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MANAGING SEVERE WEATHER - PROGRESS AND OPPORTUNITIES

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INTRODUCTION

Severe weather often becomes "high impact" weather when certain “tipping points” are reached. Rivers burst their banks, houses lose their roofs, and bushfires exceed suppression capacity as thresholds are crossed. The high adverse impact events tend to be rare, because society and the environment naturally tend to adapt to more frequent events of lower impact. They are often small scale, or a relatively small part of a larger system. And they are often subject to considerable forecast uncertainty.

Managing the impacts of severe weather is therefore about managing risk. The results of exceeding one of these thresholds are profoundly different to merely approaching it – our memories of Hurricane Katrina would be very different if the storm surge had not been high enough to overtop and breach the levees protecting New Orleans. Often, the differences in the meteorology between a close call and a disaster will fall within current forecast uncertainty. Balancing the costs of over-preparation and under-preparation in the presence of such uncertainty is a formidable task.

Managing risk when information is uncertain requires that we move from considering a single, “deterministic” forecast that is our best estimate of what will happen, to consideration of a range of possibilities that reliably reflects the forecast uncertainty. It is not enough to just consider the average (mean) forecast, which may not even be a physically plausible event (you can’t half-flood New Orleans). Even the most likely scenario (the mode) risks leaving us unprepared in the face of more destructive, if less likely, possibilities.

We therefore need to consider not just multiple scenarios, but also their relative likelihood. This paper discusses some selected examples from around the world into objectively providing such information. Making effective use of this richer but more complex information stream is a challenge, and we will also consider progress in this area.

FLIP-FLOPS AND FORECAST UNCERTAINTY

Few things annoy a forecast user more than an about-face in forecast policy. Forecast flips, flip-flops and flip-flop-flips[1] – also known as the windscreen wiper effect – make implementing a coherent preparation strategy very difficult. Nor is the problem confined to end-users of forecasts. Meteorologists also struggle when the model guidance is changing from one run to the next. Does the model really have a handle on the situation when it has flipped, and then flopped back again?

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[1] A “flip” is where forecast outcome A is replaced by the distinctly different outcome B. A “flip-flop” is where a flip is followed by a return to outcome A. And a “flip-flop-flip” contains one additional alternation. These terms were originally defined by Zsoter et al (2009).

Tropical cyclone recurvature provides a good example of the issues. Western Australian tropical cyclones often begin by running parallel to the Pilbara coast. At some point in their life, they may make a turn to the left (recurve) and impact the coast. The time between recurvature and coastal impact can be well under 24 hours, so predicting recurvature well before it happens is crucial.

Sometimes, the atmospheric conditions that cause recurvature are unequivocal, and the forecaster can confidently predict it. Other times, those conditions are present, but it is unclear whether they will become strong enough to force a direction change. In such cases, the most likely event may be a "straight runner", but the forecaster maintains a cyclone watch along the coastline as a precaution. In these cases, users may well want to know whether the chance of a landfall is 10%, or 40%.

Suppose that at one forecast time, the probabilities are 60% for straight track, and 40% for recurvature. The most likely scenario is the straight track, so that will be the official forecast, along with a precautionary watch or warning for the coast, and likely some words expressing caution about the possibility of recurvature. If, at the later time, the probabilities reverse to 40:60, so that recurvature becomes the most likely event, then the official forecast will "flip".

In this hypothetical example, a modest change in probability has led to a dramatic change in the deterministic forecast. Which would be more useful: a series of forecasts "straight", "straight with some caution", "landfall"; or instead "the probability of a landfall is 20% … 40% … 60%". Even though some users may prefer the simplicity and perceived certainty of a definitive forecast, there will be many who can make good use of the probabilistic information. Long experience with, and extensive verification of, ensemble prediction systems has shown that they can provide reliable probabilistic information. Not only do probabilities provide a means of avoiding abrupt changes in communicating forecast policy as in this example, but as recently shown by Zsoter et al (2009), ensemble forecasts are also less prone to flips and flip-flops than their deterministic cousins.

Before we leave cyclone recurvature, we should briefly consider Severe Tropical Cyclone George, which impacted the Pilbara coast in 2006 as a category-five storm, causing three deaths. George's recurvature was not predicted by the deterministic models until quite late, but the European Centre for Medium-Range Weather Forecasting (ECMWF) Ensemble Prediction Scheme (EPS) indicated a significant probability of recurvature approximately three days before landfall. Interestingly, nearly all of the more intense ensemble members recurved, while most of the weaker members ran straight (Fig 1). That is, the EPS not only predicted that there was a significant chance of landfall, but also that, if landfall occurred, then it would very likely be as an intense cyclone.

ENSEMBLE FORECASTS OF HURRICAN SANDY

Hurricane Sandy struck New York on 29 October 2012. Along with the wind and heavy rain, it bought a devastating storm surge which caused extensive flooding and major damage to infrastructure. Sandy struck a densely populated area with an enormous amount of valuable assets, an area seldom affected by such storms. The impact was huge.

Sandy was also a meteorologically very interesting storm. Most hurricanes, once they move polewards out of the tropics are captured by the mid-latitude westerlies and move rapidly to the east. Sandy began this process, but later swung back to the west and impacted New York.

