SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2024
Project Title:	A new decadal prediction system based on EC-Earth3
Computer Project Account:	spdkdrew
Principal Investigator(s):	Tian Tian
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Affiliation:	Danish Meteorological Institute
Name of ECMWF scientist(s) collaborating to the project (if applicable)	N/A
Start date of the project:	Jan 1, 2024
Expected end date:	Dec 31, 2025

Computer resources allocated/used for the current year and the previous one
(if applicable)
Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	16800000	16,036,859	15,000,000	152,209
Data storage capacity	(Gbytes)	25000	0	25000	0

Summary of project objectives (10 lines max)

The project aims to develop an advanced decadal climate prediction system using the EC-Earth3 model under the framework of atmosphere-ocean coupled assimilation. By assimilating anomalies from ERA5 surface pressure and HadISST sea surface temperatures over 5-10 years, known as spin-up times, we aim to create realistic ocean states as initial conditions in subsequent free-running decadal climate hindcasts from 1990 to 2020. This approach will test different spin-up times, performing ensemble assimilations, and conduct hindcasts following the protocol of CMIP6 Decadal Climate Prediction Project (DCPP, Boer et al. 2016). The prediction skill will be evaluated and compared with the other prediction systems, in particular the previous system with the anomaly initialization (Tian et al, 2021). The approach seeks to achieve more realistic oceanic circulation and improve prediction skill by avoiding subsurface assimilation and enhancing the balance between model dynamics and observed climate states.

Summary of problems encountered (10 lines max)

Summary of plans for the continuation of the project (10 lines max)

Our goal is to develop the next generation of decadal climate predictions, providing climate data from 1960 to 2035. To ensure optimal spin-up length for fully adjusted oceanic circulation, we designed the following experiments:

(1) **A reference simulation** using CMIP6 historical forcing and SSP2-4.5 to establish a 30-year running climatology.

(2) **Spin-up simulations with SST-restoring** over varying windows (35, 25, 20, 10 and 5 years before 2015–2024 predictions).

(3) Similar **spin-up experiments using atmosphere nudging**.

(4) **Coupled assimilation spin-up** simulations, combining (2) and (3).

List of publications/reports from the project with complete references

Summary of results

Experiment (1): Reference (baseline) Runs and Initial conditions

We prepared initial conditions from a reference simulation on the Atos HPC2020, starting in 1930 to ensure a consistent 30-year climatology before 1960. Performance is comparable to the earlier DMI Cray XC50 run: both capture the historical warming trend, confirming EC-Earth's robustness, while subtle differences highlight the need for a dedicated reference run for decadal prediction and skill assessment. Further validation is ongoing (see First Period Report).

Reconstructing assimilated data using a moving climatology

The assimilated data (atmosphere surface pressure and ocean surface temperature) will be constructed using a moving climatology from the new reference run on ATOS. For each year, the climatology is updated to include the preceding 30 years (e.g., 1950–1979 for 1980, 1951–1980 for 1981). These data are reconstructed by combining the running model climatology with the observed anomalies for each respective year. This approach ensures a dynamically consistent baseline for anomaly calculations. An example for one year is shown in Figure 1.

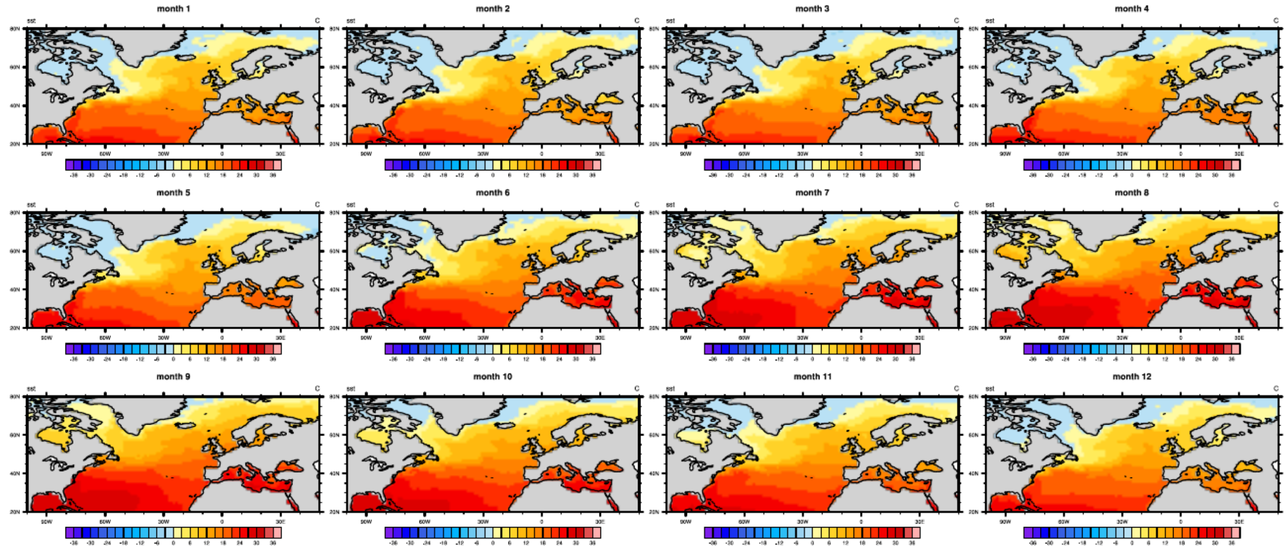

Figure1. Example of monthly SST for 1980, reconstructed using the moving climatology (1950–1979) from the new reference run, combined with the observed anomaly for that year. The global SST is prepared, zoomed into the North Atlantic.

