SPECIAL PROJECT FINAL REPORT

Project Title:	Impact of model Resolution on Ocean Dynamics (IROD)
Computer Project Account:	spitdavi
Start Year - End Year :	2018 - 2019
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Summary of project objectives

The objective of this special project is to investigate the impact of model resolution (both atmosphere and ocean resolution) on the ocean dynamics in the tropical Pacific and North Atlantic Oceans, which are two essential regions affecting the global climate. To this aim we performed both high (T511L91 ORCA025L75) and standard (T255L91 ORCA1L75) resolution coupled simulations with the EC-Earth coupled climate model (Hazeleger et al. 2010) following the HighResMIP protocol (Haarsma et al. 2016).

Summary of problems encountered

Following new agreements inside the EC-Earth consortium at the end of 2018, the initially proposed simulations covering the historical future period (1950-2014 TRANSIENT and 2015-2050-FUTURE) have been ran by other consortium partners so that they have been no longer needed. We thus decided to focus on a set of high resolution (T511L91-ORCA025L75) simulations part of the Decadal Climate Prediction Project component C1 (DCPP-C) which are based on the methodology by Boer et al. (2016). They investigate the effect of the Atlantic Multidecadal Variability (AMV), relaxing the North Atlantic oceanic upper levels towards a specified AMV state, while the rest of the coupled system is left free to drift. Two series of 10-year experiments in which the North Atlantic SSTs are forced with the signal associated with twice the positive and twice the negative phase of the AMV respectively have been performed. Seven members have been run and then compared with low resolution members run by other members of the EC-Earth consortium.

Experience with the Special Project framework

Project reporting requirements was clear and smooth, as well as administrative tasks and communication with special project office. Very good assistance by HPC staff was also provided, for instance allowing us to double the scratch storage space available when the project reached its uppermost productivity.

Summary of results

Simulation setup

IROD project has been based on the EC-Earth3P model, a EC-Earth configuration that has been frozen in early 2018 – using the EC-Earth 3.2.3 version - in order to be part of the HighResMIP protocol. Indeed, it has not been possible to take advantage of the CMIP6 version of the EC-Earth Global Climate Model since a definite version has been only released in late June 2019. This version present mainly some differences in terms of tuning and has therefore named EC-Earth3P (the TL255L91-ORCA1L75 configuration) and EC-Earth3P-HR (the TL511L91-ORCA025L75 configuration). External forcing used in the IROD project follows indeed the HighResMIP protocol which slightly differs from the CMIP6 protocol (see Haarsma et al. 2016).

A correct scaling of the EC-Earth3P and EC-Earth3P-HR allowed the best ratio for cores for both the ocean and atmosphere. A supplementary optimization has been possible due to the recent update of the EC-Earth model which now includes ELPiN (Tinto et al, 2017), a basic tool that allows for the correct reparation of the cores in the parallelization procedure of the NEMO oceanic model. This has the power of excluding the cores targeting the land allowing for a significant reduction of number of cores needed to achieve the same walltime: this increased considerably (by about 20%) the number of years that has been possible to run.

All the output has been postprocessed following the cmor requirement taking advantage of the ecec2cmor package that has been developed for CMIP6 (https://zenodo.org/record/1051094#.XRSQqJMzb1I). Finally, the data have been transferred to the BADC Jasmin server from where they have been published on the ESGF portal being part of CMIP6.

a. *1950-CONST*

The first set of simulation ran in IROD project regards a couple of control runs carried out in both configurations, the standard resolution EC-Earth3P and the high resolution EC-Earth3P-HR. These two consist of a 100-year simulation from 1950 up to 2049 with constant forcing from year 1950, which is known as control-1950 within the HighResMIP protocol.

Due to the large computational cost of running a long spinup at high resolution, it has not been possible to achieve a full equilibrium during the 52-year spinup (which have been provided by another member of the EC-Earth Consortium). Therefore these control runs are used as a reference to investigate the changes in the associated historical simulations (see Haarsma et al. 2020).

