World Meteorological Organization

GUIDELINES ON COMMUNICATING FORECAST UNCERTAINTY

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Chapter 1: Introduction

Uncertainty is an inherent ingredient in the hydrometeorological forecasting process, as noted by WMO Executive Council Fifth Session April 2002 (Annex to Paragraph 5.1.8 of the General Summary). Forecasters are very familiar with the question of uncertainty and predictability, and must deal with it every time a forecast is prepared. Sometimes the available computer models or other guidance are consistent in their predictions and the forecaster is confident of the outcome. At other times, the models may differ greatly or the weather parameter may be intrinsically difficult to forecast. Nevertheless, a forecast must be made, even when the confidence is low.

Uncertainty in the forecast can also arise from how the forecaster utilises the available information. Even if the model predictions are highly accurate, they must still be interpreted and translated by the forecaster into actual weather. This interpretation must then be rendered into a forecast, which in turn is received and interpreted by the user. Uncertainty can occur at each of these stages of the 'information chain'.

Communicating the uncertainty of the forecast is vital to users. It allows them 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.

These Guidelines address the issue of communicating forecast uncertainty. Although they include a discussion on the sources of uncertainty, and touch on the related science (e.g. probabilistic forecasting, the use of Numerical Weather Prediction (NWP) ensembles), this is not their focus. Rather, the emphasis is on how National Meteorological and Hydrological Services (NMHSs) can incorporate uncertainty information in their hydrometeorological forecast services, including the best ways to communicate this information to the benefit of users.

Strategies for addressing the issue of communicating forecast uncertainty have been, or are being, developed by many NMHSs. As these strategies are developed, it is important to be aware of some of the possible pitfalls. For example, some meteorologists – as scientists – are quite comfortable with uncertainty and the language of probabilities, while others are less so. In either case training of forecasters is essential to ensure that uncertainty is estimated and communicated consistently. In the case of the general public the degree of understanding will vary according to educational background and culture, but people are generally less comfortable with probabilities than scientists and there is a significant risk of misunderstanding.

The conventional text-based forecast offers little opportunity for expressing uncertainty. There is limited space in the forecast, it is not easy for recipients to absorb every word that is there, and it can take the forecaster a long time to get the words 'just right'. Not only that, the verbal language of uncertainty can often be rather subjective, so that what the forecaster intends may not match what the recipient understands. One possible solution is to devise a simple numerical scale for confidence and attach it to all forecasts. This idea is not new! In an article published in Monthly Weather Review in 1906, W. E. Cooke suggested a 5-point scale for describing uncertainty:

5	We may rely upon this with almost absolute certainty
4	We may rely upon this with tolerable certainty, but may be wrong about once in ten times
3	Very doubtful. More likely right than wrong, but probably wrong about four times out of ten
2	Just possible, but not likely. If showers are indicated, for example, they will not be heavy even if they occur at all
1	The barest possibility. Not at all likely

And a forecast might read: *Southwest district: Fine weather throughout (5) except in the extreme southwest where a few light coastal showers are possible (2). Warm inland (4), with a cool change expected on the west coast (3).*

Another way to express uncertainty is to include in the forecast the next most likely scenario as well as the expected one. This allows users to make contingency plans. Although many users only want a single forecast upon which to base their decisions, some users with more specialised needs can get value from knowing what the alternatives might be. This is especially true of emergency managers who need to know alternative and worst-case scenarios so they can plan their resources with all contingencies covered.

Expressing forecast probabilities is a common way of expressing uncertainty and is becoming a widespread practice. 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 derived from ensemble forecasts, for example, should not be assumed to be reliable, but should be verified and calibrated as necessary. Probabilities may also be estimated using statistical methods based on past forecast errors or subjective decision making methods. Probabilities must also be clearly defined and communicated, so that users understand what they mean.

Uncertainty may also be expressed by giving a range of values presented, for example, as an error bar or as an EPS meteogram. Many users have found this approach useful in their decision making processes.
The focus of these Guidelines is on ways to describe and communicate forecast uncertainty, highlighting the key issues that NMHSs will need to recognise and address.

1.1 About the guidelines

1.1.1 Background context

These Guidelines have been developed under the auspices of the World Meteorological Organization Public Weather Services Programme, by the Expert Team on Communication Aspects of Public Weather Services (ET-COM) and by an Expert Meeting held in Shanghai, China in September 2007. Amongst the Terms of Reference of the ET-COM is to:

> *Study and report on how to effectively communicate to end users the concepts of uncertainty and confidence that are increasingly available from the output of Ensemble Prediction Systems and other probabilistic forecasting systems.*

These Guidelines are prepared with the central aim of assisting NMHSs to develop strategies and techniques to communicate uncertainty information as part of their services. In this context, the Guidelines are a contribution to the overall objectives of the WMO PWS Programme to strengthen the capabilities of WMO Members to meet the needs of the community, and to foster a better understanding by the public of the capabilities of NMHSs and how best to use their services.

These Guidelines should be seen as complementing the science of forecasting uncertainty. This is an area that is taking on an increasingly significant role in the hydrometeorological research community and is the subject of major international projects such as the WMO World Weather Research Programme's THORPEX (THe Observing system Research and Predictability EXperiment) programme. Guidance on forecasting science is provided under the WMO Global Data Processing and Forecast System (GDPFS) programme by the Expert Team on Ensemble Prediction Systems (ET-EPS). The outcomes from these research activities will improve the scientific underpinning of probabilistic and other uncertainty forecast services – however, unless the forecast information is communicated effectively to users, its full value will not be utilised.

1.1.2 Purpose of Guidelines

These Guidelines have been developed to help NMHSs address the challenges associated with the communication of forecast uncertainty information. Emphasis is given to the different ways in which uncertainty information can be presented and described. The way users interpret this information is also discussed, as well as how to avoid common causes of user misunderstanding.

The audience for these Guidelines is primarily those who are involved in the development and delivery of hydrometeorological forecast and warning services. This includes weather and climate forecasters, broadcast meteorologists, and those who develop and manage forecast services and wish to understand the best way to present the uncertainty components of these services.

The Guidelines do not address the science of forecast uncertainty. Techniques such as ensemble NWP or statistical forecasting are not described in detail. A good source of information on the science of ensemble prediction is the Comet website at www.?? Instead, the emphasis is on how to best communicate the uncertainty information that these methods can produce.

To understand how to communicate uncertainty, it is important to understand where it comes from. For this, readers are directed to Chapter 3, 'Sources of Forecast Uncertainty' which discusses the various sources of forecast uncertainty, including the inexact nature of meteorological science, how forecasters render meteorological information into forecasts, as well as how users interpret these forecasts.

The Guidelines are designed to be a practical guide on how best to communicate uncertainty. They include useful examples that NMHSs may consider when developing their own strategies. This is the 'heart' of the document and is contained within Chapter 4, 'How to Communicate Forecast Uncertainty'.

The ultimate purpose of communicating uncertainty is to enable users to make better decisions in the face of uncertainty. Chapter 5 provides a brief outline of some ideas for decision making. For this decision making to be effective, it is essential that the forecasts have some skill and provide a reliable representation of the true forecast uncertainty – the need for effective verification and calibration of probabilistic forecasts are outlined briefly in Chapter 6.

Underpinning all this, and providing the fundamental motivation for these Guidelines, is an understanding of why it is important to communicate uncertainty. This is the focus of the next chapter – 'Why Communicate Uncertainty'.

Chapter 2: Why communicate forecast uncertainty?

There are several reasons why communicating forecast uncertainty is useful, both for users of the forecast and also for the NMHS that provides the forecast. Each of these reasons are described in the following sections.

