Capability of the BSC-CNS as a Global Producing Center for Near-Term Climate Prediction

TECHNICAL NOTE

BSC-CP-2016-003

Francisco J. Doblas-Reyes, Louis-Philippe Caron,
Javier García-Serrano, Martin Ménégoz,
Chloé Prodhomme, Virginie Guemas

Earth Sciences Department
Barcelona Supercomputing Center - Centro Nacional de Supercomputación (BSC-CNS)

16 November 2016

Series: Earth Sciences (ES) Technical Report

A full list of ES Publications can be found on our website under:

https://earth.bsc.es/wiki/doku.php?id=library:external:technical_memoranda

Summary

This report serves as a partial requirement to qualify the Barcelona Supercomputing Center (BSC) as a designated WMO Global Producing Centre (GPC) for Near-Term Climate Prediction (NTCP).

The report provides a short background on the work performed at the BSC in the field of decadal forecasting over the recent years and provides evidence that the center meets all of the minimum requirements to obtain the designation, namely:

1. The center can prepare, with at least annual frequency, global fields of parameters from multi-annual to decadal predictions performed with its own forecast system.
2. The center can make available on the WMO Information System (WIS) the range of products requested by the WMO.
3. The center can prepare the necessary verification statistics.
4. The center can provide an agreed set of forecast and hindcast variables to the lead center for NTCP.
5. The center can make available on a website up-to-date information on the characteristics of its global decadal prediction system.

Contents

1. Introduction

The Barcelona Supercomputing Center (BSC) is the National Supercomputing Facility of Spain. BSC hosts a range of high-performance computing (HPC) systems, including MareNostrum III, one of the most powerful supercomputers in Europe with 48,128 cores and 1.1 Pflops capacity. More than 350 researchers and students, from more than 40 different countries, perform research in Computer Sciences, Life Sciences, Earth Sciences and Computational Applications in Science and Engineering at BSC. The BSC is a key element of and coordinates the Spanish Supercomputing Network, which is the main framework for granting competitive HPC time to Spanish research institutions. Furthermore, BSC is one of six hosting nodes in France, Germany, Italy and Spain that form the core of the Partnership for Advanced Computing in Europe (PRACE) network. PRACE provides competitive HPC time on world-class supercomputers to researchers in the 25 European member countries. BSC has been accredited as one of the first eight Severo Ochoa Centers of Excellence. This award is given by the Spanish Government as recognition for leading research centers in Spain that are internationally well known institutions in their respective areas.

The Earth Sciences Department of the Barcelona Supercomputing Center (BSC-ES) conducts multi-faceted research in Earth system modelling. The director of the department is Prof. Doblas-Reyes, a worldwide expert in the development of seasonal-to-decadal climate prediction systems who has more than 20 years of experience in weather and climate modeling, climate prediction, as well as the development of climate services. Prof. Doblas-Reyes was a Lead Author of the Chapter 11, "Near-term Climate Change: Projections and Predictability", in the UN IPCC AR5 Working Group I – The Physical Sciences Basis report. Other members of the BSC-ES were likewise Contributing Authors to Chapter 11, namely Virginie Guemas and Javier García-Serrano.

The BSC-ES undertakes advanced research to forecast climate variations from one month to several years into the future (subseasonal-to-decadal predictions) and from regional to global scales. This objective relies on expanding our understanding of the climate processes through a deep analysis of state-of-the-art climate forecast systems in comparison with the most up-to-date observational datasets, and on exploiting these detailed analyses to refine the representation of climate processes in climate forecast systems and their initialization. Emphasis is made on forecasting changes in high-impact climate events such as the persistent winds, floods, droughts and temperature extremes.

2. Past research activities of the Earth Sciences Department

The department has been involved in a range of international activities in the field of decadal prediction in the recent years.

2.1. Development of the EC-Earth Global Climate Model

The BSC-ES is a member of the EC-Earth consortium since 2009, and is both a user and a developer of the coupled global climate model EC-Earth (https://www.ec-earth.org). The BSC-ES contributed to the decadal prediction exercise of the fifth phase of the Coupled Model Intercomparison Project (CMIP5), which is one of the key datasets used to produce the UN Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5). EC-Earth, which will be used for near-term climate forecasts, is a combination of the IFS model (atmosphere), NEMO (ocean) and the LIM model (sea-ice), assembled with the OASIS coupler.

2.2. Production of initial conditions (ocean, atmosphere, sea ice) and development of data assimilation techniques

2.2.1. Atmosphere (e.g. Du et al., 2012; Prodhomme et al., 2016a): Atmospheric initial conditions have been generated using a series of reanalyses (ERA-40, ERA-Interim, ERA-Land), for varying time periods ranging from 1960 to present, and a set of horizontal resolutions, i.e. T159 (~125km), T255 (~80km) and T511 (~40km).

2.2.2. Ocean (e.g. Prodhomme et al., 2016b): Ocean initial conditions have been generated for the ORCA1 (~1° resolution) and ORCA025 (~0.25° resolution) configurations of NEMO, with both 42 (L42) and 75 (L75) vertical levels, using several ocean reanalyses (e.g. ORAS4, ORAP5, GLORYS).

2.2.3. Sea ice (Guemas et al., 2014a): A series of sea ice initial conditions have been constructed for both the ORCA1 and ORCA025 grids by running an ocean model which assimilates observations.

2.3. Analyses of model biases and development of bias correction techniques

An important issue in decadal forecasting is the initial shock of the model due to the introduction of the initial conditions and the ensuing model drift wherein the model gradually drifts towards its preferred internal climatology over time. The BSC-ES has investigated both of these issues, through the development of new initialization techniques (Volpi et al., 2016), comparison of existing initialization techniques and their limitations (Carassi et al., 2014; Hazeleger et al., 2013; Weber et al., 2015) and the development of a posteriori adjustment of the climate simulations (Fučkar et al., 2014).

2.4. Real-time decadal forecasts

The BSC-ES is a regular contributor to the real-time decadal climate prediction exercise coordinated by the UK MetOffice (Smith et al. 2013) since 2011 [the group was at the Catalan Institute of Climate Science at the time]. The BSC quasi-operational decadal forecasts are distributed publically trough the MetOffice website (http://www.metoffice.gov.uk/research/climate/seasonal-to-decadal/long-range/decadal-multimodel).

2.5. Analyses of decadal forecasting skill

Finally, the BSC-ES has produced or contributed to a number of studies analysing the skill of decadal forecast systems at the global scale (Doblas-Reyes et al., 2013; García-Serrano and Doblas-Reyes, 2012) and over specific regions such as:

- the Atlantic ocean (García-Serrano et al., 2015; García-Serrano et al., 2013a; García-Serrano et al., 2012; Wouters et al., 2013),
- Europe (Guemas et al., 2015),
- the Indian Ocean (Guemas et al., 2013a),
- the Western North Pacific (Lienert and Doblas-Reyes, 2013; Guemas et al., 2012)
- Africa (García-Serrano et al., 2013b)

The group also analysed the skill of climate forecast systems at predicting multi-annual Atlantic hurricane activity (Camp and Caron, 2016; Caron et al., 2015; Caron et al., 2014), Arctic sea ice (Guemas et al., 2014b; Day et al., 2015) as well as the recent slowdown in climate warming (Guemas et al., 2013b).

