
Report of the Foresight conference on Seasonal Weather Forecasting and the Food Chain

London, October 28th 1997

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The Foresight Programme

The UK's Foresight Programme was first announced in the 1993 White Paper '*Realising Our Potential*'. Its aim is to create sustainable competitive advantage and enhance the quality of life, by bringing together business, the science base and Government to identify and respond to emerging opportunities in markets and technologies.

The programme is spearheaded by sixteen panels, set up to explore opportunities in different sectors of the economy. In 1995 the panels published their first reports following widespread consultation. These reports aimed to identify:

- the likely social, economic and market trends that will affect the UK in the medium to long term
- the developments required in science, engineering and technology to best address future needs
- the implications for policy and infrastructure and for business investment strategies.

Foresight is about creating a culture change in the way that the UK approaches the future. It is about working together in partnership with other organisations, exploring the potential contribution that science, engineering and technology can make - for competitive advantage, for enhanced quality of life, and for sustainable development.

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Introduction

Seasonal weather forecasting for the food chain

Seasonal weather forecasting, up to say three to six months in advance, is becoming possible as a result of the rapid improvement in the quality of mathematical weather models, increasing computer power, and better insight into the causes of climate variations on a seasonal time frame and at a range of geographical scales.

Seasonal weather affects companies in the food chain in various ways. For example, farmers would be able to cut down on time, money and labour in the use of agrochemicals if better information was available about the coming months' weather.

Again, and more simply, hot weather can ruin a crop while simultaneously multiplying customer demand - effects which could in theory be profitably managed if the spell of hot weather could be accurately forecast at the time of planting the crop.

Reliable seasonal weather forecasts should help forward planning and enable the use of preventative measures, leading to increased profits for companies in the food chain, minimised impacts on the environment, and better quality and availability of products for the consumer.

Communication

In order that these benefits should be gained, the providers of meteorological data and the data users in food chain industries need to share their information. The aim of this conference was to initiate discussion so that each side was better informed of the other's needs and capabilities, and to explore the future opportunities for seasonal weather forecasts to benefit companies throughout the food chain: farmers and growers, manufacturers and processors, distributors, and food retailers.

This conference was organised by the **Agriculture, Horticulture & Forestry** and **Food & Drink Foresight** panels.

The rapporteur of the proceedings was Dr David Brooks, and this report was edited and produced by Juliet Griffin.

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The chairman

Dr John Sherlock is Head of the Agriculture & Food Technologies Division of MAFF and a member of their Chief Scientists Group. He is also a long-standing member of the Food & Drink and Agriculture, Horticulture & Forestry Foresight Panels.

The speakers

Martin Ashburn is Technical Services Manager of Levington Agriculture Ltd and a member of the Executive Council of the UK Irrigation Association. He also sits on the Water Resources Liaison Group, which was formed two years ago as a joint venture involving MAFF, the NFU, ADAS, the UKIA, the DoE and the Environment Agency, to discuss water resources for agricultural irrigation.

Dr Mike Harrison is the manager of the Predictability & Ensemble Forecasting Team at the UK Meteorological Office. He has spent many years in Southern Africa, mainly working on causes of interannual rainfall variability and seasonal forecasting for the region. He has been at the Met office for almost 10 years, for most of which time he has been responsible for the development of ensembles on all timescales, including the development of prediction on seasonal time scales.

Peter Macielinski was appointed to the board of Geest Foods Ltd in 1993, having joined the company in 1988: he was previously the Chief Executive of Burtons Gold Medal Biscuits Ltd. During his 7 years with the company the initially small chilled food and produce side of the business has increased, now generating an annual turnover of over £400 million, mainly from coleslaws and other vegetables.

Dr Tim Palmer is Head of the Predictability and Seasonal Prediction Section at the European Centre for Medium Range Weather Forecasts.

Professor Roger Plumb is the Head of the Crop and Disease Management Department at the Institute of Arable Crop Research (IACR). He is also the Deputy Director at the IACR at Rothamsted. He is a plant pathologist by training, specialising in viruses, with a particular interest in crop management.

Dr David Wurr has worked since 1972 as an agronomist at Horticulture Research International Wellesbourne on potatoes, Iceberg lettuce and brassicas, studying environmental effects on crop growth and development. He currently has responsibility for work on climate change, leeks, salad crops, potatoes, bulbs and ornamentals.

