Barcelona Supercomputing Center
Centro Nacional de Supercomputación

CAPABILITY OF THE BSC-CNS AS A GLOBAL PRODUCING CENTER FOR NEAR-TERM CLIMATE PREDICTION

TECHNICAL NOTE

BSC-CP-2018-001

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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 over the recent years at the BSC in the field of decadal forecasting 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 forecast fields of parameters relevant to annual to decadal climate prediction.
2. The center can prepare the necessary verification statistics (stages 1 and 2).
3. The center can provide an agreed set of forecast and hindcast variables to the Lead Center for NTCP.
4. The center can make available on a website up-to-date information on the characteristics of its global decadal prediction system.

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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 IV, the third most powerful supercomputers in Europe with a 11.5 Pflops capacity. BSC employs more than 500 people, including 400 researchers and students who are distributed across four different departments: Computer Sciences, Life Sciences, Earth Sciences and Computational Applications in Science and Engineering. 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 seven hosting nodes in France, Germany, Italy, Switzerland 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 also 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 and will be Coordinating Author for Chapter 10 in the AR6 working Group I on physical science basis, “Linking global to regional climate change” in the upcoming report.

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 a deep analysis of the strengths and weaknesses of state-of-the-art climate forecast systems, via a thorough comparison with the most up-to-date observational datasets, and on exploiting these detailed analyses to refine the representation of processes relevant to climate in our 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 has been 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). The BSC-ES is also preparing to contribute to the next phase (CMIP6) of this intercomparison project. EC-Earth, which is used for near-term climate forecasts, is a combination of the IFS model (atmosphere), NEMO (ocean) and the LIM model (sea-ice), assembled using the OASIS coupler.

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

The different components (atmosphere, ocean and sea-ice) of the forecast system used to produce the predictions are initialised using the following approaches:

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., 2014): 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 (Exarchou et al., 2017), through the development of new initialization

techniques (Volpi et al., 2017a), comparison of existing initialization techniques and their limitations (Volpi et al., 2017b; Carrassi 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 Met Office (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 near real-time exchange website hosted by the Met Office (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 (Lienert and Doblas-Reyes, 2017; 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 (Caron et al., 2018; Camp and Caron, 2017; Caron et al., 2015; Caron et al., 2014), Arctic sea ice (Guemas et al., 2016; Day et al., 2015), the recent slowdown in climate warming (Guemas et al., 2013b) as well as the the impact of volcanic eruptions on decadal forecasts (Ménégoz et al., 2017; Swingedouw et al., 2017).

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 its inception. 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 and MareNostrum IV). The group can also make use of computing time obtained in the context of national and international calls and as such, the group has deployed EC-Earth on a number of supercomputers around Europe (e.g. ECMWF).

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 currently 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. (2014).

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.

The BSC-ES is currently capable of producing all the products required in stage 1 (deterministic) and stage 2 (probabilistic). Here, we provide both the deterministic and the probabilistic forecast for near-surface air temperature, precipitation and mean sea level

pressure, using our latest **10-member** forecast **initialized on November 1st 2017**. The forecasts are shown as **anomalies with respect to the 1971-2000 climatology**.

3.1.1. Surface Air Temperature - Stage 1

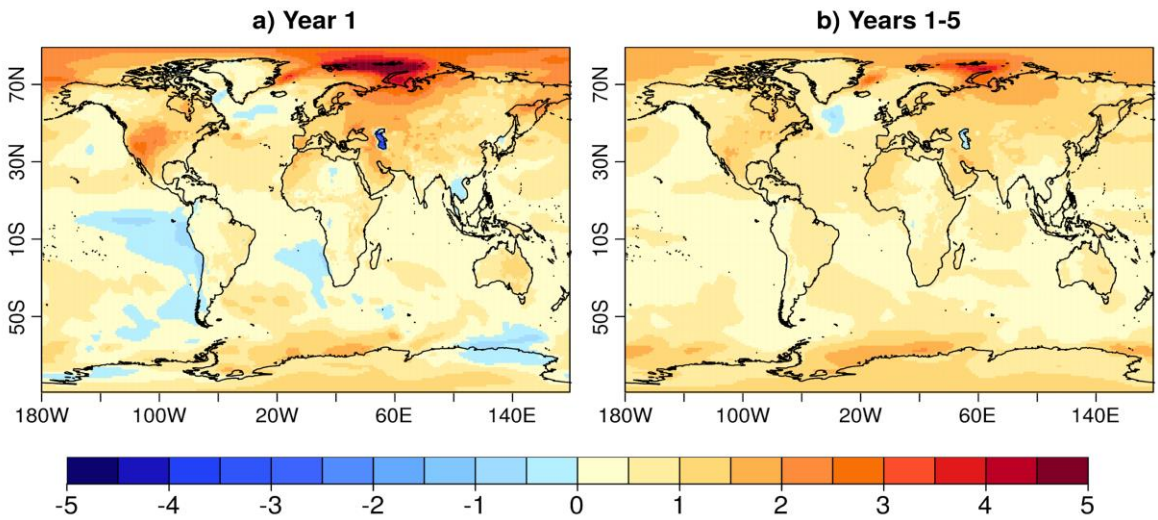

Figure 1: Mean near-surface temperature anomalies (°C) forecasted for a) November 2017 – October 2018 and b) November 2017 - October 2022.

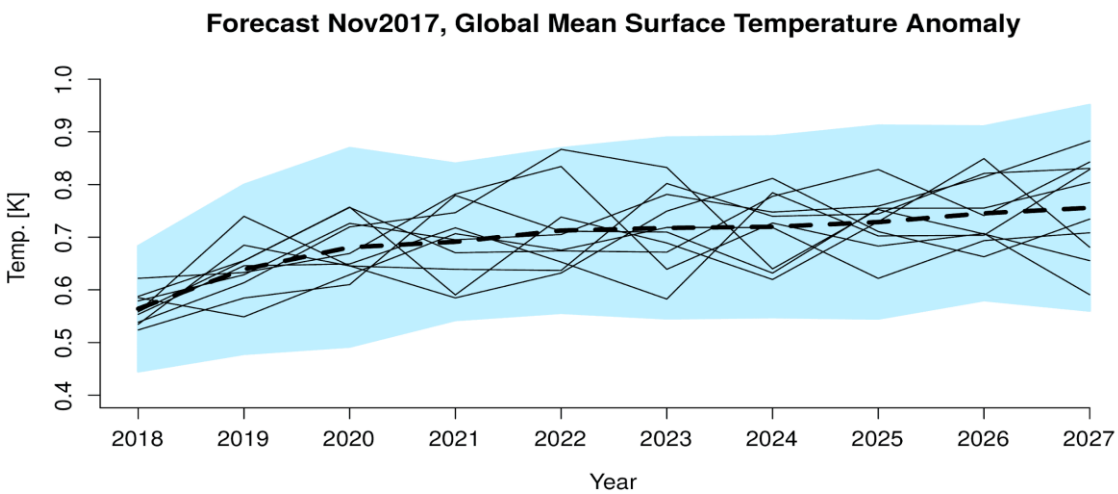

Figure 2: 10-year forecast of annual global mean near-surface temperature anomalies. The spread (light blue) is estimated as the 5th-95th percentiles of the intra-ensemble spread assuming a normal distribution. The thin black lines are the individual ensemble members and the thick dash line, the ensemble mean.

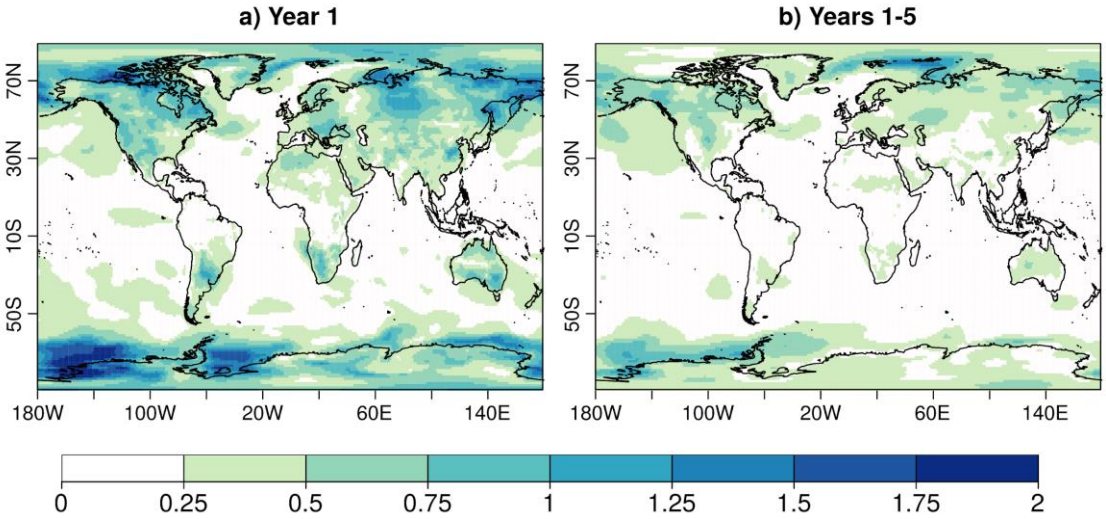

Figure 3: Near-surface temperature (°C) ensemble standard deviation for the period a) November 2017 - October 2018 and b) November 2017 - October 2022.

