Climate reality - actual and expected

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Abstract

New Zealand average surface temperatures have increased by 0.7 °C since 1871. In the last quarter of the 20th century, more prevalent west to southwest flows occurred, accompanying a higher incidence of El Niño events. This resulted in annual rainfall decreasing in eastern areas of the North Island. As well as the global warming signal, interannual to decadal climate variability is a strong feature of east coast dryland climates. The El Niño-Southern Oscillation, (ENSO), through El Niño/ and La Niña episodes, drives climate variability seasonally. The recently described Interdecadal Pacific Oscillation (IPO) shifts climate every one to three decades and changes precipitation averages in these areas. These features of the climate system leave east coast dryland farming open to considerable climate variability.

Records of potential soil moisture deficit (PSMD) around Napier and Ashburton show that significant PSMD developed in these regions by 1 December, in 50 to 85% of years with severe deficits in 20 to 55% of years. These deficits build as summer progresses. El Niño events intensify, whilst La Niña episodes normally ameliorate these conditions on seasonal time scales. The IPO climate shifts significantly change the dryness of the soil of these areas, with the transition from negative to positive phases increasing PSMD by 35 to 50 mm.

Climate change over the next few decades will be driven by the underlying trend of global warming. For New Zealand, this will be a warming of about 0.2 °C per decade. The latest scenarios and climate model results indicate that westerly circulation is likely to strengthen over New Zealand, with a drying of east coast climate in the order of 10% by 2080. These will cause an increase in PSMD in the order of 20 to 30%. ENSO and IPO variability will be a continuing feature of New Zealand climate in coming decades.

East coast dryland farms experience substantial climate variability. As climate warming continues in the decades of the 21st century, these areas will become increasingly stressed as potential evapotranspiration (PET) rates increase, particularly when the IPO next changes phase and during El Niño events. Climate forecasting is an exciting new technology that will give farmers early warning and increase preparedness for dry seasons ahead, allowing them to make key strategic decisions. A mixture of new and traditional technologies will also assist, such as intercropping and use of seasonal climate forecasting. Despite this, dryland farming systems are likely to become increasingly limited owing to low rainfall and high potential evapotranspiration rates.

Introduction

In New Zealand dryland climates rainfall does not satisfy plant water demands, because there is not enough rain to meet the demand of potential evapotranspiration (PET). The deficit in rainfall can be quantified as the potential soil moisture deficit (PSMD) - the accumulated difference between PET and rainfall over the July to June growing season. PSMD levels that will not sustain plant growth develop once values are in excess of 100 mm, with significant loss of pasture production when deficits are greater than 150 mm (McAneney *et al.* 1982; Porteous *et al.* 1994). In the dry eastern areas of New Zealand, PSMDs over the growth season typically accumulate to between 300 and 500 mm, with values in the order of 100 to 150 mm by the beginning of December, and further deficits of 120 to 150 mm accumulating in January and February. The PSMD, because it is cumulative, is a measure of the intensity and duration of drought. The historical timing, frequency and duration of such events have important implications for management options for dryland pastures.

New Zealand average surface temperatures have increased by 0.7 °C since 1871 (Folland *et al.* 2003). The warmest year on record was 1998 (Salinger *et al.* 2000). In the last quarter of the 20th century more prevalent west to southwest flows occurred accompanying a higher incidence of El Niño events. This resulted in annual rainfall decreasing in eastern areas of the North Island. East coast dryland climates are also variable. The El Niño/Southern Oscillation (ENSO) drives actual climate variability on an interannual basis (Mullan 1995). The Interdecadal Pacific Oscillation (IPO), shifts climate every one to three decades (Mantua *et al.* 1997; Salinger & Mullan 1999; Salinger *et al.* 2001; Salinger 2000a and 2000b). Climate change over the next few decades will be driven by the underlying trend of global warming. For New Zealand this translates to a warming of about 0.2 °C per decade (Wratt *et al.* 2003). However, interannual to decadal climate variability will operate in coming decades on this background trend.

As climate warming continues in the decades of the 21st century, the dryland east will become increasing stressed as PET rates increase. This paper reviews the development of drought and PSMD from the historical record at two typical east coast dryland locations. The implications of ENSO (interannual) and IPO (decadal) variability underneath the background climate trends from global warming will be discussed together with climate forecasting as a new technology that will give farmers early warning and increase their preparedness for dry seasons ahead.

