Activity 2010-2012 and Plans 2013-2016

Climate Forecasting Unit

Institut Català de Ciències del Clima (IC3)

IC3's Climate Forecasting Unit (CFU, http://ic3cfu.wikispot.org, http://www.ic3.cat/openbox.php?menu=95&area=27) was created at the end of 2009. It is made at the time of writing of 16 people, 12 of the jobs having been created through competitive funding obtained by the unit's members, plus three long-term visitors. The Unit is organized in four research groups (RG). There are also two research lines, one on polar climate prediction and another one on data assimilation, which solidly cut across the different RGs. The CFU has a commitment to use as much open source software as possible, and to publicly distribute its experiments and tools.

The future plans detailed below require a continuous search for new funding sources, where the new instruments of Horizon 2020 will play a central role. The Unit's strategic position leading the SPECS project and the membership in the panel of the European Climate Observations and Modelling for Services (ECOMS) initiative should prove helpful in this challenging task.

Seasonal prediction research group

There is growing evidence that seasonal forecast quality in extra-tropical regions is due to global change and improved forecast systems and observations. Untapped sources of predictability, such as tropical teleconnections, extra-tropical sea surface temperature (SST) and sea-ice variability also contribute to increase seasonal forecast skill. The seasonal prediction RG works towards improving current global seasonal forecast systems. Apart from investigating the characteristics of a range of operational and research seasonal prediction datasets, the members have been leading the implementation of the dynamical EC-Earth climate model as a forecast system. This implied preparing sets of initial conditions for the different model components and versions in a highly collaborative environment such as the EC-Earth international consortium.

In one of the most ambitious exercises of seasonal prediction carried out in Europe with this model, the impact of increased horizontal resolution of the EC-Earth3 ocean model component, which is expected to better represent oceanic fronts, has been assessed. Seasonal re-forecasts over the period 1993-2009, using the GLORYS 0.25º ocean reanalysis produced by MERCATOR, were carried out using resources from one of the many competitive computing projects gained in the last three years (PRACE SPIESM). Preliminary results show that the standard resolution of EC-Earth3 has a forecast quality comparable to that of the best operational seasonal prediction system, ECMWF's System 4, and that there is a beneficial impact of the horizontal resolution on both the model climate and the forecast quality.

Among the untapped sources of skill, the land component has played a central role. The results obtained (Koster et al., 2010, 2011; van den Hurk et al., 2012) suggest that soil-moisture initialization improves the forecast quality of temperature in the summer hemisphere. A new experiment with improved initial conditions has recently been completed using competitive computing resources obtained at ECMWF and is currently being analyzed.

An important activity of this RG consists in assessing the prediction of extremes in the Mediterranean region at seasonal time scales (Doblas-Reyes et al., 2013a). The group obtained private funding from the insurance company Mapfre to investigate the quality of seasonal forecasting systems to predict extreme events in Europe. This work will be extended to a global spatial scale and to include temperature extremes.

Climate predictions are produced with both physically-based (dynamical) and empirical (statistical) forecast systems. Recognizing the need for developing robust methods for combining and calibrating the predictions produced by both empirical and dynamical forecast systems, the merits of the combination of dynamic and statistical predictions of tropical sea surface temperatures (Rodrigues et al., submitted) and of West African monsoon precipitation (Philippon et al., 2010) have been explored in collaboration with CPTEC (Brazil). The combination method used known as forecast assimilation, tends to provide at least as reliable and skilful predictions as single-model systems (Figure 1).

