

IVG Forest Conservation Report 6

Future climate projections for Tasmanian IBRA regions

A report to the Independent Verification Group for the Tasmanian Forest Agreement

Produced by M. Grose, R.Harris and G.Lee, ACE CRC, Jan 2012, using material from the set of
Technical reports of the Climate Futures for Tasmania project

Future climate projections for Tasmanian IBRA regions

The Climate Futures for Tasmania (CFT) project generated climate projections specific to Tasmania to the year 2100 using the most recent climate modelling techniques available. Fine-scale climate modelling was achieved using CSIRO's Conformal Cubic Atmospheric Model (CCAM) to dynamically downscale outputs from the most recent set of global climate model (GCM) simulations. Downscaling retains the projection of global change indicated by the GCMs, and adds relevant detail at the regional scale, making the outputs appropriate for distinguishing different regions of Tasmania. A full account of the modelling strategy and methods used are presented in the CFT modelling technical report (Corney et al 2011).

Fine-scale model projections of Tasmanian climate were made for two hypothetical but plausible scenarios of human emissions for the 21st Century (taken from the special report on emissions scenarios (SRES) from the Intergovernmental Panel on Climate Change (IPCC)). The scenarios are of ongoing high emissions, A2, and one where emissions plateau and fall, B1. The climate response under the two scenarios is similar through the first half of the century, but the changes under the higher emissions scenario become much stronger than the lower scenario in the latter half of the 21st Century. The last decades of the century show a rapidly rising temperature under the high emissions scenario, but a levelling off under the low emissions scenario.

The CFT project produced multi-model ensemble simulations based on downscaling of six GCMs which were reported on in the IPCC Fourth Assessment Report (CSIRO-Mk3.5, GFDL-CM2.0, GFDL-CM2.1, ECHAM5/MPI-OM, UKMO-HadCM3 and MIROC3.2 (medres)). The six models were chosen for their performance over the Australian region. The focus in this report will be on the results of the ensemble of all the models rather than any one particular simulation, because multi-model ensemble simulations generally provide more robust information than simulations from any single model (Meehl et al 2007). Corney *et al* 2011 provide a full discussion of the uncertainties associated with modelling climate projections.

The Climate of Tasmania

Tasmania has a temperate maritime climate where temperature is moderated by the surrounding seas. There is an average daily temperature range of approximately 7°C at the coast, increasing to around 14°C inland. The seasonal temperature range is relatively small, with mean maximum temperatures of 18°C to 23°C in summer and 9°C to 14°C in winter (Bureau of Meteorology 1993).

Tasmania is mountainous in the west, central and north-east regions, affecting the flow of air over land and maintaining three distinct rainfall zones, of roughly equal size, in the east, west and north. Mean annual rainfall varies from less than 600 mm in the central midlands to more than 3000 mm near the west coast. There is a steep gradient in total annual rainfall from the western region across the eastern central plateau, resulting in a rain shadow region over the central midlands, east coast and south east regions. The midlands receives the lowest rainfall of any region in Tasmania. The west coast has a distinct seasonal cycle with the highest rainfalls in winter and early spring. There is a smaller but still distinct annual cycle in rainfall in the north, with the peak of the rainfall cycle occurring through autumn to winter. There is no distinct annual cycle in the eastern zone, with approximately 50 mm to 70 mm falling each month of the year.

Interim Biogeographic Regionalisation for Australia (IBRA regions)

The Bureau of Meteorology divides Tasmania into seven forecast districts representing distinct climate zones. The IBRA regions broadly align with these climate zones, but with greater boundary detail and the addition of the Southern Ranges and Northern Slopes regions, and the separation of the coastal strip of the Flinders Region on the north-east Tasmanian coast.

There is considerable variability both within and between the 9 IBRA regions in Tasmania in terms of current and projected future climate conditions. Following an overview of the broad changes projected for Tasmania, we provide a summary by IBRA region. The short descriptions of the Tasmanian bioregions were derived from unpublished information provided by the Department of Primary Industries, Parks, Water & Environment. We report on mean values of six model simulations, as a 'central estimate' of changes within each region. A box plot is provided to summarize the projections for rainfall for current (1961-1990) and future (2070-2099) time periods for each region. In these figures the box indicates the interquartile range, the bar provides the median, the whiskers extend up to 1.5 times the interquartile range and outliers are shown explicitly. These graphs provide an indication of the variability between the models.

Climate Projections for Tasmania (from CFT project)

a) Temperature

- Tasmanian temperatures have risen at an average rate of 0.1°C per decade since the 1950's (Figure 1). This is a lower rate than for mainland Australia (0.16°C), and the global average ($\sim 0.17^{\circ}\text{C}$). Under the higher emissions scenario (A2), Tasmania is projected to experience a rise in average temperatures of 2.6 to 3.3°C over the entire 21st Century (Figure 1). This change is also less than for mainland Australia and the global average (Figure 2). The rise in daily minimum temperature is expected to be slightly greater than daily maximum temperature. Temperature change is projected to be fairly uniform between the IBRA regions within Tasmania, and fairly similar in the different seasons (Table 1). Under the lower emissions scenario (B1), the projected change over the entire century is 1.3 to 2.0°C
- Rises in mean temperature are projected to be similar in all of the IBRA regions. Daily minimum temperatures are projected to rise slightly more than daily maximum temperatures

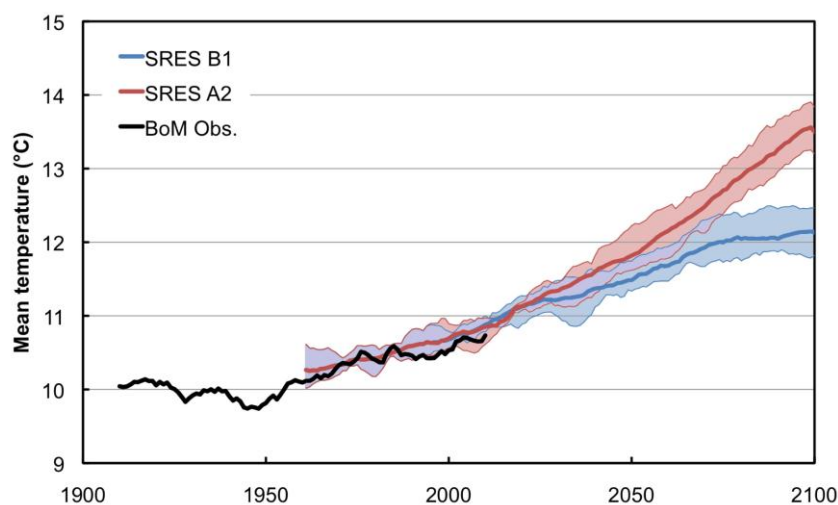


Figure 1. Tasmanian average temperature in observations (black) and model projections for the A2 scenario (red) and the B1 scenario (blue), all series are smoothed (11-year running average), shading shows the range of model projections. Changes under the higher scenario by the very end of the century (box) are discussed in the examples below

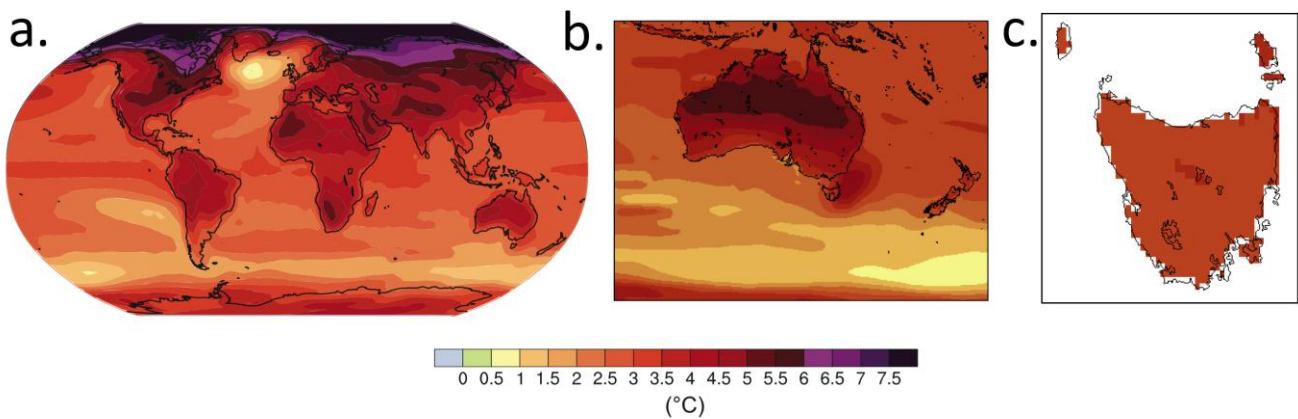


Figure 2. Projected difference in mean temperature between 1980-1999 and 2090-2099, a) the mean of 23 GCMs for the globe (adapted from IPCC 2007), b) for the Australian region, mean of six 0.5 ° resolution models, CFT project, c) for the Tasmanian land area, mean of six 0.1 ° models, CFT project

