TOWARDS THE EFFECTIVE COMMUNICATION OF WEATHER AND CLIMATE INFORMATION – HARNESSING NEW TECHNOLOGIES TO INTEGRATE MATERIAL FROM VARIOUS SOURCES ON THE WEB TO GENERATE NEW PRODUCTS

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1. INTRODUCTION

1.1. *Background*

In the context of the American Meteorological Society's (AMS) 2011 annual meeting *Communicating Weather and Climate*, the AMS observes that effective communication is essential for scientific research, education and serving the public.

It proposes effective integration of material within the weather and climate enterprise, highlights the application of rapidly-changing technologies to bring new and powerful tools to disseminate and receive information, and notes efforts being undertaken to better communicate with different populations.

1.2 *The approach used*

The approach utilised here is:

(1) To integrate material from various existing sources on the web to automatically generate a set of forecasts for Melbourne and other places - these have yielded an increase in the accuracy of predictions for a broad range of weather elements; and,
(2) To similarly integrate such material to automatically generate other weather and climate products.

2. PURPOSE

2.1 *Linked data*

Berners-Lee (2010) nominates linked data as "a great example of (the web's) future promise".

He suggests that "today's web is quite effective at helping people publish and discover documents, but (that) our computer programs cannot read or manipulate the actual data within those documents.

Berners-Lee observes that "as this problem is solved, the web will become much more useful, because data about nearly every aspect of our lives are being created at an astonishing rate" and that "locked within all these data is knowledge about how to cure diseases, foster business value and govern our world more effectively".

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2.2 *Realising value*

Berners-Lee notes that "scientists are actually at the forefront of some of the largest efforts to put linked data on the web".

It is the primary purpose of the work presented here to develop within computer programs the aforementioned "capacity to read and manipulate the actual data within web documents".

By this means, the value of the data is fully realised in the form of more accurate weather forecasts and the generation of a broader range of related weather and climate products.

3. INTEGRATING MATERIAL FROM VARIOUS SOURCES

3.1 *Consensus forecasting*

Stern (1980a) outlines a possible approach to the determination of an optimal human-machine mix.

He refers to Sanders (1973), who investigated the skill displayed by daily temperature and precipitation forecasts made in the Department of Meteorology at the Massachusetts Institute of Technology.

Sanders found that "few if any individuals who made a substantial number of forecasts outperformed consensus on the average."

Stern also refers to Thompson (1977), who, noting Sanders' work, suggested that "an objective and quantitative method" be used to reach a consensus (bearing in mind) … the incontrovertible fact that two or more inaccurate but independent predictions of the same future events may be combined in a very specific way to yield predictions that are, on the average, more accurate than either of them taken individually."

3.2 *Combining independent estimates*

Danard *et al.* (1968) discuss the subject of optimally combining independent estimates from a numerical analysis perspective whilst Danard (1977) comments on Thompson's method.

Both Thompson (1977) and Danard (1977) discuss how one may optimally combine two forecasts if the assumption that they are independent is made. If this assumption is made, it is implied that *r*, the correlation coefficient between errors produced by the two forecasting methods, is equal to zero.

Methods of forecasting a particular weather element are usually based on similar physical principles and therefore the sets of errors produced by the methods tend to be quite highly correlated. Indeed, Danard (1977) acknowledges "that ?=0 is likely to be more valid for two measurements than for two predictions." Therefore, the validity of the approaches of Thompson (1977) and Danard (1977) is limited by their assumption that r=0.

With this in mind, Stern (1980a) suggests that the approach maybe applied under the assumption that r is not equal to zero by applying multiple linear regression to forecast verification data, in order to minimise forecasts errors.

Stern (1980a&b) and Stern and Dahni (1981 & 1982) (refer also to Dahni *et al*. (1984)) subsequently demonstrated that forecasts would be improved were one to simply average predictions from different sources, whilst Woodcock and Southern (1983) showed that it was possible to improve official forecasts using predetermined linear regression equations to combine the existing official forecasts with Model Output Statistics guidance to form a new forecast.

3.3 *Mechanical integration*

Sanders and Ritzman (2001) propose that we "consider mechanically integrating judgmental and statistical forecasts instead of making judgmental adjustments to statistical forecasts".

They note that "judgmental adjustment (by humans) of (automatically generated statistical forecasts) is actually the least effective way to combine statistical and judgmental forecasts… This is because "judgmental adjustment can introduce bias (Mathews and Diamantopoulos, 1990) (see also Stern (1996), who documents forecaster overcompensation for previous temperature errors).

