Climate simulations with global storm-resolving models from transient states.

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Abstract

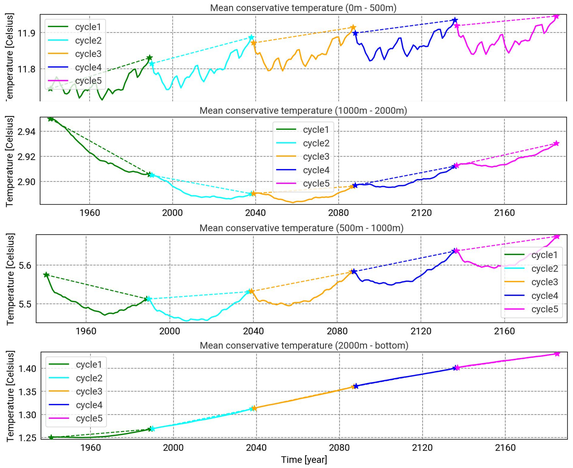
Models capable of resolving deep convection and large turbulent eddies in the atmosphere require horizontal resolutions between 1 and 10 km. Turbulent processes in the atmosphere play a major role in distributing the energy within the atmosphere, and it has been shown that atmospheric resolutions of 10 km or less significantly improve the resemblance to observations.

Before we can make the transient historical simulations from which future projections are typically initialized, the models need to be gradually spun up to achieve a climate state that is consistent with the boundary conditions at the initial time. Traditional spin-up approaches cannot be applied at very high resolutions, as they involve thousands of years of spin-up periods, which remains prohibitive for the km scale. We present an alternative ocean spinup protocol for contemporary transient upper ocean states feasible for high resolution configurations.

OMIP cycle stabilization and its use as ocean-only spin-up

The Ocean Model Intercomparison Project (OMIP) is designed to study the contemporary ocean climate. The OMIP simulation protocol comprises several cycles of forced ocean simulations using contemporary boundary forcings. The second version (OMIP2) comprises 6 cycles of 61 years forced with the JRA55-do forcing dataset v1.4.0 covering the period 1958–2018 (Tsujino, 2020, DOI: 10.5194/gmd-13-3643-2020). We use a similar protocol to bring the upper ocean levels to a balanced 1990 transient state with the aim to reduce coupled model spinup lengths for km-scale climate simulations. In alignment with the current Climate Digital Twin (ClimateDT) simulation protocol, we use an ERA5 surface forcing and EN4 derived initial conditions. Constrained to the ERA5 period and to comply with the climateDT simulation protocol with historical simulations starting in 1990, we perform OMIP-alike cycles of 49 years covering the period 1941–1990.

While we observe a stabilizing upper ocean mean temperature, issues in OMIP style spin-ups are increasing ocean heat content and jumps in forcings when resetting the boundary conditions transitioning between cycles.



