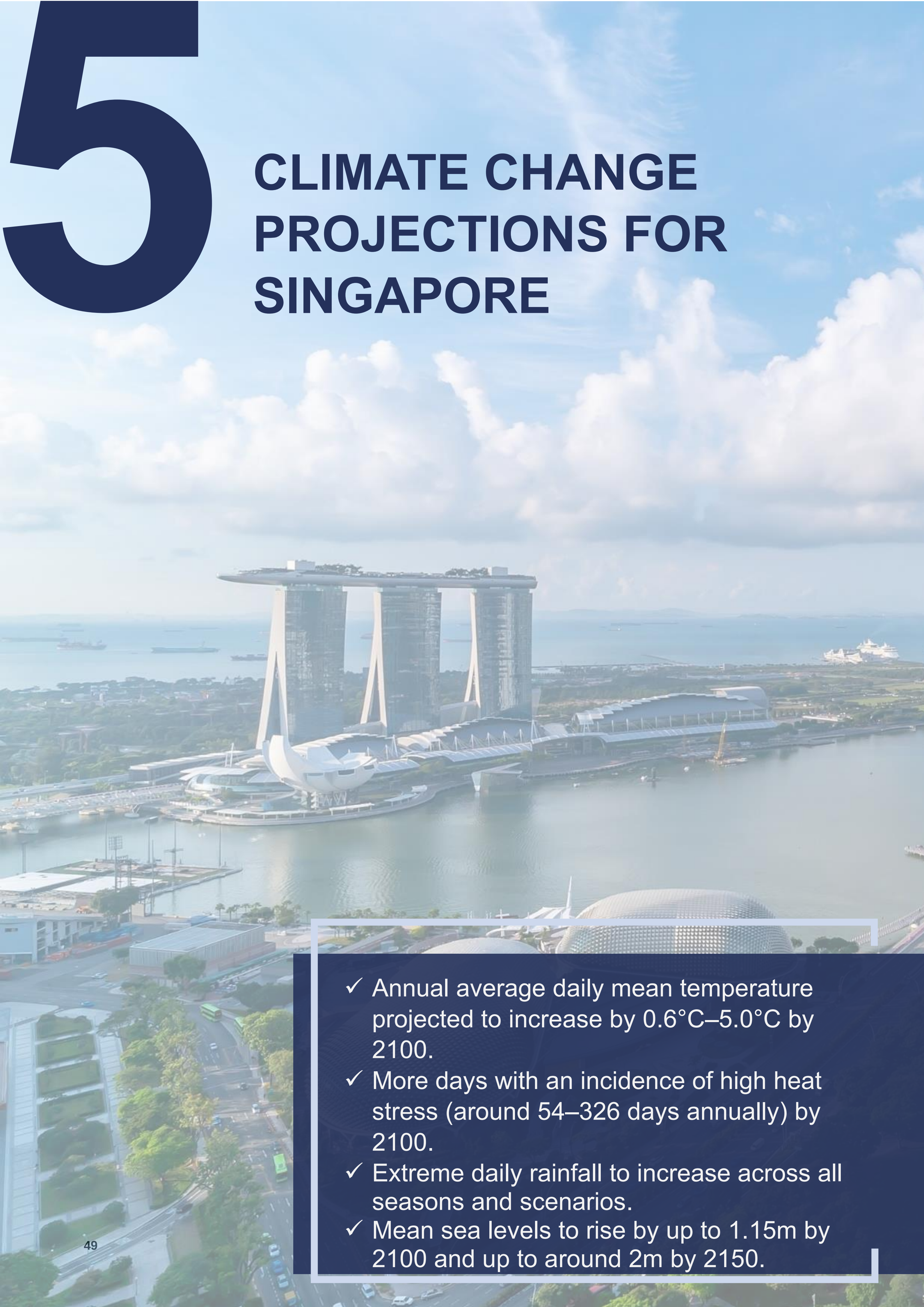
5

CLIMATE CHANGE PROJECTIONS FOR SINGAPORE



- ✓ Annual average daily mean temperature projected to increase by 0.6°C–5.0°C by 2100.
- ✓ More days with an incidence of high heat stress (around 54–326 days annually) by 2100.
- ✓ Extreme daily rainfall to increase across all seasons and scenarios.
- ✓ Mean sea levels to rise by up to 1.15m by 2100 and up to around 2m by 2150.

In this chapter climate change projections over Singapore are documented, using the 2km dynamically downscaled bias-adjusted simulations.

The climate change projections over Singapore are shown for both annual and seasonal time scales. For the seasons, periods corresponding to Singapore's monsoon and inter-monsoon months were selected: the Northeast Monsoon season, the Southwest Monsoon season and the two inter-monsoons. The Northeast Monsoon season is further divided into the wet phase comprising the months of December and January, and the dry phase comprising the months February and March. The Southwest Monsoon season comprises the months of June-through-September (considered as dry months for Singapore), and the first and second inter-monsoon periods comprise April–May and October–November, respectively.

Specifically, changes in the mean state and extremes of some key variables under the three SSP scenarios for the mid- and end-century 20-year periods are shown.

5.1 How will the daily mean temperature and WBGT change?

Projected changes in the annual average daily mean temperature and daily mean WBGT, during mid- and end-century under the three SSP scenarios are shown in Table 5.1. The table shows:

- Annual average daily mean temperature to increase by 0.6–5.0°C.
- Mid- to end-century trend in annual average daily mean temperature is projected to be up to 0.55°C per decade, based on the temperature change of 2.2°C between the 2 periods.
- Annual average daily mean WBGT to increase by 0.5–4.3°C.

The WBGT is a measure of heat stress. It is a composite measure that considers air temperature, humidity, wind, and solar radiation. It is calculated as the weighted sum of the wet bulb temperature T_w, the globe temperature T_g, and the air temperature T_{as}:

$$WBGT = 0.7\,T_w + 0.2\,T_g + 0.1\,T_{as}$$

T_w: temperature read by a thermometer covered by a cotton wick that is exposed to the natural prevailing air movement as well as radiation.
T_g: temperature measured by a dry bulb thermometer inserted into a standard black metal globe and it represents the integrated effect of air temperature, wind speed and radiant heat.
T_{as}: temperature of the ambient air measured in the shade.

As of January 2024, MSS has a network of nine WBGT stations spread across the island.

Table 5.1: Observed and projected annual average daily mean temperature and WBGT, during mid- and end-century under the three SSP scenarios. The number outside the brackets is the mean of five models and the numbers inside the bracket are the minimum and maximum values.

Scenario	Daily Average			
	Air Temperature (°C)		WBGT (°C)	
Observed	27.9		26.6 observed at current 9 stations	
Future	Mid-Century	End-Century	Mid-Century	End-Century
SSP1-2.6	28.9 (28.5 to 29.2)	29.0 (28.5 to 29.5)	27.4 (27.1 to 27.8)	27.5 (27.1 to 28.0)
SSP2-4.5	29.1 (28.7 to 29.6)	29.9 (29.3 to 30.7)	27.6 (27.3 to 28.1)	28.4 (27.8 to 29.0)
SSP5-8.5	29.5 (28.8 to 30.1)	31.7 (30.7 to 32.9)	28.0 (27.6 to 28.5)	30.0 (29.1 to 30.9)

5.2 How will the annual occurrence of warm days change?

The frequency of occurrence of warm days is projected to increase in the future. Based on the observations record, Singapore has around 76 warm days annually, and this number is projected to increase in the future, with almost every day in the year being a warm day, by end-century, under the high emissions scenario. Projected changes for the mid- and end-century for all SSPs are shown in Table 5.2.