Sanders and Ritzman suggest that "the most effective way to use (human) judgment is as an input to the statistical process" and make reference to Cleman (1989), who reviewed over 200 empirical studies on combining and found that mechanical combining helps eliminate biases and enables full disclosure of the forecasting process.

Sanders and Ritzman flag the side-benefit of "the resulting record keeping, feedback, and enhanced learning (which also) can improve forecast quality".

3.4 *Preliminary evaluation*

The approach was first evaluated in a *hindcast* mode by Stern (2005), who showed that the process of combining human (official) and automated forecasts had the potential to yield a set of predictions that is far more accurate than current official forecasts.

The human (official) forecasts explained 42.3% of the variance of the observed weather (rainfall amount, weather phenomena, minimum temperature, and maximum temperature), whilst (by itself) the automated (knowledge based) system explained only a slightly greater 43.2% of the variance of the observed weather.

However, adopting a combining strategy was shown to have the potential to lift the overall percentage variance explained to a much greater 50.2% (Figure 1).

3.5 *A "real-time" trial*

The attention of readers is now drawn to the results of a real-time trial[1] (conducted since August 2005) of a knowledge based system that mechanically integrates (combines) automatically generated and official predictions.

The system yields a graphical product that depicts all of the elements included in a public weather forecast for 56 localities in Central Victoria (Map1 and Figure 2).

A preliminary report on the outcome of that investigation (Stern, 2007) revealed that, after one year, the "real-time" trial, which is ongoing, yielded encouraging results (some of which are displayed in Table 1 and illustrated in Figure 3).

The ongoing trial continues to yield encouraging results, especially for temperature forecasts (Figures 4 and 5).

4. OTHER PRODUCTS

There are numerous opportunities, presented to us by the wealth of data on the web, to integrate various sources of information to automatically generate countless valuable weather and climate products.

Whilst the focus of the current work has been the forecasting system that this paper has concentrated upon, a broad range of other such products are presently under trial.

These include the automatic generation of terminal aerodrome forecasts, monthly and seasonal climate outlooks, and weather and climate summaries in textual as well as graphical format,

[1] Historically, the quality of new forecasting systems was tested through controlled studies on a sample of data which were analysed.

If successful in the sample, the product was deemed "good" and placed into operations.

However, no sample was ever complete enough, or any analysis extensive enough, to truly and fully reveal the strength and weaknesses of a new technique (Mahoney, *et al*., 2002).

In recent years, the advent of the web has allowed for near real-time and transparent evaluation of forecasting systems while they are still in test mode.

One may contend that now, an essential characteristic of the peer review process, which eventually leads to the operational implementation of a new system, is for that evaluation to be transparent.

This transparency allows potential users to conduct their own evaluation of system elements in which they have a particular interest.

It also allows those involved in the peer review process to confirm, for themselves, claims made by developers about system strengths and weaknesses.

and also in languages other than English (Figures 6, 7, 8 and 9).

5. CONCLUDING REMARKS

Berners-Lee (2010), looking to the future, concludes that "as long as the web's basic principles are upheld (and) its ongoing evolution is not in the hands of any one person or organisation … the web promises some fantastic opportunities".

The present paper has illustrated just a few of these possibilities in the context of the generation of various weather and climate products.

6. REFERENCES

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Element	Verification parameter	Human (official)	Combined
All elements	% variance explained	33.40	41.30
Rain or no rain	% correct	70.10	76.80
Rain amount	RMS error (mm$^{0.5}$)	1.05	0.97
Min temp	RMS error (°C)	2.39	2.27
Max temp	RMS error (°C)	2.82	2.49
Thunder	Critical Success Index (%)	17.90	21.60
Fog	Critical Success Index (%)	15.50	17.80

Table 1 Enhanced forecast accuracy for various weather elements (from Stern, 2007)

Map1. The system generates forecasts for 56 localities in Central Victoria, including all of the localities shown on the map, except for Fawkner Beacon and St Kilda Harbour Royal Melbourne Yacht Squadron (RMYS).