Following further agreements inside the EC-Earth consortium, only the high resolution run has been finally used as a reference for EC-Earth-3P-HR and has been published on the Earth System Gateway Federation (ESGF) node.

b. *DCPP-C*

As a consequence of changes mentioned above, the projected future scenarios (1950-2014-TRANSIENT and 2015-2050-FUTURE) has been run by other members of the EC-Earth Consortium so that IROD project changed its goal, always pursuing the analysis of the impact of high resolution on the oceanic dynamics. To this aim, the attention was shifted to a group of Atlantic Multidecadal Variability (AMV) sensitivity experiments part of the DCPP-C project (Boer et al. 2016). In these runs the oceanic mixed layer is relaxed toward a specific state of the AMV applying a heat and freshwater flux corrector (i.e. nudging a subdomain of the ocean model). In such way it is possible to run an experiment where the whole ocean but the North Atlantic is free to drift, and where a AMV positive phase or negative phase are obtained. These simulations are run with the same radiative forcing as the 1950-CONST: this simulation is indeed taken as initial conditions for all the ensemble members, spanning 10 years each. The integrations only last 10 years and, given the elevated cost of the high resolution, it was decided to apply a forcing that is twice the AMV signal in order to strengthen the significance of the results. A total of seven ensemble members with positive forcing and seven members with negative forcing has been run, resulting in 140 years of simulations. Other 4 ensemble members have been run by other members of the EC-Earth Consortium.

Results

Considering the multiple contributions to HighResMIP, the simulation resulting from IROD has been shared among the consortium producing several publications which have been analyzing EC-Earth simulations under a multi-model view: a few details on the simulations is here reported but the most of the details can be found in the referenced publications.

a. *1950-CONST*

The results from the EC-Earth3P and EC-Earth3P-HR simulation are detailed in Haarsma et al. (2020): here a synthesis of the findings is shown, the reader is referred to their Figure 11, 13, 14, 15, 16 and 17 for a completed discussion on EC-Earth-3P-HR 1950-CONST.

EC-Earth3P-HR control run show a weak trend in surface temperature (which is smaller than its low resolution counterpart, not shown), suggesting that the model is close to the equilibrium, although the global ocean temperature is still rising and positive heat fluxes entering into the ocean are still observed. This can be seen in Figure 1, where the evolution of globally averaged SST and of the Atlantic Meridional Overturning circulation is shown.

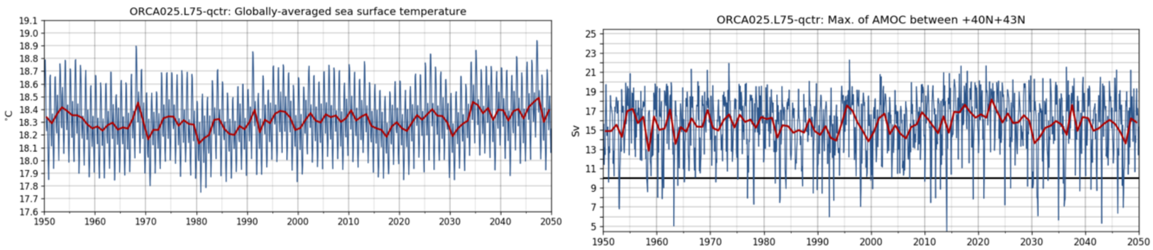

Figure 1: (left) evolution of SST in the 100-year HR control simulation (right) evolution the Atlantic Meridional Overturning Circulation (AMOC) at 40N in the HR 1950-CONST control simulation.