3.1.2. Surface Air Temperature - Stage 2

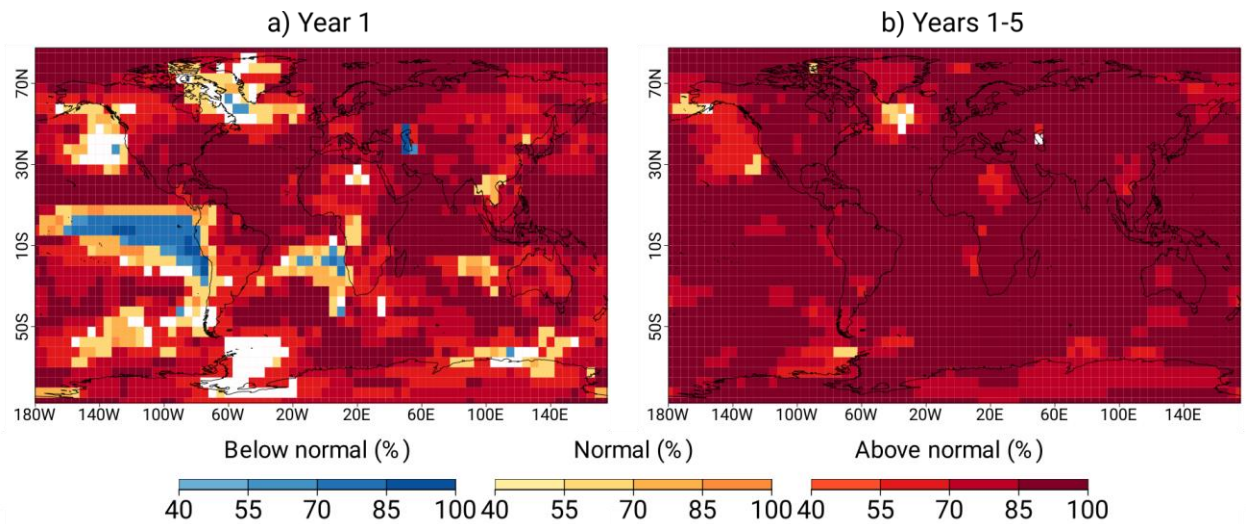

Figure 4: Near-surface temperature probabilistic forecast of most likely tercile category, for a) November 2017 - October 2018 and b) November 2017 - October 2022. The most likely category (below normal, normal, and above normal) and its percentage of probability to occur is shown. White colour indicates that the forecast probabilities are below 40% for all 3 categories.

3.1.3. Mean Sea Level Pressure - Stage 1

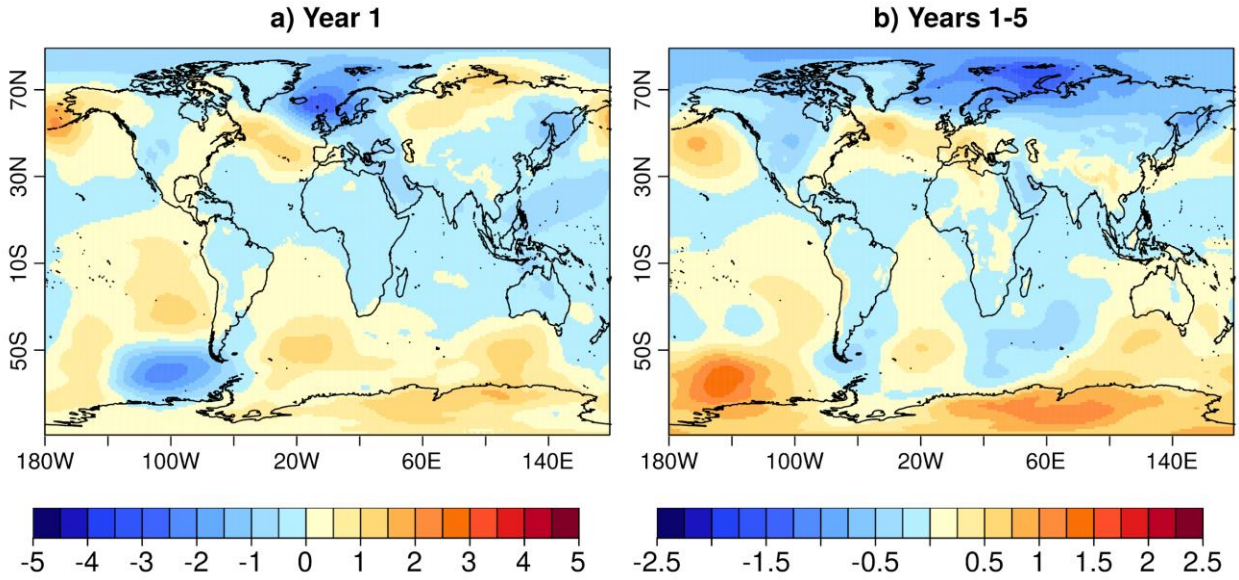

Figure 5: Same as Figure 1, for mean sea level pressure. Units are hPa.

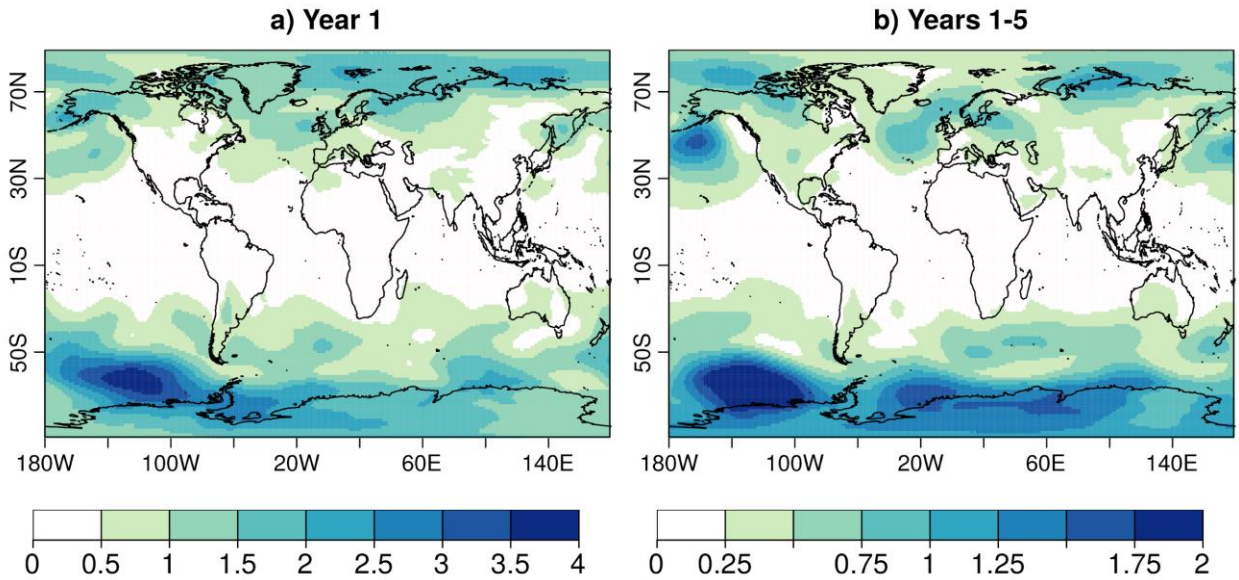

Figure 6: Same as Figure 3, for mean sea level pressure. Units are hPa.