2.1 Benefits of communicating uncertainty for improved decision making

The central reason to communicate forecast uncertainty is to assist people to make more effective decisions. This is especially so when the user of the forecast has options available to them and wants to weigh up contingencies. Such situations are very common, and range in scope from simple day-to-day decisions about such things as what clothes to wear, to major emergency responses such as evacuation planning. The following examples describe how uncertainty information can improve the quality and effectiveness of a decision:

- A farmer wishes to fertilise a crop. For this to be successful, a small amount of rain is desirable to help the fertiliser be absorbed into the soil. The farmer has established a rule that says that if the probability of rainfall is less than 80%, then the risk of wasting the fertiliser is too high, and he waits until the chances improve. The farmer needs a high degree of confidence before deciding to apply fertiliser. (Consider, on the other hand, someone organising an outdoors event. They may set a much lower decision-making threshold because even a small chance of rain is a matter of concern).

- A Government food agency is assessing food security for the coming year. The seasonal climate forecast suggests that there is a slightly greater than normal chance of below average rains over the growing season. Accordingly, the food agency initiates a food stock-piling program. The consequences of inadequate rain is so great that the food agency responds, even though the uncertainty of the prediction is relatively high.

- An emergency services agency is deciding whether to evacuate a community ahead of an approaching tropical cyclone. The forecast states that there is a 10% chance of destructive winds being experienced. Even though this is numerically low, it is high enough – relative to the potential consequences – for the agency to commence evacuations.

In each of these three cases, users have tuned their responses to differing levels of forecast uncertainty according to their own particular needs. This tuning may be optimized by assessment of costs and losses associated with the decision. This is why information on forecast uncertainty is such a useful part of the service – it allows people to react to the forecast in the way that is appropriate to their situation. Without this information, for example if a forecast was simply 'Rain' or 'No rain', the underlying uncertainty is still there and the forecaster has simply made a best estimate judgement. While the forecaster's judgement may be well matched to the needs of some users, it cannot be matched to those of all users.

It is important that users understand that when making decision in the presence of uncertainty there will be cases when "false alarms" will occur. This is an attribute of probability forecasts. For example, in the tropical cyclone scenario above, we should expect nine evacuations when destructive winds do not occur for every one when lives are saved. The cost-loss model can help assess the correct level of response at different probabilities. An example of the use of a cost-loss model is given in Appendix A from WMO/TD-NO.1292 *Guidelines on Integrating Severe Weather Warnings into Disaster Risk Management.*

2.2 Communicating uncertainty helps manage user expectations

Meteorologists 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 the forecast is always right. Forecasters also know that some situations are more predictable than others. If they are able to communicate this to users then a more open, honest, and effective relationship can be established, in which users have a realistic understanding of the accuracy and reliability of the service.

Forecasters often comment on how much benefit can be gained from face-to-face weather briefings or media interviews, where they are able to explain the confidence they have with the current forecast, and can describe alternative scenarios. Such briefings and interviews are very useful for describing forecast uncertainty and why it arises, e.g. by using statements such as "most of the models are suggesting light rain, but a couple of models are forecasting heavier rain so we must keep an eye on this possibility." In this way, users get an insight into the forecast process and develop an appreciation for its inherent uncertainty.

2.3 Communicating uncertainty promotes user confidence

Retaining the confidence of users is critical if an NMHS is to be visibly identified as the source of official forecast and warning information. Users who understand that forecasts can have a degree of uncertainty, and are able to tune their decision-making to uncertainty information provided by the NMHS, are much more likely to retain confidence in the NMHS. Surveys show that uncertainty information does not undermine people's confidence in the 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.

2.4 Forecast uncertainty reflects the state of the science

It is important that meteorological services are based on good science. Uncertainty is inherent in the predictions from NWP models and other parts of the forecast process (which are discussed in more detail in Chapter 3) and it is appropriate that this uncertainty is factored into the forecast and warning services that are provided. Little credit is given to the profession, and the credibility of the NMHS is undermined, if the accuracy of the service is overstated.

Chapter 3: Sources of forecast uncertainty

In order to effectively communicate uncertainty, it is important to understand where it comes from. Some uncertainty accumulates within the forecast process chain, as a result of the inherently chaotic behaviour of the atmosphere, limitations in our ability to measure and model the state of the atmosphere, and in our efforts to interpret the observational and model data. Further uncertainty arises when forecasters endeavour to turn their scientific understanding of the situation into plain language. Finally, uncertainty can occur when the forecast is received and interpreted by the user, who does not always have the same understanding of the terminology or the intent of the forecast. The strategies to deal with these uncertainties, in terms of communication, will vary. For example, in the case of scientific uncertainty, the use of probabilities can be an effective way to communicate uncertainty levels; in the case of uncertainty due to forecast interpretation, the use of clear language and well-defined terminology would be an important element of effective communication. The separate sources of uncertainty are discussed in more detail below.

3.1 Atmospheric unpredictability

Forecast uncertainty arises due to inherent unpredictability in the atmosphere. The atmosphere is by nature a chaotic fluid which is very sensitive to initial conditions. This coupled with an incomplete depiction of the current state of the atmosphere at the commencement of an NWP model run will always result in forecast uncertainty in the. Ensemble model prediction methods attempt to quantify the sensitivity of the situation to the initial conditions and thereby measure the degree of uncertainty that arises due to this cause.

The models themselves are only a simulation of the atmosphere, and their accuracy will be limited by how accurately they can represent complex atmospheric processes. In situations that are especially complex and difficult to model (e.g. short-term convective weather), the levels of forecast uncertainty may be quite high.

Longer range forecasts are based on the predictability of slowly varying parameters such as sea-surface temperature, but the evolution of the atmosphere is only weakly forced by coupling at the lower boundary, leading to uncertainty in forecasts.

3.2 Uncertainty of data interpretation

Once the forecaster is presented with forecast information, there is still the task of interpreting the data and rendering it into forecast policy and forecast products. For example, the output of NWP models is usually in the form of meteorological fields such as surface pressure, temperature or wind. Sensible weather (showers, fog, etc) may be represented by diagnosed fields or are interpreted according to experience and conceptual models. Models or ensembles generally perform best for fully resolved parameters, while diagnosed weather elements involve greater uncertainty.

3.3 Uncertainty when composing the forecast

The use of appropriate terminology when composing a forecast is an essential element of effective communication. However, terminology and phraseology are often unable to perfectly encapsulate the expected forecast scenario. The format and length of the forecast may also be restrictive. As a result, uncertainty may arise because the forecaster is unable to describe the full story of what will happen. For example, if the forecast applies to a large geographical area, and a wide range of weather is expected, forecasters will need to summarise or condense the situation, perhaps by giving a general description or only mentioning the most important developments. Summary phrases like “in the west”, or “evening and overnight” contain inherent uncertainty because they are broad rather than specific descriptions.

3.4 Forecast interpretation

The final source of forecast uncertainty arises when the user receives and interprets the forecast. This is the area where some of the greatest uncertainty can arise, especially if there is a lack of understanding of the forecast terminology, or where the user perceives the meaning to be different from that intended. Many NMHSs have conducted surveys to gauge the level of understanding of forecast terms and confirmed frequent misunderstandings.

Sometimes there is even a difference in the understanding of forecast terminology amongst forecasters themselves. Is ‘chance of storm’ the same as ‘possible storms’? What is the difference between ‘mainly fine’ and ‘a shower or two’? It would be quite common to find two forecasters giving two different answers to each question. If forecasters cannot agree on the meaning, then it is inevitable that users will be uncertain about the meaning. Forecast centres should develop standard definitions of terms and use them consistently.

