2

PHYSICAL SCIENCE

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2.1 Introduction

Island nations in the tropical western Pacific are truly "in the eye of the storm" in terms of climate change. The oceans are acidifying, temperature extremes are going off the scale, rainfall variability is increasing, sea level rise is occurring faster than the global average in a region where many populations live close to sea level, and tropical cyclones are becoming more intense. All these factors raise the likelihood of damaging extreme events, from coastal inundation to drought and crop failures, to unprecedented storm damage and torrential rains. This chapter outlines the current climate of the southwest tropical Pacific, and how it is likely to change through the rest of the 21st century.

2.2 Current climate

The average climate of the southwest Pacific is dominated by the trade wind circulation, combined with intrusions of cooler air from the middle latitudes. Average daytime temperatures across the region range from the mid-20s to the low 30s (degrees) Celsius, with small seasonal or interannual variability. Precipitation in most parts of the region can be divided into a dry season from May to October and a wet season from November to April. During the wet season, much of the precipitation is associated with the South Pacific Convergence Zone (SPCZ), the core of which on average lies from the Solomon Islands to French Polynesia, as shown in Figure 1.

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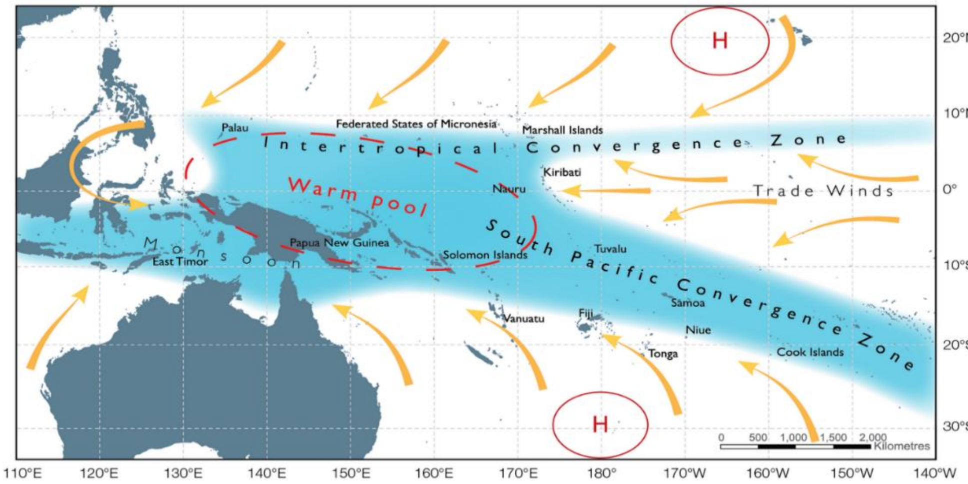

Figure 1: schematic of the factors controlling the climate of the tropical southwest Pacific. Source: CSIRO.

Annual mean precipitation for the period 1979-2018 is shown in Figure 2, from the Global Precipitation Climatology Project (Adler et al, 2003), version 2.3.[1] The SPCZ is clearly visible south of the Equator, with the Intertropical Convergence Zone to the north. Average rainfalls in the core of the SPCZ region reach around 3,000 mm per year. The subtropical region south of about 20°S and west of the Date Line is relatively dry, with average rainfall amounts of 1,000 mm or less.

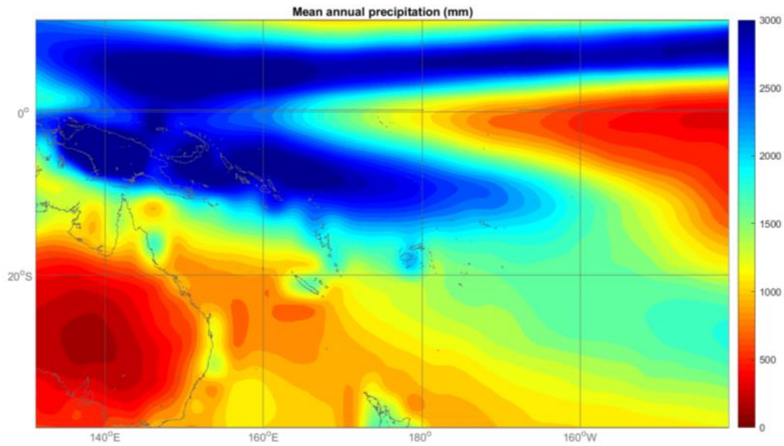

Figure 2: mean annual precipitation (mm) across the western Pacific. Source: based on Global Precipitation Climatology Project (GPCP) data for the 40-year period 1979-2018.

