Research Team – **Peter Deuter**, Horticultural Consultant, PLD Horticulture &
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Drought and Climate Adaptation Program

Carrots – Critical Temperature Thresholds

Critical Temperature Thresholds.

Local weather conditions influence all stages of plant establishment, development and growth, ultimately determining crop productivity and marketability. Every crop has a unique range of optimum and tolerable environmental conditions that favour its growth. Identifying and understanding the relationships between crop growth stages and 'expected' weather is very important in maximizing crop productivity. For a crop to be successfully grown and marketed in a region, the sequences of its growth stages must align with a favourable climate to maximise the potential of plant growth, product quality and marketable (harvestable) yield.

Most major agricultural commodities do not have well-defined yield or crop damage thresholds for a range of climate variables. Thresholds which have been identified have ranges, due to the ability of different cultivars to continue to perform (or otherwise) under the effects of high and low temperatures during different growth stages. When temperatures outside the optimum range occur at sensitive plant growth stages, physiological and cellular processes will result in adverse effects on plant growth and development, and crop productivity, marketability and profit (Hasanuzzaman, et al., 2013).

Plant growth rates may also decrease or stop completely above or below certain thresholds. A high temperature threshold may mark a point where growth and development are not halted but become increasingly impacted as temperature rises further.

Yield and quality can similarly be impacted as the temperature rises (or falls) outside the threshold range. Diurnal temperature range is also important and may be cited in the literature as the mean temperature (daily or monthly). This distinction is sometimes not clear in the literature.

Grotjahn, R. (2021) demonstrates the effect of short durations of temperatures, above or below the optimum, which can have devastating consequences on horticultural crops and their produce. For high temperatures it may be measured in hours to days. Two days in a row, above the optimum, are more severe than one day.

This makes the task of identifying Critical Temperature Thresholds (CTT) difficult, and exacerbated by the fact that, "The thresholds have ranges due to the variation among cultivars and the conditions each plant experiences over time" (Grotjahn, R., 2021, p.40).

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Introduction

Carrot (*Daucus carota* var. *sativus*) is a member of the Umbelliferae family, which includes celery, parsnip, parsley, dill, caraway, anise, coriander and fennel. Carrots are a major source of Vitamin A in the diets of many consumers around the world (McAvoy, 2012).

Carrots are a cool-season crop but will tolerate warm temperatures early in the growing season. Carrots are grown in Australia for the fresh, processing and export markets.

The majority of carrot production is concentrated in WA (Lantzke, 2021), SA, and Tasmania, with the remainder in Victoria, Qld and NSW. The main carrot growing regions are Gingin and Perth Metro (WA); Adelaide Plains and Mallee (SA); Forth (Tas); Murray Valley and Gippsland (Vic); Fassifern and Lockyer Valley regions (Qld); and the Riverina (NSW).

Anon, 2003, provides a classification four major carrot types, based on root shape :-

1. Chantenay – roots relatively short and blunt tipped and broad shouldered.

2. Danvers – pointed roots which are longer than Chantenay, moderately wide in the shoulder.

3. Imperator – long and slender roots tapering to a point, which are narrower shouldered than Danvers.

4. Nantes – moderately long root with uniform diameter along length; root tip is rounded when mature. Nantes carrot varieties, currently dominate fresh market carrot production in Australia.

A wide range of growing locations, varieties and maturity times means that production can occur year-round, particularly in more mild and cooler areas of Australia, by selecting appropriate varieties for particular locations. Western Australian production occurs all-year-round, with the major production districts being within 150Km of Perth.

Cold winter months followed by increasing day length in spring can result in carrots being exposed to conditions that induce flowering. Flower induction in carrots requires a period of six to eight weeks of temperatures below 10°C, and increasing day length will accelerate flower induction. These conditions do not occur regularly in the main carrot production districts of Australia, except where seed production is located. Once flowering is initiated, the seedstalk elongates rapidly, particularly as temperatures increase, and then carrot roots become unmarketable.

Summary

Carrots are grown to supply a number of end uses in Australia, although fresh market production is the major market. Value added products include peeled baby carrots, carrot sticks and shredded carrots; canned baby food production, as well as some frozen products.

Although carrots can be grown outside their optimum range (10-20°C) with little or no effect on tops (leaves), temperatures differing significantly from the above can adversely affect root colour, texture, flavour and shape. Lower temperatures cause slow plant growth and make roots longer, more slender and lighter in colour. Temperatures below 10°C cause carrot roots and foliage to grow slowly, greatly reducing plant size and yield. Mature carrot plants will tolerate some frost.

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Carrots are not as susceptible to variations in temperature as many other vegetable crops, but growers are careful in their selection of varieties to suit locations and production timing, but unseasonably hot or cold conditions will affect plant growth and product quality.

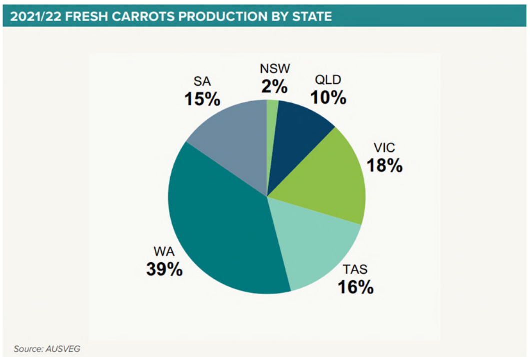
Changes in temperature affects many crops, and these effects can be complex where distinct stages of growth are affected by temperature in different ways.

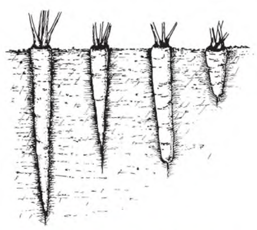
Carrots have four distinct growth stages which are affected by temperature - viz. Seed Germination, Crop Establishment, Vegetative Growth and Root Development.

A number of researchers around the world have investigated the role and impact of temperature on carrot growth and quality, during these distinct growth stages.

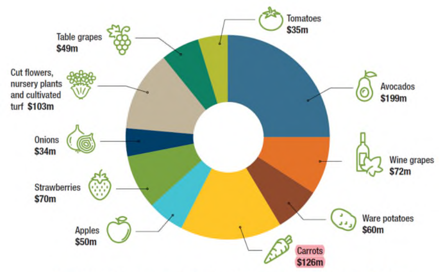
Optimum temperatures for the carrot vegetative growth stage, range from 15 -21°C.

Carotene, which is a precursor to Vitamin A, accounts for a high percentage of colour in carrots, and develops best between 10 and 20°C.





Carrot types, from left: Imperator, Danvers, Nantes, and Chantenay



Gross value of agricultural production ($) of WA's top ten horticulture industries (2018–2019)

Note: 2017–2018 data for cut flowers, nurseries and cultivated turf.

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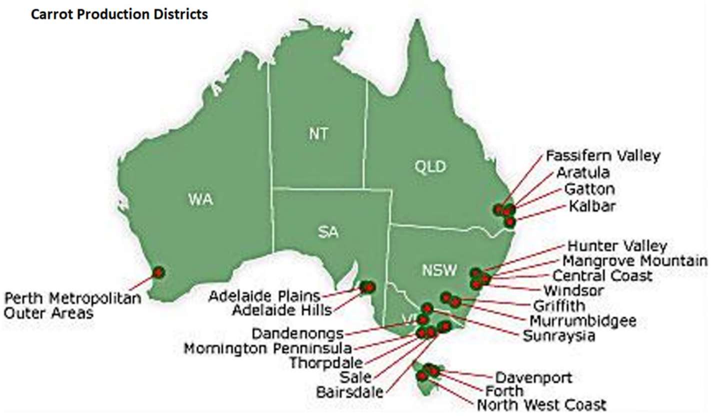

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Critical Temperatures and Development Phases

Carrot Growth and Development Stages.

The taproot of carrots (the marketable product) is a carbohydrate storage organ which also contains Carotene, which is at its highest concentration at temperatures between 10 and 20°C (Goldman, 2020). Carotene is responsible for the orange colour of the commercial varieties of carrots grown in Australia. Anthocyanins are responsible for the red and purple colours of some varieties of carrots.

1. **Seed Germination.**

The optimal germination temperature range for carrot is 20-30°C.

2. **Crop Establishment.**

Carrot foliage is frost sensitive, but frost does not usually damage the roots in production districts in Australia, as is possible in much colder climates in the northern hemisphere. Although carrots are a cool season crop, they can tolerate quite warm temperatures during the establishment phase.

3. **Vegetative Growth.**

Optimum temperatures for the vegetative growth stage range from 15-21°C, including daytime highs of 24°C and night time lows of 13°C. Carrots can be grown outside this range with minimal effects on tops, although temperatures significantly outside this range can adversely affect root colour, texture, flavour and shape.

4. **Root Development.**

Carotene, which is a precursor to Vitamin A, accounts for a high percentage of colour in carrots, and develops best between 10° and 20°C. More carotene is produced when carrots are grown under cool nights and warm days than under continuous cool conditions.

Carrots can be grown outside the optimum range, although root colour, texture, flavour and shape will be adversely affected once temperatures reach 25–30°C.

Seed Germination

Seeds germinate in a wide range of soil temperatures from 4-35°C, although the optimum range is 15-29°C (Grotjahn, 2021). Anon (2003, and 2019) report the optimum range for seed germination as 10-25°C, with a minimum of 2°C and a maximum of 35°C.

Bolton et.al (2019) report the optimal germination temperature of carrot as 20-30°C, and Nascimento et.al (2008), as 25-30°C, with a germination range of 10-35°C.

Rajasekaran et.al (2001), reported 25°C as the temperature at which the best carrot seed germination occurred, with a critical range of 5-35°C.

The Optimum Temperature for Seed Germination is 20-30°C.

The **Critical Temperature Thresholds for Seed Germination** are 5°C and 35°C.

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Crop Establishment

Carrot foliage is frost sensitive, but frost does not usually damage the roots (Anon, 2003; McAvoy, 2012). Although carrots are a cool season crop, they can tolerate warm temperatures during the establishment phase (Chambers et.al, 2015).

Vegetative Growth Phase

Optimum temperatures range from 15-21°C, including daytime highs of 24°C and night time lows of 13°C. Carrots can be grown outside this range with minimal effects on tops, although temperatures significantly outside this range can adversely affect root colour, texture, flavour and shape (McAvoy, 2012; Grotjahn, 2021; Anon, 2019; Anon, 2003; Anon, 2010). Temperatures from 18-25°C are considered ideal for shoot growth (Rubatzky, et.al, 1999).

Carrot foliage can tolerate some frost, although once temperatures drop to below 10°C, both leaf and root growth is slowed (Grotjahn, 2021; Nunez et.al, 2008; Saha et.al, 2016; Chambers et.al, 2015).

The Optimum Temperature for the Vegetative Growth Phase is 15-21°C.

The **Critical Temperature Threshold for Vegetative Growth Phase** is <0°C and >35°C.

Root Development

Long periods of temperatures above optimum will adversely affect carrot yields, cause strong terpinoid flavour and bitter taste in roots, and affect root shape. Carrots can be grown outside the optimum range (15 -21°C), although root colour, texture, flavour and shape will be adversely affected once temperatures reach 25–30°C (McAvoy, 2012; Grotjahn, 2021; Anon, 2003).

Marklein et.al (2020) and Nunez et.al (2008), report an optimum temperature range for root development of 18-21°C, and a critical temperature range from 10–30°C, outside of which yields are reduced and undesirable flavours are developed in the roots.

Carotene, which is a precursor to Vitamin A, accounts for a high percentage of colour in carrots, and develops best between 10 and 20°C. More carotene is produced when production occurs under cool nights and warm days than under continuous cool conditions (Anon, 2003; Goldman, 2020; Nunez, et.al, 2008). The highest root growth rates occur from 18 to 20°C (Rubatzky, et.al, 1999).

The Optimum Temperature for the Root development Phase is 15-21°C.

The **Critical Temperature Threshold for Root Development Phase** is 5-30°C.

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Future climate implications – crop performance and yield.

A diverse range of commercial carrot varieties are available to Australian growers. These varieties are grouped and grown according to their seasonal and district suitability. Australian commercial seed supplier catalogues indicate suggested variety, timing and location production slots - Terranova Product Guide – 2022[1]; South Pacific Seeds Product Guide – 2023[2]; Rijk Zwaan Carrot Varieties[3].

Summer production locations that are currently on the verge of being too hot in certain months, will experience more days that are above their best summer varieties' CTT. This will cause a shortening of the current summer season, so that producers can avoid quality and crop loss in a hotter summer.

Australia and Queensland's climate is warming (reference links below), and producers will need to continue to adapt to these changes, revising their production location, variety selection and timing. Production locations and production timeslots will change or may even become commercially non-viable due to a decline in marketable yield and quality, and/or shortened production season.

In cooler growing areas, warming minimum temperatures could allow earlier planting in spring and an extension of the current growing season into autumn and winter.

Queensland is already experiencing the impacts of climate change:

The Climate Change in Australia {CSIRO and Bureau of Meteorology, Climate Change in Australia website}[4] - contains the following statements :-

- All of Queensland has warmed since 1910.
- Average annual temperature has increased by 1.5°C since 1910,
- Under a high emissions scenario (RCP8.5), by mid-century, Queensland can expect an average annual temperature increase of around 1.3-2.5 °C (central **estimate of 1.9 °C**).

These statements about Queensland's changing climate refer to annual average temperature increases (1.3 – 2.5°C), so they smooth out the usual fluctuations in daily, weekly and monthly temperature at any location. The State of the Climate 2022 Report[5], Future Climate section states, "new research in Australia and around the world, together with the IPCC's Sixth Assessment Report, enhance our understanding of the state of Australia's future climate. In coming decades, Australia is projected to experience continued warming with more extremely hot days and fewer extremely cool days." This has serious implications for horticultural production in Queensland, where higher temperatures will impact existing crops, production timing, product quality and production locations. While some production may be able/forced to move to a new location, land suitability,

[1] https://terranovaseeds.com.au/wp-content/uploads/2022/03/Terranova-Product-Guide-2022.pdf
[2] https://spssales.com.au/product/carrot/

[3] https://www.rijkzwaan.com.au/vegetable-seeds/carrot-ctgCrops.carrot[3]

[4] https://www.climatechangeinaustralia.gov.au/en/changing-climate/state-climate-statements/queensland/
[5] https://www.csiro.au/en/research/environmental-impacts/climate-change/State-of-the-Climate

water availability, workforce and supporting infrastructure (e.g., road networks & power availability) pose significant constraints.

An updated version of the Queensland Future Climate web resource (Jan 2024) is available[6].

Carrot - Temperature Thresholds (from published research).

	Optimum Temperature Range ^{0}C		Critical Temperature(s) ^{0}C	
Growth Stage	**Lower**	**Upper**	**Lower**	**Upper**
Seed germination	**20**	**30**	**5**	**35**
Vegetative growth	**15**	**21**	**<0**	**>35**
Root Development	**15**	**21**	**5**	**30**

Table 1. Optimum and Critical Temperatures for Carrots.

It is important to realise that to achieve a mean monthly maximum of 30°C (for example), there will be a spread of cooler and hotter days. In a biological system, plant stress caused by several days in a row above a critical temperature tends to tip the system into decline.

[6] Queensland Future Climate | LongPaddock | Queensland Government

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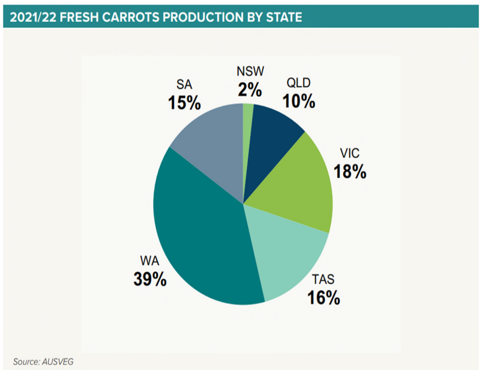
Commodity production data.

Carrots data is available from the Australian Horticulture Statistics Handbook 2020/21 (pp. 218-221)[7]

The majority of carrot production is concentrated in WA, SA, and Tasmania, with the remainder in Victoria, Qld and NSW.

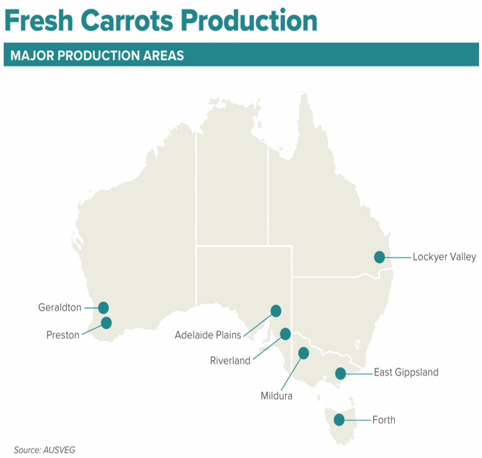
Carrots (Australia) – 306,395 tonnes (2022), valued at **$M 248**.



