delivering benefits through science

Communication and dissemination of probabilistic flood warnings – literature review of international material

Science project SC070060/SR3

Flood and Coastal Erosion Risk Management Research and Development Programme

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It's our job to make sure that air, land and water are looked after by everyone in today's society, so that tomorrow's generations inherit a cleaner, healthier world.

Our work includes tackling flooding and pollution incidents, reducing industry's impacts on the environment, cleaning up rivers, coastal waters, contaminated land and improving wildlife habitats.

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Science underpins the work of the Environment Agency. It provides an up-to-date understanding of the world about us and helps us to develop monitoring tools and techniques to manage our environment as efficiently and effectively as possible.

The work of the Environment Agency's Science Department is a key ingredient in the partnership between research, policy and operations that enables the Environment Agency to protect and restore our environment.

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- **Setting the agenda**, by identifying where strategic science can inform our evidence-based policies, advisory and regulatory roles;
- **Funding science**, by supporting programmes, projects and people in response to long-term strategic needs, medium-term policy priorities and shorter-term operational requirements;
- **Managing science**, by ensuring that our programmes and projects are fit for purpose and executed according to international scientific standards;
- **Carrying out science**, by undertaking research – either by contracting it out to research organisations and consultancies or by doing it ourselves;
- **Delivering information, advice, tools and techniques**, by making appropriate products available to our policy and operations staff.

Steve Killeen

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Head of Science

Executive summary

A review of the available international literature was carried out to establish how information about probability is communicated internationally for different natural hazards. The objectives were to:

- produce a list of examples where probability is communicated in the predictions of a range of environmental hazard forecasts internationally;
- detail the different dissemination methods, including the type of technology used for such forecast communications;
- analyse the type of language and images used to communicate probability in forecasts.

This report also provides information on:

- good practice in the dissemination of probability in hazard forecast communications;
- good practice in the language and images used for the communication of probability in the forecast of hazards.

The review covered a number of natural hazards including floods, hurricanes, tornados, avalanches and earthquakes. It also considered how probabilistic information for climate change predictions and weather forecasts is communicated to end users. Methods include:

- a variety of messages either with qualitative or quantitative probabilities;
- graphs, icons and maps including:
  - fan/plume charts;
  - bar charts;
  - pie charts;
  - icons;
  - coloured maps;
  - track forecast maps;
  - cumulative distribution function (CDF) graphs;
  - three-dimensional GIS maps;
- a combination of icons/graphs/maps and messages.

It would appear that some methods are more successful than others in putting their message across. However, there are few examples where probabilistic or uncertainty information is included explicitly in warning messages.

The main findings of the literature review are summarised below:

- No examples were readily available from the international literature illustrating probabilistic flood warnings and indicating how stakeholders would respond to them.
- Expressing probabilistic forecasts using language such as ‘possible’, ‘extremely likely’ and ‘unlikely’ is highly subjective. Limited research suggests that, using this type of language, the message which the forecaster intends to convey to the end user often does not match what the recipient understands. It is important to use consistent terminology to express probability and uncertainty;
- Expressing forecast probabilities is a becoming a more common way of expressing uncertainty especially in the field of meteorological forecasts. However, it is important that probabilities are based on objective scientific techniques and that they are reliable, trustworthy and well-calibrated to the true probability distribution of the phenomena in question.
- Probabilities can be expressed in different ways, e.g. ‘There is a 20% chance of a flood tomorrow’; ‘The odds of a flood tomorrow are 4 to 1 against’; ‘There is a 1 in 5 chance of a flood tomorrow’; and ‘There is a small chance of a flood tomorrow’. The limited research carried out into end users’ understanding of probabilities indicates that using percentages or frequencies transmits the forecaster’s message most effectively.
- Limited surveys show that probabilistic information does not undermine people’s confidence in a forecasting service. On the contrary, it reassures people that they are being dealt with honestly, and gives them confidence that the service is being provided objectively and scientifically.
- Different users will have different requirements for probabilistic information, as well as different levels of understanding. For some (e.g. those involved in emergency response), detailed quantitative estimates of probability may be required. More ‘sophisticated’ users of probabilistic information are often aware of the underpinning reasons for uncertainty and the forecaster can use technical language and speak in some detail. The engagement of specific user communities is important to define their needs and presentation preference with regard to probabilistic warnings.
- Limited end user surveys have shown that end users prefer probabilistic information to be displayed graphically or in the form of a map with an explanation in accompanying text.
- The choice of colours used to convey realistic information for forecast maps is critical to the use and interpretation of the probabilistic information. User surveys need to be undertaken to identify suitable colour scales and accompanying explanations.
- It is important to understand the roles and responsibilities for decision-makers. Limited surveys have indicated that improvements in decision-making can be made using probabilistic forecast information.
- A clear understanding of the roles and responsibilities of forecasters and decision-makers is essential for an effective communication process. Forecasters need to convey full information to the decision-makers. Maintaining the credibility of the science for the decision-maker is essential.

- It would appear that when communicating probabilistic warnings to the public, putting the forecast event in context to a recently experienced event may help with the public's understanding of the message.
- Experiences from both hurricane and weather forecasting indicate that educational programmes and materials are needed, both for decision-makers and the public to ensure proper interpretation and usage of probabilistic methods in hazard situations.

Contents

Tables

Figures

1 Introduction

1.1 Scope of the report

This report was produced as part of the Environment Agency R&D project entitled ‘Communication and dissemination of probabilistic flood warnings’. The aim of the report was to establish how information about probability is communicated internationally for different natural hazards by carrying out a review of the available international literature. The report’s objectives were to:

- produce a list of examples where probability is communicated in the predictions of a range of environmental hazard forecasts internationally;
- detail the different dissemination methods, including the type of technology used for such forecast communications;
- analyse the type of language and images used to communicate probability in forecasts.

This report also provides information on:

- good practice in the dissemination of probability in hazard forecast communications;
- good practice in the language and images used for the communication of probability in the forecast of hazards.

1.2 Structure of report

The report has been structured as follows:

Section 1 provides an introduction to the report and definitions of key terms.

Section 2 describes examples where probability is communicated for a range of natural hazards internationally.

Section 3 details methods commonly used to communicate probability in the prediction of natural hazards.

Section 4 provides a summary of the most important findings.

Section 5 contains details of the references cited in the report.

1.3 Definitions of key terms

Terms such as accuracy, error and uncertainty, together with hazard and risk, are used frequently and interchangeably in the literature reviewed. To avoid any misunderstanding, the context in which these terms are used in the report is therefore defined below:

- **Accuracy –** closeness to reality.
- **Error –** mistaken calculations or measurements with quantifiable and predictable differences.
- **Uncertainty** – a general concept that reflects our lack of sureness about someone or something, ranging from just short of complete sureness to an almost complete lack of conviction about an outcome.
- **Probability** – a measure of our strength of belief that an event will occur. For events that occur repeatedly the probability of an event is estimated from the relative frequency of occurrence of that event, out of all possible events.
- **Hazard** – a physical event, phenomenon or human activity with the potential to result in harm.
- **Risk** can be considered as having two components: the probability that an event will occur; and the impact (or consequence) associated with that event.

The terms deterministic and probabilistic process are also used frequently in the report. These are defined below.

- **Deterministic process.** A process that adopts precise, single-values for all variables and input values, giving a single value output.
- **Probabilistic process.** A process in which the variability of input values and the sensitivity of the results are taken into account to give results in the form of a range of probabilities for different.

It is also important to define the terms flood forecasting and flood warning as these are also often used interchangeably.

- **Flood forecasting system.** A system designed to forecast flood levels before they occur.
- **Flood warning system.** A system designed to warn stakeholders (e.g. members of the public, emergency responders) of the potential of imminent flooding.

The definitions above are taken from *Language of risk: project definitions* (Gouldby and Samuels 2005).

2 Examples of the communication of probability in the prediction of environmental hazards

Natural hazards such as floods, hurricanes, tornadoes, avalanches and earthquakes cover a range of phenomena that can pose a threat to the public.

Forecasting systems coupled with effective warning strategies are designed to predict impending hazards and communicate the information to a range of stakeholders (e.g. public, emergency responders) in order to help minimise the risk.

This review explores the methods used to communicate warning strategies internationally for a range of hazards, as well as in weather forecasts and climate change predictions. It also details examples of how the use of probabilistic information is communicated to stakeholders.

The methods used to communicate different hazards often vary depending on the type of hazard involved. It may be the case that a single warning concept will not serve the requirements of all hazards (Mileti and Sorensen 1990). However, different types of hazards do have several important common elements as follows:

- They represent events that often have a low probability of occurrence.
- They often pose a risk to people.
- In many cases their potential strength and impact can be forecast.
- The issuing of a warning in advance of the hazard occurring can result in a reduction in the risk.

The similarities between hazards mean that certain elements of the communication of probability may be transferable between different warning methods.

The following sections examine examples used for different hazards. The similarities and differences between the various methods are summarised in Section 2.7.

2.1 Floods

A review of flood warning strategies worldwide found that the language and tools of probability and risk estimation in flood risk management are rarely optimised for the communication challenge. In general, communication strategies do not yet routinely deal with flood risk communication probabilities and uncertainties, either at international or national levels (Faulkner et al. 2007).

Public and policy makers often look to scientists to provide deterministic solutions. However, scientists often disagree and models produce contradictory results. There is a ‘certainty gap’ between what decision-makers want and what science can provide. Often expert judgement is used when the science is uncertain. However, attempts to provide a single ‘best’ estimate do not necessarily meet the decision needs of all stakeholders.

A study in Colorado relating to estimation of flood hazards found that several practitioners argued that uniformity in guidelines and methods unduly restrict methods that would fit better conditions (Downton et al. 2005). McCarthy et al. (2007) found that, during a flood forecasting exercise carried out using probabilistic forecasts in the Thames Estuary, some emergency managers working at the public interface initially struggled to comprehend probabilistic and/or ensemble forecasts without further translation of the science. Handmer and Proudly also argued that practitioners may hesitate to interpret uncertainty tools correctly. Hall et al. (2005) argued that it is helpful when exploring the communication of uncertainty at the science/professional interface to distinguish between the decision uncertainty that preoccupies flood risk managers and the scientific uncertainty of a flood risk assessment or within a warning.

In many examples from the literature, it is argued that scientific uncertainty is an unwelcome part of decision uncertainty from the perspective of a manager. Experience in relation to flood risk management has been that professionals are initially disinclined to embrace ownership of uncertainty in the message unless its meaning is enhanced by a translation of some kind (Downton et al. 2005, Martini and de Roo 2007).

2.1.1 Grand Forks flood, North Dakota

A workshop on communicating uncertainty in 2007 organised by the US National Research Council Board on Atmospheric Sciences and Climate used the Grand Forks flood in North Dakota in 1997 to illustrate the issues associated with not incorporating uncertainty explicitly in a flood warning (Friday 2007).

At East Grand Forks, the flood crest on 22 April 1997 was 54.4 feet (16.6 m). The total estimated damage was approximately $4 billion, with $3.6 billion in losses in Grand Forks and East Grand Forks alone. These losses were the greatest per capita for a flood event in the USA. Following a major flood in 1979 at Grand Forks, with a river level of 48.8 feet (14.9 m), flood defence dikes were raised to a level of 52 feet (15.9 m).

None of the forecasts issued at the time of the 1997 flood provided any numerical measure of uncertainty, although some general words indicating uncertainty and severity were used. Based on available information, city officials decided to prepare the city for a 52-foot river level. People assumed that they were safe because the forecast level was similar to the flood defence level. This level was chosen based on the forecast of 49 feet (14.9 m) and by adding a ‘buffer’ of three feet (0.9 m). But, in reality, the forecast was not meant to be taken with such certainty. The actual flood level was higher than expected the flood defences were breached and Grand Forks was flooded.

Based on this case study, the workshop reached the following conclusions (Friday 2007):

- Understanding the uncertainty inherent in the scientific products that are being delivered is essential to delivering an accurate message to decision-makers and the public.
- Uncertainty measures of scientific products are needed. These measures can be of multiple forms, including probabilistic model outcomes, empirical verification of outlook/forecast performance, and narrative language that conveys the correct meaning of the uncertainty. Visualised presentation of the uncertainty would complement text presentation of uncertainty.
- A clear understanding of the roles and responsibilities of forecasters and decision-makers is essential for an effective communication process.

Forecasters need to convey full information to the decision-makers. Maintaining the credibility of the science for the decision-maker is vital.

- When communicating with the public, the context of the upcoming event relative to past experiential evidence of the people helps to convey the potential severity of the hazard.

2.2 Hurricanes

A review of hurricane warning systems found that some highly sophisticated forecasting and warning systems have been developed – particularly in the USA, where the communication of probabilistic information forms an integral part of hurricane advisories.

The hurricane warning system in the USA has been in place for several decades. Despite a high degree of uncertainty when forecasting the behaviour of hurricanes, improvements to the system achieved in the past 20 years have been impressive (Sorensen 2000). Recent years have seen improvements not only in scientific forecasting capabilities but also the ability to graphically represent hurricane warnings.

To illustrate the improvements, the probability of dying in a hurricane in the USA has fallen exponentially, reducing by half every 13.6 years during the 20th century (Gladwin et al. 2007). At the same time, populations in hurricane-prone areas have increased considerably since the 1960s, with a doubling of the population every 20 years (Lindell et al. 2005).

One of the main improvements has been the increased use of probabilistic information in forecasts. Probabilistic information relating to hurricane forecasts to the public was introduced in 1983 (Baker 1995) to avoid users placing undue confidence in predicted landfall locations.

The US National Hurricane Center (NHC) issues watches and warnings for long stretches of coastline in an effort to identify area where storms could strike, though this obscures the fact that some areas are more likely to be affected than others. As a consequence, the probability that the centre of a hurricane or tropical storm would pass within 65 miles (identified as the proximity resulting in damage) is issued by the NHC as part of its hurricane warnings.

The US National Weather Service (NWS) initially had reservations about releasing probabilistic information to the public but, at the time, the agency had no secure means of disseminating the probabilities to the emergency management agencies of state and local government without allowing the public access via the broadcast media. The main concern raised was that:

- probabilities would not be understood by the public;
- the use of probabilities could deter people from evacuating as early as needed in areas showing low probabilities of strike.

A study of public response to hypothetical hurricane threats using probability forecasts (Baker 1995) showed that:

- the public appeared to comprehend and use the probabilistic information reasonably;
- evacuation notices issued by local officials were seen as more important than other threat variables.

Other studies support the view that the public can understand probabilities provided the definition of the event to which the probability refers is given (Gigerenzer et al. 2005). Gigerenzer et al. found that one of the main problems relating to the understanding of probabilistic information both by the public and authorities is the missing and conflicting explanatory information provided with probabilistic information such as weather forecasts. The use of probabilities in weather forecasts is discussed further in Section 2.3.

Since 1983, there have been further improvements to forecasts and the dissemination of probabilistic information in relation to hurricane threats. In June 2004, for example, the United States Landfalling Hurricane Probability Project website was created to provide access to high wind probabilities for the entire US coastline from Brownsville, Texas to Eastport, Maine.[1] A number of different probabilities are provided on the website including:

- storm landfall, sustained wind probabilities (e.g. probabilities of tropical storm-force, hurricane-force and major hurricane-force winds);
- probabilities of being in the vicinity of damaging winds;
- 1 in 50 year probabilities;
- current year probabilities.

One of the most powerful probabilities is the current year probabilities, which are calculated based on activity in the Atlantic Ocean with storms more likely to make landfall when activity is high. Probabilities are currently presented in tabular format on the website by sub-region. The website is considered a powerful tool for both coastal residents and emergency managers.

In terms of presentation of probabilistic information, a Tropical Storm Risk (TSR) wind speed probability graphical product was developed in 2005 by the Benfield Hazard Research Centre, London (Saunders and Yuen 2005). The TSR website has been in operation since July 2005.[2]

The National Oceanic and Atmospheric Administration (NOAA) in the USA also publishes wind speed probabilities using similar graphics. The products map the likelihood that a specific area will be struck by hurricane winds (i.e. 74 mph) and/or tropical storm strength (i.e. 39 mph) one-minute sustained winds during different time periods up to five days ahead at six-hour intervals. The probabilities are based on errors during recent years in the official track and intensity forecasts issued by the NHC. Variability in tropical cyclone size (i.e. wind radii) is also incorporated. An example of the type of information displayed is shown in Figure 2.1 for Hurricane Katrina.

Other storm tracking software includes:

- HURREVAC – developed by the Federal Emergency Management Agency (FEMA);
- HURRTRAK – available from PC Weather Products, Inc.

These also have the capability of plotting uncertainty bounds, so future storm behaviour can be mapped in terms of cones.

On the NOAA website,[3] accompanying advisory information is provided along with the graphics in a tabular format. The tables show the probability that the maximum one-

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[1] http://www.e-transit.org/hurricane/welcome.html
[2] http://www.tropicalstormrisk.com/
[3] http://www.nhc.noaa.gov

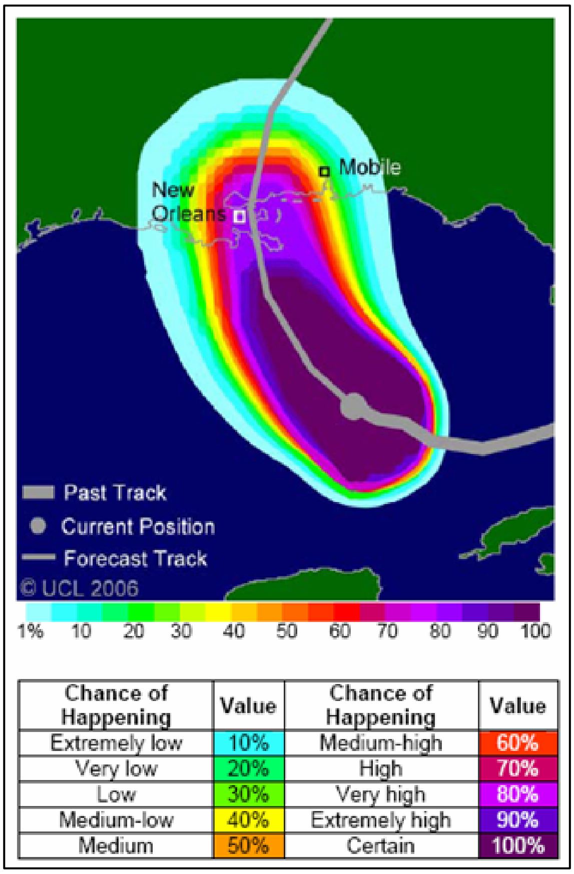
minute wind speed of the tropical cyclone will be within any of eight intensity ranges during the next 72 hours. It is based on the outcomes of similar NHC wind speed forecasts during the period 1988–1997. An example of one of these tables is shown in Figure 2.2. The database excludes unnamed tropical depressions.

Since 2007, a number of coastal offices in the USA have also issued colour-coded impact maps for the primary tropical hazards of wind, storm surge flooding, inland flooding and tornadoes as illustrated in Figure 2.3. However, some questions have arisen about the meaning of these graphics. The forecasters are effectively predicting impacts or consequences, but it is suggested that it would possibly be more prudent to communicate the potential for a range of values to occur that would create impact (Goldsmith and Ricks 2007). ‘High wind impact’ may, for example, mean different things to the mobile home dweller compared with someone living in a house constructed from brick or concrete; however, the potential for winds greater than 100 mph may be ‘high’, resulting in greater risk of widespread damage.

In terms of ongoing developments, the incorporation of uncertainty information for storm surge flooding and inland flooding during the hurricane season is underway with probabilistic storm surge information becoming more widely used by an increasing number of Weather Forecast Offices (WFOs) during the 2008 season.

Tropical cyclone storm surge probabilities based on a statistical combination of ensemble predictions by the NWS produce data for cumulative probabilities and the probability of exceeding a specific surge value. Some coastal offices (Melbourne and Miami) have developed algorithms to use these data to produce more robust storm surge threat graphics as illustrated in Figure 2.3.

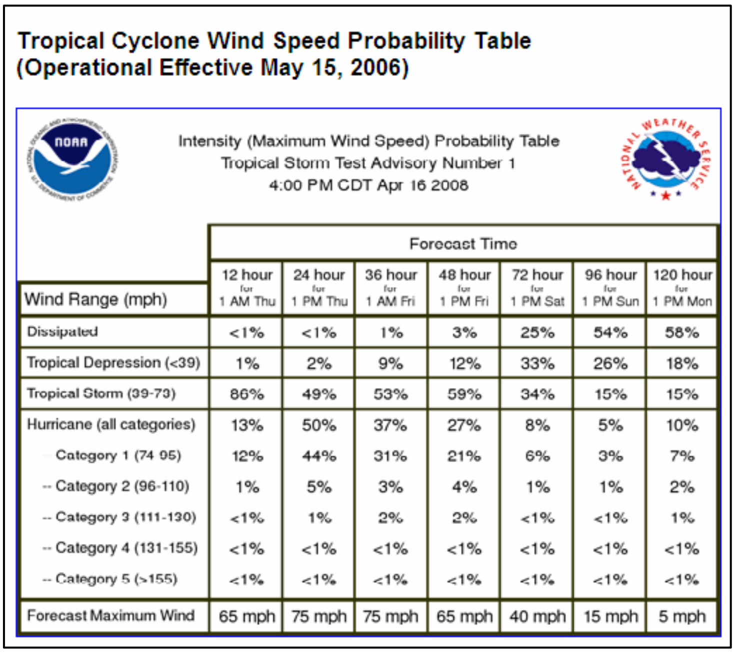
For inland flooding and tornadoes, the incorporation of uncertainty information in forecasts is only in its initial stages of development in comparison to wind and surges. A promising algorithm combines probabilistic forecasts of excessive rainfall potential issued by the NWS Hydrometeorological Prediction Center (HPC) with deterministic forecasts of precipitation amount and flash flooding guidance, resulting in a graphical depiction of threat from inland flooding (NWS SPC, 2008).