Table 5.2: Observed and projected number of warm days annually, during mid- and end-century under the 3 SSP scenarios.

Scenario	Number of warm days with daily maximum temperature exceeding 34 °C annually	
Observations	76 days *observed at any of the 4 stations with long term records*	
Future	Mid-Century	End-Century
SSP1-2.6	178 (142 to 216)	188 (132 to 246)
SSP2-4.5	201 (164 to 257)	266 (212 to 325)
SSP5-8.5	234 (186 to 287)	340 (315 to 359)

5.3 How will the annual occurrence of warm nights change?

The frequency of occurrence of warm nights (daily minimum temperature equal to or exceeding 26.3 °C) is projected to increase in the future. Based on the observations record, Singapore has around 76 warm nights annually, and this number is projected to increase in the future, with warm nights becoming an everyday occurrence, by end-century, under the high emissions scenario. Projected changes for the mid- and end-century for all SSPs are shown in Table 5.3.

Table 5.3: Observed and projected number of warm nights annually, during mid- and end-century under the 3 SSP scenarios.

Scenario	Number of warm nights annually	
Observations	76 nights	
Future	Mid-Century	End-Century
SSP1-2.6	336 (317 to 352)	342 (312 to 361)
SSP2-4.5	347 (327 to 360)	362 (360 to 365)
SSP5-8.5	354 (335 to 364)	365 (365)

5.4 How will daily maximum temperature and WBGT change?

Projected changes in the annual mean of the daily maximum temperature and daily maximum WBGT, during mid- and end-century under the 3 SSP scenarios are shown in Table 5.4. The table shows:

- Average daily maximum air temperature to increase by 0.5–5.3°C
- Average daily maximum WBGT to increase by 0.5–4.0°C

Table 5.4: Observed and projected daily maximum temperature and WBGT annually, during mid- and end-century under the 3 SSP scenarios.

Scenario	Daily Maximum			
	Air Temperature (°C)		WBGT (°C)	
Observed	31.4		30.4 (*Observed at current 9 stations*)	
Future	Mid-Century	End-Century	Mid-Century	End-Century
SSP1-2.6	32.4 (32.0 to 32.8)	32.5 (31.9 to 33.1)	31.2 (30.9 to 31.5)	31.3 (30.9 to 31.7)
SSP2-4.5	32.6 (32.2 to 33.2)	33.5 (32.8 to 34.4)	31.4 (31.1 to 31.8)	32.2 (31.6 to 32.6)
SSP5-8.5	33.0 (32.3 to 33.6)	35.4 (34.3 to 36.7)	31.8 (31.4 to 32.2)	33.7 (32.7 to 34.4)

Figure 5.1 shows the multi-model mean projections of daily maximum temperature (TXx) over Singapore across annual and monthly timescales under the SSP5-8.5 scenario. The TXx is expected to increase on annual and monthly timescales in the end-century and is expected to increase by about 3.5–4.5°C with warming across Singapore on annual and seasonal time scales with mean increases closer to 4.5 degrees over the northern, central, and western parts. This warming change across Singapore could be largely driven by large scale warming in the region (mainly land masses of Sumatra and peninsular Malaysia). Future more detailed urban studies will provide additional information on urban additional warming.

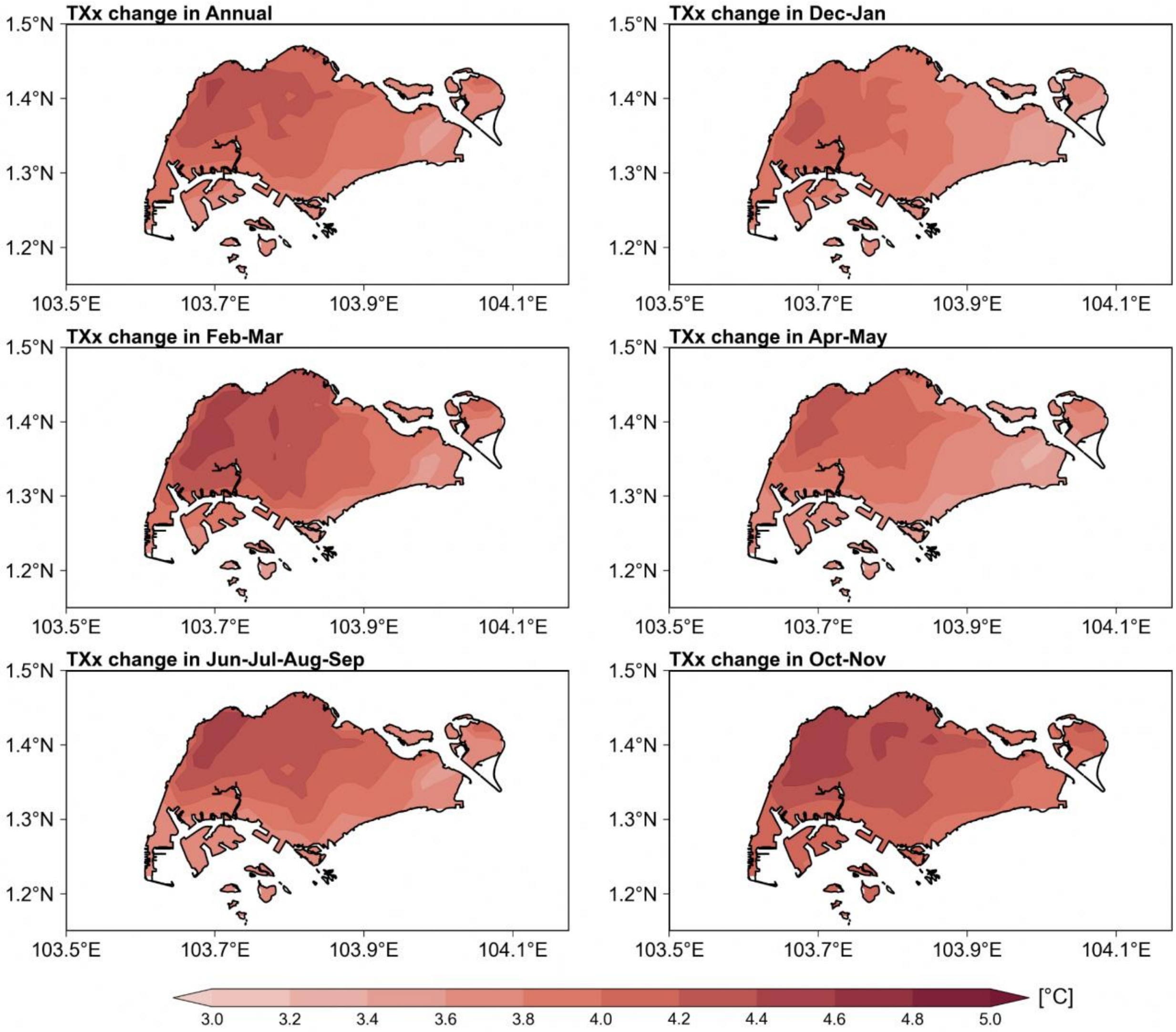


Figure 5.1: Projected spatial changes in the daily maximum temperature annually, and for each of the seasons during the end-century under SSP5-8.5.

