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EUROPEAN PROVISION OF REGIONAL IMPACT ASSESSMENT ON A

SEASONAL-TO-DECADAL TIMESCALE.

D42.2

REPORT ASSESSING THE BENEFIT OF THIS CLIMATE SERVICE PROTOTYPE USING HISTORICAL EVENTS AND HINDCASTS

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Deliverable Title	Report assessing the benefit of this climate service prototype using historical events and hindcasts	
Brief Description	Report assessing the benefit of this climate service prototype using historical events and hindcasts: The benefit of this prototype technology will be assessed using hindcasts and historical events to see how this system would have performed had all the required information been available at the time.	
WP number	42	
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V2	8/10/2015	Peter Falloon and Isadora Jiménez	Land Management prototype section added and formatted.
V3	28/10/2015	Carlo Buontempo, Isadora Jiménez,	Coordinator comments and changes to the text.
V5	29/10/2015	Isadora Jiménez (PF, EP, SC, AB, JV, LP)	All partners comments introduced
V6	29/10/2015	Isadora Jiménez	Modifications to RESILIENCE figures
V7	30/10/2015	Christoph Spirig	Meteoswiss addition to LEAP contribution

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1. EXECUTIVE SUMMARY

- **RESILIENCE prototype (IC3)**

The IC3 has developed a prototype that can operate at seasonal time scales providing seasonal wind predictions for the energy sector, the RESILIENCE prototype. Four key events in the past have been identified by energy sector stakeholders and the prototype predictions have been run in hindcast mode to assess the information that RESILIENCE would have provided. In two of the four key events the prototype would have provided a useful signal for the stakeholders improving the prediction based only on the climatology. Moreover the mechanisms driving seasonal wind speed variability of each key event have been assessed showing how RESILIENCE incorporates them in the prediction simplifying the decision making process. The results of some of the key events are limited by a low skill which highlights the prediction skill as a key communication milestone for any provider of climate services.

- **LEAP prototype (WFP, ENEA)**

For the LEAP prototype ENEA has examined the current use of seasonal forecasts as a source of information for Drought Early Warning in Ethiopia. We have analysed the complexity of rainfall patterns over the area of interest and we have conducted a preliminary evaluation of the forecasting skill of the SYS4 ensemble using simple indicators (cumulated rainfall). Finally, we have simulated the hindcast of the drought index to highlight the added value of using the ensemble forecast in the drought early warning versus the scenario in which only historical information is available. The main results are highlighted in the following sections. This is the only prototype that has some deviations from the Description of Work that have been explained at the end of its section.

- **RIFF prototype (METEO-France)**

To assess the benefit of the climate service prototype called RIFF, Meteo-france has analysed the 1993 summer drought event and has evaluated how the prototype could have been useful to the stakeholder, EPTB Seine Grands Lacs. EPTB is a water manager responsible of lake-reservoirs upstream of the Seine River. The role of EPTB is to guaranty enough water for irrigation and fresh water supply during the low-flow period. In Winter-Spring, EPTB fills the reservoir, and then in summer they drain it to sustain low river flows.

The deficit in precipitation in winter and spring 1993 leads to unfavourable conditions to complete the filling of the reservoir. In summer, EPTB released the water but did not manage to maintain river flows above the vigilance threshold. The river flow was below the vigilance threshold during several days. To avoid such a situation, the prototype RIFF proposes to provide forecasted river flows prior to the dry season. For 1993, river flow forecasts pointed out a possible severe drought in summer. Thanks to such information, EPTB would have been informed that the drought already installed in spring would extend and worsen in summer. To check the usefulness of the RIFF prototype in 1993, EPTB have replayed this particular event using forecasted products and usual observations. The results highlight the added value of the RIFF prototype to the DMP in this particular drought event. Indeed, using seasonal forecasts allows a reduction of the number of days below the low-level threshold, in particular, during the first two months of the dry season. Nevertheless, afterwards, an updated forecast seems to be necessary to adjust the water release and anticipate a possible increase of river flows in early autumn.

- **SPRINT transport prototype (Met Office)**

The Met Office has developed a prototype for transport stakeholders, SPRINT (Seasonal Prediction of Regional Impacts of the NAO[1] on Transport). We have analysed historical transport impacts information in connection with NAO index data (observed and forecast) and found that in many cases there is a relationship between NAO index and transport impact. Since the latest Met Office seasonal forecast system, GloSea5, now has skill in forecasting the winter-time NAO index (Scaife et al., 2014), we have developed a methodology to use real-time NAO index forecasts in conjunction with the historical NAO/impact relationships we have established, to predict the relative risk of impacts in a given winter. The principal aim of SPRINT is to help transport stakeholders with making decisions about de-icing of surfaces (e.g. roads, pavements, runways) and vehicles (e.g. aircraft), though we also consider other risks. Here, we have illustrated the potential utility of SPRINT by evaluating its performance retrospectively, using the winters 2009/2010 and 2010/2011.

- **Land Management prototype (Met Office)**

The Met Office along with key EUPORIAS partners (University of Leeds, Predictia, KNMI) and external stakeholders (Clinton Devon Estates and National Farmers Union) has been developing a prototype winter forecast to support land management decisions in the South West UK. We provided 3 month outlooks to a small set of land managers in Devon each month during winter 2014/2015, and are now working towards providing 3 month outlooks plus 14 day forecasts to a broader range of land managers. The 3 month outlooks are based on the UK Contingency Planners forecasts, themselves based on the Glosea5 system, which as discussed above, has skill in forecasting anomalies in winter temperature and precipitation. The work presented here investigates observed and modelled links between the NAO and weather variables, and forecast skill at different spatial scales and across the winter season. In general, across the UK the forecasting system has good skill for winter temperature, and less skill for precipitation. Although skill for county level winter precipitation is low, some specific locations within our study region indicate reasonable skill. Hence the work performed here has informed our prototype development as we intend to send temperature forecasts to all land managers in the region, but only precipitation forecasts to the farmers in regions where reasonable skill exists.

- **Hydropower prototype (SMHI)**

The SMHI has developed a multi-model forecast prototype to produce a probabilistic forecast of river flows and accumulated seasonal discharge at different lead-times. Hindcasts of the spring floods at 26 gauging stations in the Ångerman River have been made for the period 1981-2014 and the extreme spring flood of 1995 has been assessed. Although the multi-model hindcast underestimated this event it did show a much improved signal over the operational system. The results show the potential added value for operators to make more proactive decisions based on the seasonal forecast.

- **Water management in Spain case study (AEMET and CETaqua)**

A multidisciplinary team that includes water managers, regulators, meteorologists and researchers has been working to test the usage of seasonal forecasts to improve the water reservoirs management in Spain. Dam inflow forecasts are being

[1] North Atlantic Oscillation, a large-scale weather pattern influencing Northern European winter climate.

incorporated in existing modelling tools and management structure. Four key events in the past have been selected for the Cuerda del Pozo reservoir. The forecasting system has been run for each of the key events (hindcast) and the results are compatible with the observations. These forecasts have been used by CETaqua to feed into SIMRISK (the water management system) and simulate the behaviour of the reservoir

- **MeteoSwiss case study**

  Meteo Swiss have analysed the forecast skill of climate indicators related to energy consumption for heating and cooling, heating and cooling degree days respectively, in Europe and globally. We find areas of forecast skill mainly in tropical and subtropical land areas. In Europe forecasts are skilful in southern Europe in summer and marginally skilful over the British Isles in winter. In a case study, strong correlation between summer cooling degree days and electricity consumption is found for southern Italy. This illustrates the potential of using seasonal forecasts to estimate energy demand for cooling.

2. PROJECT OBJECTIVES

With this deliverable, the project has contributed to the achievement of the following objectives (DOW, Section B1.1):

No.	Objective	Yes	No
1	Develop and deliver reliable and trusted impact prediction systems for a number of carefully selected case studies. These will provide working examples of end to end climate-to-impacts-decision making services operation on S2D timescales.	X	
2	Assess and document key knowledge gaps and vulnerabilities of important sectors (e.g., water, energy, health, transport, agriculture, tourism), along with the needs of specific users within these sectors, through close collaboration with project stakeholders.		X
3	Develop a set of standard tools tailored to the needs of stakeholders for calibrating, downscaling, and modelling sector-specific impacts on S2D timescales.	X	
4	Develop techniques to map the meteorological variables from the prediction systems provided by the WMO GPCs (two of which (Met Office and MeteoFrance) are partners in the project) into variables which are directly relevant to the needs of specific stakeholders.	X	
5	Develop a knowledge-sharing protocol necessary to promote the use of these technologies. This will include making uncertain information fit into the decision support systems used by stakeholders to take decisions on the S2D horizon. This objective will place Europe at the forefront of the implementation of the GFCS, through the GFCS's ambitions to develop climate services research, a climate services information system and a user interface platform.		X
6	Assess and document the current marketability of climate services in Europe and demonstrate how climate services on S2D time horizons can be made useful to end users.		X

Table 1: Project objectives

3. DETAILED REPORT

3.1. RESILIENCE prototype (IC3)

The primary aim of the RESILIENCE prototype is to strengthen the efficiency and security of wind power supply within energy networks, by providing robust information of the future variability in wind power resources based on probabilistic climate predictions. To reach this objective the RESILIENCE prototype will operate at seasonal time scales providing seasonal wind predictions for the energy sector.

Within the energy industry there are multiple actors with specific requirements for climate information in different temporal scales. Manufacturers, project developers, project investors, consultants and energy trading companies are some of the types of users that already have shown their interest in seasonal to decadal prediction products and particularly in the outcomes of the RESILIENCE prototype on wind speeds. Seasonal and sub-seasonal wind speed predictions are of particular interest for energy trading companies. Thus, traders have been defined as the target users for the information provided by the prototype. Nevertheless, throughout the EUPORIAS project many other types of energy stakeholders have been involved in providing information for the development of the prototype. All the stakeholders contacted through interviews and workshops are willing to test the prototype and have actively participated in the definition of the key events used in this report.

Current energy practices use a deterministic approach based on retrospective climatology to estimate future climate variability over coming weeks or seasons. Most energy sector firms use their own measurements or reanalysis databases to obtain the average past observations and make their decisions based on that. This report assesses if the seasonal predictions of RESILIENCE prototype can provide additional information to the approach based on the past climatology.

3.1.1. Definition of key events in the past for the wind energy sector

A wide range of users was asked to provide key events of high or low production of wind energy in a specific location or area of their interest. Alstom, EDF Trading, EDPR, EnBW, Iberdrola and Vortex answered with a list of key events. From the set of key events gathered, four were selected to illustrate the prototype performance assessment in both European and American continents.

Key event 1: Brazil 2010 April-May-June

The stakeholder Alstom, a French multinational company, identified an area of interest for them located in the South of Brazil near the border with Uruguay, defined by the coordinates: 34.10º-34.8º S in latitude and 305.86º-306.56º E in longitude (white square in Figure 1a). They asked for the 2010 April-May-June (hereafter AMJ 2010) period as a key event for them since they have some wind farms in that location and they can compare the seasonal predictions provide by the prototype with their own wind speed measurements in situ.

Key event 2: US Winter 2009/2010

The third-largest generator of wind energy globally, identified the 2009 winter period (from December 2009 to February 2010; hereafter DJF 2009) as a key event for them due to a strong El Niño phenomenon that had implications on the wind speed resources of their US wind farms. The region of interest for the stakeholder is located in the middle of US and defined by the white square in Figure 2a.

Key event 3: US Winter 2010/2011

The same stakeholder also identified the 2010 winter period (from December 2010 to February 2011; hereafter DJF 2010) as a key event for the same region defined previously for the DJF 2009 key event, due to a strong La Niña phenomenon that affected the wind farms production in US.

Key event 4: Germany Winter 2010/2011

EnBW is one of the largest energy supply companies in Germany and Europe. The energy trading department of the firm suggested a list of key events. The winter of 2010 (from December 2010 to February 2011; hereafter DJF 2010) was highlighted as a low wind event paired with an unusual cold winter in Europe associated with a strongly negative NAO index (Maidens et al., 2013). The region of interest was northern Germany as a region where most of the wind capacity of the country is installed. This key event was also pointed by the trading department of EDF, one of the leaders in the energy market in Europe and partner of EUPORIAS.

3.1.2. Data and methods used for the assessment

To compare the seasonal predictions obtained in the RESILIENCE prototype with the use of retrospective climatology, a set of plots (assessment panel) has been generated for each key event (Figures 1 to 4). The assessment panel aims to (i) characterize the chosen key event based on the past observations (ii) assess the RESILIENCE prototype seasonal predictions and (iii) characterise possible mechanisms driving seasonal wind speed variability of each key event.

Characterization of the key event

To characterise the chosen key event, we evaluate if the ERA-Interim (reference) wind speed in the target season was below-normal, normal or above-normal average. These categories are defined based on the terciles of the past reference climatology from 1981 to the previous year of the key event. In “Figure a” of each assessment panel we have identified in which of these three categories is the reference wind speed during the key event at each grid point of the region of interest. Areas in orange indicate where the wind speed of chosen the key event is inside of the normal average wind speed category. Areas in blue (below-normal average wind speed category) indicate where there is less wind than expected from average and red (above-normal average wind speed category) where there is more wind than expected from average.

RESILIENCE seasonal wind speed predictions

In order to assess the predicted wind speed, the RESILIENCE prototype evaluates the 10-m wind speed from European Centre for Medium-Range Weather Forecasts (ECMWF) Seasonal Forecast System (System-4) with 51 ensemble members and at least one-month lead. For instance, if a key event focus on DJF 2010 season, the wind speed predictions have start dates on the first day of November of each year over the period between 1981 and 2010 (the year of the key event) and forecasting 7 months into the future. For the analysis of the prediction of each key event only the three months of the target season and the specific area indicated by the stakeholder were taken into account.

As every variable predicted in a coupled model forecast system, the prediction of wind speed is affected by biases. To overcome this, a calibration method using the “one-year out” cross-validated mode is considered for the post-processing of ensemble forecasts, providing corrected forecasts with improved statistical properties.

Both predicted seasonal wind speeds in the past over the hindcast period (1981 - previous year of the chosen key event) and the predicted wind speed for the key event (forecast) are shown in “Figure *b*” of each assessment panel. The 51-members of the hindcast and the forecast are represented with small points and the ensemble mean of the members with a large point. The time series of the 10-m wind speed from ERA-Interim reanalysis (Dee et al., 2011) is also shown with black points over the entire period (1981 - specific year of the key event).

To better characterise the wind speed prediction for the key event, three equiprobable categories (below-normal, normal and above-normal average wind speed) are determined by obtaining the lower and upper terciles values of the distribution of the wind speeds hindcast over the full period. The probabilistic forecast for the chosen key event is detailed in “Figure *c*” of each assessment panel, where a Probabilistic Distribution Function (PDF) shows the distribution of the 51 ensemble members of the forecast. In this figure it is also shown the lower and upper terciles based on the hindcast (blue and red vertical lines) and the wind speed value obtained from ERA-Interim (dashed black vertical line). The percentage of the 51 ensemble members of the forecast inside each tercile category is detailed (blue colour for below-normal, orange colour for normal and red colour for above-normal category).

Therefore the RESILIENCE seasonal wind speed predictions would be able to provide information to the end-user, with at least one month in advance, about the most probable category of the key event wind speed.

Skill assessment

To evaluate if the RESILIENCE prototype is able to provide information of the chosen key events in relation to what really happened, a forecast quality assessment of the predictions has been done. In this assessment, the simultaneous predicted and observed values are compared over the entire period (1981-year of the specific key event). This is a fundamental step in climate prediction because it assesses whether the forecast systems lead to an improvement forecast with respect to a standard or not, which is usually the climatology or a simple persistence forecast. Due to the high dimensionality of forecast verification, two verification measures were obtained (see “Figure *b*” of each assessment panel, top rectangle): the ensemble mean correlation (Corr) and the Ranked Probability Skill Score (RPSS).

The ensemble mean correlation (Corr) measures the correspondence between the mean of a seasonal wind forecast, made every year since 1981, and the ERA-Interim reanalysis (“observations”) over the same period. If they follow the same variability over time, the correlation is positive, even if their magnitudes are different. The correlation is useful to quantify the potential skill, which is the maximum skill that can be achieved for an index in a particular region given a forecast system. The correlation ranges between 1 (for perfect predictions) to -1. Correlation values equal to 0 indicate that there is no skill in the forecast; values below 0 indicate that the climate forecast system performs worse than a random prediction. A correlation value of 1 corresponds to a climate forecast that can perfectly represent the past “observations”.

The ranked probability skill score (RPSS) is a measure of the predictive skill for categorical events of the probabilistic seasonal forecast (Epstein, 1969; Wilks, 2011). The RPSS ranges between 1 (for perfect predictions) to $-\infty$, though skill scores below 0 are defined as unskilful, those equal to 0 are equal to the climatology forecast, and anything above 0 is an improvement upon climatology, up to 1, which indicates a ‘‘perfect’’ forecast.

Mechanisms driving seasonal wind speed variability

To assess the mechanisms driving seasonal wind speed variability of each key event, we have performed an evaluation of the impact of the El Niño phenomenon or the North Atlantic Oscillation (NAO) on the wind speed. This evaluation has been done with ERA-Interim reanalysis for the season of interest in each key event over 1981-2014 period. The time series of the Oceanic el Niño 3.4 Index (ONI; CPC webpage) or the NAO index (NCAR webpage; Hurrell, 1995), over 1981-2014 period, have been plotted in "Figure *d*" of each assessment panel. This figure shows the annual evolution of the El Niño 3.4 / NAO index, where the two red dotted lines are the thresholds (-0.5 and 0.5 in the case of the El Niño 3.4 index / terciles values of the distribution in the case of the NAO index) used to define the negative, neutral and positive phases of the El Niño 3.4 / NAO index. The value of the index for the key event year is marked with a red circle.

With the information of the El Niño 3.4 / NAO Index ("Figure *d*" of each assessment panel), the years inside the three equiprobable categories, determined by the thresholds defined above, were identified and three wind speed composite maps were obtained. Each of the three composite maps provides information about the observed average wind speed over the years where the ONI / NAO is positive, neutral or negative, respectively. "Figure *e*" of each assessment panel shows the results of subtracting the composite maps from positive or negative ONI / NAO phases (the phase observed in the key event year) minus neutral ONI / NAO phase. This map provides visual information on how the conditions of El Niño phenomenon / the NAO drive the wind speed and indicates the areas where the signal is statistically significant (black dots).

3.1.3. RESILIENCE prototype compared with retrospective climatology

Key event 1 – Assessment panel 1: AMJ 2010, Brazil

- **Figure 1a** shows that the AMJ 2010 wind speeds were above normal (more wind speed than average) in most of the Brazil region. The southern tip of Brazil and most part of Uruguay area which contains the location of interest for the stakeholder, exhibited also above normal wind speeds. Based on climatology, users would have expected less wind speeds that what really happened for the key event.
- **Figure 1b** shows the wind speed predictions provided by the RESILIENCE prototype prior and for the AMJ 2010 key event together with the ERA-Interim wind speed values. The Corr and RPSS verification measures are displayed on top of **Figure 1c**. Both verification measures have positives values (Corr=0.09 and RPSS=0.05), which means that the forecast can provide extra information than the climatology. Nevertheless, the value of the RPSS (0.05) is very close to zero and non-significant, being possible that this forecast for the specific Brazil region doesn't provide better information than climatology. This situation is an example of the limitations of the RESILIENCE prototype, which are related with the skill limitations of the ECMWF System-4.
- **Figure 1d** shows the time series of the ONI index over 1981-2014 period from ERA-Interim. Focus on the AMJ 2010 key event (red circle), the ONI index value is near zero (neutral phase of the index), indicating that the wind speed key event of 2010 was not influenced by El Niño phenomenon.

Key event 2 – Assessment panel 2: DJF 2009, US

- **Figure 2a** shows that a wide region of US had below normal wind speeds in DJF 2009, while the East coast and some areas of central and South US had above normal wind speeds. For this key event, the wind speed at the specific region was inside the below-normal category. With the traditionally used retrospective climatology, the stakeholder would have overestimated the wind speeds that really happened for this key event.
- The RESILIENCE prototype forecast for this winter (**Figure 2b & 2c**) would have predicted with one month in advance that the most probable category of the wind

speeds would be the below-normal category because the percentage of the ensemble members in this category (49%) was superior than in other categories. **Figure 2c** also indicates that ERA-Interim wind speed value for DJF 2009 (dashed black line) falls inside the below-normal category in agreement with the forecast. Corr and RPSS values (0.56 and 0.22 respectively, on top of **Figure 2c**) indicate that the prototype would have performed better than the climatology for this specific location and season. Therefore the RESILIENCE prototype would be able to provide extra information of the wind speed category in advance.

- The winter 2009/2010, there was a rather high positive phase of El Niño phenomenon (the fourth highest in the whole period, **Figure 2d** red circle). **Figure 2e** shows that positive conditions of El Niño event are associated with a decrease in the wind speed all over the US. Particularly, in the region of interest the wind speed differences are significant at the 95% confidence level, indicating that the observed below normal wind speeds for DJF 2009 were related with the positive ONI value.

Key event 3 – Assessment panel 3: DJF 2010, US

- For the specific winter 2010/2011, the wind speed spatial configuration, shown in **Figure 3a**, indicates that most of the regions in US have normal or above-normal average wind speed categories. Nevertheless, for the specific region in the central US, the wind speed of DJF 2010 falls inside the below-normal category.
- The RESILIENCE prototype forecast for DJF 2010 (**Figure 3b & 3c**) has positive and statistically significant skill values (Corr=0.56* and RPSS=0.22*), which means that the forecast provides extra information than the climatology. The most probable category of the wind speed would be the above-normal category (75.9% of the ensemble members fall inside this category). Nevertheless the ERA-Interim wind speed value for DJF 2010 (dashed black line in **Figure 3c**) was inside the below-normal category. The predicted probability of occurrence that the wind speed of this key event were inside the below-normal category was low (1.9 %), but this small probability given by the RESILIENCE prototype also indicated that below-normal wind speeds could happen.
- For the key event DJF 2010 there was a negative phase of El Niño phenomenon, known as La Niña event (red circle of **Figure 3d**). **Figure 3e** shows that negative conditions of El Niño event are associated with a decrease in the wind speed over the region of interest but for this specific area this decrease is not significant at the 95% confidence level.

Key event 4: Assessment panel 4: DJF 2010, Germany

- **Figure 4a** shows that the DJF 2010 wind speed was below normal (less wind speed than average) in most of Northern Europe. Southern Europe and Northern Africa regions exhibit above normal wind speeds. For this specific key event and region in Germany, of interest for several stakeholders engaged in the RESILIENCE prototype project, the wind speed was inside the below-normal average wind speed category. Based on climatology, these end-users would have expected more wind speeds that what really happened for the key event.
- **Figure 4b** shows the wind speed predictions provided by the RESILIENCE prototype prior and for the DJF 2010 key event together with the ERA-Interim wind speed values. The forecast for this key event (**Figure 4b and 4c**) would have predicted, with one month in advance, that the most probable category of the wind was the below-normal category because the percentage of the forecast

members in this category (47.7%) is superior to the number of members in other categories. The ERA-Interim wind speed for DJF 2010 falls inside the below-normal category (black dashed line in **Figure 4c**) in agreement with the forecast. The Corr and RPSS verification measures are displayed on top of **Figure 4c**. Both verification measures have positives values (Corr=0.1 and RPSS=0.03), which means that the forecast can provide extra information than the climatology.

- Time series of the NAO index over 1981-2014 period from ERA-Interim are displayed in **Figure 4d**. Regarding the winter 2010/2011, marked with a red circle in this figure, the NAO index value was very negative (the third highest negative values in the whole period). Negative phase of the NAO is associated with a decrease of the wind speed all over Northern Europe, as it is deduced from **Figure 4e**. For the specific area in Germany, this decrease is significant at the 95% confidence level, indicating that the negative NAO of this DJF 2010 was driven the observed below-normal wind speeds at that year.

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ASSESSMENT PANEL 1: April-May-June 2010, Brazil

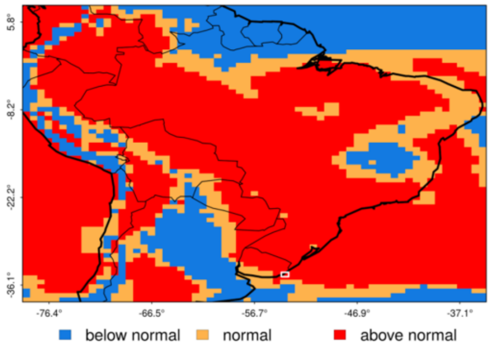
Key event characterisation

Description

STAKEHOLDER: ALSTOM
AREA: BRAZIL
COORDINATES: 34.10º-34.8º S
305.86º-306.56º E
SEASON: April-May-June (AMJ)
YEAR: 2010

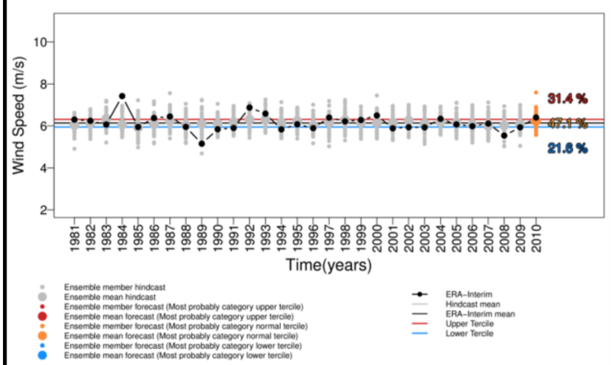
See Section 3.1.2 for further information on each figure of the panel

Brazil ERA-Interim 10m wind speed terciles categories (AMJ 2010) a



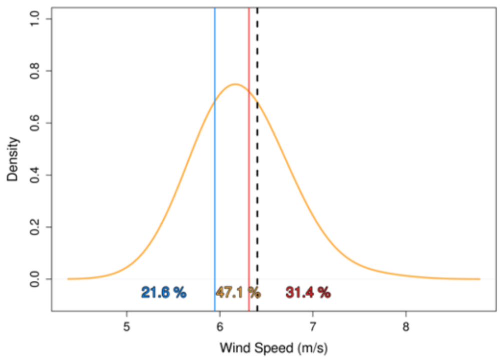
RESILIENCE seasonal wind speed prediction

b **Time series of 10-m wind speed calibrated from ECMWF System 4 and ERA-Interim reanalysis (AMJ 1981-2010)**



Skill Assessment and Probability density function (AMJ 2010 prediction) c

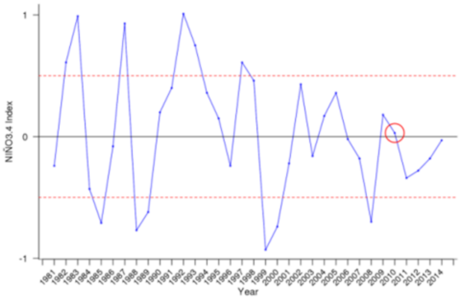
SKILL: Corr = 0.25 ; RPSS = 0.03



Mechanisms driving seasonal wind speed variability

d **Time-series of the Oceanic Niño 3.4 Index (ONI) (AMJ 1981-2014)**

e



A neutral phase of the ONI index indicates that the wind speed of this key event was not influenced by El Niño phenomenon.

