SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Impact of land surface and ocean initial conditions on sub-seasonal to seasonal forecasts
Computer Project Account:	spftbatt
Start Year - End Year :	2016 - 2018
Principal Investigator(s)	Lauriane Batté
Affiliation/Address:	CNRM (Météo-France) 42 avenue G. Coriolis 31057 Toulouse Cedex 01 FRANCE
Other Researchers (Name/Affiliation):	Constantin Ardilouze (CNRM) Matthieu Chevallier (now at Météo-France, DIROP/Mar)

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

The main objectives of this special project are to assess beyond conclusions from the FP7-SPECS project the impact of the initialization of land-surface and sea-ice components of the CNRM-CM model on sub-seasonal and seasonal predictability. Two main questions are addressed:
- What is the extent of initial condition information needed to properly initialize the sea ice and land-surface components of the model?
- Can improvement in model initialization impact the predictability of specific events?

The objective is to study these questions using land surface and sea ice initial conditions and climatologies built with the corresponding CNRM-CM components run in forced mode, and studying specific test cases with initial conditions representing extremes of the climatologies.

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

We originally intended to work with a more recent version of NEMO-GELATO but due to delays had to switch back to NEMO 3.2. As a consequence, the forced NEMO-GELATO runs initially planned were not run, because we were unable to recompile NEMO 3.2 on the new Broadwell nodes with the changes we wished to implement in the code, and we resorted to using initial conditions for sea ice derived by Mercator-Ocean by nudging the NEMO-GELATO model towards the GLORYS2V4 reanalysis. This restricts the re-forecast period to 1993-2012 instead of 1979-2012.

The most recent version of the SURFEX interface enabling nudging of land surface towards reference data is not yet ported on the Cray. We therefore chose to work on land surface initial condition sensitivity using the ERA-Land reanalysis, and an offline SURFEX run.

Experience with the Special Project framework

(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

The application procedure is quite straightforward. For the progress reporting, I understand that reporting end of June is convenient for ECMWF but for the intermediate reports it would probably be more efficient to report at the beginning of the following year.
Reporting on the use of storage was not very easy for us as we already have national accounts and it was tricky to disentangle storage for the special project from storage from other experiments done with our other account.

During the end of the Special Project, we faced unforeseen deviations from the work plan (out of the three people involved in the project, one left the CNRM, and another changed position). This is the main reason why resources for the last year of the project were not entirely used.

Summary of results

(This section should comprise up to 10 pages, reflecting the complexity and duration of the project, and can be replaced by a short summary plus an existing scientific report on the project.)

The aim of this project was to further explore the impact of land-surface and sea-ice initial conditions in the CNRM-CM model on predictions at sub-seasonal and seasonal time scales. Indeed, results from the FP7-SPECS project have shown the impact of soil moisture initialization is significant in terms of correlation for summer temperature over areas of Europe including the Balkans already identified as a "hotspot" for soil-atmosphere coupling (Ardilouze et al. 2017a). The initialization of sea ice was found to have little impact in prediction skill over the mid-latitudes in a multi-model framework, with most positive impacts found in the prediction of sea ice itself (Guemas et al. 2016).

The first step of the work consisted in reconstructing sea ice and land surface initial conditions and climatologies with the CNRM-CM model run in forced mode. We then revisited specific case studies with initial conditions from extrema years of the reconstructions to test the influence of land surface and sea ice on results from a control re-forecast with CNRM-CM using the actual initial condition of the given year.

This report is organized as follows: we first present the model version used for the project and how the initial conditions were constructed. We then summarize the main results for the land surface impacts and for the sea ice impacts.

1 – Model, initial conditions and re-forecasts

The CNRM-CM model version used for this special project corresponds to Météo-France seasonal forecasting system 5, operational at the time of the beginning of the project. This version of the model is also used for the CNRM contribution to the S2S project. A schematic of the model components, resolution and coupling frequency is shown in Figure 1.

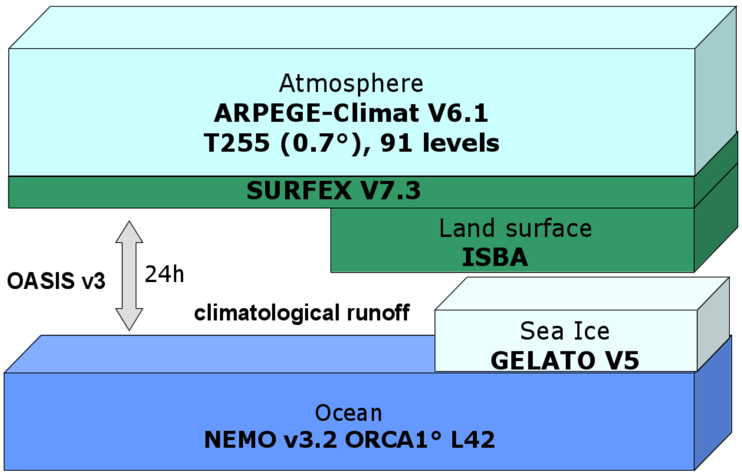

Figure 1: Schematic of the CNRM-CM model version used for this special project (unless mentioned otherwise).