Table 1. Projected change in mean temperature (°C) in the Tasmanian IBRA regions between 1961-1990 to 2070-2099 under the A2 emissions scenario, multi-model mean of six models made in the CFT project **Note different time period to above*

Region	Code	J	F	M	A	M	J	J	A	S	O	N	D
Ben Lomond	BEL	2.8	2.8	2.9	2.8	2.8	2.6	2.4	2.4	2.3	2.6	3.0	2.9
Tas. Northern Midlands	TNM	3.0	2.8	2.8	2.7	2.7	2.5	2.4	2.4	2.3	2.5	2.9	3.0
Tas. South East	TSE	2.7	2.6	2.6	2.5	2.7	2.6	2.5	2.5	2.4	2.6	2.8	2.7
Tas. West	TWE	2.7	2.7	2.6	2.4	2.5	2.4	2.3	2.2	2.0	2.2	2.5	2.5
Tas. Southern Ranges	TSR	2.7	2.6	2.5	2.4	2.6	2.5	2.4	2.3	2.2	2.4	2.6	2.6
Tas. Central Highlands	TCH	3.1	2.9	2.8	2.7	2.7	2.5	2.4	2.3	2.2	2.5	3.0	3.0
Tas. Northern Slopes	TNS	3.0	2.9	2.9	2.7	2.6	2.4	2.3	2.2	2.1	2.3	2.8	2.8
King	KIN	2.7	2.8	2.7	2.5	2.4	2.3	2.1	2.1	2.0	2.1	2.5	2.5
Flinders	FLI	3.0	3.0	3.1	2.9	2.8	2.7	2.5	2.5	2.4	2.6	2.9	2.9

b) Rainfall

- The model projections indicate that the general long-term influence of climate warming by the end of the century is for mean annual rainfall across Tasmania to remain within the historical range of 1390 ± 200 mm, but with significant changes in the spatial and seasonal patterns of rainfall across the state
- There is projected to be increased annual rainfall over the coastal regions and reduced annual rainfall over central and northwest Tasmania
- The changes in seasonal rainfall are much greater than for annual total rainfall. The west coast of Tasmania shows a steadily emerging pattern of increased rainfall in winter and decreased rainfall in summer (changes under A2 scenario is shown in Figure 3). The central plateau district shows a steady decrease in rainfall in every season throughout the 21st century. A narrow strip along the northern east coast shows a steady increase in autumn and summer rainfall (Figure 3)
- The projected pattern of change to rainfall and runoff is similar in nature between the B1 and A2 scenarios, but stronger by the end of the century under the A2 scenario
- There is a tendency for heavier rainfalls interspersed by longer dry periods, and for greater extremes, but this varies in different areas
- The long-term effect of greenhouse warming is on top of the usual cycles of rainfall, including droughts, termed ‘natural variability’. The model projections indicate that the recent dry conditions of the ‘big dry’ drought is not a new ongoing climate average state

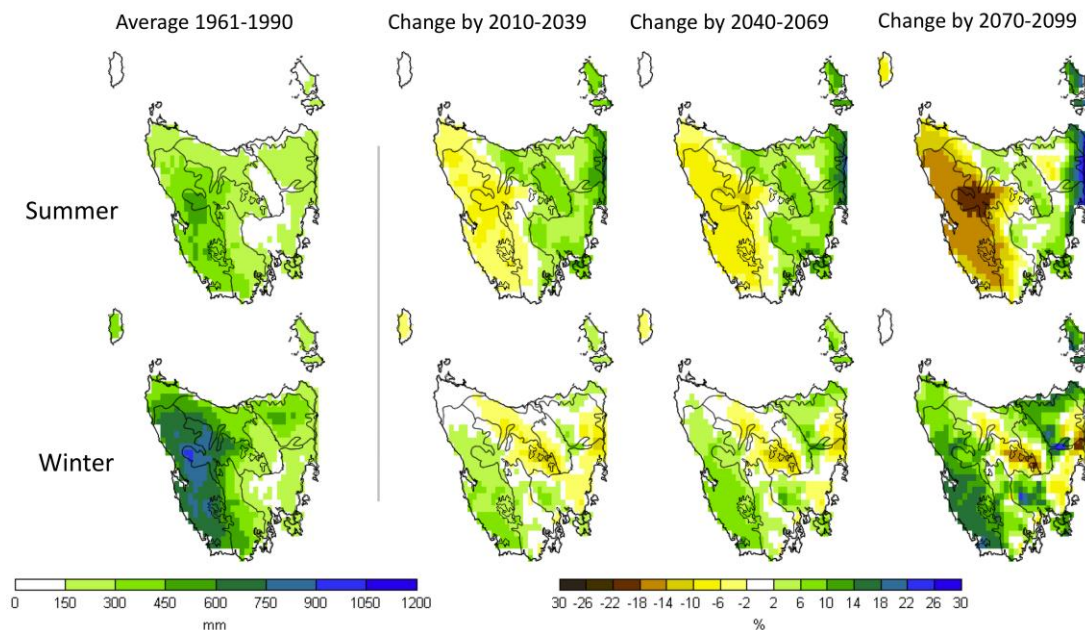


Figure 3. Average rainfall in summer and winter – the left hand side plots show the average rainfall in the baseline period (1961-1990), the plots to the right show the proportional change (%) from that amount in various periods in the 21st century in the average of six climate model projections under the A2 (higher) emissions scenario. Lines show the boundaries of the IBRA regions.

c) Cloud, Radiation, Relative humidity and Evaporation

- Total cloud cover over Tasmania is projected to decrease slightly (< 5%) by the end of the century under the A2 scenario, with a spatially complex pattern of change. The response is different in each season, with the greatest reduction in cloud cover over the west coast in summer. These changes lead to corresponding changes in radiation, including an increase in radiation in the west in summer
- Annual average relative humidity under the A2 emissions scenario is projected to increase slightly over much of Tasmania (0.5 to 1.5%), except for the Central Highland region where a slight decrease is projected. There is a different spatial pattern of change in summer compared to winter
- Pan evaporation is projected to increase across Tasmania, by up to 19% under the A2 scenario by the end of the century, driven by the increases in temperature but also changes to relative humidity, wind speeds, cloudiness and radiation
- Actual evapotranspiration from the land surface given the modelled water availability is also projected to increase through the century. The increase is greatest over a strip along some coasts. This increase is proportionally greater in winter than in summer when there is more water to evaporate. There is a slight decrease in evapotranspiration near the west coast in summer where evapotranspiration becomes more water-limited

d) Runoff and River Flows

- Changes to rainfall and evaporation lead to changes in water runoff and river flows. This in turn has impacts on the inflows into dams and water storages. Changes to mean runoff show the same sign of change as rainfall, but changes are generally magnified (where a small change in rainfall leads to a proportionally larger change in runoff)
- Mean runoff in the western region is projected to decrease in summer and increase in winter, with the largest changes possibly exceeding 60%. Mean runoff in the midlands and east coast regions is projected to increase in most seasons, again with changes exceeding 60% possible
- Runoff amounts during high events are projected to increase in much of the midlands and coastal regions, which is likely to have effects on erosion and local flooding. Runoff during low events is projected to decrease in much of the western region
- River flows and inflows to dams and power stations are projected to stay the same or increase in many coastal sites, but generally decrease in the highlands. The seasonality of many river flows is projected to change

e) Extremes indices

- As expected with an increase in mean temperature, there is projected to be an increase in the number of hot days, warm spells and hot days, as well as an increase in the temperature of the hottest days and the length of warm spells. Conversely, there is projected to be a decrease in the number of frosts, cold days, cold waves and a decrease in the length of cold spells, and an increase in the temperature of the coldest days
- There is projected to be a large decrease in the number of frost-risk days (where daily minimum temperature at the surface is less than 0°C), through the century. The greatest decreases are projected at higher elevations that currently experience the highest number of frosts (e.g. frost-risk days decrease at Miena/Liawenee by 63 days per annum (50%) by 2070-2099 under the A2 scenario)
- There is projected to be a large increase in the number of summer days (daily maximum temperature >25°C) across the whole of Tasmania, with larger increases occurring at lower elevations particularly throughout the midlands, which are projected to experience up to a threefold increase