3. Minimum requirements

3.1. Preparation, with annual frequency, of global forecast fields of parameters relevant to multi-annual to decadal prediction

The BSC-ES is a regular contributor to the decadal prediction exchange since it first started in 2010. The simulations produced in that context were performed using the EC-Earth climate model version 2.3 (IFS T159L62, NEMO ORCA1L42). To produce these simulations, the BSC-ES relies on local computing infrastructure (MareNostrum III). The group can also make use of computing time obtained in the context of national and international calls. As such, the group has deployed EC-Earth on a number of supercomputers around Europe (e.g. ECMWF, Hector, Archer, Lindgren).

Sea ice initial conditions are produced by a historical ocean-sea ice reconstruction using a state-of-the-art general circulation model forced by an atmospheric reanalysis and strongly constrained by an ocean reanalysis. We use the LIM2 sea ice model embedded in the version 3.2 of the NEMO ocean model (Madec et al., 2008, Fichefet and Morales Maqueda, 1997). NEMO3.2 is initialized (full-field approach) from ORAS4 ocean reanalysis (Balmaseda et al., 2012). During the model integration the ocean temperature and salinity are nudged (restored) towards the monthly means of ORAS4. We drive this ocean-sea ice model with surface forcing fields generated from the DFS4.3 atmospheric product (Brodeau et al., 2009) through additional wind stress perturbations based on the methodology used for the ORAS4 ocean reanalysis (Mogensen et al., 2011) and in the ENSEMBLE project (Doblas-Reyes et al., 2010). More details on applied ocean restoring and wind stress perturbation techniques are available in Guemas et al. (2014a).

Oceanic initial conditions are generated using the ORAS4 reanalysis, which are downloaded automatically from ECFS when they become publicly available. Afterwards, the files extrapolated horizontally to account for the difference in bathymetry between ORAS4 and EC-Earth 2.3.

Atmospheric initial conditions are generated using tools available at ECMWF to interpolate the atmospheric and land surface data (FULLPOS software). Generating the atmospheric initial conditions through ECMWF is also a way to benefit from the availability of the reanalysis products that are updated monthly.

3.2. Make available on the WMO Information System (WIS) a range of products.

The BSC-ES is currently capable of producing all the products required in stage 1. We provide the complete set of examples below for the climate variable surface air temperature (T2m), using our latest forecast initialized on November 1st 2015, and a series of hindcasts, initialized from 1960 to 2015. The forecasts are shown as anomalies with respect to the 1971-2000 climatology. The same forecasts are performed, but not shown here, for both precipitation and mean sea level pressure.

3.2.1. Global maps of ensemble mean anomalies - Year 1

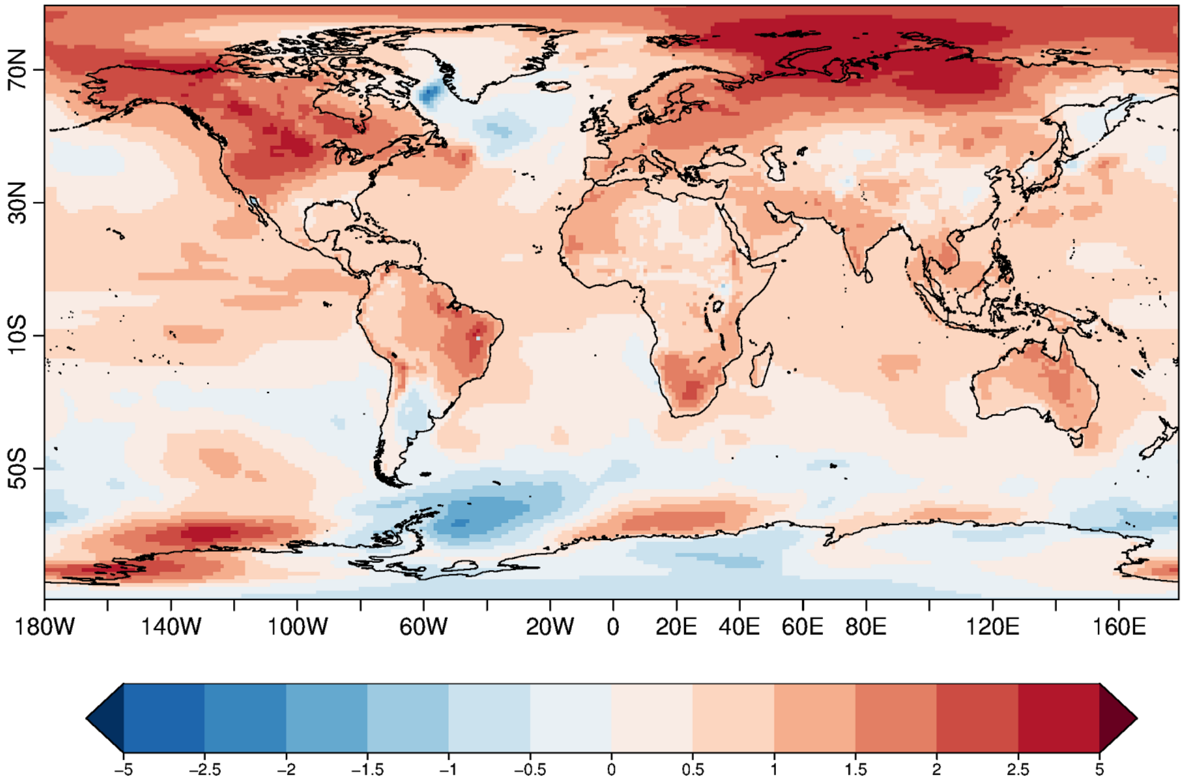


Figure 1: Average 2-meter temperature (T2m) anomaly forecasted for the period November 2015-October 2016.

