Impacts of climate change trends on the hydrologic cycle in the context of the Australian continent.

Table of Contents

Abstract

Climate change trends indicate an ongoing increase in land and sea surface temperatures, a decline in polar ice sheet masses and increasing sea levels - all due to increases in greenhouse gas emissions (Luber and Prudent, 2009). This has led to vulnerabilities in so many areas affecting human civilisation that the International Panel on Climate Change (IPCC) in 2015 created 17 Sustainable Development Goals (SDG) as guidelines for member nations to achieve to “improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests (United Nations Department of Economic and Social Affairs, 2020). SDG 6 is to “Ensure availability and sustainable management of water and sanitation for all” (ibid.). Still, it must also be acknowledged for its paramount importance to humanity, as “Water is one of the most important substances on earth. All plants and

animals must have water to survive. “If there was no water there would be no life on earth” (Australian Government Department of Health, 2020).

This study considers the overall global trends that are occurring to make clear the trajectory we are following and in particular, how this affects the hydrologic cycle in Australia, already considered to be “the driest inhabited continent in the world” (Australian Government Department of Agriculture, Water and Environment, 2020). A literature review has been undertaken to identify global trends and those locally associated with and specific to the hydrologic cycle of Australia. It further considered certain vulnerabilities it has that must be addressed by adaptation to ensure adequate future water resources.

Key Words: *SILO, variations, temperature, rainfall, water resources, agricultural industry, vegetation, adaptation.*

List of figures

List of Tables

Introduction

On a global scale, “Climate change is a long-term change in the average weather patterns that have come to define Earth’s local, regional and global climates” and “Changes observed in Earth’s climate since the early 20th century are primarily driven by human activities, particularly fossil fuel burning, which increases heat-trapping greenhouse gas levels in Earth’s atmosphere, raising Earth’s average surface temperature” (NASA, 2020)

Climate has changed throughout history, with the past 650,000 years have seen seven cycles of glacial advance and retreat, with the abrupt end of the last ice age about 11,700 years ago marking the beginning of the modern climate era — and human civilisation (NASA, 2020). However, during the recent period, circa1950, change has been so rapid and unidirectional that it has become recognised as the “Great Acceleration” (Lewis &

Maslin, 2015; Steffen & McNeill, 2007; McNeill & Engelke, 2016) with regards to overall global climate change.

“Australia is the second driest continent on Earth; reliable projections around the trends and variability in future rainfall are crucial for policymakers and water resource management” (Dey et al., 2019). It is thus important to consider how trends in this particular element of climate change will affect the Australian continent and to address any possible future vulnerabilities, particularly in the agricultural sector of the economy.

This study aims to consider the effects of a principal climatic element affecting the Australian Hydrologic Cycle and subsequently outline its impact on future water resources and how this may be improved.

The protocol followed has been to review the current literature on this subject and then to highlight general global trends initially, how this reflects on the Australian situation specifically and look at mitigation and adaptation responses available to counter future vulnerabilities. The study is then summarised and gives conclusions as to what the global and local climatic trends indicate and what future possibilities there may be to adapt to the consequences of change.

Literature Review

The literature search was conducted by choosing relevant peer-reviewed literature from the last decade to assist in producing an essay on the impacts of climate change trends globally and then on the hydrologic cycle in the context of the Australian continent. Globally, the climate is changing rapidly, and, as Kennedy et al. (2010) assert:

“Many aspects of the global climate are changing rapidly, and the primary drivers of that change are human in origin. Evidence for changes in the climate system abounds, from the top of the atmosphere to the depths of the oceans”

Climate change trends indicate its concerning effects on the hydrologic cycle. As Finlayson and McMahon (1988) state: “In comparison to other regions, as the driest inhabited continent on Earth and with the highest streamflow variability, Australia is particularly prone to large-scale changes in hydro-climatic conditions”

These conditions are considered to be the product of the principal climatic changes in greenhouse gas emissions, particularly increasing carbon dioxide (CO2) production from excessive fossil fuel use, the resulting increase in global temperature and its effect on precipitation.

Of particular concern is the effect these changes have on our agricultural industries as "Increases in atmospheric CO2 concentration are impacting the terrestrial water cycle through changes in radiative forcings (affecting precipitation and temperature) as well as plant physiological and structural responses (Betts et al., 2007). Further, "as a result, projections of future changes in water resources become complicated due to the tight coupling between the terrestrial biosphere and hydrologic cycle" (Baron et al., 2000).

This gives more specific direction to the discussion in this report, hence, the main keywords used in the literature search are *variations, temperature, rainfall, water resources, agricultural industry, vegetation, and adaptation.* From a basic literature search on the Scopus database, the following relevant documents were located as indicated in the following Figure 1.

