SUB 364

COMMONWEALTH BUREAU OF METEOROLOGY SUBMISSION TO THE

HOUSE OF REPRESENTATIVES SELECT COMMITTEE ON THE RECENT AUSTRALIAN BUSHFIRES

MAY 2003

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HOUSE OF REPRESENTATIVES SELECT COMMITTEE ON THE RECENT AUSTRALIAN BUSHFIRES

INTRODUCTION

The purpose of this submission is to inform the House of Representatives Select Committee on the recent Australian bushfires on the role of the Commonwealth Bureau of Meteorology in contributing to the management of Australia's bushfires. In particular, the Inquiry has requested submissions on "causes of and risk factors contributing to" bushfires and "alternative or developmental bushfire mitigation and prevention approaches".

Knowledge and understanding of Australia's weather and climate is an integral component of the management of Australia's land and vegetation resources and, as the national agency with statutory responsibility for meteorological observations, forecasts and warnings, the Bureau of Meteorology has a significant role to play in bushfire management activities. This submission is framed in terms of the statutory functions and responsibilities of the Bureau as set out in the Meteorology Act 1955 (Attachment 1). The Bureau is an Executive Agency located in the portfolio of the Minister for Environment and Heritage.

There are strong linkages between meteorology (weather and climate) and bushfire. The most fundamental linkage results from the contributions of the atmospheric state to fire danger and fire behaviour together with the influence through the hydrological cycle on the pre-existing fuel state. Our climate – for example the typical hot, dry summer in the southern States - creates the predisposition for bushfires, while the weather on any day or sequence of days can increase the risk of ignition and rapid, uncontrolled spread of fires.

The Bureau's observation and data collection systems are an integral component of fire danger assessment practices. Because detailed understanding of weather and climate is essential to the management of bushfires in Australia, the application of mitigation and suppression strategies based on sound meteorological science offers significant benefits to Australia's rural industries and communities.

The statutory functions of the Bureau include, *inter alia*:

"(a) the taking and recording of meteorological observations and other observations required for the purpose of meteorology;
(b) the forecasting of weather and of the state of the atmosphere;
(c) the issue of warnings of gales, storms and other weather conditions likely to endanger life or property, including weather conditions likely to give rise to floods or bushfires;
(d) the supply of meteorological information;
(e) the publication of meteorological reports and bulletins;
(g) the promotion of the advancement of meteorological science by means of meteorological research and investigation or otherwise."

The Bureau performs these functions under the Act in the public interest generally and in particular for the purpose (*inter alia*) of assisting persons and authorities engaged in primary production, industry, trade and commerce.

This submission identifies a number of key issues in relation to both the recent bushfire events and comments on future directions from the perspective of the Bureau of Meteorology and its national and international responsibilities for monitoring, research, and provision of meteorological and hydrological services. The key issues raised by the Bureau in this submission are:

- The effects of the antecedent climatic conditions on the severity of the recent fires;
- The meteorological conditions prevailing during the bushfires;
- The role of the Bureau in hazard reduction or prescribed burning;
- The planned future directions of meteorological and related research and the benefits likely to accrue;
- The nature of the collaborative arrangements between land management agencies, fire control agencies and the Bureau.

SUMMARY OF KEY ISSUES

The effects of the antecedent climatic conditions on the severity of the recent fires

The drought prevailing at the time of the recent fires was one of the most severe in the nation's recorded history. Large areas of the country were experiencing serious or severe rainfall deficiencies. Additionally, atmospheric humidity and cloudiness were below normal and daytime temperatures were at record high levels. This combination of factors led to an early curing of fuels across most of Eastern Australia. Although many of these factors were also present during previous major bushfire events the high temperatures in the lead up to the 2002/03 fire season appear to be unprecedented. The likelihood of conditions conducive to a bad fire season had been identified in seasonal outlooks as early as mid-July 2002.

An evaluation of the climatic conditions leading up to this and earlier events clearly shows the importance of the climatic conditions leading up to the period of bushfires and the value of Bureau's Seasonal Outlook services which provide information on the potential conditions over the next three months. This is discussed in more detail under Term of Reference (b).

In reviewing the bushfire seasons of 1938/39, 1982/83 and 2002/03 it is important to note that, in all three cases, the months leading up to and including the fire events were drier than normal over Victoria and southern New South Wales and at the same time, daytime temperatures were above average. Compared with the two earlier years, 2002/03 was generally not quite so dry, but was warmer across the fire-affected regions. In terms of the combination of high temperatures and low rainfall creating moisture stress in vegetation and forest fuel curing, the three seasons can be considered as being of comparable severity. In each case, the early curing of fuels during exceptionally warm and dry spring/early summer periods, and a continuation of drought conditions well into summer provided the climatological conditions for the severe fire conditions that ensued.

During 2002-03, the Bureau's Seasonal Outlook service gave qualitative guidance regarding the expected behavior of the El Niño phenomenon, and quantitative probabilistic forecasts of rainfall and day-time temperatures which provided forewarning that from spring through to summer conditions were likely to be conducive to an early curing of forest fuels, and hence a dangerous fire season.

The knowledge and information gained from previous events, combined with an improved capability to develop outlooks of climatic conditions for periods of up to three months is expected to become an increasingly important key tool in the management of land and vegetation in the lead up to the bushfire season each year. Discussion under Term of Reference (e) of this submission identifies potential future improvements in Seasonal Climate Outlooks.

The meteorological conditions prevailing during bushfires

An analysis of the Victorian and Australian Capital Territory bushfires clearly shows the influence weather conditions have on both the ignition and movement of bushfires.

Ignitions were due to natural causes, being lightning strikes during predominantly dry thunderstorms. There were many strikes in inaccessible areas making initial suppression difficult. Although fire dangers were not extreme for much of the period there were long periods with little or no rain, so there was no natural assistance to human suppression activities.

Weather information, including temperatures, wind speed and direction and the movement of fronts, is essential background knowledge to fire control and management. A fire danger index is used to indicate the difficulty of suppression of a wildfire. Stability, the tendency for the atmosphere to undergo vertical motion, can also play a large part in fire behaviour. In very unstable conditions, large plumes can develop above fires and form cumulus or even cumulonimbus clouds. The vertical motion associated with these clouds means that there is an increase in the amount of air drawn in at low levels. The vertical motion can also work to increase the potential of long distance spotting. The rate at which air cools with height, or lapse rate of the atmosphere plays an important role in development of plumes. This is discussed in more detail under Term of Reference (b).

The role of the Bureau of Meteorology in the management of prescribed burning activities

Because the issue of bushfire hazard reduction through controlled burning is likely to be an issue of interest to the Committee and addressed in other submissions, the Committee should be aware of the critical role meteorological factors play in the successful planning and management of such burning.

There is a narrow range of weather conditions suitable to start and sustain a controlled burn and at the same time keep it safe for both the fire crew managing the burn and for nearby property. Additional considerations apart from at the fire site itself are related to the transport of smoke and its potential effects on the health and environment of more distant population centres.

In recent years, fire and land management agencies have increasingly consulted the Bureau about maximising the value of meteorological advice in their prescribed burning policies and strategies and this has led to joint projects on the application of fine scale meteorological models to the prediction of the behaviour of smoke plumes. Increasingly too the Bureau's weather watch radars are able to assist in the tracking of smoke plumes.

The provision of Bureau support for prescribed burning activities therefore covers almost the full range of weather support services provided during wildfire operations, and described in more detail under Term of Reference (g) later in this submission. Any expansion of hazard reduction burning activities would have resource implications for the Bureau because, at present, the resources applied to fire weather services are focussed largely around the traditional fire seasons. Further comment on the Bureau's role in hazard reduction burning is given under Term of Reference (c).

The planned future direction of meteorological and related research and the benefits likely to accrue

The Bureau of Meteorology conducts a range of basic and applied research in meteorology in areas such as numerical modelling of the atmosphere, improved seasonal forecasting, new applications of satellite data, that enhances the Bureau's ability to provide meteorological services to the community and specialised agencies such as fire and land management agencies, but, in addition, is heavily involved in the new Bushfire Cooperative Research Centre and will be contributing to research in three areas:

- Improved fire season preparation through greater understanding of fire danger on a seasonal timescale. This would allow better focussed mitigation activities including the deployment of capital-intensive resources such as fire-fighting aircraft;
- Better fire prevention through improved day-to-day forecasting of weather parameters critical to fire danger; and
- Better and safer fire suppression activities through more accurate and more highly detailed forecasts of near-surface winds.

Further detailed comment is provided under Term of Reference (e).

The nature of the collaborative arrangements between land/fire management agencies and the Bureau of Meteorology

The arrangements for provision of fire weather services to fir and land management agencies is described in this submission under Term of Reference (g) concerning current response arrangements for firefighting.

Operational fire weather support services are provided through the Bureau's distributed network of forecasting offices located in State and Territory capitals and leverage off the major national meteorological infrastructure consisting of surface and upper air observing systems, a central supercomputer and extensive distributed computing facilities and high speed telecommunication lines. In some cases, discussion with fire agencies has led to the identification of the need for additional weather observations and these have been established on a cooperative basis with some funding support from the fire agencies.

Arrangements for fire weather services are well developed and are tailored to meet the needs of the client agencies at the State and Territory level. Collaborative development of these services is an ongoing process, usually involving pre- and post- fire season meetings in all States and Territories. Each State produces a Fire Weather Directive detailing the services to be provided.

In extensive and long running fires, fire agencies sometimes seek the secondment of a meteorologist to their headquarters or to the incident command centre for a major fire, or both. The Bureau attempts to meet these requests where possible, including by bringing back-up staff from interstate as needed.

Scientific and technical advances are incorporated into the service as they become available.

RESPONSES TO THE TERMS OF REFERENCE OF THE INQUIRY

The following responses are provided in direct reference to the Terms of Reference (ToR) of the Inquiry.

(a) The extent and impact of the bushfires on the environment, private and public assets and local communities

The Bureau of Meteorology has no comment on this ToR.

(b) The causes of and risk factors contributing to the impact and severity of the bushfires, including land management practices and policies in national parks, state forests, other Crown land and private property

Factors Contributing to Fire Danger

Fire danger in Australia is expressed as either a numerical index or a qualitative rating based on these numerical values. In both cases they provide an indication of the likely rate of spread and difficulty of suppression of fires. The indices in use are based upon the research of A.G. McArthur, and produce numbers in the range 1-100. Since fire behaviour is known to be different in grasslands from forests separate indices are used for these two cases. In a generic sense in both cases the Fire Danger Rating is a function of Temperature, Humidity, Wind Speed, and Fuel State.

The first three of these are standard meteorological parameters. Fuel state is treated differently in the cases of grassland and forest fuels. In the case of grassland fuels visual observations of the fuel curing are used, expressed as a percentage. Curing ranges from 0% indicating that fuel is very wet, through to 100%, indicating that the fuel is very dry.

Due to the complex, variable nature of forest fuels direct visual observations of fuel state are not used. Instead the fuel state is inferred from the antecedent rainfall and temperature on both the long (seasonal) and short (20 days) time scales. At the seasonal scale the cumulative effect of rainfall and temperature on soil moisture content over the season provides a measure of the deep drying of the fuel. The choice of index to quantify this varies according to jurisdiction, both the Keetch-Byram Drought Index (KBDI) and the Mount Soil Dryness Index (SDI) being used for this purpose. This longer-term index is then coupled with the significant rainfall over the last 20 days to produce the Drought Factor (DF) which provides the overall indication of the combustibility of available fuel (wood, branches, twigs, leaf litter etc) in forest areas. The Drought Factor ranges from 0 indicating that fuel is very wet, to 10, indicating that the fuel is very dry and hence will burn readily.