3.2.2. Ensemble spread (standard deviation) - Year 1

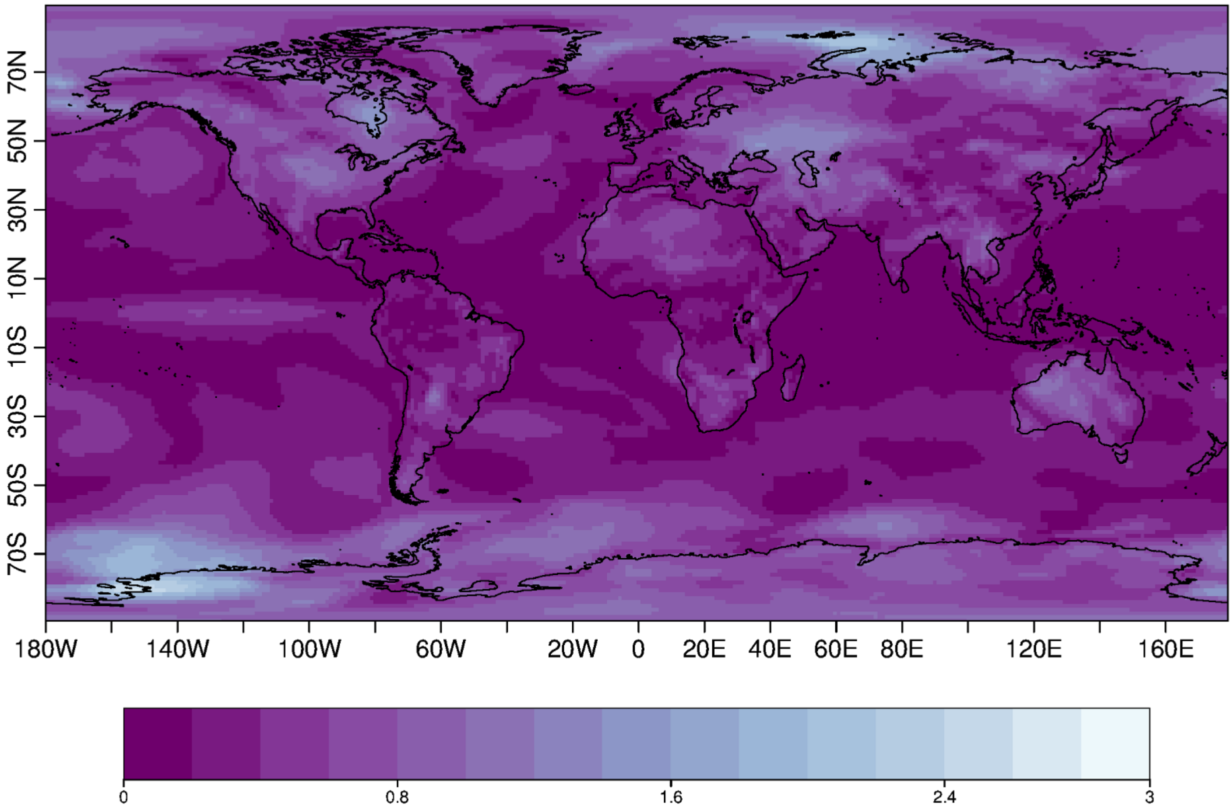


Figure 2: Ensemble spread for the 2-meter temperature prediction for the period November 2015-October 2016, computed as the standard deviation between the 5 members.

3.2.3. Global maps of ensemble mean anomalies - Year 1-5

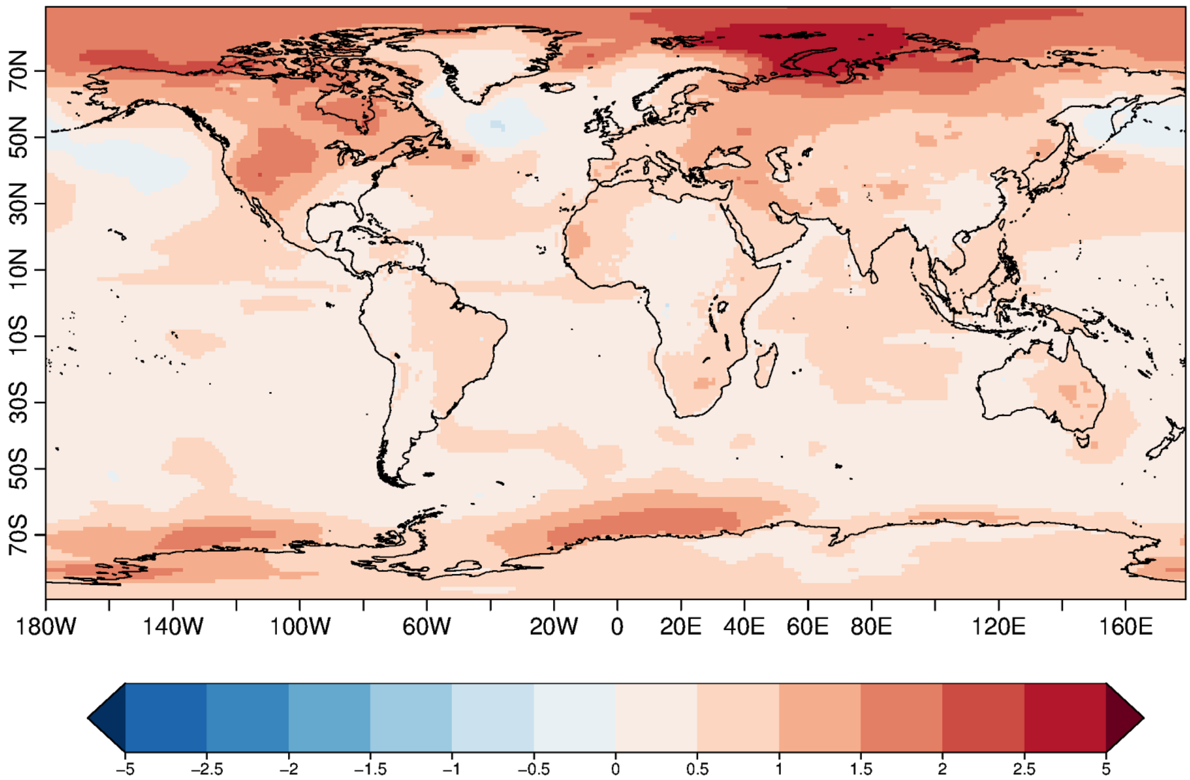


Figure 3: Average 2-meter temperature anomaly forecasted for the period November 2015-October 2020.

