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# Farmer perceptions of climate change: Associations with observed temperature and precipitation trends, irrigation, and climate beliefs

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ABSTRACT

How individuals perceive climate change is linked to whether individuals support climate policies and whether they alter their own climate-related behaviors, yet climate perceptions may be influenced by many factors beyond local shifts in weather. Infrastructure designed to control or regulate natural resources may serve as an important lens through which people experience climate, and thus may influence perceptions. Likewise, perceptions may be influenced by personal beliefs about climate change and whether it is human-induced. Here we examine farmer perceptions of historical climate change, how perceptions are related to observed trends in regional climate, how perceptions are related to the presence of irrigation infrastructure, and how perceptions are related to beliefs and concerns about climate change. We focus on the regions of Marlborough and Hawke's Bay in New Zealand, where irrigation is utilized on the majority of cropland. Data are obtained through analysis of historical climate records from local weather stations, interviews (n = 20), and a farmer survey (n = 490). Across both regions, no significant historical trends in annual precipitation and summer temperatures since 1980 are observed, but winter warming trends are significant at around 0.2–0.3 °C per decade. A large fraction of farmers perceived increases in annual rainfall despite instrumental records indicating no significant trends, a finding that may be related to greater perceived water availability associated with irrigation growth. A greater fraction of farmers perceived rainfall increases in Marlborough, where irrigation growth has been most substantial. We find those classes of farmers more likely to have irrigation were also significantly more likely to perceive an increase in annual rainfall. Furthermore, we demonstrate that perceptions of changing climate – regardless of their accuracy – are correlated with increased belief in climate change and an increased concern for future climate impacts. Those farmers that believe climate change is occurring and is human induced are more likely to perceive temperature increases than farmers who believe climate change is not occurring and is not human induced. These results suggest that perceptions are influenced by a variety of personal and environmental factors, including infrastructure, which may in turn alter decisions about climate adaptation.
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## 1. Introduction

Effectively adapting to and mitigating climate change requires both an understanding of the causes and impacts of climate change and a willingness to change behaviors: either those behaviors that contribute to greenhouse gas emissions or those that may be insolvent in the face of future climate impacts. Such actions are predicated on recognition that climate change is happening and action is necessary. Research using environmental behavior theories (Ajzen, 1991; Stern et al., 1999) has demonstrated the connection between beliefs, knowledge of an environmental issue, and behavior change. For climate change, perceived personal experiences affect climate change belief and adoption (intended or actual) of climate adaptation and mitigation behaviors (Spence et al., 2011; Broomell et al., 2015).

However, perceived changes may not always reflect reality, and climatic events or trends may be misinterpreted or wrongly remembered for a variety of reasons. With the increasing

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politicization of climate change, political party may consciously or unconsciously affect the way people perceive climatic and weather changes (Brulle et al., 2012; Hamilton and Stampone, 2013). Individuals may also have "motivated reasoning" (Kunda, 1990) to remember events in a way that support their existing worldviews on climate change (Myers et al., 2013). Recent work aims to assess not only whether people perceive climate change is happening, but also the extent to which they can accurately recall climatic events (Akerlof et al., 2013; Howe and Leiserowitz, 2013; Egan and Mullin, 2012). This line of inquiry is necessary to understand how perceptions of climate change may differ from actual changes, and how such discrepancies may influence future concerns, potential behavior change, and the degree of support for climate policies.

Human experience with climate and weather events is often mediated by infrastructure designed to help communities and landowners overcome local climate constraints (e.g. irrigation), withstand extreme events (e.g. floodwalls and levees), and maximize benefits from climate and ecosystem services (e.g. dams for water storage). The extent to which infrastructure is present within a community thus very likely influences how people perceive climate and weather events. However, to date, very little research exists that examines the mediating role of infrastructure on perceptions. This study aims to fill this gap by analyzing how perceived climate changes track with historical shifts in climate, the extent to which infrastructure may influence perceptions, and how these viewpoints are related to beliefs about climate change and concerns about climate-related impacts.

## 2. Farmers, climate change, and irrigation

Farming activities rely on favorable climate conditions and are at risk under a changing climate (Porter et al., 2014); thus it may be expected that farmers will have a long-term perspective on climate because of its direct impact on their livelihoods. Several studies have now examined farmer perspectives of climate change and its risks, as well as the potential adoption of adaptation and mitigation behaviors (e.g. Arbuckle et al., 2013; Niles et al., 2013; Niles et al., 2015; Prokopy et al., 2015). However, we are unaware of any papers that have examined the extent to which farmers' perception of climate change tracks with observed changes, despite the clear need for perceptions to be accurate if farmers are to implement appropriate adaptation measures.

While farmers may have a closer relationship to weather and climate than many laypeople, it is also possible their perceptions are influenced by the infrastructure and management strategies on their farms designed to adapt to unfavorable conditions. Irrigation infrastructure is arguably the most important management strategy farmers utilize to cope with climatic constraints. Irrigation can provide supplemental water to crops and pasture in dry or strongly seasonal climates, overcome sporadic shortfalls in soil moisture in wetter climates, and allows flooding of rice paddies.

The global scale of irrigation infrastructure, as well as its expected continued expansion, underscores the importance of understanding irrigation influences on farmer perceptions of climate change. Globally, over 324 million ha of cropland were irrigated in 2012 (FAO AQUASTAT, 2012). This irrigation is concentrated heavily in some regions, particularly China and India, which account for 42% of all global irrigation (FAO AQUASTAT, 2012). The expansive footprint of irrigation infrastructure indicates that, for many farmers across the globe, climate and water availability is viewed – at least in part – through an irrigation lens, although the degree to which this lens alters perceptions remains unknown. While irrigation currently only accounts for 21% of total cropland area (FAO AQUASTAT, 2012), irrigation water consumption is expected to increase by 11% globally by 2050 (UN WWAP, 2012) and will be critical to achieving further yield growth in certain regions (Mueller et al., 2012; Sinclair and Rufty, 2012). Understanding how irrigation influences farmer perceptions of climate change is thus important for farmers that currently utilize the infrastructure, those that will do so in the future, and policymakers intending to design climate adaptation strategies while ensuring sufficient agricultural production.

