GEOGRAPHY 309

RESEARCH METHODS IN GEOGRAPHY

ASSIGNMENT 4

GROUP REPORT

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Climate characteristics of the Waipara Valley wine district, using bio-climatic indices.

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Key words: Viticulture, terroir, climatic indices, spatial variation, Waipara Valley

Abstract
The key objective of this report is to investigate the relationship between climate and viticulture in Waipara, and to clearly define the unique climate characteristics that will support a Geographical Indications registration application. The Waipara Winegrowers Association will use this analysis in a submission to the Geographic Indications (Wine and Spirits) Registration Act (2006). The research aims to appropriately differentiate the Waipara Valley's environmental and biophysical characteristics, often described by the concept of "*terroir*" to indicate a unique wine producing area. Using the Hall & Jones (2010) Australian classification methodology, temperature records of different vineyard stations as well as the NIWA CliFlo dataset will be analysed to investigate the climate characteristics of the Waipara Valley. The output from this in the form of the four indices (*growing season temperature*, *growing degree-days*, *huglin index* and *biologically effective degree-days*) will enable us to comprehensively describe this sub-region's climate and the quality of wine it produces in a way that can be compared to other regional climates. The results of this research; the first known study in Waipara to be taken using direct measurement of up to four growing seasons of climate; have allowed preliminary classification of the sub-region as a cool-climate area. The results have also enabled the report to discuss the local and commercial implications of such a climate classification.

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Executive Summary

- This report investigates the relationship between climate and viticulture in the Waipara region.
- The key aim of the research is to provide the Waipara Winegrowers Association with a detailed report of the region's climate for an application to register under the *Geographic Indications (Wine and Spirits) Registration Act (2006).*
- The methodological process involves the calculation of four temperature indices using data sourced from five different weather stations with 22 temperature sensors. The NIWA CliFlo dataset has been used as a validation baseline to support the local records.
- The results of the data describe different characteristics of the Waipara region climate. They are then used to classify the area as a cool climate wine production region and validate the production of certain wine varieties.
- Given the application process for the submission to be recognised as a separate geographical indication (GI) is successful, the Waipara wine industry would benefit from legal protection on their produce. This is likely to have many other positive cumulative effects for the industry.

Introduction

The relationship between viticulture and climate is well-regarded. Many studies have demonstrated (Spellman, 1999; Hall & Jones, 2010; Overton & Murray, 2014) that a variation in climate can impact grapevine response and alter not only the quantity of wine produced in any given growing season- but also the quality by influencing taste and flavours. The 'where' factor (origin) of wine is very important and indicates quality to consumers. The way origin can be such a significant part of the market value makes the wine industry very unique (Overton & Murray, 2014).

The variations in wine quality, flavour and taste due to geographic location is a concept that is protected in New Zealand under the *Geographical Indications (Wine and Spirits) Registration Act (2006).* The purpose of this legislation (*as outlined in Section 3, Geographical Indications (Wine and Spirits) Registration Act 2006)* is to provide a suitable legal framework that enables development and growth in the New Zealand wine and spirits industry. It provides an effective market environment that facilitates trade in wine and spirits. The Ministry of Business, Innovation and Employment (2016) defines a *"geographical indicator*" as a term used to "identify a good as being from a particular place where the good also possesses a certain quality, reputation or other characteristic attributable to its geographical origin".

This research is working collaboratively with the Waipara Valley Winegrowers association towards finalising their application to be considered a protected area under the *Geographical Indications Act (2006)*. In order to establish a climate profile that can assist the winegrower's association in their registration, the research question is framed as follows:

"In what ways is the Waipara Valley climate unique, and does this allow the region to be legally recognised as a separate terroir/Geographic Indicator?"

The term *"terroir"* is widely used in viticulture literature. It originated in France where it derives from the Latin term *"Terratorium*" which refers to territory, region or area of land being considered for its qualities or agricultural properties (Vaudour, 2002). This definition has been developed and reworked amongst the viticulture industry and has become an official term defined by the *International Organisation of Vine and Wine* in 2010 as "a concept which refers to an area in which collective knowledge of the interactions between the identifiable physical and biological environment and applied vitivinicultural practices develops, providing distinctive characteristics for the products originating from this area. “Terroir” includes specific soil, topography, climate, landscape characteristics and biodiversity features”.

To achieve the research objectives and answer the research question, the Hall & Jones (2010) methodology, that has been used in to characterise wine regions in Australia, is being implemented for this New Zealand study. This uses secondary data sources from temperature records gathered over a 3-year growing season period from different vineyards that transect the Waipara Valley sub-region. This data is complemented by the national (NIWA) dataset as the validation baseline for measurement. Four key climate indices that represent the area's suitability for wine production are to be used in an attempt to characterise this area.

Therefore, the results of this research aim to;

- describe the Waipara Valley climate in sufficient detail to distinguish the region apart from others in New Zealand, and
- provide clear evidence for the Waipara Valley Winegrowers Association to use in their application to register as a “*Terroir”* under the *New Zealand Geographic Indications (Wine and Spirits) Registrations Act* (2006)

Study Area

The Waipara Valley is a sub-region of North Canterbury, located north of the Canterbury Plains on the east coast of the South Island, New Zealand. The area comprises of both flat alluvial plains and terraces and hillsides on limestone derived clays (Overton, 2010). The physical geography of the area impacts the climate and therefore wine qualities. The valley is sheltered from cooling easterly winds while experiencing generally higher temperatures and sunshine hours in comparison to elsewhere on the Canterbury Plains make it a unique and suitable micro-climate for viticulture (Cooper, 2002; Tipples, 2007; as cited in Overton, 2010).

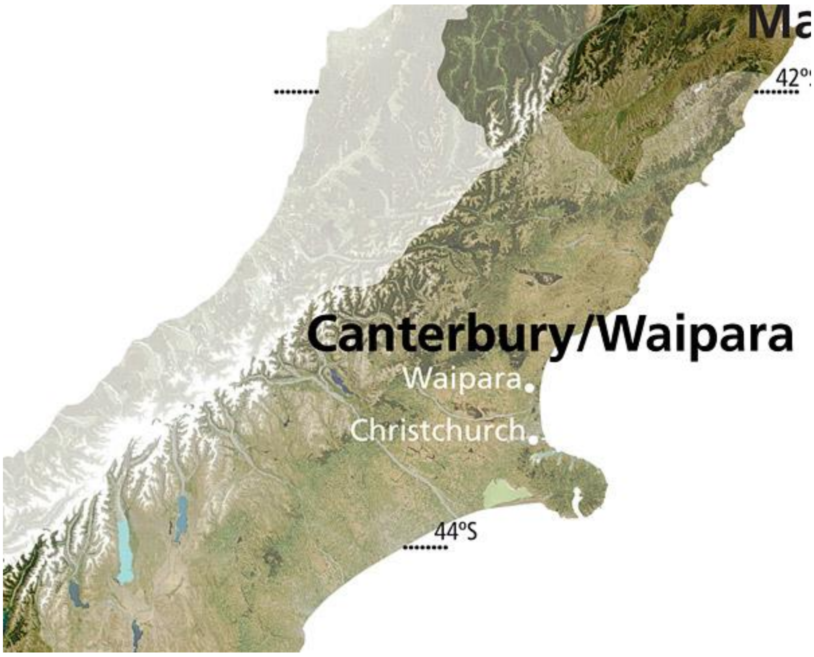

Figure 1: Site of Canterbury and Waipara in relation to the South Island of New Zealand. Source: NZ Wine.

Long term temperature trends vary inter-regionally in New Zealand and this can impact climate patterns at the local scale. Data from the long-term *NIWA* records (beginning in 1940) shows the temperature trends (*Figure 3*) nationally. The longevity of the data source reveals larger temporal scale climatic processes. Sturman and Quènol (2013) explain the causes of these significant variations in temperature for this time period. For example, a period of significant cooling after 1990 can be observed in the data *(Figure 3)* which is due to a combination of both the processes of El Nino and the effect of the Pinatubo eruption (1991). A period of La Nina is visually obvious in the temperature records between 1970-1971, as well as 1960 *(Figure 3)*. These large scale processes all proceed to have an impact on wine quality as it perturbs the inter-annual average temperature trend. This has implications for the marketing of wine from particular years. Vintage wines have a key value in the industry and represent guaranteed higher quality (when compared to non-vintage years). While these national level variations are important to consider when studying climate, New Zealand's terrain is extremely complex which offers many unique micro-climatic areas suitable for wine production.

