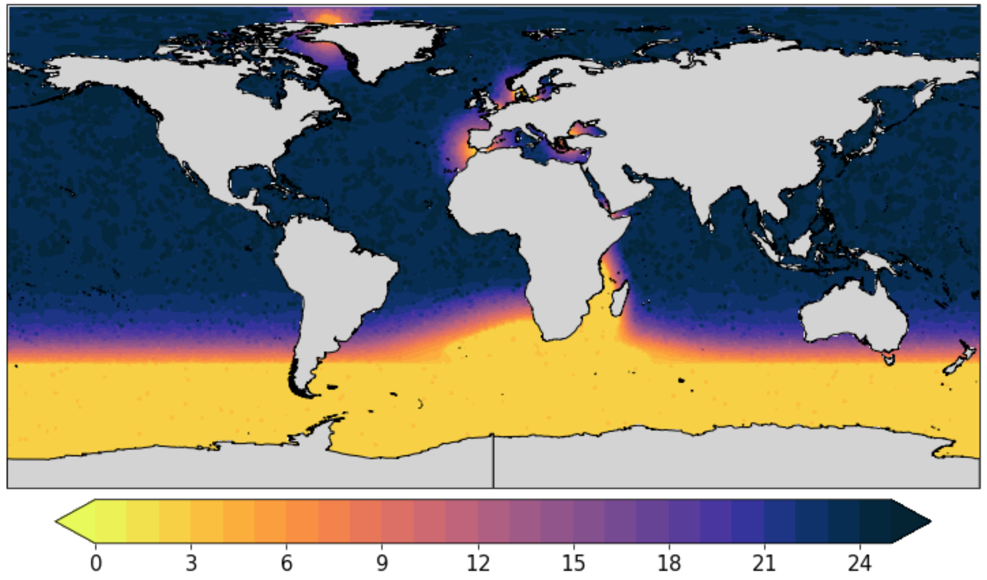
Green = better than CMIP6 average
Magenta = worse than CMIP6 average
Number = Factor by how much