Historical potential soil moisture deficit

The PSMDs have been calculated for two typical east coast locations: Napier in Hawke's Bay and Ashburton Domain in Canterbury. The PSMDs have been calculated over the July to June growing season, where PET is the accumulated difference between PET and rainfall on a daily basis. These calculations were made for the period 1930 to 2002 (Figure 1a). The rainfall records were carefully screened for possible heterogeneities of the data by examining station histories (Fouhy *et al.* 1992) to identify site changes or other possible environmental changes near the climate station site. Statistical procedures (Rhoades & Salinger 1993) were then used to homogenise the data.

Ashburton is typical of Canterbury dryland areas and had an average PSMD of 325 mm over the 71-year period. This region's PSMD was over 500 mm in 1984/85 and below 120 mm in 1950/51. Significant deficits will depend on the water holding capacity of soils, which varies depending on the soil type and depth. For the purposes of this study, 100 mm is used as a significant PSMD and 150 mm as a severe PSMD (McAneney *et al.* 1982). A significant PSMD of 100 mm or more from 1 July to 1 December occurs in about half of the years (Table 1) and for 70% of the years in January and February (Figure 1b). The frequency of severe PSMD is 18 and 33%, respectively, for the earlier and later times of the year.

Napier is typical of the dryland conditions in the east of the North Island. In contrast with Ashburton, rainfall at Napier is higher (annual mean 830 mm, c.f. with 750 mm at Ashburton), and higher PET rates, by about 140 mm, leading to higher potential deficits (Figure 1a). Significant PSMDs occur in 85% of years to the period 1 December, and also in the 1 Jan – 1 Mar period (Figure 1b). The frequency of severe PSMD also increases to a frequency of 55 and 52%, respectively, for early and late periods. The Napier average PSMD for the July to June year of 444 mm is a result of higher mean annual temperatures and more solar radiation than in Canterbury. A consequence of this is that severe PSMD develops earlier in Hawke's Bay than in Canterbury, and its occurrence is also more frequent later in the season.

Actual climate variability

The strong variability of east coast dryland climates is associated with fluctuations in the prevailing westerlies and in the strength of the subtropical high-pressure belt. There are two key natural cycles that operate over timescales of years (Southern Oscillation) and decades (IPO).

The ENSO is a tropical Pacific-wide oscillation that affects pressure, winds, sea-surface temperature (SST) and rainfall (Gordon 1986). In the El Niño phase, the easterly trade winds weaken, and SSTs in the eastern tropical Pacific can become several degrees warmer than normal. New Zealand experiences stronger than normal southwesterly airflow (Mullan 1995). This generally results in lower seasonal temperatures for New Zealand, and drier conditions in the northeast of the country. Conversely, La Niña events weaken the prevailing west to southwest airflow over New Zealand, allowing more moisture to be brought into these regions in easterly and northeasterly episodes. In contrast, dryland areas in Otago and South Canterbury receive less rain. Recently shifts in climate have been detected in the Pacific basin, driven by the IPO (Salinger & Mullan 1999), which shifts climate every one to three decades. The two phases of the IPO bring either drier conditions, especially to eastern areas of the North Island, or wetter and warmer conditions.

To quantify the impacts of these features of natural variability, potential deficit years were partitioned into (a) El Niño and La Niña years and (b) IPO positive

Table 1 Magnitude of potential soil moisture deficit (PSMD) (mm) at Ashburton and Napier from 1930-2002.

	Ashburton		Napier	
PSMD (mm)	No. Years	% Years	No. Years	% Years
1 Jul – 1 Dec > 100	36	51	60	85
1 Jul – 1 Dec > 150	13	18	39	55
1 Jan – 1 Mar > 100	49	69	61	85
1 Jan – 1 Mar > 150	23	33	37	52