Ensemble predictions from nine days ahead of impact gave some hint of this unusual track (Fig 2). A few ensemble members show the storm heading across the Atlantic, but some curve it back onto the northern part of the US east coast or onto Canada. A subsequent ensemble run from two days later “tightens up” the ensemble spread and shows a clearer signal of northwestwards movement at the end. Further runs closer to the event narrow down the region of uncertainty and provide greater certainty. If we calculate the probability of strong winds in the vicinity of New York from these ensembles (Fig 3), the first hints of trouble are evident nine days ahead of the event. As time passes, the predicted probability of an impact increases reasonably steadily. This consistent signal, in conjunction with other information, gave forecasters and emergency services personnel steadily growing confidence that action was necessary. Even though the forecast tracks were highly unusual, the confidence provided by a consistent ensemble signal, in conjunction with other information, helped provide a strong emergency response.

SOMETIMES THE ATMOSPHERE IS HARD TO PREDICT

Regular footy tippers know that some games are much easier to pick than others. Similarly, a meteorologist’s confidence in a forecast can vary widely. Sometimes, the atmosphere is just more predictable than at others.

Typhoons Soulik and Fitow provide a nice example of this difference. These two storms occurred a few months apart in 2013, in much the same part of the North West Pacific. Both tracked towards the north of Taiwan and then China, and both were intense storms that produced a significant amount of damage, with Fitow becoming the second most damaging typhoon in monetary terms for China.

Predicted tracks for the two storms from the Japanese Meteorological Agency’s EPS are shown in Fig 4. Obviously, the amount of spread in the forecast tracks varies enormously. Ensemble track diagrams from other major numerical weather prediction (NWP) centres’ EPS systems show a similar result.

Why was Fitow so much less predictable? Assigning cause in these circumstances can be difficult, but one challenge with Fitow’s forecasts was the proximity of Typhoon Danas (Fig 5). Tropical cyclones can, when close enough, interact and affect each other’s tracks. In this case, “close enough” depends not just on the physical distance, but also on the size and strength of the storms. Predicting the occurrence and strength of an interaction is therefore very subject to uncertainty, and may have contributed to the large spread in the forecasts of Fitow.

In the event, both typhoons tracked approximately through the middle of the ensemble “cloud”. But, in real time and without the benefit of hindsight, they should have prompted a very different emergency response, since the threat from Fitow extended from the northern Philippines to southern Japan, a vastly greater area than that from Soulik.

All users know that forecasts are always uncertain, and in the absence of information about that uncertainty, will often add on a bit of a “safety margin” to allow for the forecast being out by a small amount. The contrast between Soulik and Fitow shows peril of this approach, for the safety margin will depend on the situation.

TROPICAL CYCLONE OSWALD

As a wind-producing system, Oswald was one of the weakest and shortest-lived tropical cyclones in Australia's history. Oswald briefly attained cyclone strength in the Gulf of Carpentaria, before crossing Cape York Peninsula and tracking southwards parallel to Australia's east coast. Along the way, it produced some exceptional rainfall totals and significant flooding (Fig 6).

Consider the five days from when Oswald was a tropical low in the Gulf, to its reaching the Queensland east coast as a major rain system. The main deterministic NWP systems either partially or completely failed to predict this transition. However, the Australian EPS system, currently being run in research mode, had four of 24 members with a low in the right region, indicating a 17% probability. Similarly, the long-established ECMWF EPS suggested a 12% chance, with 6 out of 51 members. In addition, the mean of all AGREPS (Australian Community Climate and Earth-System Simulator (ACCESS) Global and Regional Ensemble Prediction System) members predicted a low somewhat to the northwest of reality, from five days ahead. In the case of AGREPS, the probability of rainfall exceeding 25 mm exceeded 50% along a significant part of the Queensland coast. Moving closer to the event, the forecast probabilities of 25 mm or more of rain from three days ahead were markedly higher, covered a larger area, and were now accompanied by similar probabilities from the ECMWF EPS (Fig 7). Both EPS systems continued to predict high probabilities of significant rain as ex-Oswald tracked southwards, with the probabilities generally increasing as time progressed.

Oswald was an unusual event. Its failure to weaken and long track southward are both contrary to the normally expected behaviour of tropical cyclones after landfall. Several days before the flooding began, and even before Oswald had become a cyclone, the EPS systems gave a clear indication of the risk, even though the higher-resolution deterministic NWP systems were giving the all-clear for that part of Queensland. Early warning, even at low probability, raises the possibility of better mitigation.

THE VICTORIAN HEATWAVE OF JANUARY 13-17, 2014

Victoria experienced a marked heatwave during January 13 to 17 of this year, with Melbourne having four consecutive days with a maximum temperature over 41 ^{o}C. Ten-day forecasts from the research AGREPS system gave clear indication of this event, a week in advance (Fig 8). The hot spell was followed by a cool change and cooler conditions on the 18th. The prediction of this change by AGREPS from eight days ahead is interesting (Fig 9); the maximum temperature shows a very wide range of spread and it is clear that there is a substantial chance of one, and perhaps even two, more days of heat. Looking also at the wind speed probabilities for this period, it is clear that the probability of high winds increases later in the heat-wave period, and that these are therefore the more dangerous days for fire risk.