Experiment (2): Spin-up simulations with SST-restoring over varying windows

This experiment investigates two key aspects: the spin-up duration required for SST anomalies to stabilize from different initial years and the impact of spin-up length on deeper ocean circulation and memory retention in prediction runs.

Figure 2 shows the temporal evolution of SST anomalies in the SST restoring run starting at different years, i.e., 1980, 1990 and 1995, respectively. All three restoring simulations agree strongly with the observations, confirming the correct implementation of SST-restoring. In particular, the figure demonstrates model's ability to reproduce the evolutions of the observed global and regional surface temperature, as well as the large-scale patterns, including the El Niño–Southern Oscillation (ENSO), Atlantic Multi-decadal Variability (AMV), and Inter-decadal Pacific Oscillation (IPO, not showed). The Subpolar North Atlantic is also evaluated, as our study has strong motivation of enhancing the North Atlantic predictability.

To understand the impact of the length of the spin-up time, we investigate the correlation of regional mean SSTs between each of the assimilation runs and the observation in the period 2004-2013. Notably, the correlation coefficient is lowest with a 35-year spin-up length (sr04: starting at 1980) across all regions. For the North Atlantic, a moderate spin-up length of 25 years (sr02 starting at1990) provides the best results, while shorter spin-up duration of 20 years (sr03, starting at 1995) are more effective in capturing tropical Pacific patterns. This raises two key questions for further investigation: 1) Will a 25-year spin-up remain optimal for capturing North Atlantic variability with different initial states? 2) How do shorter spin-up durations, such as 5, or 10 years, impact the model's performance?

Figure 3 highlights the response of surface air temperature (TAS) anomalies and ocean circulation (AMOC) strength during 2005–2013. The assimilated global TAS anomalies are generally consistent across simulations and align well with ERA5 observations, with better correlation in the 35- and 25-year spin-ups compared to the 20-year spin-up. AMOC strength in 25-year spin-up (1990–2013) shows the smallest deviation from observations, although the observation period (2005–2013) is relatively short for AMOC. In contrast, the 35-yr spin-up (1980–2013) shows the greatest departure from observations. This suggests that initialization conditions and deeper ocean memory from the longer spin-up period influence AMOC dynamics. These results imply the importance of spin-up duration for better simulating AMOC variability and its role in ocean-atmosphere interactions. The choice of spin-up duration should balance the representation of key processes in the target regions.

