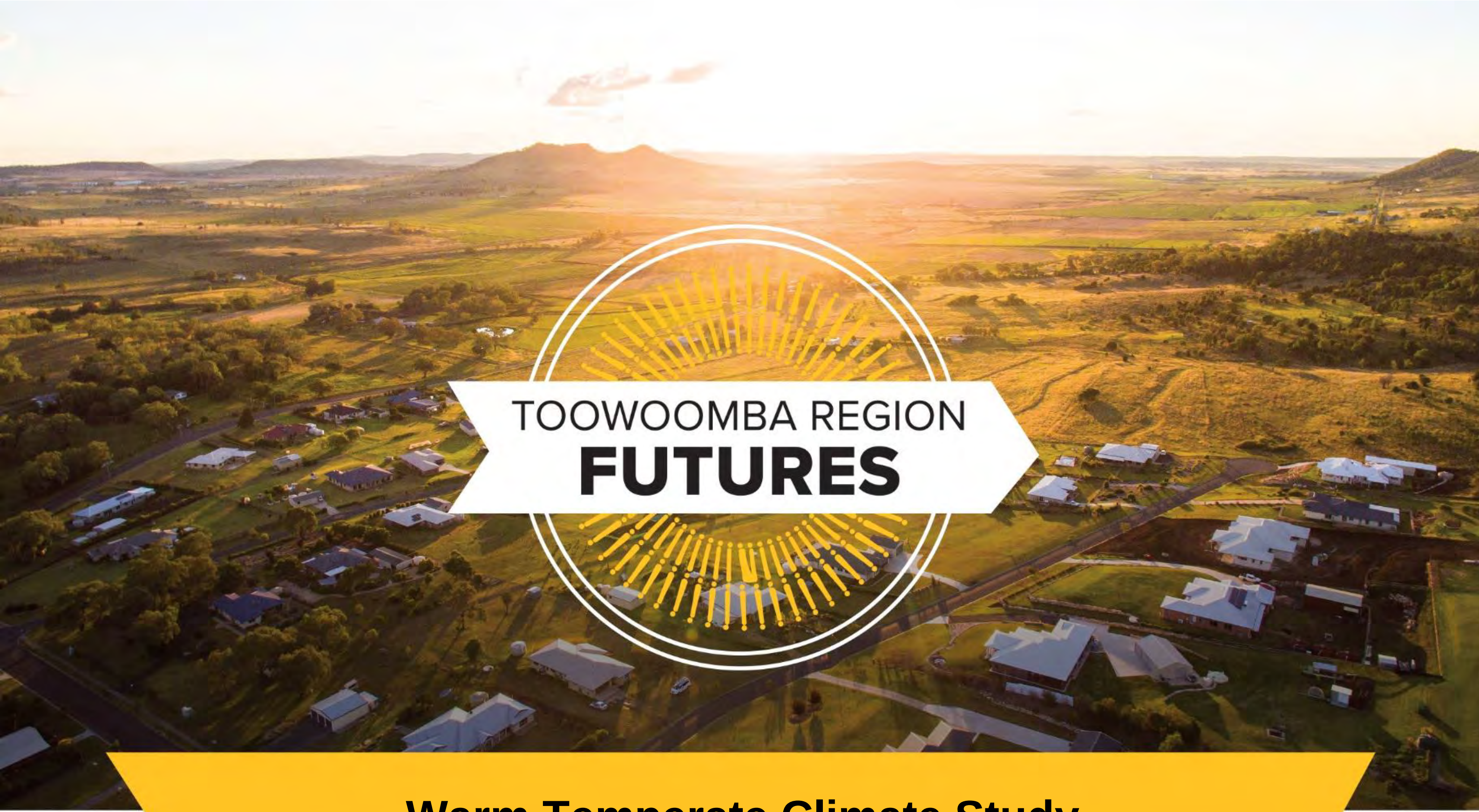

Warm Temperate Climate Study

Why have we done the strategic project, and what did we want to achieve?

The Temperate Climate Study will explore the characteristics of a warm temperate climate zone and explain how building design can respond in a manner that delivers both liveable and sustainable buildings.

What are the key components?

The study defines a warm temperate climate relative to the Toowoomba Region. It will identify building design opportunities which best respond to the Region's climate and determine warm temperate climate design solutions and interventions which could be used for various architectural typologies.

Who have we consulted with?

The study is a collaboration between Queensland University of Technology, University of Southern Queensland and Council. Consultation has occurred with academics and researchers, design professionals, peak bodies and the general community.

What are the key findings we have learned?

- The current climate classification systems for building design are based on limited data.
- The science has been reviewed and the data gathered to inform the study provides a refined understanding to inform building design.
- A Human Comfort analysis has been considered in light of the scientific data to inform building design interventions. (e.g. heating).

Disclaimer

The following study has been prepared as part of the Toowoomba Region Futures program. It was endorsed by Toowoomba Regional Council at its Ordinary Council meeting on 19 April 2022 as information to aid decision-making. The content of this study does not reflect an adopted policy position of Council and Council's endorsement of it does not include adoption of any policy position, action or recommendation put forward by the study.

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TOOWOOMBA REGION

WARM TEMPERATE CLIMATE STUDY AND GUIDELINE PROJECT

Phase One Report: Defining the Warm Temperate Climate of the Toowoomba Region

March 2021

Report Version	Authors	Issue date
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EXECUTIVE SUMMARY

The Australian Building Code Board (ABCB) Queensland climate zone map identifies the Toowoomba region as a Zone 5 Climate: Warm Temperate[1]. However, this definition for Toowoomba's climate is derived from a classification determined for building legislation and not necessarily a reflection of Toowoomba's observed (scientific) or perceived (experience-based) climate. It also does not also reflect that the Toowoomba region covers a large land area across terrain that rises from 300m to nearly 700m above sea level and the potential for substantial variation in climatic conditions across the region.

This report is presented across five sections. The first section introduces the study and establishes the methods and scope for the study. The second section analyses the definition for Toowoomba's warm temperate climate. This is examined through descriptions of Toowoomba's climate found in strategic planning documents and building legislation at federal, state and local government levels. Climate perceptions in terms of Toowoomba's location and geographic context are also analysed and discussed in this section. Additionally, this section introduces the scientific Köppen-Geiger climate classification system and the parameters that describe warm temperate climates globally and in Australia, which leads into the third section of the report.

The third section involves a scientific investigation into Toowoomba's climate. It presents data collected on rainfall, temperature, wind, solar exposure, humidity and atmospheric pressure from five weather stations within and surrounding the Toowoomba region. Data was collated from the Toowoomba, Oakey, Dalby, Kingaroy, and Warwick weather stations. From this data, the climate classification for the Toowoomba Region was determined as Cfa, according to a Köppen–Geiger scale, indicating a temperate climate, without dry season and a hot summer. Cfa is the Köppen-Geiger macro-climate classification for all of the South East Queensland region, extending West to Surat and Goondiwindi in South Western Queensland. This section also uses this data to determine climate projections for the Toowoomba region, which forecasts that Toowoomba's climate will become warmer and drier.

The fourth section of the report analyses the climate data in more detail to arrive at a deeper understanding of the Toowoomba region climate and how this information can be used to inform best practice in climatically responsive building and planning. Although the scientific classification for the Toowoomba Region is the same as Brisbane's, there are important local climate variations that are identified and discussed in this section. This is examined through a series transects and tables that compare and analyse the climate data findings as well as synthesising the data with existing literature. Finally, the climate data is interpreted according to human comfort analysis, which establishes climatically responsive strategies for buildings in Toowoomba.

[1] ABCB, "Climate Zone Map: Queensland."

The last section of the report summarises the findings from the Phase One study. An important result of this report has been to illustrate the difference between physical climate classifications with the way that building legislation determines climate zones. Noting that building legislation definitions are only provided to inform energy calculations for heating and cooling of Australian buildings. This sets out the departure point for this study in defining design guidelines for Toowoomba's climate that speaks to its unique climate, lifestyle, and cultural character. It also sets out a series of recommendations for Phase Two, specifically about how the climate data findings will inform the selection criteria for case study buildings in the Phase Two report.

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1. INTRODUCTION

A detailed understanding and analysis of climate in the Toowoomba region will inform how building design can respond in a manner that delivers both liveable and ecologically sustainable buildings. The *Warm Temperate Climate Study and Guideline* project is a strategically focussed study that will inform the urban form vision and policy for Toowoomba Regional Council's new planning scheme. It is an integral part of the Toowoomba Region Urban Form Framework, which is developing concurrently with this project.

The key objectives of the *Warm Temperate Climate Study and Guideline* project are:

1. to define the warm temperate climate as it relates to the Toowoomba region
2. to determine what warm temperate climate architecture is and the design solutions that work best in response to a warm temperate climate, and
3. to determine communicate what warm temperate climate architectural solutions and interventions could be used, for various architectural typologies, for the Toowoomba region.

This report presents the findings of Phase 1 of the research - *Defining the Warm Temperate Climate of the Toowoomba Region*. In this phase, we cover how the warm temperate climate is defined in the regulatory framework and in scientific literature and analyse local climate data to determine an evidence-based, comprehensive definition for the warm temperate climate of Toowoomba. We then relate these climate factors to desired indoor human physiological comfort criteria to understand how the results can inform climatically responsive, liveable, sustainable buildings.

1.1. Background and significance

The Australian Building Codes Board (ABCB) has defined eight climatic zones within Australia based on humidity, temperature, and rainfall characteristics. The Toowoomba region is classed as a zone 5 "warm temperate" area, which is described as:

> "Low diurnal temperature range near coast to high diurnal range inland, four distinct seasons, summer and winter can exceed human comfort range, spring and autumn are ideal for human comfort, mild winters with low humidity, hot to very hot summers with moderate humidity."[2]

[2] Australian Government, "Design for Climate."

In the regulatory context, Toowoomba, South Burnett and Southern Downs are the only local government areas (LGA's) within Queensland that are classified by the ABCB – and by association, in the National Construction Code (NCC) – as climate zone 5.

Other zone 5 areas in Australia include coastal New South Wales between Port Macquarie and Wollongong, coastal areas of South Australia west of Adelaide (including Ceduna) and coastal areas of Western Australia east and west of Esperance, including Bunbury and between Margaret River and Geraldton, including Perth. See Figure 7, NCC Climate Zone Map for Australia.

The ABCB provides very broad definitions that generally inform climatic responses for thermal comfort in buildings within macroclimates defined by the boundaries of a given LGA. The Australian Bureau of Meteorology (BOM) classifies climate types according to the Köppen-Geiger climate classification scheme. Whilst the zone 5 localities are all classified as temperate by BOM (see Figure 3, Climate Classification of Australia, Major Classification Groups) the climatology of the interstate regions differ quite markedly from their Queensland counterparts due to seasonal distinctions in dryness - an important controlling factor on vegetation (Figure 4, Climate Classification of Australia, Climate Classes.

Moreover, the Toowoomba Regional Council (TRC) area, along with South Burnett and Southern Downs LGA's are the only zone 5 areas that are inland rather than coastal, apart from some hinterland areas north of Whyalla and east of Adelaide. The Queensland LGA's in zone 5 are also the most northerly. The implications of these differences include the effects of terrain on wind speeds and direction, and solar altitude and azimuth angles, and subsequent impacts on building design. Thus, climate differences exist between LGA's with the same ABCB climate zone classification.

Climate differences may also exist within a single LGA. In Toowoomba's case, the region covers 12,973 square kilometres and is characterised by a physiography that encompasses an elevated plateau, high ridges, and alluvial flood plains. The region runs west across the Darling Downs toward the Western Downs, with the elevation ranging between 737 m - 340 m. Vegetation, topography, landform, and slope vary across the regional centres of Oakey, Pittsworth, Millmerran, Highfields, Crows Nest, Clifton, Greenmount, and Yarraman, along with numerous smaller townships. The city of Toowoomba is located 641 m above sea level and within close proximity to the escarpment of the Great Dividing Range.

The Toowoomba region's climate is generally understood to be temperate and differentiated from subtropical coastal areas of South East Queensland. In *ShapingSEQ: South East Queensland Regional Plan 2017*, the Queensland State Government describes Toowoomba city as the "Melbourne of the North" and asserts that Toowoomba's climate is a regional asset that "provides a temperate climate alternative in the region."[3] *Shaping SEQ* sets out a series of elements and strategies for the SEQ region over the next 25 years. The first element recommends that

[3] Queensland State Government, *Shaping SEQ* (2017) : 28 & 136

good quality design for temperate and subtropical climates be embedded in planning systems.[4]

To date, substantial research into design for South East Queensland's subtropical humid climate has been undertaken, but the warm temperate climate in Queensland is relatively under-researched in terms of implications for building design. In order to inform best practice in climatic responsive building design, it is imperative to understand the climate characteristics that pertain locally.

The significance of this project is that it aims to define the warm temperate climate as it relates to the TRC area, with special regard to variation across the region, and translate that climate information into place-based principles of good quality climate-responsive architecture that is specific to and for the region because it is sensitive to and strengthens local character and identity.

1.2. Phase One Aims and Objectives

The primary aim of this phase of the research is to establish a clear definition of the warm temperate climate of the Toowoomba region. The focus is on understanding the climate and any local variations to be used as a basis for selecting exemplar projects for Phase Two and the development of the Design Guideline in Phase Three.

The research objectives for this phase are:

- to establish the climate characteristics that predominate in the region based on temperature, wind, precipitation, solar radiation, humidity, and atmospheric pressure.
- to consider whether a single climate definition for the region is appropriate, or whether sub-zones within the region can be classified.
- to identify climate trends in order to identify climate change impacts to be ameliorated in the building design process.
- to establish the human comfort range for the climate and preferred internal conditions of buildings appropriate to the climate.
- to establish what general building design requirements are indicated, and
- to evaluate whether any climate variations within the region are significant enough to be reflected in building design and make an impact on indoor environment comfort.

1.3. Methods

While the ABCB Queensland climate zone map identifies the Toowoomba region as zone 5 (warm temperate)[5], a local climate character is difficult to understand at such a broad scale. Anecdotal evidence indicates substantial variation in climatic conditions across the region. At the same time, multiple definitions for a warm temperate climate exist. In this section, we first establish definitions for a warm temperate climate in the scientific literature and then review how a warm temperate climate is defined in

[4] Queensland State Government, "ShapingSEQ: South East Queensland Regional Plan 2017."*Shaping SEQ:* 94.

[5] ABCB, "Climate Zone Map: Queensland."

Australia's planning and building regulatory environment. The review reveals the differences between the scientific method of climate classification and zoning for regulatory purposes.

Climate is about long-term records, trends and averages, and *weather* is the day-to-day experience.

"Climate is what you expect; weather is what you get."[6]

To determine an evidence-based, comprehensive definition for a warm temperate climate, as well as possible variations, within the Toowoomba Region, objective historical station-based climate data, was accessed from the Bureau of Meteorology and analysed. This study identified only two fully operational stations with records collected over at least a 30-year period within the TRC area (Toowoomba and Oakey). Three nearby stations from adjacent LGA's – also in climate zone 5 (warm temperate) areas – were selected to build a comprehensive picture of climate in the region. These stations were Dalby, Warwick, and Kingaroy. We also drew on historical records to reveal significant weather events such as droughts or major precipitation to explain various anomalies to the averages.

Once the local climate parameters were established, we evaluated the climate data using criteria established by the Köppen-Geiger climate classification system. The Köppen-Geiger system contains nine Temperate climate sub-types, which are expanded upon in section 2.2 To better understand the Toowoomba region's climate, it is first important to define a warm temperate climate according to the scientific literature. This section describes the global climate classification system, followed by an overview of the Australian climate classification system

Köppen-Geiger Climate Classification System on page 11. Comparative locations nationally and globally are identified using a map of Köppen–Geiger 'C' areas (see Figure 88).

The impact of future climate change on the five locations (Toowoomba, Oakey, Dalby, Warwick, Kingaroy) has been accessed from the Queensland Department of Environment and Sciences (DES) LongPaddock Queensland Future Climate dashboard.[7] Two scenarios, known as the Representative Concentration Pathways (RCPs) were selected to project the impacts of either a business-as-usual pathway (RCP8.5 - a future with little curbing of emissions, with a CO2 concentration continuing to rapidly rise, reaching 940 ppm by 2100), or RCP4.5 - where CO2 emissions peak around 2040, and the CO^2 concentration reaches 540 ppm by 2100.

Through this research, we establish the human thermal comfort ranges for Toowoomba's climate using Dr Andrew Marsh Psychrometric Software. The psychrometric charts developed for Toowoomba were based on existing weather data files and comfort zone information from Givoni-Milne's Bioclimatic Chart (1981).[8] This method is useful to establish general building design requirements indicated by climate parameters and to

[6] This description of the difference between weather and climate was accessed from: Australian Bureau of Meteorology, "Learn about Meteorology."

[7] Syktus et al., "Queensland Future Climate Dashboard: Downscaled CMIP5 Climate Projections for Queensland."

[8] Givoni, "Comfort, Climate Analysis and Building Design Guidelines."

evaluate whether any climate variations within the region are significant enough to be reflected in building design.

1.4. Key Findings and Recommendations

- The results from this study indicate that the Toowoomba Region can be classified in the Koppen Geiger system as a Cfa climate, where 'C' is a temperate climate, without dry season and a hot summer. Brisbane is also classified as a Cfa climate
- However, data collected from weather stations within the Toowoomba Region and close surrounds show that there are variations in climate, enough variation to warrant different building responses to climate
- Current climate classifications in building legislation are based on data from the Oakey weather station and the requirement for energy efficient buildings according to the heating and cooling requirements of this area. This information is not necessarily representative for the entire Toowoomba region
- Data from the Toowoomba weather station demonstrates a benign climate that only requires passive heating and cooling solutions for buildings.
- Climate projections show that Toowoomba's climate will become warmer and drier, with lower relative humidity and precipitation.

1.5. Limitations of this Study

Availability of climate data.

- The dataset for this study was obtained from the Australian Bureau of Meteorology. Only two fully operational weather stations with adequate records collected over at least a 30-year period exist in the TRC study area, (Toowoomba and Oakey). Dalby, Warwick, and Kingaroy, three nearby stations from adjacent LGA's also designated as zone 5 were selected to build a comprehensive picture of climate in the region.
- It is an observation station-based dataset for the period extending from 1973 to the present from the Oakey station, and only from 1991 in the other cases.
- The discovery of the shortage of weather stations within the TRC region gave the Centre for Applied Climate Sciences at the University of Southern Queensland reason to purchase four additional Automatic Weather Stations (AWS) in order to expand the weather station network. The AWSs are currently being installed in Highfields, Crows Nest, Acland and Felton and may be useful in future studies.

2. DEFINING A WARM TEMPERATE CLIMATE

To better understand the Toowoomba region's climate, it is first important to define a warm temperate climate according to the scientific literature. This section describes the global climate classification system, followed by an overview of the Australian climate classification system

2.1. Köppen-Geiger Climate Classification System

The Köppen-Geiger climate classification system is the most widely used method for many applications and studies regarding climatic regimes and their differences, such as ecological modelling or climate change impact assessments.[9] The Köppen system was first proposed by climatologists Wladimir Köppen and Rudolf Geiger in the late 19th century, using the link between regional distribution of native vegetation types and climate variation as the basis for area classifications. Since then, various methods based on this system have been developed. In this report, we adopt the updated Köppen-Geiger climate classification map for the period of record 1901-2000 as published by Peel et al. (2007).[10]

The Köppen-Geiger climate classification scheme divides climates into five climate types: A (tropical), B (arid), C (temperate), D (cold), and E (polar). The classification is based on the relationship of the native vegetation of a region to threshold values and seasonality of monthly air temperature and precipitation.

Temperature is the main parameter that delineates the major climate types A, C, D, and E - while dryness (aridity, often due to evaporative losses) is the controlling factor on vegetation in B type climates. B type climates occur in similar temperature ranges.

Each major climate type is divided into several climate sub-types, differentiated by seasonal variations in temperature and precipitation. Figure 1 describes the World Map of Climate Classification. Table 1 describes the major warm to hot climate groups A, B, C and sub-types, several of which occur in Australia. While global and local trends, such as warming of global surface temperatures, have been observed due to increasing concentrations of greenhouse gases, the top-level climate types are relatively unsusceptible to temperature trends. However, the transition zones between climate types do shift.[11]

[9] Beck et al., "Present and Future Köppen-Geiger Climate Classification Maps at 1-Km Resolution"; Peel, Finlayson, and McMahon, "Updated World Map of the Köppen–Geiger Climate Classification."

[10] ibid

[11] Peel, Finlayson, and McMahon, "Updated World Map of the Köppen–Geiger Climate Classification."

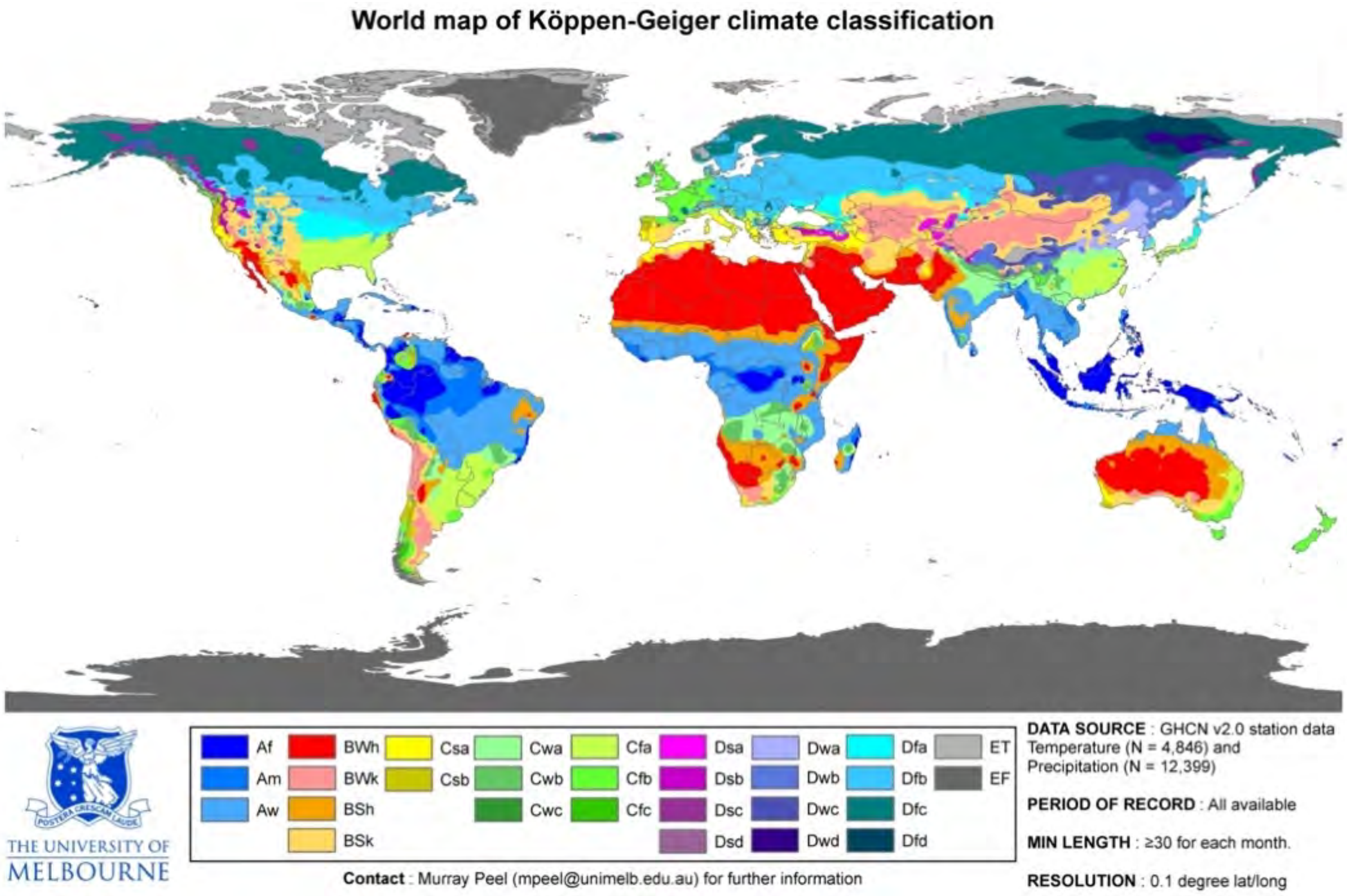


Figure 1. World map of Köppen-Geiger climate classifications.

2.2. Temperate climate characteristics

C (temperate) climate areas are designated as those in the mid-latitudes where the temperature of the warmest month is greater than, or equal to 10°C and the temperature of the coldest month is less than 18°C, but greater than 0°C. Nine Temperate C climate sub-zones are classified according to precipitation by season: s (dry summer) w (dry winter) or f (no dry season); and by the warmness of the summer (a or b) or the coolness of the winter (c). Summers are defined as the six-month period that is warmer (that is, October–March in the Southern Hemisphere), while winter is the six-month period that is cooler (April – September). Table 2 describes the classification criteria for a temperate climate, which are described in detail by Beck et al. (2018) and Peel et al. (2007).[12] Table 3 below sets out these parameters in a matrix, which describes the nine temperate climate sub-zones. Of the nine possible climate types, Csc never occurs and the Cwc climate type almost never occurs.[13]

In Australia, the A climate (8.3% of Australia's land area) is located in the northern part of the continent and subdivided into three tropical climate sub-types. The arid and semi-arid B climate (77.8% of the continent) is the dominant climate type by land area. The Temperate C type climate (13.9% in Australia) is the second largest climate type by land area. There are no D (Cold) or E (Polar) type climate classifications on the Australian continent[14] (see Figure 2).

Table 1. Köppen-Geiger climate classification for tropical, arid, and temperate climate types (Beck et al. 2018).

Major Climate Types		Major Climate Sub-Types	
Tropical (A)		Af	Rainforest (no dry season)
		Am	Monsoon (short dry season)
		Aw	Savanna (winter dry season)
Arid (B)		BWh	Desert, hot (Tropical and subtropical latitudes)
		BWk	Desert, cold
	Semi-Arid	BSh	Steppe, hot
		BSk	Steppe, cold
Temperate (C)		Csa	Dry summer, hot summer
		Csb	Dry summer, warm summer
		Csc	Dry summer, cold summer
		Cwa	Dry winter, hot summer
		Cwb	Dry winter, warm summer
		Cwc	Dry winter, cold summer
		Cfa	Without dry season, hot summer (East Coast)
		Cfb	Without dry season, warm summer
		Cfc	Without dry season, cold summer

[12] Beck et al., "Present and Future Köppen-Geiger Climate Classification Maps at 1-Km Resolution"; Peel, Finlayson, and McMahon, "Updated World Map of the Köppen–Geiger Climate Classification."

[13] Peel, Finlayson, and McMahon, "Updated World Map of the Köppen–Geiger Climate Classification." p. 1644.

[14] Peel, Finlayson, and McMahon. p. 1642

Table 2. Description of defining criteria for temperate climate classification for major climate group C.

Major Climate Group C		Temperature of warmest month ≥10°C and temperature of coldest month <18°C but ≥0°C
Precipitation	Temperature	Criterion
s		Precipitation in driest month of summer half of year < 40mm and < one-third of the wettest month of the winter half of the year.
w		Precipitation in driest month of the winter half of the year is < 0.1 of the rainfall in the wettest month of the summer half of the year.
f		Precipitation is more evenly distributed throughout the year; criteria for neither *s* nor *w* satisfied.
	a	Temperature in warmest month 22° C or above
	b	Temperature of each of four warmest months 10° C or above but warmest month not greater than 22° C.
	c	Neither *a* nor *b*, and Temperature is above 10°C in less than four months of the year.

Table 3. Köppen-Geiger Temperate Climate sub-zones for climate Group C.

	Temperate climate	a: hot summer	b: warm summer	c: cool summer
		Temperature		
Precipitation	f: no dry season	Cfa	Cfb	Cfc
	s: dry summer	Csa	Csb	Csc
	w: dry winter	Cwa	Cwb	Cwc

There are five warm temperate sub-types that occur on the Australian continent. The Cfa and Cfb sub-types predominate in eastern Australia, while Csa and Csb sub-types are found in South Australia and south west of Western Australia. Pockets of the Cwa sub-type occurs in north and Far North Queensland (see Figure 2).

In Cfa regions, summers are usually wetter than winters. Much of the rainfall comes from convectional thunderstorm activity and from tropical cyclones in some regions. The summer months generally average about 27°C. Mean daily maxima range from 30° - 38°C. Summer nights can be oppressively warm and humid. Even though frosts are not uncommon, the coldest month is usually quite mild. Cfb types usually have plentiful and frequent rainfall. Fog is common in autumn and winter. Cwa types have a larger annual temperature range than Cfa types, but winters are often sunny and cool. Csa and Csb climates on the west of the continent are characterised by dry summers. The TRC study area is located in the Cfa climate sub-type on the map.

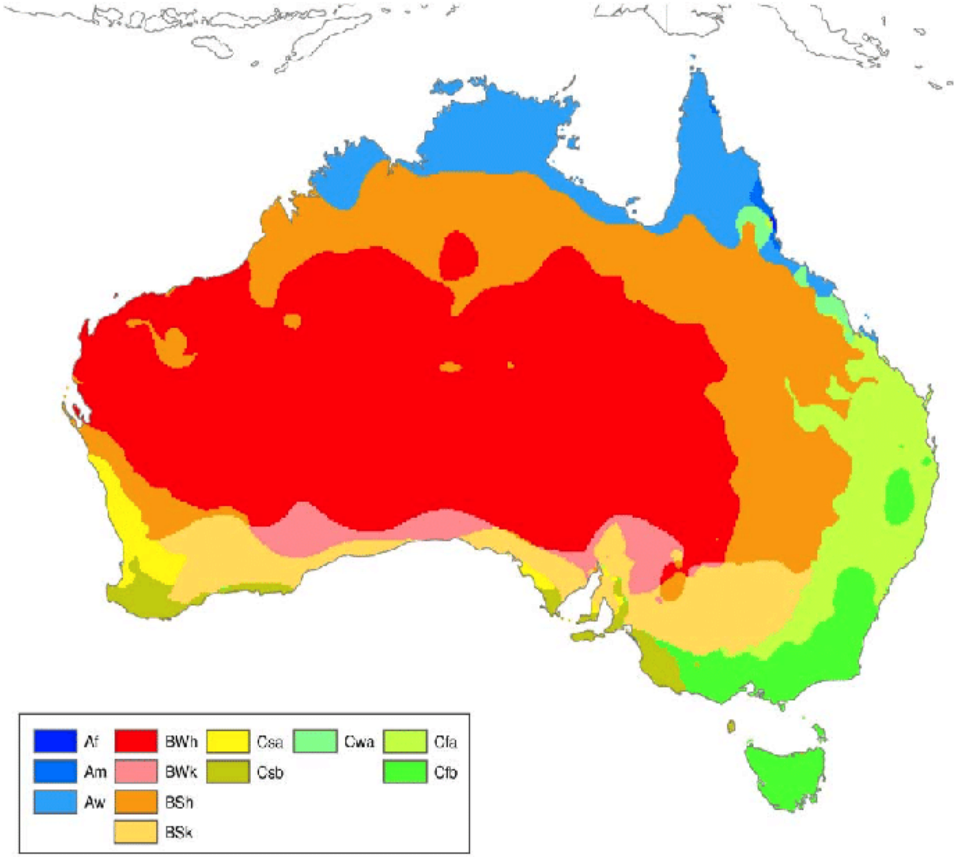


Figure 2: Köppen-Geiger Climate Map of Australia.[15]

[15] Peel, Finlayson, and McMahon.

2.3. Australian climate classification system

The Australian Bureau of Meteorology (BOM) major climate classification groups and sub-classes are based on the Köppen-Geiger system. The most recent classification is derived from data from 1961 to 1990. The main groups are Equatorial, Tropical, Subtropical, Desert, Grassland and Temperate (Figure 3). Further subdivisions of the major groups are described in Figure 4 and Table 5.

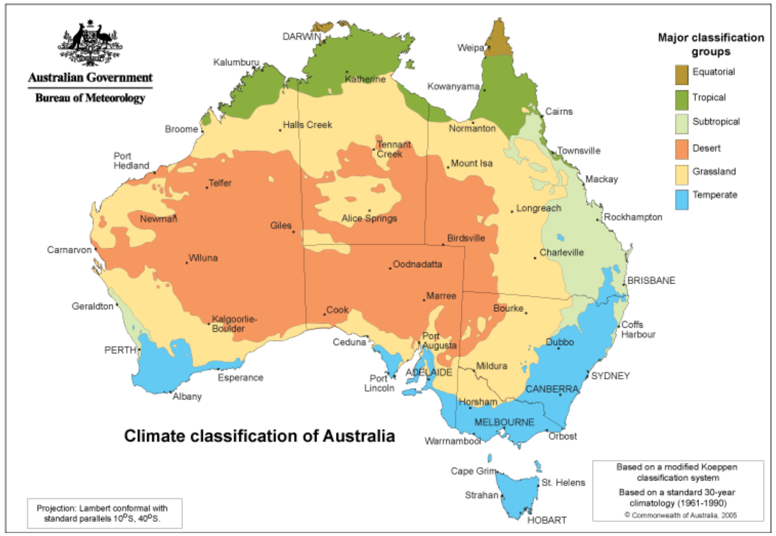


Figure 3: Major climate classification groups of Australia.[16]

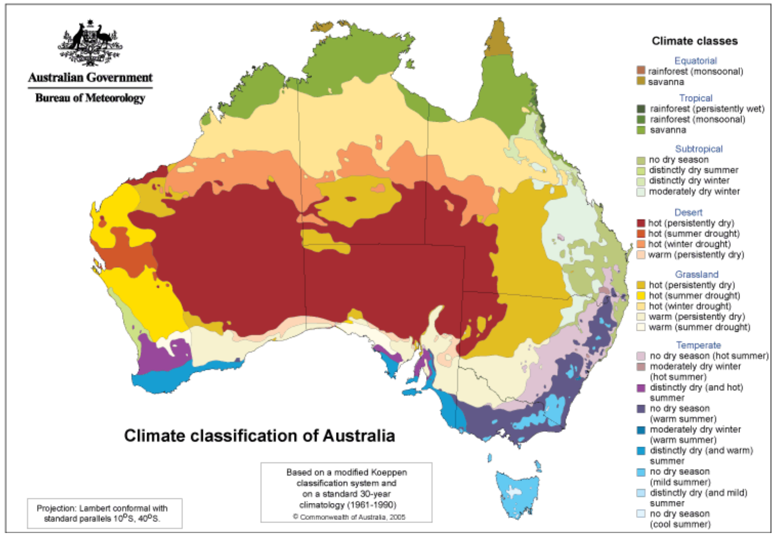


Figure 4: Australian climate classes.[17]

[16] Australian Bureau of Meteorology, "Australian Major Climate Classes."

[17] Australian Bureau of Meteorology, "Australian Climate Classes."

Table 4. Australian Bureau of Meteorology Climate Classifications.

Major Classification Groups (2005)	Climate Classes (2005)
Equatorial	Rainforest (monsoonal)
	Savanna
Tropical	Rainforest (persistently wet)
	Rainforest (monsoonal)
	Savanna
Subtropical	No dry season
	Distinctly dry summer
	Distinctly dry winter
	Moderately dry winter
Desert	Hot (persistently dry)
	Hot (summer drought)
	Hot (winter drought)
	Warm (persistently dry)
Grassland	Hot (persistently dry)
	Hot (summer drought)
	Hot (winter drought)
	Warm (persistently dry)
	Warm (summer drought)
Temperate	No dry season (hot summer)
	Moderately dry winter (hot summer)
	Distinctly dry (and hot) summer
	No dry season (warm summer)
	Moderately dry winter (warm summer)
	Distinctly dry (and warm) summer
	No dry season (mild summer)
	Distinctly dry (and mild) summer
	No dry season (cool summer)

Climate zone boundaries are often hard to distinguish across both international and Australian classification systems. Sometimes, regions with similar weather patterns and vegetation belong to different climate types, and conversely, what may present as distinctly different climate regions may be classified as the same. This is partly due to the density or scarcity of weather stations collecting data in regions. To address this, when locations satisfy certain criteria simultaneously, climatologists apply additional rules to assign sub-types.

Attempting to achieve a visual comparison between the Köppen-Geiger map for Australia and the BOM’s major climate classes is problematic due to a lack of consistency in naming and colour-coding. The Australian classification does not use the three-letter coding system and the two systems use the different colours keys for mapping purposes.

For example, the Köppen-Geiger system maps two regions with temperate C sub-types that are predominate in Queensland (Cfa), NSW and Victoria (Cfb). The modified Australian version classifies these regions into four subtropical classes (including parts of North Queensland laying north of the Tropic of Capricorn) and four Temperate classes in New South Wales and Victoria. These are as follows:

1. Subtropical - No dry season (e.g. South East Queensland and beyond the Great Dividing Range (GDR) to the Downs; parts of the coastal strip in North Queensland, and northern NSW on both sides of the GDR).

2. Subtropical - distinctly dry summer (an area in Western Australia between Perth and Geraldton, therefore likely to be a Csa type climate).
3. Subtropical - distinctly dry winter (e.g. North Qld hinterland districts behind the coastal strip like Charters Towers).
4. Subtropical - moderately dry winter (Central-western to Southern Queensland).

And

1. Temperate - no dry season (hot summer).
2. Temperate - moderately dry winter (hot summer).
3. Temperate - distinctly dry and hot summer.
4. Temperate - no dry season (warm summer) (e.g. Border Ranges and Scenic Rim).
5. Temperate - distinctly dry (and warm) summer.

Five other temperate climate classes are located in Tasmania, South Australia and Western Australia.

Tasmania:

1. Temperate - no dry season (mild summer).
2. Temperate - distinctly dry (and mild) summer.

Western Australia:

1. Temperate - distinctly dry (and hot) summer.
2. Temperate - moderately dry winter (warm summer) south coast.

South Australia:

1. Temperate, dry summer (hot summer).
2. Temperate, dry summer (warm summer).
3. Temperate, no dry season (warm summer).

In summary, the BOM climate classification system subdivides the five relevant Köppen-Geiger temperate sub-types into thirteen classes. The TRC study area is potentially represented in several climate classes indicated by BOM map including: (1) subtropical-no dry season; (2) temperate-no dry season/hot summer; (3) temperate-moderately dry winter/hot summer; and (4) temperate-distinctly dry and hot summer.

2.4. Vegetation and Climate in Australia

Typically, vegetation across global climate areas adjust to environmental change slowly and also respond to extreme events such as prolonged drought. Figure 5 and Figure 6 below present an overview of Australia's Major Vegetation Groups (MVGs) and the estimated impacts they have sustained since European colonisation of Australia.[18]

Figure 5 is a map of the estimated pre-1750 distribution of MVGs prior to European settlement. The term "pre-1750" precedes European settlement in Australia by a few decades but it is in international usage in greenhouse science and vegetation monitoring to describe the time just prior to

[18] Department of the Environment and Water Resources, "Australia's Native Vegetation: A Summary of Australia's Major Vegetation Groups, 2007."

industrialization. Figure 5 is a map of current distribution of MVGs. Comparison between them shows substantial human-induced land-use change.

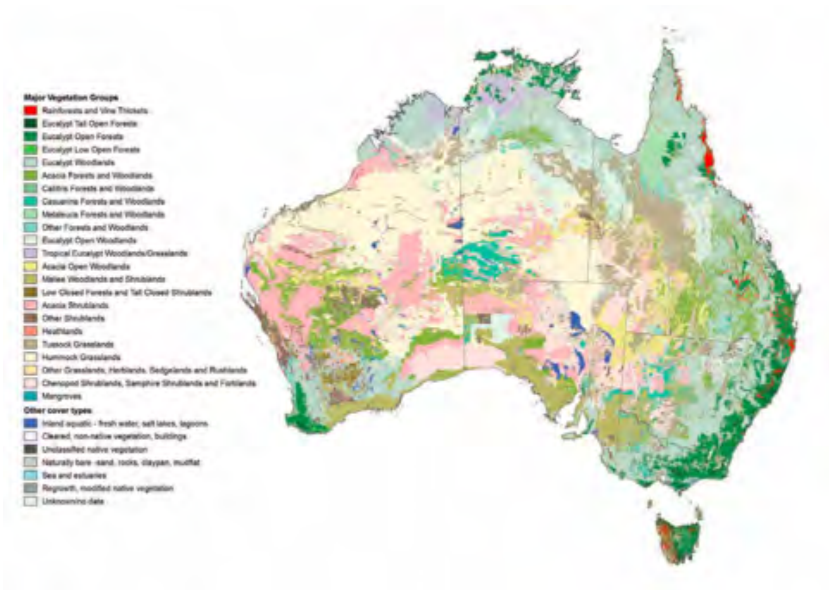


Figure 5. MGV1 Estimated pre-1750 distribution of Major Vegetation Groups prior to European settlement.[19]

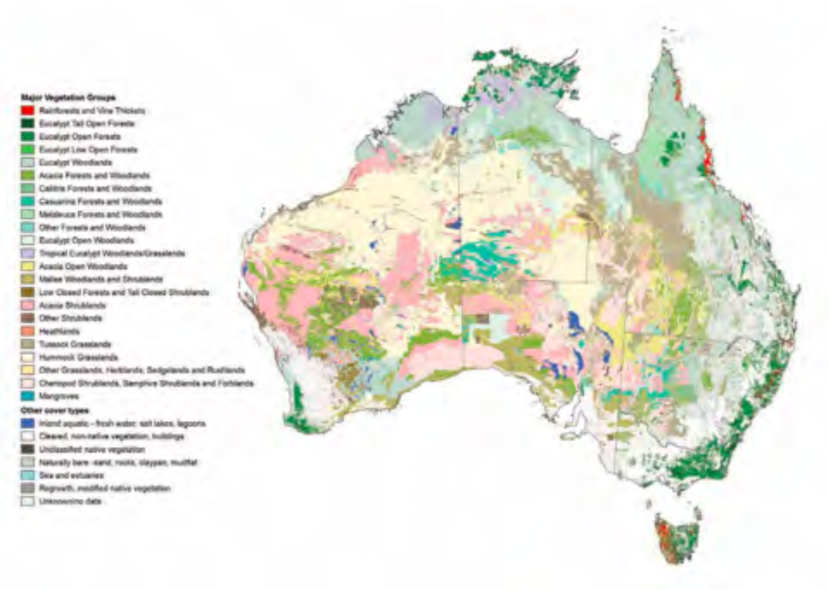


Figure 6: MVG2 Current distribution of Major Vegetation Groups.[20]

[19] Department of the Environment and Water Resources.