Chance of Happening	Value	Chance of Happening	Value
Extremely low	10%	Medium-high	60%
Very low	20%	High	70%
Low	30%	Very high	80%
Medium-low	40%	Extremely high	90%
Medium	50%	Certain	100%

Source: Saunders and Yuen (2005)

Figure 2.1 Example of percentage probabilities of experiencing one-minute sustained wind speeds of at least hurricane Category 1 strength (64 knots or 74 mph) from Hurricane Katrina during the 33 hours starting at 09:00 GMT on 28 August 2005.



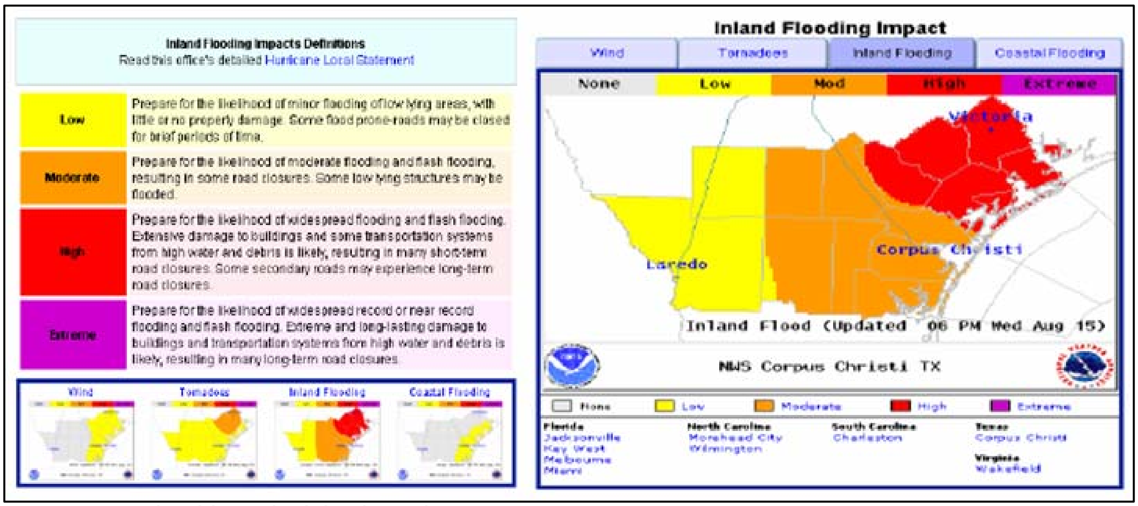
Tropical Cyclone Wind Speed Probability Table (Operational Effective May 15, 2006)

Intensity (Maximum Wind Speed) Probability Table
Tropical Storm Test Advisory Number 1
4:00 PM CDT Apr 16 2008

	Forecast Time						
Wind Range (mph)	12 hour for 1 AM Thu	24 hour for 1 PM Thu	36 hour for 1 AM Fri	48 hour for 1 PM Fri	72 hour for 1 PM Sat	96 hour for 1 PM Sun	120 hour for 1 PM Mon
Dissipated	<1%	<1%	1%	3%	25%	54%	58%
Tropical Depression (<39)	1%	2%	9%	12%	33%	26%	18%
Tropical Storm (39-73)	86%	49%	53%	59%	34%	15%	15%
Hurricane (all categories)	13%	50%	37%	27%	8%	5%	10%
-- Category 1 (74-95)	12%	44%	31%	21%	6%	3%	7%
-- Category 2 (96-110)	1%	5%	3%	4%	1%	1%	2%
-- Category 3 (111-130)	<1%	1%	2%	2%	<1%	<1%	1%
-- Category 4 (131-155)	<1%	<1%	<1%	<1%	<1%	<1%	<1%
-- Category 5 (>155)	<1%	<1%	<1%	<1%	<1%	<1%	<1%
Forecast Maximum Wind	65 mph	75 mph	75 mph	65 mph	40 mph	15 mph	5 mph

Source: NWS NHC (2008)

Figure 2.2 Example of NOAA tabular cyclone wind speed forecast information.



Inland Flooding Impacts Definitions

Read this office's detailed Hurricane Local Statement

Low	Prepare for the likelihood of minor flooding of low lying areas, with little or no property damage. Some flood prone-roads may be closed for brief periods of time.
Moderate	Prepare for the likelihood of moderate flooding and flash flooding, resulting in some road closures. Some low lying structures may be flooded.
High	Prepare for the likelihood of widespread flooding and flash flooding. Extensive damage to buildings and some transportation systems from high water and debris is likely, resulting in many short-term road closures. Some secondary roads may experience long-term road closures.
Extreme	Prepare for the likelihood of widespread record or near record flooding and flash flooding. Extreme and long-lasting damage to buildings and transportation systems from high water and debris is likely, resulting in many long-term road closures.

Source: Goldsmith and Ricks (2007)

Figure 2.3 Example of inland flood impact graphic from WFO Corpus Christi, Texas during Tropical Storm Erin in 2007 including inland flood impact definitions.

New methods of communicating hurricane information are also emerging. Fast mobile communication devices with global positioning systems (GPS) and high resolution geographical information systems (GIS) capability may, for example, allow end users to consider a spectrum of potential impacts wherever they are located. Digital television could become an interactive receiver during hazards, providing specific information to the location of the digital box.

The review of the use and communication of forecast probability in hurricane warning indicates several benefits:

- Most studies indicate that the use of probabilistic information in assessing the potential for tropical hurricane impacts improves the value of the forecast by providing an objective level of confidence that has previously been lacking (Baker 2005, Goldsmith and Ricks 2005).
- Provided the limitations of hurricane forecasts and vulnerabilities are communicated effectively, increased awareness of the probabilities in hurricane forecasting and vulnerabilities of local communities may improve the perceived credibility of official warnings.
- Due to long lead times required for evacuation combined with the natural uncertainty of the behaviour of hurricanes, 'false alarms' may occur and there is evidence to suggest that the public will be more tolerant and less likely to become complacent when uncertainty information is included in hurricane warnings by officials.
- Studies also show that educational programmes and materials are needed – both for decision-makers and the public – to ensure proper interpretation and use of probabilistic methods for hurricane warnings.

2.3 Weather forecasts

Daily weather forecasting is an area of meteorology with inherent uncertainties and, as such, provides a good example of communicating probabilities within organisations and more importantly to the wider public. While weather forecasts under normal circumstances cannot be categorised as hazardous, examples of probabilistic communication from this field illustrate how probabilistic information for extreme natural events could be used and communicated to the wider public.

In some parts of the world such as the USA and Australia, weather forecasters have used probabilities in their public weather forecasts for decades, whereas in some European countries (e.g. Greece and Italy), probabilistic forecasting is a largely unknown area (Gigerenzer et al 2005).

2.3.1 USA

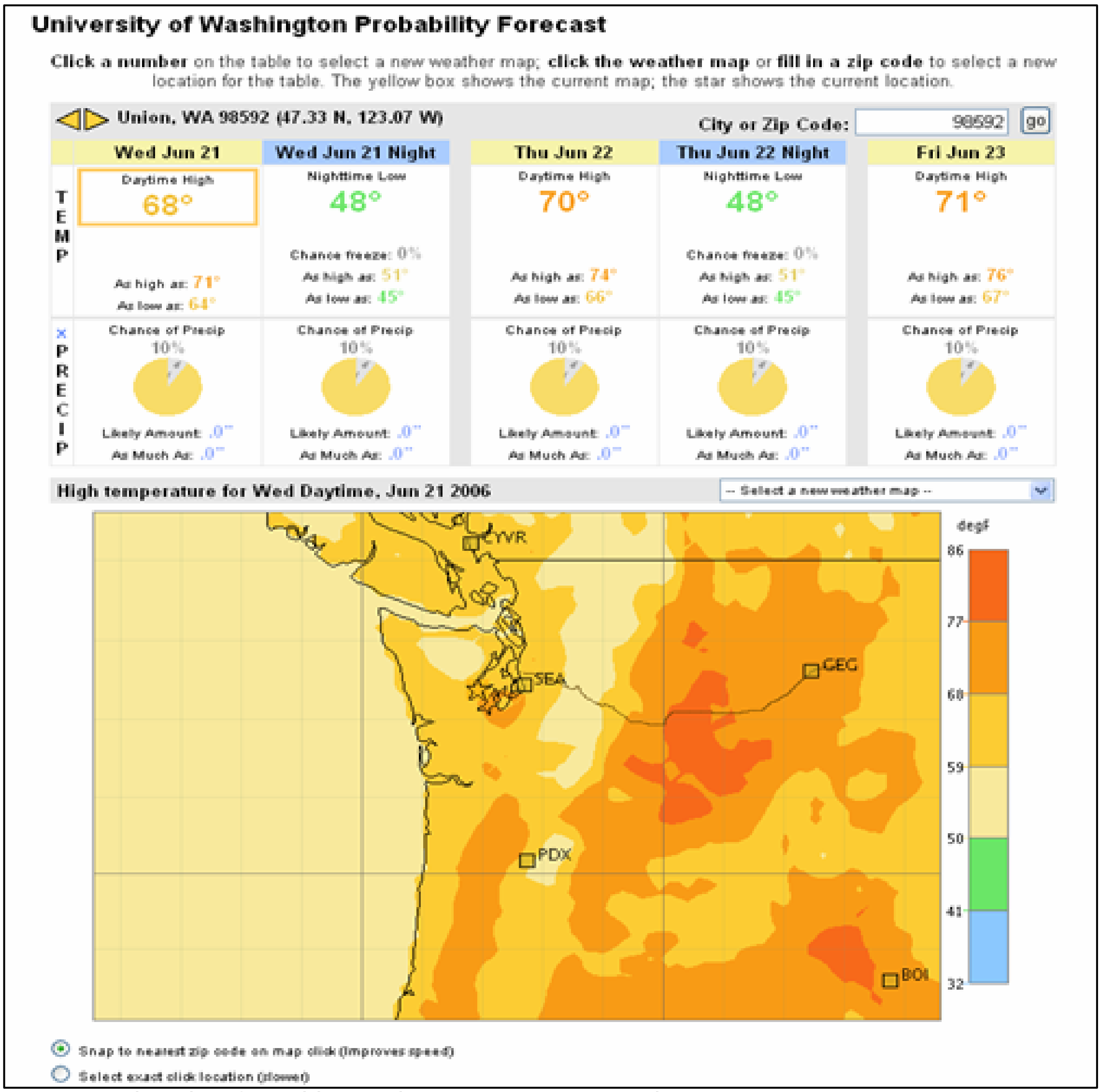
In the USA, Probabilities of Precipitation (POP) have been included in public forecasts since 1965 and the general public is therefore familiar with probabilistic information provided with forecasts (Joslyn 2007). Forecasts on television and radio are, however, still mostly deterministic and probabilities are rarely communicated or used by forecasters.

An example of the dissemination of probabilistic weather information on the web developed by Washington University is shown in Figure 2.4. The web page shows:

- intervals of temperature;
- high and low temperature;
- chance of precipitation five days ahead in time;
- colour-coded contour maps.

2.3.2 Australia

In Australia, probabilistic seasonal rainfall forecasts are issued by the Australian Bureau of Meteorology using colour-coded maps as one way of showing probability of rainfall (Figure 2.5). During the initial publication of the maps, it became clear that colour is a very powerful tool for conveying probability and that care must be taken in choosing the colours to send the right message (Gill 2008). The public response to the maps indicates that the more emotive colours should be used to apply only to the high/low probability values (as illustrated in Figure 2.5) or there is otherwise scope for misinterpretation. Another way of presenting probabilistic information also used by the Australian Bureau of Meteorology is using ensemble predictions in charts according to threshold; for example, the probability of rainfall in excess of 5 mm as shown in Figure 2.6.



University of Washington Probability Forecast

Click a number on the table to select a new weather map; **click the weather map** or **fill in a zip code** to select a new location for the table. The yellow box shows the current map; the star shows the current location.

Union, WA 98592 (47.33 N, 123.07 W)

City or Zip Code: 98592

	Wed Jun 21	Wed Jun 21 Night	Thu Jun 22	Thu Jun 22 Night	Fri Jun 23
TEMP	Daytime High 68° As high as: 71° As low as: 64°	Nighttime Low 48° Chance freeze: 0% As high as: 51° As low as: 45°	Daytime High 70° As high as: 74° As low as: 66°	Nighttime Low 48° Chance freeze: 0% As high as: 51° As low as: 45°	Daytime High 71° As high as: 76° As low as: 67°
× PRECIP	Chance of Precip 10% Likely Amount: .0" As Much As: .0"	Chance of Precip 10% Likely Amount: .0" As Much As: .0"	Chance of Precip 10% Likely Amount: .0" As Much As: .0"	Chance of Precip 10% Likely Amount: .0" As Much As: .0"	Chance of Precip 10% Likely Amount: .0" As Much As: .0"

High temperature for Wed Daytime, Jun 21 2006

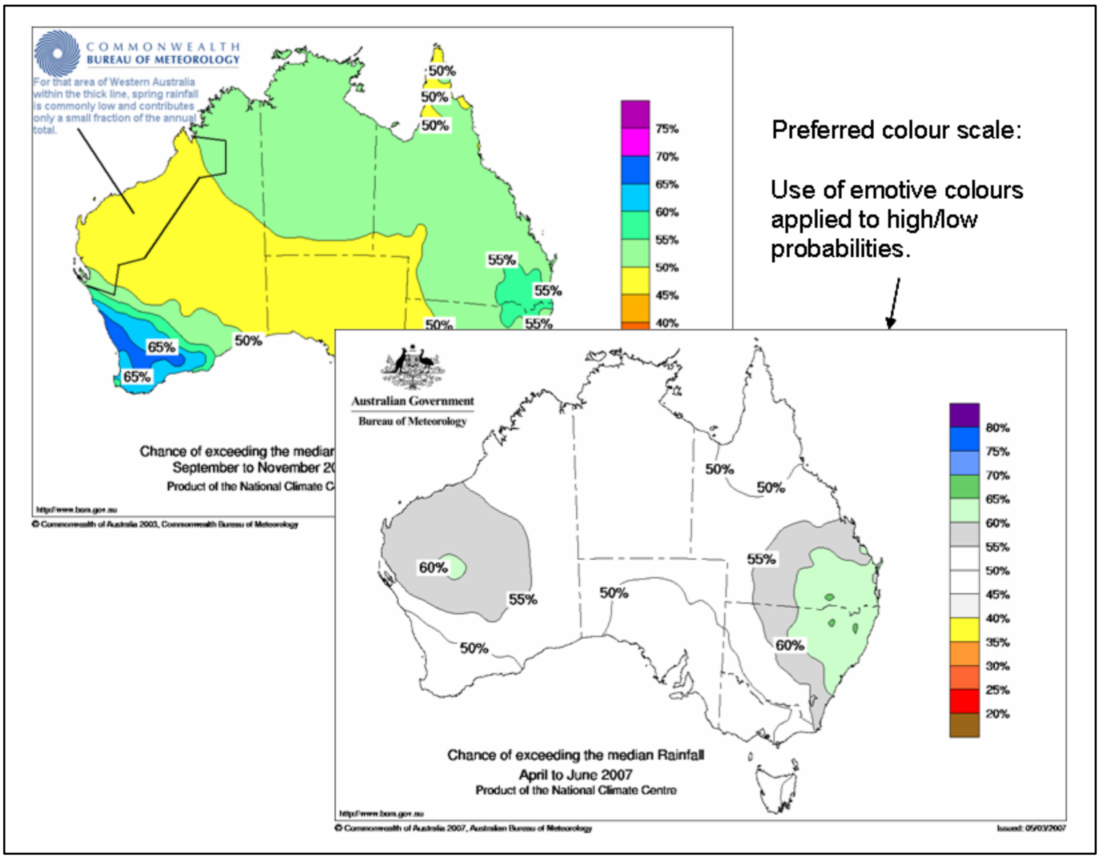
-- Select a new weather map --

● Snap to nearest zip code on map click (improves speed)

○ Select exact click location (slower)

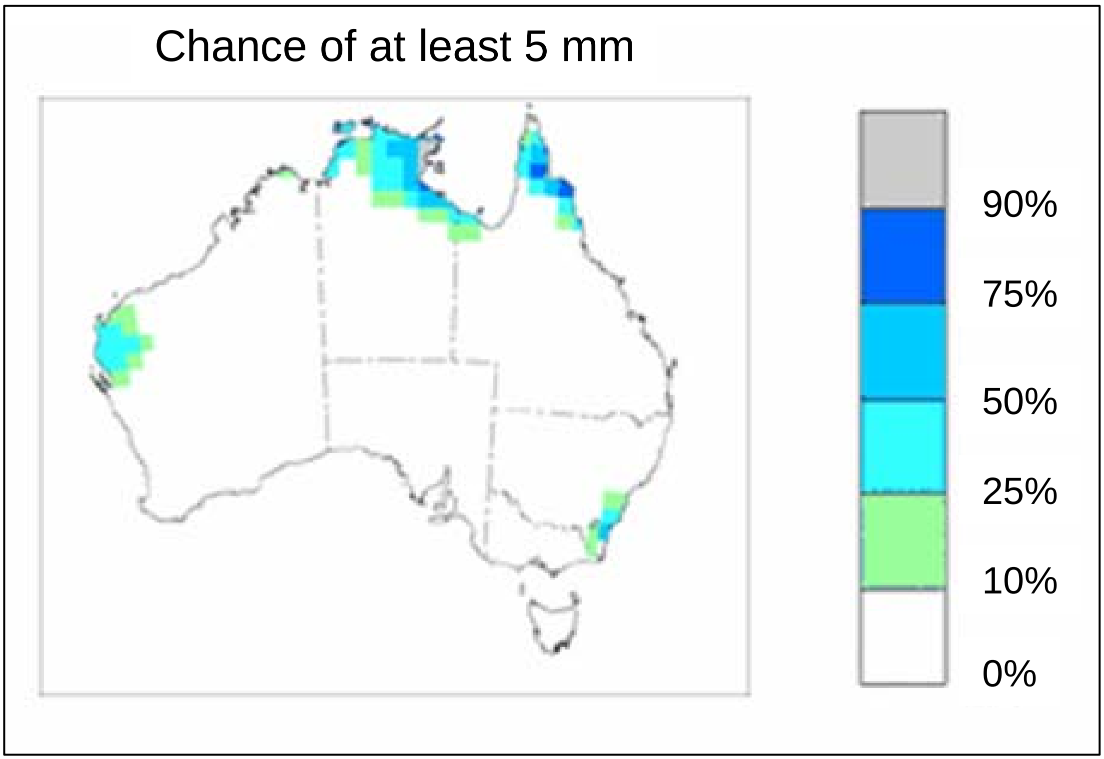
Source: University of Washington (http://www.probcast.com), 4 August 2008

Figure 2.4 Example of a web-based probabilistic weather forecast from the USA.



Source: Gill (2008)

Figure 2.5 **Example of a probabilistic seasonal rainfall forecast issued by the Australian Bureau of Meteorology.**



Source: Gill (2008)

Figure 2.6 **Example of map showing probability of at least 5 mm of rainfall.**

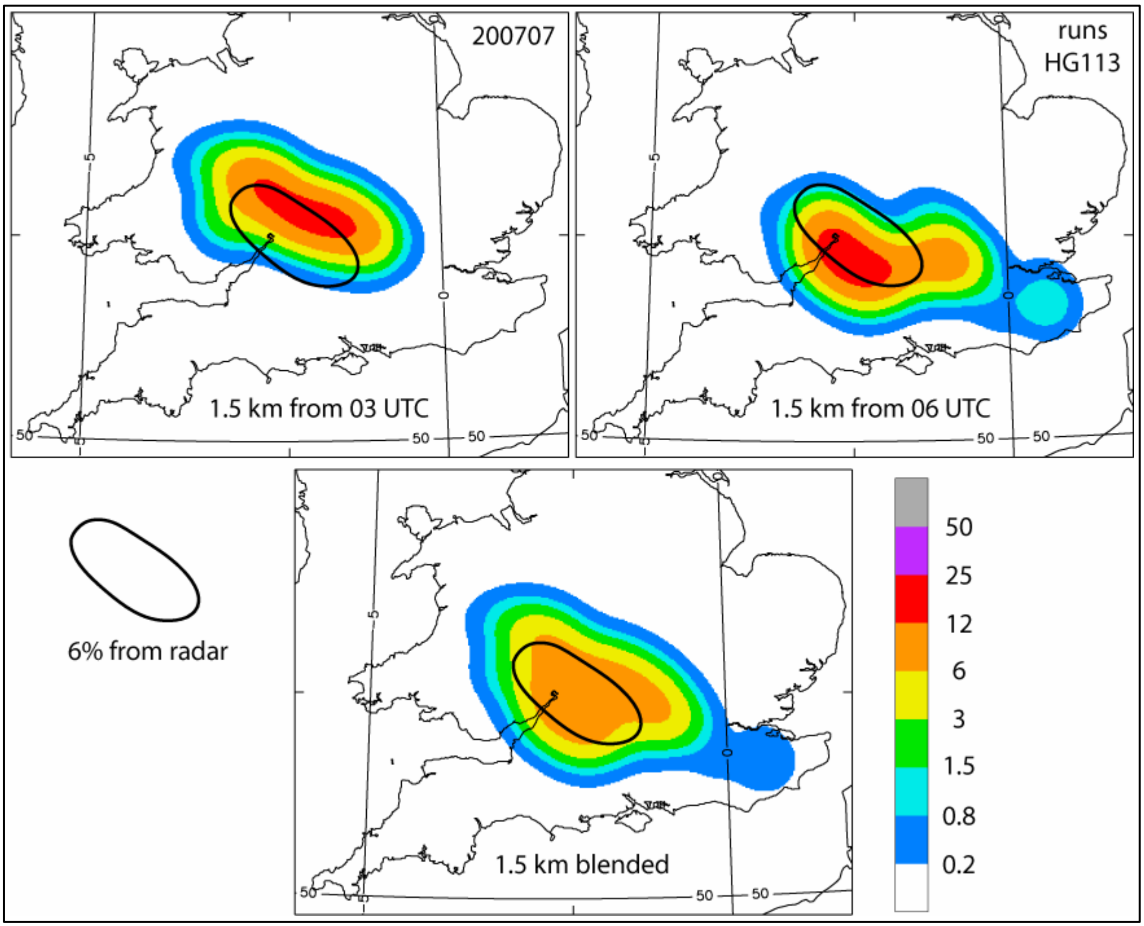
2.3.3 UK

In the UK, probabilistic information is not included in ‘normal’ weather forecasts issued by the Met Office – neither on the web nor through other media. Severe weather warnings are issued on the Met Office website, but only when confidence levels are above 60 per cent; this is explained on the website.

