Use of Seasonal Weather Forecasts in Crop Yield Modelling

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Abstract

The Joint Research Centre (JRC) of the European Commission (EU) carries out a semi-operational activity to provide the Directorate General Agriculture with real-time crop yield forecasts.
JRC contribution to the DEMETER project consisted to test ensemble of seasonal climate forecasts potential for crop yield forecasting. An innovative method for supplying seasonal forecast information to crop simulation models consists in running a crop model on each individual downscaled members output of climate models. An ensemble of crop yield is obtained and a probability distribution function (PDF) can be derived. Preliminary results of wheat yield simulations in Europe using downscaled DEMETER seasonal weather forecasts suggest that reliable crop yield predictions can be obtained using an ensemble multi-model system. A significant gain in precocity is noticed when compared to the operational system. Furthermore, PDFs of wheat yield provides information on both the yield anomaly and the reliability of the forecast. Based on the spread of the PDF, the end-user can directly quantify the benefits and risks of taking weather-sensitive decisions.
The use of seasonal weather forecast brings additional information for the remaining crop season and therefore has valuable benefit for improving the management of the European Union agricultural production.

Keywords: Seasonal Weather forecasts, Crop yield modelling, Probabilistic forecasts, European Union agricultural production

1. Introduction

The Directorate General for Agriculture (DG AGRI) of the European Commission (EC) requires timely forecasting of European Union (EU) agricultural production as information for management of the Common Agricultural Policy (CAP), mainly for setting quotas of marketable goods and intervention pricing. The EC Joint Research Centre (JRC) carries out a semi-operational activity on crop yield forecasts, providing DG AGRI with real-time estimates during the growing season. Those forecasts are mainly used by a group of experts from DG AGRI (market units, budget units, economic analysis) together with other sources of information (such as trade publications, press releases, expert opinions, bulletins from statistical offices of member states) (Meyer-Roux & Vossen 1994, Terres 1999).

As European agriculture is highly intensive, weather remains the main source of uncertainty for crop yield assessment and crop management (Vossen 1995). For this raison, skilful seasonal weather forecasts and related seasonal crop yield forecasts could generate an economical benefit for the CAP. The total value of EU agricultural production is around 200 billion € and in particular the EU production of wheat (crop used for this study) is around 100 million tons (European Commission 1999), setting EU as the second largest producer in the world after Asia (FAOSTAT 2000).

The EC funded project DEMETER (Development of a European Multimodel Ensemble System for Seasonal to Interannual Prediction), during the Vth Framework Program, leaded by the European Centre for Medium-Range Weather Foerecasts (ECMWF, UK) aims primarily to construct and to evaluate a reliable ensemble-based system for predicting fluctuations in climate on seasonal timescales.

DEMETER approach could be summarised briefly in combining the use of several climatic models to reduce the uncertainties due to model formulation (multi-model) and the used of perturbed initial parameterisations in order to reduce the uncertainties in initial conditions (ensemble).

Seven global coupled atmosphere-ocean climate models from different organisations in Europe have been incorporated in a unique multi-model ensemble system (6 of them installed on a single super-computer at ECMWF). An ensemble is composed of 63 members: 7 models run with 9 different initialisations. A set of bias-corrected data (hindcasts) for usual meteorological parameters has been produced and evaluated for the period 1958 to 2001 (Hagedorn et al 2004, Doblas-Reyes et al 2004).

The JRC contribution to DEMETER is to test the potential of seasonal climate forecasts by coupling a crop yield model to the output of climate models, with as main objective the production and assessment of seasonal forecast probability distribution for crop yields in Europe.

After having developed a strategy to integrate seasonal weather forecast in the operational JRC crop system, the principle tasks consisted in assessing skill of crop yield forecasts obtained with DEMETER hindcasts and, taking into account the probabilistic nature of these forecasts, in the evaluation of probabilities of yield anomalies.

2. Materials and Methods

2.1 JRC crop model

The Crop Growth Modelling System (CGMS) used at JRC consists in 2 modules (Terres 1999). The first module is based on the crop growth simulation model WOFOST (Vossen 1995) driven by meteorological conditions, modified by other environmental factors such as soil characteristics and crop parameters. It describes the crop cycle from sowing to maturity on a daily time scale: crop growth is simulated (i.e. leaf area index, biomass, storage organs) in combination with phenological development. In the second module, a regression analysis from historical statistical yield data and WOFOST simulated crop growth indicators is performed to forecast the crop yield of the current year at the level of administrative region (Van Diepen 1995)

2.2 Use of seasonal weather forecast to reduce weather uncertainty

The JRC system allows to make yield forecast at any time during the growing season. However, if the forecast is issued early in the season, the weather conditions leading up to harvest time are unknown and are, therefore, a major source of uncertainty. Furthermore, early in the season, simulated crop indicators are still at a very early stage (e.g. tillering for winter wheat) and the regression built on these crop indicators is not robust. In operational mode, JRC yield forecasts generally improve as the growing season goes along. Information on main patterns of meteorological conditions several months in advance and their use in input in the crop model could provide better crop growth indicators which in turn could improve the statistical regression for the yield prediction. (Strategy illustrated in Figure 1). With DEMETER forecasts data, crop yield forecast could be issued very early in the season, providing potential valuable information to agricultural production managers.

Weather data provided by DEMETER climate models being of probabilistic nature, their input in the crop model results in a forecast probability distribution of crop yield. The potential usefulness of DEMETER system can then be judged on the skilfulness of crop yield probability distribution (as compared to official yield figures).

2.3 DEMETER ensemble

2.3.1 Hindcasts weather data

DEMETER data used by the crop model consist in 6-months-ahead hindcasts (63 members of daily data) starting in February for each growing season of the test period.
Daily meteorological parameters required for the crop model were cumulated precipitation, maximum and minimum temperature, global radiation and evapo-transpiration (computed from wind speed, dew point temperature and surface net longwave radiation, using Penman formula, see Supit et al 1999).
The study was carried out over 4 years (1995 – 1998) for winter wheat (*Triticum aestivum* L.). Yield was estimated at national level for each of the 15 EU Member States and compared to official yield from EUROSTAT database.

