

Foresight

Seasonal weather forecasting for the food chain

Interim report April 1999:

Responses to the CCFRA requirements document

Executive summary

Introduction

As a result of a Foresight workshop held in April 1998 at the Campden & Chorleywood Food Research Association, a document was produced, entitled *Seasonal Weather Forecasting and the Requirements for the Food Supply Chain* (J. D. Selman & C. Dennis, eds). The workshop brought together representatives of companies and organisations operating at different stages of the UK food chain (agrochemical companies, growers, manufacturers and retailers) with the aim of considering what information food chain companies would need from forecasters in order to make serious business use of seasonal forecasts.

In October 1998 the requirements document was sent to forecasters and academics working in the field of seasonal weather forecasting for their responses, which are here collated, in an unedited format. This collection is intended to be read in conjunction with the CCFRA report and with the report of the initial Foresight workshop held in London in October 1997.

The responses

Responses were received from:

Dr Maureen Agnew, Senior Research Associate, Climatic Research Unit, University of East Anglia:

More information is needed about the requirements of manufacturers, distributors and retailers as opposed to agribusinesses. However, this information may be hard to obtain due to the commercial sensitivity of the information involved. The present fragmented nature of commercial research also presents a barrier to general understanding of the influence of weather on businesses in the food chain.

It is important to assess whether the high level of accuracy required by the food industry for long-term seasonal forecasts can be met by the meteorological community. In view of this, a useful area of the food chain to concentrate on might be chilled goods and short shelf-life products. These are reported to be particularly weather sensitive, have speedy throughputs in the chain and require only short-term weather forecasts.

Professor Richard Ellis, Head of Department of Agriculture, Reading University:

A good focus for action would be working on ways of relating the timing and quantity of agricultural inputs to both short and medium term weather forecasts, with the aim of reducing the costs and, more importantly, the environmental problems of food production.

The link between disciplines is the main barrier to the use of forecasts.

Dr David Gray, Acting Director, Wellesbourne Site, Horticulture Research International:

Future needs for weather data will be limited without continued development in the important area of crop-related research, which provides the information linking "providers" and "users" by generating appropriate algorithms and models of growth processes.

It would be useful to involve growers who have experience of supplying crops week by week throughout the year from successional sown crops in the UK and abroad, and to include discussion on crop growth models, the design of crop scheduling and the use of crop maturity prediction systems.

Dr Mike Harrison, Predictability & Ensemble Forecasting Team, UK Meteorological Office:

The way forward may be to work in very small groups in order to try and establish a common language/understanding concerning the necessarily probabilistic nature of seasonal weather forecasts.

Dr Tim Palmer, Head of the Predictability & Seasonal Prediction Section, the European Centre for Medium-Range Weather Forecasts:

It is important to realise that seasonal prediction is necessarily probabilistic and is a product of a specific process known as ensemble forecasting, which takes account of the chaotic nature of the various factors influencing the weather. The process gives rise to forecasts which predict, for instance, not that it will be warmer than average but that there is a 70% chance that it will be warmer than average.

The crucial question which must be answered if probabilistic forecasts are to be used in business decisions is what should the user do when given less than 100%

probabilities? These questions go beyond meteorology and can only be answered by coupling the seasonal forecast output to a user-specific decision model analysis. It will almost certainly be possible to develop strategies which can use the probabilities in such a way as to optimise business decisions. The next stage of the Foresight work could be to work with a small group of potential users to consider these questions in greater depth.

Dr Lester Simmonds, University of Reading

There will often be a large gap between what forecasters can predict and what users need to know in order to make decisions, especially in cases where the effects of weather are indirect. There are two approaches which could be tried to bridge this gap. The first is the use of expert systems based on the experience of the practitioners. The second is the application of appropriate process-based models.

Forecasts for any further than a few days into the future will not be able to predict daily weather, so users will need to find ways of using forecasts of a more general nature, predicting average weather over a period. One possibility might be to run a number of simulations of a process model using a number of weather predictions falling within the range forecast by the data providers.

The method of communication described in the appendix to the document might well be a powerful tool in bridging the perceived gap between the format in which forecast data is provided and the needs of the business user.