The Met Office recently started issuing seasonal forecasts that present the likelihood of deviations of UK and European climate from average conditions for temperature and precipitation for a season (i.e. approximately three months). However, the forecasts are currently limited to explanations using words and graphics are not yet applied.

An Extreme Rainfall Alert (ERA) system is being piloted jointly by the Environment Agency and the Met Office. The aim is to assist the emergency services, local authorities and utility companies to target the areas most likely to be affected by surface water flooding.

For a six month period from August 2008, the Environment Agency provided data to emergency responders showing areas naturally vulnerable to surface water flooding. Experts from the Met Office and Environment Agency were available throughout the pilot period to help emergency responders interpret the forecasts and flood data to assess likely flooding impacts (Environment Agency and Met Office 2008). The ERA system uses probabilistic forecasts of rainfall produced by the Met Office; Figure 2.7 shows a typical example.



Source: Caulket (2008)

Figure 2.7 Outputs from Met Office model of the probability of exceeding 75 mm of rain in 12 hours.

Over 600 Category 1 and 2 responders have requested registration details for the ERA project. It has wide UK coverage with representatives from 'core responders' including:

- emergency services;
- local authorities;
- health bodies;
- government agencies;
- 'co-operating responders' including utility companies and transport organisations.

Table 2.1 provides details of the probabilistic thresholds used to issues alerts, including the trigger thresholds. An 'Advisory' ERA is issued when there is a greater than 10 per cent probability of an extreme rainfall event occurring across a large geographical area. Confidence levels will increase closer to the impending rainfall event and as the meteorological situation becomes clearer. This may result in an 'Early Alert' or 'Imminent Alert' being issued. In a rapidly developing situation, alerts may be issued without being preceded by an 'Advisory'. Similarly an 'Advisory' will not always be followed by an 'Alert', e.g. if weather conditions improve (Environment Agency and Met Office 2008). The system has only recently been introduced so it is too early to report any feedback from the Category 1 and 2 responders.

Table 2.1 Alert levels for the pilot ERA system.

	Advisory	**Early Alert**	**Imminent Alert**
Probability of thresholds being exceeded: 30mm per hour; or 40mm in three hours; or 50mm in six hours.	Very low: exceeds 10%	Low: 20% to 40%	Moderate: exceeds 40%
Lead times	Issued at 14:00: valid for 24-hour period from next midnight to all counties in England and Wales. No updates or cancellations issued.	Issued 8–11 hours in advance to specific county. Note: early alerts are triggered by probabilities so lead times may be less than 8 hours. Updates or cancellations may be issued.	Issued 1–3 hours in advance to specific county. Updates or cancellations may be issued.
Guidance to responders on receipt of an ERA	Extreme rainfall may lead to surface water flooding. Be prepared should the situation worsen.	Extreme rainfall may lead to surface water flooding. Consider activating your emergency procedures.	Extreme rainfall may lead to surface water flooding. Activate your emergency procedures.

Source: Email communication with Elizabeth Cook, Environment Agency, 30 July 2008

2.3.4 Other European countries

Experiences from other European countries are generally fairly limited and are summarised below.

In the Netherlands, rainfall forecast probability has been communicated to the public since 1975, but has mostly been presented in terms of rain expected rather than in terms of probability. The expected time of day of rainfall is often also presented along with quantitative probabilities, e.g. a percentage chance and expected rainfall quantity. When quantitative probabilistic information is used, this is typically accompanied by a verbal explanation. However, evidence suggests that the explanations are typically confusing to the public as they are not very clear about the terminology used. Even Dutch meteorologists seemed to be confused about the understanding of probabilistic weather forecasts and the reference class of a probability of rain (Gigerenzer et al 2005).

In Italy weather forecasts on television, radio and in the newspapers are largely devoid of uncertainty or use of probabilistic information. The main reason is that the Italian media abhor uncertain predictions and will simply take percentages provided by meteorologists and translate into a simple message of rain or no rain (Gigerenzer et al 2005).

In Germany, the use of probabilities in the mass media is only somewhat more advanced. Some papers and news stations report probabilities of precipitation, but their meaning is rarely explained. Probabilities have thus become entrenched in the daily forecasts, but a unique definition of probabilities is lacking.

In Greece, probabilistic forecasts are not used owing to considerable disagreement among meteorologists about what numerical probabilities of rain might mean or how they should be derived.

In Switzerland, the Federal Office of Meteorology and Climatology provides some indication of uncertainty of the forecasts by including a scale from 1 to 10 (Figure 2.8) to indicate the reliability of their forecast – a simple and effective way of conveying uncertainty information (Gill 2008). However, the use of uncertainty scales does need some care because confidence can be very different for different elements of the forecast, e.g. temperature, precipitation and sunshine.

Source: Swiss Federal Office of Meteorology and Climatology

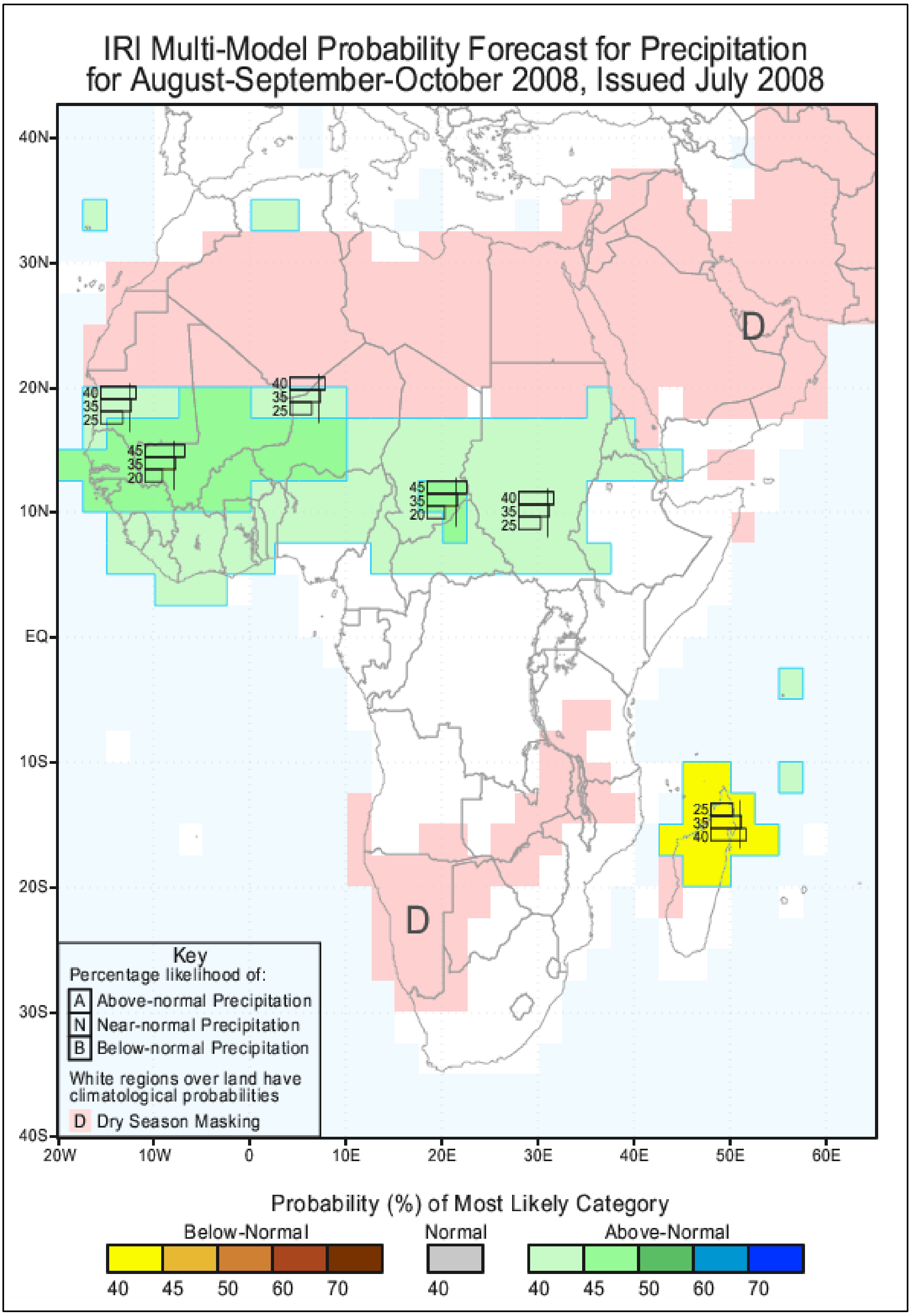
Figure 2.8 Four day forecast including measure of 'reliability'.

2.3.5 Other parts of the world

In other parts of the world, seasonal weather forecasting using probabilistic information has been used for a number of years.

The International Institute for Climate and Society in Columbia (IRI) and the Intergovernmental Authority on Development (IGAD) Climate Prediction and Applications Centre (ICPAC) in eastern Africa both issue outlooks on the web for rainfall and temperature by continent for 1–3 months with a lead time of 1–2 months.

Seasonal forecasts are provided using colour-coded maps showing equal zones/regions of probability and, for each region, a seasonal forecast is provided in a box showing percentage probability of above-, near- and below-normal rainfall. An example for Africa from the IRI website is shown in Figure 2.9.



Source: IRI (2008)

Figure 2.9 Example climate outlook for Africa.

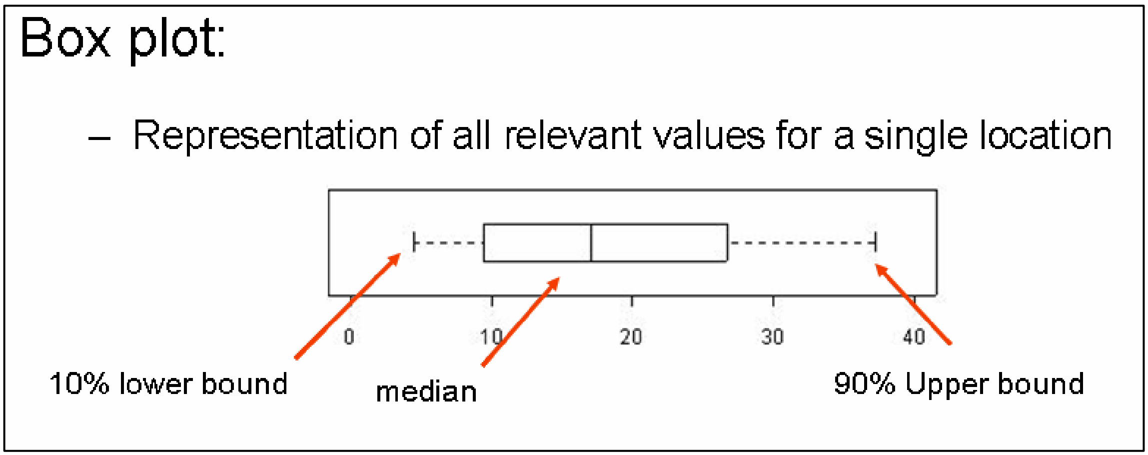
2.3.6 Recent research

A number of research projects by the Met Office (Mylne 2008a) and University of Washington (Joslyn 2007) have recently been undertaken to examine different methods – including the use of graphics and maps – for effective communication of probabilities both to forecasters and the general public. A range of experiments have compared different ways of presenting uncertainty information to ascertain the best way of communicating uncertainty in weather forecasts.

Experiments by Nadav-Greenberg et al. (2007) and Joslyn (2007) indicate that weather forecasters prefer box plot charts (Figure 2.10) to upper bound charts and margin of error charts for wind speeds in terms of posting wind advisories. Appendix A provides examples of all three types of plots.

With regard to the presentation of probabilistic weather information to the general public, experiments in the USA examined the use of icons in presenting the probability of rain compared with using words (Joslyn 2007). The study showed that, despite the use of probabilities and improved icons over the past 40 years, misunderstandings of probabilistic information are in general high (e.g. over 30 per cent of people misinterpret probabilities in weather forecasts). The use of icons improved understanding somewhat (Figure 2.11). But adding information on the chance of 'no rain' improved the understanding further, illustrating the importance of clear communication of information and use of language. Other experiments indicate that the use of probability is generally preferable to frequency as long as the whole amount is specified (e.g. 75 per cent of 100 per cent) (Joslyn 2007).

Adding a specific reference class only helps with the use of frequencies. However, these findings contradict the results of experiments by Gigerenzer et al (2005), which indicate that the use of natural frequencies including the reference class are preferable to probabilities, percentiles and confidence limits. The study by Joslyn (2007) also showed that people generally have more problems with negative information such as the use of the word 'less' compared to 'more'.

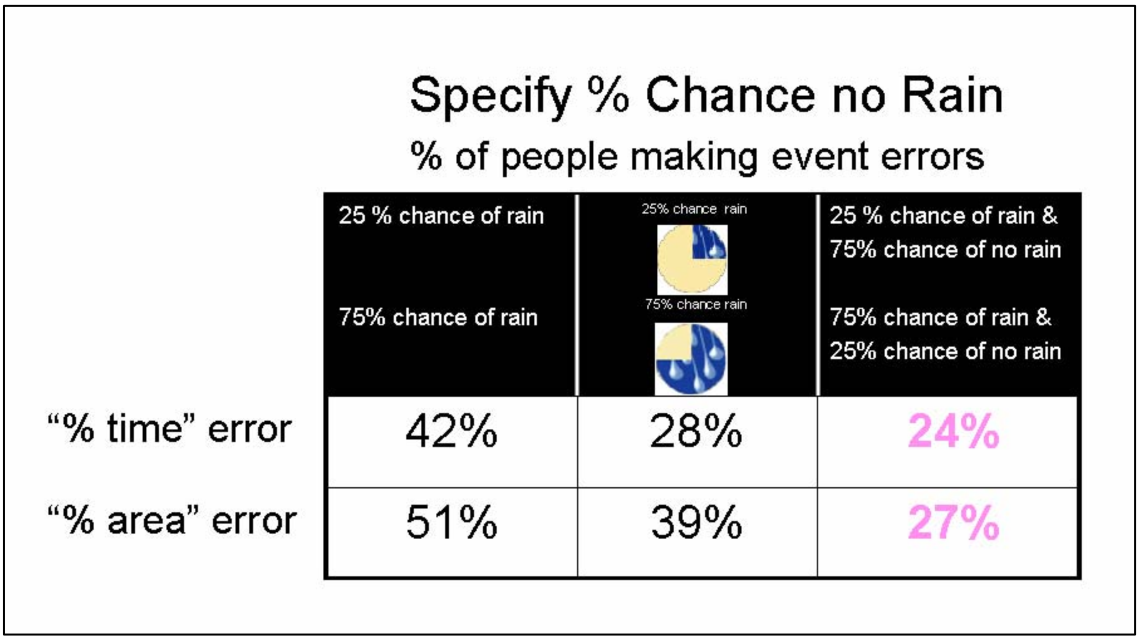


Box plot:

– Representation of all relevant values for a single location

Source: Joslyn (2007)

Figure 2.10 Example of 'box plot' showing visualisation of 80 per cent predictive interval.



Specify % Chance no Rain

% of people making event errors

	25 % chance of rain 75% chance of rain	25% chance rain 75% chance rain	25 % chance of rain & 75% chance of no rain 75% chance of rain & 25% chance of no rain
“% time” error	42%	28%	24%
“% area” error	51%	39%	27%

Source: Joslyn (2007)

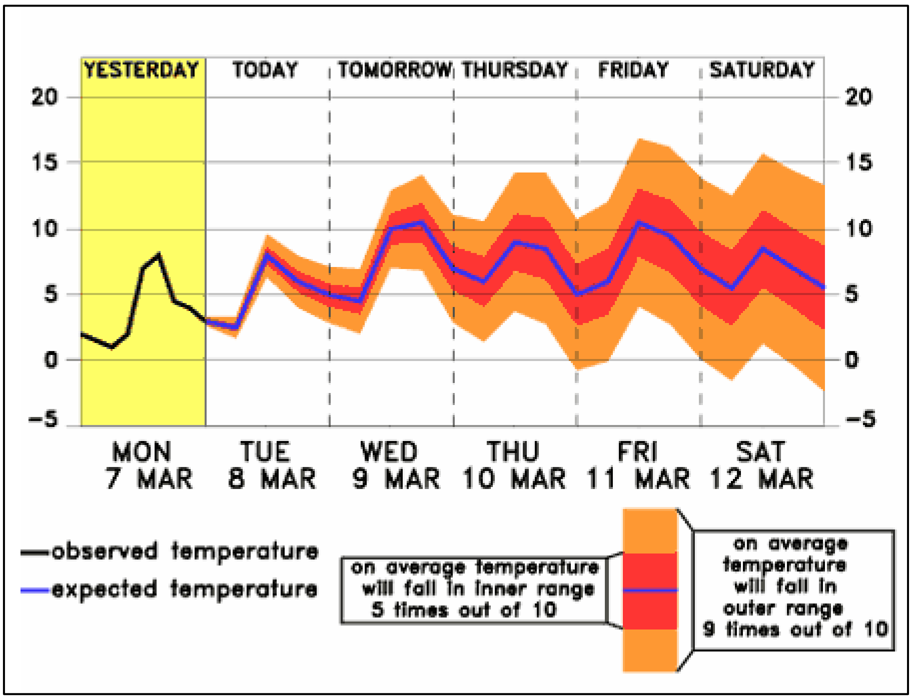
Figure 2.11 Example of the rate of misinterpretation of probabilistic forecasts of rainfall from an experiment using icons and probabilities.

Another weather forecasting survey based on a questionnaire placed on the Met Office website from Tuesday 13 June until Monday 19 June 2006 (Mylne 2008b) sought to identify preferred means of presentation by exposing both the public and students to a number of different graphics.

Figure 2.12 shows the most popular, most useful and easiest format for a five -day temperature forecast out of five options for temperature. Similarly a survey of graphics for showing precipitation identified two popular graphs for precipitation (see Appendix A). Other types of graphs used for specific purposes, which are currently being explored by the Met Office, are also included in Appendix A.

The survey also revealed that most people prefer a combination of text and graphics for presenting probabilistic weather information. Although the graph in Figure 2.12 uses frequencies (as recommended by Gigerenzer ‘and colleagues’), another survey by the Met Office found that people prefer the use of ‘percent chance of’ to probabilities, odds and frequencies.

Further tests of people’s ability to make better decisions from forecasts with probabilistic information conducted at Exeter University (Mylne 2008a) also showed significant improvements in decision-making when probabilistic information was included. This was equally true for users with a scientific background and those from other academic disciplines, indicating that most members of the public can benefit from probabilistic information.



Source: Mylne (2008b)

Figure 2.12 Preferred graphical presentation of five-day temperature forecast from experiment undertaken by the Met Office.

2.3.7 Summary

The use of probabilistic information in weather forecasting is an emerging area of meteorology, with most experiences to date obtained in the USA and Australia.

Experiences indicate that probabilistic information in weather forecasts is useful and popular with both forecasters and the general public, but care must be taken in communicating the information clearly using a combination of text and graphics.

Further research is needed in terms of determining the most efficient ways of disseminating and presenting probabilistic information, both with regard to the type of language used and graphical presentation to avoid/minimise confusion amongst forecasters and the public.

Experiences also indicate that, while there is a degree of chance of misinterpretation of probability forecasts, they do successfully convey the notion that forecasts are judgemental and uncertain in nature.

2.4 Tornadoes

Tornadoes develop in various parts of the world, but the greatest number and most severe tornadoes occur in the USA. Tornadoes are generally not well understood and are very difficult to predict owing to their rapid formation, short lifetime and relatively small size. Weather radar is an essential tool in forecasting severe weather from which tornadoes can be generated and in spotting actual tornadoes.

The US National Weather Service (NWS) is responsible for providing local storm watches and warnings including tornadoes for all states. Tornadoes in Canada are handled by the Meteorological Service of Canada. Very few other nations have specific tornado watch and warning services.