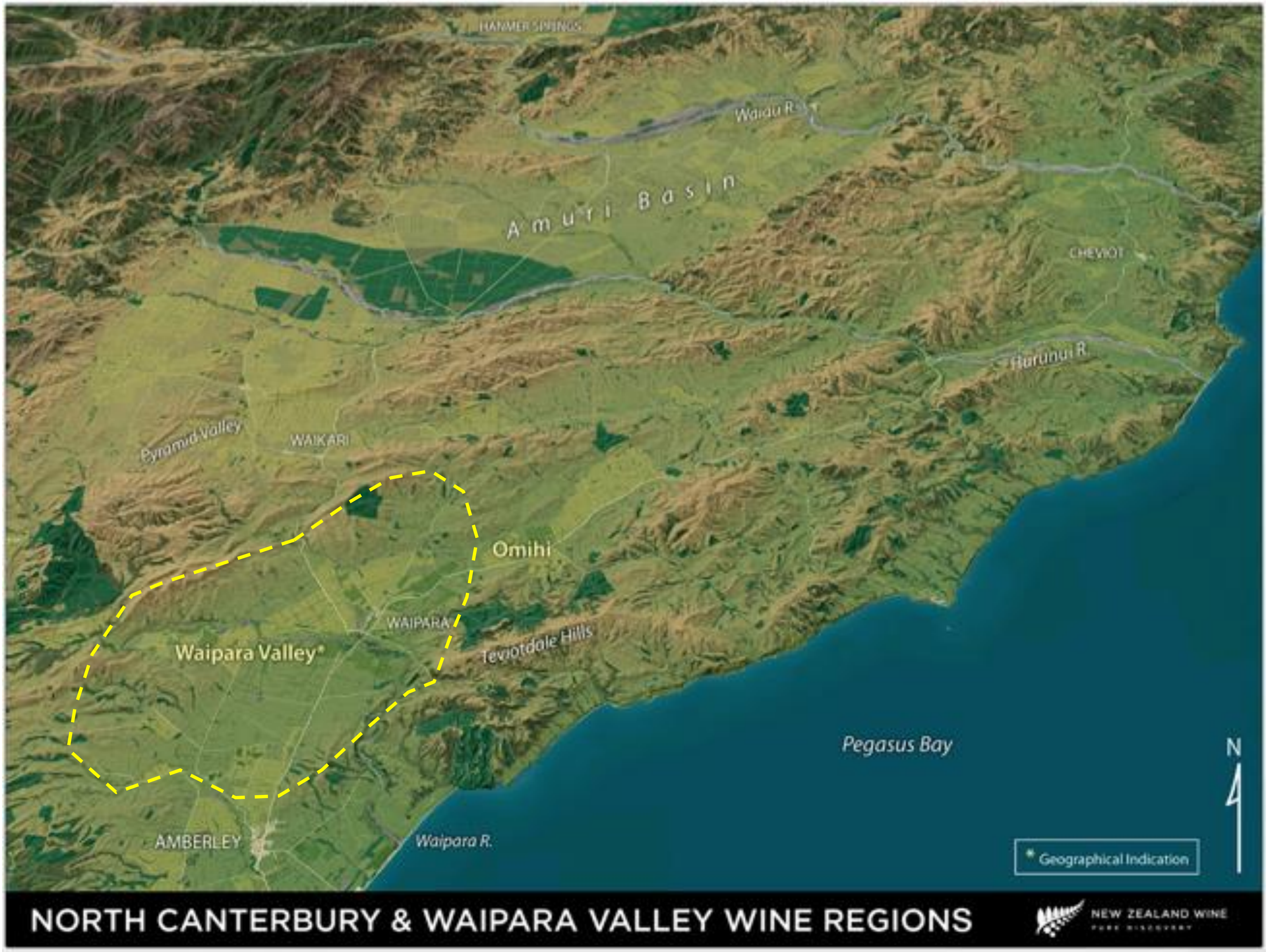

Figure 2: Map of the Waipara Valley (boundary circled) and surrounding sub-regions, North Canterbury, New Zealand. Source: New Zealand Wine

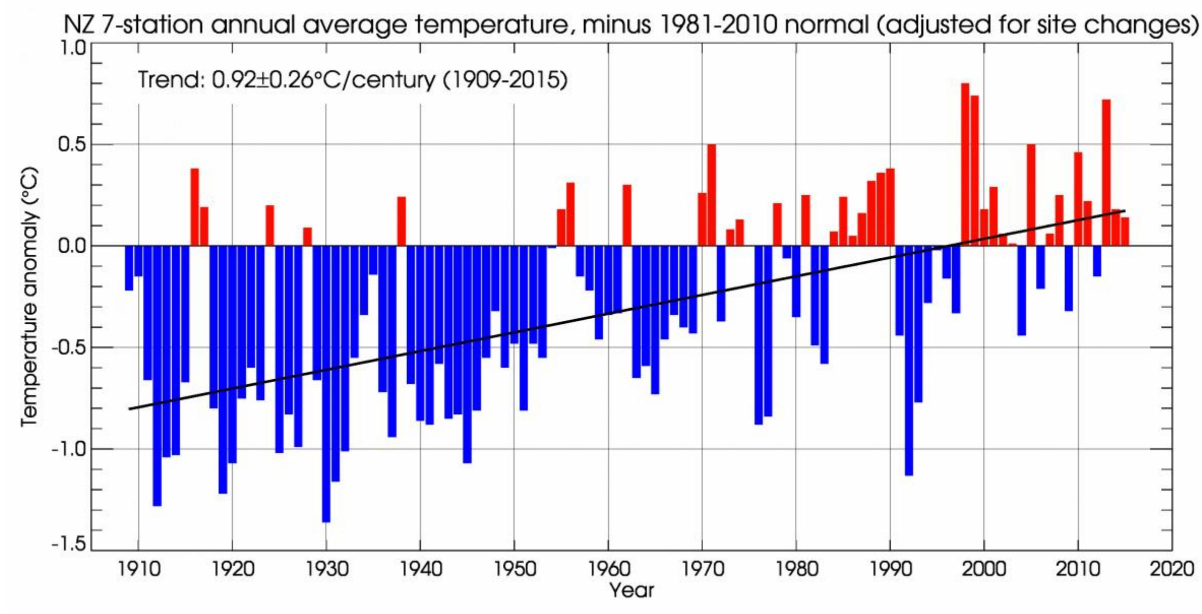

Figure 3: Mean annual temperature for New Zealand, calculated from NIWA's 'seven-station' series. This series uses climate data from seven geographically representative locations. The data are adjusted to take account of factors such as different measurement site. Source: NIWA

Wine production as an industry in Waipara has rapidly developed over the last 30 years. The land in Waipara was found to be more suitable for wine cultivation after traditional pastoral methods were found to not be very effective due to the stony and unfertile land around the 1970’s (Overton & Murray, 2014). Establishment of wineries in the 1980’s started the steady rise of Waipara’s strong viticulture industry. Comparatively, the entirety of the New Zealand wine industry was developed only in the last 30-40 years. Other major areas of vineyard production have come to be mostly by trial and error, including the Waipara Valley (Sturman & Quènol, 2013). Canterbury was an area that experimented with viticulture and although there was little success in places like Banks Peninsula and the plains, Waipara prevailed as a more successful region for this industry (Overton, 2010). Consequently, Waipara is now a significant wine producing region in New Zealand. Waipara makes up 3.4% of New Zealand’s total wine production, as of 2016. Since 2007, the area of producing vineyards has increased almost 50% from 1,034 to 1,436 hectares in 2016 (New Zealand Winegrowers, 2016).