FRESH CARROTS EXPORTS BY STATE

Exports by State of Production Origin (Tonnes)

Year Ending June	2020	2021	2022
Queensland	2,502	4,170	1,567
Western Australia	94,082	96,848	92,641
Victoria	1,320	1,490	1,607
New South Wales	158	67	261
South Australia	696	674	482
Other	5,109	5,107	2,687
TOTAL	103,868	108,356	99,247



YEAR ENDING JUNE	2020	2021		2022	
	Value	Value	%YoY	Value	%YoY
Production (t)	330,145	335,527	+2%	306,394	-9%
Production ($m)	$222.1	$256.0	+15%	$247.9	-3%
Production area (Ha)	-	-	-	-	-
Fresh Export Volume (t)	103,868	108,356	+4%	99,247	-8%
Fresh Export Value ($m)	$91.1	$97.0	+6%	$92.2	-5%
Fresh Import Volume (t)	-	-	-	<1	-
Fresh Import Value ($m)	$-	$-	-	< $0.1	-
Fresh Supply (t)	205,982	206,545	<1%	188,313	-9%
Fresh Supply Wholesale Value ($m)	$168.7	$202.3	+20%	$197.7	-2%
Supply per Capita (kg)	7.98	8.02	<1%	7.26	-10%
Retail Supply (t)	166,114	164,577	>-1%	149,218	-9%
Retail Supply Wholesale Value ($m)	$136.0	$161.2	+19%	$156.7	-3%
Food Service Supply (t)	39,867	41,967	+5%	39,095	-7%
Food Service Wholesale Value ($m)	$32.6	$41.1	+26%	$41.1	>-1%

Sources: ABS; AC; AUSVEG; CFVIWA; GTA; MP & DD (Freshlogic Analysis)

Figure 2. Carrot production by State.

[7] https://www.horticulture.com.au/growers/help-your-business-grow/research-reports-publications-fact-sheets-and-more/grower-resources/mt21006-assets/australian-horticulture-statistics-handbook/

A wide range of growing locations, varieties and maturity times means that production can occur year-round, particularly in more mild and cooler areas of Australia, by selecting appropriate varieties for particular locations – Table 2.

2021/22 FRESH CARROTS SEASONALITY BY STATE

State	Volume (t)	Value ($m)	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Western Australia	118,312	$95.7	High	Medium	Medium	Low	Low	Low	Medium	Medium	Medium	High	High	High
Victoria	53,643	$43.4	High	Medium	Medium	Medium	Low	Low	Medium	Medium	Medium	Medium	High	High
Tasmania	50,216	$40.6	High	High	High	Medium	Medium	Low	Low	Low	Medium	Medium	Medium	High
South Australia	46,907	$38.0	Medium	Medium	Medium	Medium	Low	Low	Low	Medium	Medium	Medium	Medium	Medium
Queensland	31,447	$25.4	Medium	Medium	Medium	Low	Low	Medium	Medium	Medium	High	High	High	High
New South Wales	5,869	$4.7	Medium	Medium	Medium	Low	Low	Low	Low	Medium	Medium	Medium	High	High

Availability legend: High, Medium, Low, None

Source: AUSVEG

Table 2. Carrot seasonality by State.

Production regions, seasons and critical temperature thresholds

Critical Temperature Thresholds - Climate Monitor** analysis/verification of annual historical temperatures at selected Australian lettuce production areas.

i) Queensland

a) Lockyer Valley (Gatton), South East Queensland.

The winter-based production season in the Lockyer Valley commences with the first plantings in March, followed by regular plantings until August. First harvests occur in May, and continues until December.

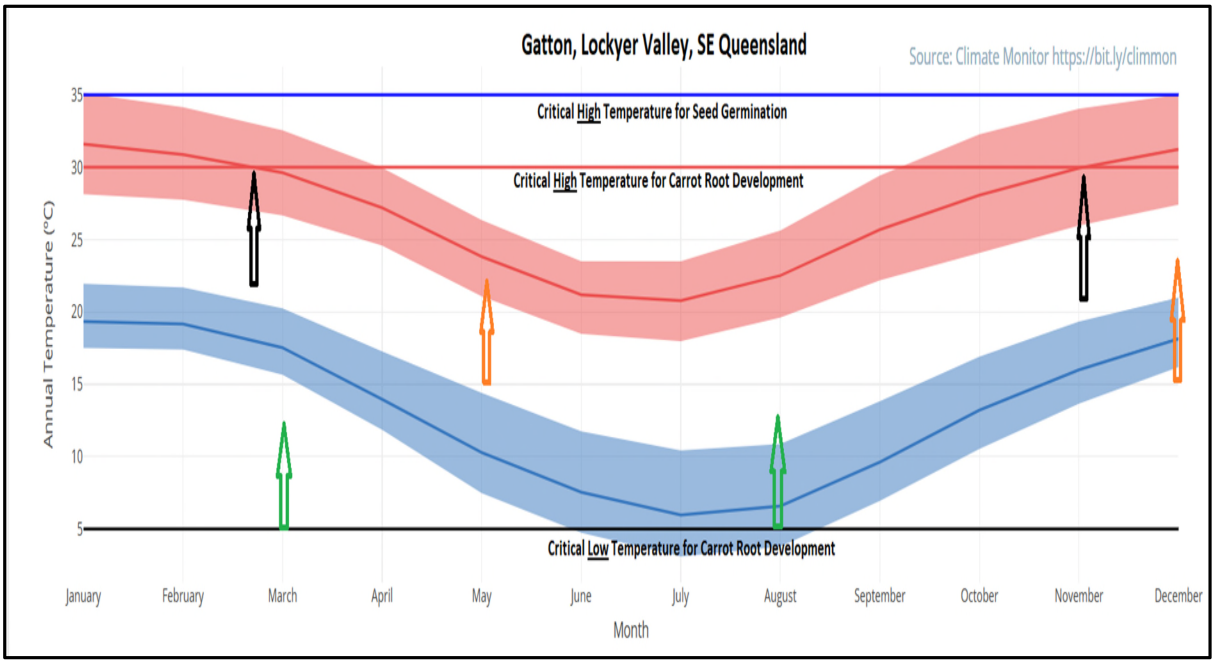


Figure 2. Monthly historical mean maximum (red) and mean minimum (blue) temperatures at Gatton (solid lines within each coloured band). Carrots – Limits to winter/spring harvest season (black arrows); Planting period (green arrows); harvest period (red arrows). Note: The graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

Using the unique weather data analysis of the Climate Monitor** Web App[8], producers can easily review historical temperatures at any location in Australia, and allows the user to analyse and graph minimum and maximum temperature and rainfall for all available years, calculate thermal time (chill and heat units) and be able to retrieve, analyse and graph temperature thresholds (for a chosen location).

An analysis of the number of days that minimum temperatures below 5°C occurred from May to August (Fig 3a) in Gatton, is displayed below. Therefore, in some years, low temperatures during the carrot root development phase will influence carotene production and root colour development.

[8] https://www.longpaddock.qld.gov.au/dcap/horticulture-industry/

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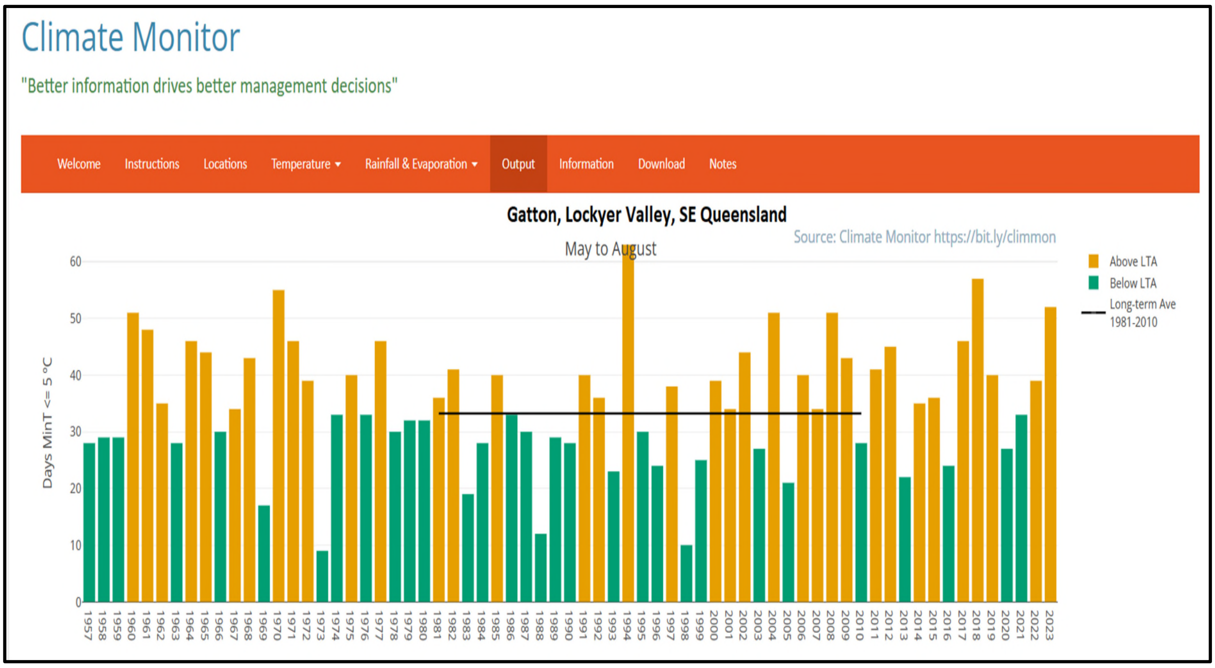

Figure 3a. Climate Monitor analysis showing the <u>number of days</u> that Gatton has experienced minimum temperatures below 5°C from <u>May to August</u>.

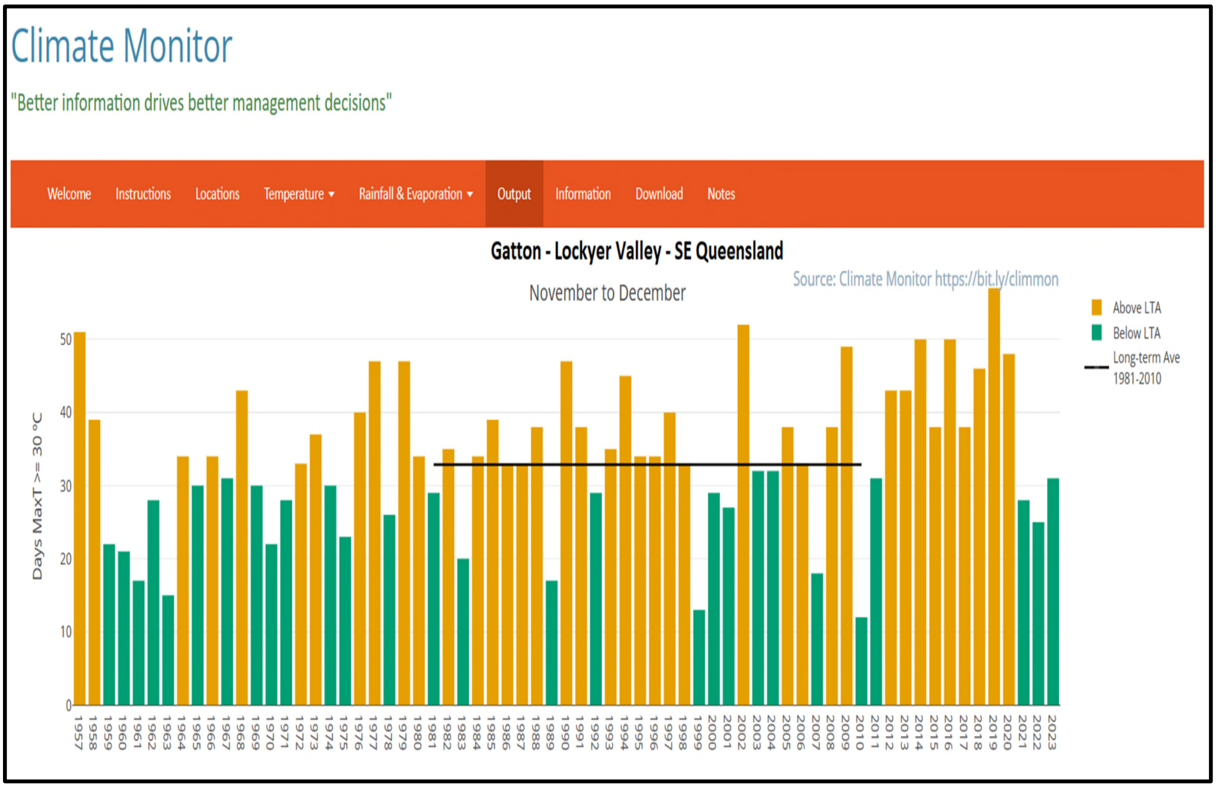

Figure 3b. Climate Monitor analysis showing the <u>number of days</u> that Gatton has experienced maximum temperatures 30°C or above in <u>November and December</u>.

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Carrots can be grown outside the optimum range (15 -21°C), although root colour, texture, flavour and shape will be adversely affected once temperatures reach 25–30°C (McAvoy, 2012; Grotjahn, 2021; Anon, 2003). This situation does occur quite regularly in the Lockyer Valley at the end of the harvest season (Fig 3b).

b) Fassifern Valley (Kalbar), South-East Queensland.

The winter-based production season in the Fassifern Valley commences with the first plantings in March, followed by regular plantings until August. First harvest occurs in May and continues until December.

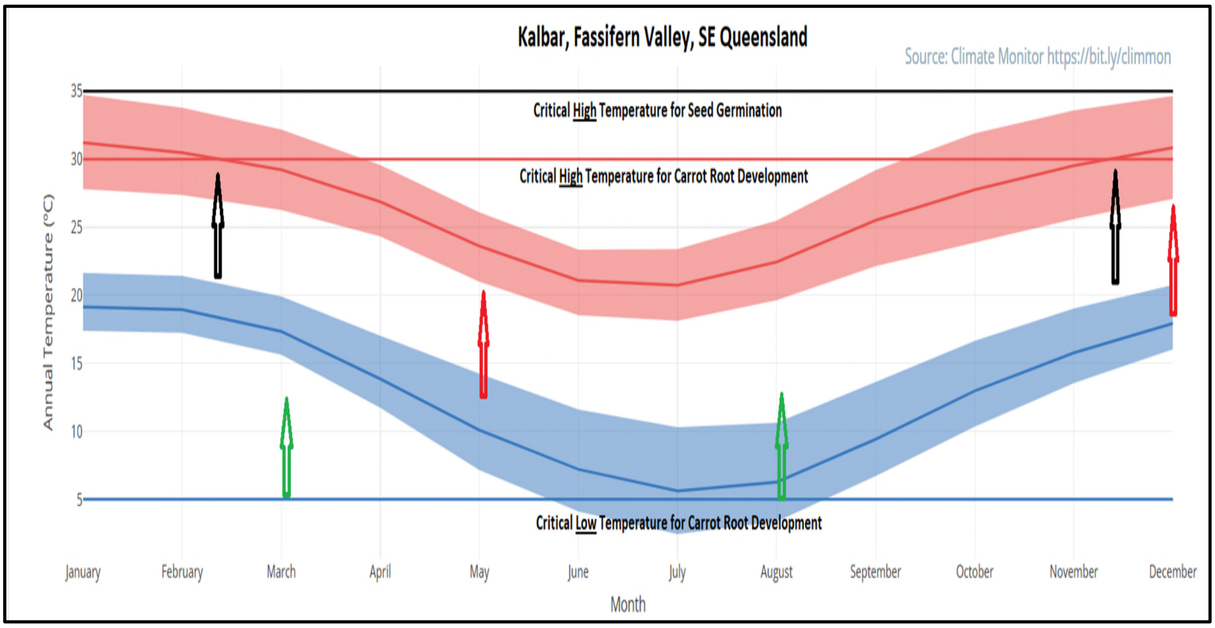

Figure 4. Monthly historical mean maximum (red) and mean minimum (blue) temperatures at Kalbar (solid lines within each coloured band). Carrots – Limits to winter/spring harvest season (black arrows); Planting period (green arrows); harvest period (red arrows). Note: The graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

Using the unique weather data analysis of the Climate Monitor Web App[9], producers can easily review historical temperatures at any location in Australia. It is important to realise that in a biological system, plant stress caused by several days in a row above a critical temperature tends to tip the system into decline.

An analysis of the number of days that minimum temperatures below 5°C occurred from May to August (Fig 5a) in Kalbar, is displayed below. Therefore, in some years, low temperatures during the carrot root development phase will influence carotene production and root colour development.

