Climate variability and human health in Australia with specific regard to Dengue fever

Aedes Aegypti

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Abstract

Climate change trends indicate an ongoing increase in land and sea surface temperatures (Luber and Prudent, 2009) but within those trends can be seen *variabilities* in climatic and weather patterns. According to the World Meteorological Organisation (WMO) “A key difference between climate variability and change is in the persistence of ‘anomalous’ conditions — when events that used to be rare occur more frequently, or vice-versa” and that climate *variability* can thus be described as “to denote deviations of climatic statistics over a given period (e.g. a month, season or year) when compared to long-term statistics for the same calendar period.” (WMO, 2019)

These climatic *variabilitie*s have led to vulnerabilities recognised in their threat to human health. These vulnerabilities, according to WMO (2019) include:

1. Effects on Nutrition
2. Water-related disease
3. Airborne and Dust-related disease
4. Vector-borne disease
5. Mental health
6. Other health effects such as injury, migration and damage to healthcare systems

These climatic *variabilities* are affected by several climate drivers, the principal of which is the El Niño Oscillation Cycle (ENSO). This discussion is how this relates to one of the above-listed vulnerabilities, Vector-borne disease.

A literature review has therefore been undertaken to identify climate variabilities and how they specifically affect the spread of one particular vector-borne illness, dengue fever (DF). It further indicates progress and recommendations regarding mitigation protocols to ensure adequate preparation for this concern.

Key Words: Climate Change Variability, ENSO, Extremes, Human health, vector-borne illness, dengue.

Abbreviations:

ACCESS - S	Australian Community Climate Earth-System Simulator – Seasonal
BOM	Australian Bureau of Meteorology
Ae. Aegypti	Aedes aegypti — Mosquito vector bearing dengue illness
DF	Dengue Fever
ENSO	El Nino Southern Oscillation
GARP	Global Association of Risk Professionals
GCM	Global Climate Model
GFDL	Geophysical Fluid Dynamics Laboratory
IOD	Indian Ocean Dipole
IUCN	International Union for Conservation of Nature
MSTA	Maximum Sub-Surface Temperature Anomaly
NASA	National Aeronautics and Space Administration
NINO 3.4	NINO3.4 is the average sea surface temperature anomaly in the region bounded by 5°N to 5°S, from 170°W to 120°W.
NOAA	National Oceanic and Atmospheric Administration
RCP	Representative Concentration Pathway
SOI	Southern Oscillation Index
SST	Sea Surface Temperature
SSTA	Sea Surface Temperature Anomaly
WMO	World Meteorological Organisation

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A. Introduction

The objective of this study is to consider the effects of the primary driver (ENSO) of climate change affecting the health of the Australian population about the appearance of a vector-borne disease. By being able to predict the elements of ENSO we can subsequently outline its impact and mitigation action required in preparation for the threat of disease transmission. Climate change trends are clear, reflecting the elements of ENSO (McPhaden et al., 2020, p. 1) and expressed well in the table presented below:

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 - 2021	415ppm	Increase of 2.4ppm/ year	https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide
Global Temperature	1881 - 2020	1.02 °C annual average anomaly	Increase of 0.18 °C since 1981	https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature
Arctic Sea Ice	1979 -2020	9300 km3	Decline of 13.1% 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 148 Gt pa 1993-2019	https://nsidc.org/cryosphere/sotc/ice_sheets.html
Land Ice in Greenland	2002 - 2020	Approx. 1.7M Gt	Decline of 279 Gt pa 1993-2019	https://nsidc.org/cryosphere/sotc/ice_sheets.html
Sea Level Rise	1993 - 2020	97+/-4mm increase since 1993	Increase of 3.3 mm 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.

The methodology of this discussion has been first to review current literature relating to this subject and then, secondly, to highlight variabilities produced by trending changes and lastly, at some of the reputable authorities giving guidance on mitigation and adaptation responses available to counter future vulnerabilities.

The study is summarised and gives conclusions as to what climatic *variabilities* may indicate, how these may be predicted and what future possibilities there may be to adapt to the consequences of change, with particular reference to the possible spread of the vector-borne disease, dengue fever.

B. Literature Review

The literature search was conducted by choosing relevant and recent peer-reviewed literature to assist in the discussion on the impacts of climate change variability resulting essentially from the El Niño Southern Oscillation (ENSO) and its effect on human health in the context of the Australian continent and specifically, regarding the vector-borne illness — Dengue fever (DF)

Dengue is a mosquito-borne virus that affects more than 50 million people a year, with correlations being found between weather and climate variability and dengue incidence, including seasonal variability and ENSO index variability (Bannister-Tyrell et al. 2013, p. 65).

This is further emphasised by Ferreira (2014, p. 141), who states that:

> El Nino Southern Oscillation (ENSO) is one climactic phenomenon related to the inter-annual variability of global meteorological patterns influencing surface sea temperatures and rainfall variability. It influences human health directly through extreme temperature and moisture conditions that may accelerate the spread of vector-borne diseases like dengue fever (DF).

Dengue fever is not naturally endemic to Australia but one of its vectors the *Ae. Aegypti* with growing evidence that the frequency ,mosquito is common in northern Queensland and intensity of extreme weather events may impact DF emergence (Bannister-Tyrell et al. 2013, p. 65).

The search was conducted in March 2021 with the initial keywords “Australian Climate Change Variability” to narrow down appropriate and relevant literature that would inform this discussion. As identified in Figure 1, this initially identified 779 papers from 2012 to date, 2021. From this group, the search was extended using the keywords “ENSO”, “Extremes”, “Human Health”, “Vector-borne disease” and “Dengue fever”, which were identified in 116, 136,7, 4 and 2 documents respectively.