5.5 How will the annual occurrence of very hot days change?

Very hot days are defined as days with daily maximum temperature exceeding 35 °C, based on the 99th percentile of daily maximum temperature. Historically, the average annual occurrence of very hot days are 21.4 days.

The frequency of occurrence of very hot days is projected to increase in the future. Based on the observations record, Singapore has around 21 very hot days annually, and this number is projected to increase in the future, with the worst case of almost every day being a very hot day by the end century under the high emissions scenario.

Projected changes for the mid- and end-century for all SSPs are shown in Table 5.5.

Table 5.5: Observed and projected number of very hot days annually, during mid- and end-century under the three SSP scenarios.

Scenario	Number of very hot days annually	
Observed	*21.4 days*	
Future	Mid-Century	End-Century
SSP1-2.6	73 (47 to 93)	85 (41 to 125)
SSP2-4.5	95 (63 to 134)	173 (103 to 261)
SSP5-8.5	129 (76 to 189)	305 (252 to 351)

5.6 How will the annual occurrence of days with high heat stress change?

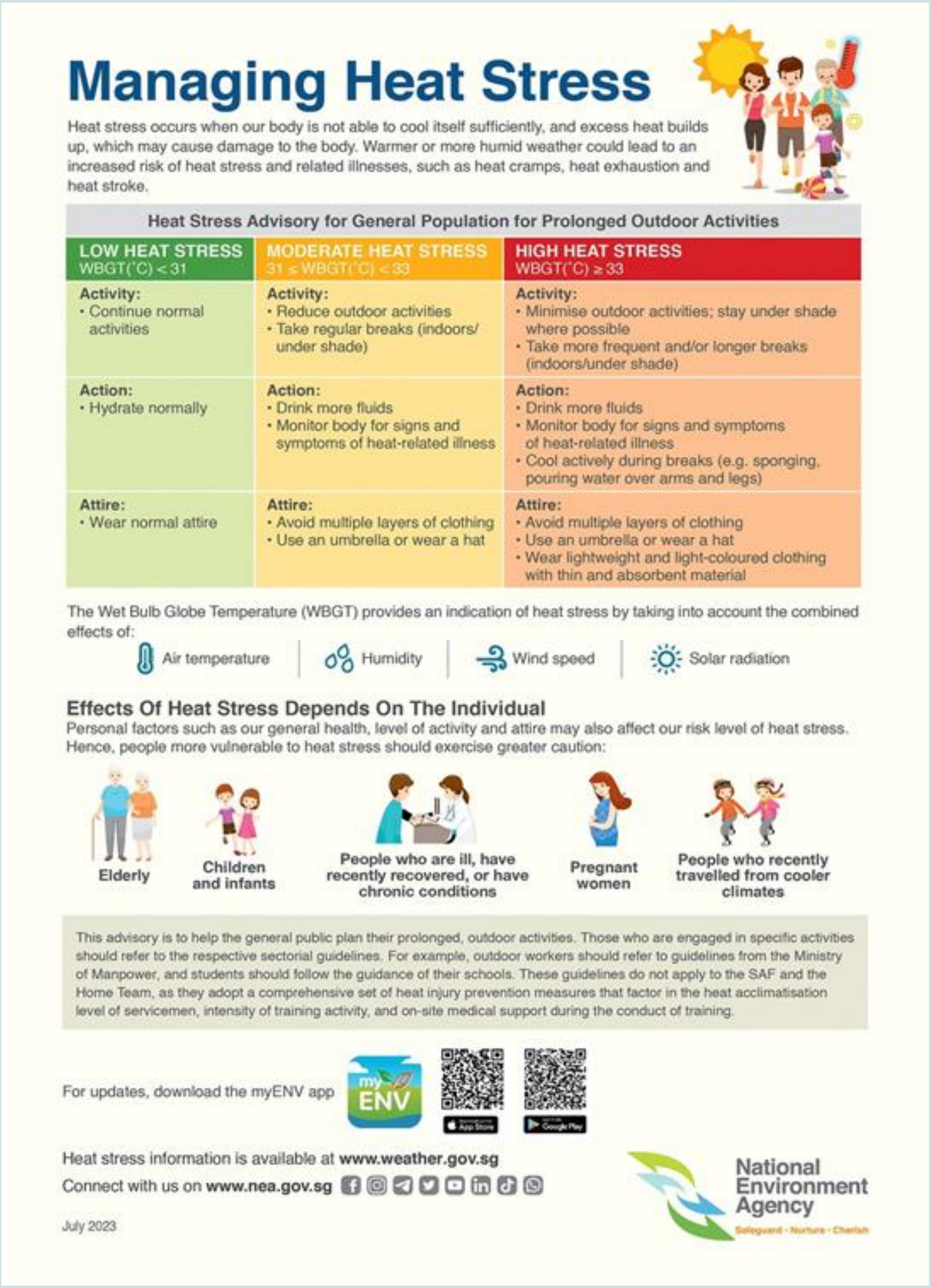
Based on the NEA heat stress advisory that was released in July 2023 (shown in Figure 5.2), WBGT is used as an indicator of heat stress, and following are the various categories of heat stress:

- Low: WBGT < 31°C
- Moderate: 31°C ≤ WBGT < 33°C
- High: WBGT ≥ 33°C

V3 projections show that the number of days with an incidence of high heat stress (as defined above) will increase, with the current annual occurrence of 24 days increasing to 54–326 days of high heat stress days annually, by end-century. Projected changes for the mid- and end-century for all SSPs are shown in Table 5.6.

Table 5.6: Observed and projected heat stress days annually, during mid- and end-century under the three SSP scenarios.

Scenario	Number of days with daily maximum WBGT equal to or exceeding 33°C annually	
Observations	24 days *observed at current 9 stations*	
Future	Mid-Century	End-Century
SSP1-2.6	75 (53 to 112)	81 (54 to 135)
SSP2-4.5	87 (61 to 131)	142 (107 to 205)
SSP5-8.5	113 (86 to 155)	270 (207 to 326)



Managing Heat Stress

Heat stress occurs when our body is not able to cool itself sufficiently, and excess heat builds up, which may cause damage to the body. Warmer or more humid weather could lead to an increased risk of heat stress and related illnesses, such as heat cramps, heat exhaustion and heat stroke.

Heat Stress Advisory for General Population for Prolonged Outdoor Activities

LOW HEAT STRESS WBGT(°C) < 31	MODERATE HEAT STRESS 31 ≤ WBGT(°C) < 33	HIGH HEAT STRESS WBGT(°C) ≥ 33
Activity: • Continue normal activities	**Activity:** • Reduce outdoor activities • Take regular breaks (indoors/ under shade)	**Activity:** • Minimise outdoor activities; stay under shade where possible • Take more frequent and/or longer breaks (indoors/under shade)
Action: • Hydrate normally	**Action:** • Drink more fluids • Monitor body for signs and symptoms of heat-related illness	**Action:** • Drink more fluids • Monitor body for signs and symptoms of heat-related illness • Cool actively during breaks (e.g. sponging, pouring water over arms and legs)
Attire: • Wear normal attire	**Attire:** • Avoid multiple layers of clothing • Use an umbrella or wear a hat	**Attire:** • Avoid multiple layers of clothing • Use an umbrella or wear a hat • Wear lightweight and light-coloured clothing with thin and absorbent material

The Wet Bulb Globe Temperature (WBGT) provides an indication of heat stress by taking into account the combined effects of:

Air temperature | Humidity | Wind speed | Solar radiation

Effects Of Heat Stress Depends On The Individual

Personal factors such as our general health, level of activity and attire may also affect our risk level of heat stress. Hence, people more vulnerable to heat stress should exercise greater caution:

Elderly

Children and infants

People who are ill, have recently recovered, or have chronic conditions

Pregnant women

People who recently travelled from cooler climates

This advisory is to help the general public plan their prolonged, outdoor activities. Those who are engaged in specific activities should refer to the respective sectorial guidelines. For example, outdoor workers should refer to guidelines from the Ministry of Manpower, and students should follow the guidance of their schools. These guidelines do not apply to the SAF and the Home Team, as they adopt a comprehensive set of heat injury prevention measures that factor in the heat acclimatisation level of servicemen, intensity of training activity, and on-site medical support during the conduct of training.