[20] Department of the Environment and Water Resources.

The degree of loss of native vegetation since European settlement is highest in the continent's temperate climates. Clearing of Eucalypt Woodlands for grazing and intense agriculture has been most widespread in the major agricultural zones of eastern Australia and the south-west of Western Australia.[21]

At the time of publication of the MVG summary, much of the study area had been cleared of native vegetation. Only 31-50% of native vegetation remained. The major vegetation groups have been replaced by cropland, grazing country and urbanisation.[22]

The loss of major vegetation groups and specifically woodlands is exacerbated by or is possibly exacerbating the transition of areas previously classified as temperate sub-humid/humid climates such as Cfa to semi-arid Bsh climates. Research has shown that over the past 60 years, regions located between Longitude 139° to 156° (E) and Latitude 10° - 40° (S) in eastern Australia, including the TRC study area, have undergone semi-arid expansion. Temperate to semi-arid transition was greater in the 15 years from 1990 - 2004 during 1948 -1962.[23]

2.5. Summary of warm temperate climate classification

The Köppen-Geiger climate classification system provides criteria that determine warm temperate climates in the C climate type. The BOM map reflects the C climate types but subdivides them into subtropical and temperate groups and expands the number of classes within these groups.

The TRC study area is represented in the Köppen-Geiger Cfa sub-type (temperate, without dry season, hot summer) and in close proximity to several BOM climate classes in the region including subtropical-no dry season, and temperate-no dry season/hot summer. A further complication has to do with how well temperate climate definitions actually correspond to distribution of natural vegetation observable today.

2.6. National Construction Code of Australia climate classification

The NCC Climate Zone Maps broadly categorise regions into eight climate areas, based on climate data from the Bureau of Meteorology, mapped to LGA boundaries and analysed by CSIRO to best inform energy efficient heating and cooling requirements for building thermal comfort outcomes. Refer to Figure 5, NCC Climate Zone Map for Australia, and Table 5: Brief Description of NCC Climate Zones. There are different measures for each climate zone. The NCC Climate Zone Maps provide very broad definitions that generally inform deemed-to-satisfy (DTS) provisions for buildings in locations across Australia with approximately similar climates. Energy efficiency rather than occupant comfort is the primary objective of these provisions regulating climatic responses for thermal comfort in buildings contained within macroclimates as per the boundaries of a given LGA. These climate definitions by zone are very high level and do not provide enough detailed information or understanding of a specific region's macroclimate nor local microclimates to inform best practice in making

[21] Department of the Environment and Water Resources. p. 18.

[22] Department of Agriculture, Water and the Environment, "The National Vegetation Information System (NVIS)."

[23] Huang et al., "Global Semi-Arid Climate Change over Last 60 Years." p. 1137.

buildings inherently more comfortable using climatically responsive design and building principles. Being aligned with LGA boundaries, climate zone boundaries are subject to change from time to time.

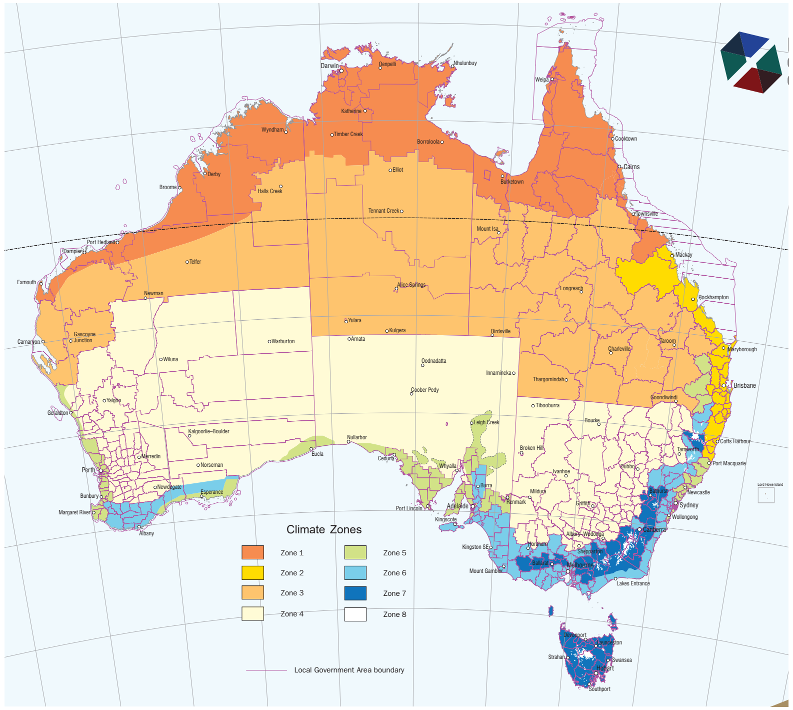


Figure 7: NCC Climate Zone Map for Australia.

Table 5: Brief Description of NCC Climate Zones.[24]

Climate Zone	Brief Description
Zone 1	High humidity summer, warm winter
Zone 2	Warm humid summer, mild winter
Zone 3	Hot dry summer, warm winter
Zone 4	Hot dry summer, cool winter
Zone 5	Warm temperate
Zone 6	Mild temperate
Zone 7	Cool temperate
Zone 8	Alpine

When comparing the NCC climate zone map with the Köppen-Geiger and the BOM maps, the differences between the scientific method of climate classification and zoning for regulatory purposes becomes apparent. Figure 8 and Figure 9 overlay the NCC Climate Zone map with Köppen-Geiger and BOM classifications. This shows how a swathe of locations that have a wide variety of climatic characteristics determined by climate science are broadly classified as zone 5 (warm temperate) by the ABCB. Six climate sub-types in the Köppen-Geiger system are designated as NCC zone 5. There are also six different climate classes in the BOM map designated as NCC zone 5.

[24] Beck et al., "Present and Future Köppen-Geiger Climate Classification Maps at 1-Km Resolution."

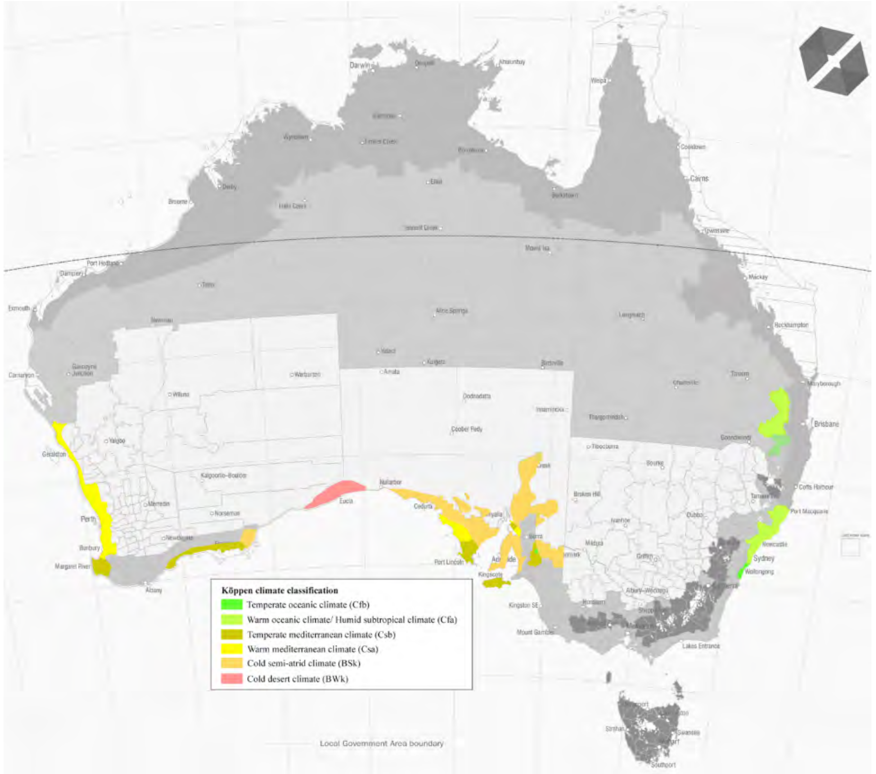


Figure 8: NCC Climate Zone Map – Zone 5 LGA's labelled by Koppen Geiger climate subtypes

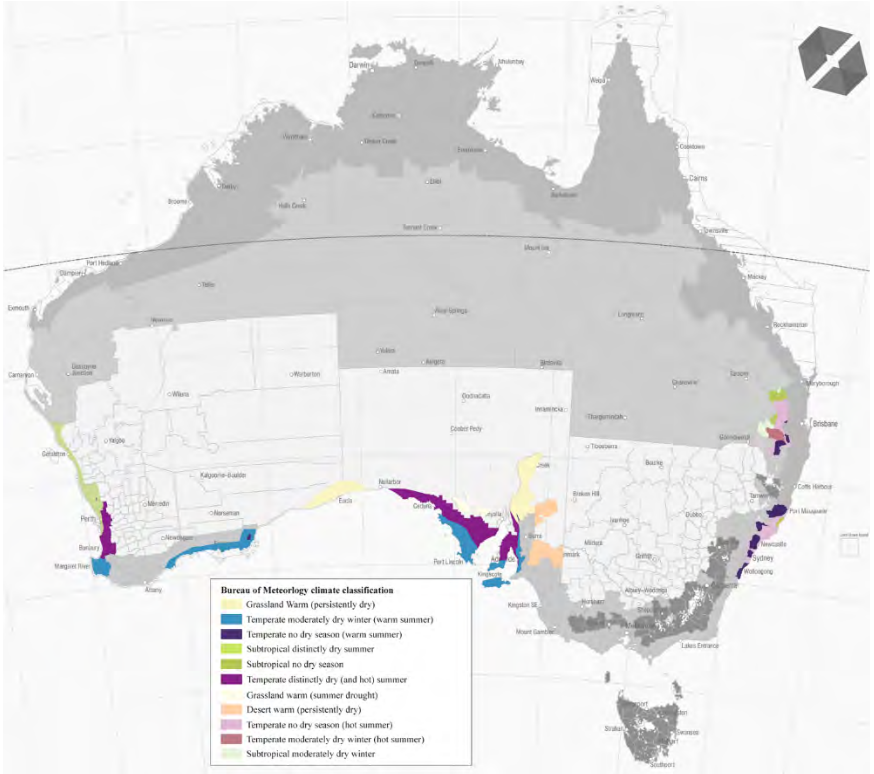


Figure 9: NCC Climate Zone Map LGA's labelled by BOM climate subtypes (this image will be updated by Kieu)

2.7. Current Understanding of Toowoomba's climate in the regulatory environment

Throughout the late 19th century and early 20th century, Toowoomba served as a holiday destination for middle class Brisbane residents to retreat from the summer heat and humidity.[25] Historically, Toowoomba's temperate climate has driven architectural responses that differ to those found in Brisbane's subtropical climate.[26] This stock of heritage buildings continues to be an important factor in defining Toowoomba's unique character.

The *Toowoomba Region Corporate Plan 2019 - 2024* celebrates Toowoomba's distinctive temperate climate and credits the climate as one of the key drivers of the region's attractiveness to existing and new residents and businesses.

This understanding of Toowoomba's climate is reflected in the National Construction Code's Climate Zone Maps (see Figures 1 and 2, and Table 1). These Climate Zone maps designate the Toowoomba Regional Council LGA as zone 5 (warm temperate). Within Queensland, there are only three LGA's that are zoned as warm Temperate in the NCC including South Burnett, Southern Downs and Toowoomba.

Another method for classifying climate is through the CSIRO's Nationwide Housing Energy Rating Scheme (NatHERS). This scheme divides Australian into 69 climate zones that are grouped together by similar climatic conditions. Interestingly, NatHERS also groups LGA areas for TRC, South Burnett and Southern Downs into the same climate zone, in the same way that the NCC does. The three LGA's are grouped under zone 5, which is based on climate data from the Oakey weather station based on the assumption that data from nearby weather stations (in Toowoomba, Dalby, Kingaroy and Warwick) does not differ enough from Oakey to warrant a different climate zone.[27]

In response to this variation within the climate in the Toowoomba region, this report sets out to analyse Toowoomba's climate using local data. Climate data collected from local weather stations informs a better understanding of the region's existing climate classification so as to make evidence-based suggestions for designing the built environment in response to the region's climate. This allowed us to establish a foundation for understanding Toowoomba's climate according to Köppen-Geiger climate *groups,* BOM and CSIRO *classifications* and, finally, the NCC and NatHERS climate *zones*.

We now examine how these different definitions for Toowoomba's climate are represented in legislation, policy and strategy documents internationally, in Australia and within state and local government.

[25] Lee, "Spirit of Place: The European Fashioning of Toowoomba."

[26] Queensland State Government, "ShapingSEQ: South East Queensland Regional Plan 2017."(Shaping SEQ, 2017, p136)

[27] CSIRO, "Climate Zones - Energy Ratings Dashboard."

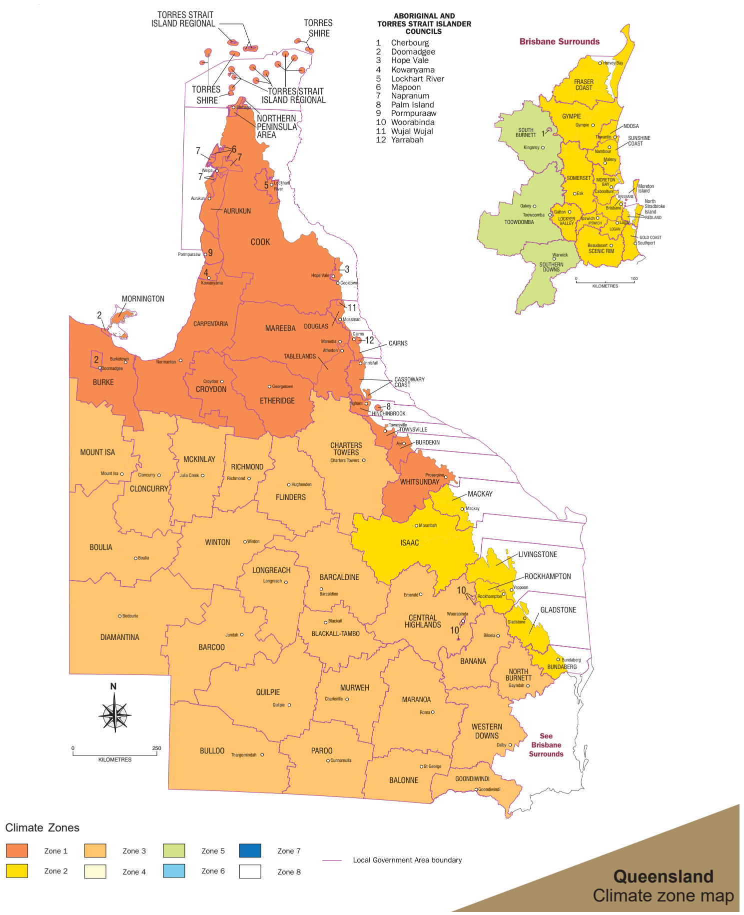


Figure 10. NCC Climate Zone Map for Queensland with detailed map for Brisbane Surrounds (which includes Toowoomba Regional Council LGA)

2.8. Legislation, Policy and Strategy

Definitions for climate zones can vary throughout Australia's legislatorial framework. To understand and apply these definitions, the hierarchical relationships between legislation, policy and strategy documents must be established, as well as the ways in which these reference each other.

The framework can be represented hierarchically, with legislation, policy and strategy documents understood, first, as either mandatory (enforceable by law) or non-mandatory. Then, according to how they reference each other, and which takes precedence; with Codes feeding into Regulations that bring about the requirements of Acts (Figure 11). Finally, definitions for climate outlined in legislation, policy and strategy documents exist across multiple domains of government, industry and scientific reports. These are considered according to whether they are adopted by a Local Government Area (LGA), State Government or Federally. Noting that LGA legislation overrules State-based mandates, which in turn overrule Federal requirements.

This is relevant in attempting to define a warm temperate climate because definitions across Australia's legislatorial framework are variously applied in ways that are context dependent. This results in different understandings of what a warm temperate climate might be. When climate definitions are then coupled with key Built Environment (BE) legislation, it can be difficult understand the characteristics of a particular climate zone beyond what is practically mandated in the Codes, Regulations and Acts.

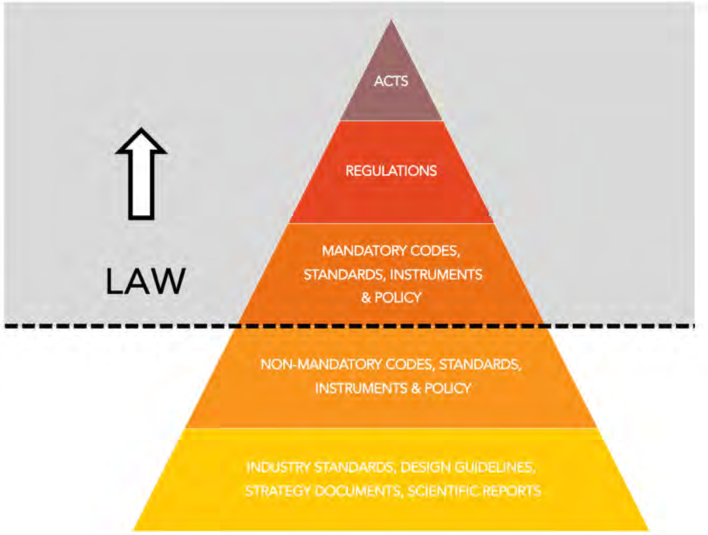


Figure 11. Representation of Australia's legislatorial framework.

Given the interrelated complexity of the legislatorial framework described, this section of the report outlines definitions and descriptions for a warm temperate climate used (1) nationally in Australia and by the Federal Government; (2) by State Governments; and (3) in the LGA of Toowoomba (and region). Listed in increasing order of how legislation, policy and strategy are afforded precedence in Australia. The review includes a cross section of sources including industry standards, design guidelines, strategy documents and scientific reports; mandatory and non-mandatory codes, standards, and policy; regulations and Acts.

2.9. International trends

Defining a warm temperate climate according to legislation and policy is difficult, given the currently limited use of climate data to inform building codes worldwide. Where data are integrated within codes, they typically reflect static climate conditions defined by data that can be up to 30 years old[28]. Increasingly, the challenge in developing data-informed building codes and climate definitions lies, not only in accessing up-to-date data records for a region, but in obtaining accurate "predictive data about the hazards that buildings are likely to face in the future" [29]. Our shifting climate is causing new risks to emerge, requiring mitigative action through built environment design. Legislation, policy, codes and strategies must now pre-empt future climate conditions or risk human suffering, loss of life and financial loss associated with extreme weather events.

The *Global Resiliency Dialogue* (GRD) was founded in July 2019 by the Australian Building Codes Board, the National Research Council of Canada, the New Zealand Ministry of Business, Innovation and Employment, and the International Code Council (US). The initiative is tasked with "identifying strategies for the identification of future risks and the development of building code solutions that support adaptation to those risks" given that, so far, no building code in the world integrates climate science projections. "The quality and coverage of weather and climate data

[28] For example, New Zealand rainfall maps utilised in their Building Code

[29] Global Resiliency Dialogue, "The Use of Climate Data and Assessment of Extreme Weather Event Risks in Building Codes Around the World: Survey Findings from the Global Resiliency Dialogue."

incorporated into building codes – especially in larger countries with diverse physical geography and climates – is variable and imperfect." [30]

At a global level, regulatory bodies are only now connecting the risks of a changing climate with how building codes must be framed. As stated in the GRD (2021) *The Use of Climate Data and Assessment of Extreme Weather Event Risks in Building Codes Around the World* review:

> Across the globe, the intensity, duration, frequency and location of extreme weather events are changing. Communities and the built environment they rely on to support their economic and social prosperity must be prepared to respond to these changing risks. Building codes are fundamental to assuring buildings support the health, safety and welfare of communities, including protecting life during hazardous events. Therefore, building code development and research organizations recognise the need to work collaboratively to address the challenges posed by changing risks.[31]

Set within this broader context of global change, Toowoomba's *Warm Temperate Climate Study and Design Guideline* will lead the way as a model for establishing forward-looking built environment strategies that are specific to its local climate. This is also in line with the Queensland Government review of "how planning instruments can better provide guidance to local governments on how to incorporate climate change consideration into local planning schemes".[32]

2.10. National Definitions for Climate in Australia

Legislation for the building sector in Australia integrates climate data from the BOM to define climate zones outlined in the NCC. These data are only updated every 15 years; and wind maps, bushfire risk and water conservation data that are updated every 10 years. [33]

According to the NCC classification system, we see a transition in southern Queensland from the west, with zone 3 (arid) areas in central Queensland, through to the zone 5 (warm temperate) region in which TRC sits, to the zone 2 (subtropical) areas of Brisbane and its surrounds (Figure 10). NCC climate zone boundaries are informed by BOM data but are also aligned with local government areas. This political boundary overlay means – as stated in the NCC – that climate zones "are therefore subject to change from time to time"[34], revealing a complex interrelationship between Australia's governance systems and climate data in determining optimal building outcomes for different climate zones. It is also important to note

[30] Global Resiliency Dialogue. P. 4

[31] Global Resiliency Dialogue, "Findings on Changing Risk and Building Codes."

[32] Queensland State Government, "Queensland Climate Adaptation Directions Statement."

[33] Global Resiliency Dialogue, "Findings on Changing Risk and Building Codes."

[34] ABCB and NCC, "Climate Zone Map: Australia Wide."

that, while the NCC is informed by BOM data, the BOM also have their own climate zone classification system with maps that do not abide by LGA boundaries, introducing another layer of inconsistency in interpreting local climate conditions.

Table 6. Climate zone descriptors for SE QLD as outlined by YourHome.gov.au.[35]

Zone	Descriptors
Zone 3 Hot dry summer, warm winter	• Distinct wet and dry seasons • Low rainfall and low to moderate humidity • No extreme cold but can be cool in winter • Hot to very hot summers common • Significant day–night temperature range
Zone 5 Warm temperate	• Moderate diurnal (day–night) temperature range near coast to high diurnal range inland • Four distinct seasons: summer and winter can exceed human comfort range; spring and autumn are ideal for human comfort • Mild winters with low humidity • Hot to very hot summers with low to moderate humidity
Zone 2 Subtropical Warm humid summer, mild winter	• High humidity with a definite 'dry season' • Hot to very hot summers with mild winters • Distinct summer/winter seasons • Moderate to low diurnal (day–night) temperature range, which can vary significantly between regions (e.g. inland to coastal)

It is important to note that the NCC climate zones are based, in part, on climate data and LGA boundaries, but that they are then translated again according to how they compare to the NCC "reference building," which sets out a standard "Heating and Cooling Loads". For example, Volume Two of the NCC defines the difference between zone 2 and zone 5; where zone 2 buildings need to meet or have more efficient cooling loads than the reference building, and zone 5 buildings must meet or have more efficient cooling *and* heating loads than the reference building.[36]

Climate data used to inform NCC climate zones reflect a static view of conditions in a given area and do not take into account either the range of typical conditions that can occur over a decade, or future projections. This is important information when simulating buildings to respond to real conditions including summer heatwaves. In the National Disaster Risk Reduction Framework[37], a stated action exists for codes to improve the resilience of buildings to extreme weather events. But, with the exception of the NCC's 2022 incorporation of 5% climate change multiplier to wind speeds in cyclonic regions, climate change risk is minimally addressed in Australian climate zone definitions and building codes.

The way in which climate zones are defined has a real impact on the provision of technical standards for the design and construction of buildings, other structures and plumbing and drainage systems according to the NCC. But, where the NCC requires that a design is 'fit for purpose', the current climate zone definitions do not inform detailed 'evidence of suitability' requirements in response to varied climatic conditions at a local level.

2.11. State-Based Approaches to Defining Climatic Conditions

[35] Australian Government, "Design for Climate."

[36] NCC, "Building Code of Australia, Volume 1."

[37] Australian Institute for Disaster Resilience, "National Disaster Risk Reduction Framework."

Figure 12 shows how State and Territory Acts and Regulations are given precedence over national acts, regulations and codes such as the NCC. But, as a rule, state government legislation, policy and strategy for building and planning reference the climate zone definitions as outlined in the NCC.

While Queensland's Building Act (1975) and Planning Act (2016) do not define nor describe climate zones, the Planning Act does reference climate change, which is expanded upon in the section of this report on Climate Perceptions and Patterns. This is also the case with the Queensland Development Code (QDC), its mandatory part 4.1 *Sustainable Buildings*, the Queensland Building Plan (2017) as well as the repealed Queensland Sustainable Planning Act (2009). There is the implicit assumption that all state-based legislation and policy align with the NCC climate zones as the industry standard, negating the need for additional definitions. There are also multiple ways in which legislation, policy and strategy documents refer to the area or region where Toowoomba is located; whether according to postcode, LGA boundaries, the "Eastern Downs region" (also incorporating Western Downs, Goondiwindi, and Southern Downs)[38] or as part of broader South East Queensland.

Figure 12: Interrelationships between State/Territory Acts and Regulations and the NCC. Source: NCC.

Where mandatory legislation and policy defer to the NCC, non-mandatory state policy and strategy frequently include descriptive references to local climatic conditions. While this is useful in helping to illustrate the lived experience of a Queensland climate, it can be problematic where climate characteristics are celebrated as synonymous with a "Queensland lifestyle"

[38] DES, "Climate Change in the Eastern Downs Region."

without regard for local variations such as those seen in the Eastern Downs region. The South East Queensland Regional Plan *Shaping SEQ* document refers to "SEQ's largely sub-tropical climate" acknowledging the "temperate climate of the western ranges" as well as the value of good design for both subtropical and temperate zones.[39] National maps that class the entire Toowoomba region as zone 5, coupled with celebrated cultural conditions of heritage buildings, laneways, coffee shops, artisan stores and a strong arts culture has perhaps reinforced descriptions of the city centre as a temperate "Melbourne of the north".[40] The appropriateness of this connection is reinforced in the *Toowoomba City Sustainability Report* commissioned by TRC, in which key targets and indicators developed for *Future Melbourne* are referenced as exemplars for carbon neutral development and community-led approaches.[41]

The *QDesign Manual* (2018), as part of the Queensland Government's commitment to achieving better urban design outcomes includes design case studies from Toowoomba. The Queensland climate is described as "diverse" with superficial reference to a singular understanding of the region's climate at a state-wide scale. The first step in the QDesign vision is to "understand and work with local climate" as "essential in managing the environmental impacts of urban areas and establishing the resilient communities of the future" but without reference to climatic variations across the region.[42]

State-based strategy documents frequently imply that the same descriptions for climate applied across Queensland and in the south-east region are applicable to the Toowoomba region. This tendency to overlook the local variation in Toowoomba's climate flows down through subsidiary guidance and notes and has a reinforcing effect on future legislation and policy for the region as evidenced in the Queensland Treasury's 2020 guidance for local governments on *Integrating Building Work in Planning Schemes*, which references *only* subtropical and tropical climate conditions for the entire state of Queensland.[43]

2.12. Regional Definitions for Toowoomba's Climate

As is the case with state-level climate definitions in legislation, policy and other documentation, Toowoomba's definitions for its local climate also defer to the national NCC definitions for climate zone 5 and zone 2. Anecdotally, locals note that these definitions do not accurately describe the specific local character of Toowoomba's climate, as evidenced by TRC's initiation and provision of support for this Temperate Climate Study and Design Guideline.

The Toowoomba Regional Council Planning Scheme establishes the following understanding of Toowoomba's climate with regard to sustainable urban development:

[39] Queensland State Government, "ShapingSEQ: South East Queensland Regional Plan 2017." Pp. 22, 94, 136

[40] Queensland State Government. p. 136

[41] Urbis, "Toowoomba City Centre Sustainability Report."

[42] Queensland State Government, "QDesign: Queensland Urban Design Principles." p.16

[43] Queensland State Government, "Integrating Planning Work in Planning Schemes Guidance." (p. 10).

> The Toowoomba Region's climate varies from the coastal subtropical climate by being warmer in summer and cooler in winter with less rainfall except for the immediate area adjacent to the escarpment. This climate has become one of the defining characteristics of design in the region.[44]

Yet, conflicting definitions for Toowoomba's climate exist even within the local Planning Scheme, where one specific outcome for the above sustainable urban development is stated as "design that responds to the local subtropical climate".[45] A subtropical climate is also referred to in relation to urban design and "front building elements" and "relaxed building setbacks"[46].

The planning scheme identifies the need for landscape design that "reflects the local context and incorporates cohesive and desirable aspects of the prevailing landscape character". This 'landscape character' is, in part, measured according to the appropriate selection of "cool temperate species".[47]

Descriptive accounts of the local climate in regional strategy documents are limited, where the Darling Downs Regional Plan (2013) does not mention climate character beyond its "quality and diversity" (p. 16) and no reference in the TRC (2010) Toowoomba City Sustainability Report. The TRC (2019) Toowoomba Region Corporate Plan (2019-24) describes the entire region as having a "temperate climate" (p.10) that is livable and liked (p.12). The *Climate Change in the Eastern Downs Region* (2019) document attributes the Eastern Downs region's temperate climate to its elevation, resulting in a climate that is cooler than the rest of the state (p.2). This document describes a climate that is "cooler than the rest of the state" with variable rainfall, much of which occurs during summer "either as heavy thunderstorms or from tropical rain depressions" (p.2). The region has a notably depleted level of soil moisture due to annual potential evaporation levels that are double annual average rainfall.[48]

2.13. Climate Perceptions and Patterns

At this stage, traditional Indigenous knowledge about seasons in Toowoomba is not reflected in resources such as the BOM's *Indigenous Weather Knowledge* database[49] or the CSIRO *Indigenous seasons*

[44] TRC, Toowoomba Regional Planning Scheme. 3.3.8:2, p. 20

[45] TRC. 3.3.8:1, p.20

[46] TRC. 3.5.4.1:4 p.29

[47] TRC. 9.4.4.3; PO3; AO3.4

[48] DES, "Climate Change in the Eastern Downs Region."

[49] Australian Bureau of Meteorology, "Indigenous Weather Knowledge."

calendars.[50] We intend to examine local knowledge through Phase 2 community consultation as part of this study.

Toowoomba's climate is shifting across the region due to climate change and future projections must be accounted for when proposing climate responsive design principles [51 52]. The Queensland State Planning Policy also recognises that climate change needs to be incorporated through planning and development frameworks.[53] The Toowoomba Regional Council Planning Scheme requires that "built forms are responsive to climatic conditions … and the variability in climate that is projected to be caused through climate change"[54]

Expectations around weather impact the way people build and occupy buildings, so addressing issues of climate change through design is as much about understanding people's perceptions as it is about climate science.

2.14. East-West transitions

Australia's regional areas are experiencing rapid population growth, as city dwellers are increasingly seeking connection to the natural environment and a more relaxed lifestyle. A 2021 study conducted by the Regional Australia Institute indicates that one-in-five city residents are looking to move to the regions, with more than half wanting to move in the next 12 months. Brisbane residents are currently the most stressed city-dwellers in the country.[55] This trend is amplified by the impacts of Covid-19 as well as the flexibility of working from home. Even prior to this, Toowoomba's population of 313,613 in 2018 was projected to increase to 361,793 by 2036.[56]

This east-to-west movement between Brisbane to Toowoomba is, in part, embedded in perceptions of climate. From the late 19th Century Toowoomba's perceived cooler temperature was seen as a more 'vitalising and health giving' climate for Europeans (or people with European ancestry) compared to subtropical Brisbane. Visitors from Brisbane felt that the temperature dropped as they ascended the range and Toowoomba became a weekend destination to retreat from Brisbane's heat and humidity.[57] At the turn of the 19th century discussions concerned with identifying an ideal climate for urban settlements in Australia were taking place nationwide informed by 'Social-Darwinist' connections between moral behaviour and temperature.[58] The appreciation of Toowoomba's

[50] CSIRO, "About the Indigenous Seasons Calendars."

[51] DES, "Climate Change in the Eastern Downs Region."

[52] Queensland State Government, "Climate Change in Queensland V1."

[53] Queensland State Government, "State Planning Policy."

[54] TRC, Toowoomba Regional Planning Scheme. 3.3.8, p.13

[55] Regional Australia Institute, "Media Release - New Research Shows Why City Dwellers Want a Life in the Country and When They Might Move."

[56] Queensland State Government, "Strengthening Darling Downs South West."

[57] Lee, Christopher. "Spirit of Place: The European Fashioning of Toowoomba." *Queensland Review* 3, no. 1 (1996): 24-30.

[58] Lee, Christopher. "Spirit of Place: The European Fashioning of Toowoomba." *Queensland Review* 3, no. 1 (1996): 24-30.

temperate climate informed what Christopher Lee has described as the 'European fashioning of Toowoomba.'[59] The connection between climate and Toowoomba's architecture from the late 19th century and early 20th century is important to a reading of the region's unique heritage and character.

The climate data also supports the east-west transition phenomenon. Conceptualising Queensland's climate as a transect through subtropical Zone 2 coastal areas through temperate Zone 5 to arid Zone 3 areas could become even more significant as the impacts of climate change become more extreme. As subtropical Brisbane becomes hotter with more volatile weather, and Western Queensland becomes hotter and drier, it is likely that Toowoomba's milder temperate climate will become even more attractive.

2.15. Climate change

Queensland is impacted by the greatest economic costs resulting from disasters out of all of Australia's states and territories.[60] It also has one of the highest per capita greenhouse gas emissions in the world.[61] Even if the ambitious targets set out in the Paris Agreement are achieved by 2030, and we limit global warming to 1.5°C, the IPCC (2018) state that we will continue to experience increasing frequency and magnitude of extreme weather events.[62] The 2021 Australian State of the Environment Report *Scoping paper for Climate* states that "regardless of changes in Australian and global emissions, substantial further climate change is inevitable, and adaptation to that change will need to take place" (p. 16).

According to the BOM *State of the Climate Report*, in the coming decades, Australia will continue to see increasing temperatures, decreasing rainfall, more droughts, more intense short rainfall events, increased dangerous fire weather days, sea level rise and acidification, with increased frequency and intensity of extreme weather events.[63]

The CSIRO/BOM *Climate Change in Australia* report reinforces predictions outlined in the *State of the Climate Report* with specific predictions for the east coast of Australia drawing attention to impacts on "important headwater catchments for a high proportion of Australia's population".[64] The impact of climate change on streamflow is emphasised in the BOM *State of the Climate Report,* which states that "this is most severe in the northern Basin where 94 per cent of the gauges show a declining trend in streamflow".[65] Rainfall-runoff modelling for the Condamine-Balonne region of the Murray-Darling Basin indicates that by 2030 climate change will

[59] ibid

[60] Steffen and Bradshaw, "Hitting Home: The Compounding Cost of Climate Inaction." p.26

[61] Queensland State Government, "Climate Change in Queensland: What the Science Is Telling Us."

[62] IPCC, "Global Warming of 1.5 °C."

[63] CSIRO and Australian Bureau of Meteorology, "State of The Climate 2020." p. 3

[64] CSIRO, "Climate Change in Australia: Projections for Australia's NRM Regions."

[65] CSIRO and Australian Bureau of Meteorology, "State of The Climate 2020." p. 9

cause a reduction in runoff between 9 – 26 per cent depending on low or high emission scenarios.[66]

The CSIRO predict that the 'east coast north' Natural Resources Management (NRM) sub-cluster is projected to experience 2.5 - 4.7°C above the 1986-2005 climate under a high emissions scenario by the end of the century.[67] Under this same scenario, the Darling Downs region is projected to experience localised warming of 2.0 – 3.8°C[68] suggesting that the area will continue to be known for its milder climate. The 2019 *Climate Change in the Eastern Downs region* predicts that by 2030, under a high emissions scenario, "the climate of Toowoomba will be more like the current climate of Kingaroy" (p.2). More complex impacts such as increased numbers of rodents in temperate areas (due to mild wet winters) and associated disease risk are also predicted.[69]

The issue of climate change is already reflected throughout the Toowoomba's Planning Scheme, with the stated outcomes to "increase community resilience to the projected impacts of climate change" and "reduce the generation of greenhouse gases".[70] The Toowoomba City Sustainability Report acknowledges that "average temperatures across the state are currently 1°C higher than they were 100 years ago". It describes a climate that is "already highly variable, but climate change is leading to shifts beyond this variability" calling for applied principles of sustainability-based planning and design to be integrated at a local level.[71]

2.16. Climate Change Adaptation

The *Queensland Climate Adaptation Directions Statement* (2020) outlines a commitment to regional engagement and local adaptation action through the Queensland Climate Resilient Councils (Q-CRC) initiative. The statement identifies the need to refine climate change projections "delivering regionally relevant, local scale projections … to improve the resolution of climate models down from 200km to 10km"[72]. Variable and imperfect weather data is a significant hindrance to developing climate-responsive building codes and design guides. The Queensland Government's commitment to "strong, coherent and consistent policy drivers in response to climate change" and to "prepare the state for the inevitable transition that it will have to make"[73] suggests that initiatives such as this *Warm Temperate Climate Study and Design Guideline* will be the first of many in the state. This is also in line with the Queensland Planning Act (2016) stated purpose, in which ecological sustainability is

[66] Queensland State Government, "Climate Change in Queensland: What the Science Is Telling Us." p. 47

[67] CSIRO, "Climate Change in Australia: Projections for Australia's NRM Regions."

[68] DES, "Climate Change in the Eastern Downs Region."

[69] Queensland State Government, "Climate Change in Queensland: What the Science Is Telling Us." p.68

[70] TRC, Toowoomba Regional Planning Scheme. p.27

[71] Urbis, "Toowoomba City Centre Sustainability Report." p. 2

[72] Queensland State Government, "Queensland Climate Adaptation Directions Statement." p.12

[73] DEHP, "Queensland Climate Transition Strategy: Pathways to a Clean Growth Economy."

defined as "a balance that integrates the maintenance of "cultural, economic, physical and social wellbeing of people and communities" and includes "accounting for potential adverse impacts of development on climate change and seeing to address the impacts through sustainable development".[74]

The design of our built environment has the potential to mitigate the loss of lives and reduce disaster risk. Resilient design reduces vulnerabilities and can, therefore, prevent a natural hazard from resulting in a disaster. A 2009 review commissioned by the Commonwealth Government found that "standards for building design and construction do not currently reflect the potential impact of climate change"[75]. A 2010 publication by the ABCB[76] investigated measures for climate change adaptation within the Australian Building Code, including the problem of increased energy consumption due to higher temperatures, adverse health effects on building occupants caused by overheating due to higher temperatures, increased damage from extreme weather events and increased moisture variation of clay soils resulting in greater ground movement impacting on foundations and services[77] - a problem that is already widely observed in Toowoomba.

The Toowoomba Regional Council planning scheme states that "good design responds to the climate of the Region and the adopted lifestyles of its residents and visitors, while acknowledging the history and traditions of the place."[78]

> The street, lot orientation and lot size facilitate buildings that conserve non-renewable energy sources through climate-responsive siting and design.[79]

This also takes into account development that minimises natural hazard risk and to protect "ecological integrity and processes necessary for biodiversity to be resilient to climate change".[80]

2.16.1. Summarising Climate Definitions

Definitions for Toowoomba's climate according to legislation, policy and strategy documents almost universally defer to the NCC climate classification system. This classification system is informed by BOM data that shows the TRC area as being warm temperate zone 5, however, this classification system is only broadly applied according to LGA boundaries

[74] Planning Act 2016 (Qld). Section 3.2;c (iv) p. 18

[75] ACG (Allen Consulting Group) 2009, Review of the Intergovernmental Agreement for the Australian Building Codes Board, Final Report, p.iv, March, Canberra *cited in* Global Resiliency Dialogue, "The Use of Climate Data and Assessment of Extreme Weather Event Risks in Building Codes Around the World: Survey Findings from the Global Resiliency Dialogue."

[76] ABCB, "Resilience of Buildings to Extreme Weather Events [Final Paper]."

[77] ABCB.

[78] TRC, Toowoomba Regional Planning Scheme. 3.3.8:3, p. 20

[79] TRC. 9.4.5:2, PO

[80] TRC. 3.4.1:2, p.24

given that – so far – the NCC only applies climate zones for basic heating and cooling load calculations according to a standard reference building.

While there are limitations in describing Toowoomba's the local climate character according to legislation, this review does reveal a number of factors that indicate how Toowoomba's climate is unique. Triangulating definitions and descriptions of climate across legislation, policy and strategy documents from national, state and local sources show that Toowoomba, South Burnett and Southern Downs are the only Local Government Areas (LGA) in Queensland that are classed as zone 5 according to the NCC. They are also the only zone 5 areas in Australia that are located inland, and not coastal (with the exception of some hinterland areas north of Whyalla and east of Adelaide). Finally, this part of south-east Queensland represents Australia's the most northern zone 5 LGA's.

The findings of this review show that definitions for Toowoomba's climate differ due to limitations at a national level that do not take into account local variations. Where Toowoomba and surrounds are classed as a zone 5 area according to mandatory codes, there are discrepancies between the NCC map and the postcode-based approach seen in the CSIRO interactive mapping tool and the BOM's climate zone classification system. At a state level, there are conflicting definitions for Toowoomba's climate in government policy and strategy documents where the area is referred to as either temperate or subtropical and frequently incorporated within broader policy that applies climate definitions as if they exist at a state-wide scale. This review confirms that a regional understanding of Toowoomba's climate shows inconsistencies, reinforcing the significance and impact of this study.

It is becoming increasingly apparent that climate change projections require that governments integrate more current climate data within building codes, which is underway through initiatives such as the *Global Resiliency Dialogue* and ABCB as a founding member as well as in the Queensland Government's *Climate Adaptation Directions Statement*. Studies such as this address a significant gap in knowledge of local climate conditions and have the potential to inform climatically responsible design to enhance human comfort as well as mitigate climate change impacts through resilient design.

3. INVESTIGATING TOOWOOMBA'S CLIMATE

3.1. Data collection methods

The purpose of this study is to determine the climate characteristics which predominate in the Toowoomba Regional Council (TRC) region in order to define what warm temperate climate is, relative to the region.

The analysis is based on available weather station data. Historical station-based climate data was accessed from Bureau of Meteorology (BoM)[81]. Whilst there are twenty weather stations in the TRC area, the dates from when weather stations started to collect climate data and the type of data vary from station to station. Some stations have only 20 years' data and most only recorded rainfall data. The network of fully operational weather stations is very limited within the TRC region (Toowoomba and Oakey). To overcome this problem additional stations outside the TRC boundary, Dalby, Warwick and Kingaroy Airport are included in this study (Figure 13).

Table 7 describes the climate data availability at these stations, and Table 8 outlines the exact location of all five weather stations including latitude, longitude and elevation.