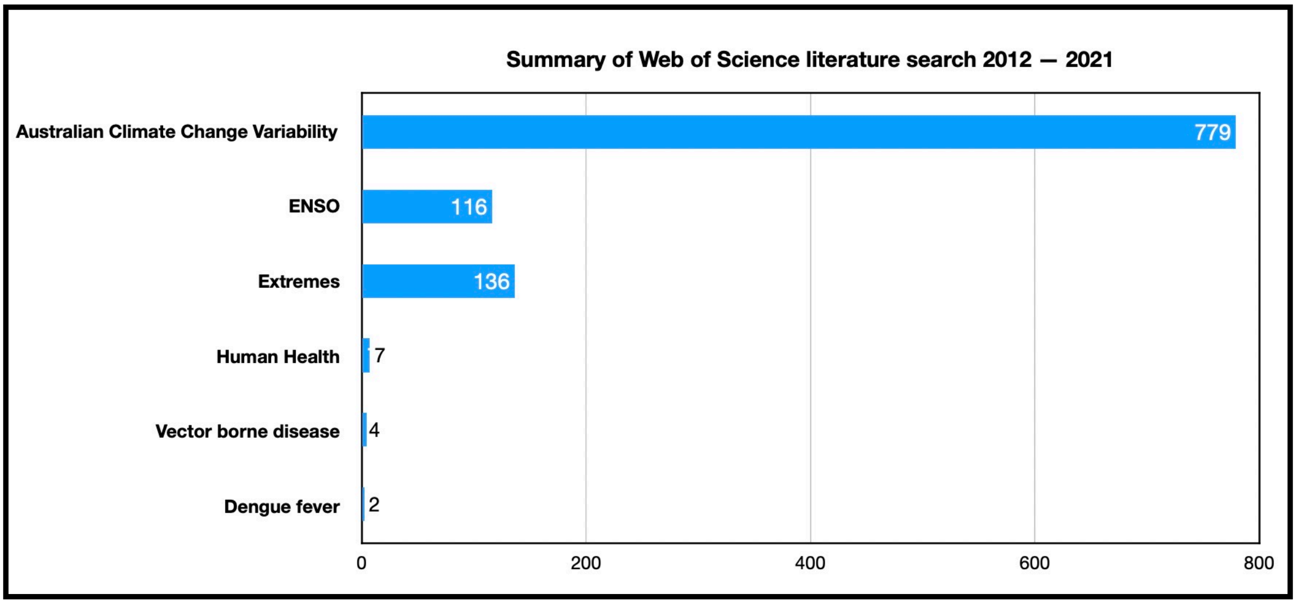

Figure 1. Web of Science Literature Search regarding the impacts of ENSO on climate change variability affecting the prevalence and future effect on one area of human health (viral—borne illness) in the context of the Australian continent.

From this basic literature search on the Web of Science database only, the following are three of the most relevant documents used in this discussion:

Bannister-Tyrrell M, Williams C, Ritchie SA, Rau, G, Lindesay, J, Mercer, G, and Harley, D, 2013. A process-based modelling approach examined weather-driven variation in dengue activity in Australia. *American Journal of Tropical Medicine and Hygiene 2013*, vol. 88, no. 1, pp. 65-72.

Beebe, NW, Cooper, RD, Mottram, P and Sweeney, AW, 2009, Australia's Dengue Risk Driven by Human Adaptation to Climate, PLOS Neglected Tropical Diseases, vol. 3, no.5, p. e429

Huang X, Williams G, Clements ACA, Hu W (2013) Imported Dengue Cases, Weather Variation and Autochthonous Dengue Incidence in Cairns, Australia. PLoS ONE, vol. 8, no. 12, p. e81887. doi:10.1371/journal.pone.0081887

These three articles present the climate change *variabilities* associated with the prevalence of vector-borne illnesses; with particular reference to dengue fever.

However, from their content, a further 180 relevant references are available, the majority of which being produced within the past 15 years.

Much of this literature has also been reviewed and would indicate a high degree of relevance and contemporaneity.

Further to the use of this literature, reference has also been made to the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA) and the Australian Bureau of Meteorology (BOM). These latter references have been used to provide a graphical representation of global and national climate variability data.

C. Climate Variability Observations

The El Niño Southern Oscillation (ENSO) is the Earth's dominant mode of climate variability on seasonal to inter-annual time scales. ENSO is a year-to-year fluctuation of sea surface temperatures (SSTs), rainfall, winds, and currents over the tropical Pacific Ocean, which affects weather, economies, and ecosystems worldwide (GFDL, 2015, p. 1). ENSO is the driving force of climate variability that is often referred to when considering future alterations to weather patterns and their effects on such elements as temperature and precipitation

According to Folland et al. (2002, p. 105):

> Observed climate change and variability are considered by addressing seven commonly asked questions related to the detection of climate change and the sensitivity of the climate to anthropogenic activity. These questions are:
>
> (i) How much is the world warming?
>
> (ii) Is the recent warming unusual?
>
> (iii) How rapidly did climate change in the distant past?
>
> (iv) Have precipitation and atmospheric moisture changed?

(v) Are the atmospheric/oceanic circulations changing?

(vi) Has climate variability, or have climate extremes, changed?

(vii) Are the observed trends internally consistent?

In brief, although these questions were generated nearly two decades ago, they are still relevant. In particular, in this discussion, these questions produce results indicating a clear relationship between global temperature increase and increased vector-borne viral diseases.

Presently, epidemic dengue is limited to regions of Queensland, with the frequency of outbreaks increasing constantly. In one Global Association of Risk Professionals (GARP) model using current [2009] climatic conditions, the mosquito *Ae. Aegypti*, the primary dengue carrier, could co-exist with 95% of the Australian population under either the 2030 or 2050 climate change scenarios (Beebe et al., 2009, p. 1).

Reflecting on the scale of climate extremes and other probable crises, vector-borne illnesses would appear to be of somewhat minor concern. Still, increasing climate variability could establish this concern as a greater threat to the health of Australia's population. Thus, it is important to consider how climate change variability will affect the Australian continent and address any possible future vulnerabilities.

Data downloaded are for those that reflect "observed changes that document the current and historic state of ENSO and provide an indication of possible future changes"

These changes are related to:

1. Sea Surface Temperature
2. Sea Subsurface Temperature
3. Southern Oscillation Index
4. Trade Winds
5. Models
6. The Indian Ocean

(University of Southern Queensland, CLI8002,TechnicalReport02.pdf., 2021)

In more detail:

1. Sea Surface Temperature (SST)

Sea Surface Temperature (SST) can be defined as:

> "…the temperature of the top millimetre of the ocean's surface. An *anomaly* is when something is different from normal, or average. A sea surface temperature anomaly is how different the ocean temperature at a particular location at a particular time is from the normal temperatures for that place." (NASA, 2011)

According to the National Aeronautics and Space Administration (NASA, 2021) earth observatory: "Sea surface temperatures have a large influence on climate and weather". In the Australian Region, the SST anomalies measured are represented in Figure 2 below, indicating an upward but variable trend in temperatures affecting the climate.