Dr Leonard Smith, Oxford Mathematical Institute

To gain the maximum benefit from seasonal forecasts users need to develop decision-making systems which harness the entire amount of information provided by the probabilistic ensemble forecasts. These forecasts are ideal for use in answering questions such as "Which stores are most likely to run out of soft drinks given their current stock and the likely extent and pattern of the current heat wave?": the interconnectedness of many different variables allows ensemble forecasts to address cost/benefit questions much better than a traditional single (yes/no) forecast can.

Several areas of the food chain, for instance distribution and retail operations, could already be benefiting from improved processing of currently available forecast information.

One way in which companies might choose to use forecast information is to gather it from the providers and then process it in-house, using user-specific systems models to analyse it and to feed in data about similar conditions in previous years to provide an accurate and continuously updatable decision support system. The cost of the raw data will vary and users may wish to combine data from more than one provider, possibly looking only at summary reports and warnings rather than the entirety of the forecasts.

Dr David Wurr, Crop & Weed Science Department, Horticulture Research International

There is a need for the development of generic risk analysis techniques which can be applied throughout the food chain.

Conclusions

The responses agree that this is a very useful area of work, and that real benefit to UK businesses could result from the development of ways to use reliable seasonal weather forecasts as part of the decision-making process of companies in the food chain.

Except in a few areas, forecasters feel that the requirements listed in the CCFRA report are not yet specific enough to enable them to understand fully the needs of food chain businesses. Also some of the requirements listed in the report are felt to be extremely optimistic, even looking some way into the future.

It is thought that in some areas organisations could already be making business decisions on the basis of existing forecasts. However in many areas of the food chain it will not be possible to make business decisions simply by examining the seasonal forecast data on its own: it will be necessary for the information provided by forecasters to be fed into expert system models. Some such models already exist, for instance those for crop scheduling, and similar ones could be developed for businesses further down the supply chain – manufacturers, distributors and retailers. Further work in this area should involve the designers of these models, as the practical means of incorporating weather data into business decision-making, and could also include work on the development of decision models for businesses at the retail end of the chain.

It is clear from many of the responses received that one of the next steps in this work is to develop a common understanding of the probabilistic nature of seasonal weather forecasting. Forecasters will need to work with systems modellers and business people to explore ways of harnessing the particular type of information offered by ensemble forecasts. The general recommendation is that this work would best be undertaken by small groups rather than in large workshops.

Juliet Griffin, Foresight, April 1999

Introduction

As a result of a Foresight workshop held in April 1998 at the Campden & Chorleywood Food Research Association, a document was produced, entitled *Seasonal Weather Forecasting and the Requirements for the Food Supply Chain* (J. D. Selman & C. Dennis, eds). The workshop brought together representatives of companies and organisations operating at different stages of the UK food chain (agrochemical companies, growers, manufacturers and retailers) with the aim of considering what information food chain companies would need from forecasters in order to make serious business use of seasonal forecasts.

In October 1998 the requirements document was sent to forecasters and academics working in the field of seasonal weather forecasting for their responses, which are here collated, in an unedited format, along with an Executive Summary which presents the main points raised by the responses. This collection is intended to be read in conjunction with the CCFRA report and with the report of the initial Foresight workshop held in London in October 1997. [\(1\)](#)

Your comments on this work are warmly invited.

(1) - Copies of all three documents are available from the Food Chain & Crops for Industry Team online at www.foresight.gov.uk, along with information on progress with this activity.

The responses

Dr Maureen Agnew

Senior Research Associate, Climatic Research Unit, University of East Anglia

General comments

- Very much needed area of research and I would therefore encourage the Office of Science and Technology to continue with this programme.
- Information on weather forecast requirements for different components of the food chain are extremely unbalanced in favour of the agri-businesses. The dearth of detailed information for manufacturing, distribution and retailing components is very clear.
- **Data:** The main problem in conducting research in this area is the issue of commercial sensitivity. Very little data on retailing and manufacturing activities are available in the public domain and it is therefore extremely difficult to undertake research on weather sensitivity. The data that are available are very general, i.e., at a monthly and national level, and for large product groupings which include food items which respond in different directions to the same weather conditions. It is therefore very difficult to perform analyses at the level required to understand the impact of weather on individual food/drink items.