Although negligible differences between EC-Earth3P and EC-Earth3P-HR are observed in several atmospheric circulation features, as the North Atlantic Oscillation representation and the frequency and properties of Sudden Stratospheric Warmings, interesting improvements are found when the characteristics of the ocean circulation are analyzed. Indeed – on top of a better representation of the climatological SST field – the variability of the mid-latitude SST in EC-Earth3P-HR is better represented (Figure 2). Indeed, the small-scale features and meanderings along the western boundary currents as well as along the sea-ice edge over the Labrador Sea show a larger variability than in its low resolution counterpart (Figure 2). In these three areas there is a substantial increase in SST variability, here expressed as monthly standard deviation. Such feature, following Haarsma et al. (2019) conclusions, is likely due to increasing ocean resolution rather than atmosphere resolution and have important consequences on the atmospheric variability too.

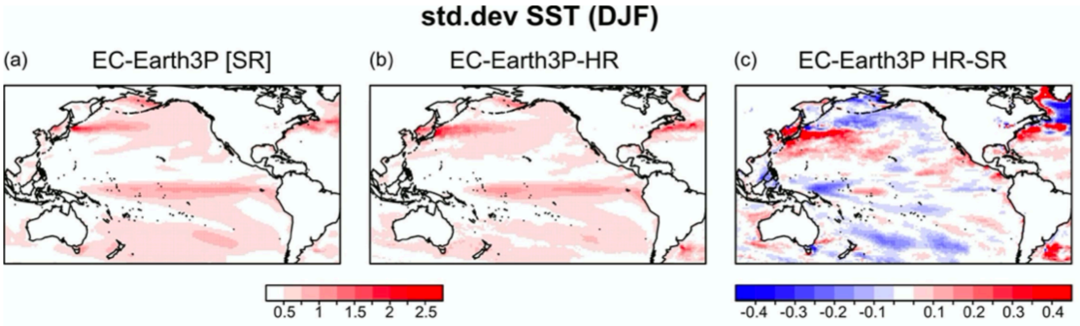

Figure 2: DJF SST interannual standard deviation from 1950-CONST in EC-Earth3P, EC-Earth3P-HR and their difference. From Haarsma et al. (2020).

The El Nino Southern Oscillation (ENSO) simulation is one of the other key feature affected by the increase in resolution, and this is shown in Figure 3. Both EC-Earth3P and EC-Earth3P-HR show a constant underestimation of the ENSO intensity from late-autumn to mid-winter. They show the minimum in July, 2 months later than what seen in HadISST. Increasing model resolution reduces the late spring bias but increases the mid-summer one. Overall, EC-Earth3P-HR shows lower ENSO variability than EC-Earth3P.

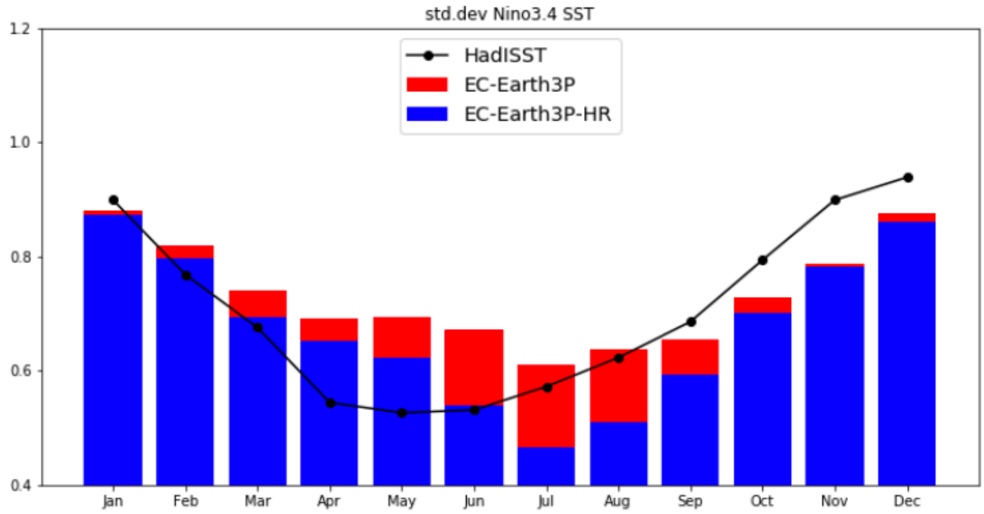

Figure 3: Monthly standard deviation of the Nino3.4 SST index (5S-5N/170W-120W) for from 1950-CONST in EC-Earth3P (red), EC-Earth3P-HR (blue) and detrended HadISST over the 1900-2010 period (black). From Haarsma et al. (2020).