## 3. Focus regions and hypotheses

Here we aim to understand how farmer perceptions of climate change track with historical climate records, whether perceptions are related to the presence and growth of irrigation, and whether perceptions are correlated with climate change belief and concerns over climate-related risks. We focus our study in two regions of New Zealand, Marlborough and Hawke's Bay (Fig. 1), where irrigation is a dominant management practice. New Zealand is expected to have an average warming up to 2 °C by 2040 and up to 5.1 °C by 2090 (New Zealand Ministry for Environment, 2008) relative to 1980–1999 averages. Changes to rainfall are expected to vary among regions, but with a general trend towards decreasing annual rainfall in the Eastern portion of the country, including Hawke's Bay and Marlborough. The expected 10% decrease in annual rainfall in Hawke's Bay is particularly notable (National

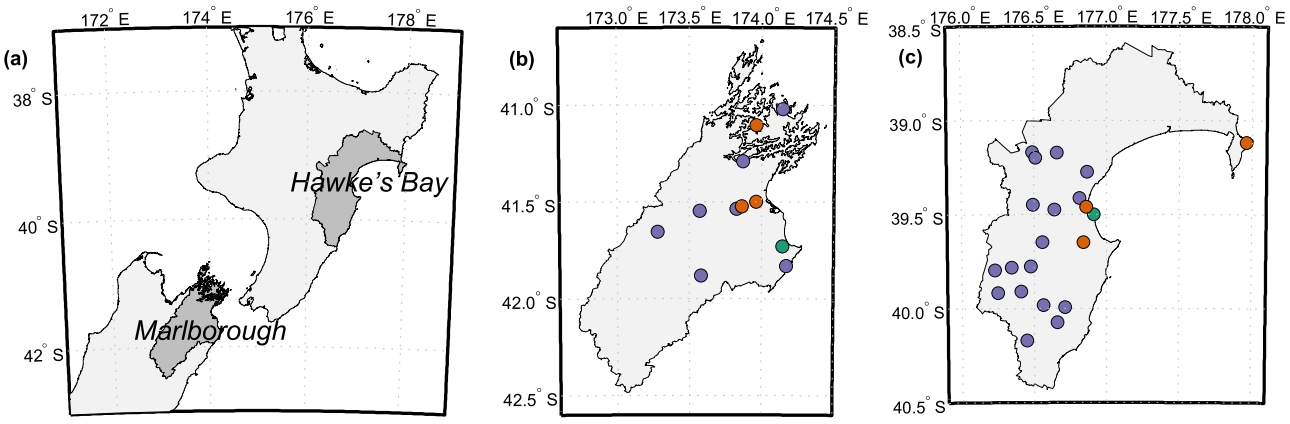



**Fig. 1.** Temperature and precipitation data were analyzed for (a) the regions of Marlborough and Hawke's Bay in New Zealand. Weather stations are shown for (b) Marlborough and (c) Hawke's Bay. Purple dots indicate the weather station was analyzed for precipitation only, orange dots indicate temperature only, and green indicates the station was analyzed for both precipitation and temperature. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Institute of Water and Atmosphere, 2008). Both regions are projected to have increased droughts (Ministry for the Environment 2008).

Hawke's Bay, New Zealand is on the eastern side of the Central North Island. According to the 2012 New Zealand Agricultural Census, Hawke's Bay had 2991 farm holdings totaling 918, 270 ha (6.3% of all New Zealand farmland area). The region is known for its extensive sheep and beef systems with 471,010 total beef cattle (12.6% of total New Zealand beef cattle) and 3,262,468 total sheep (10.4% of all New Zealand sheep). There were 1662 farms either specializing in sheep or beef or in combined sheep/beef cattle operations, making Hawke's Bay the fifth largest region for sheep production and the third largest region for beef production. Other dominant farm types are fruit tree operations (n = 228) and winegrape vineyards (n = 180) (New Zealand Census of Agriculture 2012). While Hawke's Bay is the second largest winegrape growing region (behind Marlborough), it produces only a quarter of the number of grapes produced by Marlborough.

Marlborough, New Zealand is at the northeast end of the South Island. Dominant farm types are winegrape vineyards (n = 729) and specialized sheep, beef, or combined sheep/beef systems (n = 402). Marlborough is the predominant winegrape growing region in New Zealand, producing 65% of all winegrapes for the country. The region is especially known for sauvignon blanc, a white variety often produced for export. Marlborough produced 86% of the sauvignon blanc crop for New Zealand in 2012 (Wine Marlborough New Zealand, 2012).

Irrigation is a dominant management practice in both regions, although irrigation development is primarily restricted to certain farm types. According to the 2012 data from Statistics New Zealand, Hawke's Bay had 26,036 ha equipped for irrigation and Marlborough had 29,790 ha equipped for irrigation. Irrigation infrastructure is predominantly used for crop production rather than animal production, with only a small fraction of irrigated hectares on pasture (16% in Hawke's Bay and 8% in Marlborough, Lincoln Environmental, 2000). Assuming the relative fraction for pasture has remained constant since 2000, these numbers suggest that 61% of Hawke's Bay's cropland (36,014 ha in 2012) and 86% of Marlborough's cropland (31,212 ha) are equipped for irrigation—a large majority in both cases, but particularly for Marlborough. Evidence for unequal irrigation intensity by farm type is also found in the 2012 Agricultural Production Survey of New Zealand; in Marlborough, 89% of all irrigation land in the region was in viticulture, dairy, horticulture and crop acreage, while only 11% of all irrigation acreage was on sheep and beef systems. In Hawke's Bay, only 26% of the irrigable land acreage is on sheep and beef farms, with the remaining 74% in our other farm systems (viticulture, dairy, horticulture and cropping).

Irrigation infrastructure has grown considerably in both regions (Fig. 2a). In Marlborough, we estimate that area equipped for irrigation has grown ~6x since 1980. In Hawke's Bay, we estimate that area equipped for irrigation has grown ~4x since 1980. Examination of a spatial dataset of irrigated area circa 2005 suggests that irrigation infrastructure in Marlborough is in the northeast lowlands, including the Awatere Valley and the Wairau Valley (Fig. 2b), areas known for producing wine grapes. In Hawke's Bay, extensive irrigation infrastructure exists in the Napier area where wine production has grown.