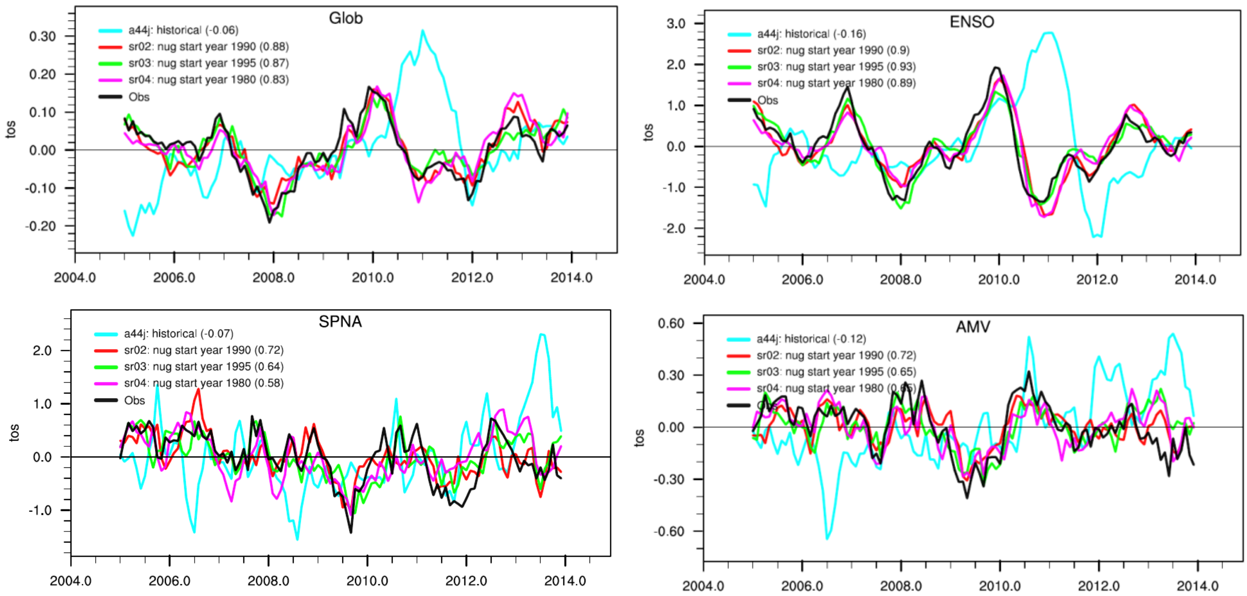

Figure 2. Time series of sea surface temperature (SST) anomalies (2005–2013) averaged over the globe (upper left), ENSO region (Upper right), Atlantic Multidecadal Variability (AMV) region (lower right), and Subpolar North Atlantic (SPNA) region (lower left). Results are shown for the reference simulation (a44j, cyan line) and three SST-restoring simulations initialized in 1980 (sr04, pink line), 1990 (sr02, red line), and 1995 (sr03, green line). Observations from HadiSST (black line) are included for comparison. The numbers in the figure legend indicate the correlation coefficient of each simulation with the observations.

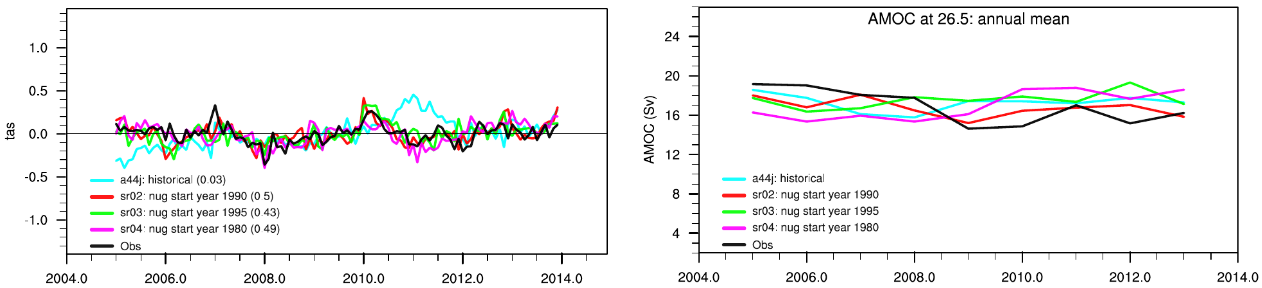

Figure 3. Time series of global TAS anomalies (left, unit: K) and Atlantic Meridional Overturning Circulation (AMOC, right, unit: Sv) strength (2005–2013). Results are shown for the reference simulation (a44j) and SST-restoring simulations initialized in 1980 (sr04, pink), 1990 (sr02, red), and 1995 (sr03, green). Observations (black) from ERA5 (TAS) and RAPID (AMOC) are included for reference.

On-going experiments and analysis:

Based on the existing experiments and results, we are extending the simulations and refining the analysis as follows:

1) **Decadal prediction simulations**: simulations will be extended from November 1, 2014, or January 1, 2015, using restart files from the assimilated runs and extended for 5-10 years, without assimilation.
2) **Additional simulations with shorter spin-up durations**: decadal prediction starting on the same date as in point (1) with shorter of 15 years, 10 years, 5 years.

We will continue the analysis with a focus on North Atlantic variability, building on our previous results using the regional 3D-nudging approach (Drews et al., 2024), and addressing the following:

1) Seasonal analysis on surface variables: Identify when the influence of restoring SST diminishes in the predictions.

2) Multi-year analysis on ocean circulation: Investigate the impact of spin-up on deeper ocean circulation and equilibration of ocean variables, including AMOC at 26N and 45N, and SPNA mixed layer depth (MLD).

Collaborative Initiatives: towards coordinated multi-model S2D prediction for CMIP7
We attended the Impetus4Change Annual Meeting 2025 (June 3–5, Prague) and discussed early progress and CMIP7 plans during the "WP2: Improving S2D Predictions" breakout session. Participants from four climate prediction groups (BSC, DMI, NERSC, MPI)—all developing next-generation systems including EC-Earth3—agreed to coordinate and align new multi-model DCPP experiments as a joint contribution to CMIP7.

References

Drews, A., Schmith, T., Tian, T., Wang, Y., Devilliers, M., Keenlyside, N., Yang, S., and Olsen, S., 2024: The crucial role of the subpolar North Atlantic for skillful decadal climate predictions, Geophys. Res. Lett., 51, https://doi.org/10.1029/2024GL109415.

Boer, G. J., and Coauthors, 2016: The Decadal Climate Prediction Project (DCPP) contribution to CMIP6. Geosci. Model Dev., 9, 3751–3777, https://doi.org/10.5194/gmd-9-3751-2016.

Tian, T., Yang, S., Karami, M. P., Massonnet, F., Kruschke, T., and Koenigk, T., 2021: Benefits of sea ice initialization for the interannual-to-decadal climate prediction skill in the Arctic in EC-Earth3, Geosci. Model Dev., 14, 4283–4305, https://doi.org/10.5194/gmd-14-4283-2021.