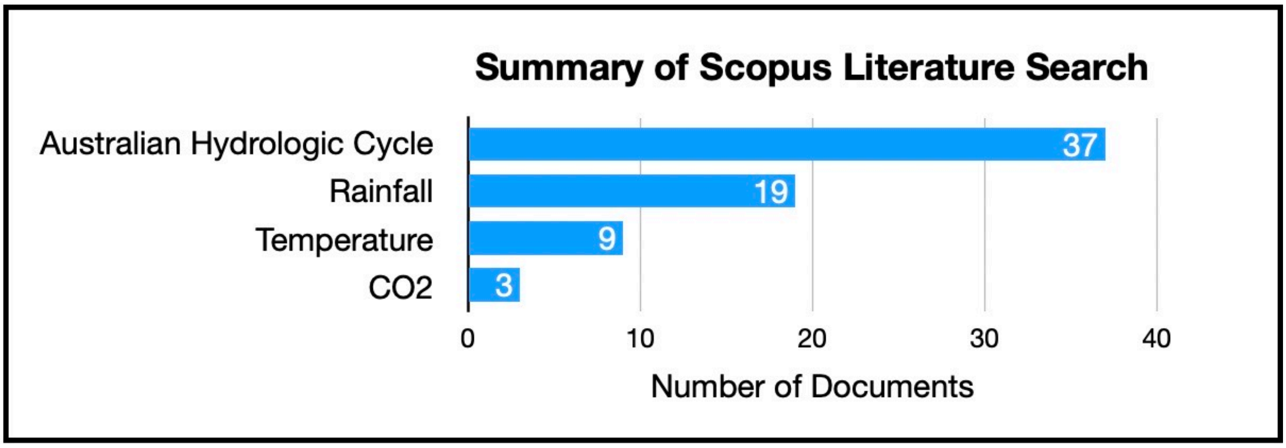


Figure 1. Summary of Scopus Literature Search regarding the impacts of climate change trends on the hydrologic cycle in the context of the Australian continent

One principal article reviewed in this search is Ma, X, Huete A, Moran S, Ponce-Campos G, and Eamus D (2015), *Abrupt shifts in phenology and vegetation productivity under climate extremes*, J. Geophys. Res. Biogeosci., 120, pp.2036–2052.
This article emphasises the concerns of "water and heat stresses on ecosystem metabolism" (ibid. p 2037) and supports the investigation of current climate trends in the hydrologic cycle.

From this, a further 65 references have been identified, of which 35 have been produced in the last ten years and a further 14 within the last 15 years. This literature has also been reviewed and would indicate a high degree of relevance and contemporaneity.

Trends in Climate Change Global Trends

To identify the impact of climate change locally, it is first necessary to identify the trends indicated globally.

The elements of Global Climate Change to be reviewed are:

1. Atmospheric Carbon Dioxide
2. Global Temperatures (Land and Ocean)
3. Arctic Sea Ice
4. Land Ice in Antarctica
5. Land Ice in Greenland
6. Sea level

The trends observed in each of these elements are graphically represented as follows:

1. Atmospheric Carbon Dioxide

Carbon Dioxide (CO2) is a heat-trapping gas released through human activities such as deforestation and fossil fuel use. The graph below shows CO2 levels measured at the Mauna Loa Observatory and indicates the latest measurement as 414ppm as of June 2020 (NASA, 2020)

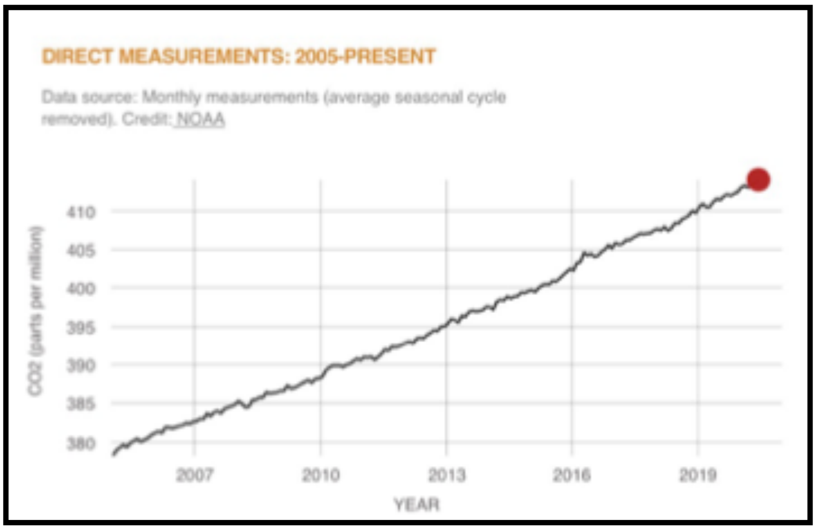
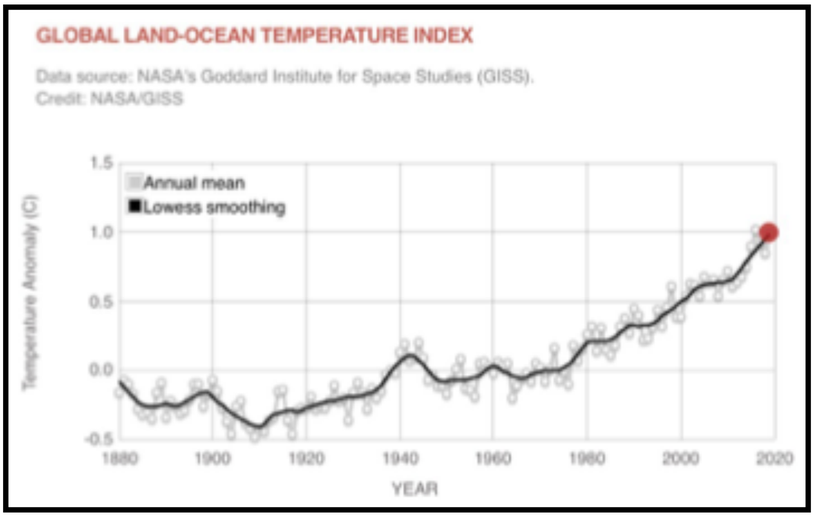