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Seasonal prediction studies using comprehensive numerical models of the atmosphere and oceans

Dr Tim Palmer, Head of Diagnostics and Predictability Section, the European Centre for Medium-Range Weather Forecasting (ECMWF)

It is now known that much of the world's weather is influenced by the interaction between the atmosphere and the ocean, and therefore any attempt to forecast seasonal weather must depend on the use of coupled ocean/atmosphere models. The paradigm for ocean/atmosphere interactions is the El Niño phenomenon in the tropical Pacific, which has a global impact, and understanding it is essential for seasonal weather forecasting.

El Niño

Normally, trade winds in the Pacific blow from east to west, causing an upwelling of cold water to the sea surface and concentration of warm water in the western Pacific. The resulting evaporation leads to thunderstorms in the western Pacific. During El Niño periods, the trade winds weaken, reducing the upwelling of cold water so that the warm water mass concentrates in the eastern Pacific, bringing storms to that region. Occurrence of the 1997 El Niño was successfully forecast by ECMWF, together with the correct prediction of abnormally dry conditions in SE Asia, severe storms on the west coast of the Americas and exceptionally heavy snow in the Andes.

Short-term forecasting

For forecasts up to 10 days ahead, it can be assumed that the sea temperature will be constant, and forecasts can be made from an atmospheric model (Fig. 1), using observations from satellites, balloons etc.

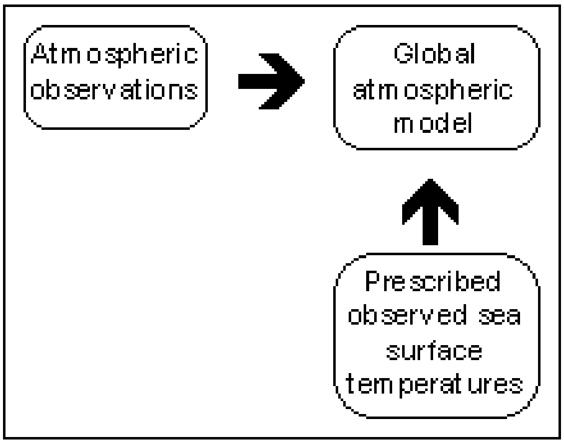

Fig.1: Schema of model for 10-day forecasts

Coupled-model forecasts

For longer term forecasts, it is necessary to consider changes in the sea as well, so the atmosphere model must be coupled to an ocean circulation model (Fig. 2).

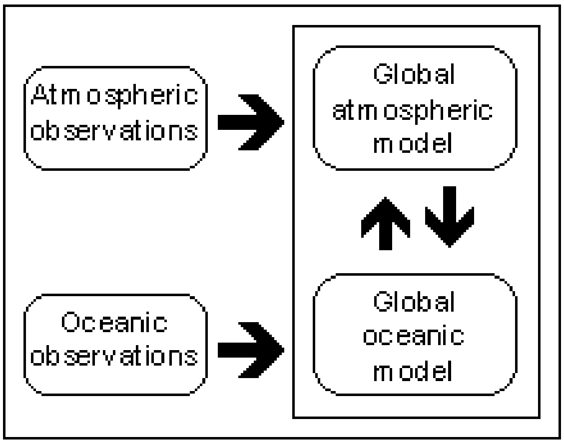

Fig.2: Schema of coupled atmospheric/oceanic model for seasonal forecasts

Data on ocean changes in the Pacific are provided in part from an array of buoys moored throughout the equatorial region of the Pacific. These provide daily data on water temperature (to a depth of several hundred metres), wind velocity and humidity, which are transmitted via satellite to global data centres, and used as initial conditions in the oceanic part of the coupled model. Atmospheric and land surface initial conditions are similarly fed in to the atmospheric part of the model.

Probabilistic forecasts

At ECMWF, coupled-model forecasts out to 6 months ahead are made three times a week. These predictions can be grouped together to form "ensembles" from which probability forecasts can be made (see Dr Harrison's paper on practical uses of ensemble forecasts).

Constraints

There are two major constraints to more accurate forecasting. Firstly the models are not perfect, are extremely complex and very demanding of finite computer time. Secondly, the atmosphere is a "chaotic" system, and therefore highly sensitive to very small changes in the initial conditions, which quickly leads to loss of predictability. Details cannot be forecast more than one week ahead. Longer term weather can therefore only be forecast in terms of probabilities, not as deterministic predictions.

Seasonal forecasts thus take the form not of specific forecasts, but of probabilistic statements of the likelihood of specific weather patterns occurring. A typical statement about seasonal weather might be: "anticyclone conditions will occur with a 10-20% higher than normal probability". The success of seasonal forecasts can only be judged using statistical measures over several seasons, and at best it will take several years for confidence in seasonal forecasts to be reliably established.