- As mentioned above, the projections indicate with a warming climate there is a tendency for heavier rainfalls interspersed with longer dry periods. This is expressed as less rain days per year (up to 15 days per year less for some areas), more rainfall per rain day (up to 1.5 mm/day), higher instantaneous rainfall rates (up to 30%), generally more very wet days (up to 7.5 days more), and more rainfall on wet days (up to 45%)
- Extreme rainfalls are projected to increase. Rainfall brought by Average Recurrence Intervals (ARI) is projected to increase (from ARI-10 through to ARI-500). The areas that already experience the most extreme rainfalls are projected to encounter the greatest increases – e.g. at St Helens the baseline ARI-200 of 145 mm is projected to increase by 92% by the end of the century

f) Extreme sea level events

- High water events causing coastal inundation comes from a combination of sea level, tide, storm surge and wind waves. Sea level has been rising at a rate of 3.3 ± 0.4 mm/year in the recent period, and is expected to continue rising with further climate warming. The last IPCC assessment report gave a central estimate of a rise of 0.82 m global average sea level by 2100 under a high emissions scenario. Projected sea level rise varies in different locations, and for the coasts of Tasmania the sea level rise for this scenario is close to the global average
- The contribution of extreme tide height and storm surge to extreme sea level events varies around the coast of Tasmania. The climate change projections indicate that effects from changes to storm surges are likely to be negligible compared to that of sea level rise. The sum of all effects means that a present 100 year event is projected to be a 2 to 6 year event in many places

g) Adaptation potential

There is growing evidence that plant and animal species are able to respond to increases in temperature by moving poleward and upward in elevation (Hughes 2000, 2003; Root et al 2003). Parmesan and Yohe (2003) report on a systematic poleward shift of species of around 6.1 km per decade. Within Tasmania, there are limited options to respond to changes in temperature profiles through latitudinal shifts. However, the potential exists for mobile species to offset increases in temperature at low elevations by shifting to higher, cooler elevations. Opportunities for movement to higher elevations will depend not only on changed temperature profiles but also on adequate rainfall, suitable soils and a suitable topography.

Plant and animal communities already restricted to high altitudes (e.g. on the Central Highlands) will be under increasing threat as temperatures at higher altitudes increase.

At the same time, increased temperatures and more growing degree days at higher elevations will provide opportunities for crops and pastures to spread into previously unsuitable higher elevation areas, potentially leading to pressure for land use change. Holz et al (2010) identified several areas that are currently primarily temperature-limited but with soils and topography capable of supporting higher intensity agricultural production under warmer temperatures. Some of these areas include a strip along the north-west coast, parts of the north-east above Ringarooma, parts of central Tasmania from Bothwell across to Tarraleah and limited areas in the Huon. For example, modelling of Growing Degree Days (GDD) along an altitudinal gradient from Burnie to Waratah suggest that cropping will become possible to altitudes of 450 m asl. by 2030 and greater than 500m asl. by 2050.

h) Growing Degree Days

In the absence of a specific growth model for particular organisms, Growing Degree Days (GDD) can be used to relate temperature and biological response. GDD is a cumulative thermal unit, calculated from daily minimum and maximum air temperature, used to indicate the time available for development above a temperature threshold (commonly 10°C). There is projected to be a gradual increase in annual GDD across Tasmania from 1961 to 2100 (Figure 4). The growing season is also projected to begin earlier in the year.

Although commonly used for agricultural applications, changes in GDD are also likely to have significant implications for native vegetation due to changes in, for example, growth rates of vegetation. They are likely to change the competitive advantage of different plant species. This change in competitive advantage is likely to lead to changes in the distributions of species and of communities. The projections suggest that the higher elevation sites will experience the greatest relative increases in GDD. This is particularly likely to have an impact on those species that exist within narrow elevation intervals. There are also likely to be other indirect impacts on native plant communities through changes to the population dynamics of herbivores, particularly insects, and on the parasites that feed on those herbivores. These are complex changes that are difficult to predict with any certainty, and need to be evaluated case by case.

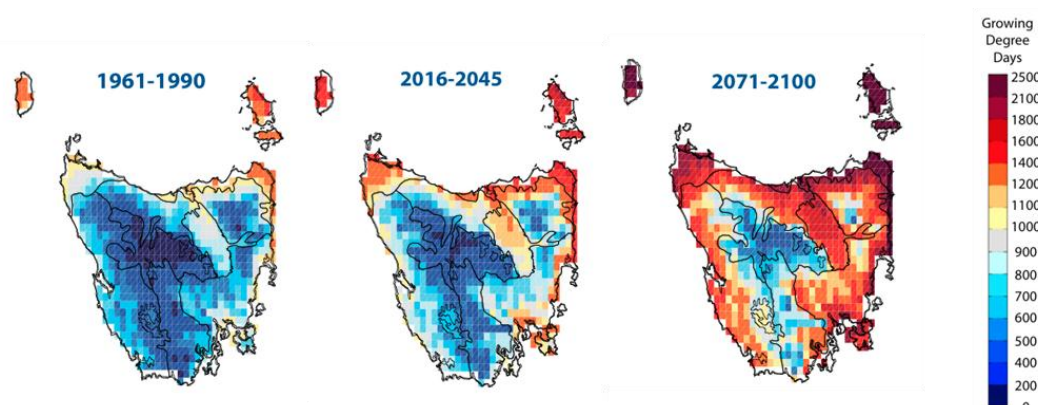


Figure 4. Annual growing degree days (GDD, 10 °C) for three periods in the average of six climate model projections under the A2 (higher) emissions scenario. Lines show the boundaries of the IBRA regions.



IBRA Region: King

The King region comprises King Island and the north-western tip of Tasmania. It is a region of subdued topography and low relief, and is significant for flora, fauna and geoconservation.

Approximately 58% of the King bioregion is covered by native vegetation. It is dominated on King Island by low closed forests and closed shrublands, heath, the grasslands group and small areas of eucalypt open forests and eucalypt woodlands. The main island portion of the bioregion is dominated by eucalypt tall open forests, eucalypt open forests, rainforest, the grasslands group and other forests and woodlands.

Current Climate

The King IBRA region has an average annual rainfall ranging from 750 – 2000mm across the region. It has a temperate climate with average winter minimum temperatures ranging from 4 to 8°C across the region, and average summer maximum temperatures ranging from 19 to 21°C.

Future scenarios

To give an impression of the strongest climate change signal that is projected, we report on results under the A2 (higher) emissions scenario by the end of the century. Results from the lower emissions scenario considered (B1) and earlier time periods show a weaker response than this.

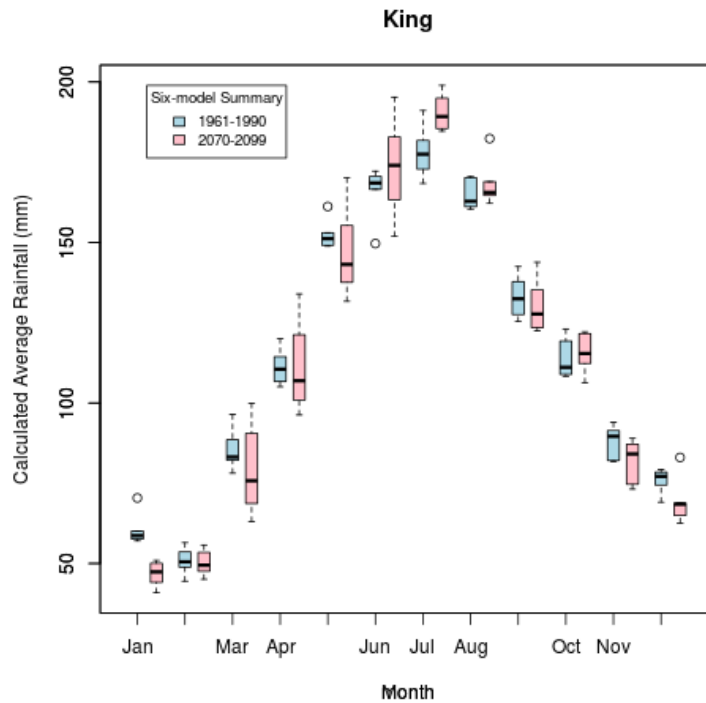
1. Temperature

- The projected change in average temperatures is similar to the rest of Tasmania (2.6 to 3.3°C)
- The projected change in average temperature is accompanied by a change in the frequency, intensity and duration of hot and cold extremes of temperature. For the King IBRA Region:
 - The average number of Summer Days (>25°C) per year generally doubles: on King Island from around 15 days per year to more than 30 days per year, and on the north coast from less than 10 days per year to more than 25 days per year
 - Warm spells (days in a row where temperatures are in the top 10% of baseline levels), which currently last around 4-7 days, are projected to last from 6-18 days longer, with the greatest increase occurring on the north coast of Tasmania
 - Tropical nights (nights with a minimum temperature >20°C), which are currently rare events, are projected to occur 5 or more times per year
 - Frost- risk days remain at a very low frequency

2. Rainfall, runoff and rivers

- Monthly average rainfall over the entire region is shown in the figure below. For King Island there is a projected decrease in rainfall in spring, summer and autumn (generally 0 to -10%), with little change in winter. This decreased rainfall is linked to an increase in drought frequency and severity, a decrease in mean runoff during summer (10 to 15%) and a decrease in runoff during low events (>20%)
- In contrast, rainfall on the northwest coast of mainland Tasmania is projected to follow the changes in the western district in response to changes in the westerly circulation, which is decreased rainfall in summer and autumn but increased rainfall in winter and spring (changes of up to 10%). The decreased rainfall in summer and autumn is associated with decreases in runoff (of up to 30%), and an increase in the frequency and severity of droughts

- Changes to rainfall and runoff lead to slight decreases in the average annual flows in rivers on King Island (central estimate -2%) and slight increases in rivers near Smithton (-2 to 7%)



Six-model summary of monthly rainfall (mm) across the King IBRA region under the A2 emission scenario for the baseline (1961-1990) and future periods (2070-2099).