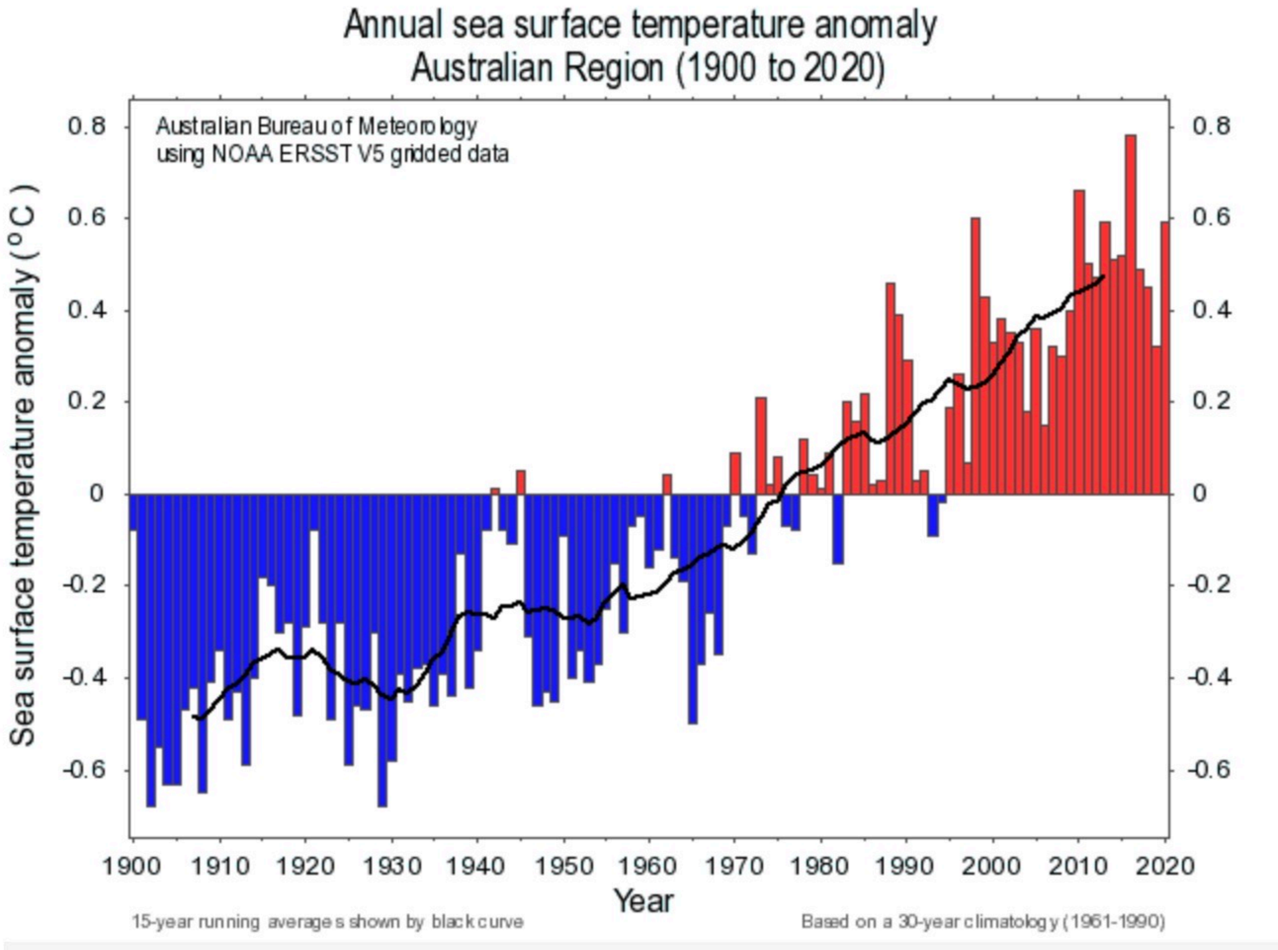

Figure 2. Annual Sea Surface Temperature anomaly (1900 to 2020) obtained from the Australian Government Bureau of Meteorology, viewed 18 March 2021, http://www.bom.gov.au/cgi-bin/climate/change/timeseries.cgi?graph=sst&area=aus&season=0112&ave_yr=15

With increasing changes in sea surface temperatures, there is greater evaporation, thus producing a higher concentration of water vapour in the atmosphere (BOM, 2021a)

2. Sub-surface seawater temperature

Measurement of this variable is required to recognise other physical variables such as heat transport, sea-level rise and marine biology, as:

> "Ocean heat content directly derived from subsurface temperature is of paramount importance in the monitoring of the Earth's climate system and marine environment. ... Heat uptake by the global ocean accounts for more than 90% of the excess heat trapped in the Earth system in the past few decades."(NOAA, 2021a)

When there is a high correlation between the maximum sub-surface temperature anomaly (MSTA) and sea surface temperature anomaly (SSTA), this can be used to not only diagnose El Niño events but also to investigate La Niña events; thus an ability to predict the state of the El Niño – La Niña cycle. (Qian et al., 2004).

Further to this, "Rising ocean temperatures also affect the benefits humans derive from the ocean — threatening food security, *increasing the prevalence of diseases* and causing more extreme weather events and the loss of coastal protection" (IUCN, 2020)

From the charts that follow in Figure 3. relating to the current sub-surface seawater temperature anomalies (SSTAs), it can be predicted that with the now receding movement of the colder mass of seawater eastward and the development of the warmer pool in the western region, that we are now departing a La Niña cycle.

The top two charts in Figure 3. indicate thermocline temperatures in degrees C and the bottom chart indicates the SST Anomalies.