b. DCPP-C

Results of those simulations are part of several works that are currently under review, with the most of the results included in Ruprich-Robert et al. (2020). Given the larger focus on multi model ensemble of these manuscripts, we provide here an outlook of the comparison between the EC-Earth3P and the EC-Earth-3P-HR AMV+ and AMV- experiments.

The results for these experiments are shown always as the difference between the positive phase of the AMV run minus the negative phase of the AMV (i.e. AMV+ - AMV-). In such way it is possible to highlight the AMV signal, which has been shown to be often quasi-linear (e.g. Peings and Magnusdottir, 2015): further details can be inferred making use of the 1950-CONST simulation which can be used as a reference.

Figure 3 shows the expected impact of the surface restoring over the North Atlantic basin, where a warmer temperature is imposed in AMV+ experiments and a colder one in AMV-. Stronger impacts are obtained in winter along the sea-ice edge, as a consequence of the larger sea-ice cover in AMV- experiments. As expected, the signal spreads over the whole Northern Hemisphere, especially in the downstream side of the Atlantic over Africa and Asia. It is interesting to notice that in winter larger impacts are observed in the high resolution configuration, with a considerable warming also over the Arctic region.

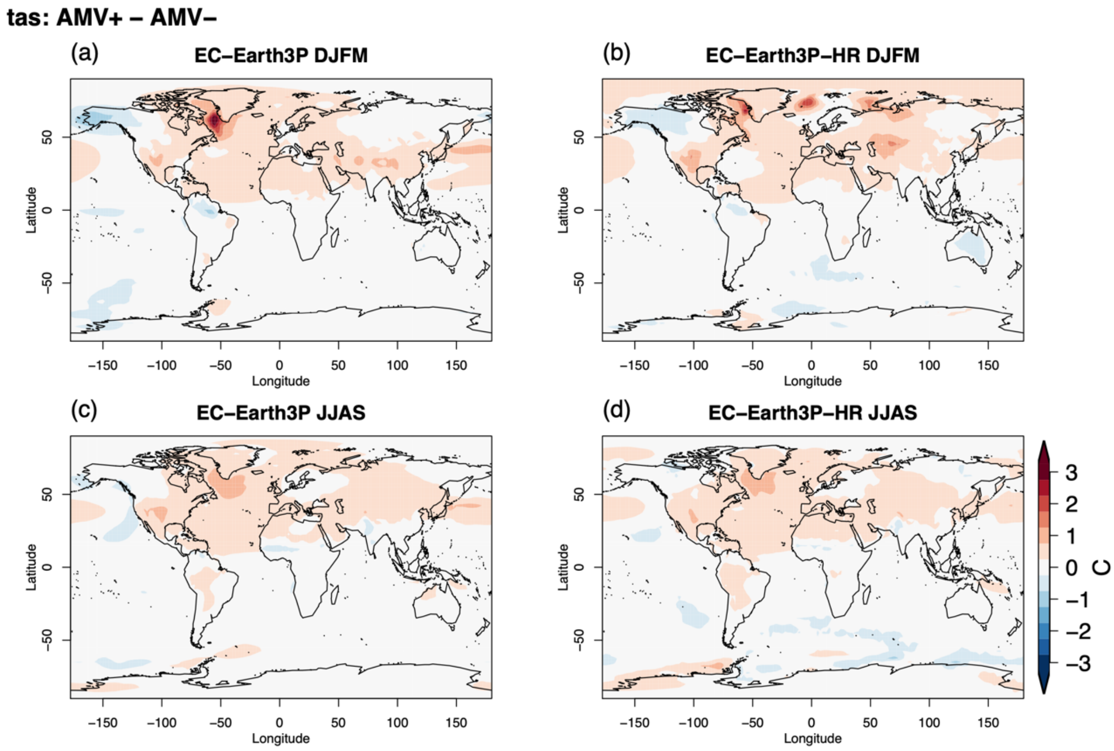

Figure 4: Surface temperature ensemble mean for AMV+ minus AMV- experiments climatology for EC-Earth3P (left) and EC-Earth3P-HR (right) in boreal winter (top) and summer (bottom).

