OFFICE OF THE PRIME MINISTER'S SCIENCE ADVISORY COMMITTEE

New Zealand's changing climate and oceans: The impact of human activity and implications for the future

An assessment of the current state of scientific knowledge
by the Office of the Chief Science Advisor

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Foreword

The purpose of this report is to provide New Zealand with an update on the current scientific understandings of climate change and the ways in which it is likely to affect New Zealand over coming years and decades. My Office has been assisted by some of New Zealand's leading climate scientists in preparing this report. The report focuses particularly on describing likely effects on various regions of New Zealand and explains why only considering predicted average changes leads to an underestimation of the impact of predicted climate change on our environment and economy.

The science of climate change is both complex and evolving, and it can therefore be difficult for the layperson and policy maker to navigate. Nevertheless, it is important that we all have an understanding of the most likely scenarios ahead as greenhouse gases continue to accumulate in our oceans and atmosphere. Climate change and associated ocean acidification have the potential to affect New Zealand directly and indirectly over the coming years. Many decisions will be required at both national and local levels, and within both the public and private sectors. These decisions will need to be made in the face of inevitable and unresolvable degrees of scientific uncertainty.

An inherent feature of climate change science is its complexity and it must deal with many unknowns. Considerable research into the effects of greenhouse gases has been undertaken globally and, despite inevitable uncertainty, there is a very high scientific consensus regarding the likely magnitude, approximate timing of and the nature of the challenges ahead. It would be highly imprudent to ignore such projected scenarios just because they must be expressed in terms of probabilities rather than certainties. It is important to apply an understanding of uncertainty and of risk and their management to address this challenge and this means using the available and accumulating evidence appropriately. Just because there is an inherent level of uncertainty does not obviate the probability of impactful climate change and the need to be proactive in addressing it through mitigation and adaptive strategies.

This report intentionally does not address questions of what policy actions should be taken in response to the currently available knowledge on the future of the global and regional climate. The key decision of when and how to respond to climate change falls beyond the scope of this report, not least because it involves considerable reflection about societal values. It will be necessary for New Zealand to address a number of challenges that have both a scientific and value component. These include:

- What is an acceptable level of climate-related risk to society?
- What are the costs and benefits of adaptation or mitigation compared with other priorities?
- How are different stakeholders affected, (either now or in the future)?

Across these considerations, there are also questions relating to inter-generational equity and international responsibility. These are among the policy-relevant questions that are, and will need to be, addressed. Science can inform these, but cannot alone answer them.

Sir Peter Gluckman

Executive summary

An assessment of current scientific reports[1] on the global climate show a very high level of consistency with previous work and with the continuing scientific consensus. There is unequivocal evidence that the Earth's climate is changing, and there is strong scientific agreement that this is predominantly as a result of anthropogenic greenhouse gas emissions. Any short-term departures from the long-term warming trend can broadly be explained through a combination of other causes of climate variability and inherent lags in the system. That is not to say that our understanding of the global climate is complete; inherent in any scientific assessment of the future is a component of uncertainty[2]. There is no way to completely remove uncertainty, given the nature of climate science and the climate system, but despite this there is strong scientific consensus on the general trends and drivers of recent climate change. The most probable future scenarios are cause for concern.

For New Zealand, the resulting impact of changes in wind patterns, precipitation, and the chemistry of our oceans can be expected to be at least as significant as the changes in temperature itself. Such changes are not expected to be uniform across New Zealand; there may be pronounced differences between the North and South Island and between the East and West coasts, and there are also likely to be unequal and important effects on seasonal patterns of rainfall and extreme weather events.

In the intermediate term (over the next 30-40 years)[3], New Zealand will face significant adaptive requirements to cope with these shifts in climate and there will need to be a consequent readjustment in expectations of frequency of extreme events. The impact of change is likely to be greatest in domains unable to adapt quickly or in those areas already close to limits of tolerance. These include natural and farming ecosystems evolved to function in current conditions and infrastructure requiring a long lead-time to plan and build, but also areas with high vulnerability such as those already prone to flooding or drought. The magnitude of environmental changes will depend in part on the global trajectories of greenhouse gas emissions and land use change. Given there is significant uncertainty in such future trajectories, and natural variability within the system, future climate projections are best represented as probabilistic distributions. It is important to understand that the average predictions represent what is calculated to be the most likely pattern of change, but there is always the potential for more or, indeed, for less extreme change to occur. Effective risk management also requires consideration of the possibility of experiencing more extreme components of the predictive range.

Continuous and on-going work is needed to monitor climate and environmental change across New Zealand, and to test and improve estimates for future changes specific to New Zealand. Advances have been made in the past five years in assessing some impacts of change, however many gaps still remain. In addition, the understanding of second-order[4] and higher level effects are very limited for all sectors. As an example, climate change may alter the spatial distribution of existing food production, leading to pressure for land use change in new areas and destabilisation of social settings where such change occurs. Finally, given that global emissions continue to track near the upper end of previous projections, it will be important to gain a better understanding of the adaptive capacity of New Zealand to more extreme scenarios of climate change.

A risk management approach is needed when New Zealand faces the likelihood of significant impacts. An upcoming paper from the Office of the Chief Science Advisor will discuss the interpretation and communication of risk generically in more detail. Active and adaptive management is required.

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[1] There is also considerable information synthesised by authoritative science bodies available to the general public, one recent example is 'The Science of Climate Change: Questions and Answers' by the Australian Academy of Science.

[2] For a good discussion about scientific uncertainty and how this is addressed within science see 'Making Sense of Uncertainty: why uncertainty is part of science'; A report from Sense about Science 2013: *http://www.senseaboutscience.org/resources.php/127/making-sense-of-uncertainty*.

[3] Over shorter time intervals, changes due to natural variability may appear to dominate over anthropogenically-driven trends.

[4] In this context, a first order effect is a change as a result of global warming, a second order effect occurs as a result of some reaction to this new change.

The strong dependence of New Zealand's economy on international trade implies that the country will also be affected by the impacts of climate change other nations' economies, and by changes in production internationally as well as in New Zealand. It is therefore important to consider New Zealand in a global context and not as an isolated system.

The table below summarises some of the projected changes by region and season, described in more detail within the report.

Table 1: Summary of projected changes (increases are relative to the 1980-2000 average)

Geographic zone	Ocean acidification	Temperature & extremes	Wind and circulation	Mean Precipitation	Seasonal & extreme precipitation and drought
All New Zealand	pH changes are greater in cooler waters.	The midrange of projections is an average temperature increase of 0.9°C by 2040, 2.1°C by 2090.	Increase in strongest winter winds by 2100.	Little change in the mean for all New Zealand but large geographical variation.	Heavier and more frequent extreme rainfalls, but also more droughts. On average, 2 or more extra weeks of drought annually by mid-century for much of North Island and eastern South Island.
North Island	Upwelling areas such as the Hauraki Gulf are more vulnerable to a given change.	Halving or more of the number of frosts by 2100 in the central plateau (to <15 days per year). 40+ extra hot days (>25°C) a year in Auckland by 2100.	Less westerly wind component and more easterly episodes, as tropical zones move south in summer.	By 2040 overall precipitation decreases in the east by up to 5% (though seasonally variable), with smaller changes in the west.	West - In summer and autumn rainfall decreases, in winter and spring rainfall increases by up to 5%. East (Gisborne/Hawkes Bay)- decrease in rainfall in winter and spring by up to 5 to 10%.
South Island (incl. Southern Ocean)	Impact in high latitude Southern Ocean expected first, from 2040 onwards.	Frosts expected to be rare in coastal locations by 2050.	More frequent and stronger westerlies during winter and spring.	By 2040, increases in the west by 5% and decreases in the east (smaller change).	In winter and spring, more precipitation in the west and south (10% or more increase – responsible for much of the annual change), reduced precipitation in the east (north of Oamaru). Heavier and more frequent extreme rainfalls.