Figure 2. NASA Carbon Dioxide, 2020, Sea Level, Latest Measurement: June 2020, viewed 7 August 2020, https://climate.nasa.gov/vital-signs/carbon-dioxide/

2. Global Temperatures

The graph following illustrates the change in global surface temperature relative to 1951-1980 average temperatures. It also indicates a present annual average anomaly:2019 of 0.99°C. Except 1988, 19 of the 20 warmest years have all occurred since 2001 (NASA, 2020)



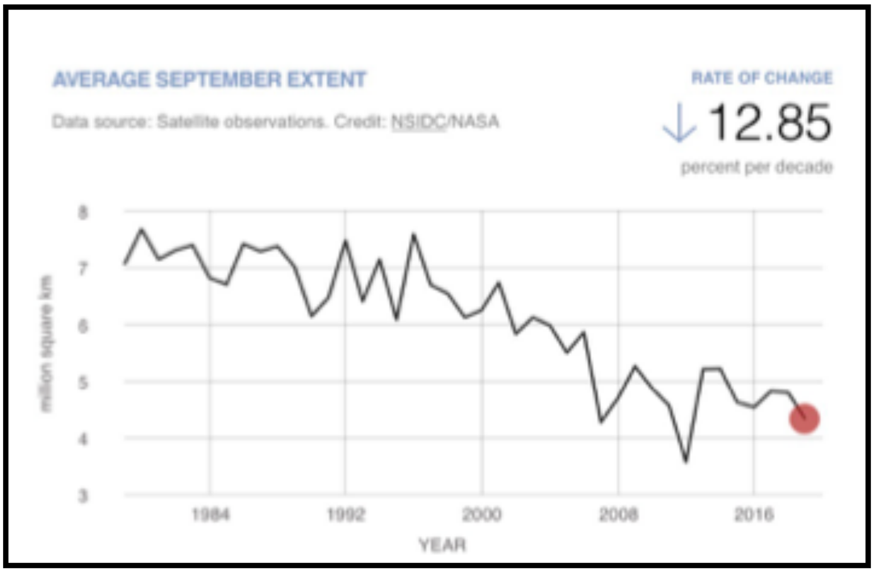
GLOBAL LAND-OCEAN TEMPERATURE INDEX

Data source: NASA's Goddard Institute for Space Studies (GISS).
Credit: NASA/GISS

Figure 3. NASA Goddard Institute for Space Studies, 2020, Global Land-Ocean Temperature Index, Latest Annual Average Anomaly: 2019, viewed 7 August 2020, https:// climate.nasa.gov/ vital-signs/global-temperature/

3. Arctic Sea Ice

Arctic sea ice reaches its minimum each September. The graph below shows the rate of decline as 12.85 per cent per decade relative to the 1981 to 2010 average (NASA, 2020)



AVERAGE SEPTEMBER EXTENT

Data source: Satellite observations. Credit: NSIDC/NASA

Figure 4. NSIDC/NASA Satellite observations, 2019, Arctic Sea Ice Minimum: Average September Extent, viewed 7 August 2020, https://climate.nasa.gov/vital-signs/arctic-sea-ice/

4. Land Ice in Antarctica

Land ice sheets in Antarctica have been losing mass since 2002 (NASA, 2020).

The graph below indicates a rate of change in mass variation in Antarctica at 147 Gigatonnes per year

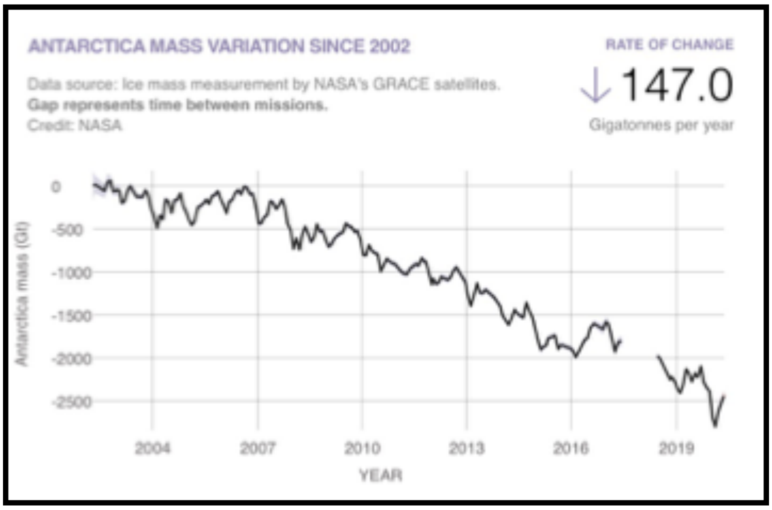


Figure 5. NASA/GRACE (Gravity Recovery and Climate Experiment), 2020, Antarctica Mass Variation Since 2002, viewed 7 August 2020, https://climate.nasa.gov/vital-signs/ice-sheets/

5. Land Ice in Greenland

Land ice sheets in Greenland have been losing mass since 2002 (NASA, 2020).