3. Growing Degree Days

- GDD for King Island is projected to increase from a current annual GDD of 1328 to 2174 GDD annually. The equivalent change near Smithton is for 1036 to 1840 GDD. As a proportion, the change in GDD ranges across the region from 60-100% (Figure 4)



IBRA Region: Furneaux (Flinders sub-region)

The Furneaux IBRA region includes the Furneaux Group of islands, coastal northeastern Tasmania and Wilsons Promontory. The Flinders sub-region is the Tasmanian portion of the Furneaux bioregion.

The Flinders sub-region is characterized by coastal plains and a granitic island chain, as well as open slopes and rugged hills and ranges. Approximately 62% of the Flinders sub-region is covered by native vegetation, including heath, eucalypt open forests, low closed forests and closed shrublands, eucalypt woodlands, other grasslands group and tussock grasslands and some eucalypt tall open forests. The coastal plains of northeastern Tasmania have been heavily modified by agriculture (grazing and dairy).

Current Climate

Most of the Flinders sub-region has an average annual rainfall of 625 -1000 mm. It has a temperate climate with average winter minimum temperatures ranging from 3 to 8°C across the region, and average summer maximum temperatures ranging from 17 to 23°C (average 21°C across the region).

The Flinders sub- region is projected to have the greatest increase in annual rainfall across Tasmania.

Future scenarios

To give an impression of the strongest climate change signal that is projected, we report on results under the A2 (higher) emissions scenario by the end of the century. Results from the lower emissions scenario considered (B1) and earlier time periods show a weaker response than this.

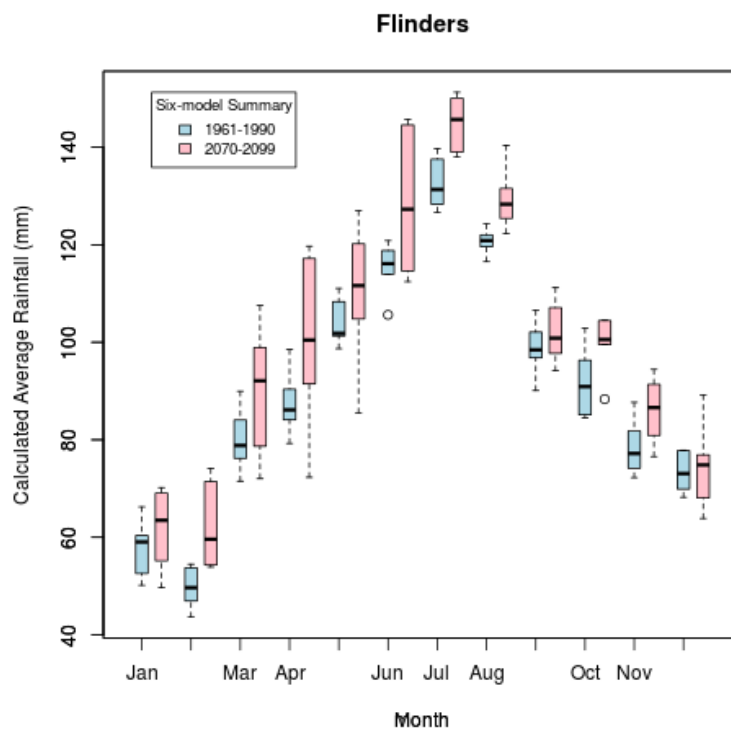
1. Temperature

- The projected change in average temperatures is similar to the rest of Tasmania (2.6 to 3.3°C)
- The projected change in average temperature is accompanied by a change in the frequency, intensity and duration of hot and cold extremes of temperature. For the Flinders IBRA region the projections indicate:
 - The number of Summer Days (>25°C) increases considerably. The greatest increase occurs on the north coast near Bridport, where the number of Summer days per year rises from less than 20 days, to more than 45 days per year
 - Tropical nights (minimum temperature >20°C), which are currently rare events, are projected to occur regularly, especially on Flinders Island (from less than 2 nights per year to up to 20), but also on the north coast of Tasmania
 - An increase in the mean annual maximum temperature by around 3°C. The mean annual minimum temperature increases by a similar amount on Flinders Island, but to a lesser extent on the north coast of Tasmania (around 2°C)
 - Warm spells (days in a row where temperatures are in the top 10% of baseline levels), which currently last around 5 days, are projected to last from 6-18 days longer, with the greatest increase occurring on the north coast of Tasmania (e.g. At Devonport, warm spells last for approximately 25 days per year, up from 6 days per year)

2. Rainfall, runoff and rivers

- Monthly average rainfall over the entire region is shown in the figure below. There is a projected increase in annual average rainfall across much of the region (between 2 - 14%), and an increase in rainfall in all seasons (generally in the 5-20% range), with some large localized increases in summer and the most widespread increases occurring Winter (Figure 3)

- A decrease in the long term drought frequency and severity is projected across the Flinders region due to the higher average rainfall
- Slightly fewer rain days per year on average is projected, but significantly more rain per rain day
- Up to 7 more very wet days each year (where rainfall exceeds the baseline 95th percentile) is projected
- The increase in rainfall leads to large increases in average annual runoff (up to 60%), with an increase in all seasons, leading to large increases in river flows (e.g. Flinders Island rivers (central estimate +46%))
- A marked increase in extreme rainfall amounts is projected (e.g. a 92% increase in the 200-year ARI at St Helens), and runoff during high events (up to 60% in some places), but with no change to runoff during low events



Six-model summary of monthly rainfall (mm) across the Flinders sub- region under the A2 emission scenario for the baseline (1961-1990) and future periods (2070-2099).



IBRA Region: Tasmanian Southern Ranges

The Southern Ranges IBRA region is an inland region covering a large and diverse area, from the mountainous and wet southwest, to the drier southeastern region near Hobart. As such, it has a large gradient of prevailing temperature and local rainfall climates.

The Southern Ranges feature a suite of landforms which are believed to have provided glacial refugia for fauna and flora during past climate changes (Leithbridge Hill, New River Lagoon, Middle Weld – Picton – Huon River valleys) (Australian Natural Resources Atlas, Department of the Environment, Water, Heritage and the Arts).

Approximately 85% of the Southern Ranges bioregion is covered by native vegetation. The region is dominated by eucalypt tall open forests, eucalypt open forests, rainforest and vine thickets, eucalypt woodlands, tussock grasslands, the grasslands group and other forests and woodlands. Small areas of heath and other low closed forests and closed shrublands occur.

Current Climate

Most of the Southern Ranges IBRA region has an average annual rainfall ranging from 625-2000 mm. Average winter minimum temperatures range from -2 to 4 °C across the region, with average summer maximum temperatures ranging from 12 to 23°C (average 18°C across the region).

Future scenarios

To give an impression of the strongest climate change signal that is projected, we report on results under the A2 (higher) emissions scenario by the end of the century. Results from the lower emissions scenario considered (B1) and earlier time periods show a weaker response than this.