The following climate variables were analysed using Excel based on the data available for each station:

a. Mean Rainfall (mm)
b. Mean maximum Temperature (°C)
c. Mean minimum Temperature (°C)
d. Mean Temperature (°C)
e. Mean Wind Speed
f. Solar Exposure
g. Mean Relative Humidity and,
h. Mean Sea Level Pressure.

[81] Australian Bureau of Meteorology, "Climate Data Online."

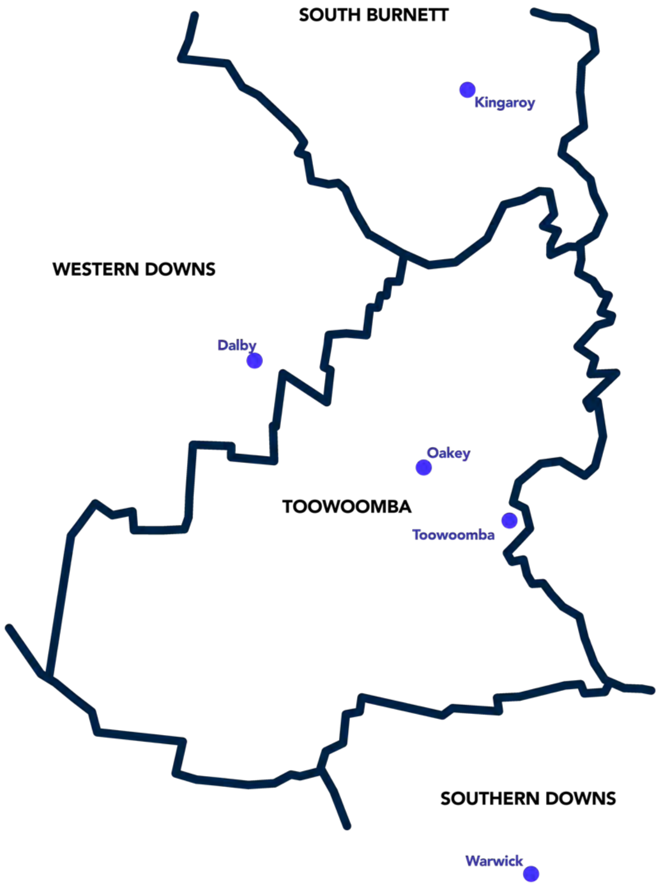


Figure 13: Location of weather stations used in the study.

Table 7.Climate data availability of variables.

Weather Station	Precipitation Data	Temperature
Toowoomba Airport	1997 - current	1997 - current
Oakey Airport	1992 - current	1992 - current
Dalby Airport	1971 - current	1974 - current
Warwick	2001 - current	1996 - current
Kingaroy Airport	2001 - current	2001 - current

Table 8: Weather Stations used in the study.

Weather Station	Station Number	Latitude	Longitude	Elevation	Location
Toowoomba Airport	41529	27.54 °S	151.91 °E	641 m	within TRC
Oakey Airport	41359	27.40 °S	151.74 °E	406 m	within TRC
Dalby Airport	41522	27.16 °S	151.26 °E	344 m	outside TRC
Warwick	41525 & 41534	28.21 °S	152.10 °E	475 m	outside TRC
Kingaroy Airport	40922	26.57 °S	151.84 °E	434 m	outside TRC

For the future climate projection analysis, information was accessed from the Queensland Government LongPaddock website. The high-resolution (~10 km grid cell size) climate change projections for Queensland are based on climate models using dynamical downscaling of Coupled Model Intercomparison Project Phase 5 (CMIP5) global climate model. The projections of two emissions scenarios (i) moderate emission scenario (RCP 4.5) and (ii) high emission scenario (RCP 8.5) was evaluated for all five locations.

3.2. Local climate data

3.2.1. Rainfall

Australia has the highest levels of year-to-year rainfall variability in the world.[82] It changes from year to year and from decade to decade. Toowoomba receives the highest amount of rainfall of all the five stations used in this study. All locations receive the highest amount of rain during the summer months (Table 9).

Table 9: Mean annual and seasonal rainfall.

Weather Station	Mean Annual Rainfall [mm]	Mean Seasonal Rainfall [mm]			
		Summer	Autumn	Winter	Spring
Toowoomba	698	303	145	93	167
Oakey	611	238	118	84	153
Dalby	584	246	110	76	153
Warwick	545	205	116	74	150
Kingaroy	631	276	122	92	140

Annual rainfall trends of the five weather stations are shown in Figure 16 to Figure 19. Toowoomba, Oakey and Dalby show a decline in rainfall over time. The time series of Warwick and Kingaroy covers only 20 years but despite that, Warwick also shows a decline in rainfall (Figure 18). It is difficult to determine the trend of Kingaroy since rainfall data is incomplete for a number of years (Figure 19).

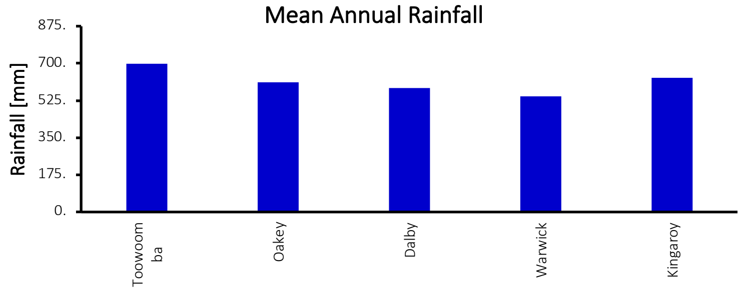


Figure 14: Mean annual rainfall recorded at the five weather stations.

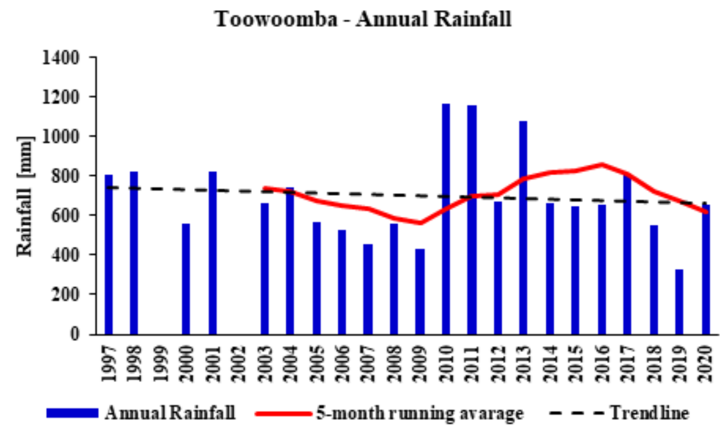


Figure 15: Toowoomba annual rainfall with trendline

[82] Love, "Impacts of Climate Variability on Regional Australia."

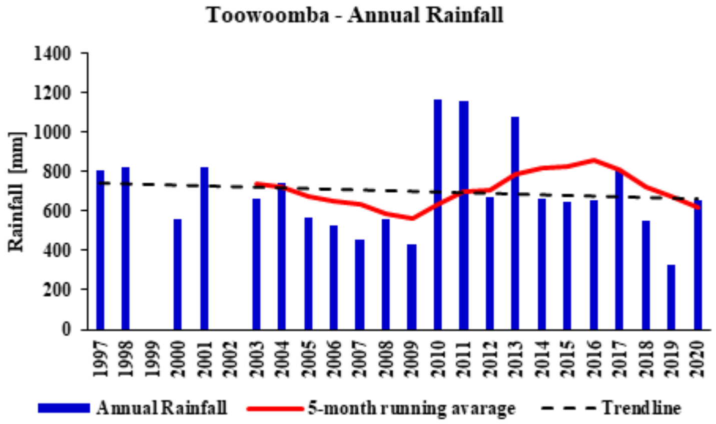


Figure 16: Toowoomba annual rainfall with trendline

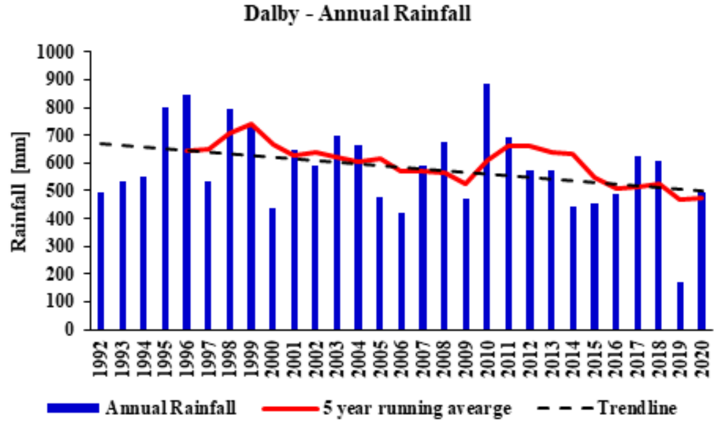


Figure 17: Dalby annual rainfall with trendline

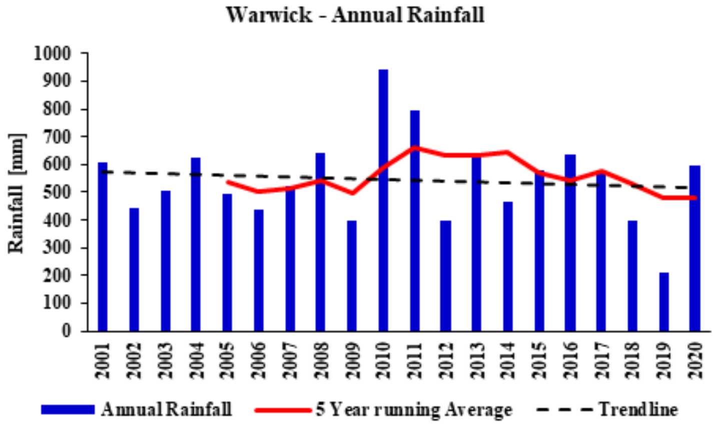


Figure 18: Warwick annual rainfall with trendline.

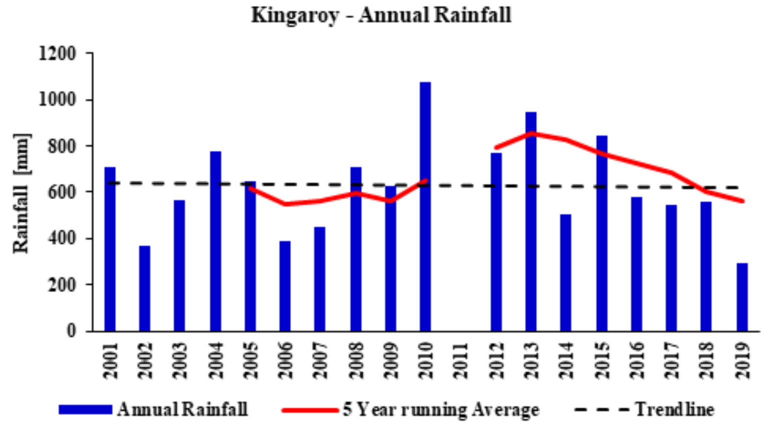


Figure 19: Kingaroy annual rainfall with trendline.

Table 10 illustrates that spring and summer rainfall has decreased at all five locations but whereas the amount of rainfall during autumn and winter varies depending on location. has not changed much in Dalby has seen little change, but rainfall has decreased in Oakey and increased in Warwick. Toowoomba and Kingaroy have both experienced increased autumn rainfall and decreased winter rainfall.

Table 10: Rainfall trend for each season at each location

Location	Spring	Summer	Autumn	Winter
Toowoomba	↓	↓	↑	↓
Oakey	↓	↓	↓	↓
Dalby	↓	↓	minimal change	minimal change
Warwick	↓	↓	↑	↑
Kingaroy	↓	↓	↑	↓

Annual rainfall anomaly is the difference from an average, or baseline, rainfall and is typically calculated by averaging 30 or more years of data. A positive anomaly indicates the observed rainfall is above the baseline, while a negative anomaly indicates the observed rainfall was below the baseline. Unfortunately, not all stations used in this study have 30 years of data available.

The annual rainfall anomaly of the individual stations is shown in Figure 20 to Figure 24. Below average rainfall is shown in red and above average in blue. The positive spike in 2010/2011 is related to the La Niña event during December 2010 and January 2011. Very intense localised rainfall in the Toowoomba CBD caused severe flash flooding and fatalities during the early afternoon of the 10/01/2011[83].

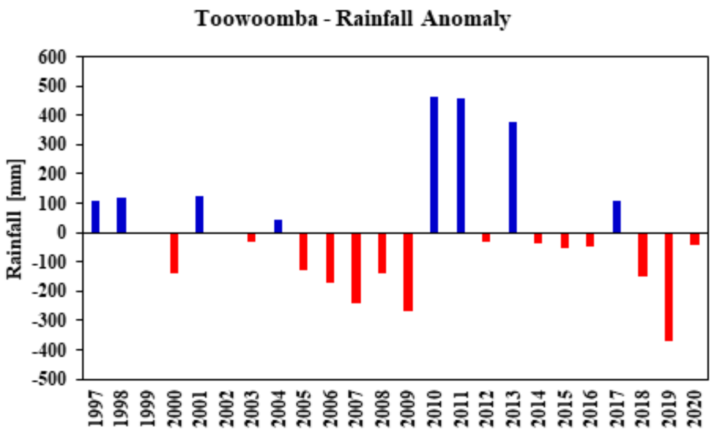


Figure 20: Toowoomba rainfall anomaly.

[83] Australian Bureau of Meteorology, "Flood Summary for Toowoomba - December 2010 and January 2011."

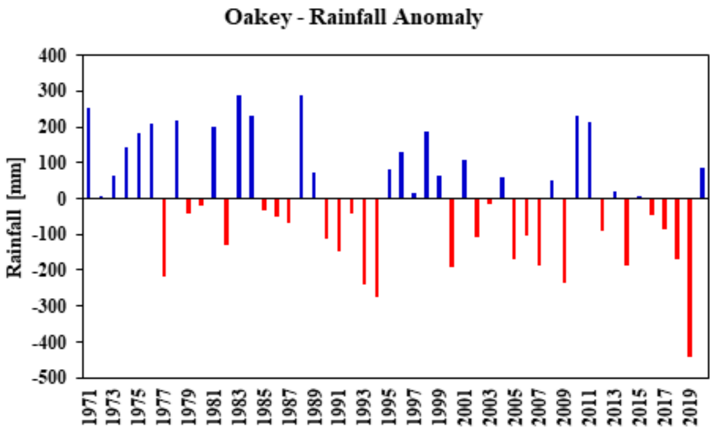


Figure 21: Oakey rainfall anomaly.

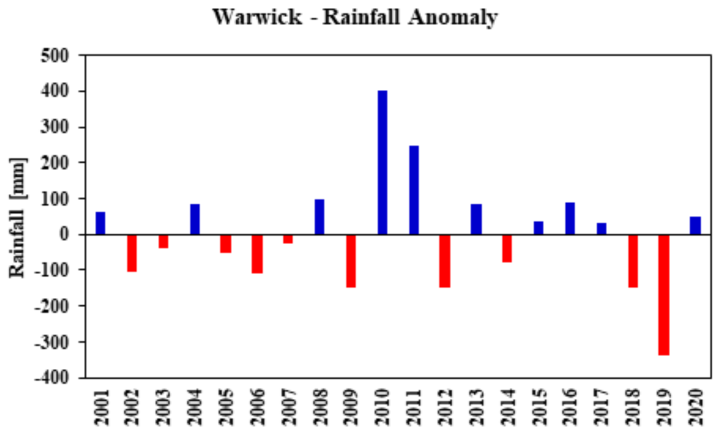


Figure 23: Warwick rainfall anomaly.

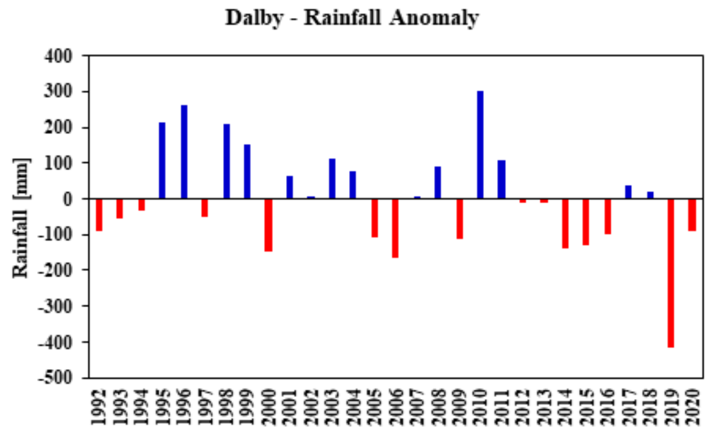


Figure 22: Dalby rainfall anomaly.

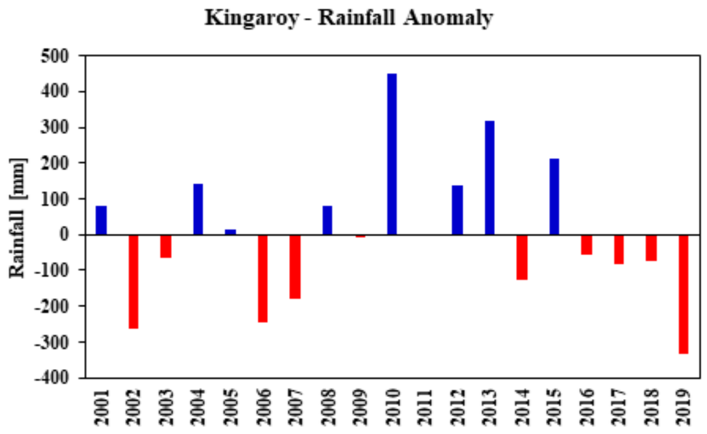


Figure 24: Kingaroy rainfall anomaly.

3.3. *Temperature*

The temperature recordings at the five weather stations follow the same trend. Toowoomba itself is located 698 m above sea level and is within close proximity to the escarpment of the Great Dividing Range and this has an influence on temperature. Toowoomba's maximum temperature is lower than all other locations for all seasons and the minimum temperature is higher than the other four locations during autumn, winter and spring. The temperature trends for all seasons at each location is listed in

Table 13. Maximum temperature has increased in summer, winter and spring at all locations whereas minimum temperature has increased for some seasons at a number of locations. The monthly mean, maximum and minimum temperatures of all five locations are displayed : Mean monthly, minimum and maximum temperature of Toowoomba (see Figure 25 to Figure 29).

Temperature anomaly is the difference from an average, or baseline, temperature. The baseline temperature is typically calculated by averaging 30 or more years of temperature data. A positive anomaly indicates the observed temperature was warmer than the baseline, while a negative anomaly indicates the observed temperature was cooler than the baseline. In this study, not all stations have 30 years of data all indicate that maximum temperature has increased.

Table 11. Average temperature, maximum and minimum temperature during summer and winter month.

Weather Station	Hottest month	Average Temperature (°C)		Tmax (°C)		Tmin (°C)	
		Summer	Winter	Summer	Winter	Summer	Winter
Toowoomba	Dec, Jan, Feb	22.1	10.8	27.9	17.5	17.3	7.2
Oakey	Dec, Jan, Feb	24.6	12.1	32.0	20.6	18.3	4.7
Dalby	Dec, Jan, Feb	23.6	11.5	30.5	19.4	15.6	3.6
Warwick	Dec, Jan, Feb	22.8	10.9	29.9	18.9	16.7	3.8
Kingaroy	Dec, Jan, Feb	23.4	11.9	30.4	20.4	17.5	4.5

Table 12: Average maximum and minimum temperature - summer, autumn, winter and spring

Weather Station	Tmax [ºC]				Tmin [ºC]			
	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring
Toowoomba	27.9	23.1	17.5	24.5	17.3	13.3	7.2	12.8
Oakey	32.0	25.6	20.6	26.6	18.3	11.8	4.7	11.1
Dalby	30.5	27.0	19.4	28.3	15.6	12.5	3.6	12.3
Warwick	29.9	24.8	18.9	26.0	16.7	10.9	3.8	10.5
Kingaroy	30.4	25.6	20.4	25.9	17.5	11.9	4.5	11.5

Table 13. Maximum and minimum temperature trends - summer, autumn, winter and spring.

Weather Station	Tmax [ºC]				Tmin [ºC]			
	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring
Toowoomba	↑	small ↑	↑	↑	↑	↑	↑	↑
Oakey	↑	↑	↑	↑	↑	↓	↑	↑
Dalby	↑	↑	↑	↑	↑	small ↑	no change	↑
Warwick	↑	no change	small ↑	↑	↑	no change	↑	↑
Kingaroy	↑	no change	↑	↑	no change	↑	↑	small ↑

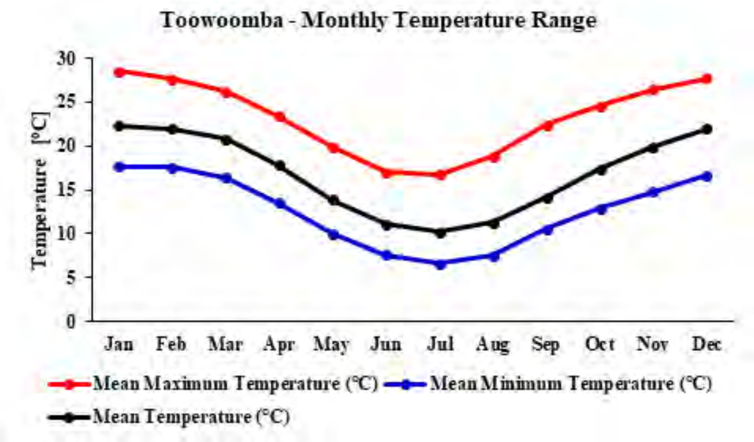


Figure 25: Mean monthly, minimum and maximum temperature of Toowoomba.

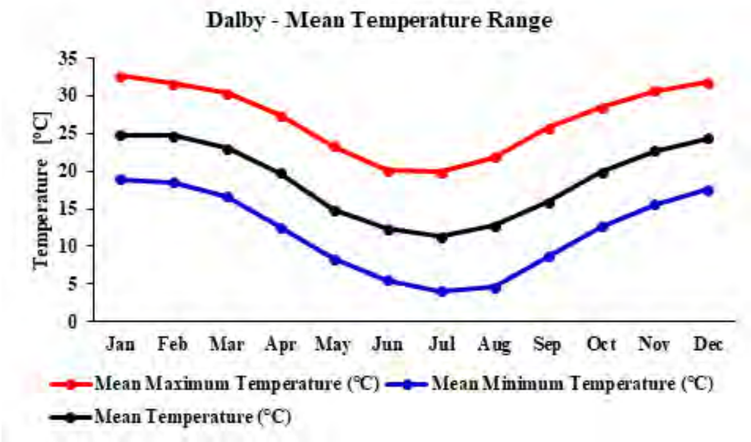


Figure 27: Mean monthly, minimum and maximum temperature of Dalby.

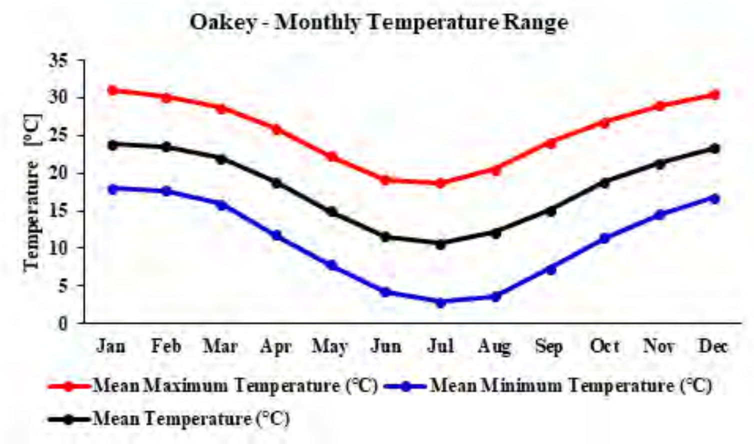


Figure 26: Mean monthly, minimum and maximum temperature of Oakey.

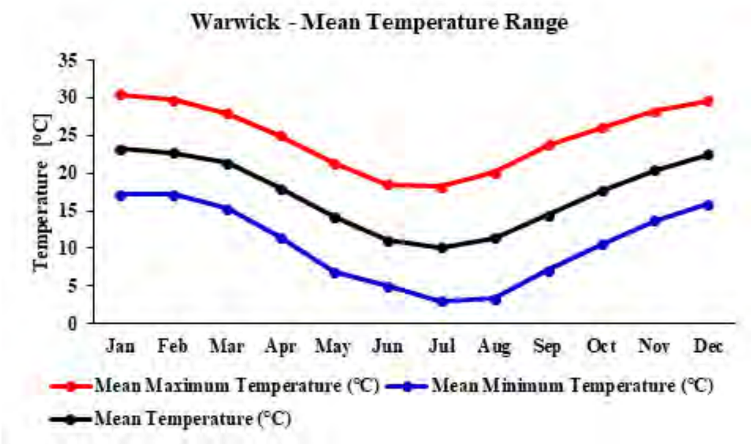


Figure 28: Mean monthly, minimum and maximum temperature of Warwick.

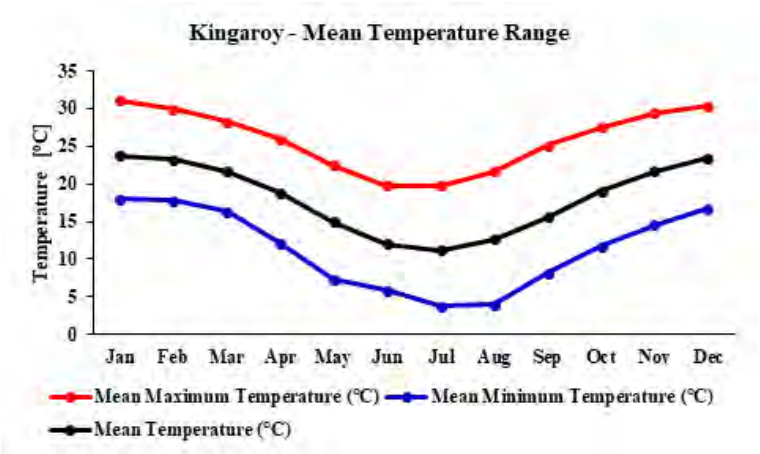


Figure 29: Mean monthly temperature, minimum and maximum temperature of Kingaroy.

The mean annual maximum temperature trends are shown in Figure 25 to Figure 29. Overall, the daytime maximum temperature has increased at all five locations. This is in line with the findings of the recently released State of the Climate Report 2020 (CSIRO and Bureau of Meteorology 2020) stating that Australia's climate has warmed on average by 1.44 ± 0.24 ºC since national record began in 1910, with most warming occurring since 1950 with each decade warmer than the one before. This continued warming is predicted to lead to an increased frequency of extreme heat events in future. The report also states that 2019 was Australia's warmest year on record, and the seven years from 2013 to 2019 all rank in the nine warmest years.

Table 14 illustrates the mean annual maximum and minimum temperature increase based on whole data set for all five locations.

In Toowoomba, the mean annual maximum temperature increased by 1.1 ºC based on 22 years of data (Table 14).

In Oakey, the mean annual maximum temperature increased by 1.8 ºC based on 43 years of data (Table 14).

In Dalby, the mean annual maximum temperature increased by 1.2 ºC based on 27 years of data (Table 14).

In Warwick, the mean annual maximum temperature increased by 1.4 ºC based on 21 years of data (Table 14).

In Kingaroy, the mean annual maximum temperature increased by 0.6 ºC based on 19 years of data (Table 14, Figure 34).

Table 14: **Mean annual maximum and minimum temperature increase based on whole data set**

Location	Years of Data	Tmax increase [ºC]	Tmin increase [ºC]
Toowoomba	22	1.1	0.5
Oakey	43	1.8	0.6
Dalby	27	1.2	0.2
Warwick	21	1.4	0.5
Kingaroy	19	0.6	0.3

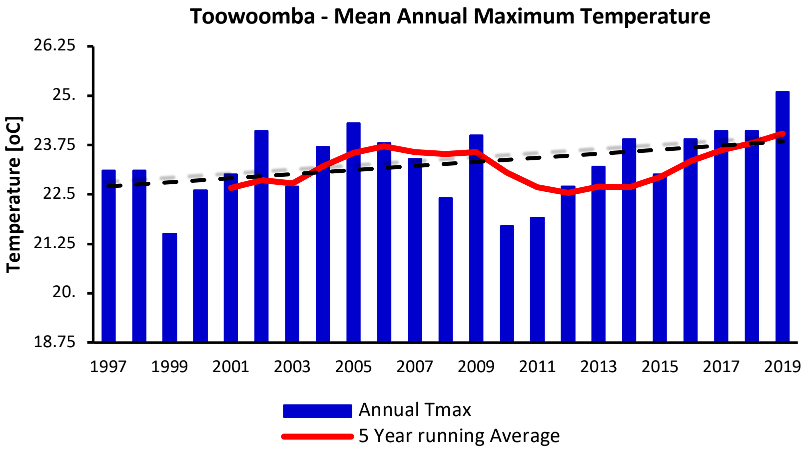


Figure 30: Toowoomba mean annual maximum temperature with trendline.

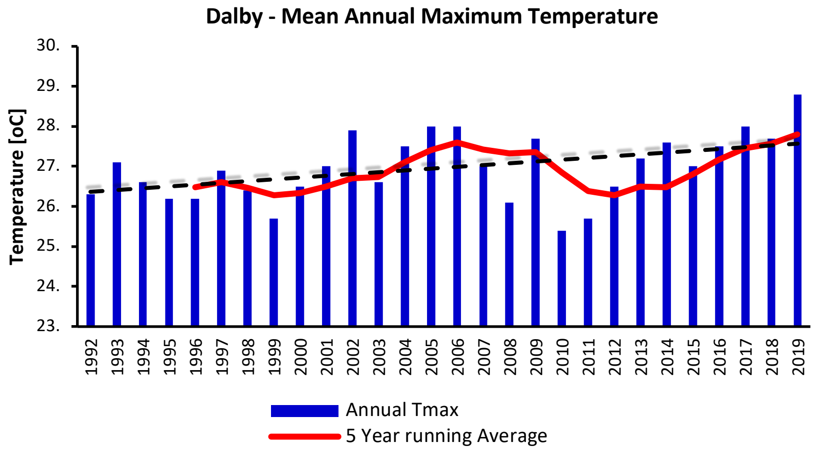


Figure 31: Dalby mean annual maximum temperature with trendline.

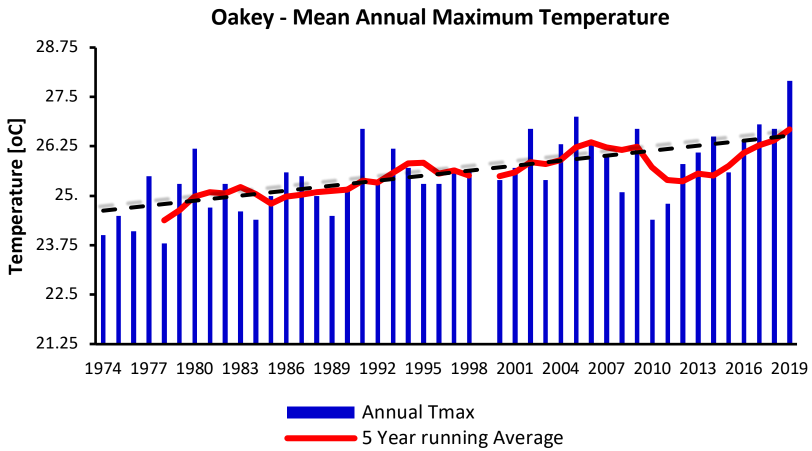


Figure 32: Oakey mean annual maximum temperature with trendline.

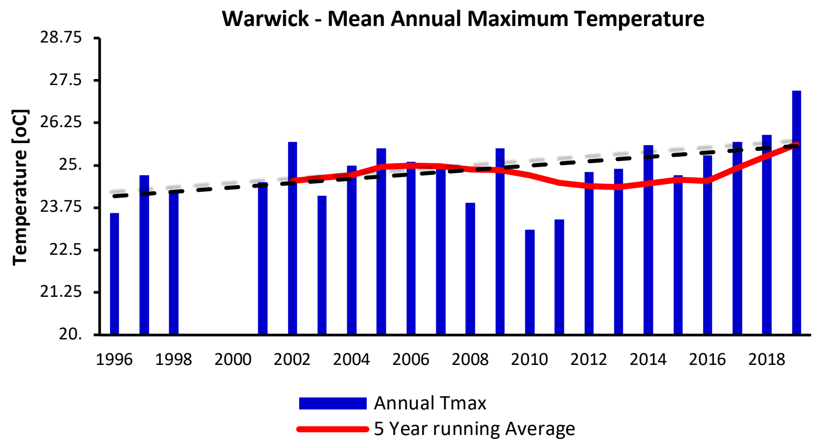


Figure 33: Warwick mean annual maximum temperature with trendline.

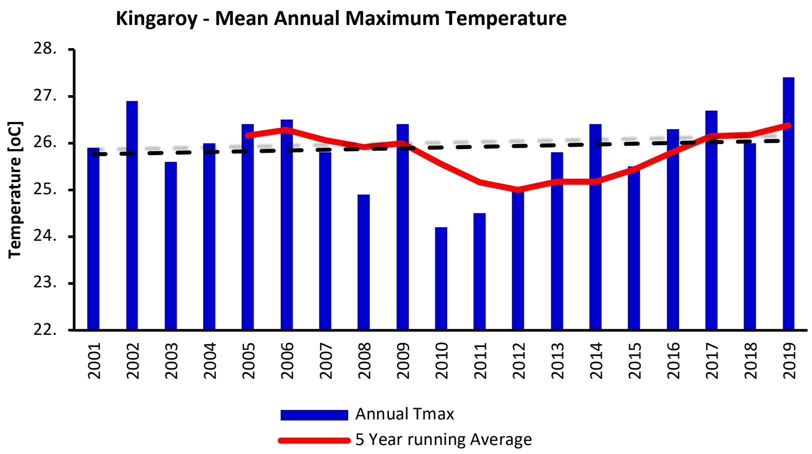


Figure 34: Kingaroy mean annual maximum temperature with trendline.

The annual mean minimum temperatures have increased above average for most parts of Australia (BoM, 2021) and were in the highest 10% of historical observations for much of Queensland. Annual mean minimum temperatures were amongst the ten warmest on record for Queensland, New South Wales, Western Australia, and the Northern Territory.

Mean minimum temperature relates to the lowest temperature averaged over a certain time period. The lowest temperature of a day usually occurs very early in the morning. The overall trend of all five station indicate that night temperatures have increased.

In Toowoomba, the mean annual minimum temperature increased by 0.5 ºC based on 22 years of data (Table 14,). In Oakey, the mean annual minimum temperature increased by 0.6 ºC based on 43 years of data (Table 14). In Dalby, the mean annual minimum temperature increased by 0.2 ºC based on 27 years of data (Table 14,). In Warwick, the mean annual minimum temperature increased by 0.5 ºC based on 21 years of data (Table 14). In Kingaroy, the mean annual minimum temperature increased by 0.3 ºC based on 19 years of data (Table 14).

The mean minimum temperature anomaly is the difference from the average temperature. A positive anomaly indicates the observed temperature was warmer than the baseline, while a negative anomaly indicates the observed temperature was cooler than the baseline. Figures 33 to 37 show that the minimum temperature is more often above the mean.

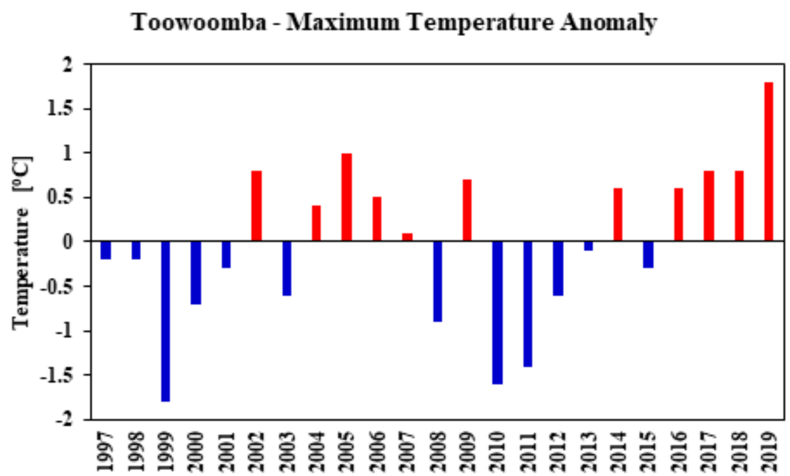


Figure 35: Toowoomba maximum temperature anomaly.

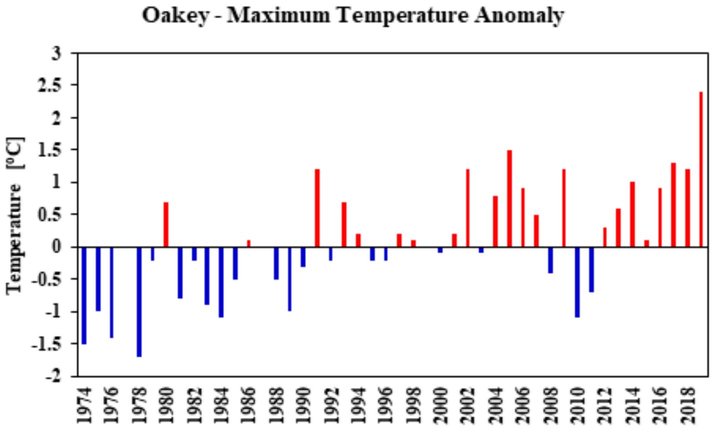


Figure 36: Oakey maximum temperature anomaly

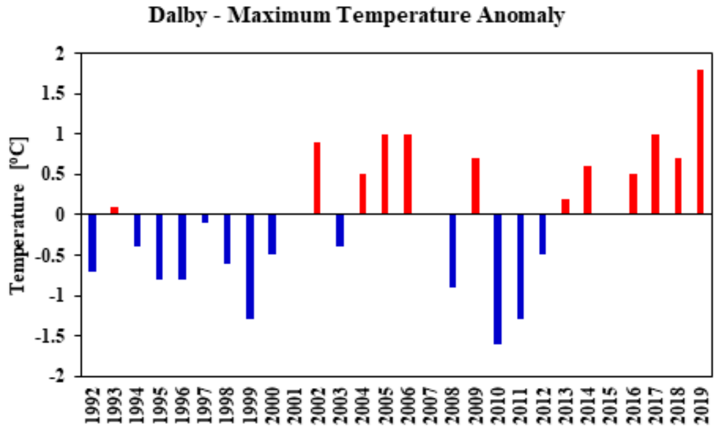


Figure 37: Dalby maximum temperature anomaly.

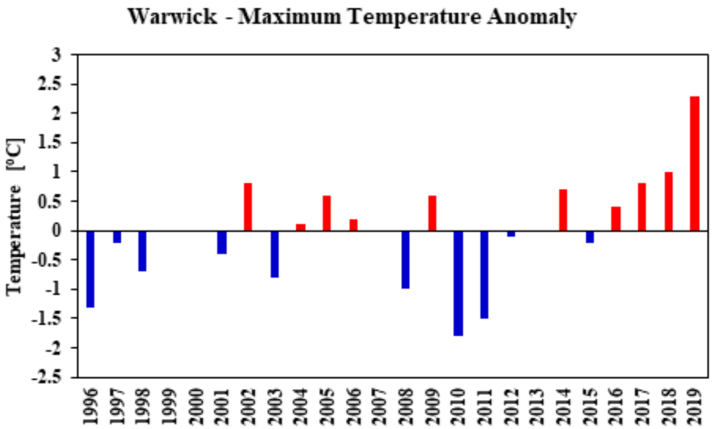


Figure 38: Warwick maximum temperature anomaly.

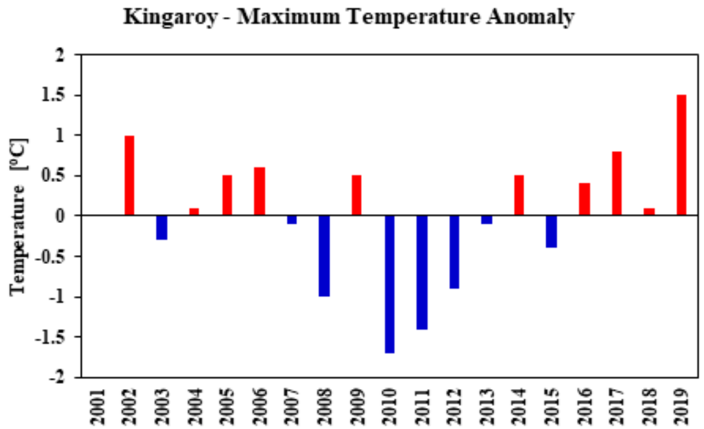


Figure 39: Kingaroy maximum temperature anomaly

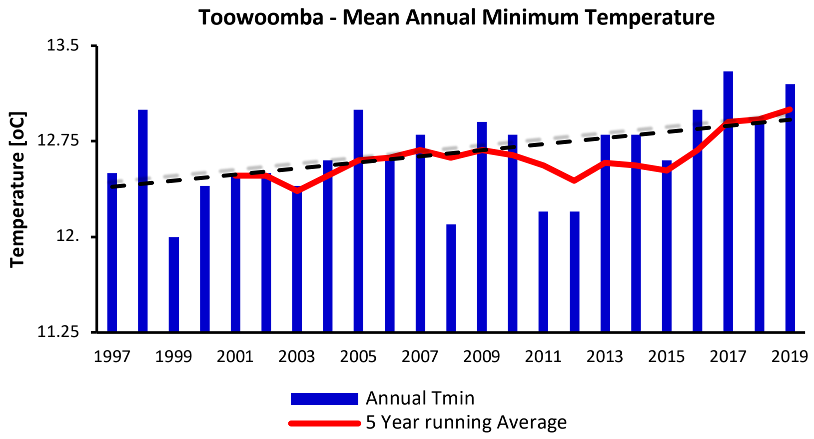


Figure 40: Toowoomba mean annual minimum temperature with trendline.