The graph below indicates a rate of change in mass variation in Greenland at 279 Gigatonnes per year

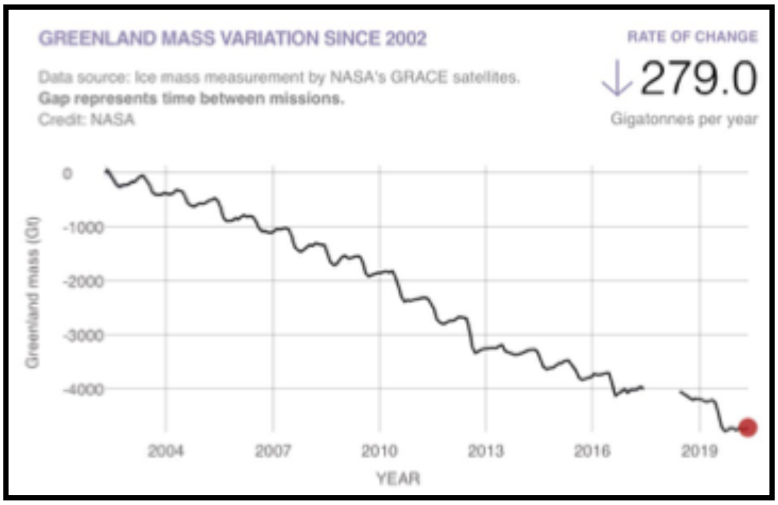


Figure 6. NASA/GRACE (Gravity Recovery and Climate Experiment), 2020, Greenland Mass Variation Since 2002, viewed 7 August 2020, https://climate.nasa.gov/vital-signs/ice-sheets/

6. Sea Level Rise

Sea level rise is caused by thermal expansion by water warming and the increased melting of land ice sheets and glaciers (NOAA, 2019). The following graph indicates a current annual sea level rise rate of change of 3.3 millimetres per year

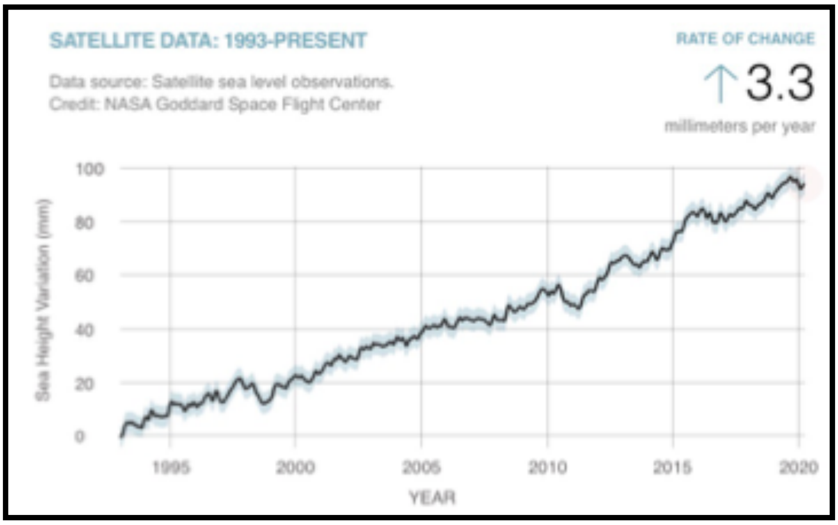


Figure 7. NASA Goddard Space Flight Center, 2020, Sea Level, Latest Measurement: March 2020, viewed 7 August 2020, https://climate.nasa.gov/vital-signs/sea-level/

The following table indicates the key information given by the foregoing graphical representations.

Summary of Data and Graphical representations of Six Climate Characteristics

Climate element	Period covered	Current value	Trend	References (in conjunction withhttps://climate.nasa.gov/vital-signs/ice-sheets/)
Carbon Dioxide (CO2)	2005 - 2020	414ppm	2.3ppm/ year	https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide
Global Temperature	1881 - 2019	0.99 °C annual average anomaly	0.18 °C since 1981	https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature
Arctic Sea Ice	1979 -2019	9300 km3	Decline of 12.85% per decade	http://psc.apl.uw.edu/research/projects/arctic-sea-ice-volume-anomaly/
Land Ice in Antarctica	2002 - 2020	Approx 14M Gt	Decline of 147 Gt pa	https://nsidc.org/cryosphere/sotc/ice_sheets.html
Land Ice in Greenland	2002 - 2020	Approx 1.7M Gt	Decline of 279 Gt pa	https://nsidc.org/cryosphere/sotc/ice_sheets.html
Sea Level Rise	1993 - 2020	94+/-4mm increase since 1993	Increase of 3.3mm pa	https://climate.nasa.gov/vital-signs/sea-level/

Table1. Data indicating changing climate elements with particular reference to the period covered, current values, trends and relevant organisational references.

Climate change trends affecting the Australian hydrologic cycle

The global trends of most relevance to the future situation in the Australian Continent are those reflecting the effects of temperature increases as a result of increased GHG emissions and how it affects Australia's hydrologic cycle.