For updates, download the myENV app

Heat stress information is available at **www.weather.gov.sg**

Connect with us on **www.nea.gov.sg**

July 2023

National Environment Agency
Safeguard · Nurture · Cherish

Figure 5.2: NEA heat stress advisory released in July 2023.

5.7 How will average annual and seasonal rainfall change?

Projected end-century changes in average annual rainfall totals are strongly dependent on the emissions scenario used. For the medium and high emissions scenarios, the projected changes could either be negative or positive.

For average seasonal rainfall totals, by end-century, the wet months of December-January are expected to get wetter by up to 58% (occurs under the low emissions scenario), and the dry months of June-through-September are expected to get drier by up to 42% (occurs under the high emissions scenario).

Indeed, the Island-wide average seasonal total rainfall during the Southwest Monsoon dry season of June-through-August could fall significantly below the historical low of 314 mm (recorded in 1997), on average, almost every three years by the end of the century. For the Northeast Monsoon wet season of November-through-January, the corresponding seasonal total rainfall is projected to exceed the historical high of 1507 mm (recorded in 2006) occasionally.

Projected end-century changes for average annual and seasonal rainfall totals for all SSPs are shown in Table 5.7.

Table 5.7: Projected percentage changes in the average annual and seasonal total rainfall during the end-century under the three SSP scenarios.

Months	End-Century Rainfall Change (%)		
	SSP1-2.6	SSP2-4.5	SSP5-8.5
Annual	11 (0 to 24)	5 (−6 to 12)	0 (−12 to 17)
DJ (wet)	20 (−12 to 58)	6 (−9 to 28)	2 (−20 to 44)
FM	13 (−2 to 49)	−7 (−39 to 48)	−18 (−43 to 30)
AM	13 (−5 to 23)	10 (−15 to 33)	18 (−6 to 52)
JJAS (dry)	5 (−10 to 17)	0 (−17 to 22)	−14 (−42 to 6)
ON	8 (−4 to 24)	14 (−2 to 31)	14 (−8 to 41)

5.8 How will heavy daily rainfall change?

Heavy daily rainfall documented in this chapter is based on RX1day, and it varies for different months and for different 2km grid locations over Singapore. RX1day is defined as the maximum daily rainfall for annual or seasonal timescale.

Figure 5.3 shows percentage change in RX1day annually, and for December–January, February–March, April–May, June-through-September, and October–November months, during end-century under the high emissions scenario.

The areas with the highest increase vary with season.

Overall, the largest changes occur during the inter-monsoon periods, with changes potentially exceeding 40% over the western and central parts of Singapore during April-May.

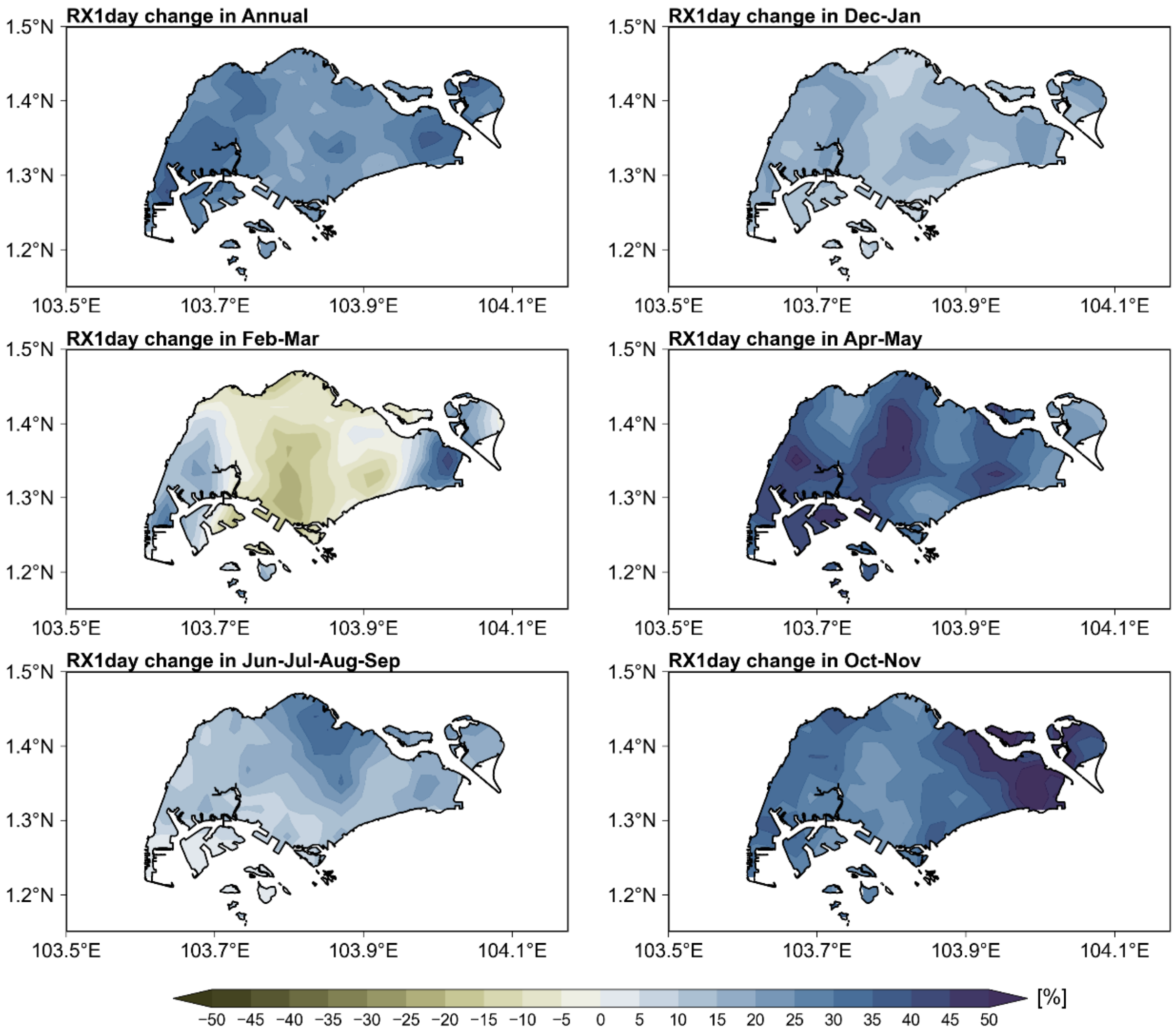


Figure 5.3: Percentage change in daily maximum rainfall annually, in December–January, February–March, April–May, June–July–August–September, and October–November months, during end-century (2080–2099) period relative to the baseline (1995–2014) under the high emissions scenario.