2.3.2 Downscaling

Ensembles from DEMETER climate models are provided at a low spatial resolution (1.5°x1.5°). Representation of orography being very coarse at such a scale, in particular for European conditions, large-scale weather systems are not yielding a reliable representation of local weather conditions, notably for precipitations. It was therefore necessary to downscale meteorological data at a finer surface resolution which provides more reliable regional details. The method consists in statistical downscaling of monthly means values using singular value decomposition analysis and model output statistics (Feddersen and Andersen 2004), then redistributed on a daily basis (for use in the crop model) with a weather-generator based on the Richardson WGEN model (Richardson 1981). The downscaling method was trained using ERA40 re-analysis data set against the JRC 50x50km gridded weather data (for the period 1987 to 1998). All meteorological parameters used as input of the crop model were downscaled.

The downscaling has increased the correlation between ERA40 and JRC for the 4 input parameters of interest (Cantelaube and Terres 2003). Without downscaling, large discrepancies were indeed observed, more particularly for daily precipitation. As an example, precipitation in 1988, using downscaling reduced the root mean square error (RMSE) by 34% and increased the R^2 value from 0.29 to 0.7 (over Europe, Figure 2-top). An interesting result was also the ability of downscaled data to reproduce realistic sequences of wet and dry days (through the weather generator), which matters for the crop model since it requires a daily water-balance (Rijks et al 1999).

Downscaled weather inputs also improved crop modelling outputs. Discrepancies between simulated crop indicators, using JRC meteo inputs or ERA40 re-analysis data, were less when the latter were downscaled. Figure 2 (bottom) shows example of simulated biomass in 1988, R^2 value increases from 0.62 to 0.69 and RMSE is reduced by 4% for the whole Europe (locally more than 10%).

Crop yield forecasting for European situation requires to downscale 1.5°x1.5° gridded meteo data to a smaller spatial resolution for taking into account local weather conditions. In the following paragraphs, DEMETER ensembles always refer to downscaled data.

3. Results: Crop Yield Seasonal Forecasts Assessment

Results of the yield simulations were evaluated from both official yield figures (Eurostat data, used as "*reference*" for wheat yield of EU Member States) and simulations made with the JRC operational system (used as "*control*", labelled JRC). The comparison to Eurostat reference provides an assessment of the skill of seasonal yield forecasts, and the comparison to "JRC control" provides a quantification of the improvement of the operational JRC system, both in terms of accuracy and in terms of precocity of the provided information for a similar level of accuracy.

Furthermore, the probabilistic nature of DEMETER ensemble seasonal forecasts allows to quantify the accuracy of the yield forecasted through obtained probability distribution of crop yield anomaly. In this purpose, a methodology was developed to quantify the confidence of yield estimates through the probability distributions of crop yield anomaly (defined as the yield deviance from the trend[1]). Probabilistic tools such as probability density functions (PDFs) or cumulative density functions (CDFs) were used to fully exploit the information provided by the ensemble of seasonal crop yield forecasts. A probability of occurrence is associated to an event through PDF function. Building the PDF with the ensemble of simulated yields, probability $\Pr[x > x_0]$ of yield anomaly x to be superior than x_0 is computed (area under the PDF curve and right of x_0 on the x-axis and similarly probability $\Pr[x < x < x_1]$ of yield anomaly x to be inferior than x_1 is the area under the PDF curve and left of x_1 on the x-axis).

Thus, this method provides, for each crop, a probability of yield anomaly (deviating from the trend); considering only the sign of the yield anomaly, probability to be either negative ($\Pr[x<x_1=0]$) or, symmetrically, positive ($\Pr[x_0=0<x] = 1 - \Pr[x<0]$) was associated to the anomalies.

3.1 Prediction Skill and Precocity

When the crop model is ran with DEMETER hindcasts, results are specific to each country, either for the ensemble mean deviance from Eurostat official figures, either for the yield ensemble variability.

The average percentage error of the DEMETER-based yield simulations over the EU for period 1995-1998 is 5.5% (average of national yield weighted by the contribution of each member state to

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[1] A trend is observed on the national yields time series, due notably to improvement in farm managing practise, technological progress, improved seeds etc… The yield time series are thus separated into 2 components: a time trend and an annual variation due to weather conditions. This allows to define the annual anomalies as the difference between actual yield value and the trend. The trend can be also used to propose a forecast only based on the past years, independent from climatic conditions.

the total European production). This value is found excluding Portugal, which showed the largest discrepancies (see below).

Variability of simulated yields is low for Germany (standard deviation (s.d.) lower than 0.12 tons.ha^{-1}, i.e. 2% of the average simulated yield), for France (s.d. ranges between 2% and 3%) or for United Kingdom (s.d. lower than 4%). However, the spread of the yield forecasts ensemble is larger in southern countries (s.d. greater than 10% in Greece, Portugal and Spain). In terms of accuracy also, DEMETER-based yield simulations perform better in EU northern countries.
The relative percentage of error (as ratio to the official yield) ranges between 1.7% in Germany and 31.3% in Portugal. After Germany, good results are obtained in France (average error 4.7%). This is particularly interesting since those 2 countries are the main contributors to the European wheat production (France represents around 38% of the EU wheat production and Germany 21%). Results are good also in United Kingdom (error: 5.2%), except in 1997 (lower skill, error = 9.6%). In Nordic countries such as Sweden and Denmark, DEMETER based yield forecasts have some skill (average percentage error for the 4 years: respectively 3.6 and 5.1%)

On the other hand, yield forecasts obtained when using DEMETER ensemble-means are not very skillful in southern countries. Major problem is found in Portugal, where for the 4 years (1995-1998) the error is high (35%, systematic positive bias). Also, the low yield in Spain in 1995 due to a severe drought was not depicted by the DEMETER hindcasts (neither by the JRC operational system).

When analysing the results accuracy as a function of earliness, yield errors and temporal analysis between DEMETER-based data and JRC operational yield forecasts demonstrates that, at the European level, the percentage error obtained with DEMETER at the end of February (5.9%, Portugal excluded and weighted by the contribution of each member states in the EU wheat production) lies between the average error found at the end of June (7%) and the error found at the end of August (5.4%) using JRC operational system (Table 1). Therefore, in terms of ensemble-mean, for the period 1995 to 1998, DEMETER-based yield forecasts issued in February are globally more accurate than JRC operational forecasts until July. This is certainly an advantage for the gain in accuracy, providing skilful information at an earlier stage in the growing season.