Forecasting for Europe

Because of the strongly chaotic nature of the atmospheric flow in temperate latitudes, seasonal forecasting for Europe is much more difficult than in equatorial regions. Even so, there have been some encouraging results such as the forecasting of heavier than usual rain in Southern Europe this summer.

The practical uses of ensemble forecasts

Dr Mike Harrison, Manager, Predictability and Ensemble Forecasting Team, UK Meteorological Office

Much of the current increase in interest in seasonal forecasting results directly from developments in our understanding of interactions between large-scale sea surface temperature anomalies (such as El Niño) and the atmosphere.

Existing projects

Expectations that current forecasting capabilities are already adequate for practical benefits to be gained are driving major projects such as PROVOST (Predictions of Climate Variations on Seasonal and Interannual Time Scales), the World Meteorological Organisation's CLIPS (Climate Information and Prediction Services) and the US IRI (International Research Institute for seasonal prediction), the latter two of which are in the process of developing systems for delivery of seasonal predictions.

Ensembles

Seasonal predictions, and more specifically probabilistic predictions, are based on ensembles. Ensembles of data are created by running forecasting models repeatedly using slightly different initial conditions. With modern computing power, up to 50 ensemble members can now be prepared in the medium range, but current seasonal systems normally use about nine members. These could be used in different ways, such as:

- Treating them as deterministic forecasts, for example by taking the mean of all the ensemble members (this is clearly wasteful of data)
- Grouping similar ensemble members and treating them as alternative deterministic scenarios; these could be provided for potential users who could decide how best to employ them
- Attempting to indicate the level of confidence in deterministic forecasts (but it may be difficult to phrase this usefully)
- Providing full probability density functions (pdf), i.e. all data from the ensemble, to users. The forecasts could be used to provide the direct likelihood of a weather event based on the pdf to a decision, or, probably better, by incorporating the pdf directly into the decision model - i.e. run a decision model for each ensemble member.

Profitable use of probabilistic forecasts Whether such predictions will be employed for crop protection strategies depends on the costs of the treatment and the likely losses resulting from lack of treatment. Treatment is desirable when the probability of a weather event likely to cause a loss is greater than the cost/loss ratio. Since the decision is based on probability, it follows that costs will sometimes be incurred unnecessarily; but this is also true for an imperfect deterministic system, and it can be shown that costs are minimised overall through the probabilistic approach. However, probabilistic decisions will be of limited value unless forecast systems are reliable, so that, for example, over many occasions when an event is predicted with a probability of 30%, then that event occurs on 30% of occasions.

The concept of "relative operating characteristics", where the hit rates and false alarm rates for predictions of an event of interest or concern are calculated, provides value guidance to the user on the potential benefits of the forecasts for that event - see table below.

Note: Hit Rate =Hits/(Hits +Misses): False Alarm Rate = False Alarms/(False alarms + Correct rejections)

		Forecast	
		Yes	No
Obser-vations	Yes	Hit	Miss
	No	False alarm	Correct rejection

Dialogue

It is very important that there is feedback between forecasters and users so that forecasters focus on providing what users need. Forecasters must explain what might be possible, and users must take on the responsibility of providing definitions of adverse weather, and appropriate values for costs of treatments and of losses. Forecasters must provide the best possible technology, and users must seek ways of adapting or adopting strategies appropriate to this technology.

Seasonal forecasts for the tropics

Several initiatives are in progress internationally to develop models with stronger user orientation. There are already areas of the world, mainly the tropics, for which forecasting is more reliable than for Europe and where seasonal forecasts are already considered to be sufficiently accurate for practical use. For example it is now possible to predict with quite high accuracy the likelihood of drought in sub-Saharan Africa, which should allow aid to be delivered when it is most needed, rather than after the worst of the crisis. In Brazil, seasonal forecasts are also sufficiently reliable to enable farmers to start to plan for anticipated drought. Lessons for Europe can be learnt from examining strategies applied in both areas.

SARCOF

One example of a project designed to bring together forecasters and users is entitled SARCOF (the Southern Africa Regional Climate Outlook Forum), a pilot scheme in which many of the issues of forecast creation and provision and estimation of benefits are being examined. It will test the benefits of a forecast created from a consensus of all the available skilled inputs to assist in determining the impact on Africa of the current El Niño event. It is believed that important lessons will be learned which could be applicable in Europe.

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The potential contribution of seasonal weather forecasts to crop management

Professor Roger Plumb, Head of Crop and Disease Management Division, Institute of Arable Crop Research, Rothamsted

The grower's objectives

The objectives of the grower of arable crops are to:

- decrease the unit cost of production
- maximise the value of the product
- comply with environmental legislation (and, if possible, concerns).