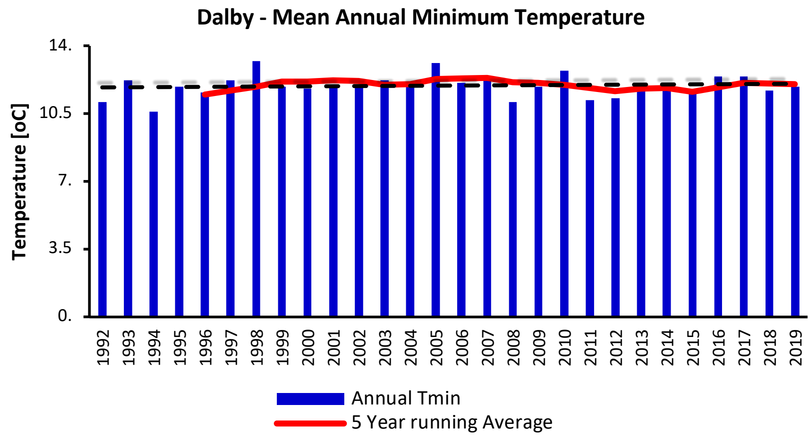


Figure 41: Dalby mean annual minimum temperature with trendline

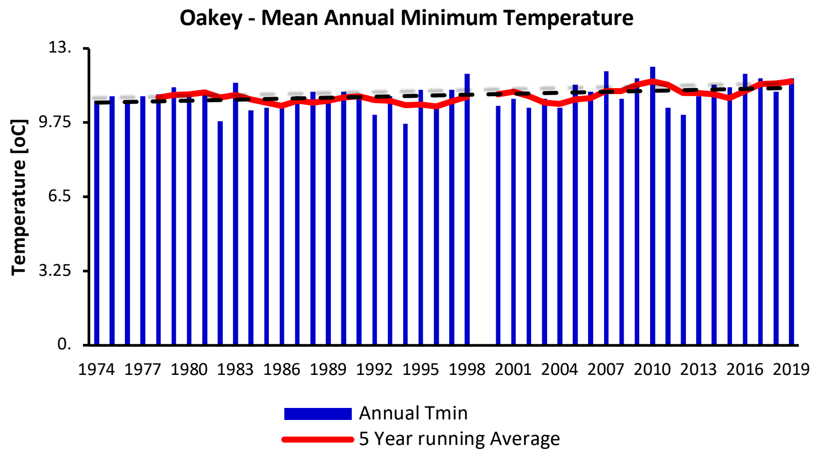


Figure 42: Oakey mean annual minimum temperature with trendline

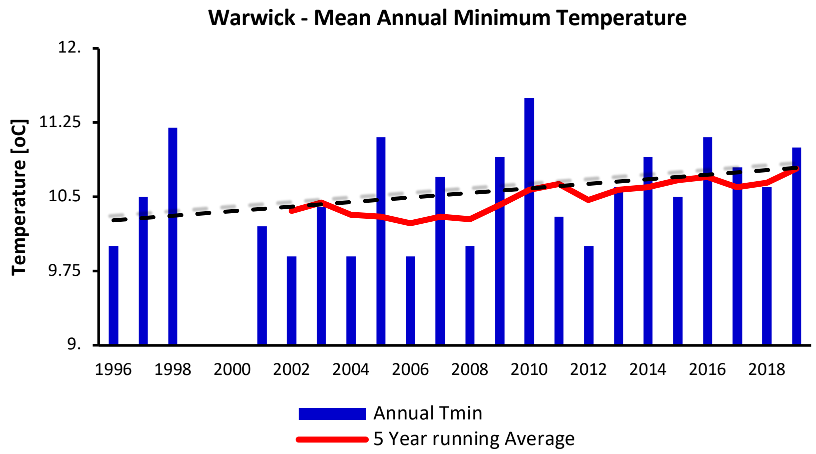


Figure 43: Warwick mean annual minimum temperature with trendline

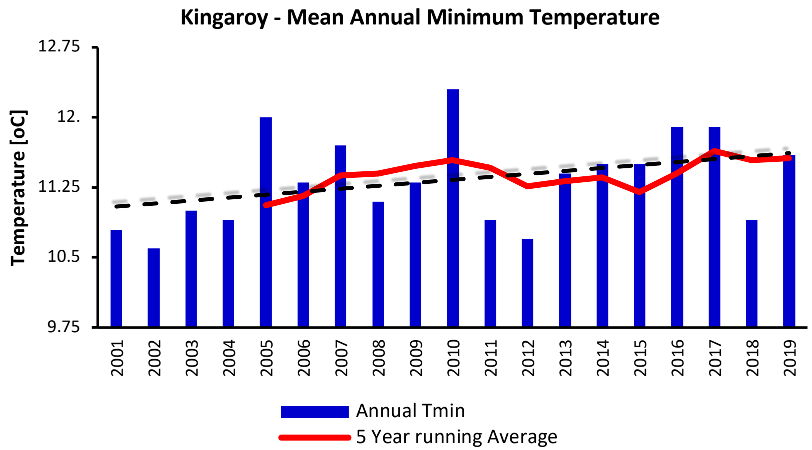


Figure 44: Kingaroy mean annual minimum temperature with trendline

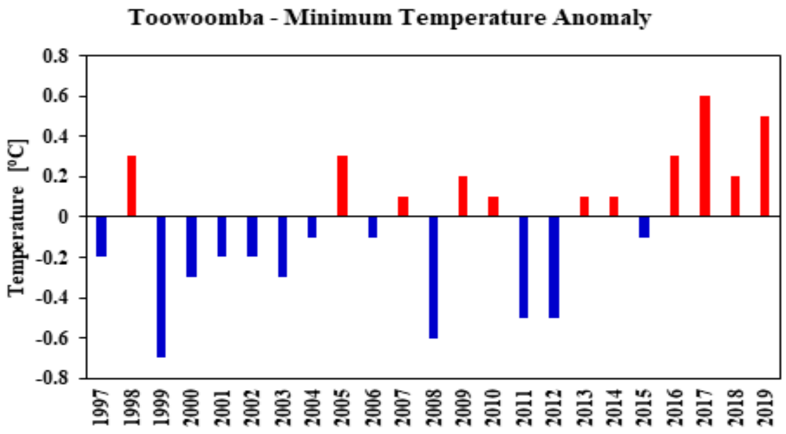


Figure 45: Toowoomba minimum temperature anomaly

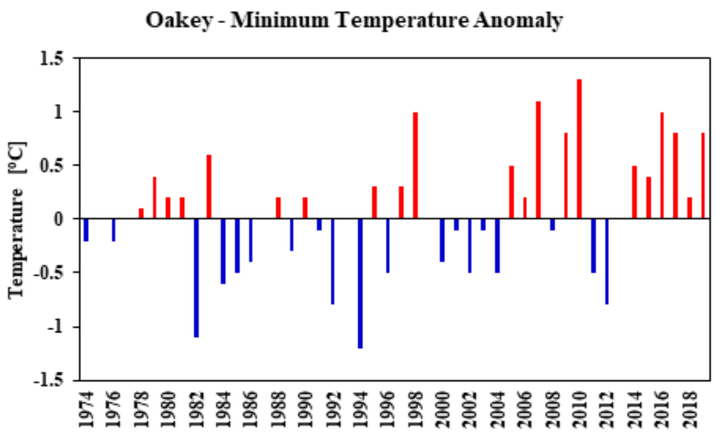


Figure 46: Oakey minimum temperature anomaly.

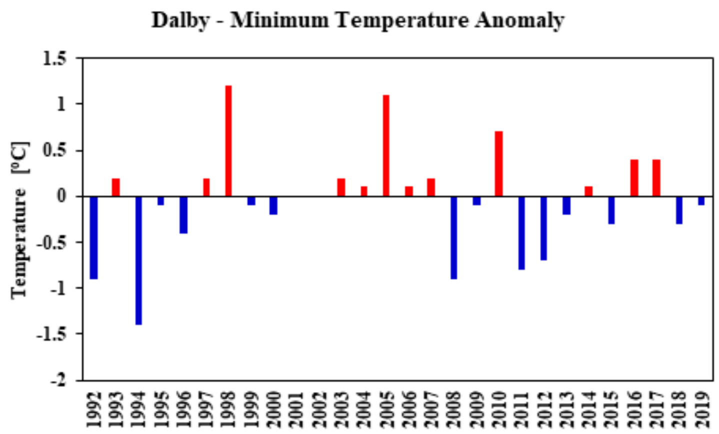


Figure 47: Dalby minimum temperature anomaly.

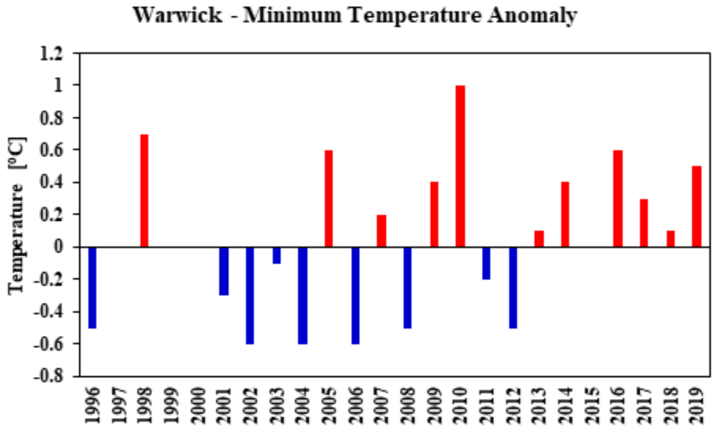


Figure 48: Warwick minimum temperature anomaly.

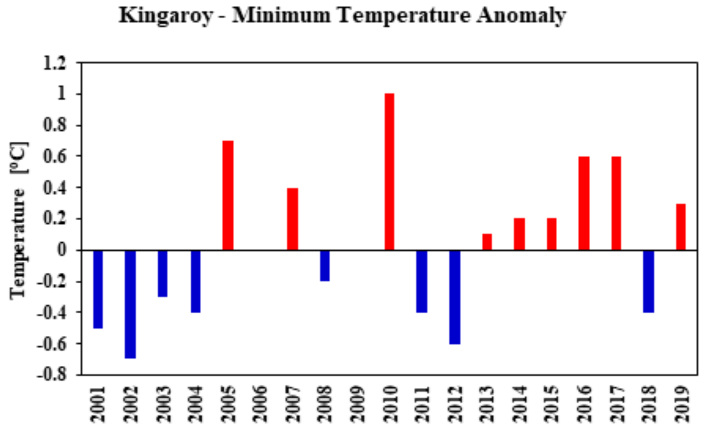


Figure 49: Kingaroy minimum temperature anomaly.

3.3.1.Wind

The direction and speed of wind at any given location is highly dependent on topography. Ridges and mountains are barriers to the horizontal movement of air. The wind is deflected over these 'obstacles' adding to the local up-slope convective winds generated by the surface heating by the sun.

The city of Toowoomba is located 698 m above sea level and within close proximity to the escarpment of the Great Dividing Range and experiences higher wind speeds than any other location used in this study. The dominant wind direction varies from location and season as shown in .

Table 15: Average wind speed recorded at 9am and 3pm during summer and winter month.

Weather Station	Average Wind Speed [km/h]			
	Summer		Winter	
	9am	3pm	9am	3pm
Toowoomba	23.1	22.7	19.6	21.5
Oakey	13.0	12.6	8.2	13.8
Dalby	16.2	17.9	9.2	17.5
Warwick	12.7	15.0	7.1	15.2
Kingaroy	14.6	15.7	10.4	15.6

Table 16.

The overall mean monthly wind speed, and at 9.00am and 3.00pm are shown in figures 52-55. It is interesting to note that wind speed in Toowoomba stays within the same range at 9.00am and 3.00pm throughout the year whereas Oakey, Dalby, Warwick and Kingaroy experience a lower wind speed at 9.00am during the autumn and winter months (Figure 67).

Table 15: Average wind speed recorded at 9am and 3pm during summer and winter month.

Weather Station	Average Wind Speed [km/h]			
	Summer		Winter	
	9am	3pm	9am	3pm
Toowoomba	23.1	22.7	19.6	21.5
Oakey	13.0	12.6	8.2	13.8
Dalby	16.2	17.9	9.2	17.5
Warwick	12.7	15.0	7.1	15.2
Kingaroy	14.6	15.7	10.4	15.6

Table 16: Dominant Wind Direction.

Weather Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Toowoomba	E	E	E	E	ESE	SSE	SW	WSW	NNE	E	ENE	E
Oakey	ENE	E	E	E	ESE	SSE	W	WSW	WNW	ENE	NE	ENE
Dalby	ENE	E	E	ESE	SE	SSE	SW	WSW	WNW	NE	N	NE
Warwick	E	SE	SE	SE	S	SSW	WSW	W	W	NNW	NNW	ENE
Kingaroy	E	ESE	ESE	SE	SSE	SSE	SSW	SW	WNW	ENE	NE	ENE

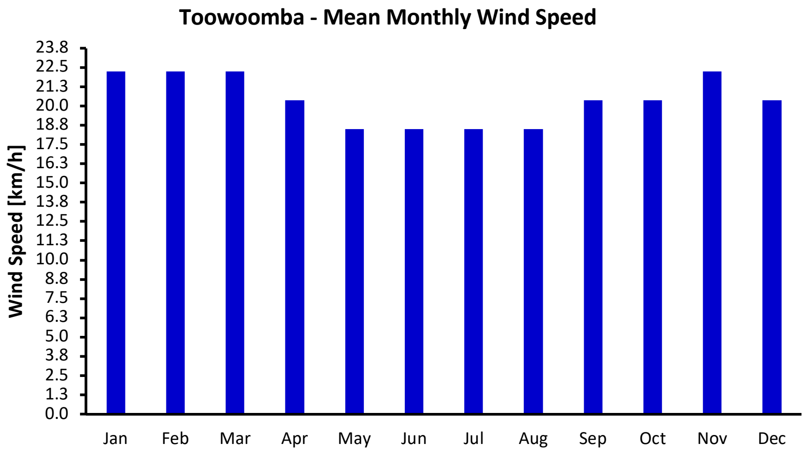


Figure 50: Toowoomba mean monthly wind speed

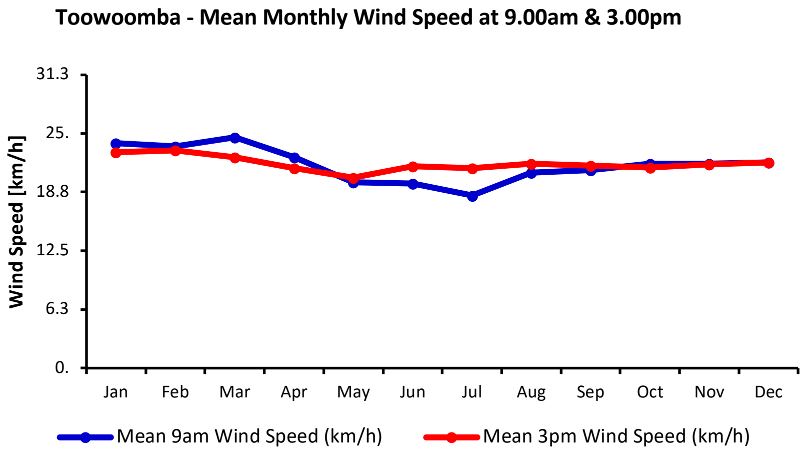


Figure 51: Toowoomba mean monthly wind speed at 9.00am and 3.00pm

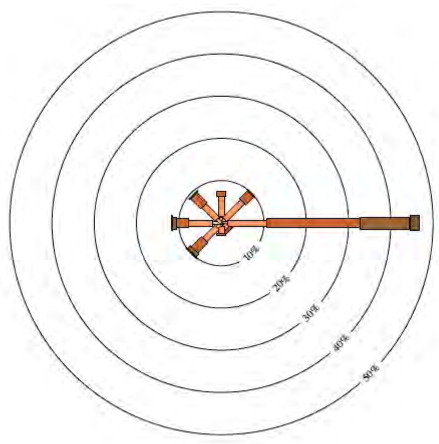


Figure 52: Toowoomba annual Wind Rose (wind direction and frequency) 9am. Source: Bureau of Meteorology Climate Statistics for Australian locations: Toowoomba.

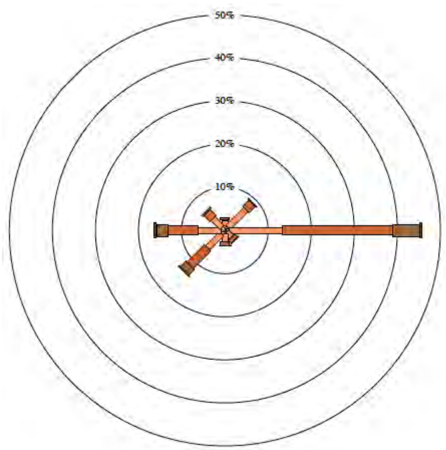


Figure 53: Toowoomba annual Wind Rose (wind direction and frequency) 3pm. Source: Bureau of Meteorology Climate Statistics for Australian locations: Toowoomba.

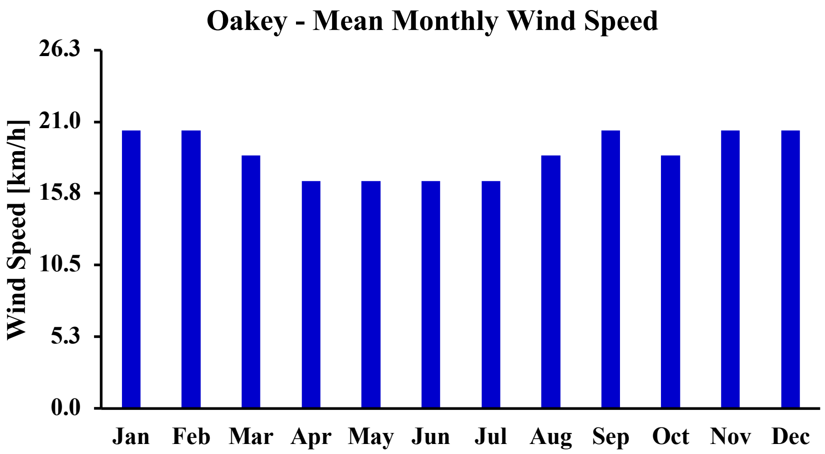


Figure 54: Oakey mean monthly wind speed

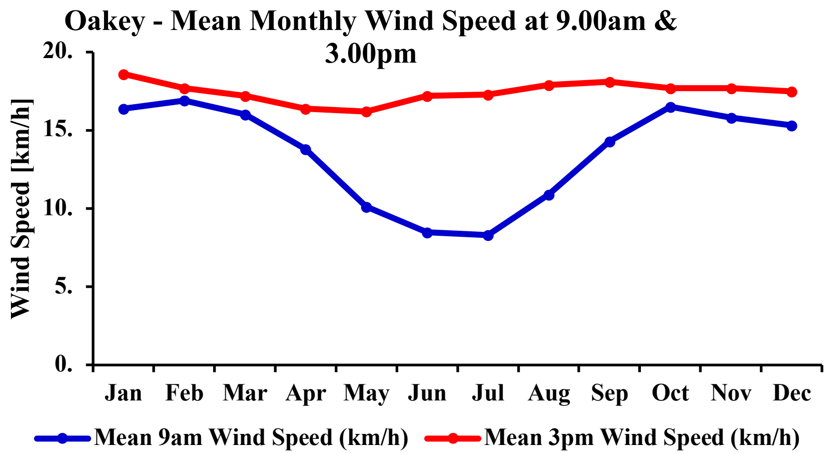


Figure 55: Oakey mean monthly wind speed at 9.00am and 3.00pm.

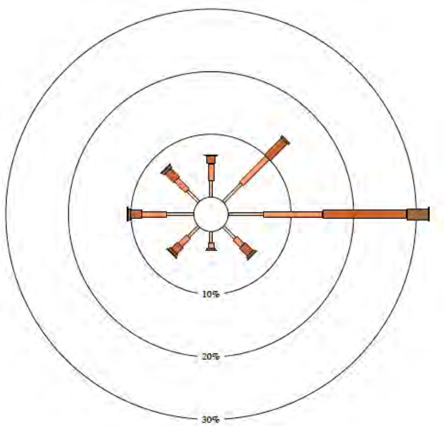


Figure 56: Oakey annual Wind Rose (wind direction and frequency) 9am. Source: Bureau of Meteorology Climate Statistics for Australian locations: Oakey

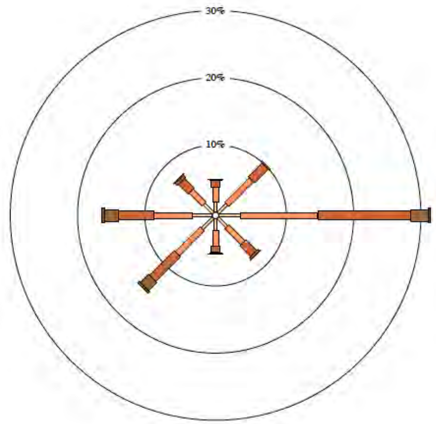


Figure 57: Oakey annual Wind Rose (wind direction and frequency) 3pm. Source: Bureau of Meteorology Climate Statistics for Australian locations: Oakey

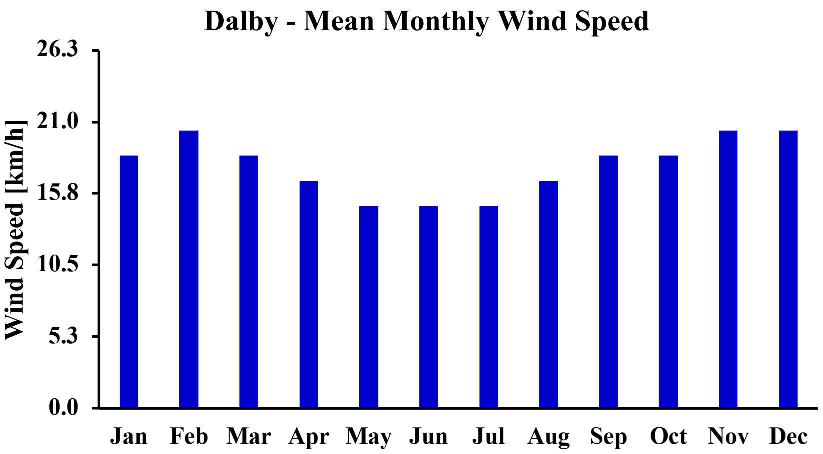


Figure 58: Dalby mean monthly wind speed

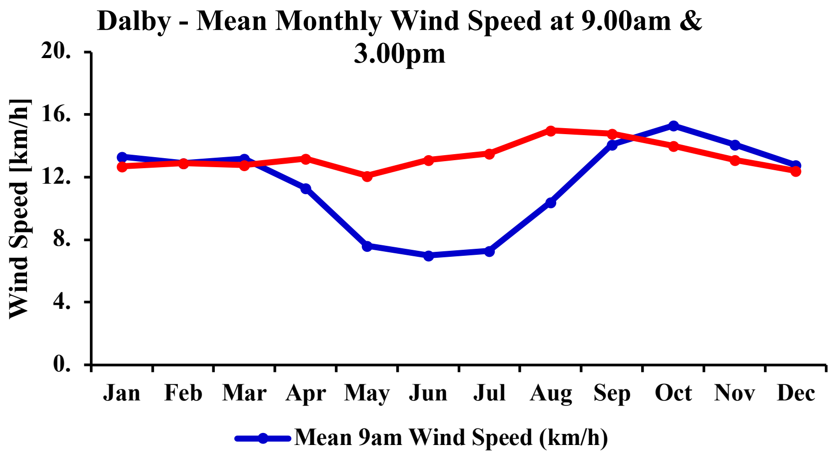


Figure 59: Dalby mean monthly wind speed at 9.00am and 3.00pm

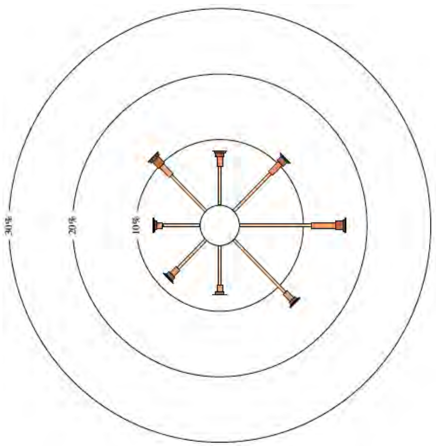


Figure 60: Dalby annual Wind Rose (wind direction) 9am. Source: Bureau of Meteorology Climate Statistics for Australian locations: Dalby.

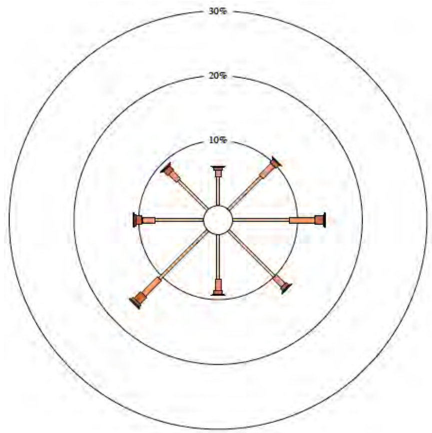


Figure 61: Dalby annual Wind Rose (wind direction) 3pm. Source: Bureau of Meteorology Climate Statistics for Australian locations: Dalby.

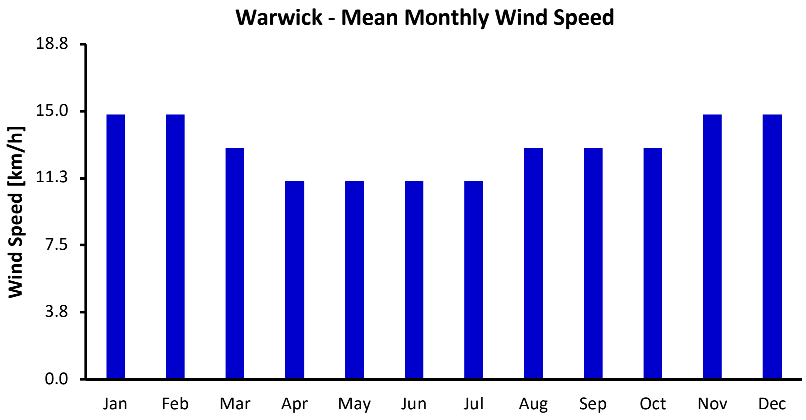


Figure 62: Warwick mean monthly wind speed.

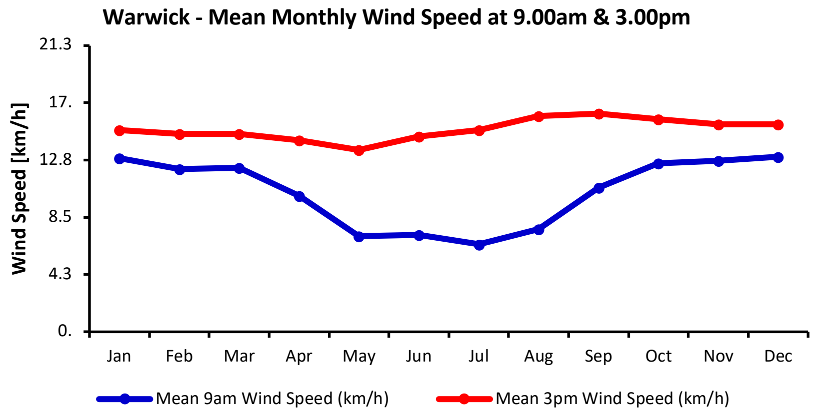


Figure 63: Warwick mean monthly wind speed at 9.00am and 3.00pm.

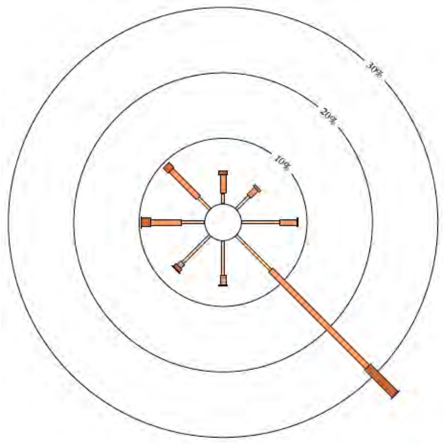


Figure 64: Warwick annual Wind Rose (wind direction) 9am. Source: Bureau of Meteorology Climate Statistics for Australian locations: Warwick.

Figure 65: Warwick annual Wind Rose (wind direction) 3pm. Source: Bureau of Meteorology Climate Statistics for Australian locations: Warwick.

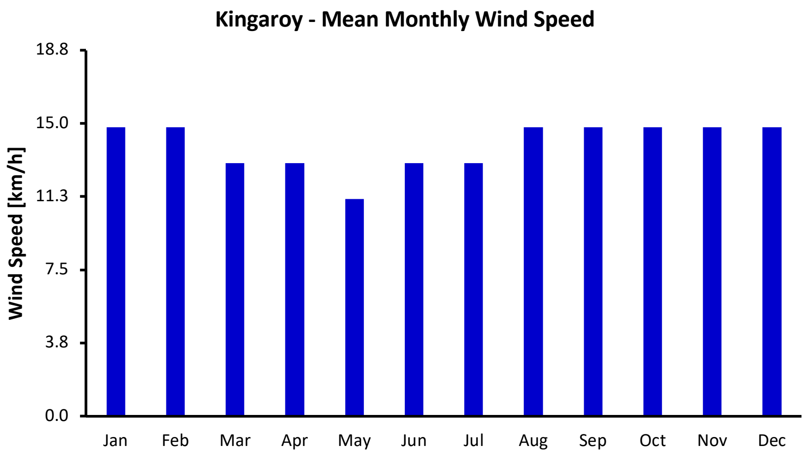


Figure 66: Kingaroy mean monthly wind speed

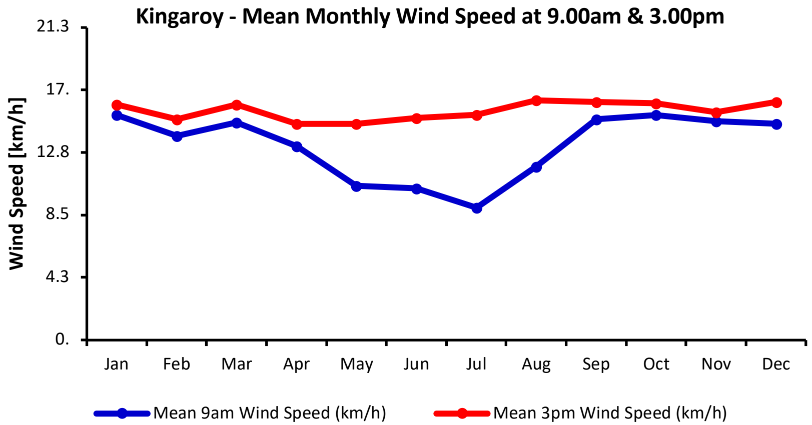


Figure 67: Kingaroy mean monthly wind speed at 9.00am and 3.00pm

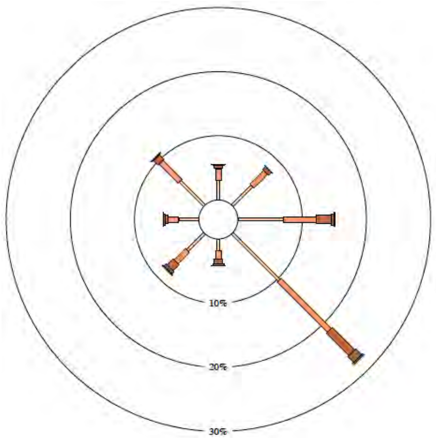


Figure 68: Kingaroy annual Wind Rose (wind direction) 9am Source: Bureau of Meteorology Climate Statistics for Australian locations: Kingaroy

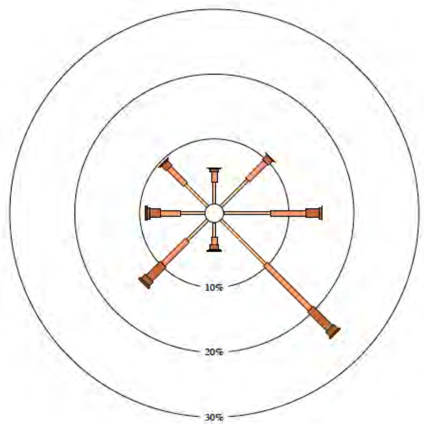


Figure 69: Kingaroy annual Wind Rose (wind direction) 3pm. Source: Bureau of Meteorology Climate Statistics for Australian locations: Kingaroy

3.3.2.Solar exposure

Global solar exposure is the total amount of solar energy falling on a horizontal surface. The daily global solar exposure is the total solar energy for a day. Typical values for daily global exposure range from 1 to 35 MJ/m^2 (megajoules per square metre). For mid-latitudes, the values are usually highest in clear sun conditions during the summer and lowest during winter or very cloudy days.

For all five locations, the highest mean daily solar exposure occurs during spring through to late summer months Figure 70 with a maximum mean monthly value of 25 MJ/m^2.

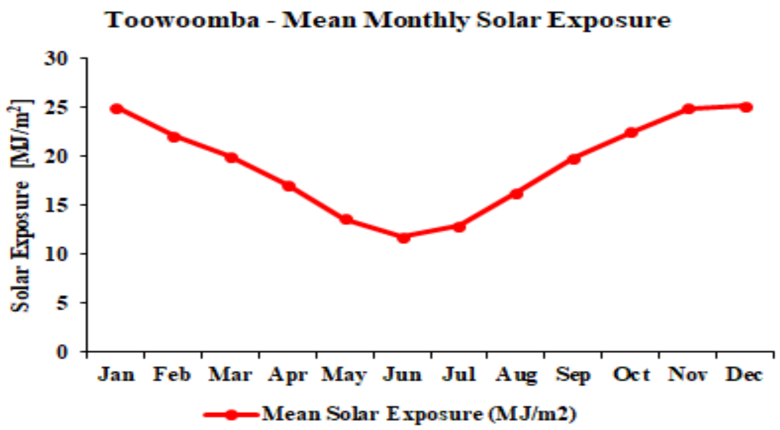


Figure 70: Toowoomba mean monthly solar exposure.

Table 17: Mean relative humidity during summer and winter recorded at 9am and 3pm.

Weather stations	Summer RH (%)		Winter RH (%)	
	9am	3pm	9am	3pm
Toowoomba	71	52	71	51
Oakey	67	46	75	44
Dalby	63	44	74	42
Warwick	63	47	73	44
Kingaroy	68	47	71	43

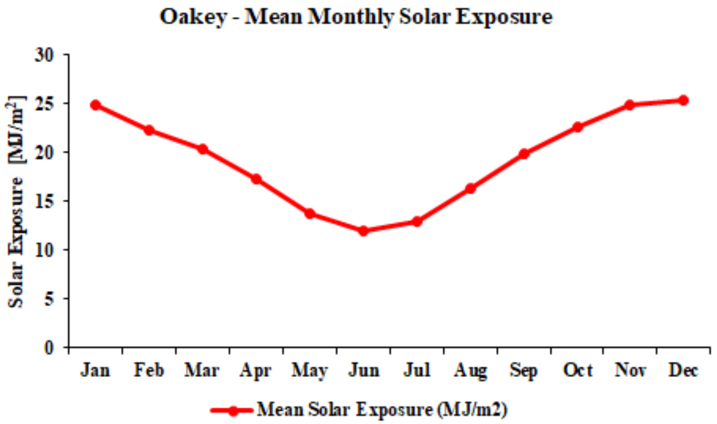


Figure 71: Oakey mean monthly solar exposure.

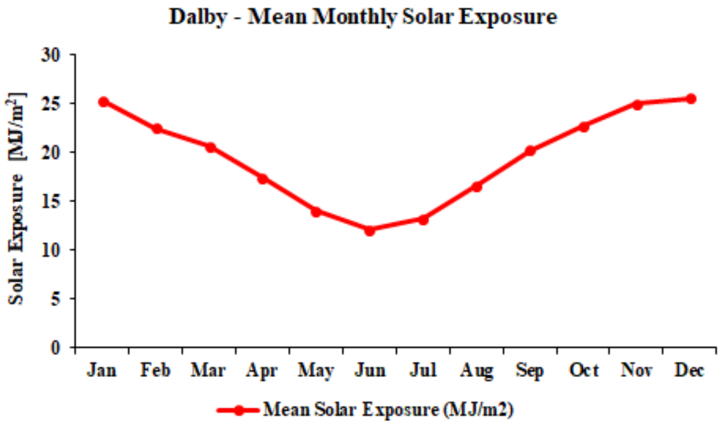


Figure 72: Dalby mean monthly solar exposure.

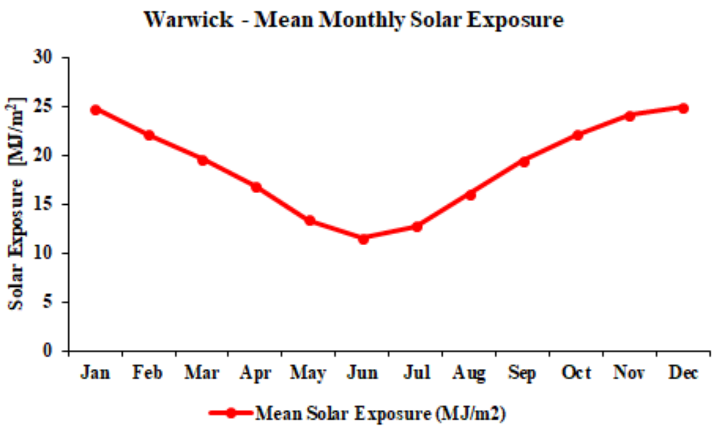


Figure 73: Warwick mean monthly solar exposure.

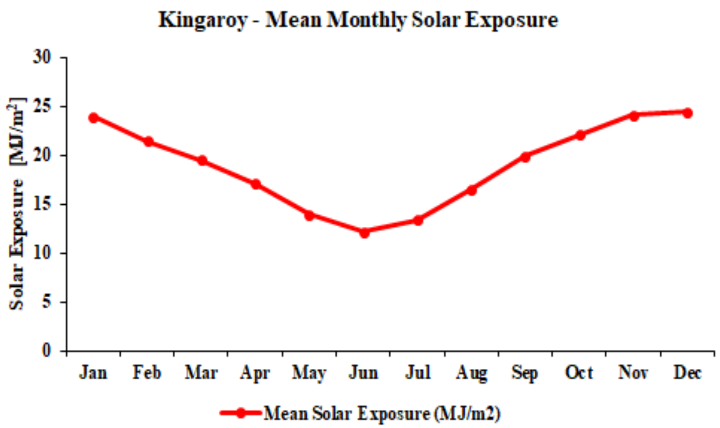


Figure 74: Kingaroy mean monthly solar exposure.

3.3.3. Humidity

Relative humidity (RH) is the amount of moisture in the air as a percentage of the amount the air can actually hold. Warmer air can hold more moisture than cooler air, which means that for a given amount of atmospheric moisture, RH will be lower when air is warm. This difference of RH is demonstrated when comparing the daily 9am data with the daily 3pm data for any month of the year.

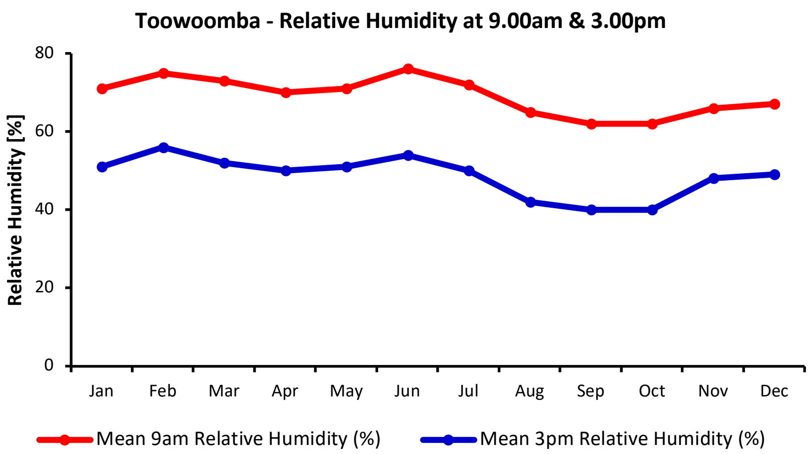


Figure 75. Toowoomba - Relative Humidity at 9.00am & 3.00pm.

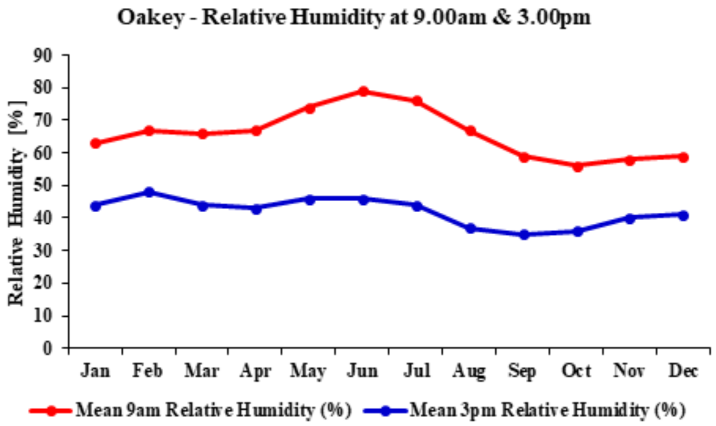


Figure 76: Oakey - Relative Humidity at 9.00am & 3.00pm

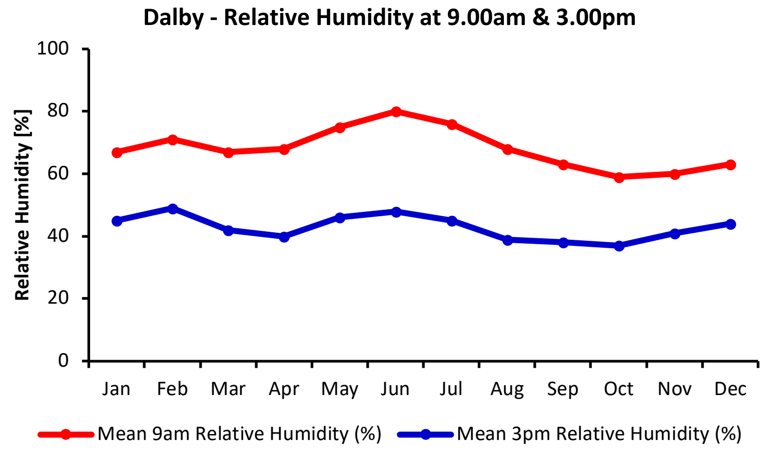


Figure 77: Dalby - Relative Humidity at 9.00am & 3.00pm

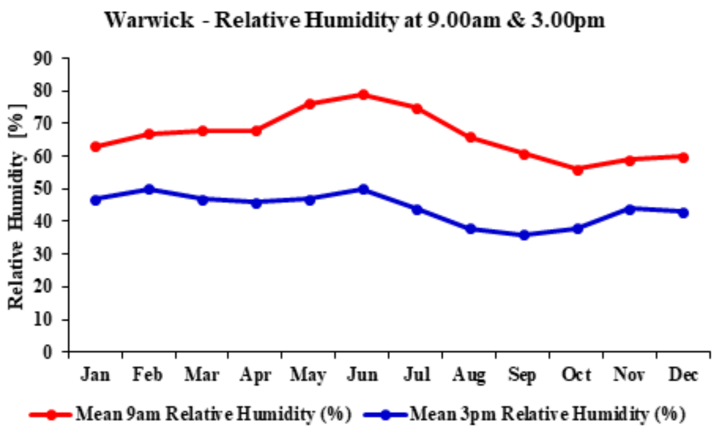


Figure 78: Warwick - Relative Humidity at 9.00am & 3.00pm

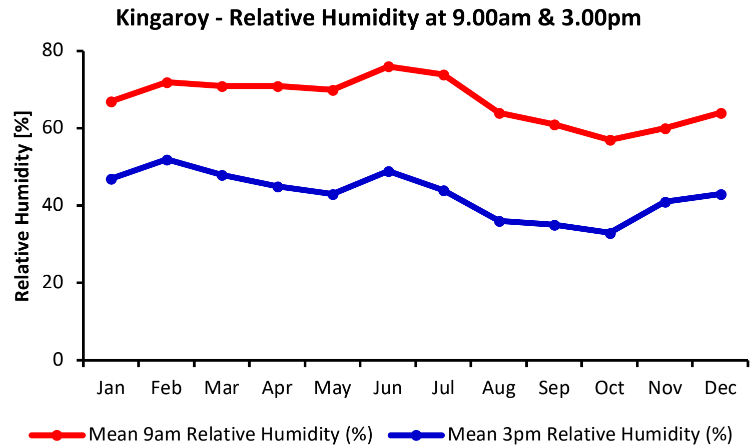


Figure 79: Kingaroy - Relative Humidity at 9.00am & 3.00pm

3.3.4.Atmospheric Pressure

The position of the Subtropical Ridge (STR) is the dominant influence on the climate in Australia. In summer, a belt of high pressure tends to sit over southern Australia, which is associated with dry weather and clear skies. Areas further north (such as the TRC area) are then under the influence of low-pressure systems which produce an increased chance of rainfall. During winter, the belt of high pressure moves further north bringing clear skies, cold nights and less rainfall. Figure 84 illustrate the pressure changes between seasons.

