Executive Summary

Background to Singapore's Third National Climate Change Study

Climate change is an existential threat for humans and other beings on Earth. Hence it needs to be strategically understood and responded to alleviate the various risks associated with it. With increasing evidence of the risks associated with climate change, countries, especially small island nations like Singapore, need reliable and actionable climate change information to be prepared well in advance to adapt to the multi-faceted risks due to climate change.

Every 6–7 years, the Intergovernmental Panel on Climate Change (IPCC) publishes Assessment Reports that provide up-to-date information about the state of scientific, technical, and socio-economic knowledge on climate change, its impacts and future risks, and options for reducing the rate at which climate change is taking place. The IPCC in its latest and sixth assessment cycle produced the Working Group-I (WG-I) report on the Physical Science Basis, the WG-II report on Impacts, Adaptation and Vulnerability, the WG-III report on Mitigation of Climate Change, and finally the Synthesis Report. While these reports are useful to inform global and large-scale climate change, they lack the necessary granularity to assess climate change at the regional and local levels and to guide adaptation planning. Hence, as a follow-up to Singapore's Second National Climate Change Study (V2), Singapore's Third National Climate Change Study (V3) provides the high-resolution climate change projections for Singapore and the wider Southeast Asia (SEA) region, by dynamically downscaling the coarse-resolution global climate model simulations. This new dataset can be readily used for adaptation planning and thus help safeguard Singapore from the adverse effects of climate change.

V3 was conducted by the National Environment Agency (NEA) as part of the work under the inter-agency Resilience Working Group. It will support Singapore's effort to understand the effects of climate change and develop whole-of-government long-term plans that ensure the nation's resilience to future environmental changes. The main body of work on producing the high-resolution downscaled climate projections was undertaken by the Meteorological Service Singapore's (MSS) Centre for Climate Research Singapore (CCRS).

This Stakeholder Report provides a summary of the findings of V3. It is mainly intended for (a) policy makers in the Southeast Asia region that will use the high-resolution projections for downstream impact studies, policy, and adaptation planning; (b) researchers in universities and research entities, locally, regionally, and globally; (c) members of the public interested in climate change and sustainability.

Visualisation of selected V3 data is available at https://www.mss-int.sg/V3-climate-projections. Complementing the Stakeholder report is a comprehensive Science Report that documents the methodology, global and regional projections from Global Climate Models (GCMs), evaluation and sub-selection of GCMs for downscaling, the main regional climate model SINGapore Variable resolution – Regional Climate Model (SINGV-RCM) used, evaluation of the downscaled simulations, bias-adjustment, regional climate change projections from V3 data, climate change projections over Singapore, and sea-level projections over Singapore and the region.

Recent climate change in Singapore

Singapore's annual mean temperature rose by 0.24℃ per decade in the past 40 years (1984–2022).

Singapore's annual rainfall has been slightly trending up (83mm each decade from 1980 to 2020), but with large year-to-year variations associated with natural climate phenomena such as the El-Niño Southern Oscillation (ENSO). It is important to note that ENSO has a substantial impact on Singapore's rainfall patterns, leading to increased rainfall during La Niña years and decreased rainfall during El Niño years.

Across Singapore, there is an observed rise in mean surface temperatures, daily minimum and maximum temperatures. While there was no discernible trend in annual mean near-surface relative humidity in Singapore during 1983–2010, there is a decreasing trend during 2011–2022.

Methodology to produce climate change projections for Singapore

To produce high-resolution climate change projections for Singapore, the first step was the evaluation and sub-selection of 49 GCMs used in the IPCC's Sixth Assessment Report (AR6) for dynamical downscaling. In addition to the evaluation of GCMs over the region, there were other technical and scientific aspects of the sub-selection process to ensure the regional climate change projections are reliable and capture as much as possible the full range of climate change projected by GCMs. Based on this, six GCMs were finally selected for dynamical downscaling.

Dynamical downscaling of the six GCMs was carried out using a modified version of the SINGV model which is used to generate numerical weather forecasts by MSS. This is an example of seamless modelling wherein the same modelling system is used for generating weather forecasts (few hours to days) as well as climate change projections (many decades). The SINGV modelling system was customised to run in a climate mode by carrying out sensitivity studies at multiple horizontal resolutions over different domain sizes (see Chapter 6 of the Science Report for details).

Table E.1 provides the summary of the downscaling simulations carried out as a part of V3. Simulations were carried out for the fifth generation European Centre for Medium-Range Weather Forecasts (ECMWF) atmospheric reanalysis (ERA5) and six GCMs for the historical period (1955–2014) and future (2015–2099) for three IPCC AR6 global warming scenarios, namely the Shared Socioeconomic Pathway 1-2.6 (SSP1-2.6), SSP2-4.5 and SSP5-8.5 as the low, mid and high scenarios, respectively, at 8km horizontal resolution over the SEA domain. Additional very high-resolution simulations were carried out at 2km horizontal resolution over the Western Maritime Continent (WMC) domain for the historical period (1995–2014) and the same three SSP scenarios using five GCMs for two 20-year time slices in the future, which are 2040–2059 and 2080–2099.