To assess our three key areas of focus, we develop hypotheses for the relationship between perceptions and irrigation and for the relationship between perceptions and beliefs. Given the expanded irrigation infrastructure in both regions, we hypothesize that farmer perceptions will be towards greater water availability; specifically we hypothesize they will perceive an increase in precipitation. However, we break this hypothesis into two components. First, as a result of the overall greater irrigation increase and use in Marlborough compared to Hawke's Bay, we hypothesize that Marlborough farmers will be more likely to perceive that annual rainfall has increased (H1a). To further understand how perceptions are related to irrigation, we also expect, regardless of region, that farmers who are most likely to have irrigation (viticulture, dairy, horticulture, and crop farmers) will be most likely to perceive an increase in annual rainfall (H1b). Finally, to examine the links between perceptions and climate beliefs and concerns, we expect farmers that believe climate change is occurring and is human induced will be more likely to perceive changes in climate (H2).

## 4. Material and methods

### 4.1. Climate data analysis

To assess the how farmer perceptions of climate change relate to historical climate trends, we downloaded and analyzed weather station data on monthly precipitation, monthly mean maximum temperatures (calculated from the maximum temperatures observed each day), and monthly mean minimum temperatures (calculated from the minimum temperatures observed each day)

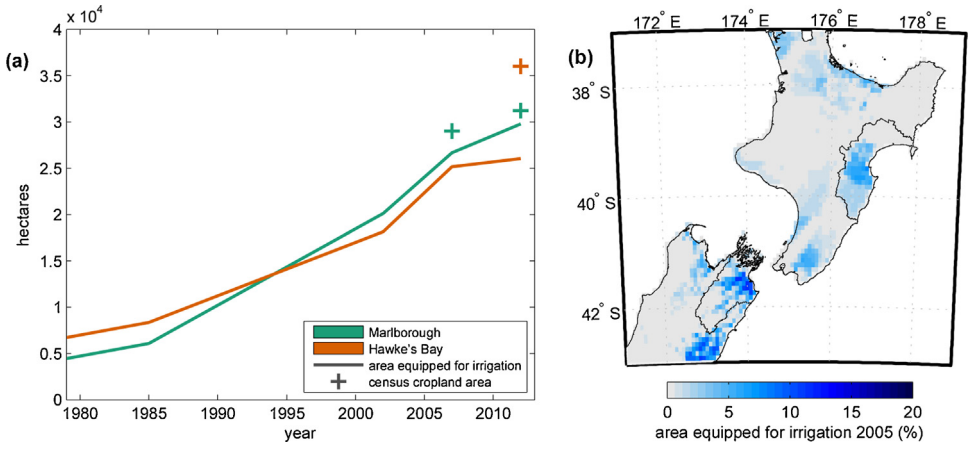



**Fig. 2.** (a) Historical changes in irrigated area from Ministry of Agriculture and Forestry and Statistics New Zealand data. Total cropland area from the recent Statistics New Zealand reports (+signs) is provided as a reference, showing the dominance of irrigation management in both regions. (b) Spatial patterns of area equipped for irrigation circa 2005 (from Siebert, et al., 2015), plotted as a percent of total grid cell area.

for 1980–2014 from New Zealand's National Climate Database (available at: http://cliflo.niwa.co.nz). This medium-term time horizon was adopted in order to be within the range experienced by most active farmers, despite the fact that longer trends would likely allow better detection of greenhouse gas driven warming. Stations were identified within each region of interest, and an initial quality screening eliminated stations with no data prior to 1997.

From the raw monthly data at each station, we calculated total annual precipitation and seasonal average temperatures. For consistency with the survey questions, we focus on temperature trends during the summer (December, January, February or DJF) and winter (June, July, August or JJA). For summer, continuous DJF periods were used, so trends were fit starting in 1981 (incorporating December 1980 and January–February 1981). When a month or months of data were missing in a given season, the annual total (for precipitation) or seasonal average (for temperature) was marked as missing. We then included a particular station in our analysis if the derived time series was at least 75% complete for precipitation or 50% complete for temperature. The scarcity of weather stations with long-term temperature records in these regions necessitated using less stringent quality criteria. Stations meeting quality criteria and utilized for the analysis are presented in Fig. 1b,c and detailed in Table S1.

Simple linear regression and bootstrap resampling are used to determine trends and their significance for each region and climate record of interest. As we are most interested in regional average trends rather than those at individual stations, we subtract the mean from each station time series and average the resulting anomalies across all available stations within a region for each year. Trends in regional average anomalies are calculated, and bootstrap resampling 1000x is used to determine confidence intervals and two-sided p-values. Residuals for every season and data type combination were tested for temporal autocorrelation using the Durbin-Watson test; no significant autocorrelation was detected at $p < 0.05$, supporting the use of each year as independent for the calculation of confidence intervals.

### 4.2. Survey methodology

Farmer perceptions of climate change, climate belief, and future risk concerns were determined through interviews and a survey in Marlborough and Hawke's Bay, New Zealand in 2012. A total of 20 interviews were conducted with farmers and agricultural industry professionals in June–August 2012. Interviews were used to inform the adaptation of a survey that was previously implemented with farmers in Yolo County, California (Haden et al., 2012; Jackson et al., 2012; Niles et al., 2013). Following survey adaptation, a telephone survey was conducted with ten pilot farmers outside the target regions with the assistance of ResearchFirst, a professional survey company in Christchurch, New Zealand. Company farmer databases and census survey databases were used to conduct a telephone survey of 490 farmers across the two regions (321 in Hawke's Bay and 169 in Marlborough) in August-October 2012 with a response rate of 41%. Survey responses were anonymous and Institutional Review Board approval was given prior to the interviews and survey implementation. A representative, stratified sample was used to implement the survey and to guide the calling process based on land-use type within the two regions to be representative of regional agricultural land use. For this reason, the total number of respondents in each region was different since the farming population within the two regions is different. Survey data was analyzed using Stata 13.0. All survey questions used in our analysis are displayed with question scales and means in Supplementary Table 2 and included in the text as necessary below.