In summary then fire dangers are determined as follows:

- Grassland Fire Danger Ratings –The McArthur Mk4 Grasslands Fire Danger Meter is used. Input variables are:
    - Temperature
    - Humidity
    - Wind Speed
    - Curing

- Forest Fire Danger Ratings – The McArthur Mk5 Forest Fire Danger Meter is used. Input variables are:
  - Temperature
  - Humidity
  - Wind Speed
  - Drought Factor – which in turn is dependent upon KBDI or SDI and significant rainfall in the last 20 days.

Clearly, antecedent meteorological conditions are pivotal in determining the fire danger and these antecedent conditions are discussed in some detail in the following section.

General climate conditions prior to and during the 2003 bushfires

The meteorological conditions conducive to bushfires are described through an analysis of the climate and weather conditions associated with the 2002-03 bushfire season. The climatic conditions in the lead-up to the bushfire season are described from a broad/regional perspective.

Over Australia as a whole, 2002 was one of the most severe drought years in the nation's recorded history, with large areas of the country experiencing serious or severe[1] rainfall deficiencies for the period commencing in March 2002. Accompanying the low rainfall, daytime temperatures across Australia were at record high levels during autumn, winter, and spring, while atmospheric humidity and cloudiness were well below normal. This combination provided the climatological conditions for an early curing of fuels across most of eastern Australia, and difficult conditions for fire suppression once wildfire activity had commenced. These broad characteristics are shared by previous severe fire seasons in southeast Australia, including the seasons of 1938/39 and 1982/83, although the high temperatures in the lead up to the 2002/03 fire season appear to be unprecedented. Climate information (precipitation and temperatures) for periods during 2002-03 for selected sites is provided in Attachment 2.

<u>El Niño</u>

The drought conditions experienced across most of Australia during 2002 through early 2003 were largely a local response to the climatological phenomenon of El Niño. El Niño events, which involve a warming of the central and eastern Pacific Ocean, typically occur every 3-7 years. They have the capacity to influence the climate across many parts of the globe. For Australia, El Niño events have historically been associated with higher than normal atmospheric pressures, poor winter-spring rainfall and a late onset to the northern monsoon, and warmer than normal daytime temperatures. It is well established that most of Australia's severe droughts have occurred in association with El Niño events, and that during such events severe fire-risk weather days and bushfires tend to be more numerous. The fact that the risk

[1] The terms **serious** and **severe** are defined by:-

- **Serious** rainfall deficiency:- rainfall is among the lowest ten per cent of recorded rainfall totals for the period in question, but not among the lowest five per cent.
- **Severe** rainfall deficiency:- rainfall is among the lowest five per cent of recorded rainfall totals for the period in question.

of drought and severe fire conditions in eastern Australia is known to be greatly elevated during El Niño years, and that there was universal agreement by June 2002 that an El Niño event was underway, means that significant advance information was available that summer 2002/03 would be a potentially very difficult fire season.

Rainfall

During the early part of the 2002/03 Australia-wide drought, the fire-affected regions *(defined as those areas of NSW, NE Victoria and the ACT directly affected by fires, and the immediately surrounding areas)* were only moderately affected. Over the period between April to September 2002, most of this area received 65% to 85% of long-term average precipitation (defined as rainfall plus the water equivalent of snowfall, where applicable), and peak snow depths at higher elevations (over 1600 metres) in the Snowy Mountains were near normal. Whilst the precipitation totals were below average, these were generally not low enough to fall within the definition of a serious or severe rainfall deficiency.

The fire-affected regions became much drier from October 2002 onwards. For the three months from October-December 2002, rainfall was only 20% to 40% of normal in most of the area. At most locations the three-month rainfall for this period was among the driest 10 such periods on record. It was the second-driest October-December period on record at Cabramurra, the third-driest at Canberra, the fourth-driest at Yackandandah and the fifth-driest at Corryong. All of these sites have observed rainfall for at least 50 years. The low rainfall during (particularly) the later spring/early summer months was instrumental in allowing a very early curing of the already dry forest fuels.

There was no relief from the dry conditions during January. By the end of January, four-month rainfall totals were at or near record-breaking low levels at many locations, including Canberra and Cabramurra (Figure 1). By mid summer (and indeed in many areas early summer), the antecedent conditions of very dry fuels were in place to support severe bushfire conditions given a source of ignition and appropriate weather conditions.

Low rainfalls once the fires became established

The very dry conditions leading into the 2002/03 fire season do not in themselves fully explain the intensity and longevity of the fire episodes. A significant contributor to the long period for which the 2003 bushfires remained active was the absence of any significant rain for several weeks after the fires were first ignited. Most of the fire-affected region did not receive substantial rainfall (*defined, for the purpose of this submission, as a daily total in excess of 5mm*) after 2 January until 21 or 22 February, a period of approximately 50 days.

Such long dry periods in summer are not unprecedented. For example, Corryong and Yackandandah have both experienced a period of 50 consecutive days without any daily total exceeding 1mm in the past; at Corryong this has occurred 10 times in 112 years of records, and at Yackandandah 5 times in 116 years of records. Nevertheless, the combination of an exceptionally dry spell during mid-summer and the pre-existing severe rainfall deficits is highly unusual in an historical context, and led directly to the longevity of the fires.

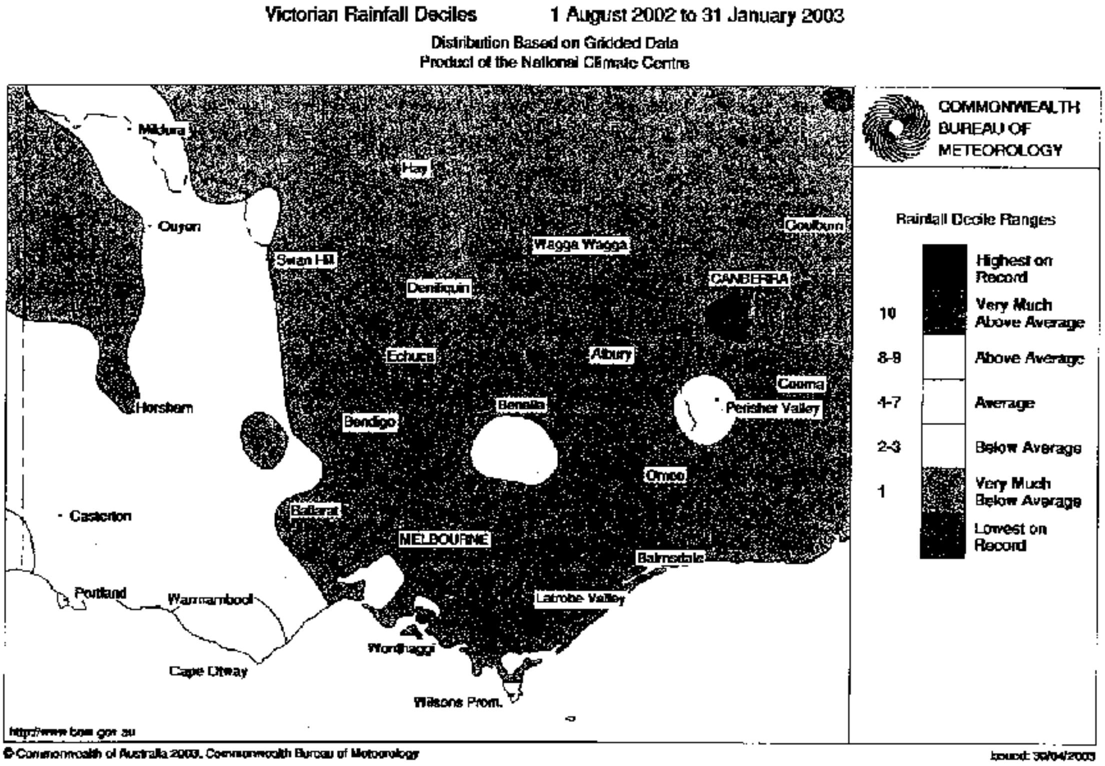


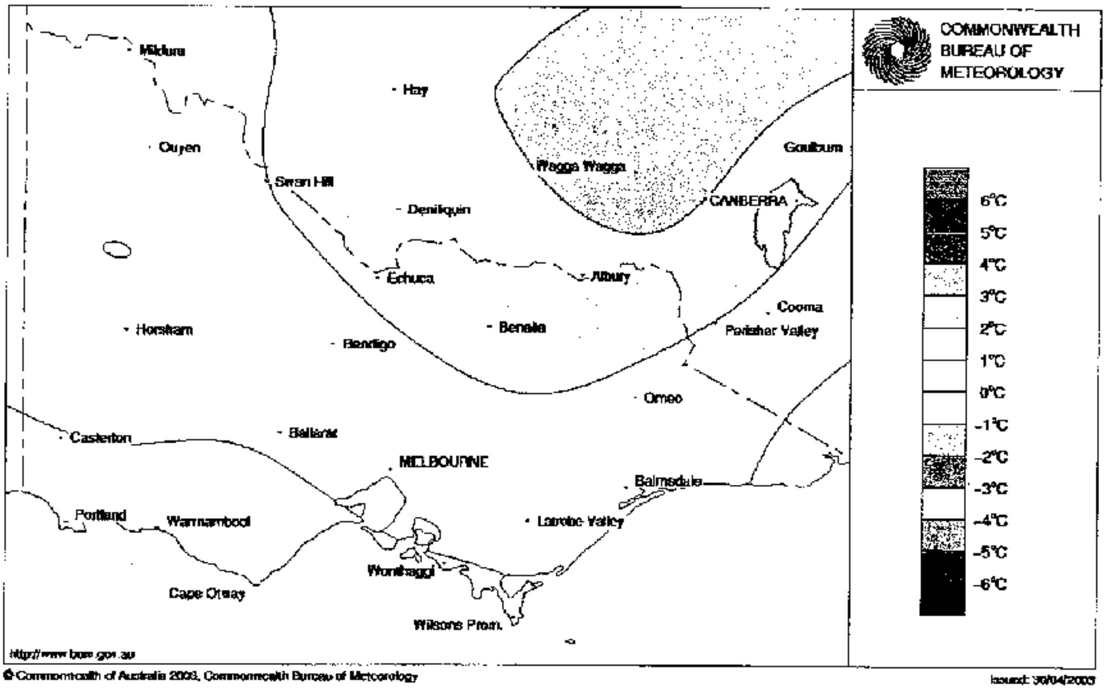
Figure 1: Rainfall deciles for the 6 months August 2002 through January 2003, covering the period prior to and including the major fire activity in southeast Australia.

Temperature

Average temperatures during 2002 were well above average across most parts of Australia, with the year being the fifth warmest nationally since records commenced in 1910. These high temperatures matched global observations, which revealed 2002 to be the second warmest year after 1998. Across Australia, daytime temperatures were very high during each of autumn, winter, and spring. As a result, the Australia-wide mean maximum temperature was significantly above the previous record for each of the three seasons.

Consistent with the national picture, daytime maximum temperatures were well above normal over most of eastern Australia from March 2002 onwards. Over the August (October)-January period, most of the region experienced average daily maximum temperatures 2 to 3°C above normal (Figure 2), making it the warmest such period on record in many parts. An important feature of the 2002/03 summer was that the exceptionally high temperatures inland provided for a number of extreme heatwave events in southeast Australia. One such event occurred on January 25th when many stations in lowland southern Victoria experienced temperatures in the range of 43 to 46°C. These heatwave events coupled with the drought conditions were sufficient to cause the death of significant tracts of native vegetation in Victoria, in areas which were otherwise unaffected by fire.