*Where years are quoted, these are the mid-years of a c.20 year average (e.g. 2040 is for 2030-2049).

Sources: PMCSA presentations 8 May 2013, James Renwick and NIWA.

1. Global context

The Intergovernmental Panel on Climate Change (IPCC) is due to release the first component of its 5th Assessment Report in late September 2013[5], updating its previous report, which was released in 2007. While it is not appropriate to pre-empt the detailed findings of the report, over the past six years the published literature has largely consolidated previous understanding of climate change. New Zealand scientists have made important contributions to writing and reviewing the IPCC report. Evidence for impactful climate change has increased, and multiple lines of evidence continue to point to anthropogenic emissions of greenhouse gases as the primary driver of global climate change over the last fifty years. Recently published analyses[6] indicate that when natural variability (e.g. due to the solar cycle and El Niño years) and volcanic effects are removed, observed multi-decadal trends are highly consistent with IPCC predictions made in the early 1990s. These predictions were based on climate modelling of greenhouse-gas induced trends.

The next IPCC report will present findings of modelling work, which uses a revised set of emissions, concentrations and land cover change projections[7] designed to assist with increasing granularity for regional analysis. These changes have the potential to cause some confusion if the results are presented out of context, but it is important to emphasise that there are no significant alterations in the climate projections for any given trajectory of increases in greenhouse gas emissions over the coming years. As will be discussed later, important advances have been made in terms of modelling and assessment capabilities for New Zealand's regions.

The 4th IPCC Assessment identified that even a 2°C increase[8] in global mean temperature is likely to have substantial environmental, economic and human impacts, however maintaining the global climate within this threshold is now extremely challenging. A recent International Energy Agency report[9], highlighted that if current trajectories of emissions continue, the average temperature increase by 2100 is more likely to be between 3.6°C and 5.3°C (compared with pre-industrial levels). To have even a 50% chance of staying below the 2°C benchmark means that no more than 1.8 trillion tonnes of CO_2 can henceforth be released into the atmosphere.[10] At current rates of emissions, this amount would have been released before 2050.

Key points: Global context

- The scientific conclusions about climate change remain consistent with previous studies and reports;
- Atmospheric concentrations of CO_2 have continued to rise. Ocean temperatures are rising and acidification is occurring;
- Climate change is happening now. A 0.8°C rise in global mean temperatures has occurred since pre-industrial times.

Since the last IPCC report in 2007, concentrations of CO_2 in the atmosphere have continued to rise at about 2 parts per million (ppm) per year. They are now near the symbolic milestone of 400 ppm[11] compared with pre-industrial levels of c.280 ppm.[12] It is thought that the last time such levels were reached was certainly more than 1 million years ago, and likely more than 3 million years ago.[13]

[5] Working Group 1 Summary for Policymakers, the full WG1 report is due January 2014, with WG2 and WG3 reports to follow later in 2014.

[6] M. R. Allen, J. F. B. Mitchell & P. A. Stott, 2013, Nature Geoscience DOI: 10.1038/NGEO1788; D. J. Frame & D. A. Stone, 2012, Nature Climate Change, DOI: 10.1038/NCLIMATE1763.

[7] These projections are not forecasts for potential emissions, land use or climate change but are designed to provide a consistent input for climate modelling. They are known as Representative Concentration Pathways (RCPs).

[8] The UN Framework on Climate Change target agreed in Cancun, 2010, measured relative to pre-industrial times.

[9] Redrawing the energy climate map, IEA, June 2013.

[10] M. R. Allen et al., 2009, Nature, DOI:10.1038/nature08019; M. R. Allen et al., 2009, The Exit Strategy, Nature, DOI:10.1038/climate.2009.38.

[11] CO_2 concentrations vary on a seasonal basis, therefore the annual average is below this level.

[12] 275-285ppm. IPCC, Synthesis Report, 4th Assessment Report, 2007.

[13] The ice core containing the oldest ice is from Antarctica (EPICA Dome C), dating back 800,000 years. Throughout this record CO_2 varies from 180ppm to 300ppm, well below current levels. Work by Pagani et al (2009) suggests that CO_2 levels were similar 3-4.5 million years ago, when the Earth was thought to be 2- 4°C warmer. Modern humans have lived on the planet for less than 200,000 years.

To date a rise of 0.8°C[14] in global mean temperature has been observed since pre-industrial times, with two-thirds of this rise having occurred since 1975. However, the full response to a rise in greenhouse gas concentrations is not felt immediately but manifests itself over many decades to centuries as different aspects of the climate system respond at different rates. Given these systemic lags, there are likely to be further temperature rises as the system stabilises, even if there were little or no additional anthropogenic emissions.[15] Given the uncertain success of mitigation initiatives (which must be considered at the global level), there is therefore now a greater need to understand the consequences of climate change in excess of 2°C.

1.1. Climate variability, lags and buffers

Various studies[16] and reports in the popular press have highlighted a relative 'pause' or hiatus in the rate of rise in the global mean surface temperature over the last decade or so. This is consistent with model simulations, in which decades of no change, or even cooling, can be expected despite the long-term trend of increasing global temperatures.[17] This internal or natural variability is driven by coupled atmosphere-ocean phenomena (such as El Niño) that are characterised by complex dynamical behaviour and multi-annual to multi-decadal timescales, examples of which can be found in Table 2. The Earth also experiences variation in energy received from the sun over short timescales (as a result of changes in sunspot activity) and temporary increases in the amount of energy reflected by the atmosphere following volcanic eruptions. Eruptions emit aerosols and dust, which leads to global cooling that can last several years.

By monitoring and understanding these causes of natural variability alongside anthropogenic changes, it is possible to distinguish the influence of each over a particular period. The current 'pause' in the overall trend is thought to be partly a response to natural variability including a temporary decline in the amount of energy received from the sun, which has naturally cycled towards a relatively strong solar minimum[18] in 2009. This has been accompanied by the effects of a series of moderate volcanic eruptions over the last decade or so.

Key points: Variability, lags and buffers

- Over short time periods, natural variability has a significant impact on the global warming trend;
- Short periods of no change or even slight cooling are to be expected, despite a continued long-term warming trend;
- At times natural variability may even amplify warming;
- Global surface temperatures are only part of the picture, the ocean is a much larger heat sink than the atmosphere;
- The reported recent 'hiatus' in the rate of rise of temperature does not signal that climate change has 'stopped' or is no longer a concern.

The atmosphere is not the only reservoir for heat. Covering the majority of the Earth's surface, and with an average depth of 4km, oceans provide the primary heat reservoir, with respect to the Earth's overall heat content.[19] Indeed, evidence points to warming of the oceans since pre-industrial times; they have absorbed about 90% of the total additional energy retained by the Earth as a result of global warming. In recent times, observations of the heat content of the top 2000m of the ocean have continued to show a warming trend, even during the period of apparent hiatus in global mean atmospheric surface temperatures (see section 2.1).[20]

Finally, the period without a significant rise in mean global temperature is relatively short (of the order of a decade) compared to the overall trends seen in the record. It should also be noted that mean global temperature is still at a historically high

[14] Goddard Institute for Space Studies (GISS), NASA.2010.

[15] T. M. L. Wigley, 2005, Science, DOI:10.1126/science.1103934.

[16] G. A. Meehl et al., 2011, Nature Climate Change, DOI: 10.1038/NCLIMATE1229.

[17] D. R. Easterling and M. F. Wehner, 2009, Geophysical Research Letters, DOI:10.1029/2009GL037810.

[18] The solar radiation, or amount of energy the Earth receives from the sun varies through time.

[19] S. Levitus et al., 2012, Geophysical Research Letters , DOI:10.1029/2012GL051106.

[20] G. A. Meehl et al., 2011, Nature Climate Change, DOI: 10.1038/NCLIMATE1229.