- **Co-operation:** The successful application of weather information to supply chain management would require a tremendous amount of co-operation and co-ordination between the linking components. I have doubts about the viability of this especially since it would depend critically on flows of information of a highly sensitive nature.
- **Fragmented commercial research:** At present the Weather Initiative (UK Meteorological Office) offers a specially tailored package to meet the needs of individual companies. This means that ongoing research is highly fragmented and, due to commercial sensitivity, the results are not available in the public domain. The aim is to give specific companies a competitive edge. Only companies of considerable size can buy into this service. This does not facilitate overall efficiency in the supply food chain and does not deepen our understanding of the weather influence.

Detailed comments

Retailing and consumer demand:

Several points that may have been overlooked:

- In-store merchandising can be planned for weather-sensitive products.
- The type of retail outlet can make a large difference to the relationship between weather and consumer behaviour. For example, in very hot summer weather, convenience shopping may increase at the expense of large multiples (consumers prefer to "pop round the corner" than travel in the car).

Production and Manufacturing:

- Not clear what is meant by the need for fiveyear forecasts for unusual weather trends for the building of a new factory on Page 10. Very doubtful that this requirement can be met.
- Not much information here regarding specific forecast requirements. Need more understanding of the lags in production scheduling and the corresponding forecast time-scales. Do manufacturers need an understanding of weather in relation to consumer demand or to the demand from intermediaries? Bread and cake-making is reported to be highly sensitive to weather conditions, especially humidity. How do the influences of weather on demand interact with other factors such as the need for bulk purchasing to gain discounts/privileges, or storage or transportation requirements? Is production planning carried out at particular times of the year for which the provision of weather forecasts would be most critical?

Stock control and distribution:

- Scheduling of deliveries to meet demand is extremely important especially for short shelf-life food items. The geographical aspect of this for a national chain may be crucial given the spatial variation in weather conditions.
- Weather relationships are thought to vary according to the type of customer that the

distributor supplies (hotelier, school, large multiple retailer, convenience/independent food stores). For example, hot weather may favour trade to hotels, outdoor cafes, and convenience stores/petrol forecourts, but large multiples may experience a downturn as people are less prepared to travel by car in the heat and prefer to buy the essentials from their local store.

- Distribution – strong winds may disrupt delivery of goods via shipping lanes. Maximum and minimum temperatures may be more useful for planning refrigeration/ environmental needs in transportation of goods overland.
- There is insufficient information on the length of forecasts required for specific activities. These will depend on the shelf-life of products, storage conditions, delivery schedules etc.

Retailing and consumer demand:

- Surely short-term forecasts for short-shelf life and chilled goods are critical here. Impulse lines (hand-held lollies/icecreams, small carton drinks) are expected to be the most weather-sensitive. There is a need to target items which are (i) more weather sensitive, (ii) for which inventory management is most critical.
- As above, insufficient detailed information is supplied.

Forecasting information required, Table 1:

- Snow will affect land transportation and delivery at all stages in the supply chain.
- High winds may affect shipment of goods.
- Humidity is important in the processing of certain food items.
- Rainfall is quoted as being the second most useful indicator of retail stocks in text, yet omitted from the table.
- Humidity could affect demand for soft drinks and fruits with a high water content.
- p14 Can't supply weather information for *all* parts of the world, need to be more specific!
- p15 Surely retailers and distributors would require region-specific forecasts.
- Need detailed list of accuracy of the weather forecasts required in relation to the list of time-scales given.

Reliability and tolerance of forecast information:

- Not clear what "accuracy" means here. For example, is it within 1°C, 2-5 mm, or just whether an event (rain, frost etc.) occurred or did not occur?
- It is very unlikely that a forecast would be 80% accurate for a 3 month forecast, what

is the lower scale here (p16)?

- I very much doubt that the level of accuracy outlined here (e.g. extremely reliable forecasts 9-12 months prior, p17) can be met by present standards of seasonal forecasts.
- If the level of accuracy required is high, it may be better focusing on those activities for which short-term (and hence more accurate) weather forecasts can be successfully applied.