When the question of forecast interpretation is examined in the context of probabilities, the situation becomes even more acute. In a survey conducted by the Australian Bureau of Meteorology, people were asked what they understood by a city forecast for 30% chance of rain. 55% of respondents said it meant 30% chance of rain anywhere in the city, whereas 36% said a 30% chance of rain everywhere in the city. This shows why it is important to define the event clearly so that both forecaster and user are perfectly clear what the probability refers to. It can also help users if probabilities of events are referenced in comparison to the climatological observed frequency of such events.

Human perceptions also have an important influence on the interpretation of uncertainty and risk. People's responses to uncertainty vary according to the consequences of the phenomenon being forecast.

Another factor which can cause misinterpretation of the message is where the user's native language is different to that of the forecaster.

The question of communicating uncertainty, and how this communication is affected by human perceptions, is discussed in more detail in the next chapter.

Chapter 4: How to communicate forecast uncertainty

4.1 Human perceptions of uncertainty information

The prime motivation for communicating forecast uncertainty information is to assist better decision making on the part of those receiving the information. For these recipients to respond however, they must first interpret and understand the information.

How people perceive and respond to language and information of this kind has been investigated by behavioural scientists. Much can be learnt from these studies.

For example, it has been shown that the way people interpret and describe uncertainty information can be influenced by the significance or magnitude of the event (Patt and Schrag 2003). Such studies suggest, for example, that if light rain and heavy rain are both objectively forecast to have a 10% chance, people subjectively *describe* the heavy rain event as being more likely. This exaggeration is demonstrated when people are asked to describe a given numerical probability using plain language – for the high magnitude event, they will use words corresponding to a greater probability than the words used to describe the low magnitude event.

People often expect this exaggeration behaviour in others, and so they will ‘decode’ what they are told. Thus, when receiving a forecast that describes a high impact event as a medium likelihood, users will often assign a lower threat level due to a belief that the provider of the forecast was exaggerating. It is important to bear in mind this tendency by users to ‘exaggerate’ and ‘decode’ the information they receive. An effective strategy is to use objective numerical measures of uncertainty (e.g. probabilities) together with plain language that is clearly defined. An example of this approach is the uncertainty scale used by the Intergovernmental Panel on Climate Change (IPCC), which clearly defines the language and the corresponding probability thresholds (Table 1).

Terminology	**Likelihood of the occurrence/outcome**
Virtually certain	Greater than 90% probability
Very likely	Greater than 99% 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

Table 1: IPCC Likelihood Scale

4.2 User sophistication

It is important to keep in mind that different users will have different requirements for uncertainty information as well as different levels of understanding. For some, particularly those involved in emergency response, detailed quantitative estimates of uncertainty are required. 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 being experienced increases beyond 20%.
It is best if such plans are developed in collaboration between the user and the NMHS so that both sides understand each others needs and capabilities.

Sophisticated users of uncertainty information are aware of the underpinning reasons for uncertainty, and NMHSs – when providing this information – can use technical language and speak in some detail. The use of relatively complex graphics is also possible. For less sophisticated users, NMHSs need to be quite careful about the use of complex information. Such users are less likely to understand the sources of uncertainty and will prefer simple messages and graphics.

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% 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 4 European cities, where probability forecasting is not used, the majority of users incorrectly interpreted the forecast to mean rain would fall 30% of the time, or over 30% of the area.

4.3 Use of colour

Colour is a very powerful tool for conveying information and meaning. Like any tool, it needs to be used carefully. It is a common practice to use colour in the graphical presentation of probability (or other uncertainty) information. Great care should be taken that the colours that are chosen send the right message.

Below (Figure 1) is an example of a probabilistic seasonal rainfall forecast issued by the Australian Bureau of Meteorology. Notice that probability values below 50% are denoted by warm colours.

all values between 40% and 60% are depicted in white or grey. The same level of information is still provided, but the 'emotive' colours have been shifted so that they now apply only to the high/low probability values.

It is also important to use colour scales which can be clearly read by those with various kinds of colour blindness. Advice on such scales can be found, for example, at: www.colorlab.wickline.org/colorblind/colorlab.

4.4 Examples of uncertainty information

This section provides some examples of effective methods for conveying uncertainty information. The examples make use of the principles and ideas

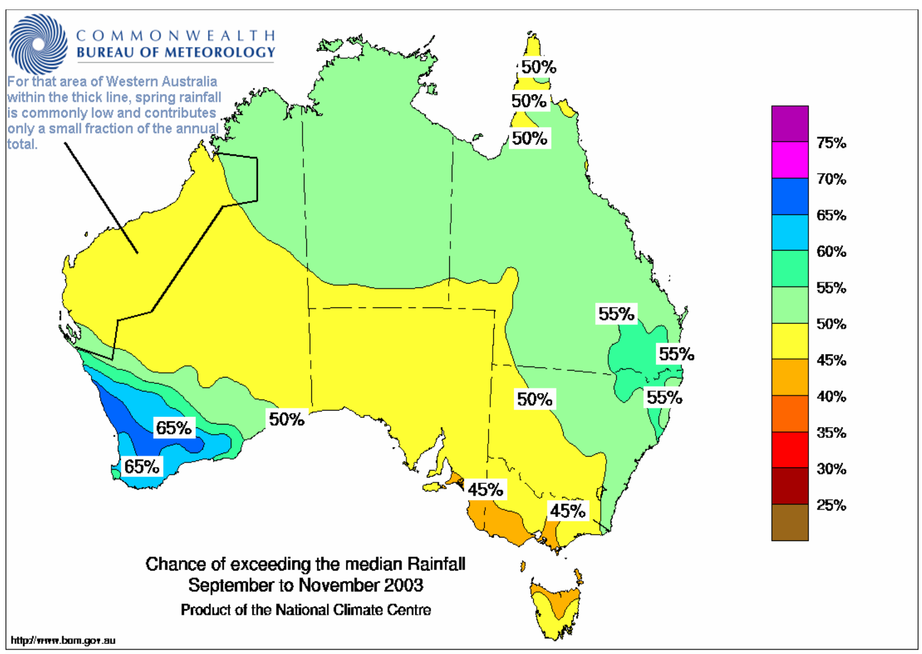

Figure 1: Seasonal rainfall forecast (Australian Bureau of Meteorology)

By using colour this way, users would often interpret the message inappropriately. Numerically, 49% is not very different from 51%, yet the colours suggest a very different message, that the yellow areas will be dry and the light green areas will be wet. This colour scale is also poorly designed because the colour used for greater than 75% is very similar to those used between 25 and 35%.

Recognising this problem, a new colour palette was devised that has been more effective in communicating the correct message. In the example below (Figure 2),

expressed above. NMHSs are encouraged to consider these examples when developing or enhancing their delivery of uncertainty information to users.

4.4.1 Terminology

The language of uncertainty can be either complex or simple. When presenting a weather briefing, or preparing a forecast for the general public, forecasters may make use of phrases such as "chance of", "one or two" or "possible". Sometimes, non-specific descriptors may be applied, such as "later", "developing" or "in the area". These descriptors are deliberately vague because the forecaster is uncertain about the precise time or location of the phenomenon being forecast.

Often the uncertainty associated with a forecast is due to the presence of an unpredictable weather pattern. A narrative description of the situation, including possible alternative scenarios, can be an effective way of conveying uncertainty to more sophisticated users. Radio is an ideal way to communicate this information.