1 Global Precipitation Climatology Project (GPCP) precipitation data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado <https://psl.noaa.gov>.

There is considerable interannual variability in southwest Pacific precipitation, largely driven by the El Niño-Southern Oscillation (ENSO) phenomenon (Wallace et al, 1998) and its effects on the location and intensity of the SPCZ (Folland, Renwick, Salinger and Mullan, 2002; Harvey, Renwick, Lorrey and Ngari, 2019). During El Niño conditions, the SPCZ moves northeast, increasing the likelihood of high precipitation and flooding in the northeast of the region, and increasing the chances of drought in the southwest of the region. The opposite occurs during La Niña, when the SPCZ moves southwest. During El Niño conditions, tropical cyclones are more likely to occur and move farther east (Diamond, Lorrey and Renwick, 2013), while they tend to be confined to the western part of the tropical southwest Pacific during La Niña conditions. During very strong El Niño conditions, such as in 1982-83 and 1997-98, the SPCZ can move far to the northeast of its average location and lie almost along a latitude line, well to the north of most Pacific Island nations. In these conditions, rainfall shortages and drought can be widespread across most of the region, while tropical cyclones roam freely from west to east. Since sea surface temperatures rise in many parts of the tropical Pacific in an El Niño, there also tend to be more tropical cyclones in total during very strong El Niños (Diamond, Lorrey and Renwick, 2013).

As a percentage of mean precipitation, year-to-year variability is largest northeast of the average location of the SPCZ, and near the Equator in eastern parts of the region, where the interannual standard deviation exceeds the mean (the ratio is greater than 100 per cent, Figure 3). There is a secondary maximum in variability southwest of the SPCZ over the Coral Sea, where the interannual standard deviation reaches between 30 and 40 per cent of mean precipitation. Along the SPCZ itself, precipitation is more reliable, with the ratio of standard deviation to the mean of between 10 and 20 per cent, as is seen at New Zealand latitudes.

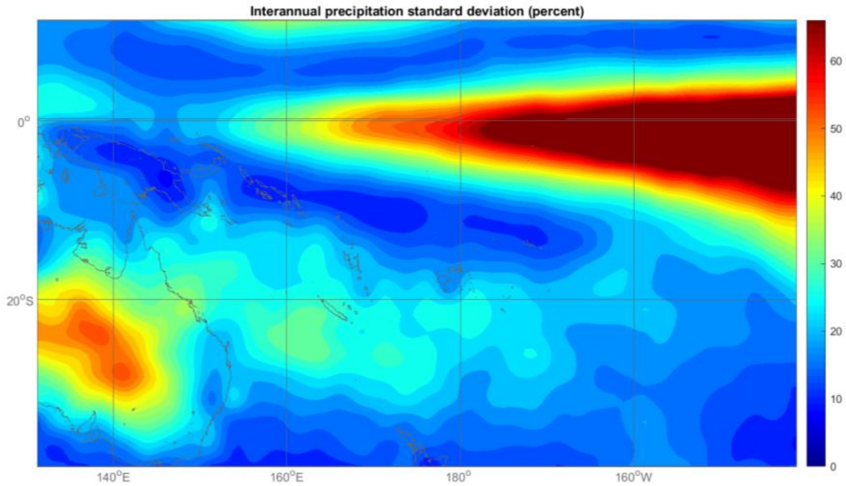

Figure 3: the standard deviation of annual precipitation as a fraction of long-term mean precipitation, as a percentage. Source: based on GPCP data for the 40-year period 1979-2018.

Tropical cyclone activity occurs during the wet season (November to May), to the south of the SPCZ. The most common location for tropical cyclone occurrence is over the Coral Sea, between Vanuatu and the Queensland (Australia) coast, although cyclones can occur across a wide swath of the tropical southwest Pacific (Figure 4).