Figure 1. Assessment panel 1: AMJ 2010, Brazil

ASSESSMENT PANEL 2: December-January-February 2009/2010, US

Key event characterisation

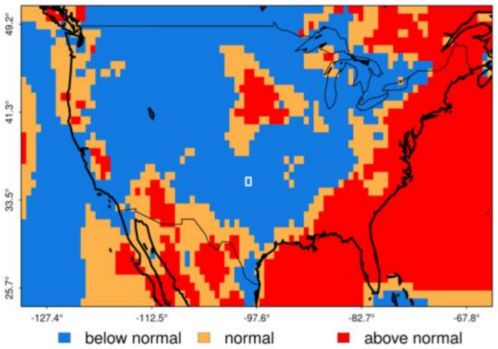
Description

STAKEHOLDER: global renewable energy company
AREA: US

SEASON: December-January-February (DJF)
YEAR: 2009/2010

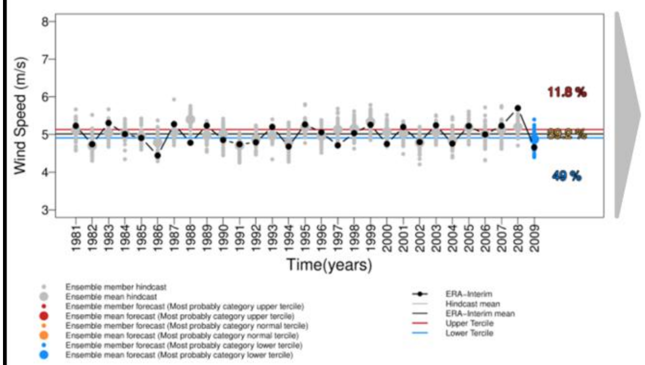
See Section 3.1.2 for further information on each figure of the panel

US ERA-Interim 10m wind speed terciles categories (DJF 2009) a



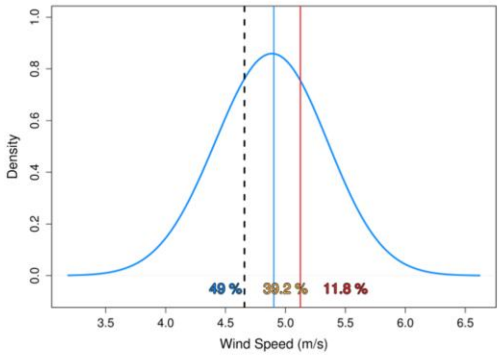
RESILIENCE seasonal wind speed prediction

b **Time series of 10-m wind speed calibrated from ECMWF System 4 and ERA-Interim reanalysis (DJF 1981-2009)**



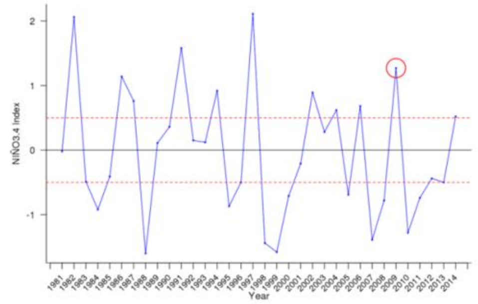
Skill Assessment and Probability density function (DJF 2009 prediction) c

SKILL: Corr = 0.56* ; RPSS = 0.22*



Mechanisms driving seasonal wind speed variability

d **Time-series of the Oceanic Niño 3.4 Index (ONI) (DJF 1981-2014)**



Impact of the positive phase of ONI on the 10-m wind speed (DJF 1981-2014) e

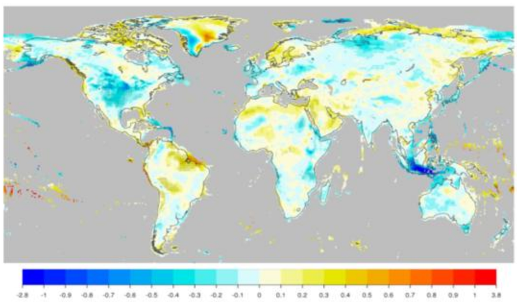


Figure 2. Assessment panel 2: DJF 2009, US

ASSESSMENT PANEL 3: December-January-February 2010/2011, US

Key event characterisation

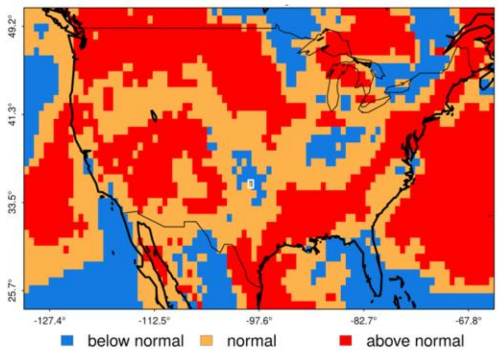
Description

STAKEHOLDER: global renewable energy company
AREA: US

SEASON: December-January-February (DJF)
YEAR: 2009/2010

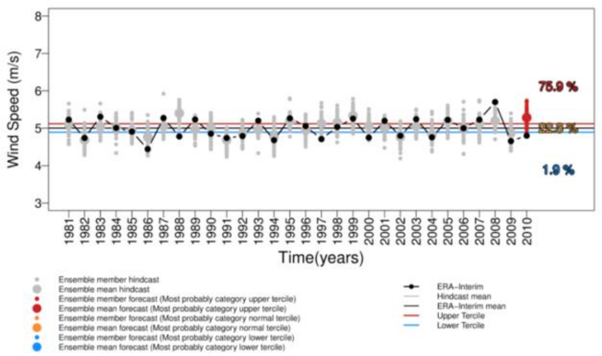
See Section 3.1.2 for further information on each figure of the panel

a US ERA-Interim 10m wind speed terciles categories (DJF 2010)



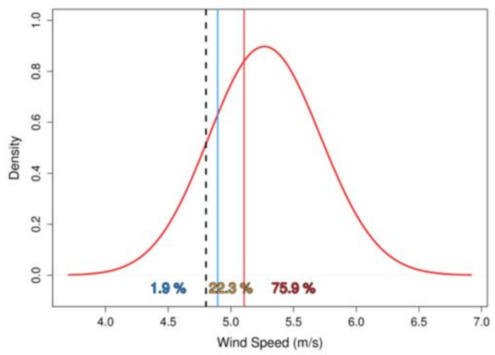
RESILIENCE seasonal wind speed prediction

b Time series of 10-m wind speed calibrated from ECMWF System 4 and ERA-Interim reanalysis (DJF 1981-2010)



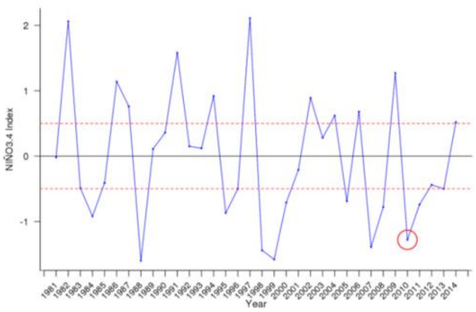
c Skill Assessment and Probability density function (DJF 2010 prediction)

SKILL: Corr = 0.56* ; RPSS = 0.23*



Mechanisms driving seasonal wind speed variability

d Time-series of the Oceanic Niño 3.4 Index (ONI) (DJF 1981-2014)



e Impact of the negative phase of ONI on the 10-m wind speed (DJF 1981-2014)

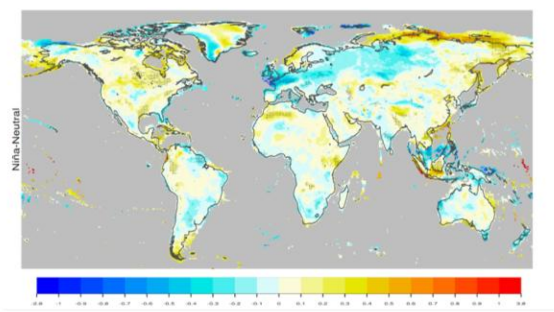


Figure 3. Assessment panel 3: DJF 2010, US

ASSESSMENT PANEL 4: December-January-February 2010/2011, Germany

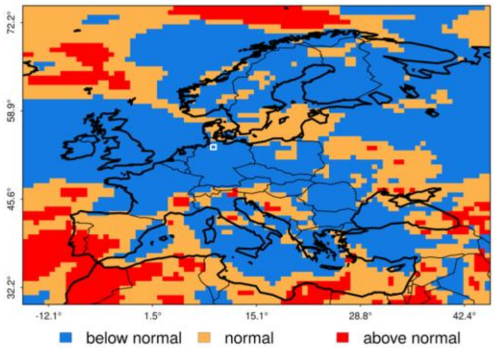
Key event characterisation

Description

STAKEHOLDER: EnBW, EDF Trading
AREA: Germany
COORDINATES: 53.09º-53.79º N
9.14º-9.84º E
SEASON: December-January-February (DJF)
YEAR: 2010/2011

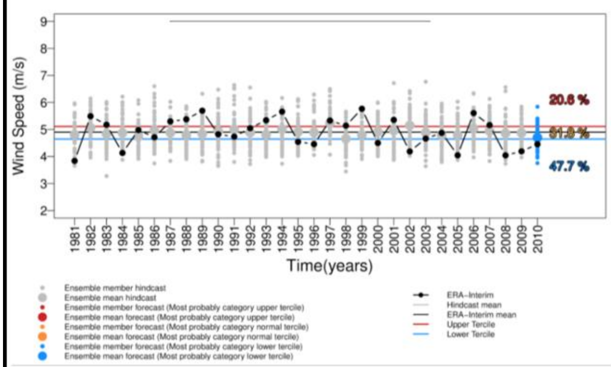
See Section 3.1.2 for further information on each figure of the panel

US ERA-Interim 10m wind speed terciles categories (DJF 2010) a



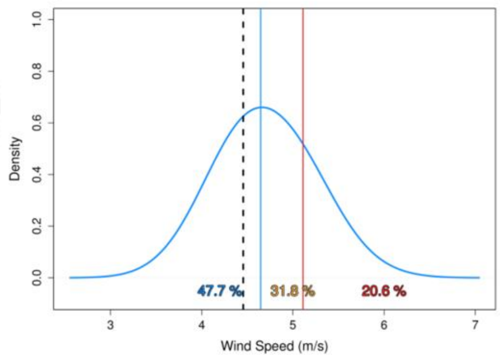
RESILIENCE seasonal wind speed prediction

b **Time series of 10-m wind speed calibrated from ECMWF System 4 and ERA-Interim reanalysis (DJF 1981-2010)**



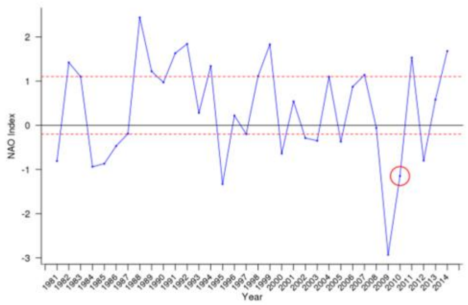
Skill Assessment and Probability density function (DJF 2010 prediction) c

SKILL: Corr = 0.1 ; RPSS = 0.03



Mechanisms driving seasonal wind speed variability

d **Time-series of the NAO Index (DJF 1981-2014)**



Impact of the negative phase of the NAO Index on the 10-m wind speed (DJF 1981-2014) e

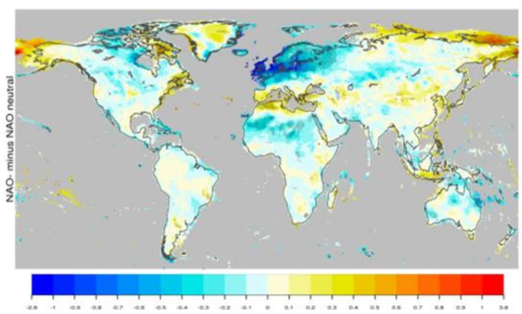


Figure 4. Assessment panel 4: DJF 2010, Germany

3.1.4. RESILIENCE value to the Decision Making Processes

The meteorology analysts that work with climate information for the energy sector have a growing interest in the temporal scales beyond two weeks. They currently use statistical predictions for the first two weeks but this method doesn't provide useful information at monthly or seasonal time scales. Diverse workshops and interviews with stakeholders of the energy sector have been carried out within the EUPORIAS project to assess the value of the RESILIENCE prototype in their Decision Making Processes (DMP). One of the main conclusions of the user's feedback was that at short time scales the grid energy balance is a priority for the energy sector and a field where the DMP would benefit from sub-seasonal and seasonal predictions. However, the current state-of-the-art in wind speed seasonal predictions cannot contribute directly to technical operations or decisions in the adjustment of the grid energy balance yet. The energy trading firms, instead, base their activity in the analysis of diverse datasets, reports and information sources. Thus, traders are a user profile open to incorporate new sources of climate information into the DMP of their daily activities. In particular, EnBW has shown its interest in the prototype and one of their analysts is available to provide feedback on how to include RESILIENCE predictions in their respective planning issues.

The expected production of wind energy affects commodity prices as well as the electricity market. Long periods of low wind power production that coincide with periods of peak demand as it happened in Key Event 4 may cause problems in managing appropriate balancing measures and it can affect the price of energy. These issues are particularly relevant in power systems where the share of wind power is high (*e.g.* Northern Germany). The out-turn graphic of Germany in winter 2010/11 (Figure 5) shows the difference between the expected production of energy based on climatology and the actual energy produced over the year. In January 2011 the production was lower than expected. This was overlapped in time with a demand peak for heating in a particularly cold winter which directly impacted in the price of other energy commodities.

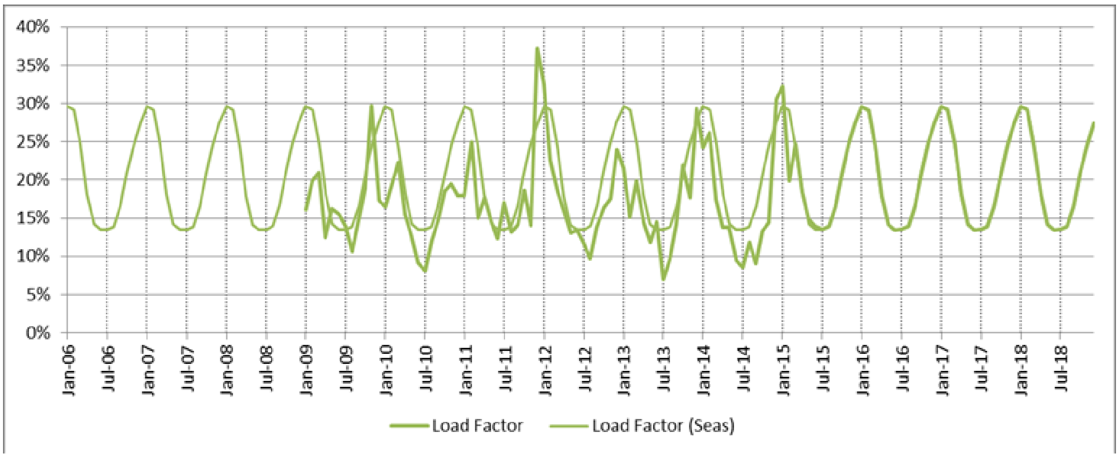


Figure 5. German wind out-turns since 2009. Percentage of energy produced compared with the climatological expected generation (Figure courtesy by EDF Trading)

Skill limitations

A key first stage in the creation of climate services products is to inform in a clear and easy way about the quality of the prediction provided. According to the forecast quality assessment, or skill assessment, the stakeholder could make the first step of their DMP, which would be deciding if they could use the prediction as a reliable source of information for a particular season and region. The information related to the skill of a particular prediction compared to the retrospective climatology (the reference system for most of the energy sector users) should be a key communication milestone for any provider of climate services. Thus, the skill measures should always be highlighted in the final product besides an indicator of its statistical significance, particularly in the cases where the skill values are too low, as it happens in the key events 1 and 4.

It is also advisable to provide stakeholders with information related to the skill of the predictions at global scale. This information allows them to have an overview of the regions where the prototype can add an extra value from a retrospective climatology. Figure 6 is an example of the RPSS global skill map for System-4 winter (DJF) wind speed predictions. Tropical SST, especially the anomalies caused by the El Niño-Southern Oscillation (ENSO) are an important source of predictability for seasonal prediction systems. For this reason, models very often display better skill over tropical regions and gradually wanes as the region moves farther away (Kirtman and Pirani, 2009). Over Europe there are large patches of unskilled predictions mainly attributed to Europe's large independence from anomalies in tropical sea surface temperatures (SST). This is a handicap as it limits the areas in Europe where the RESILIENCE prototype can provide skilful predictions. Nevertheless, the North Sea and other areas of northern Europe as well as some areas of western Mediterranean show some levels of skill. North America, though, exhibits remarkably high skill for a region outside the tropics. This is attributed to a teleconnection with ENSO events (Quan et al., 2006).

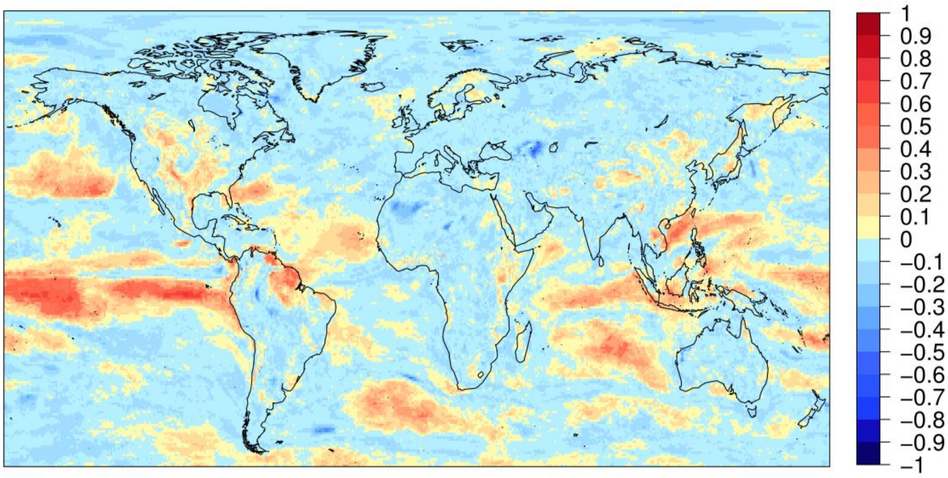


Figure 6. RPSS (Ranked Probability Skill Score) for tercile events of 10m wind speed forecasts calibrated in cross-validation, from ECMWF S4 and ERA-Interim reanalysis in winter (DJF) for the period of 1981-2012. The forecasts have been initialized the first of November.

Despite the skill assessment is a fundamental step for climate services, in order to produce robust climate information to the users; the assessment of the forecast quality also needs the computation of other different measures. Assessing alternative measures can help identifying typical problems of the seasonal predictions, for instance small-sized ensembles or imperfect reference values due to observation errors. These measures (that are being studied in WP22) could provide us further relevant information about those predictions with positive but low skill. That type of predictions, like the ones for Europe, could still be reliable despite having low skill.

Probabilistic predictions in the Decision Making Processes

A good probability forecast cannot be judged on a single forecast, but on a large number of predictions (Hagedorn & Smith 2006). This is the case of the key event 3 that illustrates a RESILIENCE prediction where the most probable category was above normal average wind speeds (75.9%), while the ERA-Interim wind speed was below normal average, the category with the predicted lowest probability (1.9%). This prediction was as valid as the predictions for the key events 2 and 4 where the ERA-Interim value fell inside the most probable category.

Energy traders are largely trained in the use of probabilistic sources, as many financial and economic reports include statistical analysis. Nevertheless, the incorporation of the RESILIENCE prototype to the DMP of energy traders requires a framework to assist the user in working with the prototype probabilistic predictions and their inherent uncertainties associated. In general, stakeholders might use different methods to include a prediction in their decision making process (Dale et al. 2014 and Dale & Wicks, 2013). A basic method, for instance, would be setting probability thresholds to trigger actions that could range from simple market recommendations to actual operational decisions. The development of this framework for the RESILIENCE prototype regarding the DMP in the energy trading activities will be further developed in EUPORIAS WP41 and particularly in Deliverable D41.2.

Incorporating climate drivers in the Decision Making Processes

Key events 2 and 4 are examples where the RESILIENCE prototype would have provided a better prediction of what would have been expected by only using climatology. Both key events are related to El Niño and NAO anomalies that have a significant effect on the observed wind speed for the regions of interest.

This information is highly relevant for traders. The prediction provided by RESILIENCE has these climate drivers as a source of predictability; therefore the prototype prediction shows the effect of these drivers in the expected wind speeds for a region of interest simplifying the integration of this information into the DMP.

3.1.5. References

CPC webpage: Climate Prediction Center. Last modified 17 Jun 2015. “Monthly Atmospheric & SST Indices”. Retrieved from: http://www.cpc.ncep.noaa.gov/data/indices/ . Downloaded on 17 Aug 2015

Dale, M., Wicks, J (2013) Delivering benefits through evidence. Decision-making with probabilistic flood forecasts. Illustrative guide for using decision-support methods. Environmental Agency, UK

NCAR webpage: National Center for Atmospheric Research Staff (Eds). Last modified 07 Jul 2015. "The Climate Data Guide: Hurrell North Atlantic Oscillation (NAO) Index (PC-based)." Retrieved from: https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-pc-based. Downloaded on 17 Aug 2015

Peer Reviewed Articles

Dale, M., Wicks, J., Mylne, K., Pappernberger, F., Laeger, S., Taylor, S. (2014) Probabilistic flood forecasting and decision-making: an innovative risk-based approach. Natural Hazards, 70 (1): 159-172

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

Hagedorn, R., Smith, L. (2009) Communicationg the value of probabilistic forecasts with weather roulette. Meteorological Applications, 16:143-155

Hurrell, J.W. (1995) Decadal Trends in the North Atlantic Oscillation: Regional Temperatures and Precipitation. Science, 269: 676-679

Kirtman, B., Pirani, A. (2009). The state of the art of seasonal prediction: Outcomes and recommendations from the First World Climate Research Program Workshop on Seasonal Prediction. *Bulletin of the American Meteorological Society*, *90*(4), 455-458

Quan, X., Hoerling, M., Whitaker, J., Bates, G., & Xu, T. (2006). Diagnosing sources of US seasonal forecast skill. *Journal of climate*, *19*(13), 3279-3293

Maidens, A, Arribas, A., Scaife, A.A., MacLachlan, C., Peterson, D., and Knight, J. (2013) The influence of surface forcings on prediction of the North Atlantic Oscillation regime of winter 2010/11. Monthly Weather Review, 141, 3801–3813

3.1.6. Planned future publications

Torralba V., Doblas-Reyes F.J., MacLeod D., González-Reviriego N., Davis M. Seasonal climate prediction: a new management tool for the wind energy sector Applied Energy.

Doblas-Reyes, F.J., Torralba, V., González-Reviriego, N., MacLeod D., Ortega, D., Pinto, A. Influences of the North Atlantic Oscillation and El Niño phases on the wind energy sector.

3.2. LEAP prototype (WFP, ENEA)

For the LEAP prototype we have examined the current use of seasonal forecasts as a source of information for Drought Early Warning in Ethiopia. We have analysed the complexity of rainfall patterns over the area of interest and we have conducted a preliminary evaluation of the forecasting skill of the SYS4 ensemble using simple indicators (cumulated rainfall). Finally, we have simulated the hindcast of the drought index to highlight the added value of using the ensemble forecast in the drought early warning versus the scenario in which only historical information is available. The main results are highlighted in the following sections.

3.2.1. Current use of seasonal forecasts

Seasonal forecasts are widely used in Africa in the broader context of the regional Climate Outlook Fora (R-COF). The National Meteorological Agency of Ethiopia contributes to the COF process mainly with information based on the analysis of sea surface temperatures and on the identification of analogue years.

On the other hand, the LEAP project has established a specific methodology for linking the climate driver (rainfall) to the computation of impacts in terms of potential needs for humanitarian assistance. Such methodology, based on indices derived from satellite rainfall estimate, has proven (technical reports available at WFP) skilful in estimating the actual needs compared to more accurate, yet expensive, field assessments.

The methodology established at WFP to link rainfall and the corresponding impact is based on two general assumptions: i) the number of people affected by a drought is proportional to the deviation of a suitable drought index from optimal conditions; ii) the marginal increase in drought affected is also proportional to the drought index deviations from optimal conditions. In other words, the climate driver-impact relation takes implicitly into account mechanisms adopted by communities to cope with external stresses. The aim of the LEAP EUPORIAS prototype is to integrate seasonal rainfall forecasts into the calculations, which will enable the model to provide earlier and more accurate projections of beneficiary numbers. At the same time, the prototype will also allow LEAP users to view seasonal forecast as "standalone" products (i.e. not integrated in the beneficiary calculations), alongside the other agro-climatic information already provided by the LEAP tool.

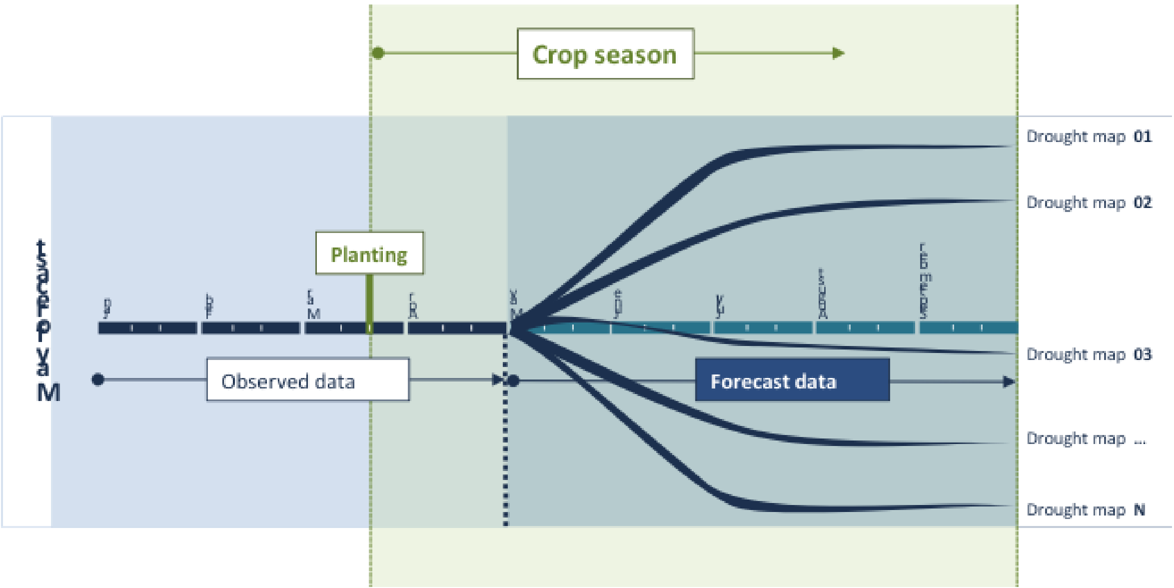
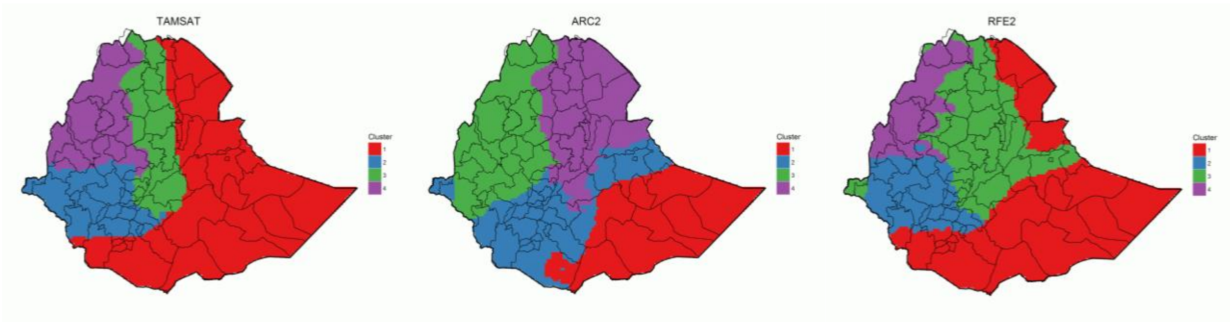


Figure 1. Forecasting scenario to be adopted in LEAP. At the beginning of the main rainy season, forecast data would be used in LEAP as an input for the computation of an ENSEMBLE of possible drought maps.

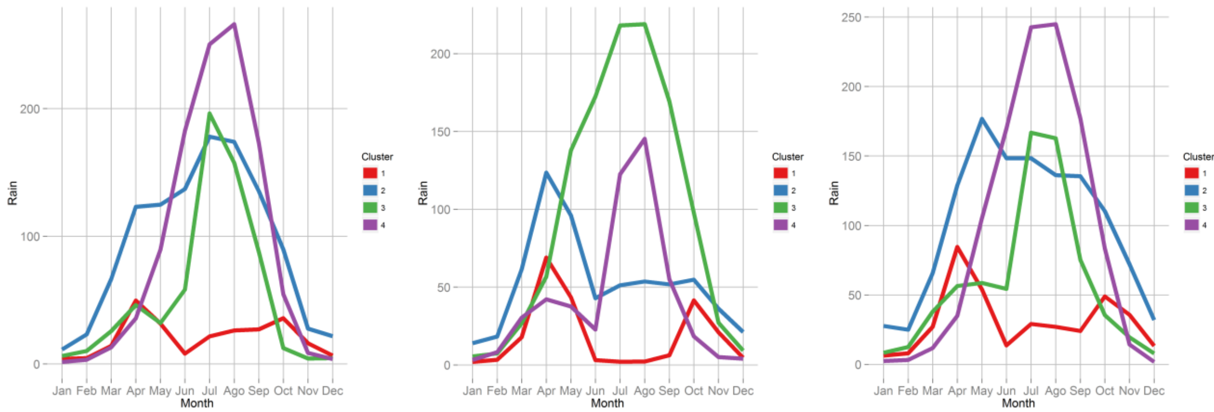
3.2.2. Rainfall Patterns

Ethiopia is characterized by a variety of different seasonal patterns of rainfall, corresponding to different farming and livelihood regimes. This creates a specific challenge for the production of reliable forecasts. In particular, the current spatial resolution of forecasting systems does not permit an accurate description of the complexity of rainfall patterns. On the other hand, from the point of view of observations, a precise description of the spatial distribution of rainfall regimes is often problematic. Figure 2 shows how different satellite based rainfall estimates produce rather different clusters of similar seasonal rainfall patterns. However, four main regions can be identified with seasonal rainfall patterns characterized by: (1) two well separated weak rainy seasons to the south west; (2) in the center/north, a slow onset (short rains) starting in February-March, followed by a main rainy season followed by a principal rainy season from June to September; (3) in the west/north west a single, long and intense rainy season; (4) to the south west an long rainy season, peaking in April/May.



(a) (b) (c)

Figure 2. Clustering of seasonal rainfall patterns according to the average seasonal cycle of the 3-month cumulated rainfall. Ward method. Variables not standardized. The cluster analysis is based on different satellite based rainfall estimates: TAMSAT (a), ARC2 (b), RFE2 (c).



(a) (b) (c)

Figure 3. Average seasonal cycle of the three-months cumulated rainfall with three satellite rainfall estimates. Rainfall datasets are TAMSAT (a), ARC2 (b), RFE2 (c).

3.2.3. Skill Evaluation

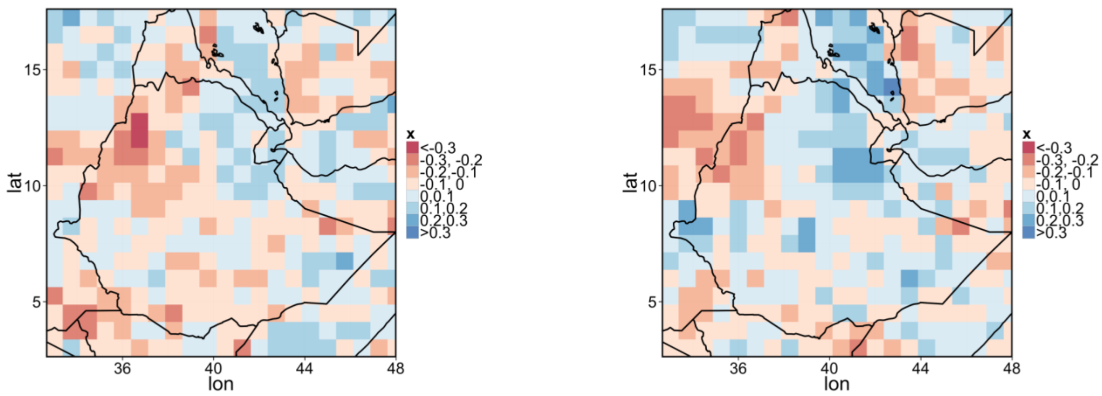
An important preliminary step for assessing the added value for the prototype climate service is to evaluate the skill of the adopted forecast data. In this case we consider the summer (JJAS) cumulated rainfall as the primary (simple) drought indicator.

We use the System IV seasonal forecasting data available through the ECOMS UDG data portal. In particular, the 51 member ensemble is considered for a preliminary evaluation of the forecasting skills, compared to the ARC2 dataset, which is, to date the most widely adopted as an input to the LEAP platform. Table 1 shows that the BSS (Brier Skill Score) for the upper and lower terciles of the average precipitation over the entire country is particularly weak.

Nevertheless, a more detailed analysis of the grid based skill score for the JJAS cumulated precipitation (Figure 4) shows that patches of positive skill can be isolated in selected areas of the country, especially where the rainy season peaks during the summer months (north-east). The north-east part of Ethiopia is one of the vulnerable areas of the country, where humanitarian intervention have had a key role in supporting households in the aftermath of severe droughts. Therefore, the positive skill of the forecasts in that area provides the basis for a deeper analysis of the potential for anticipating crises.

	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF
Upper BSS	0.09	-0.7	0.12	-1.13	-0.43	-0.05	0.04	-0.47	-0.45	-0.02	-0.28	-0.17
Lower BSS	0.27	-0.22	-0.65	-0.38	-0.27	-0.82	0.05	-0.32	-0.42	-0.16	-0.56	-0.07

Table 1. Brier Skill Score for the upper and lower tercile considering the average precipitation in all the country. Here the BSS Considering twelve starting dates (JFM, FMA, etc.). The reference rainfall data is ARC2.



(a) (b)

Figure 4. Brier Skill Score for the lower (a) and upper (b) terciles of the JASS cumulated rainfall. The reference rainfall data is ARC2.

This is also supported by first skill analyses of a simple water balance indicator (WB = precipitation – potential evapotranspiration). The Hargreaves formula was used to compute daily potential evapotranspiration. Forecast skill of System IV for the cumulative water balance over the summer months (JJAS) was assessed against the same quantity derived from precipitation and temperatures of the WFDEI data set. As Figure 5 indicates, the skill pattern of this indicator exhibits similarities with that of precipitation; the fraction of areas with positive skill scores is even higher. It seems that the skill of this water balance index may benefit from its dependence on temperature in addition to precipitation.