[9] https://www.longpaddock.qld.gov.au/dcap/horticulture-industry/

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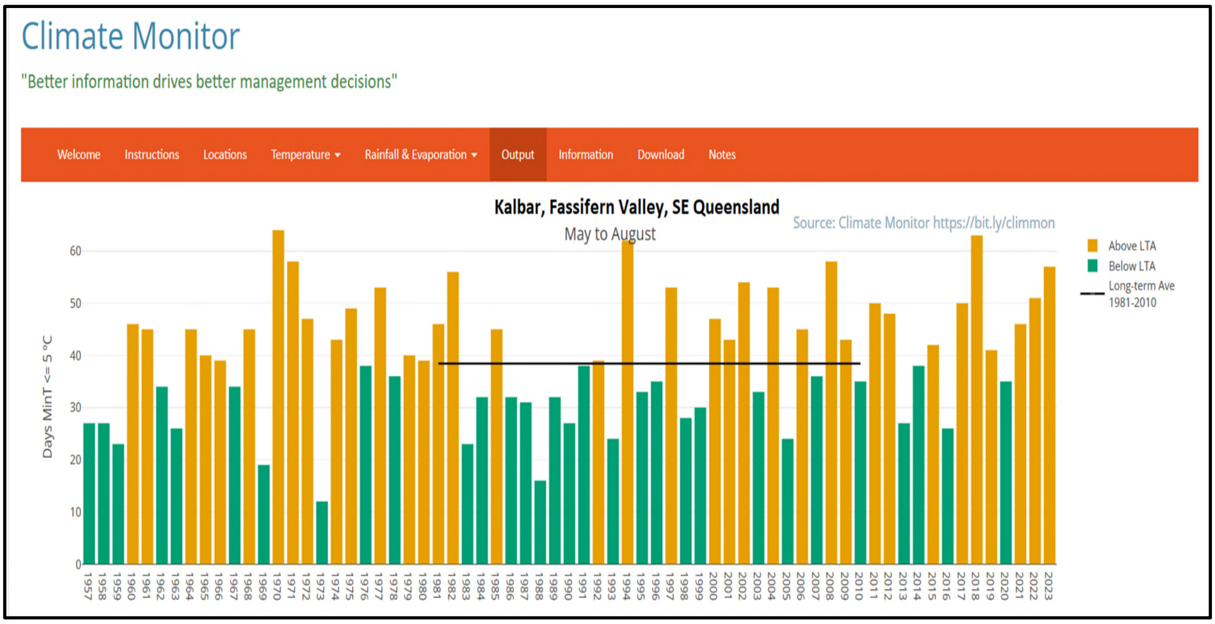


Figure 5a. Climate Monitor analysis showing the <u>number of days</u> that Kalbar has experienced minimum temperatures below 5°C from <u>May to August</u>.

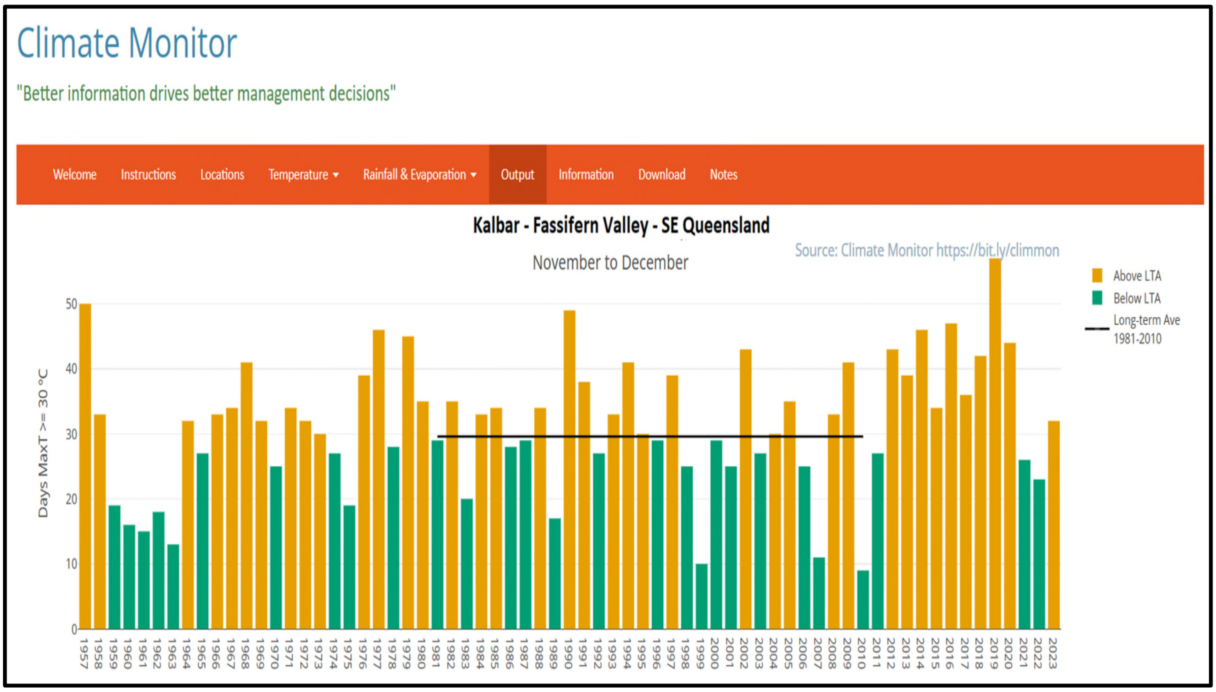


Figure 5b. Climate Monitor analysis showing the <u>number of days</u> that Kalbar has experienced maximum temperatures above 30°C or above in <u>November and December</u>.

Carrots can be grown outside the optimum range (15 -21°C), although root colour, texture, flavour and shape will be adversely affected once temperatures reach 25–30°C (McAvoy, 2012; Grotjahn, 2021; Anon, 2003). This situation does occur quite regularly in the Fassifern Valley at the end of the harvest season (Fig 5b).

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from <u>Climate Monitor</u>, a free, publicly available DCAP web-tool

Future temperature insight.

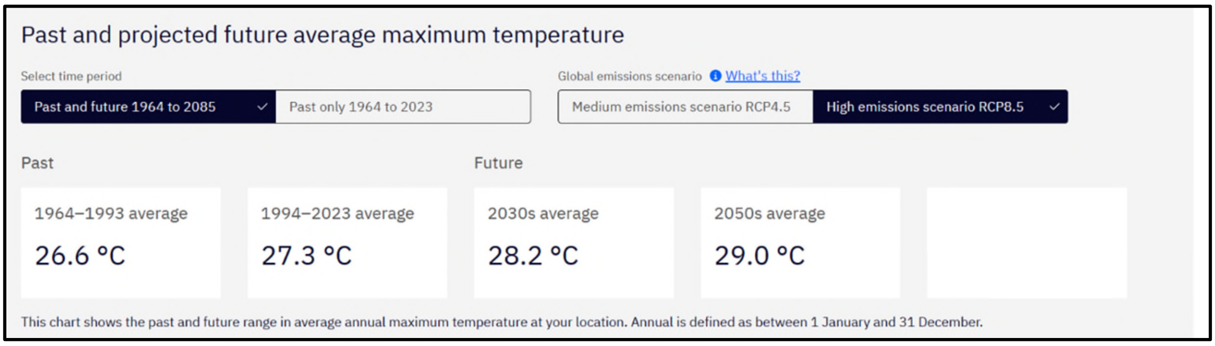
As underlying temperatures continue to rise, and warmer and hotter days become more frequent[10], it is likely that some summer crop production windows will be reduced with rising maximum temperatures. Similarly, as winter minimums also increase, summer crop production windows can extend further into autumn, and where winter minimums currently adversely affect production and quality in some years, this effect will be reduced in the future.

The Representative Concentration Pathways scenario RCP8.5 (Schwalm, et al., 2020), has been chosen in this study to represent a future climate (2030 and 2050), in an effort to understand the impacts on each of the current carrot production locations.

a) Gatton (Lockyer Valley)

Projected current and future climate data for **Gatton**.

Data source: Climate Services for Agriculture output, My Climate View[11]



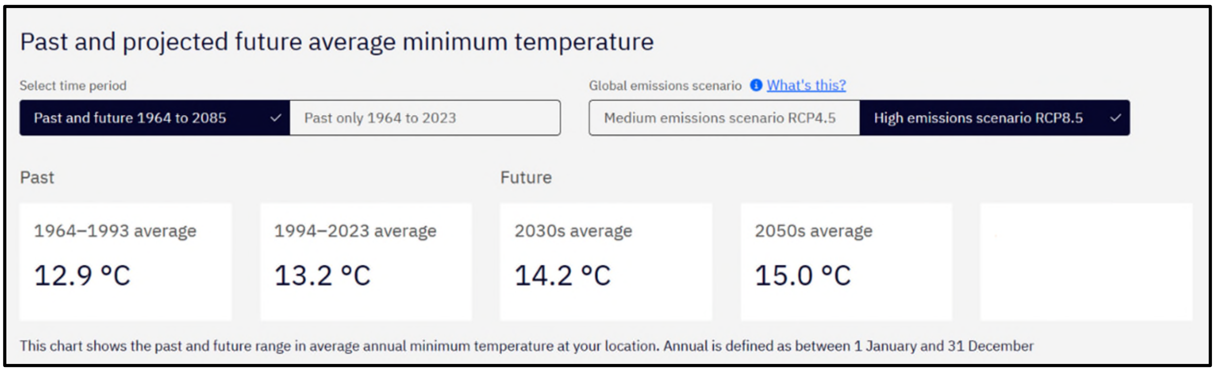


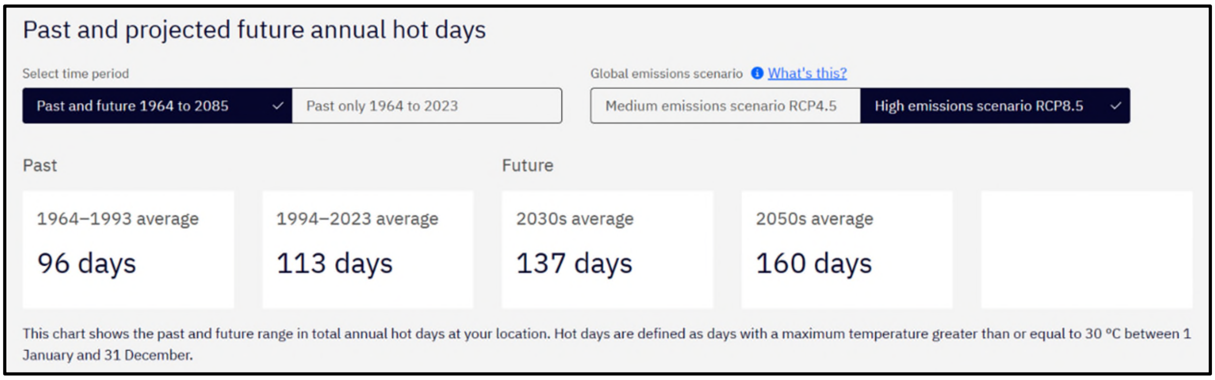
Figure 6. Projected future Maximum and Minimum temperature outlook for Gatton under high emissions scenario RPC 8.5, where Australian emissions are currently tracking (Schwalm, et al., 2020). The graphic uses 1964 – 1993 for comparison of the 2030 and 2050 average temperature shift.

[10] http://www.bom.gov.au/state-of-the-climate/australias-changing-climate.shtml
[11] https://myclimateview.com.au/

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

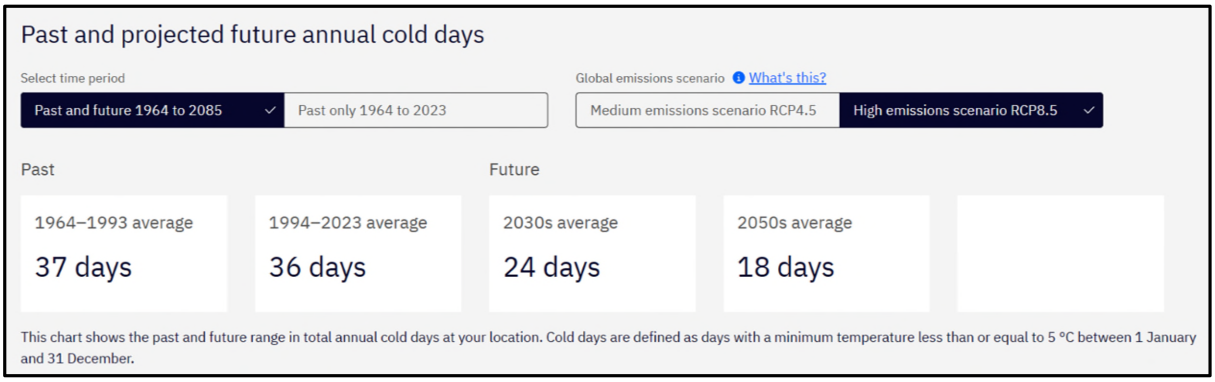
Gatton - Projected annual crop specific upper CTT hot days risk shift (1964 – 93 baseline period).



** This chart shows the average number of days in past and projected future years and year periods that **the crop specific upper CTT** has or is projected to occur using the high emissions greenhouse gas scenario RCP 8.5.*

Figure 7a. Gatton annual Hot Days (above 30ºC).
Data source: My Climate View[12]

Gatton - Projected annual crop specific lower CTT cold days risk shift (1964 – 93 baseline period).



** This chart shows the average number of days in past and projected future years and year periods that **the crop specific lower CTT** has or is projected to occur using the high emissions greenhouse gas scenario RCP 8.5.*

Figure 7b. Gatton annual Cold Days (Below 5ºC).
Data source: My Climate View[13]

[12] https://climateservicesforag.indraweb.io/
[13] https://climateservicesforag.indraweb.io/

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

Projected future and current climate data for Gatton.

Time Period	Annual Average T Max ^{0}C	Annual Average T Min^{0}C	Annual Heat Risk Days T Max ≥ 30^{0}C	Annual Cold Risk Days ≤ 5^{0}C
1964-1993 Past Average	**26.6**	**12.9**	**96**	**37**
1994 -2023 Recent Average	27.3	13.2	113	36
2030's High Emissions - Future Average	28.2	14.2	137	24
2050's High Emissions - Future Average	**29.0**	**15.0**	**160**	**18**
Difference from Past Average	**+2.4**	**+2.1**	**+64**	**-19**

Table 3. Projected future temperature comparison for Gatton under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking.

The high emissions pathway model indicates a temperature shift, showing a 2.4°C increase in maximum temperatures and a 2.1°C increase in minimum temperatures by 2050. Importantly the number of days when the maximum temperature in **Gatton** exceeds 30°C increases from 96 to 160 (64 days), and the cold risk decreases by 19 days - Table 3.

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

Future temperatures at Gatton and the impact on the timing and occurrence of carrot critical temperature thresholds (CCT).

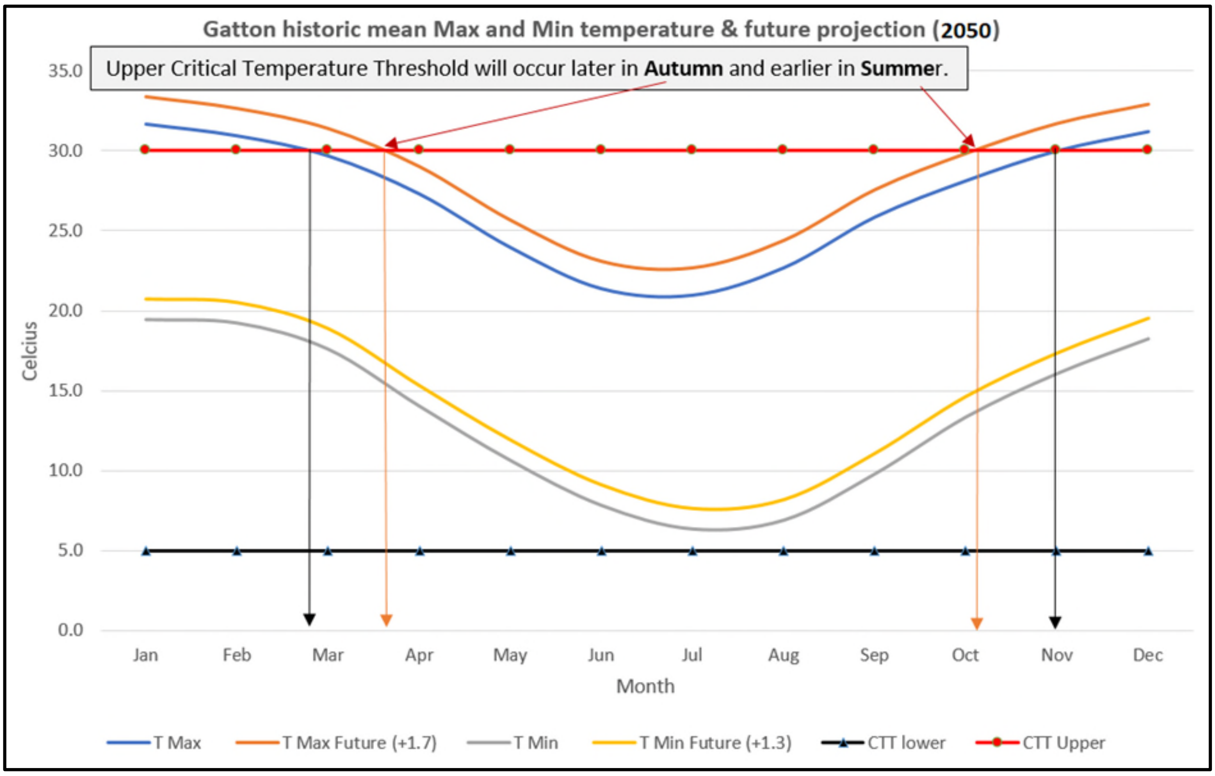


Figure 8. Current mean monthly temperatures at Gatton; Carrots upper CTT (30ºC) and Lower (5ºC) and the impact of the projected future Maximum temperatures on the maximum temperature Threshold effects for carrots.

The monthly future climate data displayed in Fig 8, is not publicly available, but it displays the individual monthly changes that underpin the projected annual changes in both maximum and minimum temperatures. The monthly projected change data has been included here, so the reader can appreciate and better understand the projected monthly changes that underpin the publicly available projected annual changes.