Table 2: Causes of natural climate variability, over a range of timescales

	Annual and Inter-annual	Inter-decadal	10,000 yr+	100,000 yr+
Ocean-atmosphere interaction	El Niño/Southern Oscillation (recurrence time 2-2.5 years) – Pacific ocean warming and global temperature rise and fall with El Niño and La Niña.	Interdecadal Pacific Oscillation recurs every 20-30 years and modulates ENSO cycle. Atlantic Multidecadal Oscillation, recurrence 50-80 years.		
Aerosols and dust	Large volcanic eruptions emit aerosols and dust leading to global cooling that can last several years.[22]			
Solar input		11-year sunspot cycle.	Earth's orbit (20,000 year and 41,000 year cycles).	Earth's orbital eccentricity cycle.

level. In fact, 17 of the 18 hottest years on record have occurred since 1995[21]. [22]

1.2. Climate sensitivity

There has been recent discussion particularly in the lay press regarding estimates of the Earth's equilibrium climate sensitivity (how much the mean atmospheric temperature might eventually change resulting from a doubling of CO_2 levels over pre-industrial levels).

In fact there are a range of estimates in the literature, which cover the central values of estimates put forward by IPCC in its past assessment reports and which reflect methodological differences in how this question is approached. There has been some disagreement over how to quantify the upper and lower bounds of climate sensitivity, (the scientific details of estimating this depend on the relative weights assigned to different data, different statistical treatments and so on). The weight of the evidence, however, continues to support the range of estimates provided by the IPCC in its first to fourth assessments. Recent estimates do not significantly affect conclusions on the likely future trajectory for the planet and the likely broad timescale of expected changes, given the magnitude of the challenge of emissions reduction.

[21] NIWA Presentation to PMCSA, 8 May 2013.

[22] The impact of Mt Pinatubo eruption in 1991 lasted for 2-3 years and resulted in a 0.5°C global cooling effect. Parker et al., 1996, Int. J. Climatol., DOI: 10.1002/(SICI)1097-0088(199605)16:5<487::AID-JOC39>3.0.CO;2-J.

2. New Zealand changes

2.1. Observations

New Zealand has world-class data records monitoring changes in our climate. The CO_2 record from Baring Head comprises the longest continuous record of CO_2 concentrations in the Southern Hemisphere. CO_2 is a well-mixed gas in the atmosphere and therefore, despite the majority of CO_2 emissions occurring in the Northern Hemisphere, the atmospheric concentration is similar in New Zealand[23] with measurements now approaching 400 ppm. When record keeping began in the early 1970s, the first measurements found CO_2 concentrations to be 325ppm.[24] Baring Head also monitors methane concentrations, which have increased from c.1660ppb to c.1760ppb since 1990.[25]

More than 25% of anthropogenic CO_2 emissions dissolve in the ocean resulting in ocean acidification. It is therefore not only the atmospheric concentration of CO_2 that requires monitoring. New Zealand now also has important time-series measurements in an ocean transect across and beyond the continental shelf from Dunedin. These measurements suggest an average pH drop of 0.02 since 2000.[26] While this

[23] There is a small lag between CO_2 records in the Northern and Southern Hemispheres due to mixing. In all records there is also seasonal variability. It is expected to be several more years before the annual average CO_2 concentration rises above 400 ppm.

[24] NIWA: *https://www.niwa.co.nz/news/internationally-significant-co2-site-celebrates-40-years.*

[25] Following a period with little increase in the period immediately before the last IPCC report, emissions have now resumed the upward trend at a comparable rate.

[26] Presentation to PMCSA, Keith Hunter, Otago University, 8 May 2013.

Box 1: Climate projections – dealing with uncertainty

Despite the overwhelming scientific consensus about the underlying causes of changes to the Earth's climate, all predictions of future climate patterns and their impacts necessarily have some degree of uncertainty arising from three main sources:

1. inherent uncertainties in the future evolution of natural variability;
2. uncertainty associated with climate model responses;
3. socio-economic uncertainty that affects such projections because of the feedback effects arising from human action or inaction in terms of emissions and population growth.

The relative importance of these sources of uncertainty varies through time, from variable to variable and with spatial scale[1]. At the global scale natural variability dominates the short term while the uncertainty of socioeconomic responses increases in significance with time. As a consequence, climate projections are typically given as likely ranges associated with a particular scenario.

The fact that modelling does not deliver a single answer or an outcome with 100% certainty does not discredit its use or potential importance as a tool. Indeed, the use of highly calibrated models is the only method we have to predict the future since there is no physical experiment conceivable that can address the questions. Nevertheless, all modelling results should be understood to be projections and benefit from calibration and review based on observational data.

To some extent, the performance of models can be verified through their ability to predict the past and their performance in predicting observed climate changes that have occurred since their creation. For example, the eruption of Mount Pinatubo in 1991 showed that the existing models accurately predicted the 0.5°C cooling which resulted over the years following the event. The best available comparisons between climate models suggest that models respond to the historical combination of natural and anthropogenic forcings in reasonable agreement with observations and typically capture aggregate features, although performance does vary with spatial and temporal scale[2].

When carrying out a risk assessment for the potential impact of climate change, it is important to recognise that there is (and will continue to be) some degree of uncertainty in the evidence. Reports and studies often present a wide range of values of what may happen in the future. In this case it should be recognised that all values are not equally likely. The 'Representative Concentration Pathway' scenarios, that are expected to be described in the 5th IPCC report, cover the full range of projections currently available in the scholarly literature. The lower bound scenario has zero or negative CO_2 emissions by 2100 (declining steeply from 2050), which would require concerted and sustained international action at an unprecedented level.

Sometimes a single likely value (rather than a range) may be reported by way of illustration of the expected effects. For example, where it is reported that 'there is likely to be a 10% increase in drought by 2040', there is also a smaller probability of a greater or lesser extreme change. But even low probability changes with more extreme consequences may still lie beyond the level of risk that society is willing to accept.

[1] Hawkins and Sutton, 2009. doi: *http://dx.doi.org/10.1175/2009BAMS2607.1*.

[2] Randall et al, (2007), IPCC AR4 WG1.

Key points: New Zealand context

- New Zealand observations are broadly in line with global observations of atmospheric CO_2 concentration and temperature rise;
- Ocean acidification is another direct result of increasing CO_2 concentration. This change is beginning to be observed here in New Zealand;
- The combination of changing pH, ocean temperature, stratification, salinity and changing currents may have significant impact on the oceans surrounding New Zealand.

change may appear small, particularly compared to seasonal variation, a small change in the mean value represents new record low pH levels for a given time of year (following the principles shown in figure 1). The small change also compounds over many years, so that over decades (and centuries) the small change becomes more significant than the annual variation, which remains broadly constant. Finally, as pH is a logarithmic scale, a decrease of one unit of pH represents a ten-fold increase in the hydrogen ion concentration.

As stated previously, oceans are not only a major sink for CO_2 but also for heat. Thousands of profiling floats (Argo Floats) have been recording ocean temperatures and salinity as part of a global research and monitoring network since 2000. This work includes coverage in the waters around New Zealand to a depth of 2000m. Data from these floats show an increase in the water temperature over the period that, when combined with historical data, suggests a mean warming of the upper 2000m of ocean by 0.09°C since 1955[27]. Though this may seem an apparently small increase, it reflects a large increase in heat content due to the volume of water concerned.

Temperature changes in the deep ocean are more difficult to study and therefore remain an important area for future investigation globally.

[27] S. Levitus et al., 2012, Geophysical Research Letters , DOI:10.1029/2012GL051106. Mean warming of the surface layer only (0 to 700m) is cited as 0.18°C.

2.2. Changing ocean chemistry,temperature and currents

As CO_2 is more soluble in colder waters, a greater change in ocean acidification can be expected in waters near New Zealand than in waters at equatorial latitudes. This change is expected to be most significant in the Southern Ocean, with impact felt within decades at the southernmost latitudes (as early as 2050[28]) and progressively moving further north over the following century. In addition, certain areas are more vulnerable to further changes in acidification, including those with naturally lower pH levels. These include areas where deep water upwells to the surface such as in the Hauraki Gulf.[29] It is these sites that are often nutrient rich, full of marine life, and have historically been suitable for aquaculture.