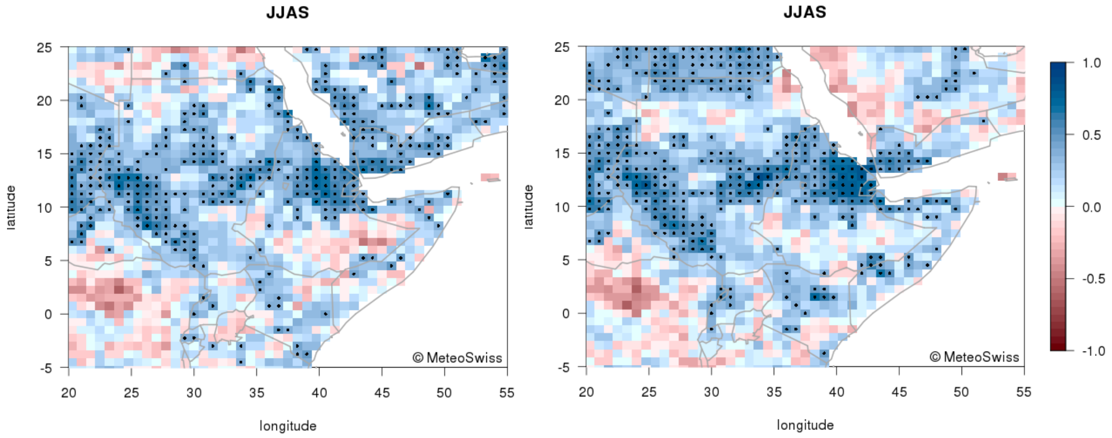


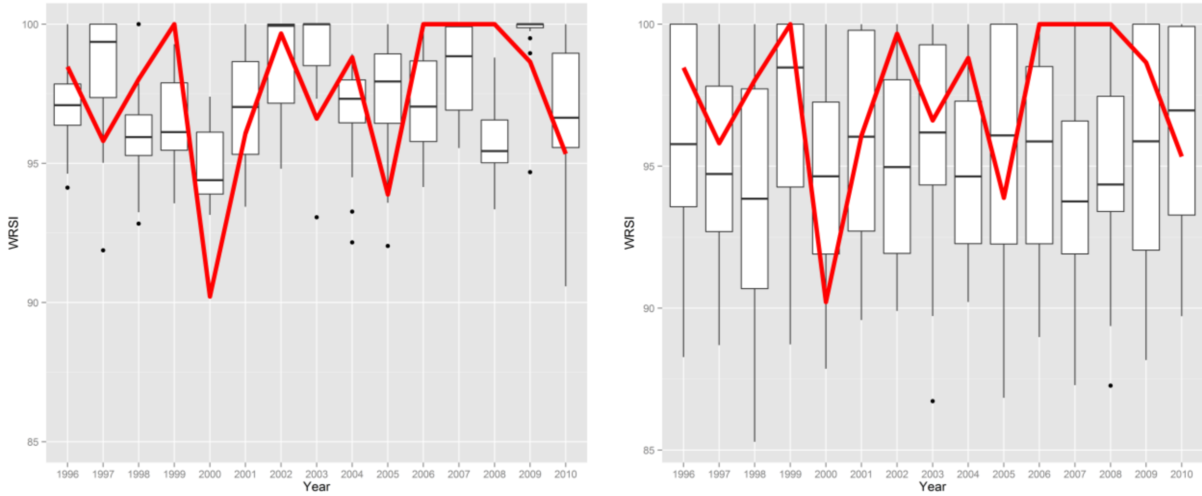
Figure 5. ROC skill score for the lower terciles of JJAS cumulated precipitation (left) and JJAS cumulated water balance (right) of System IV May forecasts. WFDEI was used as a reference data set.

3.2.4. Benefit of using global forecasts

The benefit of using seasonal forecast in LEAP is illustrated by comparing the drought index (WRSI) computed by adopting the usual satellite rainfall estimates routinely adopted for monitoring and assessing the impact of drought, with the same index computed by adopting the rainfall forecasts for the main rainy season. The Water Requirement Satisfaction Index (WRSI) measures crop performance based on the balance between water supply and demand during the growing season. The underlying conceptual scheme is that of a bucket which is replenished by rainfall and depleted by evapotranspiration. A critical step in the computation of WRSI is in the update of the soil water content. If during a given ten-day period the sum of soil water content plus the cumulated rainfall is less than the plant water requirement, then a water deficit is recorded. In more specific terms, if AET is less than the WR determined by atmospheric conditions and by the plant's growing phase, the plant suffers a determined level of water stress. Conversely, if the sum of soil water content plus the cumulated rainfall exceeds the plant water requirement there is no water deficit

To assess the benefit of using global forecasts, we simulate an operational scenario in which a ensemble forecasts are made available in May so that, for each year, the drought index (WRSI) is computed in LEAP by using the observed rainfall until the end of April and the hindcast rainfall data for the period May-October (Figure 1). The operational scenarios are simulated by using hindcasts for the period 1996-2010 (Figure 6).

In order to illustrate the potential of using the seasonal forecasts as an input, the forecast performed with the System 4 ensemble, is compared with a synthetic dataset which is generated by randomly reshuffling the 10-day cumulated rainfall ARC2 dataset, so that the synthetic data have the same seasonal cycle but random distribution of the actual rainfall in each given 10-day period. Such a comparison is equivalent to comparing the forecast with a scenario in which there is no information on the expected rainfall and only the climatology can be assumed as a relevant information. The correlation of the ensemble hindcast of WRSI with the corresponding historical, rainfall based, WRSI is rather low (r=0.30, Figure 6(a)). Nevertheless, some of the more sever rainfall events are well captured (e.g. 200, 2010). More importantly, the skill of the System IV ensemble is comparatively good with respect to the synthetic reference ensemble, which simulates the scenario in which no information is available on future rainfall patterns (r=0.08, Figure 6(b)).



(a) (b)

Figure 6. (a) Ensemble forecast of the average WRSI over Ethiopia (boxplot) compared to the historical WRSI computed by using the ARC2 satellite estimate; (b) same as (a) but the ensemble is obtained by performing a random reshuffling of the historical satellite estimates (see text for more details).

3.2.5. Deviations from DOW

There is no significant deviation from the DOW. During the design of the prototype we planned to use also statistically downscaled forecast to drive the early warning systems. Although the downscaled forecasts are not yet available to the prototype, the results obtained with the coarser resolution global forecasts are already indicating the possibility to inform decisions by the stakeholders.

3.2.6. Planned future publications

Improving drought early warning in East Africa with ensemble seasonal forecasts. S. Calmanti, M. De Felice, L. Bosi.

On the added value of statiscal downscaling for drought early warning in East Africa. R. Manzanas, S. Calmanti, L. Bosi.

3.3. RIFF prototype (METEO-France)

In order to assess the benefit of our climate service prototype called RIFF, we propose to take an example, the summer 1993, and has evaluated how the prototype could have been useful to the stakeholder, EPTB Seine Grands Lacs. EPTB Seine Grands Lacs is a water manager responsible of four lake-reservoirs upstream of the Seine River, in the Northeast quarter of France. In Spring-Summer, the role of EPTB is to anticipate the low-flow period in order to guaranty enough water for irrigation, fresh water supply for the Paris area and cooling of a nuclear power station. During winter until the end of spring, EPTB fills the reservoir in order to be able to drain it from early summer to autumn and maintains a reasonable water level in the river.

3.3.1. The 1993 Spring-Summer, a historical event with high stakes for water managers in France

Winter and spring 1993 were much less rainy than the normal in the region where the reservoirs are located. Figure 1 gives an overview of the upstream part of the Seine basin where the four lake-reservoirs are located. Figure 2 shows the deficit in precipitation during winter and spring 1993 over the reservoirs area, which could locally reach 50 %.

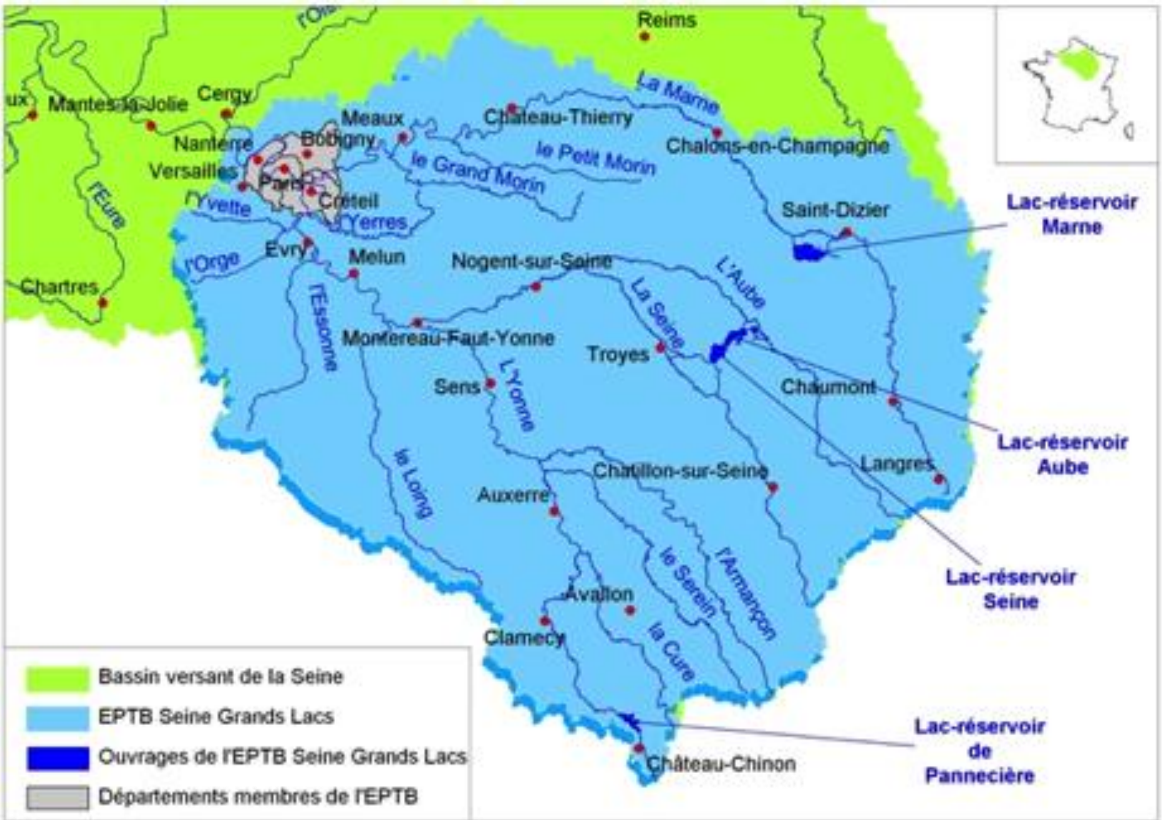


Figure 1. Action area of EPTB (light blue) covering the upstream part of the Seine basin, Paris area (grey), rivers and the four lake-reservoirs (dark blue).

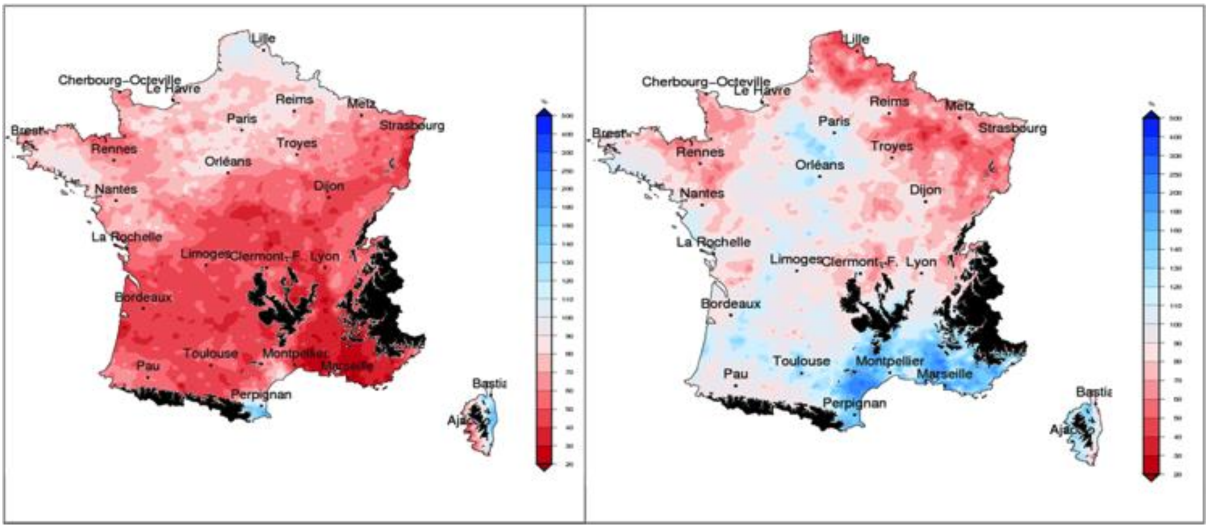


Figure 2. Observed precipitation anomalies (deficit in red and excess in blue) over France for winter (left) and spring (right) 1993.

It affected particularly one of the four reservoirs (the Marne reservoir). The deficit in precipitation during two consecutive seasons leads to low upstream river flows that should normally feed the reservoir. The upstream river flows were already very low since February and had stayed very low during the following months (fig. 3).

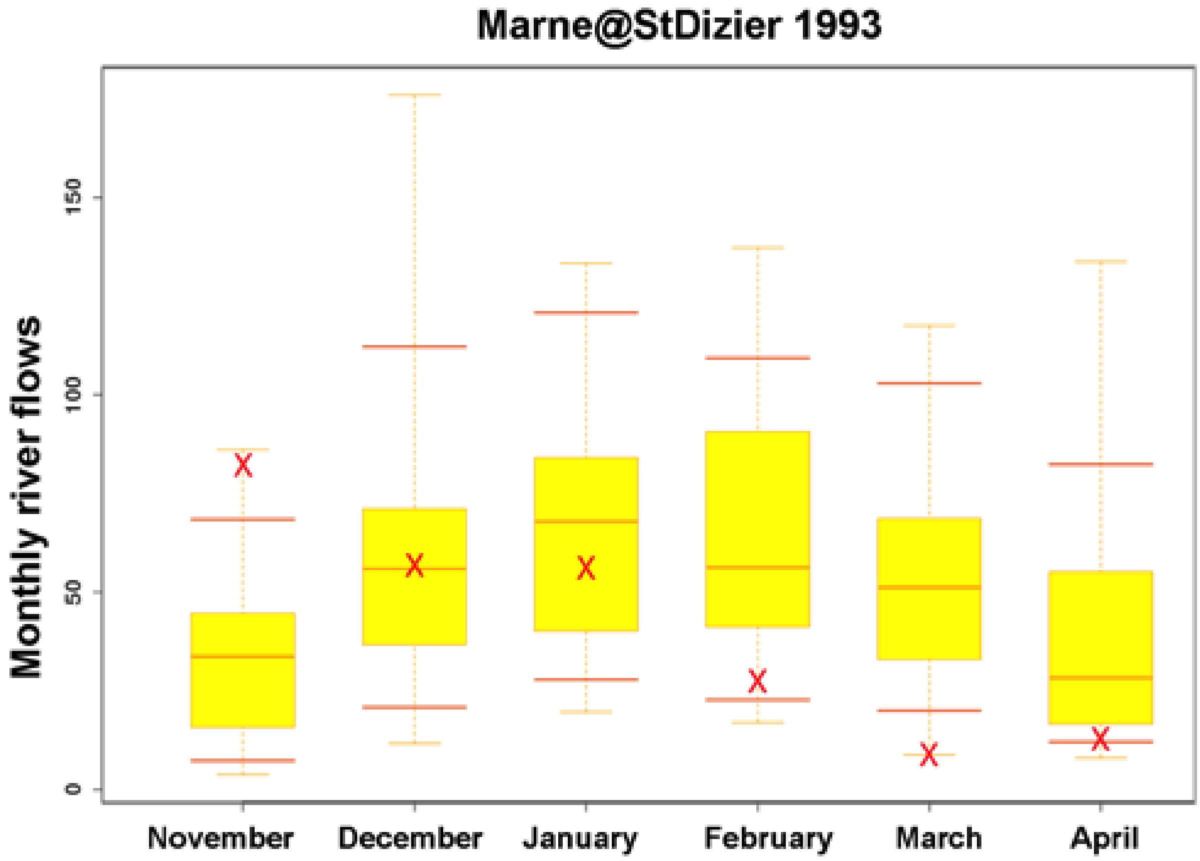


Figure 3. Monthly river flow boxplots at the upstream station for the 1979-2007 climatology (yellow). Red crosses are monthly river flows observed from November to April 1993 at this station.

These conditions were not favourable to complete the filling of the reservoir: in figure 4, the filling curve is quite far from the theoretical curve, which represents the objective to reach to guaranty an optimal filling. The water volume within the reservoir is 22 % weaker than it should be at the end of April.

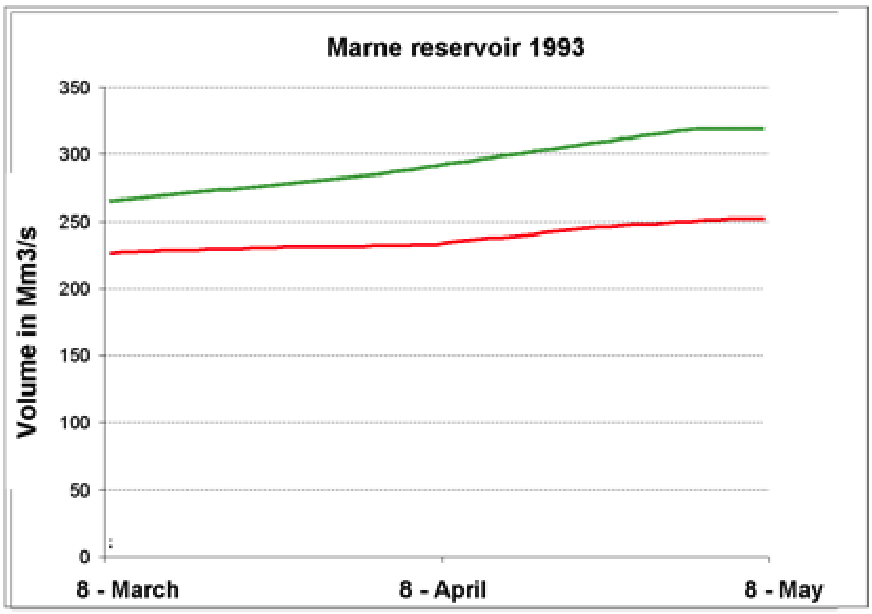


Figure 4. Water volume within the Marne reservoir from the 8th of March to the 8th of May 1993, state in red and objective in green.

Despite a non-optimal filling, EPTB had released the water since early summer to maintain river flows above the vigilance threshold (fig. 5). They managed to keep enough water in the river until the 15th of July, but after this date river flows had decreased again and had stayed below the threshold until the 18th of September i.e. 64 consecutive days. The river flow had been beneath the threshold during a total of 85 days considering the whole period, which corresponds to a volume of 32 Mm3. As soon as the river flow falls below the threshold by three consecutive days, a prefectoral decree should be taken to regulate water usage. The role of EPTB is to avoid such a situation.

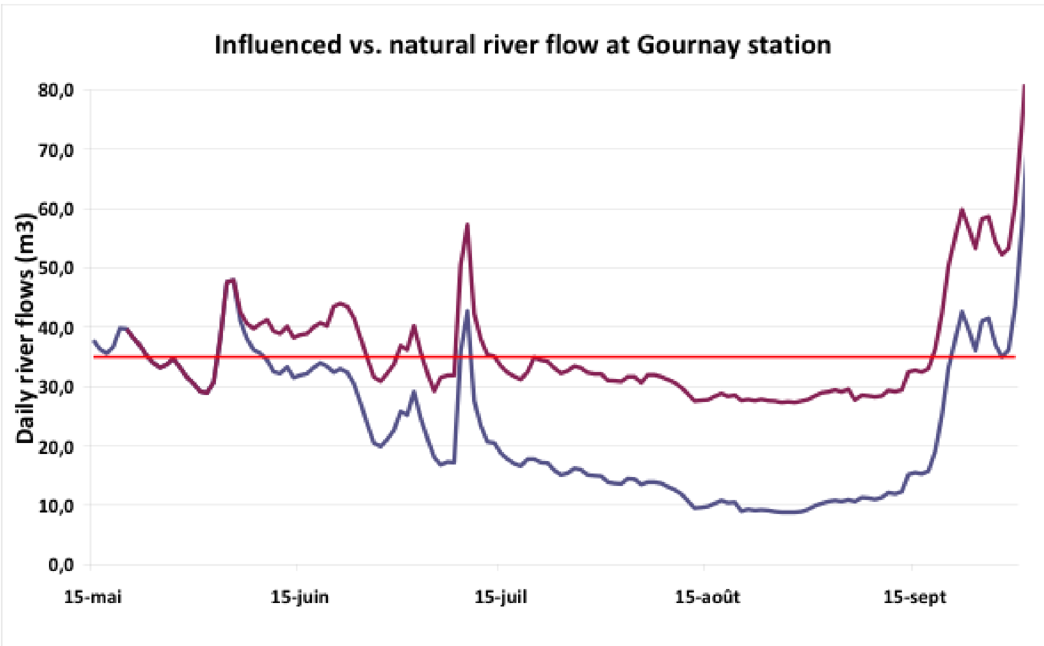


Figure 5. Natural river flows (blue) and river flows influenced (dark red) by the water release, at the downstream station (Gournay station) from the 15th May to the 30th September 1993. The light red line is the vigilance threshold.

3.3.2. Anticipated information provided by the RIFF prototype prior to this event

The climate service prototype RIFF proposes to communicate forecasted products to stakeholders via two main graphics (fig. 6 and 7). On these graphics that represent the forecasted evolution of river flows for summer 1993, it is showed that the range of forecasted river flows (in blue-gray) is clearly below the climatology (in yellow).

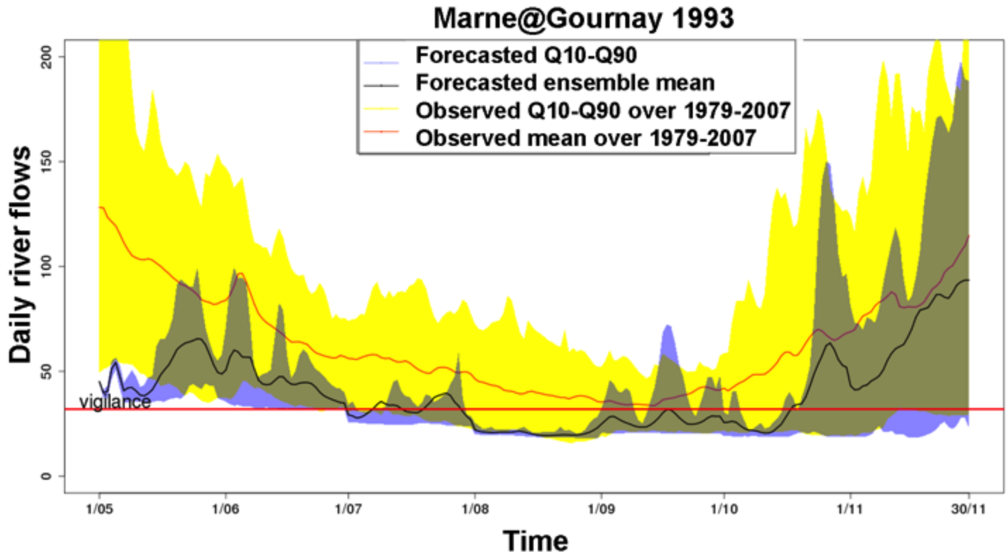


Figure 6. Daily forecasted river flows (Q10-Q90 range in blue/grey) from the 1st of May to the 30th of November 1993 at the downstream station (Gournay), the black line is the mean ensemble. The background (yellow) is the 1979-2007 observed climatology, the mean ensemble being in red.

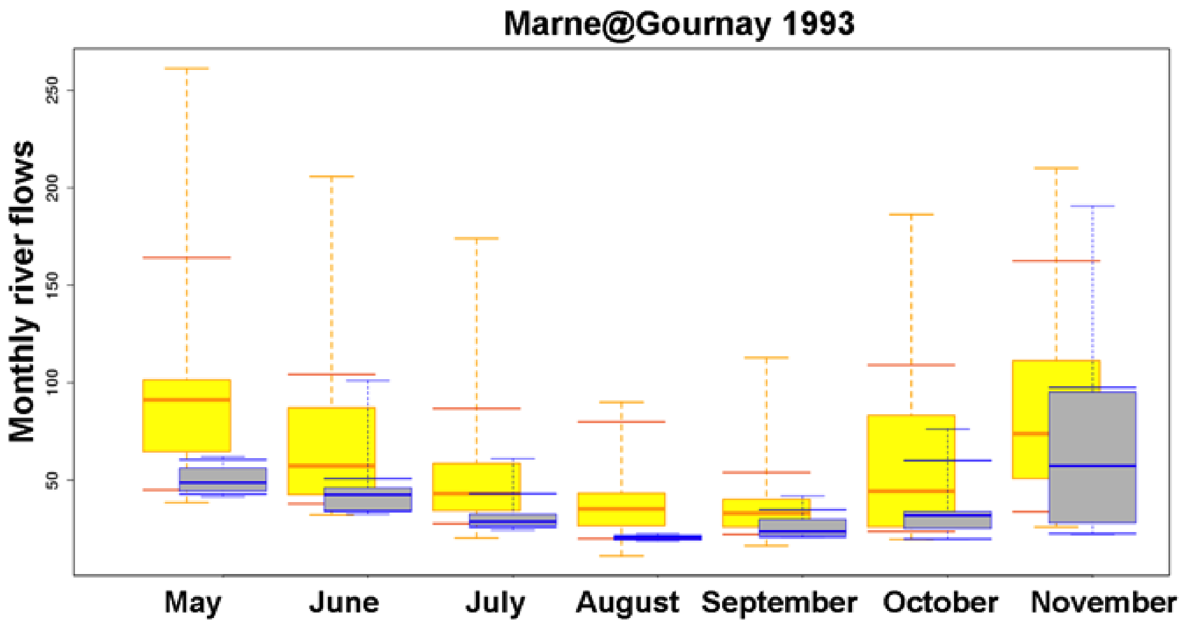


Figure 7. Boxplots of monthly forecasted river flows (blue/gray) and 1979-2007 observed climatology (yellow/red) from May to November 1993 at the downstream station Gournay

The figure 7 shows that, from May, the forecasted median (Q50) remains around the 10th quantile of the climatology, confirming figure 6.

Thanks to these two products, EPTB would have been informed of a possible severe drought in summer 1993 and overall that the drought already installed in spring would extend and worsen in summer.

3.3.3. Evaluation of the added value of the RIFF prototype to the DMP

In order to check if the RIFF prototype would have been useful in 1993, EPTB have been proposed to replay this particular year (without knowing exactly the year) using forecasted products and usual observations (river flows upstream and downstream the reservoir and water level within the reservoir).

Using the seasonal forecast information communicated by the two previous graphics (fig. 6 and 7), EPTB has modified its decision and has chosen to release water earlier than usual. It has anticipated the water release at the 15th of May instead of the 1st of June. This decision has impacted the downstream river flows and has allowed reducing the number of days below the 35 m3/s threshold (figure 8). The total number of days below the threshold is 73 days, which is more than 10 days less than in the case, where the forecasts are not used.

Nevertheless, the curve adjustment does not allow avoiding the long period of consecutive days between the 15th of July and the 18th of September and, although the number of low-flow days is reduced, the loss of water volume increases (34 Mm3 vs. 32 Mm3).

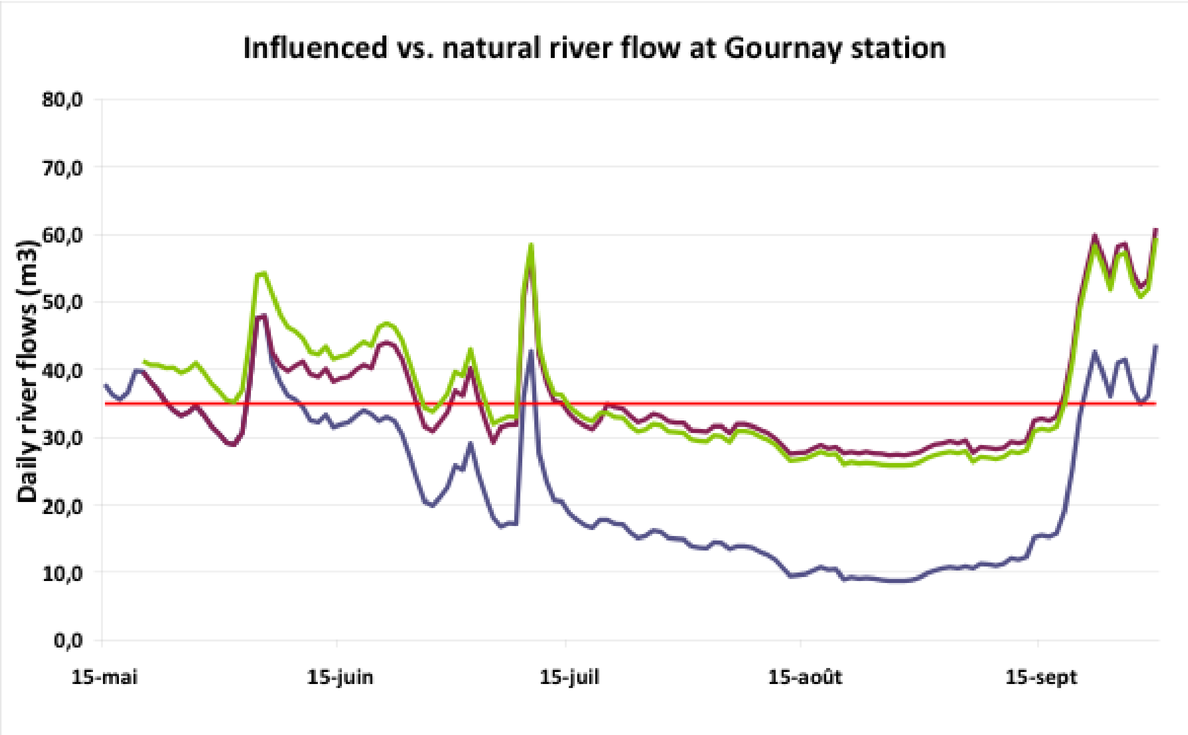


Figure 8. Natural river flows (blue) and river flows influenced by the water release using seasonal forecasts (green) and without using seasonal forecasts (brown), at the downstream station (Gournay station) from the 15th May to the 30th September 1993. The light red line is the 35 m3/s threshold.

In reality, EPTB has the possibility to adapt their decision every 15 days at the beginning of the low-flow period. In such a situation of drought, the 5th of July, they would have probably adapted their draining curve to avoid the long low-flow period between mid-July to mid-September. In this context, we have proposed to EPTB to provide up-dated river flow forecasts every month from May. Forecast products issued from a simulation initialized at 1st June have been sent to EPTB (fig. 9). They will soon replay again this particular year. Their feedback will be very useful to analyse how they would adapt their decision in such a case.