### 4.3. Irrigation analysis

To understand the extent of irrigation in both regions we examined historical irrigation data gathered from census and survey reports (Fig. 2a). Data on area equipped for irrigation for 2002, 2007, and 2012 were available digitally from Statistics New Zealand (2015). Prior to this period we rely upon data collated by Lincoln Environmental (2000), in which they report data from the former Ministry of Agriculture and Forestry (MAF) for 1965 and 1985. Data for Marlborough and Hawke's Bay were extracted from the relevant graph using a plot digitizer tool. We assume that the reported MAF numbers do not represent actual area irrigated in a given year, but rather the area equipped for irrigation (the more common statistic to be reported), although this is not explicitly stated. The only year for which we have data on both area equipped for irrigation and actual area irrigated is in 2002. In this year 66% of the equipped area in Hawke's Bay was irrigated and 86% of the equipped area in Marlborough was irrigated.

The spatial distribution of area equipped for irrigation in 2005 for Fig. 2b is plotted using the Historical Irrigation Dataset (HID) at the 5 arc-minute resolution (Siebert et al., 2015). We note that historical estimates for our regions are available in this dataset, however the only supporting subnational data prior to 2002 is from 1960 (Stefan Siebert, *personal communication 8/6/2015*), which is why we utilized other sources to characterize the time series of irrigation growth. For New Zealand, source data for the HID include census documents from Statistics New Zealand, historical irrigation data from the Department of Statistics and the Ministry of Agriculture and Forestry, and global cropland maps (Siebert et al., 2015). A local land use dataset from the Ministry of Environment was also used to help establish the high-resolution spatial pattern (Siebert et al., 2013). The HID has several different versions, which maximize consistency with various input datasets. We averaged across the "EARTHSTAT" and "HYDE" versions that maximized consistency with irrigation input data.

Data on cropland area was collected from the census, in order to provide a reference for the amount of irrigated area. We defined cropland area as the sum of the following two land use categories: "Grain, seed and fodder crop land, and land prepared for these crops" and "Horticultural land and land prepared for horticulture". We note that the category for "Grain, seed and fodder crop land" was labelled "confidential" for Hawke's Bay in 2007, so only 2012 values are shown for Hawke's Bay in Fig. 2a.

### 4.4. Farmer typologies

To assess H2, we created farmer belief typologies using three questions about farmer's perceptions of climate change including: (1) "The global climate is changing"; (2) "Average global temperatures are increasing"; (3) "Human activities such as fossil fuel combustion are an important cause of climate change" (Table S2). Five point Likert scales for each question were converted into binary variables. Four or five (agree or strongly agree) on the five point scale were recoded as one for our binary variable. One and two (strongly disagree and disagree) on the five point scale were recoded as zero for our binary variable. Neutral responses (three on the five point scale) and missing variables were coded as missing. We created an aggregate variable to combine responses for whether global average temperatures were increasing and whether climate change was occurring so that any individual that indicated agreement with either of these questions was coded as a one. This enabled us to have two measures of climate change belief: (1) whether the climate is changing (as measured by average global temperature increases or whether climate change was occurring) and (2) whether humans contribute to climate change.

Based on these two characteristics we created four belief typologies: (1) belief that climate is not changing and humans do not contribute; (2) belief the climate is not changing but humans do contribute to climate change; (3) belief that the climate is changing but humans are not contributing; and (4) belief that climate is changing and humans are contributing. To examine how individual farmer perceptions of change in climate over time were related to these different typologies we ran an analysis of variance (ANOVA) with a Scheffe's multiple comparisons test (Table 1, Supplementary Table 3). We ran a separate ANOVA to examine how climate perceptions were related to climate change risk perceptions and concerns (Table 2, Supplementary Table 4). Scheffe's multiple comparisons test is a tool to examine the between group differences in means, accounting for the potential influence of multiple comparisons on the expected significance level. When more than one comparison is conducted (six comparisons in our case as it relates to four farmer typologies across three climate change perceptions and 11 climate concerns) this can increase the probability of a significant result by chance. Scheffe's test accounts for this potential increase in a significant result, and thus is considered conservative since it reduces the likelihood of a Type 1 error (Scheffe 1959). To examine whether farmers who had been in the region longer may have had different perceptions, we also ran correlations between the year a farmer became local to the region and their perceptions of climate change. To understand the relationship between farmer perceptions of climate change and irrigation, we used a *t*-test to examine whether exclusive sheep/beef farmers (likely without irrigation) had different perceptions of annual rainfall, on average, than all other farmers.

## 5. Results

### 5.1. Farmer characteristics

The 490 respondents represented a diversity of farm types and farmer demographics. In Hawke's Bay, farmers managed an average of 442 ha and owned an average of 327 ha. In Marlborough, farmers managed an average of 398 ha and owned an average of 327 ha. Organic or biodynamic farms comprised 5% of all Hawke's Bay responses and 8% of Marlborough responses. The majority of farmers in both regions were aged between 45 and 64 (65% in Hawke's Bay and 60% in Marlborough). Female respondents were the minority (16% in Hawke's Bay and 20% in Marlborough). The majority of respondents considered themselves full-time farmers (77% in Hawke's Bay and 68% in Marlborough). Similarly, farmers averaged only 21% and 24% of their income from off-farm sources in Hawke's Bay and Marlborough, respectively.

### 5.2. Historical changes in climate

Annual precipitation has remained relatively constant since 1980, with insignificant average regional trends for both Marlborough (−18 mm per decade) and Hawke's Bay (14 mm per decade, Fig. 3). Stations exhibited considerable variability in average precipitation; in both regions, some stations had as low as ~700 mm per year and other stations had close to or greater than 2000 mm per year.

Summer (DJF) temperatures in both regions exhibit positive trends since 1980 (Fig. 3), although these trends are not significantly different than zero. In Marlborough, the trend for average daily maximum temperatures is 0.19 °C per decade ($p > 0.05$) and the trend for average daily minimum temperatures is 0.18 °C per decade ($p > 0.05$). In Hawke's Bay, the trend for average daily maximum temperatures is 0.03 °C per decade ($p > 0.05$) and the trend for average daily minimum temperatures is 0.08 °C per decade ($p > 0.05$).