Weather forecasts for crop management

Short term weather forecasts or the accumulated weather of previous weeks or months already play a vital role in making crop management decisions. Deciding the time of fertiliser applications, the likely incidence of diseases, the need to control diseases promptly and the risks of the effectiveness of chemical treatments being lost due to the conditions following treatment are just some decisions in which weather is important.

Longer term forecasts

However, many of these decisions could be improved by a longer term view which is currently lacking. At present the grower must make an assumption that the weather conditions that follow any decision will be "average" - in fact the weather in the UK is rarely "average".

Weather dependent costs

Approximately £1 billion is spent each year on the variable costs of growing arable crops, mainly as fertilisers and chemical sprays, and much of this expenditure is weather dependent.

Examples of areas in which seasonal weather forecasts could help growers

Nutrient leaching

A wetter than normal winter increases the leaching of fertilising ingredients, especially nitrogen, and crops might therefore require larger applications in the spring; but farmers normally buy their fertiliser well before it is needed to ensure adequate supplies.

Soil condition
The workability of soils is critical, especially in the autumn. Prior knowledge of how long the soil is likely to remain in a suitable condition for cultivation and drilling would be of great value. Some drilling dates could be modified to ensure that crops were not too vulnerable to cold weather as a result of too early sowing in good growing conditions or too late sowing in bad. There is a tendency to drill some crops too early because of fear that conditions might be adverse for drilling later. For some crops, e.g. winter lupins, there is a very narrow window if the emerged crop is to be frost hardy.

Disease control
Some disease control decisions need to be taken in autumn, when the crop is accessible, but are based on how much disease is present and whether it develops, factors which only become apparent during the winter. For instance, to control the aphid vector of barley yellow dwarf virus, many farmers spray prophylactically (e.g. over 60% of winter wheat), but this could be avoided if it were known that winter conditions would be severe enough to kill off the aphid vector, thus obviating the need for chemical treatment.

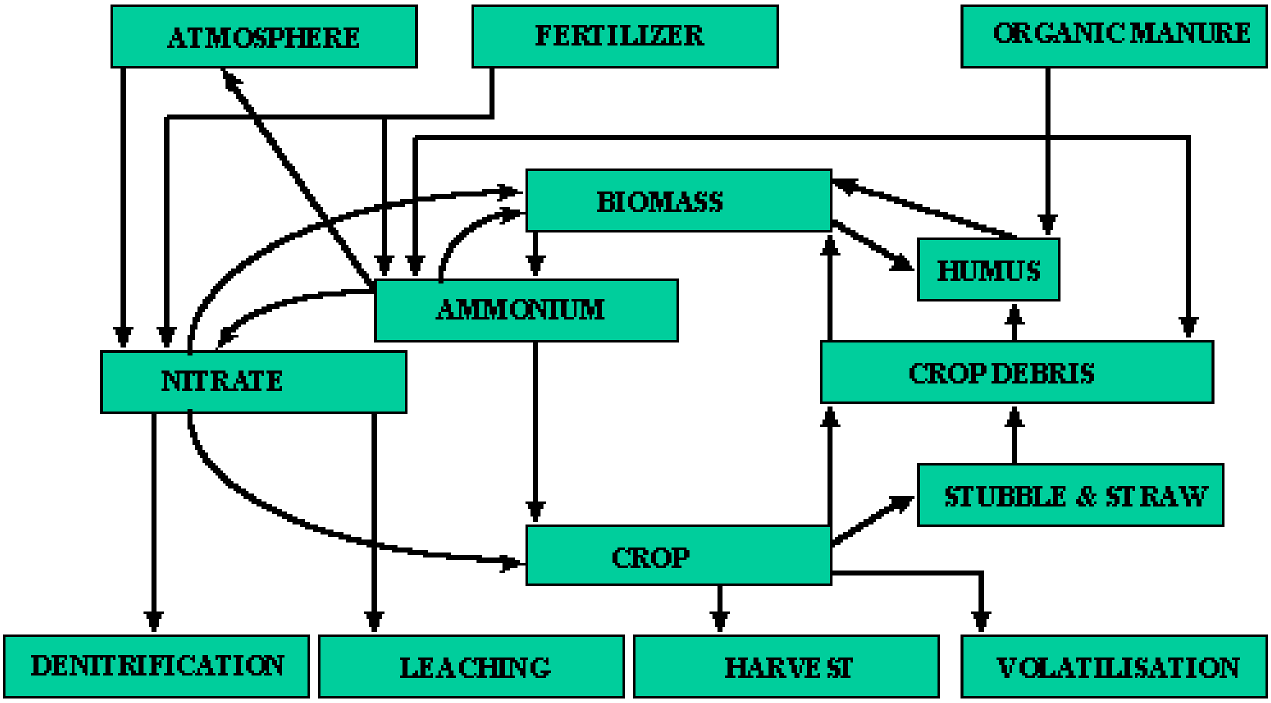
Weed control
Competition between crop and weeds is greatly influenced by growing conditions. In establishing treatment thresholds a knowledge of the weather up to harvest would be invaluable; in ideal conditions wheat, for example, can outgrow competition from the weed Galium aparine, thus eliminating the need to use herbicides.