3.2.4. Ensemble spread (standard deviation) - Year 1-5

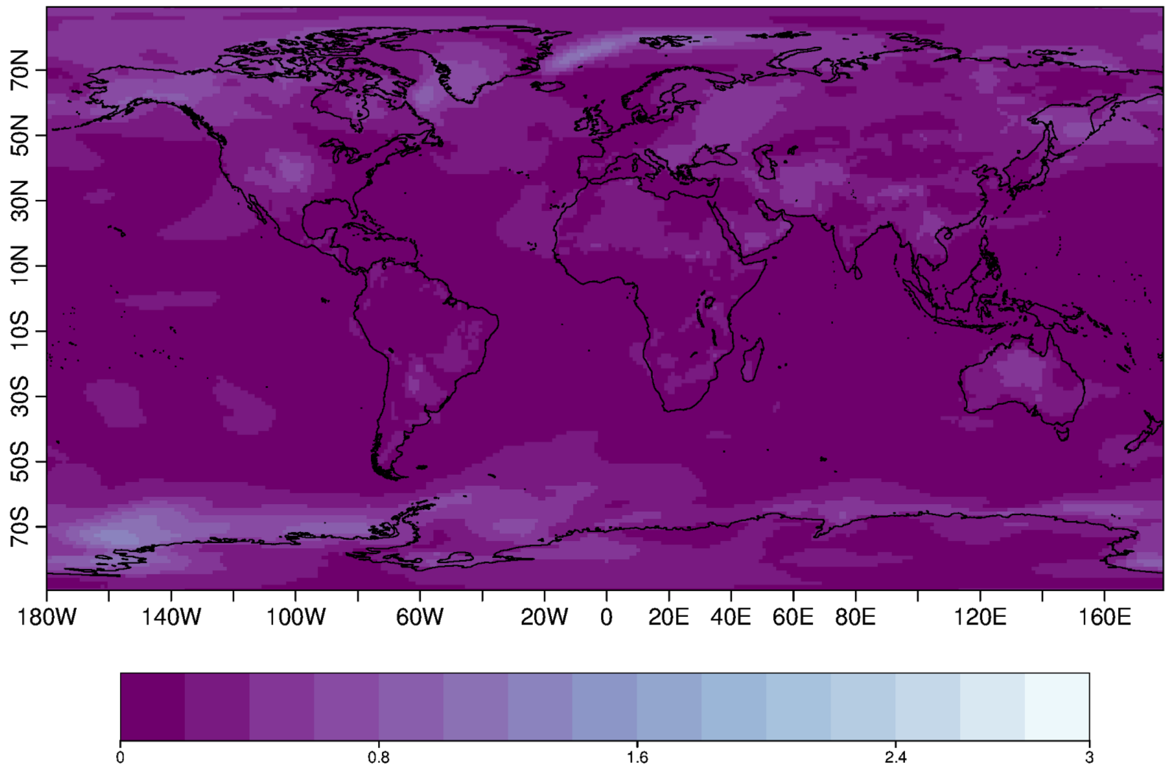


Figure 4: Ensemble spread for the 2-meter temperature prediction over the period November 2015-October 2020, computed as the standard deviation between the 5 members.

3.2.5. Ensemble mean annual global mean near-surface temperature and indications of ensemble spread, for every year of the forecast

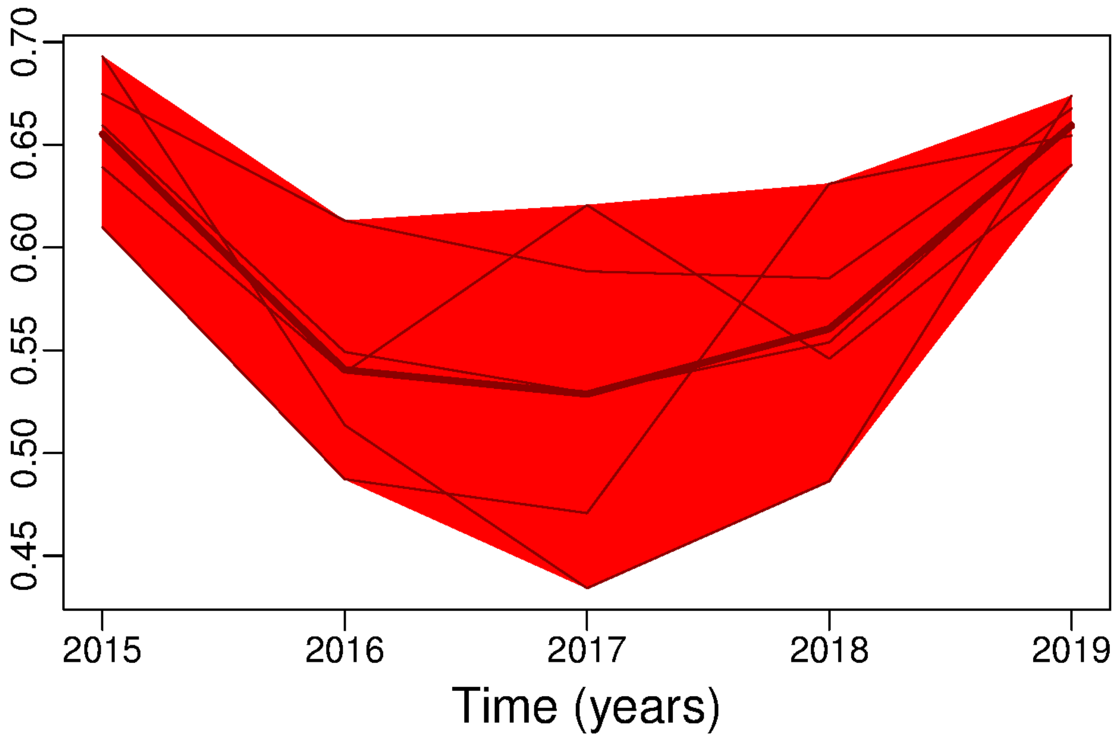


Figure 5: Mean annual global 2-meter temperature prediction for the November 2015 - October 2020 period. The thick red lines represent the ensemble mean and the thin red lines the individual members. Anomalies are computed with respect to the 1971-2000 climatology

3.3. Preparation of verification statistics

The BSC-ES sustains the development of a R package focusing on forecast quality assessment of climate predictions. The package stems from a collection of tools developed over the years by scientists from the ES-BSC and their collaborators. The **s2dverification** (wherein s2d stands in for seasonal-to-decadal) package provides tools for each step of the forecast verification process: retrieval, pairing, homogenization and filtering of forecast and observed data, assessment of the forecast quality (both deterministic and probabilistic) and visualisation. The plots and score shown in sections 3.2 and 3.4 have all been produced using this package. Finally, the package also includes the necessary functions to provide the products and verification outlined in stage 2.

3.4. Providing an agreed set of forecast and hindcast variables to the Lead Center of the NTCP

The ES-BSC can currently compute all the verification statistics required at stage 1 through the R package **s2dverification**, which is developed at the BSC-ES.