In many countries users (sophisticated and less sophisticated) do not have access to advanced communications channels like internet or television and have to rely on radio or telephone links. In these instances presenting forecasts in a narrative form via radio or telephone may be the only way of reaching these users. Relaying uncertainty information must be unambiguous and consistent in terminology. It is important to take language and cultural differences into account in defining standardized terminology for uncertainty information, as well as the level of sophistication of users. Doing a survey among users could be useful in this process. Uncertainty terminology may need to be translated into specific languages to overcome problems with interpretation. In some languages words may not exist to describe this uncertainty properly.

Although language is essential for communicating uncertainty, its verbal form can introduce confusion in the mind of the user. What, for example, is the difference between "chance of" and "possible"? Does "chance of" mean the same for one forecaster as another? While it is useful to use such words and phrases so that users do not have an expectation of certainty, it is important to try and apply some consistency. Using clear definitions and procedures will help in this respect. For example, a rule could be instigated that says that a forecast of "possible showers" would only be used when the probability is above a defined threshold of 30%. Such a rule should preferably be derived from an analysis of user decision systems.

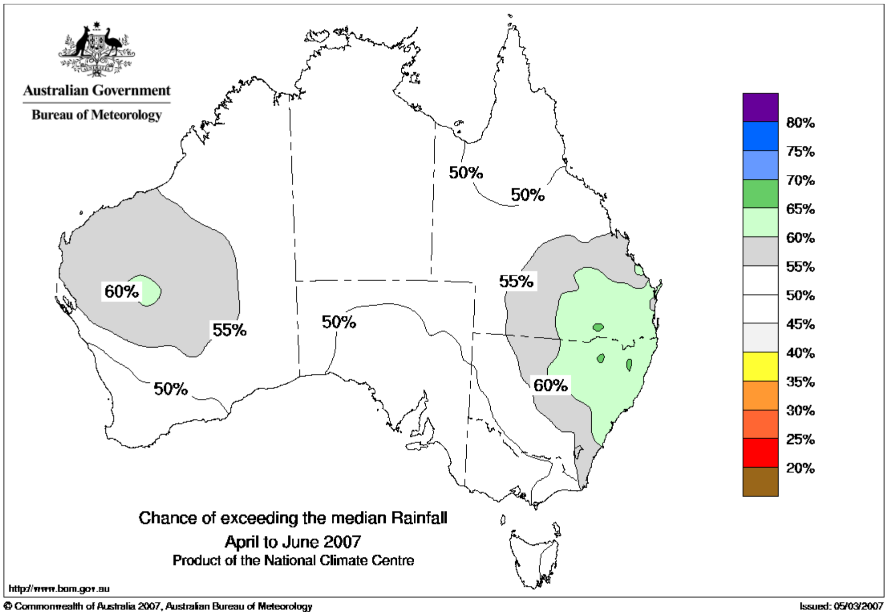

Figure 2: Seasonal rainfall forecast (Australian Bureau of Meteorology)

Table 2 provides a scale that could be used by NMHSs to define the most common uncertainty terms. It is similar to the IPCC Likelihood Scale (Table 1) and includes some extra terms that forecasters often use.

Terminology	Likelihood of the occurrence/outcome
Extremely likely	Greater than 99% probability
Very likely	90% to 99% probability
Likely	70% to 89% probability
Probable - more likely than not	55% to 69% probability
Equally likely as not	45% to 54% probability
Possible - less likely than not	30% to 44% probability
Unlikely	10% to 29% probability
Very unlikely	1% to 9% probability
Extremely unlikely	Less than 1% probability

Table 2: Forecast Likelihood Scale

One of the dangers of using a scale like this is the definitions of the words such as ‘probable’, ‘possible’ and ‘chance’, and the hierarchy to assign to them (i.e. the order to place them in the scale). Evidence from psychological research indicates that people’s interpretation of words such as “possible” can vary widely. Such terms, if used, should be clearly defined to the user and used consistently. The precise probability numbers to assign to the terms is also an area that would require careful consideration. Nevertheless, the scale could be a useful starting point for NMHSs as they seek to define the language they will use when forecasting uncertainty.

4.4.2 Graphs

Simple graphs can be a useful way to present uncertainty information in quantitative terms. The following example (Fig. 3) shows how a seasonal rainfall probability forecast could be presented as a pie chart:

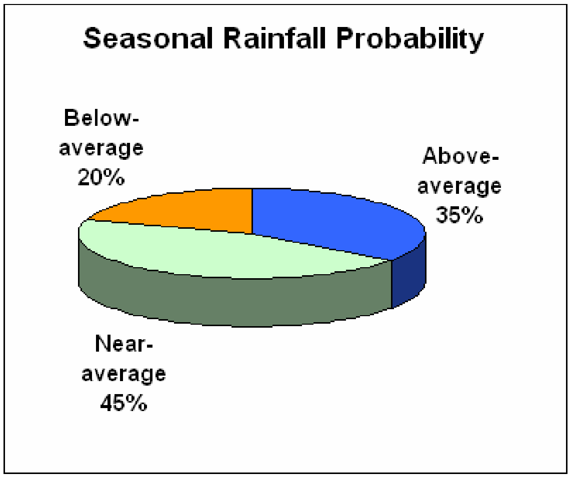

Figure 3: Example of a rainfall probability pie chart

One of the attractive features of this format is that it shows all possibilities at once. Users are therefore made aware not only of the most likely outcome, but also of the relative likelihood of alternatives.

An effective way of showing uncertainty, particularly uncertainty that increases with lead time, is the use of time series that include ‘error bars’. Figure 4 shows an example of a time series forecast of temperature that shows the uncertainty at each time step. This presentation, known as an EPS-meteogram, or EPS-gram, is commonly used by several ensemble producers.

Another presentation of the same type of information is shown in figure 5. This also shows the ensemble range between defined percentiles, but the wording in the key uses “Natural Frequencies” (eg. 9 times out of 10) which have been shown by psychologists to be more easily understood by most people. The fan-chart style graph was also found to be more popular amongst users in a web-based survey conducted by the UK Met Office. Finally, the inclusion of the previous day’s observations helps users to put the forecast temperature into a context that they can easily relate to – warmer or cooler than yesterday. A different presentation more suitable for precipitation forecasts, in the form of a bar chart, is shown in figure 6.

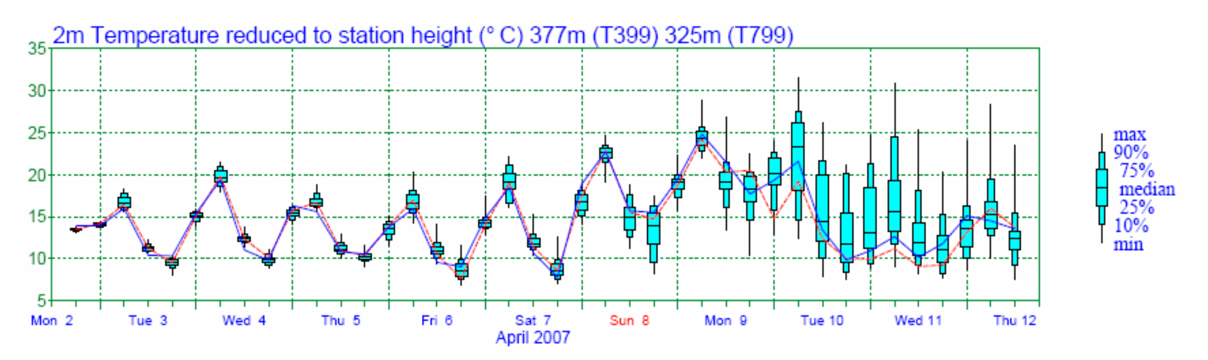

Figure 4: Meteogram of forecast temperature produced by an ensemble prediction scheme (ECMWF)