Background Theory

Development of Bioclimatic Indices

A background on the well-known influence of climate on the grapevine growth and wine quality is essential in order to understand the rationale and result of each bioclimatic indice used in this report. Generally, when assessing a location for its suitability as a grapevine and winegrowing area, climate is seen as one of the most important factors of the local environment to consider. Climate's influence on the viticultural practice is extensive and hence is a major component of a "*terroir*". For grapevine production, initial cultivar choice is dependent on climate, along with subsequent crop operation (Gladstones, 1992). As will be discussed further, the growth of the grapevine, rate of ripening and final berry composition are all determined by the surrounding climate. Therefore, local climate plays a major role in developing the characteristics of wines in any given geographic location (Fernández Seoane, 2006).

So what is the most important variable of climate to Viticulture? Research supports air temperature as the most influential out of any of the climatic variables including wind, relative humidity, precipitation and air pressure (Jackson, 2000). This is due to the ability of temperature to modify the biology of the plant, specifically the growth rate of the grapevine and its berry properties (formation and maturation). The concentration and composition of the colour and aroma of the berry that develops during the ripening period is fully dependent on the maximum and minimum air temperatures (Ramos et al, 2008). Consequently, the quality of the wine is governed by temperature (Jackson & Lombard, 1993).

As each area is inherently different from one another in terms of the behaviour of its environmental factors (e.g. local climate and soil type), "*terroir*" is a process that aims to differentiate one wine-producing zone from another and characterise each area's uniqueness (Van Leeuwen et al, 2004). Furthermore, using an area's characterisation to then compare and identify other viticulture regions of similar environments globally (Tonietto & Carbonneau, 2004; Jones et al. 2010). Applying descriptive climatic indices to study the spatial suitability of an area for grapevine and wine production, allows a more accurate classification of its "*terroir*".

Internationally there are four predominant temperature derived bio-climatic indices in use. The first to be developed was the *Winkler Index* (WI) (Amerine & Winkler, 1944). WI is based on classifying climate growing temperature regions based on heat summation/ accumulation of days over a set temperature threshold during a growing season.

Growing degree-days (GDD) is a sum total of days in which the air temperature is above a base threshold required for growth - usually 10°C (Winkler et al, 1974). *Growing season temperature* (GST), is the average daily temperature through the growing season (Jones, 2006). GST allows the cultivator to predict the duration in which a berry will take to reach its optimal sugar accumulation and ripening stage.

The *heliothermal/ huglin index* (HI), developed originally for European vineyards (Huglin, 1978), considers the mean and maximum temperatures (giving preference to diurnal temperatures) and outputs a heat summation value for the first six-months of the growing season period. The *biologically effective degree-day index* (BEDD) uses heat summation values similar to HI and GDD, and corrects for additional variables, such as day length correction, the diurnal temperature range and an optimal growing interval for the grapevine (Gladstones, 1992).

A selection of three climatic indices into one multi-criteria climatic classification system (MCC) was developed by Tonietto & Carbonneau (2004) in order to create a classification zoning of viticulture areas internationally. This method used HI, the *cool nights index* (CI), and the *dryness index* (DI) to create a holistic overview of heat summation in an area. CI is an index that incorporate minimum temperatures, allowing both extreme ranges of temperature and its effect on grapevines and wine production to be analysed. This method of zoning using multiple indices has been adopted in other research using different index combinations, including the one on which the following research in this report is based on (Hall & Jones, 2010). In New Zealand, Australia and North America, zoning studies predominantly use GST, GDD, HI & BEDD (Jones et al, 2010; Anderson et al, 2012). Given the New Zealand location of this , it was viewed as optimal to use this existing classification method (GST, GDD, HI & BEDD) in order to then create draw similarities and differences between the Waipara Valley and other wine-producing regional studies.

Methodology

This study joins a large volume of prior-research in the area of the application of climate analysis for viticulture. Secondary quantitative climate data, which makes the entirety of data for this analysis, was sourced from a variety of commercial and private automated weather stations (AWS). This included the NIWA *CliFlo* dataset recorded at the Waipara West station for the period of May 2012 to May 2016, which was used as the validation baseline for all other measurements. Also used were 3 growing seasons (2013-2016) of temperature data from 5 different vineyards in the Waipara Valley, represented by 22 different temperature sensors across all the properties. Field visits to a range of these vineyard sites enabled identification of any accuracy or precision bias from the AWS measurement, and obtaining coordinate points for each to geo-reference the dataset for mapping output. There was an acceptable level of consistency between the sensors positioning in each of the vineyards, for the exception of one sensor in an individual vineyard set at a different height of 2 metres. This was an outlier to the rest who were all set at a relatively uniform ~1m.

Figure 2 shows the spatial extent and size of the Waipara Valley GI. The elevation of all sites all fell between 60-250 m.s.l.

This elevation variation is significant enough to increase temperature ranges even at the micro-scale within some vineyards. One specific site was found to have an average range of 1.3 °C in GST values between different blocks on its vineyard, attributed to the altitude difference between river terrace heights on the site.

The limited research period and quality of secondary data gathered for this analysis led to the use of temperature as the predominant climate factor for data analysis, using general wind and precipitation to assist in the explanation of the general variation of the region. Adopting the Hall & Jones (2010) method, the research used the same four climate indices (GST, GDD, HI & BEDD) to summarise the overall characteristics of the area.

Using Microsoft Excel to perform the equations, the data gathered from the sources was calculated to the different climatic indices. For the purpose of this research it was decided to compare the data of the Waipara Region to the indices used in the research of Hall & Jones (2010) on the spatial variation of wine-growing regions in Australia. This was a simple, effective and already widely-applied method in both northern and southern hemispheres, and was seen as the most time-effective way to gain a strong-understanding of the extent of the variation in the climate of Waipara Valley to surrounding regions.

The values for the indices from each site were then tabulated for comparison of discrepancy with values calculated by the Weather and Research Forecasting (WRF) mesoscale model of the Waipara Valley developed by Professor Andrew Sturman. The WRF model uses 3 years of the data from 2013-2016 taken at an hourly temporal resolution to plot a high spatial (<1km) grid resolution of temperature values across a 50km by 50km region of the Waipara Valley, as well as the surrounding topography of varying terrain complexity. This method has been utilised in other temperature variability case studies in South Africa, and Marlborough, New Zealand. The discrepancy comparison revealed a cold bias of ~1°C, and 450 Huglin units in the model. These allowed this research's index values to be applied to the model using a correction to plot them and adjust the WRF model. A tabular format of the results was also generated for numerical analysis to complement the visual analysis of the maps.

Climate variables derived, and the median index classification frequencies of the Australian geographical indications, adapted from Hall & Jones (2010)

Variable	Equation	Months	Class limits	Count	Frequency (%)
Average GST	$\sum_{d=1}^{n}[Tmax + Tmin]/2$	1 October-30 April	Too cool <13	0	0
			Cool 13-15	9	14
			Intermediate 15-17	54	86
GDD	$\sum_{d=1}^{n}\max\left[\frac{Tmax + Tmin}{2} - 10{,}0\right]$	1 October-30 April	Too cool <850	0	0
			(Region I) 850-1389	49	100
			(Region II) 1389-1667	0	0
HI	$\sum_{d=1}^{n}\max\left[\left(Tmean - 10 + Tmax - \frac{10}{2{,}0}\right]K\right.$	1 October- 31 March	Too cool <1200	0	0
			Very cool 1200-1500	4	7
	Where K is an adjustment for latitude/day length		Cool 1500-1800	27	50
			Temperate 1800-2100	23	43
BEDD	$\sum_{d=1}^{n}\min\left[max([Tmax + Tmin] \div 2 - 10{,}0)K + TR_{adj}, 9\right]$	1 October- 30 April	<1000	0	0
	Where,		1000-1200	30	56
	$TR_{adj}\begin{cases}0.25[Tmax - Tmin - 13], [Tmax - Tmin] > 13\\ 0{,}10 < [Tmax - Tmin] < 13\\ 0.25[Tmax - Tmin - 10], [Tmax - Tmin] < 10\end{cases}$		1200-1400	24	44
	And K is an adjustment for latitude/day length.		1400-1600	0	0

Note:
n= 66 records of 22 sensors over three growing seasons. Where total observations do not add to 66, there have been gaps in data.
Some classification categories have been removed from the table due to irrelevancy

Table 1: Equations and Count of bio-climatic indices for each vineyard, adapted from Jones et al (2010)

Results

The location of vineyards and AWS in the Waipara geographical indicator region vary in altitude from 68 to 211 m above sea-level, with micro-scale topographical features in vineyards such as river terraces and mounds providing up to 1°C in temperature variation within these sites *(Table 1)*.