3.4.1. Hindcast - Global maps of grid-point temporal correlation of the ensemble mean with observations.

Year 1

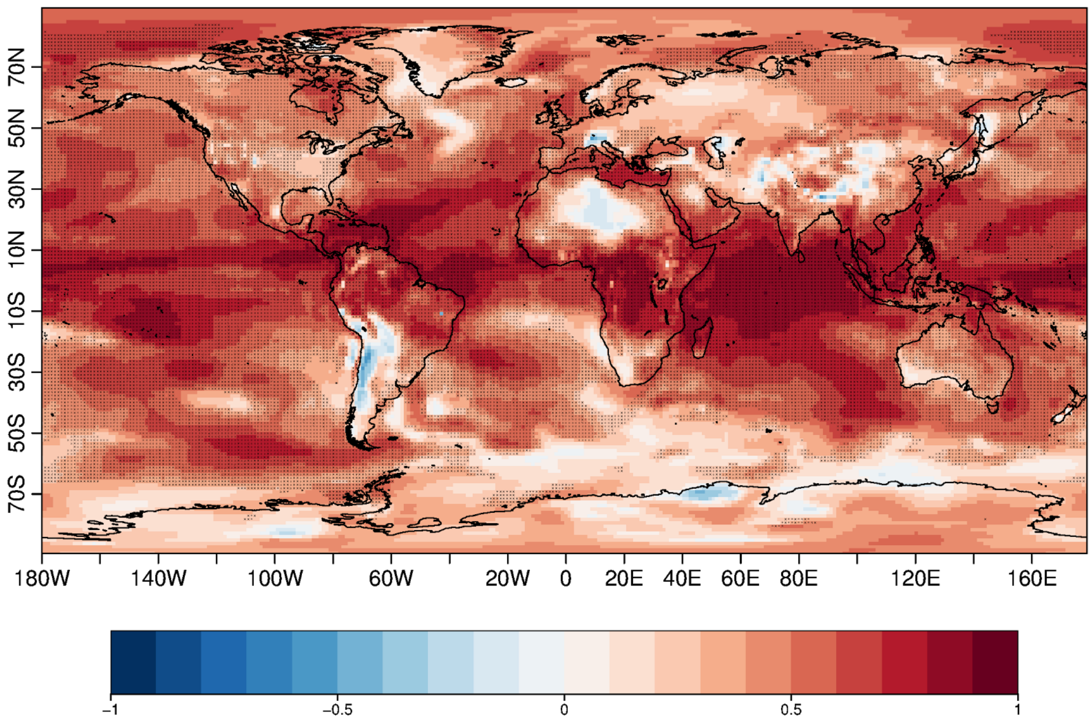


Figure 6: Two-meter temperature anomaly correlation between EC-Earth ensemble-mean predictions and NCEP data over the period 1960-2015, for the first year of forecast.

Year 1-5

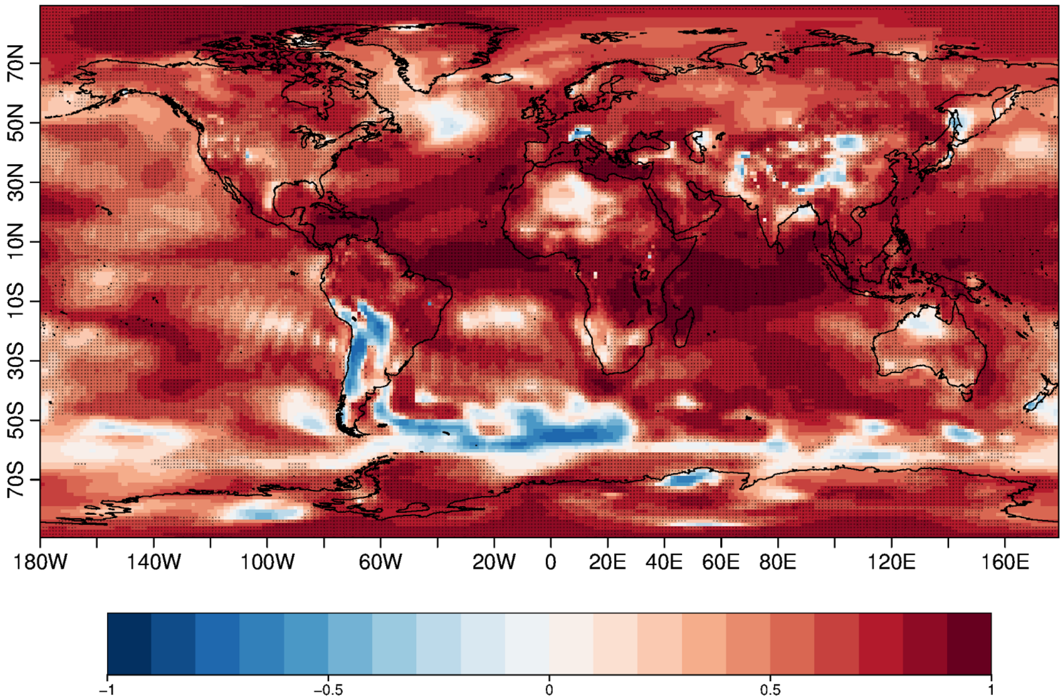


Figure 7: Two-meter temperature anomaly correlation between the EC-Earth ensemble-mean predictions and NCEP data over the period 1960-2015, for the forecast time years 1 to 5.

3.4.2. Forecast Verification - Maps of ensemble mean predicted and observed anomalies.

The NCEP and ERA-Interim reanalysis used for verification are downloaded, quality controlled and formatted automatically every month, thanks to a set of Python tools developed at the BSC-ES (Retrieve Remote Data Directly[1] and Correctness Checker for Climate Predictions and Observations[2]). This way, the reanalyses data available at the BSC-ES are operationally synchronized with the official repositories and always up-to-date.

[1] https://earth.bsc.es/gitlab/ces/R2D2
[2] https://earth.bsc.es/gitlab/ces/C3PO

Year 1

(a)

(b)