3.1.4. Mean Sea Level Pressure - Stage 2

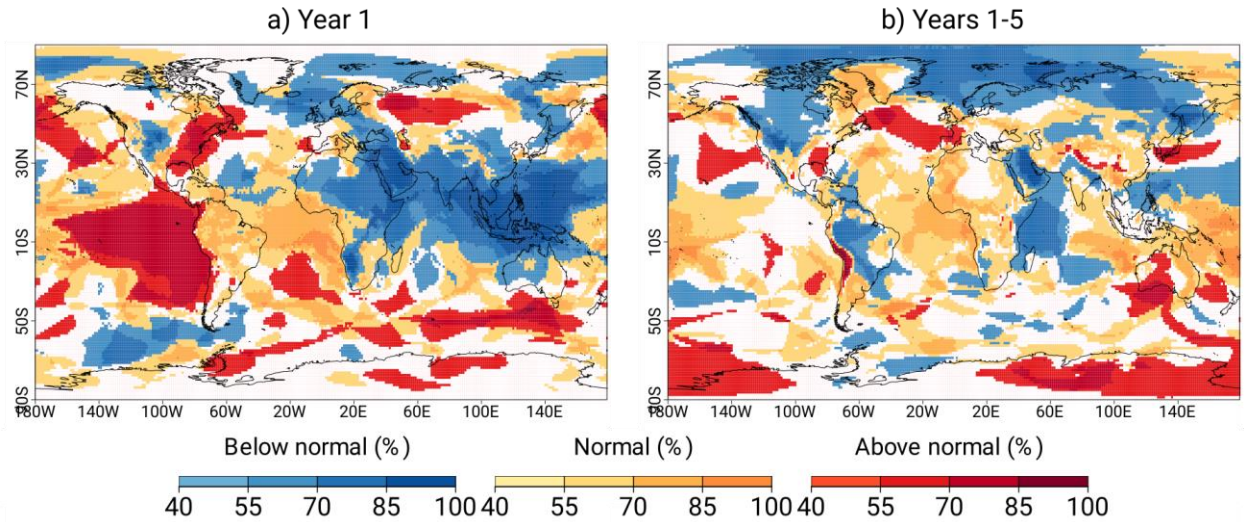

Figure 7: *Same as Figure 4, for mean sea level pressure.*

3.1.5. Precipitation - Stage 1

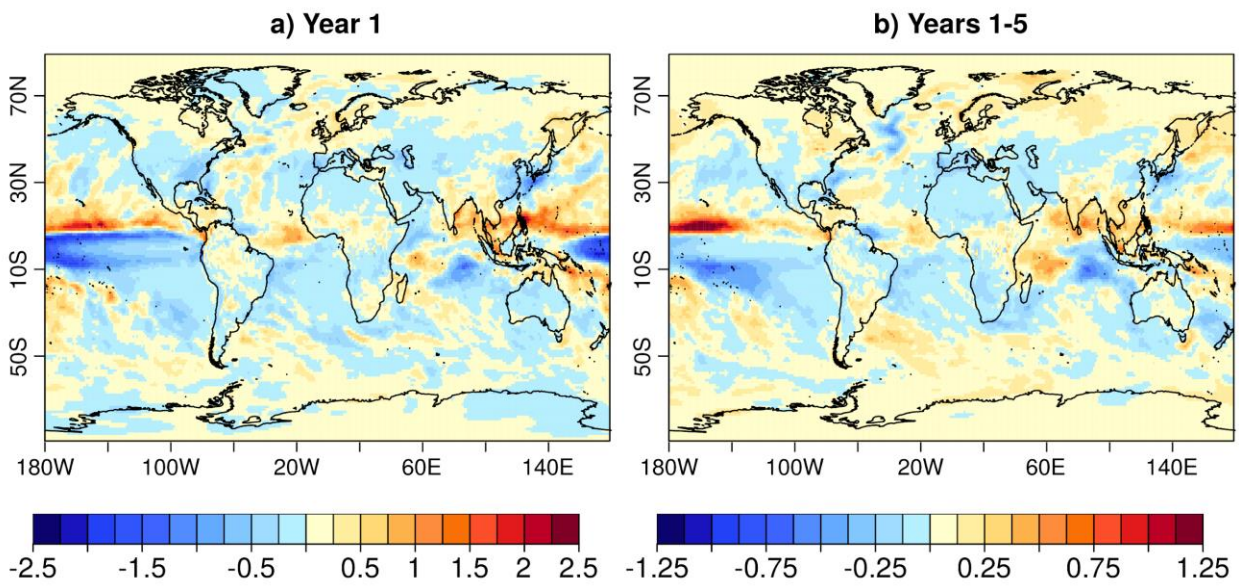

Figure 8: Same as Figure 1, for precipitation. Units are mm/day.

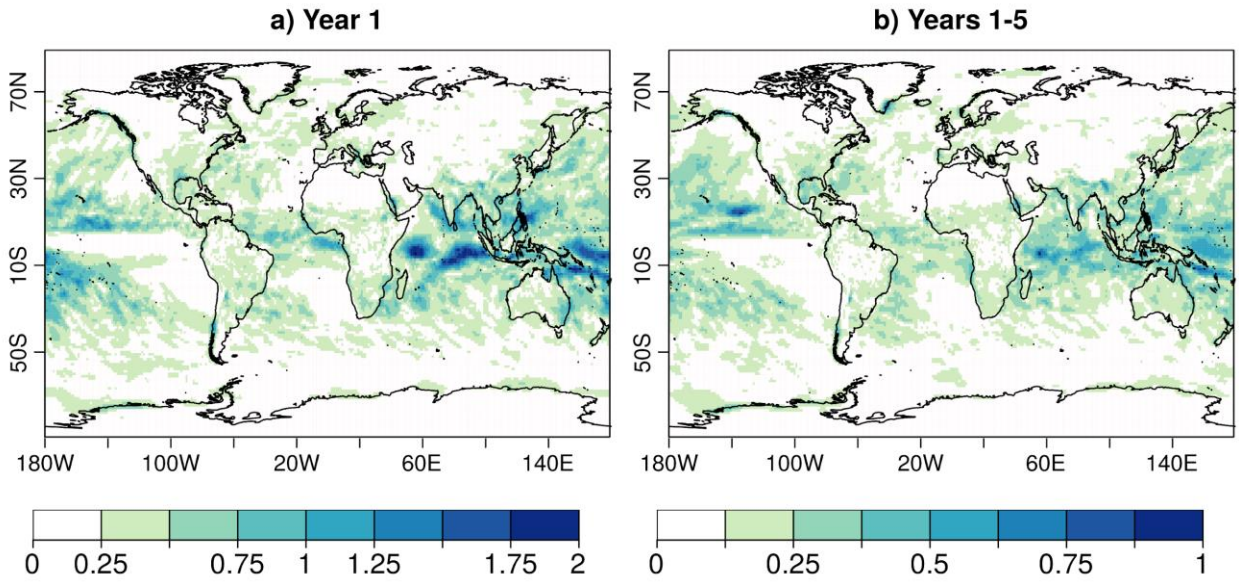

Figure 9: Same as Figure 3, for precipitation. Units are mm/day.

3.1.6. Precipitation - Stage 2

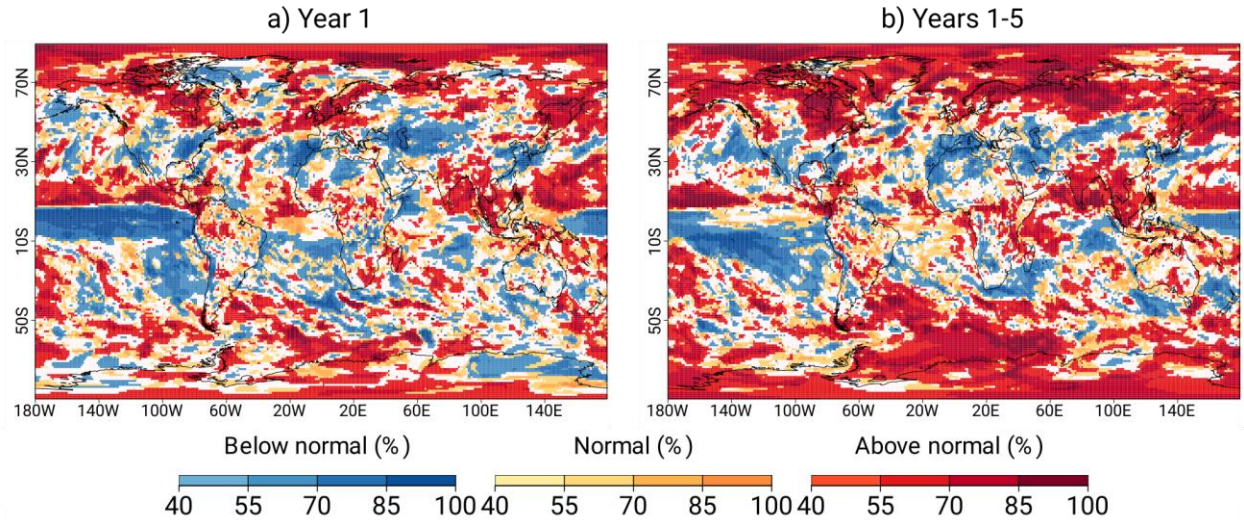

Figure 10: Same as Figure 4, for precipitation.

3.2. 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 (Manubens et al., 2018). The plots and scores shown in this report have been produced in large part using this package, which has been complemented with the R packages **easyVerification** and **SpecsVerification** for the production of the ROCSS's and the reliability diagrams, respectively.

3.2.1. Real-time verification

In this section, we verify the performance of two difference forecasts: **year 1** of the **forecast initialized on November 1st 2016**, and **average year 1-5** of the **forecast initialized on November 1st 2012**.

3.2.1.1. Surface Air Temperature

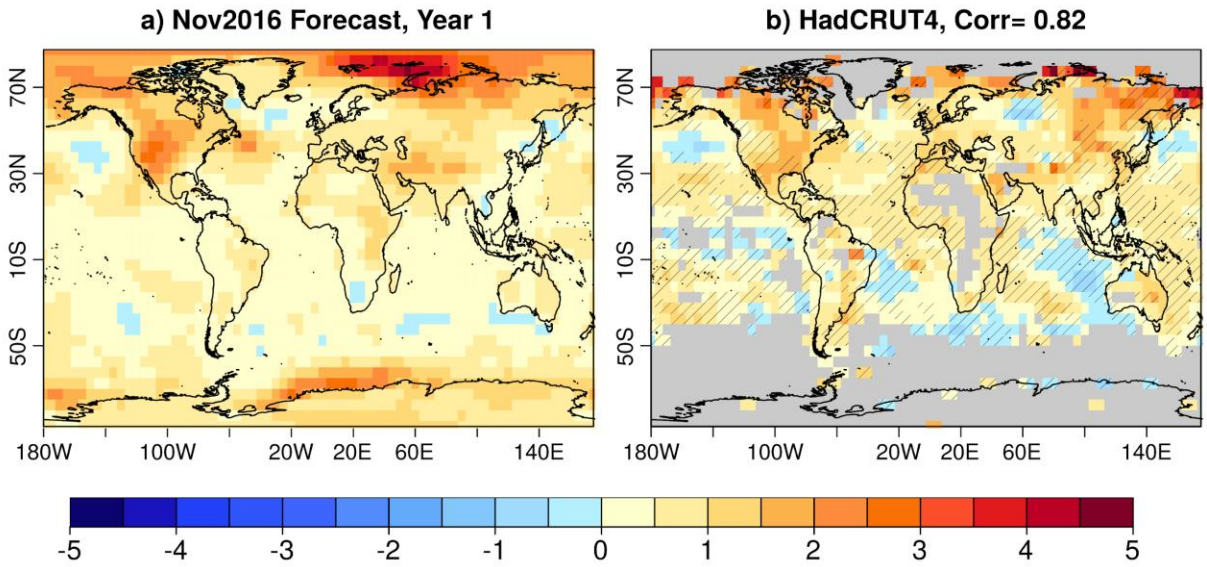

Figure 11: a) 1-year mean near-surface temperature anomalies (°C) forecasted for the period November 2016 - October 2017 by the forecast initialized on November 1st, 2016. b) Corresponding observed (HadCRUT4) anomalies. Stippled areas show the regions where the observations lie outside the 5-95% model predicted range. The spatial correlation coefficient between the observations and the ensemble mean forecast is **0.82**.

