Sensitivity of the Atlantic Meridional Overturning Circulation to Model Resolution in CMIP6 HighResMIP Simulations

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and many colleagues from PRIMAVERA project

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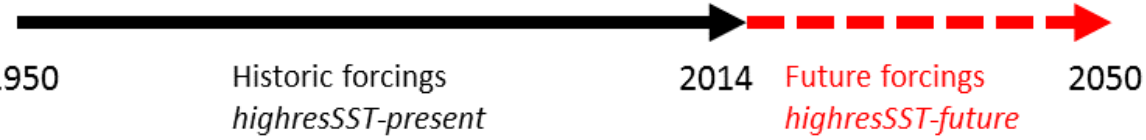
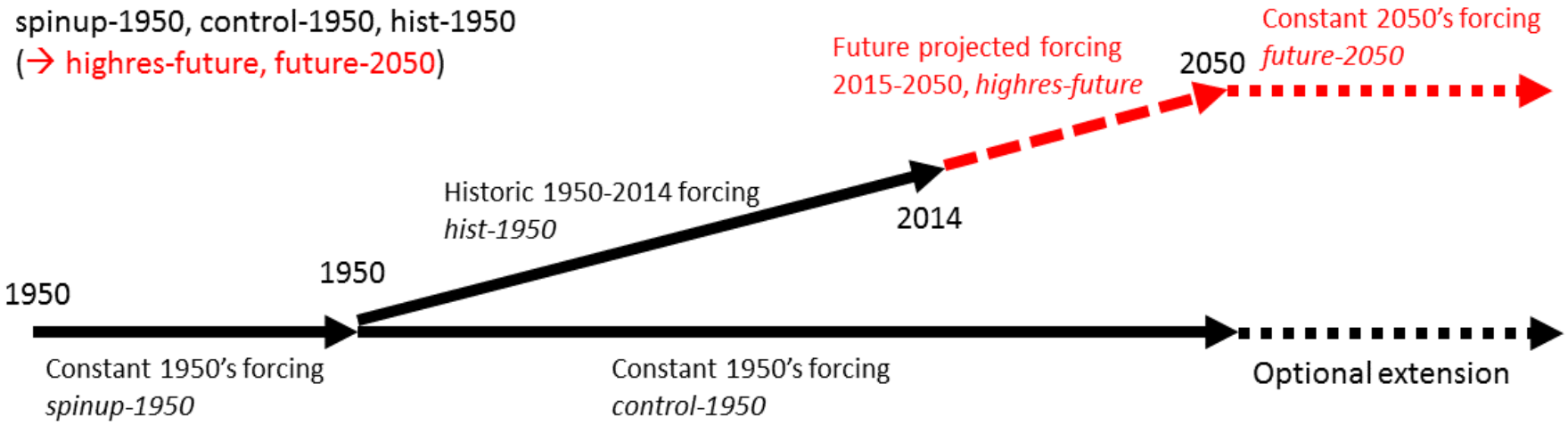
CMIP6 HighResMIP simulations

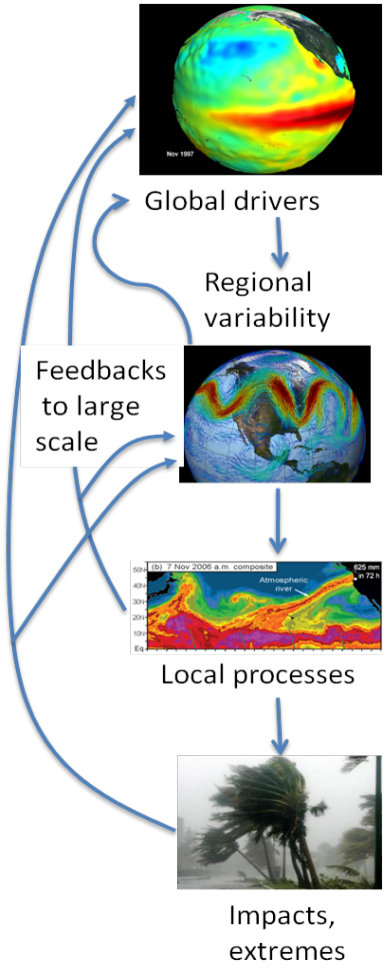
Physical model only x 2 resolutions, simplified aerosol optical properties (MACv2-SP) recommended