Crop yield forecasting
Crop yield forecasting is important in planning harvesting, and processing, operations and would be helped by seasonal forecasts.

Other considerations include:

Delivery
Even if seasonal forecasts are reliable, they need to be delivered to the farm office where weather-related decisions are being taken. How this delivery is accomplished is a significant issue. Further, it is clear that the individual growers will only be satisfied by forecasts for their own farm (if then!).

SUNDIAL
There is increasing interest in developing crop husbandry models, for which forecast weather is almost always critical. An example is the fertiliser utilisation model SUNDIAL which is one of several models being developed for the integrated delivery system DESSAC (Decision Support System for Arable Crops). In the SUNDIAL model, which aims to estimate fertiliser needs and losses, most of the variables are driven by past and forecast weather. This model could use ensemble data, and it might be possible to incorporate Meteorological Office forecasts directly into the model.



The SUNDIAL model
diagram courtesy of Jo Smith, IACR Rothamsted

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Using weather to improve scheduling, prediction and management of horticultural crops

Dr David Wurr, Horticulture Research International, Wellesbourne

The horticulturist's objective is to supply the product at the right time, of the right quality and with the right uniformity. All of these requirements are affected by the weather, and involve aspects of crop scheduling, crop prediction and crop management.

Crop scheduling is a planning exercise which aims to organise sowing and transplanting of crops which are perishable and have limited storage life, to produce an orderly sequence of maturity. Conventionally it uses long-term average weather (climatological data) but with some crops there is an opportunity for predicted (forecast) weather to be used.

Example: Iceberg lettuce
For example, a detailed investigation of crop scheduling has been carried out for the Iceberg lettuce crop. Relationships between the times of transplanting and maturity have been investigated in a range of environmental conditions. If these are transformed to a day-degree scale then the resulting unifying relationship can be used to manage crop scheduling, and hence product supply, anywhere in the UK. This can be done using average weather but flexibility and relevance will be improved if accurate forecasts are available.

Crop prediction is mainly concerned with predicting the timing of maturity of crops and can use average weather, observed weather and predicted weather. It is important because the UK rarely has "average" weather and crop sequences get disrupted because crop growth is sensitive to short-term variations in temperature and light. Thus it is used as a complementary technique to crop scheduling to provide updated information on the likely pattern of product supply. This information indicates the quantity of crop available over time and shows whether there is likely to be over- or under-supply relative to required product volume so that marketing strategies can be adjusted accordingly.

Example: Broccoli
Another example is broccoli, where a computer model (BROCCOLI) predicting the timing of maturity has been developed to aid prediction of peak labour requirements, timing of pesticide applications and marketing decisions.

The important variables for constructing crop scheduling and prediction models are temperature, solar radiation and rainfall, and improved forecasts would be useful to the industry for the short term (hours), the medium term (days), and the long term (weeks).

Crop management
In the area of crop management, more accurate weather prediction would offer opportunities to:

- interactively modify crop scheduling as the season progresses;
- develop improved prediction systems for crop maturity;
- predict rates of crop deterioration or loss of marketability;
- delay transplanting to avoid deleterious field conditions;
- adjust transplant raising conditions to provide more consistent transplants;
- develop improved irrigation scheduling;
- optimise glass house crop environments: e.g. if solar radiation could be predicted, even hours ahead, carbon dioxide levels for tomato production could be optimised; similarly if temperature could be predicted days ahead, the cost of heating could be optimised;
- modify nitrogen application and timing;
- develop good predictions of yield;
- improve prediction of pest activity;
- improve prediction of disease incidence. The above collectively provide benefits throughout the food chain: for the grower by improving control of production, for the producer and retailer by improving security of supply and confidence, and for the consumer by improving quality and safety.

