Climate variability and flood risk on seasonal and inter-annual timescales and the role of seasonal forecasting.

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1) Flood risk in Australia - "Of droughts and flooding rains"

It did not take the first European settlers to Australia long to realise something that Australia's Aboriginal peoples would have known and experienced for thousands of years, that Australia is a land of climate extremes - the "droughts and flooding rains" that soon entered our folklore. Floods in Australia represent a significant risk to property and agricultural production, as well as human and animal safety, and this risk is exacerbated by the variability of our rainfall which means that flooding in most of Australia is not a regular routine seasonal feature but a sporadic one. This paper will explore aspects of climate variability associated with rainfall and floods in Australia, focussing on those flood events caused by heavy rainfall,[1] and will then look at ways that seasonal outlooks may assist in managing flood risk.

2) The recipe for rain (…and heavy rain)

The most important factor in producing a flood is heavy rain and this is what this paper will focus on. However, it should be noted that antecedent conditions are also very important – prior rain events can "wet" a catchment leading to much higher runoff rates in subsequent events, for example.

What causes rain and, in particular, heavy rain? Rain is actually a complex phenomenon requiring several "ingredients."[2] Perhaps the most obvious is moisture, both in terms of a source and a transport process to bring the moisture to the location in question. The moisture sources for Australian rainfall are the oceans that surround us, particularly the warmer waters of the tropical seas[3], but also the Tasman Sea, southern Indian Ocean, and to a lesser extent the cooler Southern Ocean. Moisture transport is generally provided by the winds of the atmospheric circulations.

A second required ingredient is a lifting mechanism which causes the moist air to rise and hence cool, leading to condensation of the water vapour into water droplets (i.e. cloud). There are many potential lifting mechanisms that can act as triggers– fronts, troughs, convection, wind convergence and orographic lift.[4]

A third and final requirement[5] is atmospheric instability[6] which means that once lift has been triggered the air will continue to rise, leading to sufficient cloud depth for internal cloud processes to allow droplets to coalesce into drops big enough to fall through and out of the cloud as rain.

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[1] As opposed, say, to flooding caused by storm surges and sea incursion.

[2] It is this complexity that makes it harder to forecast at all time scales.

[3] The tropical Indian Ocean to our north west, the Timor, Arafura and other seas around Indonesia, and the Coral Sea to our north east.

[4] Where air is forced to rise to go over mountains – this mechanism is particularly important along the east coast of Australia due to the Great Dividing Range.

[5] Technically condensation nuclei are also required to allow the water vapour to condense and droplet formation to begin (this underlies attempts at cloud seeding). However, in most locations in Australia lack of condensation nuclei is not the principal limiting factor on rainfall.

To get heavy rain the first and third “ingredients” of this trio must be enhanced – i.e. there must be plenty of moisture available (obviously!) and enhanced atmospheric instability, such as can be provided by a mid-level trough, cut off low or cold pool. Therefore above average sea surface temperatures (SSTs), particularly in the tropical seas around our north, impact greatly on rainfall by increasing the moisture available for heavy rain events and floods.[7] Even for southern events triggered by fronts in the westerlies, for example, the source of moisture for big events is usually still the tropical warm waters to the north.[8] SST’s also play an essential role in the formation of tropical cyclones which derive their energy as well as moisture from the warm tropical oceans. Tropical cyclones do not form unless the sea-surface temperature is above 26.5°C and begin to dissipate once they move onto land or over cooler waters. SST gradients (rather than absolute value) also play a role in the formation of another heavy rain producing system known as an east coast low (see below).

3) Causes of rainfall and flood variability in Australia

The variability of floods and hence flood risk in Australia is tied to the variability of our rainfall. There is a strong correlation, for example, between annual rainfall and floods, with flood risk significantly higher in years of high annual rainfall – i.e. “big” years are usually the result of a year of “big” events and not just more events.[9]

The next section of this paper will outline this variability of Australian rainfall (and hence flood risk) on a seasonal, inter-annual and then inter-decadal timescales.

a) Seasonal variation in rainfall and systems causing flooding across Australia

Figure 1 shows the seasonal pattern of rainfall over Australia. Flood risk in an area is generally highest in the season of dominant rainfall.[10]

In the tropical north rainfall (and therefore flood risk) is summer dominant with a distinct “wet” and “dry” season. In this zone the major flood causing systems are tropical cyclones and intense monsoon depressions both of which can occur in summer or early autumn.[11] These systems can produce huge downfalls, as much as 1000mm over a few days. They can also extend or move south, bringing heavy rain and flooding to central (including the arid zone), southern and eastern Australia.

The southern fringe of the continent receives most of it’s rainfall in winter/spring when the belt of high pressure cells known as the sub-tropical ridge moves north and allows the westerlies with their embedded storms and fronts to reach southern Australia. Flooding in these regions is therefore mostly a winter/spring phenomena[12] and is largely caused by either very active or very frequent mid-latitude depressions or fronts.

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[6] I.e. a temperature profile in the lower atmosphere such that when air begins to rise it will continue to do so as, although it is cooling, it is still warmer and therefore less dense than the surrounding air.

[7] This also is part of the El Niño/La Niña phenomenon, see below.