Lowering the pH of the water below a threshold creates conditions in which calcium carbonate, which makes up the exoskeleton of many marine organisms, would naturally dissolve.[30] In such conditions, these species will have to work harder to maintain their structure or risk losing the protection it provides. As pH decreases, some organisms such as corals and shellfish are therefore prone to reduced growth rates and increased vulnerability to predators. Corals are also stressed by small increases in water temperature (of 1-2°C) resulting in bleaching.[31] The 2007 IPCC report highlighted the vulnerability of coral reefs such as the Great Barrier Reef, where up to 60% of the reef may be regularly bleached by 2020.

Prevailing pH is also important for other marine life and plays a part in controlling their physiology. Any changes potentially would have a direct impact on fish and other aquatic life as well as indirect effects through food webs.

[28] J. C. Orr et al., 2005, Nature, DOI:10.1038/nature04095.

[29] Deep waters have lower pH due to respiration of organic matter.

[30] Sites already with lower pH are closer to this threshold.

[31] Corals are no longer able to sustain their symbiotic relationship with zooxanthellae algae which provide food to corals as they photosynthesise and also give the corals colour. The algae are expelled under stress, often turning white hence the term bleaching. The corals may survive but their level of vulnerability is increased during this period. Some may recover once cooler water temperatures return and the algal symbiosis resumes.

As well as acidifying, the Southern Ocean is expected to continue to warm and become less saline, thereby changing the density of the water and the degree of ocean stratification, with further effects on aquatic ecosystems.[32] Changing circulation patterns are also possible due to the impact of changes in atmospheric circulation on ocean surface currents. The potential importance of this is reflected in research proposed via the National Science Challenge 'The Deep South: Understanding the role of the Antarctic and Southern Ocean in determining our climate and future environment.'

The distribution of marine species is also likely to shift; in northern New Zealand for example, changing currents are likely to promote the establishment of sub-tropical species which currently only appear in exceptionally warm years. Pelagic species (such as sharks and tuna) are projected to move further south.

The combined effect of the chemical, temperature and current changes in the surrounding oceans is likely to have an impact on the marine biodiversity around New Zealand[33], although the extent and exact nature of this effect is poorly understood, and this will have significant impact on the fishing industry. Expected changes are likely not only in fish-stock distribution but also in stock growth rates.

2.3. Changing temperatures

Surrounded by oceans, New Zealand is expected to experience a slight lag in mean temperature change compared with the global average over the medium term. New Zealand has, however, already observed a historical increase in average atmospheric temperature of 1°C (+/-0.28°C) since 1910[34], broadly in line with global observations over the same period. Global change also has indirect impacts on New Zealand's climate, by changing global atmospheric circulation patterns as discussed below.

While a change in the mean temperature of 1-2°C may appear to be small, it is the change in the nature and pattern of New Zealand's climate extremes, as illustrated in figure 1, that is likely to have a much more significant impact on New Zealanders and on the primary industries on which the country largely depends.

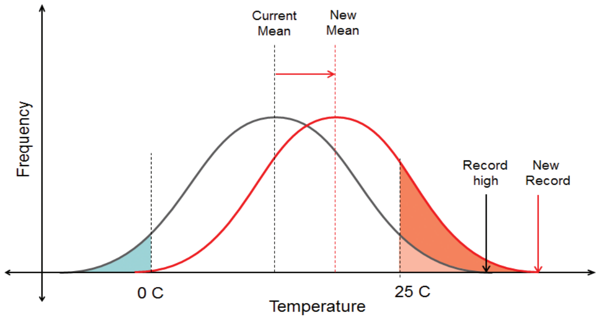
Key points: New Zealand temperatures

- Changes in the mean temperature may appear to be small, but resulting changes at the extremes have significant potential impact;
- This principle applies not only for temperature, but also for rainfall and sea level;
- New Zealand can expect new record highs for temperature;
- There is already observational evidence of changes in frequency of extreme temperatures for New Zealand.

2.4. Variation and the mean

Much attention and focus in climate change discussions have been placed on rises in global mean temperature; however, it is the shifting of the temperature distributions that translate into consequences at the extremes that are of particular significance (figure 1). The details of these changes is not as well understood, but is of critical importance to New Zealand's future climate impacts. Temperature maxima and minima, for example, are often more important than the mean shifts for species survival, and for agricultural production. A mean temperature rise of say one degree is associated with a considerable increase in the number of very warm days and a reduction in the number of very cold days.

Figure 1: The effect of increasing mean temperature on the extremes



[32] Stratification or layering in the water column affects the exchange of nutrients between levels.

[33] The oceans around New Zealand form one of the largest Exclusive Economic Zones in the world.

[34] NIWA Presentation to PMCSA, 8 May 2013. The global estimate is actually slightly lower over this period, however, due to the error margin it is not possible to say that New Zealand has warmed more or less than the global average historically.

In future New Zealand can expect what is now considered to be unusually hot weather to occur more frequently; new records will be broken for highs. While Auckland currently experiences around 21 days per year above 25°C, this figure could increase to 61 days per year by 2100 under even a low emissions scenario.[35] At the opposite end of the spectrum, there are likely to be fewer days where temperature falls below zero, resulting in record spells without frost. Already New Zealand is experiencing one third to half fewer frosts than occurred in 1930.[36] By 2050, frosts are expected to be rare throughout the North Island and all coastal South Island locations.

A discussion of the implications of these changes for the primary industries and other areas follows in section 3 of this document.

Day-to-day weather contains a chaotic element and hence cannot be predicted years in advance, climate by contrast represents a statistical average of the system. It is not possible to attribute an individual weather event to climate change, though the changing frequency of events can sometimes be linked to climate change[37]. In some cases it is possible to say extreme events will become more likely and assess their probability of occurrence. By definition extreme events occur infrequently and therefore there is less data on which to confirm increases in frequency or severity.

A 2012 special report by the IPCC on extreme events,[38] however, found that there was evidence from observations gathered since 1950 of changes in frequency of some extremes including extreme temperatures and precipitation.

2.5. Changing precipitation, atmospheric circulation and wind patterns

New Zealand already exhibits major regional climatic variation in precipitation due to its distinct geography and oceanic location. As wind and circulation patterns alter, precipitation in New Zealand is expected to change, although with significant variation between seasons and regions. Compared to 1990, mean annual precipitation is expected to increase by around 5% in the West of South Island by 2040, with most of this caused by a larger increase occurring in winter and spring (around 10% increase). By contrast mean precipitation in the east and north of North Island (around Napier and Whangarei) may decrease by 5% with a similar pattern in Canterbury. Such shifts might seem small but, for the reasons illustrated in figure 1, it is much more significant, when exposure to the extremes of summer drought are factored in.

Key points: New Zealand atmospheric conditions

- New Zealand already experiences regional variation in precipitation due to its geography. This is likely to be amplified, with even more precipitation in the west of South Island and less in the east;
- Extreme weather events are likely to increase. Significant floods and droughts are expected to be more frequent;
- An increase in extreme precipitation has already been observed.

Atmospheric circulation is driven by the redistribution of heat and therefore as global temperatures increase, changes in the dynamics and spatial patterns of circulation can be expected. The result is anticipated to strengthen differences between the existing bands of wet climate in the tropics and high latitudes, and drier sub-tropical areas. The extent of the tropical zone is also expected to widen and importantly for New Zealand, the high pressure band where warm air descends is anticipated to move southwards, from its current position (just north of the North Island) and descending over North Island in summer). This shift portends increases in the easterly wind component, with corresponding drier summer weather over the west of North Island. The predictions for summer rainfall in Gisborne and Hawkes Bay areas are less certain, with the potential for a slight increase in rain in the summer despite a drop in mean annual rainfall.

