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	2021
Project Title:	Impacts of Atlantic Meridional Overturning Circulation (AMOC) decline on European climate
Computer Project Account:	spitbell
Principal Investigator(s):	Katinka Bellomo
Affiliation:	[1]National Research Council of Italy, Institute of Atmospheric Sciences and Climate (CNR-ISAC), Turin, Italy [2]Department of Environment, Land and Infrastructure Engineering, Polytechnic University of Turin, Turin, Italy
Name of ECMWF scientist(s) collaborating to the project (if applicable)	N/A
Start date of the project:	01/01/2021
Expected end date:	31/12/2022

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)			9,880,000	3,445,000
Data storage capacity	(Gbytes)			18,000	N/A

Summary of project objectives (10 lines max)

The objectives of this project are to investigate the nonlinear response of the AMOC to increasing concentrations of CO_2, and the associated weather impacts of an AMOC decline over the European climate. To address these objectives, we proposed to run ad-hoc climate model experiments using the EC-Earth3 coupled climate model with varying degrees of coupling between the atmosphere and the ocean, specifically using the model in fully-coupled mode (ocean and atmosphere fully coupled) and in atmospheric-only mode, in which the atmospheric model is forced by a 12-month climatology of sea surface temperature (SST) pattern computed from the fully-coupled simulations.

Summary of problems encountered (10 lines max)

We didn't encounter specific problems, however we approached the objectives in a slightly different manner. Instead of running simulations with increasing concentrations of CO_2, we started by performing experiments in which the AMOC is artificially weakened imposing a freshwater flux (often referred to as 'water hosing' experiment) in the North Atlantic and Arctic Oceans. We decided to opt for this different experimental design to better separate the role of AMOC from the effects of CO_2, which we will explore next.

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

We are currently analyzing the results of the water hosing experiment and we plan to run additional years of water hosing in order to have enough model years to compute robust statistical significance in the results. As proposed in the original plan, we plan to impose the resulting SST pattern as boundary forcing for atmospheric-only simulations. We also have received funding (through a MSCA-IF fellowship) to implement a slab-ocean model in EC-Earth3, in which the ocean is thermally but not dynamically coupled to the atmospheric model. Hence, we also plan to run a simulation with the slab-ocean to test the role of AMOC (which can be set to zero in the q-flux of the slab-ocean) using the existing requested hours (note that a slab-ocean simulation consumes about the same core hours as an atmospheric-only simulation).

List of publications/reports from the project with complete references

- Bellomo K., V. Meccia, F. Fabiano, R. D'Agostino, P. Davini, J. v. Hardenberg and S. Corti. Weather impacts of an AMOC decline in the EC-Earth climate model: *TiPES General Assembly*, 7-11 June, 2021, online.

- Jackson L.C., R.A. Wood, K. Bellomo, G. Danabasoglu, A. Hu, J. Jungclaus, V. Meccia, O. Saenko, D. Swingedouw: AMOC tipping points in GCMs. *TiPES General Assembly*, 7-11 June, 2021, online.

- Bellomo K., M. Angeloni, S. Corti, J. von Hardenberg: "Future climate change scenarios shaped by inter-model differences in Atlantic Meridional Overturning Circulation response", *International workshop for mid-latitude air-sea interaction*, June 12-14, 2021, online.

- Bellomo K., M. Angeloni, S. Corti, J. von Hardenberg: "Future climate change scenarios shaped by inter-model differences in Atlantic Meridional Overturning Circulation response", *European Geophysical Union General Assembly*, April 19-30, 2021, online.

- Bellomo K.: "Future climate change scenarios shaped by inter-model differences in Atlantic Meridional Overturning Circulation response", *TiPES monthly seminar*, February 3, 2021, online.

Summary of results

We ran EC-Earth3 in its standard resolution (T255 L91, ORCA1L75) to run a water hosing simulation in which we imposed a freshwater flux anomaly of 0.3 Sv in the North Atlantic and Arctic Oceans (see fig. 1) for 50 years. After 50 years, we stopped the water hosing and let them model freely recover. Then, we examined the climate impacts during the transient climate change forced by the AMOC decline (first 50 years). We plan to soon investigate the recovery part of the experiment as well. Note that this experiment will also be an ensemble member of EC-Earth3 for a larger inter-model comparison (NAHosMIP).

