7.2 INCORPORATING AN ENSEMBLE FORECASTING PROXY INTO A KNOWLEDGE BASED SYSTEM

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1. INTRODUCTION

1.1 *The Pilot Version*

An early version of the knowledge-based system (the PILOT VERSION) was presented to the 18th Interactive Information Processing Systems (IIPS) Conference (Stern, 2002) (http://www.weather-climate.com/fc.html).

The system was developed for the small (227,000 sq km) southeast Australian State of Victoria. It was described as being capable of generating forecasts for public, aviation, marine and media interests, in languages other than English, and for more than 200 localities in Victoria - a breadth of output far greater than one could ever hope to produce utilising the current labour intensive systems.

1.2 *Benefits of Knowledge-Based Systems*

A major benefit of a knowledge-based system is that it incorporates an extensive "bank" of forecaster experience. Ramage (1993) has proposed an "iterative" approach to "locking in" improvements in forecasting methodology. The system's skill increases as new knowledge is incorporated into its operation. Hence, progress is gradually made towards the realisation of Ramage's dream. The system is (therefore) not seen as "yet another" instrument of forecast guidance. Rather, its development is seen as a logical step along the path of having the computer replicate (and ultimately replace) various aspects of the manual side of the forecast process, by systematically "locking in" new knowledge.

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2. PRELIMINARY EVALUATION

2.1 *Evaluation of the Pilot Version*

The PILOT VERSION of the system was evaluated during November 2001 for the city of Melbourne using a skill score that combines all features of a forecast. The evaluation showed that, although superiority over climatology was achieved, the forecasts (on most measures) proved to be inferior to the official forecasts.

2.2 *Evaluation of Version 1*

The system was then "scaled back", new knowledge added, and what has been termed VERSION 1 of the system was then evaluated over a 100-day trial, the results of which were presented to the 19th IIPS Conference (Stern, 2003)

http://www.weather-climate.com/internetforecasts.html

The deficiency evident with the PILOT VERSION appears to have been largely eliminated (especially for precipitation at day 1 and for temperature at days 1, 2, 3, 4 and 5).

2.3 *Further Knowledge Added*

On the basis of the results of the 100-day trial, further knowledge was added to the system to yield VERSION 2 of the system, which extends the outlook from 6 days to 7 days:

http://www.weather-climate.com/internetforecasts2.html

VERSION 2:

- Utilises an ensemble-forecasting proxy to take into account the extent of uncertainty associated with the

Numerical Weather Prediction (NWP) model output,

- Uses cyclonicity in deriving the Probability of Precipitation (PoP) and the Quantitative Precipitation Forecasts (QPFs),
- Takes into account the sharp maximum temperature gradients associated with moderate ENE flow during summer,
- Generates a short forecast in the language of the local Indigenous people, and
- Generates a Terminal Aerodrome Forecast (TAF) (Figure 1).

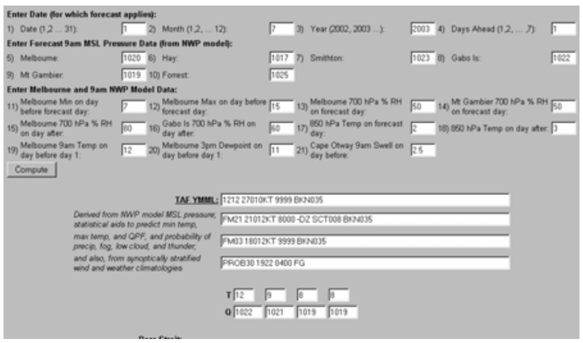

Figure 1. A TAF generated by the system.

3. THE TERMINAL AERODROME FORECAST (TAF)

3.1 *How the TAF is Generated*

I will now take the opportunity to briefly refer to how the system generates the TAF for Melbourne Airport (YMML). In so doing, a number of issues will be addressed.

The TAF is valid for the 1200 UTC to 1200 UTC period (1212), the TAF validity period most closely corresponding to 0001 to 2400 Australian Eastern Standard Time (AEST).

The 1212 period is that covered by most of the objective forecast guidance upon which the derivation of the TAF depends.

The TAF is generated via aid of:

- Several sets of prediction equations (that have been derived using synoptically stratified observational data),
- Synoptic-pattern based summaries of weather and wind, and
- Qualitative knowledge about the aerodrome's weather, such as that contained in a document prepared by one of my colleagues (Halfpenny, 2003).

The sets of prediction equations include those for:

- Probability of precipitation (Pop)
- Precipitation amount - Quantitative Precipitation Forecast (QPF)
- Probability of thunder (PoTS)
- Probability of fog (PoFog)
- Probability of low cloud (PoLCld)
- Maximum temperature (Max)
- Minimum temperature (Min)

In application, the equations are "solved" using observational data and NWP output to yield a forecast. Verification statistics, where they are available (Stern and Parkyn, 1999), are used to establish appropriate "cut-offs" to warrant including mention of particular weather elements in a TAF.

For example, to illustrate the methodology, when PoFog<10%, no reference to fog is applied, when 35%>PoFog>=10%, a PROB30 1922 0400 FG for fog is applied, but should PoFog>=35%, a PROB40 1922 0400 FG is applied.

Similarly, when PoLCld>=40%, a TEMPO for low cloud is applied, but should 30%<=PoLCld<40%, only an INTER for low cloud is applied.

