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Water in the future: is the past a good guide?

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ABSTRACT

This paper describes variations in rainfall patterns and river flows across New Zealand on inter annual, decadal and century time scales. Causes of these variations including “climate noise”, the El Niño-Southern Oscillation (ENSO), and the Interdecadal Pacific Oscillation (IPO) are discussed. The IPO is a natural pattern of climate variation in the Pacific region, which changes phase once every few decades. Averaged over the forthcoming IPO phase (which has probably already commenced and could last for the next 20—30 years), there are likely to be reduced westerly and southwesterly winds, and reduced rainfall in the southwest of the country. There are implications for hydroelectricity generation, since inflows to the major South Island hydro schemes are likely to be influenced by this projected rainfall reduction. Averaged over this same period, increased rainfall is likely in the northeast of New Zealand. Climate model projections for the coming century suggest that global greenhouse gas emissions from human activities will lead to further changes in rainfall patterns across the country and to an increased frequency of heavy rainfall events, for many of the greenhouse gas emissions scenarios that have been proposed. Natural perturbations in New Zealand’s climate in individual years due to ENSO have amplitudes comparable to the mid range projected “greenhouse warming” changes expected over the coming 30-50 years. Thus future management of our water resources should not be based only on rainfall and river flow records from the past 2—3 decades, which were dominated by the opposite phase of the IPO from the one into which we have now probably moved. Rainfall over the coming century will reflect combined influences of natural climate variability and human-induced climate change. Both multi-decadal climate statistics (developed over both phases of the IPO) and projections of anthropogenic changes in rainfall should be taken into account.

INTRODUCTION

In the late 1980s, former Prime Minister Sir Geoffrey Palmer commented that New Zealand was “an irredeemably pluvial country”. However, farmers in areas such as Marlborough and Otago, and producers and consumers of hydro-electricity, are well aware that some years are more pluvial than others. Data on rainfall and river flows from many parts of New Zealand have been extensively analysed by scientists and engineers to provide statistics on monthly and annual “average” conditions, year-to-year variations, and frequency of extremes (floods, droughts). Such statistics are used for purposes ranging from design of bridges and stormwater drainage systems through to assessing the generation potential of proposed hydroelectricity schemes.

The question posed in this paper is whether these statistics, which are based on our past experience, are a reliable guide to what is likely to occur during coming decades. To answer it we need to understand the time-scales and causes of the variations experienced during the past century, as well as attempting to predict how global emissions of greenhouse gases will affect New Zealand in the future. A key message from this paper is that there are significant natural variations in New Zealand rainfall over periods of several decades. This means that even in the absence of anthropogenic “climate change” effects, rainfall and river flow statistics from the past 20—30 years alone are probably not an adequate guide to the future.

TEMPORAL VARIABILITY IN NEW ZEALAND RAINFALL AND ITS CAUSES

Figure 1 is an example of the observed year-to-year variation in rainfall at a New Zealand recording site (in this case near Masterton). For most New Zealand stations, the standard deviation of the annual rainfall series is between 12 and 20% of the average rainfall, with rainfall totals in individual years rarely exceeding 175% of the station average or falling below 50% (Coulter 1975). Several reasons for these variations, which operate over a range of time-scales, are discussed below. They include “climate noise” (causes year-to-year variations), the El Niño - Southern Oscillation (ENSO, quasi-period of several years), the Interdecadal Pacific Oscillation (IPO, variations over several decades), human-induced climate change (“Global warming, decades to centuries), and solar and orbital changes (decades to millennia).