3.2 Probabilistic yield anomalies forecasts

In order to assess the DEMETER based yield forecasts taking into account the probabilistic nature of these forecasts (and not only the ensemble mean as previously), this section focuses on the probability distribution of yield anomalies forecasts.
Results for Germany and United Kingdom are shown on
Figure 3 and
Figure 4. Plot at the top illustrates the yield time series, the time trend (computed on the 8 past years, solid line) and the extrapolation for the expected time-trend of the current year (dashed line). Corresponding anomalies are highlighted on the bottom-right corner of the figure. The plots on the bottom part of the figures show for each year (1995-1998), the PDF of yield anomalies obtained from DEMETER-based crop yield simulations (the hatched area corresponds to the probability of negative anomaly).
For United Kingdom (

Figure 3), the 1996 positive probability (87%) and 1998 negative probability (96%) were accurately estimated. In both case, the main PDF peak is near the official yield anomaly (Eurostat figure, solid vertical line). One should emphasize that already in February (i.e. several months before harvest) the final yield deviance from the trend was forecasted accurately and with an associated probability to qualify it. For 1997 the forecasted yield anomaly is slightly over-estimated (actual negative anomaly from the official yield was almost 0.8 tons/Ha) and this was not clearly depicted from DEMETER-based crop yield simulations, but the negative sign of the anomaly was right (with a probability of 70%). In 1996 probabilities were more balanced (53% - 47%) and the main peak foresees a normal year (no anomaly, the observed yield is close to the trend), which was confirmed at harvest by official figure.

In Germany (
Figure 4) DEMETER-based yield simulations predicted correctly anomalies with a probability higher than 80% for 3 years out of 4. In 1996, simulations predicted the sign even if the yield itself is under-estimated (agreement of the whole ensemble, single peak). In 1997 the difference from the trend is very low (-0.05 tons/Ha) and DEMETER based simulations overestimates it (values of the ensemble mean around -0.15 tons/ha), but at least excludes a positive anomaly. The secondary peak of the bimodal 1998's PDF fits perfectly with the actual values (probability for the correct sign 82%). Similar results are shown in 1995, but slightly less accurate (lower probability for the correct sign: 62%).

4 Discussion

4.1 DEMETER hindcasts assessment

The previous evaluation of DEMETER-based yield forecasts was conducted by comparison against official figures and against traditional JRC forecasts. However other sources of errors independent from climatology could contribute to the deviances observed previously. Therefore, to assess the performance of the seasonal hindcasts independently of other sources of errors, ERA40 re-analysis data were used as "perfect forecast" to provide a reference. The differences obtained from ERA40 and DEMETER-based yield simulations could be considered as a measure of the bias of DEMETER seasonal hindcasts versus climatology.

Focus is given to southern countries where the largest discrepancies were found.

In Portugal, ERA40 and DEMETER accumulated precipitation (January to August) are very different. Correlation coefficients between re-analysis data and DEMETER ensembles range between -0.3 and 0.8 (around 0.5 with DEMETER ensemble mean). The error of ERA40-based simulations is 1.6 times lower than the average error of DEMETER based-yield simulations; highlighting the bias of DEMETER.

This result was unexpected since it was found (Cantelaube et al 2004) that in Portugal, wheat yield is correlated to one of the main patterns of European climate variability (similar to the Eurasian type-1 pattern of Barnston and Livezey 1987) which in turn is strongly correlated with El-Niño sea surface temperatures (SST) anomalies and which is highly predictable (Pavan et al. 2000). Consequently one could expect better performances of seasonal yield forecasts in Portugal.

In Greece the main correlation between wheat yield anomalies and the climatic European variability was found through a climatic pattern (East-Atlantic pattern described by Wallace and Gutzler 1981), which have a low predictability (Pavan et al. 2000). Thus, one could expect this low skill for DEMETER based yield forecasts in this country. In fact, the crop model driven by ERA40 data performs quite well in Greece (ERA40 error is in the range, or almost, of errors observed for most of other European countries; 6%), demonstrating the crop model ability to provide accurate results and the significant skill provided by the downscaling in this country. Thus, it point out that DEMETER hindcasts contributes significantly to the error observed for the yield simulations.

In Italy, climatic variability and winter wheat yield time series are not well correlated (Cantelaube et al 2004). In this country, ERA40 and DEMETER yield simulations are in agreement but far from official EUROSTAT yield (percentage errors: 13.5 and 15.2%).
Downscaling or crop simulation could be additional sources of error contributing to the poor performances in Italy. As a matter of fact, downscaling in this country is delicate due to complex orography and climate patterns are contrasted between the influence of Alpine climate in the North and the Mediterranean climate in the South. An analyse at a finest regional level would be necessary.

Finally, problems in Spain for 1995 and 1996 might biased conclusions coming out from this study (1995 was characterized by an exceptional drought, which finish during the winter 1995/1996, and this was not reproduced by DEMETER). DEMETER shows a very bad skill for these 2 years and since 2 years represent half of the studied period it is difficult to get reliable information about DEMETER performances through the crop yield simulations in this country (Note that some missing meteo data in the training set might have also affected the downscaling in Spain).

4.2 Probability distribution for yield anomaly forecasts

Contrary to other domain using probabilistic forecasts which can be simplified to a Yes/No statement (Rain/No rain, Flood/No flood), crop yield anomaly forecasts can not be verified by defining indices and scores based on statement like Hits, False Alarm, Correct or Missed. Crop yield anomalies forecasts are not categorical, and can not be simplified to an Observed/Not Observed event.
Reasons for that are: primarily the non binary and non symmetric aspect of a yield anomaly (the event “No positive anomaly” is not equivalent to the event “Negative anomaly”, since the yield could be “Normal” (close to the trend). Secondly, “no-anomaly/normal yield” means that the observed yield is “close” to values expected, suggested by the trend; and it suppose that thresholds need to be fixed to define this “normal yield” zone (for instance: the yield is defined abnormal if it is more than ± 2% higher than the expected trend). Finally if the positive and negative anomalies forecasts obtain from the simulation are balanced, it is difficult to take a decision. Is the event “Probability to have a negative anomaly of 52%” means “The ensemble-based yield simulation forecast a normal year” or “PDF of ensembles-based yield simulations has a bimodal shape with one peak negative and one positive (see Figure 5 left, simulations for Greece 1996) or can present a single peak centered on the null value, no-anomaly (Figure 5 right, simulations for Greece 1997: all ensembles agree on a no-anomaly situation). There is a difference between no-anomaly and no decision possible.