Types and sources of currently available weather data

- Average weather (climate) - the Meteorological Office
- Observed weather - can be obtained from the Meteorological Office, but increasingly is available from on-farm meteorological stations
- Predicted (forecast) weather - available from the Meteorological Office.

Many of the opportunities above are relatively well covered by existing research programmes and **the critical area requiring research now is the development of a software framework for scheduling to combine information on crop/weather interactions with better predictions of future weather.**

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Implications for water use

Martin J Ashburn, Levington Agriculture Limited

Irrigation
Irrigation is critical to the efficient production of UK crops: some 41% of potatoes, 22% of field vegetables and 16% of sugar beet are irrigated (though only 1% of cereals and less than 1% of grassland receives irrigation).

Water usage is highly regionalised, with the Anglia and Southern Trent areas accounting for 75% of UK usage.

Areas of concern
There are two main areas of concern: a reliable supply of water, and the agronomic considerations of water application to crops. Environmental factors, including public perception, are also important.

Competition for water resources
Water is a finite resource, so careful utilisation is essential. Both surface and ground water are regulated by the Environment Agency (previously the National Rivers Authority), who have a statutory responsibility to strike a balance between all users of these resources.

All individual farmers and growers who hold licences to abstract water for agricultural spray irrigation have to take their place alongside the demands for water by other users: domestic water supplies, large industrial consumers, recreational users and the environment. Competition is intense and resources scarce across much of the UK, particularly East Anglia. After a series of winters when rainfall has been as little as 30-40% of normal many farmers are most anxious about the continued reliability of supply.

Factors affecting demand
On a national scale, irrigation is a small user of water (usually reckoned to be less than 2% of the annual total), but there are some specific factors which dramatically affect the water supply required. In particular:

- the relatively short season over which irrigation takes place: often as little as 8 weeks but sometimes up to 6 months each year;
- the fact that irrigation is a consumptive use of water, all the applied water being lost through evapotranspiration;
- most irrigation is often needed when resources are at their lowest and being most

stretched, i.e. in hot dry weather, which particularly affects surface water supplies.

At farm level, the task of planning and managing irrigation is particularly difficult, given:

- The very variable nature of the British climate, and hence the wide variation in irrigation needs and evapotranspiration rates - this can be as high as 6mm per day, necessitating application of water every four days. Depending on the season, sugar beet, for example, might require 0-300mm of irrigation water

- The wide range of cropping on many farms, and the variable response of different crops. The financial return from irrigation might range from some £1.57 per hectare on winter wheat to £24.80/ha for raspberries. Irrigation can also influence disease occurrence - for example it can be used to reduce scab in potatoes

- Cost considerations. The capital costs of irrigation might amount to £200-400/ha, and the total variable cost to £3-5/ha (of which the cost of the actual water is only 2-7%).

The decision whether or not to irrigate during the season must take into account many factors, including:

- water availability (which might change during the season);

- crop priorities;

- an assessment of the water loss day to day and field by field;

- an assessment of the penalty for getting the decision wrong;

- when to start and stop by field.

This decision might be taken by "kicking the soil and guessing", by on-site measurement (for example with a neutron probe), or by employing specialist advice.

Improved seasonal forecasts could be used to increase the efficiency of water resource utilisation in agricultural irrigation at the regulatory level by:

- helping advanced planning (e.g. water levels are low now: what will the winter bring?);

- assisting local resource management;

- avoiding unexpected restrictions;

- helping justify resource development;

and at the farm level by:

- helping advanced planning (e.g. will restrictions occur?);

- helping tactical decisions during the season;
- avoiding water waste.

Ideally forecasts would project six months, to allow full seasonal planning at national and farm level - three month forecasts would still be useful in allowing updated rolling plans and modifications to strategy.

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Weather and the food business

Peter Macielinski, Managing Director, Geest Foods Limited

Weather has a universal impact on the food industry, affecting production, sales, marketing and quality.

Economic importance
If weather could be forecast precisely, there would be an enormous benefit to the industry. It is estimated that Geest's profits could increase by 160%, worth some £32 million.

Seasonal forecasts would have to be specific and reliable. Because of current lack of confidence in the reliability, most managers will not take decisions based on longer than 2-3 day forecasts. From past statistics, reasonable forecasts of coleslaw demand, for example, can be made in mid-January, but managers will not risk using this in their planning. Any longer term forecast based on probabilities would have to match the accuracy of 2-3 day forecasts.

Weather's influence on consumer demand
The weather can cause huge swings in buying patterns, with both short term and seasonal effects. People drink more soup when it is cold, and eat more salads when it is hot. This causes major problems in sales logistics and marketing efficiency as well as maintenance of quality.