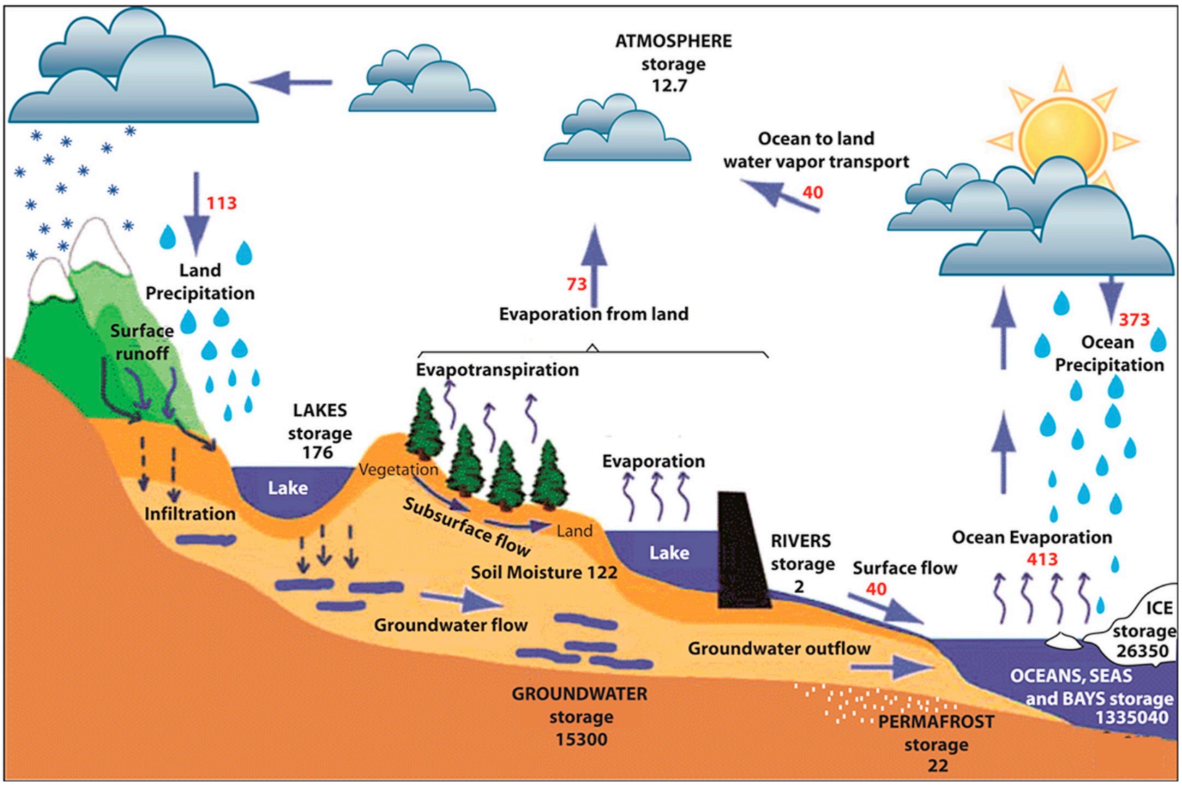


Figure 8: The hydrologic cycle. Estimates of the observed main water reservoirs (black numbers, in 10^3km^3 and the flow of moisture through the system (red numbers, 10^3km^3/yr). Adjusted from *Trenberth et al.* [2007] for the period 2002 - 2008 as in *Trenberth et al.* [2011]. Source: Gimeno et al (2012) Reviews of Geophysics, vol.50, issue 4, p.2

According to Ma et al. (2015), "Amplification of the hydrologic cycle as a consequence of global warming is predicted to increase climate variability and the frequency and severity of droughts".

And about the necessity of water as a physiological necessity to survive, it is also clear that a large section of a population's dietary needs necessitates sufficient water resources for agricultural purposes.

The importance of this is such that Beer et al. (2010) aver:

“terrestrial primary productivity through photosynthesis is the most fundamental ecosystem function not only because it provides the fuel that drives all other biological activities but also due to its significance in locking up carbon in biomass that would otherwise remain in the atmosphere as CO2” [Beer et al., 2010]

Irrigated agriculture in Australia uses about 60% of the water available for human use. Irrigated crops make up about 30% of the value of Australia’s agricultural production (Australian Government Department of Agriculture, Water and the Environment, 2020). It is thus of concern that “Vegetation phenology and productivity in Australia is highly variable and largely driven by inter-annual variations in rainfall” (Ma et al., 2015)

With these present concerns, we have to ask, “what do the existing trends in temperature change in Australia indicate regarding the possible (if not probable) changes to future water resources, particularly concerning vegetation and crop production?” And thus, how to make optimum use of how the hydrologic cycle in Australia is changing?

As Cong and Brady (2012) state: “Since temperature and rainfall are critical determinants of crop yield, accurate simulation of temperature and rainfall is important not only for meteorology but also for agricultural economics.”