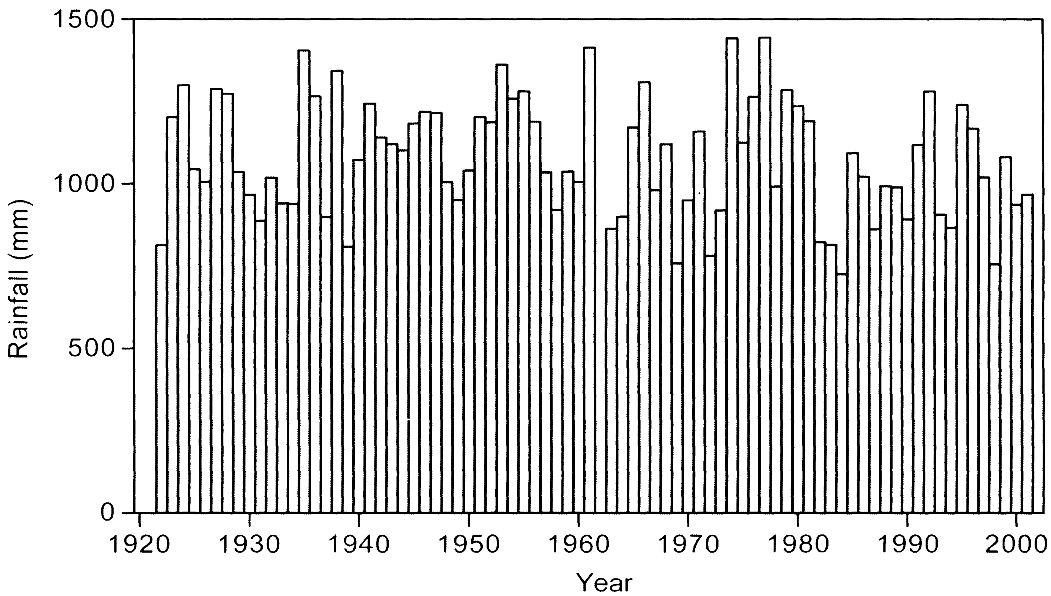

Fig. 1 Annual rainfall from 1922 to 2001 at Bagshot Station, near Masterton.

“Climate noise”: year-to-year variability

“Climate noise” refers to random year-to-year fluctuations in climate statistics including rainfall, due to the chaotic nature of atmospheric processes. For example, in some years there will be more rain-producing cold fronts crossing the country than in others, or a severe storm may travel particularly slowly over some part of the country.

El Niño—Southern Oscillation (ENSO): quasi-cycle several years

The El Niño—Southern Oscillation is a global climate phenomenon, marked by sea-saw shifts in the east-west temperature pattern across the equatorial Pacific, and in the pressure difference between Northern Australia and Tahiti. El Niño and La Niña refer to the extreme phases in this 2—7 year quasi-cycle. In an El Niño phase, drier than normal conditions often occur in the northeast of the country and wetter conditions in the southwest. This occurs because the average airflow across the country tends to be more southwesterly than usual. During a La Niña the opposite air flow anomaly often occurs, with drier than normal conditions in the south and west and wetter in the north and east. (Gordon 1986; Mullan 1995).

The difference between the rainfall averaged only over periods when El Niño conditions are present and the rainfall averaged over all conditions is large enough to have significant effects on soil moisture and river flow for parts of New Zealand. For example, the average summer rainfall in El Niño years since the 1950s is more than 120% of the "all-conditions" summer average in parts of South Westland, and less than 80% in some northeastern parts of the North Island. The average La Niña summer rainfall is more than 120% of the overall summer average in parts of Northland, and less than 80% in much of the south and west of the South Island. In addition, El Niño years generally tend to be cooler than normal for much of the country, and La Niñas warmer. However, the rainfall and temperature anomaly patterns across the country are not identical for every El Niño (or every La Niña).

Interdecadal Pacific Oscillation (IPO): decade-to-decade variability

Researchers have recently discovered a longer-term pattern of climatic variation over the Pacific, with a quasi-period of decades. This was first termed the Pacific Decadal Oscillation (e.g., Mantua et al. 1997). It is now generally called the Interdecadal Pacific Oscillation (IPO, e.g., Folland et al. 2002). Three phases of the IPO occurred during the 20 Century: a positive phase from 1922 to 1944, a negative phase from 1947 to 1977, and a positive phase from 1978 to 1998. Conditions have probably now moved back into the negative phase. Positive phases tend to be associated with an increased frequency of El Niños, and negative phases with more La Niñas.

The IPO influences New Zealand regional rainfall and temperature (Salinger & Mullan 1999). Figure 2 illustrates rainfall on New Zealand's West Coast since 1950, through negative and positive phases of the IPO. Although there are substantial year-to-year variations (caused by features such as "climate noise" and ENSO), overall it was about 10% drier than average on the West Coast through the negative IPO phase up to 1978, and about 10% wetter during the following positive phase. There was an opposite effect on rainfall over the north and east of the North Island (Salinger et al. 2004).