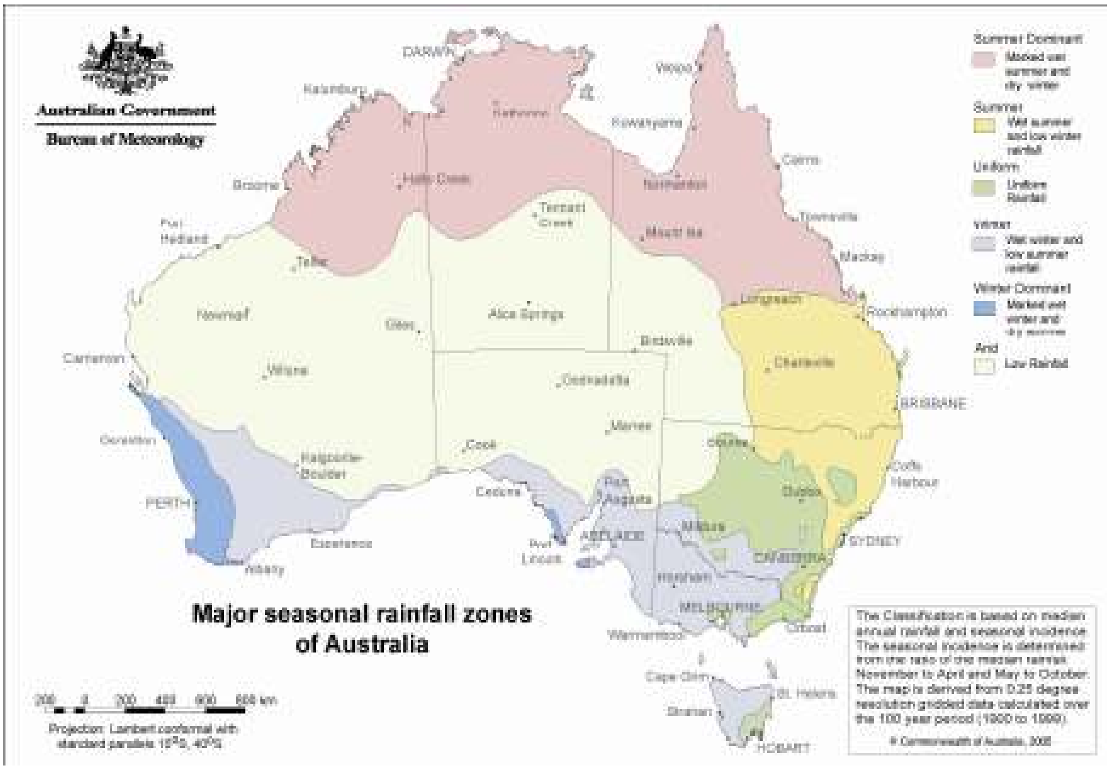
[8] North west cloud bands are an example of this sort of tropical/mid-latitude interaction.

[9] See e.g., N. Nicholls and M. Haylock, “Trends in extreme rainfall indices for an updated high quality data set for Australia, 1910-1998,” *Int. J. Climatol.* 20:1533-1541 (2000).

[10] Some exceptions will be noted below.

[11] More correctly in the “wet” season as tropical areas technically do not experience the typical mid-latitude four season cycle.

[12] With the exception of the southward moving summer tropical systems mentioned above.



The Classification is based on median annual rainfall and seasonal incidence. The seasonal incidence is determined from the ratio of the median rainfall November to April and May to October. The map is derived from 0.25 degree resolution gridded data calculated over the 100 year period (1900 to 1999).

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Fig 1. Major seasonal rainfall zones in Australia. (Bureau of Meteorology)

Sub-tropical eastern Australia comes under the influence of the easterly Trade Winds in the summer months as the sub-tropical ridge moves south below mainland Australia. The Trade Winds provide moisture for rain which can be triggered by the uplift provided by the Great Dividing Range or by the in-land trough west of the ranges which is a quasi-permanent feature during summer months. Heavy flood producing falls can be produced in particular when this moisture laden air interacts with an upper system of cooler than average air, commonly called an "upper cold pool," encroaching from the south. Along the coastal ranges heavy falls can also be produced by sustained deep easterly flow.

A further phenomenon, responsible for much of the flooding along the coast of sub-tropical eastern Australia, is a system known as an East Coast Low. These are low pressure systems which form at or just off the coast in the Tasman Sea. They can produce very heavy falls of rain on their southern flanks, often exacerbated by the orographic lift effect of the coastal ranges. They can occur at any time of the year, forming under a number of synoptic conditions, with the time of the year varying with the synoptic type. The East Coast Lows that produce the most rain are generally those which form from the summer inland trough or an easterly trough in the Coral Sea.

Central inland and south coastal NSW has a more uniform annual rainfall distribution as it comes under the influence of both the winter and summer systems mentioned above. Flood risk is therefore more uniform as well.

It should also be noted that in inland Australia, floods may be caused by rainfall events occurring many hundreds of kilometres away and flood peaks can take weeks to move down river in some regions.

Also in most locations in Australia intense shower and thunderstorm activity can produce localised flash flooding. Very heavy falls with high totals occur especially when the thunderstorm is slow moving or when there are a "train" of storms that pass over the same location. Thunderstorm activity, and associated flash flooding, is strongest in summer months triggered by day-time convection caused by solar heating of the land surface. Thunderstorms may also accompany synoptic scale systems.

b) Inter-annual variability of Australian rainfall and floods

As noted, Australia's climatic variability, particularly in relation to annual rainfall, is high. For much of Australia, the highest annual rainfall recorded in the hundred years or so of observational records is many times higher than the lowest recorded. For example, for the Bureau's Rainfall District 65 in the Central West of NSW the highest averaged annual rainfall (1277 mm in 1950) is nearly 5 times the lowest (267 mm in 1944). This variability is much higher than experienced in Europe and North America, and most of our agriculturally exporting competitors (see figures 2 and 3).