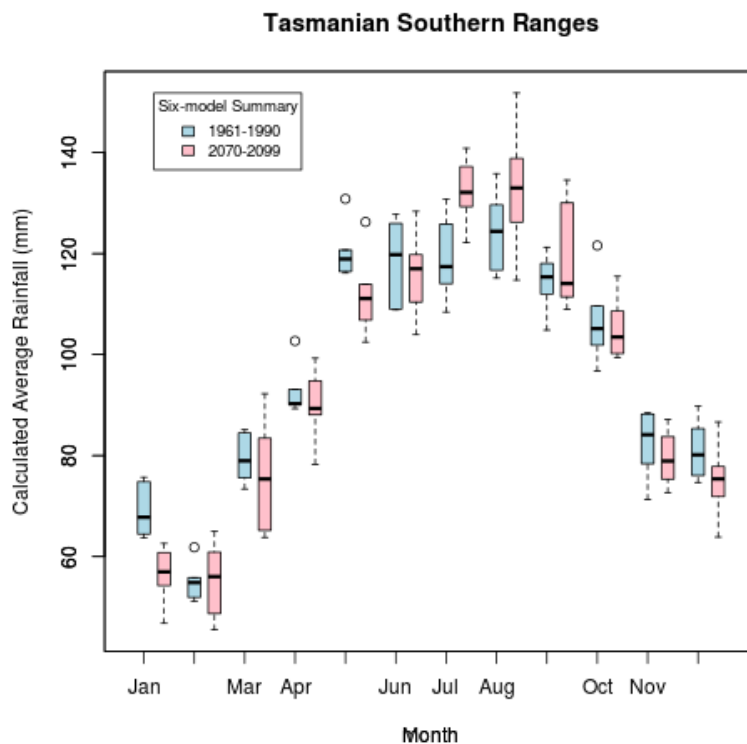
1. Temperature

- The projected change in average temperatures is similar to the rest of Tasmania (2.6 to 3.3°C)
- The projected change in average temperature is accompanied by a change in the frequency, intensity and duration of hot and cold extremes of temperature. For the Southern Ranges IBRA Region:
 - The number of Summer Days (>25°C) increases considerably. The greatest increase occurs near the coast, e.g. at Southport summer days increase from around 15 days per year to more than 30 days per year
 - The mean annual maximum and minimum temperatures increase by around 3°C
 - The number of frost-risk days reduces considerably. For example, at a site of 95 m above sea level in the Huon Valley the number of frost-risk days declines from around 40 days per year to less than 10 days per year
 - Warm spells (days in a row where temperatures are in the top 10% of baseline levels) that currently last about five days, are projected to last up to five days longer.

2. Rainfall, runoff and rivers

- Monthly average rainfall over the entire region is shown in the figure below. A decrease is projected in summer and autumn rainfall of up to 20% in the western part of the region, and increases in winter and spring rainfall of up to 15% (Figure 3)

- Changes in rainfall are linked to a projected decrease in mean runoff during summer (up to 15%) and a decrease in runoff during low events (up to 15%). Average runoff decreases in the highest altitude areas in all seasons, by more than 20% in some seasons
- Drought frequency and severity are projected to remain similar to that experienced in the twentieth century. In the Huonville area drought frequency may decrease due to increased average rainfall in this area
- Mean flows in the Huon, Russell and Little Denison Rivers are projected to remain unchanged



Six-model summary of monthly rainfall (mm) across the Southern Ranges IBRA region under the A2 emission scenario for the baseline (1961-1990) and future periods (2070-2099).

3. Growing Degree Days

The projected change in mean annual GDD ranges from 60-140% across the region, with the greatest increases projected to occur in the southern part of the region (Figure 4)

IBRA Region: Northern Slopes



The northern slopes is a geologically diverse region with large areas of coastal plains, open slopes and low hills. Approximately 54% of the Northern Slopes region is covered by native vegetation. The region is dominated by eucalypt tall open forests, eucalypt open forests, rainforest and small areas of eucalypt woodlands, the grasslands group, low closed forests and closed shrublands and heath.

Current Climate

Most of the Northern Slopes region has an average annual rainfall ranging from 750 – 2000 mm. Average winter minimum temperatures range from -2 to 5°C across the region. The region has mild summers, with average summer maximum temperatures ranging from 14 to 23°C (average 20°C).

Future scenarios

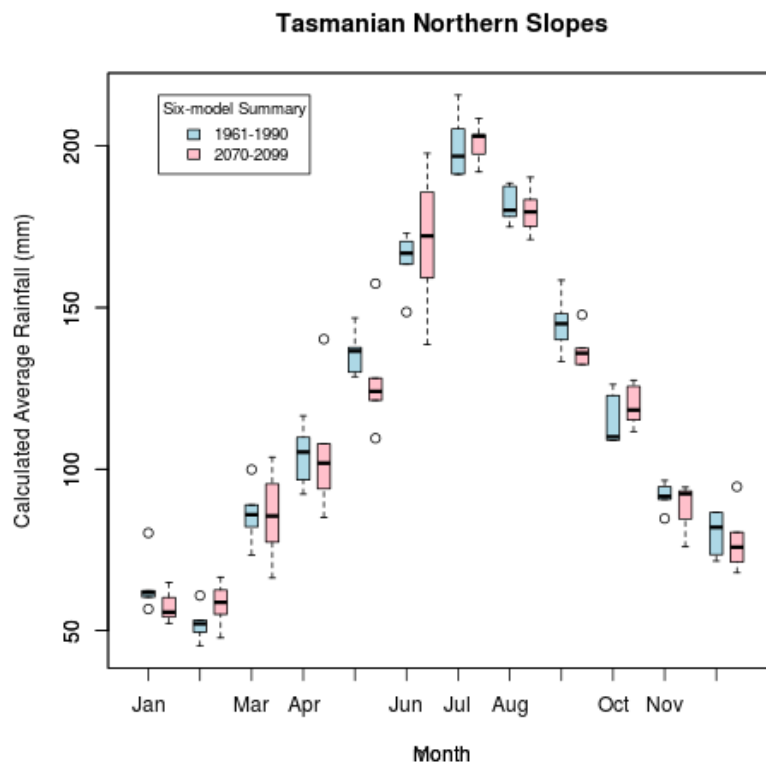
To give an impression of the strongest climate change signal that is projected, we report on results under the A2 (higher) emissions scenario by the end of the century. Results from the lower emissions scenario considered (B1) and earlier time periods show a weaker response than this.

1. Temperature

- The projected change in average temperatures is similar to the rest of Tasmania (2.6 to 3.3°C)
- Temperature limitation higher up the slopes will reduce, allowing altitudinal changes in biological groups, and could lead to increasing land-use pressure further up the hill
- The projected change in average temperature is accompanied by a change in the frequency, intensity and duration of hot and cold extremes of temperature. For the Northern Slopes IBRA Region the projections show:
 - The number of Summer Days (>25°C) more than doubles across the region, for example at Devonport the number increases from around 10 to around 30
 - The mean annual maximum and minimum temperatures increase by 2.5- 3°C
 - A decline in the number of frost-risk days is projected in areas where frosts currently occur
 - A considerable increase in the warm spell duration index (annual count of days exceeding 5 in a row where temperatures are in the top 10% of baseline levels), e.g. Devonport the number is projected to increase from 6 days to almost 20 days
 - Heat waves (>3 consecutive days exceeding 28°C) do not occur frequently in the region

2. Rainfall, runoff and rivers

- Monthly average rainfall over the entire region is shown in the figure below. For the Northern Slopes region there is a projected increase in rainfall in summer and winter (generally 0 to 10%), a slight decrease in spring, and little change in autumn (Figure 3). There is little change in mean runoff during summer or during low events
- Drought frequency and severity is not projected to change substantially
- The changes to rainfall and runoff lead to very slight decreases in the average annual flows in some rivers (e.g. Mersey River (central estimate -1%); and slight increases in others (e.g. Rubicon River (7%))



Six-model summary of monthly rainfall (mm) across the Northern Slopes IBRA region under the A2 emission scenario for the baseline (1961-1990) and future periods (2070-2099).

3. Evapotranspiration

- Increases to total annual evapotranspiration occur along the coastal strips in this region. The increases are proportionately greater in winter than summer

4. Growing Degree Days

- There is a projected increase in Growing Degree Days (GDD) across the region (Figure 4). For example, at Kindred (central part of the region) annual GDD (10°C) increases from the baseline level of 964 GDD to 1755 GDD. At Deloraine, annual GDD (10°C) doubles, from 760 GDD to 1447 GDD



IBRA Region: Ben Lomond

The Ben Lomond bioregion, situated in Tasmania's inland north-east, is characterized by humid cool/cold mountain ranges surrounded by open slopes and plains. Approximately 68% of the region is covered by native vegetation. Lowland vegetation comprises mainly open sclerophyll woodlands and heath while the upper slopes consist of wet sclerophyll forests, some rainforest, and alpine vegetation in the highest areas.

Current Climate

Most of the Ben Lomond region has an average annual rainfall ranging from 750 to 1500 mm. Average winter minimum temperatures range from -2 to 5°C across the region, with average summer maximum temperatures ranging from 12 to 23°C (average 20°C across the region).