The high pressure band is still predicted to lie north of New Zealand in the winter, leading to a stronger north-south pressure gradient across the country, resulting in more frequent and possibly stronger westerlies. With this increase in westerlies, more

[35] NIWA, Climate Change: Projections for New Zealand, 2008.

[36] NIWA Presentation to PMCSA, 8 May 2013 (based on Hamilton record).

[37] P. Pall et al, 2011, Nature, doi:10.1038/nature09762.

[38] IPCC, 2012, Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. (SREX).

winter and spring rainfall is likely in the western districts of both islands (in line with an increase in mean precipitation). Potential increases in extreme winds are likely to have an effect on soil erosion in the Canterbury Plains particularly, amongst other things, most notably through an increase in the strongest winter winds. In some eastern locations the increase in the strongest winds may be up to 10% by 2100.[39]

As well as these changes associated with lower latitudes, we can expect climates to the south of New Zealand to affect the country as well. To the south, there is the Southern Annular Mode (SAM) that comprises a ring of climate variability centred over Antarctica, but extending to the latitudes of New Zealand. This is highly significant for New Zealand's weather as it controls where and how westerly winds blow. In a high emissions scenario, the current generation of climate models expect warming from greenhouse gases to result in more positive SAM phases in summer associated with a greater frequency of light wind, settled conditions for New Zealand.[40]

It is important to not only consider the average rainfall, but also how it is distributed through time. If rainfall is concentrated in heavy precipitation events, it is harder to make use of and may overwhelm existing natural ecosystems, increase slip erosion in hill country, and affect infrastructure. The distribution of rainfall across the seasons is also critical for New Zealand's primary industries as discussed in section 3 of this document. For New Zealand, increased extreme precipitation events (both the frequency and amount of rainfall) can be expected, partly due to the physical principle that warmer air can hold more moisture. There is already observational evidence of an increase in the number of days with high intensity (>25mm) rainfall events in some western parts of South Island over the period 1930 to 2004.[41] Mid-range scenarios from NIWA suggest that 1-in-100 year flood events will become 1-in-50 year occurrences by the end of the century. Conversely, with warmer temperatures resulting in increased evaporation and changed circulation patterns, there is also an increased risk of drought. On average, two or more extra weeks of drought are expected annually by mid-century for much of North Island and the eastern South Island.[42]

2.6. Changes in sea level, snow lines and retreat of glaciers

Overall sea level has been rising at a rate of about 3mm/year since the early 1990s and is now approximately 60mm higher than in 1993. This appears to indicate an increased rate of rise compared with earlier trends (1mm/year in the late 19th Century and close to 2mm/year for much of the 20th Century).[43] Thus global projections of future sea level rises have increased slightly since the last IPCC report.[44]

Sea level rise is caused by a combination of thermal expansion of the oceans (responsible for up to 50% of the change) and melting or flow of ice situated on land masses into the ocean (such as the Greenland Ice Sheet). Melting of floating ice (such as sea ice) has no impact on sea level, but melt and increased flow of land-based ice sheets into the ocean can cause a significant increase in sea level. Dynamic processes relating to land-based ice sheets were not fully included in the 2007 IPCC Assessment Report sea level projections due to a lack of clarity surrounding likely developments at the time. The terrestrially-based Greenland and Antarctic ice sheets[45] have lost solid mass during the past two decades, contributing to sea level rise[46] and an improved assessment of the contribution from such dynamic processes is now expected to be included in the 5th IPCC Assessment sea level projections.

[39] NIWA, Climate Change: Projections for New Zealand, 2008.

[40] Understanding of SAM has improved over the past 5 years; in particular the discovery of a trade-off between the gradual repair of the ozone hole and increases in concentrations of greenhouse gases which both seem to affect SAM trends. In a low emissions scenario, this could be counteracted by the recovery of the ozone layer above Antarctica.

[41] NIWA presentation to PMCSA, 8 May 2013.

[42] Natural variation will occur on a year by year basis.

[43] J.A. Church & N.J. White, Surv Geophys, 2011, DOI 10.1007/s10712-011-9119-1.

[44] J. L. Bamber & W.P. Aspinall, 2013, Nature Climate Change, DOI:10.1038/nclimate1778.

[45] Loss of mass from the Antarctic is much less certain than the losses from the Greenland sheet. Different methods have reported varying results and this is a current area of international research; Hanna et al ,2013, Nature, DOI:10.1038/nature12238.

[46] Rignot et al., 2011, Geophysical Research Letters, DOI: 10.1029/2011GL046583).

Keypoints: New Zealand region sea, snow and ice

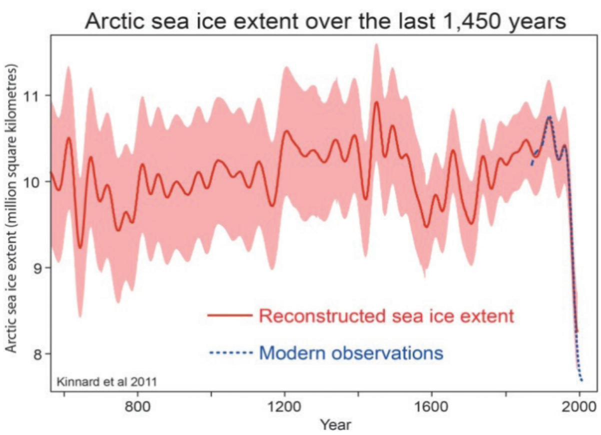
- The rate of sea level rise has been increasing and is now around 3mm/year;
- The rise is the result of a combination of thermal expansion of the oceans and the contribution of increased melting of land-based ice;
- New Zealand observed sea level rise is consistent with global change;
- New Zealand can expect an increase in the frequency of extremes of high tides and their associated risks;
- Observed changes in the Arctic sea ice are dramatic, whilst there is more variable change in the Antarctic due to the complexity of the system;
- New Zealand glacier volumes are projected to continue to decrease;
- The snow line is projected to move upwards, although at the highest altitudes snowfall may increase.

Sea level rise in New Zealand has been broadly consistent with global sea level change, with an observed rise of 170 mm (+/-10mm) since 1900. There is some regional variation (as a result of the Pacific currents, tectonic uplift and subsidence and isostatic rebound) such factors can be corrected for to separate out local and global effects. [47]

While these may seem like small average rises, their implications are serious. As illustrated in principle in figure 1, a small mean sea level rise has an exaggerated impact on the occurrence of extremes. For example current 1-in-100 tide levels can be expected to be reached more frequently and new height records set. Indeed, with a 0.8m sea level rise, the 1-in-100 high tide level will be exceeded during more than 90% of high tides[48], which will require recalibration of expectations. This has a direct impact on risk of coastal flooding, inundation, erosion and destruction of coastal habitats.

The New Zealand Ministry for the Environment guidance for local government currently recommends that a base level of sea level rise (0.5m relative to 1980-1999) be considered in planning and decision timeframes out to the 2090s. It also indicates that the impact of a potentially greater change (0.8m), and consideration of local infrastructure and storm surge levels should be included in risk assessments. Beyond 2100, it is recommended that a continued rise of 10 mm per year should be considered. These guidelines should not be treated as forecasts of sea level rise, but rather represent guides to aid in local risk assessment.

Figure2: Change in Arctic sea ice extent, Kinnard et al (2011)



Some of the most dramatic shifts have been in Arctic sea ice extent and in Northern Hemisphere snow cover. Snow cover in the Northern Hemisphere summer is now up to 10 million square km less than it was in 1967[49], while Arctic sea ice has been decreasing at a rate of 12% per decade. The Arctic is expected to be free of ice in the summer months by 2100 under a high emissions scenario, and may be ice-free much sooner if currently observed trends continue. While these aspects do not directly affect New Zealand, there are indirect feedbacks on the global climate as a whole arising from reduced snow and ice cover and associated reduced reflectance (albedo) of summer sun. Such effects will modify the Northern Hemisphere climate more directly than in the Southern Hemisphere, but New

[47] Isostatic rebound is the rise (and fall) of land masses following the removal of a weight, such as a major ice sheet following the end of the last Ice Age). Sea level can also change at a very localised level as a result of local land movements (e.g. as a result of an earthquake).