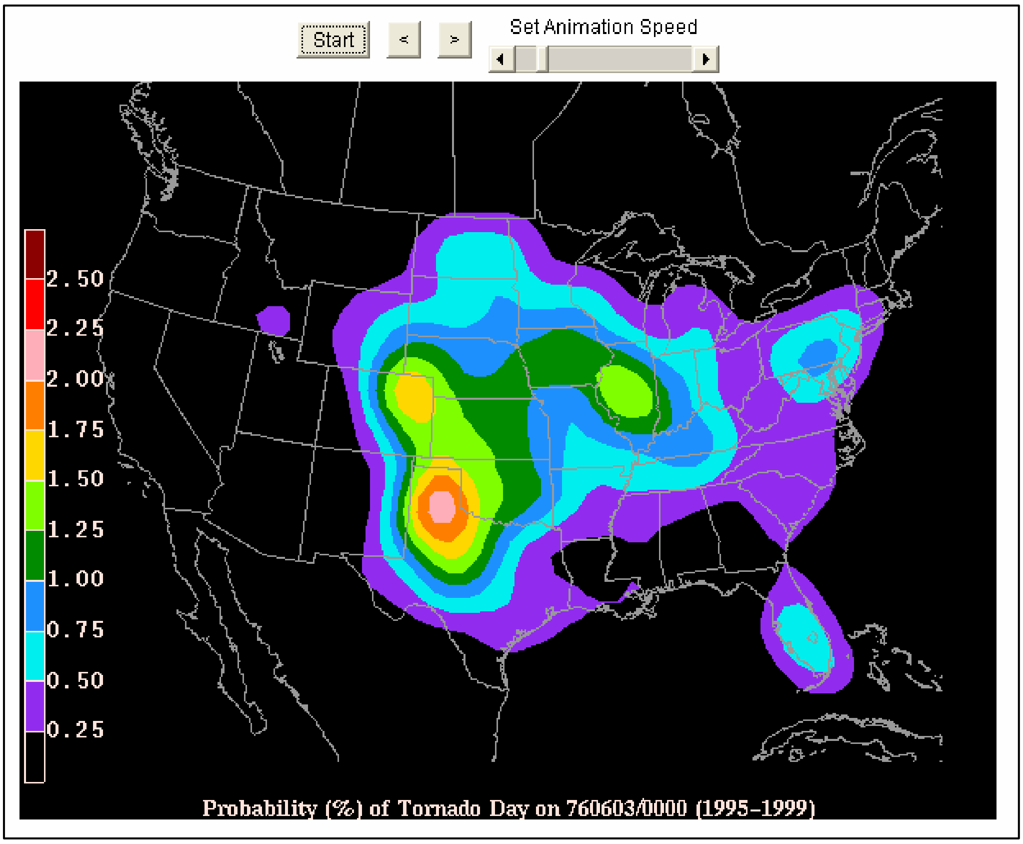
The NWS issues multi-hazard products including probability outlooks for tornadoes, wind and hail through the Storm Prediction Center (SPC) set up in 2001 (Evans and Carbin 2008). Threat probabilities are produced which convey the degree of forecaster confidence of an event and these tend to require a sound appreciation for severe weather climatology.

Examples of tornado information available to the public on the NOAA website include:

- mean number of days per year with different events (tornadoes, thunderstorms and hail) occurring within 25 miles of any point;
- animated loops of the probability of severe weather occurring within 25 miles of any point on a particular day, with images once per week throughout the year;
- graphs showing the annual cycle of the probability of severe weather occurring within 25 miles at any point in the USA.

At present the website provides the probability of tornado development based on historical data.

Figure 2.13 shows one frame of an animation of the annual cycle for tornado probability week by week. The maps help to illustrate how the likelihood of tornados changes over the course of a year and how the chances of tornados vary by region.



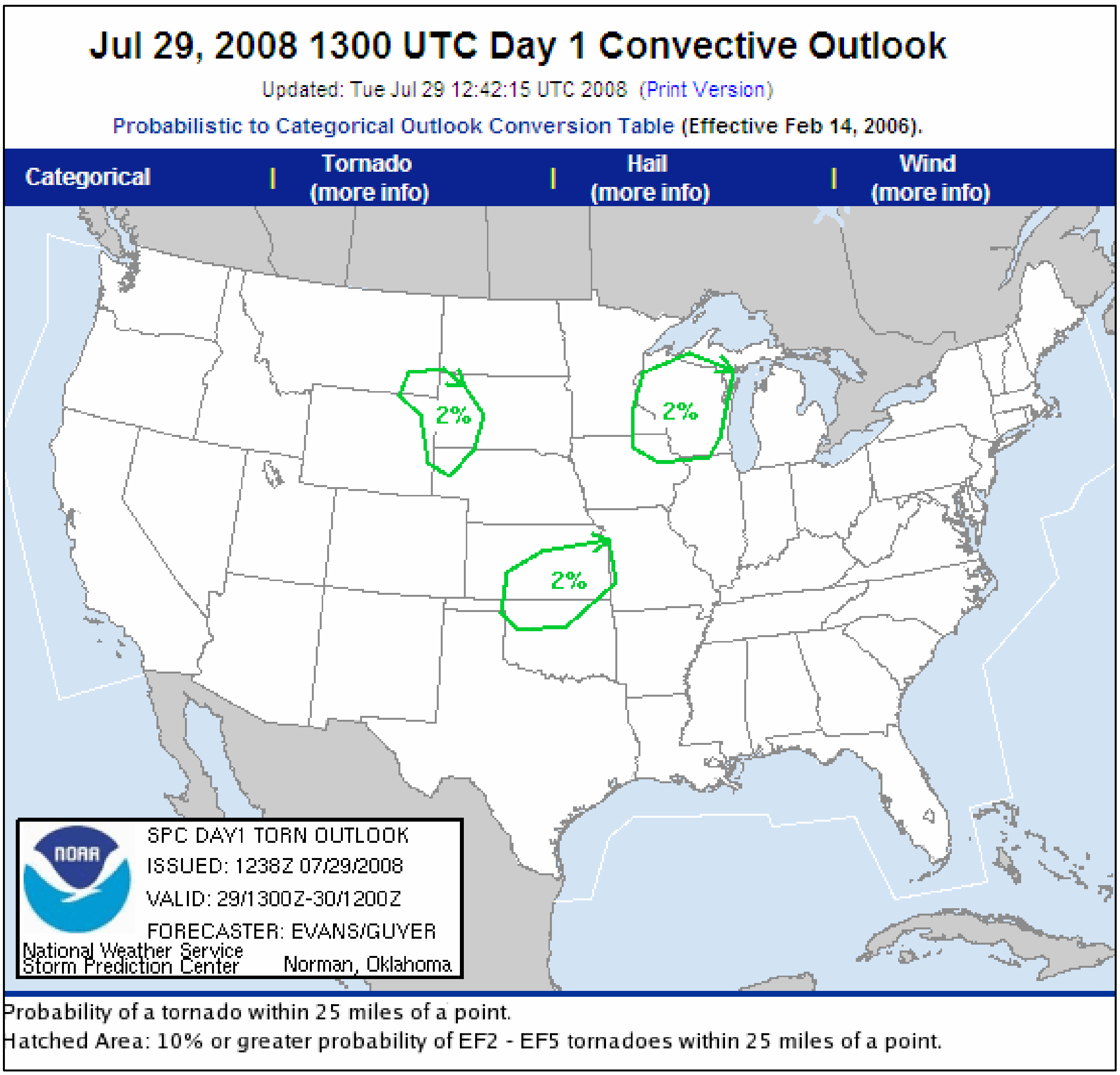
Source: National Severe Storms Laboratory (http://www.nssl.noaa.gov/hazard/tanim/torw9599.html)

Figure 2.13 Example of an animation of probability of tornado weather from 27 May to June based on historical data from 1995 to1999.

The SPC also issues real-time forecasts or outlooks for a number of days ahead including both Convective and Probabilistic Convective outlooks (NWS SPC 2008). The traditional Convective Outlook is a categorical forecast that specifies the perceived level of threat via the descriptive wording: ‘slight’, ‘moderate’ and ‘high risk’. However, this graphical outlook does not display the forecaster's expectations of the individual severe weather hazards (e.g. large hail, damaging winds, and tornadoes). Although the accompanying discussion for the outlook usually describes the forecaster's thoughts about the individual hazards, the accompanying categorical graphic does not.

A more direct method of expressing the forecaster's uncertainty is to use probabilities. Probabilistic convective outlooks directly express a level of confidence that an event will or will not occur. The probabilities used in the SPC Convective Outlooks are known as **subjective** probabilities. The forecasters make their **best estimate** of the probability of an event occurring; the probability values forecast are not created automatically by a computer or via statistics, but by the SPC outlook forecaster.

An example of a probabilistic outlook for Day 1 of a tornado is shown in Figure 2.14.



Jul 29, 2008 1300 UTC Day 1 Convective Outlook

Updated: Tue Jul 29 12:42:15 UTC 2008 (Print Version)

Probabilistic to Categorical Outlook Conversion Table (Effective Feb 14, 2006).

SPC DAY1 TORN OUTLOOK
ISSUED: 1238Z 07/29/2008
VALID: 29/1300Z-30/1200Z
FORECASTER: EVANS/GUYER
National Weather Service
Storm Prediction Center
Norman, Oklahoma

Probability of a tornado within 25 miles of a point.
Hatched Area: 10% or greater probability of EF2 - EF5 tornadoes within 25 miles of a point.

Source: SPC (http://www.spc.noaa.gov/products/outlook/archive/2008/day1otlk_20080729_1300.html)

Figure 2.14 Example of probabilistic convective outlook for tornadoes in the USA on 29 July 2008.

Probabilistic outlooks are also issued for the Day 2/3 period. But since many of the specific details of severe weather forecasting can only be determined hours ahead of time (rather than several days), the severe weather probabilities for the Day 2 and Day 3 outlooks represent the probability of any severe weather hazard (e.g. large hail, damaging wind, or tornadoes) occurring (rather than producing individual forecasts for each hazard).

2.5 Climate change

The need to produce objective, probabilistic forecasts of climate change on the decadal to centennial timescale is widely acknowledged (Stainforth et al. 2002). Progress is being made towards quantifying uncertainties using different methods such as perturbed-physics ensembles and model-based projections scaled by observations – both of which require long records of observations to obtain an objective forecast.

In terms of attempting to predict large-scale global changes, a probabilistic forecast of global precipitation constrained by global temperature observations using a physically justified transfer function has been produced. Efforts are also being made to develop transfer functions on smaller scales to be used in probabilistic climate change forecasting (Stainforth et al. 2002).

In the UK, climate change scenarios have been produced based on a large ensemble of Hadley Centre climate model runs for UKCIP02,[4] although a lack of a credible approach to quantifying the associated uncertainties was identified in this work.

More recently, advances in scientific techniques and increased computing power have resulted in the generation of more credible probabilistic projections of climate change using HadRM3 for the scenarios being developed for the UK 21st Century Climate Projections project (UKCIP08). These scenarios are intended to provide state-of-the-art assessments of uncertainties in national climate change, incorporating existing knowledge while including an assessment of the current limitations. The probabilities are therefore subjective, providing an estimate based on the available information and strength of evidence.

The main purpose of the UK Climate Impacts Programme (UKCIP) is to help organisations adapt to climate change. Although the information from UKCIP08 is not yet available publicly,[5] a number of ways to present the outputs have been proposed by UKCIP (UKCIP 2008). Presentation could include:

- hypothetical cumulative distribution functions (CDFs);
- probabilistic maps of changes to seasonal temperature;
- probabilistic projections of climate variable with time (Figure 2.15).

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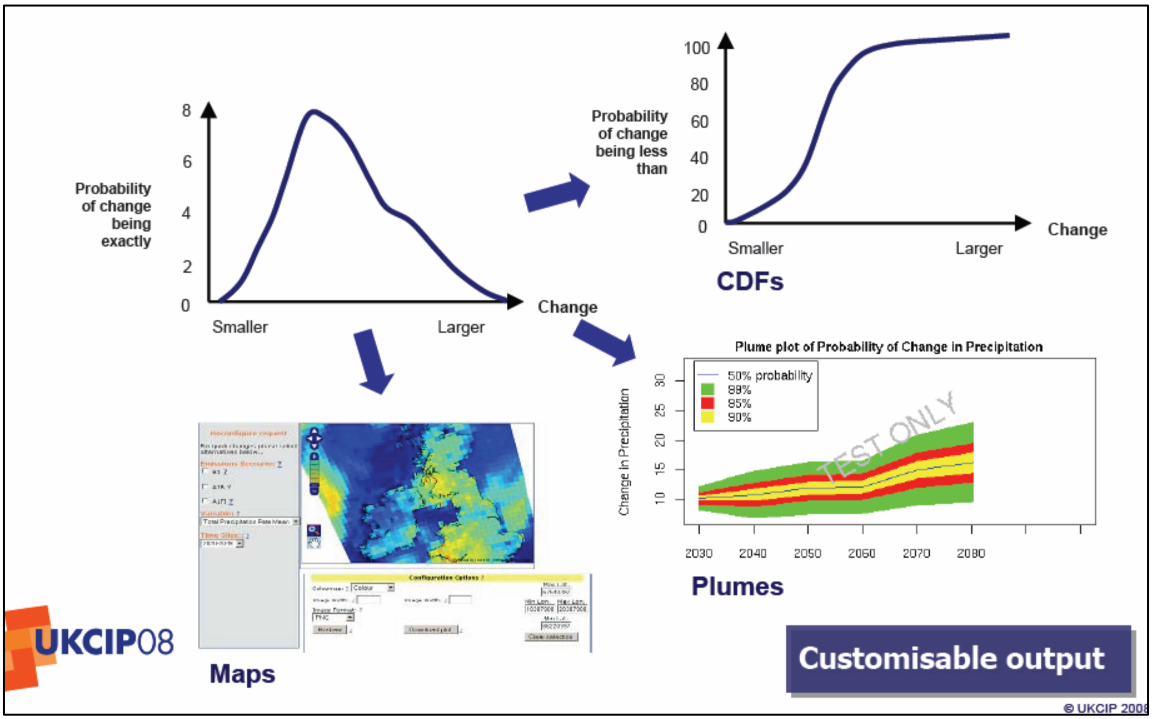
[4] See http://www.ukcip.org.uk/index.php?option=com_content&task=view&id=161&Itemid=291 for information about UKCIP02.

[5] Defra, the Met Office and UKCIP delayed the launch of UKCIP08 from autumn 2008 to spring 2009. The title of the UK 21st century climate change scenarios (short form: UKCIP08) was subsequently changed to UK Climate Projections (short form: 'the projections', or UKCP09 to denote the current version). For more details see the UKCIP website (http://www.ukcip.org.uk).



Source: UKCIP (2008)

Figure 2.15 Proposed ways of representing climate change uncertainty for the public.

In order to make the new UK Climate Projections as widely accessible as possible, the information will be made available through a new dedicated website. A major component of the new website set up by British Atmospheric Data Centre (BADC) will be a dynamic user interface which will allow users to interrogate the projections to produce customised output on expected climate change for the UK.

Due to the global nature and impact of climate change, the need to communicate and inform people worldwide of the effects led the Intergovernmental Panel on Climate Change (IPCC) to propose the uncertainty scale shown in Table 2.2. This constitutes an effective strategy to use objective numerical measures of uncertainty together with plain language that is clearly defined.

Table 2.2 Definitions of probability words and phrases used by IPCC for climate change forecasts.

Terminology	Likelihood of the occurrence/outcome
Virtually certain	Greater than 99% probability
Very likely	Greater than 90% probability
Likely	Greater than 66% probability
About as likely as not	33% to 66% probability
Unlikely	Less than 33% probability
Very unlikely	Less than 10% probability
Exceptionally unlikely	Less than 1% probability

Source: Gill (2008)

Patt and Dessai (2005) carried out surveys into how the IPPC terminology and probabilities were interpreted by different stakeholders. Evaluating the results from these surveys suggested that the IPCC approach in Table 2.2 leaves open the possibility for biased and inconsistent responses to the information (Patt and Dessai 2005).

In general, probabilistic forecasting of climate change and communication of the results to planners and the public is still very much in its early stages. As a result, experience with the use and dissemination of probabilistic climate change information to organisations or the wider public is limited.

2.6 Other hazards

Experiences from using and communicating probabilistic information in other types of natural hazards such as volcanoes, landslides, earthquakes and avalanches are fairly limited. Some of the findings from the literature review on earthquakes and avalanches are highlighted below. No significant information on communicating probabilistic information in relation to volcanoes or landslides forecasts was found.

2.6.1 Earthquakes

In the USA, where earthquakes can be severe and cause widespread damage and loss of life, a National Hazards Reduction Program (NEHRP) has been in place since 1977. The overall goal of the programme is to reduce loss of life and property, and to mitigate the severe socioeconomic consequences of earthquakes. Information on earthquake zones in the USA, including probabilistic information, can be found on the NEHRP[6] and United States Geological Survey (USGS)[7] websites where probabilities of areas affected by earthquakes are presented.

Recent new forecast advances have provided more reliable estimates of likely earthquake zones and frequencies in California (one of the most earthquake prone areas), which are now available to the public (Gordon et al. 2008). An example of the type of information conveyed is that California has more than a 99 per cent chance of having a magnitude 6.7 or larger earthquake within the next 30 years. The probabilities from the recent study will incorporated into official estimates of California's seismic hazard programme and will be used for updating building codes. The improved model does not estimate the likelihood of shaking (seismic hazard) that would be caused by the earthquake, but this is presented graphically on the USGS website using a colour-coded map for the USA and Puerto Rico (Figure 2.16).

In earthquake hazard management, the main focus to date has been to identify zones of high likelihood of impact; no information on real-time forecasting such as the use of ensemble prediction has been found, possibly due to current model capability and the nature of earthquakes that tend to have very short lead times, very low probability of occurrence and play out rapidly. Other literature on earthquakes (e.g. Nigg 1982 and Porfiriev 1993) looked more at risk perception and reactions to risk and provides limited information on actual use of uncertainty information in real disasters. Nigg (1982) argued that probabilities are not used appropriately by the public to judge the likelihood of events as they will tend to replace the laws of probability with intuitive heuristics.

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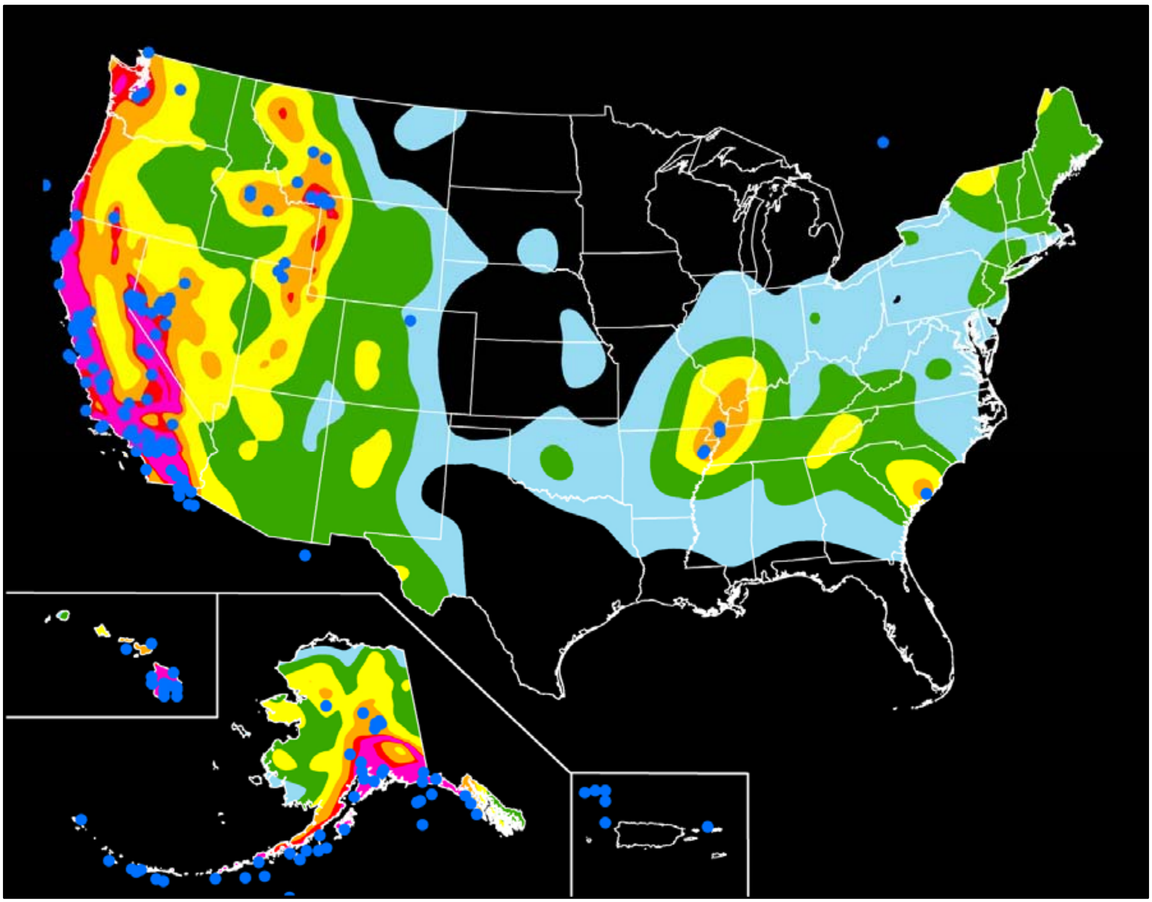
[6] http://www.nehrp.gov

[7] http://www.usgs.gov



Source: USGS (2008)

Note: During a 50-year time period, the probability of strong shaking increases from very low (white), to moderate (blue, green, and yellow), to high (orange, pink, and red). Map is not to scale.

Figure 2.16 Relative shaking hazards in the USA and Puerto Rico.

2.6.2 Avalanches

The communication of uncertainty in relation to avalanche dangers has developed significantly in recent years due to an increasing number of avalanche fatalities worldwide. In the USA this led in 2000-2001 to the establishment of the Sierra Weather and Avalanche Center (SWAC) which brings together weather forecasting and snow science to disseminate daily weather and avalanche forecasts during the avalanche season (Carter 2001). Since its establishment, avalanche forecasts for the Sierra Nevada have improved considerably from simple blanket forecasts to advanced graphical presentations using GIS technology to allow users to visualise information such as aspect, elevation, slope-angles and land-use of the mountains. These three-dimensional maps are colour-coded to represent different levels of avalanche hazard such as green for low danger and red for high danger using the US Avalanche Danger Scale (Table 2.3).

Table 2.3 US Avalanche Danger Scale.

Hazard level	Probability of avalanches	
	Natural	**Human-triggered**
Low (Green)	Very Unlikely	Unlikely
Moderate (Yellow)	Unlikely	Possible
Considerable (Orange)	Possible	Probable
High (Red)	Likely	Likely
Extreme (Black)	Certain and widespread	Certain and widespread

Source: Carter (2001)

Recent research has investigated the success of the existing colour use in communicating hazard and risk understanding to the greater public. Conger (2004) found that a four-level scale is preferable to the existing five-level scale (i.e. leaving out the middle level). Furthermore, experiments have shown that the colour orange is inappropriate for the scale as it fails to be associated with any perceived level of risk by the majority of people. Conger (2004) therefore suggested the following simplified colour model of the relationship:

- Low > Blue
- Moderate > Yellow
- High > Red
- Extreme > Red with Black

Further research in avalanche forecast communication is needed in terms of selecting appropriate symbolism to augment the colour use in a manner that maintains the importance of the specific regions covered.