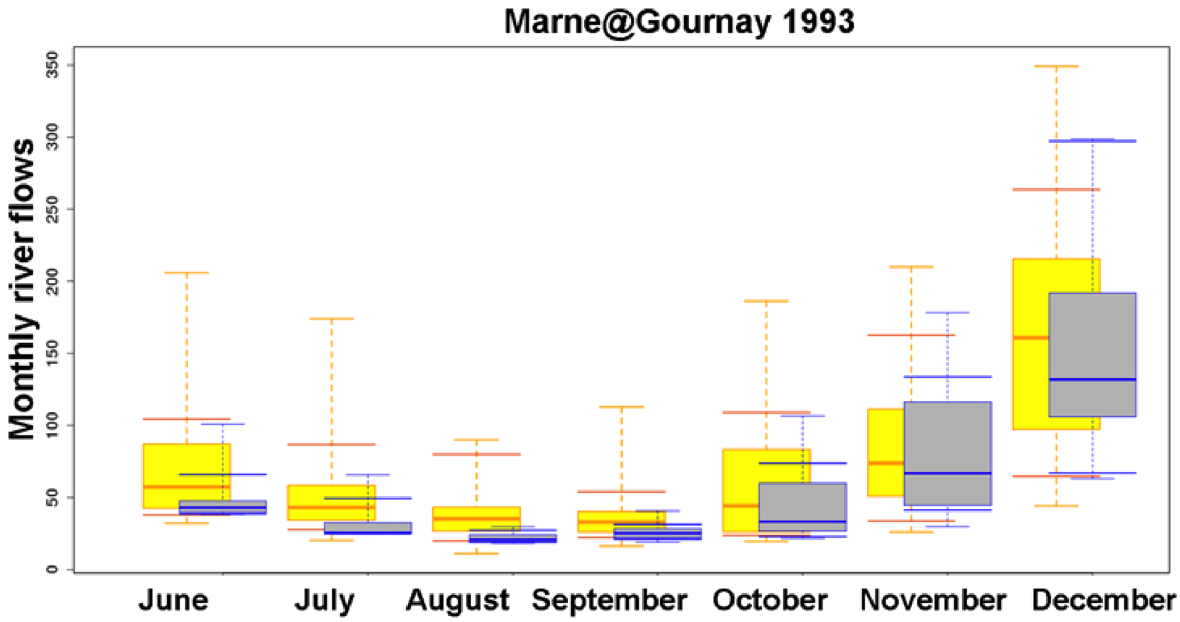


Figure 9: Same as figure 7 but for an initialization at 1st of June

The added value of the RIFF prototype to the DMP clearly appears in this particular drought event. Using seasonal forecasts allows reducing the number of days below the low-level threshold during the first two months of the dry season. Afterwards, an updated forecast seems to be necessary to adjust the water release and anticipate a possible increase of river flows in early autumn.

3.4. SPRINT transport prototype (Met Office)

The SPRINT prototype focuses on forecasting the impact of cold winter weather on transport in the United Kingdom (UK) at the seasonal timescale, i.e. for the meteorological winter defined as the 3-month period covering December, January and February.

The meteorological indicator used is the North Atlantic Oscillation (NAO) index, as forecast by the Met Office operational global seasonal forecast system, GloSea.

The NAO is a large-scale driver of Northern European winter climate. Together with the Arctic Oscillation, the NAO controls the position and strength of the Northern Hemisphere jet streams and impact on near-surface winds and temperatures across the northern mid-latitude continents (Hurrell, 1995). The NAO index is a measure of the strength of the NAO and expressed as a pressure difference between the mean sea level pressures of the Icelandic low and the Azores high. A negative (positive) index is linked to colder (milder, stormier) conditions over Northern Europe during the winter.

In this report we have presented "anonymised" data for some of the relevant impact metrics, in order to illustrate qualitatively the prototype's performance. It should be noted that, during the trialling of the impact forecasts over the coming winter, the actual forecasts to be communicated to the stakeholders will include more detailed information.

3.4.1. Summary of progress towards objectives

Activities so far have spanned engagement with stakeholders and developing and testing the prototype. All of these activities are essential for contributing to Objective 1 of EUPORIAS.

A successful workshop with many transport stakeholders in the UK, notably the Highways Agency, British Airways, Virgin Trains, Network Rail, Dorset County Council and Transport for London, was held in July 2014 and helped to identify key needs of these users in order to inform the prototype design (Objective 2). Following a trial winter forecast for the winter 2014/2015 which included monthly teleconferences, surveys were sent out to the stakeholders to examine aspects of their decision-making around a common transport sector activity (de-icing) (Objective 2). While the return rate was somewhat low, the survey results were encouraging in that they revealed that some stakeholders had used the forecast information and acted upon it.

The prototype has been in continuous development and has now reached the trialling stage (Objectives 3, 4, 5). In simple terms, it converts the winter seasonal forecast into a probabilistic transport impact forecast expressed in a quantity meaningful to the stakeholders (e.g. number of road accidents in snowy and calm conditions, number of aircraft de-iced at London Heathrow Airport). The underlying scientific approach has been extensively validated (Palin et al., 2015).

We have tested the prototype on past winters and in particular the winters 2009/2010 and 2010/2011 which both presented cold conditions over Northern Europe and were associated with severe transport impacts in the UK. Results were encouraging in that the impact forecasts were significantly different from the climatological impact and that indeed corresponded to the observed conditions.

3.4.2. Detailed results from SPRINT prototype development

Key past events with impacts on UK transport

Two winters have been identified to test the prototype based on their severely cold conditions and the widespread transport disruptions that resulted. These winters are those of 2009/2010 and 2010/2011.

- **Winter 2009/2010**

Winter 2009/2010 saw extremely cold conditions and snowfall across much of the United Kingdom – the most widespread and prolonged spell of this type across the country since the winter of 1981/1982. Over the winter as a whole, the NAO index was at its most negative value in 100 years.

Impacts on national transport (Met Office, 2013; Prior and Kendon, 2011b) included:

- road closures and accidents,
- airport closures (including Manchester and Liverpool),
- flight delays and cancellations at other airports,
- snow-related disruption to Eurostar services just before Christmas.

- **Winter 2010/2011**

December 2010 was the coldest December recorded in the UK in over 100 years (Prior and Kendon, 2011b). Impacts on national transport (Prior and Kendon, 2011a) included:

- airport closures (including Heathrow, Gatwick, Edinburgh, Glasgow),
- road closures and accidents,
- Forth Road Bridge[2] closed for first time in its history,
- vehicles stranded overnight on motorways in England and Scotland,
- East Coast Main Line railway closed when overhead power lines were brought down.

The unusually cold conditions in Europe during December 2010 and the associated strongly negative NAO index were driven primarily by ocean heat content anomalies in the North Atlantic ocean (Maidens et al., 2013).

Retrospective performance of SPRINT compared with information available at the time

a) What seasonal forecast information was available at the time?

The Met Office operational seasonal forecast system at the time was GloSea4 (Arribas et al.; 2011). Issued forecasts are expressed in terms of terciles of temperature and precipitation[3] (below average, near average, above average). At the time, forecasts were given for the whole of Northern Europe.

Forecasts issued are typically a combination of seasonal forecast system output and expert judgement, taking into account how the GloSea4 forecast compares to the forecast from other international forecast systems.

- **Winter 2009/2010**

The forecasts issued by the Met Office and the ECMWF[4] centre (System 3 at the time) mid-November 2009 for the coming winter are illustrated in Figure 1. The figure shows that real time forecasts GloSea4 exhibited a strong signal for a high-pressure anomaly over Northern Europe, a signal consistent with a negative NAO index and cold conditions in winter over Northern Europe. This was however not replicated in other centres' forecast systems, e.g. that of ECMWF shown here.

[2] A suspension bridge linking northeast and southeast Scotland, which forms a vital part of the Scottish road transport network
[3] For the transport prototype we do not discuss the precipitation forecasts.
[4] European Centre for Medium-Range Weather Forecasts, Reading, United Kingdom

In the case of this winter, expert judgement was not to place undue weight on the Met Office forecast, even if in hindsight it turned out to be closer to the truth than the other forecasts. At the time, the GloSea4 forecast did not agree with those from other centres and it was recognised that the system at the time had relatively little skill over Northern Europe in general.

The official Met Office forecast for that winter was therefore for a raised probability of milder-than-average conditions for the mean temperature over Northern Europe.

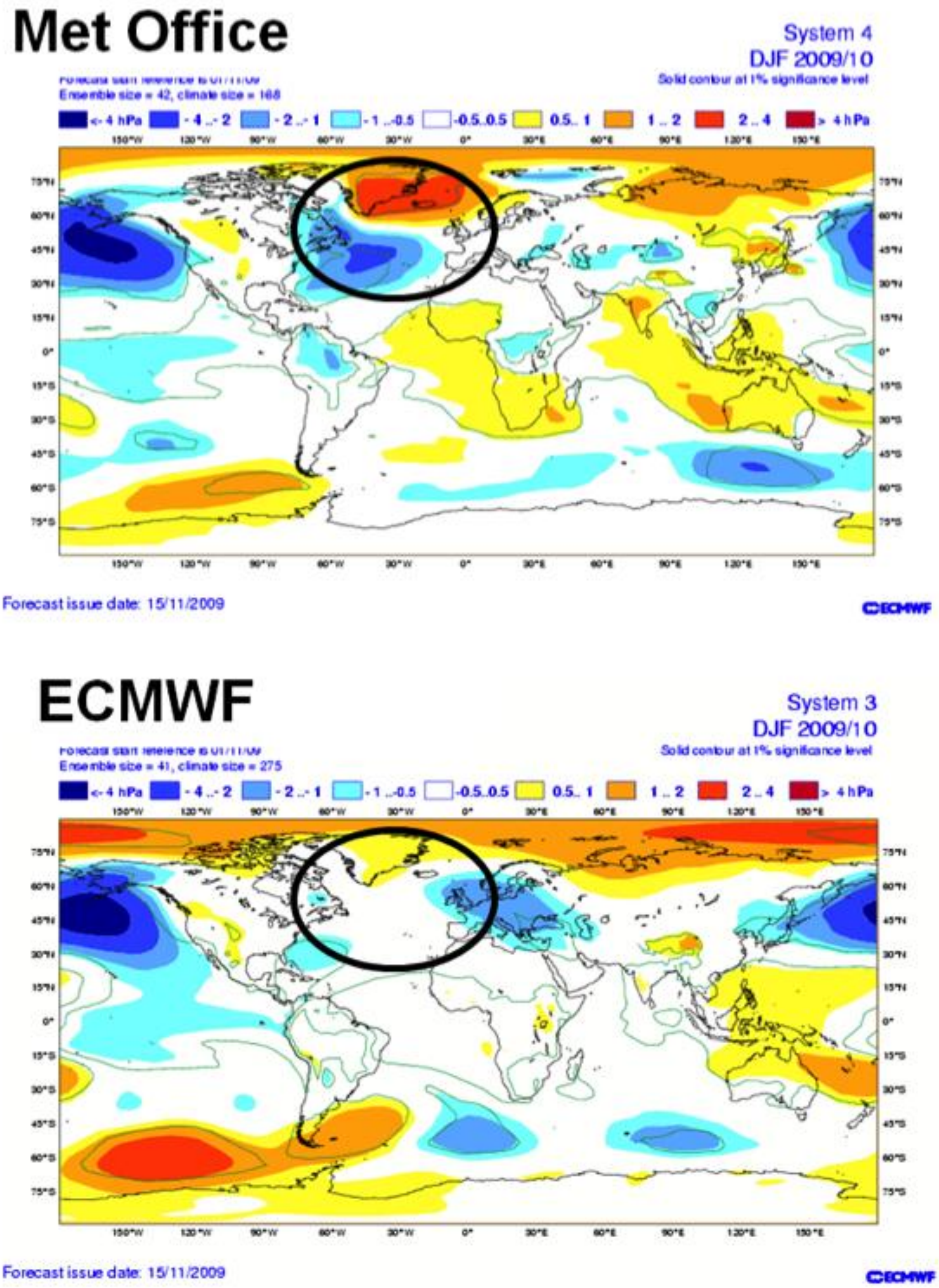


Figure 1: Ensemble mean mean sea level pressure (MSLP) anomaly forecasts from the Met Office (top) and ECMWF (bottom) forecast systems, issued on 15/11/2009 and valid for the winter 2009/2010 period. (Source: ECMWF EUROSIP analysis)

- **Winter 2010/2011**

For the winter 2010/2011, a signal was present from the October forecast onwards for an increased risk of cold conditions in the early part of winter, as indicated in Figure 2.

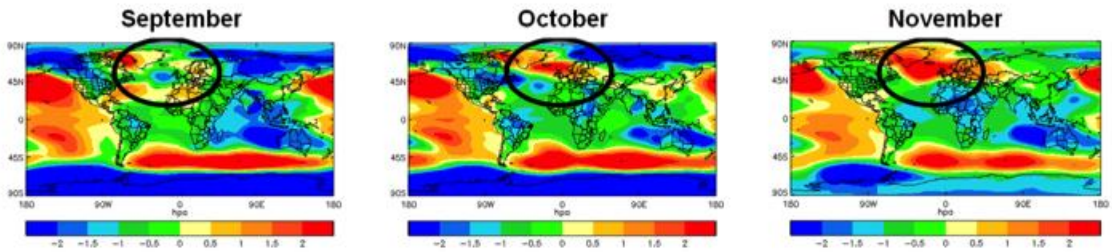


Figure 2: Forecasts for ensemble mean MSLP anomaly for the winter 2010/2011, issued at different times, from the GloSea4 seasonal forecast system. (Source: http://www.metoffice.gov.uk/research/climate/seasonal-to-decadal/gpc-outlooks/ens-mean)

Met Office forecasts for mean temperature over Northern Europe gave the following tercile probabilities (note that climatologically a tercile probability of 33% is expected for any category):

Issue date	Period covered by forecast	Temperature tercile probability:		
		Colder than average	Near average	Milder than average
Oct 2010	Nov 2010-Jan 2011	40%	30%	30%
Nov 2010	Dec 2010-Feb 2011	45%	30%	25%
Dec 2010	Jan 2011-Mar 2011	55%	30%	15%
Jan 2011	Feb 2011-Apr 2011	40%	30%	30%

Table 1. Tercile probabilities for the mean temperature forecasts over Northern Europe

The official Met Office forecast for that winter was therefore for a raised probability of colder-than-average conditions for the mean temperature over Northern Europe, and correspondingly decreased probabilities of the milder-than-average and average categories. The signal was strengthened in the November and December forecasts.

b) What was the actual outcome?

- **Winter 2009/2010**

The winter 2009/2010 turned out to exhibit an exceptionally strong negative NAO index (see Figure 3), with a high pressure over northern Europe and a low pressure over southern Europe. This created an easterly flow over the United Kingdom and consequently very cold and snowy conditions. The observed mean temperature was in the colder-than-average tercile.

In hindsight, it turned out that the weather pattern signal found in the Met Office system on this occasion was closer to the observed outcome than that found in the other forecast systems – a result that is now highly reproducible (Scaife et al., 2014; Riddle and Scaife, 2014).

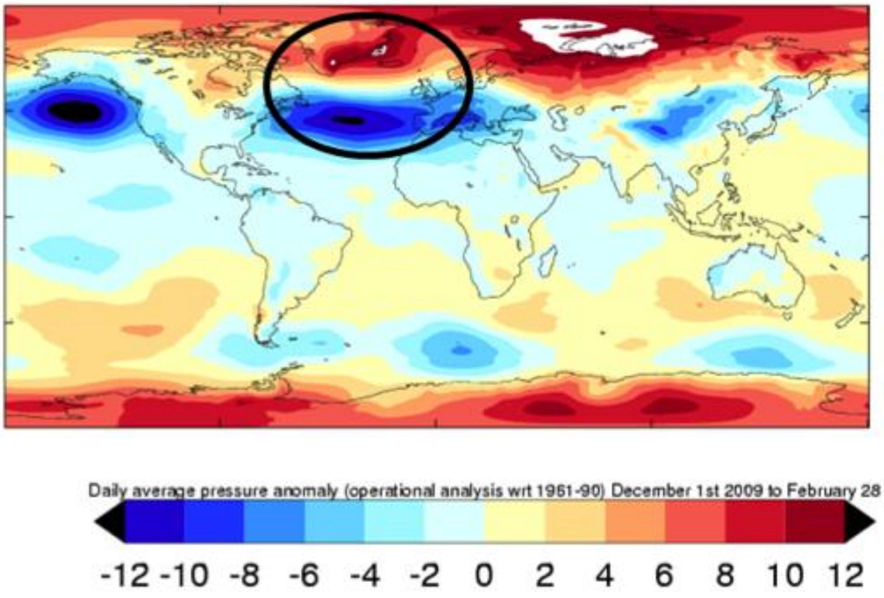


Figure 3: Observed mean sea level pressure anomaly for winter 2009/2010. (Source: HadSLP, Allan and Ansell, 2006)

- **Winter 2010/2011**

The winter 2010/2011 began in an extreme manner with the coldest December in the UK for 100 years (top panel in Figure 4 shows the pressure anomalies for December 2010; these are consistent with atmospheric circulation patterns corresponding to relatively cold conditions over the UK). Although later in winter the situation was reversed (see bottom panel in Figure 4), overall the observed Northern Europe mean temperature was the colder-than-average tercile.

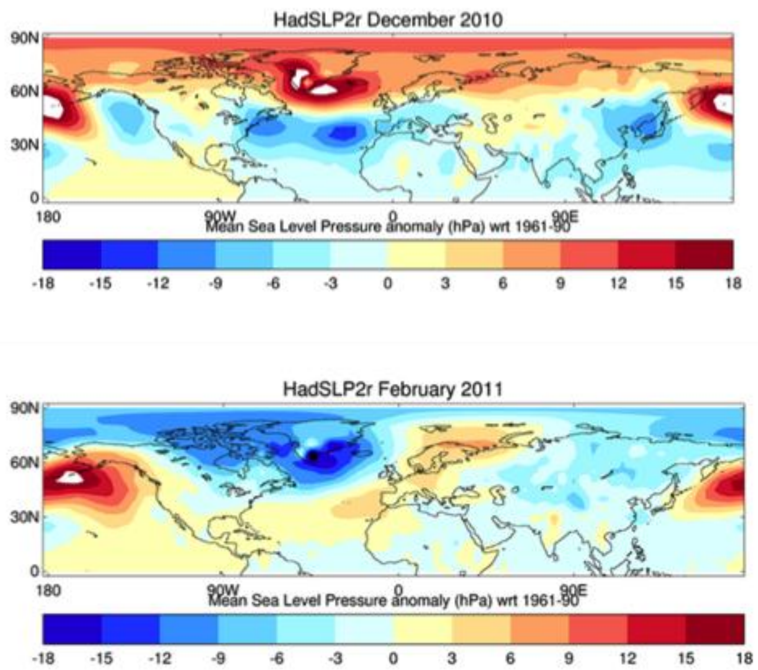


Figure 4: Observed MSLP anomaly for December 2010 (top) and February 2011 (bottom). (Source: HadSLP, Allan and Ansell, 2006)

c) What would SPRINT have predicted, had it been available at the time?

The prototype has been developed based on relationships between observed/forecast NAO index and transport impact metrics (Palin et al, 2015), where the forecast NAO index has been derived from GloSea5 forecasts (MacLachlan et al., 2014). GloSea5 is the latest version of the seasonal forecast system of the Met Office, which has been shown to have a highly significant skill in predicting the NAO index (Scaife et al., 2014; Riddle and Scaife, 2014).

In order to assess what the prototype would have predicted for past winters should it have been available at the time, several training approaches were employed:

1. Training using all valid data from preceding winters, and excluding the winter to be forecast.

2. Training using all valid data to date, including the winter to be forecast and “future” winters (i.e. those having occurred after the forecast year).

3. Training using all valid data to date, as in 2, but excluding the winter to be forecast.

Approach 1, although the most logical, was quickly abandoned as it severely limits the amount of data available for identifying a relationship between forecast NAO and impact metric. In particular, it is indeed unrealistic to train the prototype on too few pairs of past forecast NAO index and impact metric which, in addition, need not be strongly correlated. This is because the strength of the impact/NAO correlation depends on the impact considered and the number of winters for which data are available. As such, approach 1 did not satisfy the basic statistical principles of the prototype.

Approaches 2 and 3 are more robust, but may be perceived as counterintuitive: both approaches make use of data from winters that would have not yet happened at the time of the forecast, while the former also trains the prototype using information about the winter it aims to forecast. The motivation behind this approach is that each winter represents a physically accessible state which is only partially dependent on conditions in the preceding years. For the purposes of the prototype, this means that the order in which the winters occur is largely unimportant, meaning that data for “future” winters can be included in the sample to improve the statistical robustness of the prototype.

Using either approach, the prototype forecasts were for above-average impacts for both winters for all impact metrics considered here (number of road accidents in snowy and calm conditions; amount of salt used for de-icing; number of weather-related incidents for rail infrastructure, trains and rolling stock; number of aircraft de-iced at London Heathrow airport). This is consistent with a negative NAO index and therefore cold conditions over Northern Europe. Example forecasts are shown in Figure 5 for the winters 2009/2010 and 2010/2011.

All forecast risks were also found to be significantly different from the climatological level, except in one case (number of aircraft de-iced in 2009/2010, when using approach 3).

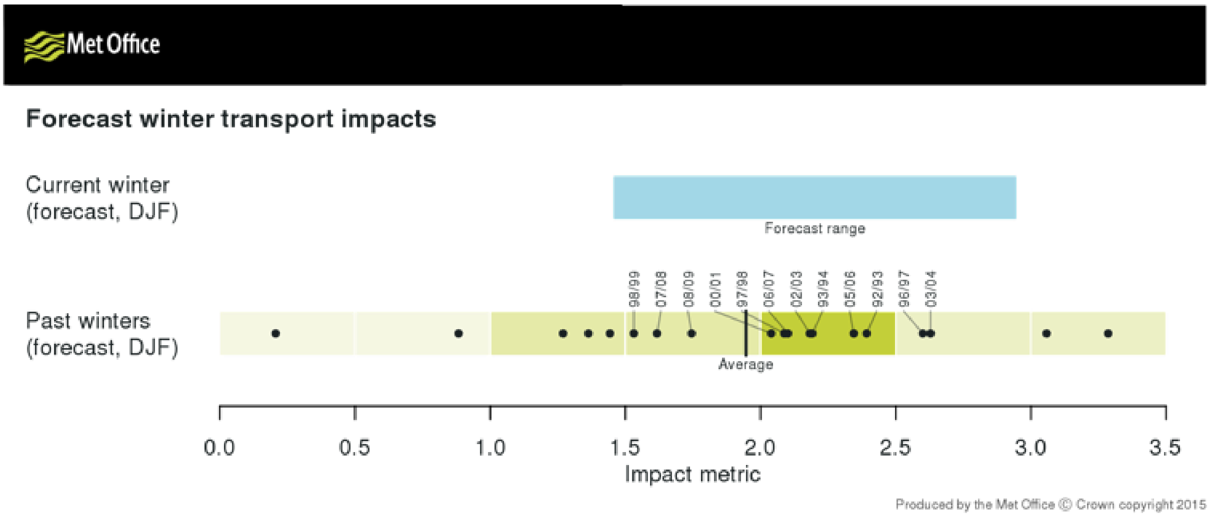


Figure 5: 2009/2010 forecast for one of the four transport impact metrics. The current forecast (blue) is expressed as a range of possible outcomes. It is to be compared to forecasts of past winters (green), where the darker the colour the more frequent that impact value range was (dots represent individual winters and winters falling within the current forecast range are labelled). Note that in the present case, the "past winters" also include future winters (see explanation in text).

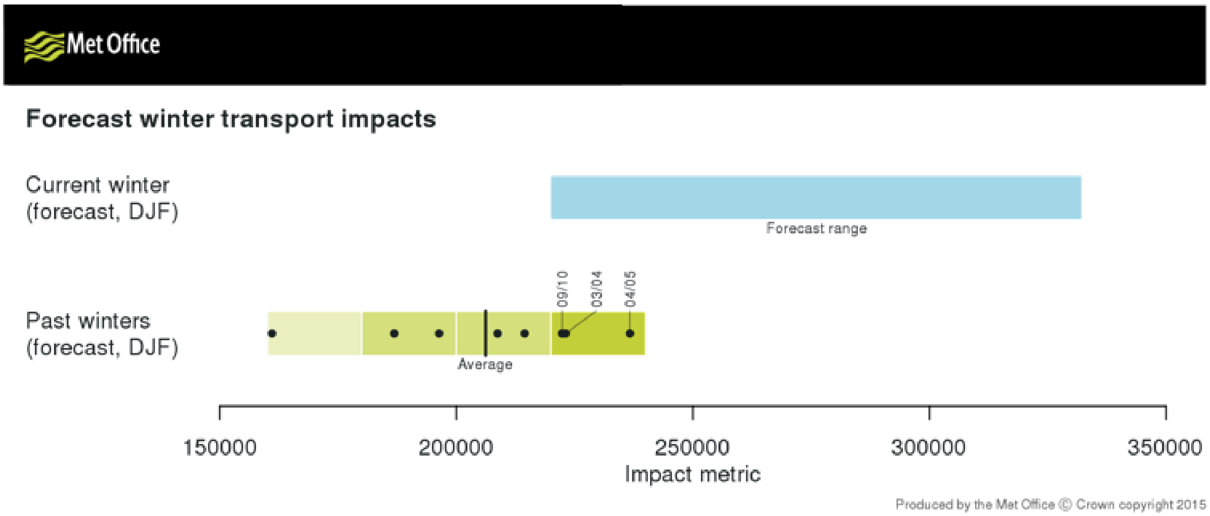


Figure 6: 2010/2011 forecast for one of the four transport impact metrics. See Figure 5's caption for more detail about the figure.

Value added by SPRINT to the decision-making process

The SPRINT decision-making process (DMP) is shown in Figure 7. There are four elements to the prototype – namely, historical context (top left), impacts forecast (top right), monthly teleconference updates (bottom right), and post-season evaluation (bottom left).

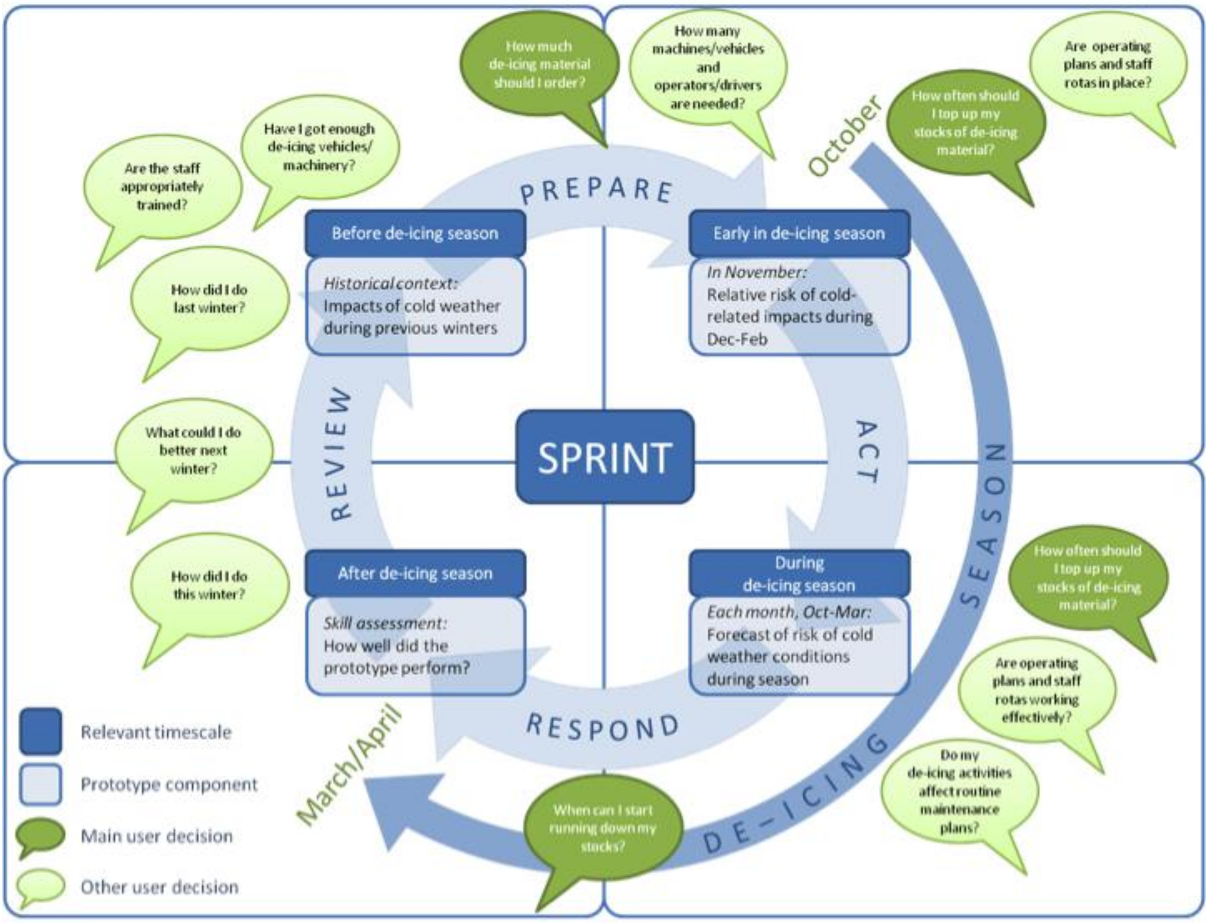


Figure 7: Decision-making process (DMP) for SPRINT.

For both selected winters, the prototype provided forecasts of above-average impacts:

- winter 2009/2010: observations showed that this was the case for all four impacts with the most extreme values or second most extreme values available in the impact records;
- winter 2010/2011: observed impacts were all well above average (except for the amount of salt used on roads which was average), but in more modest proportions with respect to 2009/2010.

a) Potential added value of SPRINT in decision-making process

Clearly, the winters of 2009/2010 and 2010/2011 were extreme from a meteorological perspective, with ensuing impacts on transport. Comparing SPRINT with the seasonal forecast information that was available at the time for these two winters, SPRINT has added value in the following ways:

- Availability of impact forecasts: there were no impact forecasts available at the time of these previous winters.
- Use of more recent (and more skilful) version of forecast system: even if it had been possible to create impact forecasts at the time of these previous winters, they would have been based on the operational seasonal forecast system at the time, which was GloSea4, and may not have been skilful as a result. SPRINT uses past and current forecast data for the NAO index computed from the most recent version of the seasonal forecast system, GloSea5, which is more skilful

than its predecessor for relevant variables and regions (Scaife et al., 2014), in particular the NAO and Northern Europe.

- Use of large-scale meteorological driver to forecast transport impacts directly: SPRINT links the NAO directly to impacts. Since the skill of the impact forecasts comes from the NAO, SPRINT gives the most skilful forecast, as opposed to alternative approaches using regional forecast output or carrying out complicated downscaling.
- Provision of forecasts of metrics with direct user relevance: seasonal weather forecasts are issued in terms of tercile probabilities of mean temperature and precipitation. Forecasts of these quantities are still made today, and this information is disseminated within SPRINT via monthly teleconferences. SPRINT however translates this information into trial forecasts of particular impacts on the transport system, which have potentially greater relevance for the user.

b) Potential effect of SPRINT on decision-making process

For cold winters, lead times for planning decisions a long way ahead of the winter season would not be supported by this prototype, as the lead time is one to three months ahead while the prototype lead time is of maximum one month. The exception is the provision of historical context of previous winters (top left panel of DMP in Figure 7).

For decisions on the shorter timescales, the prototype could add value (see examples from surveys in winter 2014/2015 – but note that those decisions were based on the meteorological forecast alone, not the impact forecast) but it depends on whether the stakeholders would be prepared to stake their decisions on the prototype. Evidence from the stakeholder workshop we held suggested that most stakeholders now plan for cold winters in the wake of the impacts experienced during these two particular winters. They are also loath to change their planning processes for fear of reprisals from regulators, etc., in the event of "getting it wrong".

One important point is that, as with all services based on seasonal forecasts, stakeholders need (a) to use SPRINT as part of a wider toolkit of forecasts and services with differing temporal and spatial scope, and (b) to evaluate SPRINT's efficacy over many forecast winters, rather than concentrating on performance over a single winter.