A plot permitting to summarise the results is presented in
Figure 6, reliability graph plotting probabilities of occurrence of negative anomalies against the actual anomaly (in percentage of expected value, i.e. the trend). Three observations are identified (lozenge) on the figure, (large errors in Portugal for 1995, 1997 and 1998), corresponding to important negative anomalies which were not depicted by DEMETER-based crop yield simulations (probability to have a negative anomaly is around 50%). Spain (square) and Denmark (triangle), both for 1995, are pointed out because the forecasted sign of the anomaly is false and associated with a high probability.

Figure 6 shows also that some of the biggest negative anomalies (in percentage) are associated to probability close to 50% (center part of the plot), indicating that either DEMETER has under-estimated the intensity of the anomaly (see Figure 3, United Kingdom 1997) either the simulations from the ensembles were scattered (see Figure 5, Greece 1996). However, the biggest positive anomalies are depicted with more accuracy (left side of the plot).
Furthermore, the figure shows that above a certain level of probability; for instance focusing on the probability to have an anomaly, either negative or positive, higher than 60% (it includes 70.5% of the cases); the sign of the observed anomaly was correctly depicted, with the only 2 exceptions of Spain and Denmark in 1995 (7% of false sign predicted). It means that forecasts with high probability are reliable enough to indicate the future yearly anomaly sign or at least to exclude correctly either a positive or a negative sign. As mentioned before, the difficulty lies in the cases of probabilities around 50%. However, more years of data would help to determine significant and reliable decision criterions.

5. Conclusion

Results from the integration of climatic seasonal forecasts in crop yield modelling suggest that reliable crop yield predictions can be obtained using an ensemble multi-model system.

An innovative tool has been developed within DEMETER project providing a reliable yield forecast earlier in the season. The evaluation of the DEMETER system in terms of what additional value can be obtained with regard to the actual operational system showed that yield predictions issued in February are globally more accurate than those made with the JRC operational system until July.

Furthermore, the use of ensemble seasonal forecast for crop yield estimates demonstrates that useful information can be obtained through the probability associated to the yield forecast and suggest that yield anomalies could be anticipated. Methodologies have been developed to fully exploit the information provided by the ensembles. Tools such as PDF permit to associate a probability to the forecast and thus provide indication of its reliability. In years and regions where there is little predictability, the resulting probability distribution will be broad, warning against specific precautionary actions. On the other hand, for years and regions where there is strong predictability, the probability distribution will be sharp, and reliable decisions for precautionary action can be made (management of agricultural markets, fixing set-aside programs etc…).

Gain in precocity coupled with (at least) comparable accuracy constitutes a potential for money save for the agricultural policy planners. Therefore further efforts in the field of crop yield seasonal forecasting are envisaged through the JRC participation in the ENSEMBLES proposal for EC-funding during the VIth Framework Program.

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Table

% of error		1995	1996	1997	1998	***Average***
Average ***(abs.value)***	JRC Feb	6.9	8.5	4.6	8.5	***7.5 %***
	JRC April	*8.3*	*8.1*	*6.3*	*7.9*	***7.7 %***
	JRC June	7.9	6.9	5.3	7.8	***7.0%***
	JRC Aug	*6.7*	*5.8*	*4.9*	*4.3*	***5.4 %***
	DEMETER	6.9	6.3	5.9	4.8	***5.9%***

Table 1 – Weighted Average Percentage error (from actual values) for JRC and DEMETER (ensemble mean) wheat yield forecasts for Europe (national level) excluding Portugal. Weights correspond to the contribution of each member states on the EU wheat production.

Figures legend

Figure 1 – Crop Growth Monitoring System and Yield Forecasting System at the JRC, current operational strategy and new strategy for seasonal forecasting.

Figure 2 – Bottom: Maps of difference JRC / re-analysis data ERA40 Raw (left) and Downscaled (right) for Rainfall in 1988 (cumulated January-end of July). Top: Maps of difference between biomass simulated using JRC data and raw ERA40 data (left) or downscaled ERA40 data (right), at the 3rd decade of July 1988 in Europe.

Figure 3 – Wheat yield time series (1987-1998) with anomalies associated for the last 4 years (top) and probability density functions (PDF) of forecasted anomalies with the DEMETER ensemble for the United kingdom 1995 to 1998 (bottom). United Kingdom is the third wheat producer in Europe with a yearly production upper than 16.000 Mtons (average 1995-1998).

Figure 4 – Wheat yield time series (1987-1998) with anomalies associated for the last 4 years (top) and probability density functions (PDF) of forecasted anomalies with the DEMETER ensemble for Germany, 1995 to 1998 (bottom), second main wheat producer in Europe (after France) with a yearly production upper than 19.000 Mtons (average 1995-1998).

Figure 5 – Probability Density Function for simulations made in Greece for 1996 and 1997.

Figure 6 – Reliability plot: yield anomaly forecasts from downscaled DEMETER ensembles plotted versus actual anomalies for the 44 simulations made in Europe for the period 1995 to 1998 (39 dots plus 5 identified outliers).