Future scenarios

To give an impression of the strongest climate change signal that is projected, we report on results under the A2 (higher) emissions scenario by the end of the century. Results from the lower emissions scenario considered (B1) and earlier time periods show a weaker response than this:

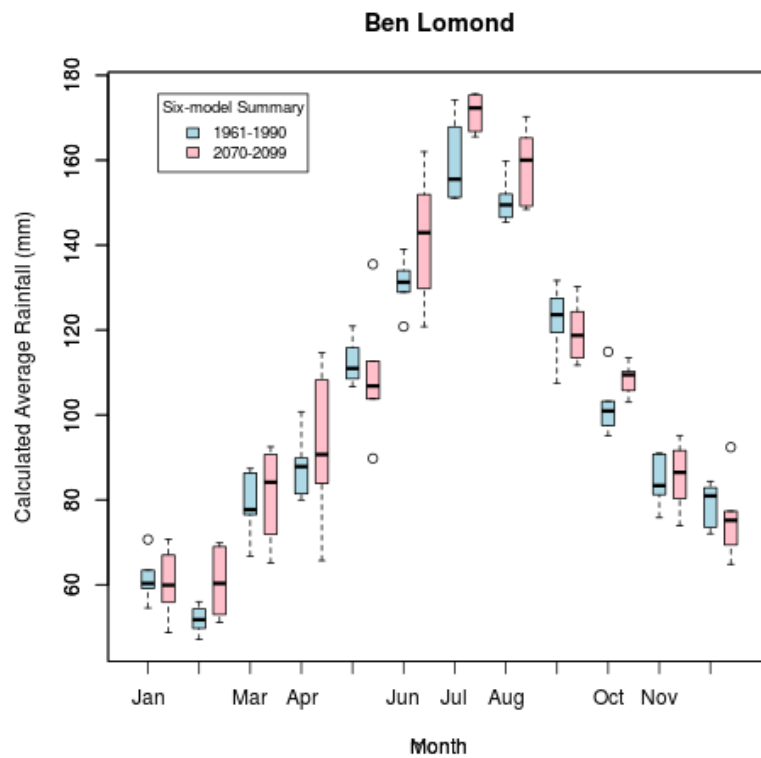
1. Temperature

- The projected change in average temperatures is similar to the rest of Tasmania (2.6 to 3.3°C)
- The projected change in average temperature is accompanied by a change in the frequency, intensity and duration of hot and cold extremes of temperature. For the Ben Lomond IBRA Region the projections show:
 - The number of Summer Days (>25°C) more than doubles in many locations in the region, with the greatest increases in the lower elevation areas (e.g. from 10-15 days up to more than 30 days per year)
 - The mean annual maximum and minimum temperatures increase by more than 3°C (more than the mean temperature increase). Extreme daily maximum temperatures increase by up to 4°C in Spring
 - The number of frost-risk days declines considerably. The most extreme example is from around 70 days per year, to less than 20 days per year at the highest altitudes
 - A considerable increase in the warm spell duration index (annual count of days exceeding 5 in a row where temperatures are in the top 10% of baseline levels) in the northern part of the region
 - A large increase in the number of warm nights – up to 28% more nights above the current 90th percentile temperature

2. Rainfall, runoff and rivers

- Monthly average rainfall over the entire region is shown in the figure below. There is a projected increase in rainfall in winter and spring of up to 10% (Figure 3). In summer and autumn rainfall declines in the high altitude areas of the region by up to 10%, and increases towards the east coast (by up to 10%)
- This is linked to a decrease in mean runoff during summer (up to 15%) and a decrease in runoff during low events (up to 15%)
- There is no substantial change in drought frequency and severity across the region as a whole but a slight decrease in the north-east

- Changes to rainfall and runoff lead to increased mean river flows (e.g. the North Esk River (central estimate 7%), South Esk River (12%))



Six-model summary of monthly rainfall (mm) across the Ben Lomond IBRA region under the A2 emission scenario for the baseline (1961-1990) and future periods (2070-2099).

3. Growing Degree Days

There is a projected increase in Growing Degree Days (GDD) across the region (Figure 4). For example, in Scottsdale annual GDD (10°C) increases from the baseline level of 1009 GDD to 1803 GDD



IBRA Region: Central Highlands

The Central Highlands region is characterized by an elevated undulating plateau and rugged mountain ranges towards the west. Approximately 86% of the Central Highlands bioregion is covered by native vegetation. There is a high diversity of vegetation including eucalypt open forests, eucalypt woodlands, rainforest and vine thickets, the grasslands group, eucalypt tall open forests, tussock grasslands, heath, low closed forests and closed shrublands and other forests and woodlands. Alpine heath is abundant on much of the Central Plateau and alpine areas of the Central Highlands.

Current Climate

Most of the Central Highlands bioregion has an average annual rainfall ranging from 625 to 2500 mm. Of the Tasmanian IBRA regions, the Central Highlands region has the coolest winter temperatures with average winter minimum temperatures ranging from -2 to 3°C (average 0.3°C) across the region. Average summer maximum temperatures range from 12 to 22°C (average 18°C across the region).

The Central Highlands region is the region with the most marked reduction in rainfall projected to occur in Tasmania. The impact of increasing temperatures on high altitude areas is also likely to be important.

Future scenarios

To give an impression of the strongest climate change signal that is projected, we report on results under the A2 (higher) emissions scenario by the end of the century. Results from the lower emissions scenario considered (B1) and earlier time periods show a weaker response than this.

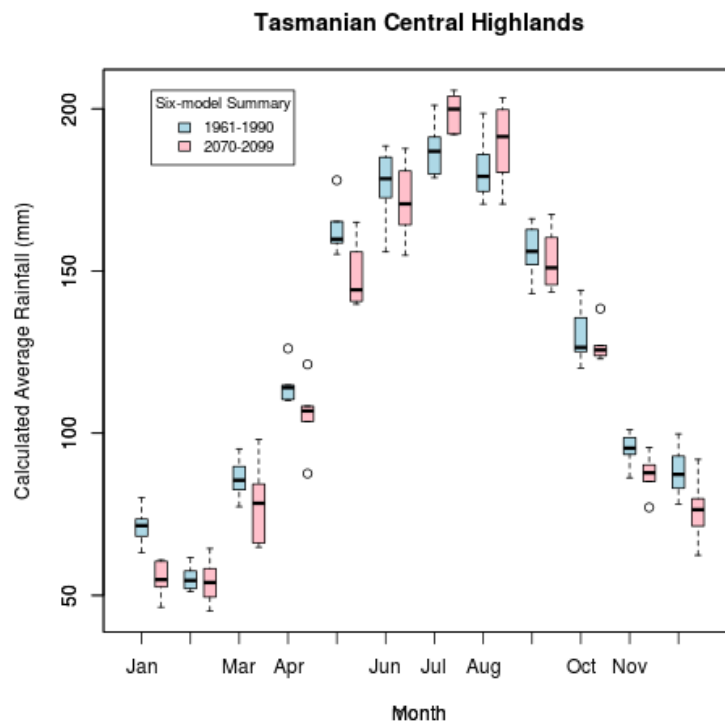
1. Temperature

- The projected change in average temperatures is similar to the rest of Tasmania (2.6 to 3.3°C)
- The projected change in average temperature is accompanied by a change in the frequency, intensity and duration of hot and cold extremes of temperature. For the Central Highlands IBRA Region, the projections show:
 - An increase in the number of Summer Days (>25°C) from less than 5 days per year to around 12 days per year across most of the region
 - A decrease in the mean annual maximum and minimum temperatures by approximately 3°C
 - The number of frost-risk days declines considerably. The most extreme declines occur in the highest altitudes areas, where the number of frost-risk days decline from around 120 days per year to around 60 days per year
 - A decline on the duration and frequency of cold spells. For example, at Miena there are currently around 2 'cold waves' per year, but these are projected to be rare events by the end of the century
 - An increase in the day-night temperature difference in all months, unlike on the coasts, due to the higher altitude of the region, and the reduction in cloud and rainfall
 - Heat waves (>3 days >28°C) will still be very rare events

2. Rainfall, runoff and rivers

- Monthly average rainfall over the entire region is shown in the figure below. In the western part of the region rainfall is projected to decrease in all seasons (generally by up to 10%, and up to 20% in Summer) (Figure 3)

- Change in rainfall is linked to a decrease in mean runoff in all seasons (up to 30% in Summer) and a decrease in runoff during low events (up to 30%)
- An increase in drought frequency and severity in the western part of the region is projected
- The reduction in rainfall and runoff will lead to reductions in flows (e.g. Iris River (central estimate -9%), Forth River above Lemonthyme Power Stn (-6%), Nive River (-12%))



Six-model summary of monthly rainfall (mm) across the Central Highlands IBRA region under the A2 emission scenario for the baseline (1961-1990) and future periods (2070-2099).