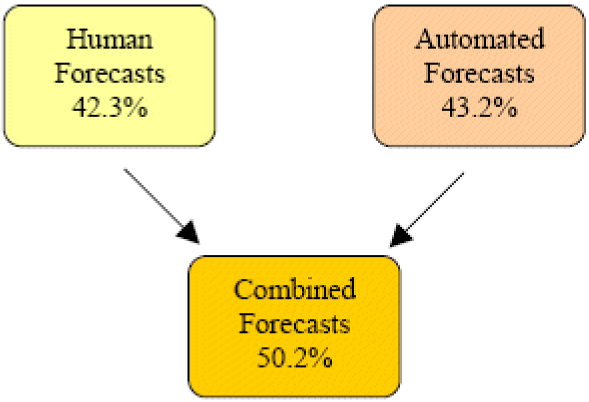


Figure 1 Showing that the process of combining human (official) and automated forecasts had the potential to yield a set of predictions that is far more accurate (in terms of % variance explained) than the then current official forecasts (from Stern, 2005).

Day & Date	Morning	Afternoon	Min Temp (deg C)	Max Temp (deg C)	Precip Amount (mm)	Precip Prob (%)	9am Wind/ 3pm Wind Melb Apt (km/hr)
Sun-9-1-2011	Shower.	Cloudy.	18	24	3.5	72	SSE 16 SSE 23 Gusts40
Mon-10-1-2011	Partly Cloudy.	Possible Shower.	18	26	0	49	SSW 8 SSE 15 Gusts40
Tue-11-1-2011	Partly Cloudy.	Thunder.	19	26	1.9	51	SSW 8 SSE 15 Gusts40

Figure 2 Illustration of a mechanically integrated forecast.

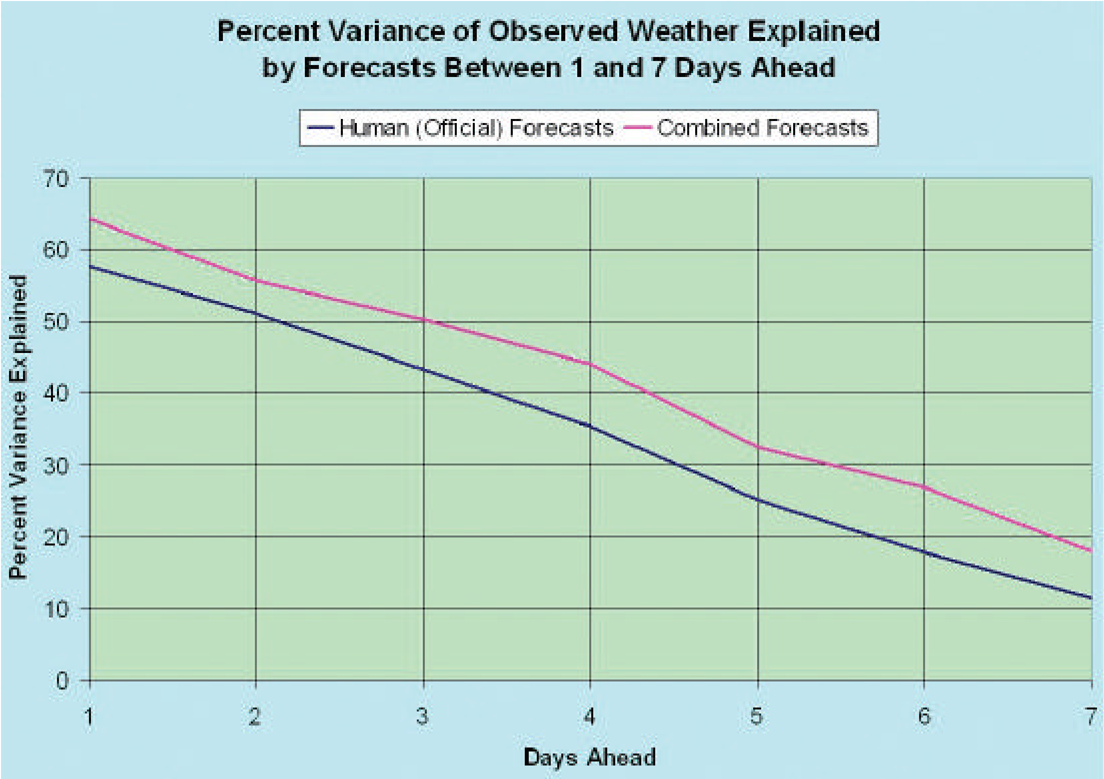


Figure 3 Percent variance of observed weather explained by forecasts from 1 to 7 days ahead (from Stern, 2007).