Atmosphere-land-only, 1950-2014 (→ 2050)
Forced by observed SST and sea-ice and historic forcings (→ projected)
highresSST-present (→ highresSST-future)



Coupled climate, 1950-2014 (→ 2050)
Forced by constant 1950 and historic forcings (→ projected)
Initial coupled spin-up period ~ 30-50 years from 1950 EN4 ocean climatology
spinup-1950, control-1950, hist-1950
(→ highres-future, future-2050)





Parameter/ model	HadGEM3-GC31	ECMWF-IFS	CNRM-CM6	EC-Earth3P	CMCC-CM2	MPI-ESM1-2	CESM1-3
Resolution names	LL, MM, HM, HH	LR, MR, HR	LR, HR	LR, HR	HR4, VHR4	HR, XR	HH
Atmosphere resolution (CMIP6, km)	250, 100, 50, 50	50, 50, 25	250, 50	100, 50	100, 25	100, 50	25
Ocean model	NEMO3.6	NEMO3.4	NEMO3.6	NEMO3.6	NEMO3.6	MPIOM	POP
Ocean hor. resolution (degrees; CMIP6, km)	1°, ¼°, ¼°, 1/12°; 100, 25, 25, 8	1°, ¼°, ¼°; 100, 25, 25	1°, ¼°; 100, 25	1°, ¼°; 100, 25	¼°. ¼°; 25, 25	0.4°, 0.4°; 50, 50	1/10°; 10
Ocean levels	75	75	75	75	50	40	62