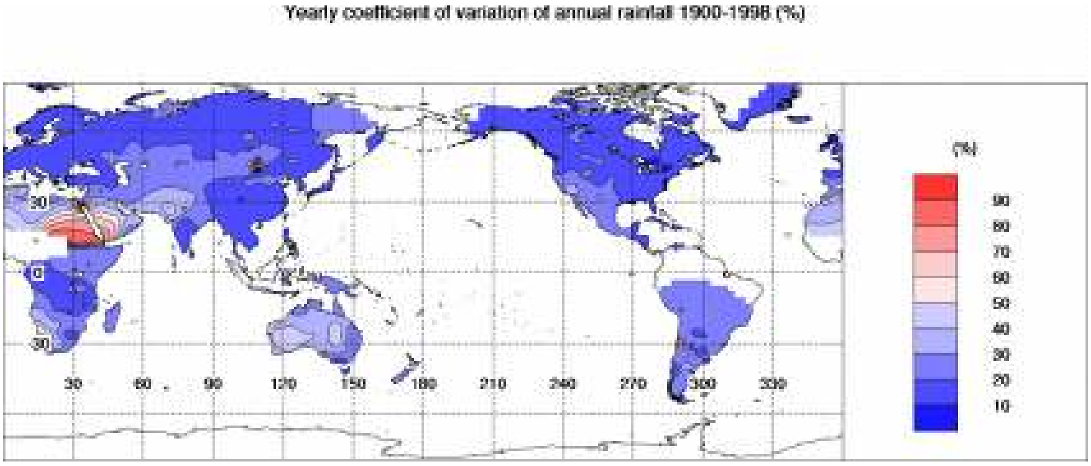

Fig 2. Global coefficient of variation of annual rainfall. White areas have insufficient data, and "bullseyes" are mostly associated with data sparse areas. (Dr Phil Reid, Bureau of Meteorology, based on Hulme dataset, see http://www.cru.uea.ac.uk/~mikeh/datasets/global/gu23wld0098_doc.pdf)

As well as having extremely variable rainfall, Australia is the driest of the inhabited continents. This, along with the variability, perhaps ironically makes it particularly prone to flooding as large rainfall events can overwhelm a "system" generally handling much lower flows. This low average annual rainfall also means it only takes one or two big rain events to result in much higher than average annual rainfall and so flood events and flood risk are strongly correlated with wet years[13].

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[13] As already noted above. Also in "wet" years there is more likely to have been precursor falls which will have increased soil moisture resulting in greater runoff for a given amount of rain.

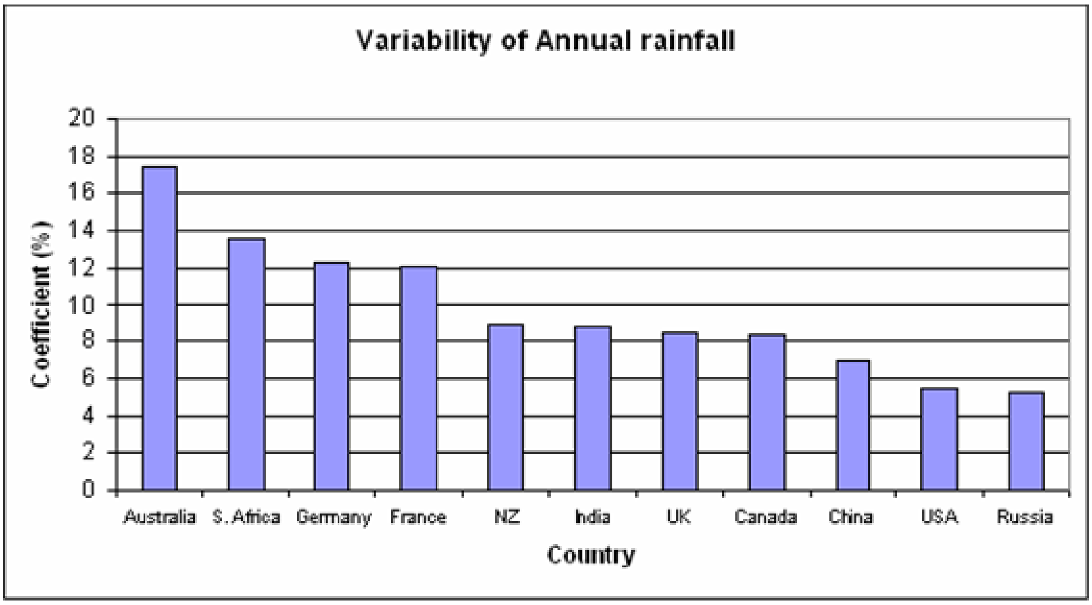

Fig 3. Comparison of rainfall variability of major agricultural exporting countries. (Dr Phil Reid, Bureau of Meteorology, based on Hulme dataset. see http://www.cru.uea.ac.uk/~mikeh/datasets/global/gu23wld0098_doc.pdf)

The main rain bearing processes for Australia (outlined above), and the total rainfall they produce, are all influenced on intra-seasonal and inter-annual timescales by several major modes of global variability. The three most significant of these relate respectively to the three ocean bodies that surround Australia and their variation is a significant part of the explanation of why Australia's rainfall in turn is so variable.[14] The first is relatively well known El Niño/ Southern Oscillation (ENSO) phenomenon of the Pacific Ocean which will be discussed in more detail separately below.