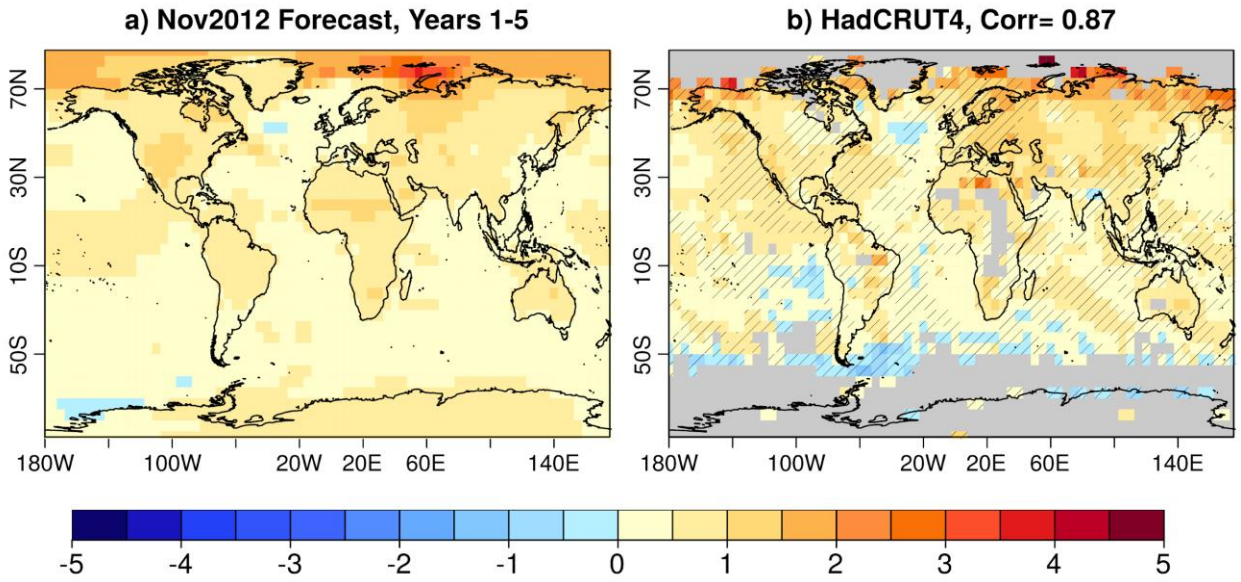

Figure 12: a) 1-year mean near-surface temperature anomalies (°C) forecasted for the period November 2016 - October 2017 by the forecast initialized on November 1st, 2012. b) Corresponding observed (HadCRUT4) anomalies. Stippled areas show the regions where the observations lie outside the 5-95% model predicted range. The spatial correlation coefficient between the observations and the ensemble mean forecast is **0.87**.

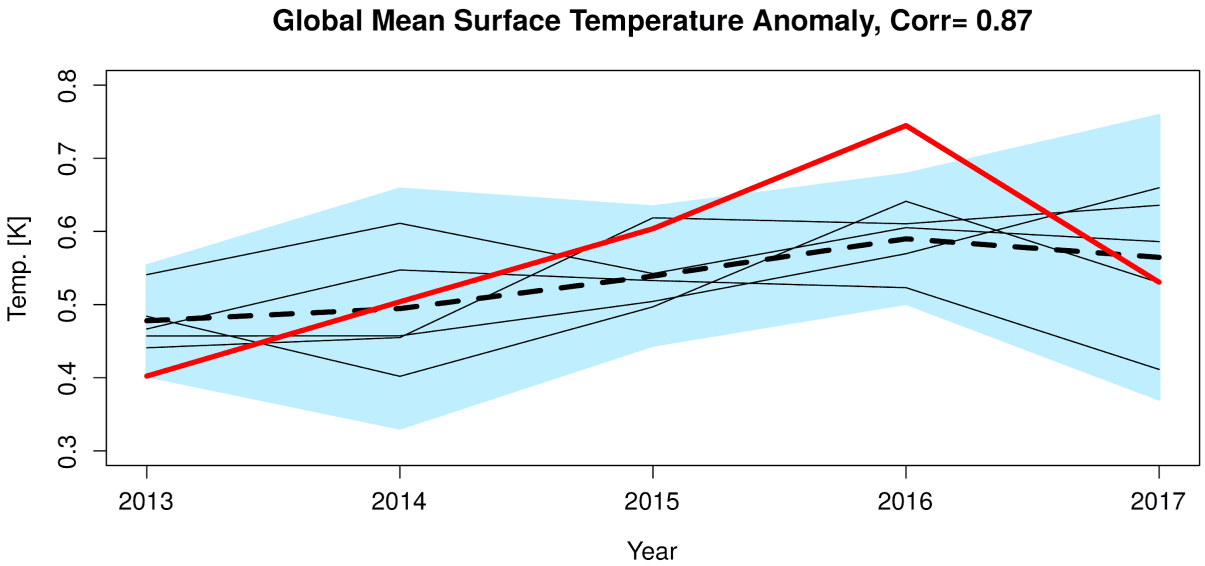

Figure 13: Five-year forecast of annual global mean near-surface temperature anomalies for the forecast initialized on November 1st, 2012. The thick dashed line represents the ensemble mean, the full thin lines, the individual members and the red line, the observation (HadCRUT4).

3.2.1.2. Mean Sea Level Pressure

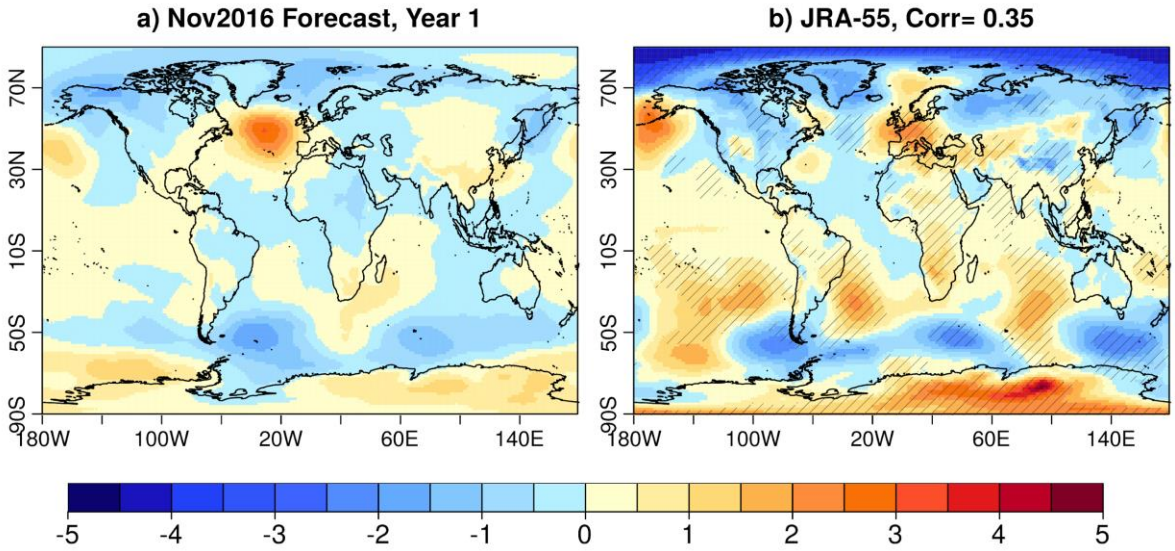

Figure 14: Same as Figure 11, but for mean sea level pressure. Units are hPa. Observations are taken from the JRA-55 reanalyses. The spatial correlation coefficient between the observations and the ensemble mean forecast is **0.35**.

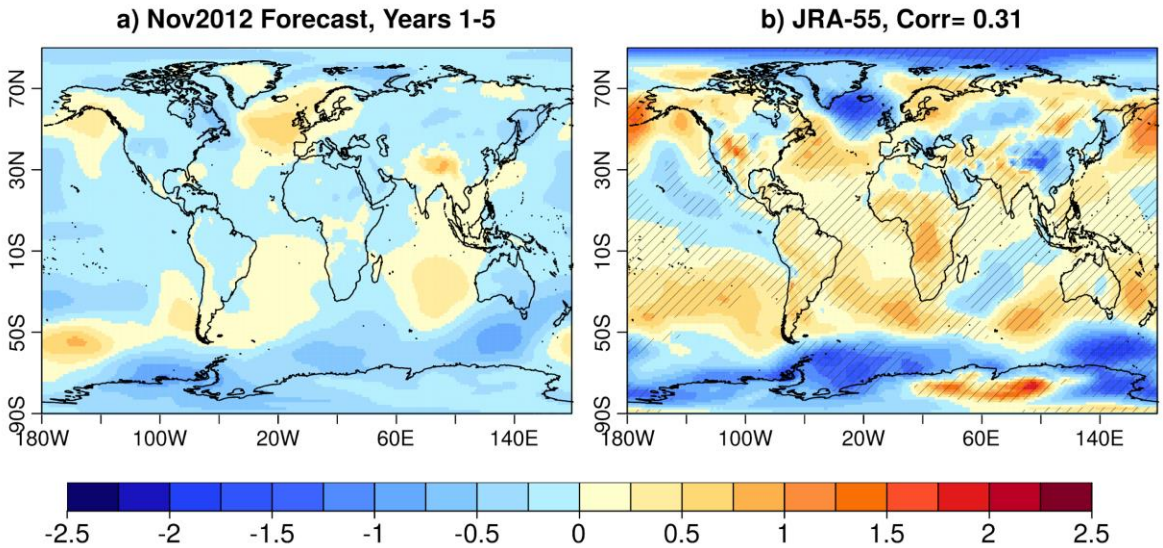

Figure 15: Same as Figure 12, but for mean sea level pressure. Units are hPa. Observations are taken from the JRA-55 reanalyses. The spatial correlation coefficient between the observations and the ensemble mean forecast is **0.31**.