In summary, decisions with lead times of more than three months cannot be informed by SPRINT, as the meteorological processes underlying the predictability of transport impacts during winter are not currently predictable at lead times longer than this. For this, we await future developments in near-term climate prediction.

3.4.3. References

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3.4.4. Planned future publications

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3.5. Land management prototype (Met Office)

3.5.1. Introduction

The Met Office, the University of Leeds, KNMI (Netherlands) and other partners are working closely with Clinton Devon Estates (CDE) and the National Farmers Union (NFU) to develop prototype seasonal weather forecasts for UK land managers. Seasonal weather forecasts (typically for 1-3 months ahead) are currently only skilful during the wintertime, so initial work on the prototype has focused on providing winter forecasts. So far, we have:

- interviewed a representative subset of CDE farmers on their needs for weather information
- developed a draft three month forecast and sent this to the farmer subset each month during winter 2014/2015
- surveyed a wider group of farmers from CDE and NFU on their needs for long-term weather information to support decision making, and then
- Built on findings from stakeholder engagement and feedback on our draft forecasts to develop a second version of the forecast for winter 2015/2016.

Production of the first draft forecasts during winter 2014/2015 was based around the UK contingency planners forecasts (CPF), which provide 3 month outlooks for temperature and precipitation for the UK as a whole each month. The CPF themselves are based on outputs from the Met Office seasonal prediction system Glosea5, which are discussed to agree expert guidance which is applied to the raw model forecasts to deliver the actual forecasts delivered on the Met Office website. Because the CPF are for the UK as a whole, we have developed a simple way to downscale the CPF to Devon. The CPF provide probabilistic forecasts, for example of the tercile categories for temperature and precipitation relative to normal conditions (defined as long-term average values for the time of year in question). For example, the long-term average (normal) probability of temperature for a three month period would be 33% in each of the categories below normal, normal and above normal. The downscaling technique used for the prototype is to scale the tercile category probabilities produced in the CPF to Devon using the observed relationship between Devon-mean and UK-mean temperature (or precipitation) for the period in question.

The forecasts for winter 2015-2016 will include a mainly text based narrative for the 3 month forecasts. The skill for the Glosea5 system over the UK is predominantly in its ability to predict the winter North Atlantic Oscillation (NAO; Scaife et al. 2014). We will therefore be providing temperature forecasts to all farmers in the case study region, and precipitation forecasts only to those farmers in regions where there are strong links between observed NAO and precipitation. In addition, we plan to send the land managers site specific 14 day forecasts for temperature and precipitation, based on the Met Office product Best Data, which blends observations and a range of different forecast models. These 14 day forecasts should provide the land managers more detailed short term information, and also meet their request for better information on more relevant variables such as wet and dry spells, and heavy rainfall events.

This report describes the work we have done to date to verify the performance of the land management prototype from a meteorological perspective, focusing only on the three-month outlooks. Whilst the stakeholder engagement activities (interviews, feedback forms and surveys) have identified a broad range of land management decisions which may benefit from the prototype, it has been very difficult to isolate specific decisions or actions that would be taken in response to the three month outlooks. Our findings also suggest a strong role of economic and policy drivers in longer-term decision making, and a lack of familiarity with probabilistic climate predictions (seasonal outlooks) compared to their frequent use of short term weather forecasts for tactical decision making. However, anecdotal evidence discussed at the 2014 General Assembly suggested that CDE decided to abandon forestry activities in one area of their estate following our initial three month outlooks which indicated wetter than normal conditions.

3.5.2. Summary of progress towards objectives

We report on several sets of verification information:

- *Assessment of observed weather variables vs. observed NAO at national/regional scale over the UK:* This provides correlations between the observed NAO index and UK regions
- *Verification of the UK Contingency Planners' forecast at UK scale*
- *Verification of forecasts sent out during winter 2014/2015* (i.e. only for one winter), based on UK Contingency Planners Forecasts (CPF) downscaled to Devon
- *Assessment of North Atlantic Oscillation (NAO) vs impact metrics at county scale*, using National Climate Information Centre (NCIC) climate data and Glosea5 hindcasts. Glosea5 is the "raw model" behind the CPF forecasts. Glosea5 is known to have particularly good skill for the UK winter NAO. This work also looked at more relevant (mostly rainfall related) variables, following feedback from the farmers. This uses the full hindcast dataset.
- *Maps of correlations between NCIC observed precipitation and NCIC observed NAO (or Glosea5 model NAO), for two baseline periods over the South West UK*

3.5.3. Assessment of observed weather variables vs observed NAO over UK regions.

Since the skill of the Glosea5 system used to produce the land management prototype forecasts is mainly related to its ability to predict the winter NAO over the UK, we investigated correlations between observed NAO and precipitation/temperature over UK regions (UK as a whole, England, Scotland, England & Wales), averaged over three month periods, annually, or monthly, and using the observational records from NCIC for 1910-2012. The aim of this study is therefore to see whether strong relationships between the observed weather variables and the NAO exists at large spatial scales, as an indicator of the usefulness of Glosea5-driven forecasts.

A full set of scatter plots are provided on the land management prototype wikidot site (https://euporias.wikidot.com/wp23-casestudyselection-euag-forecast-verification14-15) and since many plots are available, we only show a few representative examples here (Figs 3&4), and summarize the correlations in tabular form (Table 1) and as annual cycle plots (Figs 1&2).

Four key points emerge from analysis of these assessments:

A) the strongest NAO-weather variable links are during winter, compared to weaker links during summer, indicating higher skill in summer and weaker skill in winter in the forecasting system

B) there are generally stronger correlations between the NAO and temperature than for precipitation, hence indicating greater skill for temperature than precipitation

C) regionally, especially for precipitation, there are stronger links between the NAO and weather variables for Scotland compared to the other regions, and much of the correlation for the UK appears to derive from Scotland. This is less the case for temperature, where the regional correlations are more similar.

D) our study region is in England, where there are strong NAO-temperature correlations, but weaker NAO-precipitation correlations during winter, implying stronger skill for temperature and weaker skill for precipitation.

	UK		England		Scotland		England and Wales	
	Precipitation	Temperature	Precipitation	Temperature	Precipitation	Temperature	Precipitation	Temperature
JFM	0.545	0.691	0.122	0.694	0.229	0.647	0.185	0.693
FMA	0.452	0.584	0.091	0.602	0.679	0.533	0.14	0.599
MAM	0.305	0.378	0.013	0.41	0.572	0.33	0.041	0.402
AMJ	0.042	0.223	-0.181	0.216	0.31	0.248	-0.151	0.208
MJJ	-0.105	0.082	-0.206	0.073	0.08	0.139	-0.194	0.062
JJA	-0.041	-0.031	-0.202	-0.026	-0.014	-0.002	-0.193	-0.039
JJA	0.174	0.099	-0.014	0.121	0.355	0.085	0.014	0.109
JAS	0.357	0.105	0.082	0.127	0.532	0.081	0.14	0.126
ASO	0.467	0.231	0.249	0.254	0.549	0.195	0.301	0.256
SON	0.505	0.345	0.273	0.34	0.639	0.333	0.312	0.346
NDJ	0.518	0.594	0.184	0.603	0.706	0.513	0.243	0.608
DJF	0.561	0.706	0.242	0.696	0.744	0.643	0.296	0.701
January	0.645	0.656	0.337	0.665	0.779	0.568	0.39	0.67
February	0.568	0.635	0.313	0.635	0.706	0.577	0.361	0.636
March	0.396	0.524	0.042	0.556	0.654	0.46	0.091	0.548
April	0.184	0.349	-0.005	0.363	0.378	0.321	0.015	0.355
May	0.129	0.198	-0.07	0.202	0.348	0.212	-0.057	0.186
June	-0.157	0.092	-0.287	0.086	0.13	0.145	-0.272	0.064
July	0.109	0.02	0.034	0.065	0.183	-0.023	0.041	0.044
August	0.026	0.13	-0.112	0.138	0.16	0.124	-0.076	0.13
September	0.339	0.155	0.091	0.213	0.54	0.075	0.129	0.201
October	0.365	0.147	0.153	0.139	0.48	0.16	0.203	0.145
November	0.496	0.407	0.335	0.427	0.558	0.347	0.371	0.431
December	0.559	0.58	0.272	0.569	0.708	0.533	0.325	0.576
Annual	0.466	-0.101	0.229	-0.098	0.608	-0.105	0.276	-0.097

Table 1: Correlations between observed precipitation/temperature and NAO over UK regions for different seasons and months, using NCIC data from 1910-2012.

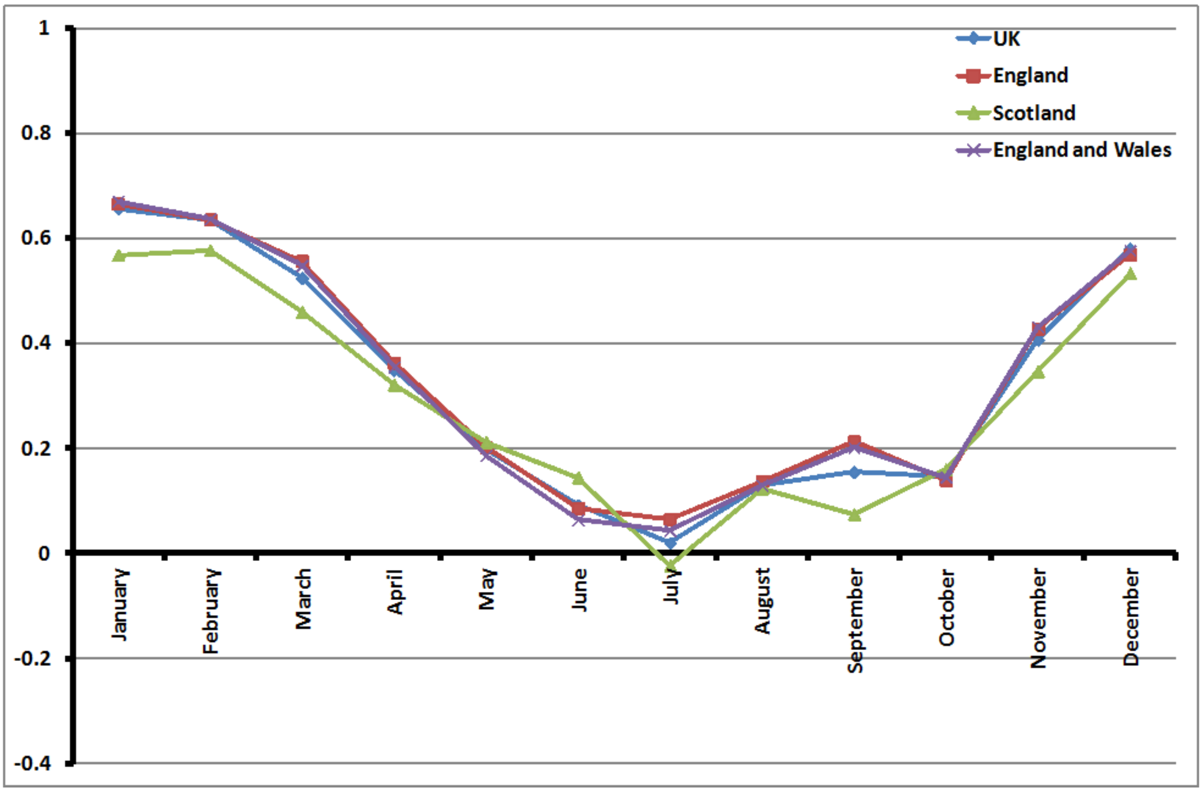

Figure 1: Correlations between observed temperature and NAO over UK regions for different months, using NCIC data from 1910-2012.

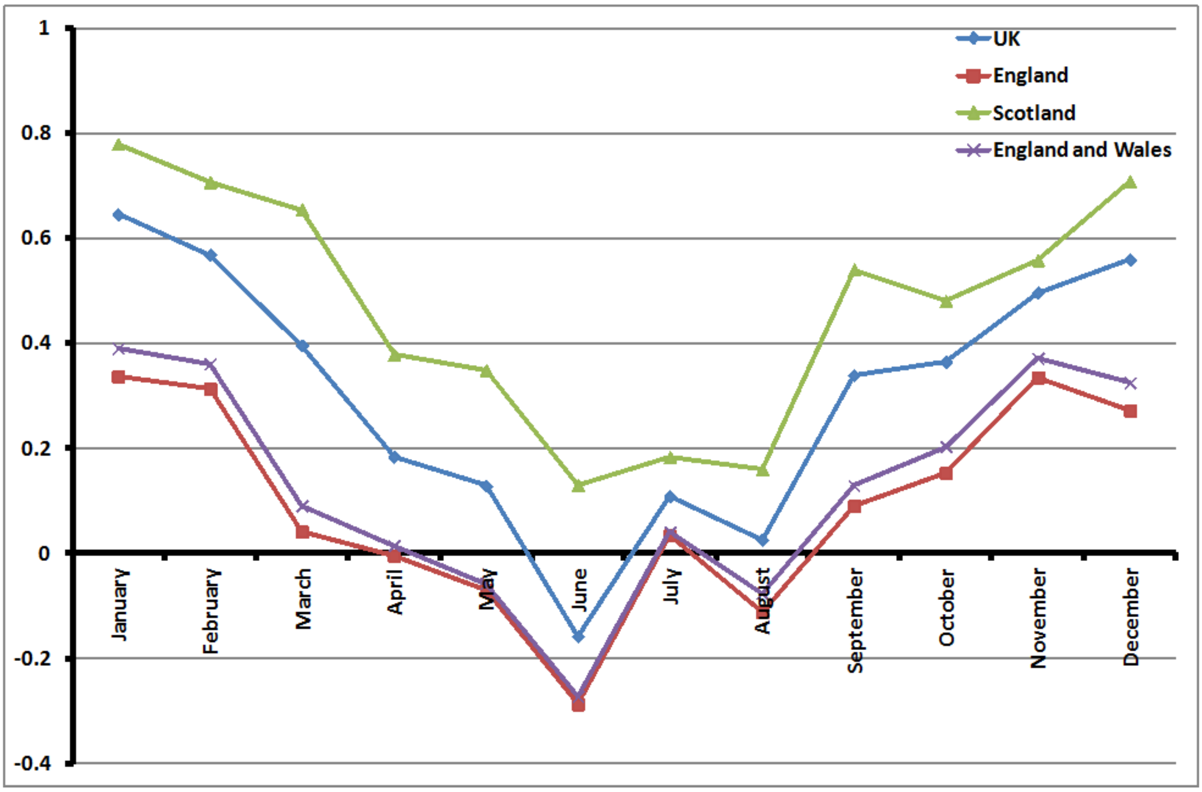

Figure 2: Correlations between observed precipitation and NAO over UK regions for different months, using NCIC data from 1910-2012.

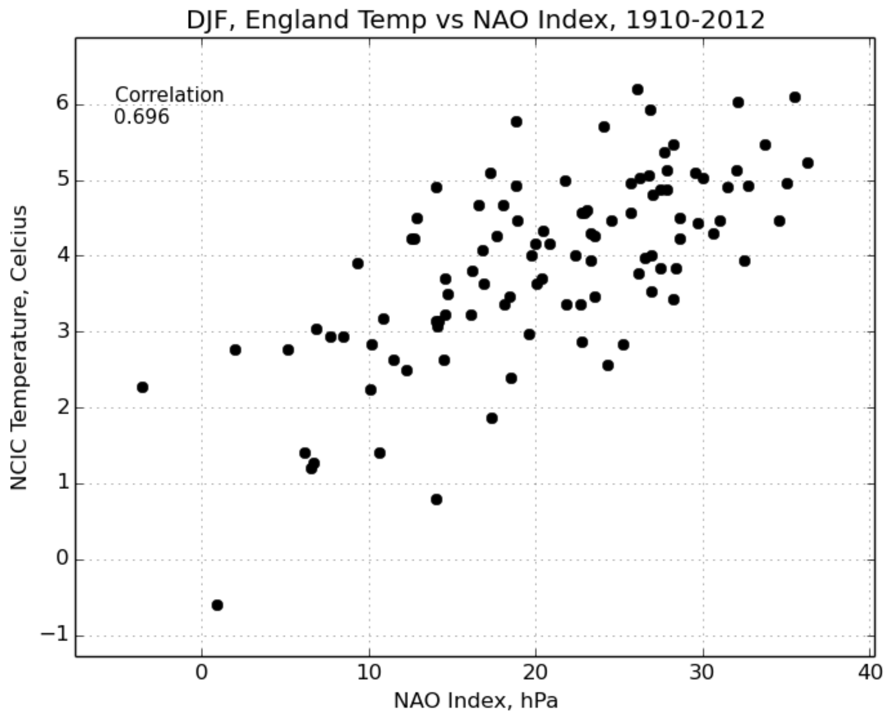

Figure 3: Correlation between observed temperature and NAO for DJF over England, using NCIC data from 1910-2012.

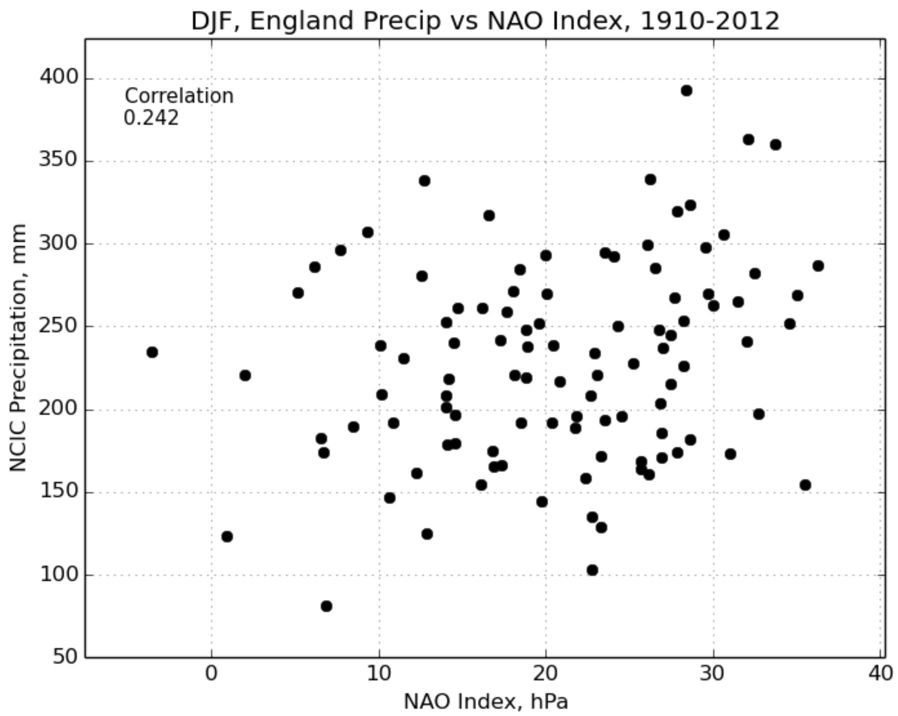

Figure 4: Correlation between observed precipitation and NAO for DJF over England, using NCIC data from 1910-2012.

3.5.4. Verification of the Contingency Planners forecasts at UK scale

Verification was also performed on the CPF, comparing the observed temperature or precipitation outcomes with the forecast categories (below-normal, near-normal and above-normal) for a range of historic seasons, over the UK as a whole. Since this is produced based on the outputs of an operational system, the forecasts have only used Glosea5 as the basis since Spring 2013, whilst an older seasonal forecasting system was used before then.

For temperature, the observed category matched (one of) those predicted to have raised probability 24 out of 35 times, whilst the fraction expected by chance is approximately 17/35. The chance of achieving this many successes (or more) by chance was calculated to be 0.018.

For precipitation, the observed category matched (one of) those predicted to have raised probability 20 out of 35 times, whilst the fraction expected by chance is approximately 20/35. The chance of achieving this many successes (or more) by chance was calculated to be 0.139.

Again, this indicates that the Glosea5 model and CPF have better skill for temperature than precipitation, and for winter compared to the other seasons of the year.

UK temp forecasts	below-normal	near-normal	above-normal
Winter 2005/6		•	
Summer 2006			•
Winter 2006/7			•
Spring 2007			•
Summer 2007		•	
Autumn 2007			•
Winter 2007/8			•
Spring 2008			•
Summer 2008			•
Autumn 2008		•	
Winter 2008/9	•		
Spring 2009			•
Summer 2009			•
Autumn 2009			•
Winter 2009/10	•		
Spring 2010		•	
Summer 2010			•
Autumn 2010		•	
Winter 2010/11	•		
Spring 2011			•
Summer 2011		•	
*Autumn 2011			•
Winter 2011/12			•
Spring 2012			•
Summer 2012	•		
**Autumn 2012	•		
Winter 2012/13	•		
Spring 2013	•		
Summer 2013			•
Autumn 2013			•
Winter 2013/14			•
Spring 2014			•
Summer 2014			•
Autumn 2014			•
Winter 2014/15			•

Black	Forecasts for UK
Blue	Forecasts for northern Europe
	Categories predicted to have raised probability
•	Category that was observed to occur

*From Autumn 2011 the baseline climatology of 1961 – 1990 has been updated to 1971 – 2000.

** From Autumn 2012 the baseline climatology of 1971 – 2000 has been updated to 1981 – 2010.

Figure 5: Verification of UK Contingency Planners Forecasts during the hindcast period for temperature, compared to NCIC observations.

UK Precipitation verification

UK precip forecasts	below-normal	near-normal	above-normal
Winter 2005/6	■ ●		
Summer 2006	●	■	■
Winter 2006/7		■	■ ●
Spring 2007		■ ●	■
Summer 2007		■	●
Autumn 2007	■ ●	■	
Winter 2007/8		■	■ ●
Spring 2008	■	■	●
Summer 2008		■	■ ●
Autumn 2008	■		●
Winter 2008/9	■ ●	■	
Spring 2009	■	■ ●	
Summer 2009	■	■	●
Autumn 2009	■	■	■ ●
Winter 2009/10	●	■	■
Spring 2010	■ ●	■	■
Summer 2010	■		●
Autumn 2010	■	■ ●	
Winter 2010/11	■ ●		
Spring 2011	■ ●		
Summer 2011	■	■	●
*Autumn 2011	■	■ ●	
Winter 2011/12			■ ●
Spring 2012	■ ●		
Summer 2012			■ ●
**Autumn 2012			■ ●
Winter 2012/13	■		●
Spring 2013	■ ●		
Summer 2013	●		■
Autumn 2013	■ ●		■
Winter 2013/14	■		●
Spring 2014			■ ●
Summer 2014			■ ●
Autumn 2014	■ ●		
Winter 2014/15			■ ●

Black	Forecasts for UK
Blue	Forecasts for northern Europe
■	Categories predicted to have raised probability
●	Category that was observed to occur

*From Autumn 2011 the baseline climatology of 1961 – 1990 has been updated to 1971 – 2000.

** From Autumn 2012 the baseline climatology of 1971 – 2000 has been updated to 1981 – 2010.

Figure 6: Verification of UK Contingency Planners Forecasts during the hindcast period for precipitation, compared to NCIC observations.

3.5.5. Verification of forecasts sent out during winter 2014/2015, based on UK Contingency Planners forecasts downscaled to Devon

Some initial assessment of the forecasts has also been performed, based on the forecasts which were sent out during winter 2014/2015, and comparing them to NCIC climate observations. The figures below show the results in two different ways:

a) Only using the most likely forecast category - as the forecast outcome (Fig 7)

b) Using all forecast categories with elevated probabilities - as the forecast outcome (Fig 8).

The bar charts show the actual forecast probabilities for each period in question, for temperature (left) and precipitation (right). The horizontal lines on the graphs show the average, or normal probability (i.e. 20% for quintiles, 33% for terciles). The most likely forecast category(ies) are highlighted with a thick black outline, and the observed category is shaded with hatching.

So far, the results show that using only the most likely forecast category, the forecast was "right" for 3 out of the 6 forecasts for temperature, but not at all for precipitation (Fig 7)., while using all forecast categories with elevated probabilities, the forecast was "right" for 4 out of 6 forecasts for temperature, and 2 out of 6 forecasts for precipitation (Fig 8). Anecdotal discussion with the farmers in our interviews and workshops suggests that while the forecast skill for temperature may be acceptable (a confidence level of around 60-70% was noted as being usable), the skill level for precipitation may be too low to make the forecasts usable at present.

Although this only provides verification for forecast produced during one season, it indicates that as shown at the UK scale, the forecasts have better skill for winter temperature than precipitation, and appear to have had a tendency towards a wet bias during this period, over-predicting the likelihood of wetter than normal conditions.

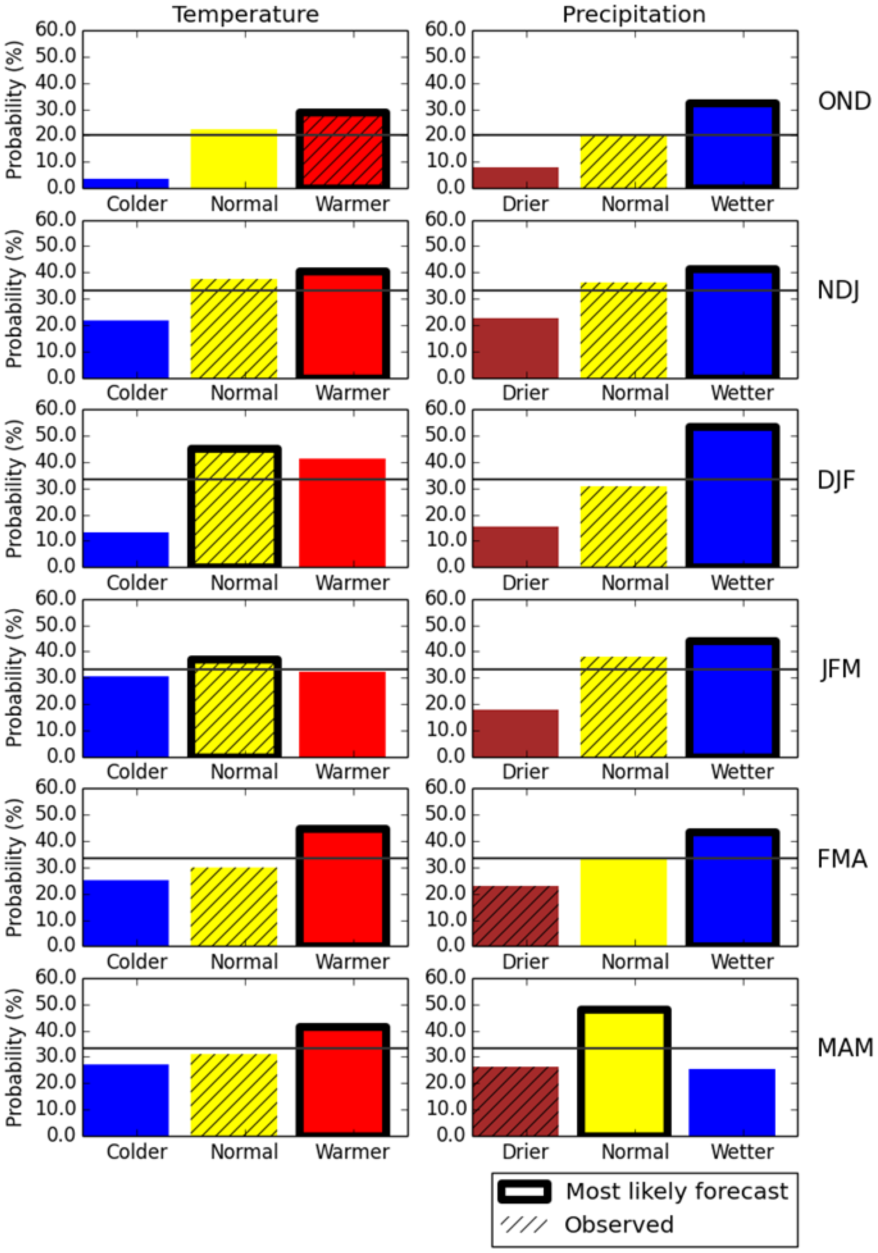

Figure 7: Verification of forecasts sent out during winter 2014/2015, based on UK Contingency Planners forecasts downscaled to Devon, only using the most likely forecast category as the forecast outcome. The bar charts show the actual forecast probabilities for each period in question, for temperature (left) and precipitation (right). The horizontal lines on the graphs show the average, or normal probability (i.e. 20% for quintiles, 33% for terciles). The most likely forecast category(ies) are highlighted with a thick black outline, and the observed category is shaded with hatching.

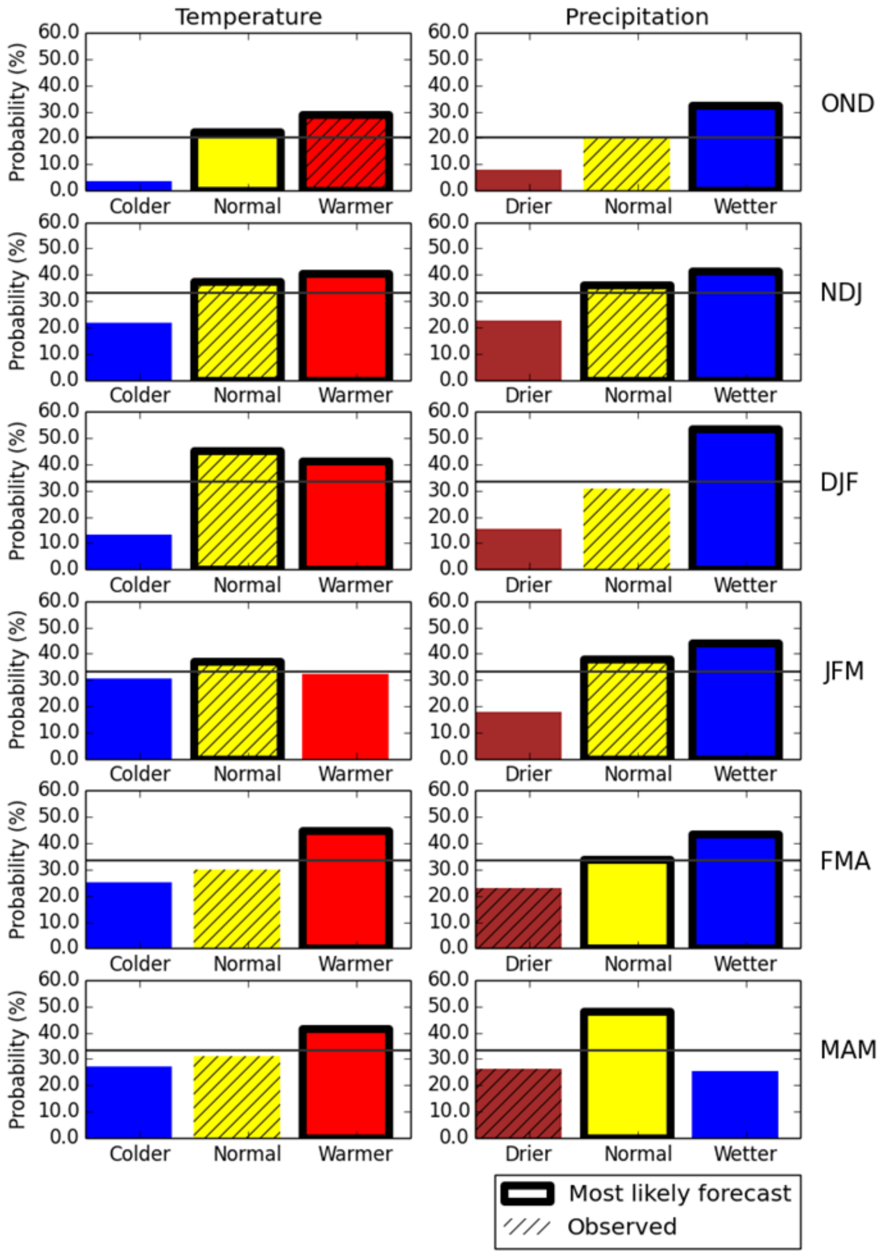

Figure 8: Verification of forecasts sent out during winter 2014/2015, based on UK Contingency Planners forecasts downscaled to Devon, using all forecast categories with elevated probabilities as the forecast outcome. The bar charts show the actual forecast probabilities for each period in question, for temperature (left) and precipitation (right). The horizontal lines on the graphs show the average, or normal probability (i.e. 20% for quintiles, 33% for terciles). The most likely forecast category(ies) are highlighted with a thick black outline, and the observed category is shaded with hatching.