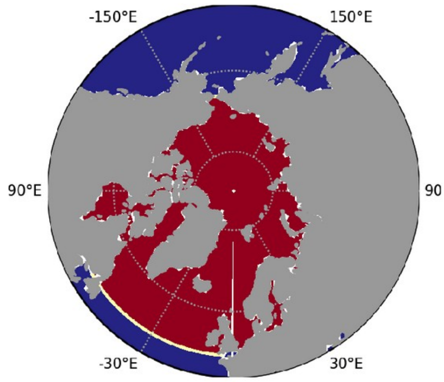


Figure 1: The 0.3 Sv freshwater flux anomaly is applied in the red regions for 50 years.

Fig. 2 shows the strength of the AMOC at 26.5 °N in the (green) control experiment (computed from a pre-industrial control simulation) and (blue) the water hosing simulation. As expected, we find that the water hosing weakens the AMOC strength for 50 years. In this model, the AMOC then starts to recover after the hosing ends.

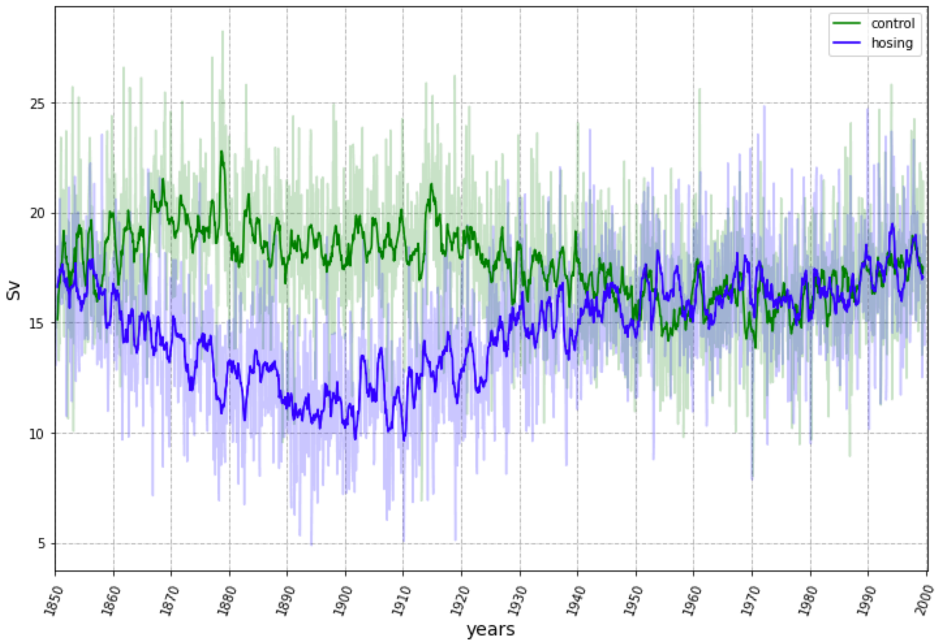


Figure 2: AMOC strength at 26.5°N in the (green) pre-industrial control simulation and (blue) water hosing experiment.

In terms of impacts of the AMOC decline in the first 50 years, we focused in particular on temperature, precipitation and large-scale atmospheric circulation changes. For what concerns temperature and precipitation, we found a general cooling in the northern hemisphere and drying over Europe, consistent with previous studies (fig. 3).