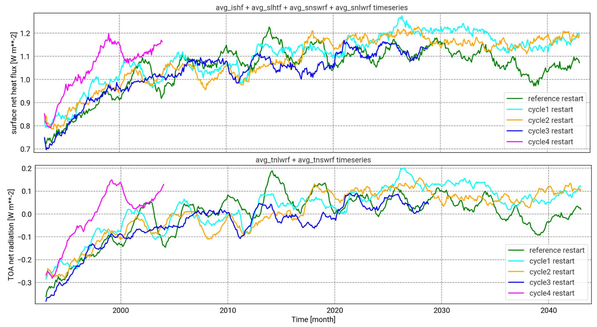
Future work

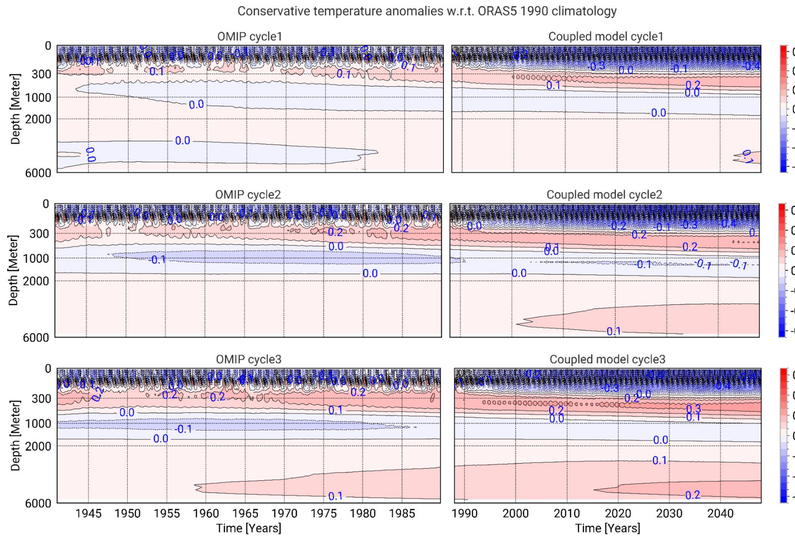
- Reduce the accumulating heat intake by revising the forcing period and data source.
- Revise the number of OMIP-like cycles to optimize the ocean stability.
- Extend the coupled model simulations to find the optimal spin-up length.
- Calculate heat budgets to investigate energy compensating drifts.
- Evaluation of the savings in computing resources and gain in simulation quality.
- Test OMIP-like spinup protocol at the km scale.

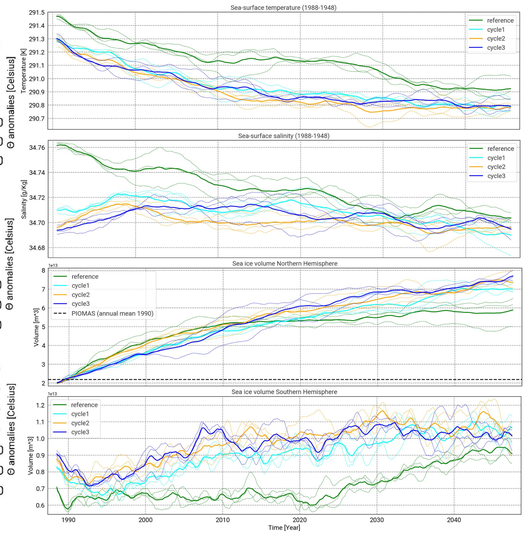
Evaluation of the coupled model simulations starting from OMIP cycle ocean states

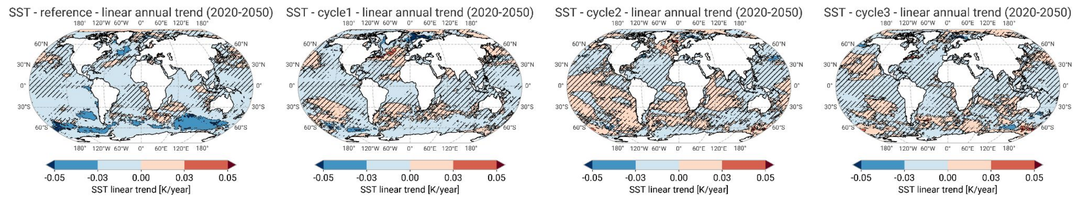
The main objective of this study is to compare the current ClimateDT spin-up protocol with an alternative protocol based on OMIP cycles. The current protocol involves a 5 year ocean only and 2 year coupled spin-up. We observe strong drifts and initial adjustments in the simulations due to insufficient time for balancing the models.