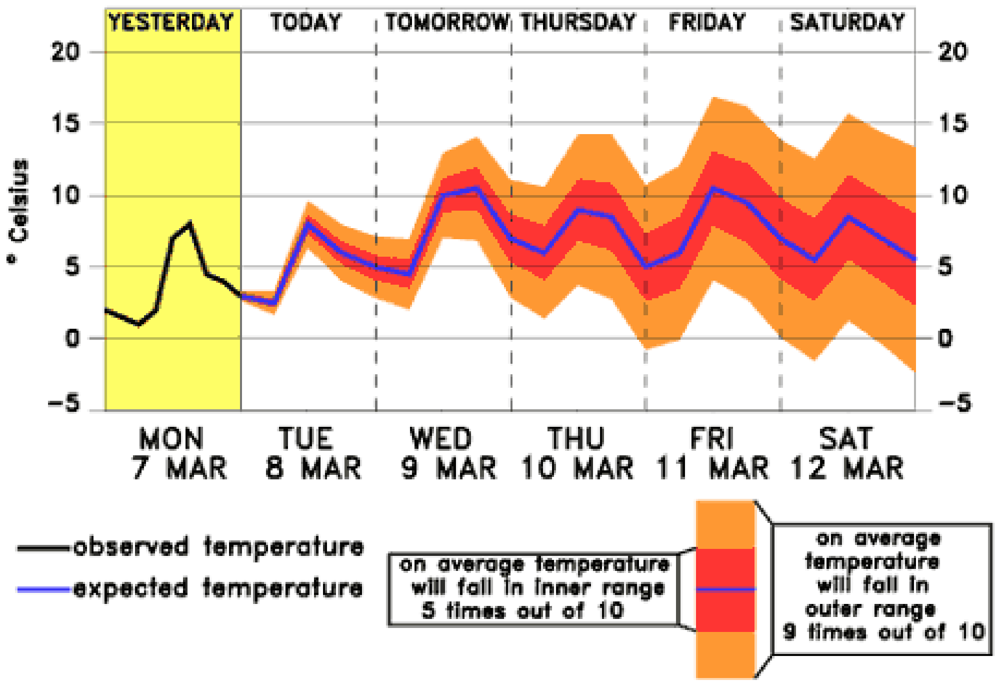

Figure 5: Fan chart of a temperature forecast produced by an ensemble prediction scheme. This design was produced taking account of research by psychologists into public understanding of information on risk, and proved popular in a survey of users of the Met Office website.

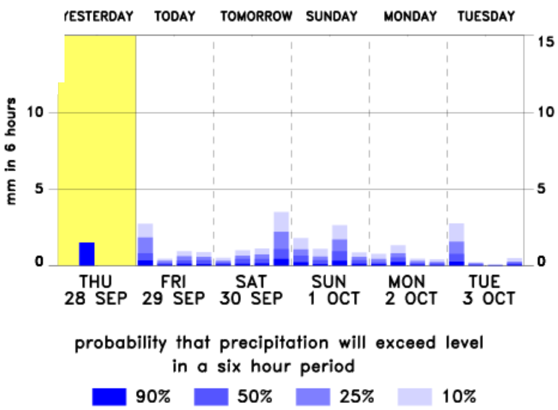

Figure 6: Bar chart of a precipitation forecast produced by an ensemble prediction scheme. This design proved popular in a survey of users of the Met Office website.

4.4.3 Icons

It can be difficult to utilise an icon for communicating uncertainty, but can be useful for a quick pictorial image on television or a web site. Where icons are used for this purpose, it is common practice simply to superimpose the uncertainty information in numerical terms (e.g. as a probability) on the icon, as shown in figure 7:

or


Figure 7: Icons showing precipitation type along with forecast probability of precipitation (NOAA National Weather Service)

It is important that the icon is chosen carefully to clearly portray the intended weather event referred to. It may be useful to put one or two words next to the icon for further clarity (e.g. showers).

4.4.4 Charts and maps

Uncertainty information lends itself well to spatial depiction. A chart or map presentation is often an effective way to present both the forecast and the uncertainty associated with it. The Greater Horn of Africa Consensus Climate Outlook shown in figure 8 is a good example. Zones of equal probability range are colour-coded (with grey for the neutral forecasts) and show at a glance the spatial distribution of rainfall likelihood.

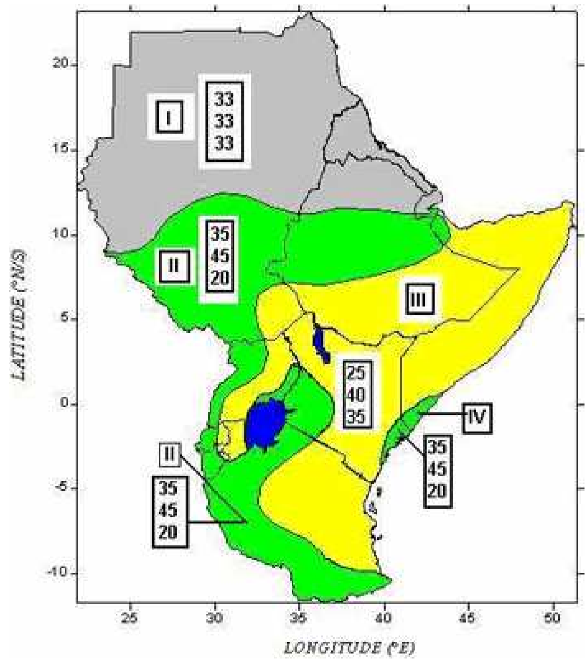

Figure 8: Greater Horn of Africa Consensus Climate Outlook
(Courtesy IGAD Climate Prediction and Applications Centre)

For each region on the map in figure 8, a seasonal forecast is provided in the form of a box containing three numbers. These numbers (from top to bottom) are the % probability of above-, near- and below-normal rainfall. The advantage of showing all three numbers together, is that all scenarios are described. In other words, it is indicated to users that although one particular outcome might be the most favoured, the alternatives are also possible. As an alternative, this information could be provided in a pie chart for each area of the map. For seasonal forecasts which may have limited skill, it is important also to provide information on the typical skill of the forecast, and where there is no skill the forecaster should issue only the climatological probability.

Experience shows that the multi-category map in figure 8 can be difficult for users to interpret, particularly less sophisticated users who are not familiar with probabilities. It would be helpful to provide further interpretation of the map in written form. It is advisable to provide information on aspects of weather that have significant predictability, for example if the forecasting systems have high confidence in predicting that dry conditions will not occur, this should be conveyed specifically to users in a drought sensitive area. Where forecasting systems have historically good skill for a particular category, this information increases the confidence in the forecast and should be conveyed to the user. It is also useful to provide typical examples of historical above normal or below normal events as a reference to users. However, in this case it should be stressed that the local details of the coming season will likely differ from the historical example.