2.7 Key findings: similarities and differences

The differences in hazard type and associated warning information mean that experiences from different hazards are not necessarily directly transferable between warning systems, although commonalities do exist.

Different types of hazard classifications have been attempted by various people in order to identify hazards of similar type which could help devise appropriate warning systems for hazards with similar characteristics.

For example, Mileti and Sorensen (1990) developed a hazard typology based on six properties characterising hazards as outlined below and summarised in Table 2.4:

- **Predictability**, e.g. magnitude, location, timing;
- **Detectability**, e.g. ability to confirm that impacts will occur;
- **Certainty**, e.g. level of confidence that predictions will be accurate and not result in false alarms;
- **Lead time**, e.g. amount of time between detection and impact of hazard;
- **Duration of impact**, e.g. time between start and end of impact;

- **Visibility**, e.g. degree to which the hazard manifests itself.

Based on this classification, the two most common flood events – riverine flooding and flash flooding – tend to fall within two different categories:

- Riverine flooding is classified as a Type 1 event which tends to exhibit long prediction time, known impacts and good detection.
- Flash floods (i.e. floods defined as having lead times of less than 12 hours) are classed as Type 6 with short prediction time, known impacts and poor detection.

The first type of hazard is one of the easiest to deal with in terms of disseminating warnings due to the slowly developing nature of the events. Sufficient time is available in these situations to put a plan into action and to provide warnings that can be made by group consensus and consultation across organisations. Different channels of communication can be used and a quick alert is not essential. In addition, detailed and informative messages can be disseminated.

On the other hand, a Type 6 hazard requires decision structures to be highly automated due to the short lead times. A quick alert is essential and limited time is available for consultation or consensus decision-making. Messages also need to be predetermined and concise, with a content and format that help the public to protect themselves or to escape from an endangered area. Education on adaptive responses in these situations is critical.

The use and dissemination of uncertainty information is likely to be different in these two types of situations due to the differences in lead time and forecast ability.

Despite the differences observed in hazard characteristics, the literature review indicates that some findings in terms of methods for the use and communication of probabilistic information could apply to several types of hazards and warning systems.

Findings with regard to language used, graphical presentation of forecast information, use of numerical information and colour use are fairly general – particularly when it comes to the perceptions and interpretation by forecasters and the general public.

Section 4 discusses good practice and experiences in the dissemination of risk and uncertainty in hazard communication, drawing out general findings and recommendations. The use of language and images is also explored further.

Table 2.4 Hazard typology.

Type and hazard category	Hazard
Type 1: (long prediction time, known impacts, good detection)	
Meteorological	Riverine flood
Geological	Slow volcano, earthquake prediction
Technological	Slow dam failure, slow nuclear power accident
Type 2: (long prediction time, known impacts, poor detection)	
Meteorological	None
Geological	Earthquake prediction
Technological	Slow fixed site, hazardous material
Type 3: (long prediction time, unknown impacts, good detection)	
Meteorological	Hurricane
Geological	Distant tsunami
Technological	None
Type 4: (long prediction time, unknown impacts, poor detection)	
Meteorological	Drought
Geological	None
Technological	Hazardous material threat
Type 5: (short prediction time, known impacts, good detection)	
Meteorological	None
Geological	None
Technological	None
Type 6: (short prediction time, known impacts, poor detection)	
Meteorological	Flash flood
Geological	Fast volcano
Technological	Fast fixed site, hazardous material
Type 7: (short prediction time, unknown impacts, good detection)	
Meteorological	None
Geological	None
Technological	None
Type 8: (short prediction time, unknown impacts, good detection)	
Meteorological	Tornado, avalanche
Geological	Local tsunami, landslide
Technological	Hazardous material

Source: Mileti and Sorensen (1990)

3 Methods to communicate uncertainty and probability in natural hazards forecasts

3.1 Sources of forecast uncertainty

A number of different types of forecast uncertainty must be dealt with when communicating uncertainty information in a hazard situation. In general, there are four different sources of uncertainty that need to be addressed to effectively communicate forecast uncertainty:

- **Atmospheric and scientific uncertainty**. This includes unpredictability of weather/nature and limitations in numerical model capability.
- **Data interpretation uncertainty**. This includes forecaster subjectivity and experience in interpreting output from numerical models.
- **Uncertainty arising during communication of forecast information**. This includes use of terminology and phraseology.
- **Forecast interpretation uncertainty**. This covers perception/understanding of forecast/warning information by the public and sometimes forecasters themselves.

This literature review has mainly investigated the use and communication of atmospheric and scientific uncertainty, focusing on using probabilities as a means of conveying uncertainty. However, all four types of uncertainty need to be addressed in order to effectively communicate the uncertainty in hazards using probabilistic information. In the case of uncertainty due to forecast interpretation, for example, the use of clear language and well-defined terminology is an important element of effective communication.

The following sections outline ‘good practice’ in communicating uncertainty and provide a summary of some of the general findings from the experiences from different warning systems and hazards worldwide described in Section 2.

3.2 ‘Good practice’ in communicating probability and uncertainty

Several examples of best practice guidelines have been produced for communicating risk and uncertainty in hazard warnings (Mileti and Sorensen 1990, Kloprogge 2007, Gill 2008, Peters et al. 2008, WMO 2008). The three key recommendations/messages for effective communication that emerge from these studies with regard to the use of probabilistic information are:

- use of consistent terminology to express probability and uncertainty;
- adaptation of the presentation of the probabilistic information to the phenomena and/or target user groups;

- engagement of specific user communities to define needs and presentation preference.

In terms of consistent terminology, experiences from different fields (particularly weather forecasting) indicate that probabilistic information is not currently communicated using consistent terminology – neither within organisations nor to the general public. Frequently there are also differences in understanding of forecast terminology between forecasters themselves that can render forecasts more subjective than necessary leading to confusion for all parties. Understanding the uncertainty inherent in the scientific products that are being delivered is essential to delivering an accurate message to decision-makers and the public. It is therefore imperative that forecast centres develop standard definitions of terms and use them consistently.

Probabilistic information needs to be communicated and presented in different ways depending on the hazard type and target user group. Presentation, both in terms of graphics and language, will to some extent depend on the phenomenon in question. For example, charts of tropical cyclone track probabilities based on ensemble forecasting to provide cyclone strike probabilities used in hurricane forecasting are not appropriate for many other types of weather applications. Similarly, the preferred probabilistic graphics used for presenting forecasts of temperature and rainfall may not be applicable to flood level forecasting or tornado forecasts.

The communication of probabilistic information also needs to be tailored to different target groups. Research indicates that different groups in the general public have different capacities for understanding probabilities depending on, for example, their profession, age group, education and exposure to probabilities in the media. Moreover, forecasters and emergency services have different requirements to the general public and need more detailed quantitative information as specific response plans may be in place that describe certain actions to be taken according to defined thresholds. For example, a community evacuation plan may be activated if the probability of cyclone-force winds increases beyond 20 per cent (WMO 2007a).

Engagement of specific user communities to define needs and preferences have successfully been applied in weather and hurricane forecasting where experiments and surveys have been conducted to identify preferred graphical methods for probability dissemination. For example, the Met Office has undertaken surveys to identify preferred ways of presenting five-day forecasts of temperature and precipitation using probabilistic information (see Section 2.3.6). Other experiments have been conducted in hurricane and weather forecasting to ascertain level of understanding using different types of graphics and language in probabilistic communication to forecasters, students and the general public.

Other general recommendations with regard to the use and communication of uncertainty in hazard situations include the following:

- There is a need for uncertainty measures of scientific products which could be of multiple forms including:
  - probabilistic model outcomes;
  - empirical verification of outlook/forecast performance;
  - narrative language that conveys the correct meaning of the uncertainty.
- A clear understanding of the roles and responsibilities of forecasters and decision makers is essential for an effective communication process. Forecasters need to convey full information including uncertainties to the decision-makers. Maintaining the credibility of the science for the decision-maker is essential.

- When communicating with the public, the context of the upcoming event relative to past experiential evidence of the people helps to convey the potential severity of the hazard.

3.3 Types of language and images

While different types of hazards may require different ways of presenting graphical information and different language or terminology, some general rules and recommendations have emerged from this literature review.

Experiences from weather forecasts indicate that probabilistic information is useful and popular with both forecasters and the general public but that care must be taken in communicating the information clearly. Similarly, probabilistic information in hurricane forecasting has proved very popular with both forecasters and the public – though most emphasis is still placed on hurricane advisories and warning.

Surveys generally indicate that using a combination of text and graphics rather than just text or graphics is preferred by most people.

3.3.1 Language and terminology

Language and terminology can be either complex or simple depending on the information conveyed and the target group. However, care must be taken to use consistent language in communicating probability in hazard warnings. For example, weather forecasts are often deliberately vague due to the forecaster being uncertain about the forecast information; this could ultimately produce confusion in the mind of the user and affect confidence in the service.

Several surveys and experiments have been conducted both in the area of weather and hurricane forecasting to examine the best language/terminology for communicating uncertainty and probabilistic information. Some studies (e.g. Gigerenzer et al 2005) indicate that, provided the reference class is provided, the use of frequencies is preferable to probabilities, percentiles and confidence limits. However, a survey by Joslyn (2007) and another survey by the Met Office (Mylne 2008b) showed that people prefer the use of 'percentage chance of' to probabilities, odds and frequencies. The use of probabilities should include the chance of the event not occurring in order to be most effective. The differences in findings could possibly be explained by previous exposure to probabilities; for example, weather forecasts in the USA have used 'percentage chance of' for many years.

Other findings from experiments in terms of language indicate that people generally have more problems with negative information such as the use of the word 'less' compared to 'more' in terms of understanding; such terminology should generally be avoided. It has also been found that numerical scales can be an efficient alternative of expressing uncertainty information to worded categories. As long as the definition of the numbers is well-defined, this can be a quick and easy way of conveying certainty.

Further research is needed in terms of determining the most efficient ways of disseminating and presenting probabilistic information with regard to the type of language used. For example, the language used in communicating probability in relation to forecasts also needs to be tailored to available communication channels. Some users, particularly the elderly, may not have access to the internet or television and may have to rely on radio and telephone links where different, simpler terminologies may be more appropriate. Surveys among particular user groups are useful in this process.

3.3.2 Graphs, icons and maps

The literature review identified numerous ways of presenting probabilistic information graphically. Studies have shown that people generally prefer and find graphical presentations with some text easier to interpret than text only. However, the graphics must generally be tailored to the hazard. The literature review indicates that some types of graphics are more suitable to particular hazards.

The types of diagrams, graphs and maps used internationally in different hazards and warning systems are listed in Table 3.1. Illustrations of the different types of graphics and maps are provided in Section 2 and Appendix A.

Table 3.1 Examples of types of diagrams, maps, graphs used in the communication of hazards forecasts to represent probability/uncertainty.

Type of presentation	**Description**	**Data type**	**Hazard**
Fan/plume chart	Ensemble prediction (EPS) with natural frequencies	Temperature forecasts Precipitation forecasts	Weather Climate change
Meteogram	EPS-gram with error bars	Temperature forecasts	Weather
Bar chart	Bar chart with probabilities	Rainfall forecasts	Weather
Pie chart	Pie chart with probabilities	Seasonal rainfall	Weather
Icons	Probability icons	Precipitation	Weather
Coloured maps	Probability map of exceedance	Seasonal rainfall	Weather Flooding
	Maximum worst-case scenario	Various	Weather
	Probability for most likely category	Various	Weather
	Probability with above-, near- and below normal	Seasonal rainfall	Weather
	Probability map of changes	Temperature Precipitation	Climate change
	Probability of occurrence	Tremors Tornado development	Earthquakes Tornados
Track forecast map	Probability of occurrence	Cyclone track	Hurricanes
Coloured forecast	Forecast with ‘reliability’ scale	Temperature Precipitation	Weather
Cumulative distribution function (CDF) – graph	Hypothetical cumulative distribution	Rainfall Temperature	Climate change
3-D GIS maps	Colour-coded 3D-GIS	Avalanche risk	Avalanches

3.3.3 Use of colour

Colour is a powerful tool for conveying probabilistic information in graphical presentations. However, it needs to be used carefully to avoid misinterpretation by users.

Findings and experiences from different types of natural hazards, particularly weather forecasting and avalanche warnings, indicate a number of issues to consider in the use of colour.

Surveys suggest that:

- emotive colours such as red and green need to apply to high/low probability values;
- similar colours at opposite ends of the scale should be avoided;
- the use of colours on either side of 50 per cent can give misleading impressions of very small differences in forecast.

From avalanche studies, there is also evidence to suggest that orange is not suitable for indicating risk as it fails to be associated with any perceived level of risk by the majority of people. It was also found that blue is superior to green in terms of expressing low risk.

Other issues to consider when selecting colour scales is whether these need to be read by those with various degrees of colour blindness.

Overall, the choice of colours in hazard warning is critical to the use and interpretation of probabilistic information. User surveys would be helpful in identifying suitable colour scales and accompanying explanations.

3.4 Benefits of probabilistic forecasts

The ultimate purpose of communicating probability is to enable users to make better decisions in the face of uncertainty. Flood forecasters within the Environment Agency are routinely faced with uncertainty when making a forecast. They can find this to be stressful if users of the forecast have an expectation that it is always right.

Some floods will be more predictable than others. For example, in the Lower Thames, it could be argued that on the Thames itself floods are easier to predict owing to the size of the catchment, the subsequent lead time and the availability of detailed forecasting models. As a consequence, uncertainty is likely to be less in flood forecasts. In small ‘flashy’, ungauged catchments, there is likely to be a higher degree of uncertainty in the flood forecasts. If forecasters are able to communicate these uncertainties to users, then a more open, honest, and effective relationship can be established in which users have a realistic understanding of the uncertainties involved and the range of possible outcomes.

Retaining the confidence of users is critical as the Environment Agency is visibly identified as the source of official flood forecast and warning information. Users who understand that forecasts can have a degree of uncertainty, and are able to tune their decision-making to the uncertainty information provided by the Environment Agency, are much more likely to retain confidence in the organisation (WMO, 2008).

3.5 Pitfalls in probability and uncertainty communication

It is important that flood forecasting services are based on ‘good science’. Uncertainty is inherent in:

- the predictions from the inputs to flood forecasting models (i.e. meteorological data);
- the models themselves;

- other parts of the forecasting process.

Although it may be appropriate to include probability and uncertainty in the forecast and warning services that are provided, the credibility of the provider of the warning services could be undermined if the accuracy of the service is overstated.

In addition, probabilistic forecasts are not necessarily ‘more accurate’ than deterministic ones. There is a danger that resources could be diverted away from the improvement of monitoring and forecasting techniques/models because probabilistic forecasts are seen to be more accurate than a deterministic forecast. It is important that the end users of probabilistic flood warnings understand that these are not necessarily more accurate than a deterministic warning. The use of probabilistic information in assessing the potential impacts of hazards improves the value of a forecast by providing a more objective level of confidence rather than more accurate warnings.

When communicating probabilities, psychology research has shown that many people have a different understanding of words such as probable, possible and chance. People think they understand the terms, but one person’s understanding is different from another’s (Mylne 2008a). Clear definitions and consistent use are vital.

Sometimes there is even a difference in the understanding of forecast terminology among forecasters themselves. There are examples from the literature where it is quite common to find two forecasters interpreting qualitative and even in some cases quantitative information differently. If forecasters cannot agree on the meaning of terms used for warnings, then it is inevitable that users will be uncertain about the meaning. Forecast centres should develop standard definitions of terms and use them consistently to avoid this pitfall (WMO, 2008).

That said experiences from, for example, tornado warnings and climate change forecasts illustrate the fact that often a degree of interpretation of numerical model information and other data is needed in order to issue a forecast. This makes the warning somewhat subjective. Nevertheless, it is important that forecast centres develop standard definitions of terms and use them consistently to minimise this type of subjectivity.

3.6 User education

Different users will have different requirements for uncertainty information as well as different levels of understanding. Over time, and with sufficient experience and user education, it is possible to improve the level of user understanding and sophistication Gigerenzer et al. (2005) showed that, in New York, where the public have lengthy experience of probability rainfall forecasts, a majority of users correctly understood a forecast for 30 per cent probability of rain to mean that there is a 3 in 10 chance of rain wherever you are in the city. On the other hand, in four European cities, where probability forecasting is not used, the majority of users incorrectly interpreted the forecast to mean rain would fall 30 per cent of the time, or over 30 per cent of the area (Gigerenzer et al. 2005). This indicates that, over time, the ability of end users to understand and use probabilistic information will increase with consistent exposure.

In general, experiences from both hurricane and weather forecasting indicate that educational programmes and materials are needed – both for decision-makers and the public – to ensure proper interpretation and use of probabilistic methods in hazard situations.

4 Summary of key findings

The challenge of communicating probabilistic information so that it will be used, and used appropriately, by decision-makers has long been recognised. Communicating the uncertainty in a flood forecast should allow users to make better decisions that are attuned to the 'reliability' of the forecast. It also helps to manage the expectations of users for accurate forecasts. The issue remains with respect to how to communicate the uncertainty and probabilities in forecasts to a variety of end users.

Numerous methods are used to communicate probabilistic information in forecasts to people for various hazard types. These include:

- a variety of messages either with qualitative or quantitative probabilities;
- graphs, icons and maps including:
  - fan/plume charts;
  - bar charts;
  - pie charts;
  - icons;
  - coloured maps;
  - track forecast maps;
  - cumulative distribution function (CDF) graphs;
  - three-dimensional GIS maps;
- a combination of icons/graphs/maps and messages.

From the limited research that has been carried out, it would appear that some methods are more successful than others in putting their message across. However, it is important to note that there are few examples where probabilistic or uncertainty information is included explicitly in warning messages.

The review's key findings are summarised below:

- No examples were readily available from the international literature illustrating probabilistic flood warnings and indicating how stakeholders would respond to them.
- Expressing probabilistic forecasts using language such as 'possible', 'extremely likely' and 'unlikely' is highly subjective. Limited research suggests that, using this type of language, the message which that the forecaster intends to reply to the end user often does not match what the recipient understands. It is important to use consistent terminology to express probability and uncertainty.
- Expressing forecast probabilities is a becoming a more common way of expressing uncertainty especially in the field of meteorological forecasts. However, it is important that probabilities are based on objective scientific techniques and that they are reliable, trustworthy and well-calibrated to the true probability distribution of the phenomena in question (WMO, 2008).
- Probabilities can be expressed in different ways. For example: 'There is a 20% chance of a flood tomorrow'; 'The odds of a flood tomorrow are 4 to 1

against'; 'There is a 1 in 5 chance of a flood tomorrow'; and 'There is a small chance of a flood tomorrow'. The limited research carried out into end users' understanding of probabilities indicates that using percentages or frequencies transmits the forecaster's message most effectively.

- Limited surveys show that probabilistic information does not undermine people's confidence in a forecasting service. On the contrary, it reassures people that they are being dealt with honestly, and gives them confidence that the service is being provided objectively and scientifically (WMO, 2008).
- Different users will have different requirements for probabilistic information, as well as different levels of understanding. For some (e.g. those involved in emergency response), detailed quantitative estimates of probability may be required. More 'sophisticated' users of probabilistic information are often aware of the underpinning reasons for uncertainty and the forecaster can use technical language and speak in some detail. The engagement of specific user communities is important to define their needs and presentation preference with regard to probabilistic warnings.
- Limited end user surveys have shown that end users prefer probabilistic information to be displayed graphically or in the form of a map with an explanation in accompanying text.
- The choice of colours used to convey realistic information for forecast maps is critical to the use and interpretation of the probabilistic information. User surveys need to be undertaken to identify suitable colour scales and accompanying explanations.
- It is important to understand the roles and responsibilities of decision-makers. Limited surveys have indicated that improvements in decision-making can be made using probabilistic forecast information.
- A clear understanding of the roles and responsibilities of forecasters and decision makers is essential for an effective communication process. Forecasters need to convey full information to the decision-makers. Maintaining the credibility of the science for the decision-maker is essential.
- It would appear that when communicating probabilistic warnings to the public, putting the forecast event in context to a recently experienced event may help with the public's understanding of the message.
- Experiences from both hurricane and weather forecasting indicate that educational programmes and materials are needed, both for decision-makers and the public, to ensure proper interpretation and usage of probabilistic methods in hazard situations.