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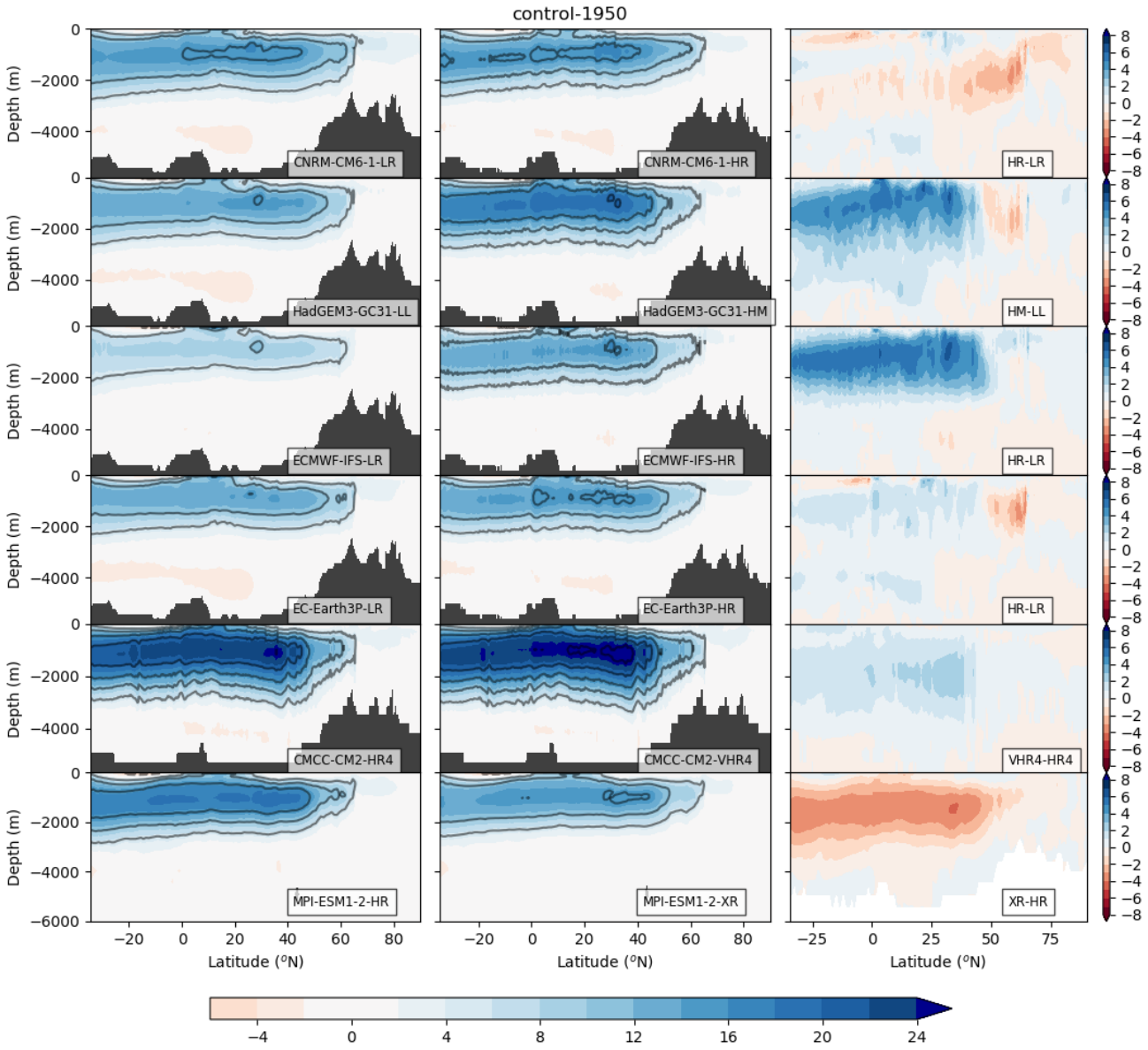
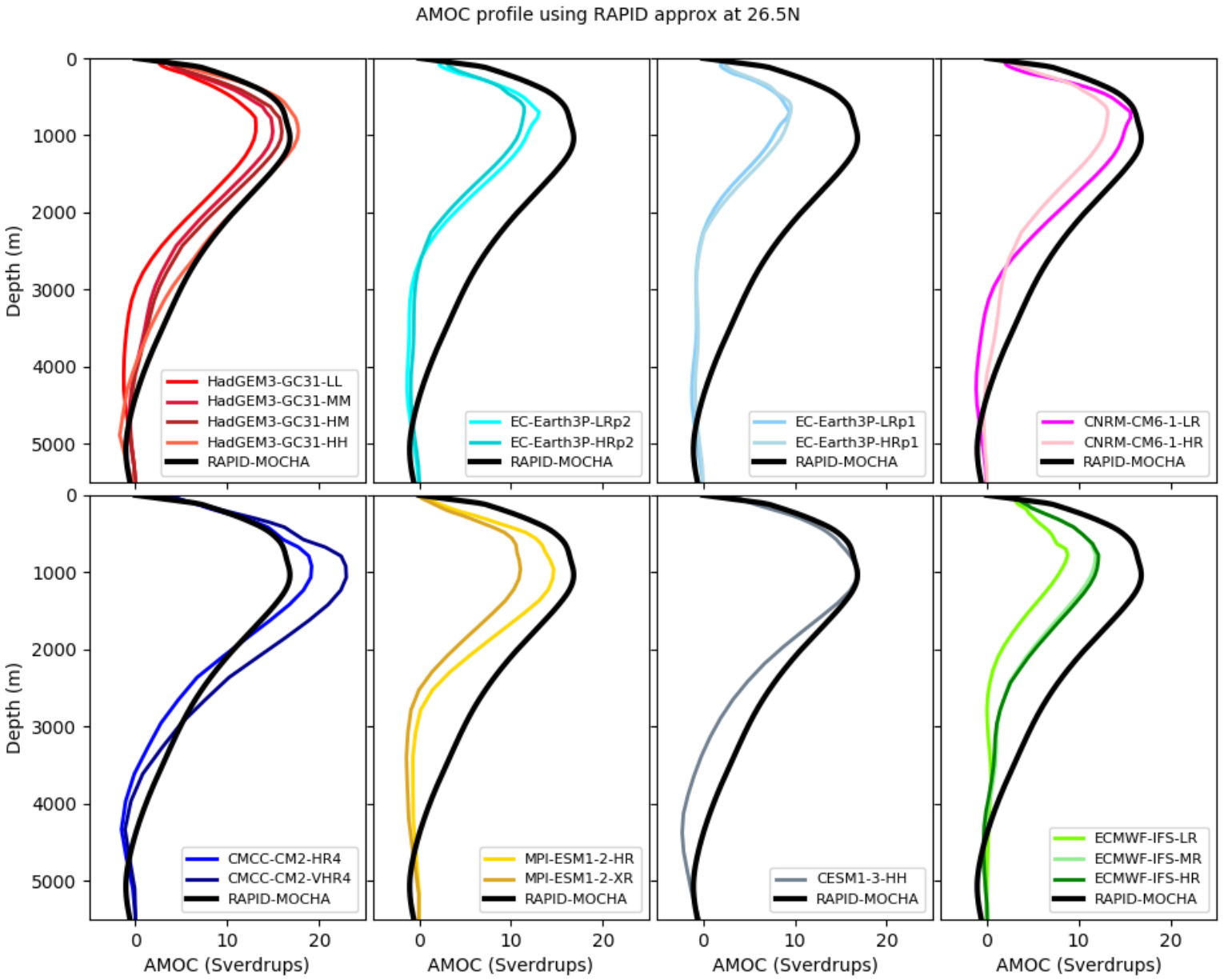