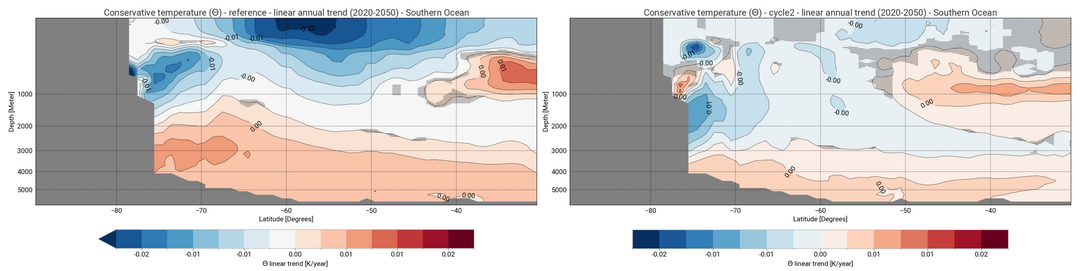
The overall heat content of the ocean increases, which is consistent with the positive TOA imbalance and surface fluxes. In contrast to an expected warming of the ocean surface caused by the heat intake, the upper ocean layers are cooling while the intermediate layers are warming. The Hovmöller plots show that the upper ocean cooling is the result of a heat redistribution in the ocean caused by compensating drifts.

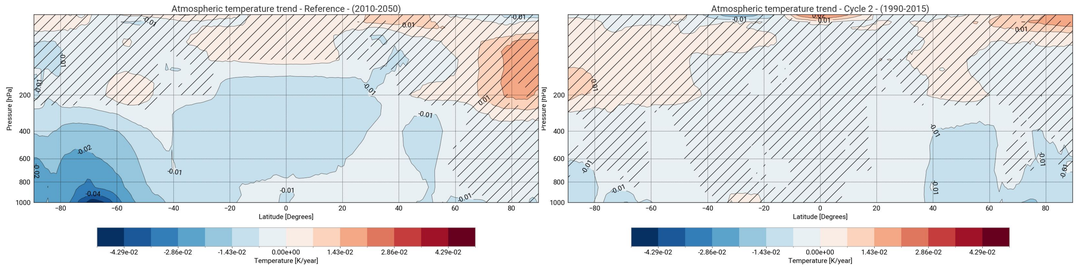












Factsheet and conclusion

Our ocean-only simulations use the ClimateDT configuration of the Nucleus for European Modelling of the Ocean (NEMO) model V4.0.7 with a horizontal resolution of about 25 km (eORCA025 - ¼ degrees). In accordance with the OMIP protocol, we apply a surface salinity restoring. In contrast to the original OMIP protocol, we nudge towards an EN4 climatology instead of WOA. Due to freshwater budget inconsistencies, we also apply a freshwater budget control to close the water budget. Without a freshwater budget control, we observe strong salinity and sea-surface height drifts. The coupled model simulations are performed with the ClimateDT IFS-NEMO version with the same NEMO version used for the spin-up and IFS with version Cy48R1 with an atmospheric resolution of about 25 km as well (Tco399/eORCA025).

We conclude that when performing at least one OMIP-like cycle, we can reduce the length of the subsequent coupled spinup considerably. The time series for literally all variables that we evaluated indicate a much smoother trend earlier. A well behaved or linear trend is essential to detrend historical simulations and future projections for more accurate assessments.

When looking at trends for the last 30 years of the coupled spinup (the plots left to this panel), we observe significantly weaker trends when starting from cycle 2 ocean states compared to starting from a 5-year ocean spinup, which is the current ClimateDT spin-up protocol. This has implications for the trends in the atmosphere as well, as we can see in the plots to the left of this panel at the bottom. Applying the OMIP-like spinup protocol can improve the simulation and save computing resources, as it is indicated in the table below.

Type	OMIP cycles	SY oce	SY atm	COST [million cH]
Current DestinE protocol	-	5	> 60	**> 84**
1 OMIP cycle	1	50	40	**62**
2 OMIP cycles	2	100	40	**68**
3 OMIP cycles	3	150	40	**74**
4 OMIP cycles	4	200	40	**80**
5 OMIP cycles	5	250	40	**86**

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