3.2 *The Beauty of the Knowledge-Based System*

The beauty of what has been developed here lies in how the system defines, and provides a "home" for, the various components of objective guidance and knowledge of associated processes, which are used in deriving the TAF.

It also represents a "vehicle" to automatically generate the TAF using all available knowledge. Indeed, if a new piece of guidance is developed - for example, one of my colleagues (Newham, 2003) is presently carrying out work on the timing of the onset of fog - then this new piece of guidance becomes a part of the process of deriving the TAF, and a new area of knowledge is added to the system.

The success (or otherwise) of the TAF is entirely dependent upon how well the associated processes have been defined, and upon how effective are the various components of objective guidance that contribute to its generation.

3.3 *Verification*

Statistics are already available about the accuracy of some of the components of objective forecast guidance upon which the generation of the TAF depends.

The overall accuracy of the TAF is no better, and no worse, than the accuracy of these individual components (and the reliability of the qualitative knowledge), that contribute to its generation.

Nevertheless, in application, the TAF is treated as a "whole" not as a "sum of parts". In view of this, it is appropriate for a comprehensive verification trial to be carried out in order to answer questions such as:

- How well does the TAF differentiate between various categories of sub-minima conditions (regardless of whether these are the result of low cloud, fog, or some other weather element)?
- How well does the TAF differentiate between INTER/TEMPO/ALTERNATE deteriorations?
- How well does the TAF compare with the Official Forecasts?

It is also intended to eventually extend the TAF to other validity periods and other localities.

4. THE EXTENT OF UNCERTAINTY

4.1 *Conventional Ensemble Techniques*

Conventional ensemble techniques seek to establish the extent of uncertainty in the forecast for a particular locality of interest in a particular situation. They achieve this by statistically analysing an array of a Numerical weather Prediction (NWP) model output. The array is derived from output generated by imposing a random set of perturbations on the initial analysis.

To illustrate this concept, suppose we take the case of 20 runs of the NWP model, with 20 slightly different initial states.

Suppose further that 17 of the 20 outcomes suggest precipitation at the locality of interest. In this situation, the ensemble of NWP output is suggesting a PoP of 85%.

4.2 *Establishing the Extent of Uncertainty in VERSION 2*

The extent of uncertainty in VERSION 2 is achieved in a different manner to conventional ensemble techniques.

Firstly, a database of observed weather, and forecast weather using the PERFECT PROG approach (that is, under the assumption that the NWP model output is perfect), is established.

Secondly, the forecast weather component of the database is expressed in terms of "departure from normal". To illustrate, a PoP of 85% at a time of year when the climatological normal is 35% is expressed as +50%.

Thirdly, these data are statistically analysed utilising regression techniques in order to determine the optimal proportion of "departure from normal" to be applied.

This yields a more accurate measure of uncertainty than what would be achieved utilising conventional ensemble forecasting techniques, as the measure is derived directly from an array of actual forecasts.

For example, regression analysis determines that, for Day 1 PoPs, the departure from the seasonal normal PoP is reduced to 68.8% of that departure. To illustrate, suppose that the seasonal normal PoP is 50%, and the PoP derived using the PERFECT PROG approach is 80%. In this situation, VERSION 2 yields a PoP of 50% + (80%-50%)x0.688 = 71% for Day 1.

Similarly, regression analysis determines that, for Day 7 PoPs, the departure from the seasonal normal PoP is reduced to 28.1% of that departure. In the above situation, VERSION 2 yields a PoP of 50% + (80%-50%)x0.281 = 58% for Day 7.

Conventional ensemble forecasting suffers from the disadvantage of the level of uncertainty in the initial analysis being unknown, whereas the uncertainty associated with a database of actual forecasts is known precisely.

5. PHILOSOPHY

It may be appropriate to ask, from a philosophical point of view, whether or not it may be premature, at this stage, to move towards computer replication of the manual forecast process. After all, the new National Digital Forecast Data Base (NDFD) of the U.S.A. National Weather Service (NWS) (Ruth & Glahn, 2003) allows for considerable manual involvement in its operation. A move to computer replication would result in a paradigm shift in the nature of the forecasting meteorologist's role.

The role increasingly would become one of utilising sophisticated methodologies to analyse the output of the automated system, and implementing changes to it (consequent upon the analyses).

However, having the computer replicate various aspects of the manual forecast process, in order to make possible the production of a greatly increased number and variety of forecast products, is already happening. For example, the highly competitive environment that the New Zealand weather service finds itself has resulted in it moving down this pathway (Linton and Peters, 2003).

Furthermore, there is pressure in the U.S.A. to allow commercial operators to take over government's traditional role in the provision of weather services (excepting the delivery of urgent warnings to protect life and property). To illustrate, AccuWeather's 31 January 2003 Media Release "expressed regret that the (National Research Council) report did not recommend that the National Weather Service end its practice of issuing routine weather forecasts."

6. CONCLUDING REMARK

Regardless of philosophy and outside of the legislative framework, competitive pressures may determine the future as private operators (and, also the general public) realise that the new technologies allow for the development and implementation of forecasting systems capable of providing a breadth of output far greater than one could ever hope to produce utilising the current approaches.

As Brooks (1995), wrote: "technology, which initially allowed humans to make routine weather forecasts, will soon close that avenue of human endeavour ... (and thereby permit) concentration on severe events."

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