SPECIAL PROJECT PROGRESS REPORT

Progress Reports should be 2 to 10 pages in length, depending on importance of the project. All the following mandatory information needs to be provided.

Reporting year	2016
Project Title:	High-resolution climate prediction with EC-Earth
Computer Project Account:	SPESICCF
Principal Investigator(s):	Francisco J. Doblas-Reyes
Affiliation:	Barcelona Supercomputing Center
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Eleftheria Exarchou, Chloé Prodhomme, Virginie Guemas
Start date of the project:	01/01/2015
Expected end date:	31/12/2016

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)	37,050,000	38,499,421	37,050,000	4,891,211
Data storage capacity	(Gbytes)	0	0	0	0

Summary of project objectives

(10 lines max)

The main objective of SPESICCF was to investigate the impacts of increased resolution in both the ocean and the atmosphere on seasonal prediction quality. To this end, we have compared seasonal predictions performed with the high- and standard-resolution configurations of EC-Earth3. Motivated by the important role of the ocean in seasonal prediction, we have also investigated the impact of ocean initialisation by using initial conditions from three different ocean reanalysis datasets, namely GLORYS2V1, ORAP5, and GLOSEA5. We plan to extend this comparison by including forecasts that are initialized by a fourth ocean reanalysis dataset, which will be available in 2016 (ORAS5). We assess the results in terms of skill, drift behaviour and structure of the oceanic circulation.

Summary of problems encountered (if any)

(20 lines max)

We found an unexpected behaviour of some runs using the CCA platform. In particular, one experiment using our high-resolution configuration did not work. We noticed in this experiment that the MPI communications, used to transfer information among components which are using different binaries, did not work correctly, missing some of the messages from the senders to the receivers. This produced a blocking where some MPI processes are waiting indefinitely for messages which never reach the destination, wasting at the same time our simulation hours produced by this blocking.

We think that this problem could be related to the platform, the compiler version and the IntelMPI libraries for two reasons. The first one is that the standard configuration works, using the same computational model and configuration environment to compile and run. The only difference would be the input data and the number of processes used. The second one is that we run the same experiment (the high-resolution configuration) using another platform (Marenostrum3) without any problem, taking into account a special configuration in order to manage the parallel execution.

Summary of results of the current year (from July of previous year to June of current year)

This section should comprise 1 to 8 pages and can be replaced by a short summary plus an existing scientific report on the project

I. Experiment description

The seasonal forecasts performed for this project have been run with the EC-Earth Earth System Model (ESM), which is developed by the EC-Earth consortium, counting close to 20 European institutions. EC-Earth consists in the coupling of different models representing the components of the Earth system: atmosphere, land, ocean, sea-ice, vegetation, glaciers, and atmospheric chemistry. In the present study, we use the version 3.1 of the coupled model. An earlier version of the EC-Earth ESM is described in detail in Hazeleger et al. (2012). The main differences between these two versions are an improved radiation scheme (Morcrette et al., 2008) and a new cloud microphysics scheme (Forbes et al., 2011). Some additional differences between the version 3.1 and the earlier version in the atmosphere are the inclusion of a Rayleigh friction, the use of an updated stratospheric aerosol optical depth, the introduction of an advection mass fix for water species, and finally, a reduction of the ocean diffusive albedo. Some modifications in the ocean model in the version 3.1 include a runoff flux correction, and a fix in an inconsistency of the bathymetry in the Gibraltar Strait. Also, the version 3.1 has some adjustments in the freshwater flux correction in the coupler.

We have completed four sets of forecasts, each comprising 4-month-long seasonal forecasts, initialized every 1st of May between 1993-2009. By forecasts, here, we refer to retrospective forecasts (equivalently, hindcasts). These sets of forecasts differ in two aspects: they have different oceanic initial conditions, namely GLOSEA5 (MacLachlan et al., 2015), ORAP5 and GLORYS2V1 (Ferry et al., 2010). They also are performed in different resolutions, where three experiments are in high resolution or "HR", where the spectral truncation of the atmospheric model (IFS) is T511 (approximately 40 km globally) with 91 vertical levels, and the grid resolution of the ocean model (NEMO3.3) is 0.25° globally (approximately 25 km) with 75 vertical levels (T511L91-ORCA025L75). One additional experiment was performed with the standard-resolution configuration or "SR" where the spectral truncation of the atmospheric model (IFS) is T255 (approximately 80 km globally) with 91 vertical levels, and the grid resolution of the ocean model (NEMO3.3) is 1° globally (approximately 110 km) with 46 vertical levels (T255L91-ORCA1L46). The main characteristics of these experiments are summarized in Table 1. In all experiments, the sea ice is initialized from GLORYS2V1 and the atmosphere from ERA-Interim (Dee et al., 2011). We assess these forecasts in three main aspects: their bias in sea surface temperature (section II.1), sea-ice extent (section II.2), ocean circulation (section II.3) and their skill in predicting the tropical climate (section II.4). The comparison among the three high resolution experiments reveals the impact of the initial conditions, and the comparison between HR-GLORYS and SR-GLORYS reveals the impact of model resolution on the aforementioned aspects of the forecasts.