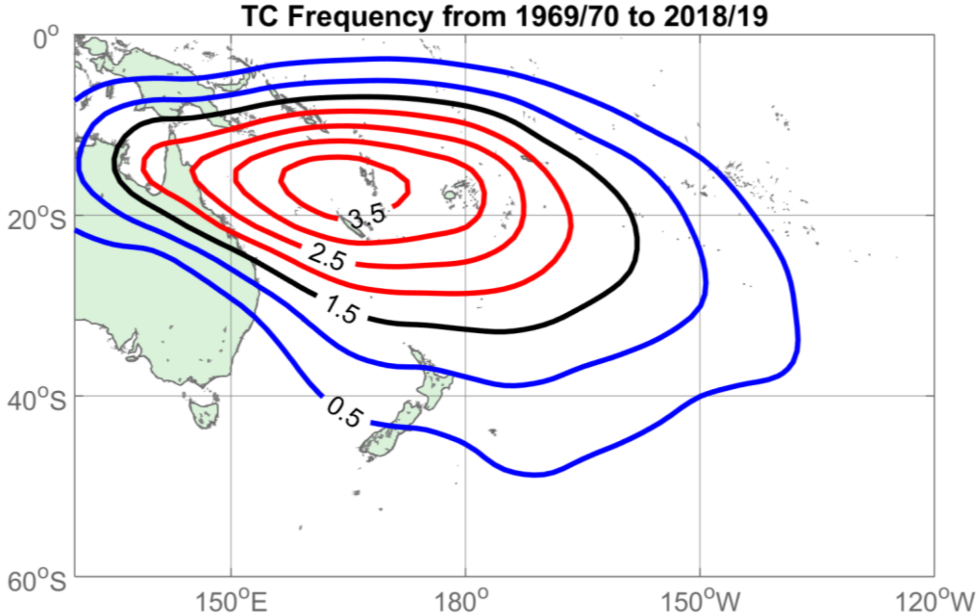

Figure 4: spatial distribution and average number of tropical cyclones per season across the southwest Pacific (during November to April) for the period 1969-1970 to 2018-2019. Source: updated from Diamond et al, 2013.

As noted above, annual average temperatures are in the mid-20s (degrees Celsius) across the region with a strong latitudinal gradient southward of around 20°S, as shown in Figure 5.

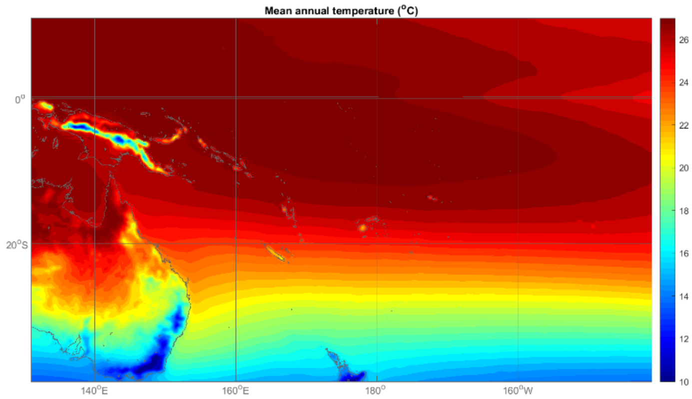

Figure 5: mean annual surface (two-metre) temperatures. Source: from the ERA5 data set for the 40-year period 1979-2018.[2]

In contrast to precipitation, interannual variability in temperature is relatively small. From one year to the next, the standard deviation of annual mean temperatures is typically less than 0.5 degrees Celsius (Figure 6), and between 0.2 and 0.3 degree Celsius in the SPCZ region. The ENSO cycle and movement of the SPCZ play a role in seasonal to interannual variability in southwest Pacific temperature variations. For most of the region, cooler conditions are experienced during El Niño events and warmer conditions during La Niña events, although this relationship reverses in the northeast of the region (Salinger et al, 1995).