[48] NIWA presentation to PMCSA, 8 May 2013.

[49] NSIDC courtesy of Rutgers University Snow Lab. Data provided by Dr James Renwick (Victoria University).

Zealand's dependence on Northern Hemisphere markets expose us to potential economic risks associated with climate change in northern mid-latitudes.

In Antarctica the story of the sea ice extent is more complex. While the land-based Antarctic ice sheet has decreased in mass overall, there has been a slight increase in the extent of sea ice albeit with regional variation. This is testament to the complexity of the prevailing weather systems and interactions, including the hole in the ozone layer which impacts on atmospheric circulation, precipitation, and ocean circulation.

Glacier melt globally is one of the most visible effects of climate change. The behaviour of New Zealand glaciers however, is again complex because they are found in areas of high precipitation. They are sensitive not only to temperature, but also to changes in wind and precipitation patterns; thus any local gains of snow trade-off with increased melt. Despite such a trade-offs, New Zealand's glacier volumes are projected to continue to decrease, and have shown a 15% decrease in ice volume over the 30 years since monitoring began.[50]

The same trade-off applies to projections of snow cover in the Southern Alps. While increases in precipitation in the west of South Island in winter and spring will bring increased snowfall, the snow line can be expected to move up by 120-270m by 2080.[51]

3. Impact on New Zealand industry and infrastructure

This section deals with expected impacts of current climate change trends on New Zealand industry and development. Different parts of society and industrial sectors have different levels of vulnerability to change, but also varying levels of ability to adapt.

3.1. Land-based primary industries

Background

New Zealand's climate is naturally variable (both regionally and temporally), and therefore primary industries have already had to face uncertainty and develop coping strategies. In some sectors (such as pastoral farming), profitable farms exist over the wide range of New Zealand's climatic environments, showing inherent adaptability. Some of the techniques involved may be translatable, even if future climates create very different circumstances to those in the past, if producers are aware of the likely changes and are prepared to apply necessary measures. However, businesses are typically not as well prepared for the increased frequency of extreme events (e.g. two or more significant droughts in consecutive years).

> **Key points: Impact on New Zealand industries**
>
> - Impacts are expected to be spatially and seasonally variable;
> - A systemic approach is needed because to consider changes individually may lead to erroneous conclusions and inappropriate action (or inaction);
> - With some degree of adaptation near-term increases in yield/profit may be possible in some farms;
> - The impact of extreme events and changing pest scenarios need to be taken into account.

Impacts, both positive and negative, vary with season and region and therefore it is not possible to summarise here all of the likely impacts in all regions and for all industries. However, an understanding of the likelihood of changes down to a local level is important for the primary sector and there is an emerging analytical base for this, much of it developed over the past five years.

Overall, to understand the true impact of climate change, a whole-farm system approach is required in order to accommodate the effects of multiple stressors and adaptation measures. If each factor is considered in isolation, there is the potential risk of inaccurately estimating the true potential impact. There are also gaps in knowledge, particularly in the understanding of interactions between changing rainfall, rising temperature, and rising CO_2 and how these may affect plant growth.

Also, while consideration should be given to the impact of climate change on New Zealand farming

[50] NIWA conference, abstract,2012. (Monitoring period - 1976 to 2008).

[51] WG II: Impacts, Adaptation and Vulnerability, Australia and New Zealand, IPCC 4th Assessment Report, 2007. (Source: Fitzharris, 2004).

practices, it is worth considering that New Zealand farms are largely exporting to an international market. Global change in climate and resulting changes in commodity prices have the potential to impart significant impact on the profitability of New Zealand farms. This requires risk analyses that lie outside the scope of this document.

Arable farming

With respect to arable farming, climate change will affect both the yield and quality of broadacre crops. Both increases and decreases in yield can be expected, dependent on the crop and locality. New Zealand based studies have shown increased CO_2 levels have a potential fertilising effect that can stimulate both photosynthesis and growth. Warmer temperatures may also increase the number of growing days.

However, these positive effects can only be realised if the required nutrients and water are available. If systems are modified to deliver the required nutrients, then the yield of cereal crops for example may increase by up to 20% by 2030-2050[52]. Such provision of the added water and nutrients, however, may be more challenging than under current conditions. This is especially so for the Canterbury plains where much of the cereal crop is grown and where decreases in rainfall and increased evapotranspiration are projected to increase irrigation demand.

Also, changes in the burden of weeds, pests and diseases are likely to be negative, while heat stress on cattle and the occurrence of extreme droughts and floods have yet to be factored into the analysis. Accelerated crop maturation as a result of temperature change, can however, sometimes lead to shortened crop cycles which may counteract the benefits of increased growth rates in some crops (e.g. potatoes), resulting in decreased yields.

Pastoral farming

Pastoral farmers will have to adapt to gradually changing pasture growth rates and quality amongst other factors, and impact is likely to be regionally variable given differences in spatial and seasonal impact of climate change on precipitation. Overall, peak daily pasture growth rates are expected to increase in spring, but this is likely to combine with lower autumn and summer growth in areas with reduced precipitation in these seasons.

A shift toward faster growing, but lower energy-providing subtropical (C4) grasses (e.g. kikuyu) and away from high energy-providing traditional ryegrass or clover pasture may also occur. This would counter some of the potential benefits of increased pasture growth as forage pastures change. The lower energy yielding C4 grasses are already found in northern New Zealand, but currently their distribution is restricted by low winter temperatures elsewhere.

Modelling of dairy farms at a whole-farm system level has taken place for five representative regions across New Zealand.[53] Results suggest that if the practice of business-as-usual is followed, this will result in mild to moderate productivity and profitability losses under both high and low climate change scenarios.

With the implementation of currently available adaptation measures, however, this change could be turned to a near-term increase in median operating profit (with adaptation requirements varying from region to region to achieve this). This work does not yet take into account potential impact of extreme heat events[54], however, results should be treated with caution as per the discussion in Box 2.

Forestry

Increased yield from rising CO_2 fertilisation is likely to benefit the forestry industry by 2040 and beyond, by increasing growth rates of radiata pine. Fungal pathogens, however, which benefit from warmer and wetter conditions, have severe impact on forests, and the risk profile of their occurrence is likely to increase as a result of climate change. In addition, the probable increased occurrence of droughts and high temperatures will lead to elevated fire risk.[55] Changes in wind patterns could add further potential perturbation to the system. Forest planning operates over much longer timeframes than horticultural and farm management, as returns are realised after many decades; as a result planning decisions made

[52] Impacts of Climate Change on Land-based Sectors and Adaptation Options, SLMACC, 2012.

[53] Impacts of Climate Change on Land-based Sectors and Adaptation Options, SLMACC, 2012, p22.

[54] On days warmer than 25°C, New Zealand cattle may start to suffer from heat stress without adaptation.

[55] Frequency, intensity and length of the fire season may all increase.

Box 2: The future of land-based industries – a note of caution

The projections described here for the land-based primary industries are based on initial modelling that does not yet account for several issues outlined herein. These considerations need to be acknowledged to understand that there remains uncertainty about the full impact of climate change on New Zealand's primary industries as follows:

- **Extreme temperature events** - Projections do not typically account for stress on animals and/or crops posed by the increase in frequency of hot days (above 25°C) or by new record-high temperatures. The risk of wild fires also is projected to increase.
- **Flooding and high winds** - These events are projected to occur more frequently and with greater extremes and will impact on both yield and quality of produce.
- **Alterations in pests and diseases** - The decrease in frosts as a result of climate change will increase survival rates of pest species. New exotic pests and diseases may become established with existing foreign invaders becoming endemic. Wetter conditions (in winter and spring in the west of both islands) are likely to encourage pathogen proliferation. Host and pest range and sources are likely to change.
- **Temperature increases beyond 2°C** - Adaptive capacity to deal with anything more than a 2°C change world is less well understood.
- **Follow-on or spillover effects** (e.g. the effects of adaptation to climate change) appear to have the potential for similar if not greater impacts than the primary effects of climate change.