In parallel to the above downscaling simulations, the other component of V3 focuses on the projections of mean sea level around Singapore and the region. V3 also produces state-of-the-art relative mean sea-level projections for Singapore using the IPCC AR6 methodology. Corrected tide-gauge data is analysed through this methodology to generate the most updated vertical land movement projections for Singapore. Regional sea-level projections in V3 are derived from the IPCC AR6 projections.

Table E.1: Dynamical downscaling simulations

	8km (driven by GCM)	2km (driven by 8km)
Recent past - ERA5 reanalysis	1979–2014	1995–2014
Recent past - CMIP6 GCMs	1955–2014 (6 GCMs)	1995–2014 (5 GCMs)
Future - CMIP6 GCMs	2015–2099 (6 GCMs)	2040–2059, 2080–2099 (5 GCMs)
Future Scenarios	SSP1-2.6, SSP2-4.5, SSP5-8.5	SSP1-2.6, SSP2-4.5, SSP5-8.5

Climate change projections for Singapore—Temperature, rainfall, winds, and sea level

Temperature

V3 projections show that over Singapore the annual average daily mean temperatures will increase by 0.6°C –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. The daily mean wet bulb globe temperature (WBGT), an indicator for heat stress, will increase by 0.5°C –4.3°C by the end of the century.

The daily maximum temperature will increase by 0.5°C –5.3°C, whereas the daily maximum WBGT will increase by 0.5°C –4.0°C.

There will be more days with an incidence of high heat stress with around 54–326 days having WBGT exceeding 33°C for an hour or more during the day.

By end-century annual number of very hot days is projected to be in the range of 41-351. Similarly, annual number of warm nights are projected to be in the range of 312-365.

Rainfall

According to the V3 rainfall projections for Singapore, the rainy months are expected to become even wetter, with a potential increase in climatological mean December–January (considered as the wet phase of the Northeast Monsoon season) combined rainfall of up to 58%, while the dry months may become even drier, with a possible decrease of seasonal mean rainfall by up to 42% (June–September is considered as the Southwest Monsoon season).

The island-wide average seasonal total rainfall during 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 months of November-through-January, the corresponding seasonal total rainfall is projected to exceed the historical high of 1507 mm (recorded in 2006) occasionally.

Extreme rainfall is expected to intensify in all seasons and scenarios, with daily rainfall potentially increasing by 6–92% during April and May, by end-century. Furthermore, dry spells could be more frequent, with Singapore experiencing on average one dry spell every 10–60 months, by end-century.

Winds

V3 projections show that the near-surface wind speed over Singapore will experience changes from −1–20% in the Northeast (December–March) and Southwest monsoon (June–September) seasons and around 1–11% in the inter-monsoon months of April and May by the end of the century.

Sea Level

By 2100, Singapore is projected to experience a relative mean sea level rise of 0.45 ± 0.03 m under SSP1-2.6, 0.57 ± 0.04 m under SSP2-4.5 and 0.79 ± 0.04 m under SSP5-8.5. These are averaged over six locations in Singapore (median). However, Singapore will likely face 0.23–1.15 m of relative sea-level rise by 2100.

Further into the future, by 2150, the projected rise in relative sea level is 0.72 ± 0.05 m, 0.95 ± 0.06 m and 1.37 ± 0.06 m under SSP1-2.6, SSP2-4.5 and SSP5-8.5, respectively. Similarly, these are the average estimates of the median values at six different locations in Singapore. Relative sea level will, however, likely reach up to around 2 m under SSP5-8.5 by 2150.

Summary table of projections

Table E.2 shows the end-century climate change projections over Singapore for the three SSP scenarios considered in V3.

Table E.2 Table summarizing V3 projections at the end of the century (2080 to 2099).

	V3 Key Findings		
Variable	**SSP1-2.6**	**SSP2-4.5**	**SSP5-8.5**
Increase in mean sea level (m)	0.23 to 0.74	0.34 to 0.88	0.54 to 1.15
Mean daily temperature (°C)	28.5 to 29.5	29.3 to 30.7	30.7 to 32.9
Mean daily WBGT (°C)	27.1 to 28.0	27.8 to 29.0	29.1 to 30.9
Mean maximum daily temperature (°C)	31.9 to 33.1	32.8 to 34.4	34.3 to 36.7
Mean maximum daily WBGT (°C)	30.9 to 31.7	31.6 to 32.6	32.7 to 34.4
No. of very hot days per year	41 to 125	103 to 261	252 to 351
No. of warm nights per year	312 to 361	360 to 365	365
No. of heat stress days per year	54 to 135	107 to 205	207 to 326
Annual average rainfall (mm)	2608 to 3234	2452 to 2921	2295 to 3052
10-m wind	10-m wind speed to increase by up to 20%, by end-century		