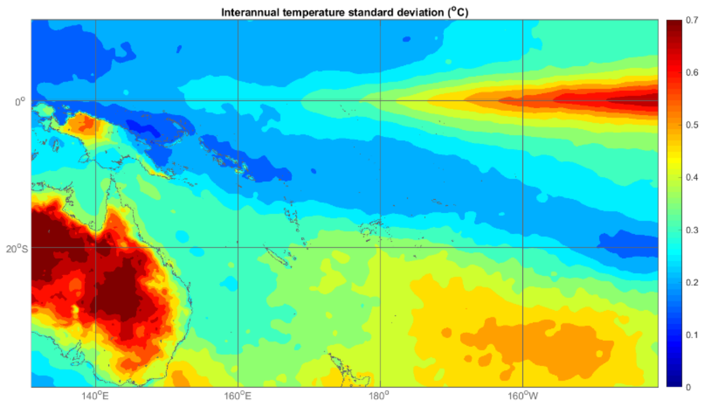

Figure 6: the standard deviation of annual mean temperature, in degrees Celsius. Source: based on ERA5 data for the 40-year period 1979-2018.

2 Copernicus Climate Change Service (C3S) *ERA5: Fifth generation of ECMWF atmospheric reanalyses of the global climate* (Copernicus Climate Change Service Climate Data Store (CDS), 2017) <https://cds.climate.copernicus.eu/cdsapp#!/home>.

The small magnitude of natural temperature variability across the tropical southwest Pacific implies that temperature rises associated with climate change are felt more rapidly than they would be in a region that experiences large temperature variability. As global warming continues, temperatures move outside the previously observed range more quickly than they would in a more variable climate such as that of New Zealand.

2.3 Climate change

The changing climate, brought about by human-induced greenhouse gas emissions, is affecting all aspects of the climate across the southwest Pacific and the globe. The oceans are soaking up the bulk of the heating (at least 90 per cent (IPCC, 2019)) and around a third of the carbon dioxide emitted from fossil fuel burning. Consequently, sea levels are rising and the pH of ocean waters is decreasing (known as "ocean acidification").

Climate futures are based on the climate change scenarios considered in the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). The various scenarios are known as Representative Concentration Pathways (RCPs) (van Vuuren et al, 2011) and range from RCP2.6 (broadly consistent with Paris Agreement goals[3]) to RCP8.5 (broadly consistent with a continuation of recent rates of increases in emissions continuing through the rest of this century). RCP4.5, illustrated in Figure 7 below, is a mid-range scenario associated with emissions peaking before 2050 and declining rapidly through the rest of the 21st century, under which global average temperatures are projected to rise by between two and three degrees Celsius by 2100, compared to pre-industrial values.

Consistent with global trends, temperatures across the southwest Pacific have risen approximately one degree Celsius since the mid-20th century (Hartmann et al, 2013) while precipitation has shown no significant trends in recent decades. Sea levels in the western tropical Pacific have risen at around 4-5 mm per year over the past 20 years,[4] faster than the global mean rate of 3.3 mm per year.

2.3.1 Precipitation

Average precipitation change is on average expected to be small across most of the southwest Pacific through the rest of the 21st century, but variability is expected to increase. Figure 7(a) shows median projected changes in wet season precipitation for the region, under a mid-range emissions scenario (RCP4.5; van Vuuren et al, 2011). Hatching indicates that average changes are projected to be smaller than typical year-to-year variability, which is the case for almost the entire region (average changes less than about 20 per cent of the late 20th century average). The exception is the Equatorial strip, east of the Date Line, where average precipitation is expected to increase significantly.

Figures 7(b) and 7(c) show how year-to-year variability is projected to change through the rest of the 21st century, for a range of emissions scenarios. In both regions shown, variability increases over

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3 Paris Agreement 55 International Legal Materials 743 (adopted 12 December 2015, entered into force 4 November 2016).

4 See "Historical Sea Level Changes" CSIRO <www.cmar.csiro.au/sealevel/sl_hist_last_decades.html>.

time. In the southern region, which encompasses much of the tropical southwest Pacific, the occurrence of dry years (more than a 20 per cent reduction) increases even though median precipitation decreases only slightly. In the Equatorial region, precipitation variability increases sharply, with a large increase in the occurrence of very wet years (more than five times the current average) under the higher emissions scenarios.