Regarding storage space, the experiments have been run using Autosubmit, the launching and monitoring solution developed by the applying team that allows the remote submission of EC-Earth and NEMO experiments. Autosubmit includes in the workflow of the experiments a job that retrieves the data back to the local storage at the BSC Earth Sciences Department as soon as each chunk of simulation has completed, releasing space in the scratch. This means that we ended up not using any permanent storage at ECMWF for the experiments.

Exp name	Ocean resolution	Atmosphere resolution	Initial conditions for the ocean	Number of ensemble members
HR-GLOSEA5	ORCA025L75	T511L91	GLOSEA5	5
HR-ORAP5	ORCA025L75	T511L91	ORAP5	3
HR-GLORYS	ORCA025L75	T511L91	GLORYS	10
SR-GLORYS	ORCA1L46	T255L91	GLORYS	10

Table 1: Summary of the experiments discussed. All experiments are four-month-long forecasts, initialized every 1st May from 1993 to 2009.

II. Results

II.1 Sea surface temperature

Fig 1 shows the SST forecast drift (the evolution of the forecast bias with forecast time) for the boreal summer (JJA) over the 1993-2009 period, with respect to HadISST observational data, for all four experiments described in Table 1. The forecast biases are expected to converge to the model biases after the model reaches quasi-equilibrium, when the model drift converges to zero. The model biases in SST (not shown here) can be mainly described by a cold equatorial Pacific bias, a warm bias in the equatorial and eastern subtropical Atlantic and a cold bias in the northern hemisphere. These features are already present in the forecasts in Fig 3. The cold bias in the northern hemisphere is weaker when initializing from GLORYS, compared to ORAP5 and HadISST. The warm bias in the Tropical Atlantic is strongest when initializing from ORAP5 and weakest when initializing from GLOSEA5. The cold Equatorial Pacific bias is weaker in high resolution, and also when initializing with ORAP5 and GLOSEA5. These results emphasize that both optimal initial conditions and higher model resolution are important in reducing model bias.

II.2 Sea ice

Fig 2 shows the prediction skill in sea ice extent estimated as the correlation of the ensemble mean prediction with two different observational datasets (osisaf and NSIDC), as a function of forecast month. In the Northern hemisphere, the correlation obtains values higher than 0.9 in May that drop to values no lower than 0.75 by August. The skill is comparable among all experiments, implying that neither the resolution, nor the oceanic initial conditions play an important role on the skill in pan-Arctic sea ice extent. This result is likely related to the sea-ice initial conditions which are the same (GLORYS2V1) for all experiments. For the Antarctic sea ice extent, however, there is hardly any skill in the forecasts, even in the first forecast month. The two experiments that are initialized with GLORYS have the highest skill, but it is significant only in the first forecast month. A possible explanation for the lack of skill in the Southern hemisphere could be related to a well known issue in EC-Earth3.1, which suffers from a strong drift in Southern sea ice where the model loses large quantities of sea ice already in the first days of the forecast. This drift is so severe that instead of predicting the increase of sea ice over Antarctica during the southern winter, the model loses more than a third of its sea ice in only four months. This is a model bug, which is likely related to the ocean convection schemes. The implication is that the results of these forecasts need to be interpreted with caution when they involve the climate in the Southern hemisphere.