5.9 How will very heavy daily rainfall change?

Very heavy daily rainfall documented in this chapter is defined as the 99.9th percentile of daily rainfall, and it varies for different months and for different 2km grid locations over Singapore.

Figure 5.4 shows projected end-century changes in very heavy daily rainfall annually, and for each of the seasons under the three SSP scenarios.

Extreme daily rainfall is expected to increase across all seasons and scenarios, with up to 92% increase in the inter-monsoon months of April and May, under the high emissions scenario.

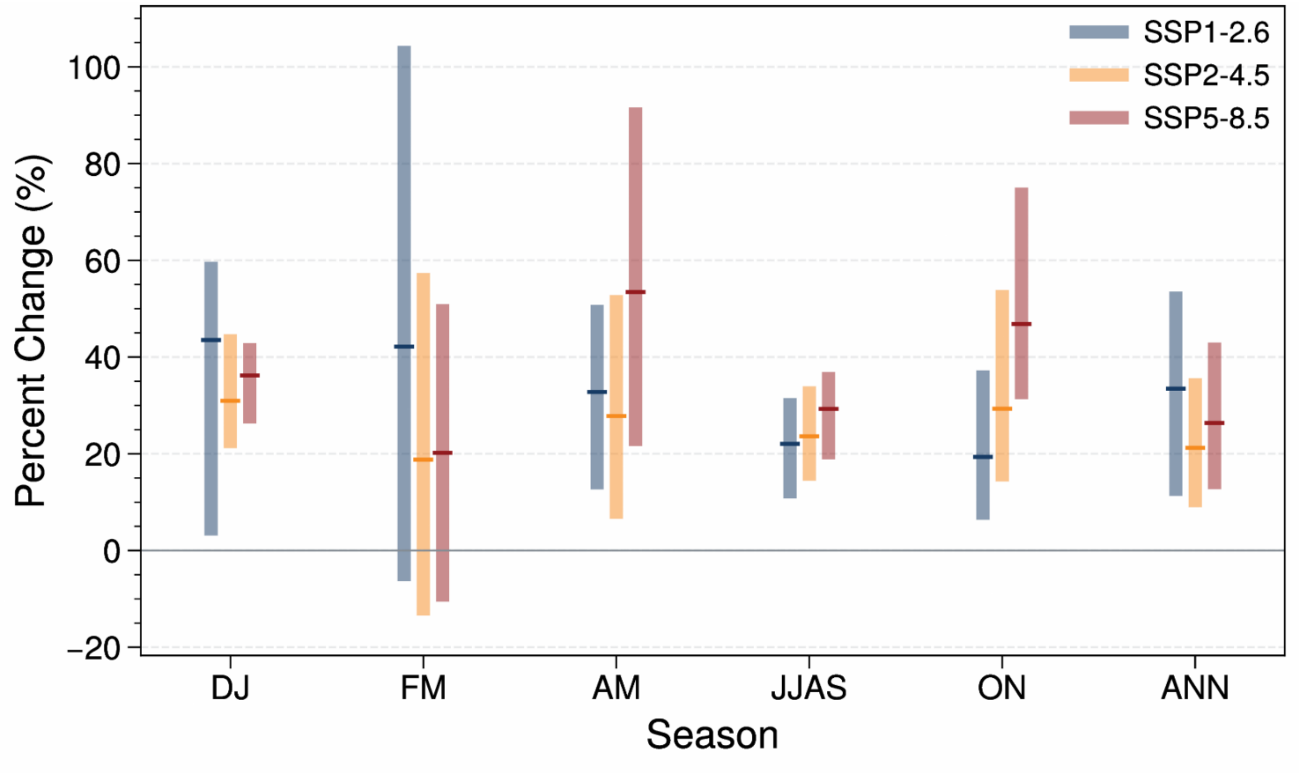


Figure 5.4: Projected changes in very heavy daily rainfall annually, and for each of the seasons during the end-century under the three SSP scenarios.

5.10 How will dry spells change?

MSS defines dry spells over Singapore as a period of at least 15 consecutive days with an island-wide average of daily total rainfall less than 1.0 millimetre (mm) for each of the days.

Figure 5.5 shows projected changes in the average number of dry spells, and average maximum duration of dry spells, expected annually, during the mid- and end-century, under the three SSP scenarios. It is expected that dry spells over Singapore will be more frequent.

On an average, there will be one dry spell every 10-60 months, with maximum duration of around 3 weeks, by end-century.

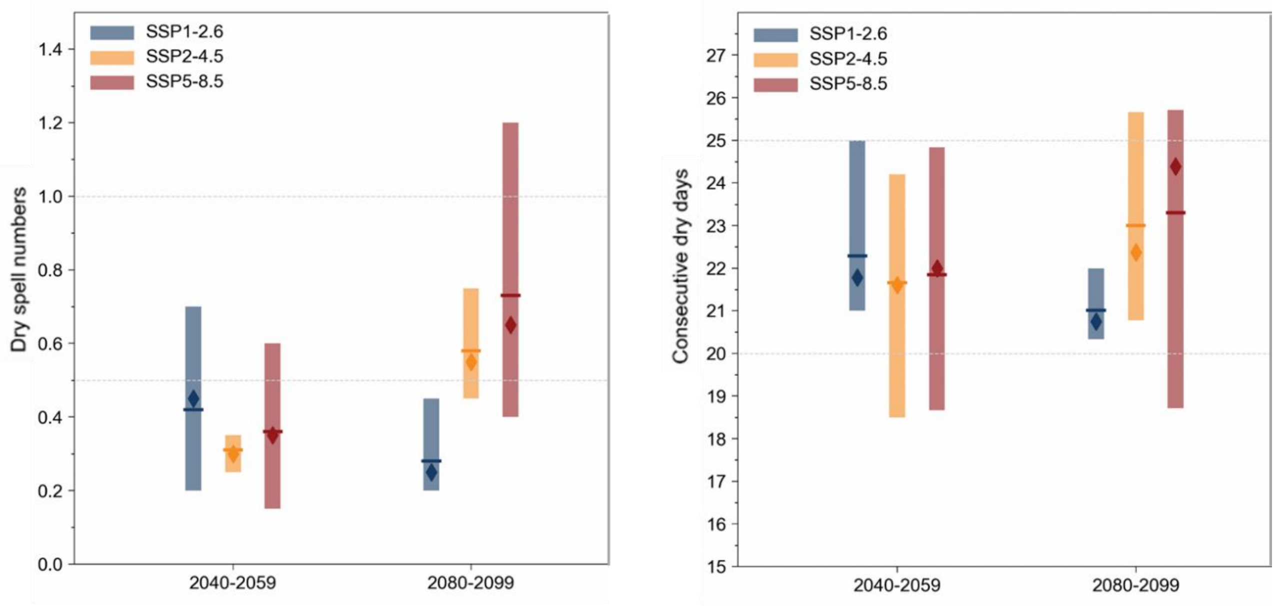


Figure 5.5: Projected annual average number of dry spells (left), annual average maximum duration of dry spells (right) under three SSP scenarios.

5.11 How will mean winds change?

> Wind speed, combined with temperature and relative humidity, plays an important role in the level of heat stress and outdoor thermal comfort.

Projected changes in 10-m wind speeds for each season during the end-century under the three SSP scenarios are shown in Table 5.8. Overall, 10-m wind speeds are expected to change from -1–20% during the Northeast and Southwest Monsoon seasons, and from 1–11% in the inter-monsoon months of April and May.