The second is the Indian Ocean Dipole (IOD), a major mode of variability in the Indian Ocean which, like ENSO, operates on an inter-annual time scale. In its positive phase SST's around Indonesia are lower than average while those in the western Indian Ocean towards Africa are warmer than average (hence the "Dipole"). Accompanying this is an enhancing of easterly winds across the Indian Ocean. In the negative phase the SST pattern is reversed and winds tend to become more westerly. Associated with these two modes and their respective SST and wind patterns are opposite impacts on Australian rainfall, with rainfall being enhanced over Australia when the IOD is negative and suppressed when the IOD is positive.

The third major influence on Australian rainfall is the Southern Annular Mode (SAM) which is the main mode of large scale variability in the extra-tropical southern hemisphere. It is an oscillation of pressure between polar regions and the mid latitudes. In its positive phase mid latitude pressures are both above average and the shifted pole-ward with a corresponding pole-ward shift and strengthening in the westerlies, and a decrease in the pressure around the pole. The negative phase is the opposite – higher polar pressures, lower mid-latitude pressures and an equator-ward shift of the pressure and wind patterns. The time-scale of major variations in SAM is of the order of weeks. Recent studies[15] have indicated that the positive phase of SAM results in lower rainfall in the southern Australia in winter and higher rainfall in some parts of eastern

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[14] For a more detailed discussion of these and other influences on Australian rainfall see, B. Murphy and B Timbal, "A review of recent climate variability and climate change in eastern Australia" *Int. J. of Clim.* (submitted).

[15] E.g., H.H. Hendon, D.W.J. Thompson and MC Wheeler, "Australian rainfall and surface temperature variations associated with the Sothern Annular Mode. *J. of Climate* (accepted 2006).

Australia in the summer, and that in recent decades there has being a tendency towards the positive phase of SAM in summer and autumn. In its positive phase this pole-ward shift of pressure and the westerlies means that rain bearing systems such fronts and storms embedded in the westerlies also contract southward away from the Australian mainland.

Although both SAM and the IOD impact on Australian rainfall in ways that are becoming better understood, it is not yet clear that either system is predictable with the lead times that are currently possible with ENSO.

c) The El Niño Southern Oscillation (ENSO) phenomenon and floods

As has been realised for some time ENSO has a significant impact on large scale atmospheric circulation and on Australian climate, particularly rainfall. The areas most affected by the El Niño and La Niña phases of ENSO are indicated in figure 4.

In the El Niño phase of ENSO the eastern to central equatorial Pacific warms above average and waters to Australia's north and east tend to be cooler than average. The Southern Oscillation Index (SOI), a measure of the pressure difference between Darwin and Tahiti, becomes persistently negative in value and hence is used as an indicator of El Niño conditions. Tropical convective activity follows the warmer water eastwards and moves away from the Indonesia and northern Australia. Trade winds are also suppressed. This represents both a loss of moisture and moisture transport onto Australia and eastern Australia consequently generally experiences below average rainfall in the winter and spring. However, El Niño's vary considerably in their impact and not in a linear way in relation to the size of the SST anomaly or magnitude of the SOI. The actual magnitude of the SOI is, in fact, a poor indicator of the size of the impact, and recent studies suggest that it is the position of the greatest temperature anomaly rather than merely its magnitude that determines the impact on Australian rainfall - the El Niño events which impact most are those where the greatest SST anomaly occurs near the dateline, not in the more "classic" El Niño pattern where it is strongest near South America.[16] Also, changes in the Indian Ocean (as mentioned above) can enhance the general tendency for reduced rainfall in eastern Australia, or mask it by contributing to timely falls.

In the La Niña phase of ENSO the central to eastern equatorial Pacific cools below average and the waters to Australia's north and east warm. Trade winds and tropical convection in Australia's north are also enhanced. Not surprisingly, the increased moisture available from warmer seas near Australia, and the moisture transport provided by the enhanced trade winds, lead to significantly increased rainfall and therefore also flood risk, particularly in the winter and spring. Unlike the El Niño

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[16] See G. Wang & H.H. Hendon, "Sensitivity of Australian Rainfall to inter-El Niño conditions", *J. of Climate* (accepted 2006).