3.2.1.3. Precipitation

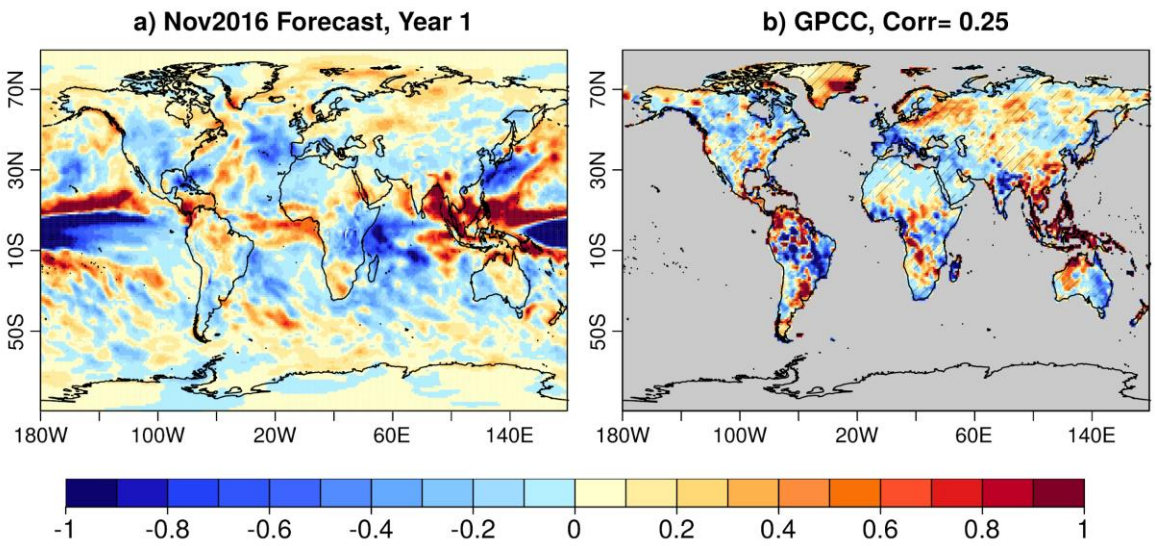

Figure 16: Same as Figure 11, but for precipitation. Units are mm/day. Observations are taken from GPCC. The spatial correlation coefficient between the observations and the ensemble mean forecast is **0.25**.

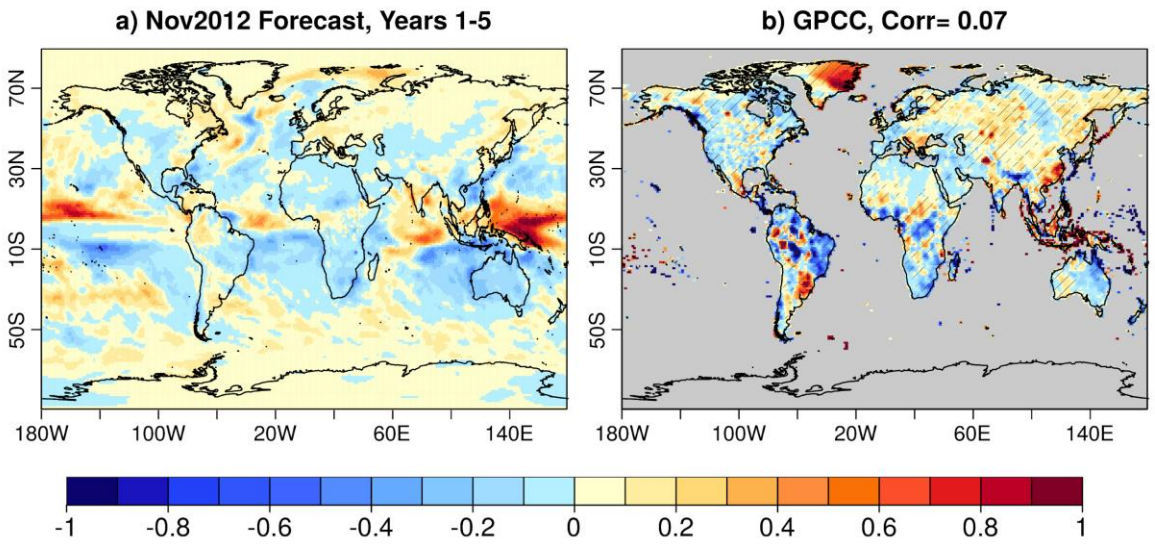

Figure 17: Same as Figure 11, but for precipitation. Units are mm/day. Observations are taken from GPCC. The spatial correlation coefficient between the observations and the ensemble mean forecast is **0.07.**

3.2.2. Hindcast Verification

The hindcasts are verified over the 1960-2017 period.

3.2.2.1. Surface Air Temperature - Stage 1

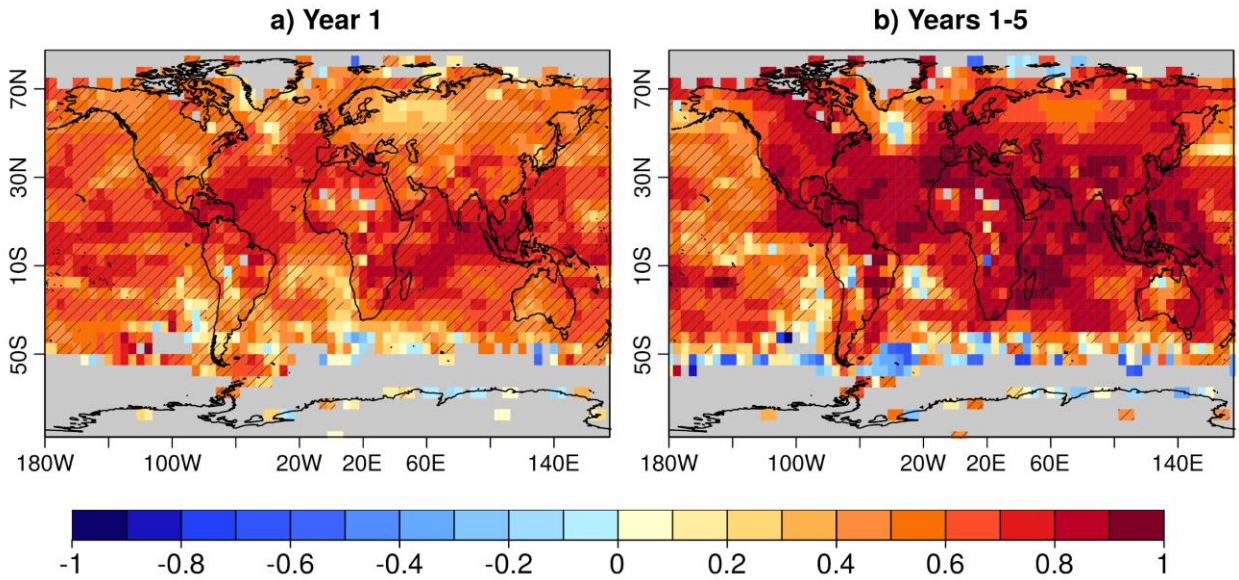

Figure 18: Anomaly correlation coefficients for near-surface temperature for a) forecast year 1 and b) average forecast year 1-5. The forecasts are verified against HadCRUT4. The stippled areas represent regions where the correlation is statistically significant at the 5% level.

3.2.2.2. Surface Air Temperature - Stage 2

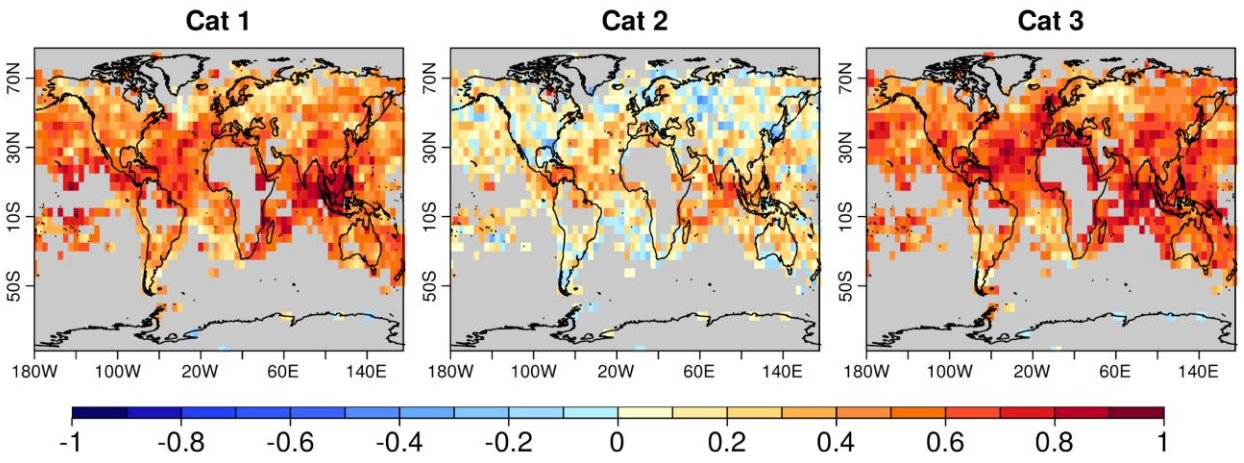

Figure 19: Forecast year 1 near-surface temperature anomaly ROC skill score (ROCSS) for a) below-normal, b) normal and c) above-normal tercile categories. The forecasts are verified against HadCRUT4.