Weather Station	Average Atmospheric Pressure (kPa)
Toowoomba	100.59
Oakey	100.63
Dalby	100.60
Warwick	100.38
Kingaroy	100.58

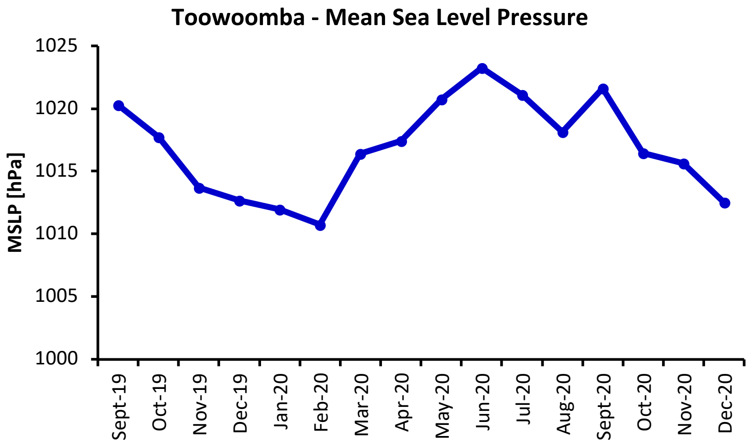


Figure 80: Toowoomba - Mean Sea Level Pressure

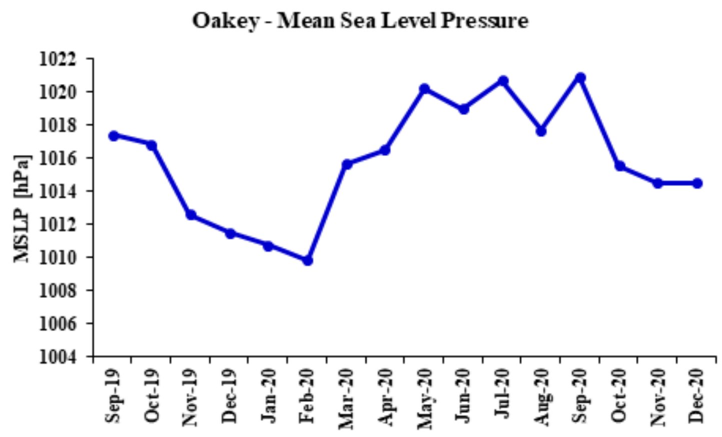


Figure 81: Oakey - Mean Sea Level Pressure

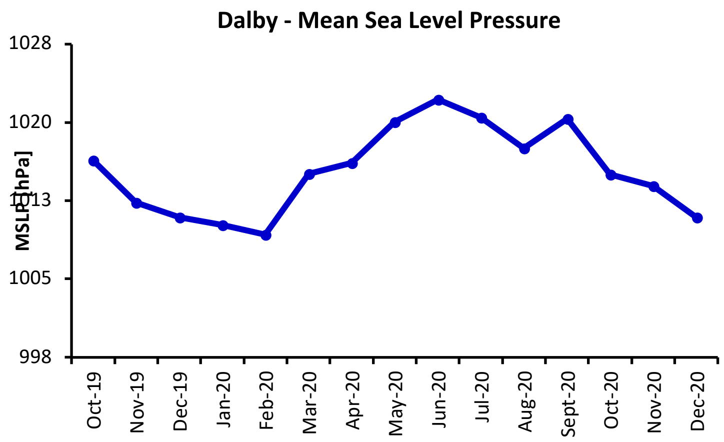


Figure 82: Dalby - Mean Sea Level Pressure.

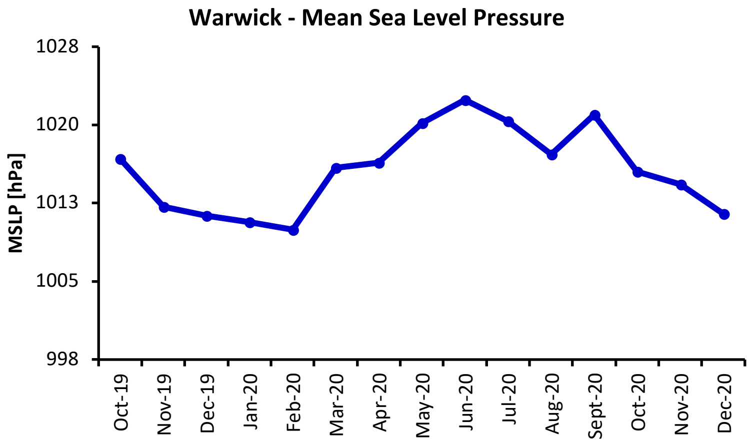


Figure 83: Warwick - Mean Sea Level Pressure.

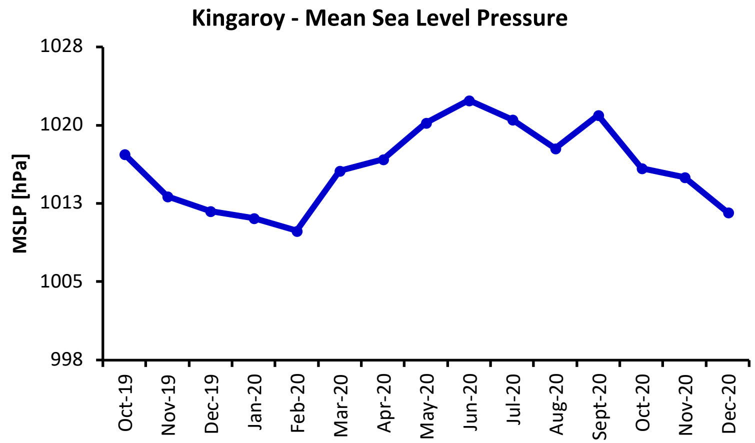


Figure 84: Kingaroy - Mean Sea Level Pressure.

3.3.5. Summary of Toowoomba Region Climate Parameters and Climate Definition

This section has established the climate characteristics that predominate in the Toowoomba Regional Council area based on temperature, wind, precipitation, solar radiation, humidity and atmospheric pressure.

Table 18 summarises the climatic characteristics that predominate.

Table 18: Summary of Toowoomba Region Warm Temperate Climate Parameters.

Parameter	Description
Annual Rainfall	Annual rainfall for all locations in the study averages 614mm - around half that received by Brisbane. Rain falls throughout the year, but winter is the driest season and summer is the wettest. The city of Toowoomba receives the highest annual rainfall in the region (698mm). Rainfall is declining across the region.
Mean maximum Temperature	Ranges from 28° - 32° across the region. Toowoomba's mean maxima, both summer and winter are the coolest in the region. Average daily temperatures are trending upwards.
Mean minimum Temperature	Ranges from 3.6 °- 7.2°C with Toowoomba's mean minimum being the warmest. Mean minimum overnight temperatures have increased over the past 30 years.
Mean Wind Speed	Toowoomba's average wind speed stays within the same range (around 21.7kmh) at 9.00am and 3.00pm throughout the year. Other locations experience lower wind velocities in autumn and winter months than in summer and spring. Wind direction changes from more easterly to more westerly during July, August and September bringing cold winds to contend with in winter.
Solar Exposure	For all five locations, the highest mean daily solar exposure occurs during spring through to late summer months with a maximum mean monthly value of 25 MJ/m2.
Mean Relative Humidity	RH at 9.00am and 3.00pm is quite uniform across the region. The diurnal cycle shows a gradual decrease in the RH from cooler mornings to the warm afternoons.
Mean Sea Level Pressure (MSLP)	MSLP is usually higher during winter (clear sky, cold nights) and lower during summer (increased chance of rainfall).

3.3.6. Toowoomba region climate definition using the Köppen-Geiger method

The climate of the Toowoomba Regional Council region was evaluated using the Köppen-Geiger Climate Classification System as described on page 11 of this report. The individual weather stations evaluated against the C-Temperate classification criteria are outlined in Table 19. The results from this study indicate that the TRC region falls within the CfA - climate category, where C = temperate, f = without dry season and a = hot summer. University of Melbourne produced a Köppen Geiger map that nominates the Highfields area as Cfb. When there is more data available from that area it should be investigated further to ascertain whether this area is a different climate and why this might the case.[84]

Table 19: Evaluation of study area climate data using Köppen-Geiger definition criteria (based on Beck et al. 2018).

Classification Criteria	Toowoomba	Oakey	Dalby	Warwick	Kingaroy
C – Temperate Thot >10 & 0 < Tcold <18	yes	yes	yes	yes	yes
s - Dry summer* Psdry < 40 & Psdry < Pwwet/3	no	no	no	no	no

[84] Peel, Finlayson, and McMahon, "Updated World Map of the Köppen–Geiger Climate Classification."

w - Dry winter* Pwdry < Pswet/10	no	no	no	no	no
f - without dry season No (Cs) or (Cw)	Cf	Cf	Cf	Cf	Cf
a - Hot summer* Thot ≥ 22	yes	yes	yes	yes	yes
b - Warm summer* Not (a) & Tmon 10 ≥ 4	no	no	no	no	no
Climate Zone	Cfa	Cfa	Cfa	Cfa	Cfa

Table 20. Legend.

Term	Description
Thot	the air temperature of the warmest month (°C)
Tcold	the air temperature of the coldest month (°C)
Psdry month-1	precipitation in the driest month in summer (mm)
Pwwet month-1	precipitation in the wettest month in winter (mm)
Pwdry month-1	precipitation in the driest month in winter (mm)
Pswet month-1	precipitation in the wettest month in summer (mm)
Tmon10	The number of months with air temperature >10°C

* Summer (winter) is the six-month period that is warmer (colder) between October-March and April-September.

3.4. Future climate in the Toowoomba Region

3.4.1. Climate Change Projections

Australia has seen an increase in temperature in response to a warming global climate. In 2020, both mean annual maximum and minimum temperatures have been above average for all states according to the Annual Climate Statement 2020[85]. Higher average daily temperatures may translate to more extreme heat days, longer heatwaves and more frequent fire danger days.

Queensland's climate is highly variable in space and time, ranging from tropical wet to arid in space and from extremely wet to extremely dry over time. Understanding how our future climate and variability is subject to changes is crucial for adaptation and preparedness.

The Intergovernmental Panel on Climate Change's Fifth Assessment Report (IPCC, 2014) reported that greenhouse gases, such as carbon dioxide, have a warming effect on global climate. Climate models are used to understand climate change and its likely impacts. Climate change projections provide the climate response to a set of greenhouse gas, aerosol and land-use scenarios. These scenarios are known as the Representative Concentration Pathways (RCPs). A Representative Concentration Pathway (RCP) is a greenhouse gas concentration (not emissions) trajectory adopted by the IPCC for its fifth Assessment Report (AR5)[86] in 2014. The four RCPs, namely RCP2.6, RCP4.5, RCP6, and RCP8.5, are labelled after a possible range of

[85] Australian Bureau of Meteorology, "Annual Australian Climate Statement 2020."

[86] IPCC, "Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (Eds.)]."

radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m2, respectively).

The Science Division from the Queensland Department of Environment and Sciences (DES) developed a comprehensive set of high-resolution climate change projections for Queensland. For this report the impact of future climate change of the five locations (Toowoomba, Oakey, Dalby, Warwick, Kingaroy) has been accessed from the Longpaddock Qld Future Climate dashboard.[87]

The results of future climate change projection are based on the following two scenarios:

- 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.
- RCP8.5 - a future with little curbing of emissions, with a CO2 concentration continuing to rapidly rise, reaching 940 ppm by 2100 – 'Business as usual' scenario.

3.4.2. Precipitation

High climate variability is likely to remain the major factor influencing precipitation changes in decades to come. Projections indicate that Toowoomba is expected to experience the highest decrease in precipitation based on RCP4.5 and RCP8.5 scenarios (Figure 94).

Table 21: Projected precipitation of five locations based on RCP4.5 and RCP8.5

Mean Precipitation change (mm)								
Location	RCP 4.5 - Annual				RCP 8.5 - Annual			
	2030	2050	2070	2090	2030	2050	2070	2090
Toowoomba	-47.5	-33.6	-54.8	-58.4	-23.7	-29.2	-40.2	-51.1
Oakey	-25.2	-13.1	-26.6	-36.5	-16.4	-19.0	-16.4	-12.8
Dalby	-17.5	0.6	-22.6	-26.3	-8.40	-13.5	-8.0	7.7
Warwick	-27.0	-9.1	-25.2	-33.2	-17.9	-11.0	-12.4	-17.9
Kingaroy	-9.9	-15.3	-27.0	-12.4	-16.1	-18.3	-7.7	-5.8

3.4.3. Temperature

Future projections indicate that the mean temperature is expected to increase based on RCP4.5 and RCP8.5 scenarios (Table 22, Figure 98 to Figure 101).

Table 22: Projected temperature change based on RCP4.5 and RCP8.5

Mean Temperature increase (°C)								
Location	**RCP 4.5 - Annual**				**RCP 8.5 - Annual**			
	2030	**2050**	**2070**	**2090**	**2030**	**2050**	**2070**	**2090**
Toowoomba	0.9	1.4	1.9	2.1	0.9	1.9	3.0	4.1
Oakey	1.0	1.4	1.9	2.1	1.0	1.9	3.0	4.2
Dalby	1.0	1.4	1.9	2.2	1.0	1.9	3.1	4.2
Warwick	1.0	1.4	1.9	2.1	1.0	1.9	3.0	4.2
Kingaroy	0.9	1.4	1.9	2.1	1.0	1.9	2.9	4.1

[87] Syktus et al., "Queensland Future Climate Dashboard: Downscaled CMIP5 Climate Projections for Queensland."

3.4.4.Relative Humidity

Based on the RCP 4.5 and RCP 8.5 scenarios, relative humidity is expected to decrease (Table 23, Figure 102 to Figure 105). This could be due to the decrease in precipitation and an increase in temperature.

Table 23: Projected relative humidity change based on RCP4.5 and RCP8.5

	Mean Relative Humidity change (%}							
Location	RCP 4.5 – Annual				RCP 8.5 - Annual			
	2030	2050	2070	2090	2030	2050	2070	2090
Toowoomba	-0.8	-0.9	-1.5	-1.6	-0.4	-1.2	-1.6	-1.9
Oakey	-0.7	-0.8	-1.5	-1.5	-0.5	-1.2	-1.7	-1.9
Dalby	-0.7	-0.8	-1.5	-1.6	-0.4	-1.3	-1.8	-2.0
Warwick	-0.8	-0.9	-1.5	-1.5	-0.5	-1.0	-1.6	-1.9
Kingaroy	-0.5	-0.8	-1.5	-1.3	-0.3	-1.2	-1.5	-1.8

3.4.5.Summary of climate change projections

The projections presented in Table 24 are given for 20-year periods centred on 2030, 2050, 2070 and 2090. They are represented as the change relative to the average for the period 1986–2005. RCP8.5 refers to the high emission rate scenarios or 'business as usual' scenario and RCP4.5 to the medium emission rate scenarios.

The modelling results indicate that annual mean precipitation will decrease at all five locations. Toowoomba will have the highest decrease in precipitation under both scenarios (RCP8.5 & RCP4.5). Annual mean temperature is estimated to increase under both scenarios equally across all locations. Annual mean relative humidity is estimated to decrease at all locations, which is due to the decrease in precipitation.

Table 24: Summary of Toowoomba Region Climate Change Projections under two scenarios.

Parameter	Location	RCP4.5				RCP8.5			
		2030	2050	2070	2090	2030	2050	2070	2090
Mean Precipitation	Toowoomba	-47.5	-33.6	-54.8	-58.4	-23.7	-29.2	-40.2	-51.1
	Oakey	-25.2	-13.1	-26.6	-36.5	-16.4	-19.0	-16.4	-12.8
	Dalby	-17.5	0.6	-22.6	-26.3	-8.40	-13.5	-8.0	7.7
	Warwick	-27.0	-9.1	-25.2	-33.2	-17.9	-11.0	-12.4	-17.9
	Kingaroy	-9.9	-15.3	-27.0	-12.4	-16.1	-18.3	-7.7	-5.8
Mean Temperature	Toowoomba	0.9	1.4	1.9	2.1	0.9	1.9	3.0	4.1
	Oakey	1.0	1.4	1.9	2.1	1.0	1.9	3.0	4.2
	Dalby	1.0	1.4	1.9	2.2	1.0	1.9	3.1	4.2
	Warwick	1.0	1.4	1.9	2.1	1.0	1.9	3.0	4.2
	Kingaroy	0.9	1.4	1.9	2.1	1.0	1.9	2.9	4.1
Mean Relative Humidity	Toowoomba	-0.8	-0.9	-1.5	-1.6	-0.4	-1.2	-1.6	--1.9
	Oakey	-0.7	-0.8	-1.5	-1.5	-0.5	-1.2	-1.7	-1.9
	Dalby	-0.7	-0.8	-1.5	-1.6	-0.4	-1.3	-1.8	-2.0
	Warwick	-0.8	-0.9	-1.5	-1.5	-0.5	-1.0	-1.6	-1.9
	Kingaroy	-0.5	-0.8	-1.5	-1.3	-0.3	-1.2	-1.5	-1.8

4. TOOWOOMBA REGION'S CLIMATE

4.1. Predominant climate characteristics

Data analysis has determined that the local climate correlates with the criteria for Köppen-Geiger classification Cfa - without dry season (hot summer). Globally, this climate subtype is found between 20° and 35°N and S latitude on the eastern sides of continents and is characterised by relatively high temperatures and relatively evenly distributed precipitation throughout the year. The warmest months generally average about 27°C with mean daily maxima from 30°C - 38°C, and nights can feel warm and oppressive. "In summer these regions are largely under the influence of moist maritime airflow from the western side of the subtropical anticyclonic cells over low-latitude ocean waters."[88]

This finding indicates that the Toowoomba Region and the adjacent coastal plain share similar macro-climatic temperature and precipitation conditions. Summers are warm to hot, humidity is high, and winters are mild. However, Toowoomba has less rainfall and is cooler than Brisbane in both winter and summer. Brisbane may often feel hotter because higher average humidity is coupled with lower windspeed at 3.00pm. Toowoomba has fewer clear sunny days than Brisbane, but nearby Dalby has more.

The transect across the TRC Area from near Dalby to the coastal plain of South East Queensland shown in figure 87 and in table 25 below is illustrative of the differences between the conditions experienced in the main centres, Toowoomba and Brisbane. The most noticeable differences are the level of rainfall, mean annual minimum winter temperatures and average number of days that are less than or equal to 2°C, and humidity at 3.00pm.

[88] Britannica, "Humid Subtropical Climate."

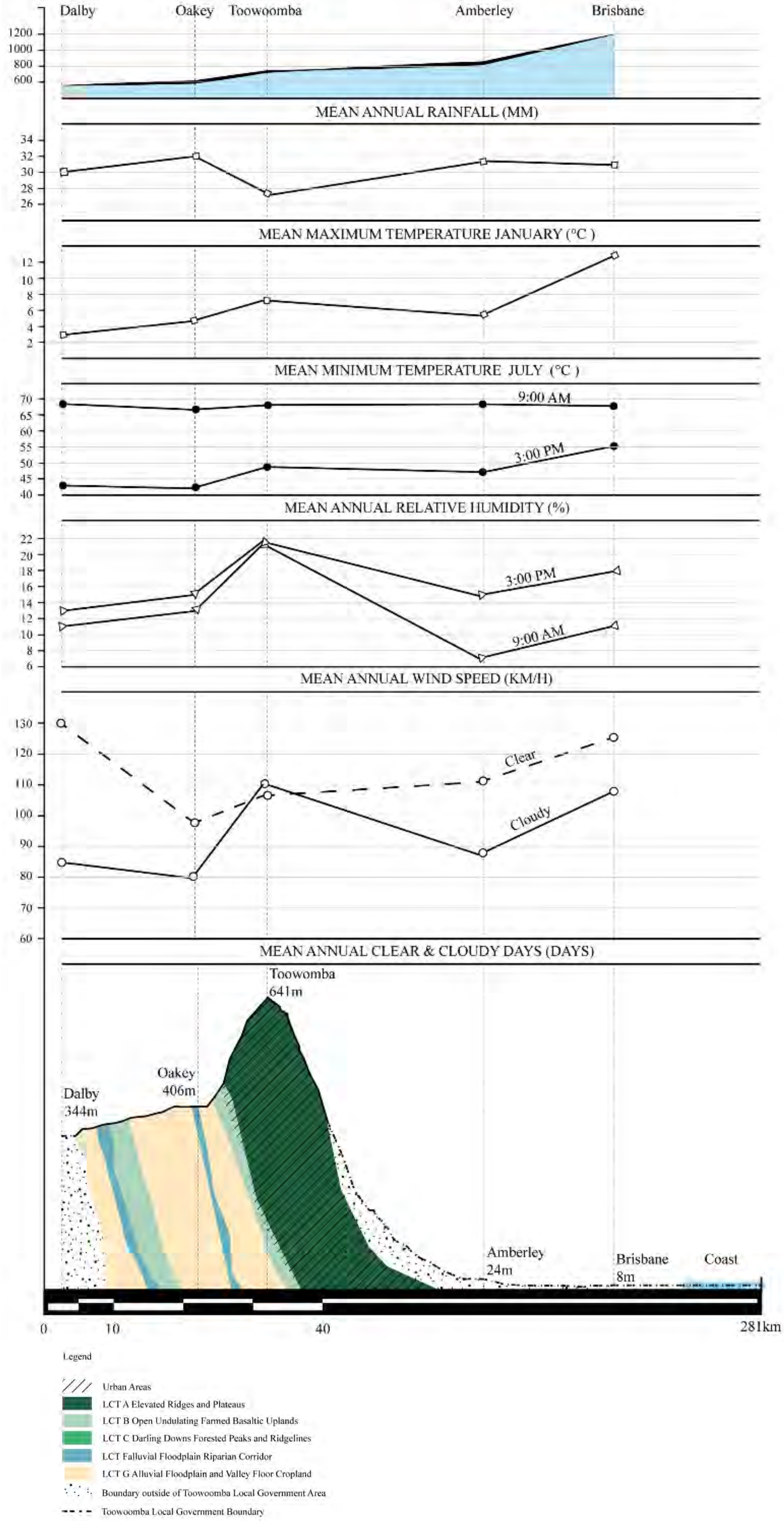


Figure 85. West to East Transect.

Table 25. East-West Transect table.

Parameter	Description				
Weather Station	Dalby Airport	Oakey Aerodrome	Toowoomba Airport	Amberley*	Brisbane Airport*
Elevation- metres above sea level	344	406	641	24	5
Distance from Toowoomba (km)	82.3	28	_	87.9	125
Landscape Character	** Alluvial Floodplain and Valley Floor Cropland (LCT G)	** Open Undulating Farmed Basaltic Uplands (LCT B)	** Elevated Ridges and Plateaux (LCT A)	Foothills (Reference heights for townships in the foothills, Helidon 143m, Gatton 94m)	Coastal Plain
Typical landscape character	**	**	**		
Mean Annual Rainfall (mm)	584	611	698	853	1021.5
Mean Annual Number of Days of Rain^	71.0	78.9	106.2	102.7	116.1
Mean Maximum Temperature Summer (January) C	30.5	32.0	27.9	31.2	30.5
Mean Annual Number of Days >or=30C ^	120.4	77.1	37.4	96.0	31.2
Mean Annual Number of Days =or > 35C ^	26.7	12.2	4.6	13.5	1.0
Mean Minimum Temperature Winter (July) C	3.6	4.7	7.2	5.4	10.4
Mean Annual Number of Days <or= 2C ^	34.3	43.9	5.3	18.4	0.2
Mean Annual Number of Days <or=0C ^	19.0	25.6	1.1	6.9	0
Mean 9.00am Annual Relative Humidity (%)	68	66	67	68	66
Mean 9.00am Annual Wind Speed (Km/h)	11.6	13.6	21.7	7.2	11.2
Mean 3.00pm Annual Relative Humidity (%)	43	42	49	46	55
Mean 3.00pm Annual Wind Speed (Km/h)	13.3	17.5	21.8	14.8	18.5
Mean Number of Clear Days^	129.5	96.7	107.2	110.3	124.3
Mean Number of Cloudy Days^	84.6	68.5	109.7	99.1	109.8
Mean daily sunshine hours					8.2

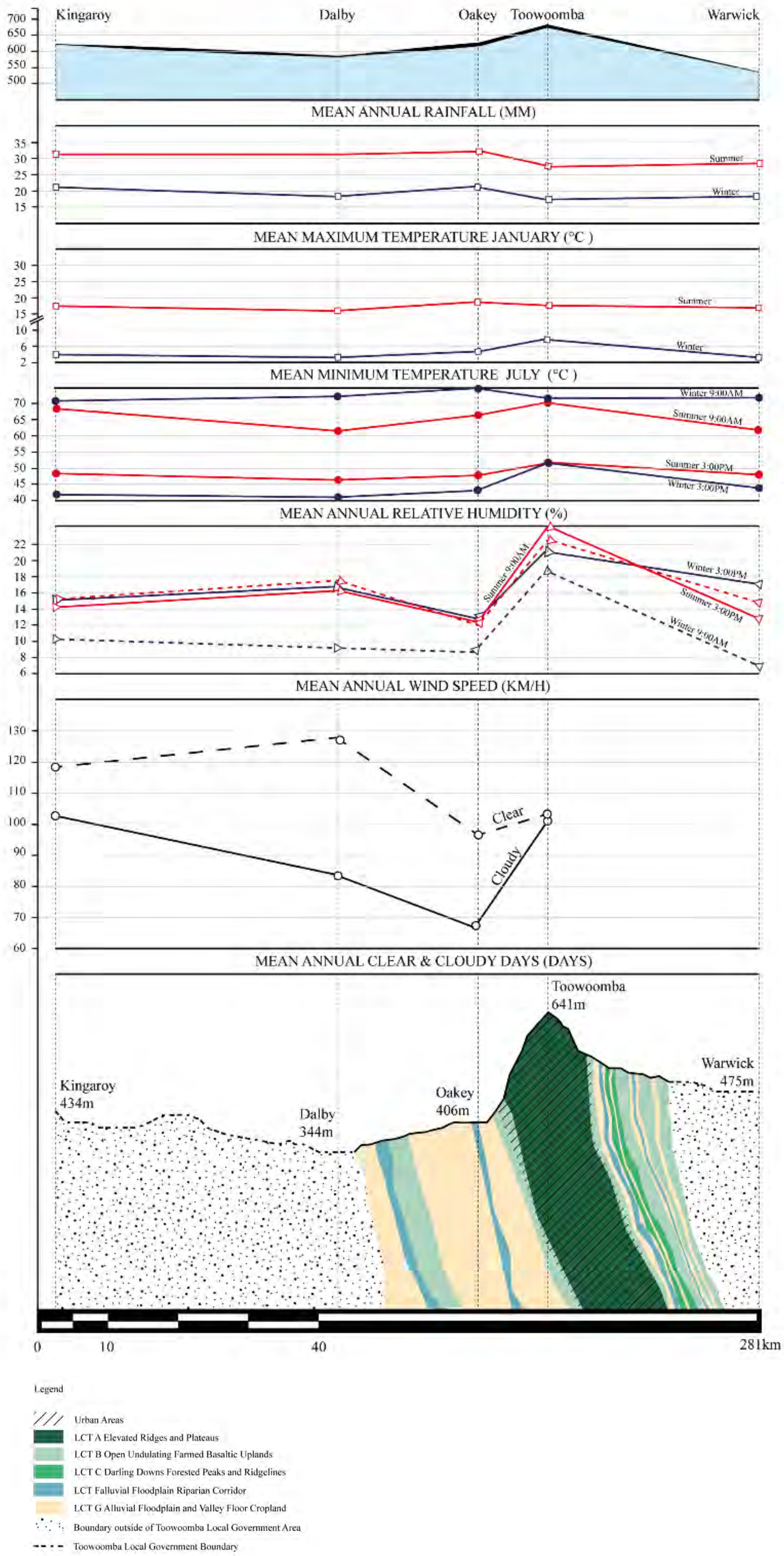


Figure 86: North to West Transect.

Table 26.

Parameter	Description				
Weather Station	Kingaroy Airport	Dalby Airport	Oakey Aerodrome	Toowoomba Airport	Warwick
Elevation- metres above sea level	434	344	406	641	475
Distance from Toowoomba (km)	155	82.3	28	_	73
Landscape Character	* Dryland production	** Alluvial Floodplain and Valley Floor Cropland (LCT G)	** Open Undulating Farmed Basaltic Uplands (LCT B)	** Elevated Ridges and Plateaux (LCT A)	* Dryland production, Low level production and undulating uplands
Typical landscape character		**	**	**	
Mean Annual Rainfall (mm)	631	584	611	698	545
Mean Annual Number of Days of Rain^	82.8	71.0	78.9	106.2	102.5
Mean Maximum Temperature Summer C	30.5	30.5	32.0	27.9	29.9
Mean Minimum Temperature Summer C	17.5	15.6	18.3	17.3	16.7
Mean Annual Number of Days >or=30C ^	60.5	120.4	77.1	37.4	68.5
Mean Annual Number of Days =or > 35C ^	5.0	26.7	12.2	4.6	12.0
Mean Maximum Temperature Winter C	20.4	19.4	20.6	17.5	18.9
Mean Minimum Temperature Winter C	4.5	3.6	4.7	7.2	3.8
Mean Annual Number of Days <or= 2C ^	31.6	34.3	43.9	5.3	45.3
Mean Annual Number of Days <or=0C ^	14.5	19.0	25.6	1.1	26.8
Mean 9.00am Summer Relative Humidity (%)	68	63	67	71	63
Mean 9.00am Summer Wind Speed (Km/h)	14.6	16.2	13.0	23.1	12.7
Mean 3.00pm Summer Relative Humidity (%)	47	44	46	52	47
Mean 3.00pm Summer Wind Speed (Km/h)	15.7	17.9	12.6	22.7	15.0
Mean 9.00am Winter Relative Humidity (%)	71	74	75	71	73
Mean 9.00am Winter Wind Speed (Km/h)	10.4	9.2	8.2	19.6	7.1
Mean 3.00pm Winter Relative Humidity (%)	43	42	44	51	44
Mean 3.00pm Winter Wind Speed (Km/h)	15.6	17.5	13.8	21.5	15.2
Mean Annual Number of Clear Days^	n/a Years 2001-2021 118.5 (Years 1957-2001)	129.5 (Years 1992-2010)	96.7 (Yrs 1973 - 2010)	107.2 (Yrs 1997-2010)	n/a
Mean Annual Number of Cloudy Days^	n/a Years 2001-2021 103.1 Years 1957-2001	84.6 (Years 1992-2010)	68.5 (Years 1973 - 2010)	109.7 (Yrs 1997-2010)	n/a
Annual Mean Daily Sunshine (hours) ^	n/a	n/a	n/a	n/a	7.7

Toowoomba is cooler, wetter, has more days of rain annually, fewer days 30°C or over, and fewer days with overnight temperatures below 2°C, than the surrounding region. It rarely experiences extreme heat (5.4 days annually are 35°C or over) and on average it only dips below freezing 1.1 day annually. Toowoomba's average wind speed at 9.00am and 3.00pm is faster than the other localities and it experiences fairly frequent high winds.

Because of its altitude and position on the edge of the Great Dividing Range escarpment, Toowoomba also experiences thick fogs that form because of either radiation or advection, though data on the number of fog days per annum is not available. According to the BOM fact sheet on fog as a hazard to aviation (2013), the incidence of fog at some places along the Great Dividing Range can be up to 40 fogs per annum, with some persisting for at least two days.

When there is a fog in Toowoomba, it often travels to the west, but because Oakey is lower, it is more likely to be experienced as low cloud rather than fog.[89] The data for Oakey indicates that it has double the number of hot days as Toowoomba and its average summer maximum temperature is 4°C hotter. It has more than eight times as many days when the minimum temperature is 2°C or below and it reaches freezing or below on just over 25 days annually. The average annual rainfall is about 87% that of Toowoomba's.

Only 56 km to the north west of Oakey and less than 10 km beyond the TRC Area boundary, Dalby in the Western Downs region is drier and hotter than Oakey. It has 114 mm less rainfall and 83 more hot days annually than Toowoomba. It has six times as many days of extreme heat (≥35°C) as Toowoomba. It also has the lowest mean winter minimum temperature and more days when the sky is clear.

Kingaroy, 155 km north of Toowoomba in the South Burnett region, receives slightly lower average annual rainfall than Toowoomba. The mean summer maximum temperature is higher but the mean summer minimum is similar. While it has a similar number of extremely hot days as Toowoomba, it reaches 30°C and above for about two months of the year, while Toowoomba experiences temperatures ≥30°C for about 37.4 days on average. Kingaroy's mean minimum temperature is colder than Toowoomba's in winter and there are about 14 more days when the minimum is 0°C or below. However, it has warmer winter days than Toowoomba with its mean maximum winter temperature reaching 20.5°C compared to Toowoomba's 17.5°C. Overall, the Kingaroy district is warmer than the TRC area.

Meanwhile Warwick, only 73 kms south of Toowoomba, in the Southern Downs is cooler and drier. It receives the least rainfall (about 150 mm less than Toowoomba but over a similar number of rainy days). Its winter mean temperatures are somewhat like what is seen in Dalby but it has half the number of hot days as Dalby does.

The data gathered from weather stations at these northerly and southern locations provide some indication of the range of the macro-climatic conditions experienced at nominated population centres in the Toowoomba Regional Council area. Therefore, a more nuanced approach to responding to local macro-and micro-climates through all scales of

[89] Backhouse, "What's Special about Fog in Toowoomba."

urban development from the regional, to the neighbourhood and individual lot is needed in response.

4.2. Toowoomba Region's future climate projections and expected implications

The foregoing analysis of the Toowoomba Region's past climate data has illustrated a climate where variability is the norm. Investigation of two potential future scenarios (business as usual, and medium emissions reductions) to identify climate trends in order to identify climate change impacts showed that climate variability is likely to continue to be a major influence in the Toowoomba region regardless of how soon and how far policy, regulation, technological and societal change take effect on influencing climate change. The lag between any emissions reductions from now on, and the expected benefits becoming noticeable, will take at least two decades. People will continue to need to manage risks associated with higher emissions for decades to come.

This report attempts to address the significance of these climate trends locally in order to identify climate change impacts at a high and general level relating to built form that should be considered in future planning to ensure buildings and public spaces provide for people's well-being and safety.

4.2.1. Decreased rainfall, increased temperature, heat waves and vegetation

The modelling shows that the Toowoomba urban area is predicted to experience the greatest decrease in its annual rainfall. In concert with this decreased rainfall, which can lead to longer and more severe droughts, the predicted increases in mean temperatures are likely to lead to more intense and longer-lasting heatwaves. Table 27 below shows the projected number of days when outside air temperatures which significantly exceed comfort can be expected in the Toowoomba Region, and in neighbouring LGA's.

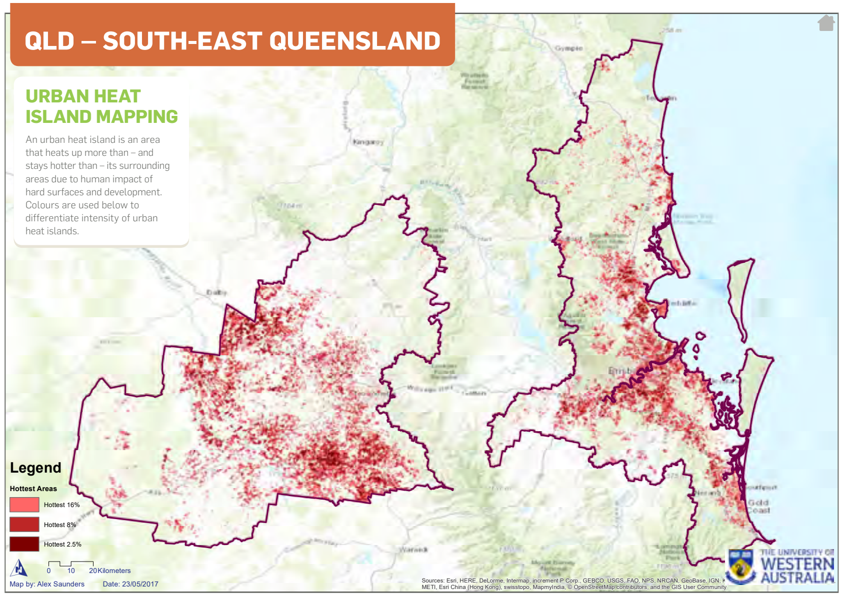
Table 27: Projected changes in heatwave frequency by Local Government Area,1998-2090)

Historical Annual Heatwave Count (days)			Projected Maximum Annual Heatwave Count (days) relative to 1986-2005 Baseline			
LGA	**1998-2008**	**2008-2018**	**2030**	**2050**	**2070**	**2090**
Toowoomba Regional	25	26	10	28	54	89
South Burnett Regional	21	21	10	28	55	92
Southern Downs Regional	20	23	10	28	58	92
Lockyer Valley Regional	20	22	10	28	58	93
Ipswich City	20	22	10	29	59	94
Logan City	21	24	17	43	81	116
Brisbane City	23	29	22	52	93	125

"Heatwaves have marked effects on human health and on regional eco-systems - thus they directly affect regional economies. The effects of heat on people, including uncomfortable nights, could be exacerbated by urban layouts and inadequate building design and construction. Demand for electricity soars during heatwaves, and power outages are not uncommon due to demand, or other issues associated with extreme weather events. Yet because heatwaves will still typically occur periodically for a small part of any given year, increasing grid capacity to meet increased peak load demands for cooling represents an inefficient use of resources."[90]

Another salient factor to take into consideration in Toowoomba's case is that though rainfall is predicted to decrease, there is still likely to be more cloud in the atmosphere. It is not possible to ascertain whether this would compromise the days available for solar power collection. However, more cloud cover does mean that the incidence of scattered and reflected ultraviolet radiation (UVR) will be higher, and the need for protective shade cover will be more important than ever to help prevent skin cancer.

Vegetative cover is one of the most important factors that can ameliorate the urban microclimate. However, in the Toowoomba Region's case the projected decreasing rainfall and increasing temperature both present challenges to keeping green spaces green and adding green canopy to urban environments. Air movements over areas of vegetation such as forest canopy can also bring cooler air into urban environments. However, major changes to vegetation through land-clearing affect air quality, soil structure and exposure to drying winds. Figure 87, reproduced from the *Where should all the trees go* report[91] maps the hottest land surface areas in the Toowoomba Region and in the 200Km urban conurbation that runs from the Qld/NSW border to the northern extent of the Noosa Shire. Unlike many of the areas shown as intensely hot in urban centres and corridors in Brisbane, Logan, Ipswich and City of Gold Coast, the hotspots in the Toowoomba Region are mostly cleared areas where croplands and grazing dominate, and most native vegetation and forest have been removed.



[90] Queensland State Government, "Queensland State Heatwave Risk Assessment." P. 73

[91] Amati et al., "Where Should All the Trees Go? Investigating the Impact of Tree Canopy Cover on Socio-Economic Status and Wellbeing in LGA's."

Figure 87. Heat Map of Toowoomba Region: Investigating the impact of tree canopy cover on socio-economic status and wellbeing. Source: Amati et al.

Other metrics beyond precipitation, temperature and relative humidity presented in regional summaries for RCP4.5 and RCP8.5 also interact with urban form to affect local microclimates. Air movement aids urban ventilation yet wind speed and direction can change significantly depending on density of built form in an urban environment. The amount of solar radiation that penetrates a space during the day relates to geometry of open spaces formed by the spaces between buildings.

Future urban development and buildings will have to deal with space for space for water collection and storage at all scales, and space for shade-giving drought resistant vegetation at all scales. The importance of climate-responsive urban form, and climate-responsive buildings to mitigate the adverse effects of heatwaves on people and the buildings and settlements they inhabit cannot be underestimated. The Queensland State Heatwave Risk Assessment contains recommendation for other ways of preventing overheating and decreasing the impacts of heatwaves on people outdoors and indoors.[92]

[92]Queensland State Government, "Queensland State Heatwave Risk Assessment." Pp. 79-83.

5. CLIMATE COMPARISONS

In this section we identify areas internationally and in Australia with comparable climate character to the Toowoomba area. These climate comparisons will direct focus areas for architectural exemplars in Phase 2 – Defining Warm Temperate Climate Architecture.

5.1. Heading required

To manage a targeted global scale investigation of architectural projects in temperate climate areas, in Phase 1 we first identify international locations with the same "Cfa" Köppen-Geiger classification system as SEQ and the TRC area. Figure 88 shows nine C temperate climate sub-types likely to reveal projects of interest to this study. During Phase 2, we will use a snowballing method to locate exemplar projects in Cfa areas, expanding to other C temperate areas depending on design principles applied in the project, the architect/designer, vernacular style, materiality, cultural relevance, or development patterns.