Pacific Ocean Equatorial Cross-Section

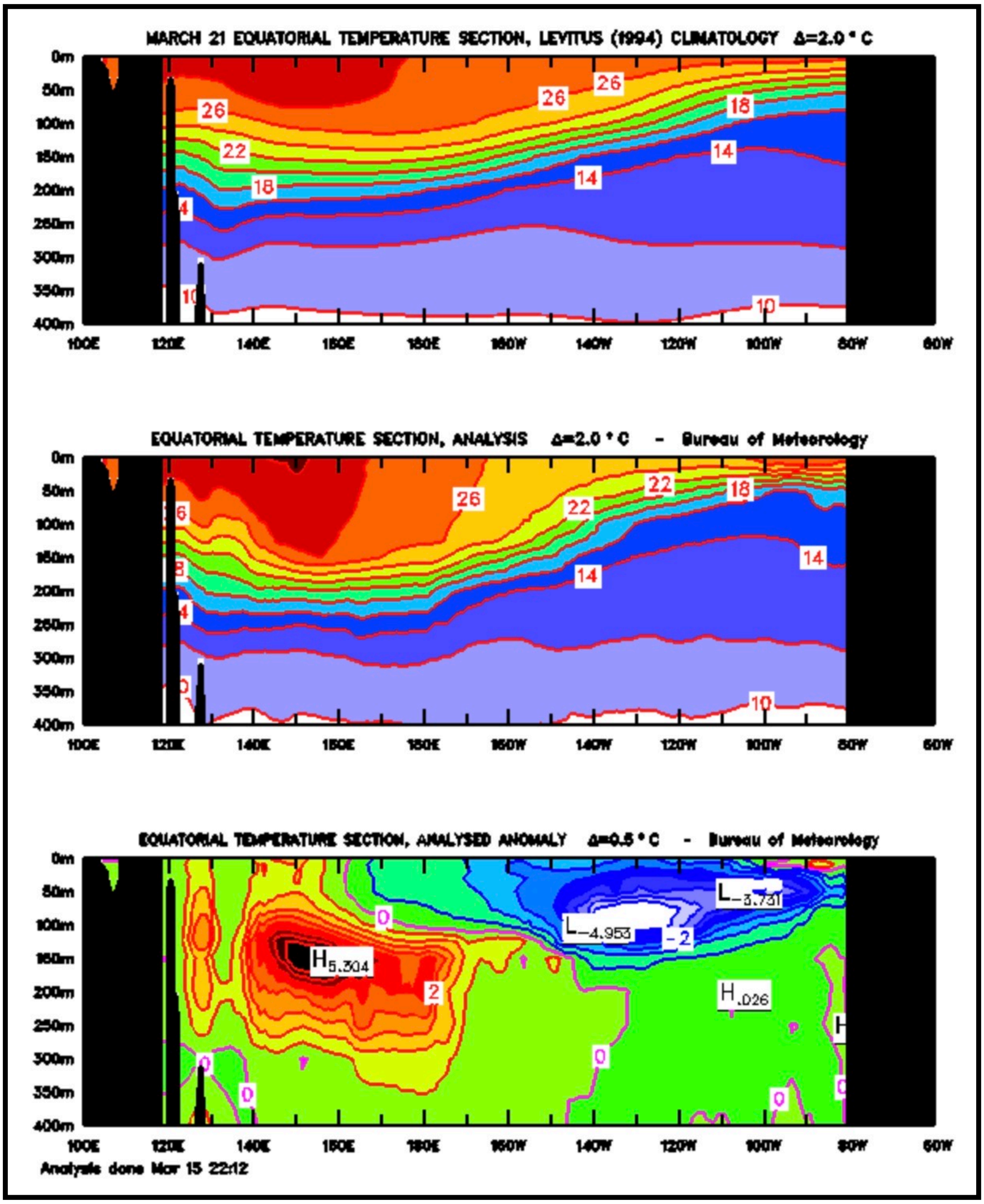

Figure 3. *Pacific Ocean Equatorial Cross-Section* obtained from the Australian Government Bureau of Meteorology, viewed 18 March 2021, http://www.bom.gov.au/cgi-bin/wrap_fwo.pl?IDYOC002.gif

3. Southern Oscillation Index (SOI)

This index indicates the development and intensity of El Niño or La Niña events in the Pacific Ocean. The SOI is calculated using the pressure differences between Tahiti and Darwin; sustained negative values of the SOI lower than –7 often indicate El Niño episodes and sustained positive values of the SOI greater than +7 are typical of a La Niña episode. (BOM, 2021c).

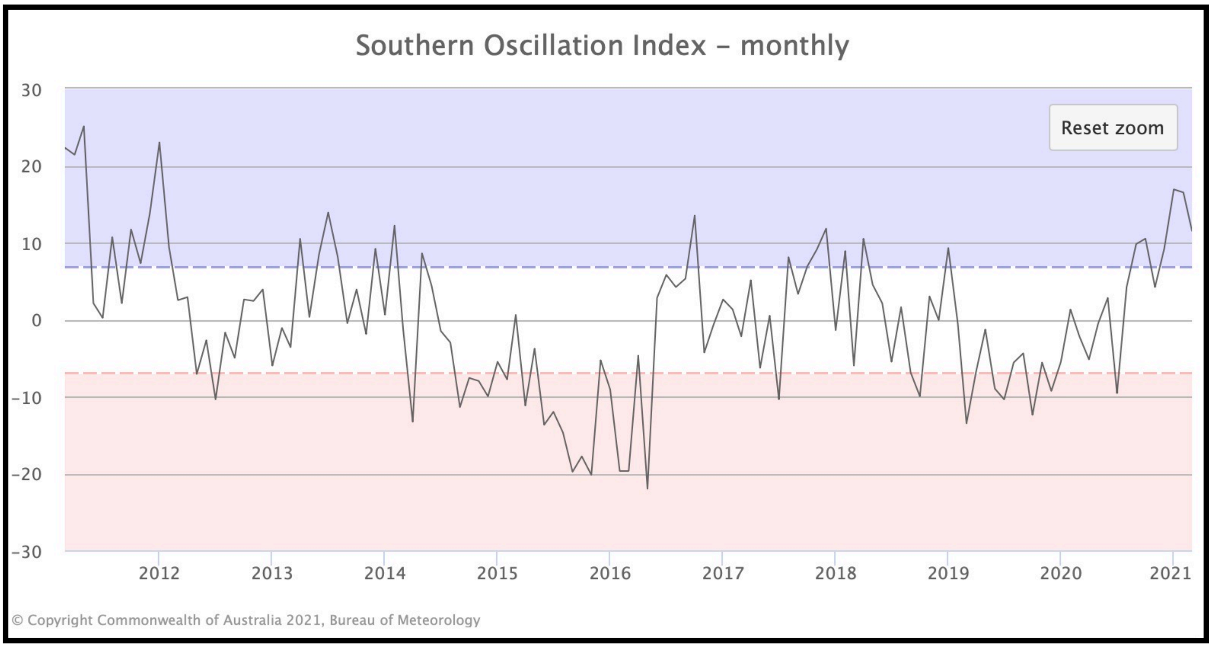

Figure 4: Monthly Southern Oscillation Index indicating pressure difference variability. Viewed 18 March 2021, **http://www.bom.gov.au/climate/enso/soi/**