Initial conditions for the land surface component (SURFEX) were prepared with an offline SURFEX run with the ISBA-DIF multilayer soil scheme forced with ERA-Interim data (except for precipitation data calibrated using GPCC). An illustration of results for the Balkans region is shown in Figure 2 for the 1st of May root-layer soil wetness index (SWI). These conditions are used in the re-forecasts discussed in section 2.

Ocean initial conditions were provided by Mercator Ocean International and are derived from the GLORYS2V4 reanalysis upscaled to the NEMO ORCA1° grid using a nudged NEMO run. The sea ice initial conditions are directly computed from this nudged run which uses the GELATO sea ice model. No sea ice concentration assimilation is used, the sea ice formation and melt is piloted by the ocean conditions in GLORYS2V4 and ERA-Interim atmospheric forcings. The run covers the 1993-2012 period, we therefore used this period as our re-forecast period for this study. Figure 3 shows the sea ice area on November 1st found over different regions with this run.

Re-forecasts with 30 members, extended to 60 members in the last year of the project for the winter runs, were initialized in May and November using initial perturbations to the ERA-Interim atmospheric conditions on the 1st of May and 1st of November, respectively. This is a different approach to the one used in the Météo-France seasonal forecasting system 5 which uses in-run stochastic perturbations of the atmospheric prognostic variables. These re-forecasts were the baseline for a set of sensitivity experiments described below.

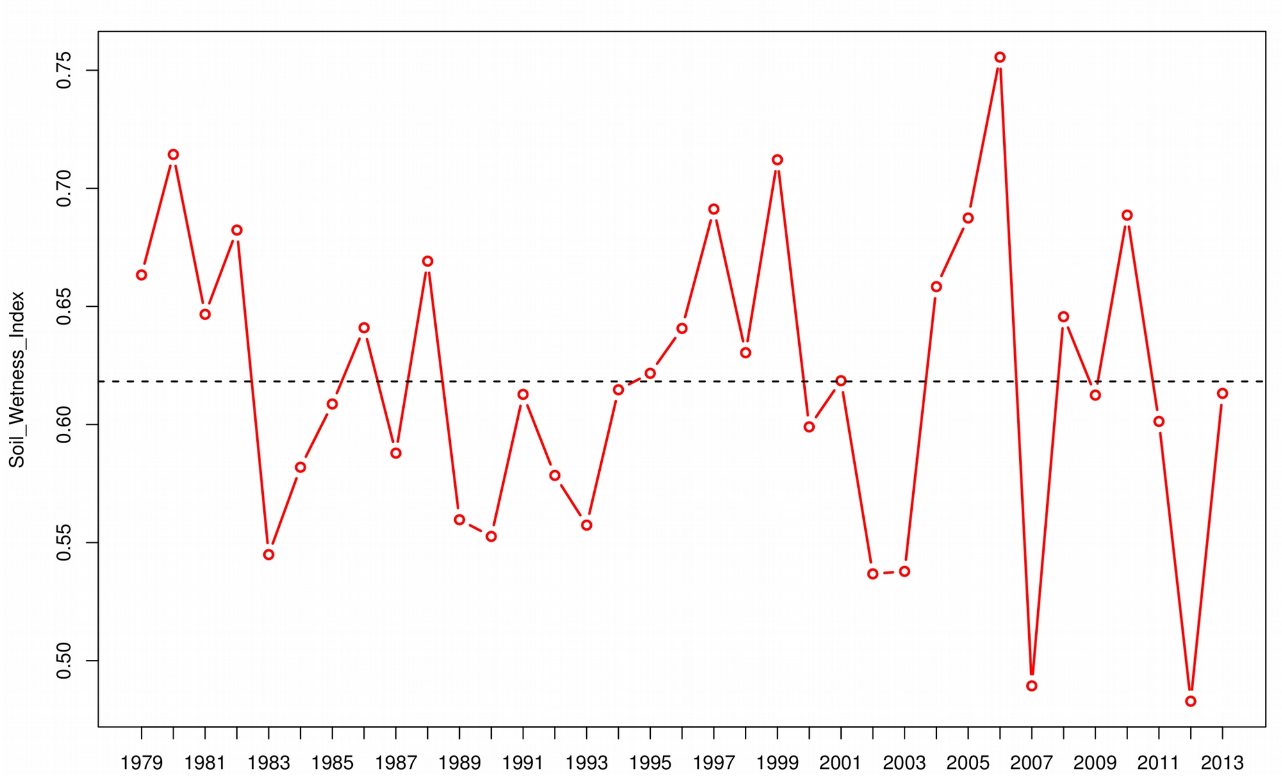

Figure 2: Root-layer soil wetness index (SWI) computed over the Balkans region for the 1st of May 1979-2013 in offline SURFEX runs forced with ERA-Interim.