Winter temperatures exhibit significant warming trends in both regions since 1980 (Fig. 3). In Marlborough, the trend for average daily maximum temperatures is 0.27 °C per decade ($p < 0.01$) and the trend for average daily minimum temperatures is 0.32 °C per decade ($p < 0.05$). In Hawke's Bay, the trend for average daily maximum temperatures is 0.25 °C per decade ($p < 0.05$) and the trend for average daily minimum temperatures is 0.18 °C per decade ($p < 0.10$).

### 5.3. Farmer perceptions of change in Marlborough

Farmers had wide variation in climate perceptions (Fig. 4). The largest group of farmers in Marlborough (45%) believed that summer temperatures had decreased over time, 42% believed they stayed the same, and 13% believed they had increased. For winter temperatures, the largest group of farmers (42%) felt that winter temperatures had stayed the same, 39% believed they increased, and 19% felt they decreased. For annual rainfall, the majority of farmers (51%) felt annual rainfall had increased, 42% felt it stayed the same, and 7% felt it decreased (H1a). Despite the indication of weakly negative precipitation trends and positive summer temperature trends, albeit ones that do not meet a significance threshold of $p < 0.05$, collectively 31% of farmers believed that both annual rainfall had increased and summer temperatures had decreased. The co-occurrence of these perceptions may be related to a localized irrigation cooling effect, which we explore in the Discussion. We examined whether the amount of time a farmer had lived in the region influenced their perceived change of our three measures of climate change. We found no significant

**Table 1**
Relationship between farmer belief typology and perceptions of summer and winter temperature and annual rainfall. ANOVA analysis with Scheffe multiple comparison tests indicate that there are significant differences ($p < 0.05$) between farmer typologies for summer and winter temperatures. Farmers that believe in climate change and think its human-caused are significantly more likely than those who don't believe in climate change or the role of humans to believe that summer and winter temperatures have increased ($p < 0.10$). There are no significant relationships between farmer climate change typologies and annual rainfall perceptions. Scale for perceptions is 1 = decreased, 2 = stayed the same, 3 = increased.

| | Mean Perceptions | | |
|---|---|---|---|
| Farmer Typology | Summer Temperature | Winter Temperature | Annual Rainfall |
| Climate change not occurring, not human induced | 1.53 (0.5046) | 2.07 (0.6179) | 2.34 (0.6078) |
| Climate change not occurring, human induced | 1.57 (0.6462) | 2.07 (0.8287) | 2.50 (0.5189) |
| Climate change occurring, not human induced | 1.62 (0.7112) | 2.26 (0.7235) | 2.26 (0.6851) |
| Climate change occurring, human induced | 1.89[a] (0.7316) | 2.38[a] (0.7112) | 2.39 (0.6428) |
| F Statistic | 3.26 | 2.71 | 0.62 |
| p-value | 0.023 | 0.046 | 0.601 |

[a] Climate change occurring, human induced significantly different than climate change not occurring, not human induced, $p < 0.10$.

**Table 2**
Relationship between farmer belief typology and concern for future climate change impacts. ANOVA analysis with Scheffe multiple comparison tests indicate that there are significant differences ($p < 0.01$) between farmer typologies for all potential future impacts except for slips intensity. Farmers that believe in climate change and think its human-caused are significantly more likely than those who don't believe in climate change and the role of humans to express greater concern for all potential impacts except for slips intensity. Scale for concern for future changes is 1 = not concerned, 2 = somewhat concerned, 3- concerned, 4 = very concerned.

| Farmer Typology | Severe Drought | Change in Rainfall | Water Supply | Flood Intensity | Slips Intensity | Winter Chill | Frost | Warm Temps | Heatwave | Weeds/ Invasives | Pests/ Diseases |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Climate change not occurring, not human induced | 1.98 (1.138) | 1.89 (0.994) | 1.955 (1.299) | 1.87 (1.036) | 1.89 (1.100) | 1.57 (0.818) | 1.75 (1.060) | 1.57 (0.807) | 1.75 (0.839) | 2.11 (1.059) | 2.59[b] (1.203) |
| Climate change not occurring, human induced | 2.60 (1.121) | 2.64 (0.929) | 2.93 (1.269) | 2.29 (1.204) | 2.31 (1.109) | 1.73 (1.10) | 2.40 (1.121) | 2.07 (0.961) | 2.07 (0.884) | 2.67 (0.976) | 3.47 (0.990) |
| Climate change occurring, not human induced | 2.27 (1.184)[c] | 2.38 (1.058)[c] | 2.45 (1.292) | 2.37 (1.200) | 1.97 (1.102) | 1.93 (1.023) | 2.02 (1.172) | 1.86 (0.926)[c] | 2.19 (1.087) | 2.48 (1.131) | 2.95 (1.011) |
| Climate change occurring, human induced | 2.891 (0.990)[a] | 2.89 (0.890)[a] | 3.02 (1.033)[a] | 2.61 (1.120)[a] | 2.33 (1.050) | 2.21 (1.007)[a] | 2.50 (1.116)[a] | 2.33 (0.954)[a] | 2.51 (0.991)[a] | 2.88 (1.087)[a] | 3.34 (0.881)[a] |
| F Statistic | 9.89 | 13.86 | 10.77 | 4.97 | 2.15 | 5.36 | 5.84 | 9.04 | 7.16 | 6.24 | 7.87 |
| p-value | 0.000 | 0.000 | 0.000 | 0.002 | 0.095 | 0.001 | 0.001 | 0.000 | 0.001 | 0.000 | 0.000 |

[a] Climate change occurring, human induced significantly different than climate change not occurring, not human induced.
[b] Climate change not occurring, not human induced significantly different than climate change not occurring, human induced.
[c] Climate change occurring, human induced significantly different than climate change occurring, not human induced.