WIND CHANGE TIMING ON BLACK SATURDAY

It is well known that the most dangerous time for bushfires is when a wind change strikes. Forecasting the timing of the wind change is therefore of critical importance. Given that the majority of fire deaths occur in conjunction with a wind change, careful risk management of the change is essential. Thus, some idea of the likely error bars on the change timing and position are needed.

Figure 10 shows the strength and location of the wind change, here detected as the line of maximum northwest component of temperature gradient, for a 24-hour forecast from the ECMWF EPS valid at

11 pm on Black Saturday (7 February 2009). The white line shows the change position in the ensemble mean, and the thin grey lines are the position in each member. The black numbers are the standard deviation of the change position in an east-west direction, in degrees of longitude (one degree of longitude is approximately 87 km at these latitudes). Interestingly, the position uncertainty varies along the change.

These data provide quantitative information on the likely progression of the change. They can be used to help answer the question of what is the earliest (or latest) the change can hit a given location. And they add to what was already a very high level of confidence that the change will indeed arrive and not "fizzle out" – every single member had a significant wind change.

SUMMARY AND DISCUSSION

Ensemble prediction systems have significant advantages over deterministic NWP systems. They:

- can be used to **assess the predictability** of the atmosphere
- give an estimate of the **probability distribution** of the forecast
- are **more valuable** than single forecasts
- are **more consistent** than single forecasts
- provide the tools to properly **manage risk.**

Against this, probabilistic information can be more difficult to interpret than categorical forecasts, and many studies have found that a level of user training is necessary to facilitate proper interpretation. For example, the final report of the FIRE-DST (Fire Impact and Risk Evaluation – Decision Support Tool) project (Cechet et al. 2014) noted that some emergency mangers were fixated on yes/no outcomes, and that probabilistic information was "too complicated".

Given the benefits of ensemble forecasting, the challenge then is to gradually move towards making better use of them, with support from the relevant stakeholders. Ensemble forecasting has many well-demonstrated advantages, and is widely regarded as being the future of NWP. Realising those benefits in practice will, however, take time and effort.

ACKNOWLEDGEMENTS

We thanks Grant Elliot for the data on TC George, David Smith for his work on AGPREPS, especially the verification, and Munehiko Yamaguchi for the data on Typhoons Fitow and Soulik.

REFERENCES

Cechet R P et al. (2014). Fire Impact and Risk Evaluation Decision Support Tool (FIREDST): Final Project Report. Bushfire Cooperative Research Centre, Australia.

Magnusson, L., J.-R. Bidlot, S.T.K. Lang, A.Thorpe, N. Wedi and M. Yamaguchi (2014). Evaluation of Medium-Range Forecasts for Hurricane Sandy. *Mon. Wea. Rev.,* **142,** 1962 – 1981.

Zsoter, E., R. Buizza and D. Richardson (2009). ''Jumpiness'' of the ECMWF and Met Office EPS Control and Ensemble-Mean Forecasts. *Mon. Wea. Rev.,* **137,** 3823 – 3836.

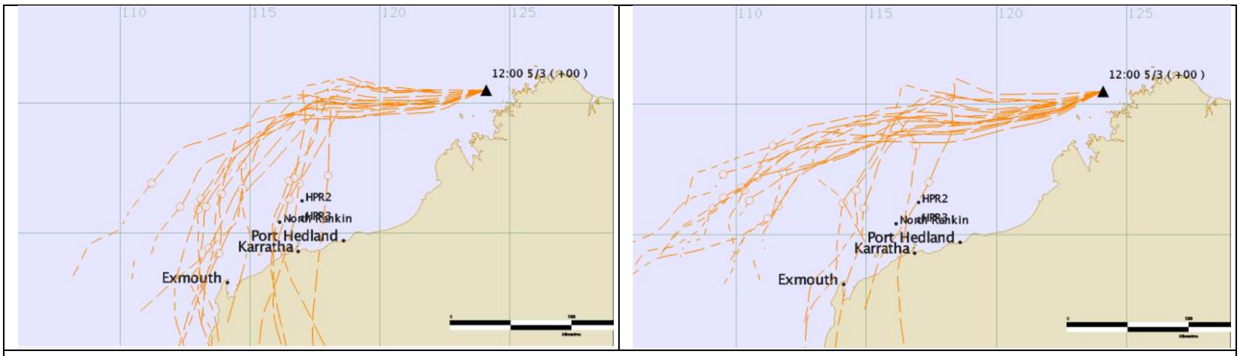

Figure 1. Predicted tracks of TC George, from the ECMWF EPS system. The left panel shows those members in which the intensity was greater than 75 kt, and the right panel those in which the intensity was below 65 kt. Figures courtesy of Grant Elliott.