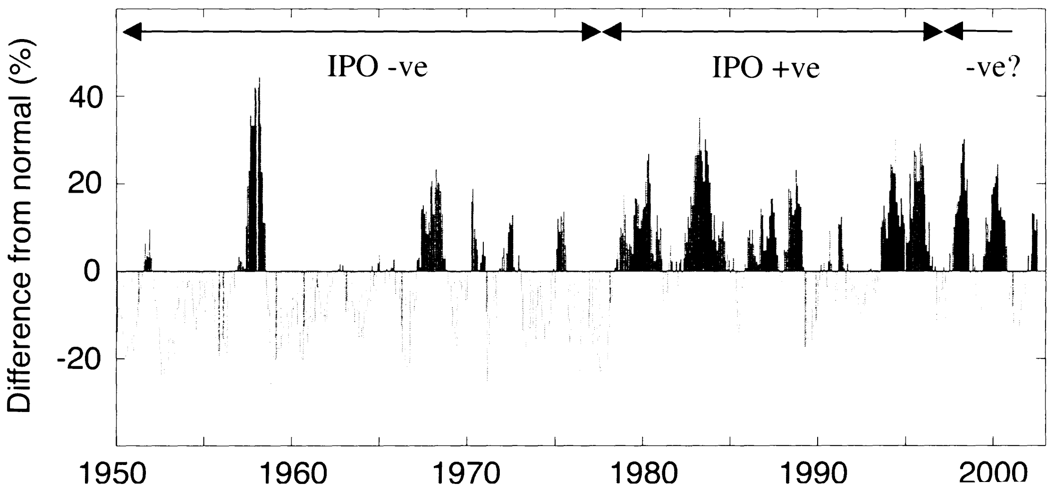

Fig.2 Annual rainfall (compared to the average between 1951 and 1980) for the southwestern part of the South Island (Wratt et al. 2004).

Figure 3 shows that the flow of the Clutha River measured at Balclutha was 14% higher averaged from 1998 to 2000, than when averaged from 1947 to 1977. This behaviour corresponds to likely changes of rainfall into the headwaters associated with the IPO phase change. These headwater rain quantities generally follow the West Coast rainfall patterns since the major South Island rivers are fed predominantly by precipitation spillover across the main divide in westerly conditions. McKerchar & Henderson (2003) have analysed stream flow records from many parts of New Zealand. They found that a decrease in flood size has occurred since 1978 in the Bay of Plenty, and that at the same time there has been an increase in the flood size and low-flow magnitude in most South Island rivers with headwaters draining from the main divide of the Southern Alps.

McKerchar and Henderson have also shown that stratifying data on flood peak volumes according to the phase of the IPO significantly affects estimates of annual exceedance probabilities for some New Zealand rivers. For example, for the Waihopai River in Southland the flood peak volume with a 1 in 100 annual exceedance probability (AEP) calculated from 1959 to 1977 observations (64 m is less than half of the value calculated using 1978—1999 data (138 m For the 3-day inflows to Lake Te Anau, the 1 in 100 AEP volume is 28% higher for the second period.

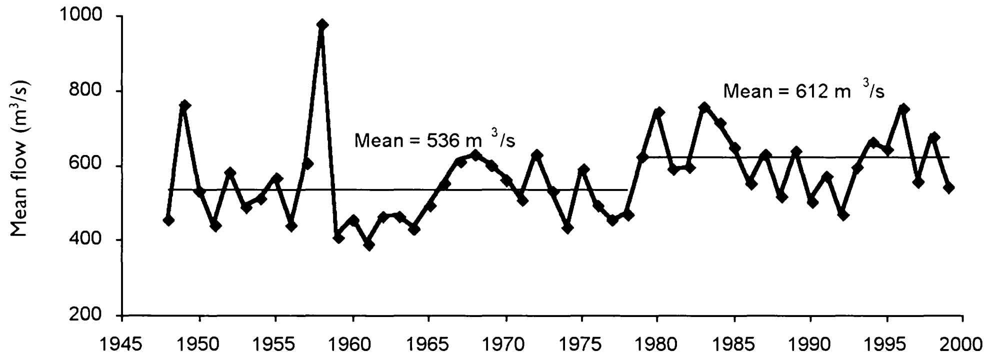

Fig. 3 Annual flows recorded for the Clutha River at Balclutha for the period 1 October 1947—30 September 1999. Flows are presented for 12-month periods commencing on 1 October (McKerchar & Henderson 2003).

Variability and trends over decades and centuries

On the millennial time-scale, New Zealand temperature and precipitation (rain plus snowfall) have exhibited substantial variations, as the globe has moved in and out of ice ages. For example, at the peak of the Otiran (the last Glacial Maximum, some 24,000 years ago), paleoclimate evidence suggests New Zealand temperatures were 4—5°C cooler than present, and the north and east of the North Island were considerably drier and windier. (Salinger & McGlone 1989). Glacial-interglacial cycles are linked to changes in the Earth's orbit around the sun and the tilt of its axis, which modify the seasonal and latitudinal variation of solar radiation impinging on the Earth's atmosphere. This solar forcing appears to be amplified by various feedback processes such as changes in the amount of radiation reflected from the earth's surface due to changes in snow and ice cover, and changes in the concentrations of various greenhouse gases in the atmosphere. (e.g., Kutzbach 1992).