https://github.com/JanStreffing/cmpi-tool/

AWI-CM3 Performance

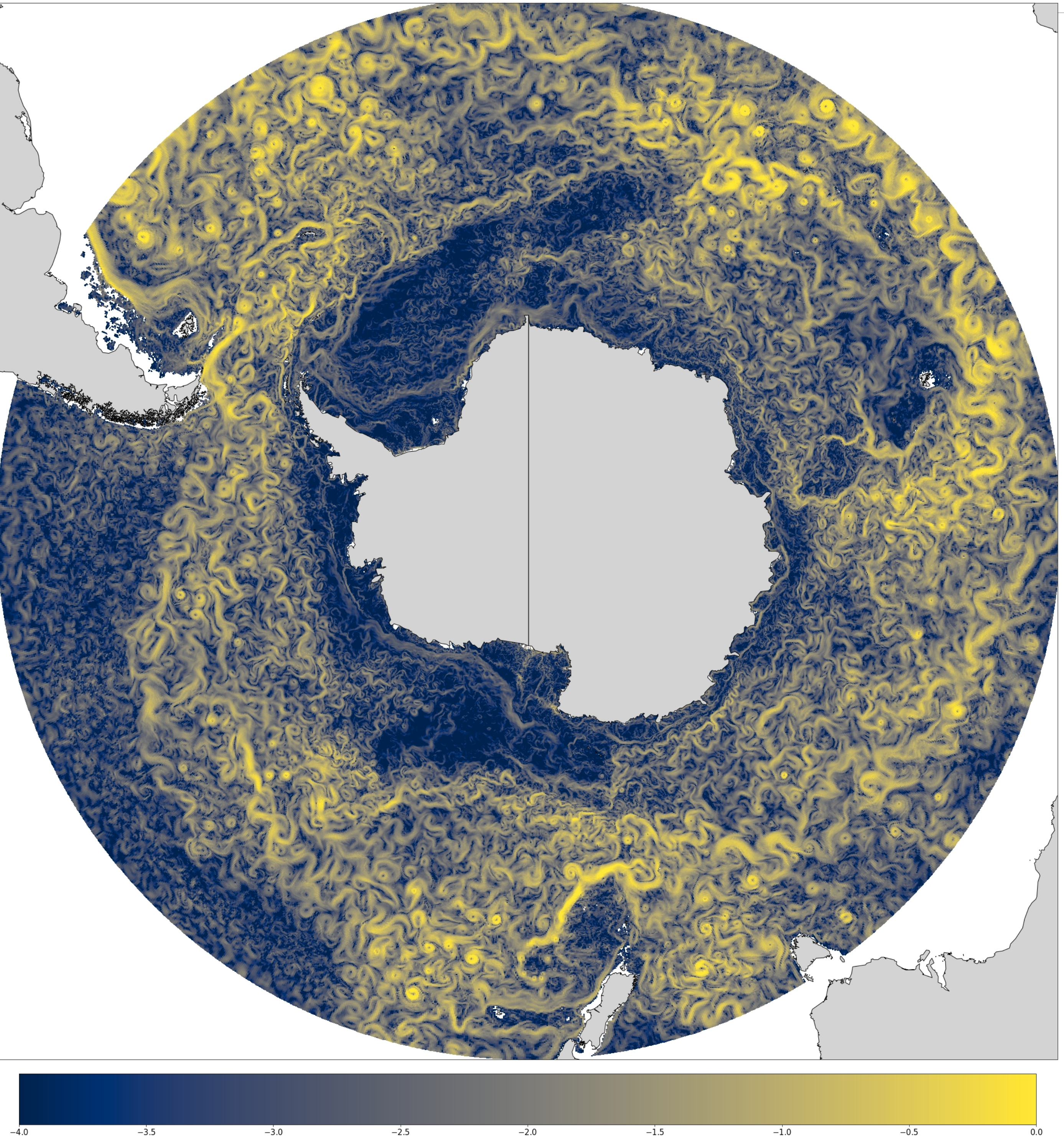


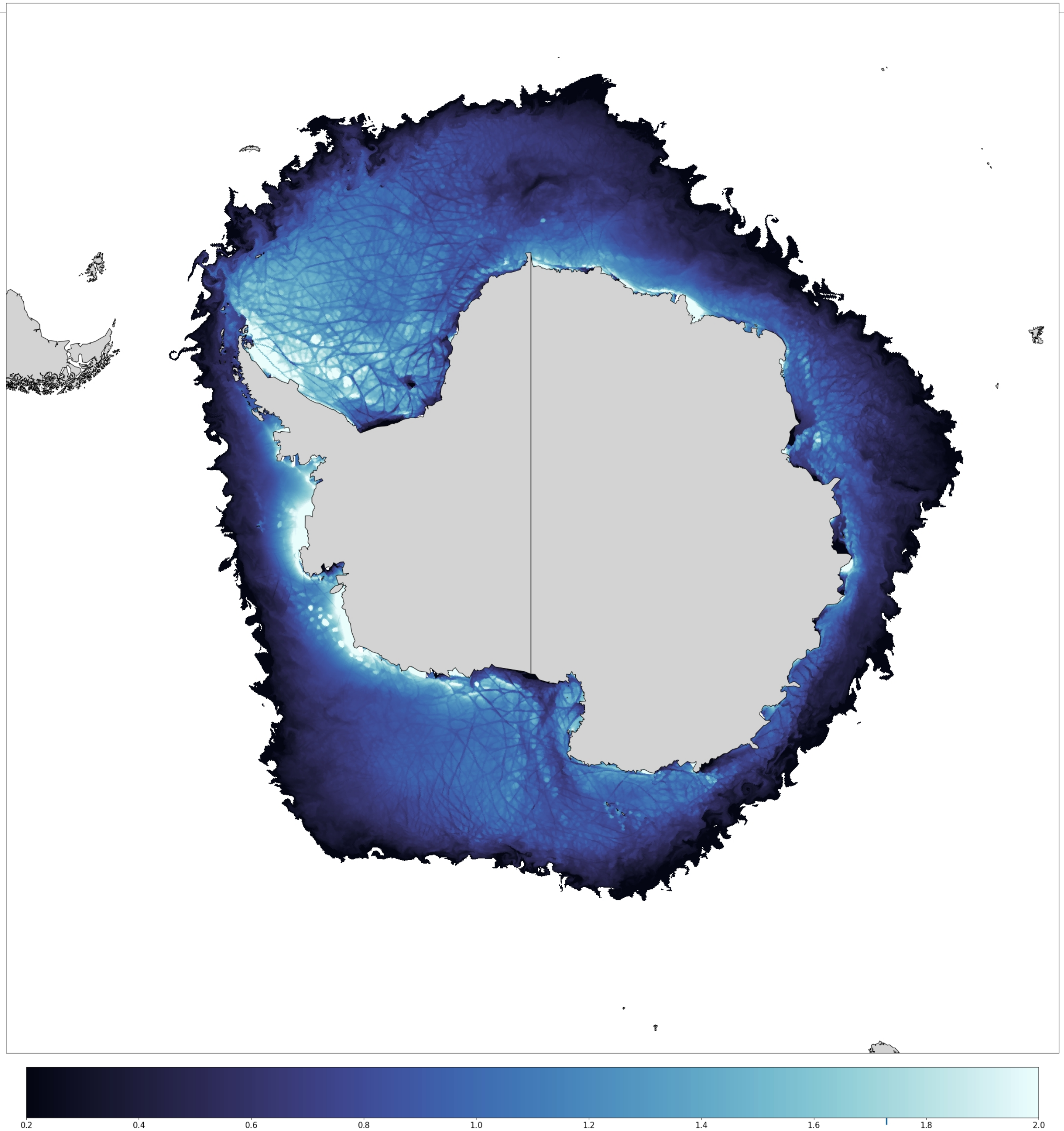
Southern Ocean setup:
Atm: 16km
Oce: 20-2.5km
SYPD: 1