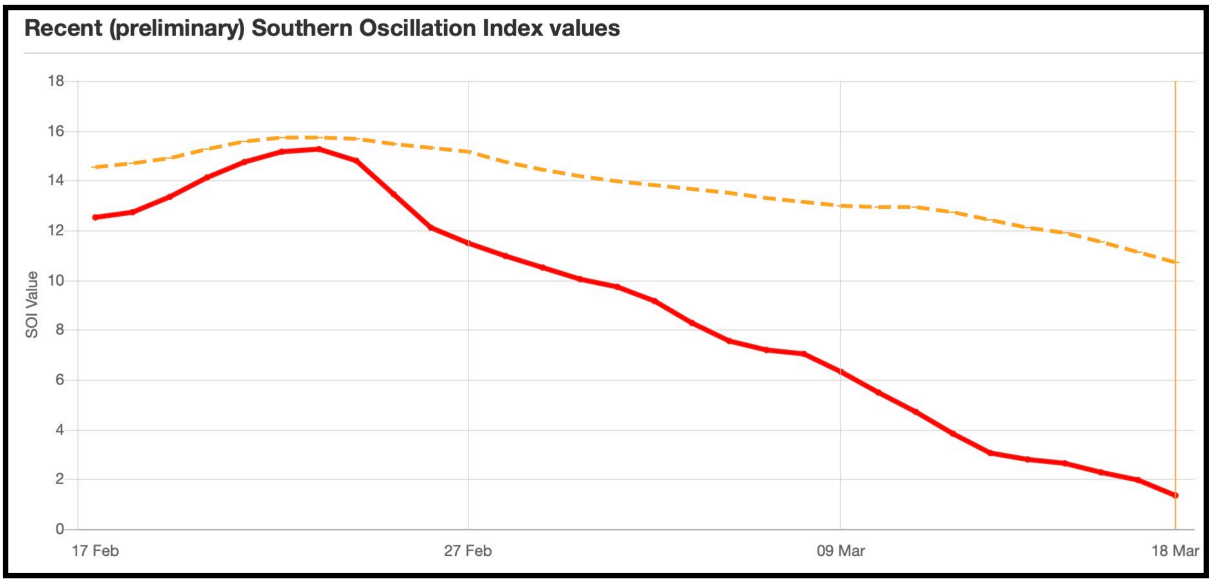

Figure 5: Recent SOI values indicating the ENSO tending towards a departure from the recent La Niña episode. Viewed 19 March 2021, https://www.longpaddock.qld.gov.au/soi/

4. Trade Winds

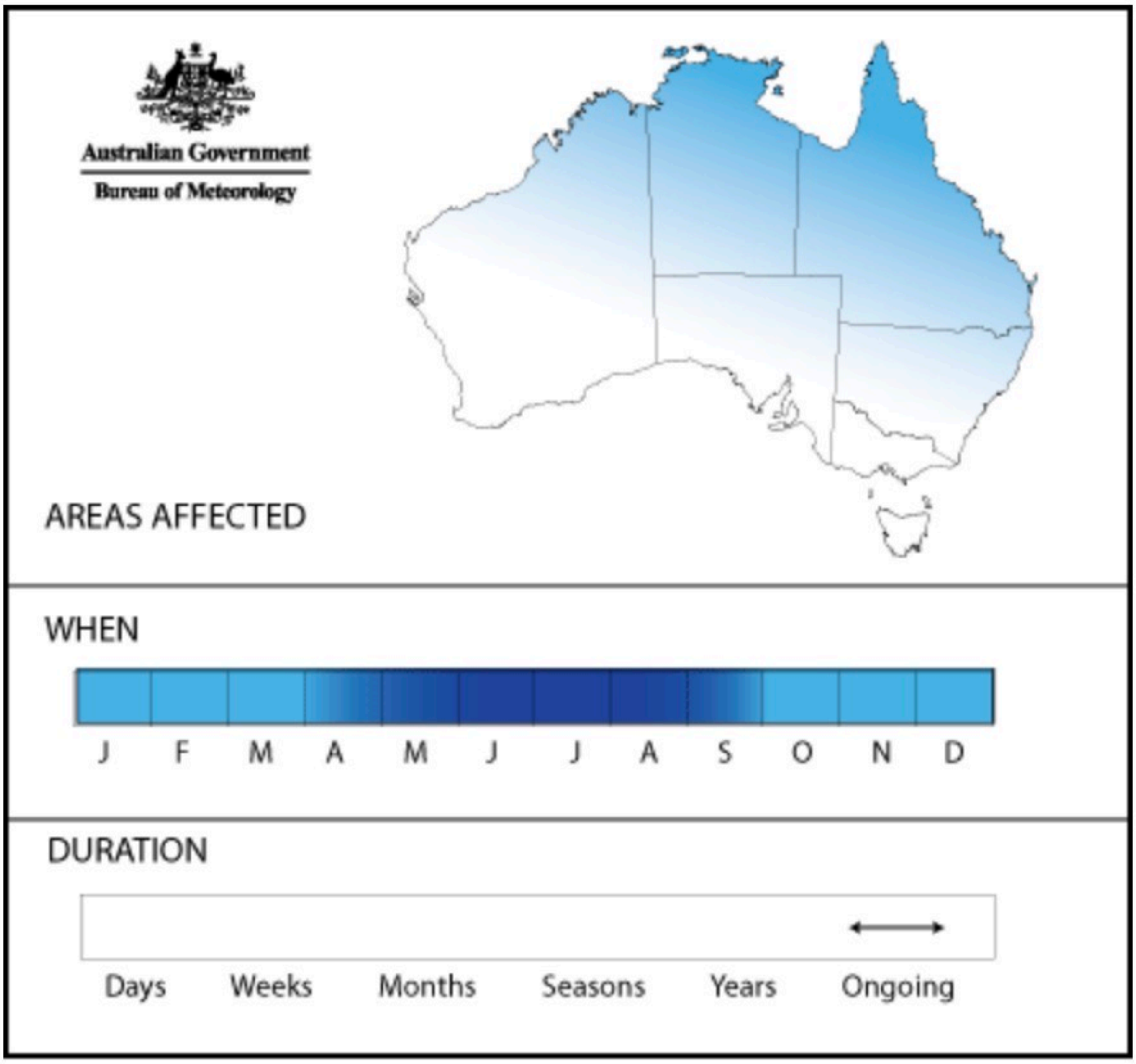

Figure 6. Areas affected by trade winds, when they occur and how long they may last obtained from the Australian Government Bureau of Meteorology, viewed18 March 2021, http://www.bom.gov.au/climate/about/?%20%20%20%20%20%20%20%20%20bookmark=trades

The Trade Winds as highlighted in Figure 6. are the east to southeasterly winds which blow across much of the southern hemisphere tropics, affecting tropical to subtropical areas of Australia.

> "The trade winds affect much of northern and parts of eastern Australia. They collect moisture as they move eastward over the tropical Pacific Ocean towards the east coast of Australia and are associated with enhanced rainfall to tropical and subtropical areas of the east coast." (BOM, 2021d)

It is the intensity of these winds and subsequent precipitation that is of great importance in the assessment of possible flooding events and the *provision of more future breeding grounds for the mosquitoes carrying vector-borne diseases.*

5. Models

Climate models are based on global patterns in the ocean and atmosphere and are often referred to as Global Climate Models (GCMs).