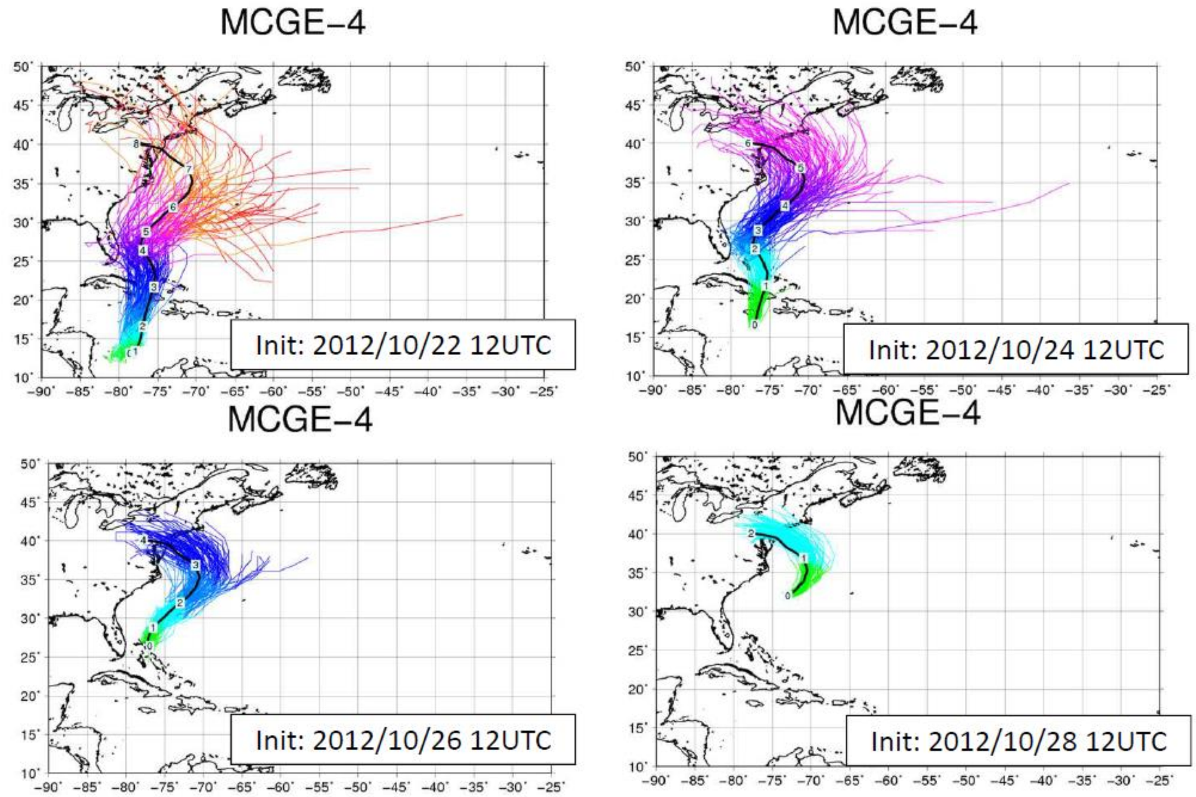

Figure 2. Predicted tracks of Hurricane Sandy from a 4-model Multi-Centre Global Ensemble, for four different start times. The colours indicate the forecast day. The observed track is shown in black. Figure courtesy of Munehiko Yamaguchi.

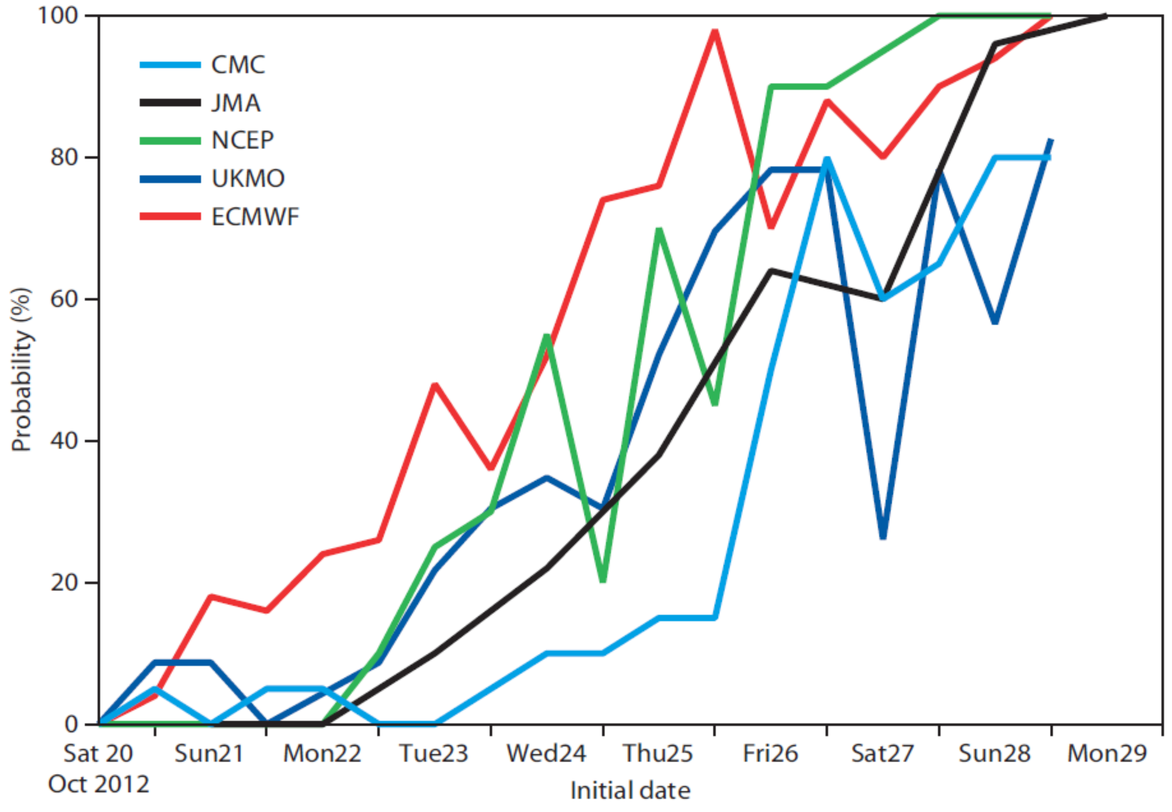

Figure 3. Probability of the wind speed at 850 hPa (about 1.5 km above mean sea level) exceeding 38 m s^{-1} within 100 km of New York Harbour during the 24 hours commencing 1200 UTC on 29 October 2012, from five different global NWP centres, as a function of forecast issue time. From Magnussen et al. (2014).