Carrots are a cool-season crop but will tolerate warm temperatures early in the growing season. Consequently, carrots are not as susceptible to variations in temperature as many other vegetable crops, and growers are careful in their selection of varieties to suit locations and production timing. Nevertheless, unseasonal warm or cool conditions will affect plant growth rates and product quality.

Maximum temperature is the critical weather factor that can influence carrot root colour and quality, especially at the end of the winter/spring harvest season in the Lockyer Valley. Increases in maximum temperatures in early summer will influence carrot root colour and quality (Fig 8).

Minimum temperatures will also increase as shown in Figs 6 & 8, and Table 3 above, however, minimum temperatures currently (and in the future), have little impact on carrot production in the Lockyer Valley.

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

b) Kalbar (Fassifern Valley).

Projected current and future climate data for **Kalbar**.

Data source: Climate Services for Agriculture output, My Climate View[14]

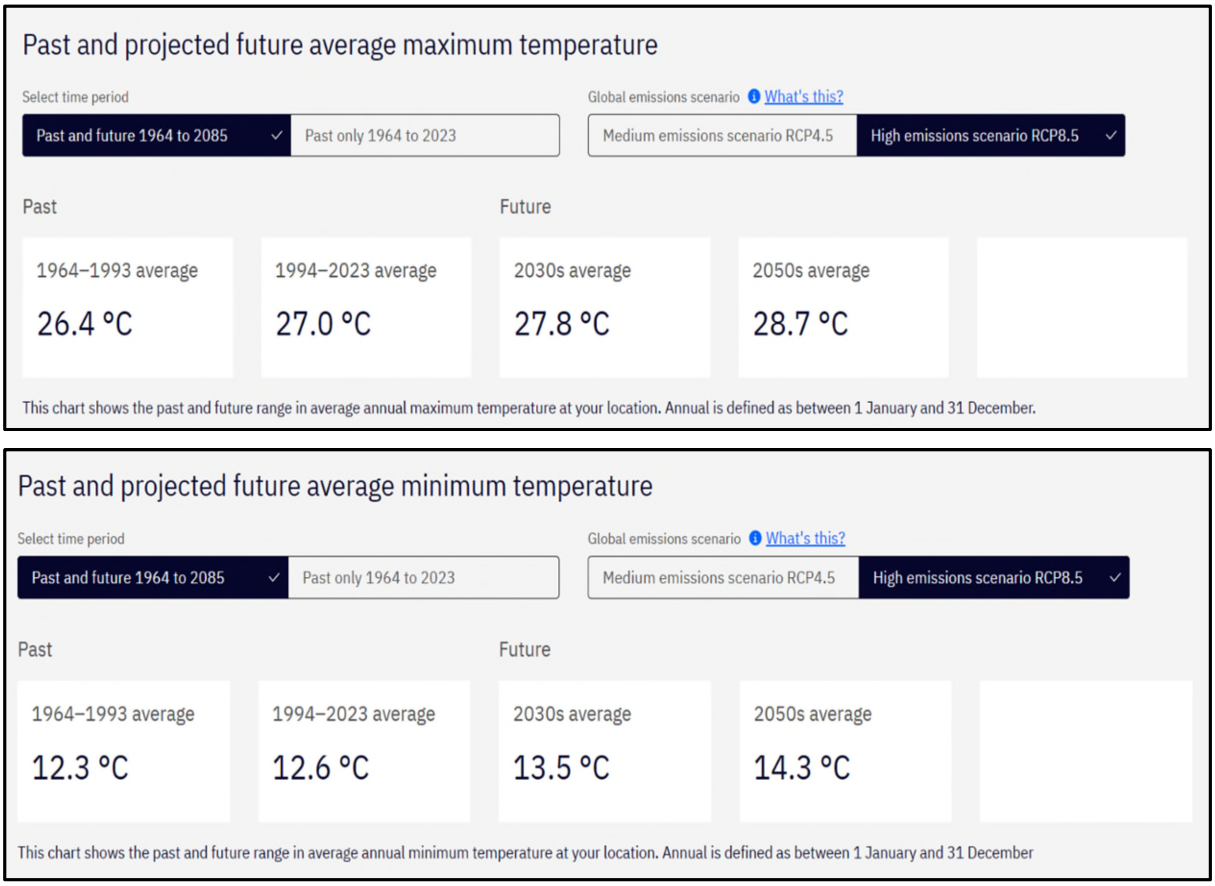


Figure 9. Projected future Maximum and Minimum temperature outlook for Kalbar under high emissions scenario RPC 8.5, where Australian emissions are currently tracking (Schwalm, et al., 2020). The graphic uses 1964 – 1993 for comparison of the 2030 and 2050 average temperature shift.

[14] https://myclimateview.com.au/

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

Kalbar - Projected annual crop specific upper CTT hot days risk shift (1964 – 93 baseline period).

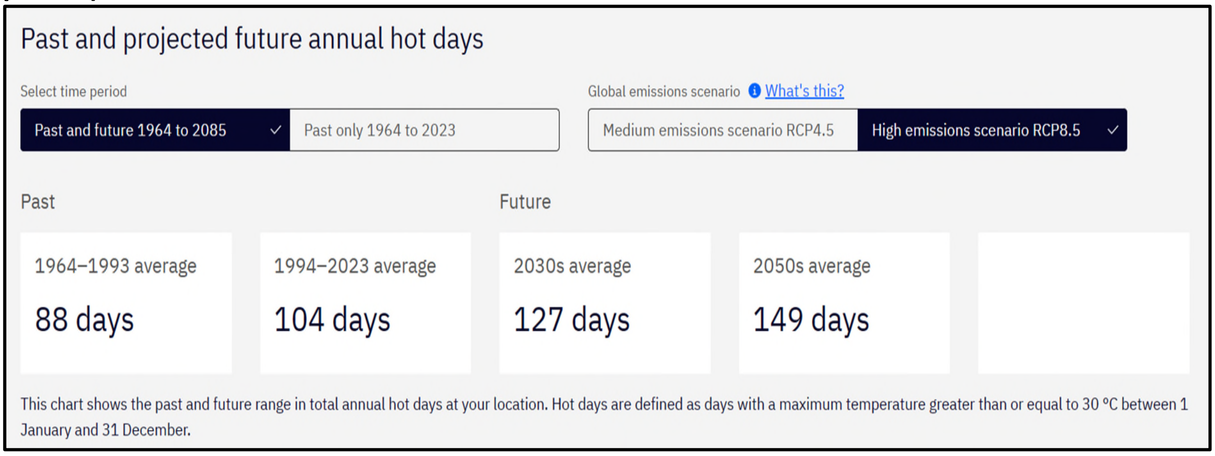


Figure 10a. Kalbar annual Hot Days (above 30ºC).Data source: My Climate View[15]

Kalbar - Projected annual crop specific lower CTT cold days risk shift (1964 – 93 baseline period).

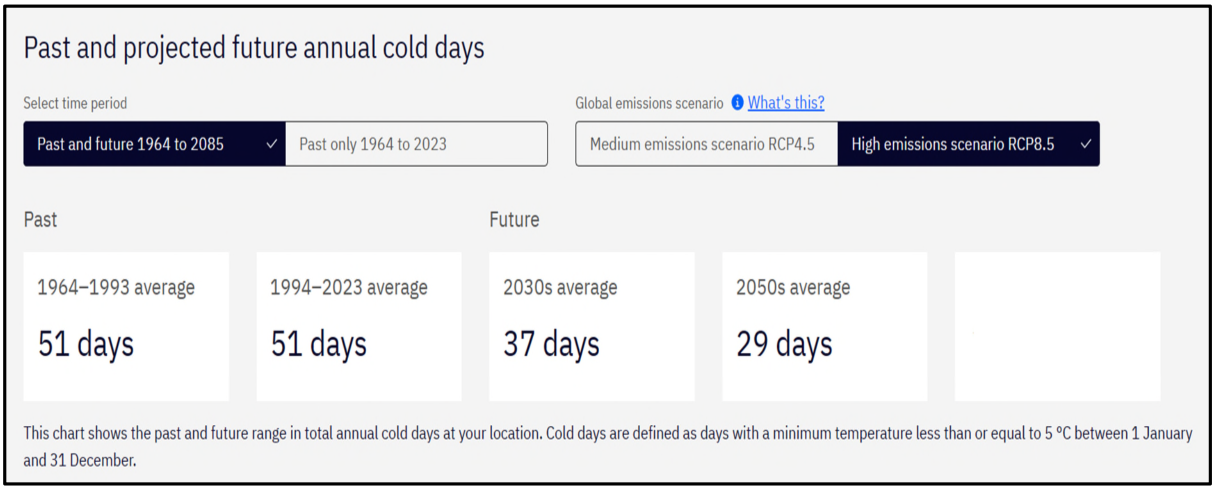


Figure 10b. Kalbar annual Cold Days (Below 5ºC).
Data source: My Climate View[16]

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15 https://climateservicesforag.indraweb.io/
16 https://climateservicesforag.indraweb.io/

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

Projected future and current climate data for Kalbar.

Time Period	Annual Average T Max ^{0}C	Annual Average T Min^{0}C	Annual Heat Risk Days T Max ≥ 30^{0}C	Annual Cold Risk Days ≤ 5^{0}C
1964-1993 Past Average	**26.4**	**12.3**	**88**	**51**
1994 -2023 Recent Average	27.0	12.6	104	51
2030's High Emissions - Future Average	27.8	13.3	127	37
2050's High Emissions - Future Average	**28.7**	**13.8**	**149**	**29**
Difference from Past Average	**+2.3**	**+1.5**	**+61**	**-22**

Table 4. Projected future temperature comparison for Kalbar under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking.

The high emissions pathway model indicates a temperature shift, showing a 2.3^{o}C increase in maximum temperatures and a 1.5^{o}C increase in minimum temperatures by 2050. Importantly the number of days when the maximum temperature in **Kalbar** exceeds 30^{o}C increases from 88 to 149 days (61 days), and the cold risk decreases by 22 days - Table 4.

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

Future temperatures at Kalbar and the impact on the timing and occurrence of carrot critical temperature thresholds (CCT).

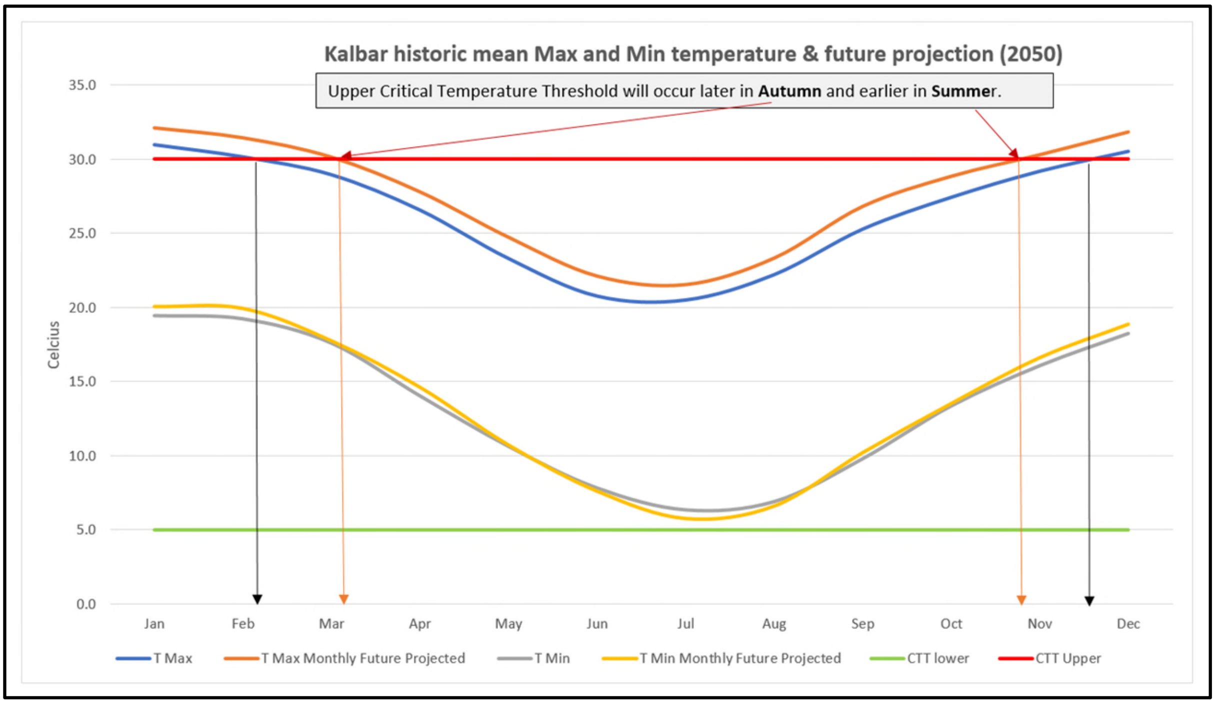

Figure 11. Current mean monthly temperatures at Kalbar; Carrots upper CTT (30ºC) and Lower (5ºC) and the impact of the projected future Maximum temperatures on the maximum temperature Threshold effects for carrots.

The monthly future climate data displayed in Fig 11, is not publicly available, but it displays the individual monthly changes that underpin the projected annual changes in both maximum and minimum temperatures. The monthly projected change data has been included here, so the reader can appreciate and better understand the projected monthly changes that underpin the publicly available projected annual changes.

Carrots are a cool-season crop but will tolerate warm temperatures early in the growing season. Consequently, carrots are not as susceptible to variations in temperature as many other vegetable crops, and growers are careful in their selection of varieties to suit locations and production timing. Nevertheless, unseasonal warm or cool conditions will affect plant growth rates and product quality.

Maximum temperature is the critical weather factor that can influence carrot root colour and quality, especially at the end of the winter/spring harvest season in the Fassifern Valley. Increases in maximum temperatures in early summer will influence carrot root colour and quality (Fig 9).

Minimum temperatures will also increase as shown in Figs 9 & 11, and Table 4 above, however, minimum temperatures currently (and in the future), have little impact on carrot production in the Fassifern Valley.

Interstate production – future insights.

Future climate data analysis for all locations is based on current projections sourced from Australias' **MyClimateView**[17]

ii) New South Wales - Griffith

The summer-based production season in the Riverina commences with the first plantings in December, with first harvests occuring in June.

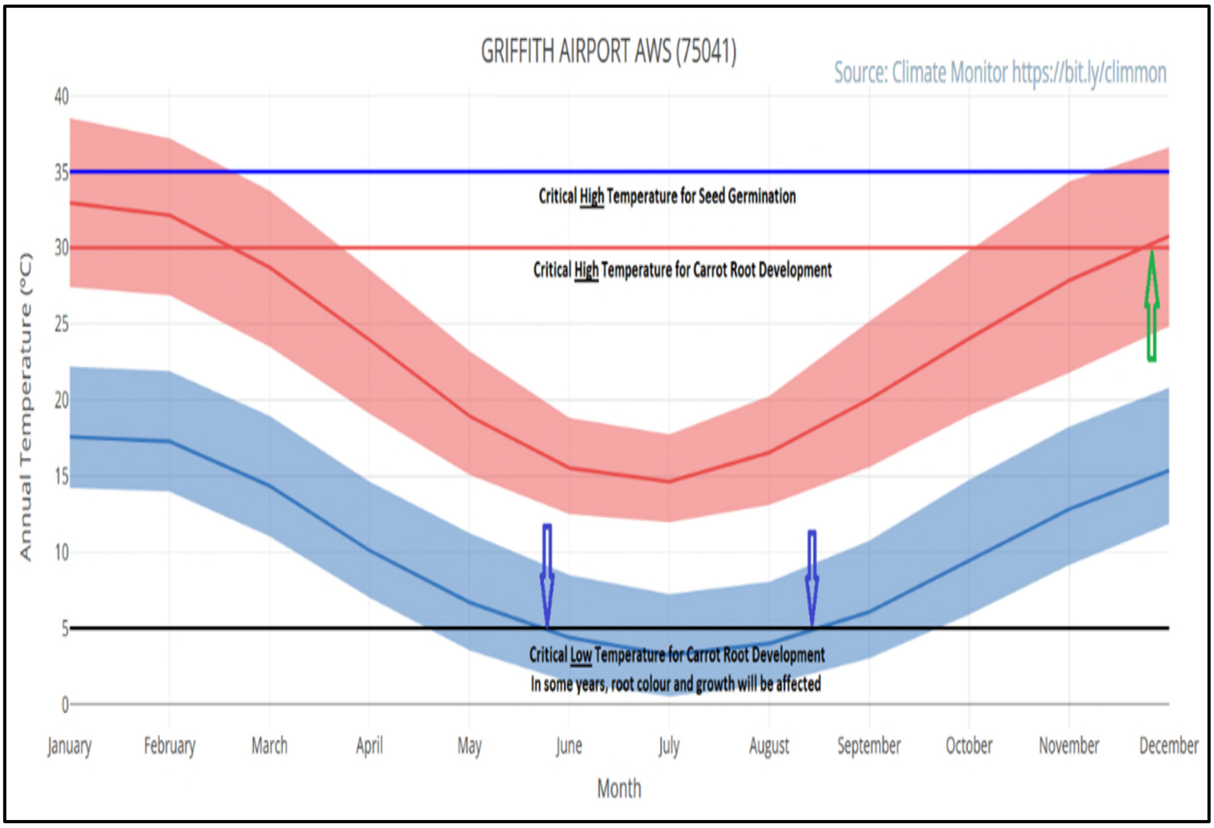

Figure 12. Climate Monitor analysis showing the annual historic monthly temperatures maximum (red) and minimum (blue) temperatures and mean temperatures (solid lines within each coloured band), with Carrots critical temperatures (blue, red and black) – overlaid, at Griffith, NSW. Arrows (green) denote the beginning main planting season, for harvest commencing in June. Note: The graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

[17] https://climateservicesforag.indraweb.io/

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

Projected future and current climate data for Griffith.