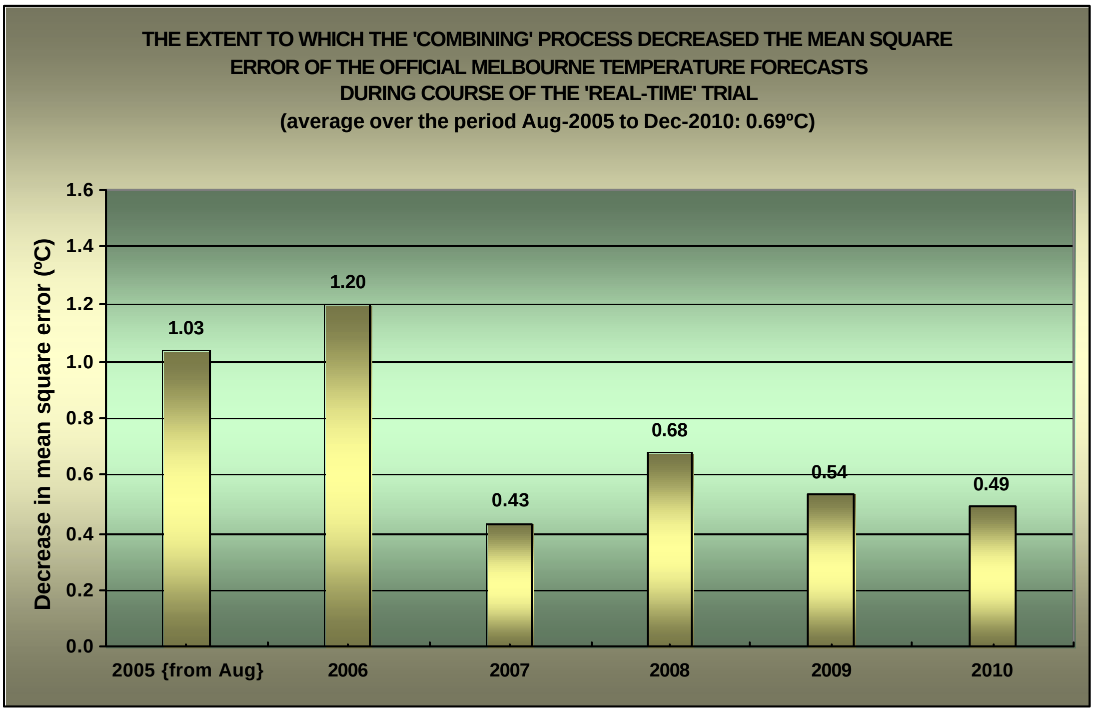


Figure 4 Enhanced forecast accuracy for temperature.