These use mathematical equations to estimate future changes to the climate from data obtained from historical and present events. From this, scenarios have been worked out representing future situations given certain changes in climatic variables. These are referred to as Representative Concentration Pathways (RCPs). The Bureau of Meteorology (BOM) in Australia uses the Australian Community Climate Earth-System Simulator – Seasonal (ACCESS- S) Model. From this, the latest outlook for the ENSO cycle is represented by the below series of charts for the NINO 3.4 region:

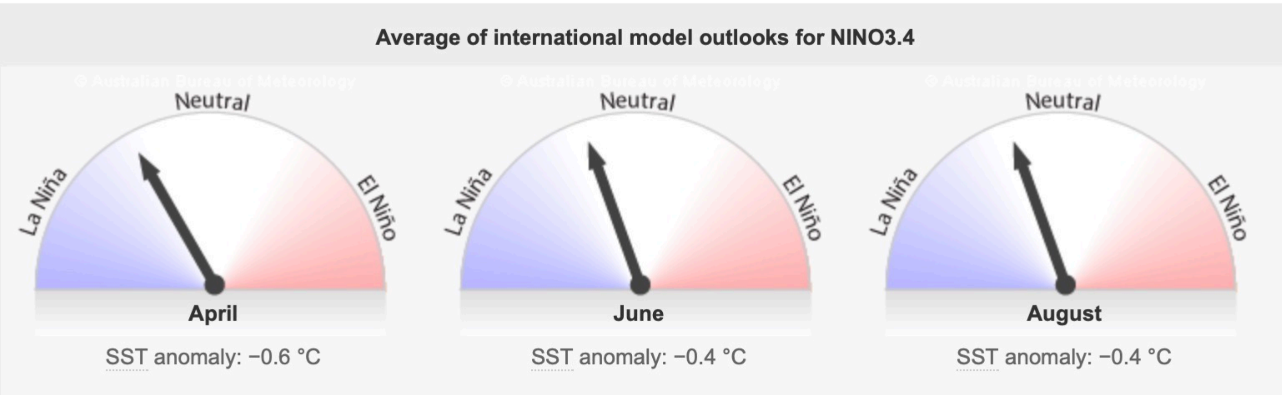

Figure 7. Average of international model outlooks for NINO3.4 obtained from the Australian Government Bureau of Meteorology, viewed 19 March 2021, http://www.bom.gov.au/climate/model-summary/#region=NINO34

The arrows on the dials are shown in Figure 5. indicate the combined average of monthly outlooks from a survey of international global climate models (BOM, 2021e).

6. The Indian Ocean Dipole (IOD)

The Australian Government's Bureau of Meteorology states, "Sustained changes in the difference between sea surface temperatures of the tropical western and eastern Indian Ocean are known as the Indian Ocean Dipole or IOD." The IOD is one of the key drivers of

Australia's climate and can significantly impact and exacerbate the intensity of the precipitation. The IOD has three phases: neutral, positive and negative. (BOM, 2021)

Currently, the Australian Community Climate earth-System Simulator - Seasonal (ACCESS-S) Model forecasts the following outlooks:

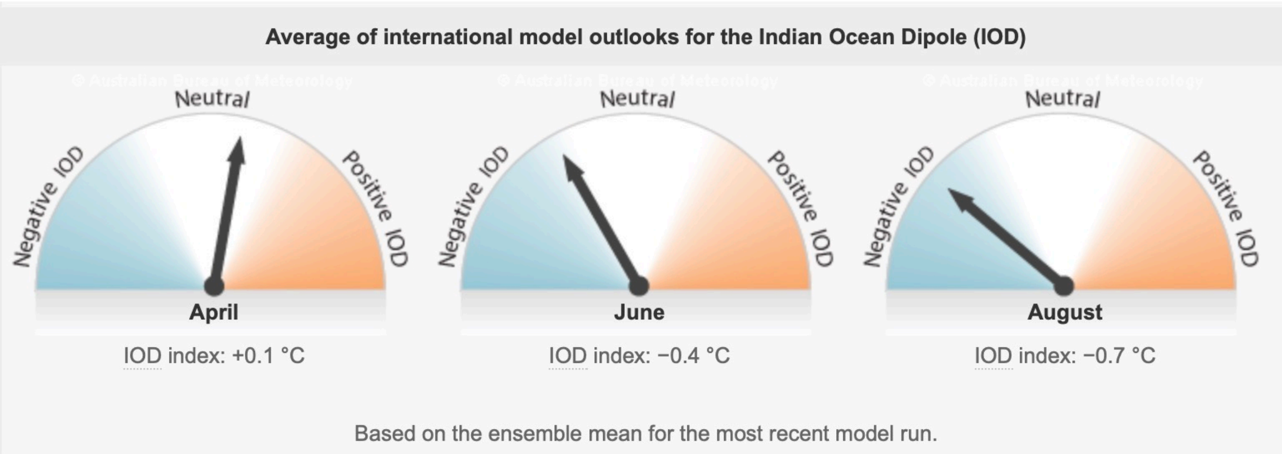

Figure 8. Average of international model outlooks for the Indian Ocean Dipole (IOD) obtained from the Australian Government Bureau of Meteorology, viewed 18 March 2021, http://www.bom.gov.au/climate/model-summary/ #region=NINO34

In Figure 8., the arrows on the dials indicate the combined average of monthly outlooks from a survey of international global climate models (BOM, 2021f).

Summary of Climate Variability Observations

Climate Variable	Description	Importance	References
Surface Seawater Temperature (SST)	Sea surface temperature (SST) is the water temperature close to the ocean's surface.	Plays a major role in regulating Earth's climate system	http://www.bom.gov.au/cgi-bin/climate/change/timeseries.cgi?graph=sst&area=aus&season=0112&ave_yr=15
Sub-surface seawater temperature anomaly (SSTA)	Temperatures that are departures from average conditions at varying depth levels and indicating thermocline depth changes.	Recognises heat transport, sea level rise and marine biology. Heat uptake by the global ocean accounts for more than 90% of the excess heat trapped. used to not only diagnose El Niño events	http://www.bom.gov.au/cgi-bin/wrap_fwo.pl?IDYOC002.gif
Southern Oscillation Index (SOI)	This is an index that indicates the development and intensity of El Niño or La Niña events in the Pacific Ocean.	As implied in the description	http://www.bom.gov.au/climate/enso/soi/ https://www.longpaddock .qld.gov.au/soi/
Trade Winds	The Trade Winds are east to southeasterly winds. affecting tropical to subtropical areas of Australia.	Affect tropical to subtropical areas of Australia.	http://www.bom.gov.au/climate/about/?bookmark=trades

Models	Based on global patterns in the ocean and atmosphere and are often referred to as Global Climate Models (GCMs).	Used to assist in future climate and weather prediction	http:// www.bom.gov.au/ climate/model-summary/ #region=NINO34
Indian Ocean Dipole (IOD)	Sustained changes in the difference between SSTs of the tropical western and eastern Indian Ocean	Can extend and exacerbate the intensity of precipitation	http:// www.bom.gov.a u/climate/ model-summary/ #region=NINO3 4

Table 2. Summary description, importance and reference for Climate Variability Observations.