Maximum Temperature Anomaly (°C) 1 August 2002 to 31 January 2003
Product of the National Climate Centre



Issued: 30/04/2003

Figure 2: Temperature anomalies for the 6 months August 2002 through January 2003, covering the period prior to and including the major fire activity in southeast Australia.

Evaporation

Evaporation totals across the fire-affected regions were generally well above average throughout the 2002/03 dry event. Evaporation over the 10 months from April 2002 to January 2003 was 5-20% above average at the locations where data were available (see Table 5). Percentage anomalies of similar size were observed over the 4 months from October 2002 to January 2003.

Evaporation over the two periods considered was the second highest on record (after 1982/83) at Dartmouth Dam and Hume Weir, two sites which are representative of the fire affected region as a whole.

Comparison with previous notable bushfire years

In reviewing the 2002/03 fire season, it is useful to make comparisons with the two exceptional bushfire seasons of 1938/39 and 1982/83. In all three cases, the months leading up to and including the fire events were drier than normal over Victoria and southern New South Wales (Figures 3 to 6), while daytime temperatures were above average. Compared with the two earlier years, 2002/03 was generally not quite so dry, but was warmer across the fire-affected regions. In terms of the combination of high temperatures and low rainfall creating moisture stress in vegetation and forest fuel curing, the three seasons can be considered as being of comparable severity. In each case, the early curing of fuels during exceptionally warm and dry spring/early summer periods, and a continuation of drought conditions well into summer provided the climatological conditions for the severe fire conditions which subsequently ensued.

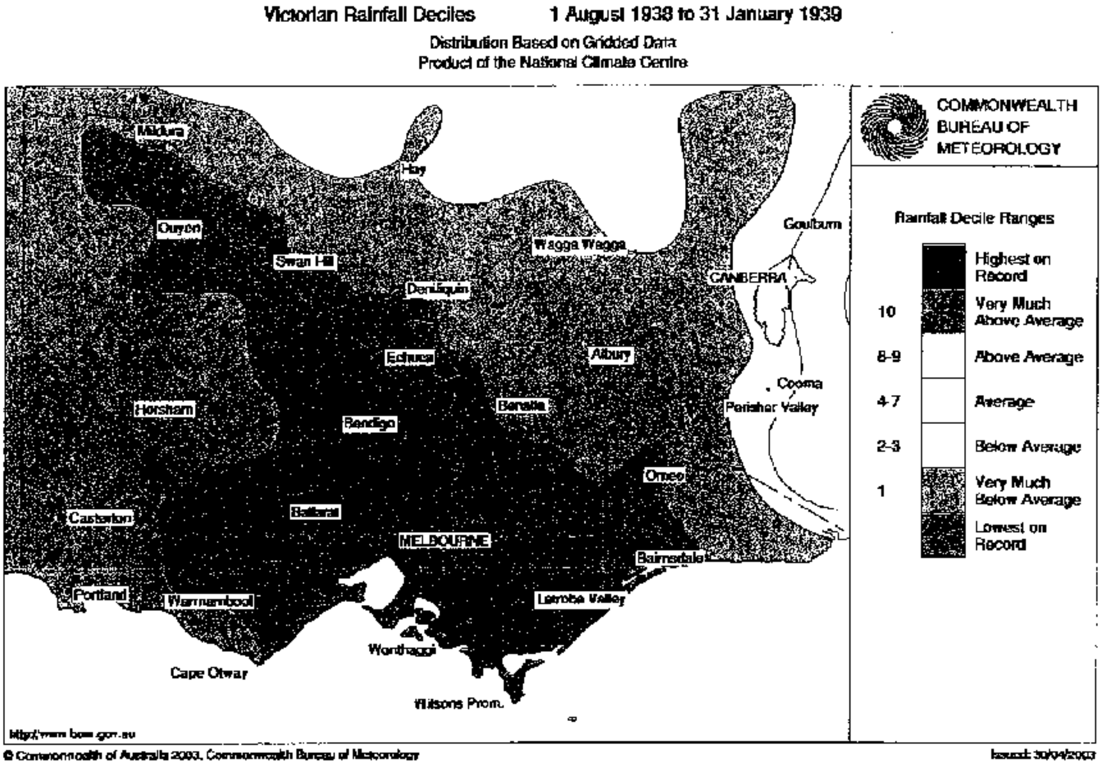


Figure 3: Rainfall deciles for the 6 months August 1938 through January 1939, covering the period prior to and including the Black Friday fires.

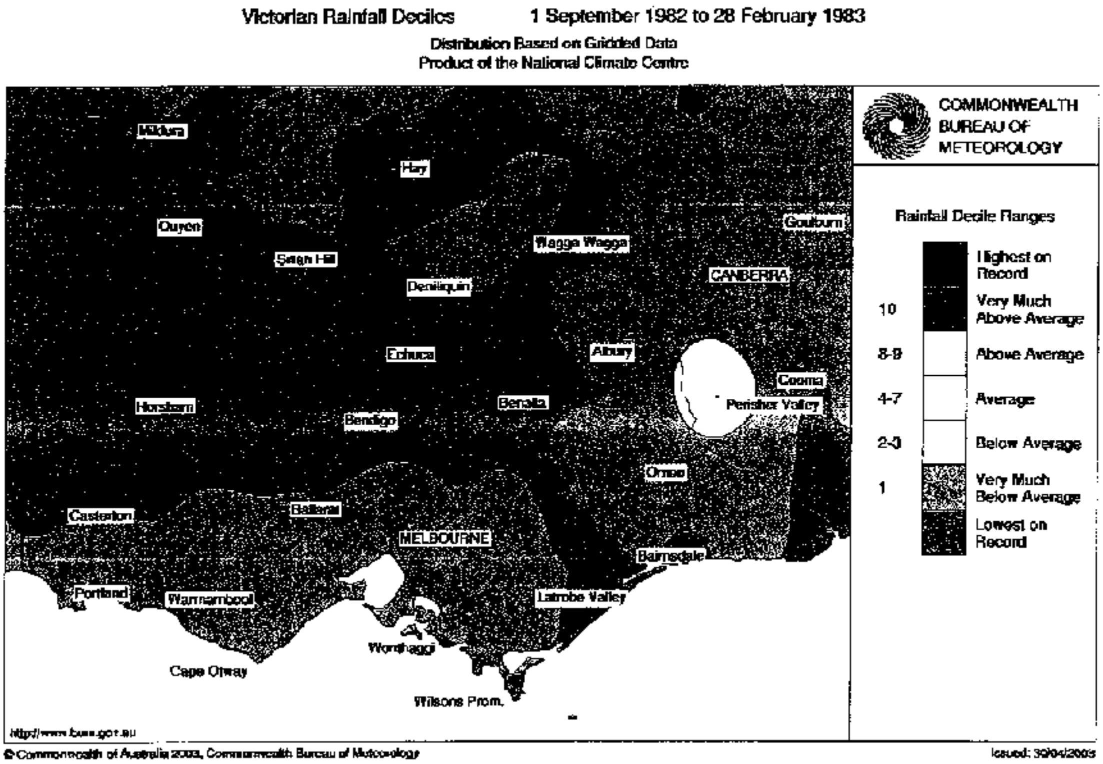


Figure 4: Rainfall deciles for the 6 months September 1982 through February 1983, covering the period prior to and including the Ash Wednesday (16 February 1983) fires.

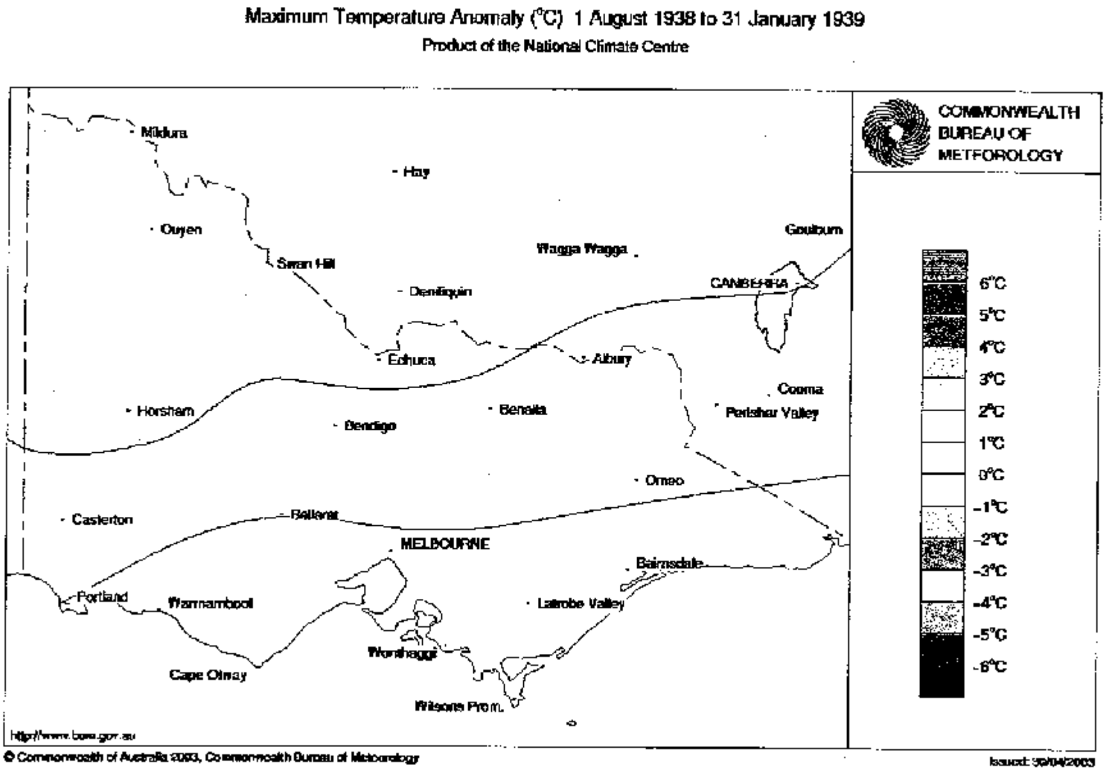


Figure 5: Temperature anomalies for the 6 months August 1938 through January 1939, covering the period prior to and including the Black Friday fires.