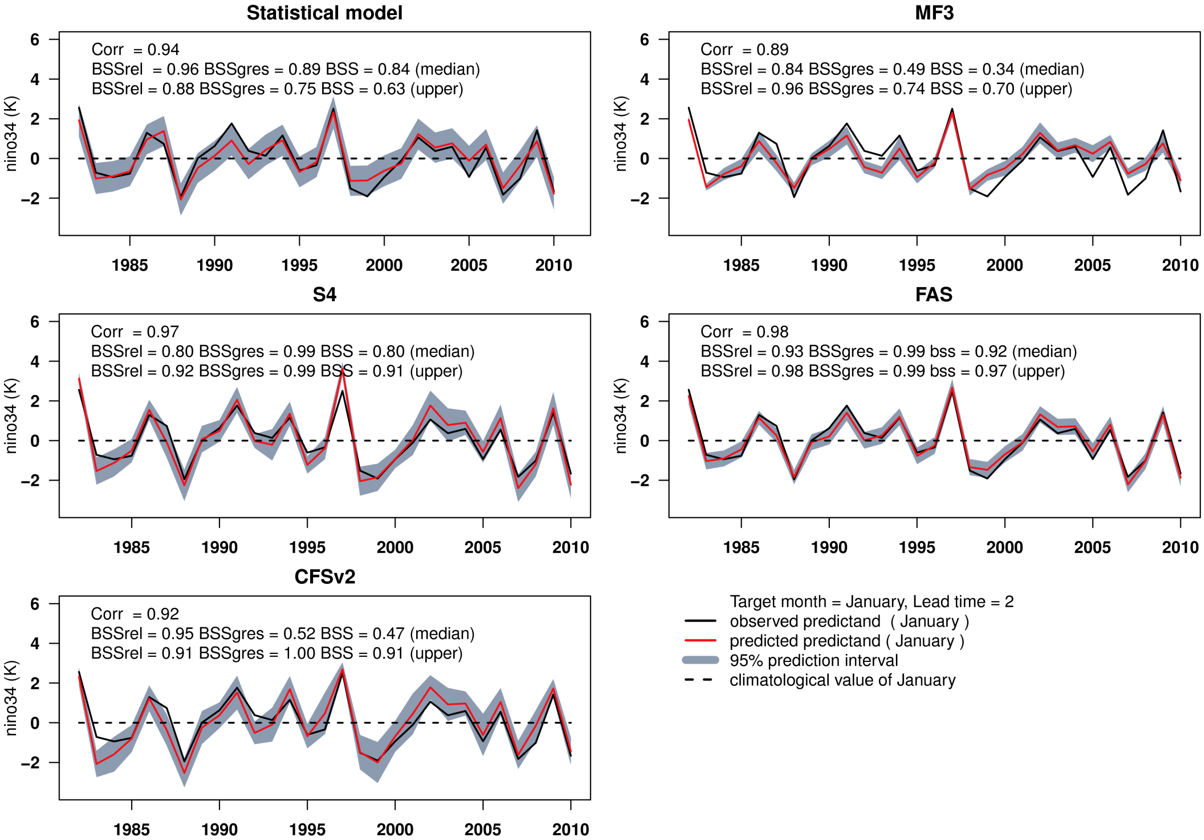

Figure 1: *Monthly forecast anomalies of the Niño3.4 index for a linear-regression based statistical model, ECMWF's System4, CFSv2, Météo-France's System3 and the combined prediction from the forecast assimilation with the statistical model as prior prediction. Forecasts are for the target month of January with two months lead time. Observed values (black solid line), predicted values (red solid line), 95% predicted interval (grey area) and the climatology value of November (black dashed line). Several scores are displayed in each panel: the correlation coefficient of the ensemble mean, and the Brier skill score and its reliability and resolution components for dichotomous events of SST anomalies exceeding the median and the upper quartile.*

In the coming years, this RG will work on the development of a detection and attribution methodology based on seasonal predictions for the analysis of recent extreme events over Europe. Within the framework of the EU-funded SPECS project led by the CFU, the RG members will pursue the goal of building a climate prediction capability at seasonal time scales and reducing uncertainties in predictions about future climate and related changes. The impact of soil moisture, snow and sea ice initialization and variations in external radiative forcings on the forecast skill will be assessed further. The analysis of high resolution seasonal forecasts and the development of empirical statistical forecast systems as a benchmark for dynamical ones will be pursued. The impact of stochastic parameterizations on the different aspects of the forecast quality (Weisheimer et al., 2011a) will be explored in the framework of a long-standing collaboration with Météo-France. The prediction capability for the West African monsoon will be explored in the wake of the results obtained within the QWeCI project, in line with IC3's missions. The activity of this RG links to the role played in international committees, such as WGSIP, the Polar Prediction Project of WWRP and ECOMS.

Decadal prediction research group

Decadal prediction stands as a newly emerged research field (Doblas-Reyes et al., 2011). The recent fifth Coupled Model Intercomparison Project (CMIP5) included a retrospective decadal prediction exercise for the first time. In collaboration with the EC-Earth partners, this RG developed a near real time decadal prediction capability (Du et al., 2012; Smith et al., 2013), which has lead to a large number of international collaborations in decadal prediction (MPI-Germany, ECMWF-International, CERFACS-France, SMHI-Sweden, KNMI-The Netherlands, IRI-USA, Univ. Buenos Aires). Following this capability, IC3 participated in the CMIP5 multi-model experiment, a primer in the Spanish climate community, producing a set of decadal re-forecasts with EC-Earth initialized every year. This is a milestone reached by only eight institutions around the world, among which only the MetOffice and SMHI/IC3 could complete a full set with full and anomaly initialization. The assessment of precipitation and surface temperature skill over the recent observational period (Corti et al., 2012; Doblas-Reyes et al., 2013b; Volpi et al., submitted) has become a basic reference for the upcoming Fifth Assessment Report of the Intergovernmental Panel on Climate Change. An example of the positive impact of the initialization with CMIP5 climate predictions is illustrated in Figure 2, where the error of the future climate information is substantially reduced with respect to the standard information released up to now for climate adaptation.