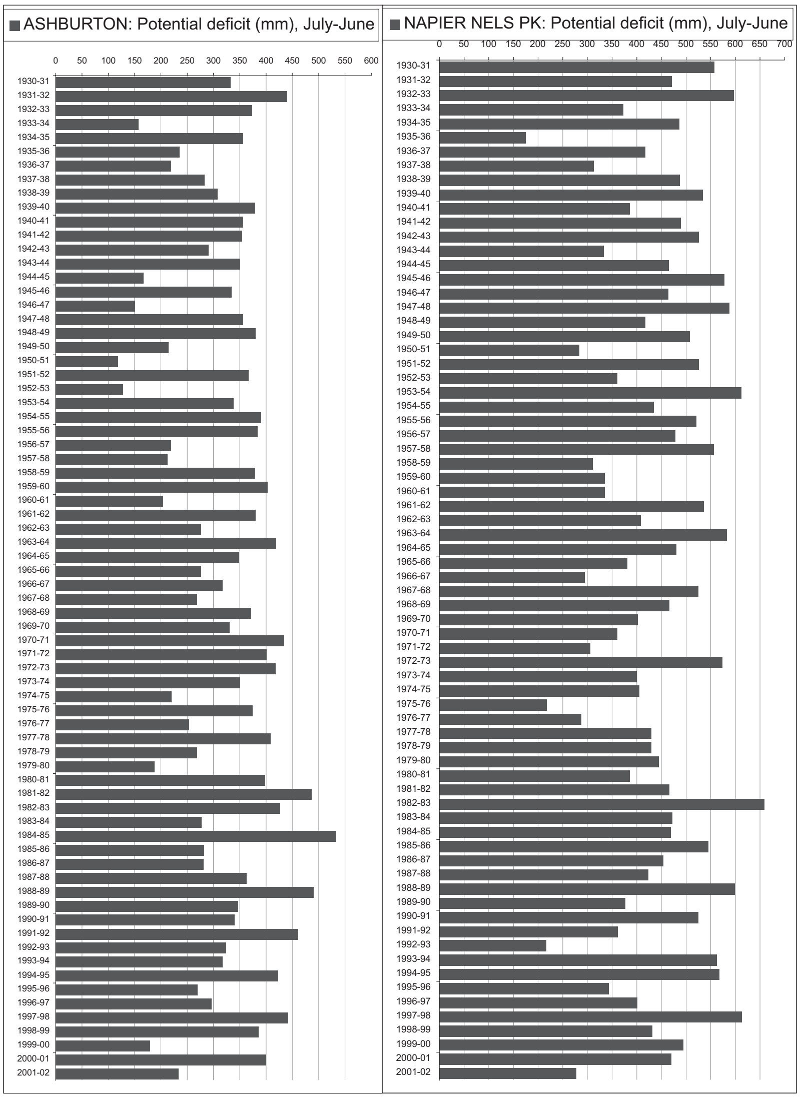

Figure 1a Potential soil moisture deficit (PSMD) in mm accumulated over the July-June growing season for Ashburton and Napier for the period 1930-2002.

and IPO negative years. El Niño seasons were drier at both Ashburton, and especially Napier, in comparison with La Niña seasons (Table 2). Similarly, the IPO positive phase, decades when stronger westerlies prevail with more anticyclones over northern New Zealand, is associated with significantly higher PSMD values at these two sites compared with the wetter, more easterly negative phase.

Expected climate change

For New Zealand the effects of global warming translates to a warming of about 0.2 °C per decade. The latest scenarios and climate model results indicate that the westerly circulation is likely to strengthen over New Zealand, with a drying of east coast climate in the order of 10% by 2080 (Wratt *et al.* 2003). Changes in annual and seasonal temperature and precipitation for regional council areas (Table 3) have recently been published (Wratt *et al.* 2003).

These scenarios show clearly that the dryland areas of New Zealand will become warmer and drier, except in the western parts of Otago and Canterbury foothills. Midrange precipitation decreases are in the order of 15% in Gisborne and Hawke's Bay and 5 to 10%, respectively, in Marlborough and eastern parts of Canterbury. The midrange temperature increase of 2 °C will increase PET rates in the order of 5%. This will translate to an increase in PET of about 50 mm at Napier and 40 mm at Ashburton, with respective midrange decreases in annual rainfall by 125 and 55 mm. Thus, climate warming will significantly increase PSMD at these two locations. The magnitude of change is in the order of 175 mm at Napier and 90 mm at Ashburton, implying earlier development of significant and severe PSMD in dryland east coast areas.

Climate variability will operate in coming decades on these background trends. The IPO very likely changed phase in or near 1998 (Salinger *et al.* 2003). This is expected to produce a warmer and wetter climate for many east coast dryland areas, but with lower precipitation in Otago and South Canterbury for the next two decades. On top of these decadal changes, ENSO will continue to increase the interannual variability that already occurs. Finally, other phenomena, such as volcanic eruptions, which inject aerosols into the stratosphere, produce significant climate perturbations sporadically.