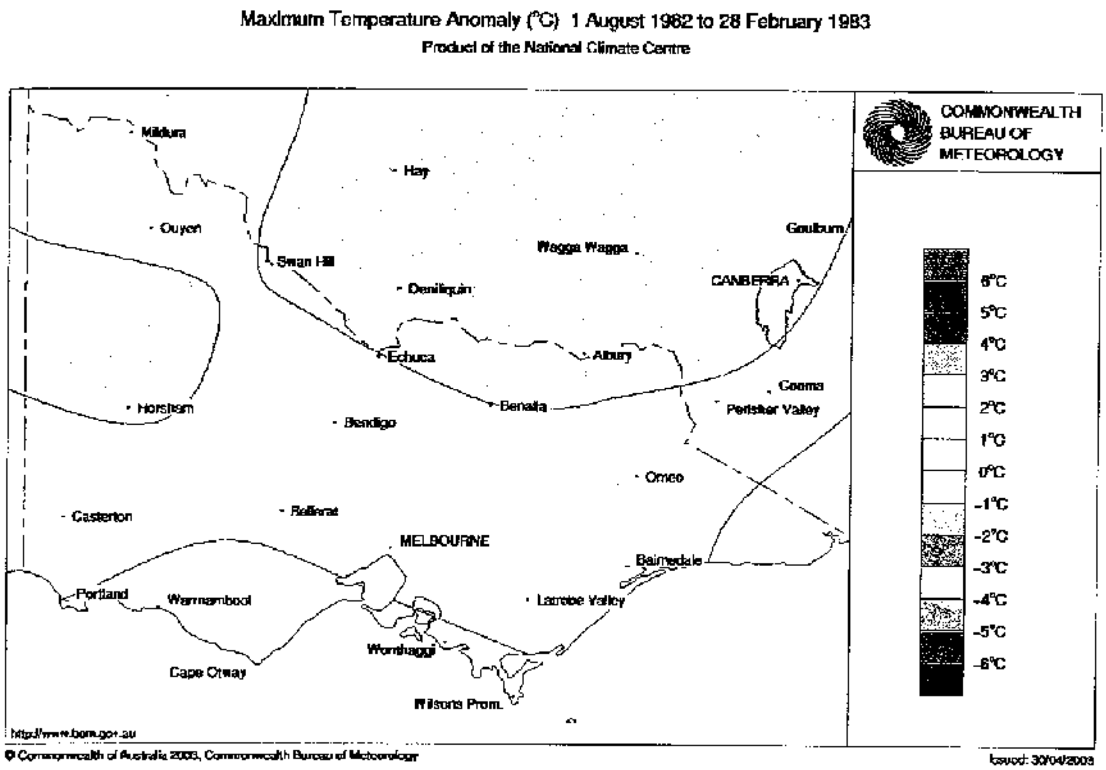


Figure 6: Temperature anomalies for the 7 months August 1982 through February 1983, covering the period prior to and including the Ash Wednesday fires (16 February 1983).

Seasonal climate outlooks issued prior to the 2003 bushfires

Since 1989 the Bureau of Meteorology has provided a range of climate forecast products to the Australian public. Based on the best available science from the Bureau of Meteorology, CSIRO, and elsewhere, this service has been progressively upgraded over the past decade. The present service, provided to the general public and a wide range of key interest groups including rural producers, water managers, and emergency service agencies is provided as part of the Bureau of Meteorology basic service.

These seasonal forecasts use a non-linear forecast system, which relates the variation of sea surface temperatures in both the Indian and Pacific Oceans to Australian climate variability. The forecasts, which are produced operationally every month, are for a three-month period at one-month lead-time. For example, a winter (June-July-August) forecast is produced early in May.

During 2002/03 the Bureau of Meteorology issued outlooks of the probability of above- or below-normal seasonal rainfall, mean maximum and mean minimum temperatures. These outlooks were publicly issued around the middle of each month for the three calendar months following, and distributed through the media, the Bureau's website, in the printed (and electronic) publication called the Seasonal Climate Outlook, and to stakeholders in special briefings and/or via a dedicated email notification system. In addition, the Bureau ran a frequently updated web-based service (weekly to fortnightly depending upon the rate of change in conditions) called the El Niño wrap-up. The El Niño wrap-up contained not only objective model based El Niño forecasts, but also specialist commentary on the current status of the event, comparisons to the behavior of past El Niño events and interpretation of model outlooks.

The Bureau's seasonal outlook service advised as early as February 2002 that the development of an El Niño was a significant possibility by winter/spring. When El Niño conditions developed in late autumn, regular commentary and forecasts issued by the Bureau emphasised that the event was very likely to continue through to at least early 2003.

The Bureau's Seasonal Climate Outlook first identified a probability of dry conditions substantially worse than the climatological norm in the Alpine region in mid-July. The forecast probability of below-normal seasonal rainfall was as follows for the partially overlapping seasons:

- August-October 55-60%
- September-November 55-65%
- October-December 55-65%
- November-January 55-60%

(the long-term background probability is defined as 50%)

A high probability of above-average mean maximum temperatures was also forecast over this period, as follows:

- August-October 65-70%
- September-November 60-65%

- October-December 75-80%
- November-January 55-60%

Hence, the qualitative guidance regarding the expected behavior of the El Niño, and the quantitative probabilistic forecasts of rainfall and (particularly) day-time temperatures provided forewarning that spring through summer conditions were likely to be conducive to an early curing of forest fuels, and hence a dangerous fire season.

Dissemination of climate information

The Bureau of Meteorology issues its official Seasonal Climate Outlook around the middle of each month. This outlook includes rainfall and temperature outlook maps for the coming season, as well as commentary on the current status of the El Niño – Southern Oscillation. A summary of this outlook, including maps of seasonal rainfall and temperature probabilities, is available free of charge on the Bureau of Meteorology's web site every month, while a subscription (cost recovery only) service with greater detail is also available. Information is also available by fax and email to those that request delivery in such a way. The Bureau of Meteorology also provided a weekly to fortnightly web and email service during the El Niño event named the El Niño wrap-up, which provided El Niño commentary as described earlier. A weekly rainfall update web site was also produced, giving users up to date information on regions which may have experienced some relief from the dry conditions.

Prior to the 2002/03 fire season (September/October), senior officers from the Bureau of Meteorology's Victorian Regional Office, the Canberra Meteorological Information Office and the New South Wales Regional Office met with and briefed their respective regional fire services on current rainfall deficiencies and the Seasonal Climate Outlooks for both temperature and rainfall. Agencies briefed included the NSW Regional Fire Service, NSW National Parks and Wildlife Service, State Forests NSW, NSW Fire Brigade, ACT Emergency Services Bureau, the Victorian Department of Natural Resources (now the Department of Sustainability and Environment), and the Victorian Country Fire Authority. The National Climate Centre also invited agencies to its Monthly Climate Meetings, at which seasonal outlook policy for rainfall and temperature is formulated. The Victorian Country Fire Authority and the Victorian Department of Natural Resources and Environment sent representatives to several pre fire season meetings. Further updates were supplied via monthly email documents to NSW and ACT fire agencies, whilst in Victoria, regular updates on seasonal outlooks for rainfall and temperature were provided to fire agencies through direct communication with the Regional Office's severe weather section.

(c) The adequacy and economic and environmental impact of hazard reduction and other strategies for bushfire prevention, suppression and control

As described in the summary of key issues early in this Submission, the main involvement of the Bureau of Meteorology in this aspect is in relation to the effect of meteorological parameters on the planning and conduct of hazard reduction burning. The challenge for the fire/land managers is to work within the narrow range of weather conditions suitable to start and sustain a controlled burn, and, at the same time, keep the fire safe for both the fire crew managing the burn and for nearby property. Additional considerations apart from at the fire site itself are related to the transport of smoke and its potential effects on the health and environment of more distant population centres.

In recent years, fire and land management agencies have increasingly consulted the Bureau about maximising the value of meteorological advice in their prescribed burning policies and strategies and this has led to joint projects on the application of fine scale meteorological models to the prediction of the behaviour of smoke plumes. Increasingly too the Bureau's weather watch radars are able to assist in the tracking of smoke plumes.

The provision of Bureau support for prescribed burning activities therefore covers almost the full range of weather support services provided during wildfire operations, and described in more detail under Term of Reference (g) later in this submission. Any expansion of hazard reduction burning activities would have resource implications for the Bureau because, at present, the resources applied to fire weather services are focussed largely around the traditional fire seasons.

While the Bureau of Meteorology has no statutory responsibilities with regard to air quality, it does have the capacity to provide guidance as to the likely transport and dispersion of airborne particulates such as those contained in the smoke from both prescribed burns and wildfires. The Bureau has also been involved in a collaborative project, originally supported by the Natural Heritage Trust, with CSIRO and the State EPA's of New south Wales and Victoria to develop an integrated air quality forecasting system.

Forecasts of the likely movement of bushfire smoke have been developed over a two-year period in a joint project involving the Bureau and the Australasian Fire Authorities Council with the aim of assisting fire and emergency agencies responsible for prescribed burns and wildfires in minimising the impact of emissions from these. This is achieved by providing fire agencies with improved meteorological information on forecast smoke dispersion. Use of these allows for improved planning of prescribed burns and the consequent reduction in the effects of smoke from these on the community.

These forecasts are currently in transition from a pilot program to a full operational service, but the system will also need improvement to deal with a wider range of burning conditions and this is the subject of further research planned under the Bushfire Cooperative Research Centre as discussed in submission under Term of Reference (e).

Under the current arrangements forecasts are automatically produced twice daily. In the afternoon these are based on an agreed set of standard locations. Overnight a second set of forecasts is produced using locations for possible burn sites specified by the land management agencies on the basis of the afternoon forecasts. A sample smoke dispersion forecast is shown in figure 7.

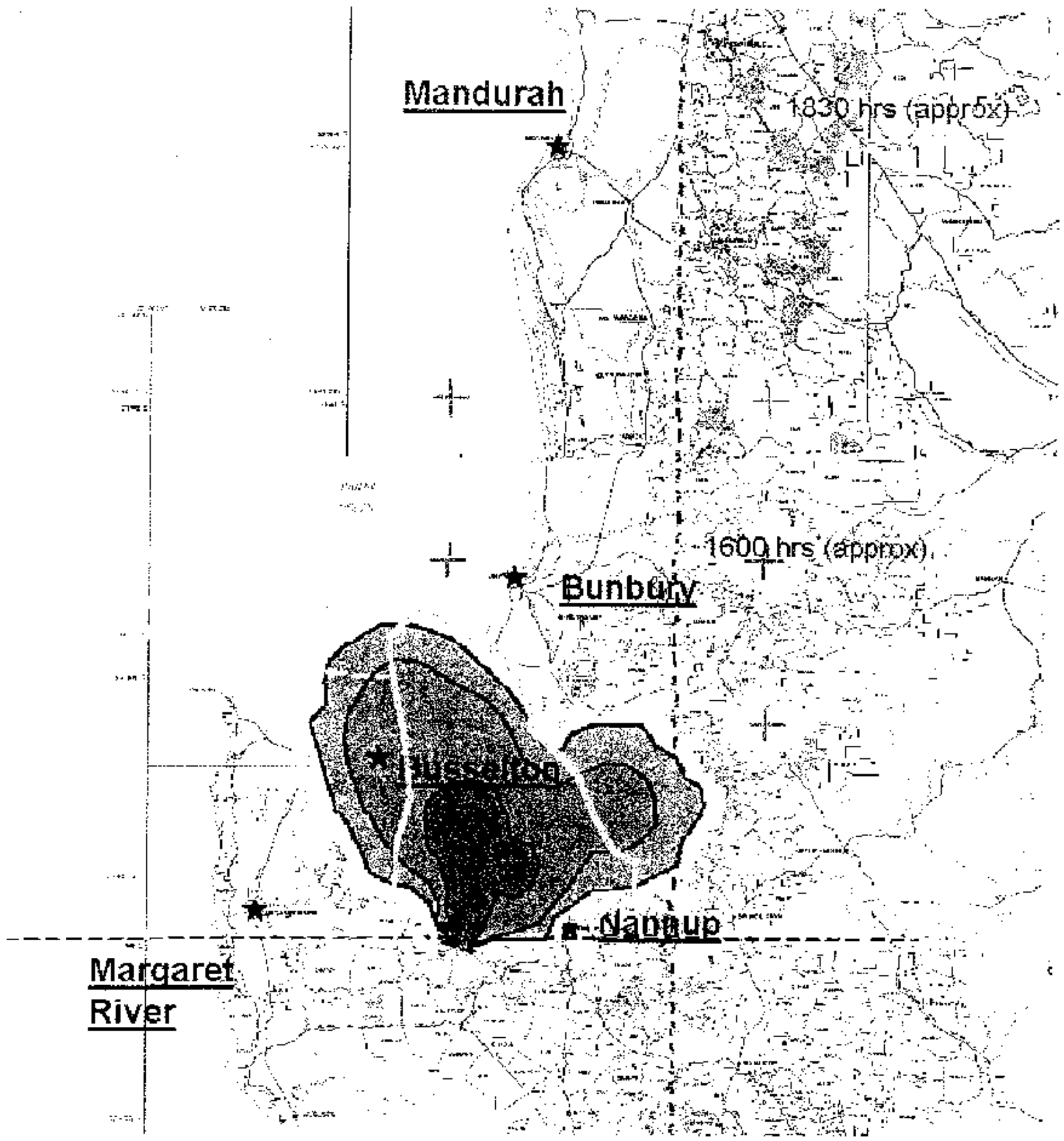


Figure 7: Sample smoke dispersion forecast for a fire at Butler in the southwest of Western Australia. Superimposed is the outline of the smoke plume observed in satellite imagery.