Systematic air temperature measurements began in New Zealand in the 1850s. The temperature averaged over the country rose by about 0.7°C during the 20th Century (Salinger et al. 1996). In line with the conclusions of the Intergovernmental Panel on Climate Change (IPCC) regarding globally averaged temperatures (IPCC 2001), it is likely that at least part of this New Zealand warming, especially during the last 50 years, has been due to the increase in the concentration of greenhouse gases such as carbon dioxide, caused by human activities.

To date, no statistically significant century-long New Zealand rainfall trends for the 201 Century have been identified in the scientific literature. What have been observed are the shifts in rainfall distribution patterns across the country around 1950 and 1975, associated with changes in the phase of the IPO described earlier in this paper. Shifts have also been identified in indices of extreme rainfall and of frequency of intense rainfall in some parts of the country (Salinger & Griffiths 2001).

OBSERVED AND PROJECTED CHANGES DUE TO HUMAN ACTIVITIES

In 2001 the IPCC examined global mean temperature trends and concluded that "most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations" (IPCC 2001). They also concluded it is: very likely that precipitation increased by 0.5—1% per decade in the 20th Century over most mid and high latitudes of Northern Hemisphere continents; likely that rainfall decreased over Northern Hemisphere sub-tropical land areas by about 0.3% per decade; and likely that rainfall increased by 0.2—0.3% per decade over tropical land areas over the same period. However no comparable changes have been detected in broad latitudinal averages over the Southern Hemisphere. It is also likely that through the latter half of the 20111 Century there has been a 2—4% increase in the frequency of heavy precipitation events.

For the future, the IPCC projects it is likely that by the second half of the 2P Century precipitation will have increased over northern mid-to-high latitudes and Antarctica in winter, and that larger year-to-year variations in precipitation are very likely over most areas where an increase in mean precipitation is projected. More intense precipitation events are very likely, over many areas.

New Zealand rainfall

As discussed in the previous section, there is as yet no statistically significant published evidence of greenhouse gas influences on rainfall over New Zealand through the 20 Century. However when global climate change model results for the JPCC emission-scenario range are downscaled to New Zealand, some substantial changes are predicted in seasonal and annual rainfall over the coming century (Mullan et al. 2001; Wratt et al. 2004). There are considerable variations between different climate models, but many suggest a gradient from an increase in the southwest of the country to a decrease in the northeast. This gradient in projected rainfall is largest in winter. Projected changes in annual precipitation by the 2080s, for the mid-range JPCC emission scenarios (averaged across climate models) extend from an increase of about 20% on parts of the South Island West Coast to decreases of around 15% in parts of Hawkes Bay and Gisborne (Wratt et al. 2004). Projected changes by the 2030s follow a similar spatial pattern, but are half or less of those projected for 2080.

Various modelling studies suggest that heavy rainfall events will occur more frequently in New Zealand over the coming century, but the likely size of this change is uncertain. Wratt et al. (2004) have provided some initial estimates for use in preliminary scenario studies. For a mid-range IPCC emissions scenario for the 2080s, these suggest an increase of around 10% in the 72-hour rainfall total for a given average recurrence interval, and around 16% increase in the 10-minute rainfall total. However, we stress these factors are still quite uncertain.

Evaporation, runoff and river flows

The projected changes in New Zealand temperature are also expected to increase evaporation rates. Some further work on likely climate change impacts on evaporation, runoff and river flows is very desirable. Wratt (2002) drawing on calculations by

Griffiths (1990) has suggested mid range IPCC scenarios could lead to runoff decreases of around 40% from land in eastern Marlborough and eastern Canterbury, and runoff decreases of 10—40% in eastern areas of the Gisborne, Hawkes Bay and Wairarapa regions by late this century.

So far, few quantitative projections are available for changes in river flows, apart from an initial study of three river catchments by Lincoln Environmental (2001). Flows in some of the long rivers that rise in the central high country may in fact increase, reflecting the projected rainfall increases in the west. But rivers which rise east of the central ranges may experience reduced flows. The projected increased frequency of heavy rainfall events may lead to more frequent floods.