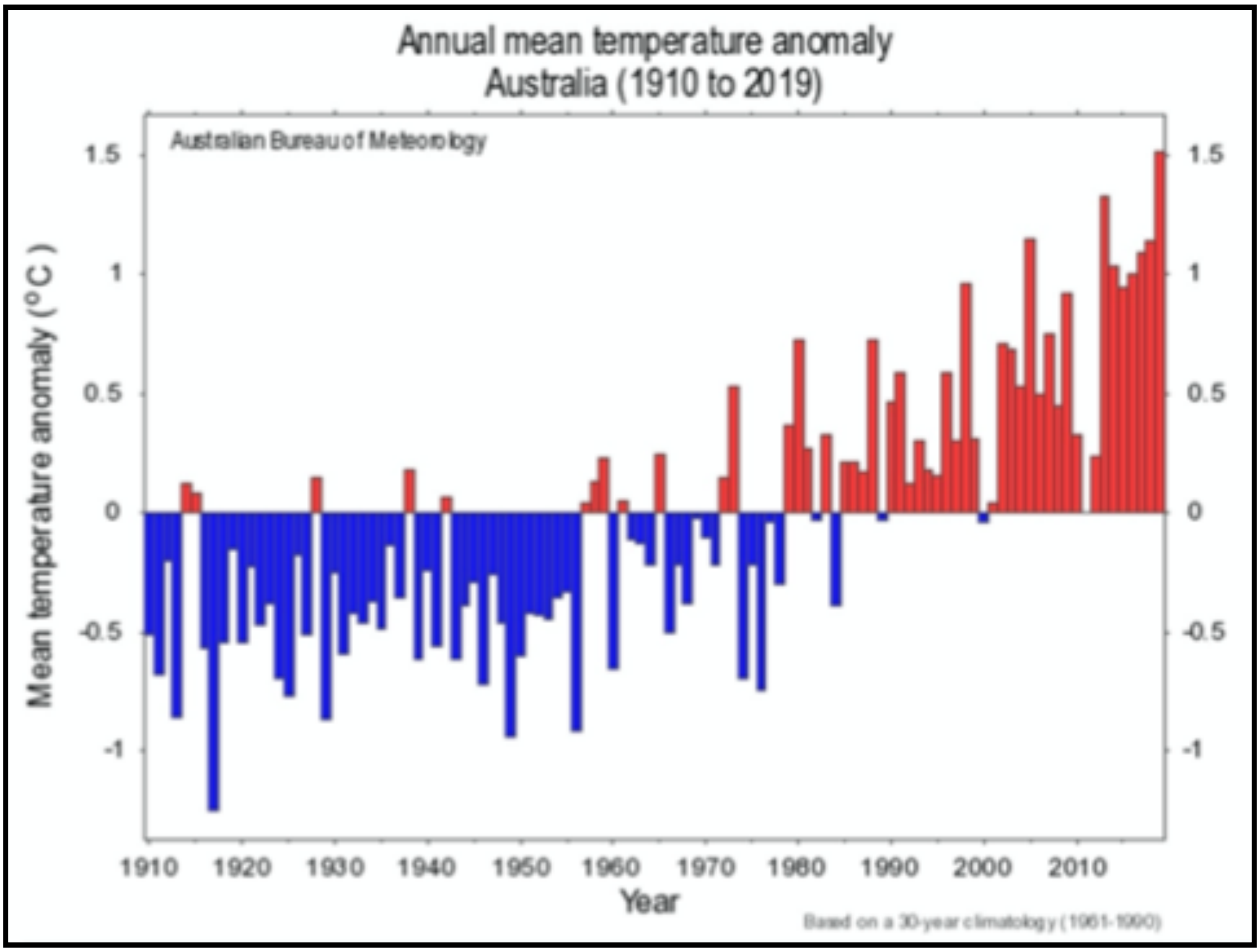


Figure 9: Bureau of Meteorology (BOM), Annual mean temperature anomaly Australia (1910 - 2019) viewed 8 August 2020, http://www.bom.gov.au/climate/change/#tabs=Tracker&tracker=timeseries

Climate Impact Analysis

According to the Australian Government BOM (2020), the annual mean temperature anomaly (1910 - 2019) is trending unidirectionally upwards. This environmental forcing, indicated by this increasing climatic extreme, will create complex vegetation phenology and productivity responses among biomes (Keenan et al., 2014). With the complexity of responses, measures are required to adapt to these changes to minimise climatic extreme impacts. Australia has recently experienced an increase in the frequency and severity of climate extremes (e.g. drought, flooding, heatwave; Cleverly et al. 2016).

As a specific example of how the relatively recent trend in climatic elements can be seen to imply future vulnerabilities, the following data is displayed graphically. Using data from The Queensland Government's SILO (Scientific Information for Land Owners) site, a location in South East Queensland has been chosen to visualise the relationship between precipitation (rainfall) and temperature over the last decade. The location is nominated “site 40004” and is located at Amberley near Brisbane.