Forecasts of smoke dispersion form only a part of the overall service in support of prescribed burns. The effort to focus on a particular area and forecast the narrow range of conditions suitable to sustain a controlled burn and at the same time keep it safe requires application of almost the full range services provided in support of wildfire operations.

A significant increase in the amount of prescribed burning could have significant resource implications for the Bureau as, under the current arrangements, specialist fire weather forecasters are occupied with developmental work once the fire danger period has passed.

(d) Appropriate land management policies and practices to mitigate the damage caused by bushfires to the environment, property, community facilities and infrastructure and the potential environmental impact of such policies and practices

No additional comment on this ToR.

(e) Any alternative or developmental bushfire mitigation and prevention approaches, and the appropriate direction of research into bushfire mitigation

The Bureau of Meteorology devotes considerable resources to the operation of its own research through the Bureau of Meteorology Research Centre, which conducts a multi-faceted meteorological and related research program addressing issues such as improved techniques for monitoring the atmosphere, improved numerical modelling of the atmosphere on all time and space scales, climate change, oceanographic monitoring and enhanced environmental services.

Advances in weather forecasting techniques will have immediate application in the field of fire weather research and services. For example, following a major international research project conducted during the Sydney 2000 Olympics Australia, through the Bureau, is one of the leading countries in the development of detailed short range forecasting or "nowcasting".

Specifically in connection with bushfire research, the Bureau is a major partner in the nascent Bushfire Cooperative Research Centre. Particular aspects of research aimed at improving bushfire mitigation are described are discussed in the following.

Prediction of the Onset and Development of Fire Weather Events

Currently the Bureau of Meteorology's suite of numerical weather prediction (NWP) models provides the basis for operational weather forecasting up to seven days ahead. The models assimilate detailed meteorological observations on the current state of the atmosphere and then solve the physics-based equations of motion to give estimates of the state of the atmosphere into the future. The models include representations of processes such as clouds and the exchanges of heat and moisture between the land surface and the atmosphere. At present the models do not include specific fire-related aspects.

Research would lead to developments in the NWP models so that the potential for fire weather would be estimated routinely. The research should include studies of the atmospheric circulation that lead to extremely low humidity, and this work would yield a climatology of the conditions under which extreme fire events can occur.

A significant component in the production of fire danger estimates is the determination of the fuel state on a district basis across Australia every day. This could be improved through the development of improved algorithms for remote sensing and the integration of remotely sensed and ground based observations. Procedures for curing modelling in the absence of observations are required together with methods for the use of fire-scar mapping to modify fuel states.

Investigations are needed into the effects of antecedent rainfall and underlying soil moisture on forest fuels. Methods for operational determination of soil moisture deficit, including the use of remote sensing and numerical modelling of both ground moisture and near-surface relative humidity, should be assessed and developed. Regional differences in the field capacity of soils and the resulting effects on fuel drying rates need to be assessed.

Further review of the fire danger rating systems could include assessment of the importance of additional parameters such as atmospheric stability and degree of sun/cloud. There is also a requirement for the development of a shrub/heath fire danger rating system. Such a system would be complementary to the existing grassland and forest rating systems and, once determined, would then provide coverage of the three most significant vegetative fuel types. The shrub/heath fire danger ratings subsequently determined would be particularly applicable to many coastal fringe and urban/rural interface areas.

Additional research should involve evaluation and development of the Bureau's operational NWP suite to enhance its capability to support real-time fire weather operations. Research is required to evaluate the accuracy of model predictions of wind changes, including the structure of the wind field ahead of and behind frontal systems. The accuracy is expected to vary geographically across the country and with season. The studies would lead to modifications of the model to improve the accuracy of the predictions.

The research would focus on the use of the models to predict parameters of direct relevance to fire fighting. Such parameters could include gustiness of the wind and a "spotting potential" and an outcome would be enhanced support for fire fighters during fire events.

Improved Seasonal Climate Outlooks

Previous research has shown a strong link between interannual climate variability, in particular that associated with the El Niño-Southern Oscillation phenomenon (ENSO), and the intensity of the subsequent fire season. Recent work coordinated by the Bureau of Meteorology, and operational climate forecasting and monitoring experience based on newly developed climate models, has revealed that much of this variability is predictable. Further work is required on the adaptation and extension of existing climate prediction and monitoring systems, to provide advance warning of climatic conditions likely to affect the level of fire danger in an approaching fire season. The focus would be on refining, and in some cases further developing, knowledge about interannual variability of key climate-related parameters that precede and drive extreme fire weather, and incorporating this knowledge into a suite of routinely-available, tailored products. This information would greatly enhance the effectiveness of pre-season resource planning, and within-season operational planning. As such, it would provide considerable potential economic and logistical benefits in better targeting of resources by fire authorities (including coordinating at the national level the deployment of high cost resources). There would also be benefits from enhanced awareness and planning at the community level (certain climate patterns imply a higher level of risk than usual), and in environment-related activities such as pre-season fuel reduction activities.

Likely outcomes would include:

- Improved scientific understanding of the factors controlling climate anomalies with the capacity to influence overall fire danger and associated damaged during the fire season.
- A suite of operational climate monitoring and prediction products, specifically targeted to provide objective input into decisions such as the future allocation of fire

management resources, and other pre-season planning activities, as well enabling updates relevant to likely fire frequency and severity once the season is underway. Products would include, but not necessarily be limited to:

- predictions of rainfall and temperature anomalies prior to and within the fire season (which are directly related to fuel state, water resources, etc), especially tailored to fire-prone areas and seasons;
- predictions of the likely relative frequency of extreme events relevant to fire danger, such as the frequency of very hot days;
- diagnostic products derived from climate models, displaying likely climate anomalies of factors likely to influence fire danger;
- ongoing monitoring of variables relevant to fire danger such as rainfall and moisture indices (e.g., the Keech-Byram Drought Index).

• Explanatory material, via articles written for fire authorities and suitable for information purposes at the community group level.

Matching Fire Weather Forecasts to Community and Firefighter Decision Making

An important input to community fire action plans is information on weather. Forecasts of fire weather influence community behaviours, both in the short term when dangerous fire weather conditions are forecast, and on longer, seasonal time-scales. There is presently a gap in terms of matching the scope and content of fire weather services to community fire season preparedness and community response during an event. For example, seasonal climate outlooks rarely address the needs of communities for specific information on the expected severity of a fire season. Likewise, fire danger ratings used in fire weather forecasts are not well understood by the general community and new strategies are needed to ensure direct linkages exist between fire danger forecasts and specific community actions.

Similarly, effective fire fighter decision-making relies on an adequate knowledge of current and expected weather conditions and the influence that these conditions have on the behaviour of fire.

Community information needs for the formulation of effective action plans should be assessed as should the levels of firefighter needs for weather information, both in terms of relevance and timeliness, and understanding of the effects of current and expected weather conditions on the behaviour of fire. Information flows to both the general community and fire agencies should be examined in both the pre-suppression and active suppression phases of a fire weather event together with an assessment how that information is used operationally when making critical strategic and tactical fire fighting decisions.

Community safety will be increased through the enhancement of the capacity to manage the fire risk within the broader community and through the development of better-informed fire suppression strategies

World Meteorological Organization (WMO) Statement on the Scientific Basis for, and limitations of, Weather and Climate Forecasting

Notwithstanding the marked improvements in weather forecasting in recent years and the hopeful indications offered above, weather forecasting remains a very difficult area of scientific endeavour in which it is sometimes important and necessary to ensure that community expectations of the performance of weather forecasters is in keeping with the current limitations of the science. In this regard, the WMO (2002) has recently issued a statement on the scientific basis for, and limitations of, weather and climate forecasting (Attachment 3). This statement confirms the fundamental importance of the global observational data. The statement also points out that while scientific understanding of physical processes has made considerable progress through a variety of research activities, including field experiments, theoretical work, and numerical simulation, atmospheric processes are inherently non-linear, and not all physical processes can be understood or represented in Numerical Weather Prediction (NWP) models. Based on the current observed state of the atmosphere, weather prediction can provide detailed location and time-specific weather information on timescales of the order of two weeks. The grid scales used in these models mean however that they are currently of limited use in providing detailed forecasts of local weather such as cloud, fog and extremes such as intense precipitation and peak wind gusts. Some predictability of temperature and precipitation anomalies has been shown to exist at longer lead times out to a few seasons. This comes about because of interactions between the atmosphere, the oceans, and the land surface, which become important at seasonal time scales. The statement concludes by pointing out that skill in weather forecasting has advanced substantially since the middle of the twentieth century but that each component within the science and technology of weather forecasting and climate projection has its own uncertainties.

(f) The appropriateness of existing planning and building codes, particularly with respect to urban design and land use planning, in protecting life and property from bushfires;

The construction of buildings in bushfire prone areas is covered by the Australian Standard AS3959-1999. A draft revision of this standard currently in preparation seeks to take into consideration the regional differences in bushfire risk due to climatic variation. Updated tables for determination of the category of bushfire attack are provided in the draft revision based upon climatological values of the Fire Danger Index (FDI).

The climatological analysis has been undertaken only in Tasmania, Victoria and New South Wales and provides a single value of FDI for use in each of those States. Should the draft revision be adopted Queensland and the Australian Capital Territory would use the NSW value and South Australia, Western Australia and the Northern Territory would use the Victorian value.

While noting that the draft standard does at least recognise some variation in climate across the country which is not present in the current edition of the standard, it is disappointing that a fuller analysis of the fire danger climatology was not incorporated into the draft revision of the standard.

(g) The adequacy of current response arrangements for firefighting;

The role of the Commonwealth Bureau of Meteorology in providing Fire Weather Services

Statutory Responsibility

Under the *Meteorology Act 1955* among the functions of the Bureau is "the issue of warnings of gales, storms and other weather conditions likely to endanger life or property, including weather conditions likely to give rise to floods or bush fires".

This is to be carried out in the public interest generally and in particular " .... for the purpose of assisting persons and authorities engaged in primary production, industry, trade and commerce".

Operational Services

The broad objectives of the Bureau's fire weather service are:

(a) To provide the public with:
  1. Routine forecasts of fire danger during the fire season by way of public weather forecasts;
  2. Public Fire Weather Warnings when the fire danger is expected to exceed a certain critical level; and

(b) To provide fire management authorities, civil defence organizations, police and other emergency services with;
  1. Detailed routine forecasts during the fire season;
  2. Warnings when the fire danger is expected to exceed a certain critical level;
  3. Operational forecasts to assist in combating ongoing fires;
  4. Special forecasts for prescribed burns;
  5. Advice regarding the installation and operation of special meteorological stations operated by fire authorities;
  6. Consultative advice and climatological information to assist with assessment of risk, development of fire prevention strategy and other aspects of fire management.