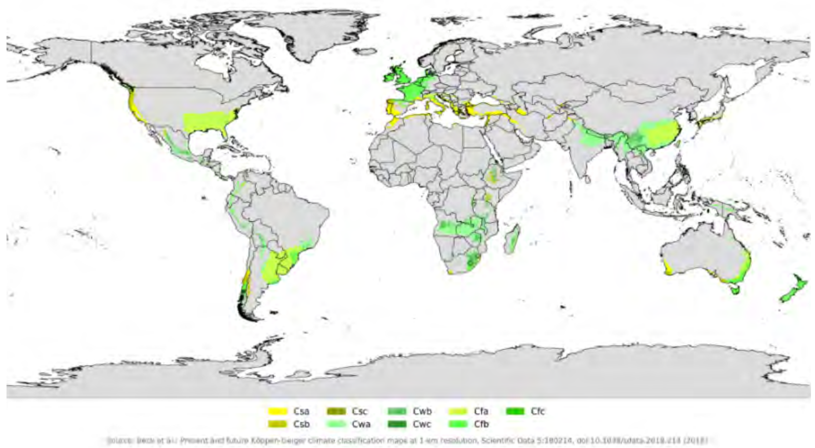


Figure 88: Temperate C zone climate distribution. Source: Beck et al. (2018).

Figure 10. NCC Climate Zone Map for Queensland with detailed map for Brisbane Surrounds (which [93]

Table 28: Examples of international "marine east coast" CFa areas include:

North America	Atlanta, Georgia
	Dallas, Texas
	Washington, D.C.
	Nashville, Tennessee
	New Orleans, Louisiana
	New York City, NY
	Philadelphia, Pennsylvania
South America	Buenos Aires, Argentina
	Rosario, Argentina
	Montevideo, Uruguay

[93] Beck et al., "Present and Future Köppen-Geiger Climate Classification Maps at 1-Km Resolution."

	Asunción, Paraguay
	Florianópolis, Brazil
	Porto Alegre, Brazil
	São Paulo, Brazil
Africa	Durban, South Africa
Europe	Astara, Azerbaijan
	Samsun, Turkey
	Split, Croatia
	Belgrade, Serbia
	Lugano, Switzerland
	Tirana, Albania
	Milan, Italy
	Bolgna, Italy
	Venice, Italy
	Lyon, France
	Toulouse, France
Eastern Europe	Sochi, Russia
	Tbilisi, Georgia
Asia	Srinagar, India
	Ulsan, South Korea
	Jeju, South Korea
	Shanghai, China
	Chongqing, China
	Guangzhou, China
	Taipei, Taiwan
	Tokyo, Japan
	Osaka, Japan
	Rasht, Iran

Figure 89: Locations of Cfa classified areas according to continent. Source: Peel et al. (2007).[94]

5.2. Australian Climate Comparisons

The NCC climate zone 5 areas s Cfa areas such as Toowoomba but also areas that are classed as Cfb, Csa, Csb, Bsk, Bwk according to the Köppen-Geiger system.

In total, 136 LGA areas are located in NCC zone 5 areas (Table 29), noting that these areas vary in size significantly between states. In Perth and Sydney, it is common for LGA’s to incorporate only a small cluster of suburbs.

Within Australia, this study considers both Köppen-Geiger classifications and NCC climate zones. In this Phase 1 report we outline NCC climate zone 5 locations in Australia as the focal point of Phase 2 BE exemplars and to identify relevant LGA design guidelines. This process will reveal common design principles that are successfully applied across climate zone 5 areas, regardless of Köppen-Geiger classification subtype. These principles will be used to triangulate which international projects in temperate zones other than Cfa should be considered as part of the study.

[94] Peel, Finlayson, and McMahon, “Updated World Map of the Köppen–Geiger Climate Classification.”

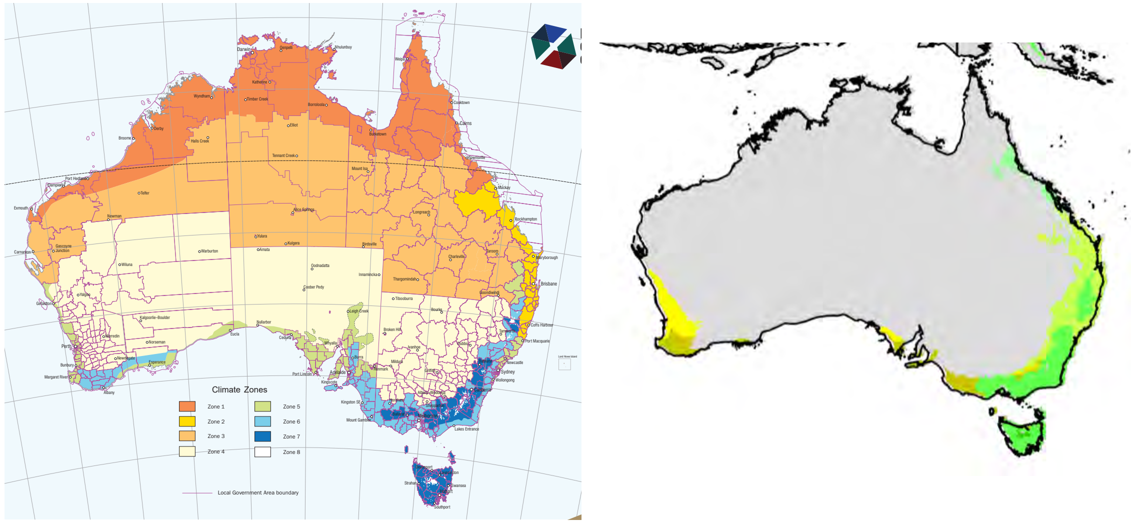


Figure 90: NCC Climate Zone Map adjacent to Beck et al. (2018) map of Australia with C zones indicated.

Table 29: LGA climate zone 5 areas in Australia. Source: NCC Climate

Western Australia

Perth Urban	Stirling
	Bayswater
	Cambridge
	Vincent
	Subiaco
	Nedlands
	Claremont
	Cottesloe
	Peppermint Grove
	Mosman Park
	East Fremantle
	Fremantle
	Perth
	Belmont
	Victoria Park
	South Perth
	Canning
	Melville
Perth Surrounds	Dandaragan
	Gingin
	Chittering
	Swan
	Armadale
	Wanneroo
	Mundaring
	Joondalup
	Kalamunda
	Gosnells
	Cockburn
	Kwinana
	Rockingham
	Serpentine-Jarrahdale
	Mandurah
	Murray
	Waroona
	Harvey
	Collie
	Bunbury
	Dardanup
	Capel
	Busselton
Greater WA	Northampton
	Chapman Valley
	Greater Geraldton
	Irwin
	Mingenew
	Carnamah
	Coorow
	Augusta- Margaret River
	Jerramungup
	Ravensthorpe
	Esperance

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South Australia

Adelaide Urban	Adelaide
	Burnside
	Campbelltown
	Charles Sturt
	Gawler
	Holdfast Bay
	Marion
	Mitcham
	Norwood/Payneham & St Peters
	Playford
	Port Adelaide/Enfield
	Prospect
	Salisbury
	Tea Tree Gully
	Unley
	Walkerville
	West Torrens
Adelaide Surrounds	Aldinga Beach
	Barossa
	Mallala
	Onkaparinga
	Wakefield
Greater SA	Barunga West
	Berri/Barmera
	Ceduna
	Cleve
	Copper Coast
	Elliston
	Flinders Ranges
	Franklin Harbor
	Gerard
	Goyder
	Kimba
	Le Hunte
	Lower Eyre Peninsula
	Loxton/Waikerie
	Mid Murray
	Mount Remarkable
	Northern Areas
	Orroroo/Carrieton
	Outback Areas Community Development Trust
	Port Lincoln
	Renmark/Paringa
	Streaky Bay
	Tumby Bay
	Yalata
	Yorke Peninsular

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NSW

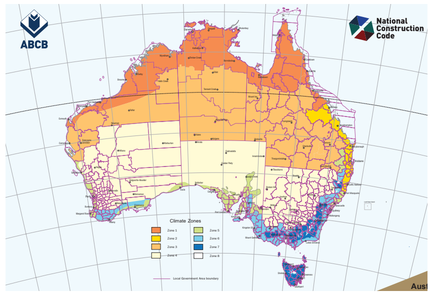
Sydney Urban	Bayside
	Burwood
	Canada Bay
	Canterbury-Bankstown
	Georges River
	Hunters Hill
	Inner West
	Lane Cove
	Mosman
	North Sydney
	Randwick
	Strathfield
	Sydney
	Waverley
	Willoughby
	Woollahra
Sydney Surrounds	Hornsby
	Ku-Ring-Gai
	Northern Beaches
	Ryde
	Sutherland
Greater NSW	Central Coast
	Cessnock
	Dungog
	Kiama
	Lake Macquarie
	Maitland
	Mid-Coast
	Newcastle
	Port Macquarie-Hastings
	Port Stephens
	Shellharbour
	Wollongong

33

Queensland

Brisbane Surrounds	Cherbourg
	South Burnett
	Southern Downs
	Toowoomba

4



6. HUMAN COMFORT ANALYSIS

In this section the data collected from the for this report, is analysed in terms of thermal, respiratory (indoor air quality), and visual comfort. Human comfort analysis usually involves an analysis of acoustic qualities, but this was not included in the scope for this project. However, acoustics are an important aspect of climatic design and should be considered in planning and building legislation and instruments. Phase Two of this project will investigate exemplar architectural responses to environmental acoustics to inform this aspect of the study. The following analysis focuses mostly on thermal comfort as it relates to building legislation and provides a more detailed understanding of building thermal performance and climatic responsive design for buildings in the region.

6.1. Heating and Cooling Degree Days

Heating and Cooling Degree Days are defined as the number of days that the average temperature drops below or is above the range for human thermal comfort. For the purpose of this study, that range is accepted as between 18°C and 24°C. Therefore, Heating Degree Days are defined as the days where the average temperature is below 18°C and these are days when people are most likely to use active heating in internal spaces to achieve thermal comfort and Cooling Degree Days are when the average temperature is over 24°C and people are most likely to use active cooling to achieve thermal comfort. The Australian Bureau of Meteorology (BOM) has collated data for Heating and Cooling Degree Days over a 30-year period, between 1961 and 1990. The data shows in daily ranges for locations across Australia. For Toowoomba, the data shows that:

Table 30: Toowoomba Heating and Cooling Degree Days.

Period	Days
Heating Degree Days (1961-1990)	500-1000
Cooling Degree Days (1961-1990)	50-100

This data demonstrates that the need for active heating is more prevalent than the need for active cooling. For context, the Heating Degree Days for Brisbane are 250-500 days and Cooling Degree Days are 50-100 days, meaning that Brisbane’s climate has less days where active heating would be required, although still more Heating than Cooling Degree says, but has the same range of days where active cooling would be required.

Table 31: Brisbane Heating and Cooling Degree Days.

Period	Days
Heating Degree Days (1961-1990)	250-500
Cooling Degree Days (1961-1990)	50-100

It is important to note that BOM’s current data for Heating and Cooling Degree Days is historic and that in the 30 years since the collection of this data, Australia’s climate has changed. As our climate data findings from the first section of this report found, Toowoomba’s climate since 1990 has become warmer and that the projections for Toowoomba’s future will see temperatures continue to rise. Therefore, it is possible to project that the Cooling Degree Days may increase, and the Heating Degree Days may decrease.

Heating degree days and cooling degree days also partially relate to the way that the NCC determines climate zones in terms of the need for heating and cooling energy efficiency in buildings.

6.2. Psychrometric Charts for Thermal Comfort

Psychrometric charts are used to analyse climate data so that it can be applied to indoor thermal comfort for buildings. The charts graphically portray the relationship between temperature, relative humidity, atmospheric pressure and enthalpy (air movement based on the expansion of air caused by heat). This information is used predominately by mechanical engineers to calculate the needs for air conditioning in buildings because it provides information on the parameters for human comfort in terms of heating and cooling as well as locating the dew point, which is used to manage condensation in air-conditioned buildings. Bioclimatic charts can then be overlaid onto psychrometric charts to provide ranges in temperature and relative humidity for human thermal comfort.

Mechanical engineers most commonly use the ASHRAE bioclimatic chart, which provides indoor thermal comfort for 'sedentary users,' which is where the building's HVAC system is the only working system to maintain a comfortable interior environment. It was designed for office buildings to maintain comfort for stationary workers sitting in one location throughout the day, but it is now also used to inform air conditioning design of housing and residential developments.[95] For this study, the Givoni-Milne Climatic chart has been used. The Givoni-Milne bioclimatic chart was designed for warmer climates, specifically hot and humid climates. The chart is based on building users who are not accustomed to air-conditioned environments and can therefore tolerate variations in air movement and speed as well as temperature and humidity. It is also based on users who are active in the heating or cooling of their environments by moving to warmer or cooler areas of a building as required and opening and closing fenestrations to adjust the temperature as desired. The charts presented in this study are generated by software created by Dr Andrew Marsh.

The first three psychrometric charts document existing data from weather and data files, called .epw files. These files are used for various software to analysis climatic data for building design and analysis. However, these files are not available for all weather stations, they are only created where there is sufficient climate data available and where the climate varies enough between weather stations to justify a different climate zone and relevant epw file.[96] For the Toowoomba Region, the climate zone is informed by climate data gathered from the Oakey weather station. The epw data file for Oakey is used to define the climate for TRC, South Burnett and Southern Downs regions. The three LGA areas are grouped together in climate zone 50 in the NatHERS (Nationwide House Energy Rating Scheme), which overlays directly to the climate zone 5 on the NCC climate map.

The three psychrometric charts are created using data from epw files for Charleville (Climate Zone 3, Hot Arid), Oakey (Climate Zone 5, Warm Temperate) and Amberley (Climate Zone 2, Subtropical)—moving from West to East. Th following psychrometric charts for these three regions

[95] Givoni, "Comfort, Climate Analysis and Building Design Guidelines."

[96] NatHERS, "NatHERS Climate Zones and Weather Files."

demonstrates the different thermal comfort responses required according to the different climatic conditions.

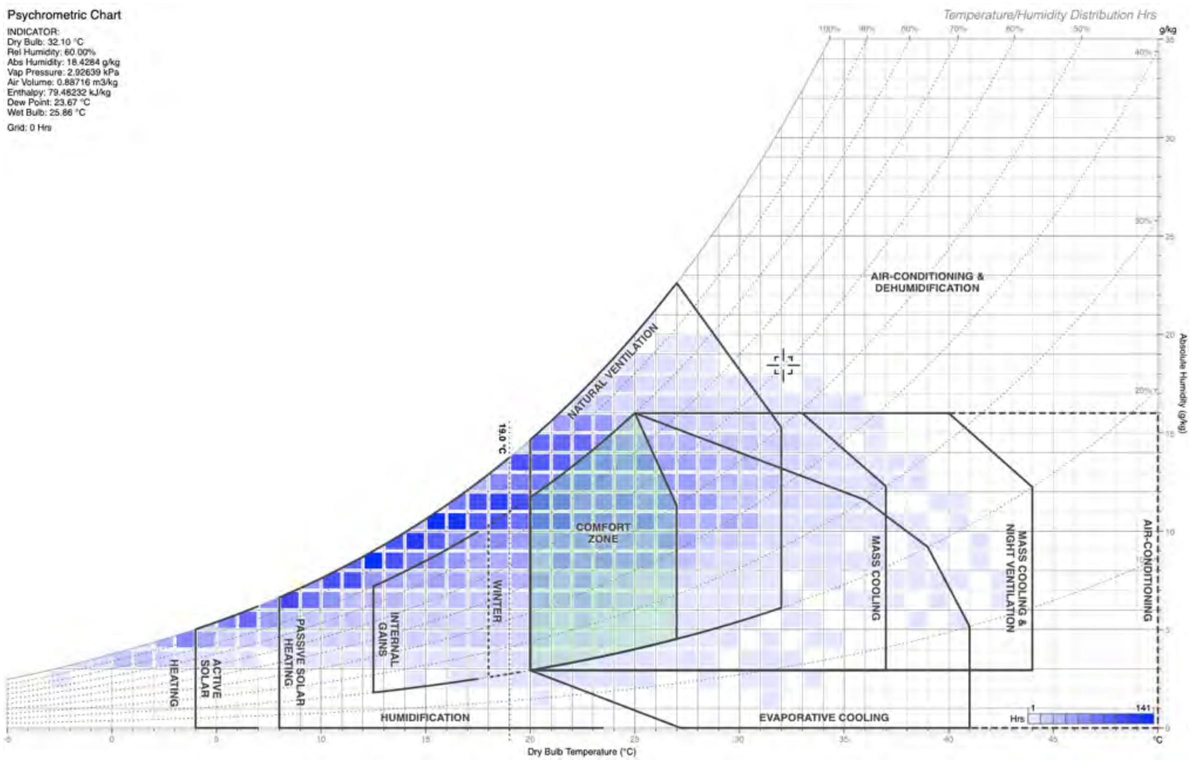


Figure 91: Psychrometric Chart for Oakey

The Givoni bioclimatic chart for Oakey (in the TRC region) indicates the need for active heating systems in buildings in winter. In terms of passive heating, it indicates that thermal mass, passive solar gain, and active solar gain would provide adequate heating. There are very few days that require active cooling. Passive cooling can be achieved by thermal mass and natural ventilation. The chart suggests that thermal mass as the predominate strategy for both heating and cooling

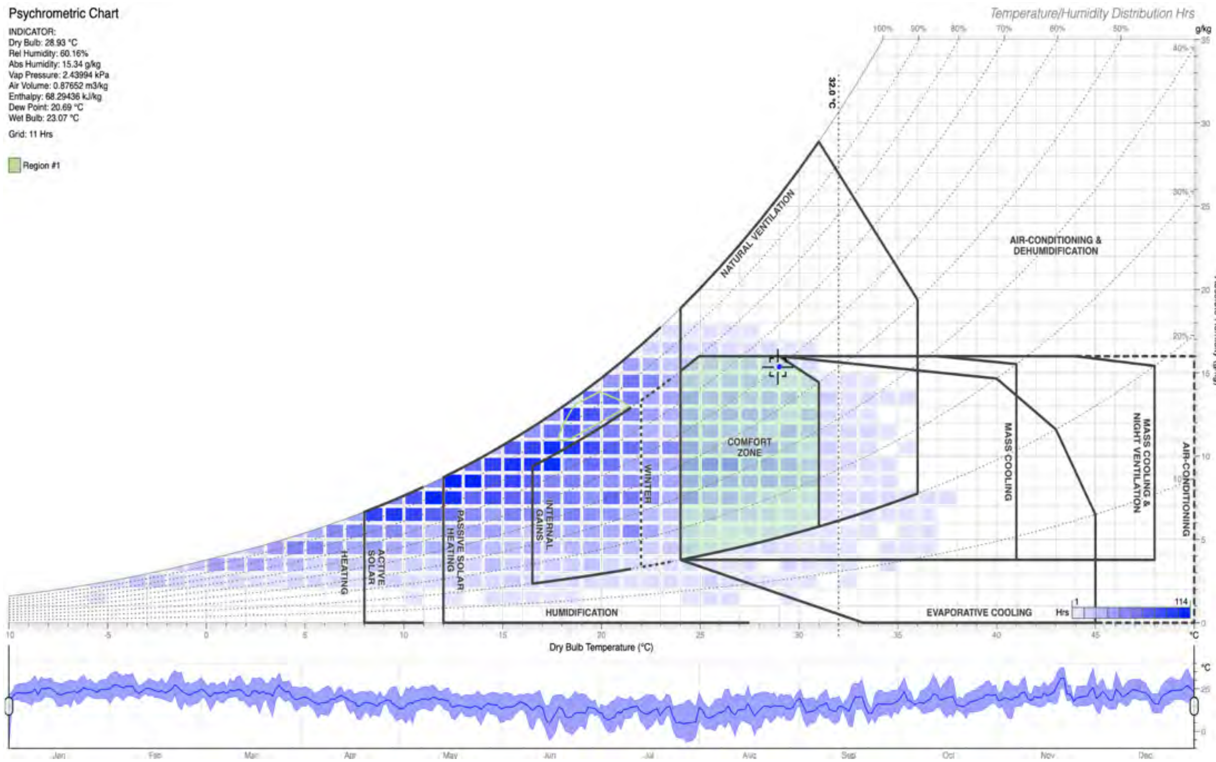


Figure 92: Psychrometric Chart for Brisbane (Amberley)

The bioclimatic chart for Brisbane (Amberley weather station) indicates the need for active cooling, through air-conditioning and de-humidification on a few days throughout the year. It shows a greater need for natural ventilation, including night purging and as a strategy in response to the frequency of days with higher relative humidity.

There are markedly fewer days that require passive or active solar heating and very few days require mechanical heating in comparison to Oakey.

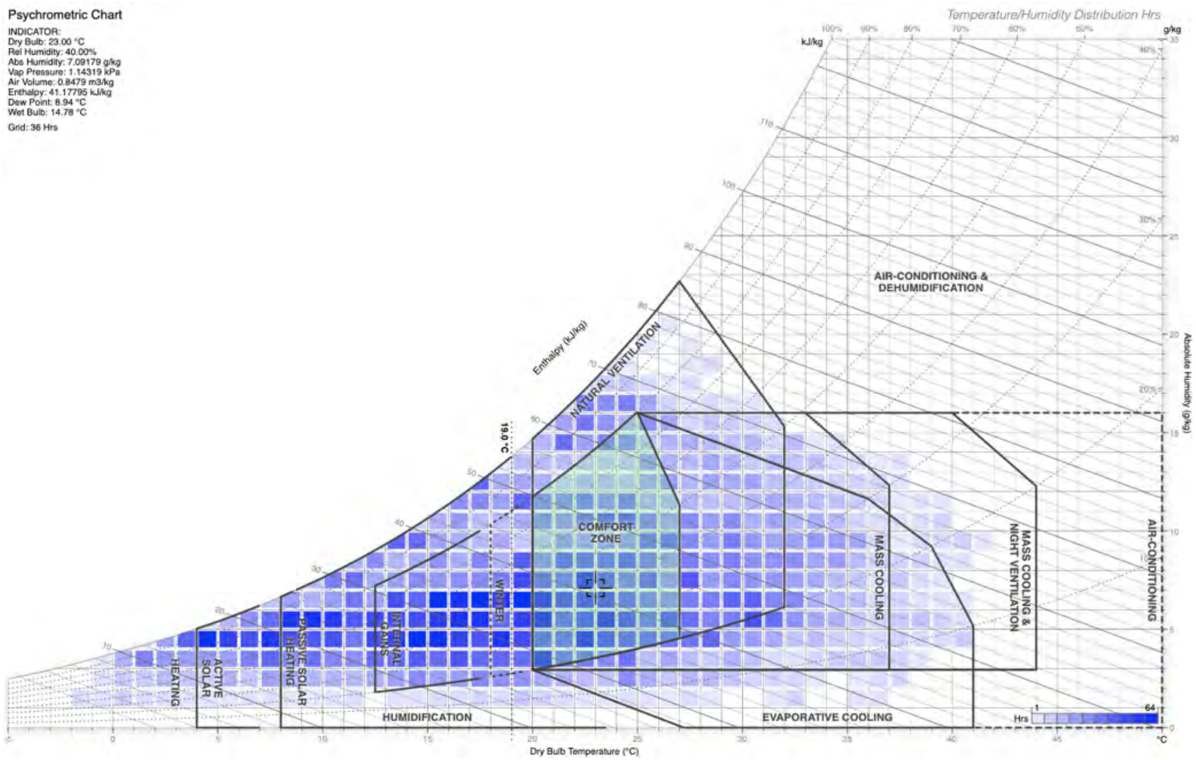


Figure 93: Psychrometric Chart for Charleville

The bioclimatic chart for Charleville to west shows a low concentration of days with high relative humidity. Therefore the suggested passive cooling strategies include natural ventilation and thermal mass cooling. Passive heating strategies including thermal mass, passive solar, active solar. Active hearting is also required in winter.

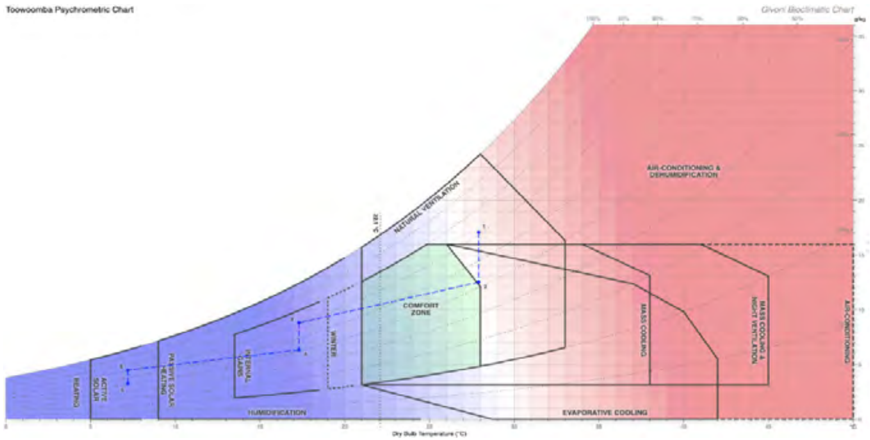
6.3. Chart Analysis and Comparison

The data shown on the three psychrometric charts shows the climatic variation moving from West in Charleville (Zone 3, Hot-Arrid), through Oakey (warm temperate, zone 5) and East to Amberley (Brisbane, zone 2, subtropical). While the Köppen-Geiger system classifies these three regions under one climate classification, Cfa, there is enough variation to warrant different building responses to climate. The charts show the different strategies for passive and/or active heating and cooling for buildings in each region. The charts show that the climate around the Oakey area is reasonably mild and that buildings can achieve thermal comfort with mostly passive strategies and only requires active heating in winter. The findings from these charts proffer some criteria for determining climatic responses for buildings in Oakey, however, they do not reflect the climate variation within the Toowoomba Region itself. In the findings presented in Section 3 of this report, it found noticeable differences in temperature and relative humidity for each weather station. The following psychrometric charts plot the findings of the data from the five weather stations in and around the Toowoomba region to arrive at a more detailed criteria for buildings that respond to Toowoomba's region.

6.4. Psychrometric Charts for Localised Data

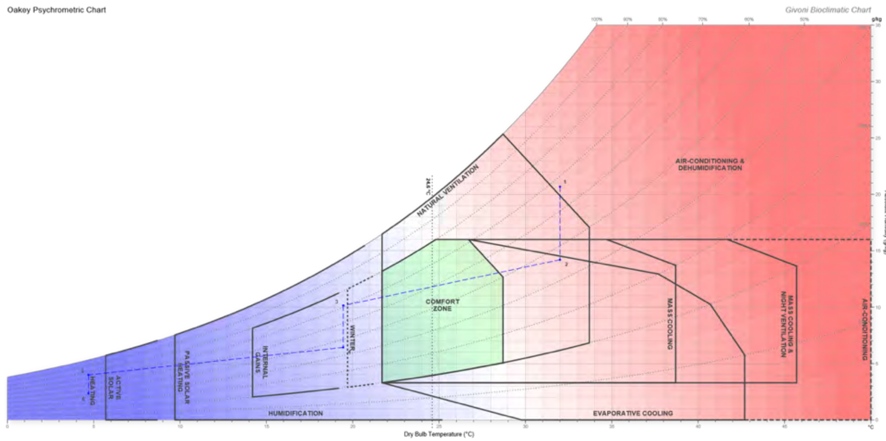
The following psychrometric charts plot the climate data on temperature and relative humidity presented in section two of the report. These charts suggest appropriate thermal responses to local climate data. These charts are generated based on the following assumprions:

- Air velocity at 0.3 m/s (pleasantly still)
- Clothing Level at 0.65, typical day work wear (business shirt, trousers, and shoes)
- Metabolic Rate 1.00 (seated with sedentary activity)
- Normal Room Temperature set at 22°c (based on mean outdoor temp of 22.1)



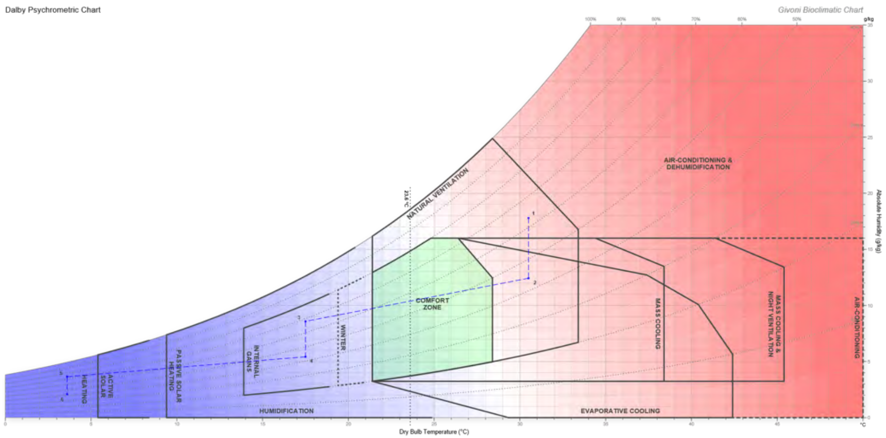
Point	Toowoomba Temperature and Relative Humidity
1	Summer TMax 27.9°C RH 9am 71%
2	Summer TMax 27.9°C RH 3pm 52%
3	Winter TMax/Summer Tmin 17.3-17.5 RH 9am 71%
4	Winter TMax/Summer Tmin 17.3-17.5 RH 3pm 51-52%
5	Winter TMin 7.2°C RH 9am 71%
6	Winter TMin 7.2°C RH 3pm 51%

This first chart plots out the TMax (Summer) and TMin (Winter) as well as the relative humidity for 9am and 3pm from the Toowoomba weather station. The chart shows that Toowoomba's relative humidity and temperature range are all within a range that can be addressed with passive design strategies, including thermal mass for both heating and cooling, natural ventilation and passive and active solar heat gain for heating. Additionally, the difference between the Oakey and Toowomba bioclimatic charts also support the scenario that at a post code level, the CSIRO interactive NCC Climate zone map classifies the Toowoomba CBD and surrounds as a different climate (Zone 2, subtropical).



Point	Oakey Temperature and Relative Humidity
1	Summer TMax 32°C RH 9am 67%
2	Summer TMax 32°C RH 3pm 46%
3	Winter TMax/Summer Tmin 20.6 - 18.3°C RH 9am 75 - 67%
4	Winter TMax/Summer Tmin 20.6 - 18.3°C RH 3pm 44 - 46%
5	Winter TMin 4.7°C RH 9am 75%
6	Winter TMin 4.7°C RH 3pm 44%

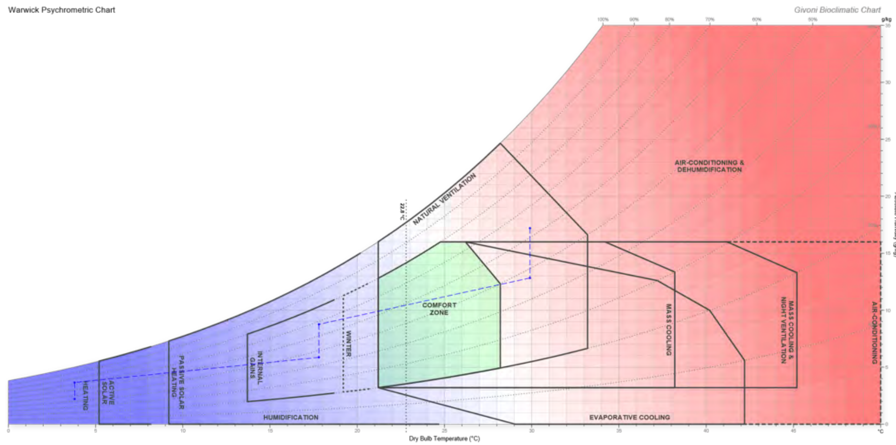
This second chart plots out the TMax (Summer) and TMin (Winter) as well as the relative humidity for 9am and 3pm from the Oakey weather station. Oakey's temperature and relative humidity vary much more significantly than Toowoomba's. It shows that both active heating and cooling is required—that is air conditioning and mechanical heating. Considering that both NCC and NatHERS climate zones have been informed by climate data from the Oakey weather station, it explains why buildings in the region are required to demonstrate energy efficiency for both heating and cooling.



Point	Dalby Temperature and Relative Humidity
1	Summer TMax 30.5°C RH 9am 63%
2	Summer TMax 30.5°C RH 3pm 44%
3	Winter TMax/Summer Tmin 19.4 - 15.6°C RH 9am 74 - 63%
4	Winter TMax/Summer Tmin 19.4 - 15.6°C RH 3pm 42 - 44%
5	Winter TMin 3.6°C RH 9am 74%
6	Winter TMin 3.6°C RH 3pm 42%

This first chart plots out the TMax (Summer) and TMin (Winter) as well as the relative humidity for 9am and 3pm from the Dalby weather station.

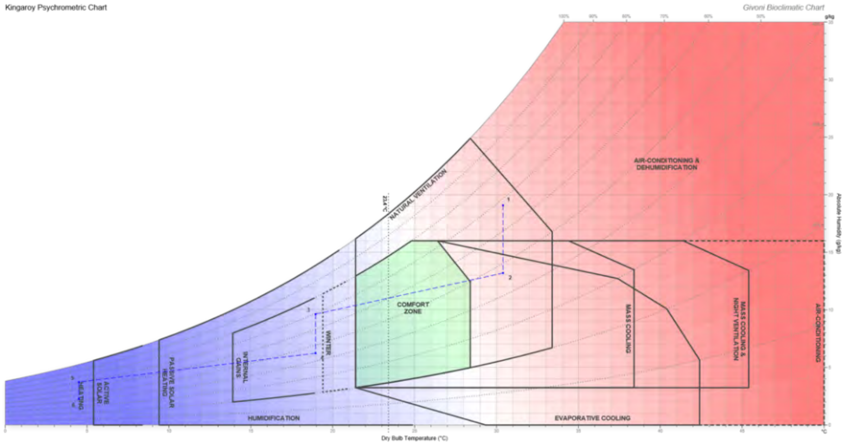
Other than the requirement for active heating in winter, the chart shows that Dalby's relative humidity and temperature range are all within a range that can be addressed with passive design strategies, including thermal mass for both heating and cooling, natural ventilation and passive and active solar heat gain for heating.



Point	Warwick Temperature and Relative Humidity
1	Summer TMax 29.9°C RH 9am 63%
2	Summer TMax 29.9°C RH 3pm 47%
3	Winter TMax/Summer Tmin 18.9 - 16.7°C RH 9am 73 - 63%
4	Winter TMax/Summer Tmin 18.9 - 16.7°C RH 3pm 44 - 47%
5	Winter TMin 3.8°C RH 9am 73%
6	Winter TMin 3.8°C RH 3pm 44%

This first chart plots out the TMax (Summer) and Warwick (Winter) as well as the relative humidity for 9am and 3pm from the Dalby weather station.

The chart shows that Warwick's climate requires a very similar thermal response for buildings as Dalby.



Point	Kingaroy Temperature and Relative Humidity
1	Summer TMax 30.4°C RH 9am 68%
2	Summer TMax 30.4°C RH 3pm 47%
3	Winter TMax/Summer Tmin 20.4 - 17.5°C RH 9am 71 - 68%
4	Winter TMax/Summer Tmin 20.4 - 17.5°C RH 3pm 43 - 47%
5	Winter TMin 4.5°C RH 9am 71%
6	Winter TMin 4.5°C RH 3pm 43%

This first chart plots out the TMax (Summer) and TMin (Winter) as well as the relative humidity for 9am and 3pm from the Kingaroy weather station.

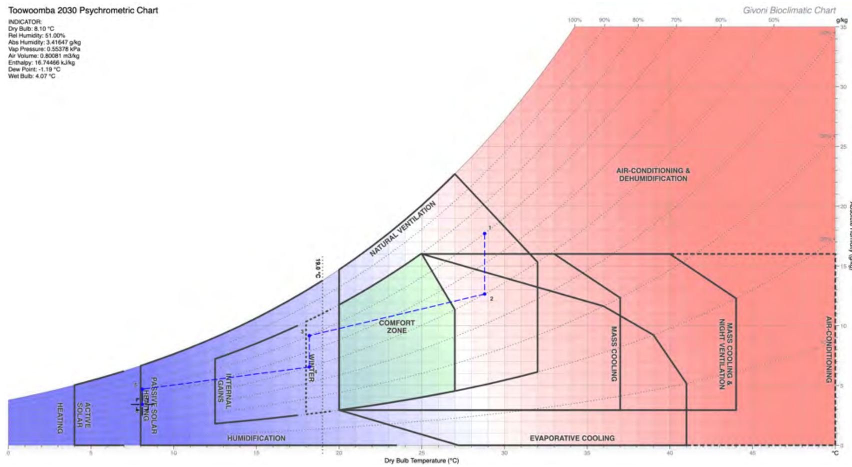
Kingaroy's relative humidity and temperature range are similar again to Dalby and Warwick, however there is a higher range in temperature, which means that there are more days in the year that require natural ventilation for cooling.

6.5. Localised Climate Psychrometric Charts Summary

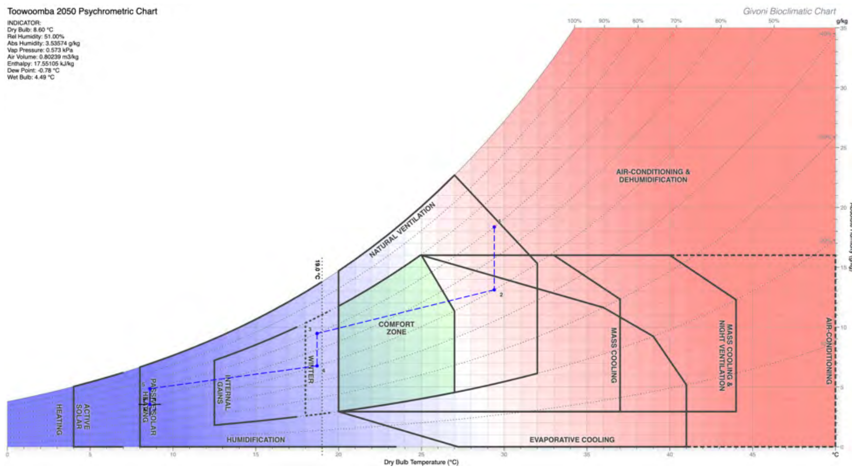
The Psychrometric and bioclimatic charts for the localized climate data collated in this report show that there are different thermal requirements in each area. Dalby, Warwick and Kingaroy have the most similar requirements for thermal performance in buildings. The predominate strategies for these three areas are thermal mass for heating and cooling, natural ventilation for cooling, and passive and active solar for heating as well as mechanical heating systems. Oakey's climate requires the most intensive thermal performance for buildings, with both air conditioning and mechanical heating required. In comparison, Toowoomba's climate requires the least intensive thermal performance for buildings, with a climate that can be addressed almost entirely by passive methods, including thermal mass, natural ventilation and active and passive solar heat gain.

6.5.1. Psychrometric Charts with Climate Projections

As part of the climate data collated in section three of this report, we also calculated climate projections for the region based on two scenarios. The following charts plot out these climate projections for temperature and relative humidity Toowoomba and Oakey. The projections used for these charts were the most likely scenario, where 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. The projections plotted are for 2030 and 2050. Overall, the projections show that temperatures will rise by about 1°C and relative humidity will decrease by about 1%.

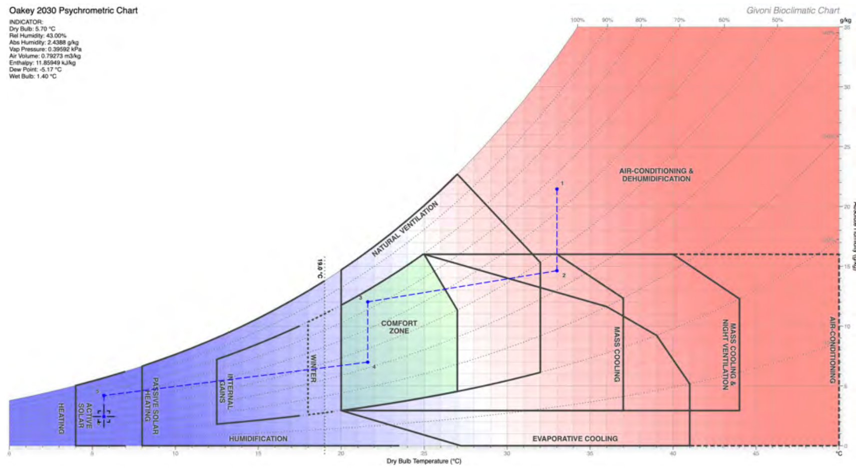


Point	Toowoomba 2030 Temperature and Relative Humidity
1	Summer TMax 28.8°C RH 9am 70%
2	Summer TMax 28.8°C RH 3pm 51%
3	Winter TMax/Summer Tmin 18.2°C RH 9am 70%
4	Winter TMax/Summer Tmin 18.2°C RH 3pm 50%
5	Winter TMin 8.1°C RH 9am 70%
6	Winter TMin 8.1°C RH 3pm 51%

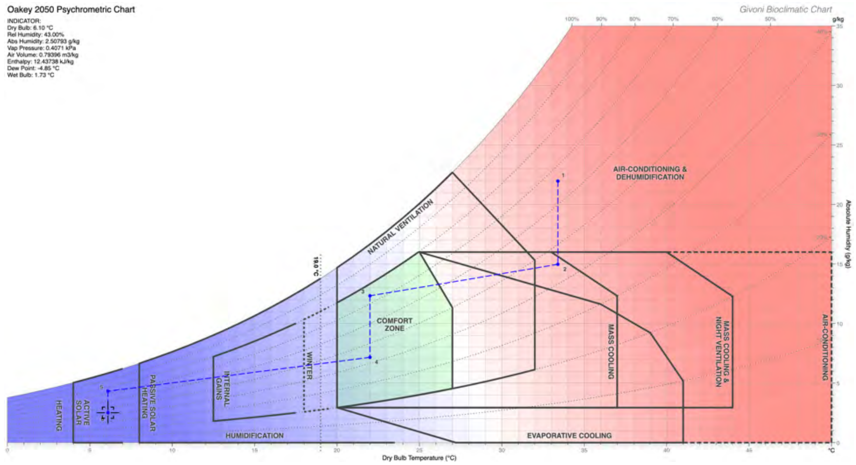


Point	Toowoomba 2050 Temperature and Relative Humidity
1	Summer TMax 29.4°C RH 9am 70%
2	Summer TMax 29.4°C RH 3pm 51%
3	Winter TMax/Summer Tmin 18.7°C RH 9am 70%
4	Winter TMax/Summer Tmin 18.7°C RH 3pm 50%
5	Winter TMin 8.6°C RH 9am 70%
6	Winter TMin 8.6°C RH 3pm 510%

The climate projections for Toowoomba will require a slightly different thermal performance of buildings. Although it does not suggest a different cooling strategy, with natural ventilation and thermal mass still the predominant methods for cooling. However, in terms of heating there is a less intensive requirement for active heating, with only passive solar gain and thermal mass required in winter.