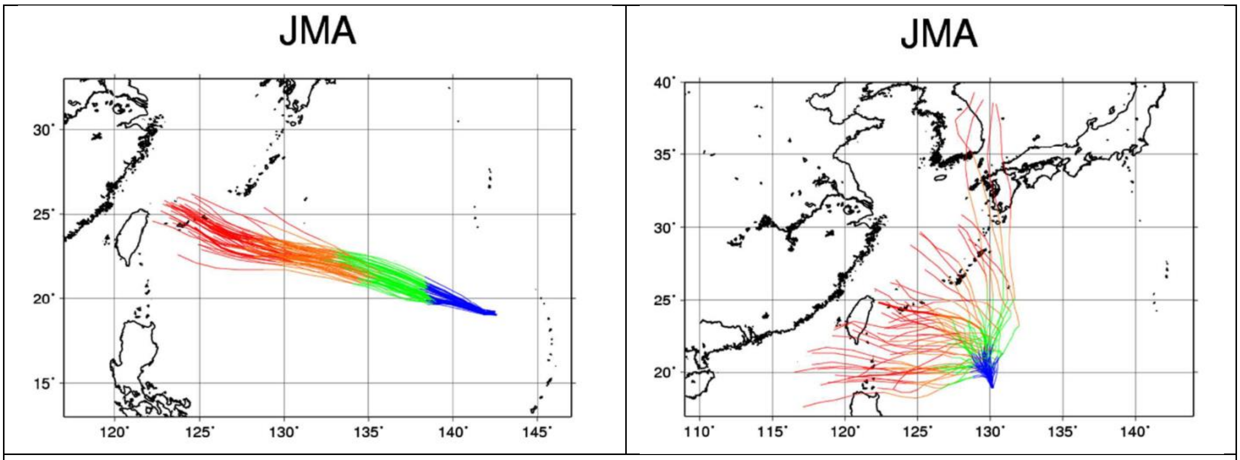

Figure 4. Ensemble track predictions for Typhoons Soulik (left) and Fitow (right) from the Japanese Meteorological Agency's EPS. The tracks each extend for four days, with the colour indicating the forecast day. Figure courtesy of Munehiko Yamaguchi.