Growing season data from the 2012/13 to 2015/16 season at the NIWA Waipara West station forms the baseline for the individual vineyard climate stations. The vineyard data was sourced from different locations across the Waipara Valley *(see Figure 4a-b)* and analysed from the 2013/14 to 2015/16 growing seasons. The index and elevation data is summarised by the 23 individual locations within the Waipara Valley GI using whole values in *Table 2*.

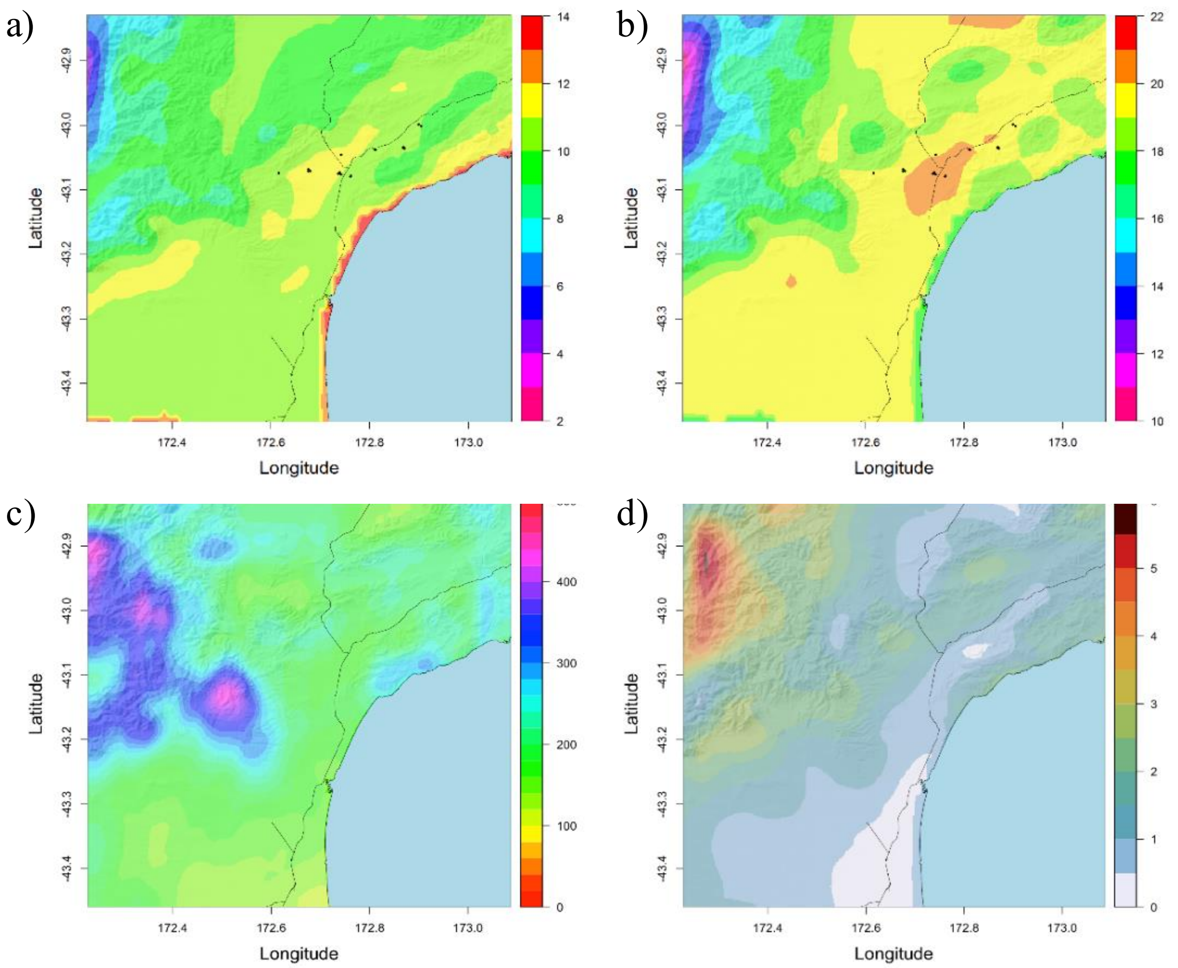

Figure 4: WRF model maps created by Professor Andrew Sturman of the Waipara Region at 1km Spatial Resolution showing (a) minimum temperatures (Tmin), (b) maximum temperature (Tmax), (c) rain map (scale showing precipitation in mm and (d) wind map (scale showing wind intensity from 0-5). Black lines inland represent state highways and black dots on (a) and (b) represent location of AWS's used in study.

General Climate

Minimum Temperature

As modelled by Prof. Sturman in *Figure 4a*, the Waipara Valley minimum average temperature is generally between 9-12°C. This prediction is supported by the research findings which were predominantly in the 9-11°C range. As already highlighted in this study, temperature is a significant contributing factor to wine quality. Minimum temperature over the growing season should ideally not drop below 0°C as this causes frost which can be extremely damaging to the crop. During the final month of ripening, a climate that is too cool can cause immaturity in the berry producing an inferior product of higher acidity (Spellman, 1999).

Maximum Temperature

The Waipara Valley has been modelled to show a range of maximum average temperature of between 19-21°C *(Figure 4b)*, complemented by the recorded vineyard data. Grapevines need a certain level of warmth along with sunshine hours in order to ripen optimally. The maximum temperature results validate Waipara as a suitable wine growing climate, that doesn't exceed the 23°C threshold that is detrimental to plant growth (Jones et al, 2015).

Precipitation

The Waipara Valley receives around 200mm/year. As shown in figure 4c, this does not vary much across the flat basin of the valley. However, the hills and Southern Alps to the west experience much higher rates of precipitation. Records from the 2014-16 growing seasons are consistent with this precipitation model, whereas 2013/2014 experienced above average rainfall for the year, affected the wine produce for that year. The variation is due to the areas susceptibility to synoptic conditions generated by the complex topography and the general maritime climate.

Wind map

The general wind trend for the Waipara area is low overall. The average is around 0.5-1.5 m/s *(Figure 4d)*. The valleys protection from the Teviotdale hills reduces some of the local wind anabatic gusts. Data from a selected local vineyard weather station show the extreme maximum wind gusts recorded over the last three growing seasons. These gusts tend to vary in strength significantly during the growing season (*Figure A1*) as well as between seasons, and are caused predominantly by katabatic processes (i.e Foehn effect).