Successful retrospective predictions that include all the potential sources of climate predictability can only be improved by performing sensitivity experiments whose analysis allows highlighting the main reasons behind a given climate signal. The North Atlantic (García-Serrano and Doblas-Reyes, 2012) and the Indian (Guémas et al., 2013a) oceans are the two regions where the current generation of climate models perform the best. The group members have also highlighted the crucial role of the internal variability of the North Atlantic subpolar gyre (García-Serrano et al., 2012) in the success of climate predictions in capturing climate signals in the North Atlantic Ocean. It has also been found that the high skill of multi-annual North Atlantic surface temperatures is linked to the successful prediction of tropical Atlantic cyclone frequency (Caron et al., 2013), a research undertaken in collaboration with SMHI (Sweden), and improves the relatively poor prediction of the always important West African precipitation (García-Serrano et al., 2013). Successful retrospective predictions of the XXIst global temperature plateau have allowed for an attribution of this plateau to an increased ocean heat uptake (Guemas et al., 2013b).

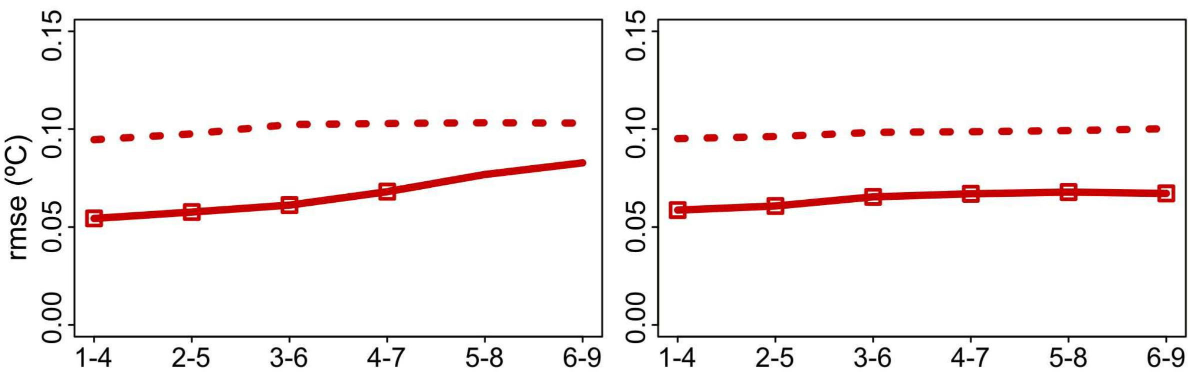

Figure 2: *Root mean square error of the ensemble-mean CMIP5 multi-model forecast anomalies (Init, solid) and the accompanying non-initialized (NoInit, dashed) simulations of the (left) global-mean near-surface air temperature and (right) the multi-decadal Atlantic variability index as a function of the forecast time for four-year forecast averages. The predictions have been initialized once every year over the period 1961-2006. Squares are used where the Init skill is significantly better than the NoInit skill with 95% confidence using a two-sided F test where the number of degrees of freedom takes into account the autocorrelation of the observation minus prediction time series.*

The North Pacific Ocean, instead, is the region where the state-of-the-art climate models perform the worst worldwide (van Oldenborgh, 2012; Lienert and Doblas-Reyes, submitted). An extensive analysis highlighted a too intense ocean vertical turbulent mixing as the main cause for the variety of model climate behaviour (Guémas et al, 2012). The diagnosis of the difficulties of current decadal prediction systems over the Pacific basin is carried out in collaboration with AORI (Japan) using a unique set of ocean re-analysis and decadal re-forecasts.

The efforts of the CFU members to increase our understanding of past and present climate variability and change and to enhance decadal prediction capability will be pursued in the next years within the framework of the CFU-led RUCSS, SPECS and PICA-ICE projects. The focus will be to assess the added-value of increasing the horizontal resolution of dynamical models, to estimate the forecast quality of multiannual predictions over the Pacific and Atlantic basins using the largest multi-model system available, to assess the contribution of the sea-ice initialization and an improved description of the atmospheric aerosols to the decadal climate forecast quality, and to understand how dynamical model biases in the tropical Atlantic affect the performance of the interannual predictions using both EC-Earth and the CMIP5 multi-model ensemble. The close involvement in the WGSIP and Decadal Climate Prediction Panel (DCPP) groups, as well as in the preparation of the IPCC AR5 offers a unique platform to keep playing an international relevant role in the decadal prediction field.