IBRA Region: West

The West is the largest IBRA region in Tasmania (> 1.5 million hectares), including most of coastal and inland western Tasmania. 87% of its area is in the National Reserve System. The region is characterized by lowlands, low hills and rugged dissected inland mountain ranges.

Approximately 95% of the West region is covered by native vegetation. The region is dominated by the grasslands group, rainforest and vine thickets, low closed forests and closed shrublands, eucalypt open forests with small areas of heath, eucalypt tall open forests and eucalypt woodlands.

Current Climate

The West region has a cool, superhumid climate, and is the wettest of Tasmania's regions, with most of the region having an average annual rainfall ranging from 1250 mm to over 2500 mm. Average winter minimum temperatures range from -2 to 6°C across the region. The region has the coolest summers, with average summer maximum temperatures ranging from 13 to 21°C (average 18°C across the region).

The West region exhibits the largest projected changes to seasonal rainfall across Tasmania, linked to changes in the mid-latitude westerly circulation and storm tracks. Increases in Winter and Spring rainfall contrast with decreases in Summer and Autumn.

Future scenarios

To give an impression of the strongest climate change signal that is projected, we report on results under the A2 (higher) emissions scenario by the end of the century. Results from the lower emissions scenario considered (B1) and earlier time periods show a weaker response than this.

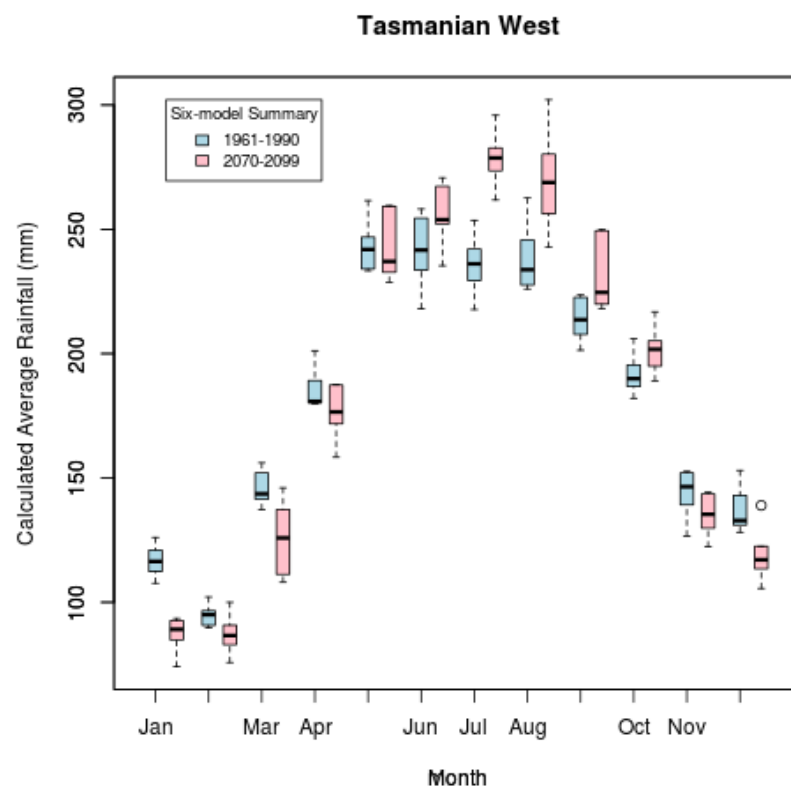
1. Temperature

- The projected change in average temperatures is similar to the rest of Tasmania (2.6 to 3.3°C)
- The projected change in average temperature is accompanied by a change in the frequency, intensity and duration of hot and cold extremes of temperature. For West IBRA Region, the projections show:
 - A significant increase in rainfall in winter and a significant decrease in summer rainfall after 2050
 - An increase in the number of Summer Days (>25°C) by 4-20 days per year across much of the region, with increases of up to 28 days per year at the most easterly extent (to more than 40 days per year). For example, in Strahan the number of Summer days increases from 19 per year to more than 42 days; in Strathgordon the increase is from a baseline of around 14 Summer days to more than 30 days per year
 - An increase in the mean annual maximum and minimum temperatures by around 3°C
 - A reduction in the number of frost-risk days (e.g. In Strahan the number of frost-risk days declines from around 6 per year to about 1 per year. At Strathgordon it declines from over 15 days per year to less than 3)
 - Warm spells (days in a row where temperatures are in the top 10% of baseline levels), which currently last around 5 days, are projected to last up to 6 days longer (3 days longer in both Strahan and Strathgordon)

2. Rainfall, runoff and rivers

- Monthly average rainfall over the entire region is shown in the figure below. There is a projected decrease in rainfall in summer and autumn (by over 10 to 20%) but an increase in winter and spring (by up to 20%) (Figure 3)

- No significant change to drought frequency and severity is projected across the region as a whole, but there is a tendency to decreasing drought frequency and severity in the far south-west
- An increase in the frequency of extreme precipitation events in winter and early spring is projected, combined with a decrease in summer events, leading to more intense and heavy downpours interspersed with longer dry periods
- Projections of increased rainfall in winter and spring and lower rainfall in summer and autumn result in only small changes to average annual river flows. (e.g. the Collingwood River (central estimate is -3%), the Davey River (+2%), the upper part of the Franklin River (-5%), Lost Creek (+4%) and the Stitt River (+1%). However, there is a projected change to the seasonality of flows



Six-model summary of monthly rainfall (mm) across the West IBRA region under the A2 emission scenario for the baseline (1961-1990) and future periods (2070-2099).

3. Evapotranspiration

- Total annual evapotranspiration will increase, but there is a slight decrease in summer when evapotranspiration becomes more water limited



IBRA Region: South East

The South East IBRA region encompasses much of coastal eastern Tasmania, the Midlands and the lower Derwent Valley. The region has a highly indented coastline, large areas of open slopes, plains and hills and low mountain ranges.

Approximately 65% of the South East bioregion is covered by native vegetation. The region is dominated by eucalypt woodlands, eucalypt open forests and tall open forests and the grasslands group. Smaller areas of rainforest, eucalypt open woodlands, heath, chenopod and samphire shrublands, low closed forests and closed shrublands, casuarina communities and tussock grasslands occur. Extensive areas of vegetation have been converted to improved pasture and cropland.

Current Climate

The South East region has a subhumid, warm climate. Most of the region has an average annual rainfall ranging from 375 to 1000 mm, with the rainfall occurring uniformly through the year. Average winter minimum temperatures range from -1 to 6°C across the region. The region has mild summers with average summer maximum temperatures ranging from 13 to 23°C (average 19°C across the region).

Future scenarios

To give an impression of the strongest climate change signal that is projected, we report on results under the A2 (higher) emissions scenario by the end of the century. Results from the lower emissions scenario considered (B1) and earlier time periods show a weaker response than this.