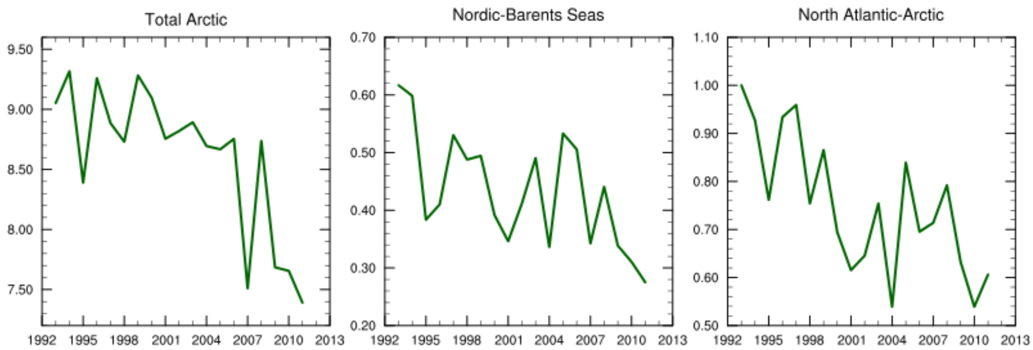

Figure 3: Sea ice area (SIA) in millions of km² in the initial conditions used in the CNRM-CM runs in this project over the Arctic (left), Nordic and Barents seas (center), and the Artic seas linked to the Atlantic sector (right).

Soil moisture experiments

For soil moisture the focus season was boreal summer (JJA for the seasonal time scale, and a case study in July for the sub-seasonal time scale).

A first set of paired experiments aimed to revisit the study by Ardilouze et al. (2017a) with the version of CNRM-CM used for the special project, and therefore compared the skill of the re-forecasts initialized in May with soil moisture conditions from the offline SURFEX run (SINI) to those initialized using the climatology of 1993-2012 1st of May conditions from the same run, therefore suppressing the inter-annual variability of the surface conditions in the initial state (SCLI).

Several sets of case study experiments comparing results to SINI were run for the 2012 summer. Indeed, as shown in Figure 2, the SWI over the Balkans area was exceptionally low in May 2012 (record low over the time period). We therefore investigated the impact of this low SWI in the initial condition by comparing the JJA re-forecast for 2012 in SINI and SCLI, but also re-running the 2012 season starting from "average" SWI conditions (SNEU, using 2009) and anomalously wet conditions (SWET, using 2006 from the reconstruction).

Finally, focusing more on the sub-seasonal time scale, the CNRM S2S forecasts which are based on the same model version as in the special project were re-run for the 2015 heat wave study discussed in Ardilouze et al. (2017b), but changing the soil initial conditions to test the influence of soil moisture in our model in amplifying the warm signal over Western Europe. For this we chose to replace the 2015 land surface initial conditions provided by the IFS operational analysis by conditions one year later. Spring 2016 was unusually wet in France, which led to strong positive SWI anomalies. The contrast with 2015 actual conditions is quite striking and shown in Figure 4.

Ocean and sea ice conditions

The impact of sea ice conditions was investigated at the seasonal time scale, focusing on the boreal winter season (DJF initialized on 1st of November).

The reference re-forecast (IINI) uses initial sea ice conditions from the nudged NEMO-GELATO run constrained by GLORYS2V4. The case study focused on the 2009/10 winter which was marked by a strong negative NAO at the seasonal time scale. We chose two years from the last decade of the reanalysis period to avoid too much impact from the sea ice concentration trend over the re-forecast period and ran two seasonal re-forecasts with minimum and (local) maximum sea ice area conditions, IMIN using 1st November 2011 sea ice conditions, and IMAX using 1st November 2005 conditions.

For the summer season, we also investigated the role of the ocean conditions over the North Atlantic region in the 2015 summer season during a master's thesis. Unfortunately, these simulations had to be run on the Météo-France supercomputer for technical reasons (code compilation issues) but since results are relevant for this project they are also summarized in this report.