The provision of fire weather services to the fire agencies and the community is mainly through the Bureau's distributed service delivery structure. The Bureau of Meteorology operates a Regional Office in the Capital city of each State and Territory in Australia, except in the case of the ACT, where a smaller satellite office is operated under the guidance of the NSW Regional Office in Sydney. Within the structure of each Regional Office, there is a Regional Forecasting Centre (RFC) which carries overall responsibility for forecast production and dissemination. Day to day operational output from each Region is the responsibility of the Shift Supervisor (Senior Meteorologist) who works under the general direction of a senior line manager. Ultimately, each Regional Office is operated under the guidance and direction of the Regional Director.

The range of services provided under (b) above is determined by consultation between the Land Management and Fire Fighting Agencies and the Bureau at the State and Territory level. The service is reviewed and modified in detail at pre and post fire season meetings in the dual context of operational fire fighting and emergency management requirements, and, in terms of new technology and communication.

Currently these services can include:

- a fire weather forecast;
- a fire weather briefing;
- a fire weather outlook;
- spot forecasts on request for wild fires and prescribed burns
- wind change charts;
- fire weather warnings, on a district basis;
- the provision of an out posted fire weather forecaster if so requested;
- verbal briefings when sought by the Fire Fighting Agencies.

Fire weather warnings are issued when the fire danger, described below, is expected to reach Extreme on the McArthur scale. These warnings do not carry detailed and specific predictions of meteorological or fire weather parameters, but are intended to warn of likely extreme fire weather conditions.

Operational fire weather support services are provided through the Bureau's distributed network of forecasting offices located in State and Territory capitals and leverage off the major national meteorological infrastructure consisting of surface and upper air observing systems, a central supercomputer and extensive distributed computing facilities and high speed telecommunication lines. In some cases, discussion with fire agencies has led to the identification of the need for additional long-term weather observations to improved routine weather monitoring in fire prone areas and these have been established as new Automatic Weather Stations on a cooperative basis with some funding support from the fire agencies.

For major, long-running fires the Bureau has developed a capability in conjunction with fire and land management agencies, to deploy Portable Automatic Weather Stations to provide additional weather information close to the fire locality, and to provide a dedicated forecaster to work on location with the Incident Control Team. Alternatively, or in addition, the Bureau has sometimes provided a dedicated forecaster to work in fire agency headquarters to provide a high-level liaison and briefing service to the fire agency executive and senior operational personnel.

An example of the multi-purpose usefulness of the output from the national meteorological infrastructure is the detailed short-range numerical weather prediction models that provide a detailed forecast of the future wind field on a grid scale of 5 km – see Figure 8.

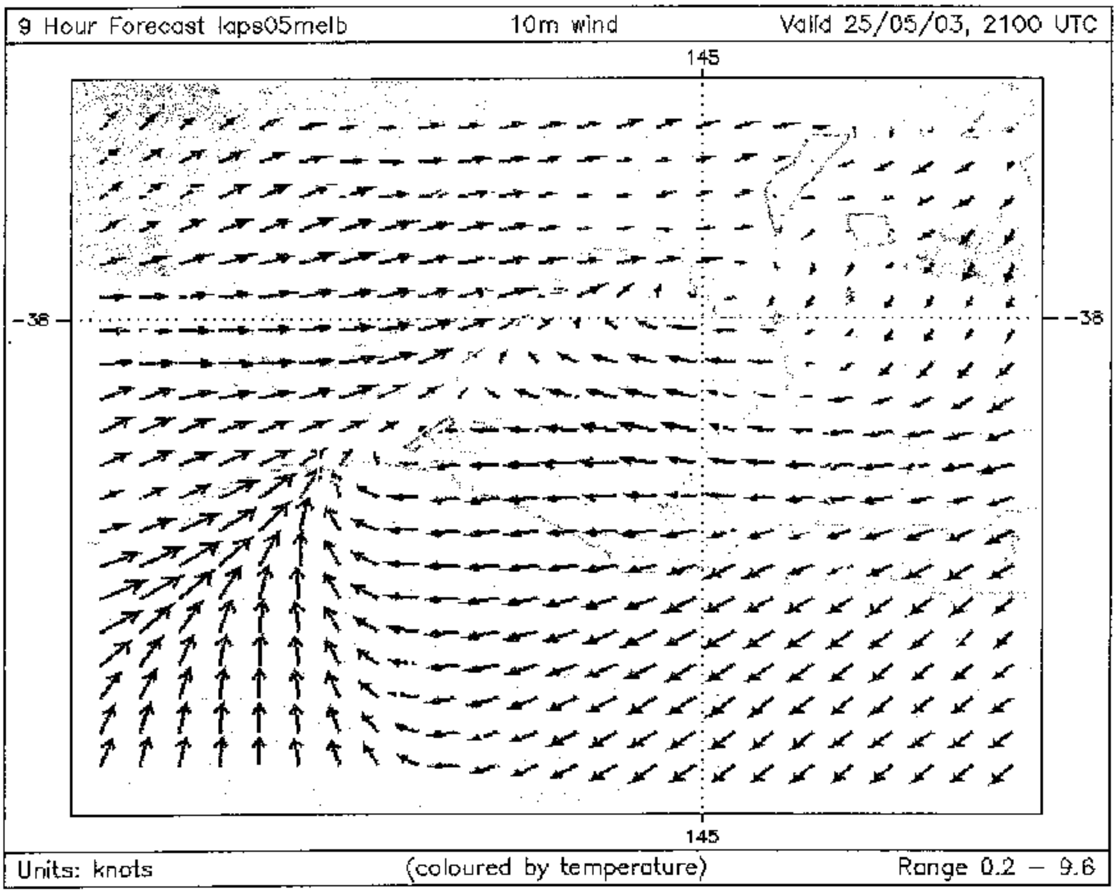


Figure8: Sample model output showing forecast winds at the 10 metre level over the greater Melbourne area. Approximate horizontal resolution is 5 Km.

A particularly important aspect of the fire weather services is the degree of consultation and interaction involved. Although the routine forecast products provide a comprchensive service, the interpretation of satellite and radar imagery and numerical model output is best achieved in an interactive situation. Bureau staff provide detailed briefing to fire chiefs, senior operational personnel and, sometimes, participate in mass briefings, both in person and by teleconference. They are also available for consultation as required.

Forecasts for ongoing fires deal in considerably greater temporal and spatial detail than Routine Fire Weather Forecasts. In contrast with Routine Fire Weather Forecasts, which focus on fixed timeframes and the same routine set of broadly representative sites, Special Fire Weather Forecasts are issued for specific localities, as identified by fire authorities, and take into account, where possible, the range of elevations, topography and other known local effects particular to those specified areas.

In addition to standard meteorological variables such as temperature, wind velocity, relative humidity and rainfall, fire weather forecasts contain other parameters which are either derived meteorological parameters, derived from both meteorological and non-meteorological parameters, or wholly non-meteorological parameters. Other parameters included in fire weather forecasts may include the following:

- Indicative Wind Speed and Direction at upper levels;
- A descriptor of atmospheric Turbulence;

- Cloud Amount;
- Atmospheric Stability Class;
- Lightning Probability or lightning activity level, to indicate the likelihood of lightning strikes.

During the agreed fire danger period estimates of fire danger are produced twice daily for approximately 250 sites nationwide. During periods of intense fire activity the level of support within the affected state or territory is increased as appropriate.

Because of the central role that weather plays in fire management, the ways in which fire agencies use meteorological information are varied and best described by the agencies themselves, but, for the interest of the Committee, the Bureau lists some that we are most aware of:

- Seasonal Outlooks for pre season planning;
- Medium range forecast (3-5 days) for readiness and resource deployment and general strategy;
- 24-36 hour forecasts for detailed daily plans and declaration of total fire bans;
- 12 hour forecasts for fine tuning daily plans;
- Site specific or "spot" forecasts (3-12-36 hour) for going fires;
- Smoke dispersion forecasts to be able to alert the public or to deploy aircraft in a way that minimises the risk of them becoming unoperational due to poor visibility.

Examples of the simultaneous application of different Bureau products would be an Incident Controller looking at a detailed site specific forecast, while a fire chief officer may be studying the 3-5 day outlook with a view to ensuring adequate personnel, tankers and aircraft to suit the appropriate medium term strategy for the whole State.

Further examination of the service is ongoing and upon investigation and consultation modifications made to embrace new technology and/or techniques as they become available.

(h) The adequacy of deployment of firefighting resources, including an examination of the efficiency and effectiveness of resource sharing between agencies and jurisdictions

This ToR is largely outside the Bureau's responsibilities except that we note that the Bureau's medium range forecasts and advice are a possible influence on decisions to call in extra resources on the basis of expected continuation of sever weather conditions for a protracted period, and that the Bureau itself has used its own interstate resources to cope with the heavy workload placed on the Bureau in long running severe fire situations.

(i) liability, insurance coverage and related matters

This ToR is largely outside the responsibilities of the Bureau of Meteorology.

(j) The roles and contributions of volunteers, including current management practices and future trends, taking into account changing social and economic factors

Volunteer weather observers provide essential meteorological information used by the Bureau of Meteorology in the provision of its services in bushfire periods as well as contributing to the valuable climate record.

CONCLUSION

The submission has raised a number of issues of direct relevance to the management of bushfires seasonal climatic conditions conducive to bushfires, severe weather affecting the risk of bushfires on any one day, the role of meteorological factors in prescribed burning, future research in meteorology related to bushfires and the collaborative arrangements between the Bureau of Meteorology and fire agencies.

The Bureau would be pleased to expand on these issues and any related matters of interest to the House of Representatives Select Committee on the recent Australian bushfires.

ATTACHMENT 1
THE METEOROLOGY ACT 1955

METEOROLOGY

No. 6 of 1955.[1]

An Act relating to the Commonwealth Bureau of Meteorology.

[Assented to 23rd May, 1955]

[Date of Commencement, 20th June, 1955]

Be it enacted by the Queen's Most Excellent Majesty, the Senate, and the House of Representatives of the Commonwealth of Australia, as follows:

Short title

1. This Act may be cited as the *Meteorology Act* 1955.

Repeal

2. The *Meteorology Act* 1906 is repealed.

Definitions

3. In this Act, unless the contrary intention appears -
"the Bureau" means the Commonwealth Bureau of Meteorology established by this Act;
"the Director" means the Director of Meteorology.

Extension to Territories

4.[2] This Act extends to all the Territories of the Commonwealth.

The Commonwealth Bureau of Meteorology

5. (1) For the purposes of this Act, there shall be a Commonwealth Bureau of Meteorology and a Director of Meteorology.
(2) The Bureau shall be under the charge of the Director of Meteorology, who shall, subject to the directions of the Minister, have the general administration of this Act.

Functions of the Bureau

6. (1) The functions of the Bureau are-
(a) the taking and recording of meteorological observations the Bureau and other observations required for the purposes of meteorology;
(b) the forecasting of weather and of the state of the atmosphere;
(c) the issue of warnings of gales, storms and other weather conditions likely to endanger life or property, including weather conditions likely to give rise to floods or bush fires;
(d) the supply of meteorological information;
(e) the publication of meteorological reports and bulletins;

[2] Amended by No. 123 of 1973

(f) the promotion of the use of meteorological information;
(g) the promotion of the advancement of meteorological science by means of meteorological research and investigation or otherwise;
(h) the furnishing of advice on meteorological matters; and
(i)[1] co-operation with the authority administering the meteorological service of any other country in relation to any of the matters specified in the preceding paragraphs of this sub-section.
(2) The Bureau shall perform its functions under this Act in the public interest generally and in particular-
(a) for the purposes of the Defence Force;
(b) for the purposes of navigation and shipping and of civil aviation; and
(c) for the purpose of assisting persons and authorities engaged in primary production, industry, trade and commerce.