Forecast System Development research group

Climate prediction research requires a solid scientific and technical infrastructure. The Forecast System Development RG develops sets of techniques and tools required to carry out experiments of global and regional climate variability on time scales ranging from a few weeks to several years.

The CFU is currently working with the EC-Earth, NEMO and IFS models. All the experiments require a complex and efficient infrastructure. The CFU has shown an extraordinary capacity to obtain computing resources on several, but disperse, high-performance computing platforms. The computational resources to carry out the CFU experiments are obtained through competitive calls at ECMWF (3.5 million units), the Barcelona Supercomputing Centre (BSC, 3.2 million CPU hours) and, via PRACE, through other HPC platforms such as PDC (Sweden, 3.5 million CPU hours) and BSC (35 million CPU hours). These resources are complemented with a sizeable allocation in the IC3 linux cluster, Ithaca. The use and management of such distributed computing resources is done using Autosubmit v2 (http://ic3cfu.wikispot.org/Autosubmit), a Python-based software developed by the group (Figure 3), which allows using several scheduling systems and easily rerunning chunks of experiments that have produced erroneous output (Donners et al., 2012). An online storage system with 120 Tb is maintained and regularly increase to store the huge output generated. The search for new sources of computing resources is endless, and includes platforms outside Europe such as Titan at the Oak Ridge Leadership Computing Facility (OLCF). In the preparation for a proposal to the INCITE programme, a unique scaling exercise of EC-Earth3 was completed using 0.5 million CPU hours.

The initialization of the experiments is the main scientific focus of this RG. Different initialization techniques, those known as full-field and anomaly initialization (Hazeleger et al., submitted), have been compared. Other aspects of the initialization are detailed in the description of the data assimilation research line.

These activities as well as the development of EC-Earth3 as a competitive climate prediction system will be pursued within the framework of the SPECS and IS-ENES2 projects in the next years. The RG members plan to implement an initialization setup using SST, ocean and atmosphere nudging for climate prediction experiments with EC-Earth. Initialization techniques will be explored using simple prototypes of climate systems as it is described in the data assimilation research line. The maintenance of the CFU technical capability will also require a substantial attention, for which the membership in the European Network for Earth System Modelling (ENES) High-Performance Computing Task Force will be helpful.

The storage capability will be increased to 300 Tb, with appropriate replication of the most sensitive datasets, to cope with the current growth rate of ~60 Tb a year. The third version of Autosubmit with improved capabilities and a more user-friendly interface will be released under a GNU licence. A more reliable monitoring system for the CFU local computing infrastructure will be implemented. Besides, a common set of tools are also developed to assess, among other aspects, forecast quality.