If the weather is hot and sunny in May, the demand for "wet" salads (coleslaw etc.) might rise by 350% in one day, and "dry" salad by 250%. Retailers typically place orders late in the afternoon for delivery early the next morning. To cope with such sudden peaks, extra labour must be employed, at a time when the lettuce yield might have been reduced and the outer leaves browned by the weather (more labour is then required to remove the unusable leaves, and more waste is generated). Yet the public would resist a price increase to compensate for the extra costs.

Effects on processing
Some weather-related changes are more subtle. For example, small weather-related changes in flour quality, which are not easily detected, can be sufficient to alter the efficiency with which the flour can be processed, bringing production runs to a halt. Such changes might be specific to the crop from individual fields.

Strategic considerations
The massive operational difficulties caused by the vagaries of the weather necessitate strategic solutions. For example, to reduce risks in the "dry" salad business, large critical

mass is needed. If this cannot be achieved by organic growth, it might necessitate heavy investment, acquisitions or strategic alliances. These have to be chosen carefully to minimise weather effects. For example, when Geest were planning production in Spain, local advice was taken on the micro-climate of individual fields to minimise risk.

Because of its large size (turnover £460 million), Geest is able to use its ability to cope with the weather, by spreading production, as a source of competitive advantage; an advantage which would be lost if accurate weather forecasting created a level playing field for smaller competitors.

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Discussion

Representatives of the forecast providers Weather Action were present at the conference and asked the delegates to consider the importance of sunspot activity to forecasting, as well as the terrestrial weather system.

It was noted that global warming was incorporated into the weather models because they took into account carbon dioxide levels; the models might not be suitable for predicting long term climate change, however.

The Meteorological Office was looking at the possibility of publishing forecasts for the relatively short term (three to ten days) as they currently did for a thirty-day period. Such short term information was already provided to some retailers, but the Met Office would like to involve representatives of the whole supply chain in discussions.

World weather was important because many businesses relied on crop imports. Since El Niño effects could be predicted with high confidence in some regions, companies with global interests might be able to make use of seasonal forecasts in the tropical areas of their operation. This might be relevant for strategic decisions, and could help in reducing losses due to weather calamities.

The use of seasonal forecasts for the UK

The company representatives present commented that the usefulness of probabilistic forecasts depended on their timescale. Data providers estimated that at the moment the limit was likely to be 2-3 seasons (6-9 months) for El Niño influenced weather, but seasonal forecasting was more difficult in the UK than in the tropics and the reliability of such forecasts for Europe would need to be tested to see how they compared to the climate norms. Forecasts of the weather anomalies in 1997 had been quite good. (The reliability of models was verified by comparing "hindcasts" of seasons with observed conditions). Forecasts approaching 100% reliability were unlikely. What needed to be established was the degree of usefulness which could be expected from forecasts with different levels of reliability. A continued and enhanced dialogue between forecasters and users was needed to determine the priorities for further development of seasonal forecasting, and a new forum for such discussions was needed. There were existing barriers. It was remarked that it would be helpful if users of weather data could be allowed access to Meteorological Office data at an earlier stage, in order to test experimental applications, rather than having to wait while the Met Office established their suitability for a commercial product.

Probabilistic forecasts

There would be advantage for growers in being more flexible in their use of forecasts, and starting to think in terms of probabilities rather than predictions. They were already used to taking decisions in areas of uncertainty and should be able to adapt to the use of probabilities. The level of probability at which a producer would take a major decision depended on a number of factors including his/her risk averseness, the cost of the action, and the perceived risk of not performing it. Probabilities would be particularly useful if built into decision support systems. They might also be of help to suppliers in making a weighting on whether to use the information in planning.

Forecast requirements

From the other side of the dialogue, the data providers were keen for the users to provide them with specific forecast requirements. These needed to be quite detailed: for example, "temperatures must not exceed x degrees for y weeks". The next step would be for the forecasters to assess their capability of providing this information and with what reliability (probability), and users could then comment on whether the probabilities are adequate. In many cases there was not sufficient basic information on crop agronomy to specify the required weather information. However, it was possible to define fairly precisely the detailed forecast requirements for some crops:

- Knowledge that the weather would be one per cent above the normal average for the next six weeks, for instance, might be very useful. For the lettuce crop, temperature was an important factor, since plants integrated temperature well.

- It was remarked that winter weather tended to be a neglected area compared to other seasons; yet it was critical for UK arable crops which are 80% autumn sown.