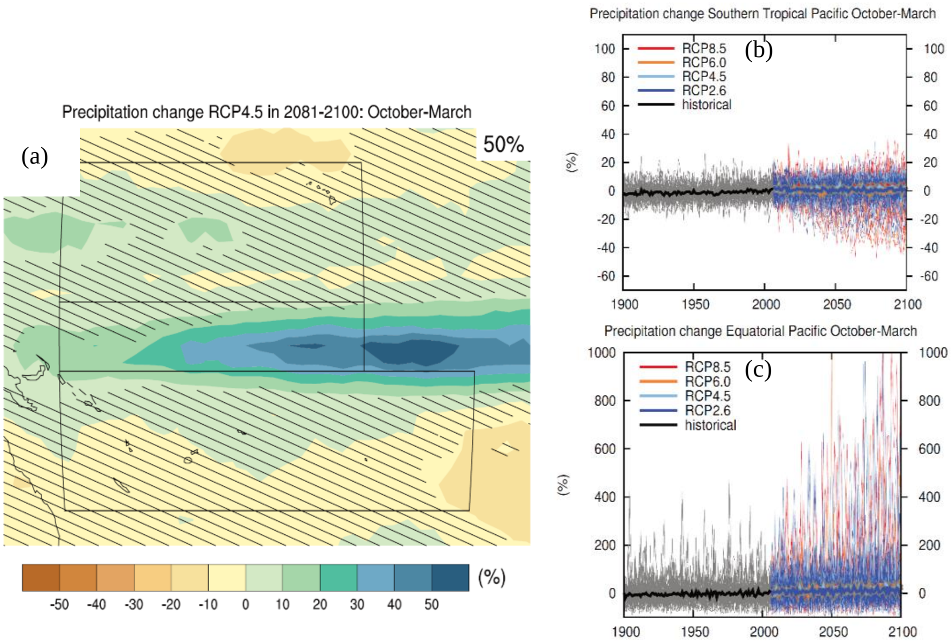

Figure 7: projected changes in precipitation for the tropical Pacific, based on CMIP5 models: (a) median change in precipitation, 20-year average 2081-2100 divided by 1981-2000 (per cent change) for the RCP4.5 scenario; (b) time series of yearly variations in precipitation in the lower box outlined in (a), for the historical period and four future scenarios (per cent differences from 1981-2000); and (c) as in (b), but for the middle box outlined in (a). Note the different vertical scales in (b) and (c). Source: IPCC, 2013.

Increasing precipitation variability is a consequence of a moister atmosphere combined with circulation changes. For many regions of the globe, this translates to the rule of thumb "the wet get wetter and the dry get drier". This applies to individual events (storms deliver more rain, droughts are more intense), seasons and years. The SPCZ is expected to become more variable in its movements in the future (for instance, Cai et al, 2012) and the ENSO cycle is expected to be associated with more intense precipitation extremes as the planet continues to warm (Power et al, 2013; Cai et al, 2014; Wang et al, 2017), as discussed below.

2.3.2 Temperature

The future magnitude of climate change impacts for the southwest Pacific depends strongly on how global greenhouse gas emissions reduction policy and technology develop. At the low end of the scale, if the most stringent goals of the Paris Agreement[5] are met, global temperatures would rise around 0.5 degrees Celsius from the present day (approximately 1.5 degrees Celsius above pre-industrial temperatures) by 2100. At the high end, if emissions of greenhouse gases continue as they have done over the past 20 years, global temperatures would rise by at least another three degrees Celsius from the present day (four degrees Celsius above pre-industrial levels) by 2100. Whatever the future of emissions, global temperatures are virtually certain to rise another 0.2-0.3 degrees Celsius above present-day levels over the coming 30 years (IPCC 2013).

Future temperature rise across the southwest Pacific is expected to be somewhat slower than the global average rate, but all future scenarios show temperatures rising significantly above what has been observed in recent decades. Figure 8 shows projected temperature change during December-February for the range of RCPs considered in the AR5 (IPCC, 2013). Even with moderate warming scenarios, the occurrence of extreme events increases rapidly (Frame et al, 2017).