Table 5.8: Projected percentage changes in 10m wind speeds for each season during the end-century under the three SSP scenarios.

Months	End-century wind speed change (%)		
	SSP1-2.6	SSP2-4.5	SSP5-8.5
Northeast Monsoon (DJFM)	3.1 (−1.0 to 5.5)	6.6 (2.6 to 11.9)	11.0 (4.5 to 19.8)
First Inter-monsoon (AM)	3.5 (1.2 to 6.9)	3.3 (1.0 to 6.0)	8.6 (5.3 to 11.1)
Southwest Monsoon (JJAS)	3.9 (1.4 to 7.7)	7.3 (2.9 to 12.4)	13.8 (10.3 to 20.3)
Second Inter-monsoon (ON)	0.0 (−2.2 to 1.4)	0.5 (−6.6 to 3.5)	5.8 (−4.7 to 11.2)

5.12 How will daily maximum wind gusts change?

Strong wind gusts are often associated with thunderstorms and Sumatra squall lines and can potentially cause substantial damage to Singapore’s infrastructure (buildings and roads), uprooting of trees, and threat to the safety of human beings.

Figure 5.6 shows the projected change in the average daily maximum wind gusts over Singapore during the mid- and end-century under the high emissions scenario.

Overall, there is an upward trend in the speed of the daily maximum wind gusts, with expected mid-century increase of up to 3%, and that during end-century of up to 10%.

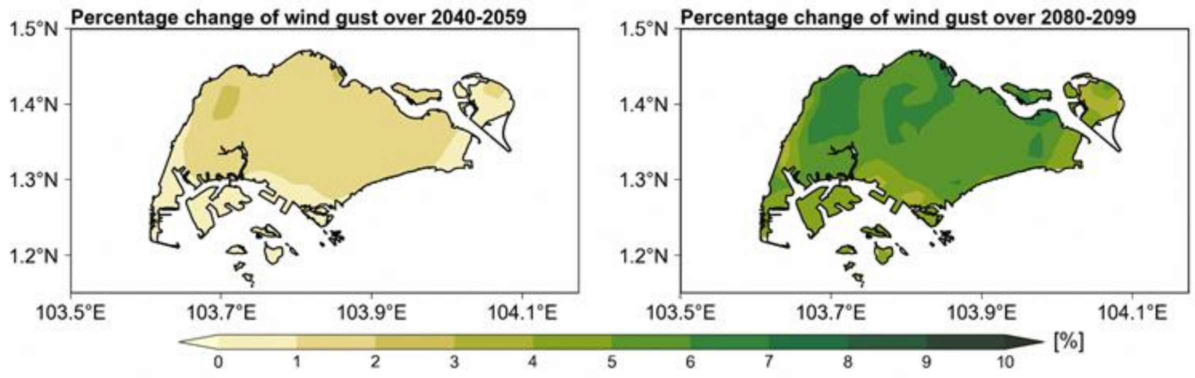


Figure 5.6: Projected percentage change in the average daily maximum wind gusts over Singapore in the mid-century (left) and end-century (right) under the high emissions scenario.

5.13 How will relative humidity change?

Table 5.9 shows projected changes in mean 1.5m relative humidity on annual and seasonal timescales during the end-century under the three SSP scenarios. Overall, relative humidity is projected to decrease in the future. For example, projected change in the months of February and March by end-century is in the range of -5.3 – 0.7%.

Relative humidity is expressed as a percentage and is a measure of saturation of the ambient air. It includes the combined effect of temperature and water vapour in the air. In simple terms, it is an indicator of how much water vapour the air contains compared to the maximum it could contain at a given temperature and pressure.

With increase in temperature, the amount of water vapour in the air is expected to increase. This is because of the Clausius-Clapeyron (CC) equation, which suggests that the air can generally hold around 7% more water vapour for every 1°C increase in air temperature. Therefore, under global warming, for the relative humidity to be constant the water vapour content in the air should increase at the same rate i.e. 7% increase for every 1°C increase in air temperature.

However, Singapore's observation records show a decreasing trend in relative humidity. The reasons for this are: (1) large part of water vapour in the air over land comes from the seas surrounding Singapore, and (2) the land surface has been warming at a faster rate than the surrounding seas. Hence, the moisture from the surrounding seas is *not enough* to increase the water vapour over land at the CC rate, leading to a decreasing trend in RH.

Table 5.9: Projected percentage changes in the relative humidity annually, and for each season during the end-century under the three SSP scenarios.

Months	End-Century Relative Humidity Change (%)		
	SSP1-2.6	SSP2-4.5	SSP5-8.5
Annual	−0.5 (−1.2 to −0.1)	−0.9 (−2.0 to −0.5)	−1.9 (−3.6 to −1.0)
DJ	−0.4 (−1.5 to 1.1)	−0.7 (−1.9 to 0.8)	−1.9 (−3.6 to 0.4)
FM	−1.2 (−2.0 to -0.2)	−1.8 (−3.3 to 0.1)	−2.6 (−5.3 to 0.7)
AM	−0.5 (−1.1 to 0.2)	−0.5 (−1.3 to 0.4)	−0.8 (−1.1 to −0.3)
JJAS	−0.5 (−1.3 to 0.4)	−0.9 (−2.2 to 0.1)	−2.0 (−3.8 to −0.6)
ON	−0.5 (−1.3 to 0.4)	−0.8 (−1.7 to 0.7)	−2.2 (−3.9 to 0.3)

5.14 How will relative sea-level change around Singapore?

In the following sub-sections, a comprehensive exploration of anticipated relative sea-level changes in Singapore for both the current century and the next is documented. To set the stage, a concise overview of the projected global mean sea level is first discussed, as outlined in the IPCC AR6.

This introduction is paramount due to the influential role of global mean sea-level drivers, including thermal expansion of seawater and polar ice cap mass loss, which exert a significant impact on local projections.

5.14.1 How will global-mean sea-level change?

According to the IPCC AR6 WGI Report, global-mean sea-level (GMSL) is projected to rise across all future climate scenarios. Until 2050, in accordance with the AR5 and Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) reports, the projected global mean sea level (GMSL) rise shows little variation depending on different scenarios.

There is medium confidence in these projections, with a likely sea-level rise of 0.19 (0.16–0.25) m under SSP1-2.6 and 0.23 (0.20–0.30) m under SSP5-8.5 (Figure 5.7). However, after 2050, the scenarios start to show more significant differences (Fox-Kemper et al., 2021).

The IPCC AR6 suggests an alternative approach to addressing uncertainty in future GMSL rise by factoring in the uncertainty associated with the timing of specific sea-level rise thresholds. Focusing on projections that only incorporate processes with medium confidence, it is likely that GMSL will surpass 0.5 m sometime between 2080 and 2170 under SSP1-2.6 and between 2070 and 2090 under SSP5-8.5.