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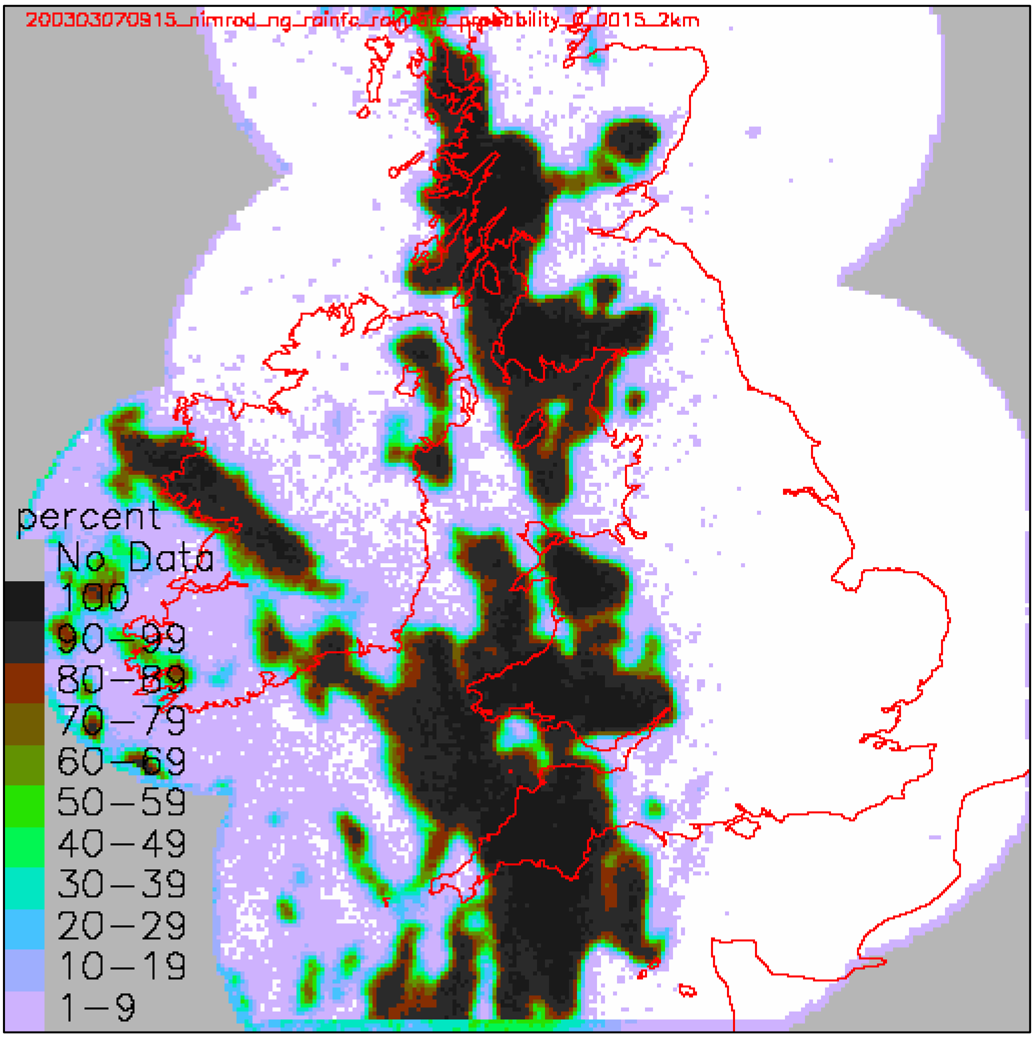
List of abbreviations

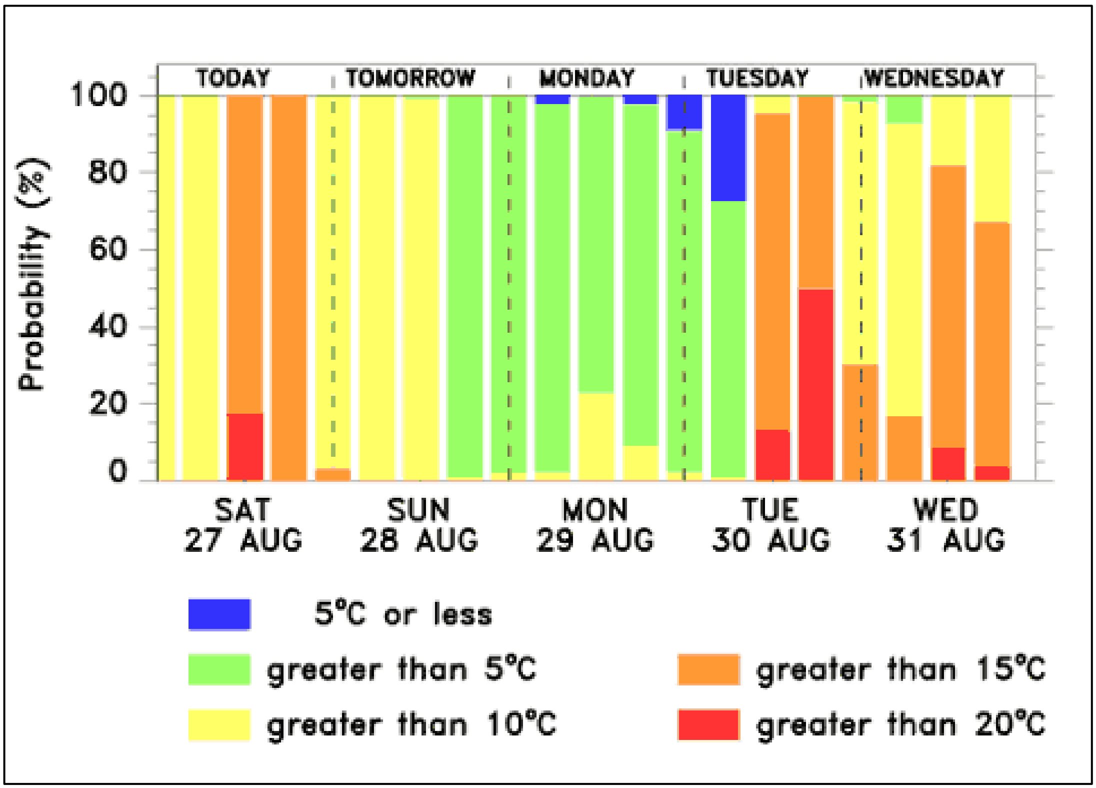
CDF	cumulative distribution function
EPS	ensemble prediction
ERA	Extreme Rainfall Alert
FEMA	Federal Emergency Management Agency [USA]
GIS	geographical information system
GPS	global positioning system
HPC	Hydrometeorological Prediction Center [USA]
IPCC	Intergovernmental Panel on Climate Change
NEHRP	National Hazards Reduction Program [USA]
NHC	National Hurricane Center [USA]
NOAA	National Oceanic and Atmospheric Administration [USA]
NWS	National Weather Service [USA]
POP	Probabilities of Precipitation
SPC	Storm Prediction Center [USA]
TSR	Tropical Storm Risk
UKCIP	UK Climate Impacts Programme
USGS	US Geological Survey
WFO	Weather Forecast Office

Appendix A Examples of methods used to illustrate uncertainty and probability in hazard forecasts



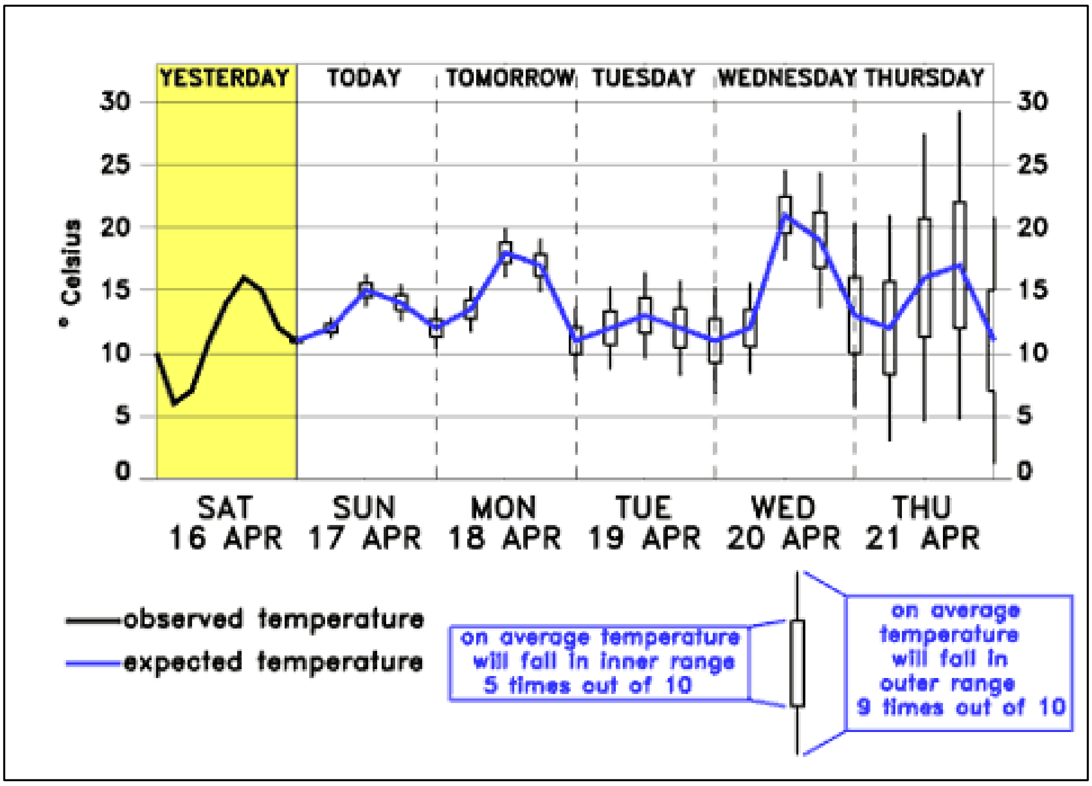
Source: Pierce and Orrell (2008)

Figure A1 Met Office map showing probability of rainfall for the UK.



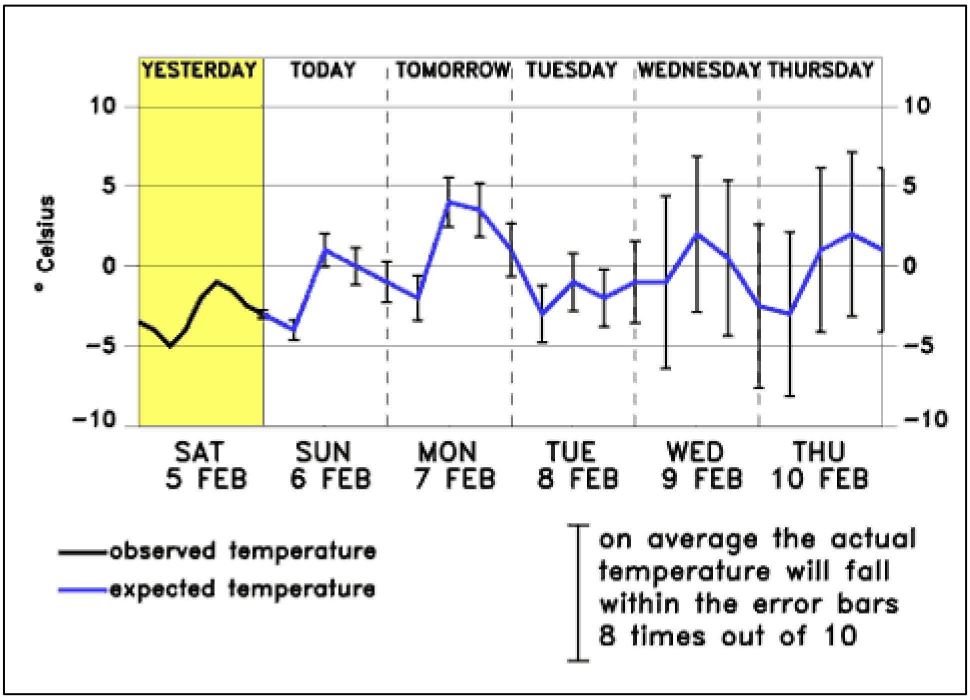
Source: Mylne (2008b)

Figure A2 Method of showing probabilistic temperature forecasts using bar charts.



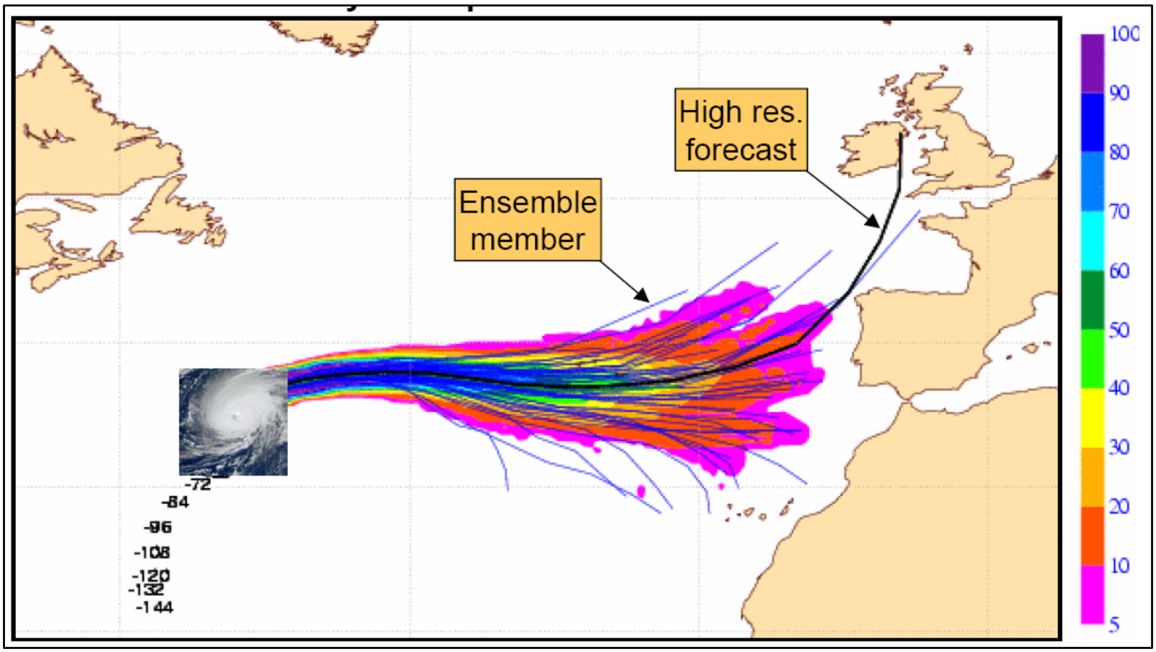
Source: Mylne (2008b)

Figure A3 Method of showing probabilistic temperature forecasts using uncertainty boxes.



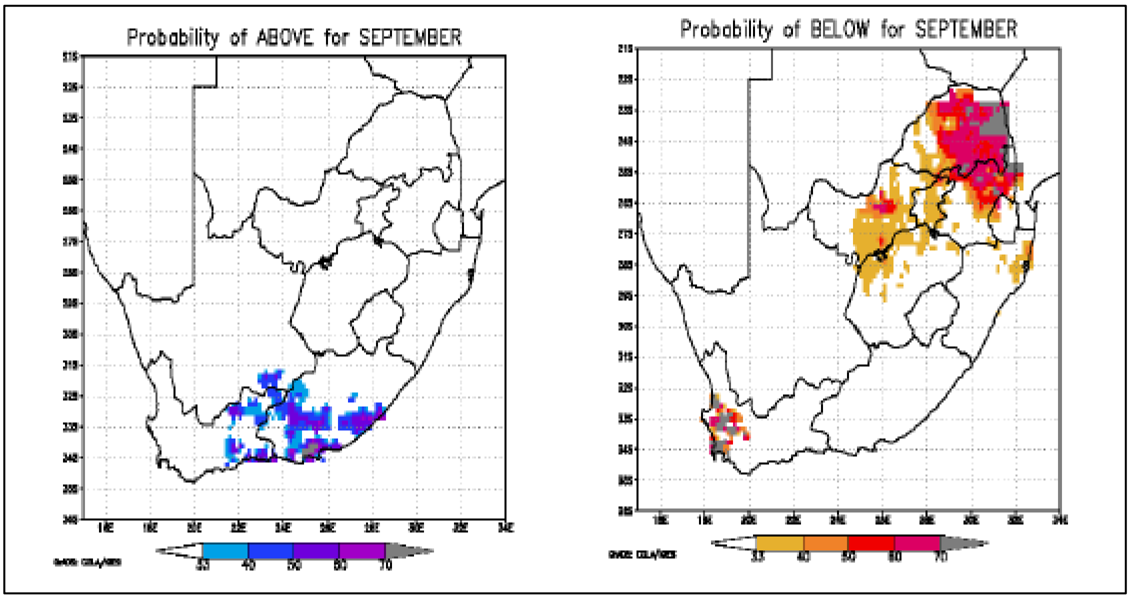
Source: Mylne (2008b)

Figure A4 Method of showing probabilistic temperature forecasts using uncertainty bands.



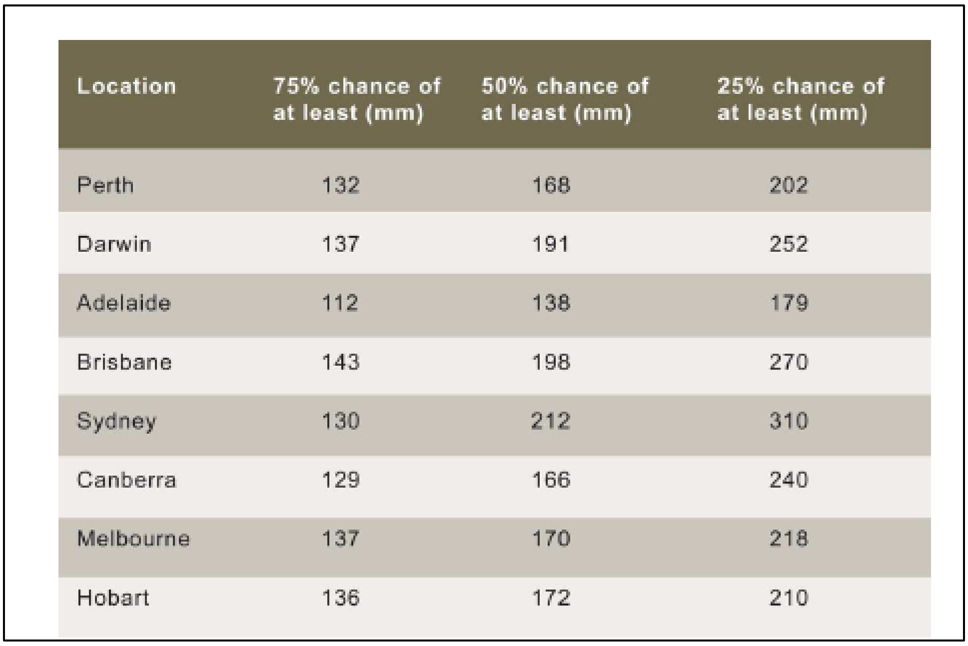
Source: Mylne (2008a)

Figure A5 Example from the UK Met Office of probabilistic hurricane forecast.



Source: WMO, 2007a

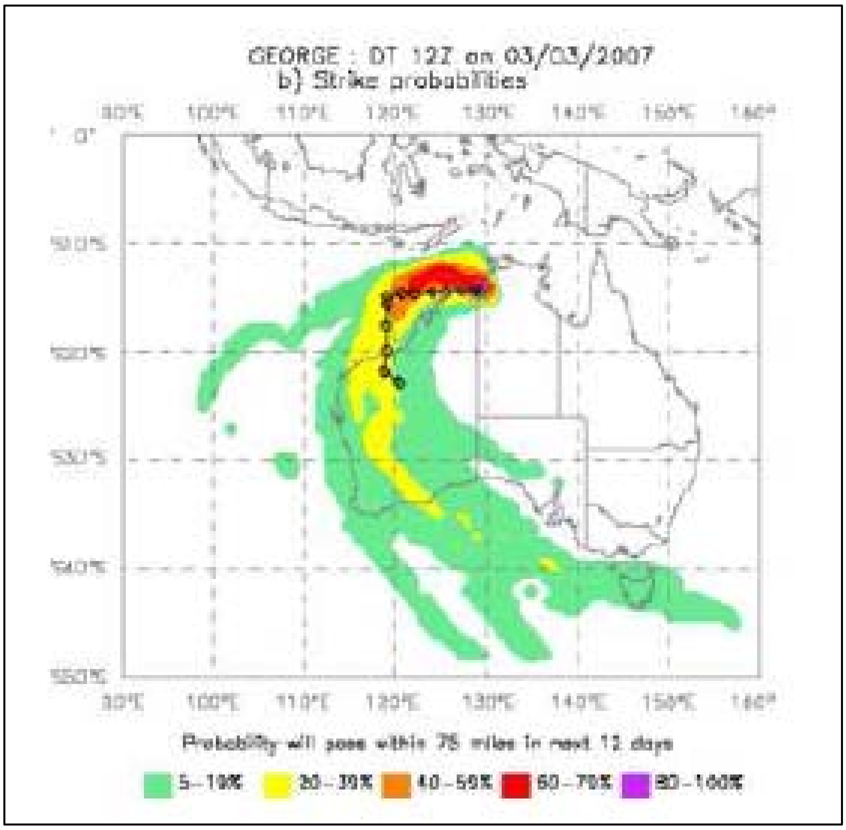
Figure A6 Forecast probabilities for southern Africa above normal (left) and below normal (right) categories of monthly precipitation.