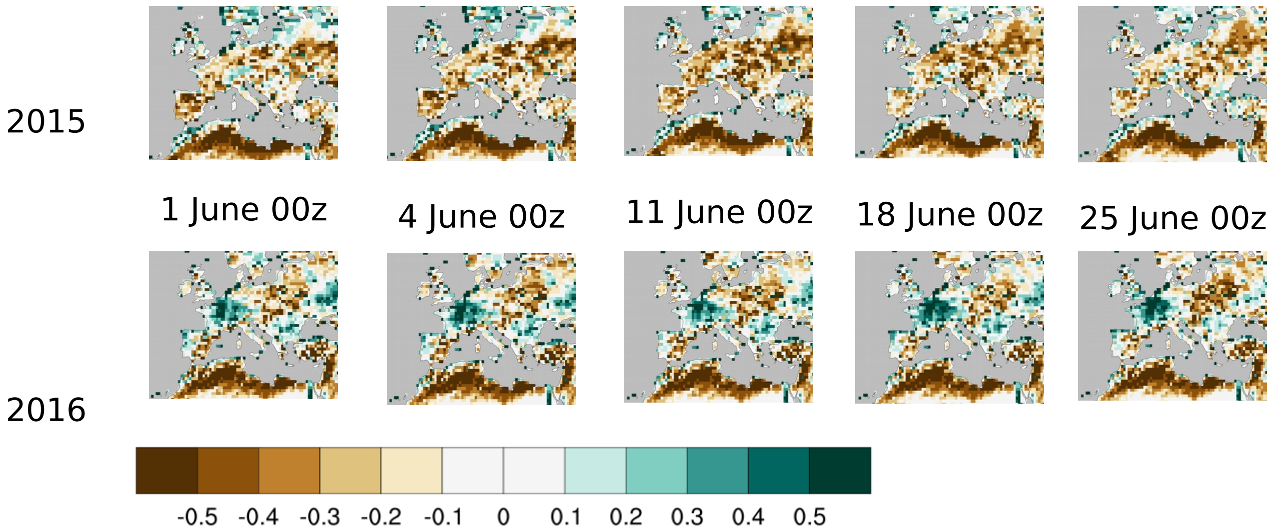

Figure 4: SWI anomalies in the IFS analyses used to initialize the S2S forecasts with CNRM-CM for the 2015 heat wave case study in the real-time run (top) and case-study sensitivity experiment which uses 2016 land surface initial conditions (bottom)

2 – Main results on soil moisture sensitivity

Seasonal time scale

Figure 5 shows the impact of soil moisture initialization on correlation of maximum 2-meter temperature in summer re-forecasts with CNRM-CM, by comparing correlation levels with respect to EOBS data in the climatological surface initialization runs (SCLI) with SINI.
Similar improvements with land surface initialization are found over Western and Central Europe using the CRUTS4 dataset. Note that results over Central Europe are consistent with Ardilouze et al. (2017a).

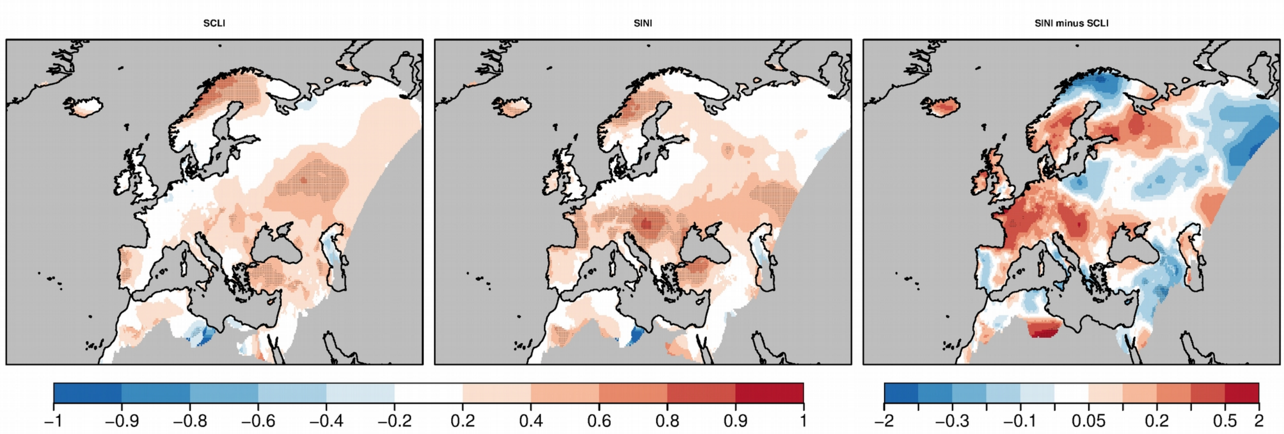

Figure 5: Correlation of JJA maximum temperature with EOBS data over 1993-2012 in the SCLI (left) and SINI (center) re-forecasts, and correlation difference (right).

However, in the specific case of 2012, the land surface initialization does not improve (and even slightly degrades) the near-surface maximum temperature anomaly found over the Balkans area, in contradiction with previous results (Figure 6).

In a more recent version of the model, a correction of precipitation fed into the land-surface component is shown to partially alleviate biases over key regions for atmosphere-soil coupling and improve skill (Ardilouze et al. 2019). However, this wasn't investigated with the version of CNRM-CM ran for the special project, and the lack of improvement found for a specific case study is in contradiction with average skill over the region, making it difficult to draw a general conclusion in the case of the Balkans.