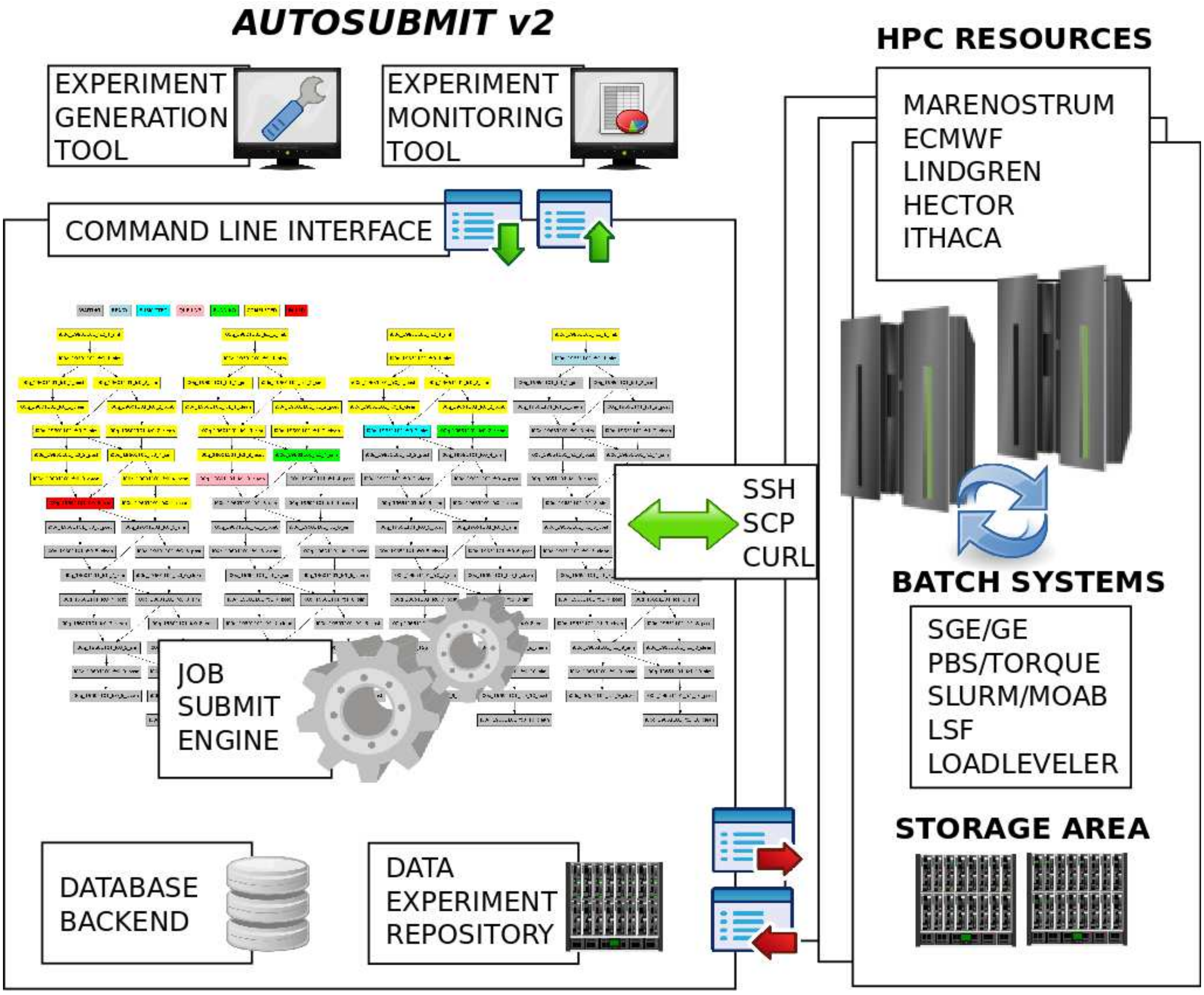

Figure 3: *Illustration of the tools developed at IC3 to perform dynamical climate predictions on different HPC platforms. Autosubmit is used to generate, launch and monitor climate prediction experiments, where the work flow is managed as a set of small jobs. While the experiments are run on a range of computer platforms as the CFU obtains computing resources, Autosubmit is run locally to offer a transparent and simple interface with the user, the communication using protocols such as ssh, scp and curl. The data are then automatically transferred back to IC3.*

Climate Services research group

While the knowledge transfer in climate modelling is usually carried out via peer-reviewed publications, web sites, social networks and media interventions, which are all aspects explored in the past three years, technology transfer in this field is somehow peculiar. For instance, it is uncommon to patent any of the discoveries, and a public sharing of the developments is common policy (and largely acknowledged). However, in a prediction context there is a regular source of information of interest to a variety of socio-economic actors. A new paradigm, known as climate services, has emerged that recognizes the need for climate risk management and tries to bridge the gap between, for instance, the industry and the climate community.

Climate variability directly influences renewable energy (RE) yield, while the predictions of energy yield are core to decisions of both investors and socio-economic managers. On the other hand, climate events have been seen to cause major economic damage, in particular for the insurance industry. In response to the World Meteorological Organization (WMO) Global Framework for Climate Services, stating the need for climate risk management in key sectors of society, the Climate Services RG facilitates the communication and application of seasonal-to-decadal climate information across the energy and insurance sectors. The RG works in partnership with climate scientists and energy and insurance stakeholders, to disseminate state-of-the-art, seasonal-to-decadal climate information from research to the downstream, actionable decisions at local, national and global scales (Doblas-Reyes et al., 2013a). Partnerships have been initiated with several key energy stakeholders from the private, public and research areas via the FP7 project CLIM-RUN. For the first time, probabilistic forecasts for wind and solar energy have been produced and disseminated to a number of stakeholders (Figure 4). This innovative effort has led the RG members to start the Advancing Renewable Energy with Climate Services (ARECS) initiative to create a research, networking and communication platform for RE climate services. Additional funding from AGAUR facilitated further dissemination of the ARECS initiative.