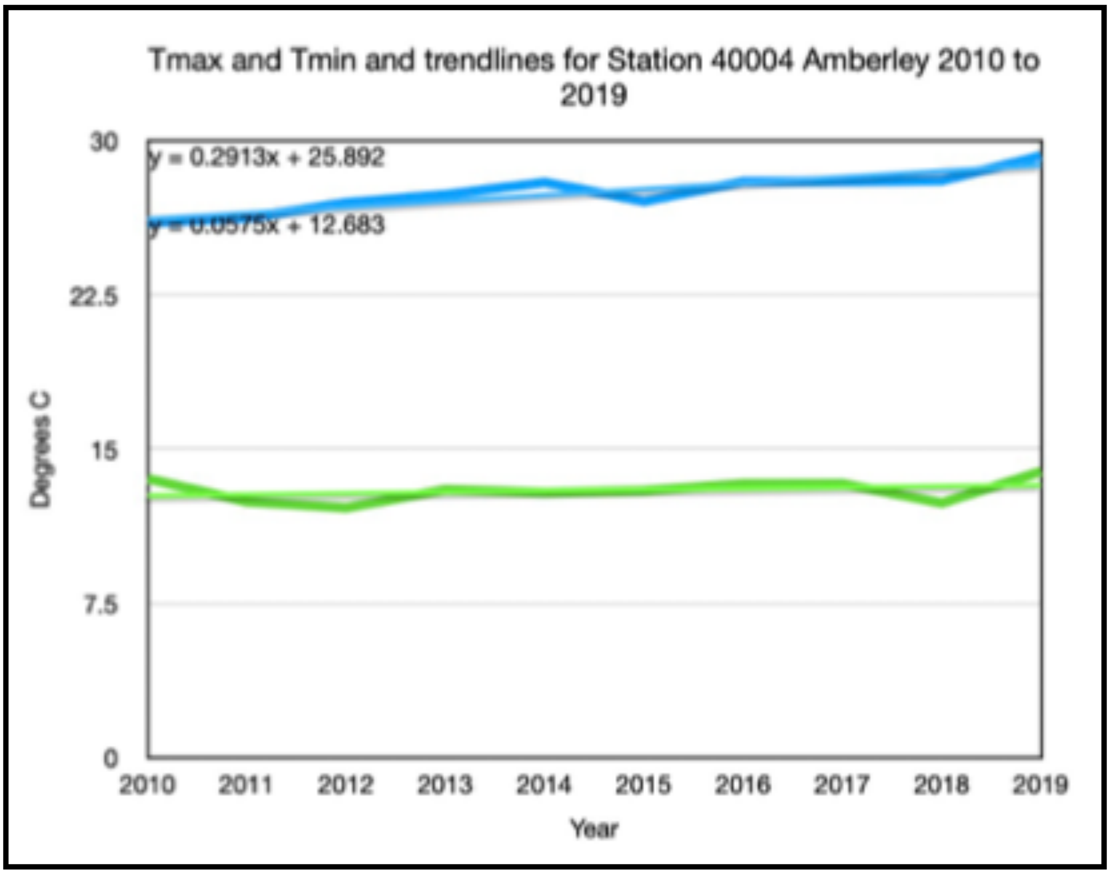


Figure 10. The above figure indicates the annual average temperature and trend lines for Site 40004 in Amberley from 2010 to 2019. Data obtained from the Queensland Government SILO - Australian climate data from 2010 to 2019, viewed 15 August 2020, https://www.longpaddock.qld.gov.au/

Although the minimum temperatures show a relatively low increase over the past decade, the increase in maximum temperatures is clearly on a continuous rise. Compared with precipitation over the same period at the same location:

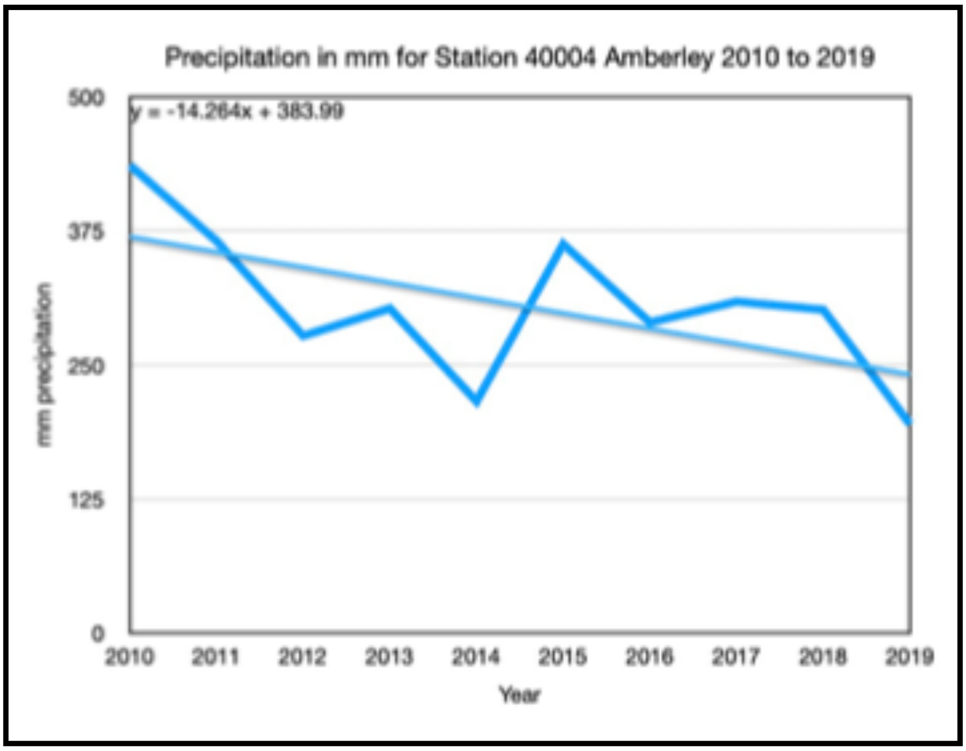


Figure 11. The above figure indicates the total amounts of precipitation on an annual basis and the trend line for Site 40004, Amberley. Data obtained from the Queensland Government SILO - Australian climate data from 2010 to 2019, viewed 15 August 2020, https://www.longpaddock.qld.gov.au/

It is also evident that there appears to be an inverse relationship between temperature increase and a trend in a decrease in annually-averaged precipitation. This would suggest concerns about a future scarcity of water resources should the temperature continue to rise as indicated.

The dataset from which these graphs were constructed was from the Queensland Government's SILO database, collating raw observational data from the Bureau of Meteorology and other providers for the entire continent (Queensland Government, 2020). From this database, other geographical locations throughout the country could be selected to understand better which areas may have more affected conditions through the extremes of drought and flooding. This way, adaptation and mitigation efforts can be designed to respond to those vulnerabilities.

As seen in Figure 11., although it clearly indicates the trend in overall precipitation, it also shows that each year has been at variance with another. These variations can also indicate trends that would exacerbate the already severe effects of localised changes in climate. It is therefore also necessary to understand what causes these variations and what strategies can be adopted, particularly in drought situations from perceivable and continuously declining levels of precipitation.