Time Period	Annual Average T Max °C	Annual Average T Min°C	Annual Heat Risk Days T Max ≥ 30°C	Annual Cold Risk Days ≤ 5°C
1964-1993 Past Average	**23.4**	**9.8**	**80**	**92**
1994 -2023 Recent Average	24.3	10.2	95	88
2030's High Emissions - Future Average	25.0	11.1	102	73
2050's High Emissions - Future Average	**26.0**	**12.0**	**118**	**61**
Difference from Past Average	**+2.6**	**+2.2**	**+38**	**-31**

Table 5. Projected future temperature comparison for Griffith under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020).

The high emissions pathway model indicates a temperature shift, showing a 2.6°C increase in maximum temperatures and a 2.2°C increase in minimum temperatures by 2050. Importantly the number of days when the maximum temperature at **Griffith** exceeds 30°C increases from 80 to 118 (38 days), and the cold risk decreases by 31 days - Table 5.

The projected temperature shift, with hotter summers (increase in Maximum temperatures and Annual Heat Risk Days), will alter the existing summer dominated production pattern, although warmer minimum temperatures will allow production to extend further into the winter.

When considering projected maximum and minimum temperature shifts at any location, the reader should keep in mind the daily duration (number of hours each day) the plant is likely to experience these conditions.

Griffith - Projected annual crop specific upper CTT hot days risk shift (1964 – 93 baseline period).

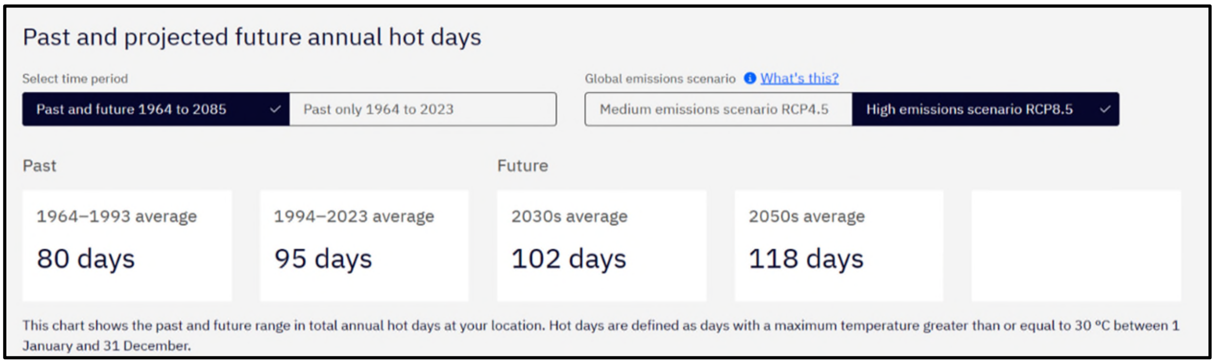

Figure 13a. Griffith annual Hot Days (above 30°C).
Data source: My Climate View

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

Griffith - Projected annual crop specific lower CTT cold days risk shift (1964 – 93 baseline period).

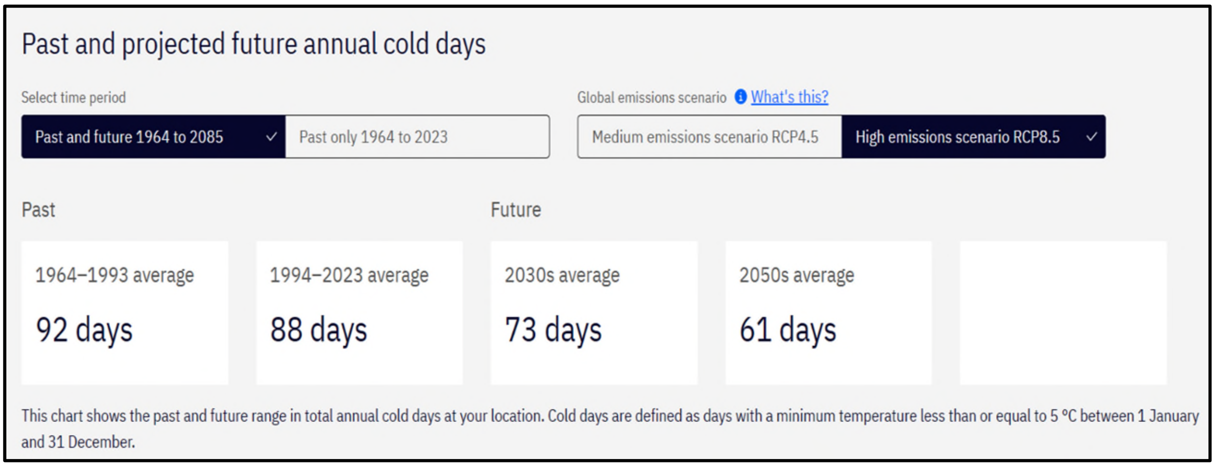

Figure 13b. Griffith annual Cold Days (Below 5°C).
Data source: My Climate View[18]

[18] https://climateservicesforag.indraweb.io/

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

iii) Victoria

The main carrot growing regions of Victoria occur in the north (**Murray Valley** – winter production) and south of the state (**Gippsland** and East Gippsland – summer production).

a) Longford, Gippsland, Victoria

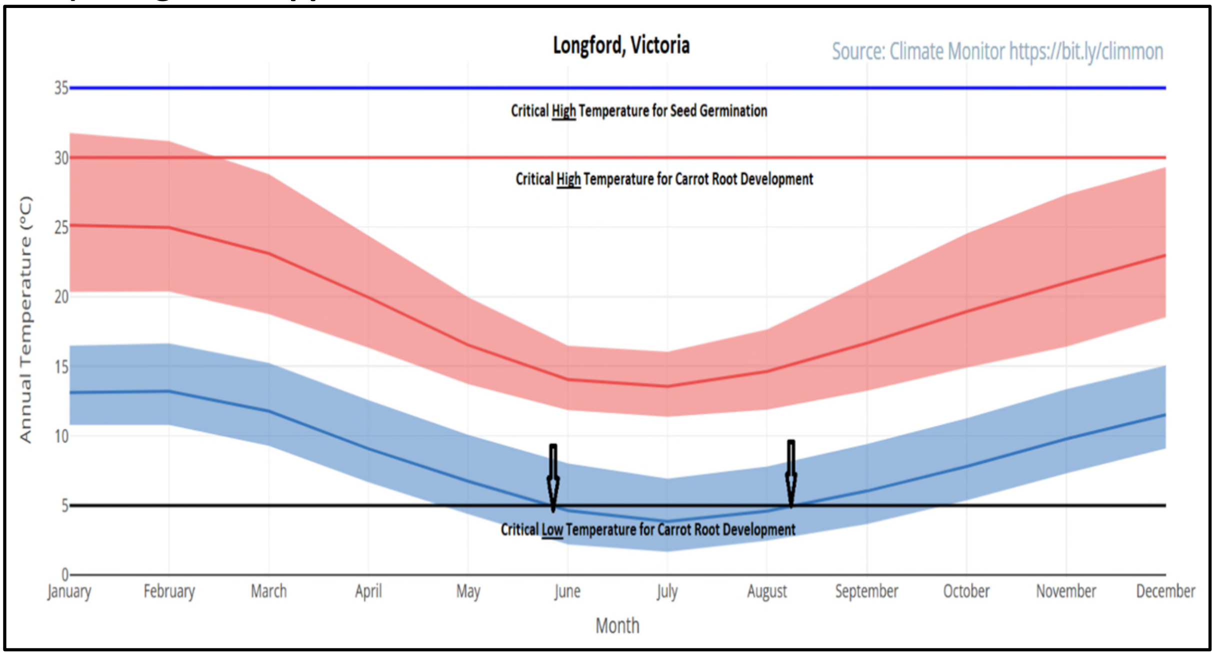

Figure 14. Climate Monitor analysis showing the annual historic monthly temperatures maximum (red) and minimum (blue) temperatures and mean temperatures (solid lines within each coloured band), with Carrots critical temperatures (blue, red and black) – overlaid, at Longford, Vic. Note: The graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

Projected future and current climate data for Longford.

Time Period	Annual Average T Max ^{0}C	Annual Average T Min^{0}C	Annual Heat Risk Days T Max ≥ 30^{0}C	Annual Cold Risk Days ≤ 5^{0}C
1964-1993 Past Average	**19.8**	**8.6**	**21**	**84**
1994 -2023 Recent Average	20.3	9.1	25	77
2030's High Emissions - Future Average	21.0	9.6	28	62
2050's High Emissions - Future Average	**21.8**	**10.3**	**33**	**49**
Difference from Past Average	**2.0**	**1.7**	**12**	**-35**

Table 6. Projected future temperature comparison for Longford, Vic. under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020).

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

The high emissions pathway model indicates a temperature shift, showing a 2.0°C increase in maximum temperatures and a 1.7°C increase in minimum temperatures by 2050. Importantly the number of days when the maximum temperature at **Longford** exceeds 30°C increases from 21 to 33 (12 days), and the cold risk decreases by 35 days - Table 6.

The projected temperature shift, with hotter summers (increase in Maximum temperatures and Annual Heat Risk Days), will alter the existing summer dominated production pattern, although warmer minimum temperatures will allow production to extend further into the winter.

When considering projected maximum and minimum temperature shifts at any location, the reader should keep in mind the daily duration (number of hours each day) the plant is likely to experience these conditions.

Longford - Projected annual crop specific upper CTT hot days risk shift (1964 – 93 baseline period).

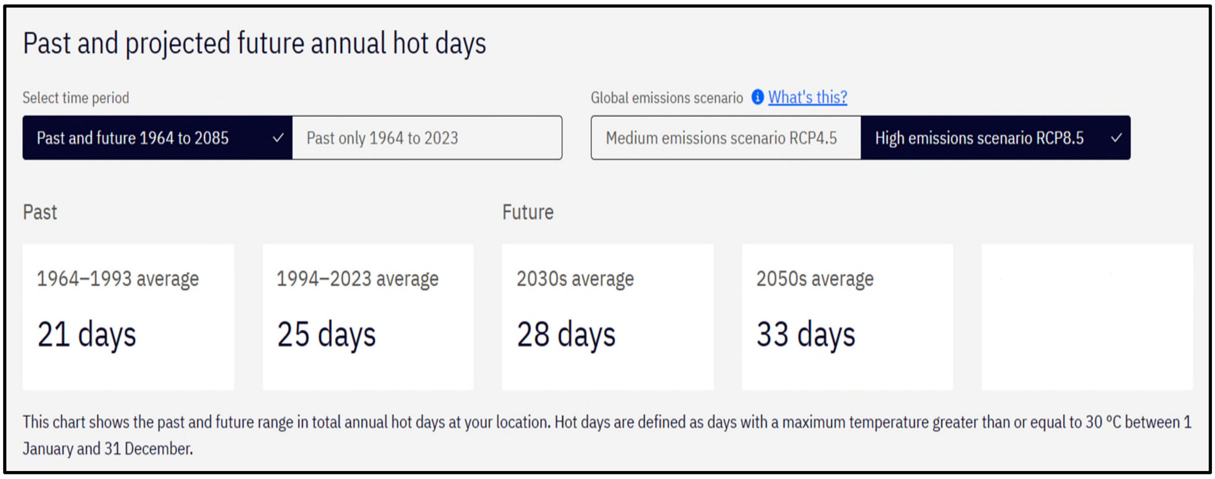

Figure 15a. Longford annual Hot Days (above 30°C).
Data source: My Climate View[19]

[19] https://climateservicesforag.indraweb.io/

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

Longford - Projected annual crop specific lower CTT cold days risk shift (1964 – 93 baseline period).

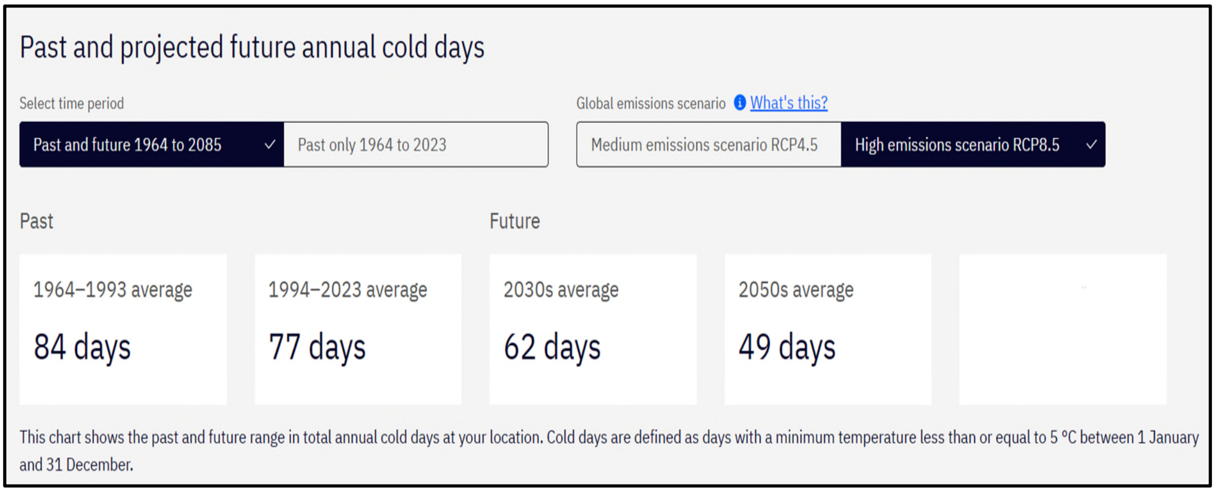

Figure 15b. Longford annual Cold Days (Below 5°C).
Data source: My Climate View[20]

b) Wemen, Murray Valley, Victoria

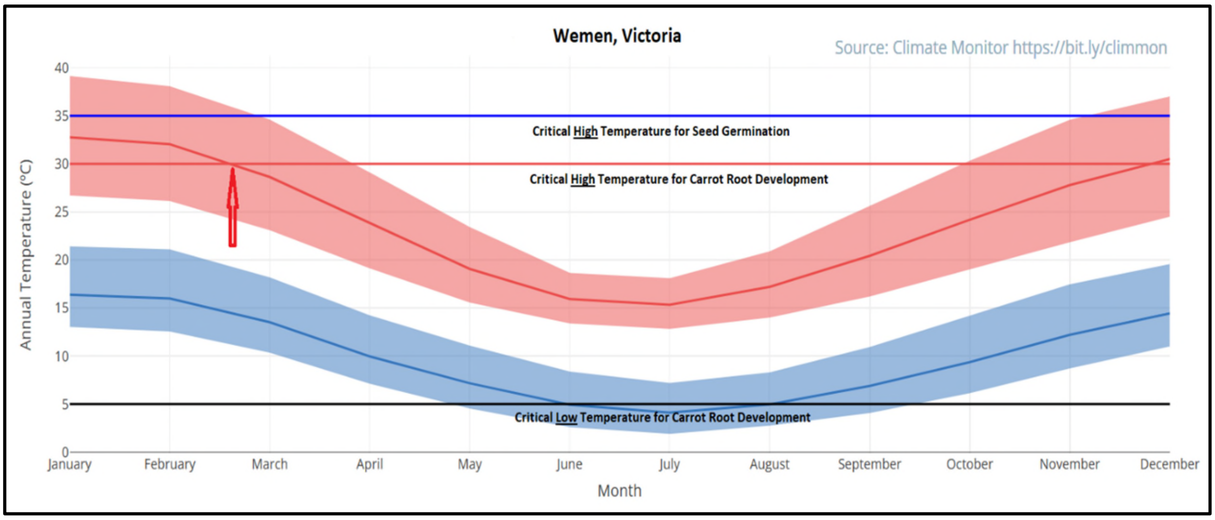

Figure 16. Climate Monitor analysis showing the annual historic monthly temperatures maximum (red) and minimum (blue) temperatures and mean temperatures (solid lines within each coloured band), with Carrots critical temperatures (blue, red and black) – overlaid, at Wemen, Vic. Note: The graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

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[20] https://climateservicesforag.indraweb.io/

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

Projected future and current climate data for Wemen.

Time Period	Annual Average T Max ^{0}C	Annual Average T Min^{0}C	Annual Heat Risk Days T Max ≥ 30^{0}C	Annual Cold Risk Days ≤ 5^{0}C
1964-1993 Past Average	**23.7**	**9.8**	**80**	**81**
1994 -2023 Recent Average	24.5	10.0	92	77
2030's High Emissions - Future Average	25.2	10.9	99	59
2050's High Emissions - Future Average	**26.1**	**11.6**	**112**	**48**
Difference from Past Average	**2.4**	**1.8**	**32**	**-33**

Table 7. Projected future temperature comparison for Wemen, Vic. under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020).