II.3 Meridional Overturning Circulation

Fig 3 shows the Atlantic meridional overturning circulation (MOC), described by the meridional overturning streamfunction (in Sv, where 1 Sv = 10^6 m^3/s), as a function of the j-coordinate of the model grid (roughly corresponding to north-south), and averaged for all the months and all the years of the forecasts of Table 1. Positive values denote clockwise circulation, and negative values counterclockwise circulation. For comparison, the MOC of ORAS4 (Mogensen et al, 2011; Balmaseda et al, 2012) is also shown. The Atlantic MOC is characterized by two cells: one is associated with northward transport close to the surface, and southward transport of deep North Atlantic water below 1 km depth. The second cell is associated with the northward transport of Antarctic bottom water below 4 km, and the southward transport of water masses that are mixed with the southward branch of the upper cell below 3 km. While the strength of the top cell is comparable among all experiments, and similar to ORAS4 (reaching about 20-22 Sv), the structure is different. While in ORAS4 and SR-GLORYS the maximum values are obtained at about 50^{o}N , in the HR experiments the maximum values are obtained southwards, at about 10^{o}N. Moreover, the bottom cells are weaker in ORAS4 and SR-GLORYS, reaching about 2 Sv in magnitude, while in the HR experiments, they reach about 4 Sv or more. The similarity in MOC between ORAS4 and SR-GLORYS is likely due to the similar ocean resolution, which differs only in the number of vertical levels (ORAS4 has been run with 42 vertical levels and SR-GLORYS with 46 levels. The resolution, therefore, plays an important role in setting up the structure and the strength of the ocean circulation, which is likely related to better resolved convective processes, mixing and therefore flows in the polar regions, where the deep water formation is taking place.

II.4 Skill in the tropical ocean

Fig 4 shows that increasing the resolution lead to a significant increase of skill in the Niño 3.4 region, consistent with Prodhomme et al. (2016). The skill in the region is further enhanced when the seasonal forecast is initialized with the GloSea5 initialization product. This initialization products also gives better results in the prediction of several SST indices in the Indian Ocean: Western Indian Ocean (WIO), Indian Ocean Basinwide (IOB) and Indian Ocean Dipole (IOD). However, the change of resolution does not affect the skill in the Tropical Atlantic. Exarchou et al. 2016 shows that the biases in the equatorial Atlantic where mainly related with a misrepresentation of the subtropical overturning cell, this processes are not expected to be affected by resolution change. The initialization with ORAP5 and GLOSEA5 degrades the skill of the tropical Atlantic, especially when the initialization is done with GLOSEA5. This results might be consistent with the slight increase of biases in the equatorial Atlantic in the HR-GLOSEA5 simulation compared to SR-GLORYS and HR-GLORYS (figure 1). It might suggest an issue with the data assimilation method in those two products in this region.