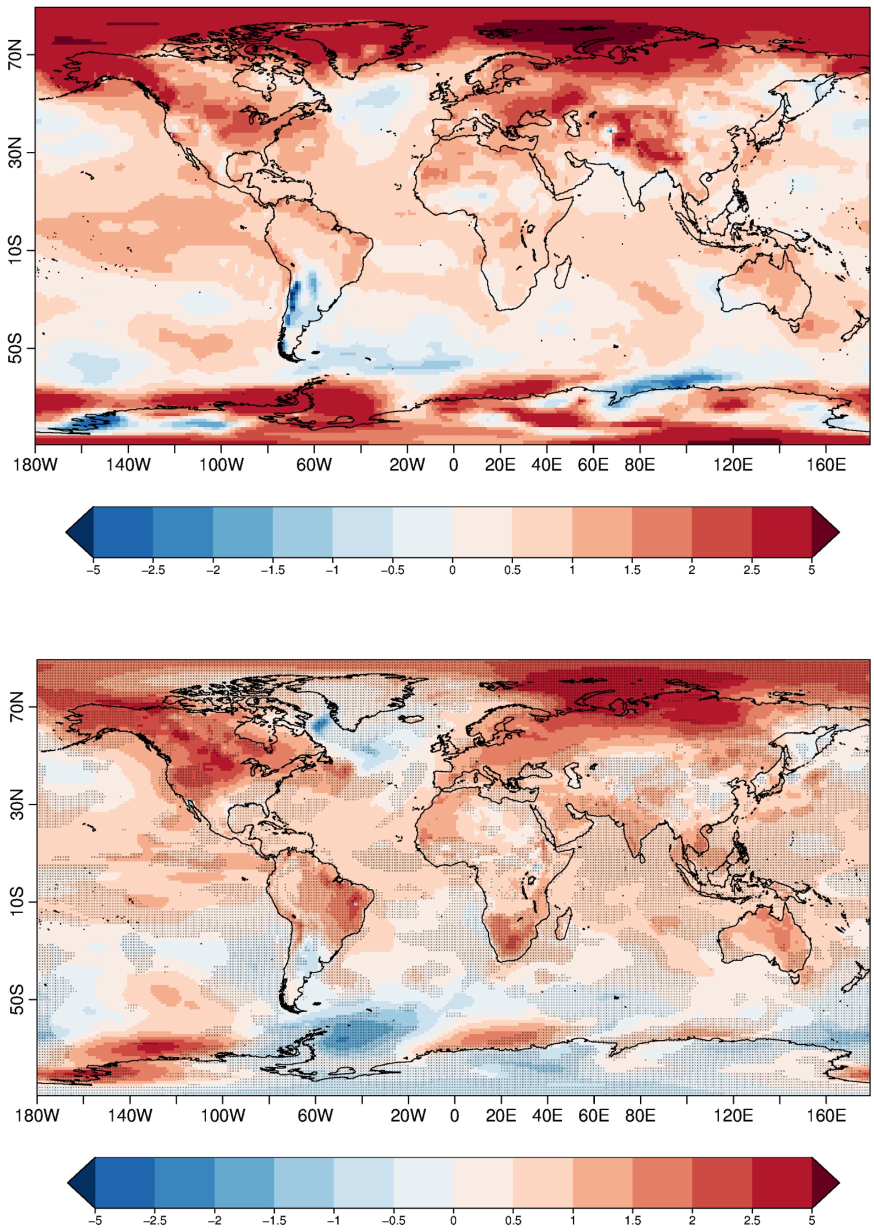
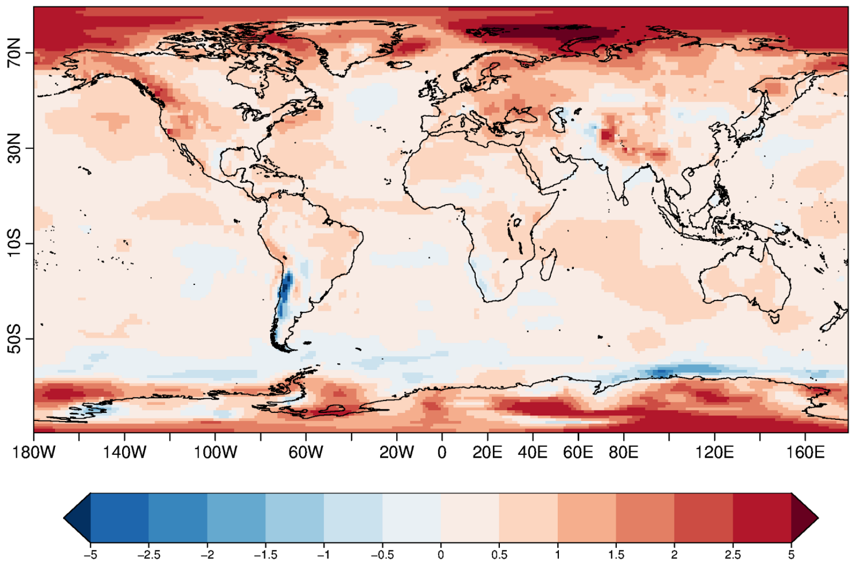


*Figure 8: Average 2-meter temperature anomalies for the November 2015 - October 2016 period for a) NCEP reanalyses and b) EC-Earth forecasts. Stippled areas show the regions where the observations lie outside the 5-95% model predicted range. The spatial correlation coefficient between the observations and the ensemble mean forecast is **0.68**.*

Year 1-5

(a)



(b)

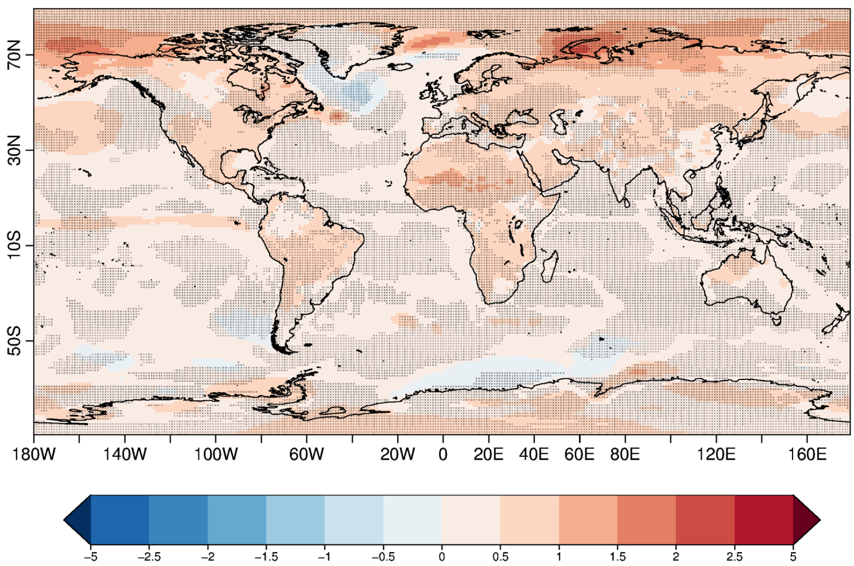


*Figure 9: Average 2-meter temperature anomalies for the period November 2011 - October 2016 for a) NCEP reanalyses and b) EC-Earth forecasts. Stippled areas show the regions where the observations lie outside the 5-95% model predicted range. The spatial correlation coefficient between the observations and the ensemble mean forecast is **0.76**.*