There are other useful formats to present seasonal forecast information, for example maps indicating the percentage probability of above normal rain and below normal rain where there is a strong signal, as in Figures 9 and 10. Once again it is important to note that this kind of product is only useful where the verification

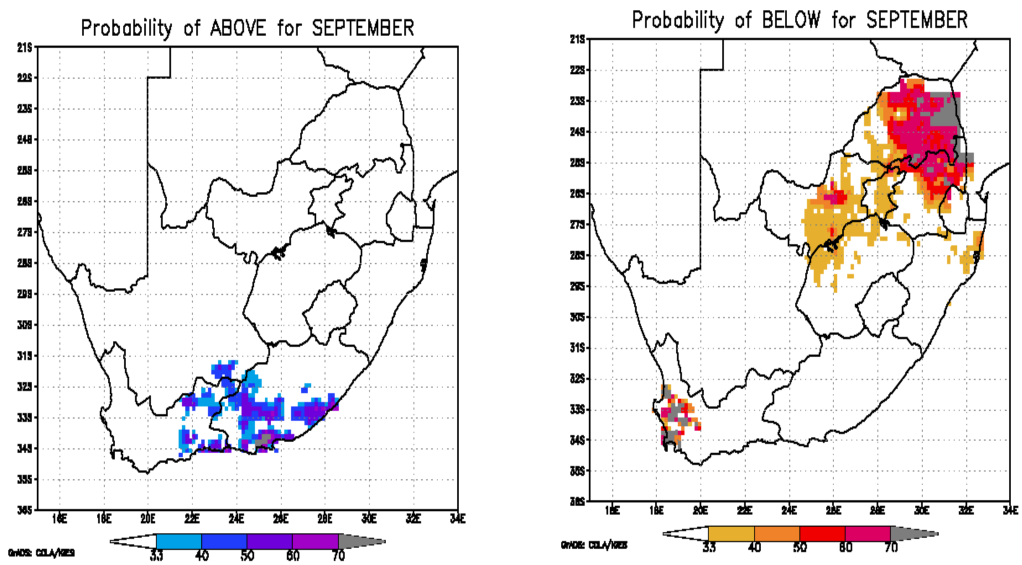

Figure 9: Forecast probabilities for above normal (left) and below normal (right) categories of monthly precipitation.

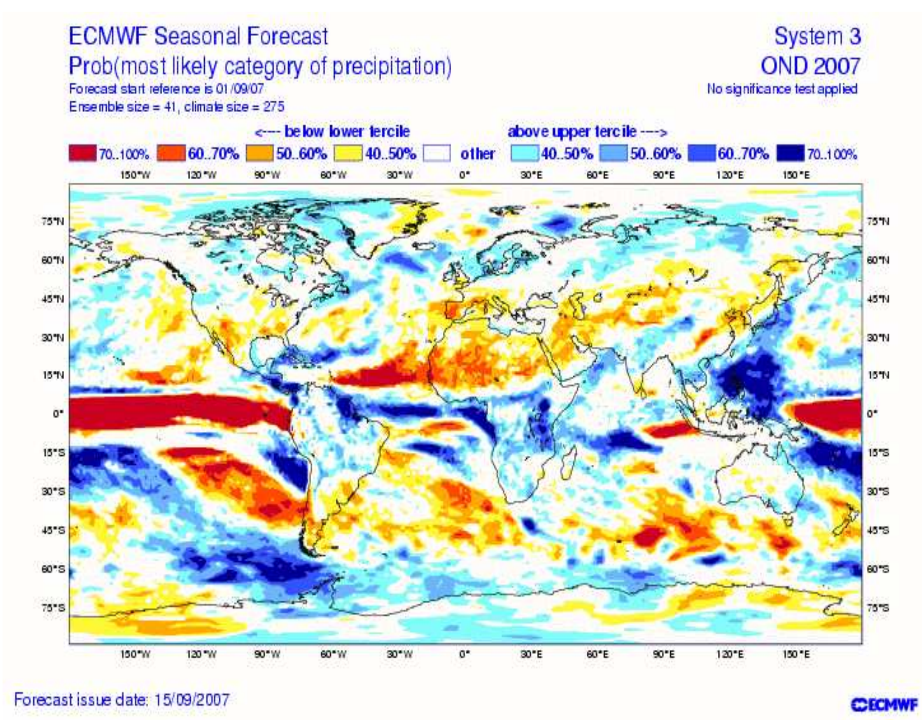

Figure 10 Forecast probabilities for the most likely category of seasonal precipitation.

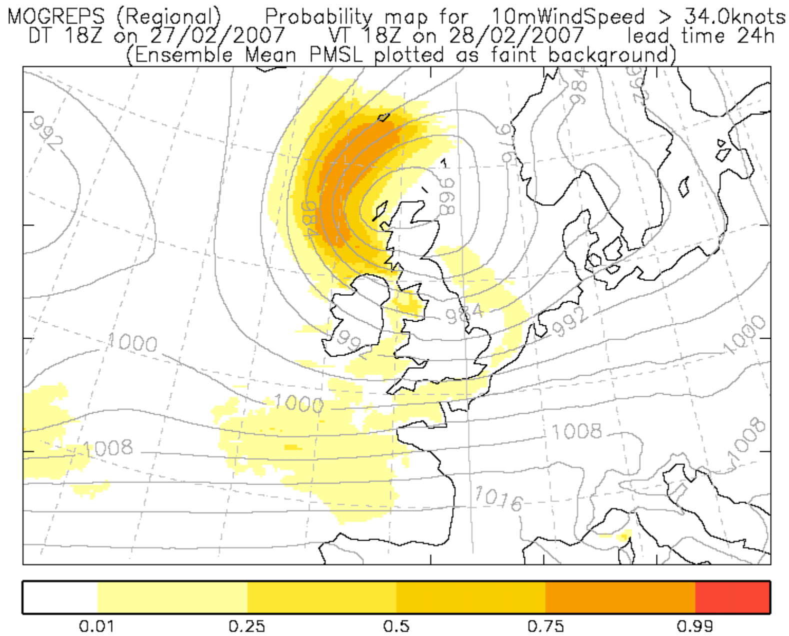

Figure 11: Map showing probability of wind-speed exceeding 34kt (gale force) produced from the UK Met Office MOGREPS ensemble. In this example, which is designed primarily for use by forecasters or users with some meteorological knowledge, the ensemble mean surface pressure is also included to show the weather system generating the wind.

indicates skill, and this information must be conveyed to users. One way to do this is the use of skill masks, where the signal in the forecast is masked out in regions with low skill.

Map formats are frequently used for short and medium-term probability forecasts as well. Such forecasts are most commonly produced by ensemble prediction systems. Probability charts can be presented according to defined thresholds, for example the probability of wind-speed exceeding 34kt (gale force) as shown in figure 11.

Another useful presentation can be a map showing the values of a weather parameter, such as rainfall accumulation, which occur at a particular probability level. For example, a water resource manager may be interested to know the 10th percentile of rainfall as an estimate of the lowest level he is likely to receive, while a flood control manager might want the rainfall at the 90th percentile, or the maximum. An example of the worst-case scenario rainfall from the UK Met Office MOGREPS ensemble is shown in figure 12. A tabular presentation of similar information is shown in Table 3.

Another example of effective graphical presentation of uncertainty is the tropical cyclone forecast track (Figure 13), issued by the Cuban National Forecast Center. The depiction of the forecast track as a cone ensures that the general public do not put too much emphasis on a single path and assume they are safe if the path is not shown passing directly over them. Also, this depiction reinforces the fact that, due to its size, a hurricane can affect a very large area and is not confined to a point or narrow swath. The explanatory note at the top of the graphic is very important: "Assuming AVERAGE FORECAST ERROR – the EYE should track in the white cone in next 72 hours".