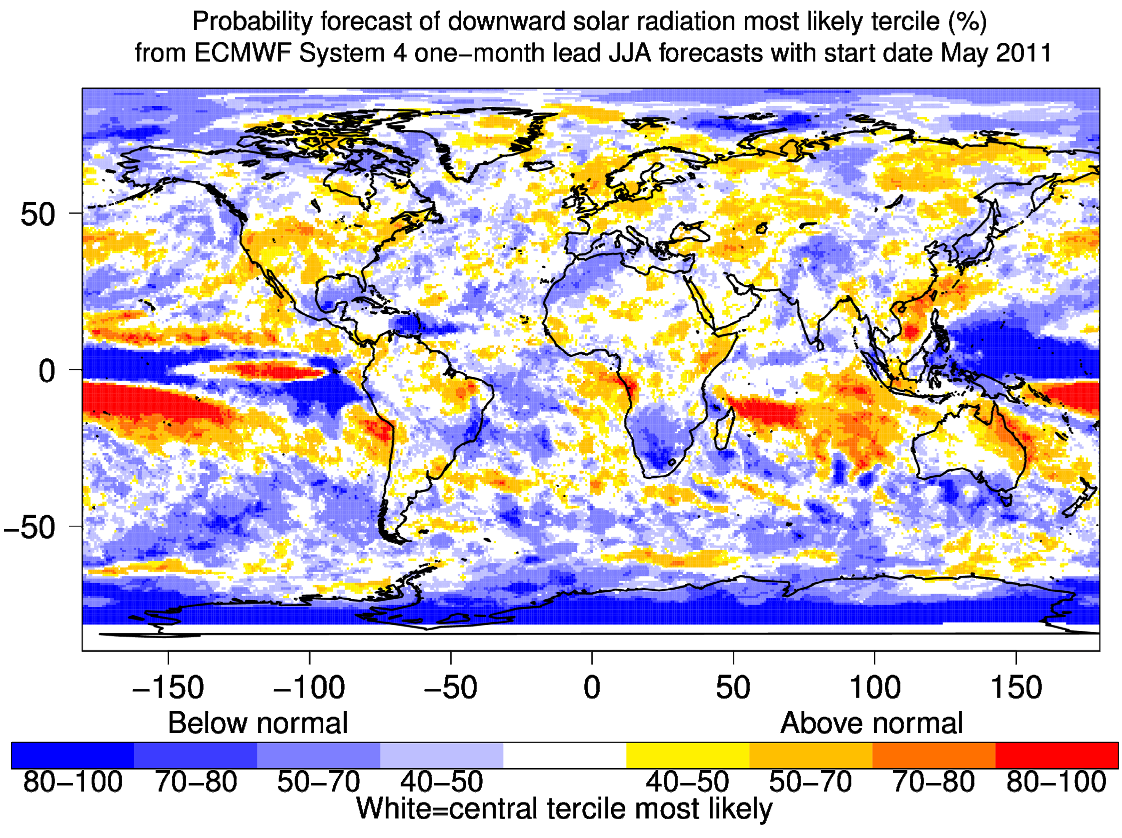

Figure 4: *Global seasonal probability forecast (%) of the most likely downward solar radiation tercile (below normal, normal or above normal) for summer 2011 (June, July, August) started in May from ECMWF's System 4.*

Climate services for insurance and re-insurance intend to provide climate information to minimise economic losses following extreme climate events like high-wind storms, or floods caused by heavy or persistent rainfall. Some success in predicting this kind of events has been documented (Weisheimer et al., 2011b). Via private funding from the MAPRE Foundation, a report with the analysis of seasonal prediction of extreme precipitation over the Mediterranean basin and the frequency of Atlantic tropical cyclones has been carried out and is expected to trigger an efficient communication with this sector.

The RG will pursue its activity linked to the RUCSS, DENFREE, CLIM-RUN, EUPORIAS and SPECS projects. Detailed research will be conducted to further understand the decision-making processes of energy stakeholders and the best approach to integrate climate-forecast information. Wind and solar probabilistic climate forecasts will be produced across a wider range of temporal and spatial scales. The ARECS platform will be developed to leverage information and research coming from the three FP7 climate services projects the CFU is involved in, as well as search for additional funding for this initiative. Promotional material that describes the basis of seasonal and decadal climate prediction and its potential applications in the insurance sector will be prepared.

Polar Climate Prediction research line

The Polar Climate Prediction research line aims at furthering our understanding of the intra-seasonal to multi-decadal changes in Arctic sea ice cover and its interaction with the other climate system components, with a particular focus on its impact on the Mediterranean climate. Indeed, numerous studies have brought evidence of an impact of the Arctic sea ice cover on the North Atlantic Oscillation (NAO) / Arctic Oscillation (AO) (e.g. Guémas et al., 2009), which in turn influences the European and Mediterranean temperature and precipitation.