Further examination of these factors will inform potential adaptation decisions for arable, pastoral and horticultural farms alike.

now need to consider the changes in growth, fire hazard and biosecurity threats.

Horticulture

Horticulture crops (such as grapes, kiwifruit, vegetables and apples) are generally significantly managed, offering potential for adaptation strategies to be developed and any benefits to be maximised. With rising temperatures, it may be possible to grow crops currently confined to northerly latitudes (such as certain grape varieties) further south: moreover the frequency of damaging frosts is likely to be reduced. Shifting rainfall and even extreme heat events, may change the characteristics of products from a given region (such as grape sugar content for wines) and/or producers may adapt (e.g. by changing the grape varieties grown in a given location). They may also deploy adaptation mechanisms such as increasing the use of overhead shelter to protect crops from extreme temperatures as already occurs in Australia and some parts of New Zealand.

In reality, however, climate change will also have a range of other less desirable impacts that interact to affect yield and product quality and caveats listed in Box 2 require serious consideration. In general, water and irrigation demand is likely to be increased and also the degree of winter chilling will reduce, with possible adverse effects on fruit production (such as kiwifruit).

3.2. Fishing

Understanding of likely impact on fisheries and aquaculture is currently less well developed than for land-based industry counterparts. While some studies have been carried out in Australia[56] this area remains poorly understood and further work is required to understand potential implications for New Zealand. One identified area of impact is the potential strengthening of the East Auckland current, promoting the establishment of tropical or sub-tropical species currently seen only in La Niña years.[57] The 'Climate Change Impacts and

[56] A. Norman- Lopez et al.,2011, Climate Change Economics, DOI: 10.1142/S2010007811000279; A. Hobday and E. Poloczanska, 2010, Marine fisheries and aquaculture, in: Adapting agriculture to climate change: preparing Australian agriculture, forestry and fisheries for the future, pp. 205-228. ISBN: 9780643095953.

[57] Climate change and the New Zealand marine environment, NIWA, 2007.

Implications' project (2012-2016) run by NIWA and Landcare Research and funded by MBIE, includes work on coastal systems and the marine food web and will hopefully add to the knowledge base in this area.

Aquaculture is also likely to require adaptation to changing conditions, for example, migration to areas initially less affected. In localised restricted areas it may be theoretically possible to deploy chemical measures to temporarily increase pH levels, however such geo-engineering solutions only offer short-term solutions and may have unintended consequences at a system level.

3.3. Tourism

Tourism is economically and socially important to New Zealand and with a significant focus on outdoor activity; it is therefore vulnerable to direct and indirect impacts of climate change. With regard to ski tourism, lower elevation sites are particularly vulnerable, particularly in the North Island where precipitation is also projected to decrease. A 2°C rise in temperature approximately translates to a snow line about 300m higher, which could make lower elevation resorts non-viable. At the highest elevations, however, in South Island, there may be marginally more snow due to increased precipitation.

New Zealand ski fields are also likely to be affected later than their Australian equivalents. The final impact will depend on the level to which investment in artificial snow-making infrastructure can be sustained in both locations.[58]

3.4. Impact on ecosystem function, biosecurity and human health

New Zealand hosts many endemic species and the country's natural heritage is important to its national identity and ethos. Many of these species have been severely impacted upon by the arrival of exotic predators and competitors and, as a result, there have been numerous extinctions. Of those species that have survived, they very often have seriously depleted gene pools. This limits their flexibility as a group to deal with change, such as shifts in ecosystem dynamics or extremes of their surrounding climate. Further, local species are adapted to prevailing status quo conditions and may well be less able to handle change than exotic invasive species from warmer climes. Exotic weeds and pests will have an increased chance of survival as frosts decline and average temperatures warm. Existing biosecurity measures and controls may become less appropriate as previously considered invasive species become well established, requiring a new set of tools and approaches.

Key points: Ecosystem biodiversity and human health

- Climate change can be expected to impact New Zealand's biodiversity;
- New Zealand native species may be more vulnerable to climate change than those newly able to establish themselves due to changing environment;
- Changes in timing of key seasonal events (such as flowering of crops) may disrupt ecosystems;
- The prevalence and distribution of human disease vectors (e.g. mosquitoes) may shift as the climate warms.

It is not only changes in the extremes that pose a threat to species. Numerous plants and animals take their seasonal cues from temperature and day length phases, so altered timing of key seasonal events (such as flowering of crops) and population dynamics (such as reproductive cycles) has the potential to disrupt existing ecosystems.

In terms of ecosystem function, climate shifts are therefore likely to result in numerous non-linear and interacting feedback loops, as different species are affected in the food webs. Ultimately this has the potential not only to directly impact on biodiversity across the board, but also disrupt ecosystem services[59] such as nutrient cycling, water regulation, erosion control and provision of shelter.

Geographical locales that are particularly vulnerable to wider ecosystem change include alpine ecosystems (with changes in glacier coverage and snow lines), and coastal and estuarine systems (e.g. a result of seawater reaching further inland, salinizing fresh water or expansion of coastal habitats such as mangroves).

[58] J. Hendrikx, C. Zammit, E. Ö. Hreinsson, and S. Becken, 2013. Climatic Change, 1-14. DOI: 10.1007/s10584-013-0741-4.

[59] Humans benefit from a multitude of resources and processes that are supplied by natural ecosystems.

There are also potential consequences for human health, not only directly from environmental shifts (such as reduced cold days in winter, increased heat-waves and extreme weather events) but also through changes in the behaviour of existing disease vectors or the appearance of new ones. Diseases currently typical of more tropical climes, such as those spread by exotic insect and ectoparasite vectors may appear. Vectors such as mosquitoes, currently with their populations limited by frosts, may increase in abundance as the climate warms.[60]

3.5. Energy and infrastructure

Much of New Zealand's population and infrastructure is located in coastal areas. In recent years coastal development has continued, resulting in an increase in potential impact of coastal hazards. The probability of flooding and damaging storms is also increasing. Extreme high tides and storm surges are expected more frequently as the result of mean sea level rise and increases in winds. As the result of circulation changes, sub-tropical cyclones are also expected to track south more frequently, potentially affecting the north of North Island.

mosquit 3: Hutt Valley train line, Wellington
Photo: David Morgan/Source: Dominion Post 2013

Existing coastal defences have typically been engineered based on historical frequencies of events and not to cope with future conditions with more extreme events occurring more frequently. Impact is expected in terms of increased coastal erosion, more extensive inundation and higher flooding. The recent scouring of the Hutt Valley train line by a major storm is a good example of the kinds of impact that an extreme weather event can induce. This highlights the interaction between extreme events, sea level rise and the location of infrastructure and development near the coast, increasing exposure to risk. Other areas with significant coastal hazards also include the Kapiti Coast, Bay of Plenty and parts of Northland where extensive development has occurred in vulnerable locations.

> **Key points: Energy and infrastructure**
>
> - The high and increasing percentage of population and infrastructure in coastal settings in New Zealand, results in high vulnerability to storm surges;
> - Existing physical defences are typically built to cope with past frequencies of extreme events but may be at risk with more frequent future challenges.

At a local level, the impact may vary as different parts of the system interact, for example an increase in sedimentation from rivers as a result of locally increased precipitation may make a channel shallower if the rate of sedimentation build-up exceeds the rate of sea level rise. It is therefore important to assess the conditions locally rather than solely on a national or even global level.