7. (1) The Director has such powers as are necessary to enable the Powers of Bureau to perform its functions under the last preceding the Director section, and, in particular, may- Powers of Director
(a) establish meteorological offices and observing stations;
(b) arrange with any Department, authority or person to take and record meteorological observations and transmit meteorological reports and information;
(c) arrange means of communication for the transmission and reception of meteorological reports and information; and
(d) arrange for the training of persons in meteorology.
(2)[3] The Departments and authorities with which, and the persons with whom, arrangements may be made under the last preceding sub-section include Departments and authorities of a State or Territory of the Commonwealth and persons in the service of such a State or Territory or of such a Department or authority.

8. The Director may, subject to any directions of the Minister, make charges for forecasts, information, advice, publications and other matter supplied in pursuance of this Act. Charges

9. The Governor-General may make regulations, not inconsistent Regulations with this Act, prescribing all matters which by this Act are required or permitted to be prescribed, or which are necessary or convenient to be prescribed for carrying out or giving effect to this Act. Regulations

[3] Amended by No. 123 of 1973

ATTACHMENT 2

SELECTED CLIMATE INFORMATION 2002-03

Station	Rainfall for period (mm)	Percentage of normal	Decile value	Ranking, if in lowest 10 (previous or existing record in brackets)
Adaminaby	260.2	78	3	
Beechworth	406.6	70	2	
Cabramurra	733.4	73	2	
Canberra	187.0	67	3	
Corryong	326.2	77	3	
Mt Buffalo	928.0	78	3	
Omeo	212.1	65	1	
Yackandandah	400.8	68	2	

Table 1. Rainfall at selected stations, April-September 2002

Station	Rainfall for period (mm)	Percentage of normal	Decile value	Ranking, if in lowest 10 (previous or existing record in brackets)
Adaminaby	93.6	50	1	10th (33.0, 1977)
Beechworth	99.8	46	2	
Cabramurra	93.4	22	1	2nd (73.4, 1999)
Canberra	40.2	22	1	3rd (11.4, 1977)
Corryong	64.6	32	1	5th (49.0, 1922)
Mt Buffalo	172.7	40	1	4th (86.6, 1938)
Omeo	88.0	44	1	7th (64.6, 1895)
Yackandandah	57.0	27	1	4th (37.5, 1938)

Table 2. Rainfall at selected stations, October-December 2002

Station	Rainfall for period (mm)	Percentage of normal	Decile value	Ranking, if in lowest 10 (previous or existing record in brackets)
Adaminaby	96.8	40	1	3rd (80.9, 1918/19)
Beechworth	115.6	44	1	
Cabramurra	105.0	20	1	1st (133.4, 1999/2000)
Canberra	51.6	21	1	1st (66.0, 1982/83)
Corryong	69.8	27	1	2nd (68.0, 1922/23)
Mt Buffalo	217.1	42	1	5th (127.0, 1938/39)
Omeo	93.4	37	1	3rd (88.3, 1895/96)
Yackandandah	64.0	25	1	2nd (46.4, 1938/39)

Table 3. Rainfall at selected stations, October 2002 – January 2003

Station	Mean maximum temperature (°C)	Departure from normal (°C)	Mean minimum temperature (°C)	Departure from normal (°C)
Cabramurra	18.4	+2.7	8.1	+1.6
Canberra	26.9	+3.0	10.6	+0.9
Corryong	28.5	+2.5	10.6	+0.3
Omeo	23.4	+0.9	7.2	0.0
Wangaratta#	29.2	+2.6	9.5	-0.9

Wangaratta Airport averages calculated from only 16 years of data; other sites from 30 or more years.

Table 4. Temperatures at selected stations, October 2002 – January 2003

Station	Evaporation Apr 2002 – Jan 2003 (mm)	Percentage of normal	Evaporation Oct 2002 – Jan 2003 (mm)	Percentage of normal
Canberra	1525.4	115%	990.2	116%
Corryong	956.4	108%	692.5	110%
Dartmouth Dam	1002.6	114%	728.5	118%
Edi Upper	no data	-	753.2	121%
Hume Weir	1214.4	114%	870.2	116%

Table 5. Evaporation at selected stations, 2002/2003

ATTACHMENT 3

WMO STATEMENT ON THE SCIENTIFIC BASIS FOR, AND LIMITATIONS OF, WEATHER AND CLIMATE FORECASTING

1. INTRODUCTION

1.1. Every day around the world, the National Meteorological Services (NMSs) and private sector meteorological service providers of the Member States and Territories of the World Meteorological Organization (WMO) provide hundreds of thousands of forecasts and warnings of weather and climate conditions and events. These forecasts and warnings provide information, for the benefit of the community at large and for a wide range of specialized user sectors, on a broad spectrum of atmospheric phenomena ranging from those with time scales of seconds to minutes and space scales of metres to kilometres, such as severe storms, through to those, such as El Niño related drought, with multi-year and global impact. The forecast information provided is used to inform and improve decision making in virtually every social and economic sector and the globally aggregated economic benefits of meteorological services are reckoned to be of the order of hundreds of billions of US dollars.

1.2. The capacity to provide these socially and economically beneficial services to the citizens of the 185 Members of the WMO results from the operation of the unique international system of cooperation of the WMO World Weather Watch which is based on:

- Collection and international exchange of the global observational data that are essential to describe the current (initial) state of the atmosphere (and the underlying land and ocean) at any point in time;

- The fact that the physical and dynamical processes governing the behaviour of the atmosphere and ocean can be represented in numerical models which are capable of providing forecasts of daily weather conditions with significant skill out to several days from the 'initial' state as well as useful indications, in certain circumstances, of general trends of climate for months and seasons ahead;

- The existence of a coordinated international meteorological system of global, regional and national data processing and modelling centres producing real-time products from which skilled professional forecasters are able to prepare forecasts and warnings in forms that are relevant and useful to the user community;

- The ability to monitor extreme events in real-time and to issue warnings by combining classical meteorological observations, model output and information from remote sensing systems such as satellites and radar.

1.3. The scientific understanding and technological capabilities underlying this globally cooperative system of weather and climate forecasting have made enormous progress over the past twenty-five years as a result, in particular, of such cooperative international research programmes as the WMO-ICSU (International Council for Science) Global Atmospheric Research Programme (GARP), the WMO World Weather Research Programme and the WMO-ICSU-IOC (Intergovernmental Oceanographic Commission of UNESCO) World Climate Research Programme (WCRP). The skill levels and utility of the resulting forecasts and warnings have steadily increased. Indeed three-day forecasts of surface atmospheric pressure are now as accurate as one-day forecasts twenty years ago. But the observational data base necessary to describe the 'initial' state of the atmosphere will always be limited by considerations of scale and measurement accuracy, the processes governing the behaviour of the atmosphere are non-linear and the phenomenon known as chaos imposes fundamental limits on predictability. While new techniques are emerging which help potential users of weather and climate forecasts to better understand, and make allowance for, the inherent uncertainties in the forecasts, the WMO Executive Council believes it is important that all those who make use of such forecasts in decision making should be made better aware of both their scientific foundation and their scientific and practical limitations. It therefore requested that the WMO Commission for Atmospheric Sciences (CAS) prepare a statement on the current status of weather and climate forecasting.

1.4. This statement has been prepared by CAS with input from other WMO and external scientific organizations and programmes including the WCRP. It was approved by the thirteenth session of CAS in Oslo in February 2002 and endorsed by the Executive Council at its fifty-fourth session in June 2002. It is provided for the information of all those with an interest in the scientific foundations and limitations of weather and climate forecasting on time scales from minutes and hours through to decades and centuries.

2. THE SCIENCE OF WEATHER FORECASTING

Dynamical and physical processes within the atmosphere, and interactions with the surroundings (e.g. land, ocean, and ice surfaces), determine the evolution of the atmosphere, and hence the weather. Scientifically based weather forecasts are possible if the processes are well enough understood, and the current state of the atmosphere well enough known, for predictions to be made of future states. Weather forecasts are prepared using a largely systematic approach, involving observation and data assimilation, process understanding, prediction and dissemination. Each of these components has, and will continue to benefit from advances in science and technology.

2.1 Observations and data assimilation

2.1.1 Over the past few decades, substantial advances in science have resulted in improved and more efficient methods for making and collecting timely observations, from a wide variety of sources including radar and satellites. Using these observations in scientifically based methods has caused the quality of weather forecasts to increase dramatically, so that people around the world have come to rely on weather forecasts as a valued input to many decision making processes.

2.1.2 Computer generated predictions are initialized from a description of the atmospheric state built up from past and current observations in a process called data assimilation, which uses the numerical weather prediction (NWP) model (see 2.3.2) to summarize and carry forward in time information from past observations. Data assimilation is very effective at using the incomplete coverage of observations from various sources to build a coherent estimate of the atmospheric state. But, like the forecast, it relies on the NWP model, and cannot easily use observations of scales and processes not represented by the model.

2.1.3 The international scientific community is emphasizing the still very poorly observed areas as being a limiting factor in the quality of some forecasts. As a consequence, there is a continued need for improved observation systems, and methods to assimilate these into NWP models.

2.2 Understanding of the atmosphere: inherent limitations to predictability

2.2.1 The scientific understanding of physical processes has made considerable progress through a variety of research activities, including field experiments, theoretical work, and numerical simulation. However, atmospheric processes are inherently non-linear, and not all physical processes can be understood or represented in NWP models. For instance, the wide variety of possible cloud water and ice particles must be highly simplified, as are small cumulus clouds that can lead to rain showers. Continued research effort using expected improvements in computer technology and physical measurements will enable these approximations to be improved. Even then, it will still not be possible to represent all atmospheric motions and processes

2.2.2 There is a wide spectrum of patterns of atmospheric motion, from the planetary scale down to local turbulence. Some are unstable and they are arranged so that flow is amplified using for example energy from heating and condensation of moisture. This property of the atmosphere means that small uncertainties about the state of the atmosphere will also grow, so that eventually the unstable patterns cannot be precisely forecast. How quickly this happens depends on the type and size of the motion. For convective motions such as thunderstorms the limit is of the order of hours, while for large scales of motion it is of the order of two weeks.

2.3 Weather Prediction

2.3.1 *Nowcasting*: Forecasts extending from 0 out to 6 to 12 hours are based upon a more observations-intensive approach and are referred to as nowcasts. Traditionally, nowcasting has focussed on the analysis and extrapolation of observed meteorological fields, with a special emphasis on mesoscale fields of clouds and precipitation derived from satellite and radar. Nowcast products are especially valuable in the case of small-scale hazardous weather phenomena associated with severe convection and intense cyclones. In the case of tropical cyclones, nowcasting is an important detection and subsequent short-term prediction approach that provides forecast value beyond 24 hours in some cases. However, the time rate of change of phenomena such as severe convection is such that the simple extrapolation of significant features leads to a product that deteriorates rapidly with time - even on time scales of order one hour. Thus methods are being developed that combine extrapolation techniques with NWP, both through a blending of the two products and through the improved assimilation of detailed mesoscale observations. These are inherently difficult tasks and, although accuracy and specificity will improve over coming years, these products will always involve uncertainty regarding the specific location, timing and severity of weather events such as thunder and hail storms, tornadoes and downbursts.

2.3.2 *Numerical Weather Prediction (NWP)*: Forecasts for lead times in excess of several hours are essentially based almost entirely on NWP. In fact, much of the improvement in the skill of weather forecasts over the past 20 years can be attributed to NWP computer models, which are constructed using the equations governing the dynamical and physical evolution of the atmosphere. NWP models represent the atmosphere on a three-dimensional grid, with typical operational systems in 2001 use a horizontal spacing of 50-100 km for large-scale forecasting and 5 to 40 km for limited area forecasting at the mesoscale. This will improve as more powerful computers become available.