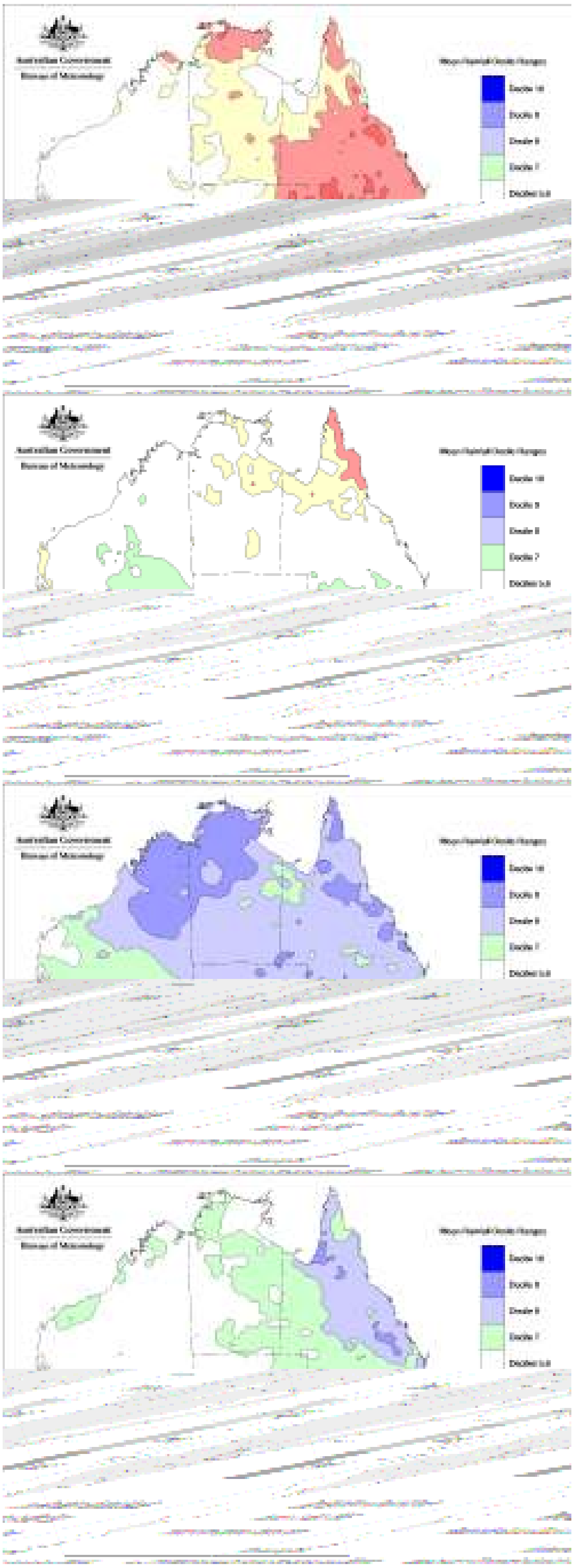

Fig 4. Rainfall decile maps typical of El Niño in winter/spring and summer, and La Niña in winter/spring and summer. (Bureau of Meteorology)

phase, the impact of the La Niña phase on Australian annual rainfall does appear to be linear, with the more positive the SOI the greater the rainfall.[17]

Over much of Australia, flood risk is considerably higher than usual during La Niña years and lower in El Niño years. Some of the worst and most widespread in the 20th century occurred in the La Niña years of 1916, 1917, 1950, 1954-1956, 1973-1975, and 1998-2000 (see figure 5). It is important to note, however, that floods still can occur in El Niño years.[18] Also, there is a tendency for La Niña's to directly follow El Niño which means that droughts are often broken in Australia by floods (what might be called the "Hanrahan effect").

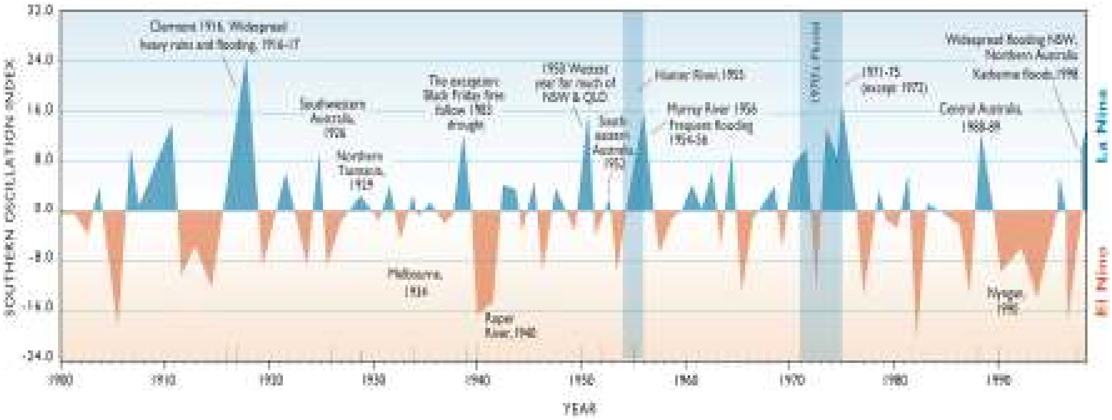

Fig 5. Time line showing the relationship between major Australian flood episodes and the Southern Oscillation Index. (Bureau of Meteorology)

ENSO also particularly impacts on rainfall and flooding in Australia due to its impact on the frequency of occurrence of some heavy rain bearing systems. In La Niña years tropical cyclones are more frequent and form closer to the Australian coast (particularly the Queensland coast), bringing higher risk of flood to those regions. Also some varieties of East Coast Low, namely those forming from an easterly trough in the Coral Sea or the summer inland trough in Queensland and northern NSW (which are the varieties which are most likely to be associated with heavy rain) are also reduced in frequency in El Niño years and occur with greater frequency in non-El Niño years, especially La Niña years.

Also is should be noted that the rainfall suppressing(enhancing) effects of the El Niño (La Niña) type ocean pattern can begin to impact Australia before the Pacific Ocean reaches the formal threshold criteria used to declare an El Niño (La Niña) event. Indeed, warmer (cooler) than average central to eastern equatorial waters already predispose the Australian region to lower (higher) rainfall, even if threshold criteria are not met.

d) Inter-decadal climate variability and relationships to floods

As well as seasonal and inter-annual variability, Australian rainfall also exhibits variability on an inter-decadal time scale. While this has been long realised it has recently come more to the fore due to the prolonged dry spells experienced recently in parts of Australia - in south west WA (over 30 years), Victoria and south east Queensland (10 years) and NSW (6 years). The time series of NSW average annual rainfall illustrates this variability (see figure 6). As can be seen from the figure the first half of the 20th century (actually beginning in the mid 1890's when station

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[17] See S. Power, M. Haylock, R. Colman, and X. Wang, "The predictability of inter-decadal changes in ENSO teleconnections. *J. Climate*, 8, 2161-2180 (2006).