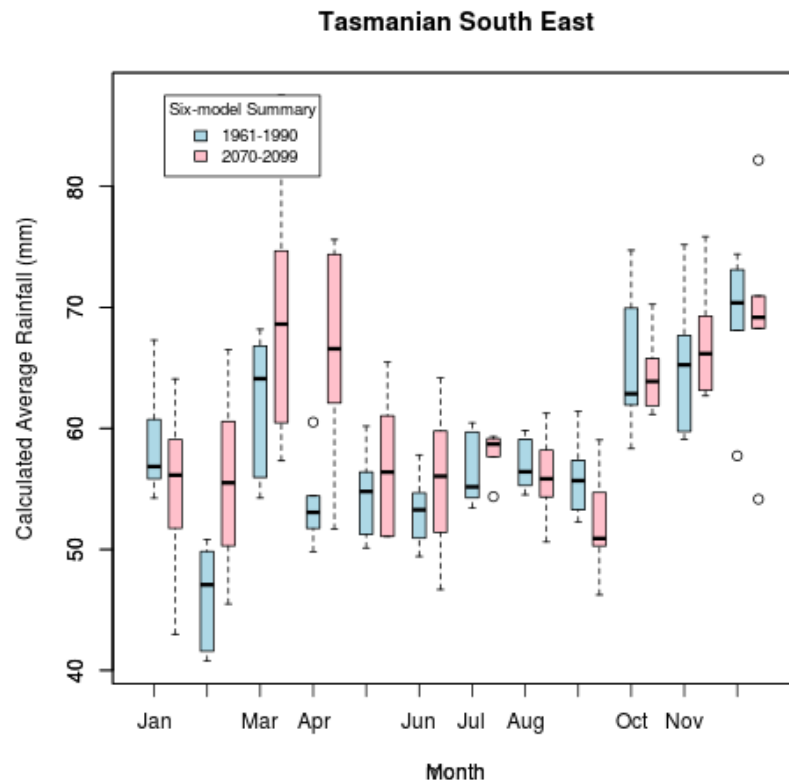
1. Temperature

- The projected change in average temperatures is similar to the rest of Tasmania (2.6 to 3.3°C)
- The projected change in average temperature is accompanied by a change in the frequency, intensity and duration of hot and cold extremes of temperature. For the South East IBRA Region, the projections show:
 - An increase in the number of Summer Days (>25°C). For example in Hobart, the number increases from 18 days per year to around 40 days per year. In Swansea the number increases from 17 days per year to around 44 days per year
 - The mean annual maximum and minimum temperatures increase by approximately 3°C
 - The number of frost-risk days declines considerably. For example in Hobart, the number decreases from 5 days per year to around 1 day per year. In Swansea, frost-risk days decline from a current 9 days per year to less than 1 day per year
 - The incidence of heat waves (>3 consecutive days exceeding 28°C) increases, to occur every year or two
 - The average hottest day of the year, which is high in the southeast compared to most places in Tasmania (up to 36°C), is projected to increase by up to 3°C

2. Rainfall, runoff and rivers

- Monthly average rainfall over the entire region is shown in the figure below. Average rainfall is projected to increase in Autumn and Summer (up to 10%) and decrease in Spring (up to 5%). In winter, rainfall is projected to decrease in the northern part of the region (up to 5%) and increase in the south and west (up to 10%) (Figure 3)
- Changes in rainfall are linked to an increase in mean annual runoff, with a substantial increase in Summer (up to 30%) and Autumn (> 60%). There is little change to runoff during low events

- No marked change to drought frequency and severity is projected to occur across much of the region, except in the south-east where there will be a slight decrease
- The increase in rainfall and runoff will lead to increases to river flows (e.g. The Derwent Estuary (central estimate 10%), Little Swanport River (15%), Prosser River (12%))



Six-model summary of monthly rainfall (mm) across the South East IBRA region under the A2 emission scenario for the baseline (1961-1990) and future periods (2070-2099).

3. Growing Degree Days

- There is a projected increase in Growing Degree Days (GDD) across the region (Figure 4). For example, in the Coal Valley, annual GDD (10°C) increases from the baseline level of 1154 GDD to 1905 GDD



IBRA Region: Northern Midlands

The Northern Midlands region is an extensive lowland plain bordered in the east and west by hilly topography. Extensive agriculture is supported in the region.

Approximately 35% of the area of the Northern Midlands region remains under native vegetation. There are eucalypt open forests, eucalypt woodlands and open woodlands, other grasslands, tussock grasslands and other shrublands. Of the Tasmanian IBRA regions, the Northern Midlands region has the lowest area in the National Reserve System (5% as of June 2009).

Current Climate

The Northern Midlands region has an average annual rainfall ranging from 375 to 1000 mm across the region. Average winter minimum temperatures range from 0 to 3°C across the region. This region has the warmest summer temperatures of all Tasmanian IBRA regions, with average summer maximum temperatures ranging from 18 to 24°C (average 22°C across the region).

The Northern midlands region is in the rain shadow of the Great Western Tiers and has the lowest rainfall of any region in Tasmania. This makes it a difficult area to model, and biases tended to be higher than in other regions of Tasmania.

Future scenarios

To give an impression of the strongest climate change signal that is projected, we report on results under the A2 (higher) emissions scenario by the end of the century. Results from the lower emissions scenario considered (B1) and earlier time periods show a weaker response than this.

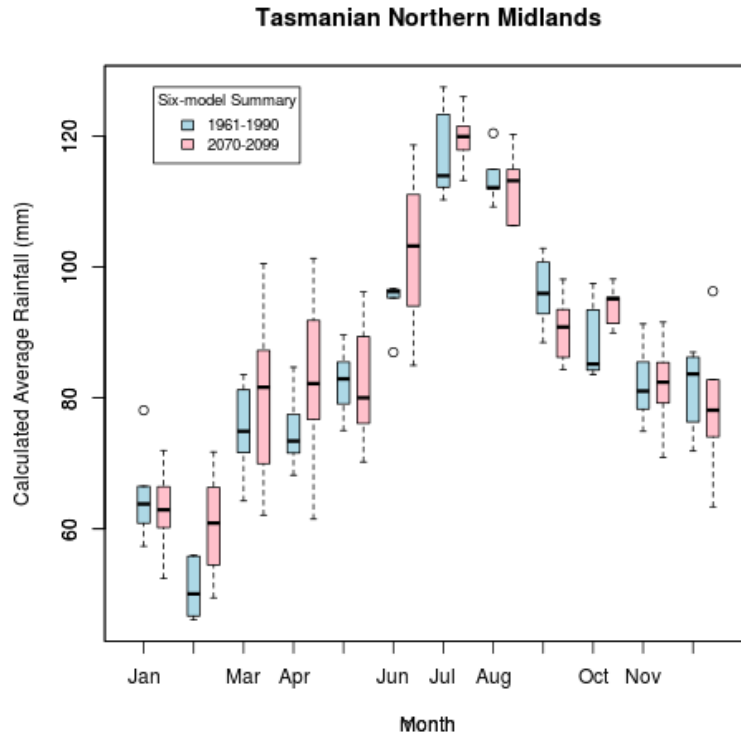
1. Temperature

- The projected change in average temperatures is similar to the rest of Tasmania (2.6 to 3.3°C)
- The projected change in average temperature is accompanied by a change in the frequency, intensity and duration of hot and cold extremes of temperature. For the Northern Midlands IBRA Region, the projections show:
 - The number of Summer Days (>25°C) increases considerably across the region. The Northern midlands shows the greatest increase in the state. For example, at Launceston the frequency of summer days is projected to increase from around 29 per year to over 70 per year
 - An increase in the mean annual maximum and minimum temperatures by approximately 3°C
 - A marked decline in the number of frost-risk days
 - Heat waves (>3 consecutive days exceeding 28°C) occur around twice every year
 - The mean annual maximum temperature, currently amongst the highest in Tasmania, increases by around 3°C. The mean annual minimum temperature increases by 2-3°C

2. Rainfall, runoff and rivers

- Monthly average rainfall over the entire region is shown in the figure below. Average rainfall is projected to increase in all seasons (up to 10%) (Figure 3)
- Increased rainfall leads to an increase in mean annual runoff (up to 20%). There is no substantial change to runoff during low events
- No marked change in drought frequency and severity is projected

- There are projected increases to river flows (e.g. Macquarie River (central estimate 17%), South Esk River (12%))



Six-model summary of monthly rainfall (mm) across the South East IBRA region under the A2 emission scenario for the baseline (1961-1990) and future periods (2070-2099).

Appendix – details of climate projections

Greenhouse gas emissions have an influence on the Earth's climate system, along with other human activities such as the emission of ozone-depleting substances, emission of aerosol (particles) and changing the land cover (e.g. deforestation). Sophisticated model simulations can be used to project the likely effect of these influences into the future given our current state of knowledge. It is impossible to predict exactly what future human emissions will be, so models are run under a set of plausible hypothetical *emissions scenarios*. A model simulation shows the likely effect if we follow that scenario, so it is not a single 'prediction' of the future. The simulation can't include the effect of things that are impossible to predict (such as major volcanic eruptions)

Climate warming causes many complex changes to the earth's climate system. These changes include alterations to ocean currents, average atmospheric circulation and ocean-atmosphere cycles such as the El Niño Southern Oscillation. Projected effects that are relevant to Tasmania include a continued extension of the East Australia Current bringing warmer waters off the east and northeast coast of Tasmania, a pole-ward shift of the subtropical ridge of high pressure and shifts in the mid-latitude westerlies (the 'Roaring 40s'), and a change in remote climate drivers such as atmospheric blocking, the El Niño Southern Oscillation and the Southern Annular Mode. The position of Tasmania adjacent to the Southern Ocean means that the effect of climate warming is not as severe as other more continental regions.

The results presented in this report were made using established methods, including:

- Extreme value distribution fitting in a generalized Pareto distribution to calculate the average recurrence intervals (ARIs)
- Hydrology runoff models developed and calibrated for the Tasmanian Sustainable Yields project to estimate the runoff, river flows and inflows to storages
- 10 °C threshold to calculate Growing Degree Days

All information is drawn from the *Climate Futures for Tasmania* Technical reports. Please see these reports for more details, and to cite in other written work.

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