D. Climate change variability affecting the Australian Continent

Variability, by definition, means a lack of consistency or fixed pattern; liability to vary or change (Lexico, 2020). This infers the possibility of changes that may reach extremes going well beyond the norm and produce, in terms of climatic conditions, impacts where Dey et al. (2019) suggest: "This variability can lead to droughts and floods that have widespread impacts on various sectors such as food production, human health, and water management."

The drivers of climatic *variability* all interact to create a complexity of issues greatly influenced by changing sea temperatures and atmospheric movements such as trade wind influence. However, as mentioned earlier, with ENSO being considered the Earth's dominant mode of climate variability on seasonal to inter-annual time scales (NOAA, 2021b) it is the *variability* of this principal driver that is of greatest concern about future climatic impacts on the vector-borne disease in this discussion.

Data produced by NOAA (ibid.) indicates that the variability in the intensity of ENSO is increasing in direct relation to increasing SST, as indicated in Figure 9. below (Nino3.4 temperatures from 1950 to 2020).

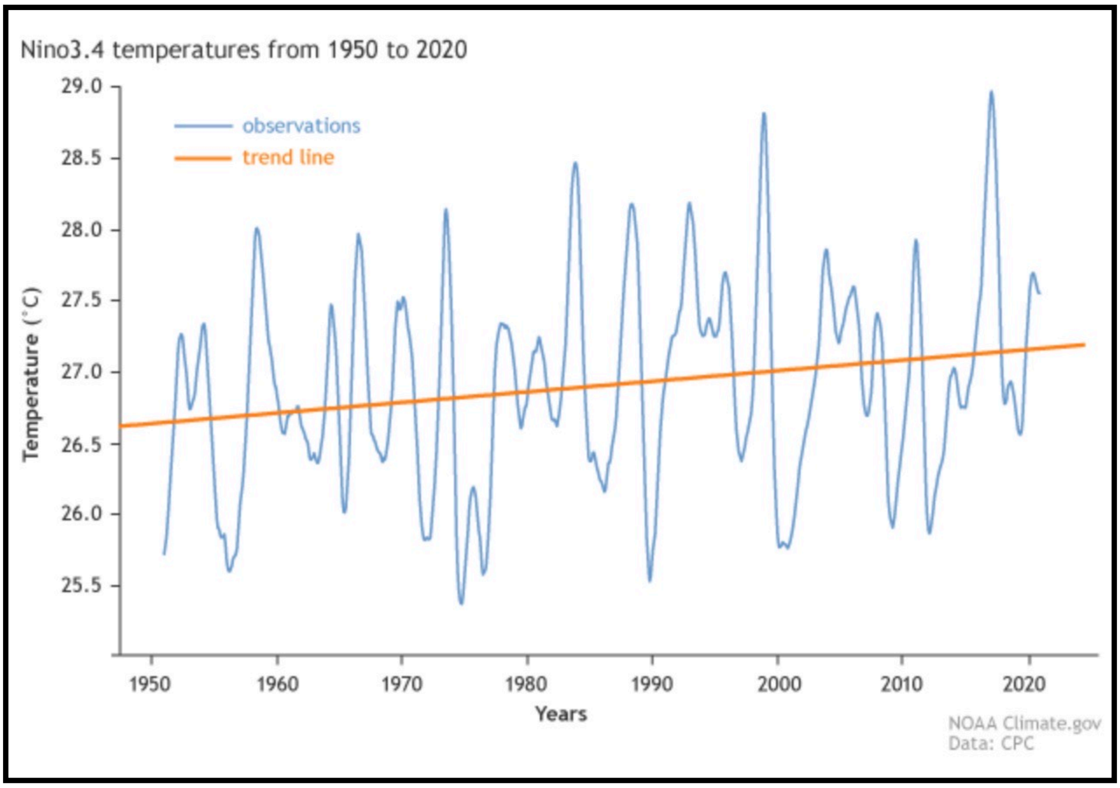

Figure 9. SST trend line from observations in the Nino3.4 range from 1950 to 2020

This concurs with Wang et al. (2019), who states that :

> The onset changes and more frequent occurrence of the extreme events in the past four decades arise from a background warming in the equatorial WP [Western Pacific]and the associated enhanced zonal SST gradients in the equatorial CP [Central Pacific]

In recent years these climatic extremes have produced disastrous conditions of both droughts associated with excessive heat and flooding through greater than normal precipitation (Forootan et al., 2018).

This, in turn, would suggest that the conditions for developing vector-borne disease carriers will increase by similar proportions.

E. Climate Impact Analysis

1. Drought and Excess Heat Impacts

The impact of drought and its occurrence in Australia is a frequent event forced by *variability* at inter-annual and inter-decadal scales associated with El Nino (Chiew et al.,1998).

Contributing to the severity of these events have been drought conditions considered to be the most severe on record in some affected areas together with “record-breaking runoff above-average monthly temperatures, lasting 36 months to October 2019” (Noyes, 2019, p. 1).

2. Extreme rainfall and Flooding Impacts

Rainfall throughout the entire Australian continent has “large and temporal variability” (Dey et al, 2019). Further, Gallant & Karoly (2010) aver: “Since 1910, the percentage of the area experiencing extreme heavy rainfall has increased while the percentage of the area experiencing dry conditions has declined”.

3. The impact of excessive heat and flooding on the spread of the dengue virus

Owing to the increasingly excessive and variable impact of climate extremes, *Ae. Aegypti*, the DF-carrying mosquito, for years being geographically restricted to the African continent and Southeast Asia, has now colonised most continents (Kraemer et al. 2015). This includes the Australian continent and is thus a concern for our future health and well-being.

It is suggested that globalisation and changes to the climate have exacerbated the emergence and spread of arboviruses via such vectors as the *Ae. Aegypti* mosquitoes and become potential pandemic drivers (Lwande et al. 2020).

In 2007, the WHO undertook a study of future possible dengue fever transmission and avers that;

Climate change is likely to increase the land area with a climate suitable for dengue fever transmission in Australia. An increased number of people are expected to live in the dengue-risk region (Figure 10).