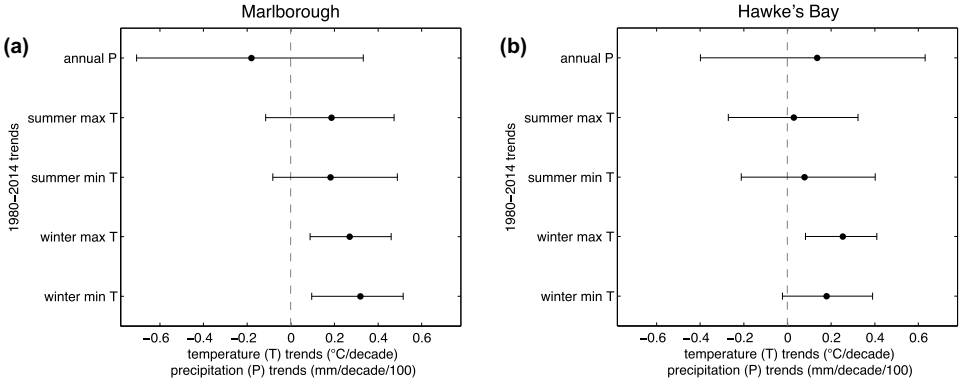



**Fig. 3.** In both (a) Marlborough and (b) Hawke's Bay, winter temperatures have warmed significantly since 1980, while both summer temperatures and precipitation have remained relatively more stable. Dots indicate mean regional trends across all stations examined, and gray bars indicate the 95% confidence interval as determined through bootstrap resampling. Trends where the uncertainty bars do not overlap with the zero line can be interpreted as being significantly different than zero at $p < 0.05$. The winter minimum temperature trend in Hawke's Bay is marginally significant at $p < 0.10$.

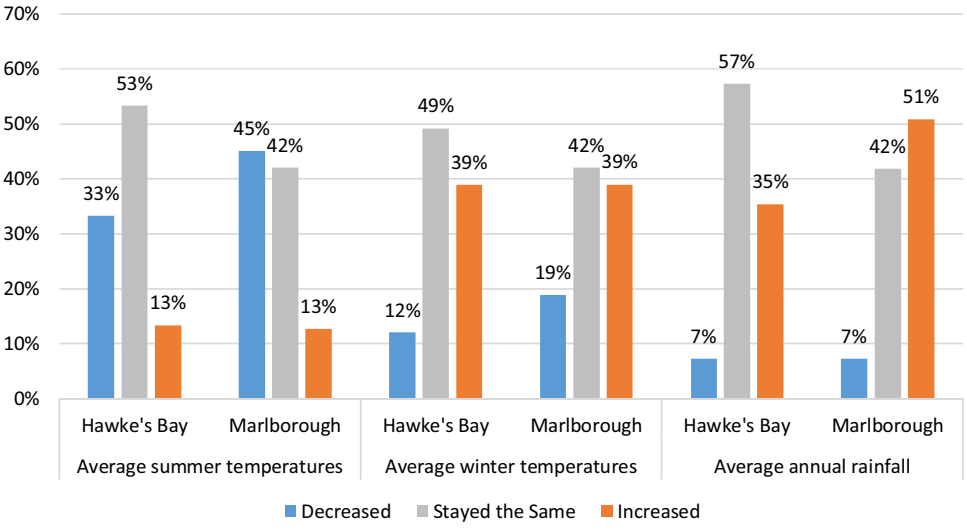



**Fig. 4.** Farmer perceptions of historical climate change for summer temperatures, winter temperatures, and annual rainfall.

correlation between farmer time in the region and perceived changes in summer temperature, winter temperature, or annual rainfall.

### 5.4. Farmer perceptions of change in Hawke's Bay

Unlike Marlborough, in Hawke's Bay the majority of farmers (53%) believed that summer temperatures had not changed, 33% believe they had decreased, and 13% believed they had increased. Similar to Marlborough, the largest group of farmers (49%) also perceived that winter temperatures had stayed the same, 39% thought they had increased, and 12% felt they had decreased. Most (57%) farmers felt that annual rainfall had stayed the same, 35% believed it had increased, and 7% thought it had decreased (H1a). Fewer farmers in Hawke's Bay collectively felt that annual rainfall had increased and summer temperatures had decreased (19%). There was no significant correlation between perceived summer temperature and annual rainfall and the time a farmer had been in the region. However, there was a significant ($p < 0.01$) negative correlation between perceived winter temperature and the time in a region, indicating that farmers who had been in Hawke's Bay longer were more likely to perceive an increase in winter temperatures.

### 5.5. Associations between irrigation prevalence and perceptions

The proportion of farmers that perceived increases in annual rainfall was greater in Marlborough (51%) than in Hawke's Bay (35%) ($p \leq 0.01$). Given that irrigation is a more dominant management practice in Marlborough, this difference between the regions is consistent with H1a. We also found greater perceptions of summer temperature decreases in Marlborough (45%) than in Hawke's Bay (33%) ($p < 0.05$). This differential between the two regions is also consistent with greater irrigation use in Marlborough, and may be related to the local cooling effect of irrigation due to increases in evapotranspiration.

To further understand how perceptions of climate change were related to the prevalence of irrigation, we used a *t*-test to explore how farm type affected perceptions. We found statistically significant ($p < 0.01$) differences, with sheep/beef farmers having lower mean perceptions of annual rainfall change (mean = 2.26 on our 1–3 scale, where 1 = decreasing, 2 = no change, and 3 = increasing) than other farmers (viticulture, dairy, horticulture, cropping systems) that are more likely to have irrigation (mean = 2.42). These results lend further support to the inference that irrigation is correlated with perceptions (H1b), as farmers that would typically have irrigation were more likely to perceive an increase in annual rainfall than rainfed, non-irrigated sheep/beef farmers.

We found that crop farmers (the most likely to be using non-drip irrigation, which is perhaps most likely to cause an irrigation cooling effect) did have the lowest overall average perception of summer temperature change (1.69) compared with viticulture only farmers (1.75, likely to use drip irrigation) and sheep/beef farmers (1.78); however, these results were not statistically significant. However, perceptions of annual rainfall were significantly ($p < 0.01$) negatively correlated ($r = -0.24$) with perceptions of summer temperature.