Table 1: Numerical data and location for each of the vineyard AWS sensors used in study. Source: 5 Waipara Valley vineyards

Waipara 2013-2015 Growing Season statistics for average GDD, HI, GST and BEDD. Adapted from Hall & Jones (2010)

	2013/2014				**2014/2015**				**2015/2016**			
GI Name	**GDD**	**HI**	**GST**	**BEDD**	**GDD**	**HI**	**GST**	**BEDD**	**GDD**	**HI**	**GST**	**BEDD**
Black Estate												
Road	959.6	1709.4	15.44	1118.6	1028.5	1863.3	15.47	1181.2	1121.3	1861.7	15.88	1242.7
Central	N/A	N/A	N/A	N/A	1069.7	N/A	15.67	1223.4	1174.0	1942.8	16.10	1297.4
Top Block	1071.3	1883.4	15.96	1272.0	N/A	2054.0	16.73	1314.4	1205.9	2008.4	16.72	1362.4
Caravan	N/A	N/A	13.68	N/A	1018.9	1772.1	15.45	1158.2	1186.7	1944.9	16.38	1288.2
Limestone Hills												
	N/A	N/A	14.94	1004.8	N/A	N/A	15.3	1093.6	N/A	N/A	15.78	1149.1
Mud House: The Deans												
River	976.5	1593.2	14.74	1029.6	1078.6	1674.2	15.19	1107.3	1134.1	1739.0	15.58	1175.0
Pinot Gris	971.6	1559.5	14.98	1020.3	1100.4	1678.5	15.44	1105.5	1156.1	1729.9	15.58	1147.4
Road	968.9	1569.8	14.62	1007.5	903.1	1362.7	15.16	N/A	1149.9	1738.2	15.48	1162.5
Mud House: Glasnevin												
SB	1071.3	1805.2	15.94	1202.8	N/A	1150.4	16.06	N/A	N/A	1835.3	15.97	1237.6
CY	1052.6	1650.9	15.14	1094.8	1047.3	1751.1	15.93	1067.8	1047.3	1837.5	16.11	1279.3
WP	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1197.7	1873.2	15.91	1273.7
Mud House: The Mound												
Road 2	1026.8	1623.9	14.83	1046.9	1131.0	1722.4	15.41	1144.2	1128.1	1737.5	15.70	1138.8
Middle	857.2	1624.9	16.12	N/A	928.8	1550.7	15.44	1053.7	N/A	1296.6	14.38	N/A
Road 1	1025.2	1640.3	14.95	1074.7	1107.9	1756.8	15.63	1082.8	1157.1	1751.9	15.62	1176.1
Mount Brown												
	957.5	1699.6	15.06	1111.6	1078.9	1763.3	15.33	1156.6	1078.6	1880.0	16.29	1278.3
Mount Brown: Weka Gravels												
Air	1093.5	1779.2	15.43	1180.8	N/A	1924.0	16.21	1269.1	N/A	1951.8	16.33	1314.1
Remote	1106.1	N/A	15.42	1175.1	N/A	N/A	16.27	1276.2	N/A	N/A	16.48	1334.9
Muddy Water												
Base	1108.2	1779.0	15.44	1168.6	1218.9	1866.2	15.98	1229.0	1295.7	2211.8	16.29	1271.6
Block 13	1055.8	1818.6	15.51	1208.6	1159.4	1849.5	15.81	1227.3	N/A	N/A	15.96	N/A
Old Chardonnay	960.8	1565.8	15.29	N/A	1182.3	1978.8	16.07	1291.3	N/A	N/A	14.91	N/A
New Chardonnay	967.2	1807.4	15.20	1201.0	1111.1	1899.7	15.49	1241.5	1160.3	1853.9	15.54	N/A
Greystone	1097.2	1793.0	15.52	1375.9	1119.1	1810.2	15.66	1190.8	1124.1	1783.2	16.04	1182.2

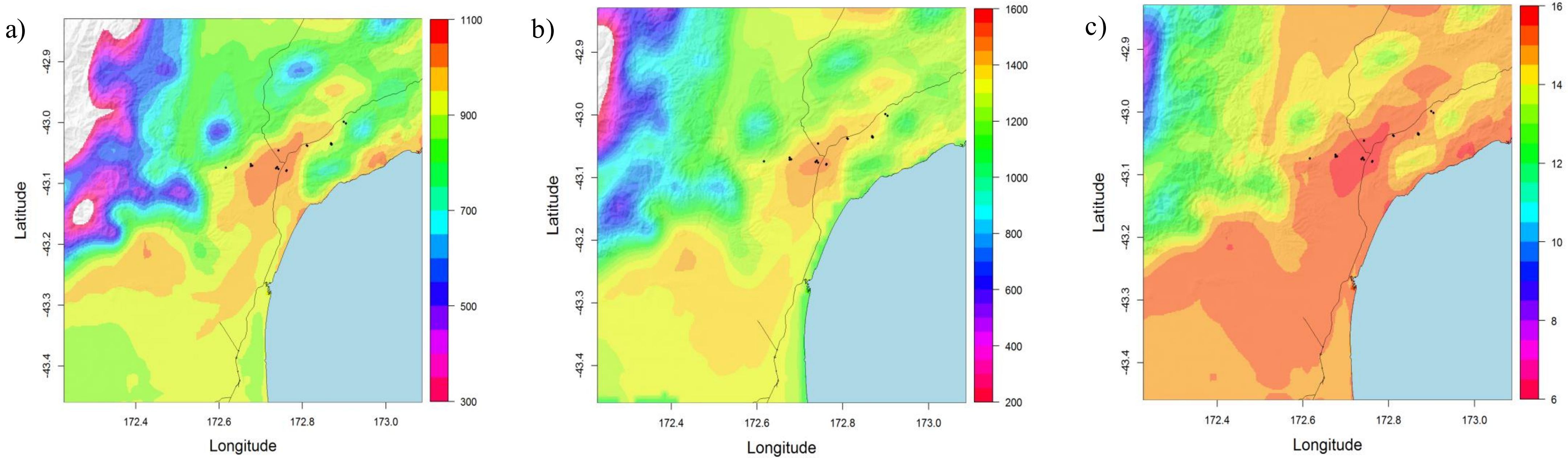

Figure 5: WRF model maps created by Professor Andrew Sturman of the Waipara Region at 1km Spatial Resolution showing (a) *Huglin index* (HI), (b) *Growing degree days* (GDD) and (c) *Growing season temperature* (GST). Black lines inland represent state highways and black dots on (a), (b) and (c) represent location of AWS's used in study.

Bioclimatic Indices

The following results discussion is based on specific viticulture climatic indices. This provides a more comprehensive understanding of climate's influence of phenology of the grapevine using specific components of air temperature. The measurements are calculated to give viticulture-specific information about the area's climate. The first is the Huglin Index, which considers the mean and maximum temperatures, giving preference to diurnal values, outputting a summation of days representing heliothermal potential. Secondly, growing degree-days identifies the amount of days in the growing season that the temperature reaches above the 10°C, hence the amount of days where berry growth and ripening is biologically possible. Thirdly, growing season temperature identifies the average temperature of the growing season, and hence can forecast stages of the maturation cycle given the temperature is consistent. Finally, biologically effective degree days uses a summation of days above the 10°C threshold, however is corrected for additional variables such as length of day, and position on earth through latitude.

The spatial distribution and therefore variability of index values is high due to non-uniformity of vineyard topography *(Table 2)*. For example, at the Mud House winery, the vineyards are dispersed across three different sites with three different sensors recording measurements at each. At the first site, The Deans, a river terrace causes slightly lower temperatures than what occurs at a nearby block (Glasnevin). The Mound block specifically records a large temperature variation due to the wider dispersal of sensors over the larger area of this block, especially compared to Glasnevin where the observed temperature sensors were within ~30m of one another compared to ~100m apart.

Huglin Index

The range in HI values *(Figure 5a)* crossed 3 different classification limits *(Table 1)*, but predominantly all values were between 1500-1800 which complements the common acknowledgement of the area as a cool climate region.

Growing degree-days

GDD values *(Figure 5b)* all fit into the lower end of the category (Region I) 850–1389, as were predominantly of values between 900-1050. For purposes of comparison, this value is less than the Region II (1100-1280) range attributed to the overall North Canterbury region for this index.

Growing Season Temperature

The range in average GST between all study sites was 1.5°C, enough to cross two GST classifications *(Table 1)*, cool and intermediate climate. Majority of these values however were on the threshold temperature that separates a cool and intermediate climate GST value, with ~40% of sites analysed being within 0.5°C of the 15°C upper threshold for a cool climate. Data for this calculation comes from the growing seasons between 2014-2016, some of the warmest on record *(Figure 3)*.

Biologically effective degree-growing days

The BEDD values *(Table 1)* range from a minimum of 1000 to a maximum of 1450. This crosses 3 different class limits, all on the cooler end of the scale.