To better investigate the atmospheric circulation changes associated with this forcing, the geopotential height at 500hPa is shown in Figure 5. Here it is possible to see that in some unexpected way the larger impact of the AMV anomalies is produced over the Pacific ocean rather than over the Atlantic one. Both the models show a consistent weakening of the Aleutian low in winter time, suggesting a clear connection between the two basins. On the contrary, the signal over the Atlantic is different between the two models, projecting on the negative phase of the North Atlantic Oscillation but with the shape of a wave train in the high resolution configuration. Indeed, zonal wind too is highlighting different changes over the Atlantic in the two configurations (not shown): in EC-Earth3P the jet is shifted poleward following the more common NAO-like responses (Peings and Magnusdottir, 2015, Ruprich-Robert et al. 2016) while in EC-Earth3P-HR the jet is mainly weakened. This opens to two different alternatives: 1) the model is characterized by an extremely large interannual variability which covers the impact of the AMV forcing over the Atlantic basin 2) there exists a considerably strong dependence on the mean state of the AMV response over the Atlantic region. Further work in this direction is ongoing.

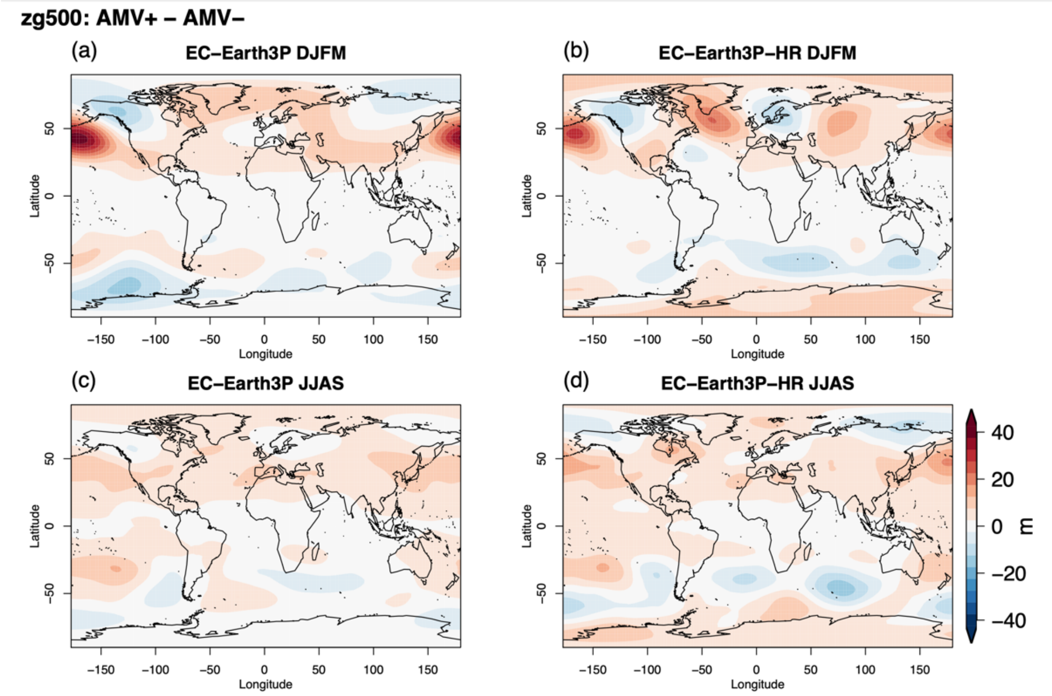

Figure 5: Same as Figure 4, but for geopotential height at 500hPa.