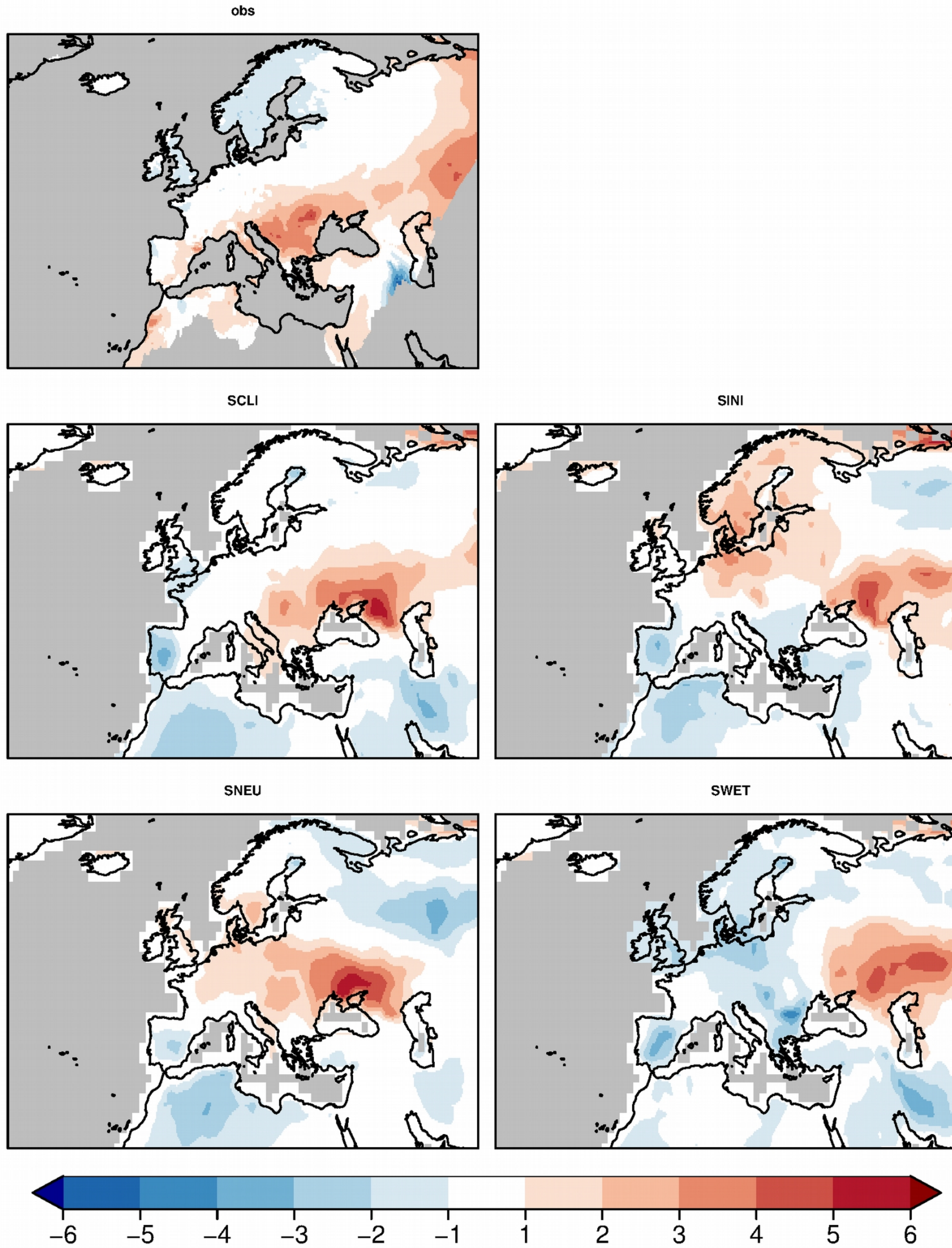

Figure 6: JJA Tmax anomaly for 2012 with respect to the 1993-2011 climatology from SCLI in EOBS (top) and re-forecasts (middle row to bottom, left to right) SCLI, SINI and case study re-forecasts SNEU and SWET.

Sub-seasonal time scale

At the sub-seasonal time scale, soil moisture seems to play a key role in the correct S2S forecasts for the 2015 heat-wave (Ardilouze et al. 2017b). Indeed, when the dry soil moisture conditions over France are replaced by anomalously wet conditions from the following year, the ensemble forecasts with CNRM-CM yield distributions of Tmax averages over France during the peak of the heatwave (July 1-6 2015, noted 6DS) that are shifted towards cooler values, even for the last initialization of the 1st of July (see Figure 7).