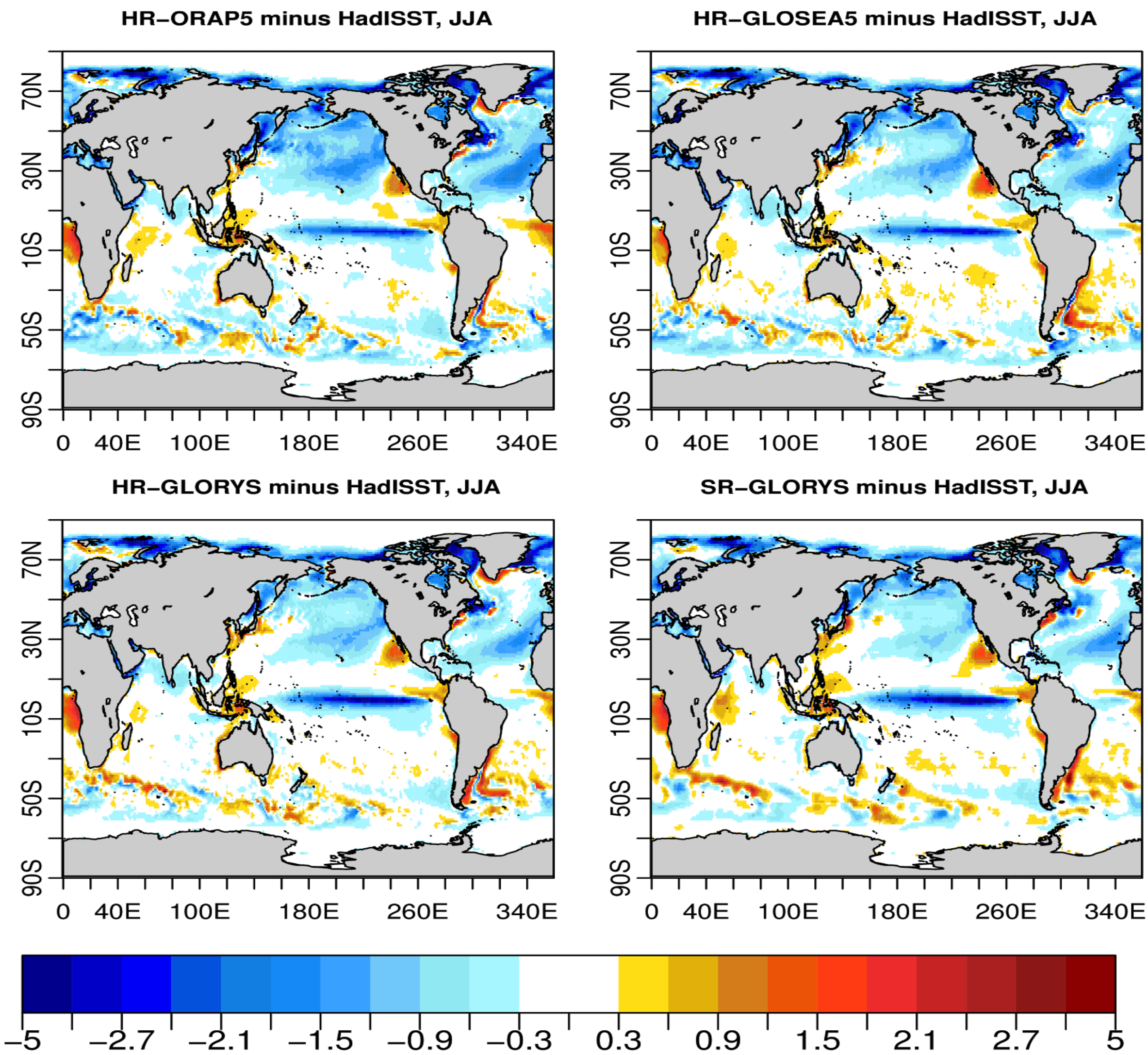

Figure 1: Forecast bias in SST during summer (JJA), defined as the difference between the seasonal forecasts and observations from HadISST (Rayner et al., 2003) for 1993-2009.