It is from the “combinations of heatwave and drought, in particular, also known as global change-type drought, that can have consequences on ecosystems as severe as tree mortality and forest dieback” (Breshears et al. 2009). This “likelihood of mortality is expected to increase as the frequency, intensity and duration of heatwaves increases” (Cleverly et al., 2019). This was earlier described by van Gorsel et al. (2016), who stated, “increases in the intensity, frequency or duration of heatwaves in future might have seriously detrimental consequences for even Australia’s wettest forests”.

Adaptation

In adapting to these changes in climatic conditions, Howden et al. (1999) suggest that “ We hypothesise that as rainfall and temperature regimes change, there will be a change in pasture composition towards species/ecotypes better adapted to the new climate”. But this, this and other observations require “analysis of vulnerabilities and possible policy actions include seasonal climate risk assessment” (McKeon et al. 1992; Stokes et al. 2008). Adaptation to the impacts of increasing temperatures and variations in precipitation involves adjusting practices, processes, capital and infrastructure in response to actual or anticipated climate change (Cradock-Henry, 2017)

Regarding water resources, Jones (2010) offers a comprehensive list of adaptation options that can be used for managing resource limitations. These are listed in Table 2 as follows

Adaptation Options Priority	
Operational	🟦
More effective on-farm use of water through improved technology and scheduling	1
Develop and apply probabilistic forecasts of water allocation changes	1
Improve distribution system operation and delivery	1
Increase monitoring of the water cycle and water makes performance	1
Increase use of water management tools (crop models, decision support tools)	2
Increase crop choice to maximise efficiency and profit	2
Minimise losses and maintain environmental values in channels and streams	2
Strategic	🟩
Develop more equitable sharing of climate risks among different users	1

Improve water trading rules remove perverse incentives and reduce the transfer of risk, especially during drought	1
Improve understanding of sustainable yield	1

Adaptation Options Priority	
Build climate change risks into caps/bulk allocation arrangements	2
Prepare for altered flood risks	2
Exercise control over private water storage and land use affecting supply	2
Improve income spreading strategies to spread risk	2
Build flexibility into allocation choices between agricultural, environmental, urban and industrial uses	2
Improve understanding of groundwater-surface water-climate interactions	2
Long-term planning	🟩
Build climate change into integrated catchment management and strategic planning	1
Build adaptation to climate change into new infrastructure	1
Develop understanding of critical thresholds and limits within water collection delivery and use systems	1
Develop groundwater storage options	2
Provide design guidelines for land use to maximise water yield and water quality within a framework of long-term sustainability	2
Institutional capacity	🟩
Develop risk-based decision-makinginto all levels of operation and planning from tactical to long-term	1
Develop better understanding of integrated catchment management among different users	1
Develop contingency-based decision-making of ‘one action fits all circumstances’	1
Improve multiple understandings of water related though research, discussion and community consultation	1
Develop a ‘whole of climate’ approach to operational and strategic decision-making	1

Table 2: Summary of climate change adaptation options for water in agriculture. Priority 1 (high and 2 (medium). Adapted from “Adapting Agriculture to Climate Change: Preparing Australian Agriculture, Forestry and Fisheries, edited by Chris Stokes, and Mark Howden, CSIRO Publishing, 2010

Further to this, more recent changes in policy and practice include: agricultural diversification, reduced conversion of grassland to cropland, Integrated water management, reduced deforestation, and soil erosion control (Smith et al., 2019)

However, these changes must also consider the general trend in climatic elements and their variability brought about by other driving forces, such as the annual cycle and the El Nino Southern Oscillation (ENSO). This discussion will be continued in Part 2 - Impacts of climate change ***variations*** on the hydrologic cycle in the context of the Australian continent.

Summary

Initially, this study conducted a comprehensive literature review focussing on critical global climate trends and those specifically affecting the Australian continent and its hydrologic cycle. This followed through with a discussion of increasing temperatures and related changes to precipitation, reflecting on some of the adaptation protocols that could be used to minimise the

Long-term effects of expected changes, particularly concerning Australia's agricultural sector.

It further identified that although general trends indicate an inverse relationship between increasing temperature and decreasing precipitation, it also recognises variability in those changes.
These changes are affected by other driving forces such as ENSO and require further study better to understand their effect on our increasingly warming climate.

Conclusion

Data has been obtained from reputable sources such as the National Aeronautics and Space Administration (NASA), the National Climatic Data Center (NOAA), the National Oceanic and Atmospheric Administration (NCDC) and the Australian Government's Bureau of Meteorology (BOM). This is supported by considerable peer-reviewed research on the changes to both global and local climatic changes.

It is with little doubt that temperature, through the capture of excess heat due to increasing GHG emissions, is increasing at an accelerated rate. This creates climatic disturbances that alter precipitation frequency and intensities (or lack thereof). Water resources supplied and maintained through the normal hydrologic cycle are being disrupted. This is proving increasingly problematic for decisions to adapt to protocols for managing changes to the hydrologic cycle and, in particular, optimisation of agricultural production necessary to feed a population.

There is a definite localised indication of an inverse relationship between temperature and precipitation. Variations in data gained showing this relationship also suggest a need for understanding the role of other driving forces, such as the effects of ENSO.

The further understandings considered as part of the institutional section of the aforementioned adaptation options listed in Table 2 must be urgently addressed.

Without understanding, little energy will be made to the efforts that ***must*** be made to retard, or hopefully reverse, the apparent unstoppable trends evident in both local and global climate change.

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