Discussion

The results of this study have shown the details of the Waipara climate. This section will lead on from the results and describe how that impacts the production of wine. Firstly, this will distinguish the unique value of the Waipara climate by comparing it to other regions. This comparison will provide more evidence to meet the criteria for the *Geographical Indications (Wine and Spirits) Registration Act (2006)* application. Following this is a discussion of grapevine response to the climate characteristics described in the results. This further emphasises the aim of explaining the relationship between climate and viticulture in Waipara. To conclude the discussion, the legal and other formal implications will be summarised and related to the Waipara Winegrowers Association application to register under the Act.

Comparative analysis

The Waipara Valley when compared with the neighbouring regions of Marlborough and North Canterbury shows a cooler climate (*Appendix A, Figure A2*), which correlates to a stronger cool climate classification than its warmer, more intermediate climate contemporaries. The variation of temperature across the Waipara sub-region *(Figures 4-5)* also makes the area specifically unique, especially when compared to its encompassing North Canterbury region which is more homogenous in temperature distribution because of its topography, a plain – rather than enclosed valley. This *"terroir"* gives the Waipara Valley the ability to produce a large selection of cultivar choices *(Figure 6)* unmatched by any other cool climate zone in New Zealand. Internationally, this research's preliminary indice values align with other cool climate zones in the U.S.A and Europe where a sufficient comparative analysis has been undertaken using the Jones et al (2010) methodology *(Appendix A, Figure A3).* These areas also have similar cultivar choices (e.g. Pinot Noir, Chardonnay and Savignon Blanc).

Grapevine response to climate characteristics

This research has validated Waipara as a cool climate region, which is defined as "one that is capable of imparting certain distinct sensory nuances to its wines as well as possessing a unique combination of climate characteristics" (Shaw, 1999). It is important to recognise the meaning of a cool climate region and how it influences choice of grape variety, as well as quality, taste and flavour. The chemical composition of grapes is heavily impacted by climatic influences. According to Jones (2015), there are several identifiable berry characteristics that can be attributed to a cool climate and a GST between 13-15°C. This includes a lean, tart fruit style, light body and crisp, tangy acidity. He describes the overall style of wine produced from these berries as subtle and elegant. We can expect these qualities in the berries produced from Waipara vineyards based on a HI of 1500-1800 and BEDD of >1200. An important aspect of managing a vineyard is the ability to choose the most appropriate grape variety given not only the market demand forces but the unique climate conditions that enable the grapes to grow and ripen best (Shaw, 1999). This is important in relation to the Waipara area and the grape varieties winegrowers choose to invest in.

Climatic influences on viticulture initially at the macro scale, which determines whether or not the vine will grow and produce a fruit at all. Warmth is the key factor that gives the fruit sugar content. Grapes require an average annual temperature ~15°C and sustained warmth over the growing season expressed by a consistent growing season expressed by a GDD of >1000 to ensure a high sugar content for the fruit to convert to alcohol without the need for additives in later production stages (Spellman, 1999). The average GST for Waipara from the analysis supports this idea *(refer to Table 1)* as the range of results were all between around 14°C and 16°C.

Generally, the most suitable common grape varieties for a cool climate region of similar temperature range to Waipara would be the fast developing variety (Sluys, 2006), Reisling, Pinot Gris, Pinot Noir, Chardonnay and Savignon Blanc (*Figure 6*). The suitability of different grape varieties is a viticulture concept also determined by climate.

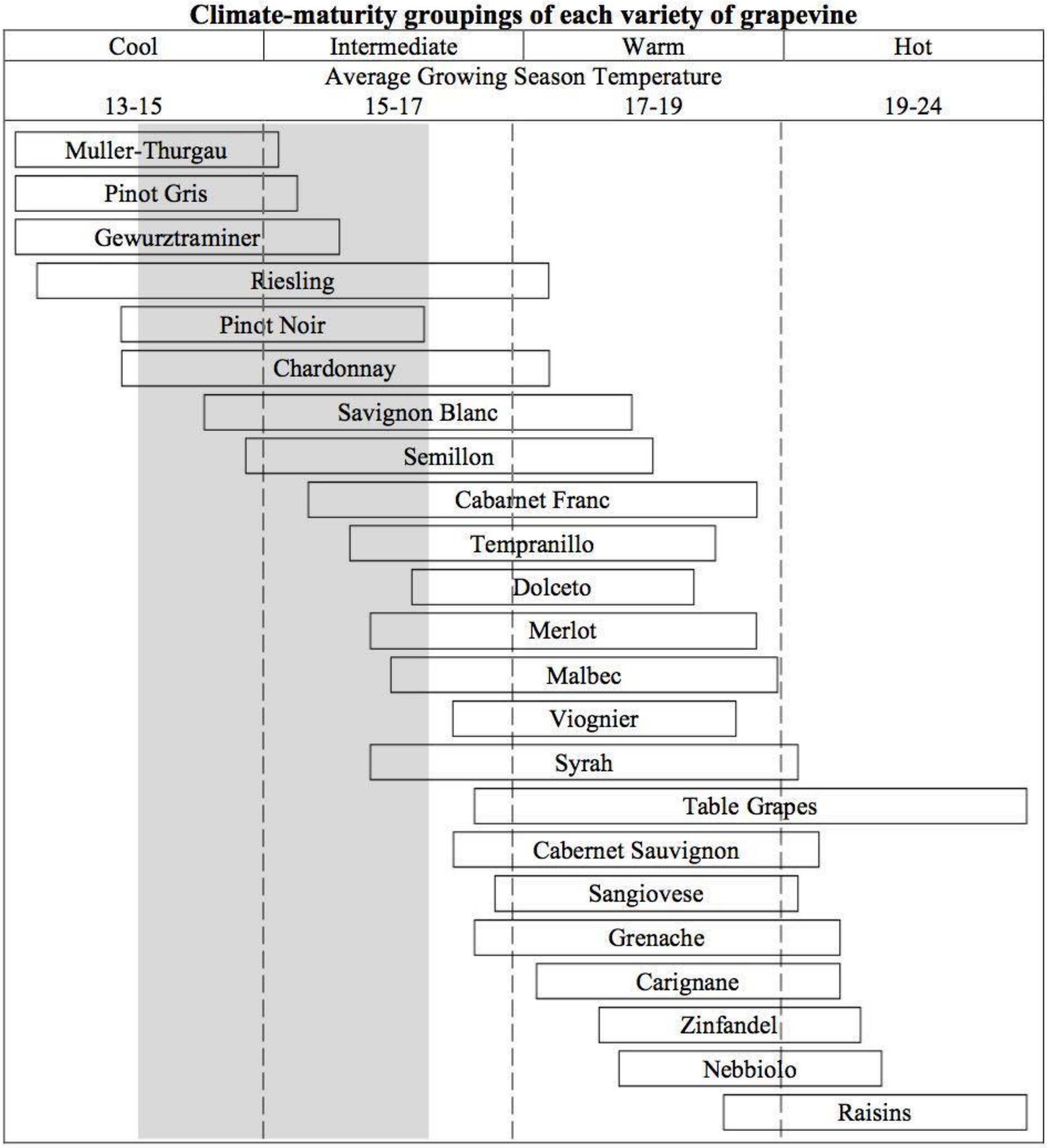

Figure 6: Wine cultivar temperature ranges, adapted from Jones (2007), grey shaded area representing cultivar possibilities for the Waipara sub-region based on AWS data, North Canterbury, N.Z

Legal and Formal Implications

Given the details of the *Geographical Indications (Wine and Spirits) Registration Act (2006),* the findings from this report will be valuable to the Waipara Winegrowers Association registration application. Climate is one of the most important factors influencing wine geographical indicators. Therefore, this research is essential to the application process.