Point	Oakey 2030 Temperature and Relative Humidity
1	Summer TMax 33°C RH 9am 66%
2	Summer TMax 33°C RH 3pm 45%
3	Winter TMax/Summer Tmin 21.6°C RH 9am 74%
4	Winter TMax/Summer Tmin 21.6°C RH 3pm 43%
5	Winter TMin 5.7°C RH 9am 74%
6	Winter TMin 5.7°C RH 3pm 43%



Point	Oakey 2050 Temperature and Relative Humidity
1	Summer TMax 33.4°C RH 9am 66%
2	Summer TMax 33.4°C RH 3pm 45%
3	Winter TMax/Summer Tmin 22°C RH 9am 74%
4	Winter TMax/Summer Tmin 22°C RH 3pm 43%
5	Winter TMin 6.1°C RH 9am 74%
6	Winter TMin 6.1°C RH 3pm 43%

The projections for Oakey show a high frequency of days that will require air conditioning and de-humification for cooling. Similar to Toowoomba the need for heating shifts from active systems to passive solar heat gain and thermal mass.

6.5.2. Visual Comfort

Toowoomba shares the same latitude as Brisbane and therefore building performance for buildings to achieve building comfort are the same both cities. With Toowoomba being a warm temperate climate that is closer to the equator than other areas of Australia that are classified with the same climate, it does have a few impacts in how visual comfort is addressed.

Considering that solar heat gain is suggested as a passive heating strategy, this will need to achieved while still mitigating glare from direct sunlight, especially in winter.

Additionally, as Toowoomba's population grows and the city becomes more dense, consideration around buildings heights and setbacks will need to be considered in terms of access to solar heat gain and access to natural daylight.

6.5.3. Indoor Air Quality

The Queensland State Government monitors and reports on air quality throughout the state, however, there is currently no government monitoring station for Toowoomba. Air quality data for Toowoomba can be derived from community air quality sensors that are voluntarily operated through the IQAir organisation.[97] The data available shows

[97] IQAir, "Become a Contributor: IQAir Community Sensors."

that Toowoomba's overall air quality is "good to very good" where the pollutant concentration in the air is less than 33.[98] However, there are occasional major weather events that impact on Toowoomba's air quality, including bushfire smoke and dust storms. The bushfire study as part of Toowoomba Futures study will inform whether this requires a specific building response in terms of screening from bush fire smoke for indoor air quality. As motioned in section four of this report, a better understanding of the effect of tree clearing on air quality needs to be understood. This is especially in the case of projecting the likelihood of dust storms and designing buildings that protect internal air quality from these events.

6.5.4.Human Comfort Analysis Summary

While scientific and legislated definitions for climate are useful for determining general standards for buildings, they do not address the needs for human comfort within buildings. This section of the report of has used traditional models for interpreting climate data to arrive at strategies for buildings to achieve human comfort. It has predominately focused on thermal comfort. The findings from this section of the report will inform the criteria for selecting suitable buildings to be included in the Phase Two report.

[98] Queensland State Government, "Indoor Air Quality Index."

7. REPORT FINDINGS

This report establishes a variety of ways to define Toowoomba's warm temperate climate according to conventional classification systems, legislation and finally, using local climate data collected as part of this study.

When comparing the Köppen-Geiger macroclimate "Cfa" classification with the Australian major climate classification groups and sub-classes developed by BOM and CSIRO, as well as the NCC climate zone map, it is clear that definitions for Toowoomba's climate as zone 5 – temperate are not nuanced enough to inform climate-responsive built environment design. Particularly when definitions for a temperate climate also vary between international classification systems, BOM, the NCC and government definitions provided through authoritative sources such as YourHome.

The NCC climate zones are an inadequate tool for informing locally specific climate-responsive built environment design. This is because its current purpose is *only* to inform heating and cooling load calculations according to a standard reference building. Additionally, the climate zones areas are averaged according to LGA boundaries, which do not account for climate variability between Australian zone 5 areas, nor does it reflect localised variation within LGA's. The NCC classification system does, however, reveal that Toowoomba is unique in that it is only one of a few zone 5 LGA's in Queensland, the only area located inland and is Australia's most northern zone 5 LGA.

A review of legislation and policy definitions for Toowoomba's climate character revealed further inconsistencies, where the Toowoomba area is frequently referred to, interchangeably, as "temperate" and "subtropical". These inconsistences serve to obscure an accurate understanding of Toowoomba's climate character, pointing to the need for finer grained data to inform a locally specific warm-temperate climate definition for Toowoomba and the broader Eastern Downs region.

Accurate local data is essential for developing codes and guidelines that are responsive to our changing climate. This study, initiated by the Toowoomba Regional Council, is reflective of its progressive stance as an Australian front-runner and aligns with moves internationally to incorporate climate science within built environment codes. One widely acknowledged limitation is access to local climate data. This study identified five local weather stations, of which only 2 are located in the TRC area. This prompted USQ to obtain grant funds to install more weather stations to inform ongoing climate studies for the region.

Climate data collected from five weather stations in the region showed that area surrounding Toowoomba's CBD has a climate that can be described as the "Goldilocks" (not too hot, not too cold) of the Eastern Downs region. However, the climate to the West, North and South varies from these conditions and will require a different architectural response.

Future projections show that rainfall will decrease across all five weather stations, where Toowoomba will experience the greatest decrease. The resulting decrease in humidity, coupled with higher temperatures, will see Toowoomba transition to a hotter, drier climate in coming decades. The main implications of this include reduced streamflow across the region, expansion of arid areas to the west and loss of arable land. Also, the increased risk of dangerous fire events.

An accurate understanding of local climate character, as well as future projections, is essential to inform climate-responsive design for human comfort.

Developing this detailed understanding of Toowoomba's climate will move the reading of climate beyond energy efficiency and inform architectural and city planning responses for the region that enhance lifestyle, visual identity and encourage livable, comfortable spaces for people to enjoy.

7.1 Recommendations for Phase Two

From our findings in the Phase One report, we have arrived at the following recommendations for Phase Two.

1. Address inconsistencies between definitions of climate and climate science through consultation with local practitioners, developers and the community
2. Understanding the climate is defined by more than scientific and legislative classifications, we will engage with local, tacit and cultural knowledge about climatically responsive buildings and draw from that knowledge to inform the selection of exemplar buildings
3. Establish a criteria for selecting suitable exemplar buildings based on climate data findings
4. Continue to investigate how and where energy efficiency and climate overlap (or not) in the design of buildings and determine best practice strategies within the legislative framework.
5. Prioritise human comfort in our search for exemplars. Buildings are for people and buildings that respond to climate should also provide pleasant experiences for people
6. Search for exemplars that enhance climatic conditions to arrive at meaningful climate for people to enjoy.

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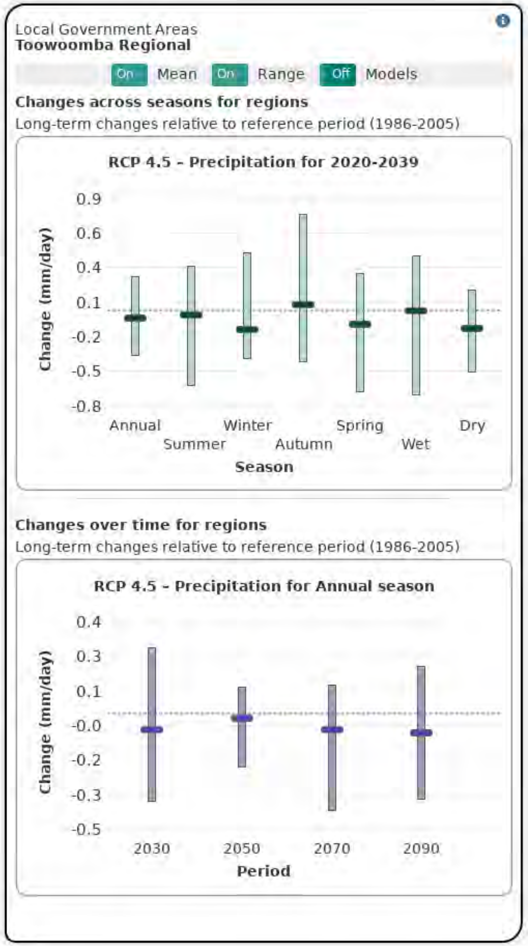
APPENDIX

Climate Projection Calculation Graphs



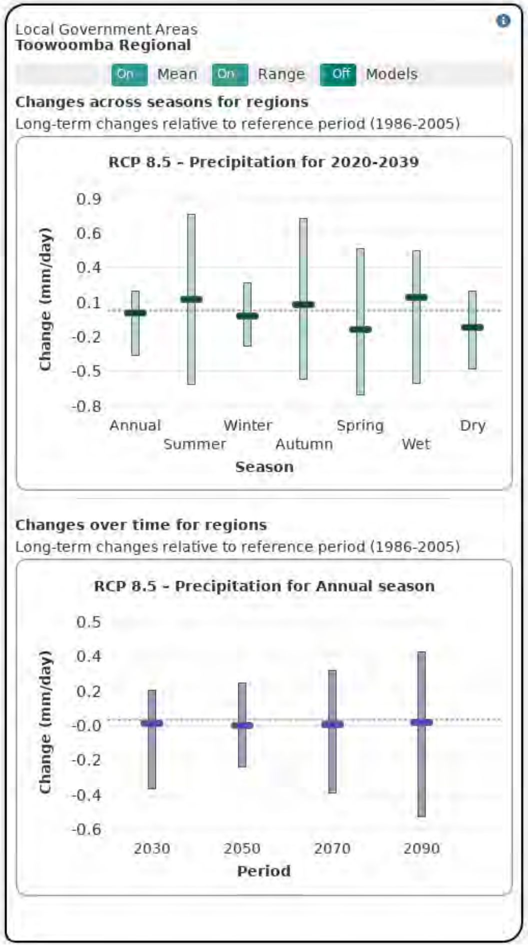


Figure 94: Toowoomba Region – Precipitation prediction based on RCP4.5 & RCP8.5

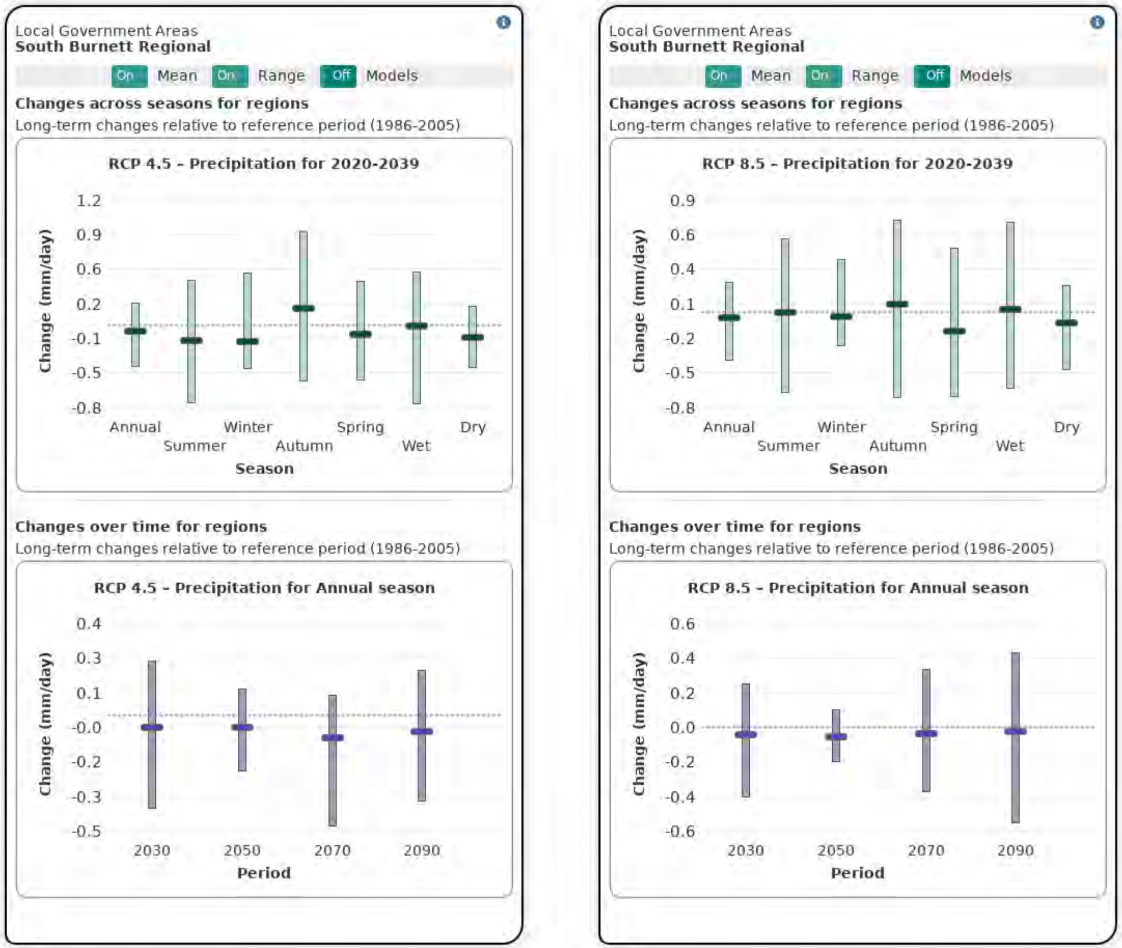


Figure 95: South Burnett Region – Precipitation prediction based on RCP4.5 & RCP8.5

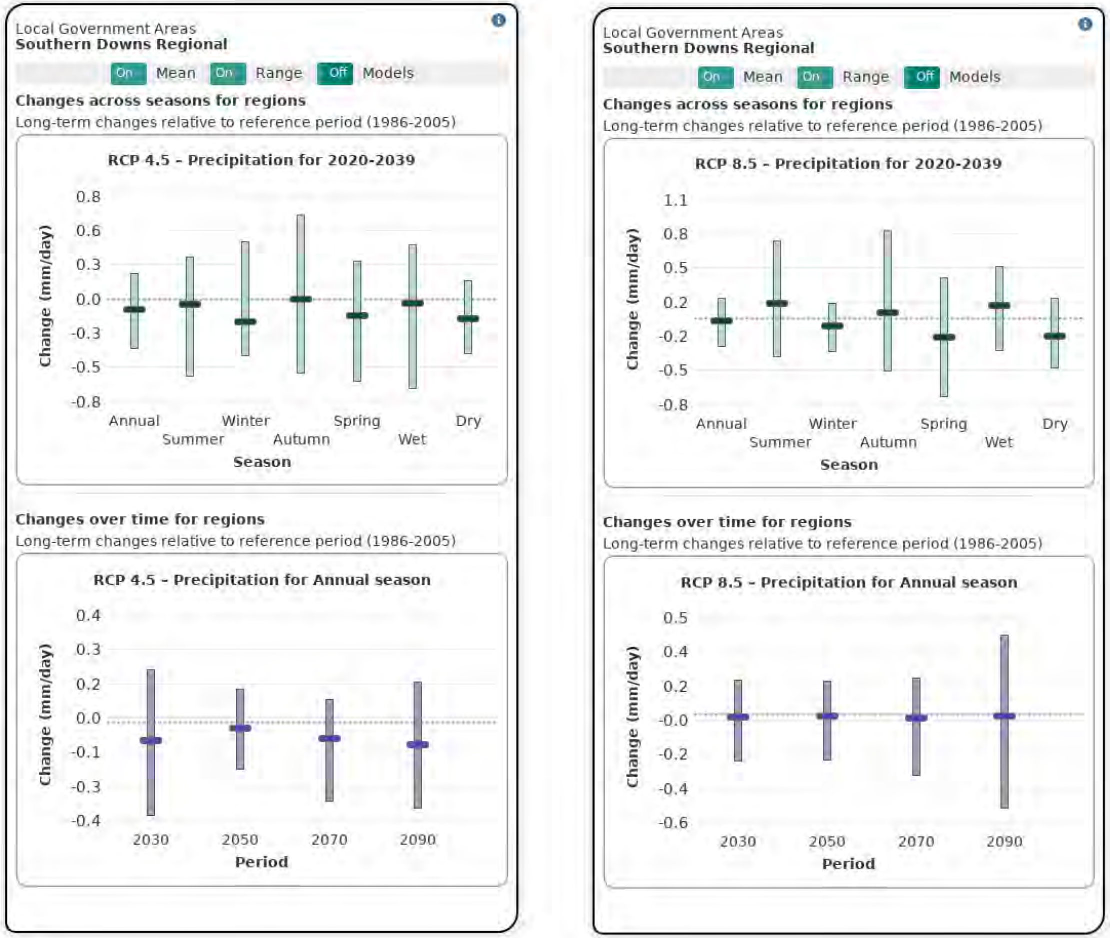


Figure 96: Southern Downs Region – Precipitation prediction based on RCP4.5 & RCP8.5

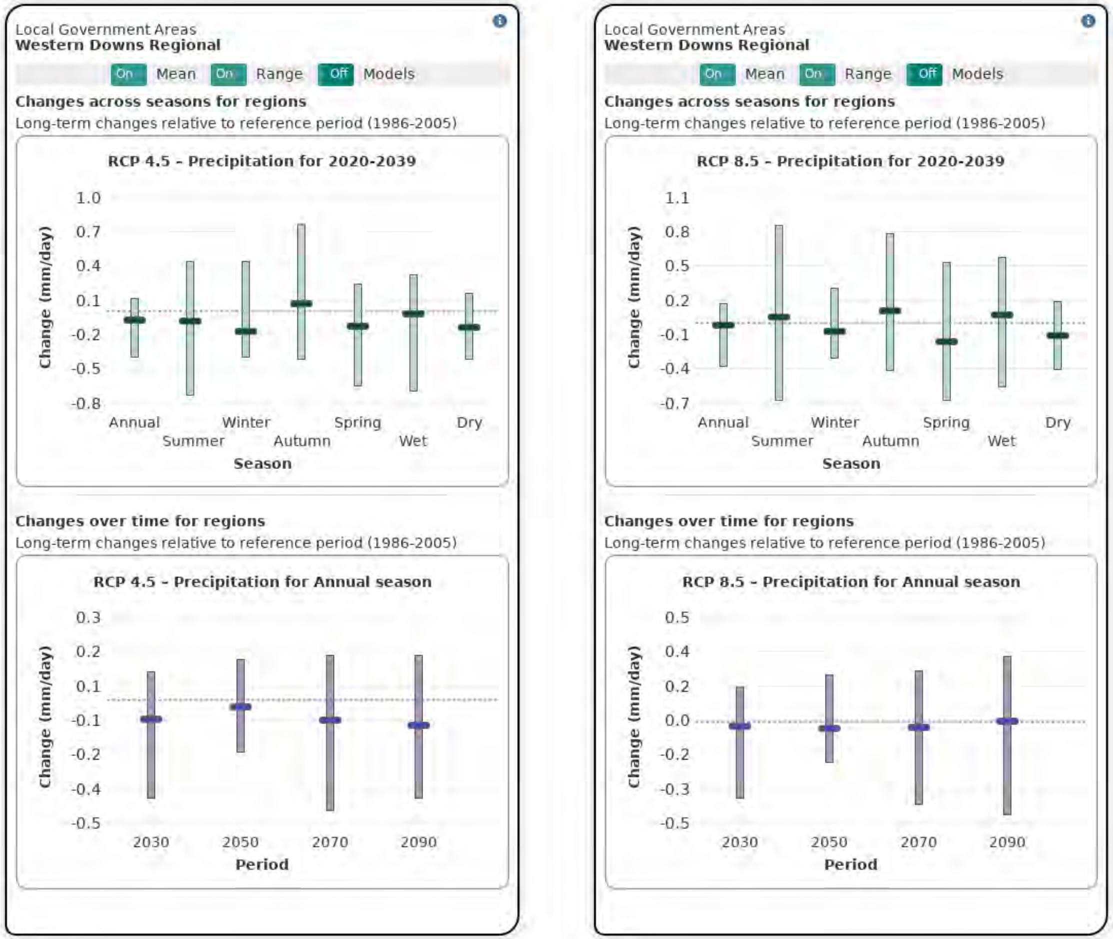


Figure 97: Western Downs Region – Precipitation prediction based on RCP4.5 & RCP8.5

Temperature

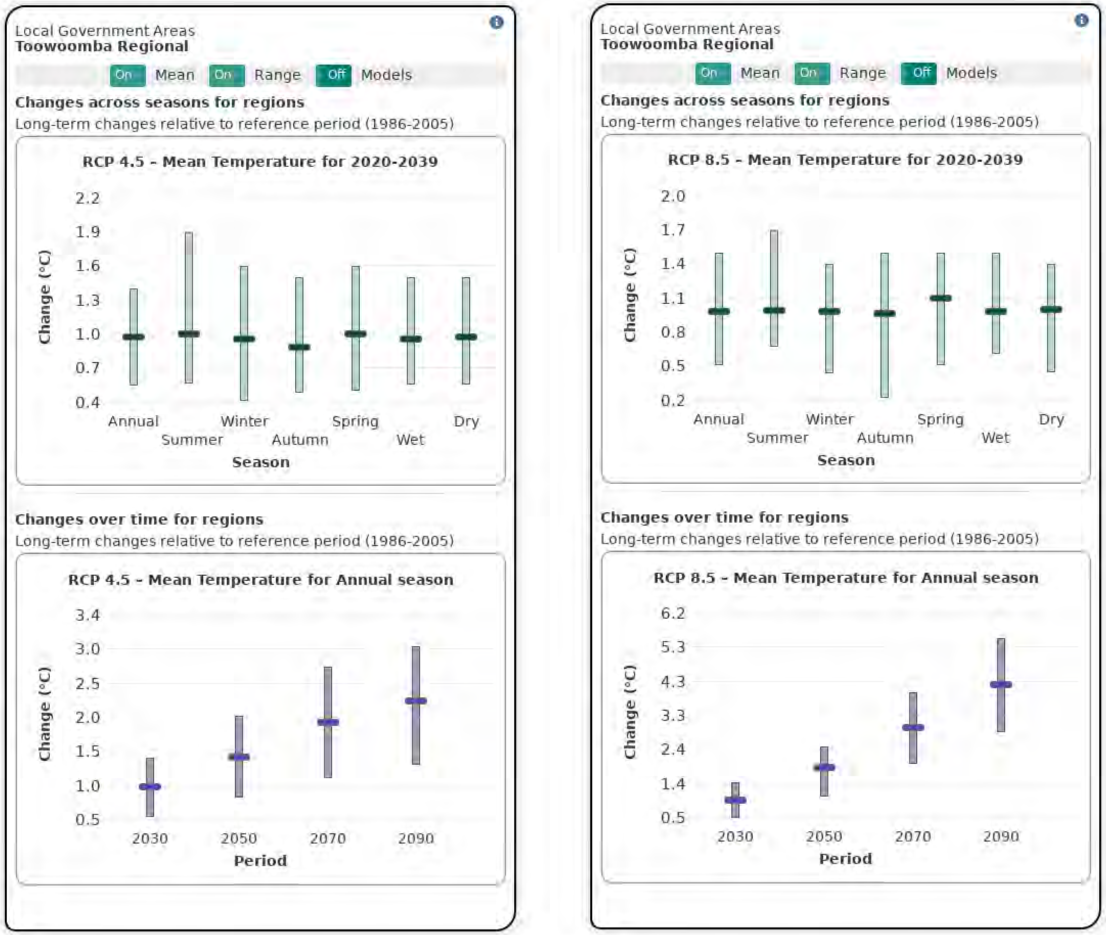
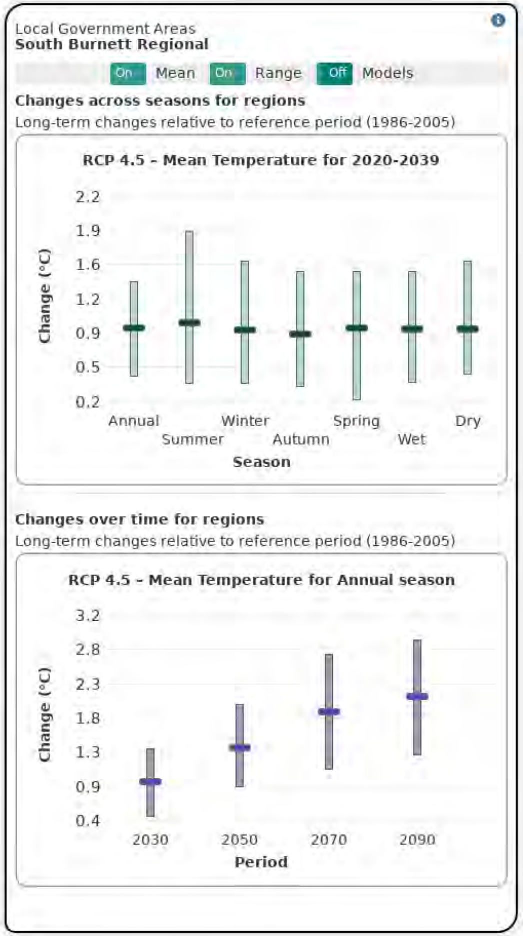


Figure 98: Toowoomba Region – Temperature prediction based on RCP4.5 & RCP8.5



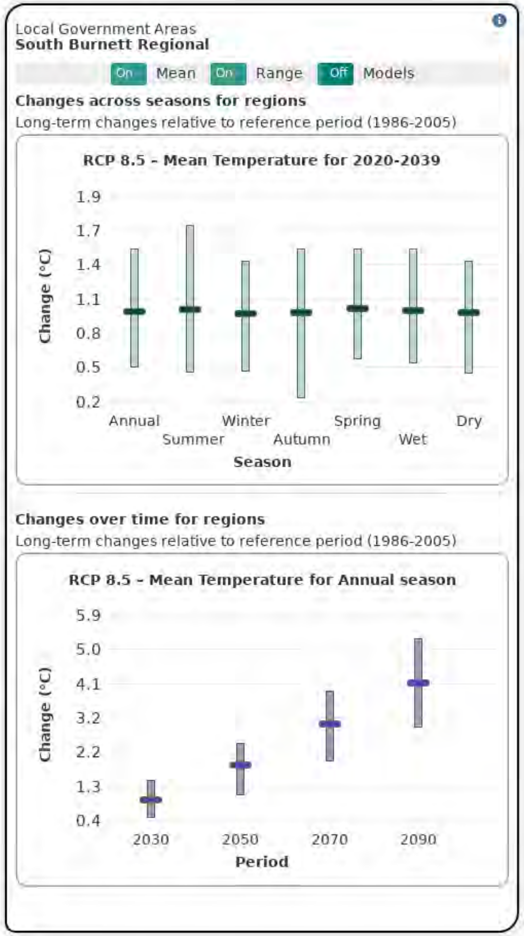


Figure 99: South Burnett Region– Temperature prediction based on RCP4.5 & RCP8.5

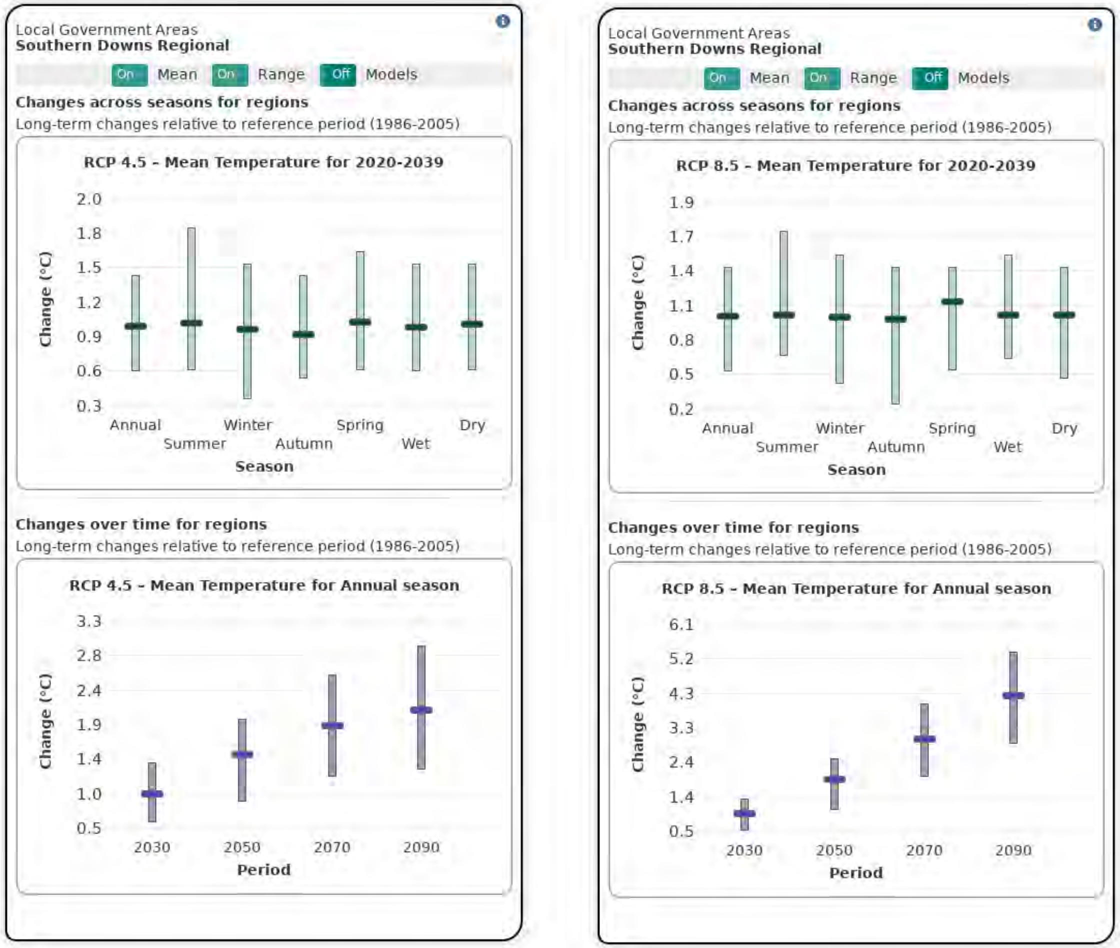
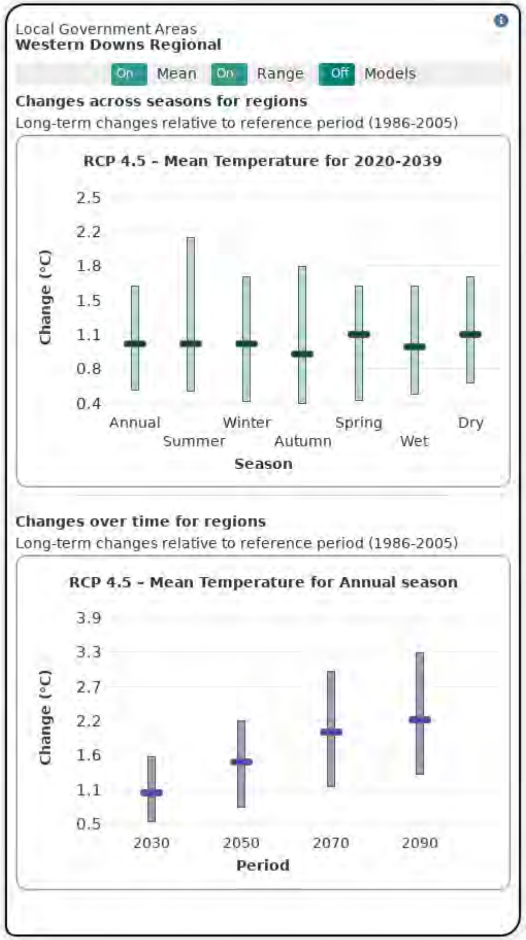


Figure 100: Southern Downs Region– Temperature prediction based on RCP4.5 & RCP8.5



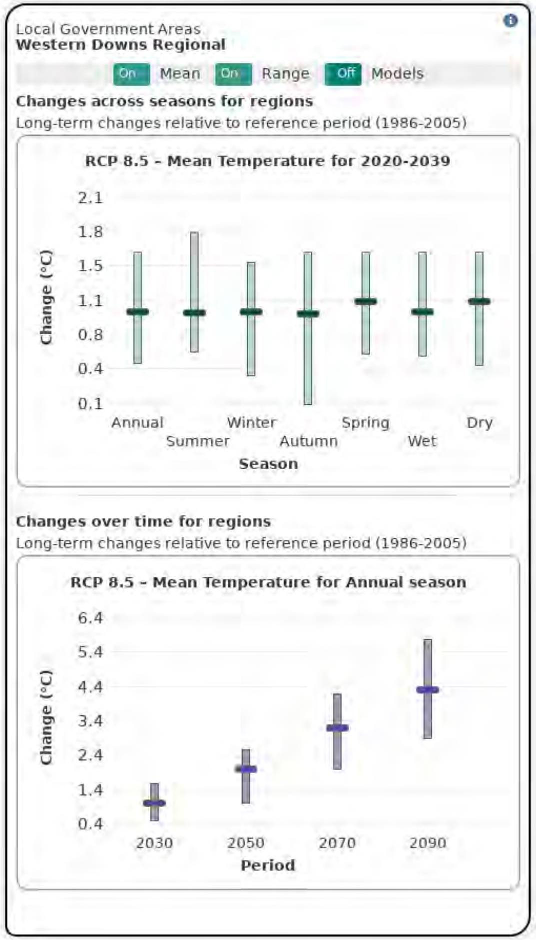
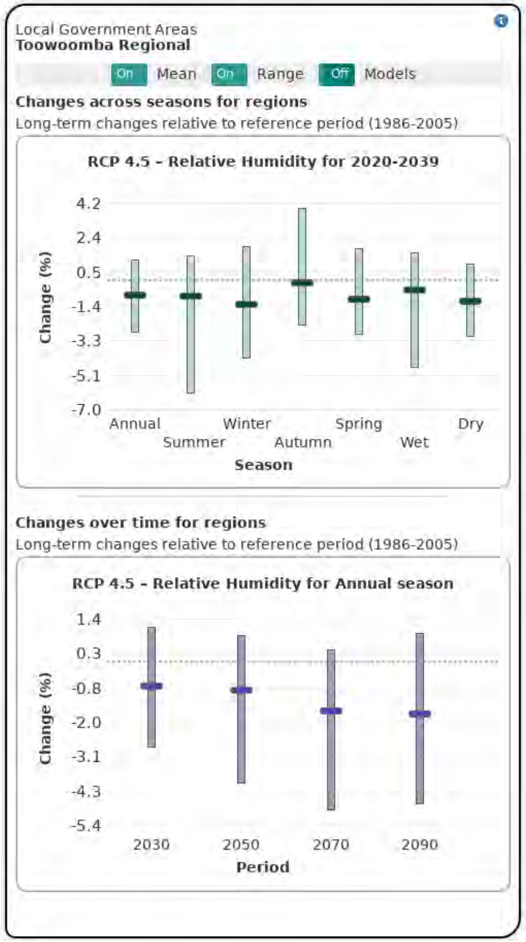


Figure 101: Western Downs Region– Temperature prediction based on RCP4.5 & RCP8.5

Relative humidity



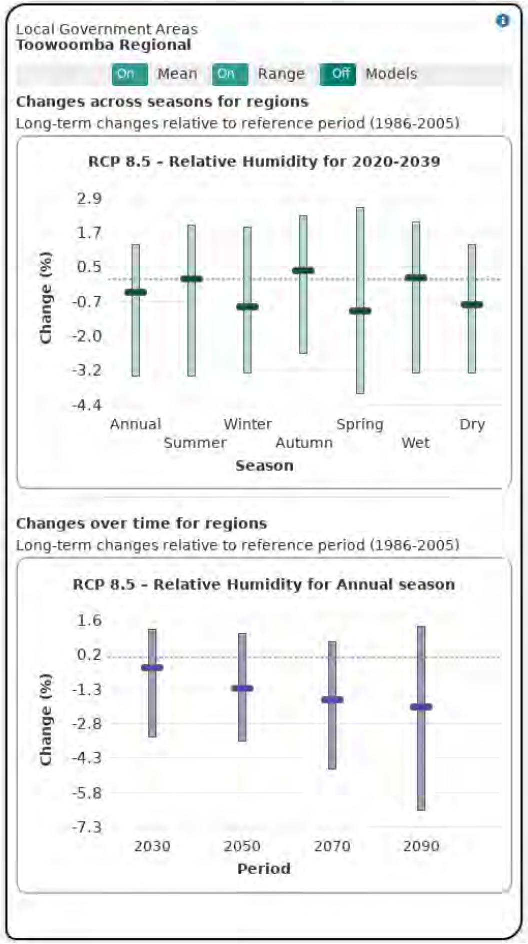


Figure 102: Toowoomba Region – Relative Humidity prediction based on RCP4.5 & RCP8.5

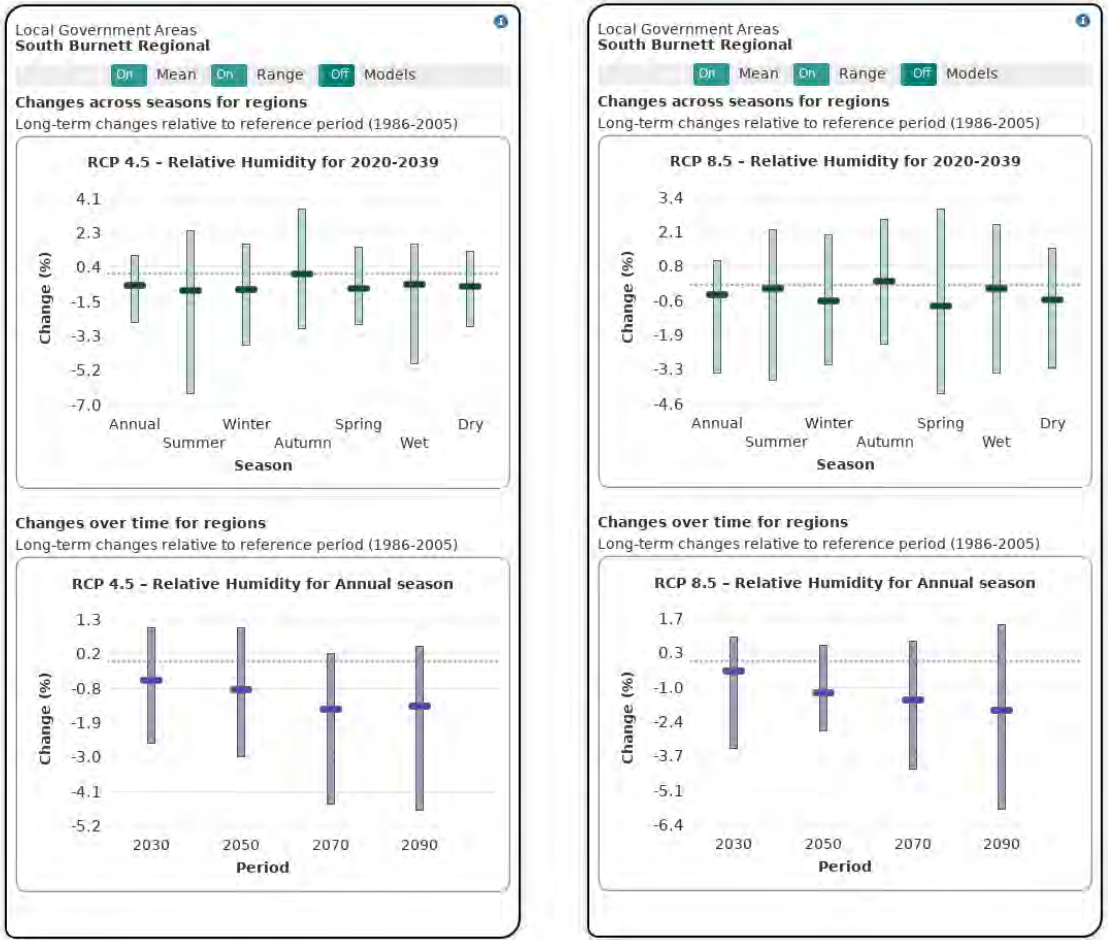


Figure 103: South Burnett Region – Relative Humidity prediction based on RCP4.5 & RCP8.5

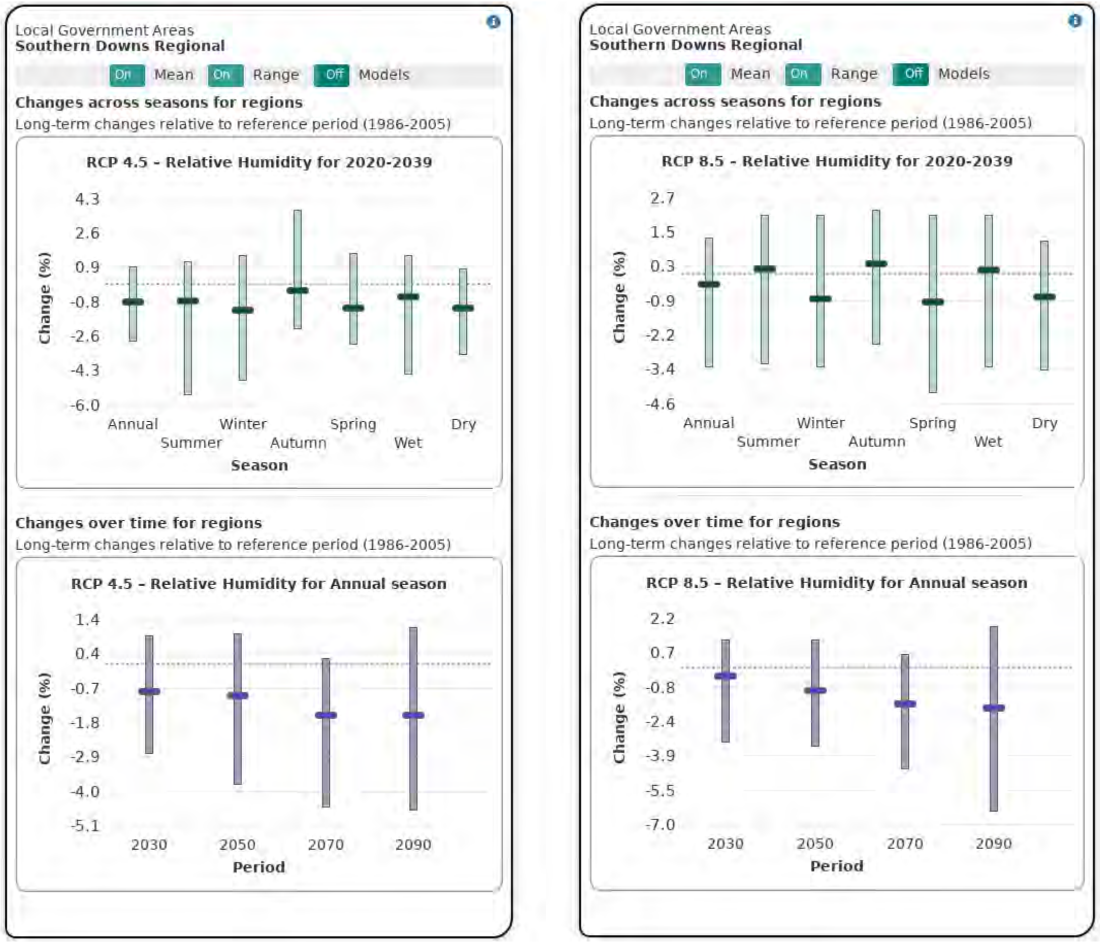


Figure 104: Southern Downs Region – Relative Humidity prediction based on RCP4.5 & RCP8.5