Only weather systems with a size several times the grid spacing can be accurately predicted, so phenomena on smaller scales must be represented in an approximate way using statistical and other techniques. These limitations in NWP models particularly affect detailed forecasts of local weather elements such as cloud and fog, and extremes such as intense precipitation and peak gusts. They also contribute to the uncertainties that can grow chaotically, ultimately limiting predictability.

2.3.3 *Ensemble Prediction:* Uncertainty always exists - even in our knowledge of the current state of the atmosphere. It grows chaotically in time, with a gradual decay in the value of the new information introduced at the beginning, until only climatological information remains. The rate of growth of this uncertainty is difficult to estimate since it depends upon the three-dimensional structure of the atmospheric flow. The solution is to execute a group of forecasts - an ensemble - from a range of modestly different initial conditions and/or a collection of NWP models with different, but equally plausible, approximations. If the ensemble is well designed, its forecasts will span the range of likely outcomes, providing a range of patterns where uncertainties may grow. From this set of forecasts, information on probabilities can be derived automatically, tailored to users' needs.

Forecast ensembles are subject to the limitations of NWP discussed earlier. Additionally, since the group of forecasts are being computed simultaneously, less computer power is available for each forecast. This requires grid spacings to be increased, making it more difficult to represent some severe weather events of smaller horizontal scale. Together with the limited number of forecasts in an ensemble, this makes it harder to estimate probabilities of very extreme and rare events directly from the ensemble. Moreover it is not possible at present to modify the NWP models so they can sample modelling errors properly; so sometimes all models will make similar errors

2.3.4 *Operational Meteorologist:* There remains a critical role for the human forecaster in interpreting the output and in reconciling sometimes seemingly conflicting information from different sources. This role is especially important in situations of locally severe weather. Although vigorous efforts are being made to provide forecasters with good quality systems such as interactive workstations for displaying and manipulating the basic information, they still have to cope with vast amounts of information and make judgements within severe time constraints. Furthermore, forecasters are challenged to keep up to date with the latest scientific advances.

3. PREDICTION AT SEASONAL TO INTERANNUAL TIME-SCALES

3.1 Beyond two weeks, weekly average predictions of detailed weather have very low skill, but forecasts of one month averages, using NWP with predicted sea surface temperature anomalies, still have significant skill for some regions and seasons to a range of a few months.

3.2 At the seasonal time scale, detailed forecasts of weather events or sequences of weather patterns are not possible. As mentioned above, the chaotic nature of the atmosphere sets a fundamental limit of order two weeks for such deterministic predictions, associated with the rapid growth of initial condition errors arising from imperfect and incomplete observations. Nonetheless, in a limited sense, some predictability of temperature and precipitation anomalies has been shown to exist at longer lead times out to a few seasons. This comes about because of interactions between the atmosphere, the oceans, and the land surface, which become important at seasonal time scales.

3.3 The intrinsic time scales of variability for both the land surface and the oceans are long compared to that of the atmosphere, due in part to relatively large thermal inertia. Ocean waves and currents are slow in comparison to their atmospheric counterparts, due to the large differences in density structure. To the extent that the atmosphere is connected to the ocean and land surface conditions, then, a degree of predictability may be imparted to the atmosphere at seasonal time scales. Such coupling is known to exist particularly in the tropics, where patterns of atmospheric convection ultimately important to global scale weather patterns are quite closely tied to variations in ocean surface temperature. The most important example of this coupling is found in the El Niño/Southern Oscillation phenomenon, which produces large swings in global climate at intervals ranging from 2-7 years.

3.4 The nature of the predictability at seasonal time scales must be understood in probabilistic terms. It is not the exact sequence of weather that has predictability at long lead times (a season or more), but rather some aspects of the statistics of the weather – for example, the mean or variance of temperature/precipitation over a season -- that has potential predictability. Though the weather on any given day is entirely uncertain at long lead times, the persistent influence of the slowly evolving surface conditions may change the odds for a particular type of weather occurring on that day. In rough analogy to the process of throwing dice, the subtle but systematic influence of the boundary forcing can be likened to throwing dice that are "loaded". On any given throw, we cannot foretell the outcome, yet after many throws the biased dice will favor a particular outcome over others. This is the sort of limited predictability that characterizes seasonal prediction.

3.5 Currently seasonal predictions are made using both statistical schemes and dynamical models. The statistical approach seeks to find recurring patterns in climate associated with a predictor field such as sea surface temperature. Such models have demonstrated skill in forecasting El Niño and some of its global climate impacts. The basic tools for dynamical prediction are coupled models – models that include both the atmosphere and the other media of importance, particularly the oceans. Such models are initialized using available observations and integrated forward in time to produce a seasonal prediction. The issue of uncertainty is handled using an ensemble approach, where the climate model is run many times with slightly different initial conditions (within the range of observation errors or sampling errors). From this a distribution of results is obtained, whereupon statistics of the climate can be estimated. Recently, encouraging results have been obtained from ensemble outputs of more than one model being combined.

3.6 There are several limitations associated with current predictions. Most coupled models (and to a lesser extent uncoupled models) exhibit some serious systematic errors that inevitably reduce forecast skill. Data availability is a limitation for both statistical models and for dynamical models. In the latter case, very limited information is available for much of the global oceans, and for the land surface conditions. Also, current initialization methods do not account properly for systematic model errors, further limiting forecast performance. A final set of limitations arises for practical reasons. Due to resource requirements, most seasonal predictions cannot be done at resolutions comparable to weather prediction. Further, rather small ensemble sizes (of order 10) are used for some models, certainly less than is optimal for generating robust probabilistic forecasts. Current research is addressing the potential for regional "downscaling" of climate forecasts by various means, and the possibilities for more detailed probabilistic climate information from expanded ensembles of one or more models.

3.7 Possible use of seasonal forecasts is currently being explored in various contexts. In each case, effective use will require careful attention to the issue of uncertainty inherent in seasonal forecasts. Future advancements can be expected to improve the estimates of uncertainty associated with forecasts, allowing better use of forecast products.

4. PROJECTION OF FUTURE CLIMATE

4.1 As explained above, based on the current observed state of the atmosphere, weather prediction can provide detailed location and time specific weather information on timescales of the order of two weeks. Some predictability of temperature and precipitation anomalies has been shown to exist at longer lead times out to a few seasons. This comes about because of interactions between the atmosphere, the oceans, and the land surface, which become important at seasonal time scales. At longer timescales the current observed state of the atmosphere and even those large scale anomalies which provide predictive skill at seasonal to interannual timescales are no longer able to do so due to the fundamental chaotic nature of the earth-atmosphere system. However, long term changes in the earth-atmosphere system at climate timescales (decades to centuries) are dependent on factors which change the balance of incoming and outgoing energy in the earth-atmosphere system. These factors can be natural (e.g., changes in solar output or volcanoes) or human induced (e.g., increased greenhouse gases). Because simulations of possible future climate states are dependent on prescribed scenarios of these factors they are more accurately referred to as "projections" not "predictions" or "forecasts".

4.2 In order to perform climate projections, physically-based climate models are required in order to represent the delicate feedbacks which are crucial on climate timescales. Physical processes and feedbacks that are not important at NWP or even at the timescales of seasonal prediction become crucial when attempting to simulate climate over long periods, e.g., cloud-radiation interaction and feedback, water vapour feedback (and correctly modelling long-term trends in water vapour), ocean dynamics and processes (in particular an accurate representation of the thermohaline circulation). The treatments of these key features are adequate to reproduce many aspects of climate realistically though there remain many uncertainties associated with clouds and aerosols and their radiative effects, and many ocean processes. Nevertheless, there is reasonable confidence that state-of-the-art climate models do provide useful projections of future climate change. This confidence is based on the demonstrated performance of models on a range of space time scales.

4.3 Notably, the understanding of key climate processes and their representation in models (such as the inclusion of sea-ice dynamics and more realistic ocean heat transport) has improved in the past few years. Many models now give satisfactory simulations of climate without the need for non-physical adjustments of heat and water fluxes at the ocean-atmosphere interface used in earlier models. Moreover, simulations that include estimates of natural and anthropogenic forcing are well able to reproduce observed large-scale changes in surface temperature over the twentieth century. This large-scale consistency between models and observations lends confidence in the estimates of warming rates projected over the next century. The simulations of observed natural variability (e.g., ENSO, monsoon circulations, the North Atlantic Oscillation) have also improved.

4.4 On the other hand, systematic errors are still all too apparent, e.g., in simulated temperature distributions in different regions of the world or in different parts of the atmosphere, in precipitation fields, clouds (in particular marine stratus). One of the factors that limits confidence in climate projections is the uncertainties in external forcing (e.g., in predicting future atmospheric concentrations of carbon dioxide and other greenhouse gases, and aerosol loadings).

4.5 As with NWP and seasonal forecasts, ensembles of climate projections are also extremely important. Ensembles enable the magnitude and effects of natural climate variability to be gauged and its impact on future projections, and thereby permit any significant climate change signal to be picked out more clearly statistically (the magnitude of natural climate variability will be comparable with that of climate change for the next few decades).

5. DISSEMINATION TO END-USERS

5.1 The weather forecasts have to be communicated to a vast array of users such as emergency managers, air traffic controllers, flood forecasters, public event managers, etc., in a timely and user-applicable form. This in itself poses another major challenge that is increasingly benefiting from advances in information technology. Predictions at seasonal to interannual timescales and climate projections are also being used by an increasingly wide range of users.

5.2 The value of forecasts to decision-makers is greatly enhanced if the inherent uncertainty can be quantified. This is particularly true of severe weather, which can cause such damage to property and loss of life that precautions may be well advised even if the event is unlikely, but possible. Probabilities are a natural way of expressing uncertainty. A range of possible outcomes can be described with associated probabilities, and users can then make informed decisions allowing for their particular costs and risks.

5.3 Forecasts expressed as probabilities, or ensembles, contain much more information than deterministic forecasts, and it is difficult to convey it all to users. Broadcast forecasts can only give a broad picture of the most likely outcome, with perhaps some idea of important risks. Each user's decision may be based on the probabilities of a few specific occurrences. What these are, and the probability thresholds for acting on the forecasts, will differ. So for important user decisions it is necessary to apply their particular criteria to the detailed forecast information.

6. CONCLUSIONS

6.1 The skill in weather forecasting has advanced substantially since the middle of the 20th century, largely supported by the advancement of computing, observation (radar and satellite, in particular), and telecommunications systems, and the development of numerical weather prediction models along with the associated data-assimilation techniques. This has been greatly facilitated because of the vast experience of both forecasters and decision-makers in producing and using forecast products. Nevertheless, each component within the science and technology of weather forecasting and climate projection has its own uncertainties. Some of these are associated with a lack of a complete understanding of, or an inherent limitation of the predictability of highly complex processes. Others are linked still to the need for further advances in observing or computing technology, or an inadequate transfer between research and operations. Finally, one cannot under-estimate the importance of properly communicated weather forecasts to well-educated users.

6.2 Without a doubt, significant benefits will result from continued attention to scientific research and the transfer of knowledge gained from this work into the practice of forecasting. Furthermore, a recognition of the limitations of weather forecasts and climate projections, and when possible an estimate of the degree of uncertainty, will result in the improved use of forecasts and other weather information by decision-makers. Ultimately the objective is for the scientific and user communities to work better together, realizing even greater benefits.