Water management is another potential area of vulnerability for New Zealand, as it will have to be managed amid increasing variability (both through seasons and geographically). Most of the projected rainfall increases in the Southern Alps will occur in winter and spring and combined with earlier snow melt, this results in predicted increase (of 5-10%) in eastward-flowing rivers with headwaters in this area over these seasons. In contrast summer flows, when irrigation is most necessary, are expected to decrease. Increases in heavy rainfall events may place strain on existing infrastructure and also have consequences for water quality. Overall this places significant challenges for those designing and managing irrigation systems, regional water resources, and flood defences. Industry and planners are used to strong year-to-year variability due to El Niño/Southern Oscillation events, fluctuations in SAM and regional variability, however as discussed above, climate change is likely to shift both the means and the extremes. The 50 year and 100 year flood peaks

[60] S.L. Goldson, 2011, Journal of Consumer Protection and Food Safety 6: 41-47, DOI: 10.1007/s00003-011-0673-8.

for rivers in many parts of the country are expected to increase by 10-20% by 2050.[61] Infrastructure typically has long lead times and therefore requires looking further into the future where predictions are naturally subject to greater uncertainty.

The bulk of New Zealand's electricity supply is from hydroelectricity (55% of total) which, combined with a small but growing fraction from wind generation and geothermal energy, makes for one of the lowest carbon electricity supplies in the world. However, as a result New Zealand's energy generation is also uniquely sensitive to climate and seasonal shifts. Changes in seasonal river flows and snow melt are likely to influence future electricity generating capacity which is likely to be higher in winter/spring and lower in summer/autumn. Demand is also likely to shift with changes in climate. The increase in mean temperatures could have a positive impact in terms of projected energy demand, levelling off the winter peak requirements[62] as a result of reduced heating requirements (although conversely summer demand will expect to increase with more use of air conditioning).

4. New Zealand emissions

New Zealand's gross greenhouse gas emissions have increased significantly since 1990 with gross emissions now standing at around 73 million tonnes CO_2-equivalent per year.[63] During this period CO_2 emissions increased by 32% while methane emissions went up by 5.5%.[64] In 1990 the contribution to New Zealand's gross emissions from methane and CO_2 were nearly equal but an increase most notably from road transport has led to CO_2 overtaking methane slightly as New Zealand's main contributor to greenhouse gas emissions. New Zealand has a road fuel consumption per capita that is more than 1.5 times that of the Euro area, and significantly above the OECD average.[65] In 2011, transport was responsible for 19% of all New Zealand's greenhouse gas emissions.

Key points: New Zealand emissions

- Transportation is responsible for 19% of New Zealand's greenhouse gas emissions, and per capita road fuel consumption is high compared to other developed nations;
- Agriculture remains the largest sector emitter for the country (47% of total emissions), and New Zealand has taken the initiative globally in seeking mitigation strategies;
- The electricity grid is low-carbon compared to other countries globally, with over half of New Zealand's electricity supplied by hydroelectric power;
- Forestation has significant impact, substantially reducing New Zealand's reported net emissions.

Public electricity and heat generation are responsible for 7% of the country's emissions of CO_2 equivalent greenhouse gases. This fraction has increased slightly since 1990 as demand continues to grow (currently at a rate of c.1.8% per annum) and fossil fuels are used to fuel the increased demand while absolute generation from hydroelectric sources remains roughly stable.

The largest sector emitter, however, remains the agricultural sector (47% of total emissions). As a result New Zealand has taken global leadership in seeking strategies for mitigation in this area in forming both a New Zealand Agricultural Greenhouse Gas Research Centre and the Global Research Alliance on Agricultural Greenhouse Gases, which now involves 33 countries.

The New Zealand Greenhouse Gas Inventory also considers forestation and land use change when reporting emissions, to take into account removal of CO_2 from the atmosphere via these sinks. CO_2 removals (though forestation and land use change) reduce New Zealand's gross emissions, so that the reported net emissions are less than the total gross emissions for a given year. These CO_2 removals reduced New Zealand's reported emissions from an absolute 73 to a net 59 million tonnes (13Mt reduction) in 2011. In 1990, however, CO_2 removals were even higher, resulting in a reduction of 28Mt (or

[61] NIWA presentation to PMCSA, 8 May 2013.

[62] The current electricity peak requirement occurs in winter and is c.7GW, (NZCCC, Renwick et al., 2010, in: Climate change adaptation in New Zealand, NZCCC, p70).

[63] 73 Mt in 2011. Greenhouse Gas Inventory: 1990-2011, Ministry for Environment, 2012.

[64] Greenhouse Gas Inventory: 1990-2011, Ministry for Environment, 2012. This equates to a 1% annual increase of greenhouse gas emissions.

[65] Based on 2010 data from World Bank.

47% of the gross emissions) for that year.[66] The difference between 1990 and 2011 net CO_2 removals has been largely the result of deforestation (mainly in planted forests) since 2004. Over this period, the rate of forest removal exceeded the rate of establishment of new forest. It is therefore clear that forest management and land use changes can have significant impact on New Zealand's future reporting of net emissions.

New Zealand's net greenhouse gas emissions represent but a minute fraction of global emissions (less than 0.2%). Any action from New Zealand to mitigate emissions would have negligible direct global impact in real terms. Therefore, New Zealand's contribution to the global effort to reduce greenhouse emissions is more of a geopolitical issue than a scientific one. Irrespective of what happens globally to emissions, the New Zealand challenge will involve adaptation to climate change.

5. Summary

New Zealand's climate is changing as a result of historical emissions across the globe, and will continue to change over the coming decades. By the late 21st century New Zealand is expected to be at least 2°C warmer on average compared with 1990[67] but also the extremes will have shifted, probably with fewer frosts and more extremely hot days and lengthy droughts. Precipitation patterns are expected to have altered, with more frequent heavy rains and dry spells. Changes are not expected to be uniform across the North and South Islands however, with increases in rain in the west and decreases in the east and north.

The sea level rise is expected to exceed the current rate of 30mm per decade, which, while it is seemingly small, will result in the today's highest tide levels and storm surges occurring much more frequently. Our surrounding oceans are also subject to change, not only from temperature but also from acidification as CO_2 dissolves in the surface waters. The impact of acidification in the Southern Ocean is likely to be felt within decades.

Not all changes to climate will necessarily be negative, but to realise any near-term benefits and minimise risk, adaptive planning will be required. However, these marginal benefits are likely to be small compared to the adverse effects associated with climate change on society as a whole. Further work is required to understand interactions with extreme events, changes to disease and pests, and secondary level impacts and interactions which may alter current findings significantly.

Further work is also required to understand better regional interactions of systems around New Zealand to improve the quality of estimates and to test models for changes in temperature more extreme than the 2°C relative to pre-industrial levels (1.5°C relative to 1975), which have been the predominant focus to date. Indeed progress in reducing emissions at the global level has been minimal and thus higher temperature predictions are now more likely and need to be planned for.

New Zealand is engaged in pursuing this urgent need for further research. Several of the recently-announced 'National Science Challenges' will assist in advancing understanding and implications of climate change. Linked to this research the Global Research Alliance on Agricultural Greenhouse Gases and the New Zealand Agricultural Greenhouse Gas Research Centre are focused on mitigating agricultural greenhouse gas emissions.

There are also many other components related to climate research that are funded by diverse sources across several New Zealand departments, agencies and CRIs. In common with numerous other areas of cross-disciplinary research linked to multiple governmental stakeholders in New Zealand , the need for effective and greater ongoing coordination of the research effort across stakeholders is desirable if maximum value for the research investment is to be obtained.

[66] A reduction from to 60Mt (gross) to 31.5Mt (net).

[67]. NIWA presentation to PMCSA, 8 May 2013, stated New Zealand was likely to be 2°C warmer relative to 1990 by 2100 (or roughly 2.75°C warmer than 1910). This is expected to be around three quarters of the global mean temperature change for the same period.

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