Forecast requirements:

Somewhat idealistic! It is extremely doubtful that long-term weather forecasts can be supplied at the required level of accuracy and reliability outlined.

My recommendation is that if high standards of forecasts are required, users should highlight those weather-sensitive activities within their enterprise which rely on short-term forecasts. Chilled goods and short shelf-life products are reported to be particularly weather-sensitive and have speedy throughputs in the chain. This might be a particularly profitable area of research to concentrate on (see Agnew, 1996 [\(2\)](#)).

(2) - M. D. Agnew, Modelling the Weather Sensitivity of Retail Demand for Fresh Food in the United Kingdom (1996) Unpublished PhD thesis, University of Birmingham (147pp).

Professor Richard Ellis

Head of Department of Agriculture at Reading University

We have distributed the report to colleagues in seven departments of The University of Reading (Agriculture, Agricultural Botany, Applied Statistics, Geography, Horticulture and Landscape, Meteorology and Soil Science). I have asked colleagues to respond directly to you.

My own view is that the report is reasonably comprehensive (within the dictates of space, of course) but I do have three comments, which you might wish to consider.

1. Reducing the environmental problems of food production by relating the timing and quantity of inputs (e.g. agrochemicals) to both short and medium term weather forecasts should be a major goal of government and industry. If a single focus were required for action then this topic would have a double pay-off - reduced production costs and reduced environmental problems.
2. Much (though not all) of the information required from the perspective of production is known (or can be estimated adequately). It is the link among disciplines which is the weakest element (and the feedback, which would result from that). I am surprised no mention was made of the potential of the Teaching Company Scheme to ensure what is known in Universities begins to be applied in a manner suitable to the industry.
3. As a follow on from the above, the recent decision of the Ministry of Agriculture, Fisheries and Food to end its Postgraduate Studentship Scheme will not help. OST might wish to consider research studentships in this subject area, preferably

combined with TLS staff.

Dr Mike Harrison

Predictability & Ensemble Forecasting Team, UK Meteorological Office

The main difficulty is that the CCFRA report does not show a grasp by the industry representatives of the necessarily probabilistic nature of seasonal weather forecasts.

One way forward would be to work in very small groups – possibly even one-to-one – consisting of a forecaster and a business person, in order to try and establish a common language/understanding concerning risk, probability and reliability, which will enable useful discussions about the nature of the forecasts needed. The groups could work to examine the limitations of the forecasts, decision processes and contingency actions against inappropriate decisions, and the benefits to be achieved.

Dr Tim Palmer

Head of the Predictability and Seasonal Prediction Section at the European Centre for Medium-Range Weather Forecasts

The report brought out very well indeed the dependence of the food supply chain on seasonal weather. If we were able to provide perfect and detailed forecasts over the coming season, then the impact on this sector (and many others) would be enormous.

The particular issue I would like to comment on is the statement in the report that the forecasts should be at least 75% reliable. It was never quite stated what precisely this meant, but I interpreted it to mean that if we were to make a forecast such as "It will be unusually warm" or "It will be unusually dry" or whatever, then these forecasts will be right 75% of the time.

Unfortunately life isn't quite as simple as this, and it is unlikely we would give forecasts of this type. Both Mike Harrison and myself tried to stress at the first workshop, that seasonal prediction is necessarily probabilistic. That is to say, to make seasonal predictions we run an ensemble of our coupled atmosphere-ocean models from slightly different starting conditions. The forecasts within the ensemble will diverge from one another (a prediction of chaos theory if you like), but if the underlying ocean and land-surface anomalies are sufficiently large, then a significant fraction of the ensemble will forecast some kind of anomalous weather state. This fraction determines the probability that we attribute to the forecast of the anomalous weather. So if 70% of the ensemble members have unusually warm temperature, we would not say "It will be warmer than average", but "There is a 70% chance that it will be warmer than average". The notion of reliability of a probability forecast can be said in this way: over a large number of cases where we predict warmer than average weather with a 70% probability, it should turn out to be warmer than average 70% of the time.