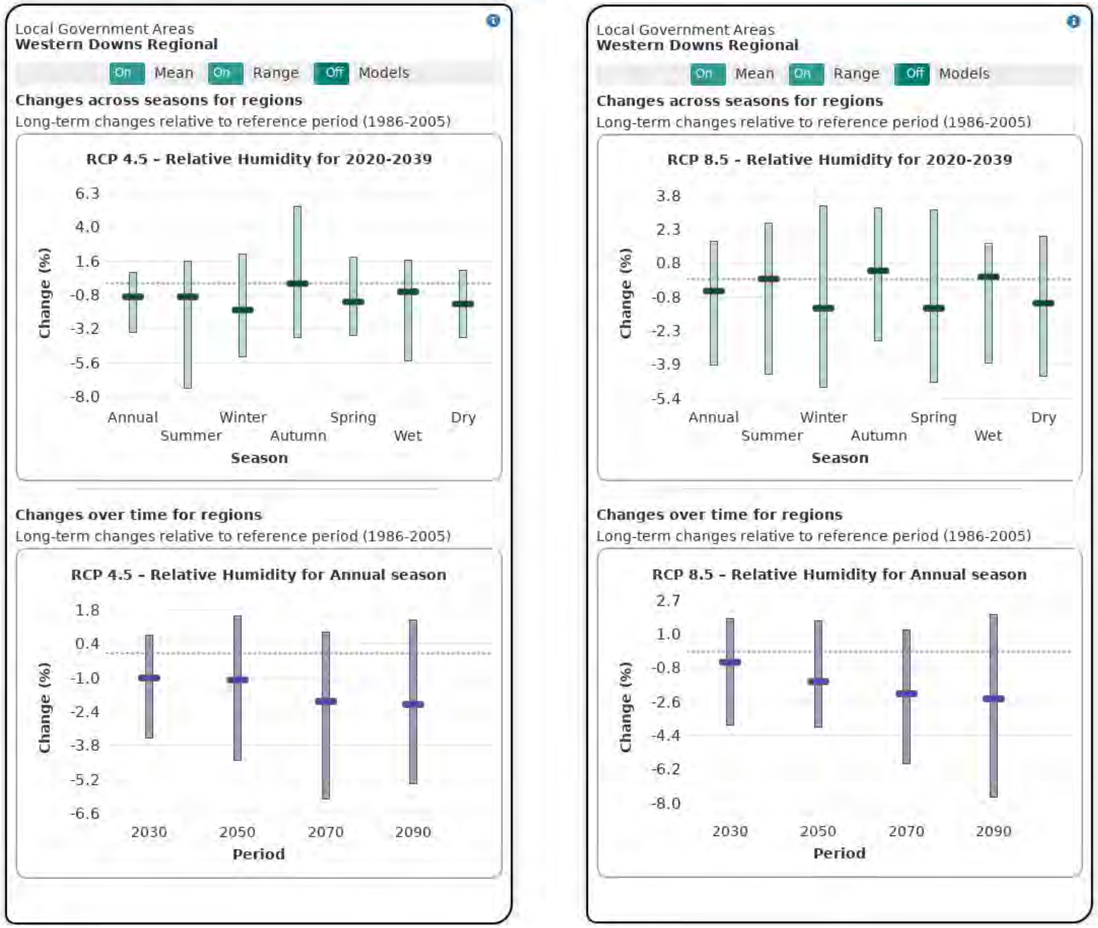
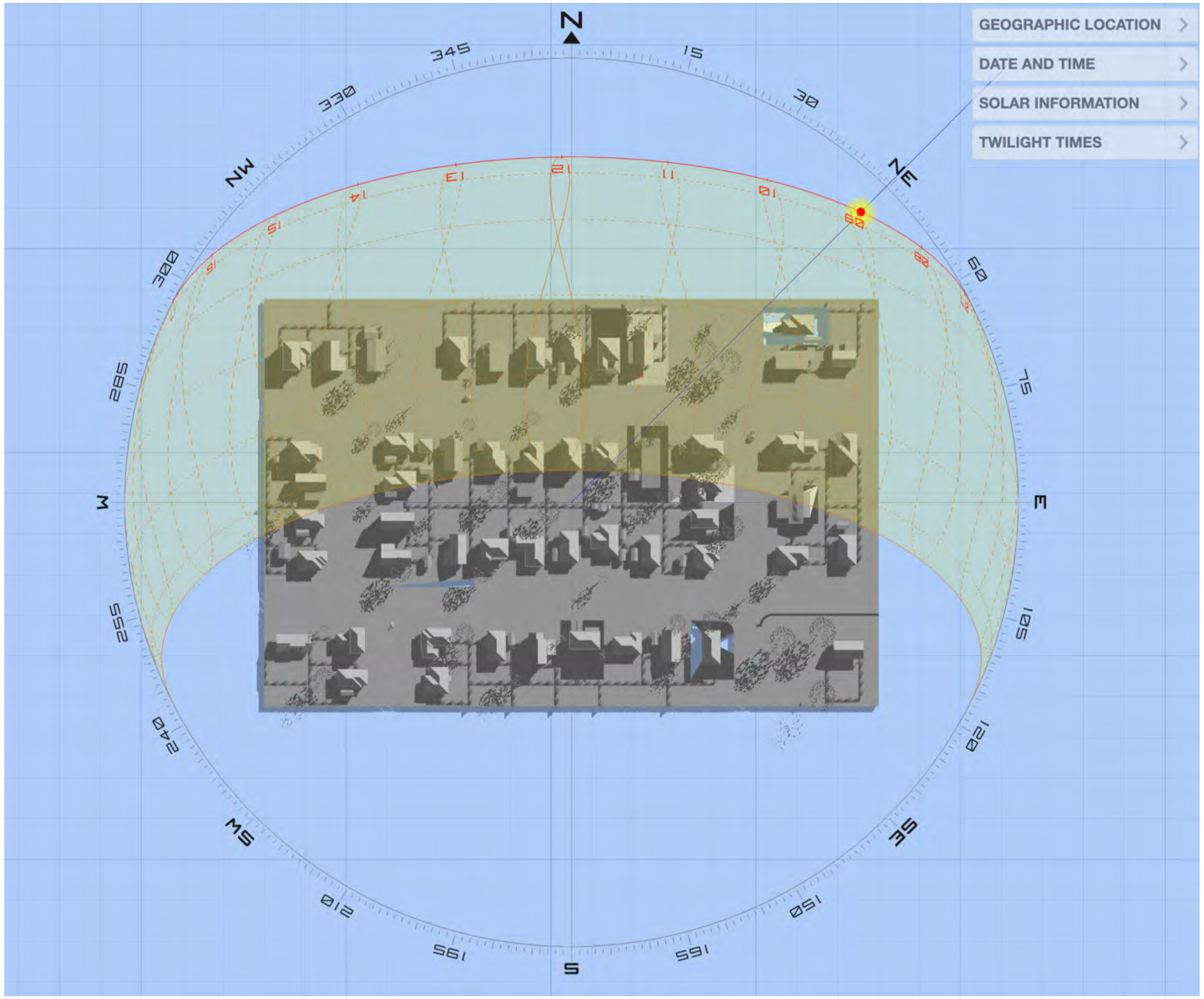
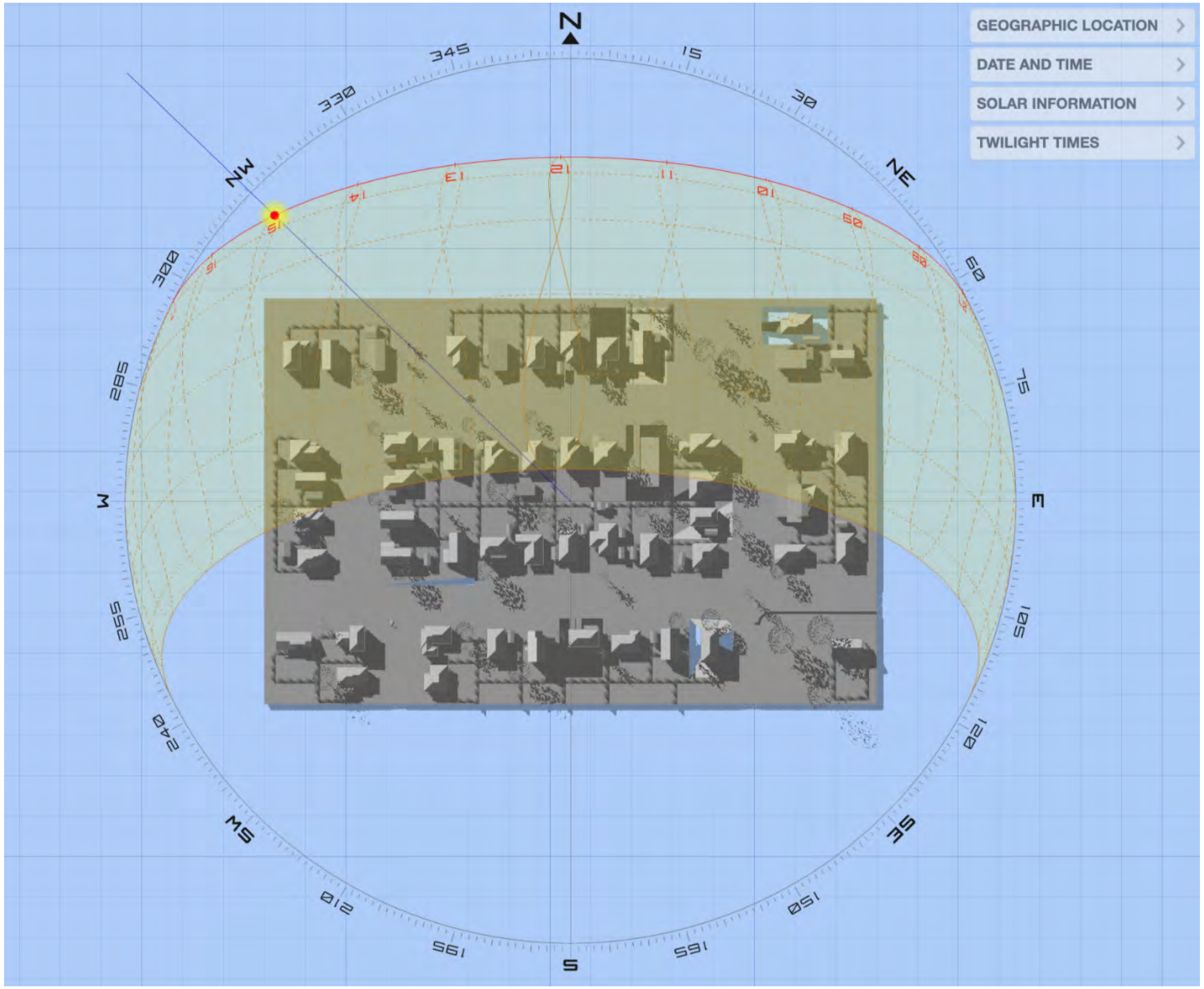


Figure 105: Western Downs Region – Relative Humidity prediction based on RCP4.5 & RCP8.5

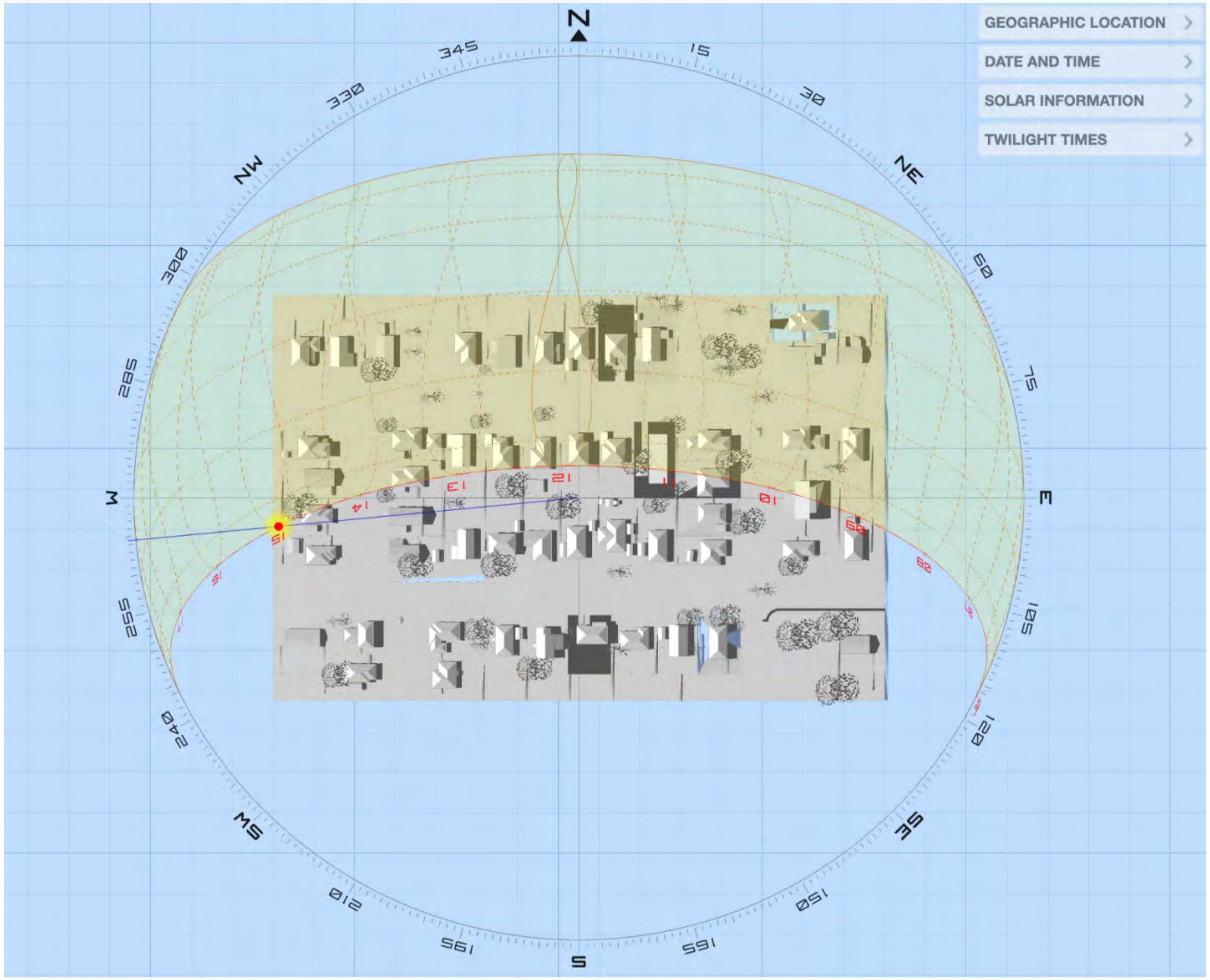
Toowoomba Low Density and High Density Sun Studies



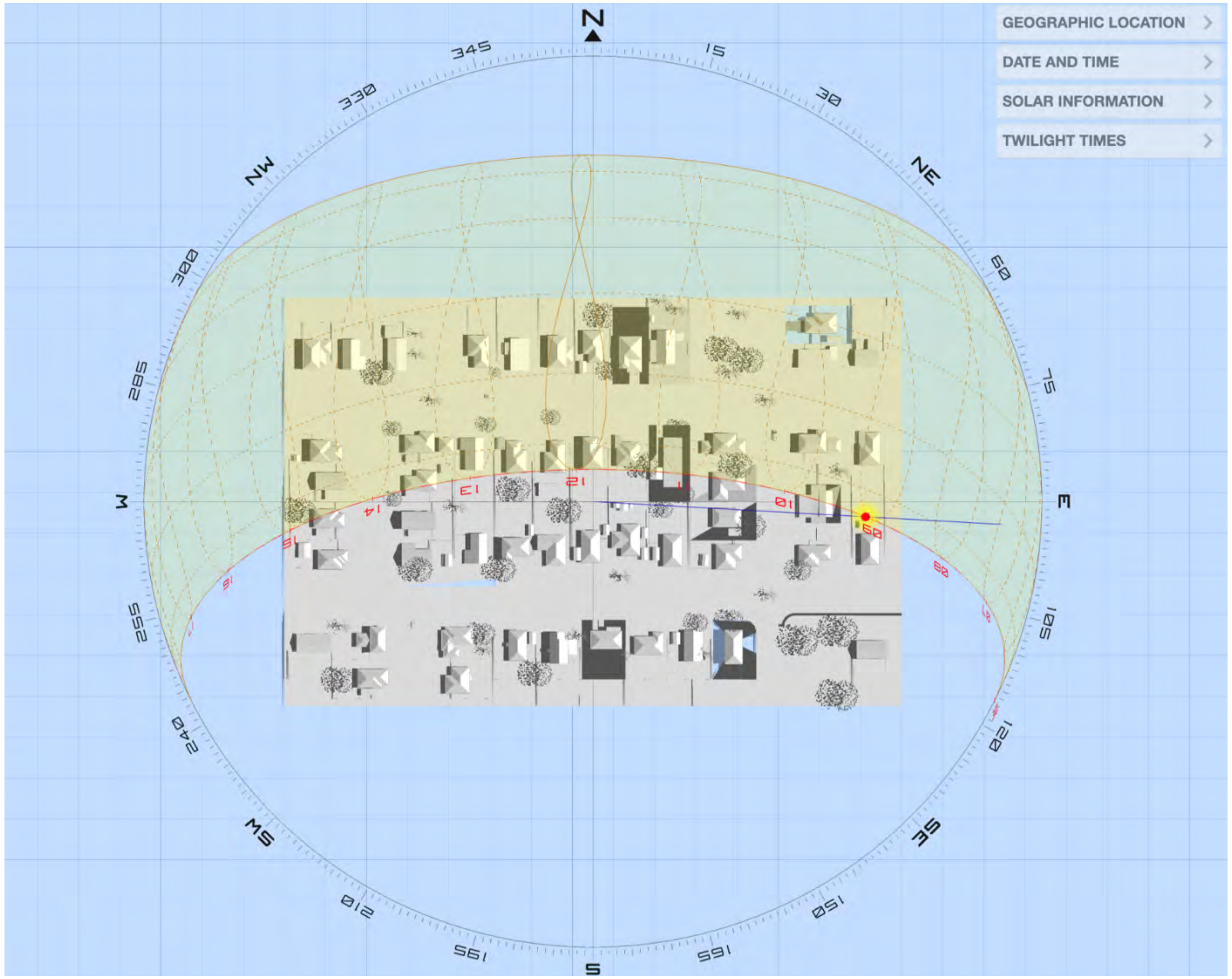
Low Density Winter 9am Sun study



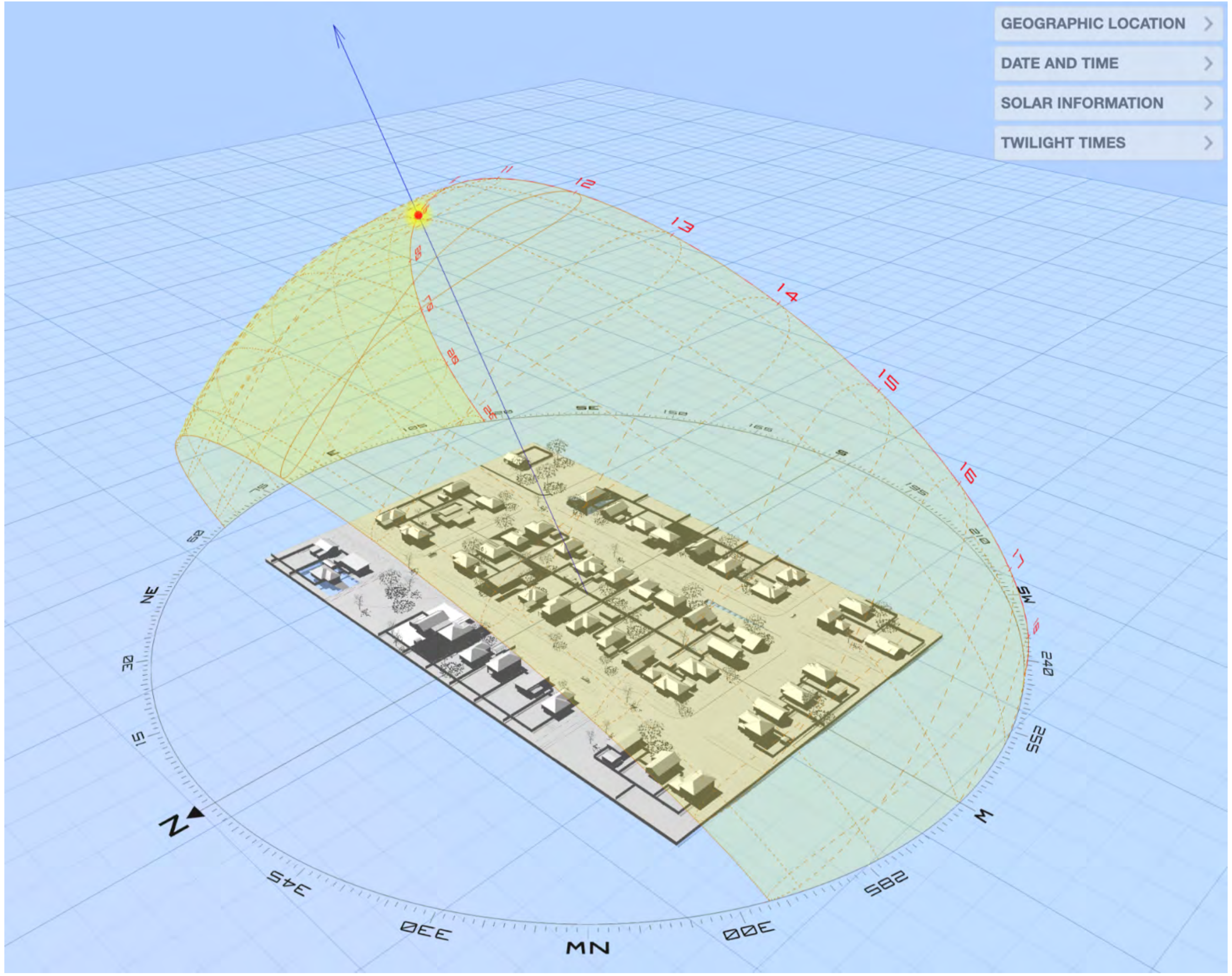
Low Density Winter 3pm Sun study



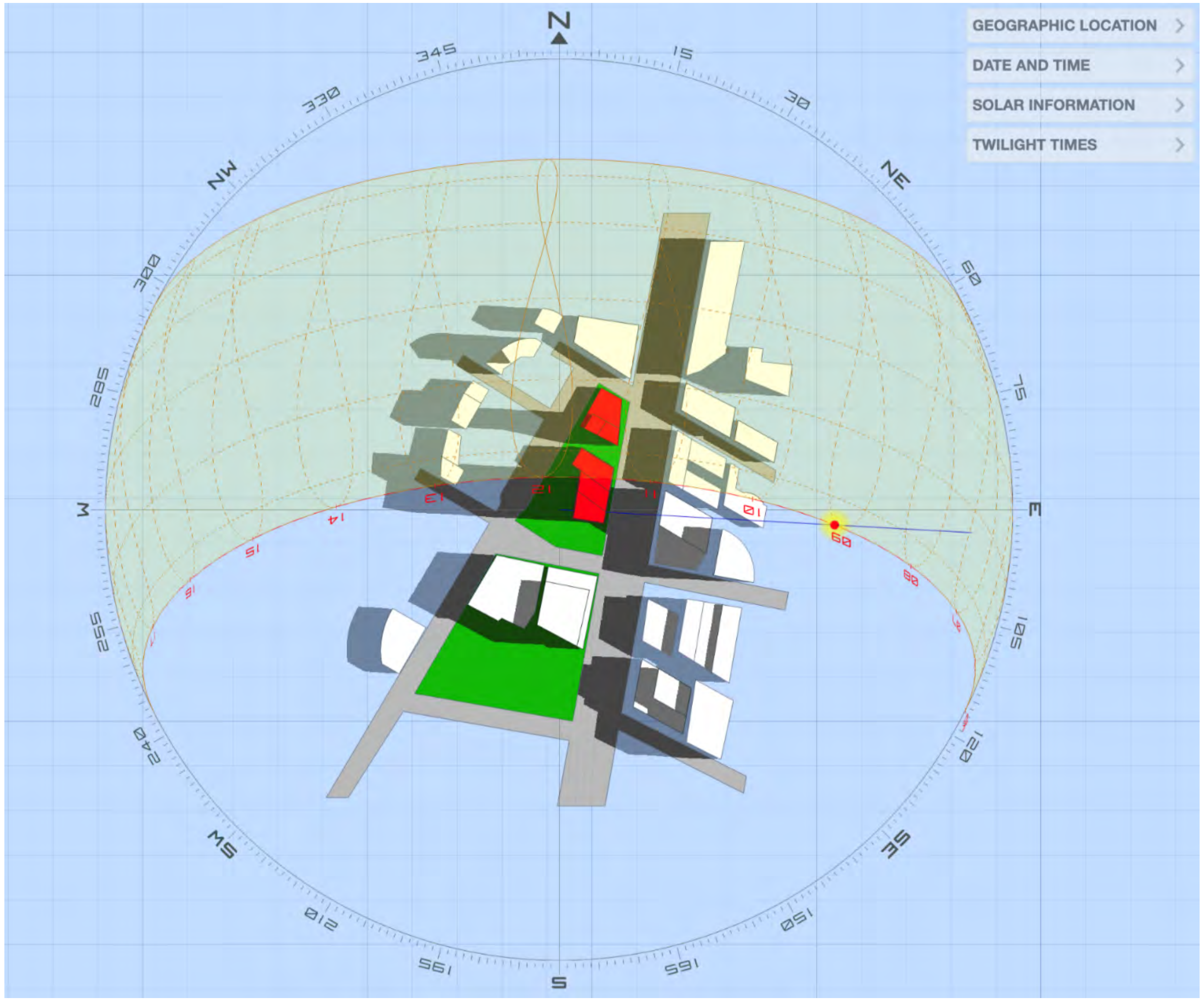
Low Density Summer 3pm Sun study



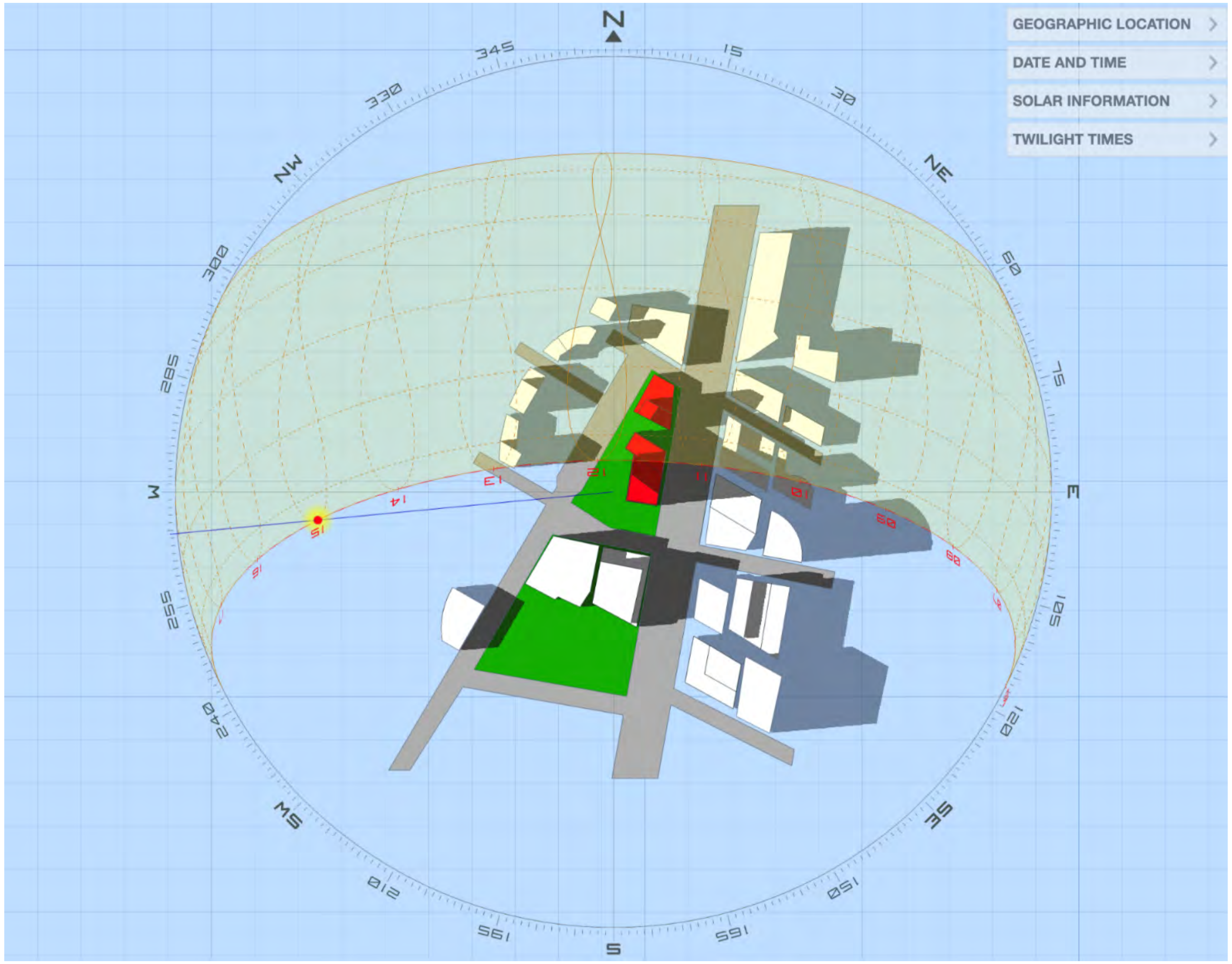
Low Density Summer 3pm 9am study



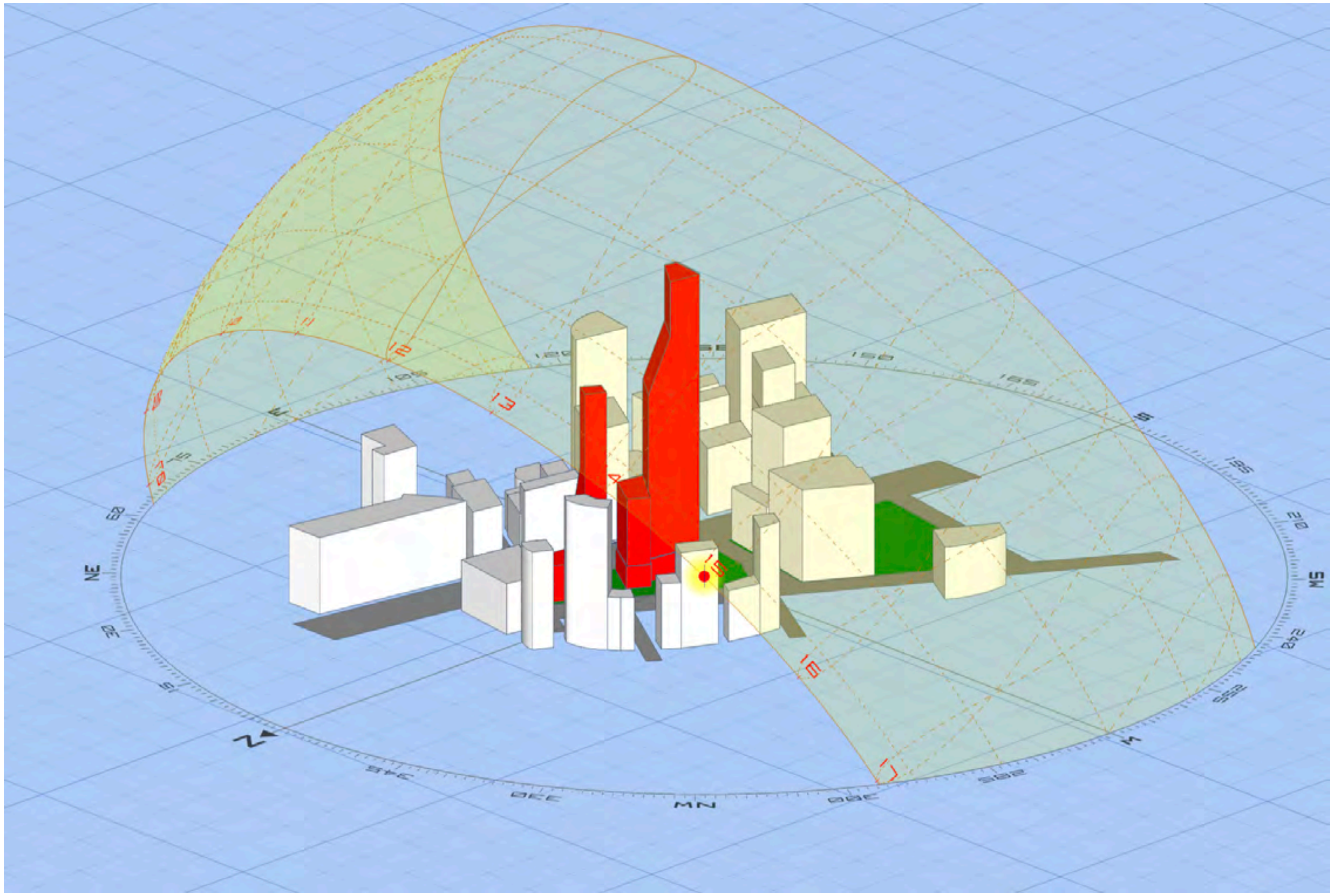
Low Density Sun Study Model



High Density Summer 9am Sun Study Model



High Density Summer 3pm Sun Study Model



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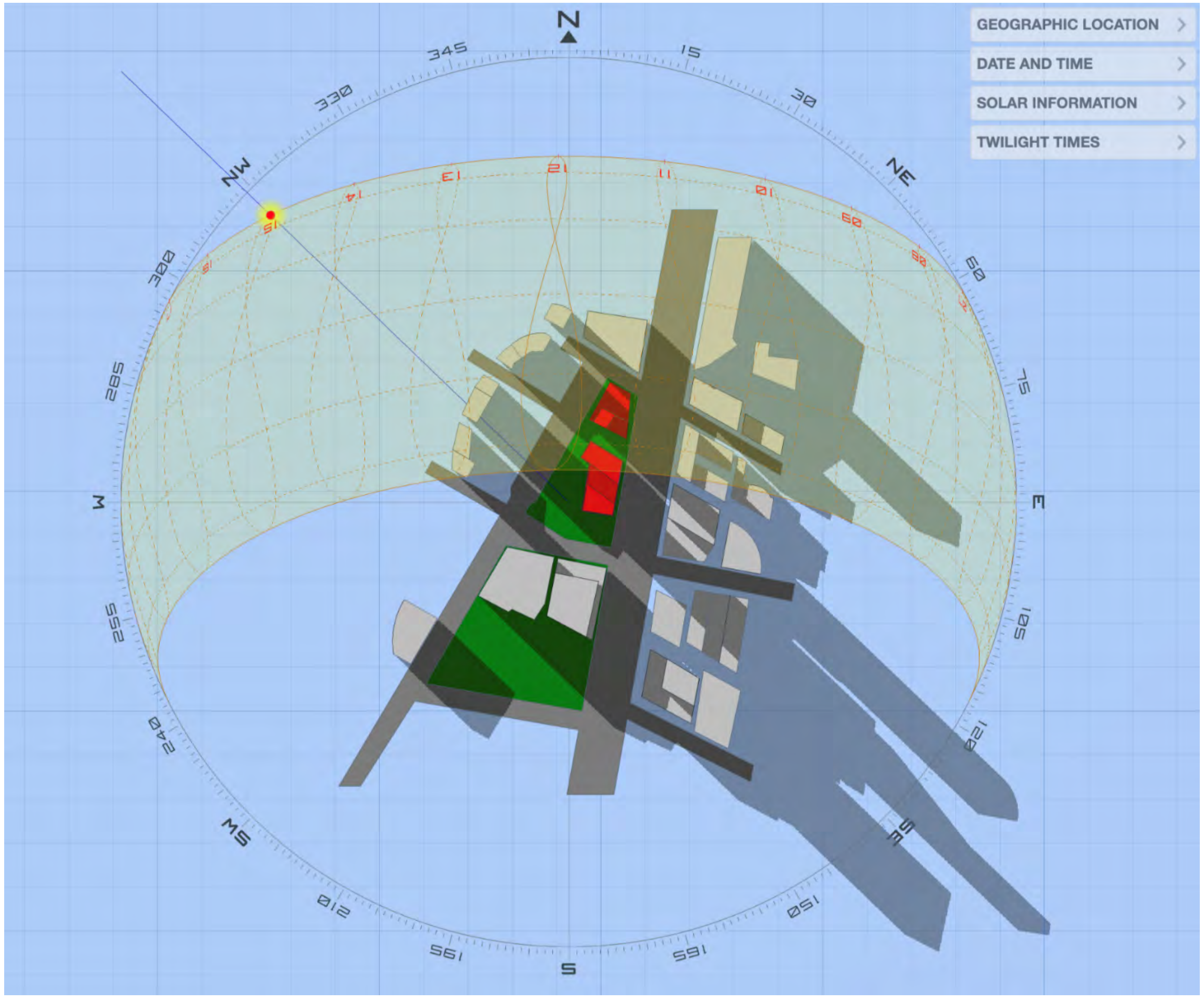

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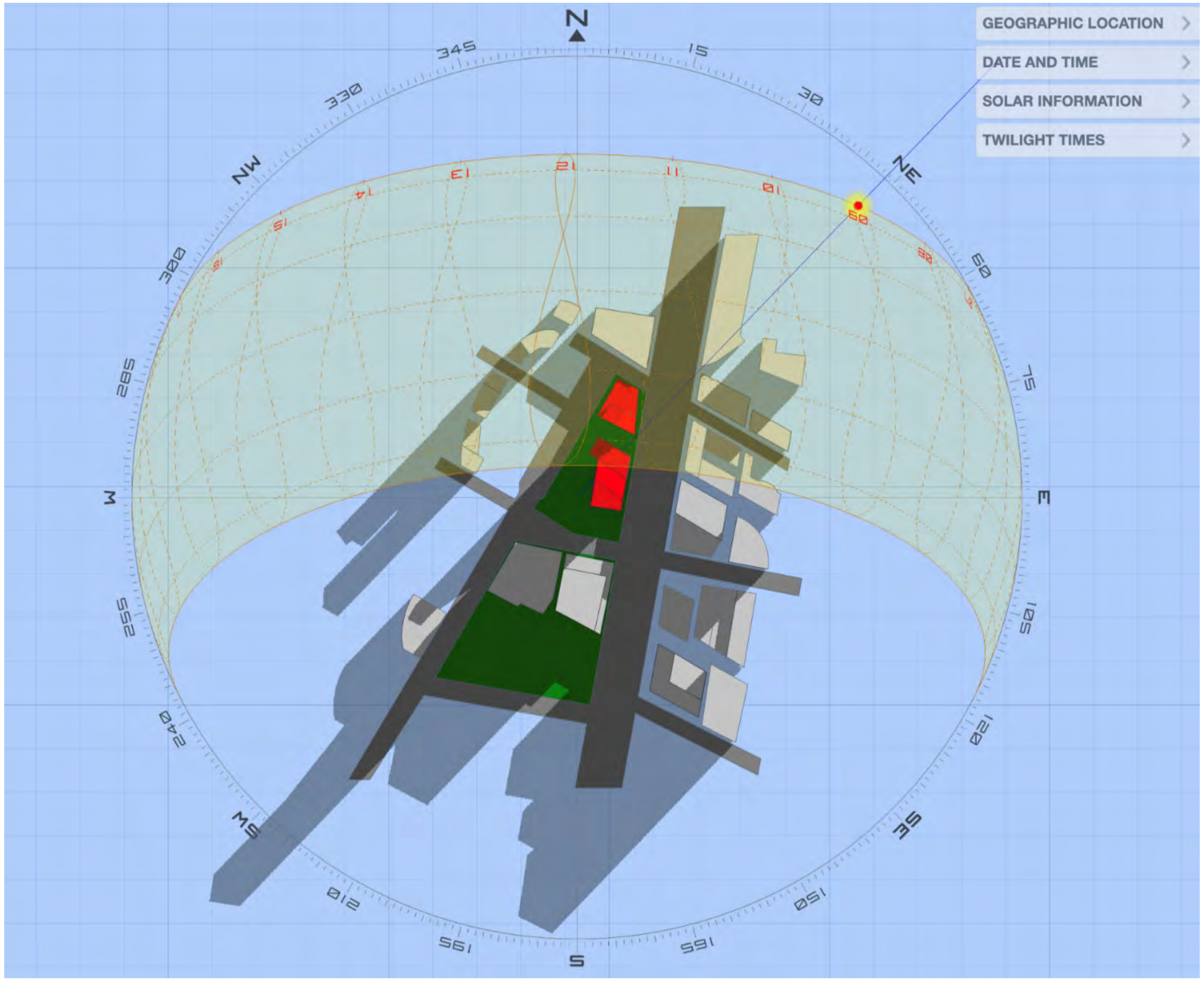

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