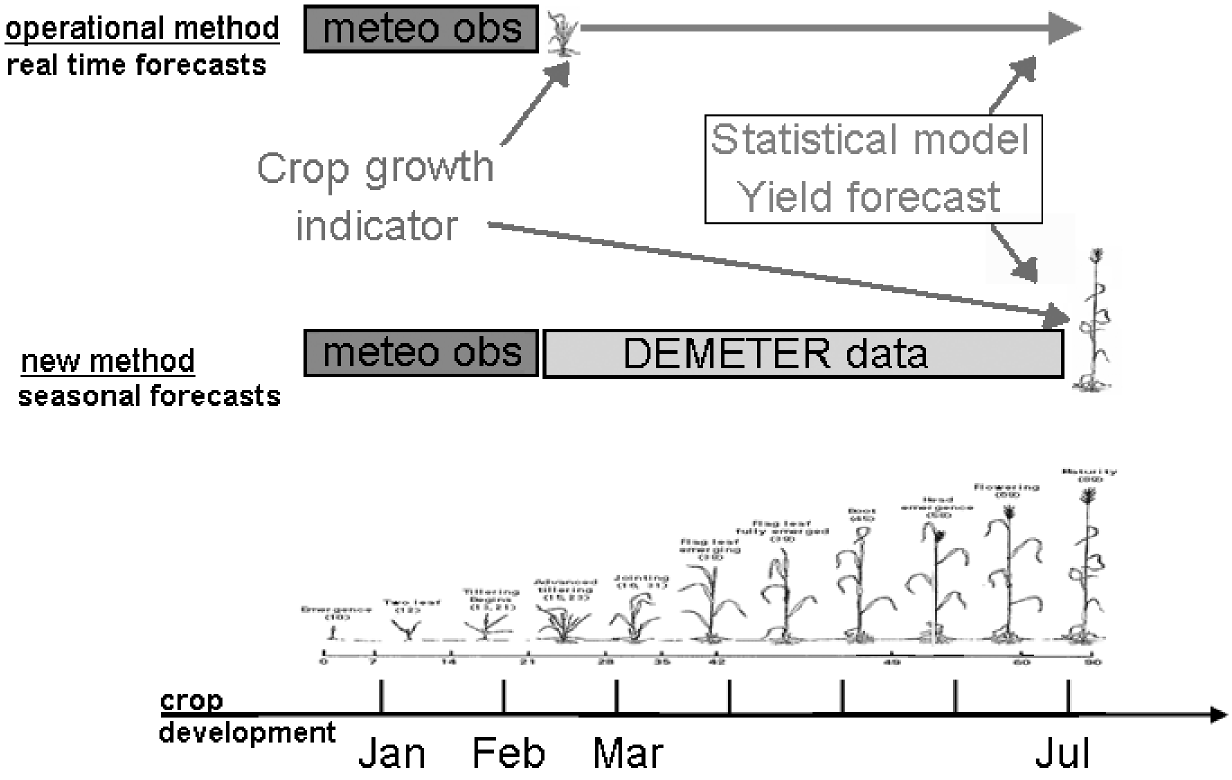
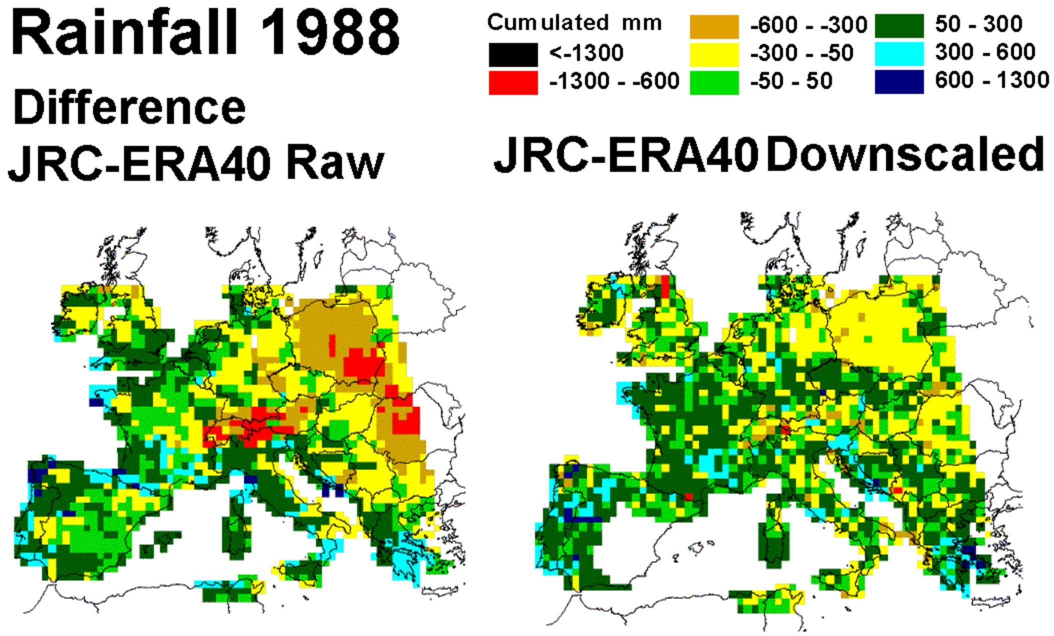

operational method
real time forecasts
meteo obs
Crop growth indicator
Statistical model
Yield forecast
new method
seasonal forecasts
meteo obs
DEMETER data
Emergence
Two leaf
Tillering Begins
Advanced tillering
Jointing
Flag leaf emerging
Flag leaf fully emerged
Boot
Head emergence
Flowering
Maturity
0
7
14
21
28
35
42
49
60
90
crop development
Jan
Feb
Mar
Jul

Figure 1


Rainfall 1988
Difference
JRC-ERA40 Raw
JRC-ERA40 Downscaled
Cumulated mm
<-1300
-1300 - -600
-600 - -300
-300 - -50
-50 - 50
50 - 300
300 - 600
600 - 1300