AMOC overturning circulation in z-space from control-1950 simulations

(left) low resolution
(middle) high resolution
(right) high – low difference

HadGEM3-GC31 and ECMWF show the largest increase in the AMOC strength with higher resolution.
Smaller differences in other models

Only a change in atmospheric resolution



Mean depth profile of AMOC at 26.5°N from hist-1950 simulations over 2004-2014, together with RAPID-MOCHA over 2004-2017.

Most models underestimate the depth of the return flow. The notable exceptions are the *eddy-rich* HadGEM3-GC31-HH model with an overturning stream function very close to the observed profile, the CESM1-3-HH that captures the maximum, the CMCC-CM2 models with overturning maxima that are much higher than observed.

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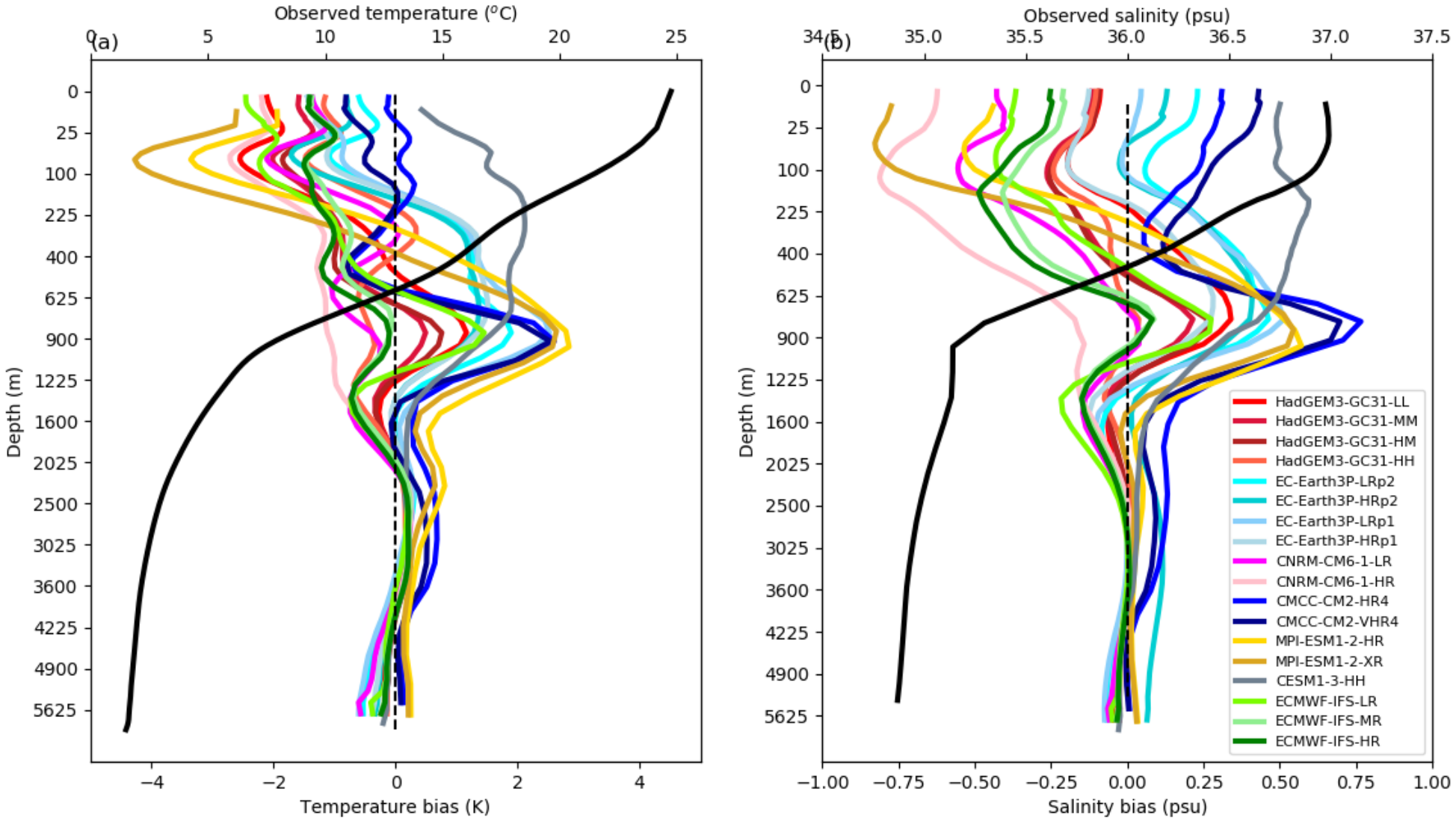
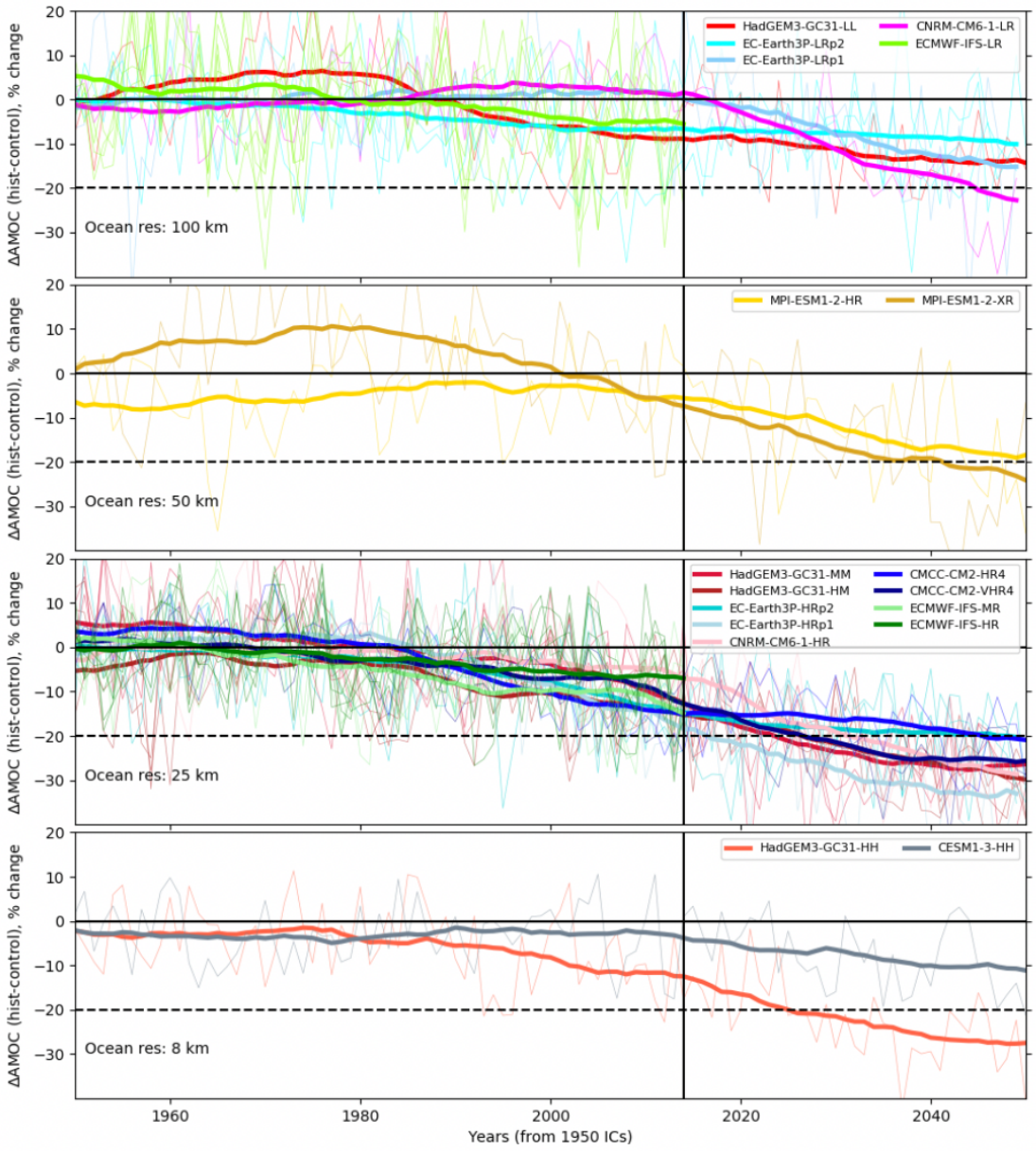
Zonal mean temperature and salinity biases at 26.5°N compared to EN4 (black) for 1979-2014