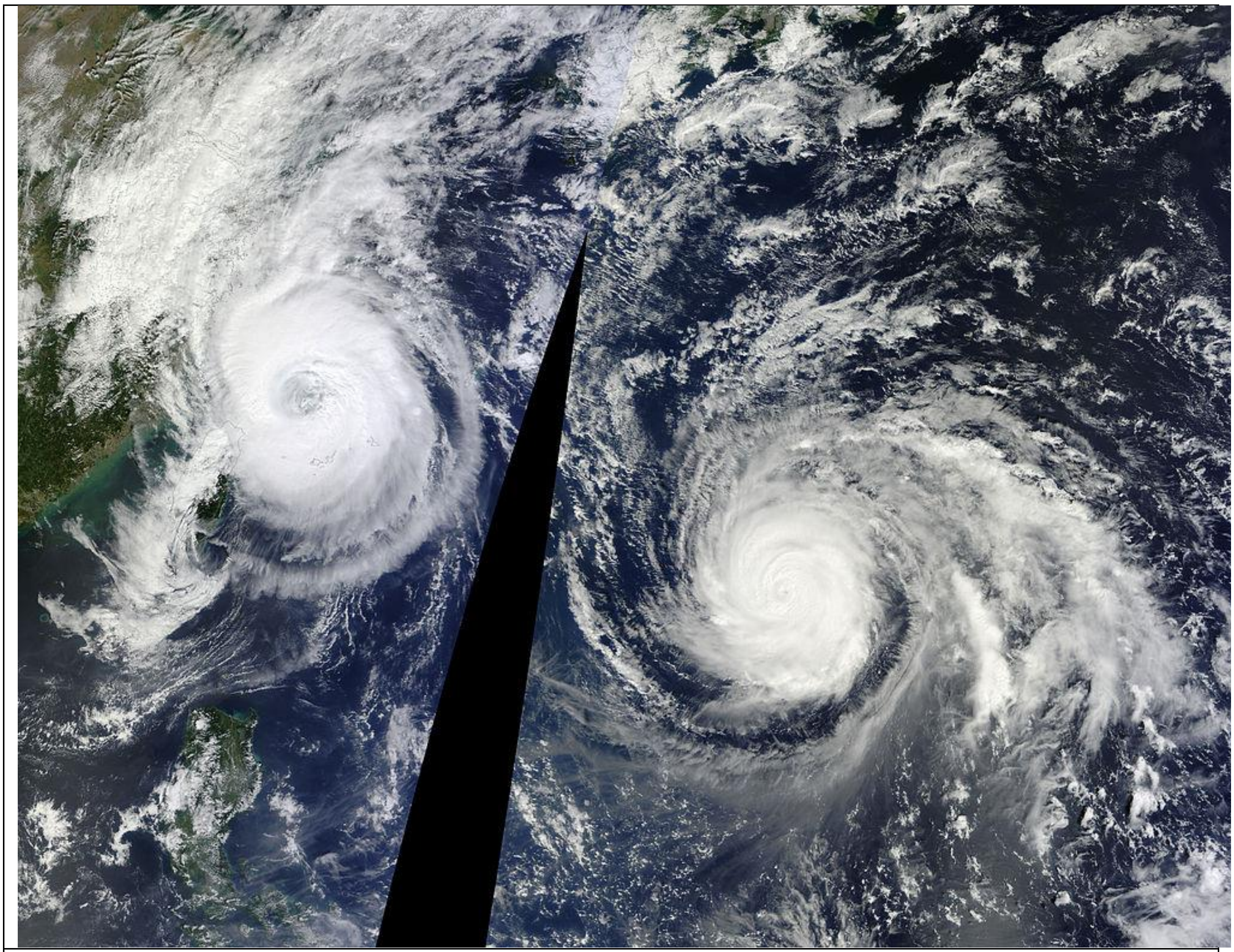

Fig 5. MODIS composite satellite image at 0255UTC 6 Oct 2013, showing Typhoons Fitow (left) and Danas (right).

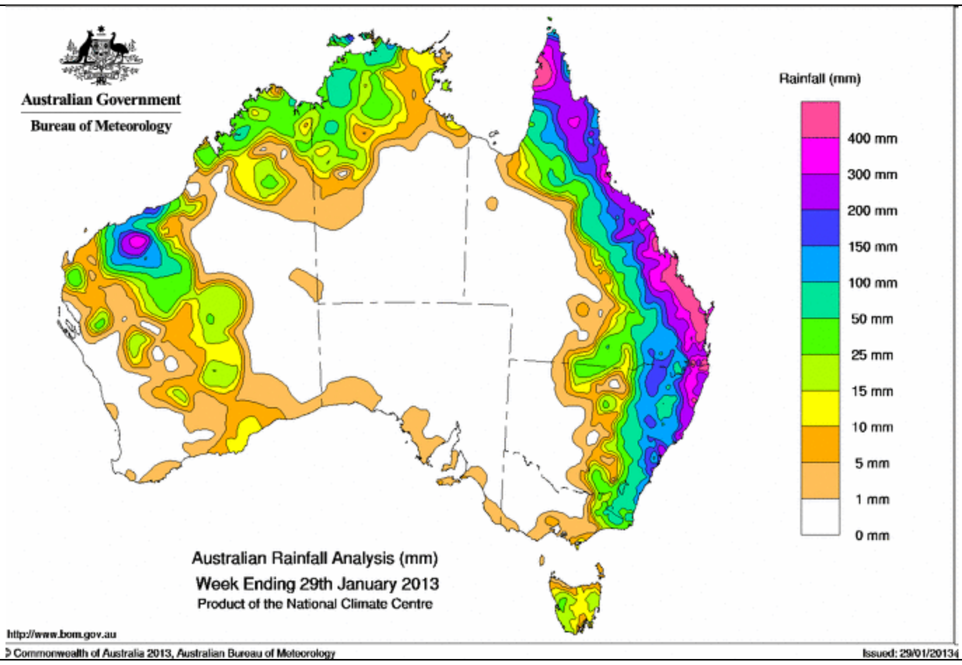

Figure 6. Rainfall totals for Australia for the week ending 29 January 2013.