The success of the Waipara Winegrowers Association application will offer winegrowers within the region significant benefits, specifically legal protection within national and international markets. The Geographical Indications Act creates a register of Geographical Indication regions and boundaries that is administrated by the Intellectual Property Office of New Zealand (IPONZ). This means that any wine produced within the criteria of the Waipara GI (Geographical Indication) is protected in key markets both domestically and internationally. Consequences of breaking the guidelines set out in the act will be administrated through the Fair Trading Act (1986). The act is an opportunity for the Waipara Winegrowers Association to formalise the name and boundary of Waipara. This research helps to achieve that by constructing the first detailed analysis of key temperature indices, as used by other viticulture-climate experts. A potential entailment of this act would include the economic market value of obtaining an official GI for the region. The reputational value of an official GI could have an influence on market value for Waipara wine. As discussed earlier, the ‘where’ factor of wine seems to have significant influence on consumer demand behaviour (Overton & Murray, 2014).

To conclude on the legal and formal implications, the success of the Waipara Winegrowers Association’s application would have significant beneficial impacts on the industry. Any negative impacts of obtaining an official GI status for Waipara have not been observed, although there is always the possibility of unforeseen circumstances arising. Identifying the unique climate of Waipara is a significant part of obtaining the official GI status for Waipara. Therefore, reinforcing the relationship of climate and viticulture which is the key focus of this study.

Conclusion

In relation to the initial aims of the project, the results of this study present the Waipara Winegrowers Association with a detailed description of the climate features that influence their wine production. This is essential to the Geographical Indications Act which specifies the importance of climate on viticulture. The information regarding climate that is provided in this study further enforces that Waipara should be identified as a separate Terroir/GI due to the verified cool climate classification of the region. The figures computed in the analysis stage of the study are the first to be available for the Waipara region, taken from observed rather than modelled data. The four temperature indices that were calculated contribute significantly to the understanding of climatic processes within the region. The analysis also provides an insight into the impacts of certain climate characteristics for berry ripening processes. This significantly improves the understanding of climatic influences for viticulture.

Limitations in this study exist mainly due to the time and resource constraints inflicted by the nature of the course. A much more comprehensive analysis could have been completed if both the quantity and quality of data sources could be increased. The number of local vineyard weather stations that temperature records were obtained from is limited by the time available to compute the results as well as privacy for the vineyard owners. Differences in some parts of existing work that this study has compared to could be the cause of inaccuracy. In particular, the values for indices in this analysis has been averaged rather than divided into quartiles. The comparison has therefore been based on median versus mean results. The analysis could also be improved if given more than three growing seasons of data but this was not available at the time of research. The field visit to check temperature sensors for potential bias was limited by time and unfortunately a small proportion of sensors were not able to be investigated. This study assumes that they were at the standard vineyard height and were placed in sensible locations to ensure accurate recordings.

Given these limitations, future work that could investigate the Waipara climate with a much larger scope would be a significant development on the existing level of understanding. A larger sample size of temperature sensors at vineyard locations, as well as an extended time period to analyse data would be optimal conditions for this study.

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Finally, thanks to the Waipara Winegrowers Association, for giving us the opportunity to study such an intriguing area and topic. We have been grateful for the support you have given us throughout the project assuring us that our work is appreciated and will be useful to the application to be made later in the year.

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Appendix A

Figure A1: Wind gust graphs sourced from Muddy Waters Vineyard AWS for (a) 2013/14, (b) 2014/15 and (c) 2015/16 growing seasons

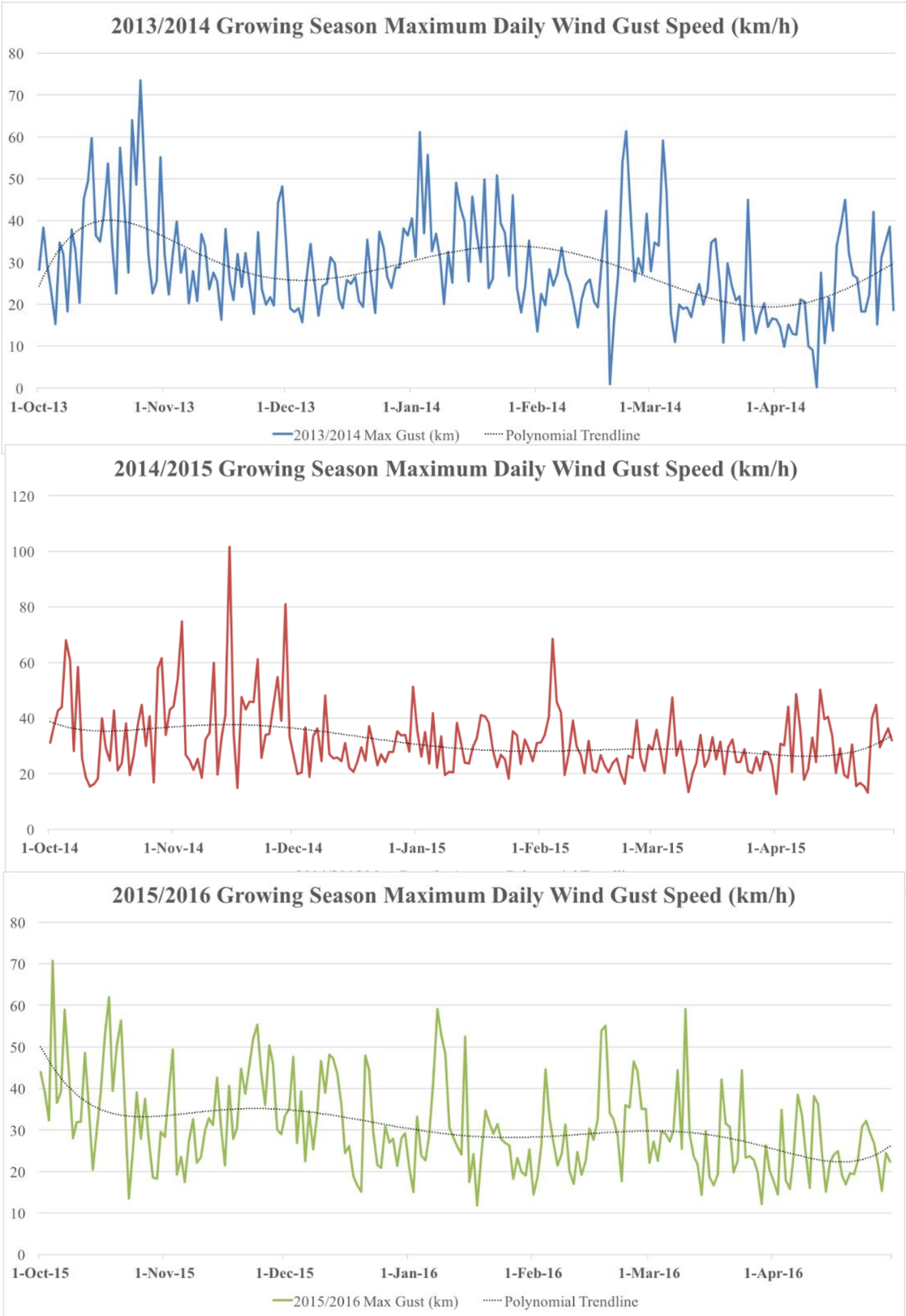
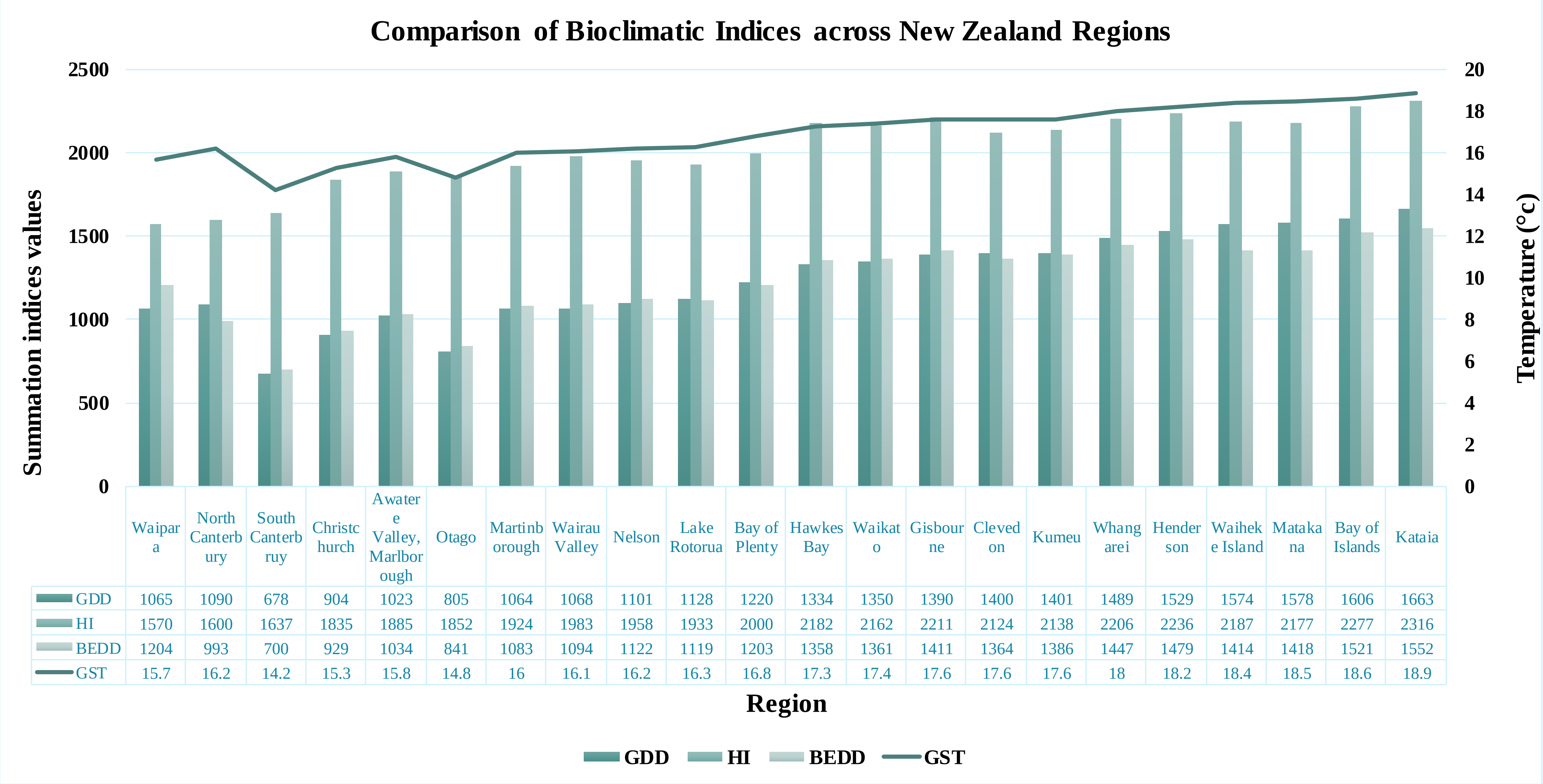