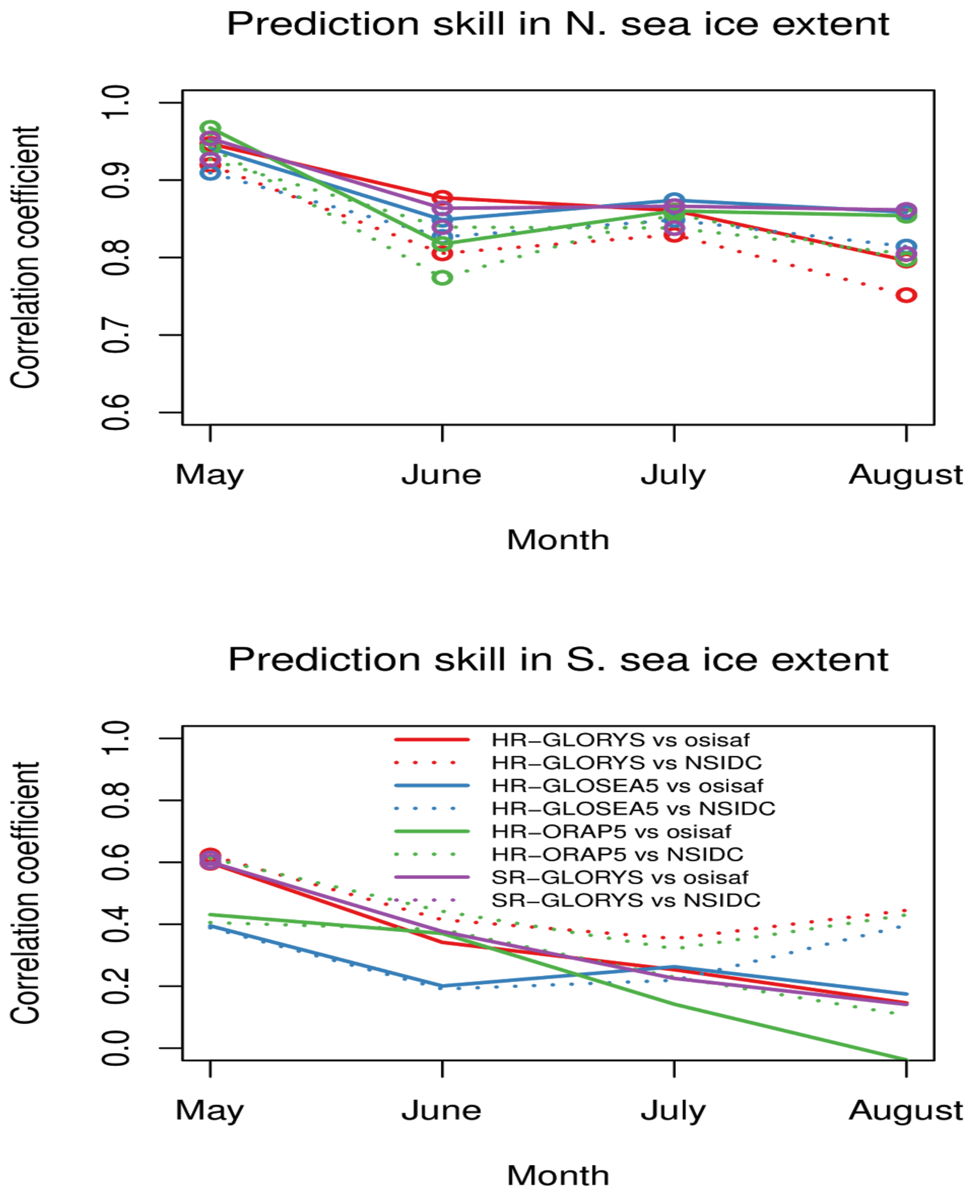

Figure 2: Prediction skill in sea ice extent in the Northern hemisphere (top panel) and Southern hemisphere (bottom panel), shown as the correlation of the ensemble mean prediction with two different observational datasets (OSISAF and NSIDC). Circles denote statistically significant values with a significance level of 5%.