Location	75% chance of at least (mm)	50% chance of at least (mm)	25% chance of at least (mm)
Perth	132	168	202
Darwin	137	191	252
Adelaide	112	138	179
Brisbane	143	198	270
Sydney	130	212	310
Canberra	129	166	240
Melbourne	137	170	218
Hobart	136	172	210

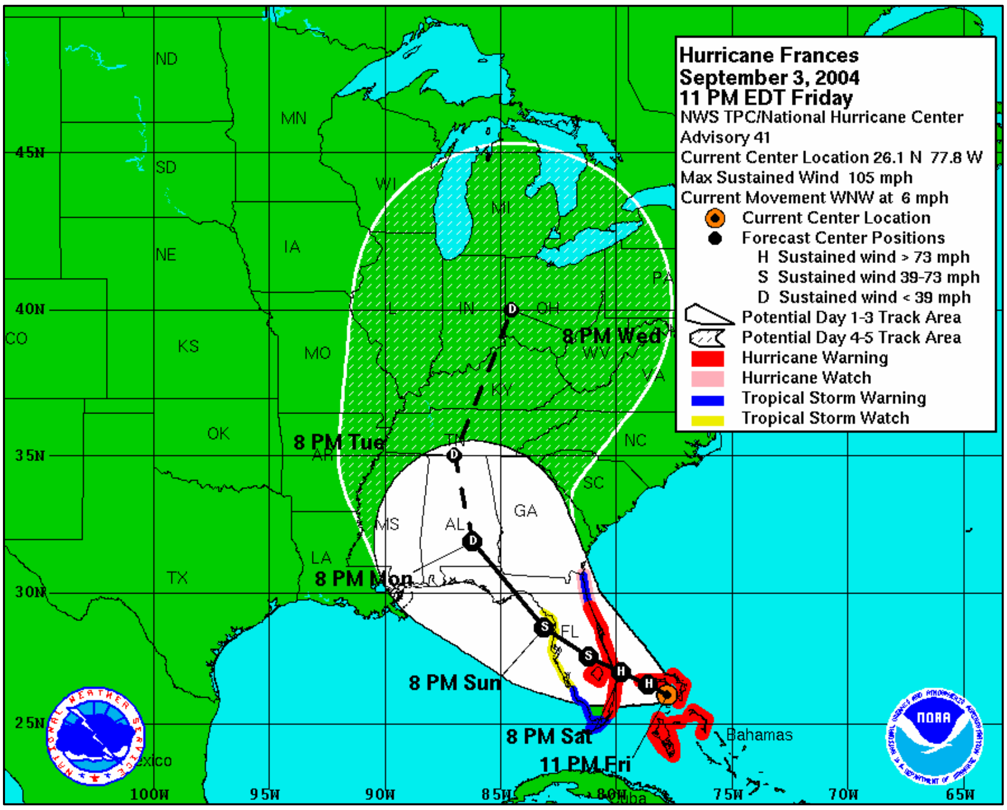
Source: WMO, 2007a

Figure A7 Predicted rainfall amount stratified by probability threshold produced by Australian Bureau of Meteorology



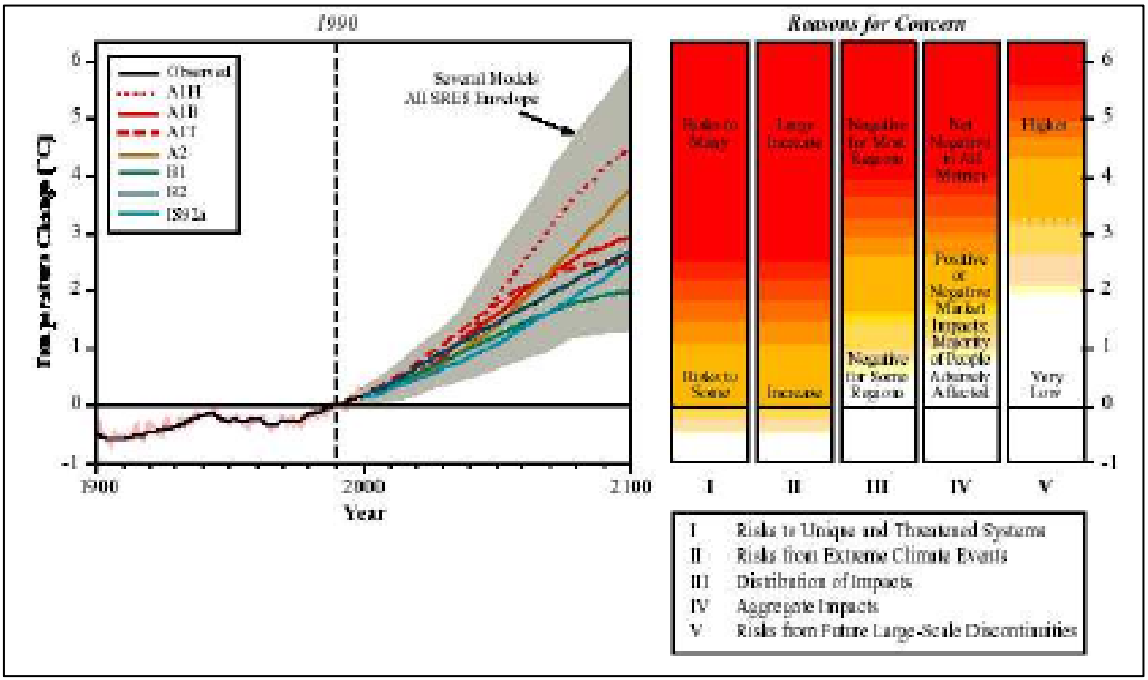
Source: WMO, 2007a

Figure A8 Tropical cyclone track forecasts presented as the probability that the storm will pass within a distance of 75 miles from any location.



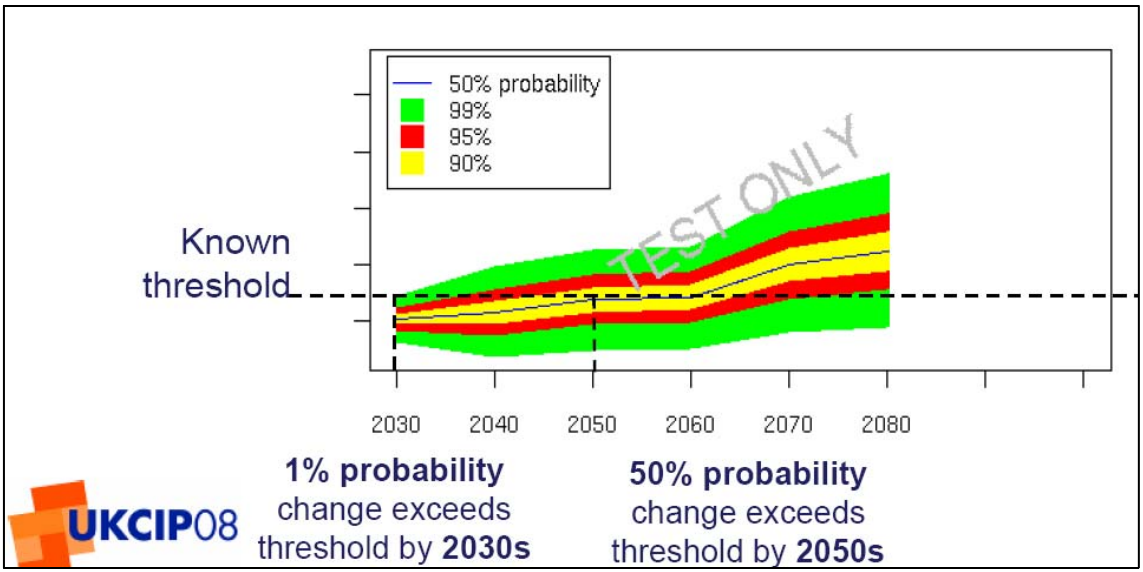
Source: WMO, 2007a

Figure A9 NOAA hurricane forecast showing potential area affected.



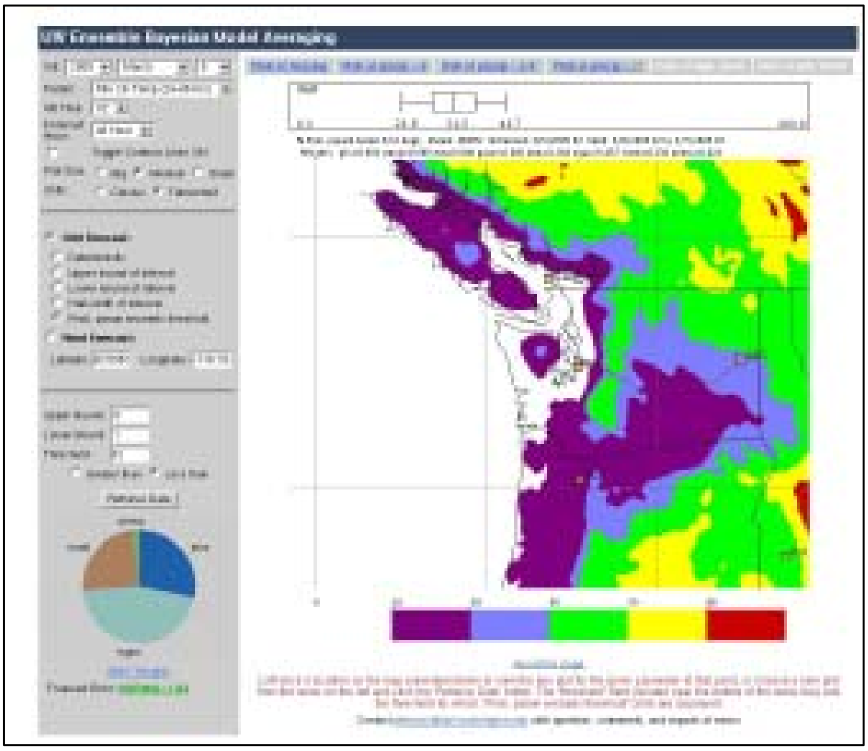
Source: Wardekker (2005)

Figure A10 'Risk' diagram for climate change: risks associated with various temperatures increases.



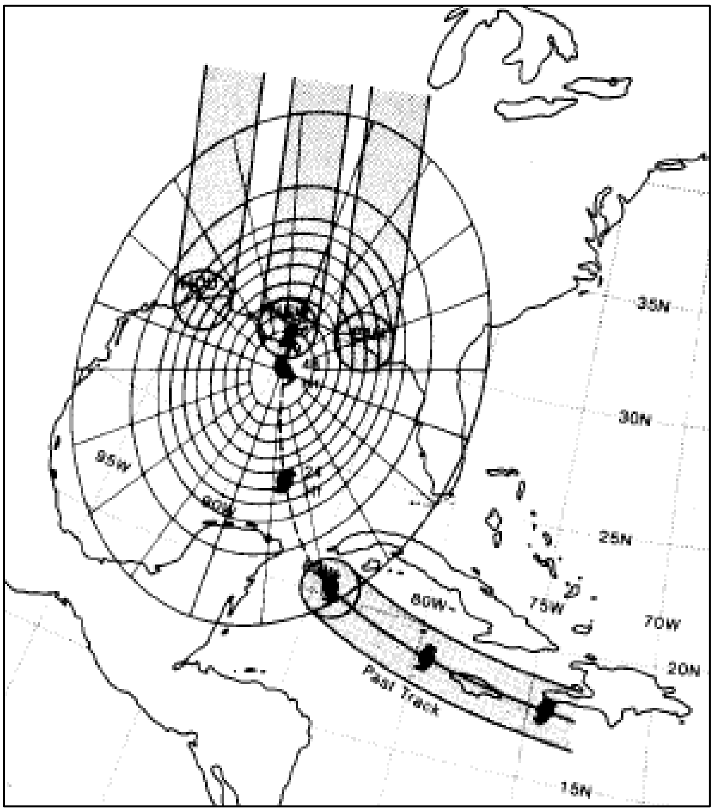
Source: UKCIP (2008)

Figure A11 Plume diagram to show possible future changes in climate.



Source: Tewson (2007)

Figure A12 Map showing the probability of temperatures falling below freezing in Washington State, USA.

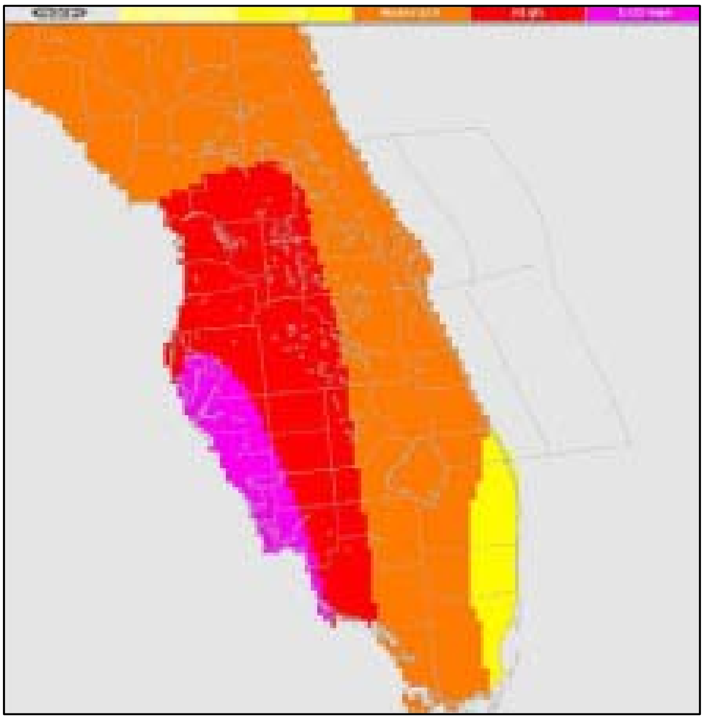


Source: Sheets (1985)

Figure A13 Hypothetical hurricane forecast track overlayed with 48-hour bivariate normal forecast error distribution.

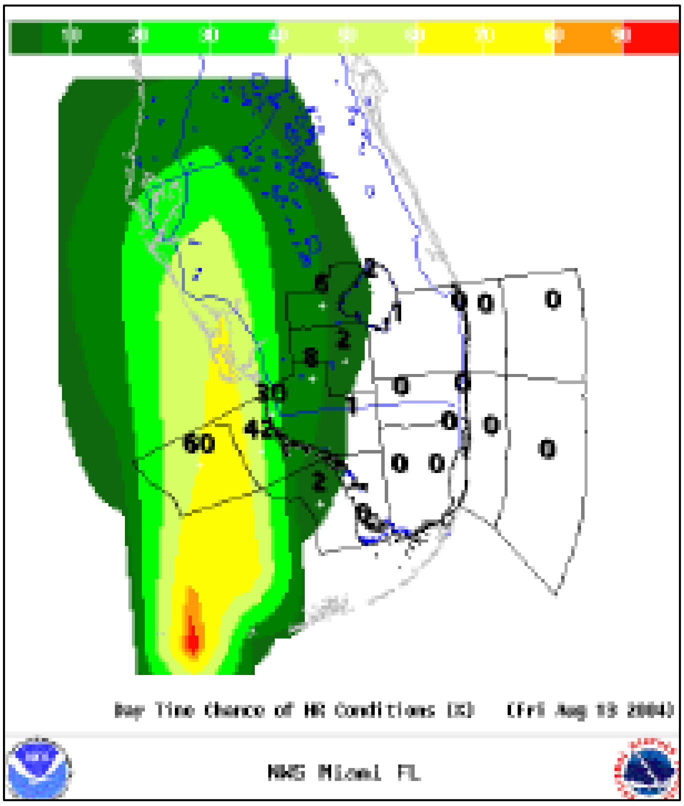
Source: Sharp and Volkmer (2006)

Figure A14 An example of the cumulative form 64-knot tropical cyclone wind probabilities (graphic output; 0–120 hours) for Hurricane Charley issued 12:00 UTC, 12 August 2004.



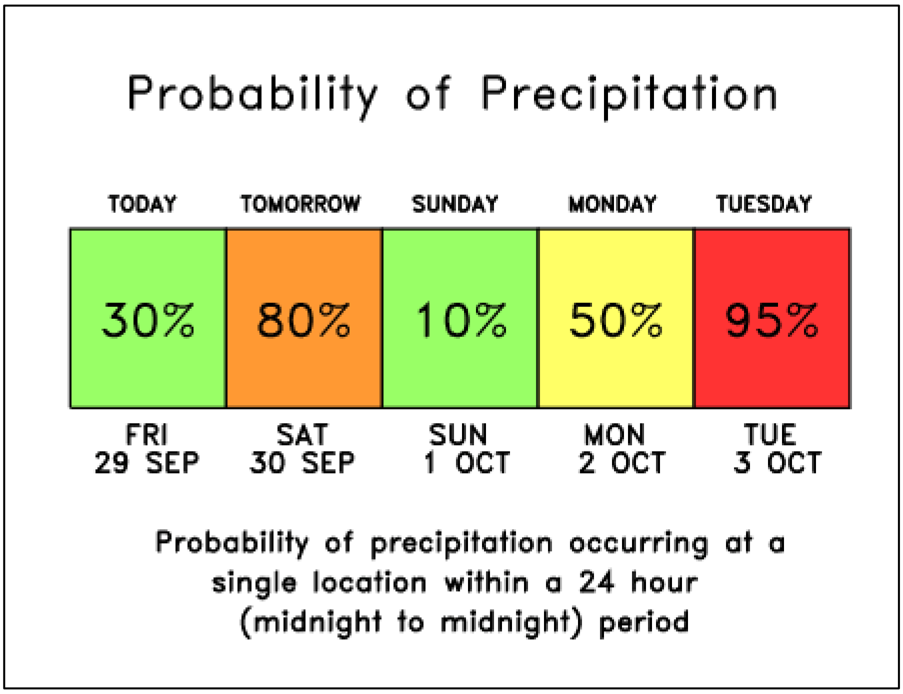
Source: Santos et al, 2004

Figure A15 Using cumulative form tropical cyclone wind probabilities, to produce first-guess map depicting the Tropical Cyclone Wind Threat Index for Hurricane Charlie.



Source: Santos et al, 2004

Figure A16 64-knot incremental wind speed probability grid valid for the afternoon of 13 August 2004 using TPC's 1500 UTC advisory data.



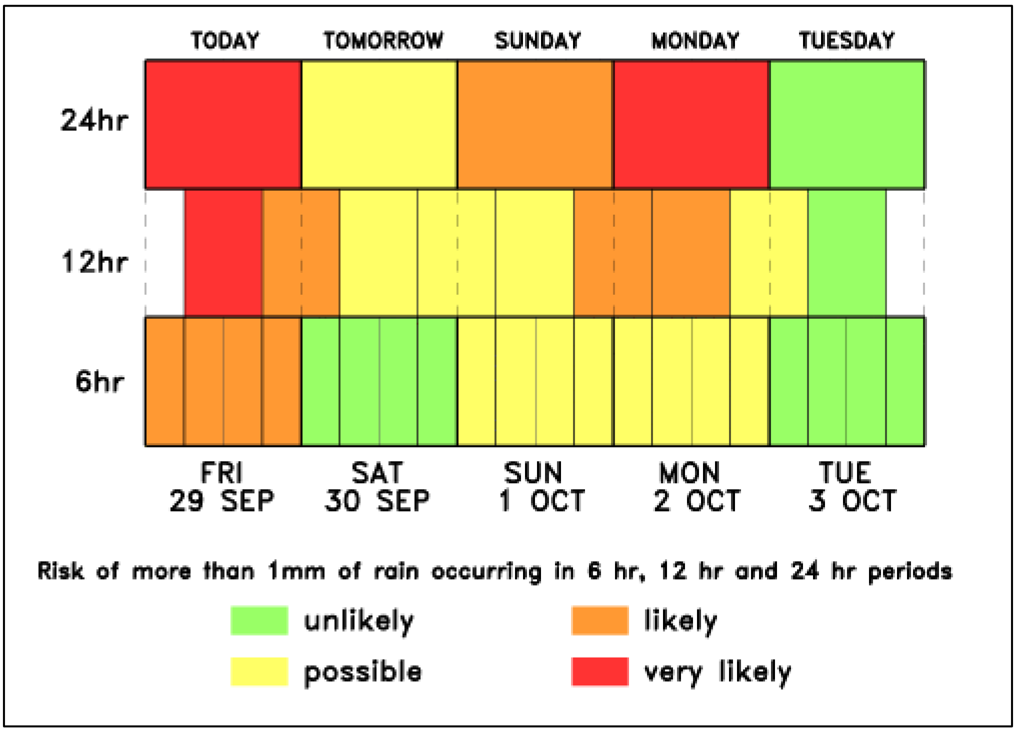
Probability of Precipitation

TODAY	TOMORROW	SUNDAY	MONDAY	TUESDAY
30%	80%	10%	50%	95%
FRI 29 SEP	SAT 30 SEP	SUN 1 OCT	MON 2 OCT	TUE 3 OCT

Probability of precipitation occurring at a single location within a 24 hour (midnight to midnight) period

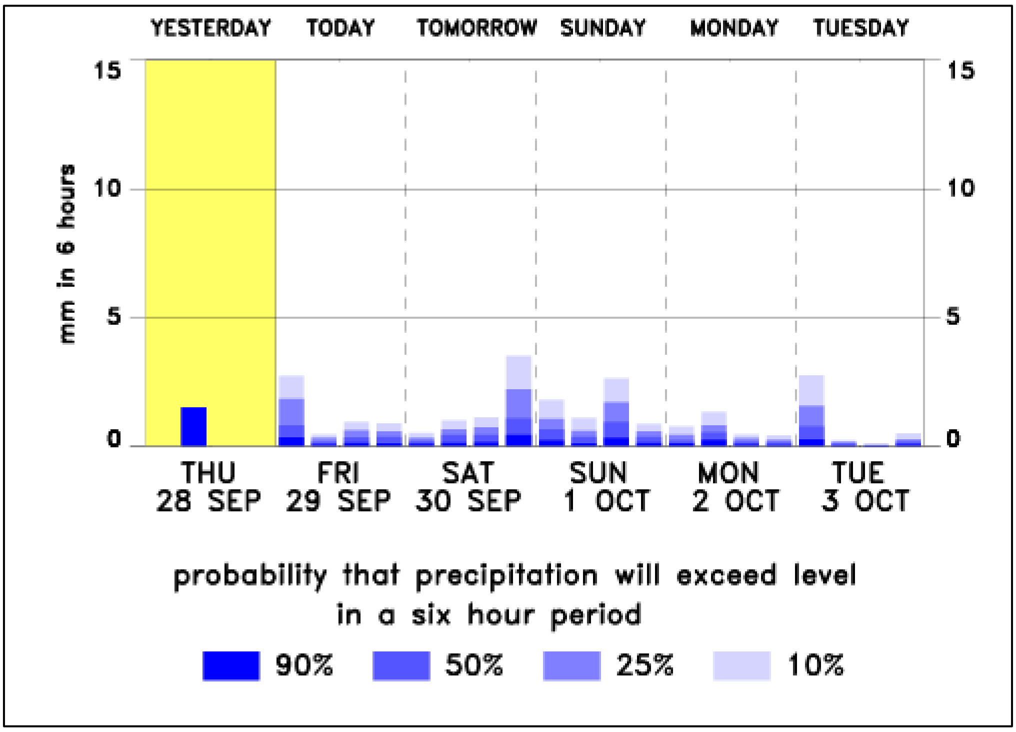
Source: Mylne (2008a)

Figure A17 Method to communicate the Probability of Precipitation.