The high emissions pathway model indicates a temperature shift, showing a 2.4°C increase in maximum temperatures and a 1.8°C increase in minimum temperatures by 2050. Importantly the number of days when the maximum temperature at **Wemen, Vic** exceeds 30°C increases from 80 to 112 (32 days), and the cold risk decreases by 33 days - Table 7.

The projected temperature shift, with hotter summers and warmer winters, are likely to have a positive impact on the existing winter dominated production pattern, with warmer minimum temperatures reducing the potential low temperature effects on root growth and colour during the winter.

When considering projected maximum and minimum temperature shifts at any location, the reader should keep in mind the daily duration (number of hours each day) the plant is likely to experience these conditions.

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

Wemen - Projected annual crop specific upper CTT hot days risk shift (1964 – 93 baseline period).

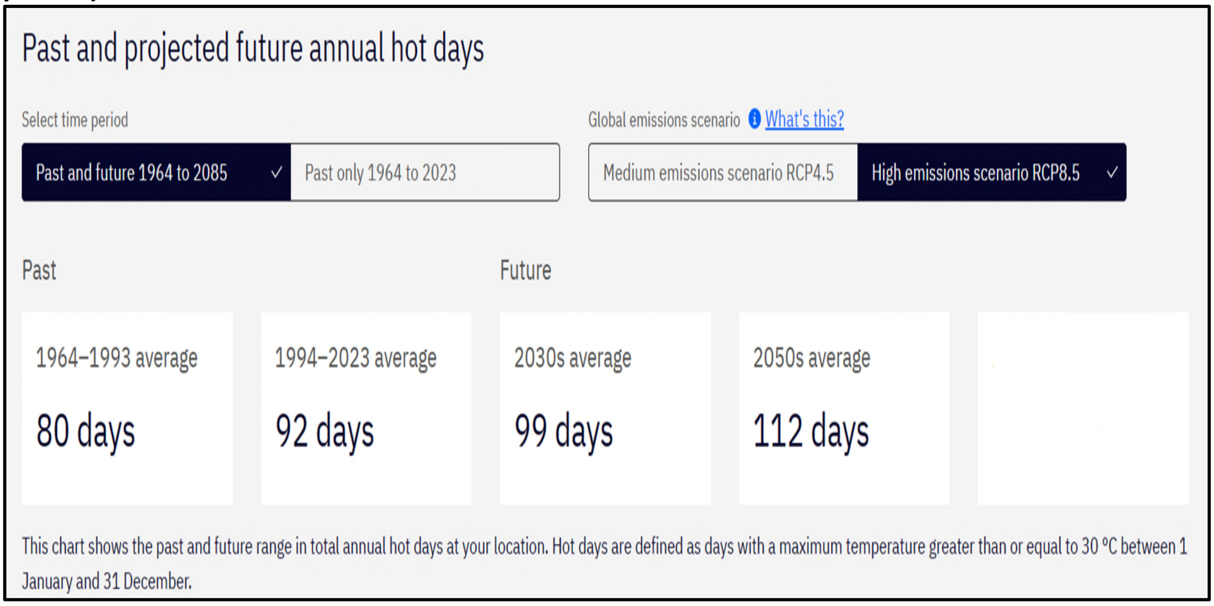

Figure 17a. Wemen annual Hot Days (above 30°C).
Data source: My Climate View[21]

Wemen - Projected annual crop specific lower CTT cold days risk shift (1964 – 93 baseline period).

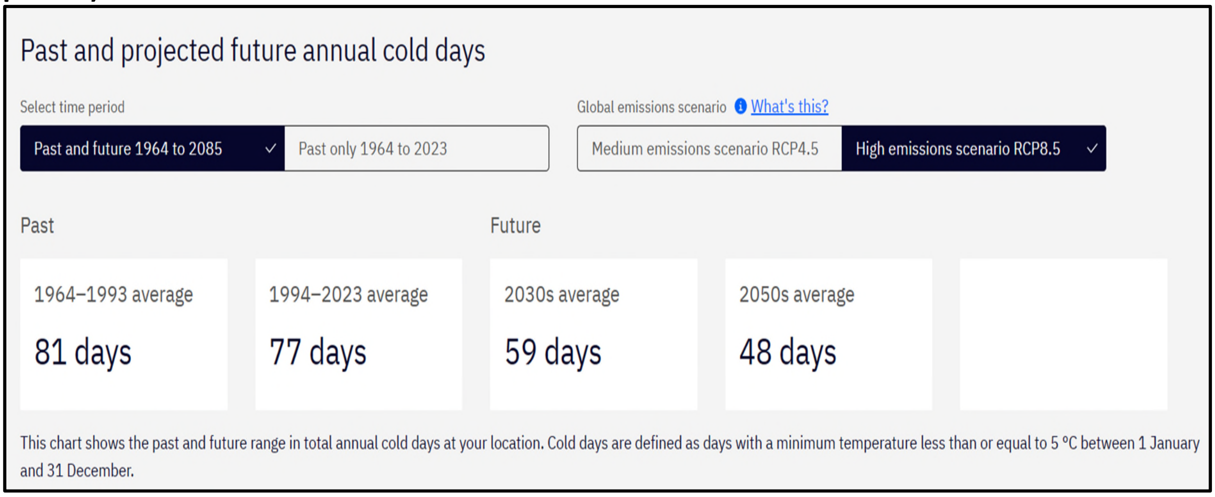

Figure 17b. Wemen annual Cold Days (Below 5°C).
Data source: My Climate View

[21] *https://climateservicesforag.indraweb.io/*

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

iv) <u>Western Australia</u> – a) Gingin, WA

The mild winters and hot summers along the Peth Coastal Plain provide an ideal environment for year-round carrot production.
The carrot growing areas are within 150km of Perth, at Lancelin and West Gingin to the north, and Myalup and Baldivis to the south.

Summer carrot crops can be ready for harvest in 16 weeks from sowing, while crops growing through the cooler winter months may grow for up to 24 weeks, and produced for fresh local, interstate and international markets year-round.

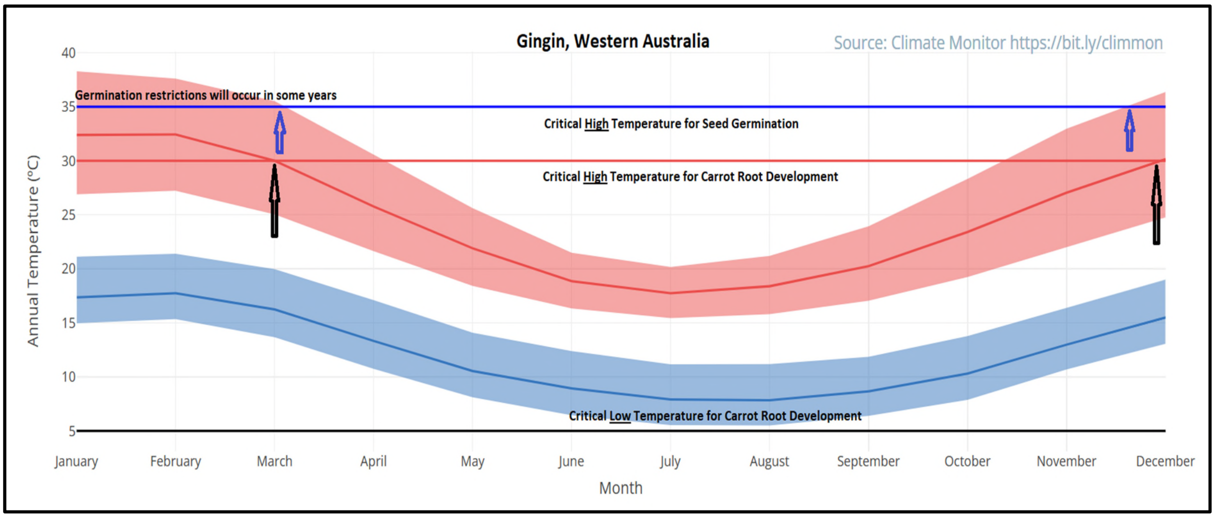

Figure 18. Climate Monitor analysis showing the annual historic monthly temperatures maximum (red) and minimum (blue) temperatures and means (solid lines within each coloured band), with carrots critical temperatures – overlaid, at Gingin. Note: The graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

Projected future and current climate data for Gingin.

Time Period	Annual Average T Max ^{0}C	Annual Average T Min^{0}C	Annual Heat Risk Days T Max ≥ 30^{0}C	Annual Cold Risk Days ≤ 5^{0}C
1964-1993 Past Average	**24.5**	**12.5**	**76**	**12**
1994 -2023 Recent Average	25.3	12.7	91	19
2030's High Emissions - Future Average	25.8	13.4	97	10
2050's High Emissions - Future Average	**26.7**	**14**	**111**	**8**
Difference from Past Average	**2.2**	**1.5**	**35**	**-4**

Table 8. Projected future temperature comparison for Gingin, WA. under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020).

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

The high emissions pathway model indicates a temperature shift, showing a 2.2°C increase in maximum temperatures and a 1.5°C increase in minimum temperatures by 2050. Importantly the number of days when the maximum temperature at **Gingin** exceeds 30°C increases from 76 to 111 (35 days), and the cold risk decreases by 4 days - Table 8.

The projected temperature shift, with hotter summers and warmer winters, are likely to have a negative impact on the existing year-round production pattern, with warmer maximum temperatures adversely affecting summer production.

When considering projected maximum and minimum temperature shifts at any location, the reader should keep in mind the daily duration (number of hours each day) the plant is likely to experience these conditions.

Gingin - Projected annual crop specific upper CTT hot days risk shift (1964 – 93 baseline period).

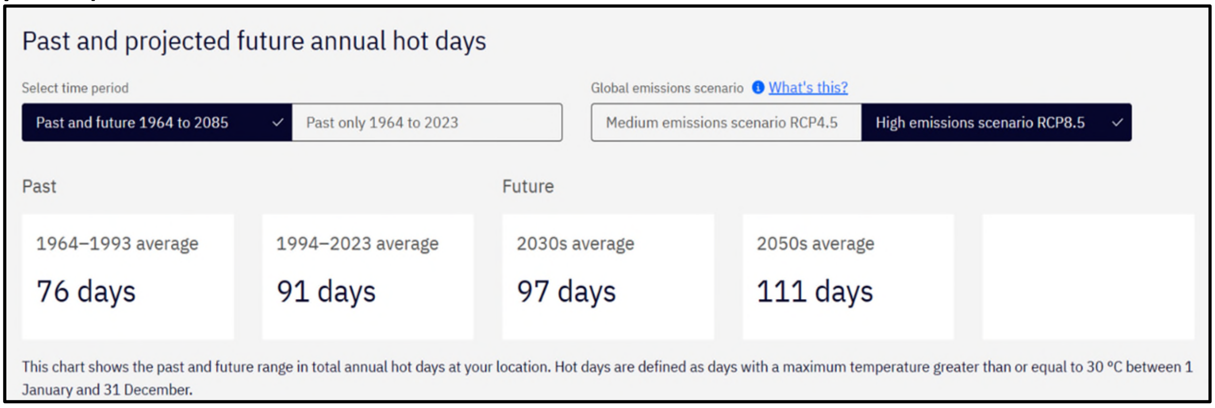

Figure 19a. Gingin annual Hot Days (above 30°C).
Data source: My Climate View[22]

Gingin - Projected annual crop specific lower CTT cold days risk shift (1964 – 93 baseline period).

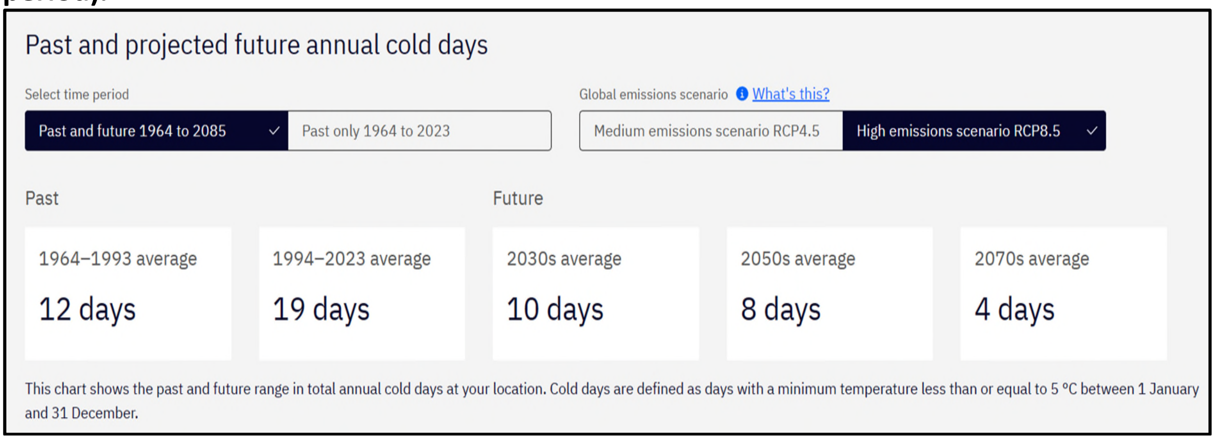

Figure 19b. Gingin annual Cold Days (Below 5°C).

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[22] https://climateservicesforag.indraweb.io/

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

b) Baldivis, WA

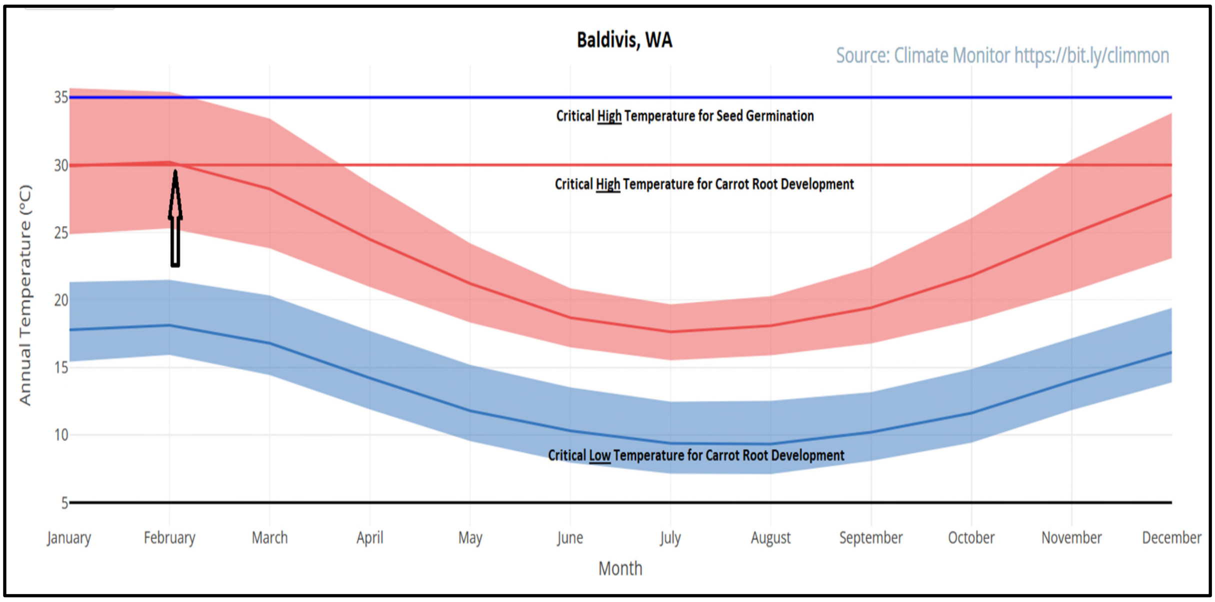


Figure 20. Climate Monitor analysis showing the annual historic monthly temperatures maximum (red) and minimum (blue) temperatures and means (solid lines within each coloured band), with carrots critical temperatures – overlaid, at Baldivis, WA. Note: The graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

Projected future and current climate data for Baldivis.

Time Period	Annual Average T Max ⁰C	Annual Average T Min⁰C	Annual Heat Risk Days T Max ≥ 30⁰C	Annual Cold Risk Days ≤ 5⁰C
1964-1993 Past Average	**23.3**	**13**	**51**	**6**
1994 -2023 Recent Average	24.1	13.4	62	4
2030's High Emissions - Future Average	24.6	14.1	67	3
2050's High Emissions - Future Average	**25.3**	**14.6**	**79**	**2**
Difference from Past Average	**2**	**1.6**	**28**	**-4**

Table 9. Projected future temperature comparison for Baldivis, WA. under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020).

23 https://climateservicesforag.indraweb.io/

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

The high emissions pathway model indicates a temperature shift, showing a 2.0°C increase in maximum temperatures and a 1.6°C increase in minimum temperatures by 2050. Importantly the number of days when the maximum temperature at **Baldivis** exceeds 30°C increases from 51 to 79 (28 days), and the cold risk decreases by 4 days - Table 9.

The projected temperature shift, with hotter summers and warmer winters, are likely to have a negative impact on the existing year-round production pattern, with warmer maximum temperatures adversely affecting summer production in some future years.

When considering projected maximum and minimum temperature shifts at any location, the reader should keep in mind the daily duration (number of hours each day) the plant is likely to experience these conditions.

Baldivis - Projected annual crop specific upper CTT hot days risk shift (1964 – 93 baseline period).