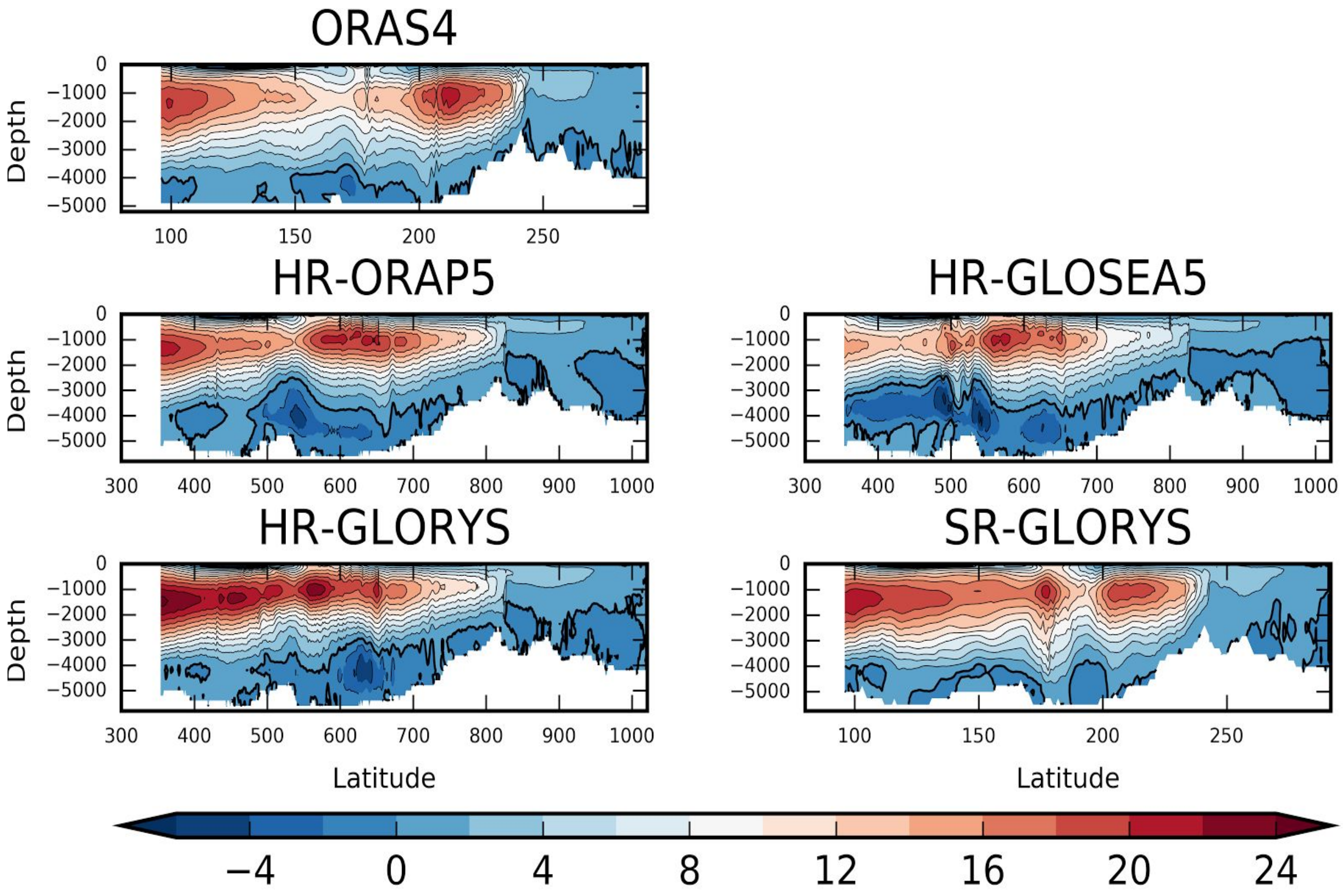

Figure 3: Atlantic meridional overturning streamfunction (in Sv) for the MJJA time mean circulation between 1993-2009, for ORAS4 and the four experiments of Table 1, as a function of the j-coordinate of the model grid (roughly corresponding to north-south latitude). Contour interval is 2 Sv, and the thick line corresponds to the zero value.