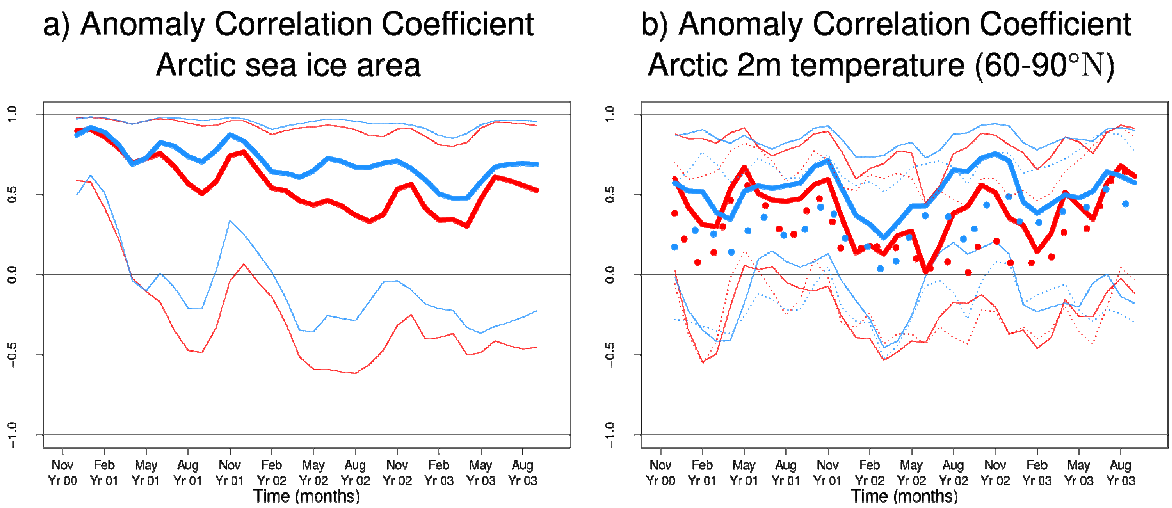

Figure 5: *Forecast skill in a set of twenty-eight five-member retrospective predictions initialized from the sea ice cover states produced by the PCP research line in blue, and in a sister ensemble produced within the context of the CMIP5 project in red. The thin lines provide the 95% confidence interval of the ACC shown by thick lines versus a) HadISST, b) the NCEP (continuous lines) and the ERA40 (dotted lines) reanalyses. Taken from Guémas et al (submitted a).*

These objectives contribute to the Seasonal and Decadal Prediction RGs. Unfortunately, polar climate studies are severely hampered by the lack of sea ice observations. As an early achievement, ensembles of sea ice historical simulations strongly constrained by atmospheric and oceanic observations were produced to generate sea-ice initial conditions for seasonal-to-decadal climate predictions (Guémas et al., submitted a), hence contributing to the Forecast System Development RG. Their added value in terms of forecast skill is illustrated in Figure 5. This activity made IC3 the provider of sea-ice initial conditions for the EC-Earth consortium, therefore strengthening its international influence. An extension of this activity is planned within the MINECO-funded PICA-ICE project by introducing additional constraints towards the few sea-ice concentration observations to obtain an ensemble of sea-ice reanalyses. Such challenging objective is currently pursued by very few institutes (Polar Science Center, ECMWF, UCL, Météo-

France) with which IC3 maintains a close collaboration. The sea-ice reanalyses will offer a new opportunity to investigate the physical mechanisms underlying the natural variability of the Arctic climate and to refine estimates of the rate of anthropogenic sea-ice loss for the coming decades. An original methodology based on clustering and classically applied to atmospheric fields will be exploited to extract sea-ice variability modes. Those analyses will substantially contribute to IC3's mission towards a better understanding of climate variability and climate change since the Arctic system is the most vulnerable to global warming (e.g. Guémas et al., submitted b). As a complementary objective, the CFU intends to investigate the sources of predictability of the Arctic sea ice cover and of its impact on the Mediterranean climate within a potential predictability context in the framework of the international NERC-funded APPOSITE project as well as within the context of a real prediction exercise exploiting the newly produced sea-ice initial states. This objective is fully in line with IC3's mission to enhance our capacity to predict climate variability and change. Given the strong connection between the Arctic sea-ice cover and the ocean circulation in the North Atlantic basin, emphasis will also be put on the understanding of the natural variability of the North Atlantic thermohaline circulation, which will be investigated from the most recent available ocean reanalyses and from sensitivity experiments performed with dynamical forecast systems. The overall goal is to increase our prediction capability on seasonal-to-decadal time scales for the Arctic sea-ice cover, the North Atlantic Ocean thermodynamic state and, subsequently, for the European and Mediterranean climates.