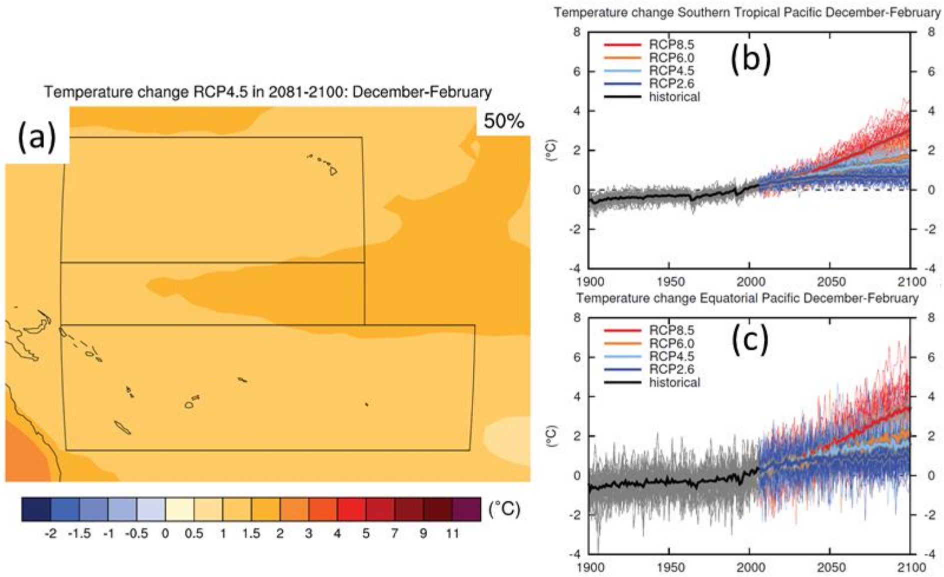

Figure 8: projected changes in temperature for the tropical Pacific, based on CMIP5 models – (a) median change in temperature, 20-year average 2081-2100 minus the 1981-2000 average for the RCP4.5 scenario; (b) time series of yearly variations in precipitation in the lower box outlined in (a), for the historical period and four future scenarios (differences from 1981-2000); and (c) as in (b), but for the middle box outlined in (a). Source: IPCC, 2013.

2.3.3 ENSO, the SPCZ and tropical cyclones

The spatial pattern of temperature change shows greater warming in the eastern Equatorial region than in the west and southwest, reminiscent of the pattern of sea surface temperature change associated

5 Paris Agreement, above n 3. See Chapter 7 and 9 in this book.

with El Niño events (Wallace et al, 1998). While such a change in sea surface temperatures across the tropical Pacific may facilitate the occurrence of El Niño events in the future, there is no clear signal from climate models about the future of the ENSO cycle. The majority of models included in the AR5 show future conditions that are relatively El Niño-like, although some models show a more La Niña-like average future. The magnitude of future events is also uncertain, with roughly half of models suggesting larger amplitude El Niño and La Niña events, while the other half suggests weaker amplitude events in future (Christensen et al, 2013).

Research over the past few years does suggest that very strong El Niño events may become more common in the future, although they will remain relatively rare (Cai et al, 2012; Cai et al, 2014). Such extreme El Niño events lead to more variability in the location of the SPCZ, as strong El Niño events have in the past been associated with extreme northward swings of the SPCZ (Cai et al, 2012). Such movements expose many south Pacific nations to greater risk of drought, and in part contribute to the very large variability in rainfall seen in future scenarios for the region (see Figure 7).

Since tropical cyclones form and move only to the south of the SPCZ, significant northward swings of the SPCZ expose eastern parts of the region to much increased tropical cyclone risk, on a seasonal basis (Basher and Zheng, 1995; Diamond, Lorrey and Renwick, 2013).

On average, tropical cyclone behaviour over the southwest Pacific is expected to change relatively gradually. As shown in Figure 9, both the incidence of very strong cyclones (categories 4-5) and the lifetime of cyclones at their maximum intensity are expected to remain about the same as they have been over recent decades. The total number of tropical cyclones over the southwest Pacific is expected to decrease by around 20 per cent on average (around two less named cyclones per year) by the end of this century. The amount of precipitation in southwest Pacific tropical cyclones is, however, projected to increase significantly, associated with the general increase in atmospheric moisture in a warmer climate (Christensen et al, 2013).