Discussion and conclusions

Managing climate variability and change requires climate-proofing activities that address increasing variability, extremes, shifts and changes from seasons to decades and longer-term change during the 21st century. In particular, adaptation of dryland farming systems to increasing climate

Table 2 Impacts of annual and decadal variability on potential soil moisture deficit: Ashburton and Napier.

	Ashburton PSMD (mm)	Napier PSMD (mm)
El Niño	367	494
La Niña	340	429
IPO positive	361	466
IPO negative	312	431

Figure 1b Potential soil moisture deficit (PSMD) in mm accumulated over the 1 July to 1 December (black) and 1 January to 1 March (grey) seasons for Ashburton and Napier for the period 1930-2002.

Table 3 Range of predicted changes for each regional council area in seasonal and annual mean temperature (in °C) and precipitation (in %), for 1990 to 2070-2099 (the "2080s"), scaled to the full IPCC range of global warming (adapted from Wratt *et al.* 2003).

	Temperature (°C)				
	Summer	Autumn	Winter	Spring	Annual
Gisborne	0.4 to 3.9	0.5 to 3.8	0.8 to 4.1	0.6 to 3.4	0.6 to 3.8
Hawke's Bay	0.3 to 3.9	0.5 to 3.8	0.8 to 4.0	0.5 to 3.3	0.5 to 3.8
Marlborough	-0.2 to 3.5	0.4 to 3.6	0.9 to 4.1	0.2 to 3.3	0.4 to 3.5
Canterbury	0.0 to 3.3	0.4 to 3.5	0.8 to 3.9	0.3 to 3.1	0.5 to 3.4
Otago	-0.1 to 2.7	0.4 to 3.3	0.7 to 3.5	0.2 to 3.0	0.4 to 3.1
Precipitation (%)					
Gisborne	-22 to +19	-56 to +13	-38 to +24	-72 to -4	-35 to +4
Hawke's Bay	-31 to +26	-54 to +11	-43 to +25	-59 to -1	-37 to +5
Marlborough	-23 to +46	-22 to +12	-32 to +37	-37 to +14	-24 to +15
Canterbury	-28 to +51	-44 to +36	-70 to +93	-47 to +34	-41 to +42
Otago	-11 to +46	-25 to +46	-22 to +129	-16 to +45	-9 to +57

variability and extremes will provide some protection to long-term change. Such strategies include improved paddock, grazing and livestock management and better water supply in paddocks.

Modern climate forecasting provides climate guidance for the next three months, with a lower level of trend guidance in climate to six months. El Niño seasons, compared to La Niña seasons, are consistently drier in the eastern dryland regions of New Zealand, by 25 to 50 mm, with significant and severe PSMD developing earlier in the growing season. This seasonal climate forecasting can increase preparedness and lead to better social, economic and environmental outcomes for farmers and their communities. Such forecasting is one of many risk management tools that can play an important role in decision-making. To effectively manage risk, a participatory, cross-disciplinary research approach is needed that brings together institutions (partnerships), disciplines (such as climate science, agricultural systems science, rural sociology, etc.) and people (scientists, policymakers and direct beneficiaries) as equal partners to reap the benefits from climate forecasting. Climate science can provide insights into climatic processes, agricultural systems science can translate these insights into management options and rural sociology can help to determine the options that are most feasible or desirable from a socio-economic perspective.

The IPO climate shifts provide medium-term planning horizons that can be made for the decade commencing 2000. The recent shift to the negative phase of the IPO implies a wetter and warmer climate, especially in dryland areas of Gisborne and Hawke's Bay. This reduces PSMD deficits by 35 to 50 mm. Such a reduction will be of benefit to dryland management systems. However, the predicted next IPO shift to the positive phase in the decade 2010 or 2020 will provide a challenge.

Climate models of 21st century global warming coupled with climate scenarios provide sensitivity analysis tools for long-term planning. To implement these successfully requires close cooperation between research agencies and agribusiness. Dryland pastoral systems need to be resilient to wetter and drier seasons and decades. It is essential that emphasis be placed on long-term planning for the management of dryland systems with global warming. All projections indicate that a drying of climates in these areas will place more limitations on farming systems because of lower soil moisture levels. East coast climates will continue to vary as they warm with drying from Gisborne to North Canterbury, should the scenarios of future climate prove correct.

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