[18] Including but not limited to flash flooding due to thunderstorms.

data is examined) was significantly drier than the second half. The second half of the century includes, of course, the exceptionally "wet" decades of the 50's and 70's in which eastern Australia experienced significant flood events (see figure 5). Also of note is the "step-like" nature of the change between the two regimes.

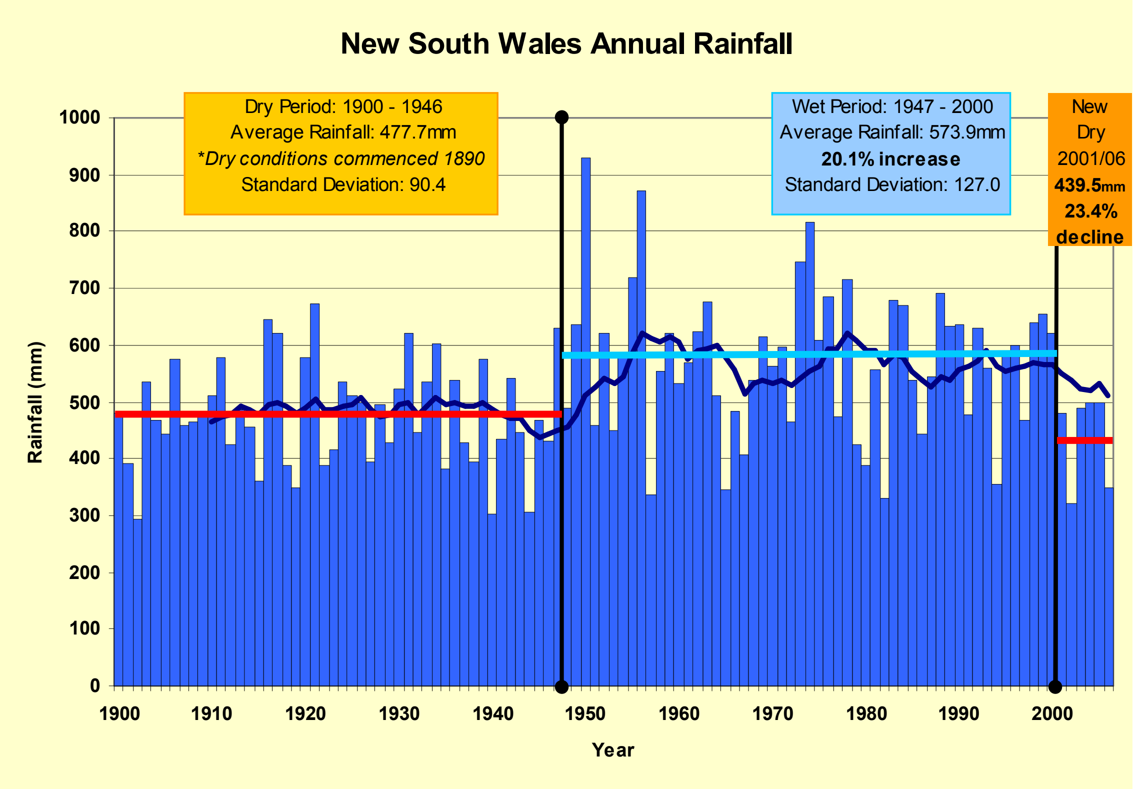

Fig 6. Time series of NSW annual rainfall from 1900 to 2006 showing a "dry" period between 1900 and 1946, a "wet" period from 1947 to 2000, and drier conditions since 2001. The dark blue line indicates the 11 year moving average. (Clinton Rakich, Bureau of Meteorology)

This variation in rainfall is also reflected in the flood record. Records of river observations exist for NSW dating back to 1799,[19] and these too show abrupt shifts between multi-decadal drought and flood dominated periods, corresponding (where these record overlap with the rainfall record) with the periods of lower and higher rainfall respectively.[20]

Investigations by palaeo-climatologists, who use lake sediments, stalagtites, etc to find evidence of rainfall amounts back beyond our observational record, seem to confirm that Australian rainfall has varied between "drier" and "wetter" periods on this inter-decadal timescale for millennia.

The reasons for this variability in rainfall and floods are not fully understood, but at least part of the explanation seems to lie with a phenomenon called the Inter-decadal Pacific Oscillation (IPO).[21] The IPO is an "ENSO-like" pattern of Pacific Ocean SST variability that operates on a

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[19] See e.g. W.D. Erskine & R.F. Warner, "Geomorphic effects of alternating flood and drought dominated regimes on NSW coastal rivers," *Fluvial Geomorphology of Australia* (pp. 223-244; Academic Press, Sydney, 1988)

[20] See C Rakich, "An index to capture moisture transport affecting rainfall over eastern Australia," *Geophys. Res. Letters* (submitted, 2007).

[21] Recent work suggests variations in summer/warm season rainfall can also be directly related to the strength of the trade wind flow and hence moisture transport onto eastern Australia, see Rakich (2007, submitted).

decadal time scale and which appears to modulate the impact of ENSO events on Australia.[22] When the IPO is in a negative phase the relationship between ENSO and Australian rainfall is strong, when the IPO is in its positive phase the relationship is weak.[23] It is not yet completely clear whether the IPO is merely a reflection of random chances in ENSO statistics, or a separate albeit related phenomenon in its own right, but in either case there does yet appear to be any significant predictability in the IPO and its indices that would enhance seasonal forecast skill.