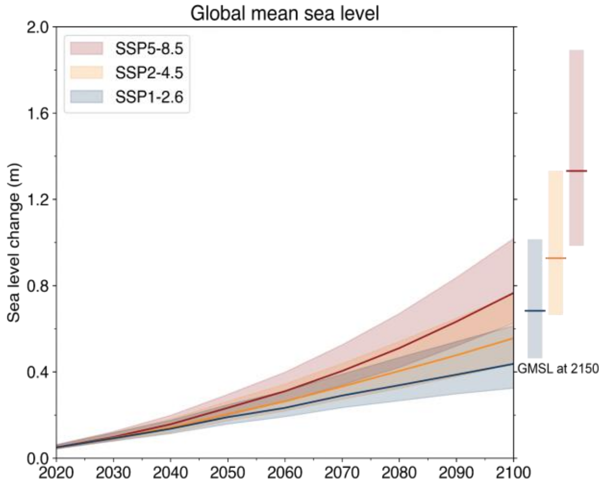


Figure 5.7: Projected rise in global-mean sea-level up to 2150, relative to IPCC AR6 baseline 1995 - 2014, under three emission scenarios (SSP1-2.6, SSP2-4.5 and SSP5-8.5). Solid curves represent the median (50th percentile), whilst the shaded bands represent the likely range (17th to 83rd percentile).

It is likely that GMSL will exceed 1.0 m between 2150 and beyond 2300 under SSP1-2.6, and between 2100 and 2150 under SSP5-8.5. However, it is unlikely to surpass 2.0 m until after 2300 under SSP1-2.6, whereas it is likely to do so between 2160 and 2300 under SSP5-8.5 (Fox-Kemper et al., 2021).

5.14.2 How will sea-level change around Singapore by 2150?

V3 provides an overview of mean sea-level projections extending up to the year 2300. These projections encompass varying degrees of confidence—namely low and medium. This section places its focus on the medium confidence projections up to 2150. For a comprehensive documentation of the methodology underpinning these projections, we direct readers to delve into Chapter 12 of the Science Report. All sea-level projections are computed in relation to the AR6 baseline period of 1995–2014.

Relative sea-level projections by 2100 and 2150 are provided at the six tide-gauges in Singapore by 2150 under all three emission scenarios (Figure 5.8 and Table 5.10). Our results indicate a small spatial variance of projected relative sea-level rise across the six locations.

Under SSP1-2.6, the average (average of the median value at all six tide gauges) projected rise stands at 0.45 ± 0.03 m by 2100 and 0.72 ± 0.05 m by 2150. Similarly, the moderate emissions scenario, SSP2-4.5, suggests a likely rise of 0.57 ± 0.04 m by 2100 and 0.95 ± 0.06 m by 2150. Under the highest emissions scenario, SSP5-8.5, the projections point to an average relative sea level rise of 0.79 ± 0.04 m by 2100 and 1.37 ± 0.06 m by 2150. The one standard error reflects the spatial variations observed across the median values recorded at the tide gauges.

Sultan Shoal emerges with the largest projected rise by 2100 and 2150 under all emission scenarios. At this station by 2100, relative sea level is projected to likely rise by up to 0.74 m under the low emission scenario (SSP1-2.6) and up to 1.15 m under the high emissions scenario (SSP5-8.5). By 2150, this could likely reach up to 1.24 m under SSP1-2.6, and up to 2.12 m under SSP5-8.5 (Figure 5.8).

Table 5.10: Projected relative sea-level rise and global-mean sea-level rise by 2100 and 2150 (median and *likely* range in brackets), under three emission scenarios (SSP1-2.6, SSP2-4.5 and SSP5-8.5) of *medium confidence*.

Tide Gauges	**SSP1-2.6**		**SSP2-4.5**		**SSP5-8.5**	
	2100	**2150**	**2100**	**2150**	**2100**	**2150**
Sultan Shoal	0.51 (0.34 – 0.74)	0.82 (0.50 – 1.24)	0.63 (0.46 – 0.88)	1.05 (0.72 – 1.52)	0.85 (0.66 – 1.15)	1.47 (1.03 – 2.12)
Sembawang	0.42 (0.26 – 0.63)	0.67 (0.38 – 1.07)	0.53 (0.38 – 0.77)	0.9 (0.59 – 1.36)	0.75 (0.58 – 1.04)	1.32 (0.90 – 1.95)
Raffles Light House	0.42 (0.24 – 0.65)	0.68 (0.35 – 1.09)	0.54 (0.36 – 0.79)	0.9 (0.56 – 1.38)	0.76 (0.56 – 1.06)	1.32 (0.88 – 1.97)
Tanjong Pagar	0.44 (0.24 – 0.69)	0.71 (0.35 – 1.16)	0.56 (0.36 – 0.82)	0.94 (0.56 – 1.43)	0.78 (0.56 – 1.10)	1.36 (0.89 – 2.02)
West Coast	0.46 (0.24 – 0.72)	0.74 (0.34 – 1.21)	0.58 (0.35 – 0.86)	0.97 (0.55 – 1.49)	0.80 (0.55 – 1.13)	1.39 (0.88 – 2.07)
West Tuas	0.45 (0.23 – 0.72)	0.72 (0.33 – 1.19)	0.57 (0.34 – 0.85)	0.95 (0.54 – 1.47)	0.79 (0.54 – 1.12)	1.37 (0.87 – 2.05)
Singapore Average	0.45 ± 0.03	0.72 ± 0.05	0.57 ± 0.04	0.95 ± 0.06	0.79 ± 0.04	1.37 ± 0.06
Global mean	0.44 (0.32 – 0.62)	0.68 (0.46 – 0.99)	0.56 (0.44 – 0.76)	0.92 (0.66 – 1.33)	0.77 (0.63 – 1.01)	1.32 (0.98 – 1.88)

Figure 5.8: Projected relative sea-level rise in Singapore at six tide-gauges (Sembawang, West Tuas, West Coast, Tanjong Pagar, Raffles Light House and Sultan Shoal) by 2150 under three emission scenarios (SSP1-2.6, SSP2-4.5 and SSP5-8.5). Values shown reflect the median (*likely* range) projected sea-level change by 2150 relative to the IPCC AR6 baseline 1995 - 2014.

The projected median values for global-mean sea-level closely align with the average relative sea-level projections for Singapore by 2100 and 2150 (Table 5.10).

However, across all emission scenarios, the upper bounds (83rd percentile) of Singapore's relative sea-level projections at all six tide gauges consistently exceed those of the global projections for both 2100 and 2150. This is primarily attributed to local factors, particularly vertical land movement, which contributes to some degree of land subsidence in Singapore, consequently driving relative sea-level rise.

More importantly, these projections emphasise a pragmatic reality: even under the most optimistic low-emission scenarios, both Singapore and the global community are facing an inevitable ‘locked-in’ sea-level rise in the coming decades.

Difference between V2 and V3

V3’s sea-level projections mark a significant advancement over its predecessor, V2, in several critical aspects. Firstly, it extends its medium confidence sea-level projections up to the year 2150, providing a more extensive outlook for Singapore's climate resilience planning. Unlike V2, which relied on the RCPs, V3 adopts the more comprehensive SSPs introduced in AR6, aligning its projections with the latest scientific advancements. Notably, V3 introduces a more localised perspective by offering projections for six crucial tide gauges around Singapore, a significant departure from V2's singular representation.

In V2, the projected total mean sea-level rise for the year 2100 under RCP4.5 and RCP8.5 was 0.53 m (median) and 0.73 m (median), respectively. These figures are remarkably similar to the median relative sea-level rise values projected in V3 under SSP2-4.5 and SSP5-8.5 scenarios. However, a closer examination focused on the tide-gauge with the highest projections, Sultan Shoal, reveals notable disparities. In this case, both the median and the upper limit of the likely range (83rd percentile) in V3 exceed the projections in V2 by tens of centimetres.