1st of June and 4th of June initializations are no longer shifted towards warmer values, and the tails of the distributions no longer encompass anomalies as extreme as +10 K. Note that since surface conditions have been modified around the globe, and not only over the region of interest, we cannot exclude that some remote effects are also at play (see e.g. van den Hurk et al. (2012)).

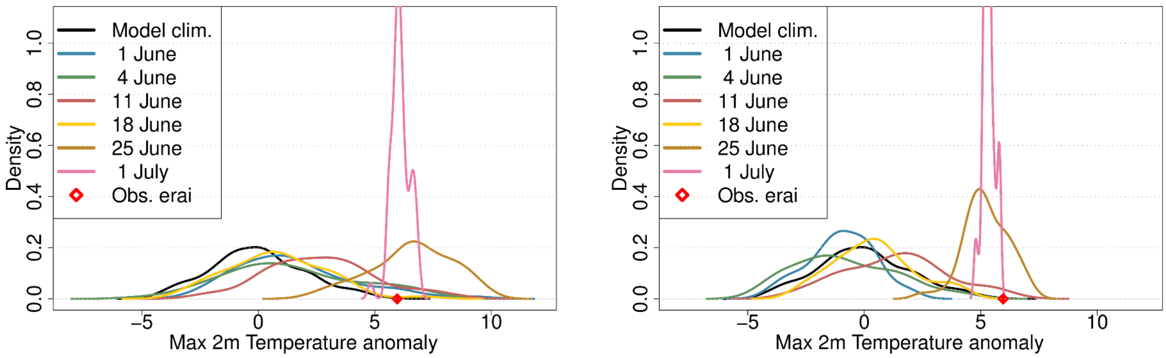

Figure 7: PDFs of maximum 2-meter temperature anomalies averaged over France during the 6 first days of July 2015 in several forecasts with CNRM-CM: S2S contribution (left), and simulations where land surface conditions are replaced with 2016 conditions for the same start date (right). Model climatology for the 1993-2014 period is shown in black, and ERA-Interim averaged anomaly for 2015 is depicted by the red diamond.

These results suggest that over Western Europe, soil moisture did play a role in the amplification of the heat wave and a correct initialization is one key ingredient to a successful forecast.

3 – Main results on sea ice and ocean conditions

Sea ice sensitivity

Interpretation of results for the sea ice sensitivity experiments is quite tricky because of the choice of actual past years for sea ice conditions instead of an idealized framework where sea ice concentration can be entirely suppressed over specific regions.
For instance, although 1st November 2011 does correspond to a minimum in total Arctic sea ice area in the GLORYS sea ice conditions used over the 1993-2011 period, it is not the case for the Atlantic sector seas (see Figure 3).

We focused on the impacts of these sea ice conditions on a specific winter, DJF 2009/10. Results suggest that sea ice only had a very limited influence on the NAO re-forecast with our model, as shown by distributions of the NAO index in the IINI, IMAX and IMIN re-forecasts for 2009 shown in Figure 8 (a). The tail of the IMAX distribution is slightly shifted towards negative NAO values and on the other end, IMIN has slightly higher positive NAO values but these differences are very small and only related to one or two members of a highly dispersed ensemble.

Similar results are found when computing the Tibaldi and Molteni (1993) blocking index for the different experiments. The model clearly underestimates blocking frequency over the Atlantic sector with respect to ERA-Interim, and completely misses the very strong blocking frequency anomaly over the Atlantic in the 2009/10 winter seen with ERA-Interim data. The three sea ice initial conditions seem to play a very minor role in the winter circulation in the re-forecasts, since little to no clear difference is found between these simulations, suggesting that possible impacts in sea ice initial conditions are very quickly drowned in noise over the mid-latitudes in this version of the model.