### 5.6. Belief typologies

We developed four farmer typologies to understand how climate change perceptions are related to climate beliefs and future concerns. Farmer perspectives of climate change differed across two dimensions: (1) the extent to which farmers believe climate change is happening and (2) the extent to which farmers believed humans were contributing to climate change. Fig. 5 shows the percent of farmers within each typology across regions. In both regions, the majority of farmers believed that climate change was both occurring and caused by human actions (66% in Marlborough, 52% in Hawke's Bay). The second largest typology was farmers that did not believe climate change was happening or that it was human-caused (17% in Marlborough and 20% in Hawke's Bay). A third typology of farmers believed the climate was changing, but that it was not human-caused, and this group comprised 12% of Marlborough farmers and 21% of Hawke's Bay farmers. Finally, a small number of farmers fell into a fourth typology where they did not believe the climate was changing, but did believe that humans are contributing to climate change (5% in Marlborough and 7% in Hawke's Bay). We expect this fourth category includes farmers that do not believe climate change is happening within their area, but believe humans are contributing at a global level to climate change. Alternatively, these farmers may not believe climate change is happening at all, but they do think humans impact the planet. However, we cannot validate these perspectives since we did not interview anyone with these beliefs.

### 5.7. Perceptions, belief, and risk relationships

Using an ANOVA with Scheffe's multiple comparisons test, we explored how farmer belief typologies were related to farmer

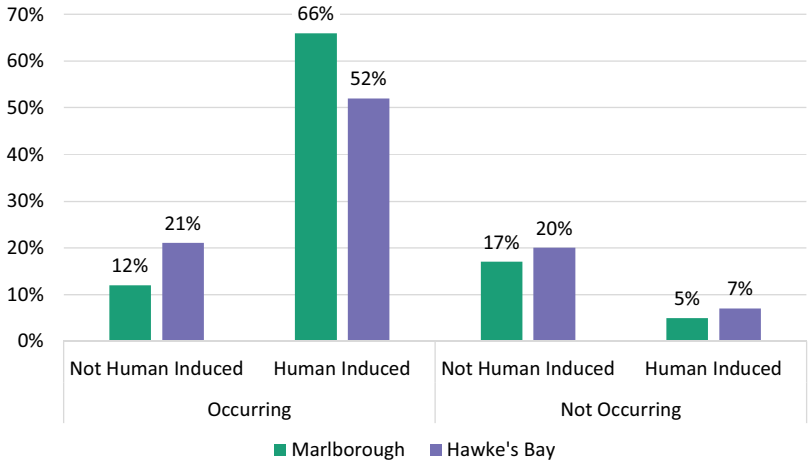



**Fig. 5.** Farmers are divided into belief typologies based upon whether they believe climate change to be occurring and whether they believe climate change to be human induced. The largest typology group in both regions thought that climate change was occurring and was human induced.

perceptions of historical climate change. We found evidence that there were significant differences between typologies for summer temperature perceptions ($F = 3.26$, $p = 0.03$), significant differences between typologies for winter temperature perceptions ($F = 2.71$, $p = 0.05$), but no significant differences between typologies for annual rainfall perceptions ($F = 0.62$, $p = 0.60$). Specifically, for summer temperature and winter temperature, farmers with greater belief in climate change and its human contributions had, on average, greater perception that temperatures had increased (H2); (Table 1; Supplementary Table 3).

We also find significant evidence for how farmer typologies are related to variation in future climate change concerns. Across 11 different measures of future climate change impacts there was a statistically significant ($p \leq 0.01$ except for landslides/slips) variation between typology and concern ($F = 2.15–13.86$, $p = 0.09–0.00$). These results indicate that those farmers with a greater belief that climate change is happening and is human induced were more likely to be concerned about future impacts, consistent with H2 (Table 2; Supplementary 4).

## 6. Discussion

Our study aimed to understand how farmer perceptions of climate change tracked with historical climate records, whether perceptions are associated with irrigation, and whether perceptions are correlated with climate change belief and future risk. We hypothesized that farmers would perceive annual rainfall to have increased – in part – because of proximity to increasing irrigation infrastructure (H1), and that farmers who felt the climate was changing would have greater climate belief and risk perceptions for the future (H2). We find evidence for both of our hypotheses as well as several other notable results, which we describe more completely below.

Overall three key findings emerge from the results: (1) Farmers' perceptions of local climate change do not consistently track with historical climate changes over time (Detailed in Sections 5.2–5.4). (2) Irrigation infrastructure appears to be influencing these perceptions of change (Detailed in Section 5.5). (3) Perceptions – whether accurate or not – are correlated with climate change belief and future climate concerns and risks (Detailed in Sections 5.6 and 5.7). We handle each of these findings in additional detail below.

Temperatures have changed in both Marlborough and Hawke's Bay during the timeframe in which we examined. These trends are strongest in the winter, when average maximum and minimum temperatures exhibit significant warming trends of ~0.2–0.3 °C/decade. In contrast, the warming trends exhibited in summer are smaller and not significant. These results are consistent with the findings of Folland and Salinger (1995), who also find stronger recent warming in winter for the entire country. The warming trend experienced thus far is still relatively small, which may limit the ability for farmers to detect the trend. We found no significant trends in precipitation across either region.

Farmer perceptions of climate change do not necessarily track the regional trends recorded in the instrumental record. Only 42% in Marlborough and 53% in Hawke's Bay felt that summer temperatures had stayed the same, the perception most consistent with our finding of minor regional warming trends not significantly different from zero. Similarly, only 39% of farmers in Marlborough and Hawke's Bay felt that winter temperatures had increased, perceptions consistent with our finding of significant regional winter warming trends. For annual rainfall, 42% felt rainfall had stayed the same in Marlborough and 57% felt so in Hawke's Bay, consistent with our finding of minor trends not significantly different than zero.

Two perceptions stand out as surprising given our examination of climate records. First, a large percent of farmers in both regions feel summer temperatures have decreased: 45% of farmers in Marlborough and 33% in Hawke's Bay. Second, the majority of farmers in Marlborough and 35% in Hawke's Bay believe that annual rainfall has increased (providing supporting evidence for H1). Neither of these perceptions appear historically accurate based on our regional climate analysis, so why might farmers perceive these changes differently?