Snow and ice

It is likely that snowlines will retreat, although there are possible confounding issues. (Warmer air holds more moisture, and during winter this moisture could be precipitated as snow at high elevations). Further retreat of glaciers is expected. In the 100 years up to 1978, a period in which New Zealand's temperature increased by about 0.6°C, glaciers in the Southern Alps shortened by (on average) 38% and lost 25% of their area (Chinn 1996). However large glaciers such as the Tasman Glacier, are expected to exist for at least several centuries (Chinn 1989).

THE FUTURE—NATURAL PLUS ANTHROPOGENIC CHANGES

The rainfalls and temperatures that New Zealanders will experience over coming decades will result from the combined effects of chaotic fluctuations, natural climate variations (such as ENSO and the IPO), and human-induced climate change. The current year-to-year natural fluctuations in New Zealand rainfall and temperatures have amplitudes similar to the mid-range anthropogenic changes projected in 30—50 years. This means that, for example, today's unusually warm year could be the norm in 30—50 years' time. In 30—50 years' time an unusually warm year is likely to be hotter than anything we experience at present.

The significance of natural variations should not be overlooked, by focusing only on climate change effects. In particular, the past 2—3 decades were dominated by the opposite phase of the IPO from the one into which we have now probably moved. This implies that averaged over the coming 20—30 years the rainfall in the southwest of the country may be less than recently experienced, and the rainfall in the northeast may be higher. This may offset the "climate-change" influences on west-east rainfall patterns projected in the previous section. Later in the 2l Century when the IPO phase changes again, the IPO and "climate change" may have mutually reinforcing effects on rainfall.

IMPLICATIONS

The ENSO and IPO-influenced natural rainfall variations described above, and the potential impacts of increasing greenhouse gas concentrations, have significant implications for New Zealand water resources and their management. Skill is increasing in predicting the onset, development and ending of El Niño and La Niña conditions, although the model predictions for doing this are not always correct. ENSO predictions and other information about broad-scale climatic conditions across the Pacific are used by NIWA to make seasonal predictions of New Zealand rainfall patterns, temperatures and river flows, which can help farmers and other water users make management decisions. Because the effects of individual El Niños on regional rainfall patterns can vary, and because there are sometimes very dry or wet seasons when there is no ENSO signal present, such predictions are generally probabilistic (giving guidance on the relative probabilities of above normal, normal or below normal rainfall), rather than deterministic.

We have already mentioned that the next 2-3 decades may (on average) experience less rainfall in the south and west of the South Island than has been the situation for the last 2-3 decades, because of the IPO. This has implications for (e.g.) hydroelectricity production, the need for other back-up systems for electricity generation, and possible national greenhouse gas emissions (through any increases in thermal generation to make up for reduced hydro power).

Looking further into the 21st Century, when “greenhouse warming” influences on rainfall patterns are expected to grow, there are possible implications for a range of activities and infrastructure. For example in the eastern parts of both islands there could be an increasing agricultural demand for irrigation but less water available from those rivers which rise well to the east of the central mountains. In many parts of the country there could be increasing flood-related risks or pressures on various aspects of infrastructure, e.g., flood-prone bridges, roads and buildings in low-lying areas, and stormwater drainage systems. There could also be more problems from erosion driven by heavy rain. On the other hand, if some of the water currently stored in the Southern Alps snow pack through the winter falls instead as rain, there may be more winter hydro-generation capacity (Fitzharris & Garr 1996).

Even though the likely size of some of these projected regional changes is still uncertain, some prudent activities to adapt would be wise. This is particularly the case when such actions will also build resilience to the extremes (for example floods and droughts) already experienced. Many structures and land-uses developed now may exist for 50—100 years into the future. Thus it is sensible to consider implications of natural climate variations and human-induced changes when designing irrigation systems, roads, bridges, and urban drainage systems. For farmers, climate change may bring opportunities to develop new high-value crops in some areas, as frost risk decreases and growing-degree days increase. But farmers may also face increasing challenges of managing for dry conditions and competing for irrigation water in the east.

The question posed in the title of this paper is: Is the rainfall experienced in the past a good guide to what to expect in the future? The short answer is: Past conditions, particularly those over just the most recent 2—3 decades, are not an adequate guide to future rainfall and water availability in some parts of New Zealand. Initial information is available on how regional climate may change over coming decades (e.g., Wratt et al. 2004). There are still significant uncertainties, but research programmes are under way to understand and reduce these. Ongoing monitoring of New Zealand’s climate and river flows is also important, so that predictions can be tested against reality, and the differences used to improve understanding and modelling capability.

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