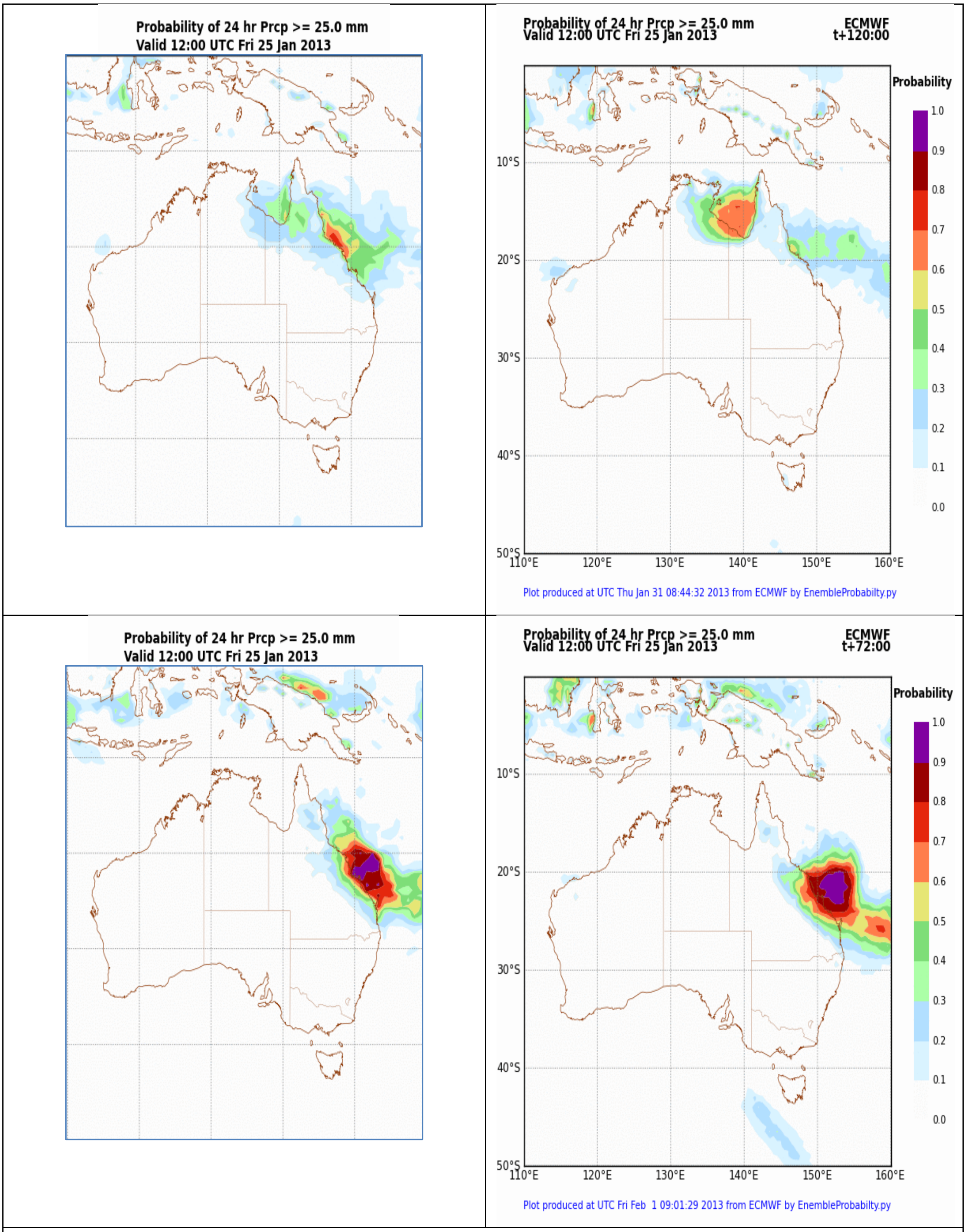

Figure 7. Probability of precipitation exceeding 25 mm in the 24 hours commencing 1200 UTC 25 January 2013, from the AGREPS (left) and ECMWF (right) EPS systems, at 5 (top) and 3 (bottom) days prior to the event.

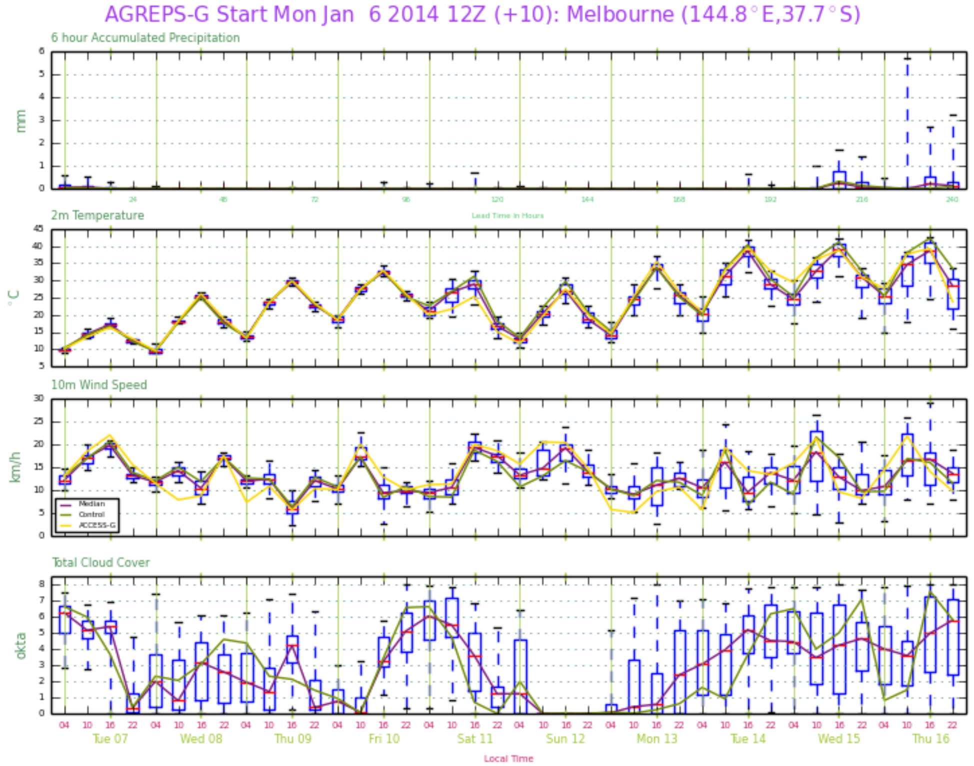

Figure 8. Meteograms of precipitation, 2-metre air temperature, wind speed and cloud amount for Melbourne according to the AGREPS ensemble for a 10-day forecast commencing 1200 UTC 6 Jan 2014. Note the heat-wave conditions, with maximum temperatures exceeding 40°C, for the last three days.