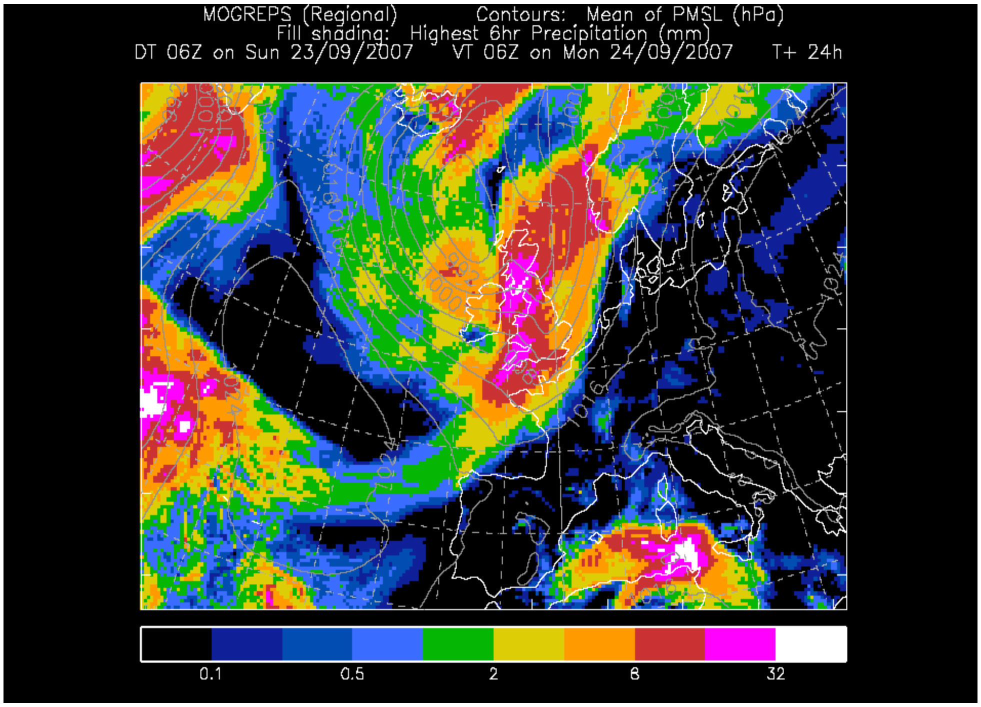

Figure 12: Maximum 6h-rainfall forecast by the UK Met Office MOGREPS ensemble – at each grid-point the highest rainfall predicted by any of the ensemble members is shown, giving the user a picture of the worst-case scenario.

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

Table 3: Predicted rainfall amount stratified by probability threshold (Australian Bureau of Meteorology)

One limitation of the chart in figure 13 is that it gives no indication of the areas at greatest risk within the cone. Figure 14 shows an alternative presentation which shows the full cone of uncertainty but also retains some information on the area of greatest risk. This chart shows the probability that the storm centre will pass within 75 miles of any location within the forecast period, showing the highest probabilities in the core of the cone of uncertainty.

time, otherwise, there is a danger that nothing more

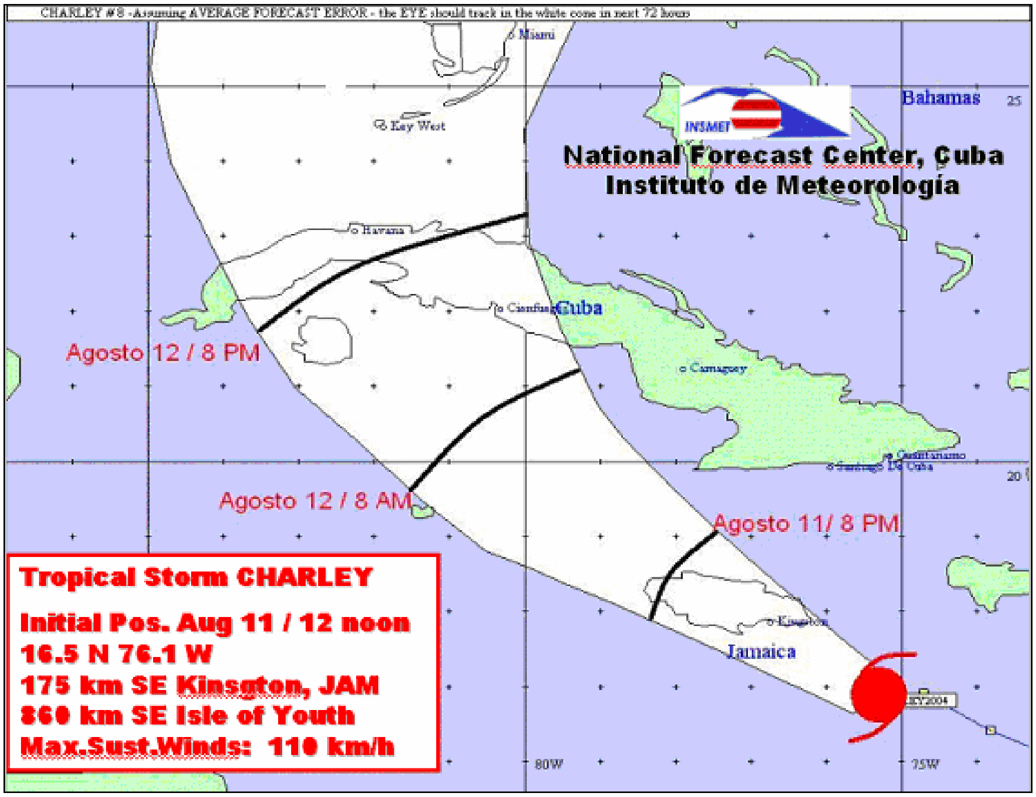

Figure 13: Tropical cyclone track forecast and cone of average forecast error (Cuban National Forecast Center)

than high confidence is provided at short lead times with low confidence at long lead times. As long as users know how the confidence level indices are defined, they can be a quick and efficient method to convey uncertainty information.

4.4.5 Scales of uncertainty

Worded categories

When describing uncertainty, it is often useful to use pre-defined categories that have specific meaning. This assists users to understand the precise level of uncertainty that the forecaster has in mind. Such an approach is demonstrated by the IPCC Likelihood Scale in Table 1 and the alternative scale in Table 2.

Confidence Indices

Uncertainty ratings can also be assigned to forecasts using a confidence index. This is a simple approach that can be popular with users. The Swiss Federal Office of Meteorology and Climatology use such a confidence index in some of their forecast products, represented as a “reliability” measure on a scale from 1 to 10 (Figure 15). Some care should be taken in using confidence indices to avoid over simplification. For example, confidence may be high for temperature but not for precipitation so the use of a single confidence index for the entire forecast can be misleading. The index should allow for the normal variation with lead

Probabilities

Perhaps the most common way to express uncertainty information is to use probabilities. Probabilities should be defined carefully and their meaning should be clearly explained to users. When defining a forecast probability, the first decision is to choose what quantity the probability will refer to. It may be the occurrence of some phenomenon at a particular location and time, e.g. the probability of a thunderstorm. Frequently it is the value of a weather parameter exceeding a defined threshold value, such as temperature falling below 0 Celsius. It may also be a category, e.g. the probability of 10-50 millimetres of rain at a particular location over a given period of time. A common choice for long range forecasts is an anomaly category, e.g. the probability of above average rainfall. The choice will be dictated by the phenomenon under consideration and the service requirement.

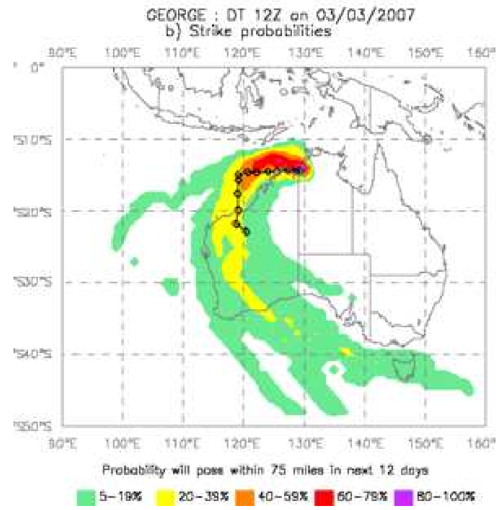

Figure 14: Tropical cyclone track forecasts presented as the probability that the storm will pass within a distance of 75 miles from any location. This example is generated automatically from the UK Met Office MOGREPS system, but the same presentation can also be generated by a forecaster. (The black dots show the observed track of the cyclone.)