The challenge for the potential user of seasonal predictions will be to make quantitative use of these

probability forecasts. To do this the user must know the cost of the alternative actions that are available to him/her. Let's suppose we have a perfectly reliable probability forecast system, and we predict with 99% probability a drought in the growing season. Then the farmer may well decide to plant some sort of drought-resistant crop. The cost to him in terms of reduced yield and possibly more expensive seed, would be worth taking compared with the more-or-less complete loss of a more normal drought-sensitive crop in the almost certain event of a drought. But what if the probability of drought was 80%, or 60%? Even if these probabilities could be shown to be perfectly reliable in the sense described above, what should the farmer do given such probabilities? There is almost certainly a strategy for using these probabilities in a way in which his crop yields are optimal, but these sorts of questions go beyond pure meteorology. They can only be answered by coupling the seasonal forecast output to a user-specific decision model analysis. However, they are the sort of questions that must be addressed if we are to make progress in this area.

Whilst Mike and I did emphasise the probabilistic nature of seasonal prediction, the working group report really has not taken this into account. I suspect that the next stage must be to target a small sub-group of potential users who are willing to consider these probabilistic aspects more explicitly. In this respect, two colleagues and I have recently written a paper highlighting the nature of probability forecasts with respect to a simple and idealised dichotomous decision model.[\(3\)](#)

Dr Lester Simmonds

Department of Soil Science, University of Reading

My principal reaction to the report is that in many of the areas where there is potential use in seasonal forecasting there seems to be something of a gap between what a weather forecaster might predict, and what the industry needs to know in order to make decisions. In some cases it is the meteorological events *per se* that are of direct interest to industry (e.g. likelihood of frost damage). In other cases, the effects of weather are more indirect (e.g. the effect of anomalous rainfall on crop growth, irrigation requirements and soil trafficability), and it is difficult for the user to define what they need to know in simple meteorological terms (such as "rainfall in the Trent valley being 80% less than normal"). This is an area where there might be valuable contributions from expertise that exists in modelling of processes such as crop growth, soil water dynamics and the fate of fertilisers and pesticides.

Does the report provide sufficient specific detail of what potential food chain users require? If not, what amplifications would you like to see?

An important step in the use of weather forecasts by the agrifood industry is how to translate predictions made by weather forecasters (particularly in terms of predicted deviations from 'normality') into the corresponding deviations in parameters of direct relevance to the industry. This is an area where I feel there is need for amplification. Examples of such parameters include:

- the timing of maturity of crops, and implications for sowing/planting times
- irrigation scheduling and water requirements
- optimal fertiliser and pesticide applications
- soil trafficability at harvesting, and the implications for prioritising deployment of harvesting equipment.

(3) - T. N. Palmer, C Brankovic & D. S. Richardson, A Probability and Decision-Model Analysis of PROVOST Seasonal Multi-Model Ensemble Integrations, (October 1998) ECMWF, Reading.

There is little discussion in the report of how this perceived gap between weather forecasting and parameters of direct interest might be bridged in cases where the effects of weather are indirect.

There are two general approaches that might be taken. The first is through the use of expert systems based on the experience of the practitioners. An alternative is to use process-based models. Examples of the latter would include:

- the use of crop growth/water balance models to predict effects of water stress on crop growth and the amounts and timing of irrigation
- the use of models to predict effects of deviations in temperature on the timing of crop maturity
- the use of leaching models with respect to the leaching of nitrate and pesticides
- the use of soil water dynamics models to predict soil trafficability.

Where appropriate, validated models exist, they can be a powerful tool in predicting impacts of weather deviations that take account of other factors (such as soil type) that mediate the impact of weather. In some cases, local expert knowledge might be quite sufficient to make judgements about consequences of predicted weather variation on management, whereas other parties might lack the local knowledge and require an alternative approach. For example, farmer X might have the local knowledge and experience to predict the impact on farming operations of a given deviation from normal weather, whereas a remote planner will not have the same local knowledge and will be reliant on some algorithm on which to base judgements.

Can any of the requirements be met with existing technology?

There are many simulation models that require meteorological data as inputs that might have a useful role to play. These include soil water balance/irrigation scheduling/soil trafficability models, crop growth models and nitrate/pesticide leaching models. In each case, there will be examples of models that range from the very simple to the highly complex, and an important task would be the selection of appropriate models.