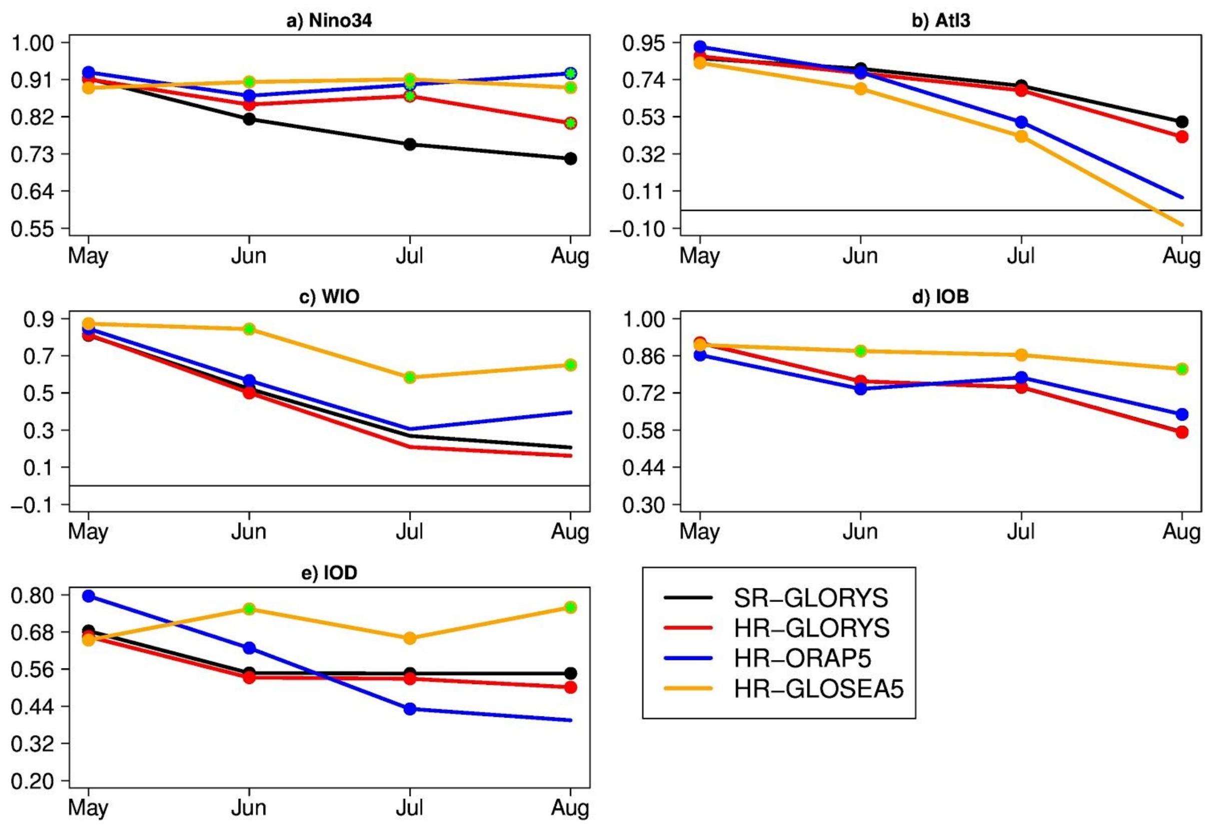

Figure 4: Correlation of different tropical variability indices as a function of forecast time for SR-GLORYS (black), HR-GLORYS (red), HR-ORAP5 (blue), HR-GLOSEA5 (yellow), with respect to the ESA SST. For all figures dots indicate correlations that are significant with a 95% confidence level and green stars indicate correlations in the HR experiments that are significantly different from SR-GLORYS with 95% confidence level. a) Niño 3.4 (190ºE240ºE-5ºS5ºN) b) Atlantic 3 (20ºW0-3ºN3ºS) c) Western Indian Ocean (WIO): SST averaged in the region 60ºE80ºE-10ºS10ºN. d) Indian Ocean Basin (IOB): SST averaged in 40ºE110ºE-20ºS20ºN. e) IOD (difference between SST average in 60ºE80ºE-10ºS10ºN and 90ºE110ºE-10ºS0).

List of publications/reports from the project with complete references

Exarchou E., Prodhomme, C., Guemas V., and Doblas-Reyes F., 2016: Sources of EC-Earth bias in the Tropical Atlantic. Submitted to Climate Dynamics

Prodhomme C., Batte L., Massonet F., Davini P, Bellprat O., Guemas V., and Doblas-Reyes F., 2016: Benefits of increasing the model resolution for the seasonal forecast quality in EC-Earth. Submitted to Journal of Climate.

Summary of plans for the continuation of the project

(10 lines max)

An additional set of forecast is still planned in this special project, one with the configuration ORCA025L75 but initialized from ORAS5. It will be available in 2016.

We also plan to complete the forecast initialized in November from GLOSEA5 and ORAP5 (HR-GLOSEA5, HR-ORAP5).

References

Balmaseda, M. A., K. Mogensen, and A. T. Weaver, 2013: Evaluation of the ECMWF ocean reanalysis system ORAS4. Quarterly Journal of the Royal Meteorological Society, 139 (674), 1132-1161, doi:10.1002/qj.2063.

Dee, D. et al., 2011: The ERA-Interim reanalysis: Configuration and performance of the data assimilation system. Quarterly Journal of the Royal Meteorological Society, 137 (656), 553-597.

EUMETSAT Ocean and Sea Ice Satellite Application Facility. Global sea ice concentration reprocessing dataset 1978-2015 (v1.2, 2015), [Online]. Norwegian and Danish Meteorological Institutes. Available from http://osisaf.met.no

Ferry, N. et al., 2010: Mercator global eddy permitting ocean reanalysis GLORYS1V1: Description and results. Mercator Ocean Quart. Newsl 36, 15-27.

Forbes, R. M., A. M. Tompkins, and A. Untch, 2011: A new prognostic bulk micro-physics scheme for the IFS. ECMWF Tech Memo 649.

Hazeleger, W. et al., 2012: EC-Earth v2.2: description and validation of a new seamless earth system prediction model. Climate Dynamics, 39 (11), 2611-2629.

MacLachlan, C., Arribas, A., Peterson, K. A., Maidens, A., Fereday, D., Scaife, A. A., and Camp, J., 2015: Global Seasonal forecast system version 5 (GloSea5): a high-resolution seasonal forecast system. Quarterly Journal of the Royal Meteorological Society, 141 (689), 1072-1084.

Morcrette, J., H. Barker, J. Cole, M. Iacono, and R. Pincus, 2008: Impact of a new radiation package, mcrad, in the ecmwf integrated forecasting system. Monthly Weather Review, 136 (12), 4773-4798.

Rayner, N. A., 2003: Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century. Journal of Geophysical Research, 108 (D14), 4407, doi:10.1029/2002JD002670.

Tietsche, S., Balmaseda, M. A., Zuo, H., and Mogensen, K., 2014: Arctic sea ice in the ECMWF MyOcean2 ocean reanalysis ORAP5. ECMWF Tech Memo 737.