Figure 15: 4-day forecast, including measure of reliability (i.e. *Feabilité*) **(out of 10). (Télévision Suisse and Swiss Federal Office of Meteorology and Climatology)**

One particular challenge for users of probability information is having a reference point for the information. This is particularly important to assist with interpretation and response. One of the best ways to do this is to accompany the probabilistic prediction with a comparison to the observed frequency of such events. For example, a prediction such as "60% chance of a storm this afternoon" is enhanced if a message such as the following is attached: "This is about twice the normal chance for this time of year."

Challenges with understanding probabilities

Although probabilities are a commonly accepted means to convey uncertainty information, they do come with particular communication difficulties. For a start, many users simply wish to know whether the forecast event will happen or not. These users are not interested in probabilistic predictions and will often view such predictions as an attempt by the NMHS to avoid responsibility and to 'hedge its bets'. This is where effective user education is required, so that there is an appropriate understanding of why meteorology is not an exact science. The consequence of this is that, in the absence of a categorical yes/no forecast, a user may turn to the probabilistic forecast and translate it into a categorical one. For example, a seasonal prediction for an increased chance of above average summertime temperatures may be interpreted as a statement that it will be a hot summer. There are countless examples where the media have oversimplified probabilistic outlooks in this way, in order to generate a catchy headline.

A second challenge is to understand what the probability of occurrence actually refers to. Is it at a point? Over a spatial area? Or over time? This is discussed in more detail earlier in this chapter, but is worth repeating here. Every effort needs to be made to ensure that the terminology is clearly defined and understood, not just by the users, but by the forecasters who issue the forecast as well. A good test of the definition is to ask "Could I objectively verify this forecast?" – if not, refine the definition.

A third challenge is the 50% probability problem. Users often consider forecasts of 50% probability to indicate that the forecaster is simply "sitting on the fence". However, if the observed frequency of the event is low, for example, then a 50% probability could be a strong signal. Also, where the forecast is part of a long sequence of forecasts using a wide range of probabilities it is perfectly reasonable that on some occasions the probability will genuinely fall in the middle of the range. It has been shown that hedging, where the forecaster avoids using 50% probabilities by going slightly above or below, degrades the overall verification of the forecasts.

4.4.6 Weather indices

A weather index indicating the suitability of expected weather conditions for certain activities, for example air quality index, UV index, or even a mountaineering index, may be a simple way to interpret the uncertainty on behalf of the user. Where confidence is high, extreme values of the index are appropriate, whereas greater uncertainty would imply use of mid range values. A wide range of such indices for public purposes are produced by China Meteorological Administration.

4.5 Different media - different methods

The choice of method and format for communicating uncertainty information will greatly depend on the media being utilised. What works well in one channel may not be effective in another.

For face-to-face weather briefings, or radio interviews, or wherever the forecast can be provided verbally, the use of plain language and narrative can be effective. In these settings, the forecaster has time to explain the situation, can discuss alternative scenarios, explain why and how the NWP models are different, and give an overall and comprehensive view of the situation. The use of non-verbal communication skills, such as speech intonation, or body language, can also be very effective ways to give the listener a sense of the forecast confidence.

Where the forecast is presented in a more prescriptive way, such as in writing, then the forecaster should ensure that their description of uncertainty is confined to pre-defined or well-understood terms. If phrases such as "a chance of" are used, there should be some underlying definition that specifies what this chance is numerically equivalent to. Numerical measures of uncertainty may also be used.

Graphical depictions of forecast uncertainty are a very useful presentation style and are especially suitable to web-based display. These can be accompanied by explanatory information to help users interpret what can be rather complex information. For television, the options are more restricted due to the limited broadcast time available, but some maps or graphs may be suitable.

Chapter 5: Application of probability forecasts by decision makers

The key purpose of producing probabilistic forecasts is to enable better decision making by end users for risk reduction. The optimization of decision making requires a good understanding of the decision and its impact on the user. Firstly, the event for which the probabilities are provided must accurately represent the weather sensitivity of the user. If the user is then able to identify costs associated with taking protective actions, and the potential losses if they are unprotected and adverse weather occurs, then they may be able to identify the optimal probability threshold for taking preventative action. However, many decisions are not as simple as this would suggest. A user may be able to take different levels of protective or beneficial actions according to how high the probabilities are. Many situations are more complex where there are multiple categories or potential responses, and the best outcome is likely to come from a strong partnership between the user and the NMHS. This helps the NMHS to better understand user needs and the user to understand the limitations of forecasting capability.

For many applications, it can be useful to couple ensemble forecasts data to application models for example, storm surge, wind power output, energy demand, flood risk, ship routing. By running an ensemble forecasts with the application model the uncertainty in the weather forecast can be propagated through into uncertainty for the user's application.

Tests of peoples' ability to make better decisions from forecasts with uncertainty information have been conducted in the Experimental Economics lab of Exeter University. Students from a variety of backgrounds were asked to make a number of decisions based on forecasts presented in the format shown in figure 5, with or without the uncertainty information included. These tests showed that users receiving information on uncertainty made significantly better decisions than users without the uncertainty information. This was equally true for users with a science background or those from other academic disciplines, indicating that most members of the public can benefit from uncertainty information.

Chapter 6: Verification and calibration

Regardless of how uncertainty information is presented, it is important that it provides an accurate representation of the true forecast uncertainty. Forecast verification is crucial to ensure that reliable information is provided, and can also form a basis on which to calibrate the forecast. Forecast verification should therefore be an integral part of the forecasting process. The forecaster is working in a multi-model forecasting environment with deterministic and probabilistic products. Choosing between different forecasting systems and reducing uncertainties in communicating or interpreting the forecast relies on a good knowledge of model skill.

A knowledge of verification can also provide useful information on forecast uncertainty even where no information from advanced systems, such as ensembles, is available.

More confident and simple statements can be issued when models have skill in predicting the expected events in the past. Some verification methods are particularly designed for assessing the quality of probabilistic forecasts, notably reliability diagrams, Rank Probability Skill Score (RPSS) and Relative Operating Characteristic Skill Score (ROCSS). In the case of a multi category forecast, the RPSS may help to determine whether or not a forecasting system performs better than a climatological forecast or any other benchmark forecast. Reliability diagrams will facilitate calibration or adjustment of forecast probabilities particularly when over-forecasting or under-forecasting is identified from these diagrams. The ROCSS is suitable to verify if the forecasting system is skilful for a specific event of interest, and may form the basis of a skill map which may be used to mask the forecast in areas where there is no skill. Where verification shows that forecasts have no skill, or where there is no strong signal in the forecast, the forecaster is advised to revert to climatological observed frequencies to define the forecast probabilities.

Chapter 7: Conclusion

Uncertainty is an inherent ingredient of forecasting and communicating it effectively is of great benefit. It helps users make better decisions, and it helps NMHSs manage the expectations of users for accurate forecasts.

These Guidelines have addressed the issue of communicating forecast uncertainty. The emphasis has been on how NMHSs can incorporate uncertainty information in their meteorological forecast services, including the best ways to communicate this information to the benefit of users. Examples have been given of effective presentation methods and some of the pitfalls have been highlighted. NMHSs are encouraged to use this information as a guide on how best to communicate forecast uncertainty and make it a routine and effective part of their service.

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