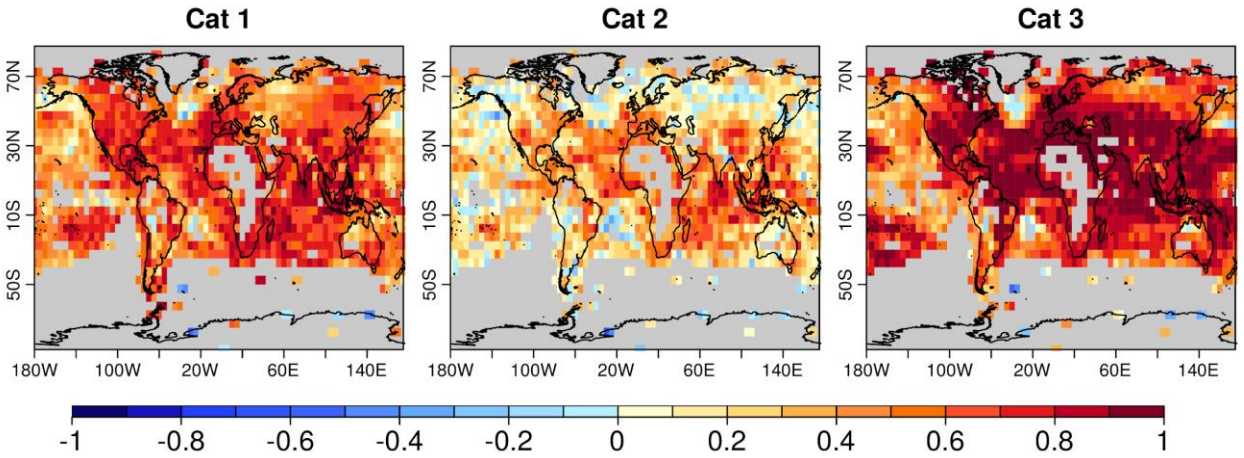

Figure 20: Average forecast year 1-5 near-surface temperature anomaly ROC skill score (ROCSS) for a) below-normal, b) normal and c) above-normal tercile categories. The forecasts are verified against HadCRUT4.

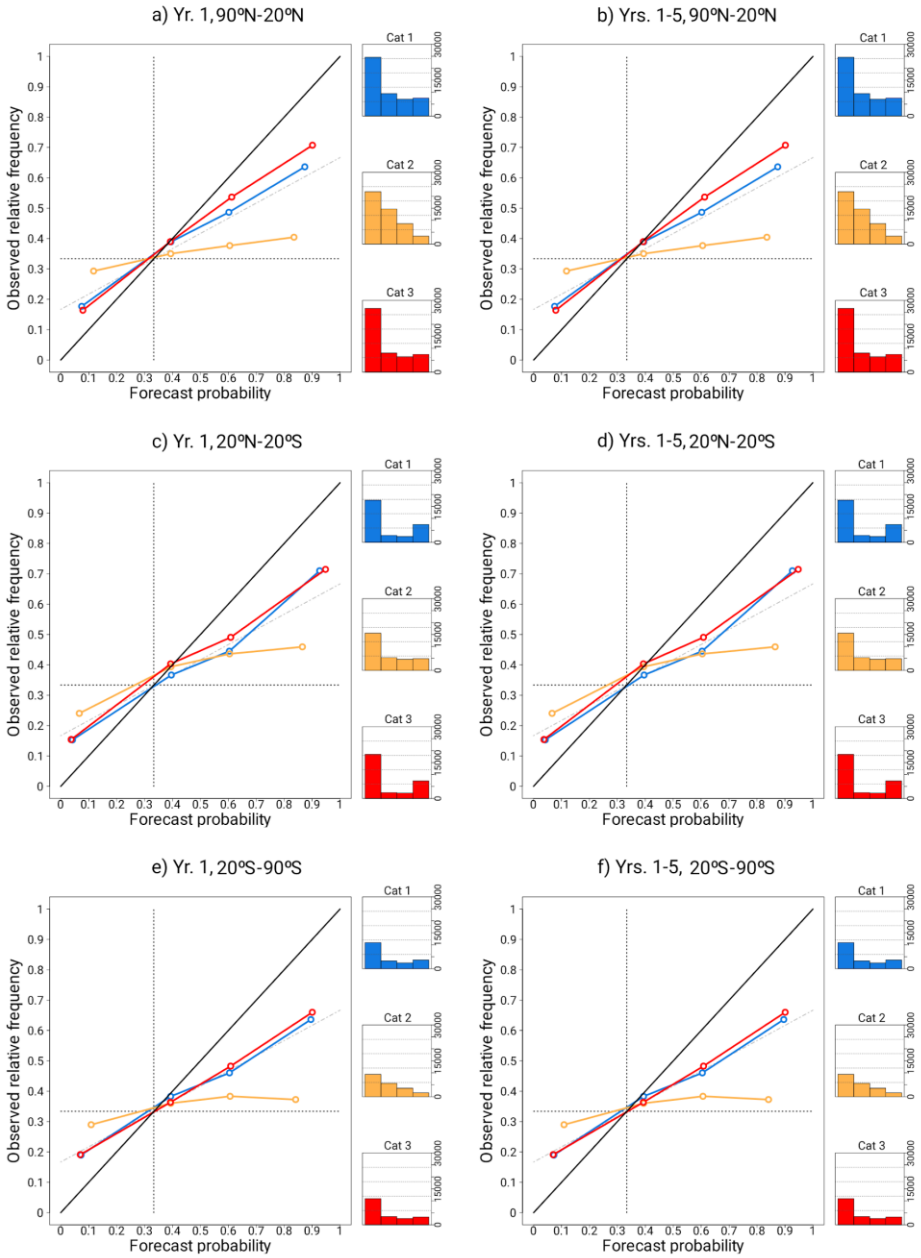

Figure 21: Near-surface temperature anomaly reliability diagrams, for forecast year 1 (left column) and average forecast year 1-5 (right column) for the region limited by a,b) 90ºN-20ºN c,d) 20ºN-20ºS e,f) 20ºS-90ºS. For each diagram, three events are represented: above-normal (red), normal (orange) and below-normal (blue). The sharpness diagrams (smaller panels) show the predicted frequencies for each event and probability range. The diagonal line indicates perfect reliability. The dot-dashed line represents the no-skill line (forecasts below this line are not better than a climatological forecast).

3.2.2.3. Mean sea level pressure - Stage 1

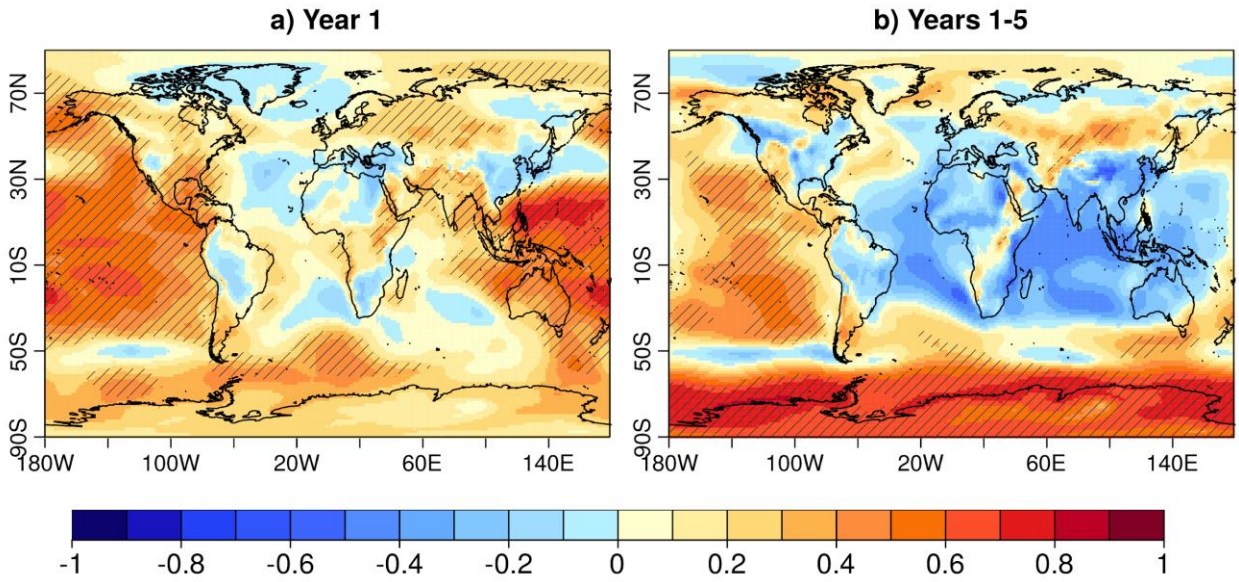

Figure 22: Same as Figure 18, but for mean sea level pressure. The forecasts are verified against the JRA-55 reanalyses.