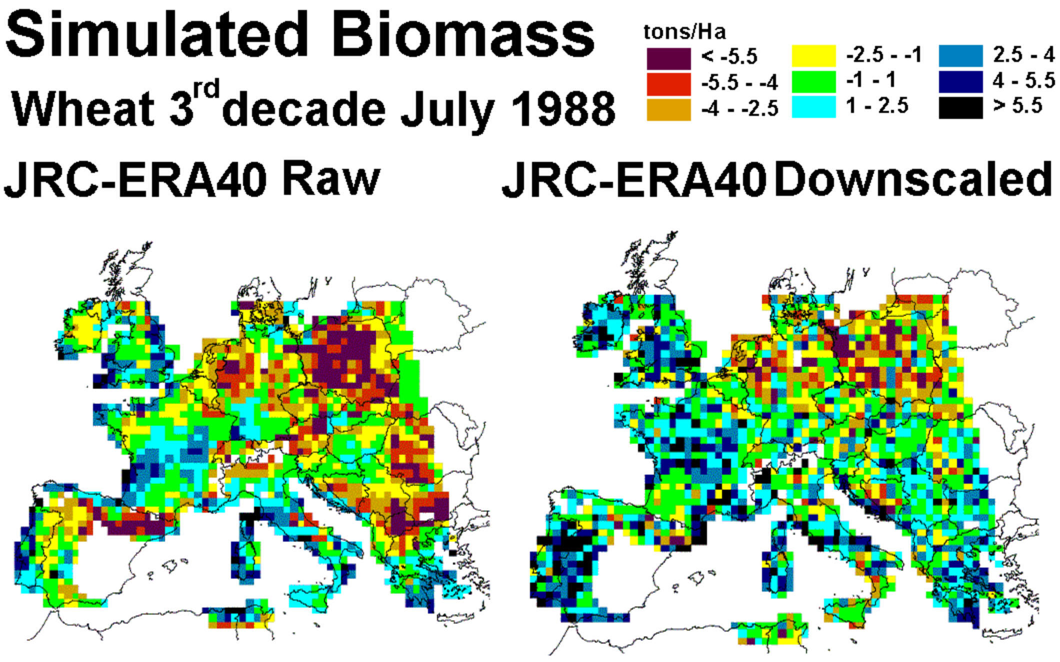
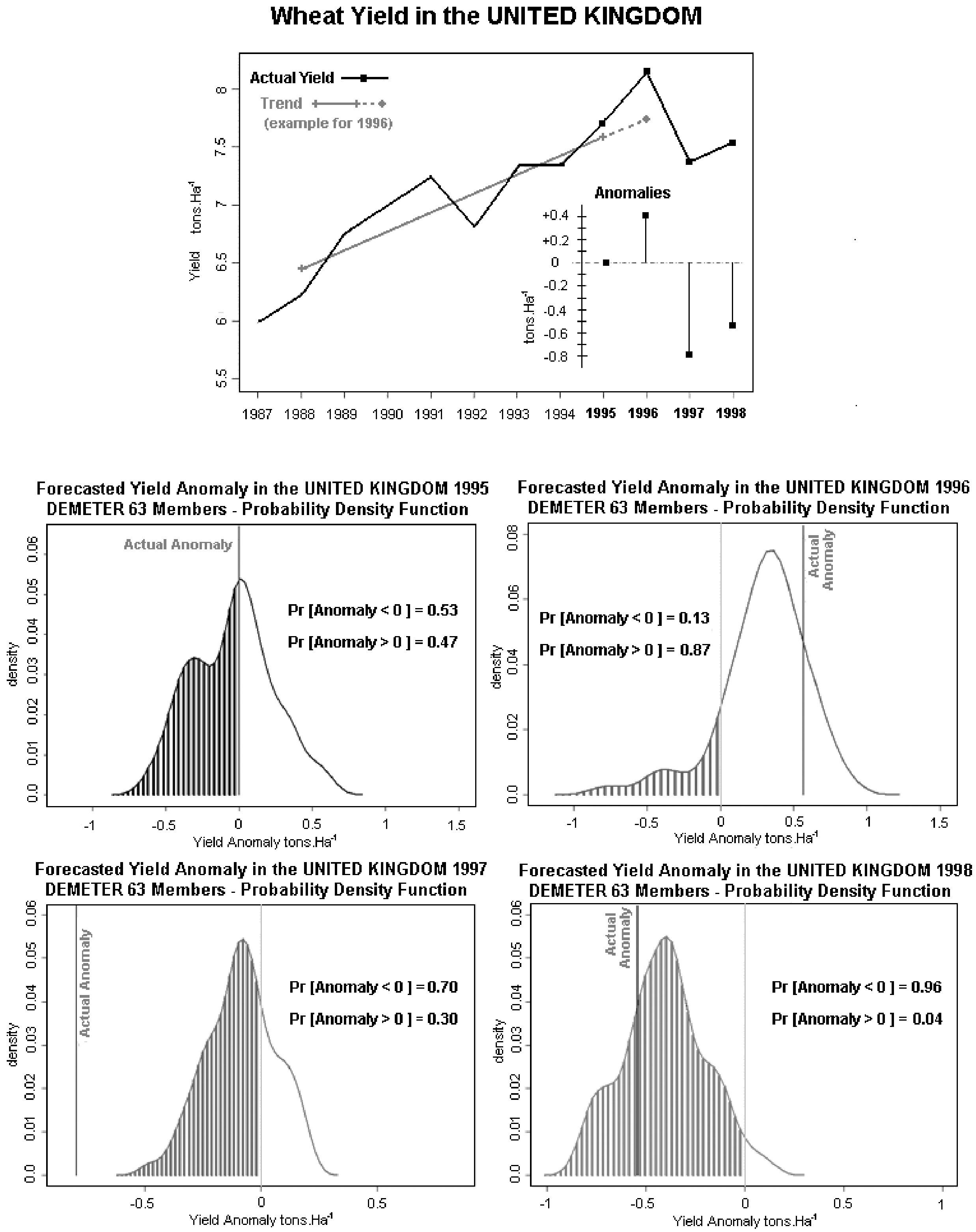

Simulated Biomass
Wheat 3rd decade July 1988
JRC-ERA40 Raw
JRC-ERA40 Downscaled
tons/Ha
< -5.5
-5.5 - -4
-4 - -2.5
-2.5 - -1
-1 - 1
1 - 2.5
2.5 - 4
4 - 5.5
> 5.5

Figure 2


Wheat Yield in the UNITED KINGDOM
Actual Yield
Trend
(example for 1996)
Yield tons.Ha⁻¹
Anomalies
tons.Ha⁻¹
+0.4
+0.2
0
-0.2
-0.4
-0.6
-0.8
5.5
6
6.5
7
7.5
8
1987
1988
1989
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1996
1997
1998
Forecasted Yield Anomaly in the UNITED KINGDOM 1995
DEMETER 63 Members - Probability Density Function
Actual Anomaly
Pr [Anomaly < 0] = 0.53
Pr [Anomaly > 0] = 0.47
density
Yield Anomaly tons.Ha⁻¹
Forecasted Yield Anomaly in the UNITED KINGDOM 1996
DEMETER 63 Members - Probability Density Function
Actual Anomaly
Pr [Anomaly < 0] = 0.13
Pr [Anomaly > 0] = 0.87
density
Yield Anomaly tons.Ha⁻¹
Forecasted Yield Anomaly in the UNITED KINGDOM 1997
DEMETER 63 Members - Probability Density Function
Actual Anomaly
Pr [Anomaly < 0] = 0.70
Pr [Anomaly > 0] = 0.30
density
Yield Anomaly tons.Ha⁻¹
Forecasted Yield Anomaly in the UNITED KINGDOM 1998
DEMETER 63 Members - Probability Density Function
Actual Anomaly
Pr [Anomaly < 0] = 0.96
Pr [Anomaly > 0] = 0.04
density
Yield Anomaly tons.Ha⁻¹