Month long tests done
Use of MCT4 & MCT5 features:
- Parallel rmp weight gen
- Coupled performance opt

AWI-CM3 Performance



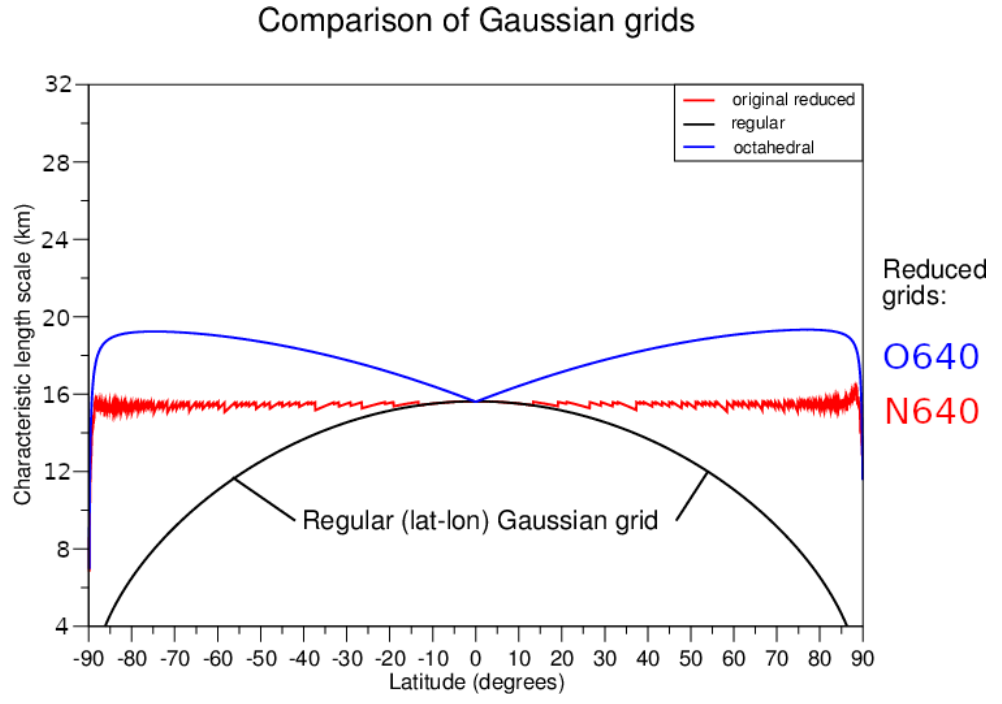


Stochastic coupling

Issue: Large and variable resolution ratio

$$Ratio_{Grids} = \frac{Res_{Atm}}{Res_{Oce}}$$

Range from $\frac{16^2}{20^2} = \boxed{0.64}$ to $\frac{19^2}{2.5^2} \approx \boxed{58}$



GAUSWGT with N neighbors:

```
GAUSWGT D SCALAR LATITUDE 1 25 0.1
```

Weighting favors points nearby.
Underutilization of information available on ocean grid