3.2.2.4. Mean sea level pressure - Stage 2

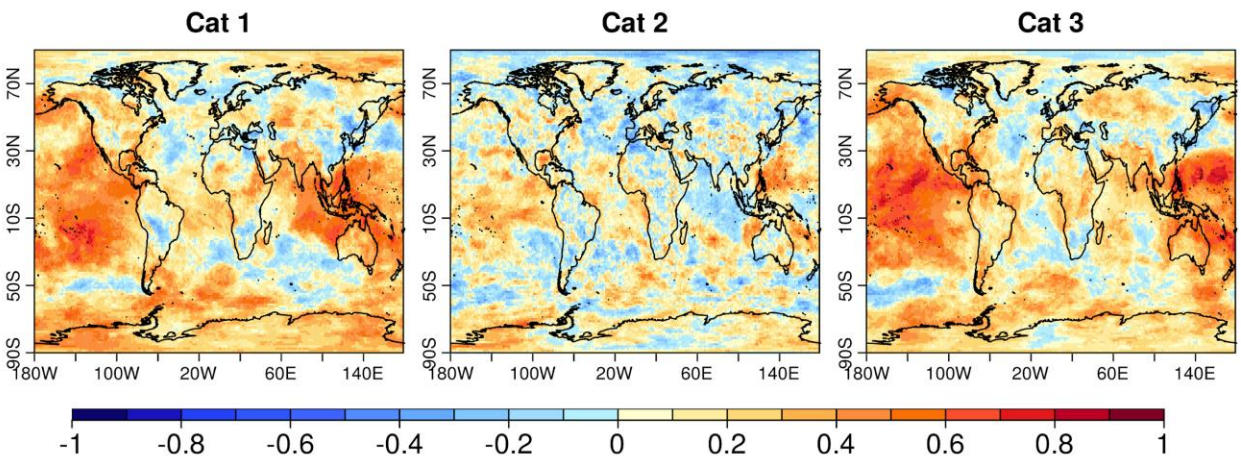

Figure 23: Same as Figure 19, but for mean sea level pressure. The forecasts are verified against the JRA-55 reanalyses.

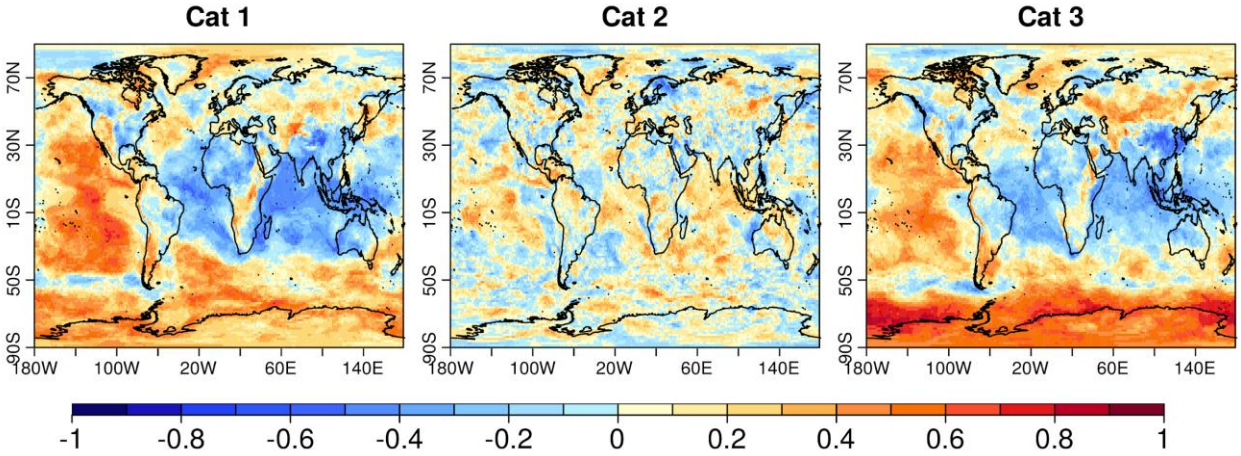

Figure 24: Same as Figure 20, but for mean sea level pressure. The forecasts are verified against the JRA-55 reanalyses.

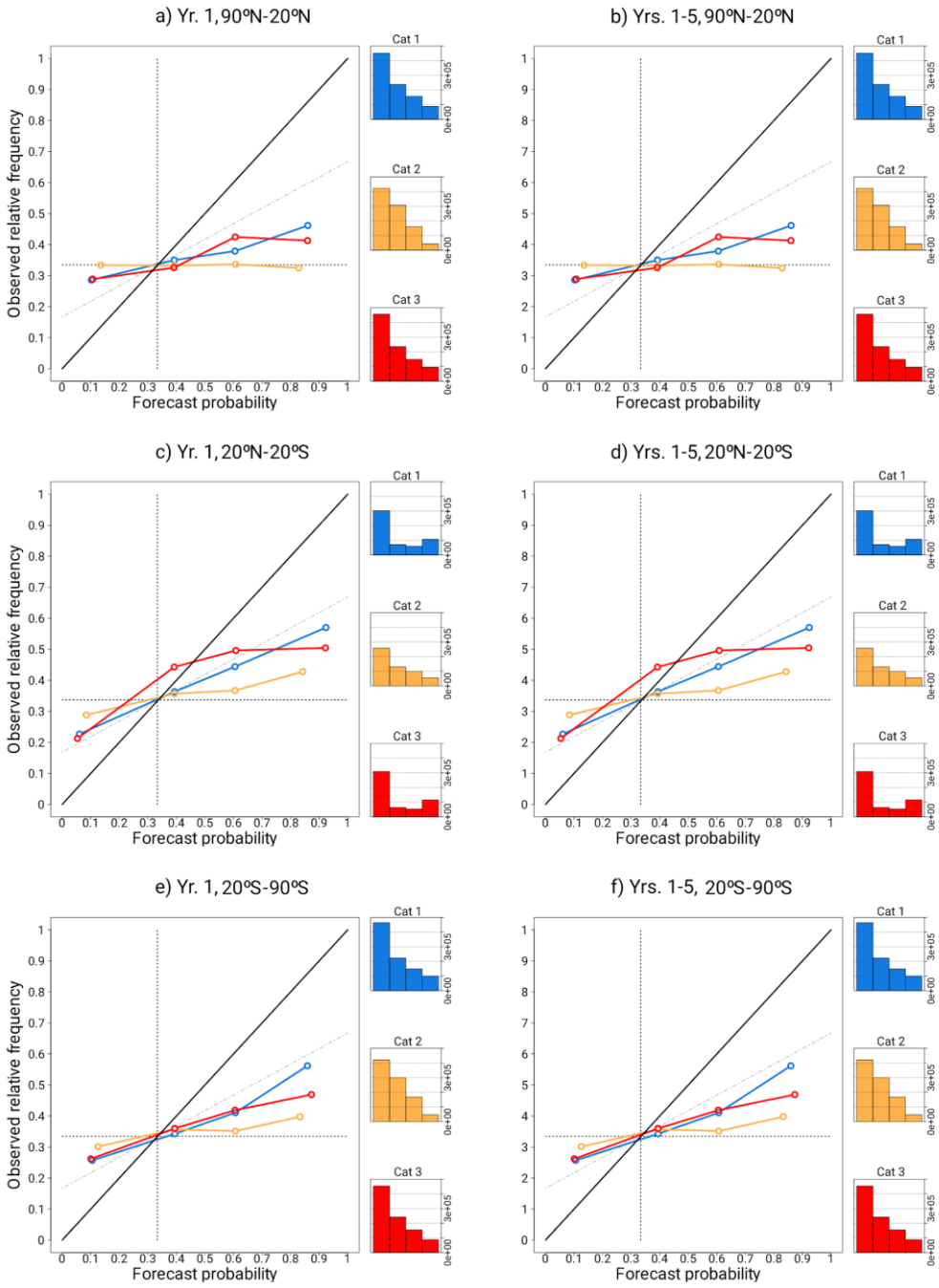

Figure 25: Same as Figure 21, but for mean sea level pressure. The forecasts are verified against the JRA-55 reanalyses.

3.2.2.5. Precipitation - Stage 1

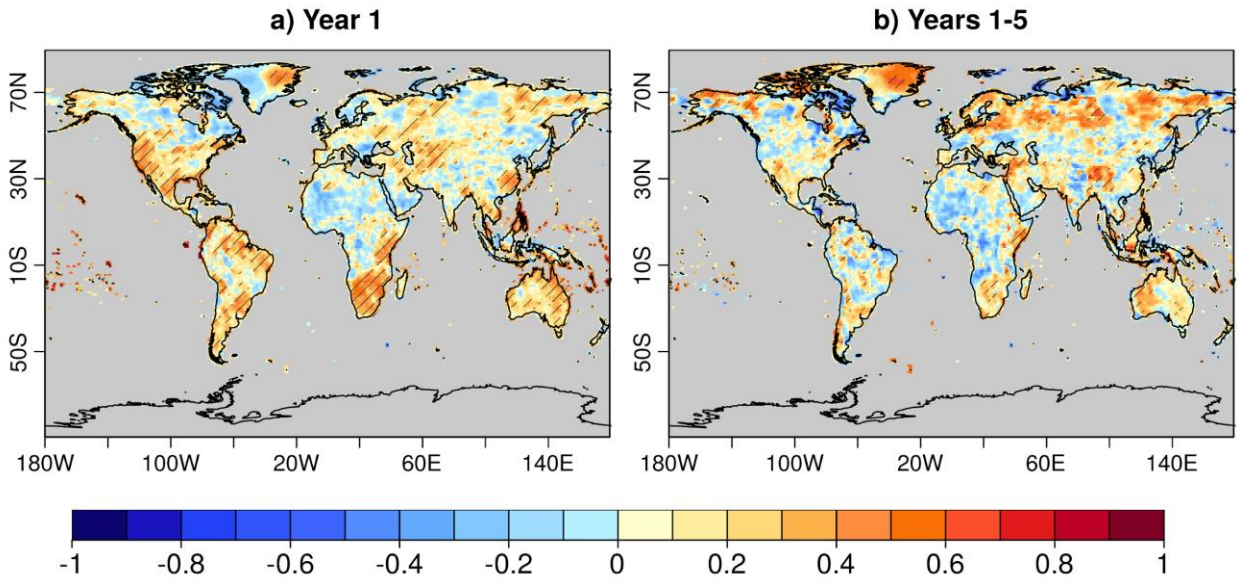

Figure 26: Same as Figure 18, but for precipitation. The forecasts are verified against GPCC.