Figure 3

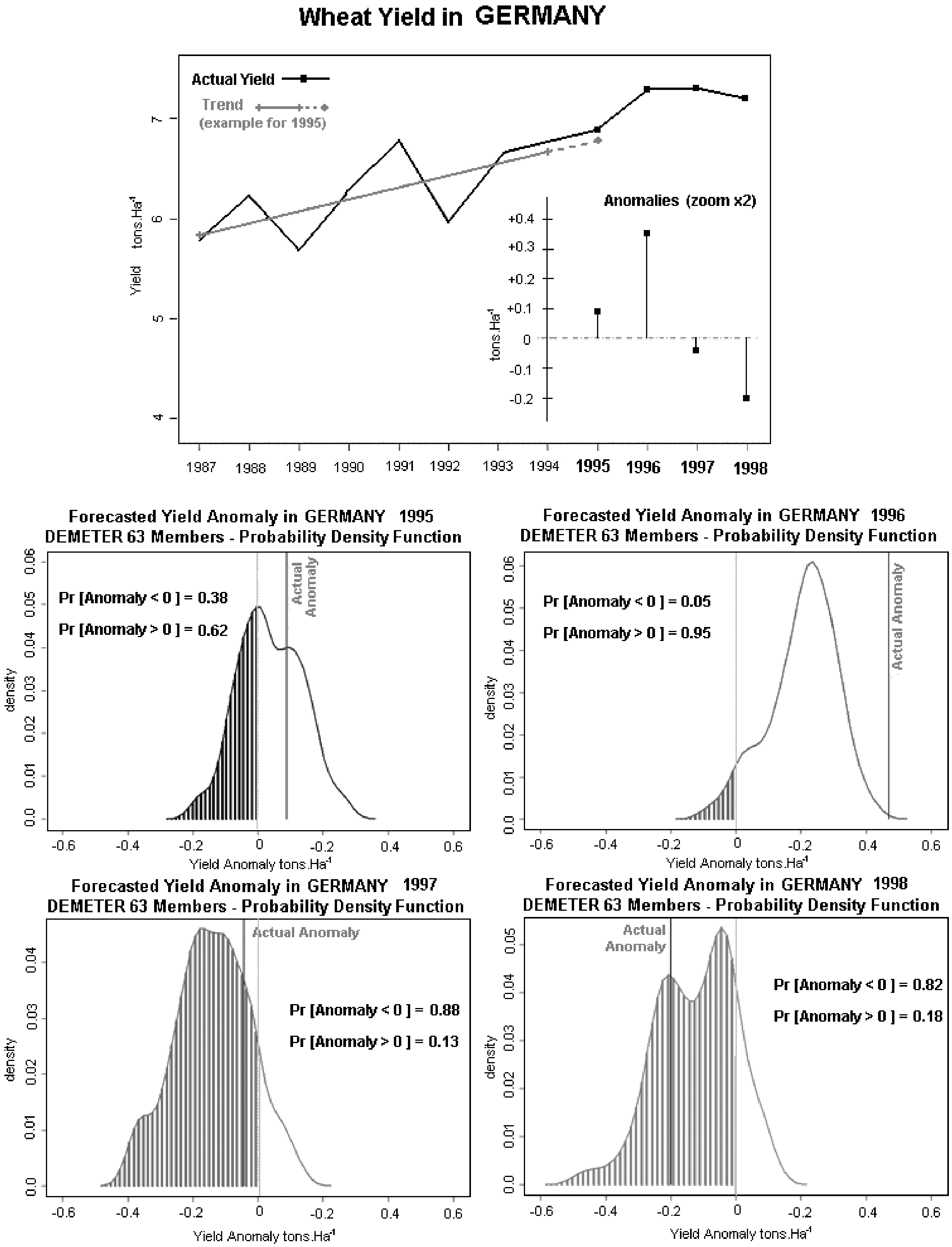
Wheat Yield in GERMANY
Actual Yield
Trend
(example for 1995)
Yield tons.Ha-1
4
5
6
7
Anomalies (zoom x2)
+0.4
+0.3
+0.2
+0.1
0
-0.1
-0.2
tons.Ha-1
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
Forecasted Yield Anomaly in GERMANY 1995
DEMETER 63 Members - Probability Density Function
Pr [Anomaly < 0] = 0.38
Pr [Anomaly > 0] = 0.62
Actual Anomaly
density
Yield Anomaly tons.Ha-1
Forecasted Yield Anomaly in GERMANY 1996
DEMETER 63 Members - Probability Density Function
Pr [Anomaly < 0] = 0.05
Pr [Anomaly > 0] = 0.95
Actual Anomaly
density
Yield Anomaly tons.Ha-1
Forecasted Yield Anomaly in GERMANY 1997
DEMETER 63 Members - Probability Density Function
Actual Anomaly
Pr [Anomaly < 0] = 0.88
Pr [Anomaly > 0] = 0.13
density
Yield Anomaly tons.Ha-1
Forecasted Yield Anomaly in GERMANY 1998
DEMETER 63 Members - Probability Density Function
Actual Anomaly
Pr [Anomaly < 0] = 0.82
Pr [Anomaly > 0] = 0.18
density
Yield Anomaly tons.Ha-1
-0.6
-0.4
-0.2
0
-0.2
0.4
0.6
0.0
0.01
0.02
0.03
0.04
0.05
0.06