3.5.6. Assessment of NAO vs impact metrics at county scale, using NCIC climate data and Glosea5 hindcasts

County-scale scatter plots and correlations have been produced of the NCIC precipitation variables against both observed NAO for a range of seasons/. As noted earlier, since Glosea5, the model behind the CPF forecasts used in this prototype, has skill in predicting the UK winter NAO, these correlations indicate the potential skill of it forecasting system. The GloSea5 data come from the Glosea5 research hindcast set. Our stakeholder engagement activities (feedback forms, interviews and surveys) indicated interest from land managers in a range of precipitation related metrics such as wet spells, dry spells and heavy rainfall events, and in forecasts produced at finer spatial resolution. Investigating correlations between the NAO and weather metrics in the model and observations should therefore provide insights into the expected skill of the forecasts for such metrics. The aim of this study was therefore to see whether there would be value in providing winter seasonal forecasts of more specific metrics at county scale.

Figures 9-11 are for NCIC observed weather variables plotted against Glosea5 NAO, and are plotted for DJF only (there are more years and forecast ensemble members for available for DJF), for 1992-2011. Figures 12-14 are for NCIC observed weather variables plotted against NCIC observed NAO, for three historic periods (1996-2009; 1992-2011; 1910-2014 or 1961-2014). Note that while the records of monthly mean rainfall go back to 1910, the counts of daily values only go back to 1961, hence figure 12 uses the period 1910-2014 while 1961-2014 is used for figures 13 and 14. While the regressions and plots were created for rolling three month periods, Figures 12-14 only show examples for DJF. The full results from both sets of plots are summarized in Table 2. 1996-2009 and 1992-2011 are seasonal hindcast periods, while the NCIC data cover 1910-2014 (or 1961-2014). Note that HadObs data were used for the extended period back to 1910.

Initial analysis suggests that the relationships shown between NAO and impact variables are not obvious. Initial findings for wet days and heavy rain do not show great skill at the county scale. So, at least at the scale of South West UK and counties (or even more specific regions), the three month outlooks are not particularly reliable for these rainfall-based metrics – and may not yet contain enough information on rainfall related variables to be beneficial to land managers.

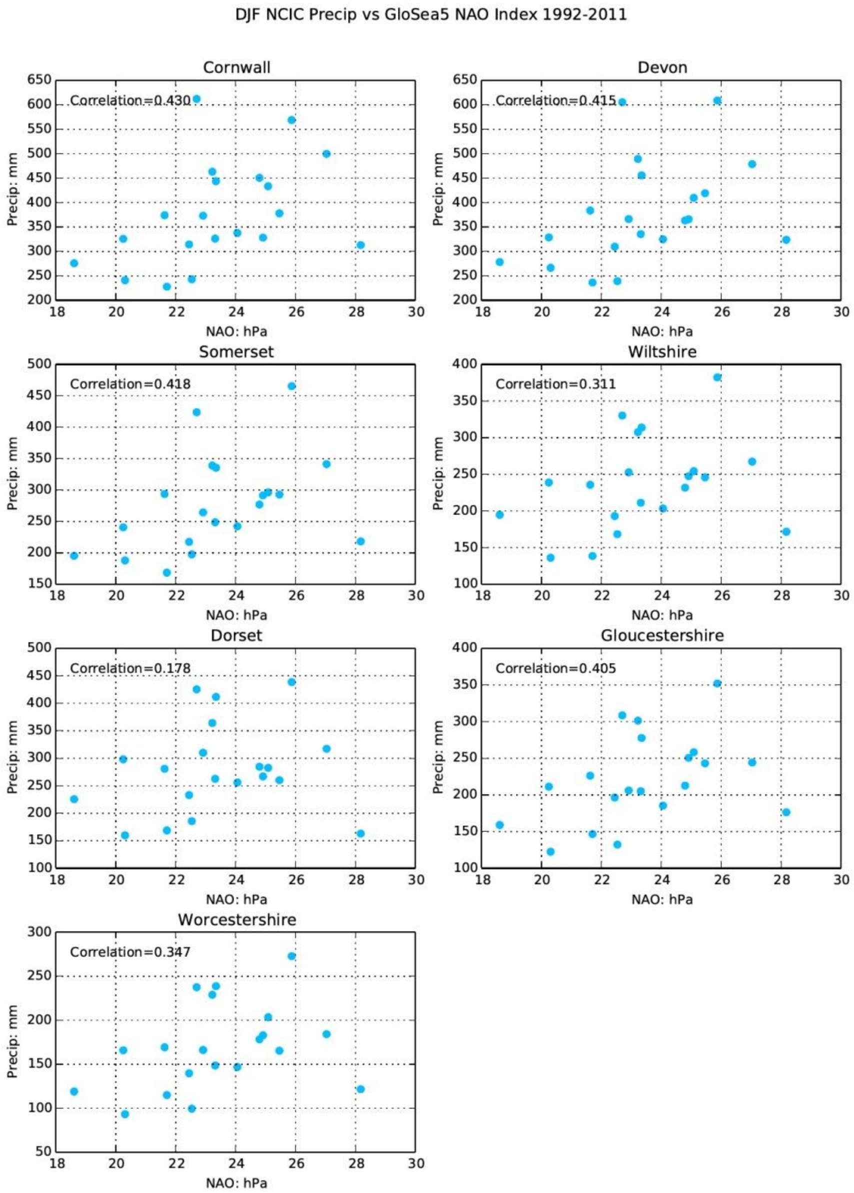

Figure 9: Scatter plot of NCIC (observed) NAO vs Glosea5 precipitation for counties in South West UK, for the DJF period 1992-2011.

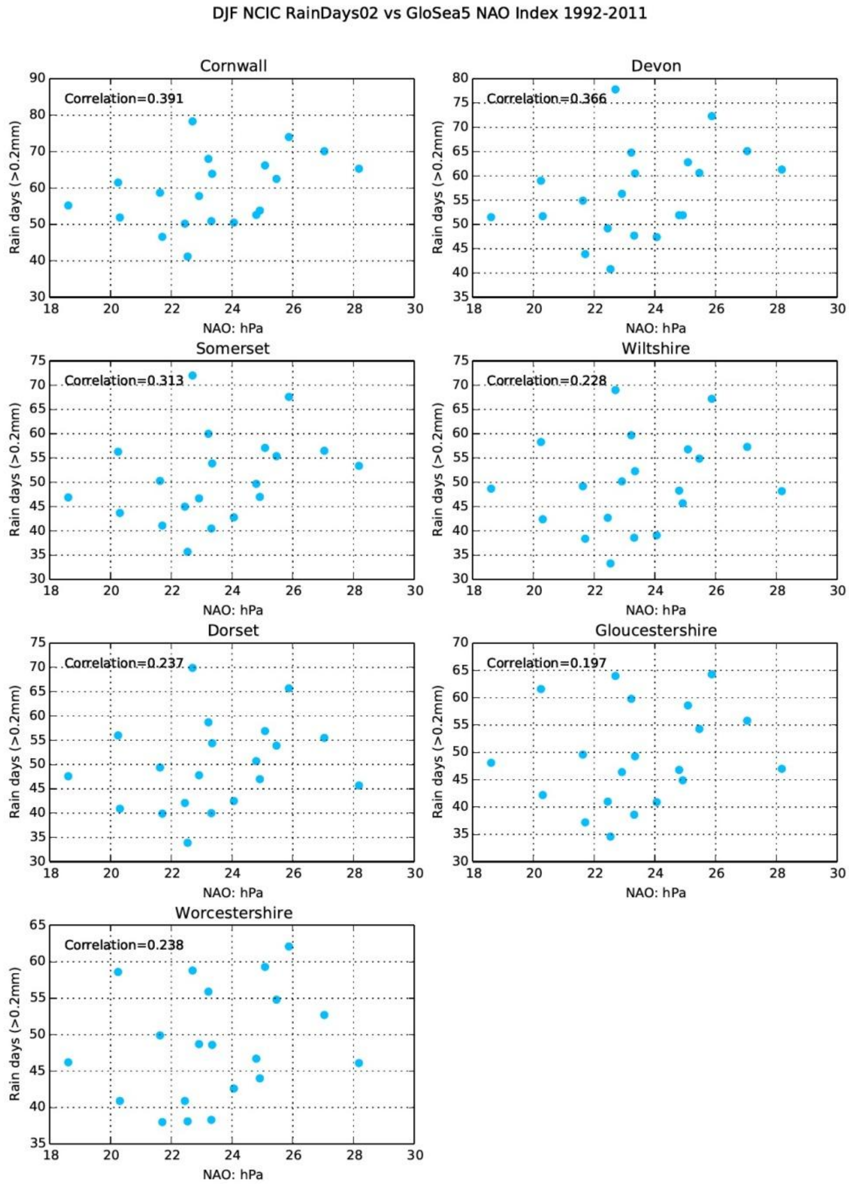

Figure 10: scatter plot of NCIC (observed) NAO vs Glosea5 rain days >0.2mm for counties in South West UK, for the DJF period 1992-2011.

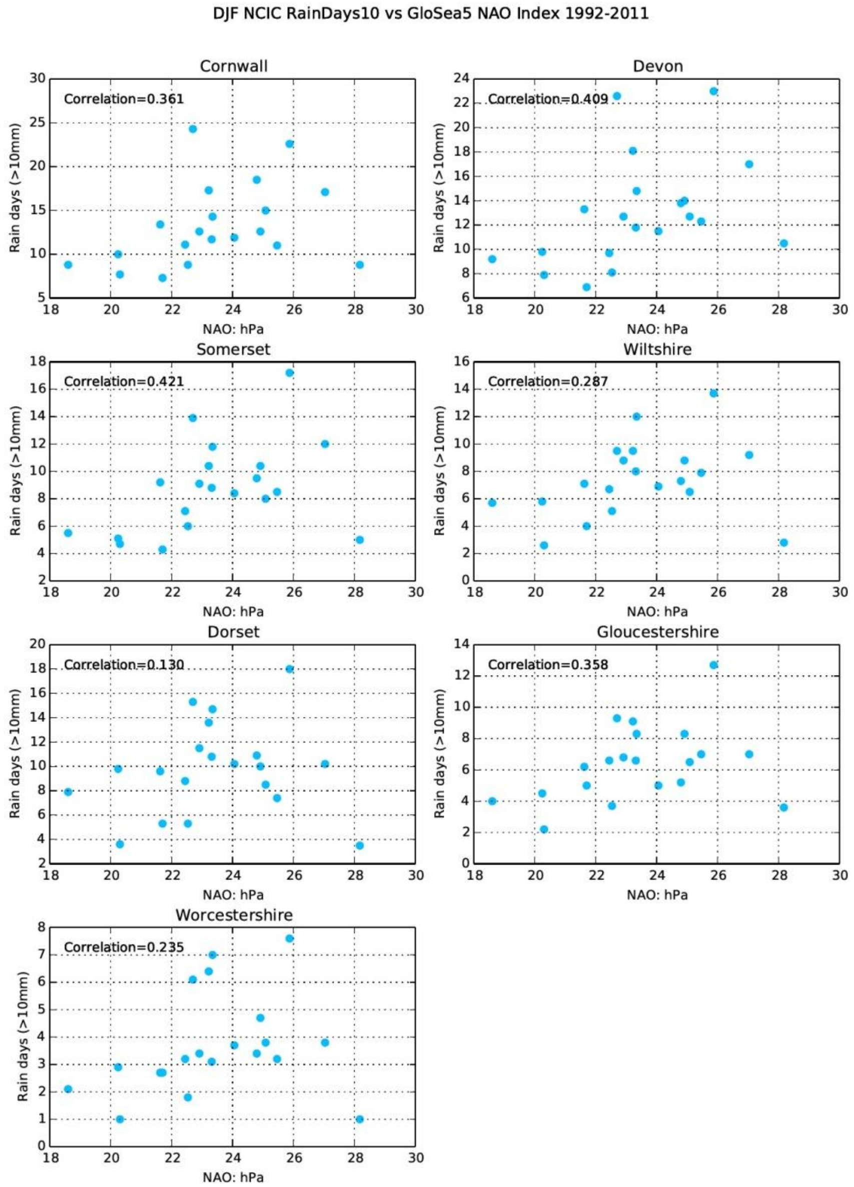

Figure 11: scatter plot of NCIC (observed) NAO vs Glosea5 rain days >10mm for counties in South West UK, for the DJF period 1992-2011.

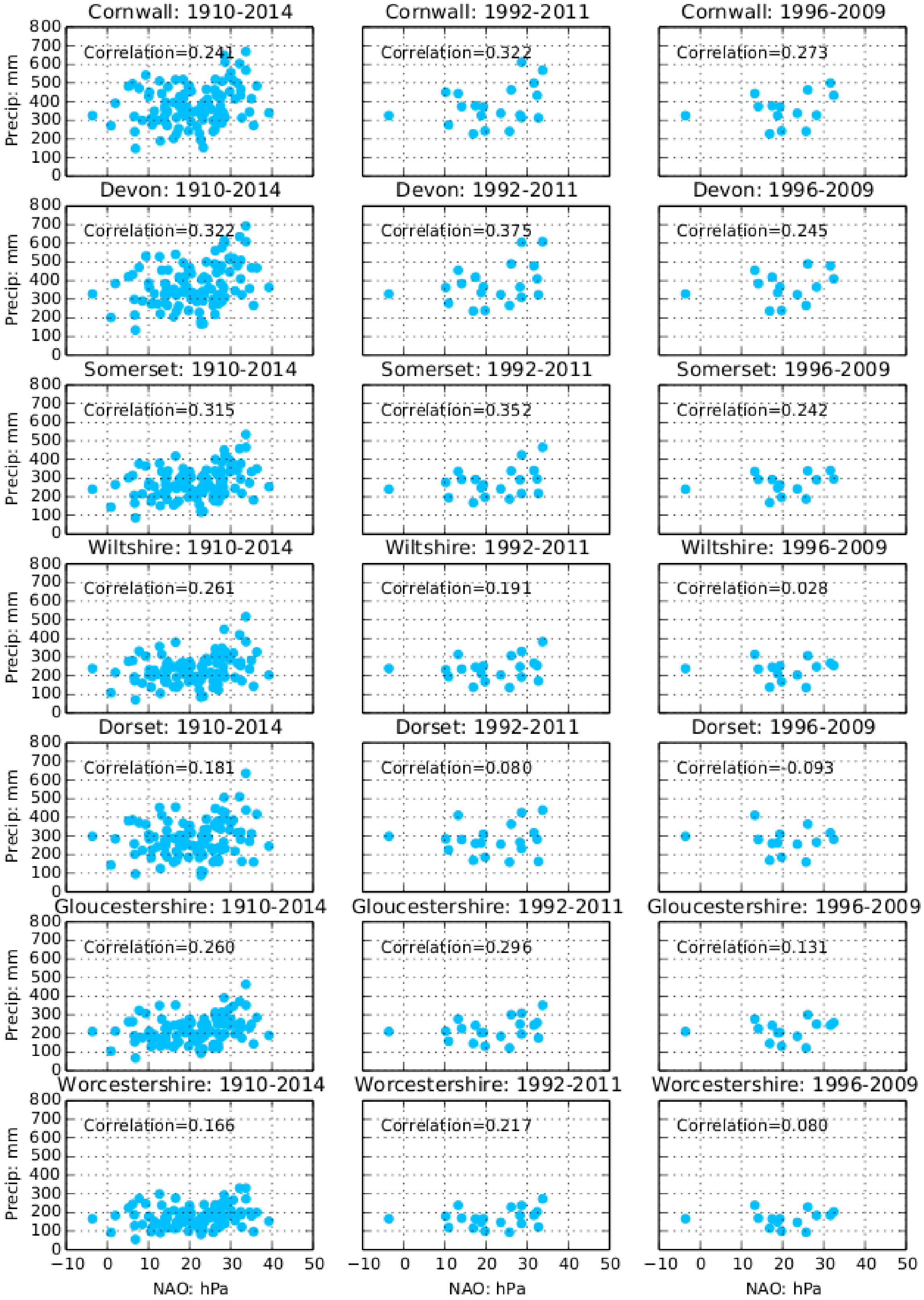

Figure 12: scatter plot of NCIC (observed) NAO vs NCIC (observed) precipitation for counties in South West UK, for the DJF period (1996-2009, 1992-2011 and 1910-2014)

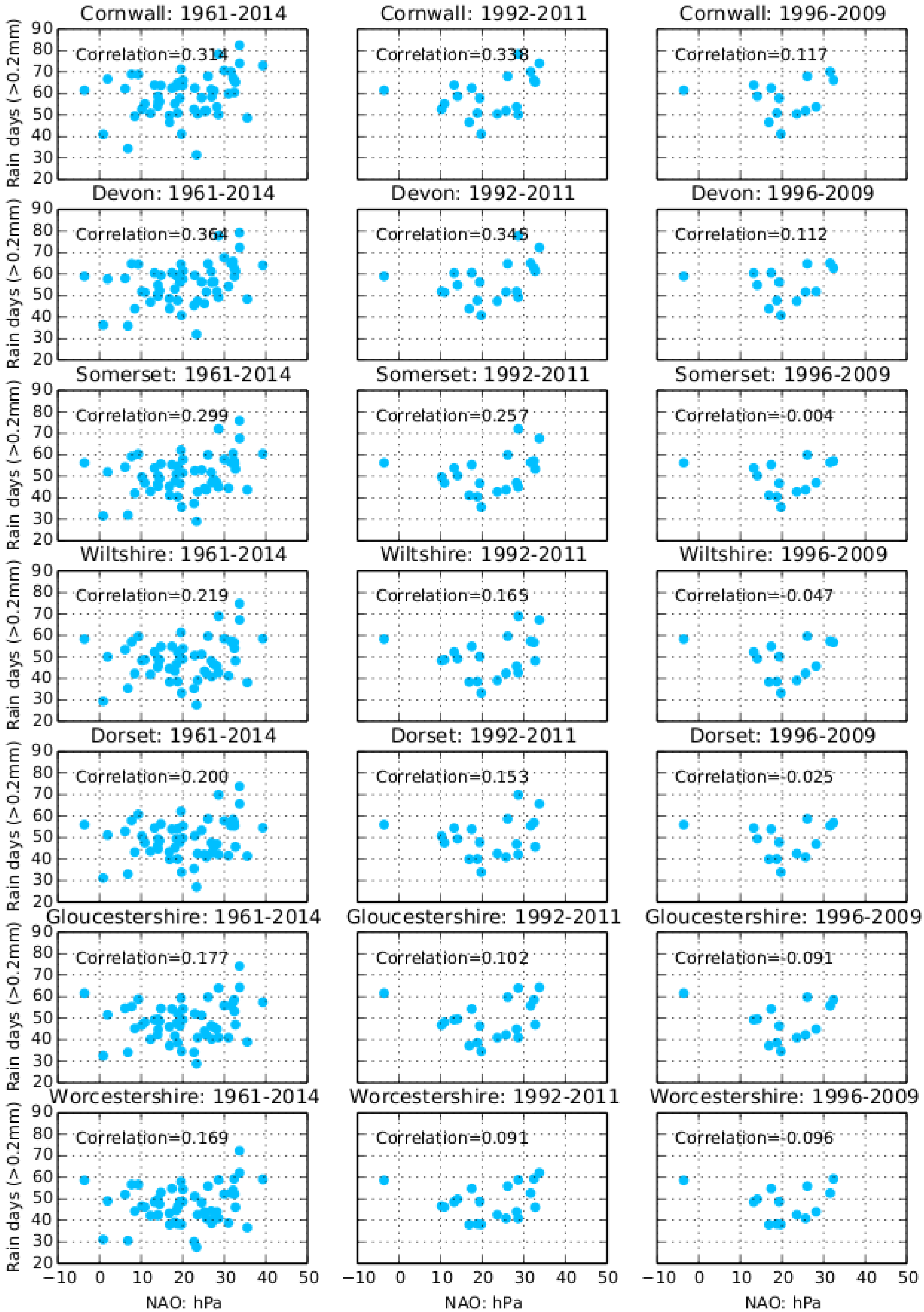

Figure 13: scatter plot of NCIC (observed) NAO vs NCIC (observed) rain days >0.2mm for counties in South West UK, for the DJF period (1996-2009, 1992-2011 and 1961-2014)

	Total Precipitation	Rain days >0.2mm	Rain days >10mm
Cornwall	0.43	0.391	0.361
Devon	0.415	0.366	0.409
Somerset	0.418	0.313	0.421
Wiltshire	0.311	0.228	0.287
Dorset	0.178	0.237	0.13
Gloucestershire	0.405	0.197	0.358
Worcestershire	0.347	0.238	0.235

Table 2: summary of correlations between observed (NCIC) precipitation metrics and Glosea5 NAO for the DJF period (all years across 1992-2011), for counties in South West UK.

	Total precipitation		
	Cornwall		
	1910-2014	1992-2011	1996-2009
SON	0.281	-0.025	0.035
OND	0.268	0.134	0.176
NDJ	0.187	0.116	-0.174
DJF	0.241	0.322	0.273
JFM	0.116	0.177	-0.01
FMA	0.14	0.138	0.161
	Devon		
	1910-2014	1992-2011	1996-2009
SON	0.296	0.052	0.145
OND	0.286	0.144	-0.156
NDJ	0.253	0.268	-0.102
DJF	0.322	0.375	0.245
JFM	0.209	0.262	0.171
FMA	0.2	0.09	0.17
	Somerset		
	1910-2014	1992-2011	1996-2009
SON	0.255	0.009	0.162
OND	0.25	0.082	-0.176
NDJ	0.215	0.225	-0.066
DJF	0.315	0.352	0.242
JFM	0.234	0.277	0.145
FMA	0.207	-0.07	0.033
	Wiltshire		
	1910-2014	1992-2011	1996-2009
SON	0.191	-0.186	-0.084
OND	0.209	-0.018	-0.259
NDJ	0.158	0.11	-0.101
DJF	0.261	0.191	0.028
JFM	0.181	0.209	0.175
FMA	0.172	-0.102	-0.033
	Dorset		
	1910-2014	1992-2011	1996-2009
SON	0.145	-0.318	-0.16
OND	0.157	-0.122	-0.346
NDJ	0.123	-0.006	-0.208
DJF	0.181	0.08	-0.093
JFM	0.082	0.141	0.005
FMA	0.131	-0.056	0.014
	Gloucestershire		
	1910-2014	1992-2011	1996-2009
SON	0.254	0.012	0.169
OND	0.239	0.031	-0.207
NDJ	0.203	0.261	-0.014
DJF	0.26	0.296	0.131
JFM	0.186	0.276	0.277
FMA	0.165	-0.096	0.002
	Worcestershire		
	1910-2014	1992-2011	1996-2009
SON	0.163	0.071	0.26
OND	0.208	0.089	-0.092
NDJ	0.134	0.202	-0.062
DJF	0.166	0.217	0.08
JFM	0.046	0.235	0.193
FMA	0.044	-0.145	-0.144

	Rain days >0.2mm		
	Cornwall		
	1910-2014	1992-2011	1996-2009
SON	0.304	0.339	0.302
OND	0.363	0.256	-0.086
NDJ	0.363	0.414	0.049
DJF	0.314	0.338	0.117
JFM	0.263	0.278	0.26
FMA	0.09	0.103	-0.133
	Devon		
	1910-2014	1992-2011	1996-2009
SON	0.312	0.36	0.345
OND	0.355	0.277	-0.096
NDJ	0.399	0.414	0.01
DJF	0.364	0.346	0.112
JFM	0.315	0.32	0.207
FMA	0.149	0.142	-0.14
	Somerset		
	1910-2014	1992-2011	1996-2009
SON	0.267	0.289	0.289
OND	0.324	0.213	-0.12
NDJ	0.368	0.371	-0.021
DJF	0.299	0.257	-0.004
JFM	0.242	0.271	0.168
FMA	0.103	0.072	-0.122
	Wiltshire		
	1910-2014	1992-2011	1996-2009
SON	0.25	0.234	0.229
OND	0.267	0.088	-0.186
NDJ	0.298	0.294	-0.029
DJF	0.219	0.257	-0.004
JFM	0.16	0.206	0.197
FMA	0.019	-0.038	-0.201
	Dorset		
	1910-2014	1992-2011	1996-2009
SON	0.268	0.184	0.22
OND	0.297	0.099	-0.173
NDJ	0.264	0.238	-0.098
DJF	0.2	0.153	-0.025
JFM	0.16	0.209	0.164
FMA	0.075	0.044	-0.128
	Gloucestershire		
	1910-2014	1992-2011	1996-2009
SON	0.207	0.255	0.311
OND	0.213	0.065	-0.188
NDJ	0.257	0.251	-0.015
DJF	0.177	0.102	-0.091
JFM	0.124	0.13	0.126
FMA	0.008	-0.048	-0.249
	Worcestershire		
	1910-2014	1992-2011	1996-2009
SON	0.175	0.24	0.371
OND	0.218	0.008	0.209
NDJ	0.194	0.128	-0.11
DJF	0.169	0.091	-0.096
JFM	0.076	0.108	0.111
FMA	-0.037	-0.1	-0.326

	Rain days >10mm		
	Cornwall		
	1910-2014	1992-2011	1996-2009
SON	0.07	-0.122	-0.019
OND	0.224	0.126	-0.143
NDJ	0.167	0.072	-0.187
DJF	0.234	0.331	0.402
JFM	0.205	0.142	-0.111
FMA	0.222	0.182	0.305
	Devon		
	1910-2014	1992-2011	1996-2009
SON	0.127	-0.02	0.112
OND	0.229	0.128	-0.153
NDJ	0.221	0.208	-0.083
DJF	0.274	0.398	0.348
JFM	0.206	0.235	0.084
FMA	0.205	0.094	0.186
	Somerset		
	1910-2014	1992-2011	1996-2009
SON	0.061	-0.045	0.222
OND	0.158	0.027	-0.182
NDJ	0.142	0.133	-0.104
DJF	0.263	0.376	0.359
JFM	0.271	0.321	-0.066
FMA	0.249	0.026	0.054
	Wiltshire		
	1910-2014	1992-2011	1996-2009
SON	-0.041	-0.269	-0.08
OND	0.072	-0.069	-0.232
NDJ	0.134	0.035	-0.127
DJF	0.185	0.156	0.076
JFM	0.316	0.267	0.184
FMA	0.275	-0.014	0.059
	Dorset		
	1910-2014	1992-2011	1996-2009
SON	-0.039	-0.414	-0.24
OND	0.043	-0.2	0.355
NDJ	0.062	-0.043	-0.189
DJF	0.133	0.067	0.086
JFM	0.185	0.19	-0.042
FMA	0.269	0.057	0.013
	Gloucestershire		
	1910-2014	1992-2011	1996-2009
SON	0.016	-0.045	0.282
OND	0.099	0.035	-0.121
NDJ	0.208	0.264	-0.065
DJF	0.184	0.363	0.213
JFM	0.272	0.404	0.4
FMA	0.248	0.058	0.174
	Worcestershire		
	1910-2014	1992-2011	1996-2009
SON	-0.068	-0.022	0.167
OND	0.031	0.056	0.022
NDJ	0.111	0.17	-0.086
DJF	0.089	0.22	0.107
JFM	0.152	0.326	0.273
FMA	0.069	-0.043	-0.06

Table 3: summary of correlations between observed (NCIC) precipitation metrics and NAO for counties in South West UK, using different averaging periods, and for rolling three month winter periods.

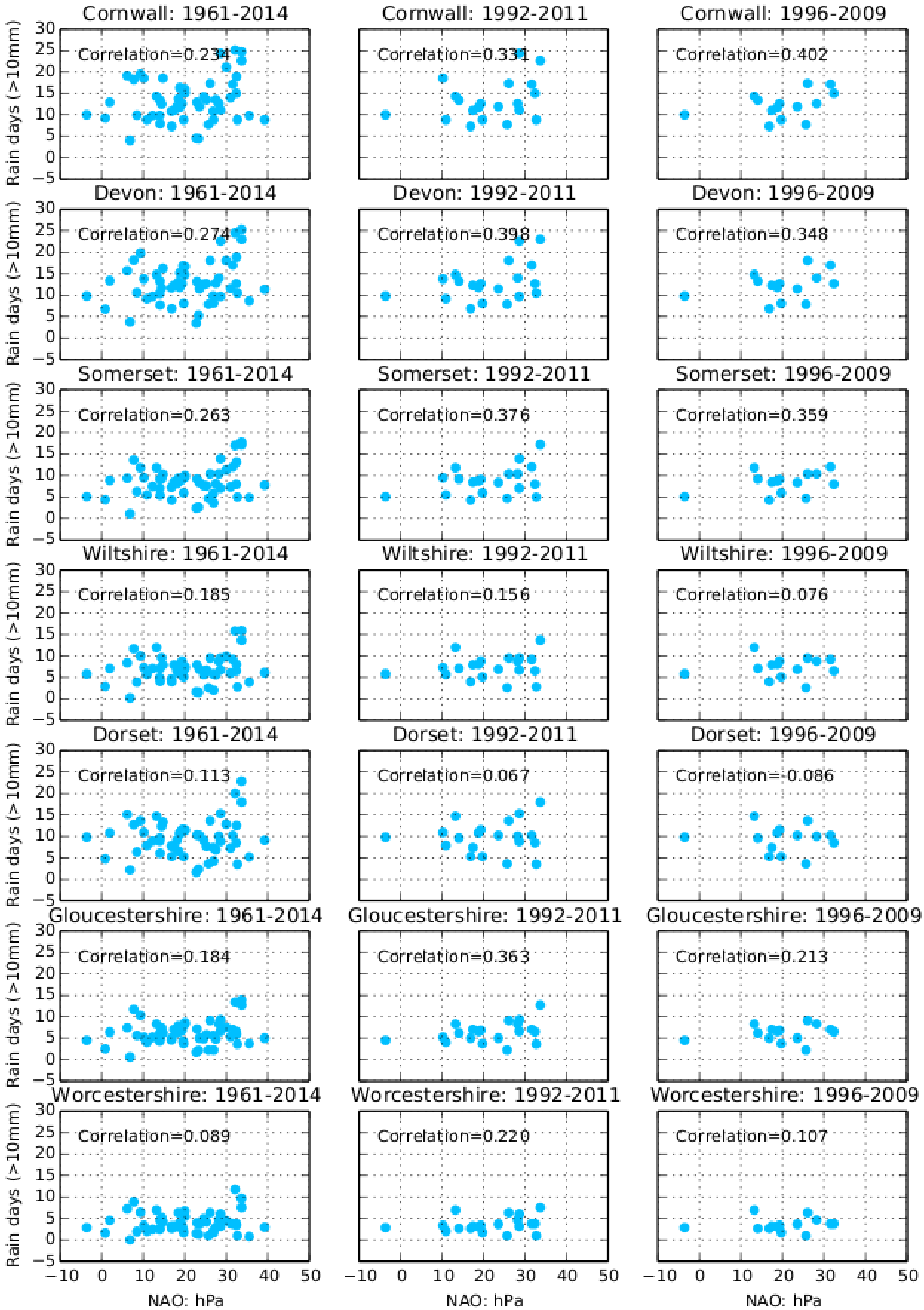

Figure 14: scatter plot of NCIC (observed) NAO vs NCIC (observed) rain days >10mm for counties in South West UK, for the DJF period (1996-2009, 1992-2011 and 1910-2014)

3.5.7. Maps of correlations between NCIC observed precipitation and NCIC observed NAO (or Glosea5 model NAO), for two baseline periods over the South West UK

Finally, building on these findings, we investigated whether there was any localised skill in the Glosea5 seasonal forecasting system for winter precipitation in the South West UK. Similar to the previous studies, we plotted maps of correlations between observed (NCIC) precipitation during DJF, and either Glosea5 or observed (NCIC) NAO for two baseline periods, 1996-2009 and 1992-2011 (Figure 15). As discussed previously, strong links between the NAO and precipitation would indicate the potential for good skill in our seasonal forecasts since the main skill of Glosea5 is in its ability to predict the UK winter NAO. The key plot is the top right panel in Figure 15, plotting the correlation between observed NAO and observed precipitation, which does show some areas of reasonable correlation across the region, and interestingly the results vary with baseline period. In addition, for the 1996-2009 baseline period, the strongest correlation was found between Glosea5 NAO and observed precipitation for DJF (bottom left panel). This provides useful information for the prototype in that it indicates areas in our study region where precipitation forecasts may be provided and applied with more confidence.