We suggest that these "inaccurate" perceptions are likely influenced by the irrigation infrastructure within the region as hypothesized (H1a). The presence of water, and ability to apply water to crops and pasture, even if there has not been rain, may affect how farmers perceive water availability and influence their perceptions of annual rainfall. The shift towards irrigated viticulture in both regions, and away from land use for grazing, may also create greener landscapes and influence farmer perceptions. Notably, irrigation in Marlborough is comparatively more dominant and has had a greater proportional increase in area equipped for irrigation since 1980 than in Hawke's Bay (Fig. 2, Section 3); Marlborough also has a greater fraction of farmers that perceive rainfall increases, lending support to our hypothesis (H1a). Likewise, our analysis of farmers by farm type found that farmers likely to have irrigation on their farms (including viticulture, dairy, horticulture, and other cropping system farmers) perceived significantly greater increases in annual rainfall than sheep and beef farmers, who are less likely to have irrigation (H1b). A useful further test in subsequent work would be to examine a region with little irrigation infrastructure and minimal growth in irrigation.

While we did not hypothesize a relationship between temperature perceptions and irrigation, our survey responses about temperature perceptions also suggest a role for irrigation. In our survey 45% and 33% of farmers in Marlborough and Hawke's Bay, respectively, felt that summer temperatures had decreased. These perceptions may actually be accurate at the local level, as the use of irrigation can lead to localized cooling. Irrigation provides enhanced soil moisture and encourages crop growth, thus allowing for greater evapotranspiration which alters the surface energy budget by increasing the latent heat flux. This cooling of the land surface and near-surface air temperature from irrigation is well documented in both modeling (Harding and Snyder, 2012; Lu et al., 2015) and observational (Bonfils and Lobell, 2007; Lobell et al., 2008; Mueller et al., 2015) studies. The effect size for air temperature is on the order of 1–2 °C for heavily irrigated areas, so irrigation can locally counteract expected warming from greenhouse gas forcing. The results from our survey are also consistent with those from a farmer survey in California, in which 21% of farmers perceived that summer temperatures had decreased (Haden et al., 2012), possibly related to irrigation-driven cooling evident in the region (Christy et al., 2006; LaDochy et al., 2007; Lobell et al., 2008; Jackson et al., 2012). Analysis by farm type found that crop farmers, the most likely to be using non-drip irrigation, had the lowest overall average perception of summer temperature change, and that sheep/beef farmers had the highest overall average perception of summer temperature change; however, these results were not statistically significant. Furthermore, we found that perceptions of annual rainfall are significantly ($p < 0.01$) negatively correlated ($-0.24$) with perceptions of summer temperature, suggesting that farmers who felt annual rainfall had increased were more likely to think that summer temperatures had decreased, consistent with our irrigation hypothesis.

Our work also demonstrates that perceptions of climate change significantly correlate with climate change belief and future risk perceptions (H2)—regardless of whether these perceptions are

consistent with the historical record. Farmers with greater belief that climate change is happening and is human-induced were more likely to have perceived increases in summer and winter temperature, though not in annual rainfall (Table 1). Interestingly, the perceptions of warming held for summer temperatures and not only winter temperatures, despite the finding that summer temperatures have not significantly increased in either region. Farmers that believe climate change is happening and human-induced also reported greater concern about climate-related risks (Table 2). These results are consistent with others who suggested that "motivated reasoning" may be occurring among some individuals—those that believe in climate change are more likely to perceive a change in temperature to match their worldview on climate change (Myers et al., 2013; Howe and Leiserowitz, 2013). Elucidating causation between climate change belief and climate perceptions is thus challenging. That farmers may perceive changes inconsistent with the local historical record may also be related to scales at which individuals perceive change. Farmers perceiving a change in local summer temperatures may be influenced by localized irrigation-driven cooling, even though this perception is not reflective of trends at a regional or global scale. Simultaneously, farmers perceiving an increase in summer temperature would be globally accurate, though not necessarily regionally accurate. This highlights the importance of scale in designing questions for surveys about climate change. Regardless of whether these perceptions are accurate, we find consistent evidence that these perceptions are correlated with farmer belief in climate change, which is positively correlated with concern for a diversity of future biophysical climate change impacts, consistent with other work (Akerlof et al., 2013; Arbuckle et al., 2015) and our hypothesis (H2).

## 7. Conclusions

The ways that individuals perceive climate change is highly personal, place-based, and influenced by a number of factors. In this paper, we assessed how farmer perceptions of climate change are related to historical trends in climate, how irrigation infrastructure may influence perceptions, and how climate perceptions are related to climate beliefs and future concerns. Farmer perceptions of climate change varied considerably and were not systematically consistent with the direction and significance of climate trends calculated from the observational record, lending support to the idea that other personal and environmental factors are important for determining perceptions.

We found evidence that irrigation is correlated with farmer perceptions of annual rainfall, potentially influencing perceptions that annual rainfall has increased, despite evidence from the historical climate record that regional rainfall has remained relatively stable. This finding is important for both researchers and practitioners to consider how infrastructure may affect how people perceive and believe they can respond to climate change, particularly considering the global importance and expected growth of irrigation infrastructure. Beyond agriculture, the connections between infrastructure and perception are relevant for regional planning, adaptation efforts, and climate change communication. If current or future infrastructure affects how individuals think the climate is changing, it may then influence the extent to which they believe climate risks are relevant or that they need to change their behaviors. However, simply having infrastructure does not necessarily mean that farmers or others will not be affected by climate change. In the case of irrigation, the infrastructure provides considerable flexibility across a range of weather conditions, but the water resources that support irrigation may also be threatened by climate change.

Farmer perceptions of climate change and their concern over specific climate-related risks were also systematically related to personal beliefs about climate change. Those farmers that believed climate change is occurring and is human-induced were more likely to perceive temperature increases, even if these increases were not consistent with the climate record. Furthermore, these farmers also reported a higher degree of concern about climate change impacts, including severe drought, heatwaves, and changes in rainfall.

Climate change perceptions are likely processed across multiple scales, some of which may be highly personal. For example, some farmers perceived decreases in summer temperatures, which could be related to localized irrigation cooling, while others perceived increased summer temperatures that do not appear to be regionally accurate, but are globally accurate. These contrasts highlight the importance of survey question wording and scale framing to ensure that individuals respond to questions at the intended scale. Understanding how perceptions track with observations and beliefs across scales will be useful for determining how adaptation measures may be adopted. Future research should also examine the relationship between perceptions and other forms of infrastructure, as well as the consistency of irrigation–perception relationships in other regions and farming systems.

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.gloenvcha.2016.05.002.

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