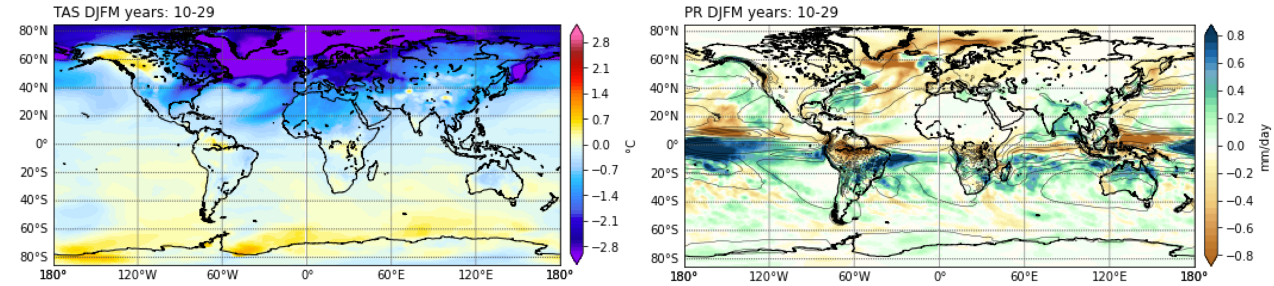
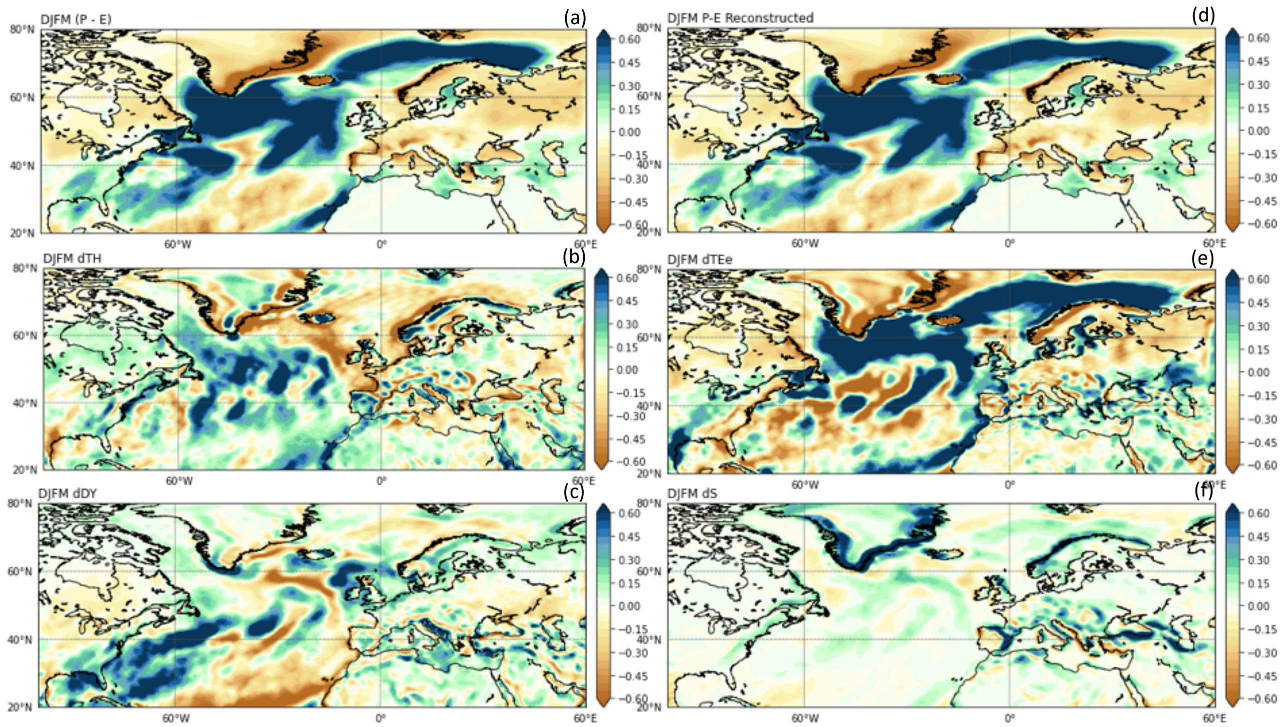


Figure 3: (left) near-surface air temperature difference between the water hosing (mean of years 10-29 of the experiment) and the pre-industrial control (mean of 150 years) in winter (DJFM); (right) same as (left) but for precipitation.

Further, we computed the moisture budget for the precipitation change (fig. 4), deconstructing the moisture change (precipitation minus evaporation) into thermodynamic (fig. 4b), dynamic (fig. 4c), transient eddies (fig. 4e), and orography (fig. 4f) processes. We found that the drying over Europe is largely driven by a northward shift of the transient eddies over the Nordic Seas.



We also examined changes in weather regimes and frequency of blocking (not shown). We found an increase in the occurrence of positive North Atlantic Oscillation (NAO+) days and blocking over northern Europe in winter.

We are currently working on increasing the water hosing years to improve statistical significance testing, and we are designing the upcoming experiments to be performed with atmosphere only and slab-ocean coupling. Note that we haven't used the requested storage yet because we used storage from other members in our research group, but with the upcoming experiments that we have planned, we will have a need for it.