If models have a role in the interpretation of weather predictions with respect to the impact on the operations of the food production sector, then it is important that the weather forecasters provide the information required to drive these models. In particular, forecasts for any further than a few days into the future will not be able to predict daily weather. Three or six month forecasts are, at best, only likely to be able to indicate average deviations from the norm. In some cases, this may be all that is required. For example, the time of maturity of many crops can be accurately predicted from average temperatures, because the effect of temperature on crop development is cumulative. Similarly, seasonal rainfall predictions might be useful for planning likely annual irrigation requirements at local to regional scales.

However, in other cases there is a need to be able to predict likely day-to-day fluctuations. Examples include the impact of weather on the trafficability of fields or on the likelihood of foliage being continuously wet for periods long enough to substantially increase the risk of some diseases. Given that daily rainfall cannot be predicted months in advance, then it would be useful in these cases for the rainfall predictions to be expressed in terms of parameters such as deviations from the norm in the number of rainy days, or in the frequency distribution of the amount of rainfall per rainday. Such

information would provide the basis for driving stochastic weather generators for driving simulation models that require daily information.

One of the ways that stochastic daily weather generators might be used is to run a number of simulations of, say, an irrigation scheduling model using a number of daily weather simulations that fall within the bounds predicted by the seasonal forecast. The output of such a series of runs could be interpreted in terms of the probability distribution for the parameter of interest to the industrial user (e.g. the amount of irrigation water required). The ability to put confidence limits on predictions is clearly an important element in determining the value to industry of weather forecasts.

The appendix to the report "*Basic ideas for co-ordinating forecast quality assessment with application value assessment*" by Mike Harrison of the Met Office was extremely interesting, and likely to be a powerful tool in identifying areas where weather forecasting might prove useful to the user community, and to help in the development of techniques to bridge the perceived gap between the output of weather forecasters and the requirements of the user community. Clearly, the use of algorithms which 'add value' to the weather predictions by predicting such things as crop growth and soil water status are an important element of this gap bridging exercise. The conceptual framework presented by Dr Harrison might easily be adapted to assess the utility of such algorithms. Indeed, I can envisage very interesting studies that involve weather forecasters, soil/crop modellers and industrial users to explore the extent to which soil/crop modelling might bridge the gap between weather forecasters and the end users.

How long do you estimate it would be before forecasters might be in a position to be able to provide this data?

This is a difficult question to answer, as in many cases it is not clear what data are required from weather forecasters.

Can you estimate the sorts of costs involved in providing the data required?

There is need for work to be done in developing techniques for predicting the impacts of forecasted deviations from weather norms in terms that are useful in guiding industrial decision making. In the case of the 'raw material supply' sector, my feeling is that considerable progress could be made in a three year project involving meteorologists, soil/crop specialists and industrial counterparts that focused on a number of high priority topics selected by the end users.

I hope these comments are of use. At the University of Reading there is a unique blend of research groups covering the spectrum of soil science, agriculture, horticulture and meteorology that is required in work of this sort. In addition, there are research groups within the University (particularly Applied Statistics and the NERC Environmental Systems Science Centre) that specialise in how to bring together models and data sources to produce operationally useful tools. Colleagues I have spoken to would very much welcome any opportunities for contributing in future.

I look forward to seeing how this programme develops.

Dr Leonard Smith

Mathematical Institute, Oxford

1) Does the report provide sufficient specific detail of what potential food chain users require?

The report provides a good introduction to the needs of food chain users, and in particular what they need in order to benefit from traditional seasonal forecasts. Nevertheless I believe it does not reflect the vast potential value-added of ensemble seasonal forecasts. It is my view that the long range information requested by users (global in scope, regional in detail, and "reliable") is precisely the information that could be supplied by a seasonal ensemble forecast. To benefit from these forecasts, however, the users must play a larger role in interpreting the entire ensemble of forecasts; the user wishes to adopt a strategy that is good in each and every forecast scenario, not the strategy that is good given the "average" of all scenarios (while being poor in each one!). For example, if the forecast is for either drought or flood (the forecaster cannot say which), the user may wish to bet on one or the other (or not plant in that region), but certainly the user does NOT wish to plan on the average of the forecasts ("normal rainfall with high uncertainty"). Uncertainty in the future is quite different from not knowing which of several options will happen; the food supply chain should be able to exploit this difference today (in terms of 3 to 8 day forecasts) and seasonally in the future.