3.4.3. Comparison of observed and forecasted annual mean global temperature time series.

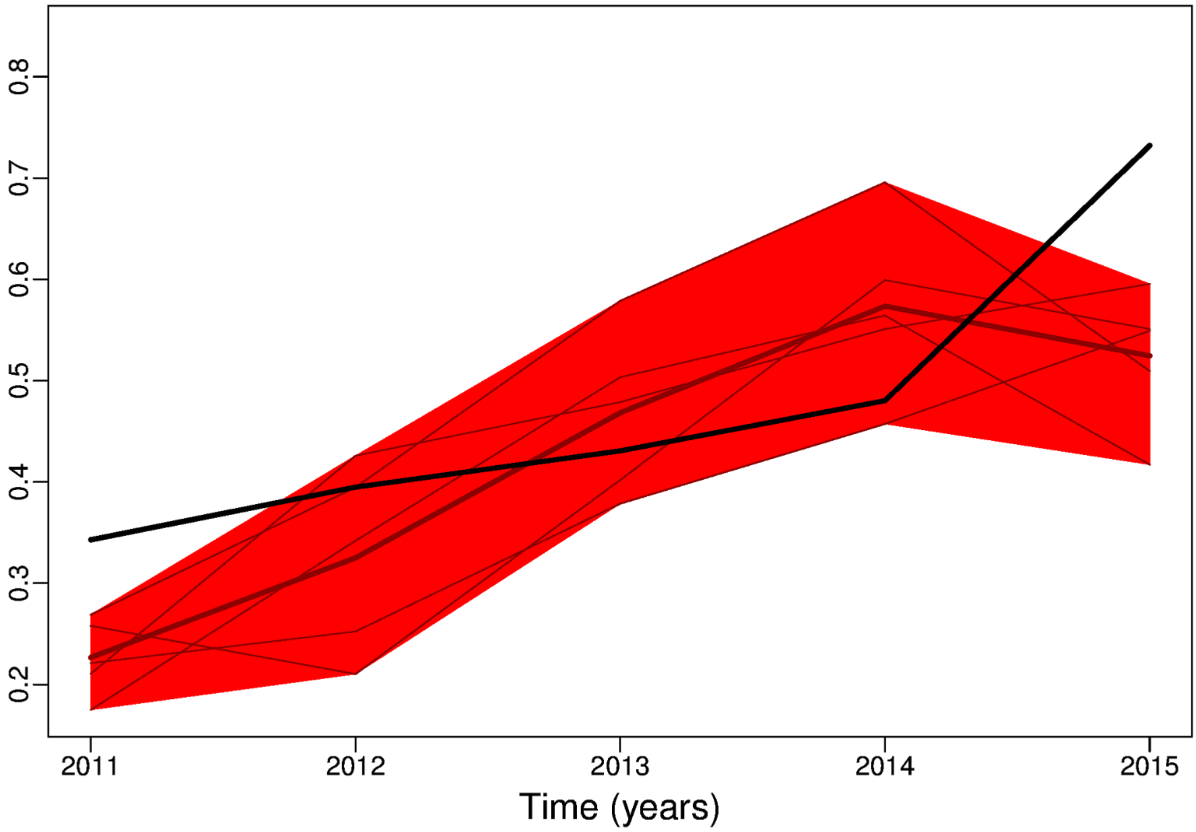


Figure 10: Global yearly average of 2-meter temperature forecasts for the period November 2011 to October 2016 (forecast initialised in 2011). The black curve shows the NCEP data, the thick red curve the ensemble mean and the thin red lines the individual members. Anomalies are computed with respect to the 1971-2000 climatology.

3.5. Public global decadal prediction system information

The following table will be made available with up-to-date information on the characteristics of the global prediction system on both the BSC-ES website and the LC-NTCP site.

Date of implementation of current long-range forecast system	June 2011
Coupled forecast system	Yes
Tier-2 forecast system	No
Atmospheric model and resolution	IFS; T159L62 (around 125 km horizontal resolution and 62 vertical levels)
Ocean model and resolution	NEMO; ORCA1L42 grid (1 degree horizontal resolution and 42 vertical levels);
Sea Ice model	LIM2
Source of atmospheric initial conditions	FULLPOS tools (ECMWF capability)
Source of ocean initial conditions	Interpolation of ORAS4 data
Source of sea ice initial conditions	Ocean and sea ice model experiment using observational data assimilation
Hindcast period	1960-2015 (one forecast per year)
Ensemble size for the hindcasts	5 members
Hindcast ensemble configuration	A set of hindcast has been run over the period 1960-2015, with one forecast initialised in November of each year. Each member has a specific sea-ice, ocean and atmosphere initial conditions (ICs). Home-made sea-ice ICs are produced by assimilating observation in a ocean-sea ice model while the atmospheric and oceanic ICs are produced by introducing small perturbations in, respectively, the ERA and the ORAS4 datasets. The set of forecast is completed each year.
Length of forecasts	10 years

Data format	Netcdf
What is the latest date predicted anomalies for the next month/season become available?	Forecast initialised in 2015 for the period November 2015 to October 2024
How are the forecast anomalies constructed?	Departure from 1971-2000 climatology
URL where forecast are displayed	http://www.metoffice.gov.uk/research/climate/seasonal-to-decadal/long-range/decadal-fc
Point of contact	virginie.guemas@bsc.es

4. Future Plans

The Barcelona Supercomputing Center is actively involved in the Decadal Climate Prediction Project (DCPP) of the upcoming CMIP6 effort. As such, it is currently developing the next version of his climate forecasting system. The new coupled model, EC-Earth 3.2, is now going through the final testing and tuning stage and is expected to be ready in 2017. It will offer higher resolution for both the ocean (1 degree horizontal resolution; 75 vertical levels) and the atmosphere (~60 km horizontal resolution; 91 vertical levels). It will also include a new version of the sea ice model, LIM3 (Rousset et al., 2015). Hindcasts performed with the preliminary model version show encouraging results and significant improvement over the previous version . And while this version of the model is expected to be operational in 2017, BSC is looking past EC-Earth 3.2 and already started the production of his next generation of climate forecasting system. As such, BSC will be providing quasi-operational decadal forecasts, with an ever improving system, for the foreseeable future.

5. References

Balmaseda M.A., K.S. Mogensen, A.T. Weaver (2012). Evaluation of the ECMWF Ocean Reanalysis ORAS4. Q J R Meteorol Soc. doi:10.1002/qj.2063

Brodeau, L., B. Barnier, A.M. Treguier, T. Penduff, S. Gulev (2009) An ERA40-based atmospheric forcing for global ocean circulation models. Ocean Modelling, 31, 88-104, doi: 10.1016/j.ocemod.2009.10.005

Camp, J. and L.-P. Caron (2016). Analysis of Atlantic hurricane landfall forecasts in coupled GCMs on seasonal and multi-annual timescales. Chapter in Hurricanes and Climate Change. 3rd edition. Springer.

Caron, L.-P., L. Hermanson and F.J. Doblas-Reyes (2015). Multi-annual forecasts of Atlantic U.S. tropical cyclone wind damage potential. Geophysical Research Letters, 42, 2417-2425, doi:10.1002/2015GL063303.

Caron, L.P., C.G. Jones and F.J. Doblas-Reyes (2014). Multi-year prediction skill of Atlantic hurricane activity in CMIP5 decadal hindcasts. Climate Dynamics, 42, 2675-2690, doi:10.1007/s00382-013-1773-1.

Carrassi, A., R.J.T. Weber, V. Guemas, F.J. Doblas-Reyes, M. Asif and D. Volpi (2014). Full-field and anomaly initialization using a low-order climate model: a comparison and proposals for advanced formulations. Nonlinear Processes in Geophysics, 21, 521-537, 2014, doi:10.5194/npg-21-521-2014.

Day, J., S. Tietsche, M. Collins, H. Goessling, V. Guemas, A. Guillory, W. Hurlin, M. Ishii, S. Keeley, D. Matei, R. Msadek, M. Sigmond, H. Tatebe and E. Hawkins (2015). The Arctic Predictability and Prediction on Seasonal-to-Interannual TimEscales (APPOSITE) data set. Geoscientific Model Development Discussions, 8, 8809-8833, doi:10.5194/gmdd-8-8809-2015.

Du, H., F.J. Doblas-Reyes, J. García-Serrano, V. Guemas, Y. Soufflet and B. Wouters (2012). Sensitivity of decadal predictions to the initial atmospheric and oceanic perturbations. Climate Dynamics, 39, 2013-2023, doi:10.1007/s00382-011-1285-9

Doblas-Reyes, F.J., I. Andreu-Burillo, Y. Chikamoto, J. García-Serrano, V. Guemas, M. Kimoto, T. Mochizuki, L.R.L. Rodrigues and G.J. van Oldenborgh (2013). Initialized near-term regional climate change prediction. Nature Communications, 4, 1715, doi:10.1038/ncomms2704.