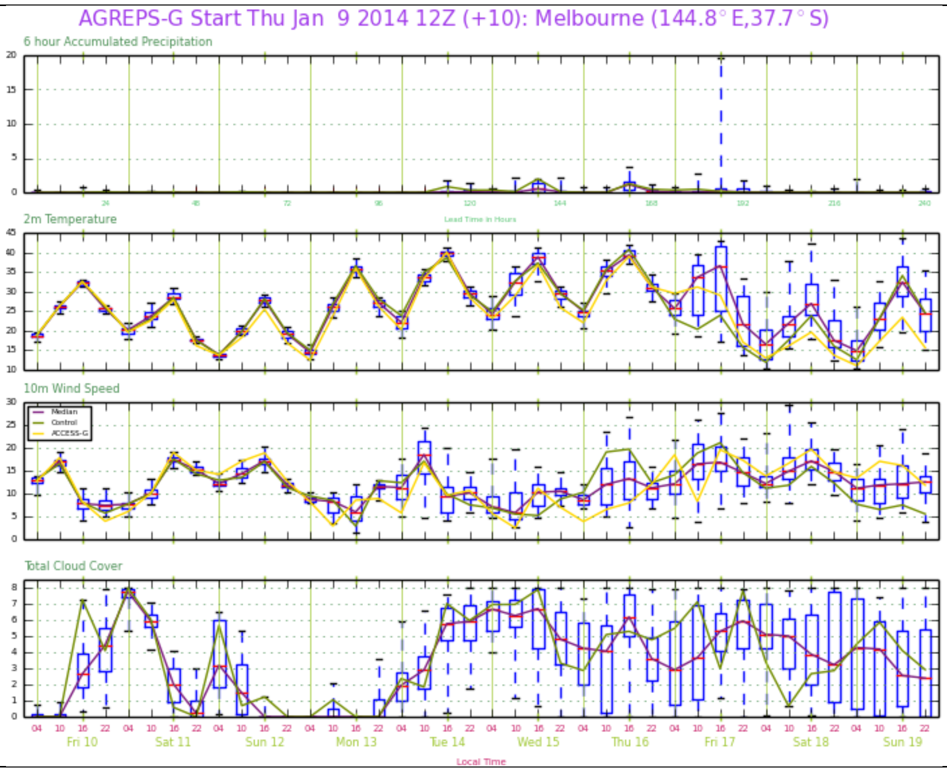

Figure 9. As in Figure 8, except commencing three days later, at 1200 UTC on 9 Jan 2014. Note the continued consistent forecast of the heat wave, and the considerable uncertainty surrounding the eventual cool change on the 17th. Note also the strong winds, and consequent extreme fire danger, with the possible hot conditions on the 16th and 17th.

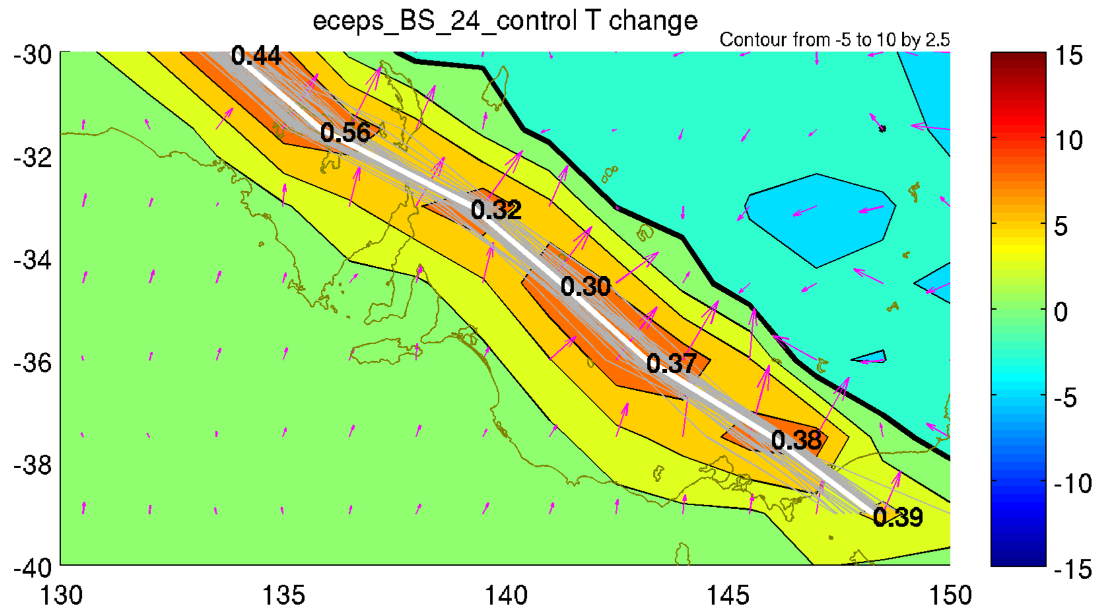

Figure 10. Ensemble prediction of the wind change at 11 pm EDT on Black Saturday, 7 February 2009. The arrows show the magnitude and direction of the surface air temperature gradient, and the colour shading shows its north-west component, in the ensemble mean. The change is diagnosed as the line of strongest north-west temperature gradient, and is shown in the ensemble mean as the white line and in the 51 members as the thin grey lines. The numbers show the standard deviation of the location of the change in degrees longitude.