Levels of reliability. The report notes desired "levels of reliability" of 75-80%, this is a tall order if the question is "Yes or No: Will it rain in the morning a week from Friday?". Ensemble forecasts answer the question "Will it rain?" with a probability (say 60%); while not as easy to interpret as a Yes/No answer, I would argue that users can benefit from an accurate probabilistic answer, and benefit much more than from an inaccurate Yes/No forecast.

Alternatively the questions like "Where in the UK is it most likely to be sunny?" "Which shipping routes are most likely to be snow free?" "Which stores are most likely to run out of soft drinks given their current stock and the likely extent and pattern of the current heat wave?", are naturally addressed within the ensemble forecast scheme. Similar questions, involving which cultivar is most likely to be planted where (in the world) and when it would be ripe for harvest/delivery, could be phrased in terms of seasonal ensemble forecasts. It is precisely the interconnectedness of many different variables which allows ensemble forecasts to address cost-benefit (action/inaction) questions much better than a traditional single forecast can. Because these questions are industry specific and are likely to vary from year to year, members of the food supply chain may wish to control the information by processing the forecasts in-house as noted under (4) below.

2) Can any of the requirements be met with existing technology?

In terms of 2 to ~10 day time-scales, yes. In particular, several of the items listed under the headings Stock Control and Distribution, Retailing and Consumer Demand and to a lesser extent Production and Manufacturing could benefit from improved processing of the information currently produced by forecasters. Stock control of soft drinks, ice cream, and so on would be aided by existing technology; for example a temporary increase in supply is a small price to pay to avoid running out of drinks on the hottest days of the year, as more small shops move towards computerised inventory control, it will also be possible to link past weather data as well as short term forecasts (thus one can know not only how many drinks were sold in this week last year, but how many drinks were sold on weekdays with this temperature in the corresponding month of last year).

Nowcasting is also available with current technology, and could estimate, for example, whether or not carrots from any region of the globe might have been frozen in the ground before they reached market. The key is to set up a large number of questions like this one, and a system which gives advanced warning of potential problems, revising the probabilities right up to the current day without requiring the direct attention of a user.

Contributions toward longer time-scales are also possible, but require a sharper definition of what is needed. The context will differ from the traditional "single best" forecast; perhaps the best way to clarify this difference for seasonal time-scales is to first design a system on the 2 to 8 day time-scale where additional value can already be derived from existing ensemble forecasts.

4) Can you estimate the sorts of costs involved in providing the data required?

The costs of obtaining forecast data depend on the particular weather centre involved and the industry might wish to combine information from several including the European (ECMWF), British (BMO), American (NCEP) and Japanese (JMA). An industry may find it preferable to process this information in-house, allowing a much wider range of questions to be asked and keeping both questions and answers confidential. The computational costs of processing the forecasts are much less than making them, requiring workstations rather than super computers and a handful of programmers and consultants; say two workstations, two programmers, and various consultants to design the system (take specific questions of interest to industry and design computer code to answer these questions based on existing weather data).

5) What sort of information delivery systems might be workable or appropriate for the provision of such forecasts to the users?

End users might not be so interested in the weather forecasts themselves, but in summary reports and warnings generated daily and easily distributed by automated fax or email. Users wishing to see more detail could remotely login to a central system (one of the two workstations noted above) to obtain greater detail, not just of the forecasts but of the forecasts processed so as to display the information relevant to the food supply chain. Daily realtime processing over the internet could get the raw weather forecasts to the central system, I have a graduate student who downloaded the (public domain) NCEP ensemble forecasts from the US daily for a few weeks as part of her thesis research; this process is easily automated (although a phoneline backup might be desirable).

Dr David Wurr

Crop & Weed Science Department, Horticulture Research International

I firmly believe that we need to make greater use of weather data in its various forms in order to improve the planning for, manipulation of and prediction of product supply throughout agriculture and horticulture. I think that there is a need for the development of generic risk analysis techniques, which can be applied throughout the food chain by growers, packers and retailers, making use of meteorological data to improve certainty of supply and decision making.