Doblas-Reyes F.J., A. Weisheimer, T.N. Palmer, J.M. Murphy, D. Smith (2010). Forecast quality assessment of the ENSEMBLES seasonal-to-decadal Stream 2 hindcasts. ECMWF Tech Memo 621, 45 pp

Fichefet, T. and M.A. Morales Maqueda (1997) Sensitivity of a global sea ice model to the treatment of ice thermodynamics and dynamics J. Geophys. Res., 102, 12,60912,646.

Fučkar, N.S., D. Volpi, V. Guemas and F.J. Doblas-Reyes (2014). A posteriori adjustment of near-term climate predictions: Accounting for the drift dependence on the initial conditions. Geophysical

Research Letters, 41, 5200-5207, doi:10.1002/2014GL060815.

García-Serrano, J., V. Guemas and F.J. Doblas-Reyes (2015). Added-value from initialization in predictions of Atlantic multi-decadal variability. Climate Dynamics, 44, 2539-2555, doi:10.1007/s00382-014-2370-7.

García-Serrano, J., I. Polo, F.J. Doblas-Reyes and R.J. Haarsma (2013a). Multi-year prediction of the Atlantic Niño: a first approach from ENSEMBLES. Revista Física de la Tierra, 25, 57-71.

García-Serrano, J., F.J. Doblas-Reyes, R. J. Haarsma and I. Polo (2013b). Decadal prediction of the dominant West African monsoon rainfall modes. Journal Geophysical Research, 118, 5260-5279, doi:10.1002/jgrd.50465.

García-Serrano, J., F.J. Doblas-Reyes and C.A.S. Coelho (2012). Understanding Atlantic multi-decadal variability prediction skill. Geophysical Research Letters, 39, L18708, doi:10.1029/2012GL053283.

García-Serrano, J. and F.J. Doblas-Reyes (2012). On the assessment of near-surface global temperature and North Atlantic multi-decadal variability in the ENSEMBLES decadal hindcast. Climate Dynamics, 39, 2025-2040, doi:10.1007/s00382-012-1413-1.

Guemas, V., J. García-Serrano, A. Mariotti, F.J. Doblas-Reyes and L.-P. Caron (2015). Prospects for decadal climate prediction in the Mediterranean region. Quarterly Journal of the Royal Meteorological Society, 141, 580-597, doi:10.1002/qj.2379.

Guemas, V., F.J. Doblas-Reyes, K. Mogensen, S. Keeley and Y. Tang (2014a). Ensemble of sea ice initial conditions for interannual climate predictions. Climate Dynamics, 43, 2813-2829, doi:10.1007/s00382-014-2095-7.

Guemas, V., E. Blanchard-Wrigglesworth, M. Chevallier, J.J. Day, M. Déqué, F.J. Doblas-Reyes, N. Fučkar, A. Germe, E. Hawkins, S. Keeley, T. Koenigk, D. Salas y Mélia and S. Tietsche (2014b). A review on Arctic sea ice predictability and prediction on seasonal-to-decadal timescales. Quarterly Journal of the Royal Meteorological Society, 142, 546-561, doi:10.1002/qj.2401.

Guemas, V., Corti S., J. García-Serrano, F.J. Doblas-Reyes, M. Balmaseda and L. Magnusson (2013a). The Indian Ocean: the region of highest skill worldwide in decadal climate prediction. Journal of Climate, 26, 726-739, doi:10.1175/JCLI-D-12-00049.1.

Guemas, V., F.J. Doblas-Reyes, I. Andreu-Burillo and M. Asif (2013b). Retrospective prediction of the global warming slowdown in the past decade. Nature Climate Change, 3, 649-653, doi:10.1038/nclimate1863.

Guemas, V., F.J. Doblas-Reyes, F. Lienert, Y. Soufflet and H. Du (2012). Identifying the causes of the poor decadal climate prediction skill over the North Pacific. Journal of Geophysical Research, 117, D20111, doi:10.1029/2012JD018004.

Hazeleger, W., V. Guemas, B. Wouters, S. Corti, I. Andreu-Burillo, F.J. Doblas-Reyes, K. Wyser and M. Caian (2013). Multiyear climate predictions using two initialisation strategies. Geophysical Research Letters, 40, 1794-1798, doi:10.1002/grl.50355.

Lienert, F. and F.J. Doblas-Reyes (2013). Decadal prediction of interannual tropical and North Pacific sea surface temperature. Journal Geophysical Research, 118, 5913-5922, doi:10.1002/jgrd.50469.

Madec, G., and the NEMO team (2008) NEMO ocean engine. Note du Pôle de modélisation, Institut Pierre-Simon Laplace (IPSL), France, No 27, ISSN No 1288-1619.

Mogensen K.S., M.A. Balmaseda, A. Weaver (2011) The NEMOVAR ocean data assimilation as implemented in the ECMWF ocean analysis for system 4. ECMWF Technical, Memorandum 668

Prodhomme, C., F.J. Doblas-Reyes, O. Bellprat and E. Dutra (2016a). Impact of land-surface initialization on sub-seasonal to seasonal forecasts over Europe. Climate Dynamics, 47, 919-935, doi:10.1007/s00382-015-2879-4

Prodhomme, C., L. Batté, F. Massonnet, P. Davini, O. Bellprat, V. Guemas, and F.J. Doblas-Reyes (2016b): Benefits of increasing the model resolution for the seasonal forecast quality in EC-Earth. Journal of Climate, doi:10.1175/JCLI-D-16-0117.1.

Rousset, C., M. Vancoppenolle, G. Madec, T. Fichefet, S. Flavoni, A. Barthélemy, R. Benshila, J. Chanut, C. Levy, S. Masson, and F. Vivier (2015). The Louvain-La-Neuve sea ice model LIM3.6: global and regional capabilities. Geosci. Model Dev., 8, 2991-3005, doi:10.5194/gmd-8-2991-2015.

Smith, D.M., A.A. Scaife, G.J. Boer, M. Caian, F.J. Doblas-Reyes, V. Guemas, E. Hawkins, W. Hazeleger, L. Hermanson, C.K. Ho, M. Ishii, V. Kharin, M. Kimoto, B. Kirtman, J. Lean, D. Matei, W.J. Merryfield, W.A. Müller, H. Pohlmann, A. Rosati, B. Wouters and K. Wyser (2013). Real-time multi-model decadal climate predictions. Climate Dynamics, 41, 2875-2888, doi:10.1007/s00382-012-1600-0.

Volpi, D., V. Guemas, F.J. Doblas-Reyes, E. Hawkins and N. Nichols (2016). Decadal climate prediction with a refined anomaly initialisation approach. Climate Dynamics, doi:10.1007/s00382-016-3176-6.

Weber, R.T.J., A. Carrassi and F.J. Doblas-Reyes (2015). Linking the anomaly initialization approach to the mapping paradigm: a proof-of-concept study. Monthly Weather Review, 143, 4695-4713, doi:10.1175/MWR-D-14-00398.1.

Wouters, B., W. Hazeleger, S. Drijfhout, G.J. van Oldenborgh and V. Guemas (2013). Multiyear predictability of the North Atlantic subpolare gyre. Geophysical Research Letters, 40, 3080-3084, doi:10.1002/grl.50585.