Figure A2: Bar graph showing indices value for each region of New Zealand (adapted and adjusted for ~1°c and 450 HI unit cold bias from Anderson et al, 2010 model values)



	Waipara	North Canterbury	South Canterbruy	Christchurch	Awatere Valley, Marlborough	Otago	Martinborough	Wairau Valley	Nelson	Lake Rotorua	Bay of Plenty	Hawkes Bay	Waikato	Gisbourne	Clevedon	Kumeu	Whangarei	Henderson	Waiheke Island	Matakana	Bay of Islands	Kataia
GDD	1065	1090	678	904	1023	805	1064	1068	1101	1128	1220	1334	1350	1390	1400	1401	1489	1529	1574	1578	1606	1663
HI	1570	1600	1637	1835	1885	1852	1924	1983	1958	1933	2000	2182	2162	2211	2124	2138	2206	2236	2187	2177	2277	2316
BEDD	1204	993	700	929	1034	841	1083	1094	1122	1119	1203	1358	1361	1411	1364	1386	1447	1479	1414	1418	1521	1552
GST	15.7	16.2	14.2	15.3	15.8	14.8	16	16.1	16.2	16.3	16.8	17.3	17.4	17.6	17.6	17.6	18	18.2	18.4	18.5	18.6	18.9

Figure A3: Cool climate indices comparison of Waipara Valley with other international regions. Source Jones et al (2010).

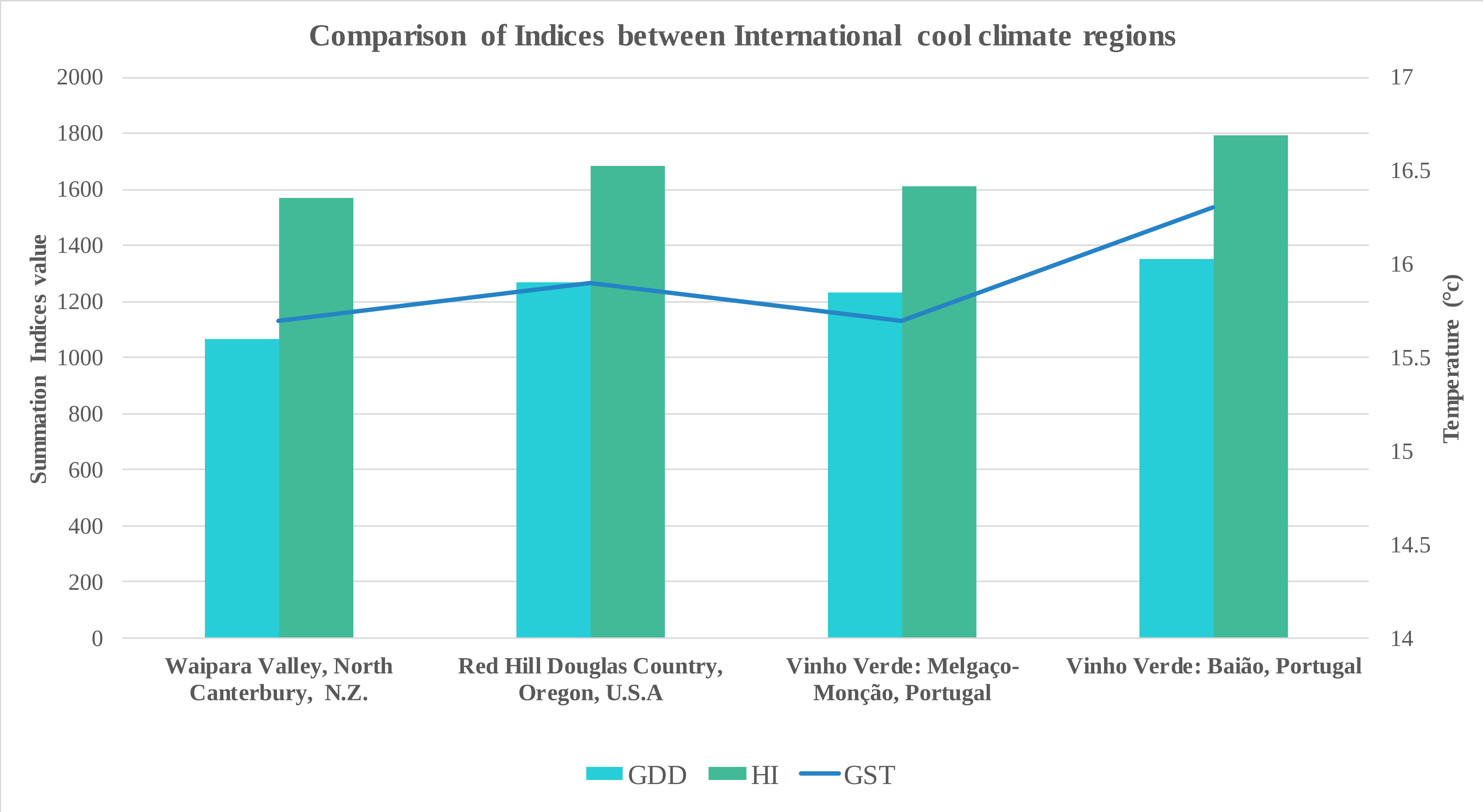


Figure A4: AWS Validation baseline of temperature trends for study period. Source: CliFlo