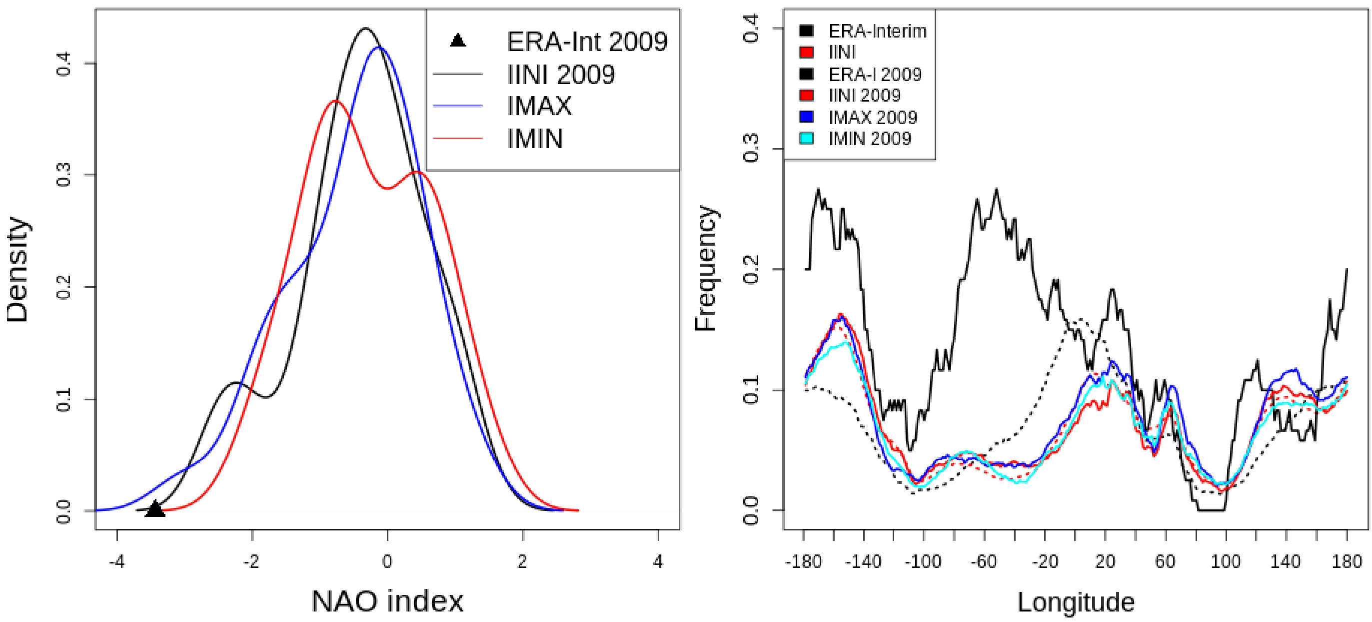

Figure 8: (a) Distribution of the DJF 2009/10 NAO indices (computed by projecting model anomalies onto the leading EOF of ERA-Interim Z500) of each ensemble member for IINI (black), IMAX (blue) and IMIN (red) re-forecasts. The ERA-Interim index is plotted as the black triangle. Anomalies used to compute the indices for IMAX and IMIN are with respect to IINI over the other years of the re-forecast. (b) Tibaldi and Molteni (1993) blocking index in ERA-Interim (black) and IINI (red) climatologies for NDJF 1993-2012 (dashed lines), and NDJF 2009/10 blocking frequency in ERA-Interim (black line) and IINI, IMAX and IMIN experiments (red, blue, and cyan lines, respectively)

Impact of ocean conditions on summer 2015

We present here additional results based on experiments run on the Météo-France supercomputer, but related to the topic of this special project.

The aim of these experiments were to investigate with the CNRM-CM model used for System 5 the hypothesis relating the "cold blob" anomaly in the North Atlantic ocean to the abnormally warm summer 2015 (see e.g. Duchez et al. 2016). To this end, sets of ensemble forecasts starting from May 1st 2015 were run up to end of August, with surface relaxation of the NEMO model towards the GLORYS ocean reanalysis, either only the cold anomaly region, or the entire globe.

In Figure 9, we show results in terms of box plot distributions of the ensemble members near-surface temperature anomalies over the Central Europe region defined by Duchez et al. (2016). Our reference forecast (without relaxation) failed to correctly capture the warm anomaly over this region, and despite nudging the ocean over the cold anomaly region (RANO) to correctly represent SSTs over this area, the temperature distribution is not significantly shifted. Only by implementing a global relaxation (RGLO) does our model represent an anomaly closer to the reference data.

We conclude from these results that if the cold anomalies over the Atlantic did play a role, the mechanism is not correctly represented in the coupled forecast system, and other phenomena may likely have played a key role in the occurrence of a warm summer.