➡ **Stochastic coupling to use „sub-gridscale“ Information?**

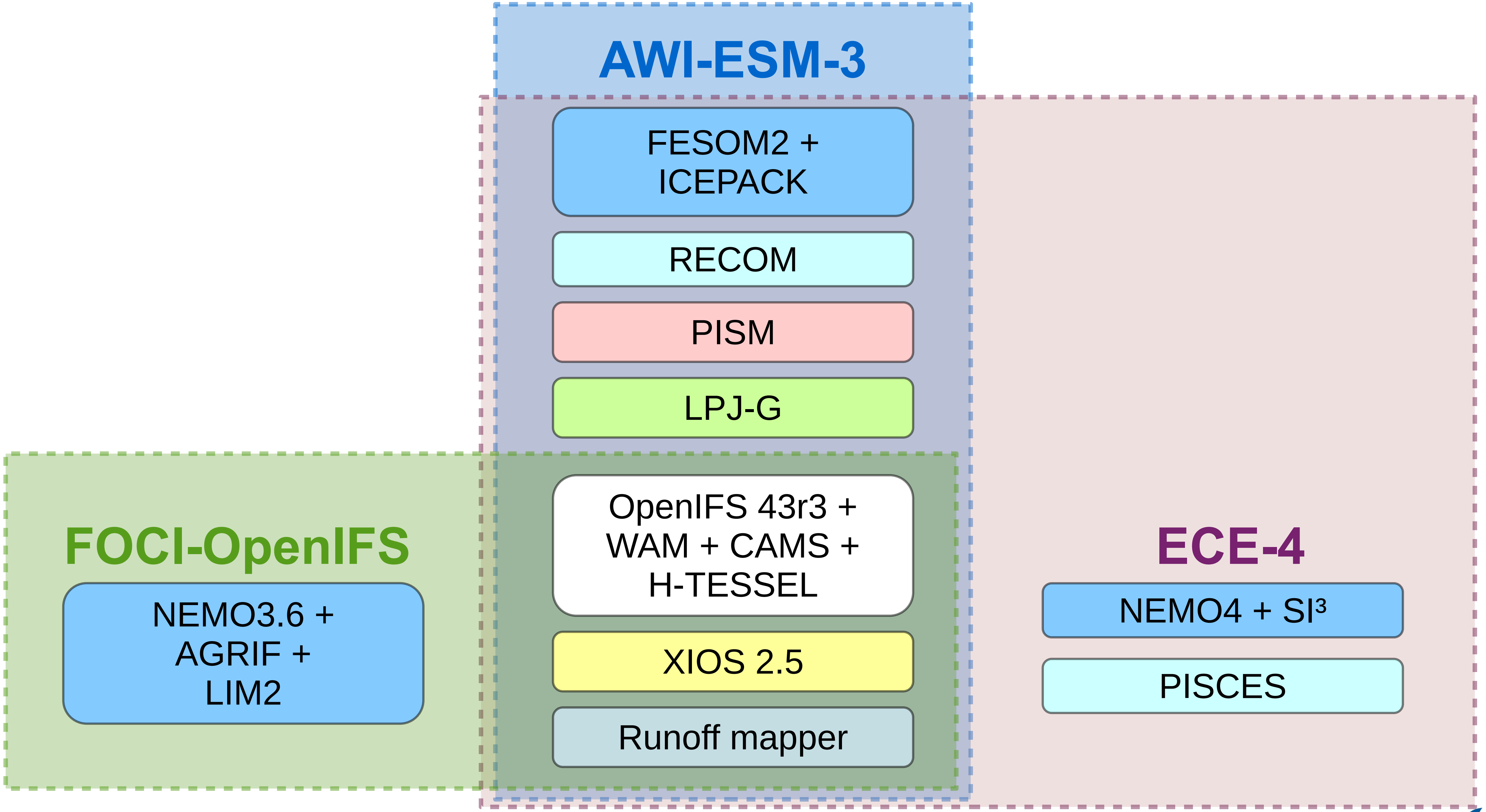
Stochastic coupling

Background:
Random selection > Arithmetic mean (Rackow and Juricke 2019)
Random selection > GAUSWGT / DISWGT / BILINEA / BICUBIC ???

Idea:
- Take scripr/conserv grid overlap detection
- Init: `remap_stoch.F90` as copy of `remap_conserv.F90` without weighting
- Stochastically eliminate all but one weight per target point at runtime
- Runtime: Modify `sMatP` on the fly inside `mod_oasis_advance.F90`

Further potential:
Smarter than fully random elimination of weights
e.g. Markov chain jumping through subgrid or data space.

Wider infrastucture



Questions / Comments