- Growers also needed to know not only the probability of general conditions, but also the risk of significant deviation from this. For example, the number of days in which the temperature fell below zero in a forecast period might be more important than the average temperature (for example for pest destruction).

- The occurrence of frost was crucial too, as a single frost could destroy a lettuce crop.

- Similarly it would be important not only to know the likely total rainfall over a period, but how much of this was likely to fall as heavy rain (which caused splash dispersal of some fungal spores).

Suggestions for action

It was suggested that following the example of the Southern Africa pilot scheme SARCOF, six pilot areas could be chosen for focused studies of the crop/weather requirements from forecasting in the UK. A good sector to choose for a pilot study was agreed to be the glasshouse sector, where growers could accurately control conditions and have a chance to change them in response to the forecasts of, say, a certain number of hours of sunlight per day. The sugar beet industry was suggested as another useful guinea pig given that there were strong links between researchers and growers, and the processors were involved in modelling and forecasting. It was agreed that future studies should endeavour to involve more of the potential users of seasonal forecasts from food chain businesses, since they had been under-represented at this conference.

Conclusions and action

It was agreed that Professor Colin Dennis of the Campden & Chorley Wood Food Research Association would organise and host further work, taking forward the suggestions that users should develop detailed accounts of their requirements for seasonal weather forecasts in order that data providers could aim to produce targeted, specific forecasts.

Liaison on scientific detail between weather forecasters and agricultural scientists should take place by direct contact.

Appendix: Conference participants

Martin Ashburn	Levington Agriculture Ltd
Dr Richard Baker	Central Science Laboratory
Kourosh Bamsi-Yazdi	Weather Action
Dr J Biddulph	IACR - Rothamsted
Mary Bosley	The Albert Fisher Group plc
Jon Boxall	IACR - Rothamsted
Dr David Brooks	Consultant
Adrian Buckland	ADAS Wolverhampton
Ian Cochran	Rhone Poulenc Agriculture
Nigel Collins	NERC
Colin Creese	Grower Marketing Services
Gordon Dailey	IACR - Rothamsted
J Dempsey	UAP Ltd
Prof Colin Dennis	Campden and Chorleywood Food Research Association
Dr Nigel Dungey	Van Heyningen Bros Ltd
Tijs Gilles	IACR - Rothamsted
Dr David Gray	Horticulture Research International
Richard Harden	Kentish Garden Marketing Ltd
Dr Mike Harrison	UK Meteorological Office
J Hilton	Morley Research Centre
Dr Martin Hims	Central Science Laboratory
K Jaggard	IACR - Brooms Barn
Patrick Jarvis	British Sugar PLC
E Johnson	G.S. Shropshire & Sons
Julie Jones	Horticulture Research International
Dr R Kennedy	Horticulture Research International
Ian Kent	Dalgety plc
Peter Kettlewell	Harper Adams College
Cathy Knott	Processors & Growers Research Organisation
Dr William Lahoz	Centre for Global Atmospheric Modelling
Martin Lainsbury	Morley Research
Dr John Law	NIAB

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Dr S Lucey	Horticulture Research International
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Nicholas Marston	Kentish Garden Marketing Ltd
George Marston	Tesco Stores Ltd
David May	Tesco Stores Ltd
Dr J Mayes	Institute of Arable Crops Research
Dr David McIlroy	Master Foods
Ingrid Meakin	MAFF (Chief Scientists` Group)
Dr E Moorhouse	Mack Multiples Division
Dr Tim Palmer	European Centre for Medium-Range Weather Forecasts
Dr S Parker	ADAS
Dr John Pidgeon	IACR - Broom's Barn
Prof Roger Plumb	IACR - Rothamsted
John Prichard	Grower Marketing Services
Andrew Rush	Weather Action
Teresa Rush	Farming News
Neil Runnalls	Institute of Hydrology
Dr Gregory Sage	PBI Cambridge
Larry Saunders	The Grower
Dr Alan Seal	MAFF (Chief Scientists` Group)
Dr John Sherlock	MAFF (Chief Scientists` Group)
Dr Julia Slingo	Centre for Global Atmospheric Modelling
Graham Smith	National Remote Sensing Ltd
Julie Steed	IACR
Simon Thirkell	J Sainsbury plc
Dr Roger Turner	British Society of Plant Breeders
P Verrier	Institute of Arable Crops Research
Melvyn Wallis	Weather Action
Steve Walton	Horticulture Research International
Alan Wilson	Waitrose Ltd
Dr David Wurr	Horticulture Research International
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Dr David Rawlins	Office of Science & Technology
Juliet Griffin	Office of Science & Technology
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