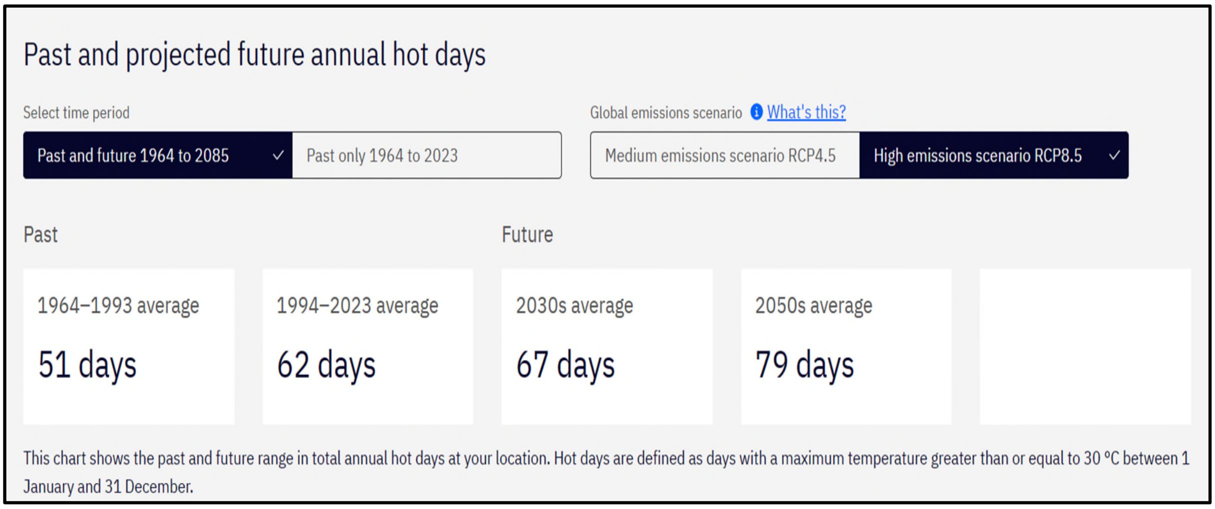


Figure 21a. Baldivis annual Hot Days (above 30°C).
Data source: My Climate View[24]

[24] https://climateservicesforag.indraweb.io/

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

Baldivis - Projected annual crop specific lower CTT cold days risk shift (1964 – 93 baseline period).

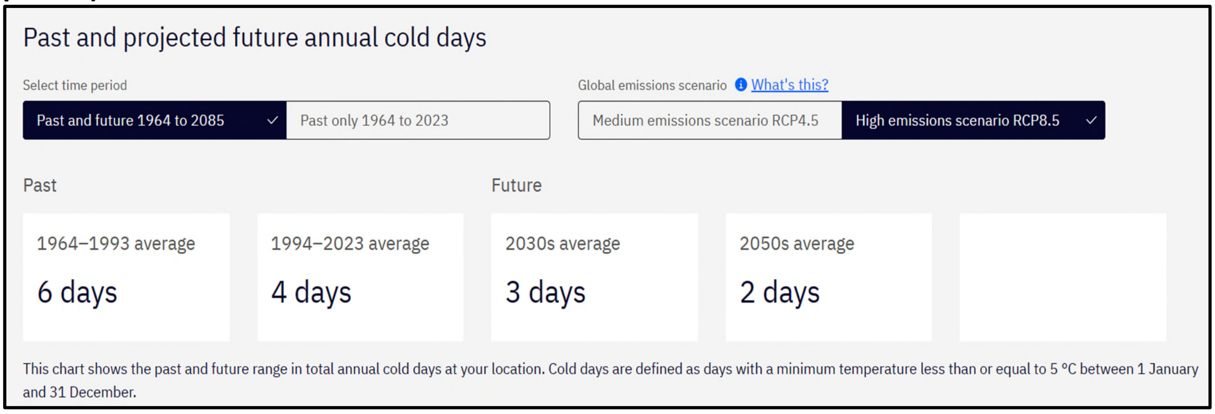


Figure 21b. Baldivis annual Cold Days (Below 5ºC).
Data source: My Climate View[25]

[25] https://climateservicesforag.indraweb.io/

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

v) Tasmania

Production in northern Tasmania occurs all year round, although there is a seasonal peak from January to May. The main planting commences in early June for harvest in early December, and then harvesting continues from December to June, with smaller production until October. The majority of production is sold on the domestic market, locally and on the mainland, with processing accounting for 25% of production.

Forth

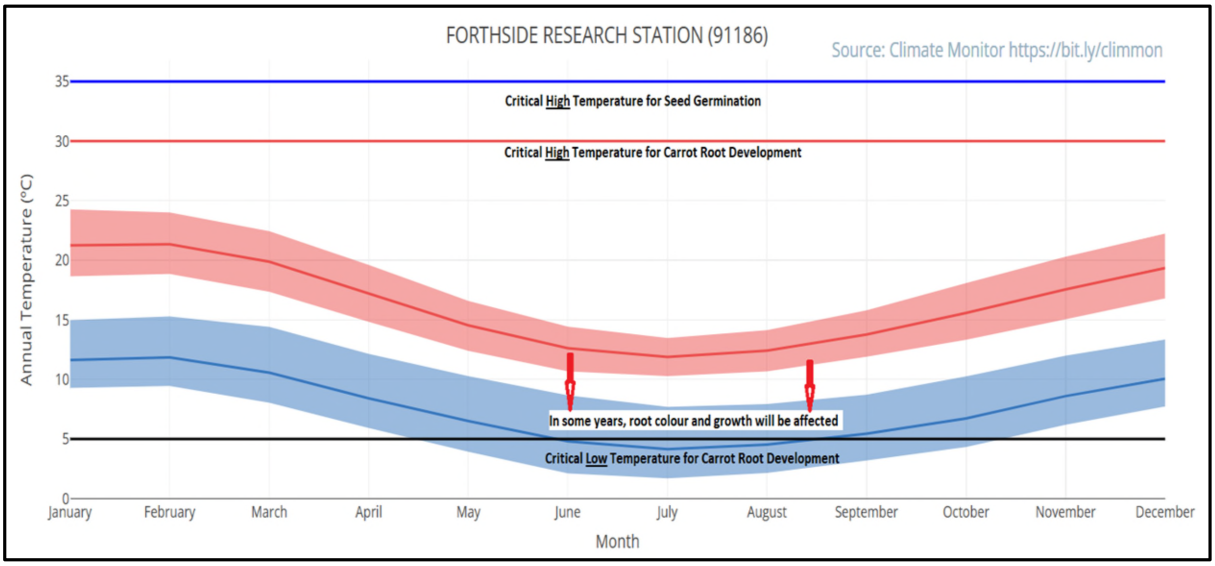


Figure 22. Climate Monitor analysis showing the annual historic monthly temperatures maximum (red) and minimum (blue) temperatures and means (solid lines within each coloured band), with carrots critical temperatures – overlaid, at Forth, Tas. Note: The graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

Projected future and current climate data for Forth.

Time Period	Annual Average T Max ⁰C	Annual Average T Min⁰C	Annual Heat Risk Days T Max ≥ 30⁰C	Annual Cold Risk Days ≤ 5⁰C
1964-1993 Past Average	**17.0**	**8.0**	**0**	**90**
1994 -2023 Recent Average	17.4	8.4	0	78
2030's High Emissions - Future Average	18.0	9.1	1	63
2050's High Emissions - Future Average	**18.7**	**9.7**	**1**	**50**
Difference from Past Average	**1.7**	**1.7**	**1**	**-40**

Table 10. Projected future temperature comparison for Forth, Tas. under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020).

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

The high emissions pathway model indicates a temperature shift, showing a 1.7°C increase in maximum temperatures and a 1.7°C increase in minimum temperatures by 2050. Importantly the number of days when the maximum temperature at **Forth** exceeds 30°C increases from 0 to 1 (1 day), and the cold risk decreases by 40 days - Table 10.

The projected temperature shift, with hotter summers and warmer winters, are likely to have a positive impact on the existing production pattern, with warmer winter minimum temperatures reducing the potential low temperature effects on root growth and colour during the winter. Summer maximum temperatures are unlikely to meet the upper CTT for carrots in the near future.

When considering projected maximum and minimum temperature shifts at any location, the reader should keep in mind the daily duration (number of hours each day) the plant is likely to experience these conditions.

Forth - Projected annual crop specific upper CTT hot days risk shift (1964 – 93 baseline period).

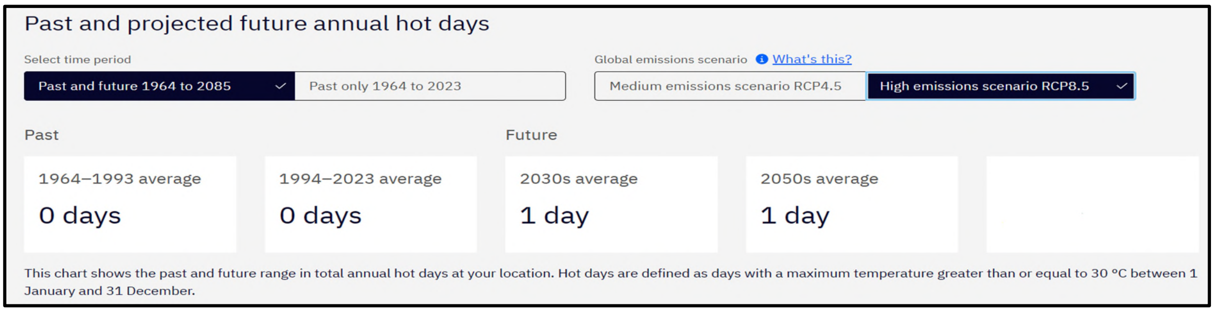


Figure 23a. Forth annual Hot Days (above 30°C).
Data source: My Climate View[26]

Forth - Projected annual crop specific lower CTT cold days risk shift (1964 – 93 baseline period).

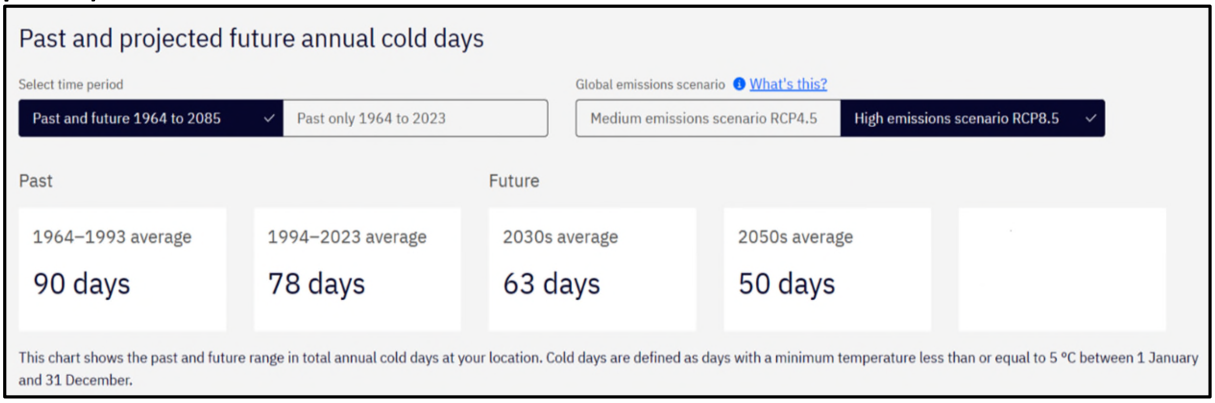


Figure 23b. Forth annual Cold Days (Below 5°C).Data source: My Climate View[27]

[26] https://climateservicesforag.indraweb.io/
[27] https://climateservicesforag.indraweb.io/

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

vi) South Australia

Carrots are grown on the Northern Adelaide Plains (winter/spring), the Riverland and the Mallee (all year – peak harvests from April to October).

a) Virginia, Northern Adelaide Plains, SA.

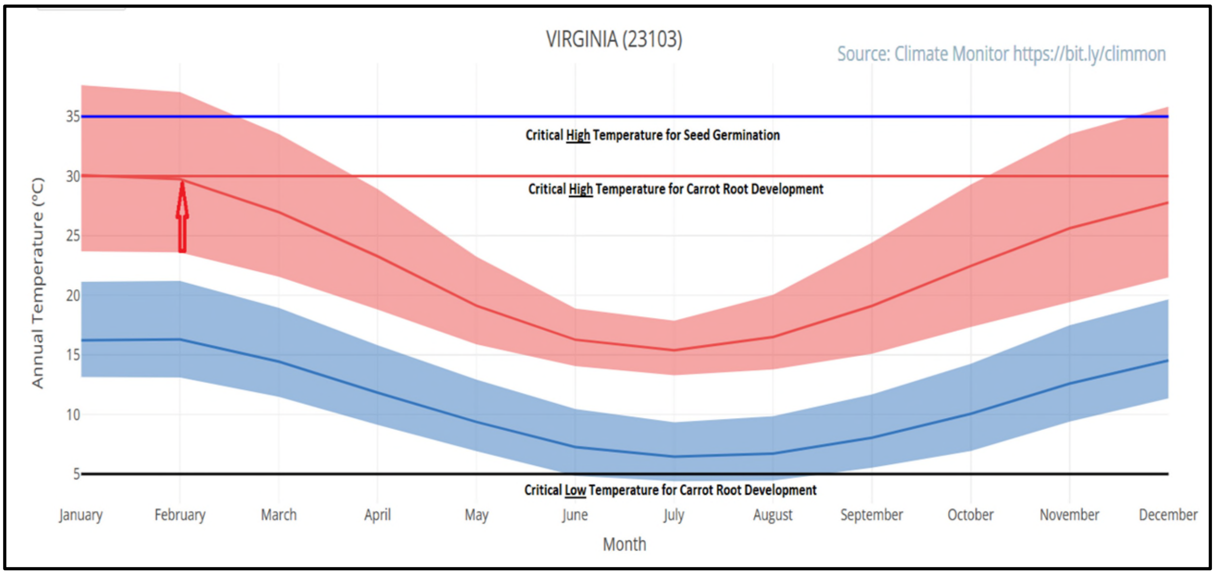


Figure 24. Climate Monitor analysis showing the annual historic monthly temperatures maximum (red) and minimum (blue) temperatures and means (solid lines within each coloured band), with carrots critical temperatures – overlaid, at Virginia, SA. Note: The graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

Projected future and current climate data for Virginia.

Time Period	Annual Average T Max ^{0}C	Annual Average T Min^{0}C	Annual Heat Risk Days T Max ≥ 30^{0}C	Annual Cold Risk Days ≤ 5^{0}C
1964-1993 Past Average	**25.3**	**15.3**	**38**	**4**
1994 -2023 Recent Average	25.9	15.7	52	3
2030's High Emissions - Future Average	26.7	16.5	75	2
2050's High Emissions - Future Average	**27.4**	**17.2**	**99**	**1**
Difference from Past Average	**2.1**	**1.9**	**61**	**-3**

Table 11. Projected future temperature comparison for Virginia, SA. under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020).

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

The high emissions pathway model indicates a temperature shift, showing a 2.1°C increase in maximum temperatures and a 1.9°C increase in minimum temperatures by 2050. Importantly the number of days when the maximum temperature at **Virginia** exceeds 30°C increases from 38 to 99 (61 days), and the cold risk decreases by 3 days, down to 1 - Table 11.

The projected temperature shift, with hotter summers and warmer winters, are likely to have a positive impact on the existing production pattern, with warmer minimum temperatures reducing the potential low temperature effects on root growth and colour during the winter.

When considering projected maximum and minimum temperature shifts at any location, the reader should keep in mind the daily duration (number of hours each day) the plant is likely to experience these conditions.

Virginia - Projected annual crop specific upper CTT hot days risk shift (1964 – 93 baseline period).

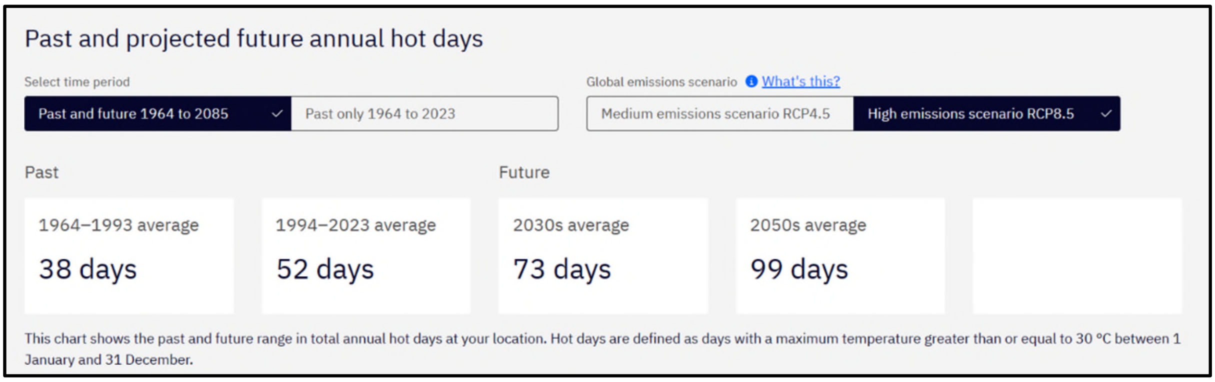


Figure 25a. Virginia annual Hot Days (above 30°C).
Data source: My Climate View[28]

Virginia - Projected annual crop specific lower CTT cold days risk shift (1964 – 93 baseline period).