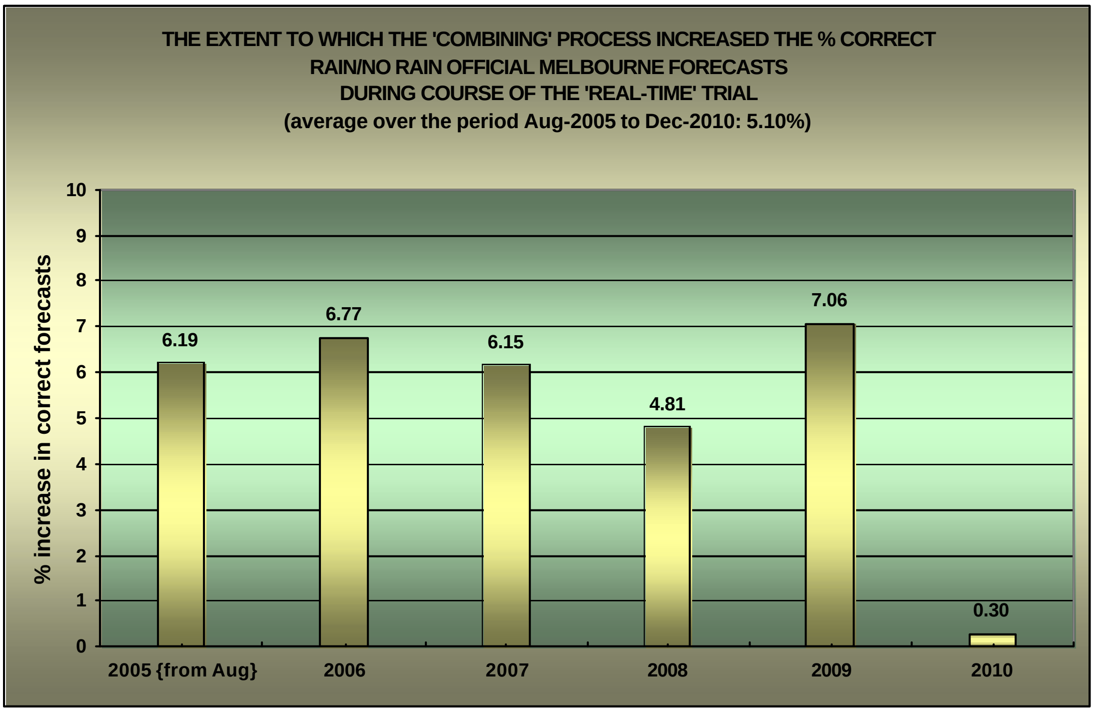


Figure 5 Enhanced forecast accuracy for rainfall.

Melbourne Forecast for Sun-9-1-2011

Cloudy at times during the morning with a few showers gradually clearing. A cloudy afternoon, but without precipitation. Following a very mild night, a mild to warm day. Mainly light wind.

PRECIS SHOWERS CLEARING MIN 18°C MAX 24°C

PRECIPITATION Amount 3.5mm Probability 72%

FOG Probability 0% THUNDER Probability 4%

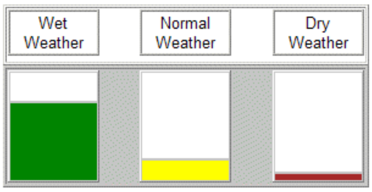
Figure 6 Example of a forecast in text format.

日期	早晨	下午	最低温度	最高温度	雨量	雨可能性
星期天 9-1-2011	阵雨	多云	18	24	3.5	72
星期一 10-1-2011	部分多云	可能的阵雨	18	26	0	49
星期二 11-1-2011	部分多云	雷	19	26	1.9	51

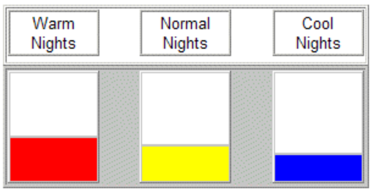
Figure 7 Example of a forecast generated in Chinese.

In Melbourne, at this time of the year, a combination of the MEI, the DMI, and the MJO Phase, such as what we have operating now, suggests, over the following 30 days:

RAINFALL: There is a 72% chance of it being wet, a 20% chance of normal rainfall, and a 8% chance of it being dry.



OVERNIGHT TEMPERATURES: There is a 41% chance of warm nights, a 33% chance of normal overnight temperatures, and a 26% chance of cool nights.



DAYTIME TEMPERATURES: There is a 27% chance of warm days, a 32% chance of normal daytime temperatures, and a 41% chance of cool days.

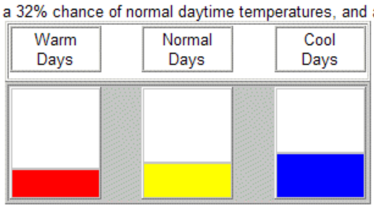


Figure 8 Example of a monthly climate outlook.

Victorian climate summary for the month of January 2010

Rainfall slightly less than that usually received.

Highlights:

- Overnight temperatures near to those in most years
- Daytime temperatures much warmer than those in most years
- Rainfall slightly less than that in most years

Summary

Bureau of Meteorology data show that across the State of Victoria, overnight minimum temperatures were near to those usually experienced (average departure from normal 0.3°C). Daytime maximum temperatures at most localities were much warmer than those registered in the past (average departure from normal 1.7°C). Total rainfall for the month was generally slightly less than that usually recorded (average percentage of normal received 68.5%).

Over the northern plains, minimum temperatures were near to those usually experienced (average departure from normal 0.1°C). Daytime maximum temperatures at most localities were much warmer than those registered in the past (average departure from normal 2.1°C). Total rainfall for the month was generally slightly less than that usually recorded (average percentage of normal received 72.6%).

In southern districts, minimum temperatures were slightly warmer than those usually experienced (average departure from normal 0.6°C). Daytime maximum temperatures at most localities were warmer than those registered in the past (average departure from normal 1.3°C). Total rainfall for the month was generally less than that usually recorded (average percentage of normal received 63.3%).

Figure 9 Example of a monthly climate summary.