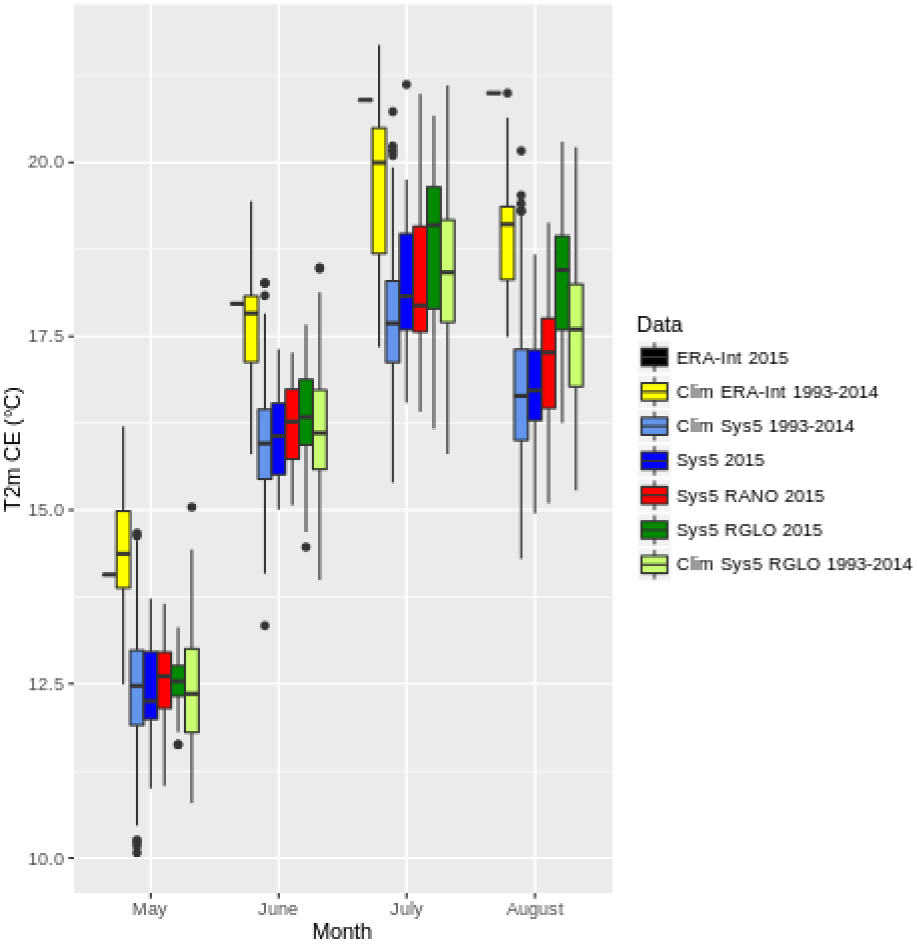

Figure 9: Box and whisker plots for near-surface air temperature values in May, June, July and August over the Central Europe (CE) region defined by Duchez et al. (2016), in System 5 CNRM-CM runs for the 2015 case study and ERA-Interim data. Climatologies (over 1993-2014) for ERA-Interim and System 5 as well as globally nudged (RGLO) System 5 are shown in yellow, dark blue and light green, respectively. 2015 experiments are in dark blue (Sys 5 reference), red (surface nudging over the cold anomaly region) and dark green (global surface nudging). See text for further details.

Key conclusions

Results found in the framework of this special project are often limited by the very large levels of uncertainty in the evaluations of seasonal re-forecasts over the Northern Hemisphere mid-latitudes, whether for the winter or the summer season.

Although the role of soil moisture seems quite crucial in the correct representation of heat waves at the subseasonal time scale, and a more realistic soil moisture initialization does partly improve forecast skill over the midlatitudes, confirming previous results (Ardilouze et al. 2017a), the impact of Arctic sea ice and North Atlantic ocean surface conditions on seasonal forecasts seems very limited (at least in the setups used for this project). This could be due to several factors, including the misrepresentation of key processes in the coupled model, the very low signal-to-noise ratio and predictability levels over the regions of interest, as well as errors in the initial conditions and initialization process.

These aspects are addressed in ongoing work and projects CNRM is involved in, whether in a seasonal forecasting framework or more idealized studies.

List of publications/reports from the project with complete references

Ardilouze, C., L. Batté, F. Bunzel, D. Decremer, M. Déqué, F. Doblas-Reyes, H. Douville, D. Fereday, V. Guemas, C. MacLachlan, W. Müller, and C. Prodhomme (2017a), 'Multi-model assessment of the impact of soil moisture initialization on mid-latitude summer predictability', *Climate Dynamics* 49(11-12), 3959–3974.

Ardilouze, C., L. Batté, and M. Déqué (2017b), 'Subseasonal-to-seasonal (S2S) forecasts with CNRM-CM : a case study on the July 2015 West-European heat wave', *Advances in Science and Research* 14, 115–121.

Ardilouze, C., L. Batté, B. Decharme, and M. Déqué (2019), On the link between summer dry bias over the US Great Plains and seasonal temperature prediction skill in a dynamical forecast system. *Weather and Forecasting, in press,* doi:10.1175/WAF-D-19-0023.1

Ardilouze, C. (2019), Impact de l'humidité du sol sur la prévisibilité du climat estival aux moyennes latitudes. *PhD thesis for Université de Toulouse. (In French, available upon request and online as soon as accepted)*

Souan, C. (2017), Impact de l'anomalie froide en Atlantique Nord sur les prévisions saisonnières de l'été 2015. *Master's thesis and Ecole Nationale de la Météorologie final project report. (In French, available upon request)*

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

Continuation of research on soil moisture and atmosphere coupling is led by C. Ardilouze, partly in the framework of the ERA4CS-MEDSCOPE project.

Activities related to predictability of sea ice are closely tied to the ongoing APPLICATE project in which CNRM is involved. Sea ice and ocean initialization are aspects investigated in collaboration with Mercator Ocean International.

These activities are not linked to a current or prospective Special Project led by CNRM.