Figure 4

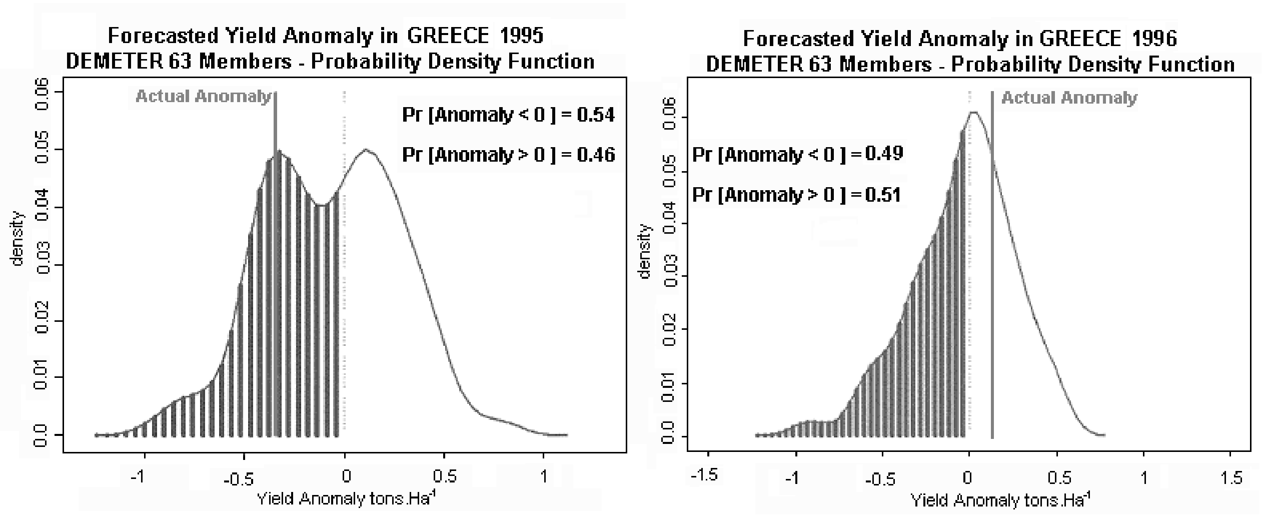
Forecasted Yield Anomaly in GREECE 1995
DEMETER 63 Members - Probability Density Function
Actual Anomaly
Pr [Anomaly < 0] = 0.54
Pr [Anomaly > 0] = 0.46
density
0.0
0.01
0.02
0.03
0.04
0.05
0.06
-1
-0.5
0
0.5
1
Yield Anomaly tons.Ha-1
Forecasted Yield Anomaly in GREECE 1996
DEMETER 63 Members - Probability Density Function
Actual Anomaly
Pr [Anomaly < 0] = 0.49
Pr [Anomaly > 0] = 0.51
density
0.0
0.01
0.02
0.03
0.04
0.05
0.06
-1.5
-1
-0.5
0
0.5
1
1.5
Yield Anomaly tons.Ha-1

Figure 5

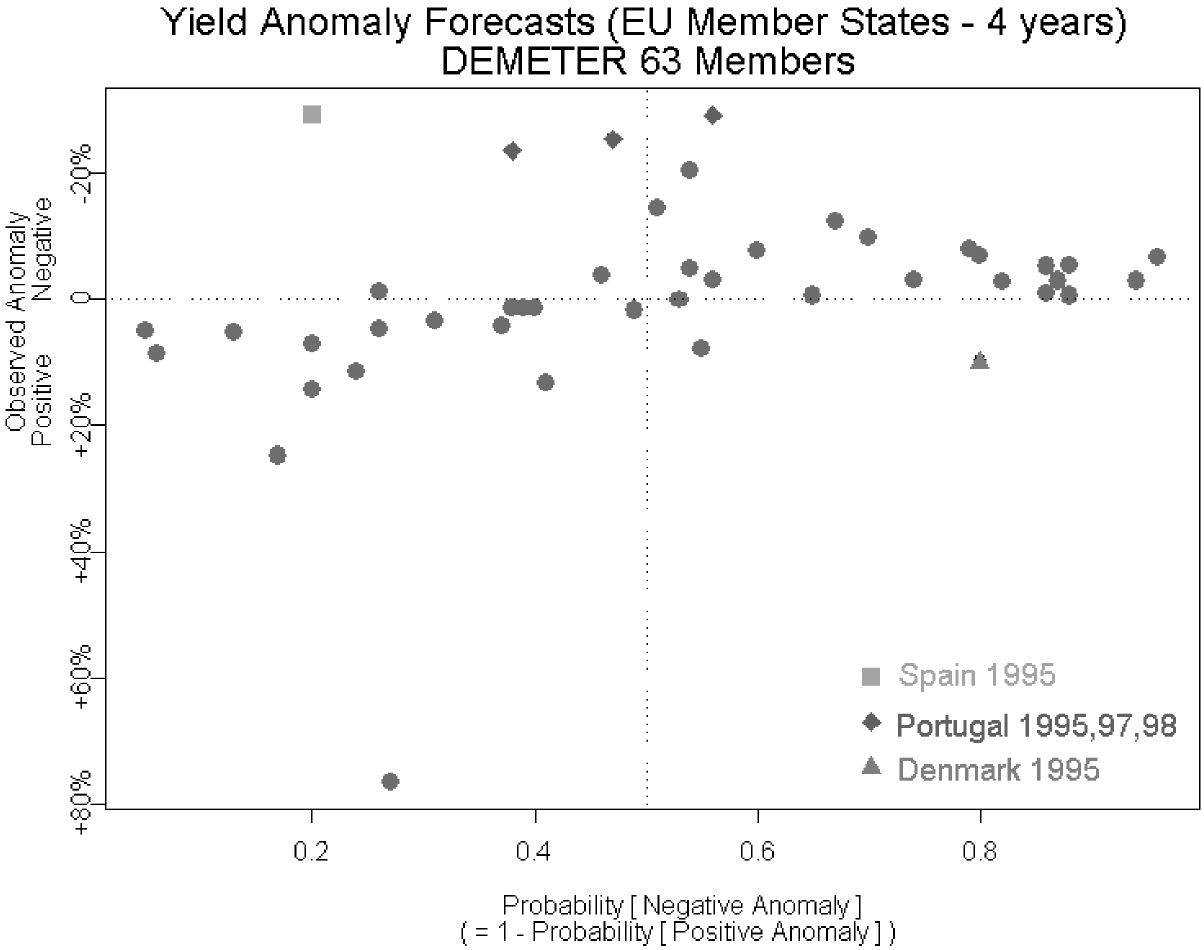
Yield Anomaly Forecasts (EU Member States - 4 years)
DEMETER 63 Members
Observed Anomaly
Negative
Positive
-20%
0
+20%
+40%
+60%
+80%
0.2
0.4
0.6
0.8
Probability [Negative Anomaly]
(= 1 - Probability [Positive Anomaly])
■ Spain 1995
◆ Portugal 1995,97,98
▲ Denmark 1995

Figure 6