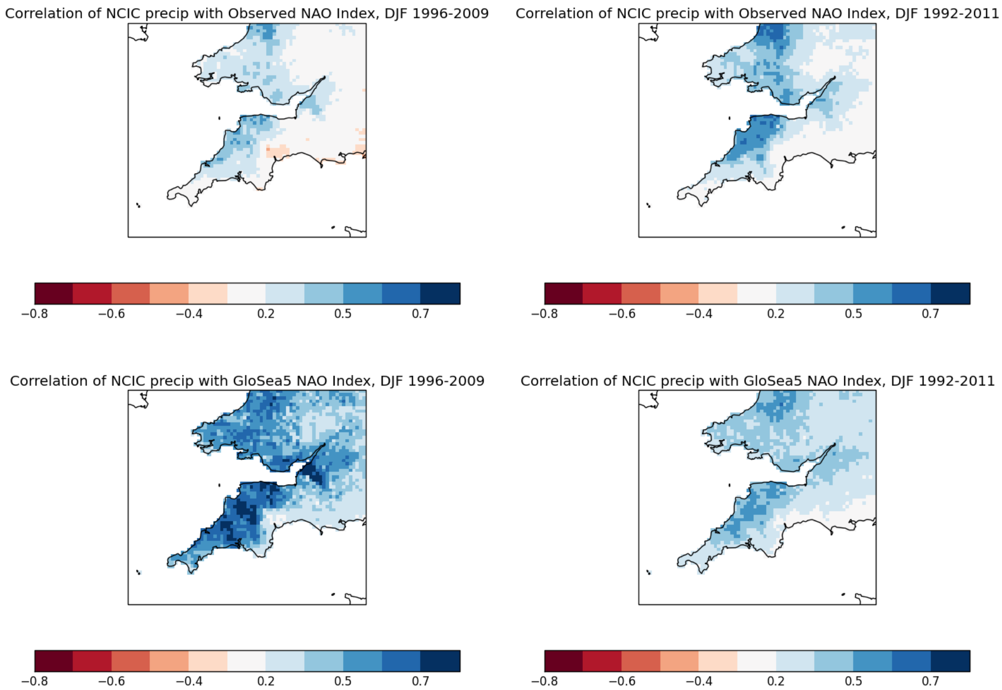

Figure 15: Maps of correlations between NCIC DJF observed precipitation and NCIC observed NAO (or Glosea5 model NAO), for two baseline periods (1996-2009;1992-2011) over the South West UK.

3.5.8. References

Scaife, A. A., Arribas, A., Blockley, E., Brookshaw, A., Clark, R. T., Dunstone, N., Eade, R., Fereday, D., Folland, C. K., Gordon, M., Hermanson, L., Knight, J.R., Lea, D. J., MacLachlan, C., Maidens, A., Martin, M., Peterson, A. K., Smith, D., Vellinga, M., Wallace, E., Waters, J., and Williams, A. (2014) Skillful long-range prediction of European and North American winters. Geophysical Research Letters, 41, 2514–2519.

3.6. Hydropower prototype (SMHI)

Hindcasts of the spring floods at 26 gauging stations in the Ångerman River have been made for the period 1981-2014. These hindcasts are initialised on the first of each month prior to the spring melt period, a total of five initialisations per year. One spring flood was highlighted as of extra interest. The spring flood of 1995 was the third largest of the hindcast period and the operational forecast system at SMHI failed to predict it. The operational forecast was for a below normal to near normal springflood. While no definite reason for this error has been found it is hypothesised that the system is unable to accurately represent snowpack conditions during winters with anomalous NAO activity. Although the multi-model hindcast also underestimated this event it did show a much improved signal over the operational system (figure 1). This result together with others, where an improved signal was demonstrated by the multi-model, have shown potential added value for operators to make more proactive decisions based on the seasonal forecast.

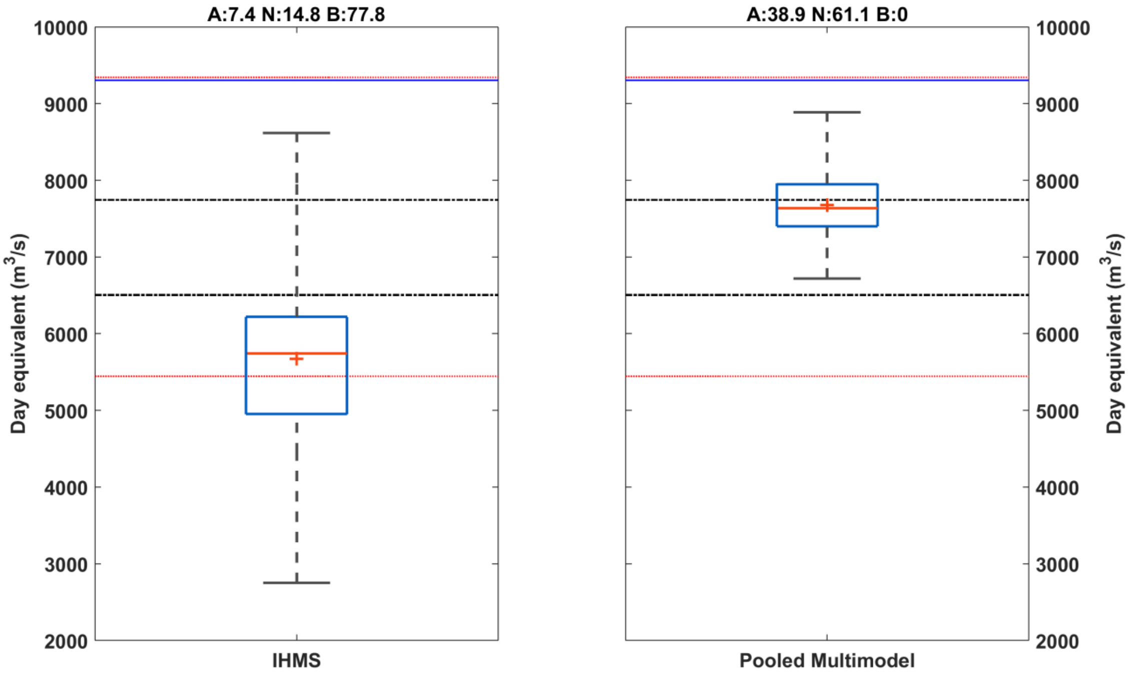

Figure 1. Boxplots of the 1995 spring flood. The red and black horizontal lines represent the 10th/90th and 33rd/75th percentiles of the observed climatology respectively. The blue line represents the observed spring flood volume for 1995. The box and feelers represent the 0, 25th, 75th and 100th percentiles for the ensembles. The percentages of the ensemble members that fall into the three different terciles are shown above the plots; A = above normal or upper tercile, N = near normal of middle tercile, and B = below normal or lower tercile.

Analysis of the hindcasts show that the multi-model was able to reduce hindcasted volume errors over all the gauging stations, initialisations and years by nearly 5%on average (figure 2); improvements of as much as 52% were attainable for individual stations and hindcast initialisations. These improvements translate into the multi-model outperforming the operational model in 64% of the hindcasts made i.e. the ensemble mean is closer to the observed volume than that of the operational model. The most promising improvement that the multi-model has shown is in the skill to predict anomalies. ROC skill scores suggest that the multi-model has improved skill in the upper and lower terciles (figure 3) when compared to the operational system. However, the operational system shows better skill in the near normal tercile, partly due to the climatological nature of the system.

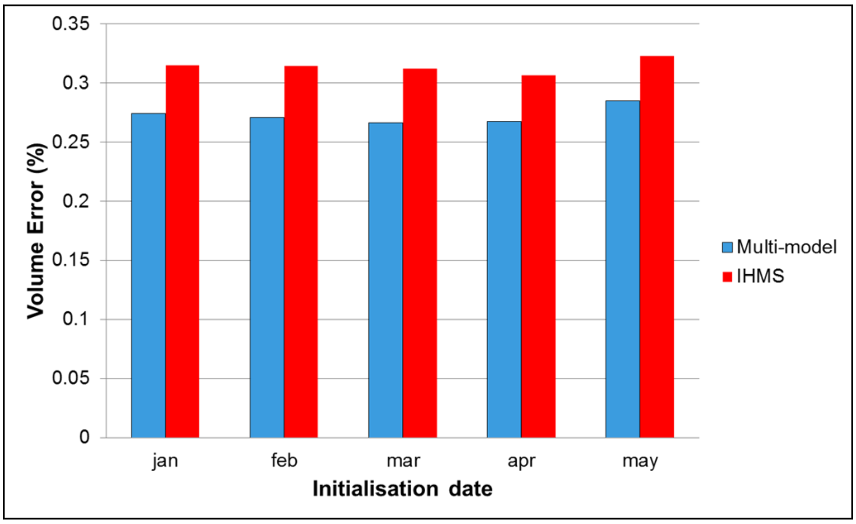

Figure 2. A comparison of the volume error in the hindcasts, as a percentage of observed volumes, made by the multi-model (blue) and the operational system (red). The explanation for the larger volume errors in May is that during some years the spring flood onset is earlier than the 1st May and as such some of the volume missed.

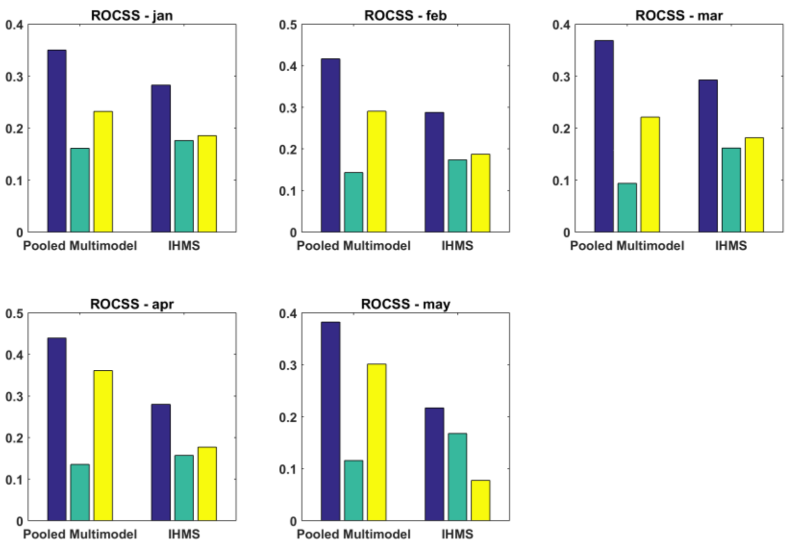

Figure 3. Tercile ROC skill scores for the Multi-model and the operational forecast system. The scores for the lower tercile are in blue, the near normal tercile in green and the upper tercile in yellow.

3.6.1. References

Olsson, J., Uvo, C. B., Foster, K., and Yang, W.: Initial assessment of a multi-model approach to spring flood forecasting in Sweden, Hydrol. Earth Syst. Sci. Discuss., 12, 6077-6113, doi:10.5194/hessd-12-6077-2015, 2015.

3.6.2. Planned future publications

We have not finalised which parts of this work will be published in peer reviewed journals. We hope to publish two, one on the statistical seasonal model chains and either one on the visualisation of the forecasts or one on the sources of predictability in the prototype.

A report on the application of this prototype in the seven largest hydropower river systems will be published by the stakeholder, Energyforsk.

3.7. Water management in Spain case study (AEMET and CETaqua)

A multidisciplinary team that includes water managers, regulators, meteorologists and researchers is working to test the usage of seasonal forecasts to improve the water reservoirs management in Spain. A seasonal forecasting system of dam inflows has been developed based on empirical methods by AEMET. These forecasts are being introduced in existing modelling tools and management structure by CETaqua.

Water managers are providing the users requirements, have proposed appropriate water reservoirs to test this new tool for decision-making, and are actively participating in the assessment. In particular, four past events have been selected over the Cuerda del Pozo reservoir, located in the Duero river basin.

Cuerda del Pozo reservoir is widely used for water supply, irrigation, flood control, electricity generation and recreation. All these uses are affected by the inflow variability. Empirical forecasts of the winter dam inflow present significant skill associated to the predictability of the North Atlantic Oscillation (NAO) that strongly influences the precipitation variability pattern in this region. The reservoir management can be improved by making use of skilful inflow forecasts.

3.7.1. Key events description (AEMET)

Four key events have been selected based on the historical reservoir inflows, taking into account the time evolution of the reservoir level and the winter reservoir inflow. On each of the key events the seasonal forecasting system developed, based on the Snow Advance Index in Eurasia in October as source of predictability of the winter NAO, has been run to draw the seasonal inflow forecast for the corresponding winter.

The selected key events are:

DJF (1976-77). Wet winter

- SAI (October): 10876860 (very high) -> Forecasted NAO (DJF): Quite negative -> Forecasted inflow (DJF): quite high

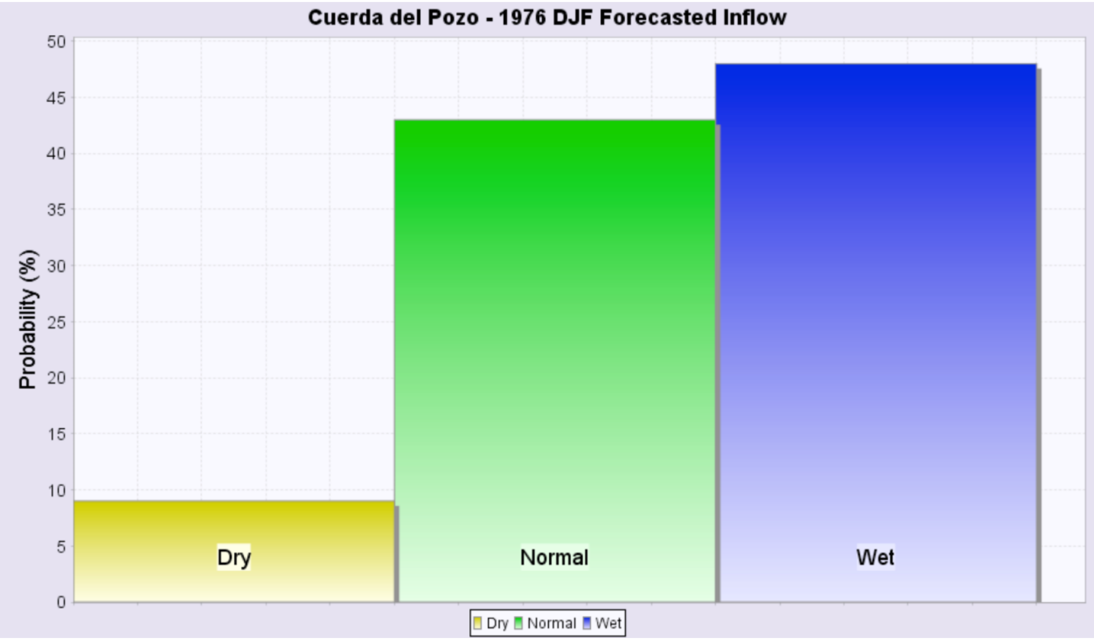

Figure 1. DJF (1976-77)

- Observed inflow in DJF: 178.024 Hm3 -> Wet

- The forecasts indicate that the likelihood of being a dry winter was very low and that of being a normal or wet year was quite high. Actually, the winter was wet.

DJF (1980-81). Dry winter

- SAI (October): 3226560 (low) -> Forecasted NAO (DJF): positive -> Forecasted inflow (DJF): low

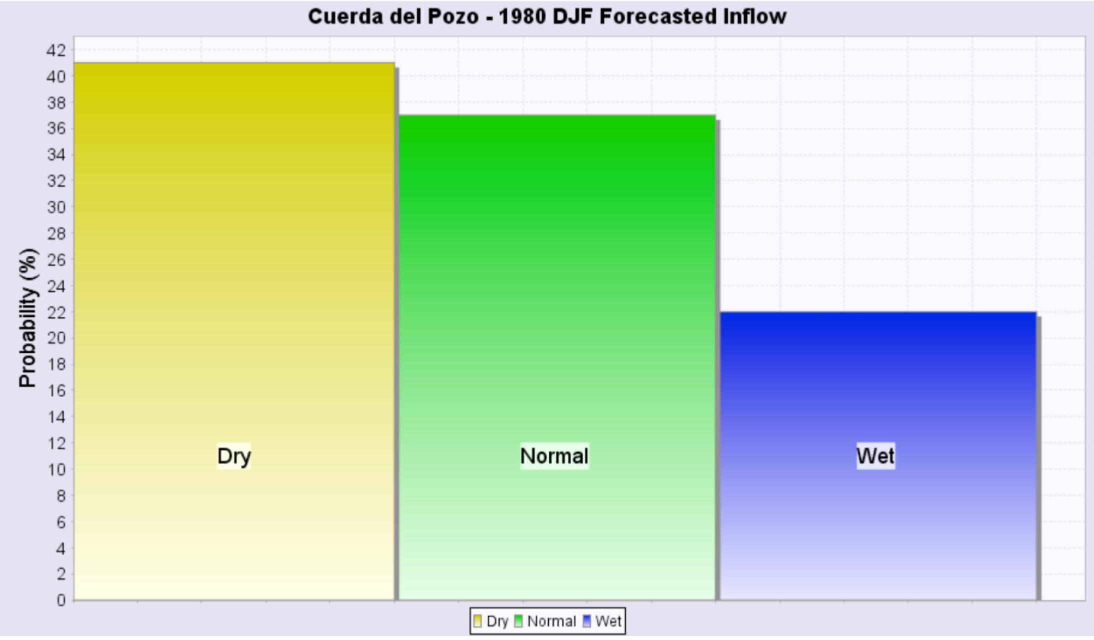

Figure 2. DJF (1980-81)

- Observed inflow in DJF: 19.146 Hm3 -> Quite dry
- The forecasts indicate that the likelihood of being a wet winter was low and that of being a normal or dry year was quite high. Actually, the winter was quite dry.

DJF (2007-08). Dry winter

- SAI (October): 3441930 (low) -> Forecasted NAO (DJF): positive -> Forecasted inflow (DJF): low

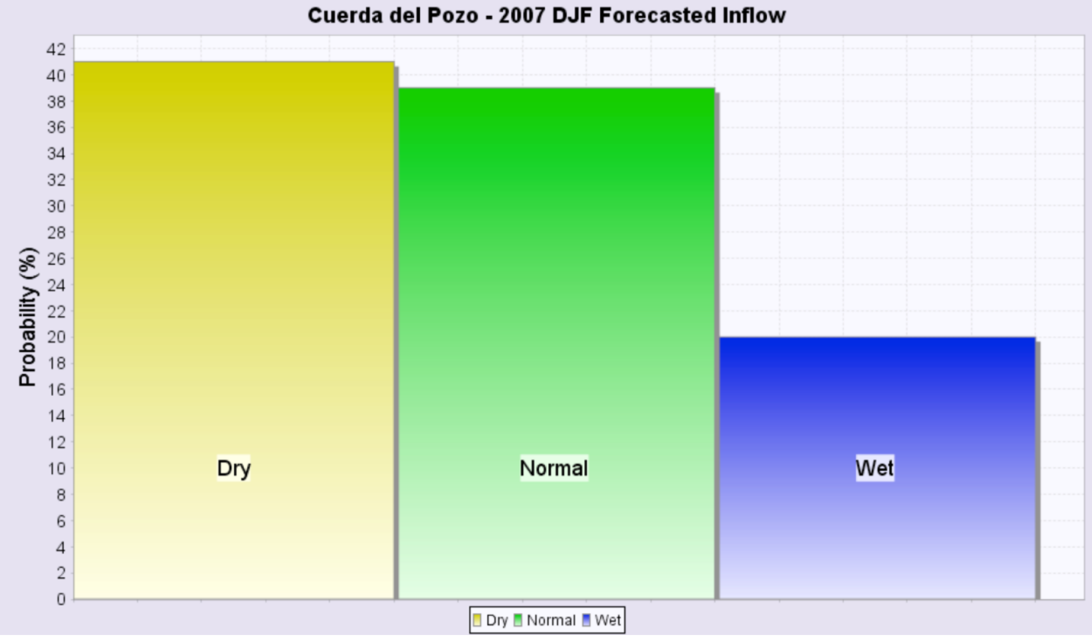

Figure 3. DJF (2007-08)

- Observed inflow in DJF: 12.226 Hm3 -> Very dry
- The forecasts (quite similar to that of the 1980-81 winter) indicate that the likelihood of being a wet winter was low and that of being a normal or dry year was quite high. Actually, the winter was very dry.

DJF (2009-10). Wet winter

- SAI (October): 7983000 (high) -> Forecasted NAO (DJF): negative -> Forecasted inflow (DJF): high

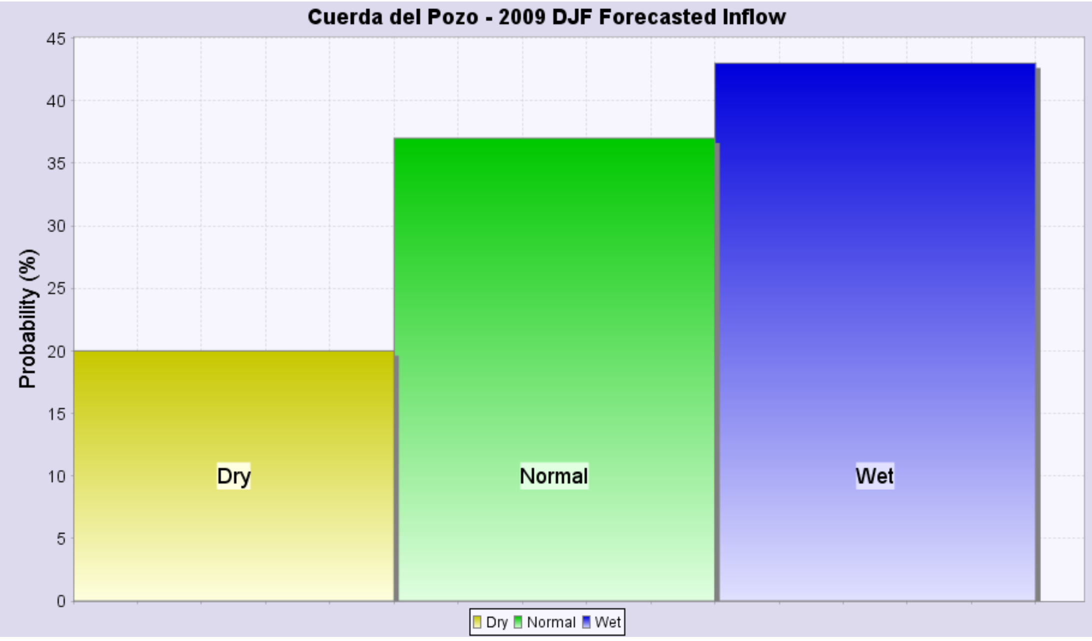

Figure 4. DJF (2009-10)

- Observed inflow in DJF: 151.533 Hm3 -> Wet

- The forecasts indicate that the likelihood of being a dry winter was low and that of being a normal or wet year was quite high. Actually, the winter was wet.

The possible changes in the reservoir management are going to be discussed by all the partners at the next “Use of Seasonal Forecasts to Improve the Reservoirs Management” workshop to be held in Madrid in October 2015.

3.7.2. Implications in the DMP (CETaqua)

Key events in the past where the prototype could have been particularly useful:

As described above, four events were selected, corresponding to high and low inflows to the dam in the winter period. The table below shows the seasonal forecasts used for the selected year, as well as the observed inflow for the same period and the dam reserved (Hm3) on the 1st of December. The years of the event refer to the hydrological years (“winter 1976” means December 1976, as well as January and February 1977).

Year	Inflow				Dam reserve
	Seasonal Forecast (Dic-Jan-Feb)			Observed DJF	Observed
	% BN (Dry)	% NN	% AN (Wet)	Category	1st December
1976	9	43	48	AN	71
1980	41	37	22	BN	105
2007	41	39	20	BN	132
2009	20	37	43	AN	147

LEGEND

Inflow - Observation

Tercile limits calculated using 1950-2011

Dry trimester

Normal trimester

Wet trimester

Dam Reserve - Observation

Thresholds from the Drought Plan of 2007, based on the % of filling of the dam compared to average values (period 1973-2010)

- Reserve > 50% (Normal Situation)
- 50% ≥ Reserve > 30% (Prealert situation)
- 30%≥ Reserve > 10% (Alert situation)
- 10% ≥ Reserve (Emergency)

Table 1. Selected events- low and high inflow to the dam in winter

The dam considered is mostly used for supplying water to agriculture, but also for urban demand and ecological flow. The dam is also used to produce electricity (hydropower of 7.000 kW). The dam is filled and emptied every year, and the management priority is to have a dam almost full before the start of the irrigation period (March-April).

The four events selected are significant from a water management perspective:

- 1976: before winter period the reserve in the dam was very low and high inflow was observed during winter.

- 1980: before winter period the reserve in the dam was almost normal and low inflow was observed during winter.
- 2007: before winter period the reserve in the dam was normal and low inflow was observed during winter.
- 2009: before winter period the reserve in the dam was above normal and high inflow was observed during winter.

The availability of seasonal predictions before the winter period (October or November) could have been particularly useful to adjust the decision making process. Indeed, in the current situation, decisions are mostly linked to the state of the reserve in the dam at the time the decision is taken – but do not consider any seasonal forecast:

- 1976: since reserve was low before winter, decisions were taken according to potential low water availability during the hydrological year for the different water uses in the river basin. As an example, agriculture sector might have prepared for low water consuming crops. Nevertheless, high inflow occurred during winter so this kind of adaptation was not necessary.
- 1980 and 2007: since the reserve was normal, the agriculture sector might have prepared for irrigated crops, nevertheless low inflow occurred during winter so part of water needed for irrigation was not available.
- 2009: since the reserve was normal to high, the dam management regarding flood control and hydroelectric production occurred with the same rules as usual, nevertheless high flow occurred during winter so a better management could have been possible (more sustained release for hydroelectric production, less sudden released for flood control).

What climate signal does the prototype provide prior to these events:

For the selected events, climate forecasts provide a higher percentage of probability for the tercile that has occurred (for all the year) and in one case a very low probability for the "opposite" tercile (in 1976, a wet year, forecasts give a 9% of probability of having a dry year).

These forecasts have been used as input for the simplified water management model of the catchment. Broadly speaking, the model allows to translate climate information (dry or humid period) into information relevant for water management (potential deficit, reserve in dam, etc.). The period of simulation encompasses winter but also all the irrigation period (spring and summer). As a results the probability of being above a below different thresholds have been calculated.

The selected thresholds and indicators were the following:

- Probability of having reserve in the dam < 30Hm3 or < 70Hm3 at the end of the irrigation period (1st of October) –sufficient water should be available to ensure environmental flow and urban water demand supply in autumn
- Probability of having reserve in the dam > 98% Maximum volume in the period of maximum filling (1st of March) – which mean that the dam is full
- Probability of having deficit in the water demand > 5% of the total demand. – such significant deficit would imply water restriction measures in the catchment (environmental flow, agricultural demand and in the most extreme cases, urban demand)

The results of the simulations with the seasonal forecast are presented below and compared with the results of simulations using only climatology as input. The table presents the results for the selected thresholds and indicators; the two graphics provide an example of the results of the simulation.

The following comments can be made:

- 1976 and 1980 present very different reserves in the dam before winter but if we use the forecasts it appears that the potential risks are equivalent (e.g. 23% of being below 70hm3 at the end of the irrigation period). This does not appear if the climatology is used as input, since a much higher risk is simulated for 1976 (39% of being below 70hm3 at the end of the irrigation period) and a lower risk for 1980 (18% of being below 70hm3).
- The reserves in the dam before winter are quite similar between 2007 and 2009 but if we use the forecasts it appears that the probability of filling completely the reservoir are much higher for the year 2009 (e.g. 52% of probability compared to 22% for 2007). Again, this does not appear in the results of the simulation using climatology (41% and 33% of probability of filling the dam for 2009 and 2007, respectively)

Year	Inflow				Dam reserve				Demand deficit
	Seasonal Forecast (Dic-Jan-Feb)			Observed DJF	Observed	Forecasted 1st Octuber		casted. 1st M	orecasted 1st Octube
	% BN (Dry)	% NN	% AN (Wet)	Category	1st Dicembe	roba < 30Hm	roba < 70 hm	>98% Vol max	Fallo>5%
1976	9	43	48	AN	71	5%	23%	26%	5%
1980	41	37	22	BN	105	6%	23%	13%	6%
2007	41	39	20	BN	132	0%	10%	22%	0%
2009	20	37	43	AN	147	0%	0%	52%	0%

Table 2: Results of the simulations using seasonal forecast as input of the water management model.

Year	Inflow				Dam reserve				Demand deficit
	Climatology			Observed DJF	Observed	Forecasted 1st Octuber		recasted. 1st Mar	Forecasted 1st Octuber
	% BN (Dry)	% NN	% AN (Wet)	Category	1st Dicember	Proba < 30Hm3	Proba < 70 hm3	>98% Vol max	Fallo>5%
1976	33	33	33	AN	71	13%	39%	18%	13%
1980	33	33	33	BN	105	5%	18%	20%	5%
2007	33	33	33	BN	132	0%	8%	33%	0%
2009	33	33	33	AN	147	0%	0%	41%	0%

Table 3: Results of the simulations using climatology as input of the water management model.