4) The Seasonal Climate Outlook service as a risk management tool

In response to Australia's highly variable climate, and in particular its highly variable rainfall, there has been a need and demand for seasonal forecasts that would extend beyond the week or so provided by current numerical weather prediction (NWP) to cover the seasonal and inter-annual time-scales that are particularly significant for decisions in agriculture and other climate impacted industries. This is the domain of seasonal forecasting and the Bureau of Meteorology, along with other organisations, has sought to meet this need through various seasonal climate outlook products. In the remainder of this paper we will briefly survey the methods available, the particular products currently offered by the Bureau and whether they might assist in the flood risk management, and then finally sketch the likely direction of future developments and advances in this area.

a) Seasonal forecasting methods

There are basically two main methods underlying seasonal forecasting - what are known as statistical methods and dynamic methods. It is also possible to use methods which are a hybrid of these two.

i) Statistical seasonal forecasting

Statistical seasonal forecasting methods involve searching for meaningful relationships between the climate parameter to be forecast (e.g. rainfall) and other parameters that can serve as predictors for the forecast parameter (e.g. SST's). Various techniques exist, including:

- regression methods;
- stratified climatology methods;
- analogue methods;
- linear discriminant analysis methods.

Statistical seasonal forecasting methods produce probabilistic forecasts, rather than categorical or definite forecasts, generally assigning a probability that the outcome will fall into one of a number (2 or more) of mutually exclusive categories.[24]

The various statistical seasonal forecasting methods share a number of common assumptions, perhaps the most basic one being that the past (as represented by a some base period) adequately captures the range variability of the system and so can be a guide to the future. For this assumption to be valid the base period has to be long enough to give a sufficient sample space[25] and to capture any inter-annual or inter-decadal oscillations. With only just over 100 years of observational data statistical forecasting schemes will have difficulty in dealing with

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[22] See Power et al (2006).

[24] E.g. "There is a 65% chance of above median rainfall in the next 3 months."

[25] Thus they will not deal well with extremes (such as floods) which by definition happen infrequently – they will deal better with events such as 3 monthly accumulated rainfall.

multi-decadal variability. In addition, of course, the assumption that the past is a guide to the future may break down under a regime of climate change.[26]

Another limitation is the need to find statistical relationships which do evince predictability. Most of inter-annual predictability (as opposed to merely variability) so far uncovered for Australia relates to ENSO. However, for most parts of the country and for most parts of the year ENSO accounts for well less than half of the observed variability and this reduces even more when looking at a lag, as is needed for predictability.[27] Although we have a handle on at least some of the other causes of the variability, as yet no further significant predictability has been unearthed.

A further aspect of statistical methods is that predictability increases as the timescale of the forecast goes up (from 1 month to 3 months to annual etc), but usefulness correspondingly goes down. Also as the lag (the time span forward at which the forecast period begins) increases, predictability decreases. Predicting 3 month rainfall at a lag of 0 or 1 month is about as best as can currently be achieved with any real skill.

ii) Dynamic seasonal forecasting methods

Dynamic seasonal forecast methods make use of computer models known as Coupled General Circulation Models (CGCM's). These are in principle similar to the computer models (sometimes referred to as Numerical Weather Prediction or NWP) used with great success to predict or forecast the weather out to a time scale of a few days to a week. The differences are that the spatial resolution is generally less, a trade off needed for a given computer power in order to be able to run the models out further – months rather than days. Also climate models must include the ocean (hence the term "coupled") as on the time scale of weeks to months the ocean and atmosphere strongly interact (for NWP one can get by with a "snapshot" ocean and not include any ocean dynamics).

Dynamic models evolve an initial state forward in time. In principle they can give categorical forecasts, however, in practice there are several limitations which mean that they are better used to produce probabilistic forecasts. These limitations are:

- model error – models are imperfect (for example, due to resolutions, deficiencies in the mathematical representation of the physical system, etc);
- errors in the initial state (for example, gaps in the observing network, how accurate observations are, data assimilation systems etc);
- chaos – because the climate system is non-linear small un-measurable errors or changes in the initial state can lead to quite different outcomes (the so called "butterfly effect").

As intimated, these limitations mean that it is preferable, for the time scales required, to use the models to produce a probabilistic forecast by "ensembling" various runs of the model, each with the initial state perturbed slightly (for instance, by initialising with data from consecutive days). Further, any bias due to errors in the model itself (rather than the initial state) can also be partly corrected by using a number of different models to form "multi-model ensembles".

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[26] Indeed, this does seem to be impacting on the BoM operational product where warming SST's mean that ocean temperatures indices are becoming "phase locked" into a warmer pattern, reducing the utility of the forecast system.

[27] This is part of the reason that the BoM SCO does not ever vary very much away from 50% of above/below median rainfall.

The main advantages of dynamic seasonal forecasting over statistical methods are:

- it is physically based (ie it is possible to unravel mechanisms not just abstract statistical relationships);
- it can deal with a non-stationary climate (by including greenhouse gas forcing);
- it can in principle deal with individual events and extremes and not just mean relationships(though note the caveat above);
- using ensembles it can be used to predict uncertainty and assign probability distributions to events.

The main disadvantage is that it is far more complex than the statistical methods in terms of computing power required (and hence also many times more expensive to run operationally), and also in getting all the physics correctly included. All climate models show a drift error to some degree which requires that this drift be estimated and removed from the forecast. A further disadvantage is that skill assessment is generally done on a much shorter period than for statistical methods due to the computer time required to do the necessary hindcasts.