Estimated population at risk of dengue transmission under current and projected conditions in 2050

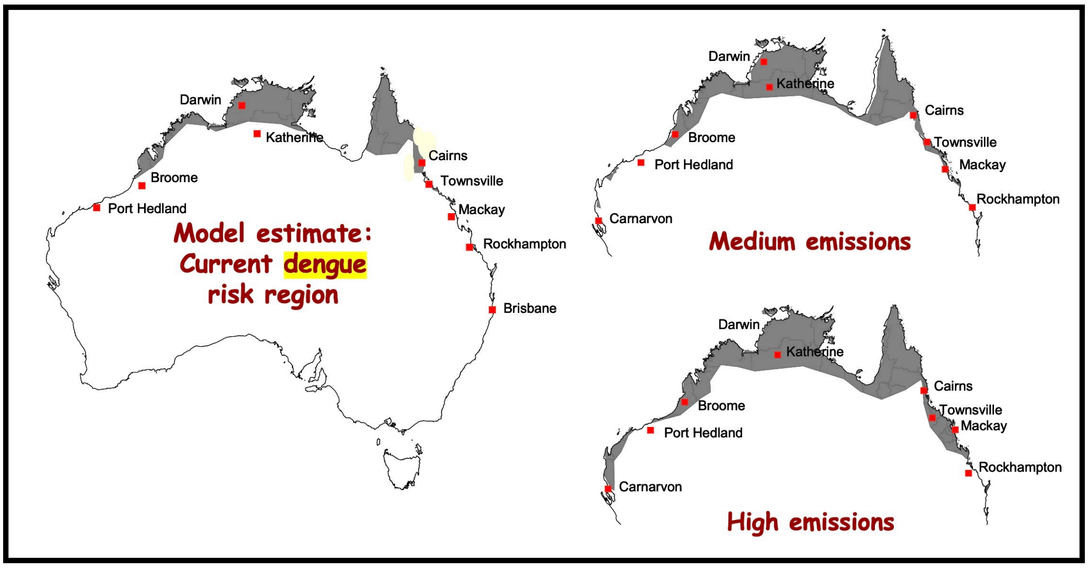

Figure 10. Results of a logistic regression model with vapour pressure (humidity) as the predictor of dengue fever risk (Hales et al., 2002). Adapted from Figure 7. WHO (2007) Climate Change: Quantifying the health impact at national and local levels.Viewed 20 March 2021, https://apps.who.int/iris/bitstream/handle/10665/43708/9789241595674_eng.pdf?sequence=1&isAllowed=y

As a result of this, "The Asia Pacific Dengue Strategic Plan for both regions (2008–2015) has been prepared in consultation with member countries and development partners in response to the increasing threat from dengue" (WHO, 2009)

Specific to this, Forino et al. (2014) state that "Australia is considered one of the most vulnerable developed countries to the effects of climate change, and thus policies geared towards activating adaption strategies are required."(p.475)

Recent impacts and revealed vulnerabilities from climatic extremes are of great concern. The above brief review of these events provokes increased concern for observation, predictive abilities and methods for mitigation and adaptation toward the spread of vector-borne disease.

But as early as 2008-2009, the largest outbreak in Australia occurred in Cairns, far northern Queensland, with more than 1000 reported cases which overwhelmed the capacity of the local Dengue Action Response Team (Bannister-Tyrell, 2012, Huang, 2013)

In consideration of future preparedness for the projected rainfall reduction, Beebe et al. (2009) observe that:

> Southeast Australia has seen the installation of large numbers of government-subsidised and ad hoc domestic water storage containers that could create the possibility of the mosquito Ae. Aegypti expanding out of Queensland into southern Australian's urban regions" and that "human adaptation to climate change – through the installation of large stable water storage tanks – may pose a more substantial risk to the Australian population than do the direct effects of climate change (p.1)

This poses a conundrum for mitigating potential water shortage whilst attempting to limit the spread of potential habitats for disease-bearing mosquitoes. This might call for some slight adaptations to the mechanical engineering required to improve water catchment (Ibid. p. 1)

More recently, further work has been performed in the production of the Queensland Dengue management plan (2015 —2020), which gives comprehensive information and guidance on vector management response — risk assessment, mosquito control, disease surveillance and control, managing dengue outbreaks and efforts towards greater public awareness and community engagement. (Queensland Health, 2015).

However, more recent promise in mitigation strategies is also being evidenced through bio-engineering, in the deployment and observed success of the insect bacterium *Wolbachia* strains into the existing *Ae. Aegypti* mosquito populations and comparative levels of protection are increasing. Studies of long-term effects are still ongoing (Flores et al., 2020; Waltz, 2017). In April this year (2021), the United States released their first genetically modified mosquitos in the Florida Keys. (Waltz, 2021)

F. Summary

Initially, this study conducted a comprehensive literature review focussing on critical global climate change variability and focussing specifically on the El Nino Southern Oscillation climate change variability and its effect on human health in the context of the Australian continent and specifically, on one particular vector-borne illness - dengue fever.

This was effected by a discussion of the six key climate *variability* observations and a summary of the variables, their description and their relative importance to predicting change. It further inferred how these variables affected the increasing likelihood of vector-borne disease concerning the prime climate drivers, the most significant of which is the El Nino Southern Oscillation.

A Climate Impact Analysis followed that was briefly directed specifically at the extreme ends of climate variability — drought and excess heat and flooding and excess precipitation. This then reviewed the conundrum of earlier adaptation efforts to improve water retention, its potential for increasing mosquito habitats, and future improvements for mitigation and adaptation through mechanical and bio-engineering.

Further details given by Queensland Health (2015) have produced a comprehensive Dengue management plan. More recent efforts in bio-engineering mitigation are proving successful in reducing the spread of vector-borne disease.

G. Conclusion

As this discussion has revolved essentially around the Australian situation, data has been principally obtained from the Australian Government Bureau of Meteorology. Other reputable sources such as the National Aeronautics and Space Administration (NASA), and National Oceanic and Atmospheric Administration (NOAA) have also been consulted, supported with considerable peer-reviewed research on climate change variabilities, particularly with an emphasis on the extremes of variability being frequently and recently experienced.

The variables reviewed indicate changes in temperature, heat accumulation, pressure and wind movement, most of which influence, and in turn, are influenced, *among other systems*, by the climate drivers of El Niño, the Trade Winds and the Indian Ocean Dipole (IOD) as reviewed in this discussion.

In the complex interaction of driving forces and physical parameters such as changing pressures and temperature, *variability* is experienced often resulting in climate extremes producing severe droughts and flooding. The resulting impacts of these events cause devastating destruction to land, homes and buildings, displaced populations, loss of life and livelihoods and the insidious development of habitats for disease-transmitting mosquitoes.

To counter these extremes, adequate mitigation and adaptive measures must be taken to prepare and add resilience to our response to these probable changes. These now include successfully proven bioengineering methodologies.

For further information on this problem and the efforts to reduce the effect of vector-borne diseases, the reader is initially referred to the Queensland Dengue management plan (2015-2020) produced by Queensland Health.

H. References

Australian Government Bureau of Meteorology, 2021a, *Annual Sea Surface Temperature anomaly* (1900 to 2020), viewed 18 March 2021, <http://www.bom.gov.au/cgi-bin/climate/change/timeseries.cgi?graph=sst&area=aus&season=0112&ave_yr=15>.

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