3.2.2.6. Precipitation - Stage 2

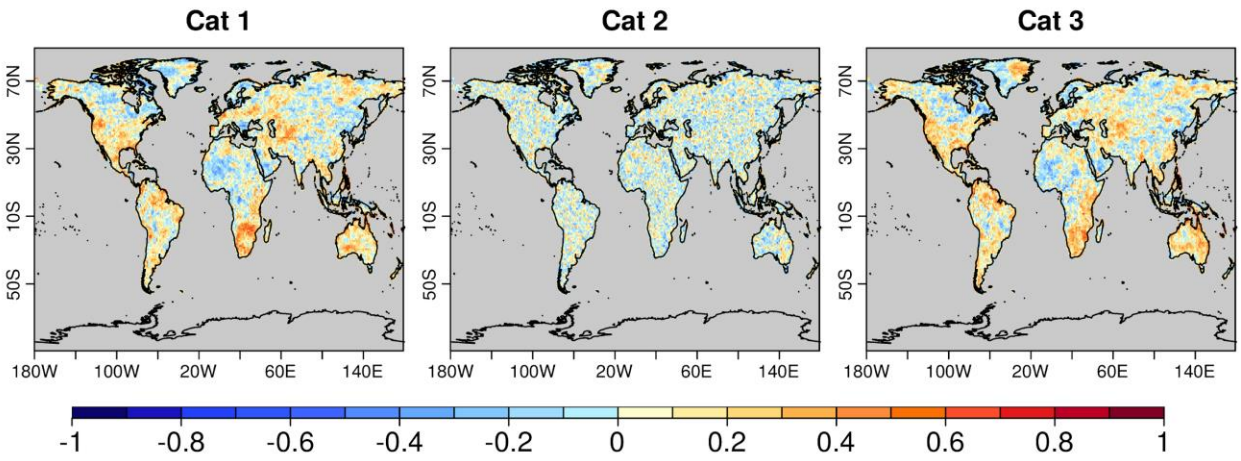

Figure 27: Same as Figure 19, but for precipitation. The forecasts are verified against GPCC.

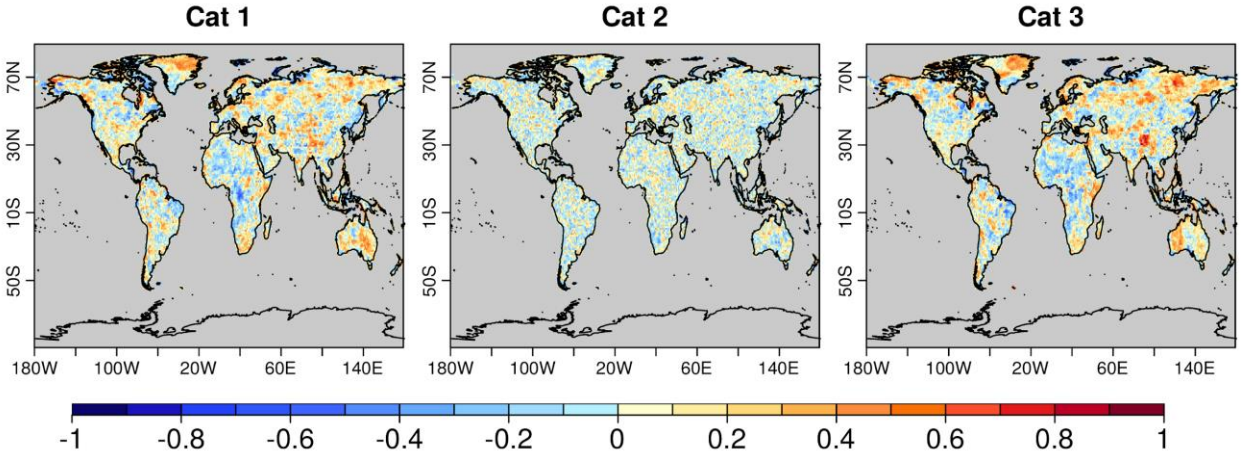

Figure 28: Same as Figure 20, but for precipitation. The forecasts are verified against GPCC.

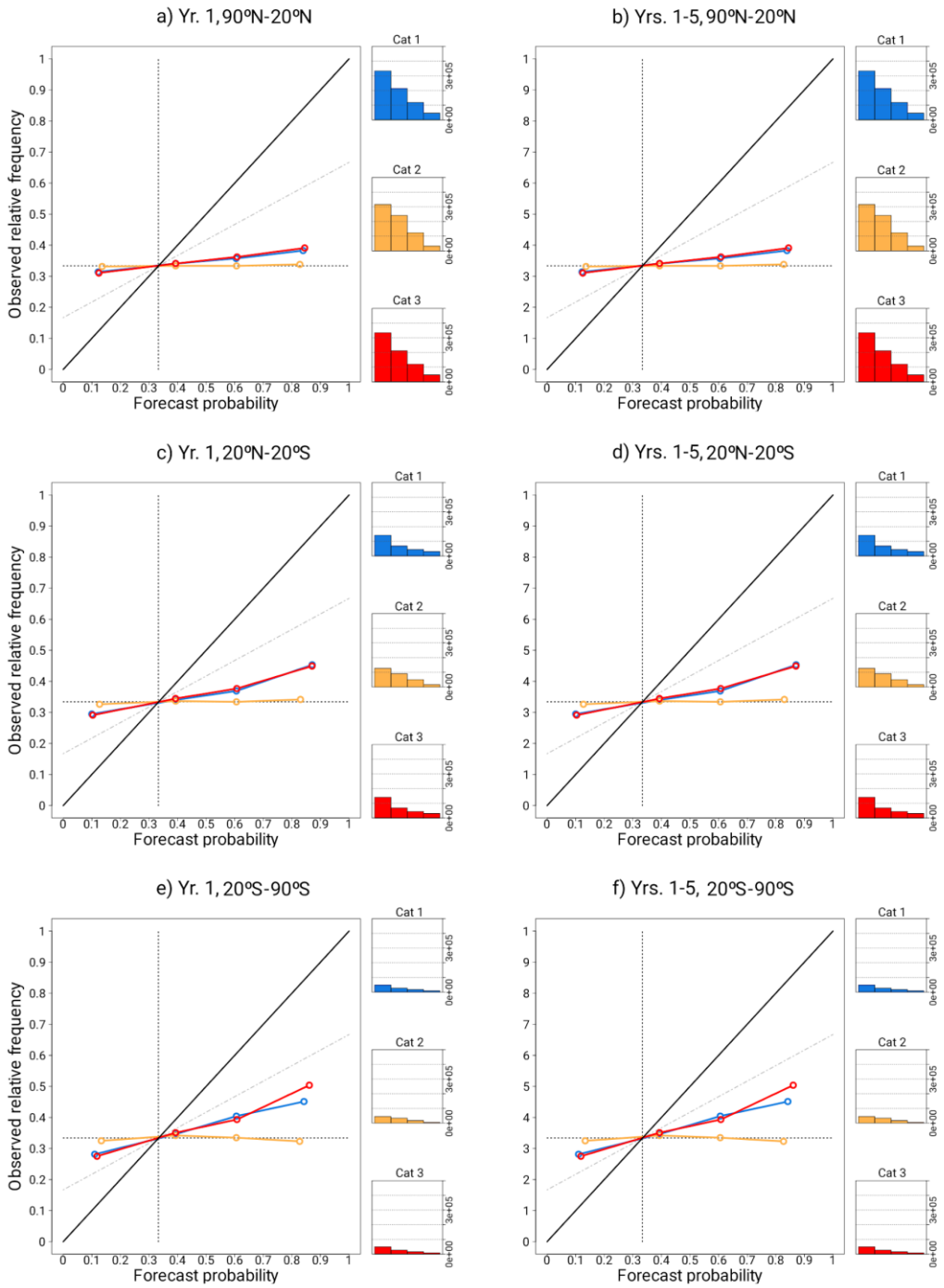

Figure 29: Same as Figure 21, but for precipitation. The forecasts are verified against GPCC.

3.3. Public global decadal prediction system information

The following table can 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	1960-2017 (one forecast per year)
Ensemble size for the hindcasts	10 members
Hindcast ensemble configuration	A set of hindcast has been run over the period 1960-2017, 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 2017 for the period November 2017 to October 2026.
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	louis-philippe.caron@bsc.es

4. Future Plans

The Barcelona Supercomputing Center is actively involved in the Decadal Climate Prediction Project (DCPP) linked to 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 2018. 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. Furthermore, in the context of the H2020 project EUCP, BSC plans to produce a set of decadal hindcasts at even higher resolution: ~25km in the ocean and ~40km in the atmosphere. And while this version of the model is expected to be operational in 2018, BSC is looking past EC-Earth 3.2 and already started the production of his next generation of climate forecasting system. As such, the BSC will be providing quasi-operational decadal forecasts, with an ever improving system, for the foreseeable future.

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