A further limitation is that climate models deal with some climate parameters much better than others. For example, they generally are better at more spatially uniform variables, such as maximum temperature and mean sea level pressure, than for rainfall, particularly when it comes to events rather than averages. This is partly a result of the trade off in spatial resolution to achieve sufficient run length of the forecast with the given computer resources, but also simply from the fact that rainfall forecasting is “difficult” due to its complex nature discussed earlier. A way forward in this case is the use of a hybrid method which uses the dynamical method to produce a forecast for a variable such as mean sea level pressure (MSLP) and then a statistical method to make the connection between MSLP and rainfall, say.[28]

b) The Bureau’s seasonal forecasts

The Bureau of Meteorology has two main operation seasonal forecasts. These are the Seasonal Climate Outlook (which uses statistical methods) and the ENSO Wrap-up which, along with various diagnostics, is based around a dynamic method using the Bureau’s operation coupled ocean /atmosphere model called POAMA to forecast temperature anomalies (and hence ENSO) in the equatorial Pacific.

Space precludes further detailed explanation of these products but this can be found, along with the products themselves, and verification/validation information at:
http://www.bom.gov.au/climate/ahead/rain_ahead.shtml
and
http://www.bom.gov.au/climate/enso/

c) Using seasonal forecasts in risk management

Decisions that need to be made on the basis of uncertain outcomes lend them selves to a risk management framework, where the benefit or injury of an outcome can be weighed against its probability to assess overall risk.

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[28] Such “statistical downscaling” methods are also used in climate change modelling for the same purpose.

The probabilistic nature of the seasonal climate outlook of the Bureau and other similar seasonal forecasts, means that a risk management approach is required to best make use of the information. A forecast of a probability of above median rainfall of 60%, for example, means that about 6 out of 10 years with conditions (in the Bureau's SCO case, this is SST patterns in the Indian and Pacific Ocean) like the present will have above median rainfall – however, that of course means that about 4 out of 10 will still have below median rainfall. Decisions using this information therefore need to be made on this basis and not as though they were categorical or definite forecasts. At any given time, it is of course possible for the less likely outcome to occur. While this may seem to make the forecast "wrong" from time to time what it really shows up is the error of treating the forecast in a categorical manner. Taken over several years, the advantages of making decisions to minimise risks on the basis of the odds should outweigh the disadvantages.

This though highlights one of the potential problems of using seasonal forecast to manage flood risk. In agriculture, for which these products were originally designed, over many years one would expect the outcomes to fall out about as forecast on the probabilities, and so for decisions made on the basis of them to lead to a successful outcome overall **over that period.** In any one year, of course, this may not be the case. That is, one must be able and willing to absorb the costs of short term setbacks on the basis that in the long run the probabilities will assert themselves. If any short term loss is too catastrophic then the overall long term "outcome" becomes irrelevant – you don't get the multiple "throws of the die" needed for the probabilities to assert themselves! Thus the use of seasonal forecasts in flood risk management must take account of how serious or catastrophic a negative outcome might be – in some instances the outcome is so serious that action to remove or at least minimise the risk must be taken, rather than accepting the risk. The outcome of the failure to heighten the levies around New Orleans is a tragic warning against playing the odds when the stakes of flood are so high.

The other difficulty with using seasonal outlooks for flood risk management is that they generally forecast the probability of certain rainfall accumulations over a period of time, usually measured in months. Even if these forecast probabilities show skill they can only very indirectly give an indication of the probability of flood occurrence. Having said that, given the correlation between high rainfall and extreme rainfall events observed above, a strong "signal" towards La Niña conditions will also mean a swing in the odds towards increased risk of flood, even if current products and methods do not enable that risk to be quantified in the same manner as the rainfall probabilities.

5) The future of seasonal to inter-annual climate prediction

Although there are a number of ways that statistical methods can be tweaked,[29] it is generally thought that significant advances in seasonal forecasting will come through advances in dynamic methods, including the use of hybrid methods mentioned above.

Dynamic methods can be improved in a number of ways, including:

- Improving the models - capturing the physics better;
- Improving the model initialisation – more and better data assimilation (satellites, buoys etc);

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[29] And this includes for BoM products more useful ways of displaying the information they already produce, e.g. production of exceedance probability maps for certain threshold rainfall amounts rather than just the % above or below median maps.

- Higher resolution - requiring more computer power;
- Using larger ensembles;

However, the non-linear chaotic nature of the system means that “noise” will always limit predictability.

Current Bureau plans for improved seasonal forecasts include:

- Improved presentation of outputs of current statistical seasonal products – including for example, probability of exceedance maps.
- Improving statistical seasonal forecasting – the current operational scheme is being updated to use more recent data and ‘smarter’ techniques. Results suggest an increase in skill in most seasons and that this scheme may better separate out global warming.
- Increased range of outputs from dynamic seasonal forecasting model (POAMA) being made available as products, e.g:
    - forecasts of rainfall, daily max, min, mean temp, MSL pressure
    - new probabilistic forecasts – above/below median, terciles, etc.
    - as well as deterministic forecasts – ensemble mean anomalies (bias corrected)
    - and seasonal forecasts with increased lead time – 3 monthly out to 6 months ahead
- Australian Climate Community Earth System Simulator (ACCESS) – a proposed joint venture with the CSIRO to resource and produce a world class state of the art CGCM (and a super-computer on which to run it!), which will handle NWP, climate change forecasting and also seasonal forecasting.

While there will always be uncertainty due to the chaotic nature of the climate it is hoped and expected that these plans as they are implemented will move us along in our understanding and ability to forecast the harsh extremes of our land “of droughts and flooding rains.”