Difference between timeseries of hist-1950 and high res-future minus control-1950. thin lines represent each member, thick line the ensemble mean with a 30year running.
The difference is expressed as a percentage change compared to the respective control-1950 mean strength.

AMOC decreases in all simulations over time (though not all have a decrease over the historical period), and this tends to become more pronounced in the future 2015-2050 period.
All but one of the low-res ocean models have an AMOC weakening at year 2050 of less than 20%, while all the 25 km models have a stronger than 20% weakening (all of these latter models use NEMO).
The 50km MPI-ESM1.2 models have AMOC decline between the 100km and 25km results, but the CESM-1-3-HH model at 10km has a smaller decline of about 10%.

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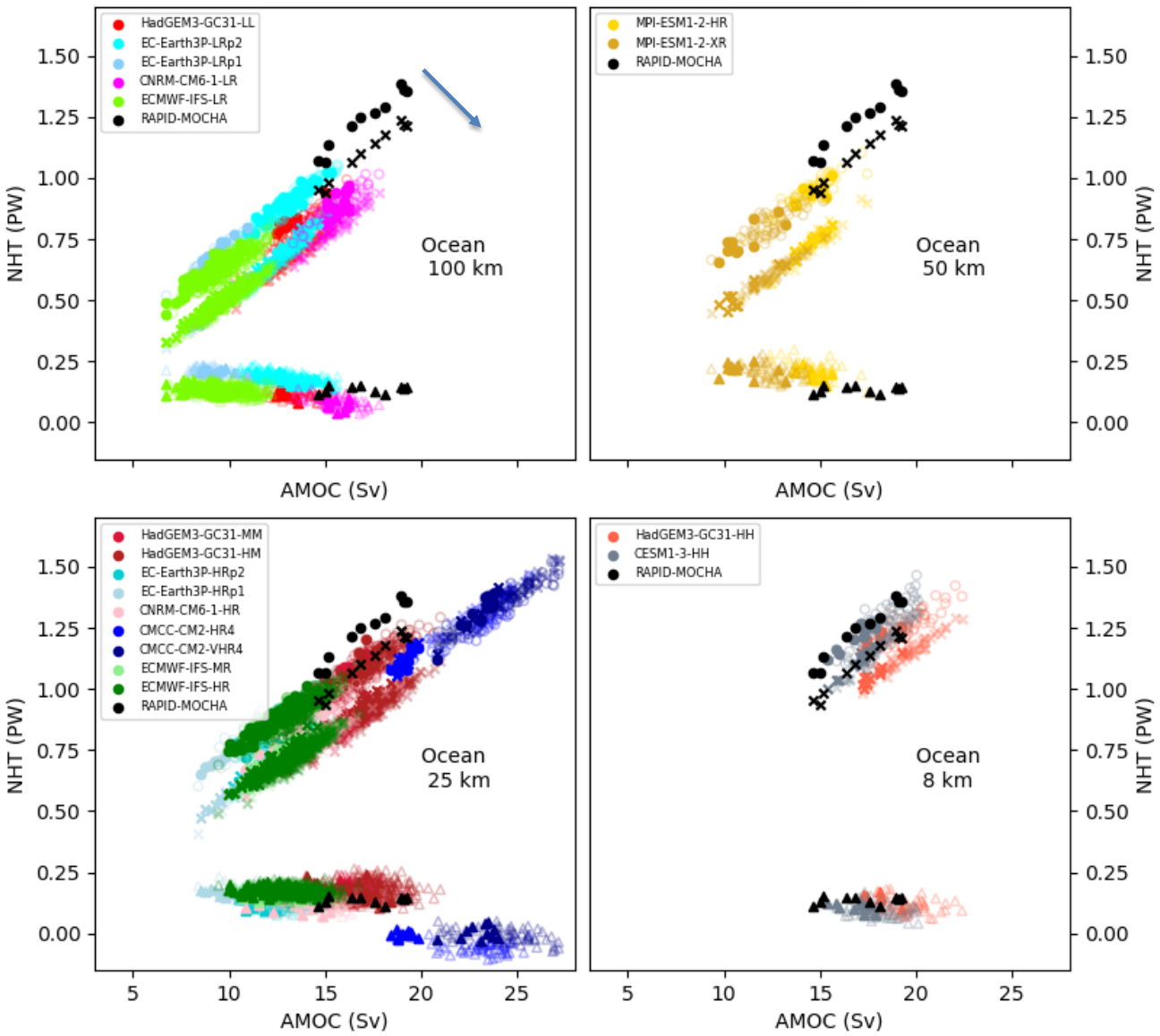
Relation of AMOC and NHT at 26.5°N