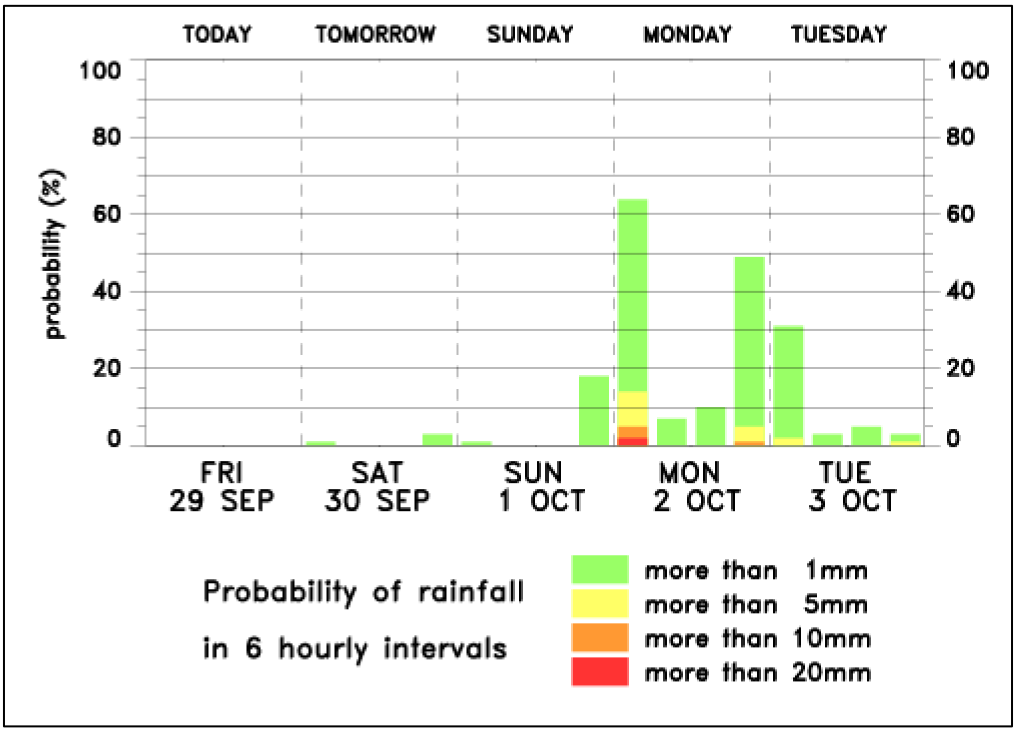
Source: Mylne (2008a)

Figure A18 Method using colour codes to communicate the probability of precipitation over a 6, 12 and 24 hour period for the next five days.



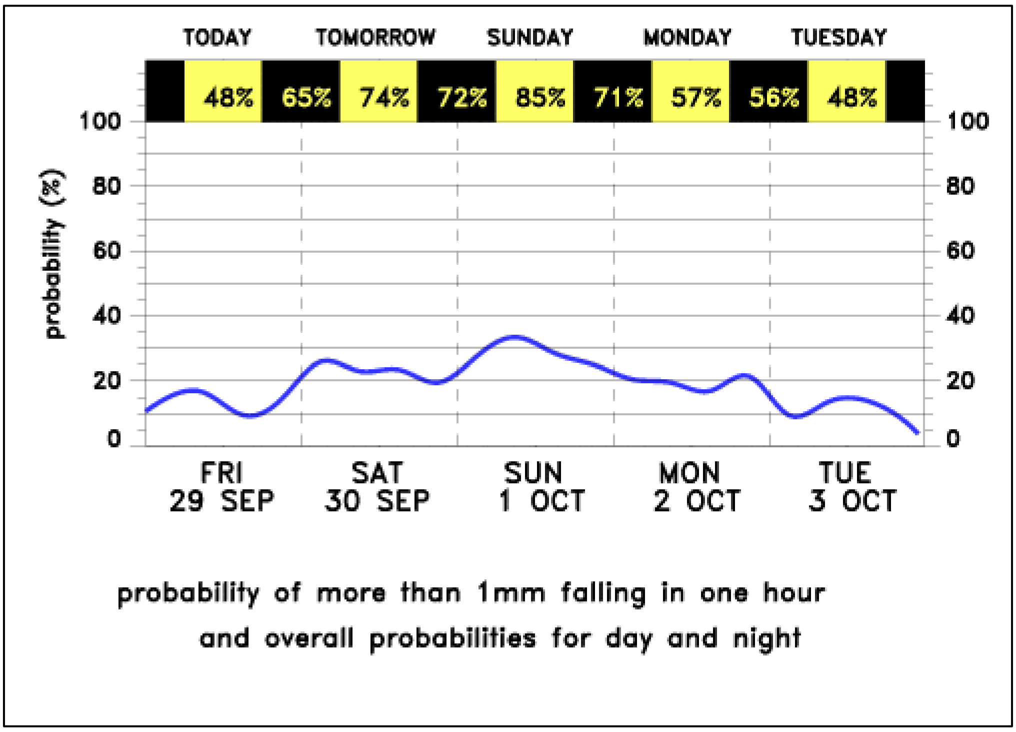
Source: Mylne (2008a)

Figure A19 Method using bar charts to communicate the probability of precipitation exceeding a certain threshold over the next five days.



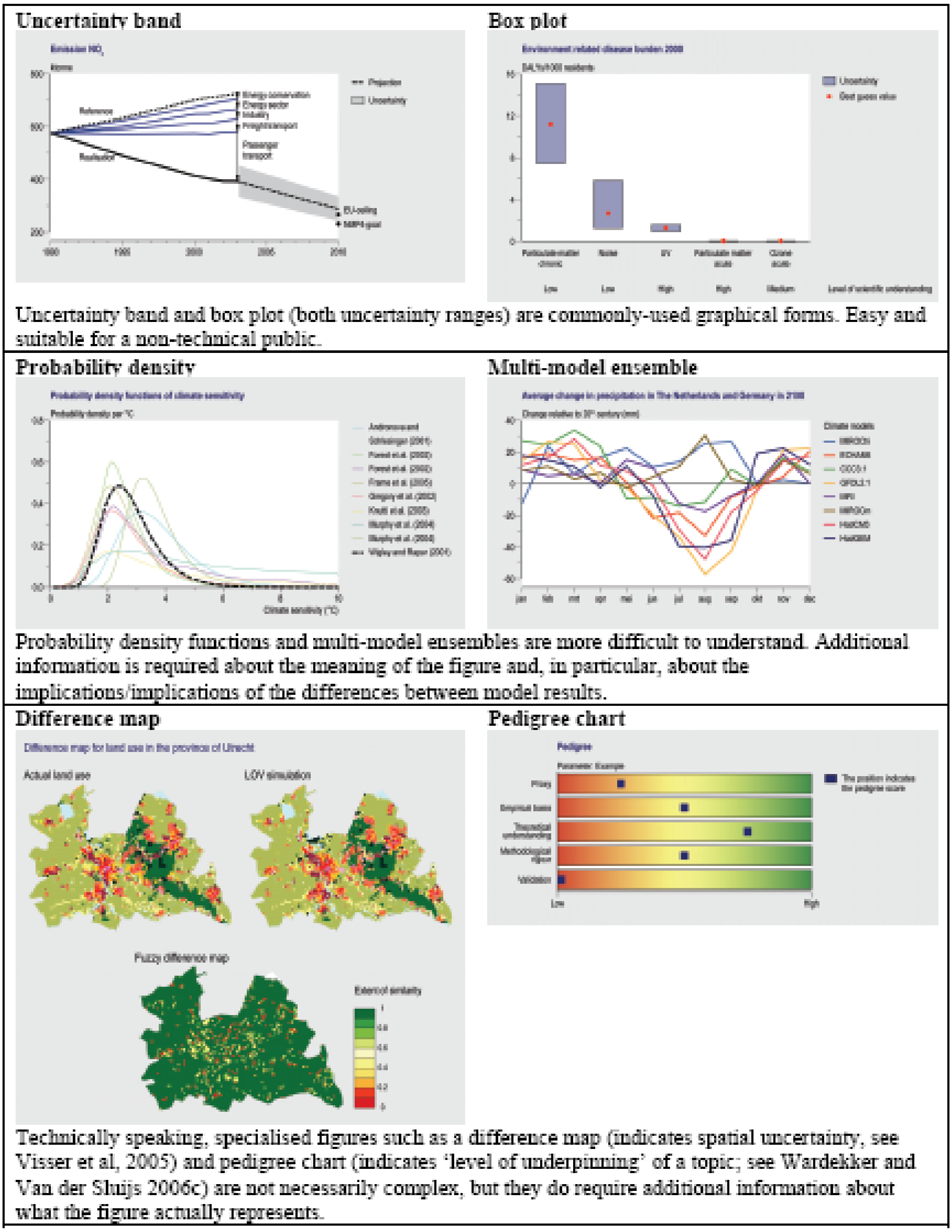
Source: Mylne (2008a)

Figure A20 Method using bar charts to communicate the probability of rain for certain intervals over the next five days.



Source: Mylne (2008a)

Figure A21 Method used to show the probability of more than 1 mm of rain falling in one hour over the next five days.



Uncertainty band

Box plot

Uncertainty band and box plot (both uncertainty ranges) are commonly-used graphical forms. Easy and suitable for a non-technical public.

Probability density

Multi-model ensemble

Probability density functions and multi-model ensembles are more difficult to understand. Additional information is required about the meaning of the figure and, in particular, about the implications/implications of the differences between model results.

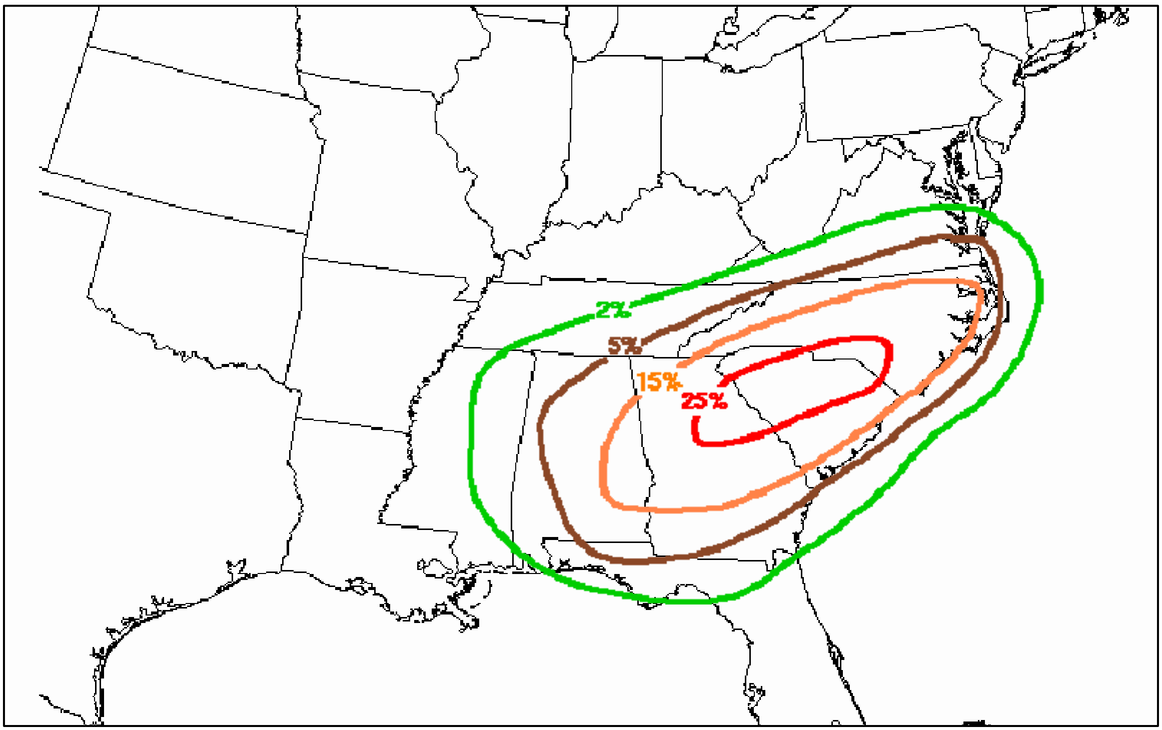
Difference map

Pedigree chart

Technically speaking, specialised figures such as a difference map (indicates spatial uncertainty, see Visser et al, 2005) and pedigree chart (indicates 'level of underpinning' of a topic; see Wardekker and Van der Sluijs 2006c) are not necessarily complex, but they do require additional information about what the figure actually represents.

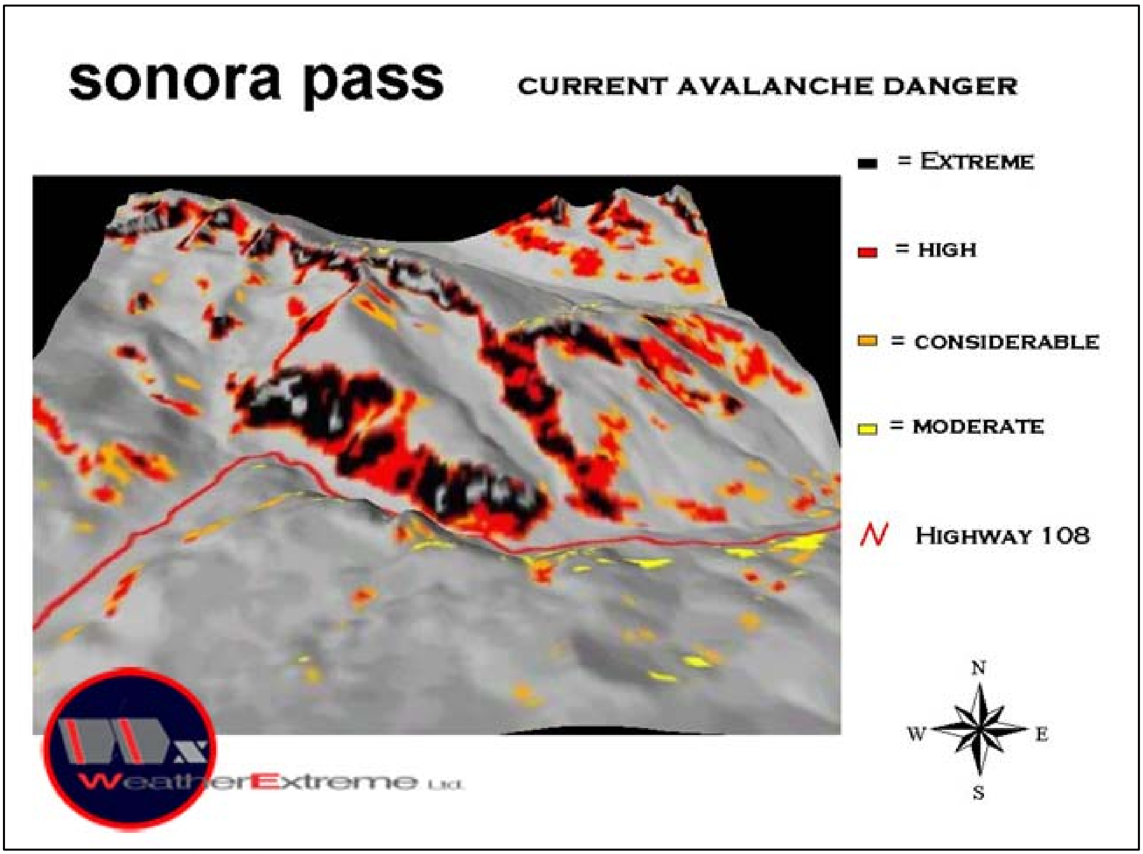
Source: Kloprogge et al. (2007)

Figure A22 Examples of graphics intended specifically to illustrate uncertainty.



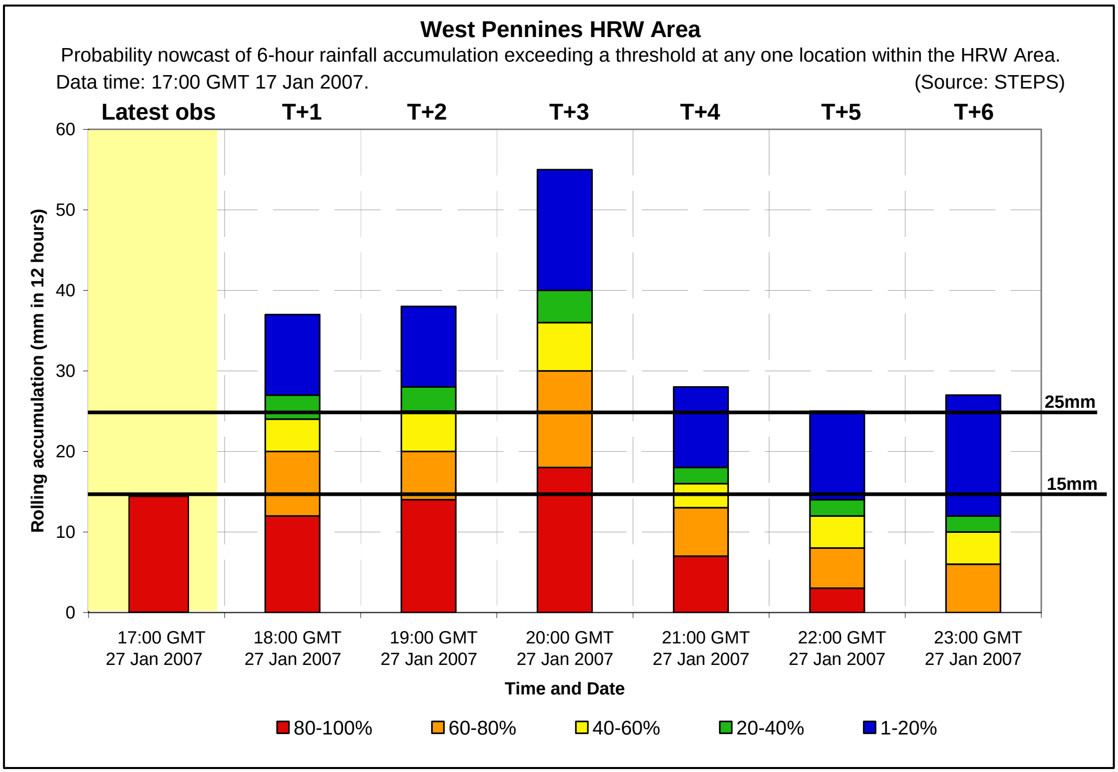
Source: Evans and Carbin (2008)

Figure A23 Example of tornado probability map.



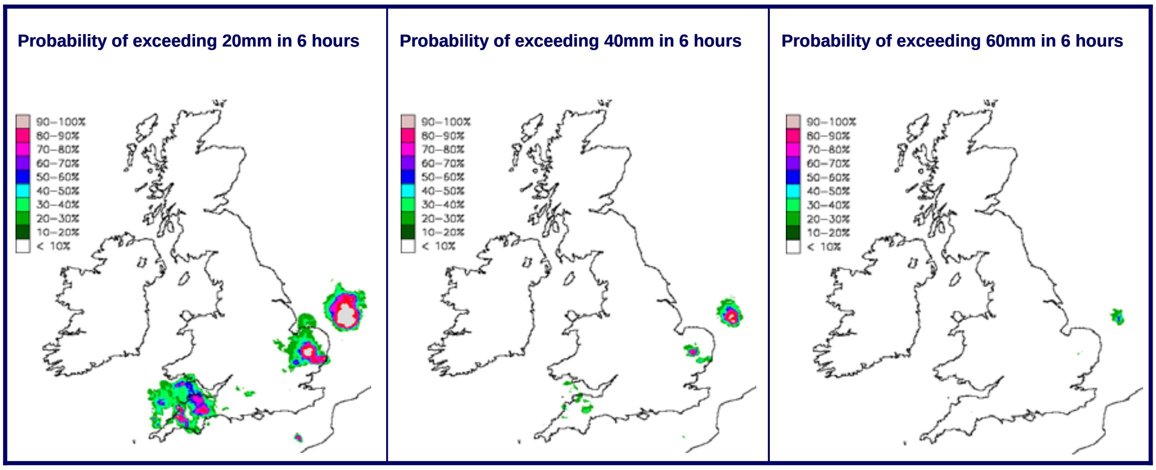
Source: Carter (2001)

Figure A24 Example of a 3D avalanche forecast map.



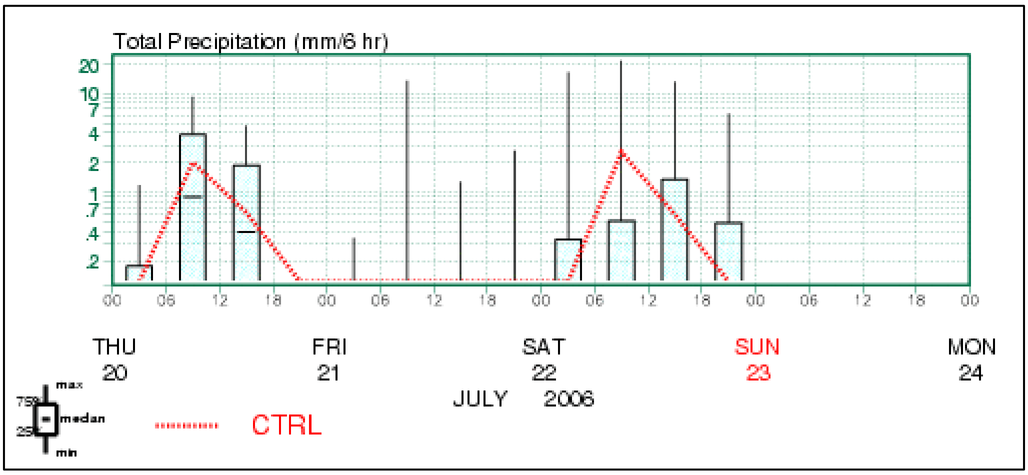
Source: Pierce and Orrell (2008)

Figure A25 Probabilistic nowcast by UK Met Office for 6-hour rainfall exceeding a threshold at any one location.



Source: Met Office

Figure A26 Extreme Rainfall Alert examples of maps using a grid.



Source: Met Office

Figure A27 Example of a meteogram.

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