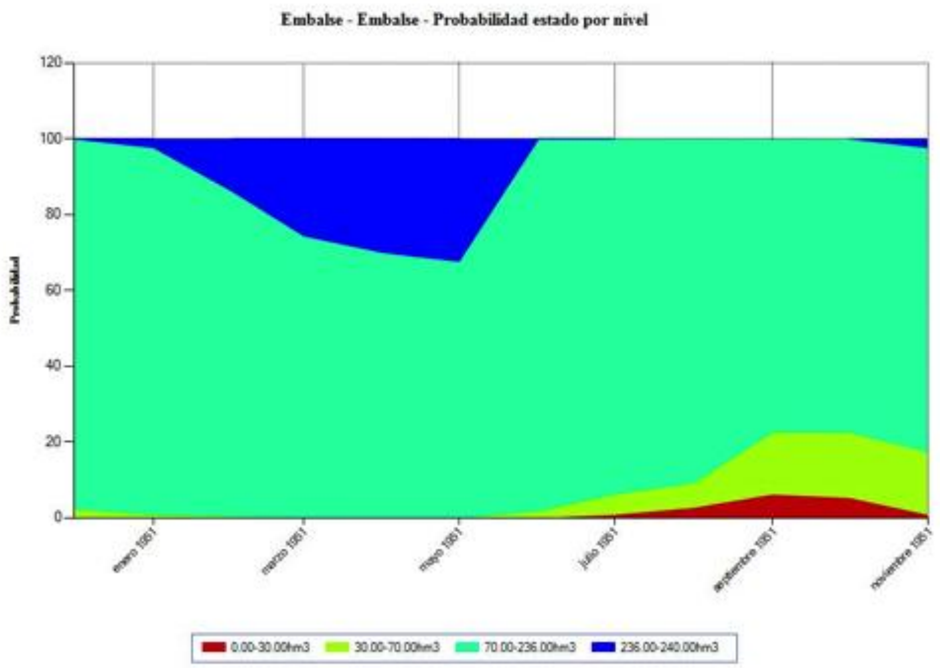

Figure 5. Example of results for the year 1976 and with forecast: probability of having reserve between different thresholds (SIMRISK interface).

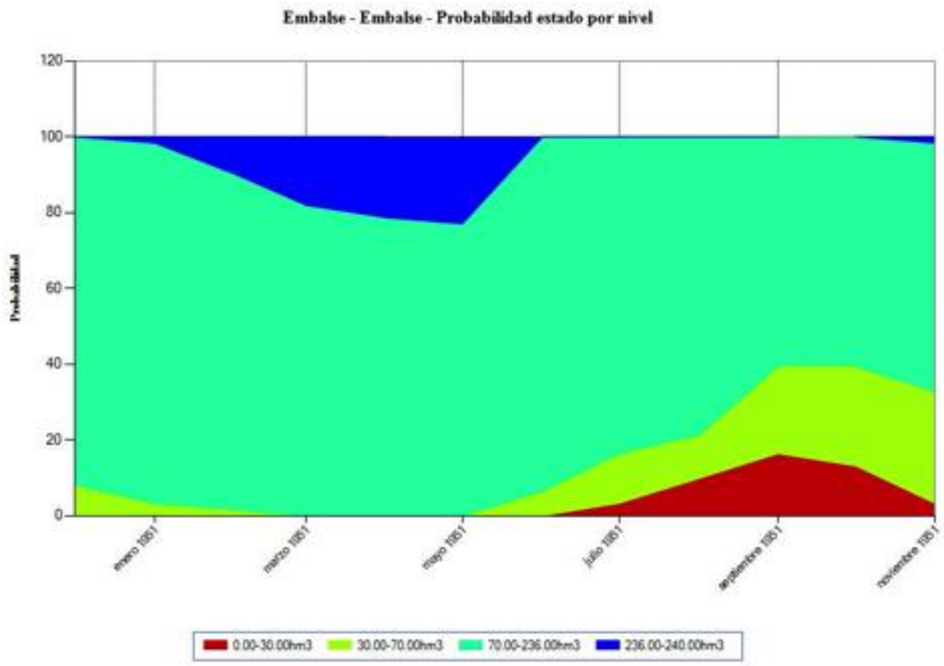

Figure 6. Example of results for the year 1976 and with climatology: probability of having reserve between different thresholds (SIMRISK interface).

Evaluate the value of the prototype to the DMP:

The historical decision made during the events and the potential value of the forecasts can be analysed by looking the release curve of the dam (figure below):

- Hydrological year 1976 and 1980: while the simulation done with the forecast would recommend similar dam release for 1976 and 1980 (since the risk is similar), no release have been done in December 1976 and January 1977 but a very high release in February 1977. The impacts of the no release period (e.g. ecological flow not maintained, no hydropower generation) could have been avoided.
- Hydrological year 2007 and 2009: while the simulation done with the forecast would recommend much higher dam release in 2009 during winter (starting in December), low release have been done in December 2009 conducing to very high release in February and March 2010. The impacts of the low release period (e.g. no hydropower generation) could have been avoided.

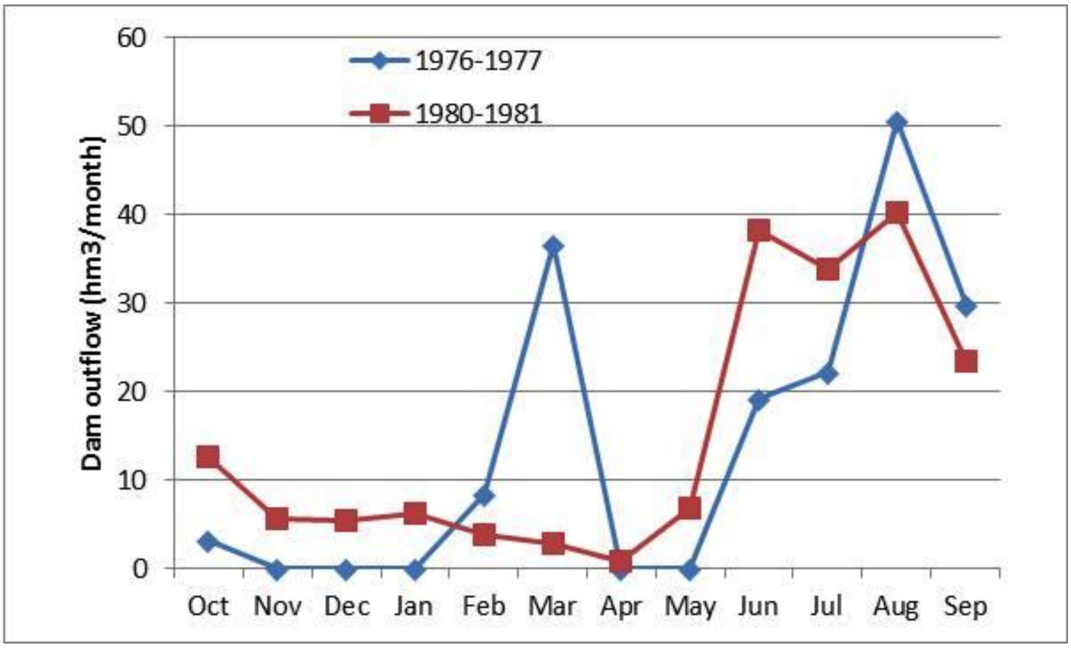

Figure 7. dam release for the hydrological year 1976 and 1980 (Hm3 per month).

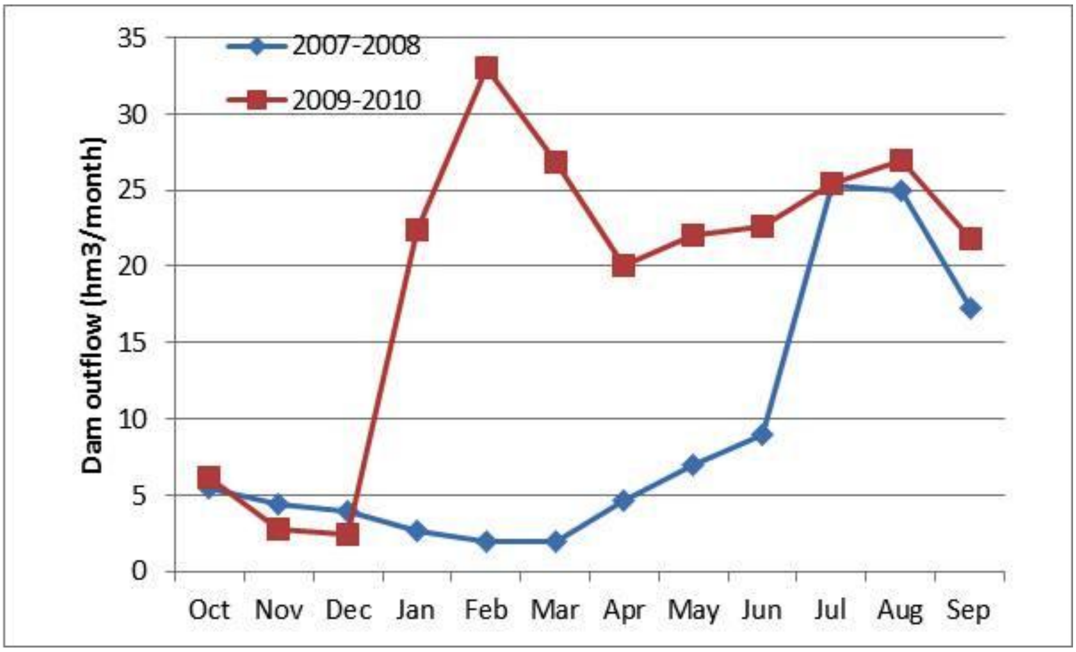

Figure 8. dam release for the hydrological year 2007 and 2009 (Hm3 per month).

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Brown, C., K. M. Baroang, E. Conrad, B. Lyon, D. Watkins, F. Fiondella, Y.Kaheil, A. Robertson, J. Rodriguez, M. Sheremata, and M. N. Ward, 2010: Managing Climate Risk in Water Supply Systems. IRI Technical Report 10-15, International Research Institute for Climate and Society, Palisades, NY, 133 pp.

Cohen, J. and J. Jones (2011), A New Index for More Accurate Winter Predictions, Geophys. Res. Lett. 38: L21701

3.7.4. Planned future publications

1 oral presentation planned in October 2015 in a national congress (Jornadas de Ingeniería del Agua (JIA) – Cordoba).

3.8. MeteoSwiss case study

3.8.1. Data and Methods

We present seasonal forecasts of the European Centre for Medium-range Weather Forecasts' (ECMWF) System 4 forecasting system (Molteni et al. 2011) for the summers (JJA) from 1981-2014 and winters (DJF) from 1981-2013. We derive seasonal heating degree days (HDD) and cooling degree days (CDD) forecasts from bias corrected daily temperature time series of ECMWF System 4 initialized in May for summer forecasts and initialized in November for winter forecasts.

The daily time series are bias corrected against ERA Interim reanalysis time series (Dee et al. 2011). Daily bias correction is estimated using a local linear regression smoothing of the daily observed and forecast climatologies as suggested by Mahlstein et al. (2015). Bias correction is performed in leave-one-out crossvalidation mode using data from 1981-2010 to estimate the correction factors.

We use the following definitions for heating and cooling degree days.

$$HDD = \frac{1}{n}\sum_{i=1}^{n} \begin{matrix} 0 & if\ T_i > 12℃ \\ 18 - T_i & if\ T_i \leq 12℃ \end{matrix}$$

$$CDD = \frac{1}{n}\sum_{i=1}^{n} \begin{matrix} T_i - 22 & if\ T_i > 22℃ \\ 0 & if\ T_i \leq 22℃ \end{matrix}$$

Where T_i is the daily mean temperature, and n is the number of days per seasons.

We validate seasonal time series of HDD and CDDs against HDDs and CDDs derived from daily temperature time series of the ERA Interim reanalysis.

In addition to the analysis of skill of seasonal forecasts, we relate the seasonal forecasts to electricity consumption data for southern Italy for the period from 2005 to 2012. The electricity data for southern Italy comprise of monthly demand for the Campania, Apulia, Basilicata, and Calabria regions (southern Italy excluding Sicily) and have been provided by TERNA, an Italian electricity transmission operator.

3.8.2. Seasonal forecast skill for heating and cooling degree days

Heating and cooling degree days relate strongly to energy demand for heating and cooling respectively. Therefore, we present the skill of HDD and CDD forecasts in Figure 1. Correlation between the ensemble mean forecast and observed HDD and CDDs are positive in large parts of the northern hemisphere. In Europe, correlations are significantly larger than zero in winter in the UK and in summer in southern Europe with correlations generally below 0.6 (Figure 1a,c). In addition, we analyse the ranked probability skill score (RPSS) that measures skill of probabilistic tercile forecasts (i.e. probabilities for above normal, normal and below normal conditions). RPSS larger than zero indicates forecasts that are more skilful than a constant climatological forecast. We find very limited regions with positive RPSS in the northern hemisphere in winter (Figure 1b). In summer, on the other hand, positive RPSS can be found in southern and eastern Europe, throughout the subtropics and tropics, and in the western US. Therefore, while forecasts of energy demand for heating may be of limited use due to the marginal skill in HDD forecasts, there is potential for using CDD forecasts to forecast energy demand for cooling in summer.

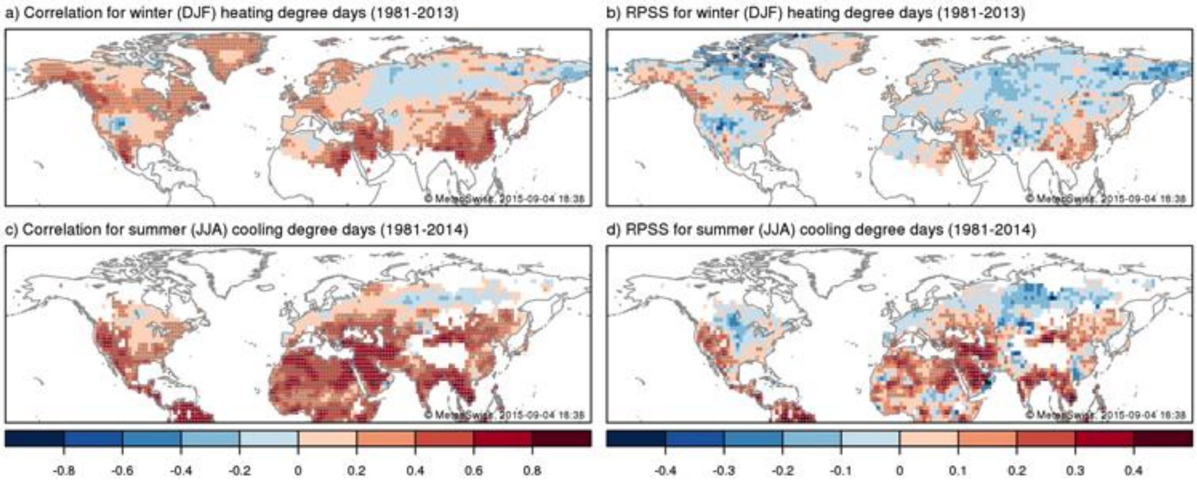

Figure 1: Correlation (a, c) and ranked probability score for tercile forecasts (b, d) of winter (DJF) heating degree days (a, b) and summer (JJA) cooling degree days. Stippling in a-d indicates scores that are significantly (10% level) larger than zero.

3.8.3. Forecasting energy demand in southern Italy

In the following, we present a case study to show how seasonal forecasts might be used to augment electricity demand forecasts a few months in the future. To study this, we relate observed and forecast CDD to electricity consumption in southern Italy and analyse the impact of using seasonal forecast information to describe electricity demand in the hot summer of 2012.

In Figure 2, we compare electricity consumption in summer (JJA) to the observed cooling degree days. Total electricity consumption (top panel) may be affected by trends unrelated to climate and thus unrelated to cooling demands. Therefore, we present the fraction of JJA electricity of the annual total consumption to reduce the effect of confounding factors. For actual forecasts, on the other hand, we also present the fraction of JJA electricity consumption of the January to April consumption as this is the information available at the time of forecast initialization on the 1st of May.

We find that summer electricity consumption in southern Italy correlates strongly with observed CDDs. Correlation is highest when electricity consumption is expressed as a fraction of the annual total, with a correlation of 0.94. When expressing electricity consumption as a fraction of the first third of the year (bottom panel in Figure 1), and thereby when relating summer electricity consumption to the electricity consumption until the initialization date of the forecast, the correlation is slightly reduced.

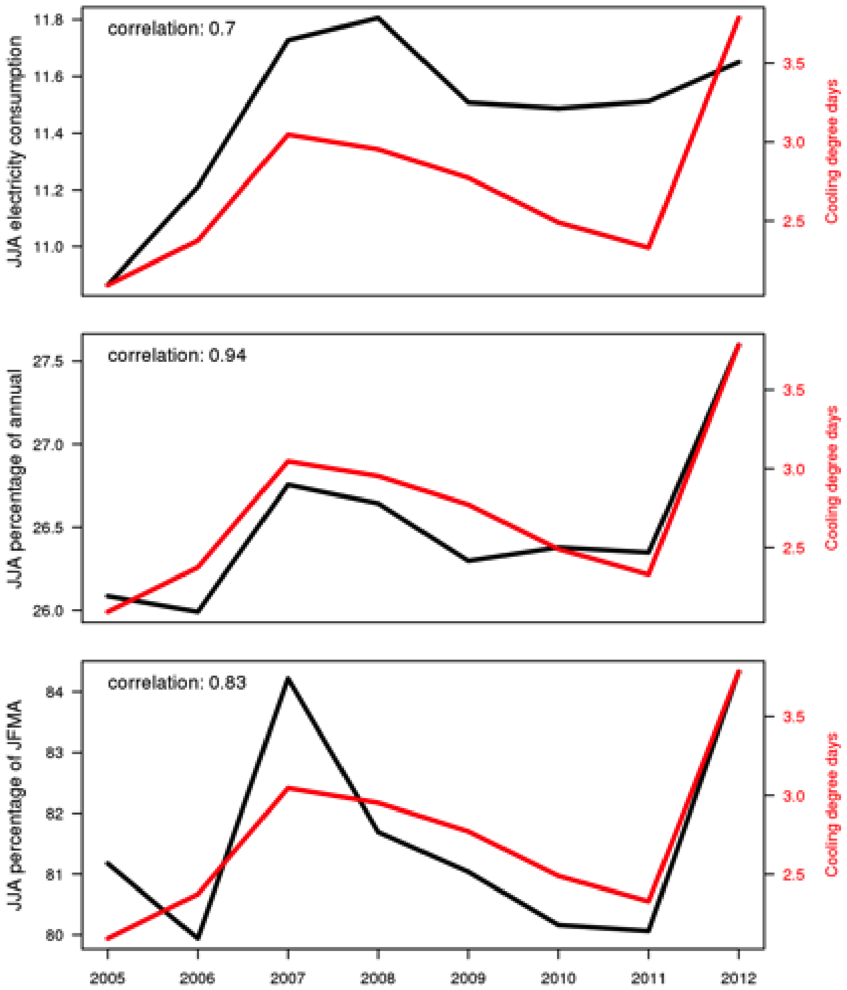

Figure 2: Electricity consumption (black lines) and observed cooling degree days (red lines) for southern Italy. The top panel shows total summer (JJA) electricity consumption, the middle and lower panel show the percentage of JJA electricity consumption of the total annual consumption (middle panel) and January to April consumption (bottom panel).

From the above relationship between summer electricity consumption and observed CDDs in southern Italy, we derive a regression model to forecast electricity consumption. Such a forecast is presented in Figure 3. We account for uncertainty in the CDD-consumption relationship by fitting the regression model in leave-one-out cross-validation fashion (blue lines in Figure 3). Such a forecast is compromised both by the limited skill of the CDD forecast and by the uncertainty in the CDD-consumption relationship. Consequently, the year-to-year variations (the signal) of this regression-based forecast are rather small. Nevertheless, the forecast indicates above normal energy demand in the hot summer of 2012. On the other hand, the only forecast indicating below normal energy demand in this period was followed by an energy intensive summer (2007).

Due to the limited sample size, the uncertainty in the regression relationship is likely overestimated and an operational forecast system with access to more and more targeted electricity consumption data is expected to be more skilful. To illustrate the potential benefits of such a system, we also present the perfect forecast (green dashed lines in Figure 3) as an upper bound to what levels of forecast skill may be expected. This forecast uses observed CDDs as input (i.e. assuming a perfect forecast of the meteorological conditions) and uses all available data to fit the model and thereby neglects uncertainty in the CDD-consumption relationship. Obviously, in such a hypothetical forecast, the signal for the summer of 2012 is much stronger and the uncertainty reduced compared to the forecast based on the operational seasonal forecasting system.

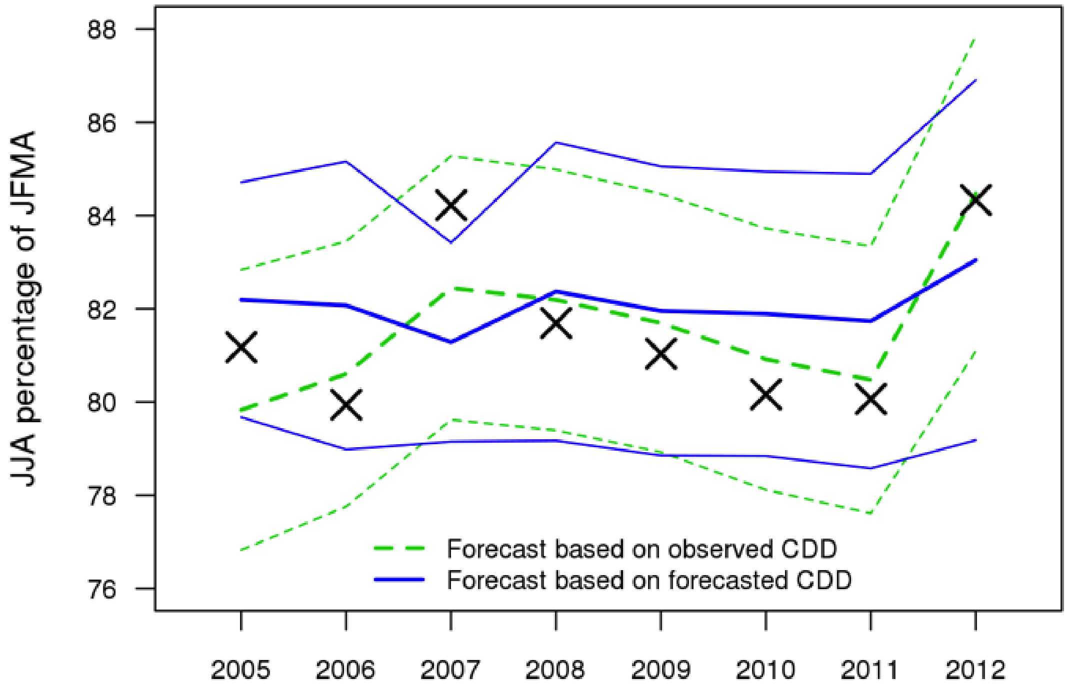

Figure 3: Forecast of summer electricity consumption in southern Italy based on CDD forecasts of ECMWF System4 (blue lines) compared to a retrospective forecast using observed CDD (green lines). For both forecasts, the ensemble mean is shown in solid lines, the thin lines denote the 95% confidence interval. Observed electricity consumption is indicated by the black crosses.

We conclude that while our case study suggests a strong relationship of cooling degree days and electricity demand, there are only a few regions in Europe where such forecasts are skilful enough to be useful.

3.8.4. References

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Peer Reviewed Articles

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3.8.5. Planned future publications

Bhend, J., I. Mahlstein, M.A. Liniger. Insights on the use of climate indices in seasonal forecasting and improvements due to aggregation. In preparation.

4. LESSONS LEARNT

4.1. RESILIENCE prototype (IC3)

- Many stakeholders from the wind energy sector have provided feedback to the RESILIENCE prototype development. However, for a truly user-driven developed prototype it is important to have one target stakeholder and a contact person to ensure that the final specifications and outputs of the prototype fit the requirements of this user.
- Skill limitations and how they should be taken into account in the interpretation of the prediction is a key issue that we are still developing, particularly for Europe where skill values are much lower that other areas.
- This prototype has been selected to have a visualisation tool developed by a professional designer. Designers and Scientists have different perspectives on how information should be displayed and that is a source of frictions. To have a good visualisation it is key to have the end user closely involved in all the steps of the the visualisation development.
- Having a visualisation tool is extremely useful to disseminate the outputs of the climate predictions and bridge the gap between climate scientists and end-users.

4.2. LEAP prototype (WFP, ENEA)

- This prototype has a key dependence on input from local stakeholders in setting up the underlying drought monitoring platform (WFP country office, DRMFSS). On one hand this implies a greater potential for the prototype to be adopted as an operational tools. On the other hand, during the project we do not have the possibility to explore the full capabilities of the system.

4.3. RIFF prototype (METEO-France)

- Communicating prediction skill remains a difficult notion. Forecasts with no skill could be taken into account by our stakeholders even if it is clearly precised that scores are too low to be meaningful.
- RIFF is seen as a scientific approval for our stakeholders, who have to explain their decisions to the members of the river basin technical committee.
- Defining a common vocabulary is crucial to well understand users needs.
- Working with stakeholders whose decision can be translated into a scientific format (curve, quantity…) allows to objectively quantify the impact of using seasonal forecasts and by the way, the added value of such a prototype.

4.4. Transport prototype (Met Office)

At this stage of the development of the prototype, we can make the following observations:

- SPRINT has consulted with a wider stakeholder group than that associated with the other prototypes typically working with only one major “decision-maker”. It has been challenging to engage this wider group sufficiently with the project. However, it may be that – after the first real-time forecast is issued this winter – the stakeholders’ interest increases once again.
- We have tried to develop an approach to the forecasts, which is relatively simple, visually pleasing, and scientifically appropriate. However, before even

considering how the stakeholders might use the impacts forecasts, it remains to be seen how easy they will find them to interpret. We anticipate providing some explanatory text alongside the diagrams.

4.5. Land management prototype (Met Office)

- The stakeholder engagement process so far has provided useful information on the broad kinds of decisions that farmers make, how these relate to weather, and the potential uses of seasonal forecasts. However, it has been much more difficult to identify specific decisions relating to seasonal forecasts, and their value
- In addition, the users generally poorly understood seasonal forecasts unless given detailed explanations; perhaps due to their familiarity with weather forecasts, rather than probabilistic seasonal climate predictions.
- Combining research on forecast skill and stakeholder engagement has been very beneficial, for example allowing focus on variables and regions of interest, and providing practical direction for the development of the prototype.
- since communicating these probabilistic seasonal forecasts in a graphical form that is readily understood by farmers has proven difficult, this supports the need for even stronger activities with stakeholders including training and familiarisation, and working through trusted intermediaries such as farm advisors

4.6. Hydropower prototype (SMHI)

- It is important to cultivate a close working relationship with the end-users/stakeholders. This allows for more open dialog about what are the expectations, limitations and possibilities when developing a prototype.
- It is important to establish a common vocabulary. It is very easy to assume that the parties understand each other when they might not.
- Although end-users/stakeholders may have high demands with regards to what they want from a climate service, they are more than often satisfied with incremental improvements so long as they are robust.

4.7. Water management in Spain case study (AEMET and CETaqua)

The lessons learnt from the analysis performed are the following:

- It is crucial to pay attention to the way in which the scientific information is communicated to the other partners. In this regard, the experience gained through the WP33 has been crucial.
- The knowledge on forecasting systems based on statistical learning methods has been improved.
- The use of seasonal forecast could allow a better evaluation of the future risks in a river basin
- Decision making processes could be adjusted according to the results of the risk analysis in order to be more efficient

The main limitations of the study are the following:

- A very simplified water management model has been used - we assume that this is enough for estimating the value of basic indicators and comparing scenarios but this should not be considered as an operational model
- The selected events correspond to period were the forecasts were “successful” (the most likely category was the one observed), but this is not the case for all the events – a more exhaustive analysis, considering a larger period (e.g. 1973-2010), is recommended to avoid misleading results (this will be done in the coming month)
- The potential changes in the decision making processes have not been assessed in detail yet, a workshop with the stakeholders will be organized in October 2015 to get more information on this point

4.8. MeteoSwiss case study

- Skill of seasonal forecasts in Europe is limited to specific regions, such as southern Europe in summer. While the relationship between meteorological quantities (here cooling degree days) and target variables (here electricity consumption) can be strong, the limited skill of seasonal forecasts along with the often limited data base and confounding trends in the target variable pose serious challenges in the application of seasonal forecasts.

5. LINKS BUILT

5.1. RESILIENCE prototype (IC3)

- Collaboration with Daniel Funk (DWD, WP11) regarding preparation of vulnerability analysis report.
- Collaboration with Irina Mahlstein (Meteoswiss, WP22) regarding Skill assessments.
- Collaboration with Rodrigo Manzanas (Predictia) regarding the development of the prototype microsite and prototype dissemination.
- Collaboration with Laurent Pouget (Cetaqua, WP45) regarding the characteristics of the energy sector for the creation of a methodology to assess business opportunities of the prototypes.
- Collaboration with partners of the twin EU project SPECS (Vortex) for the dissemination of the prototype results and energy sector feedback.

5.2. LEAP prototype (WFP, ENEA)

- Collaboration with UNICAN on the statistical downscaling. Although the downscaling is not yet ready for the prototype, information has been shared in order to align the activities on both sides.
- Collaboration with PREDICTIA for the development of the EUPORIAS microsites.
- Collaboration with WP11 for the development of the Vulnerability Assessment Framework
- Collaboration with partners of the twin EU project SPECS for accessing the forecast data portal.

5.3. RIFF prototype (METEO-France)

- Collaboration with Daniel Funk (DWD, WP11) regarding preparation of vulnerability analysis report.
- Collaboration with Rodrigo Manzanas (Predictia) regarding the development of the prototype microsite.
- Collaboration with Peter Bissolli (DWD) and Christiana Photiadou (KNMI) in the framework of the case study : «Water level forecasts for the Rhin river catchment»
- Collaboration with Laurent Dubus (EDF, EUPORIAS partner) concerning the comparison between two downscaling methods of atmospheric forcings and between two hydrological models.

5.4. Transport prototype (Met Office)

- Liaison with Met Office colleagues involved in the production of real-time seasonal forecasts to prepare for the delivery of specific parameters required for SPRINT.
- Liaison with Daniel Funk (DWD, WP11) regarding preparation of vulnerability analysis report.
- Liaison with Rodrigo Manzanas (Predictia) regarding the development of the prototype microsite.

5.5. Land management prototype (Met Office)

- Links were made with the University of Leeds (stakeholder engagement), Predictia and KNMI (technical aspects), and internal Met Office colleagues on forecast verification and production.
- Strong links have been built with our stakeholders Clinton Devon Estates and the National Farmers Union, both through our engagement activities and also with the former providing press releases and publicity.
- WP33 findings have been used to assist our work in communicating uncertainty.

5.6. Hydropower prototype (SMHI)

- A modified version of the SMHI hydropower prototype is being used in WP61 in the SPECS project where it is being used to evaluate the value of the new data produced in Research Themes 3 (RT3) and RT4 of the same project.
- Energiforsk, the Hydropower industry stakeholder formally known as ELFORSK, are funding a project to expand the prototype to include six additional hydropower producing river systems in Sweden. These six river systems together with Ångerman River account for nearly 75% of hydropower production in Sweden.

5.7. Water management in Spain case study (AEMET and CETaqua)

- Results from WP33 will be used to communicate levels of confidence and uncertainty to the stakeholders.
- Complementary information can be found in the reports of WP23 (modelling method: SIMRISK model and simulation) and WP41 (decision making

processes). The work on the case study will continue and new results will be presented in the reports of WP41, WP42 and WP45.

5.8. MeteoSwiss case study

- The case study of southern Italian electricity consumption strongly links with analysis of climate indicators carried out for WP22.