Scatter plot of annual mean AMOC vs heat transport NHT components at 26.5°N for hist-1950 simulations (total is o, overturning is x and gyre is Δ). Filled/bold symbols indicate years 2004-2014, unfilled/light symbols for 1950-2003, with RAPID-MOCHA 2004-2017 in black. Different resolution ocean models are grouped together.

For the low-res models (around 100 km), it is rare for the total NHT to lie within the observed range (1.05-1.4 PW), and this improves as ocean resolution increases to 50km, 25km and 8-10km for most models. This systematic model offset compared to the observations in PW/Sv means that only models with stronger than observed AMOC span the range of observed NHT

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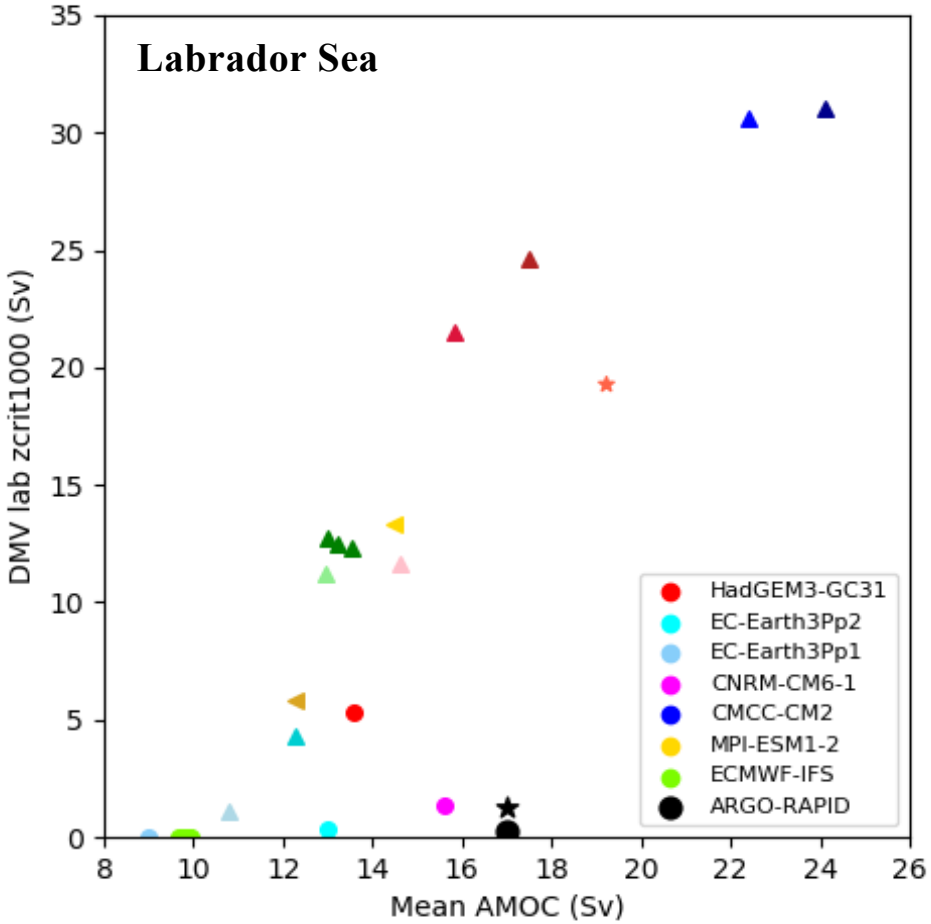
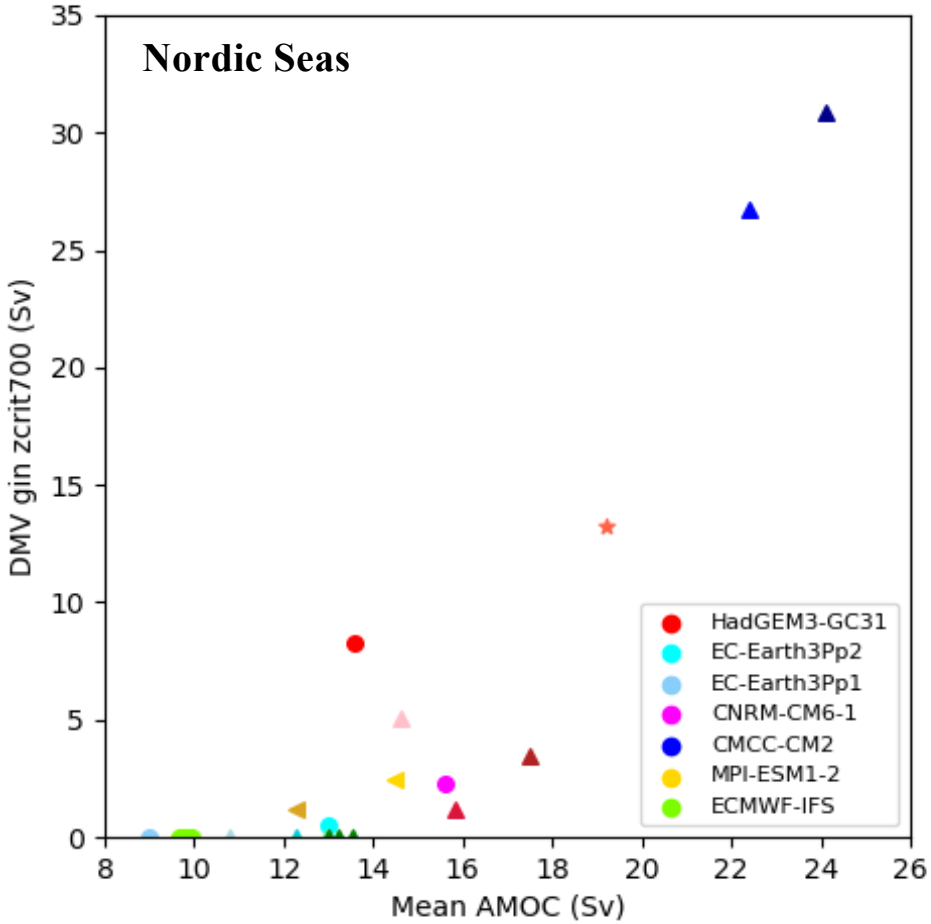
Relationship between the mean AMOC from hist-1950 simulations, and the mean Deep Mixed Volume (DMV) in the Labrador Seas and Nordic Seas, an indicator of deep mixing . The black symbols are observations (currently only for the Labrador Sea) from ARGO DMV mean over 2000-2015, and from RAPID-MOCHA for the AMOC mean over 2004-2017. The model symbols: circles are 100 km, side triangle 50 km, triangles 25 km, * 8 km ocean resolutions. The DMV volume has been converted to Sv.





AMOC summary

- The AMOC and heat transport typically increases with a higher resolution ocean component, and this is associated with enhanced water mass transformation in the subpolar gyre and generally improves the models compared to the RAPID-MOCHA observations at 26.5°N

- the eddy-rich models are among the best performing models

- NEMO models have AMOC that declines more quickly at higher resolution, but CESM at 1/10° does not – need more models, more model diversity

- Currently models tend to agree with observations at 26.5°N by having too much activity in the subpolar gyre

- The higher resolution models tend to project a stronger decline in AMOC in the SSP585 projections to 2050. This is due to a larger decrease in water mass formation in the subpolar gyre and Labrador Sea as the climate warms.

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