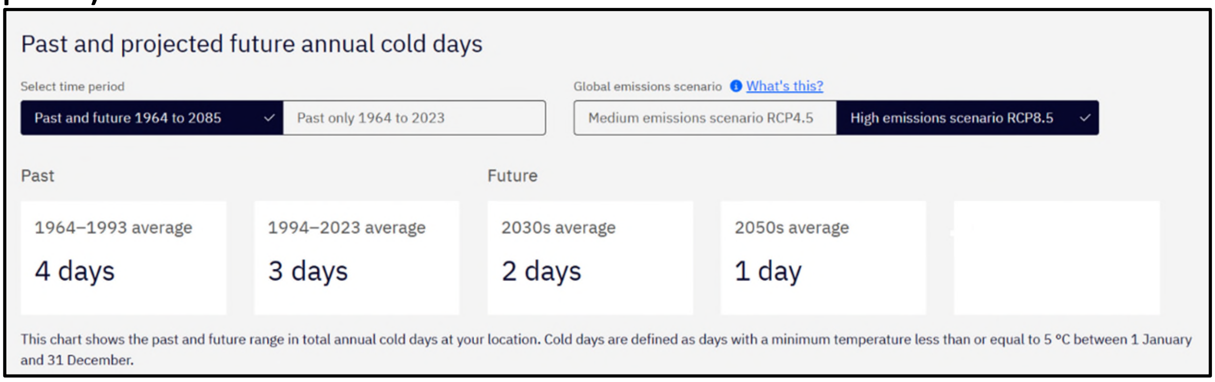


Figure 25b. Virginia annual Cold Days (Below 5°C). Data source: My Climate View

[28] https://climateservicesforag.indraweb.io/

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

b) Parilla, Mallee, SA

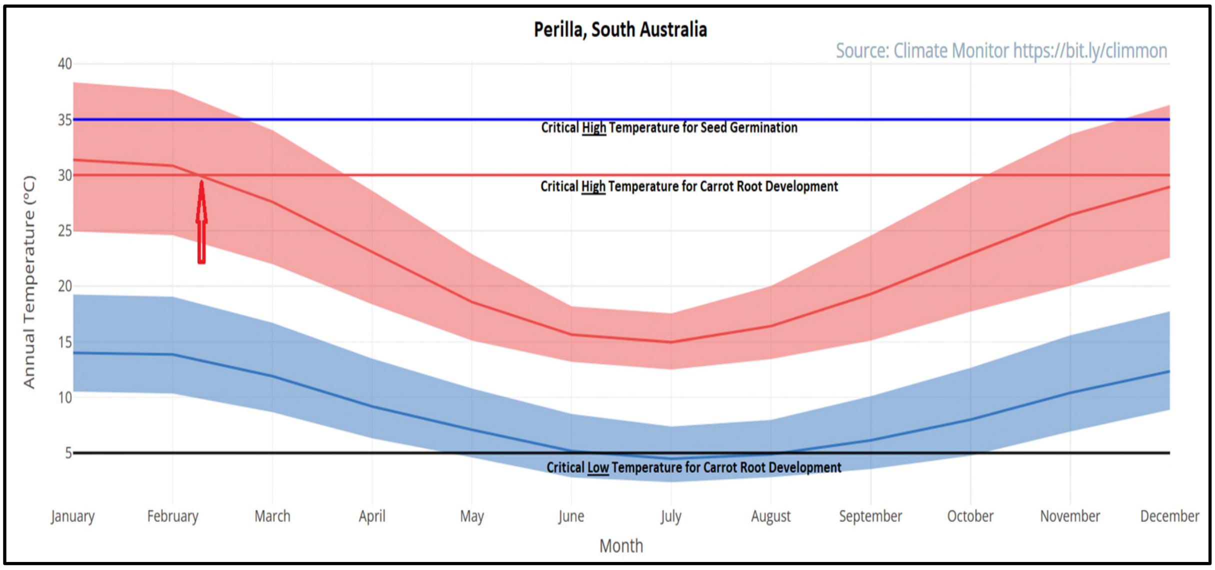


Figure 26. Climate Monitor analysis showing the annual historic monthly temperatures maximum (red) and minimum (blue) temperatures and means (solid lines within each coloured band), with carrots critical temperatures – overlaid, at Perilla, SA. Note: The graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

Projected future and current climate data for Parilla.

Time Period	Annual Average T Max °C	Annual Average T Min°C	Annual Heat Risk Days T Max ≥ 30°C	Annual Cold Risk Days ≤ 5°C
1964-1993 Past Average	**22.8**	**8.7**	**65**	**87**
1994 -2023 Recent Average	23.5	8.8	75	89
2030's High Emissions - Future Average	24.2	9.8	83	62
2050's High Emissions - Future Average	**25.0**	**10.4**	**94**	**49**
Difference from Past Average	**2.2**	**1.7**	**29**	**-38**

Table 12. Projected future temperature comparison for Parilla, SA. under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020).

The high emissions pathway model indicates a temperature shift, showing a 2.2°C increase in maximum temperatures and a 1.7°C increase in minimum temperatures by 2050. Importantly the number of days when the maximum temperature at **Parilla** exceeds 30°C increases from 65 to 94 (29 days), and the cold risk decreases by 38 days - Table 12.

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

The projected temperature shift, with hotter summers and warmer winters, are likely to have an impact on the existing summer dominated production pattern; warmer winter minimum temperatures reducing the potential low temperature effects on root growth and colour; and higher summer maximum temperatures delaying planting at the beginning of the season.

When considering projected maximum and minimum temperature shifts at any location, the reader should keep in mind the daily duration (number of hours each day) the plant is likely to experience these conditions.

Parilla - Projected annual crop specific upper CTT hot days risk shift (1964 – 93 baseline period).

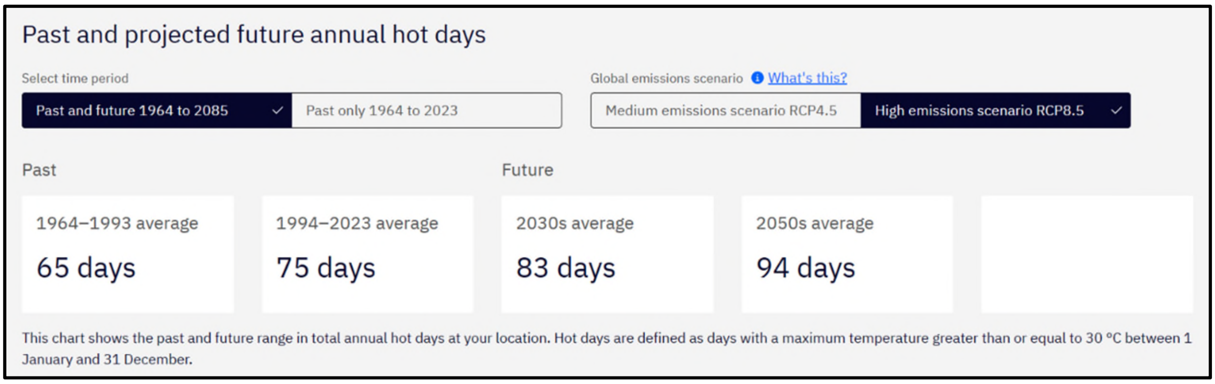


Figure 27a. Parilla annual Hot Days (above 30°C).
Data source: My Climate View[29]

Parilla - Projected annual crop specific lower CTT cold days risk shift (1964 – 93 baseline period).

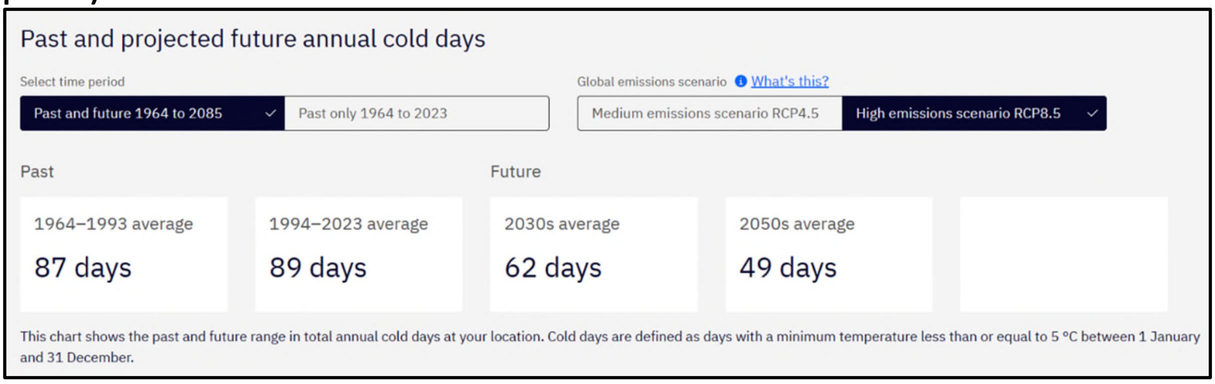


Figure 27b. Parilla annual Cold Days (Below 5°C).
Data source: My Climate View[30]

[29] https://climateservicesforag.indraweb.io/
[30] https://climateservicesforag.indraweb.io/

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

Annual Heat and Frost Risk, by the year 2030, for Carrots production at various locations in Australia

Growing Location	Recent Max Temp °C	Projected Max temp change °C by 2050	Recent Min Temp °C	Projected Min temp change °C by 2050	Recent number of hot days ≥ 30°C	Projected number of hot days ≥30°C by 2050	Recent number of cold days ≤5°C by 2050	Projected number of cold days ≤5oC by 2050
Gatton	27.3	29.0	13.2	14.2	113	137	36	18
Kalbar	27.0	28.7	12.6	13.8	104	149	51	29
Griffith	24.3	26	10.2	12	95	118	88	61
Longford	20.3	21.8	9.1	10.3	25	33	77	49
Wemen	24.5	26.1	10	11.6	92	112	77	48
Gingin	25.3	26.7	12.7	14	91	111	19	8
Baldivis	24.1	25.3	13.4	14.6	62	28	4	2
Forth	17.4	18.7	8.4	9.7	0	1	78	50
Virginia	25.9	27.4	15.7	17.2	52	99	3	1
Parilla	23.5	25.0	8.8	10.4	75	94	89	49

Table 13. Annual Heat and Frost Risk, by the year 2050, for Carrot production at various locations in Australia.

The projected future climate data used in this CTT document are sourced from the most recent (February 2024) My Climate View website (formerly CSA). The updated site underwent some changes, it now displays the 2030 and 2050 average projections. The data and graphics format used in each individual crop CTT document in this DCAP funded work, varies slightly to reflect changes made to the layout of the underlying Climate Services for Australia (My Climate View) publicly available data set.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool

Do your own analysis.

If you are interested in other production locations within Australia, you can evaluate a location yourself.

1. Use Climate Monitor to easily analyse and graph the location of interest.

   Access Climate Monitor at

   https://www.longpaddock.qld.gov.au/dcap/horticulture-industry/

   Click on the **Go to Climate Monitor** button under the picture.

2. Use the Climate Services for Agriculture site to explore the projected temperature, rainfall and evaporation changes**.**

   Access Climate Services for Agriculture *and My Climate View* at

   https://myclimateview.com.au/

Appendix I

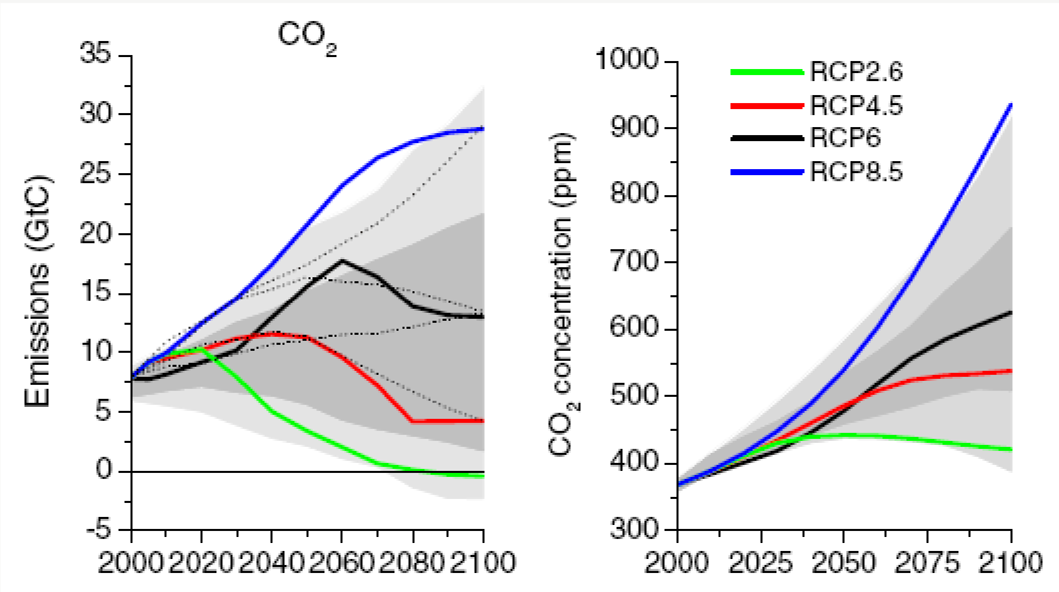
GREENHOUSE GAS SCENARIOS[31]

(REPRESENTATIVE CONCENTRATION PATHWAYS - RCPS)

The future of anthropogenic greenhouse gas and aerosol emissions (and hence their resultant radiative forcing) is highly uncertain, encompassing substantial unknowns in population and economic growth, technological developments and transfer, and political and social changes.

The climate modelling community has developed Representative Concentration Pathways (RCPs) to explore credible future options. The Australian climate change projections found on this site are derived from climate models forced by the RCPs.

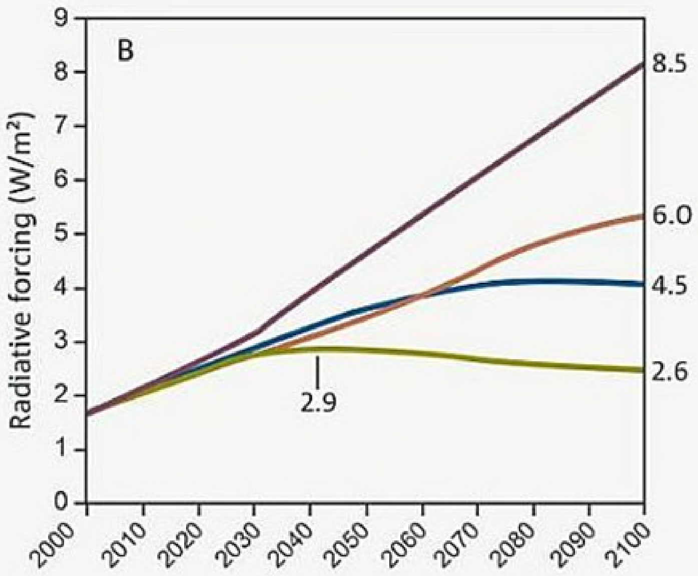
These scenarios span the range of plausible global warming scenarios. They provide a range of options for the world's governments and other institutions for decision making.



Emissions of CO_2 across the RCPs (left), and trends in concentrations of carbon dioxide (right). Grey area indicates the 98th and 90th percentiles (light/dark grey) of the values from the literature). The dotted lines indicate four of the SRES marker scenarios.

SOURCE: van Vuuren et. al. (2011)

[31] https://www.climatechangeinaustralia.gov.au/en/changing-climate/future-climate-scenarios/greenhouse-gas-scenarios/



Radiative forcing for the different RCPs. The numbers on the right show the final radiative forcing at 2100 and give each scenario its name (8.5, 6.0, 4.5 and 2.6 W/m²)

SOURCE: Climate Change in Australia Technical Report

RCPs are prescribed pathways for greenhouse gas and aerosol concentrations, together with land use change, that are consistent with a set of broad climate outcomes used by the climate modelling community. The pathways are characterised by the radiative forcing produced by the end of the 21st century. Radiative forcing is the extra heat the lower atmosphere will retain as a result of additional greenhouse gases, measured in Watts per square metre (W/m²).

The RCPs represent a wider set of futures that the previous emissions scenarios used by climate modelling community (SRES), and now explicitly include the effect of mitigation strategies. As with SRES, no particular scenario is deemed more likely than the others, however, some require major and rapid change to emissions to be achieved.

THERE ARE FOUR RCPS

RCP8.5- a future with little curbing of emissions, with a CO_2 concentration continuing to rapidly rise, reaching 940 ppm by 2100.

RCP6.0– lower emissions, achieved by application of some mitigation strategies and technologies. CO_2 concentration rising less rapidly (than RCP8.5), but still reaching 660 ppm by 2100 and total radiative forcing stabilising shortly after 2100.

RCP4.5- CO_2 concentrations are slightly above those of RCP6.0 until after mid-century, but emissions peak earlier (around 2040), and the CO_2 concentration reaches 540 ppm by 2100.

RCP2.6 - the most ambitious mitigation scenario, with emissions peaking early in the century (around 2020), then rapidly declining. Such a pathway would require early participation from all emitters, including developing countries, as well as the application of technologies for actively removing carbon dioxide from the atmosphere. The CO_2 concentration reaches 440 ppm by 2040 then slowly declines to 420 ppm by 2100).

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