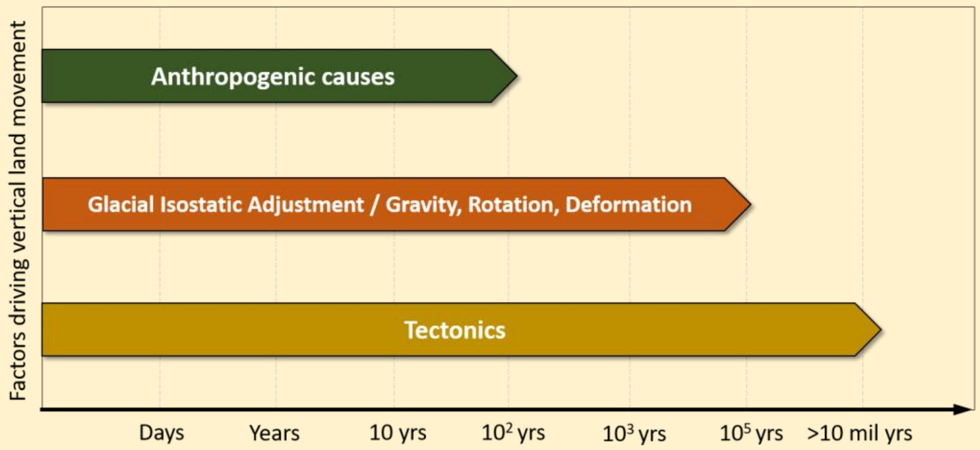
The substantial differences observed between V2 and V3, particularly in the context of the Antarctic ice sheet, can be primarily attributed to advancements in modelling introduced in AR6 compared to its predecessor, AR5, which formed the foundation of V2's methodology. AR6 incorporates more sophisticated ice-sheet models that consider a wider range of processes and feedback mechanisms. This enhanced modelling includes improved representations and understanding of ice shelf dynamics and ice dynamics.

Consequently, V3 shows higher estimates of future sea-level rise as AR6 includes more considerable uncertainties surrounding the behaviour of the Antarctic ice sheet, diverging notably from the methodology of V2.

Furthermore, V3's approach to estimating vertical land movement and its contribution to relative sea-level rise represents another significant enhancement. While V2 primarily considered glacial isostatic adjustment, V3 now encompasses a wider spectrum of potential outcomes and processes, leading to a larger range of uncertainties in relative sea-level rise projections for all scenarios.

5.14.3 How will sea-level change around Singapore up to 2300?

However, when accounting for inherently unstable processes such as marine ice cliff instability (MICI) and marine ice shelf instability (MISI), Singapore's projected mean sea-level rise increases significantly. These projections, while produced with low confidence, introduce a new perspective. Low confidence projections up to 2300 are provided in the Science Report.



Vertical Land Movement: Significant factors driving vertical land movement (VLM) in Southeast Asia that are explained in Section 12.6.1 of the Science Report. The temporal extent to which these factors affect VLM vary from days to millions of years (tectonics). Information is adapted from Pfferfer et al. (2017).

While global sea-level rise results from various factors, VLM, which can lead to land subsidence or uplift, is a significant contributor for many coastal cities other than Singapore. VLM stems from natural and human-induced processes, affecting regions like Southeast Asia and exacerbating the impact of sea-level rise. Understanding VLM is essential for accurate sea-level projections, as it can either raise or lower local sea levels relative to land occupants while the global mean sea level remains constant.

VLM is influenced by various factors, including natural and anthropogenic mechanisms. One key natural factor is GIA, a response to the loss of ice sheets from the Last Glacial Maximum, leading to ongoing vertical displacements worldwide. Contemporary changes in ice sheets and land water storage also impact VLM and contribute to relative sea-level changes. Seismic activity, such as earthquakes, can cause sudden land uplift or subsidence, affecting local sea-level rise. The extent of these movements depends on factors like earthquake magnitude, fault location, and geological properties. Anthropogenic factors, including groundwater withdrawal, can induce land subsidence, impacting cities like Mexico City, Bangkok, and Jakarta (shown in Figure 5.9). Additional anthropogenic activities like oil extraction, mining, and dam construction can also lead to land subsidence. Further discussion on VLM's effects on projected sea-level rise in Southeast Asia is provided in the V3 Science Report (Section 12.5.3).

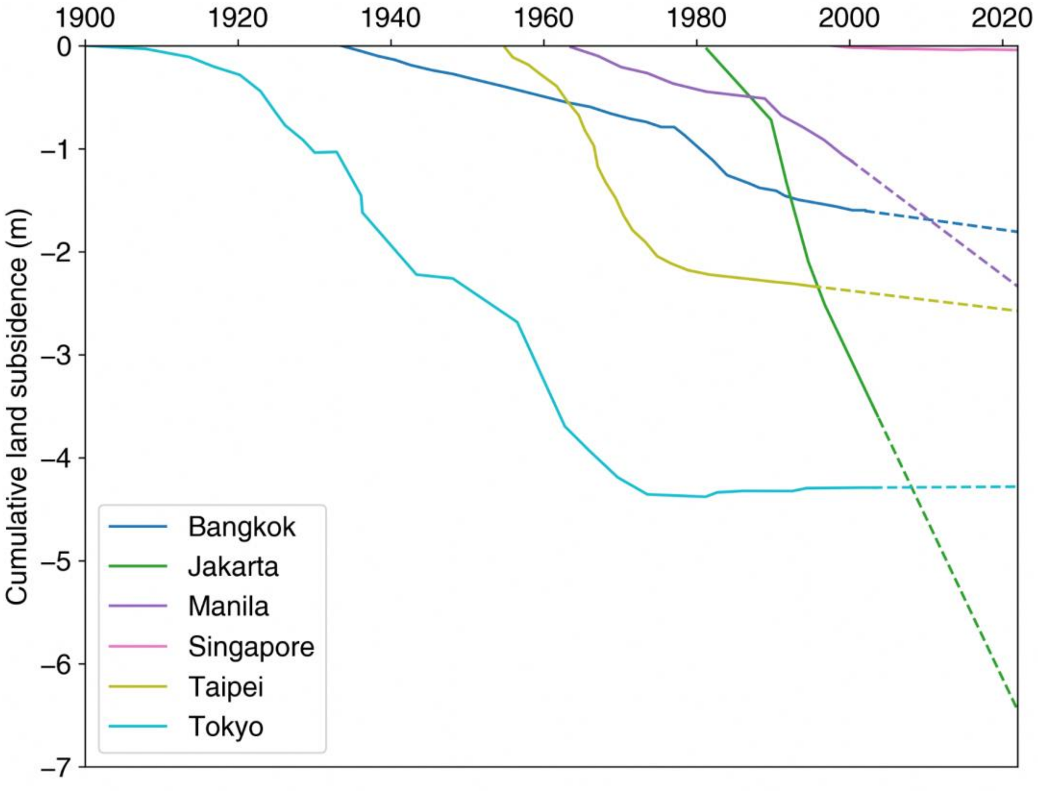


Figure 5.9: Cumulative land subsidence at Bangkok, Jakarta, Manila, Singapore, Taipei, and Tokyo. Solid curves were recreated from Kaneko and Toyota (2011), except for Singapore where data was taken from the GNSS station NTUS from Nevada Geodetic Lab on 13 September 2023. Dashed lines represent the projected cumulative subsidence in the respective cities until 2022, assuming a consistent rate of VLM observed over the past 5 years.