Finally, Figure 6 investigates the connection between the AMV and the Pacific, which was evident in Figure 5. This is done looking at the vertical velocity: indeed, changes in the Walker circulation guided by the tropical Atlantic can affect the tropical Pacific convection, and from there, as it happens during ENSO events, Rossby waves are triggered influencing extratropical Pacific. This is confirmed by Figure 6, where in both models a strong redistribution of tropical convection is observed, with increased convection over the Western Atlantic and the Indonesia regions, associated with a marked subsidence over the Central Pacific. The sensitivity of convection to the AMV changes is actually what drives the multi model spread of the AMV response over the Pacific (Ruprich-Robert et al. 2020).

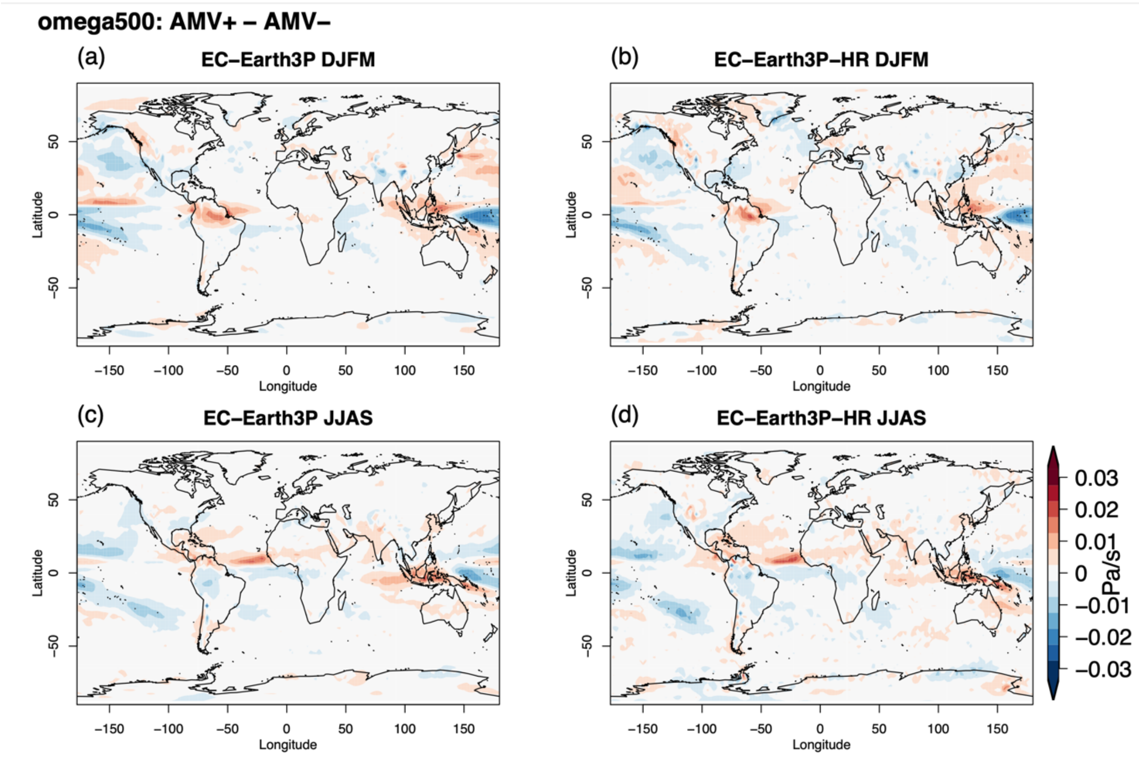

Figure 6: Same as Figure 4, but for vertical velocity at 500hPa.

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List of publications/reports from the project with complete references

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Future plans

No further activity is planned at the moment with high resolution EC-Earth