Data Assimilation research line

State estimation theory in geosciences is commonly referred to as data assimilation (DA). This term encompasses the entire sequence of operations that, starting from the observations of a system, and from additional statistical or dynamical information (*i.e.* the model), provides the best possible estimate of its state. This estimate, known as *analysis*, is then used for diagnostic purposes or as initial condition for dynamical weather and climate predictions. The ultimate goal of DA is to give a dynamically consistent reconstruction of all the elements of the climate system. The demand for accurate predictions from a few hours to decades has fostered the use of Earth System Models as the unified modelling instrument. At the same time, the deployment of refined measurement networks offers nowadays the opportunity to observe the Earth with a detail never attained before. DA appears as the natural framework to optimally merge and exploit both sources of information and enhances both forecast quality and the understanding of climate phenomena. Climate research requires the development of Coupled Data Assimilation (CDA) to improve the forecast capabilities of phenomena, such as those connected to the air-sea exchange like hurricanes or costal processes or in seasonal-to-decadal prediction where climate conditions are often driven by coupled processes such as El Niño Southern Oscillation (ENSO) or the Madden-Julian Oscillation (MJO). Another potential application of CDA is as a tool for observation-based external forcing estimation, contributing to the detection and attribution problem. Research efforts within this research line are aimed at addressing the theoretical and technological issues towards the development of novel CDA strategies ranging from the theory up to practical solutions suitable for realistic environmental prediction. The outcome of this research line supports the work of every CFU RG.

In the efforts to develop a DA capability at IC3, an innovative approach to simultaneous state and parameter estimation, the Short-Time Augmented Extended Kalman Filter (STAEKF) has been tested in a soil model (Fig. 6 from Carrassi et al., 2012). The STAEKF belongs to the class of deterministic model error DA methods whose review is given in Carrassi (2012). This research line has contributed to the development of the original approach to DA referred to as Assimilation in the Unstable Subspace (AUS), in which an efficient error control is achieved by tracking a reduced number of unstable modes of the DA cycle (Palatella et al., 2013). An international collaboration has been started to reconcile ideas in DA and in detection and attribution of climate events, leading to the submission of the research project Data assimilation for Detection and Attribution of Climate Change (DADA) to the French National Research Agency. The European Research Council (ERC) proposal on CDA Data Assimilation for Coupled Dynamics: A new challenge for environmental prediction (DACOD) is currently under consideration.

Work has been also initiated in collaboration with the Dept. of Physics of the University of Heidelberg (Germany) to test ideas to initialize complex models with a more simple set up, leading to the preparation of an MsC thesis. A collaboration is also ongoing with the Instituto de Física de Cantabria (Spain) to study advanced ensemble prediction strategies in coupled systems and their application to CDA.

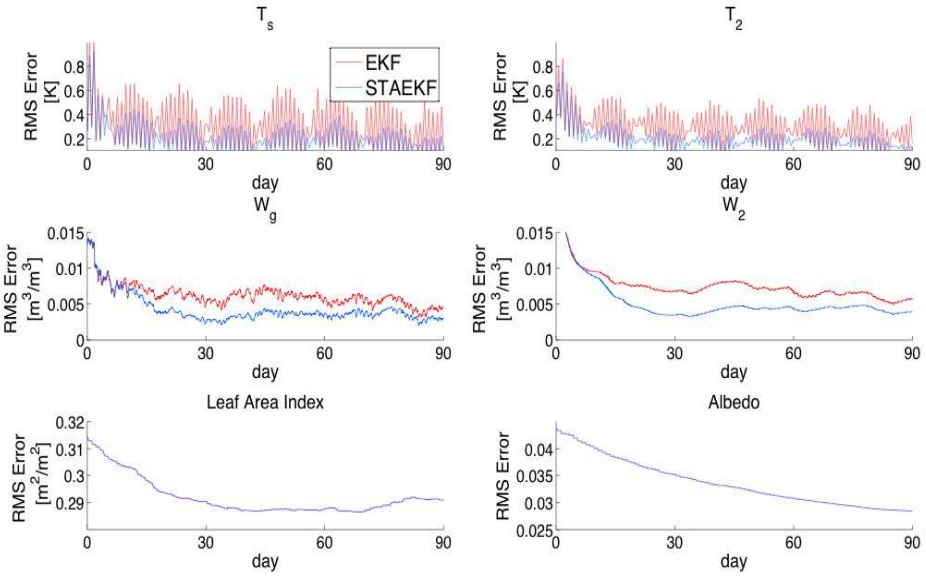

Figure 6: *Root mean square error in the state variables (soil temperature in two levels, Ts and T2, and moisture content, wg and w2) and two model parameters (Leaf Area Index and Albedo) obtained with the Extended Kalman Filter (EKF) and with the State Augmented Extended Kalman Filter (STAEKF) implemented in the soil model ISBA.*

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