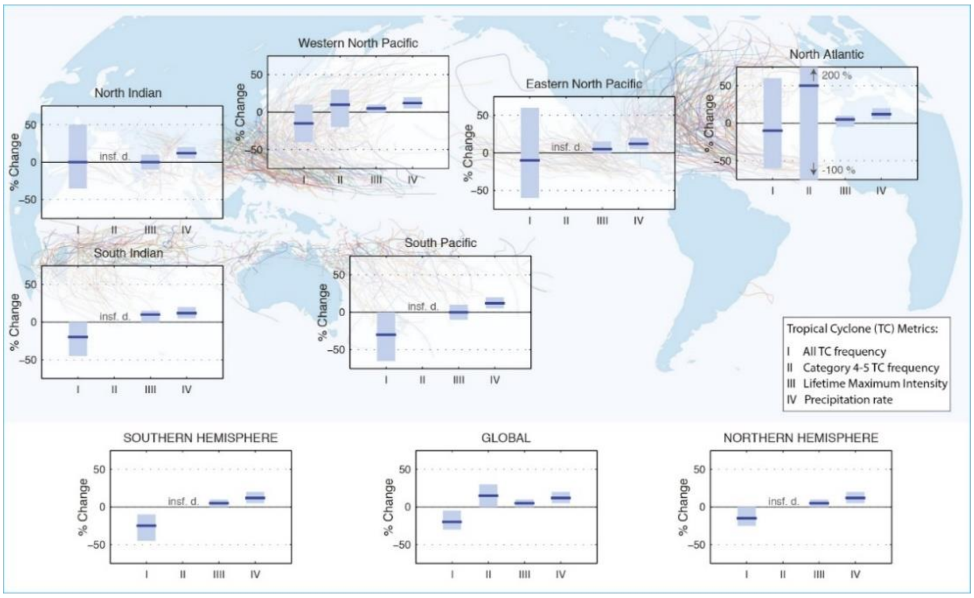

Figure 9: projected percentage changes in tropical cyclone behaviour across all global basins for the period 2081-2100, compared to 2000-2019. Statistics reported are (I) frequency of occurrence of all tropical cyclones, (II) frequency of category 4-5 cyclones, (III) cyclone lifetime at maximum intensity, and (IV) precipitation rate. Source: sourced after Figure 14.17 in Christensen et al, 2013.

2.3.4 Ocean change

Sea level rise in the southwest Pacific is projected to continue at a rate a few per cent greater than the global average. Globally, sea levels are projected to rise by between ~ 50 cm and ~ 80 cm by the end of the century, depending on emissions scenario. Should warming reach two degrees Celsius or more globally before 2100, there is the possibility that parts of the West Antarctic Ice Sheet may start melting irreversibly before the end of the century. This could result in up to 1.5 m of sea level rise (global average) by 2100 and several metres more in the centuries beyond that (Golledge et al, 2015; DeConto and Pollard, 2016).

For all scenarios, sea levels keep rising for centuries, with an eventual rise of around one metre for the lowest warming scenario (RCP2.6 in Figure 8) and possibly tens of metres for the highest warming scenario (after several centuries, RCP8.5). For all scenarios, around 20 cm further rise (compared to the present day) is projected by mid-century.

Absorption of carbon dioxide by the oceans lowers the pH of ocean water (making it more acidic) and reduces the availability of calcium carbonate in the water column, interfering with coral growth and shell formation (from micro-organisms to shellfish). Average surface pH has fallen around 0.1 unit over the past century. Under RCP2.6 (close to the Paris Agreement), pH would fall less than one more point and would start to recover by 2100. Under RCP8.5, ocean surface pH would keep falling through this century and beyond, going down by around another 0.3 points by 2100. Such conditions, combined with decreased oxygen levels and changes in nutrient cycles, would pose major risks for many marine ecosystems (Bindoff et al, 2019).

2.4 Summary

The southwest Pacific faces a wide range of challenges as a result of the changing climate. Temperatures are rising rapidly, and will move outside of observed ranges more rapidly than in many other parts of the world. Precipitation variability is increasing, with a tendency towards more frequent dry conditions in the southwest of the region and more frequent heavy rainfall and flooding in the northeast of the region. Tropical cyclones will bring more heavy rain in future and may travel much farther east than normal, more often. Sea levels have been rising for a century and more and will rise at least another half a metre this century, and may rise well over a metre if global warming passes two degrees Celsius. Ocean waters are becoming warmer and more acidic, affecting all marine life.

All the current and projected changes put stresses on water availability, food security and habitability. In the lowest-lying nations, sea level rise (and the associated salination of ground waters) may make some areas uninhabitable well before the end of the century. Across the whole region, high temperature extremes and more erratic rainfall patterns are likely to lead to major challenges for agriculture and food security, challenging populations across the board.

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