LIVING LAB

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Sea level rise: Importance to the insurance sector

Acknowledgement

We thank the projection authors for developing and making the sea-level rise projections available, multiple funding agencies for supporting the development of the projections, and the NASA Sea Level Change Team for developing and hosting the IPCC AR6 Sea Level Projection Tool. We would also like to thank the GAIP Partners for their valuable input and feedback into the paper.

Global Asia Insurance Partnership

Foreword

The science is clear: while sea levels will rise globally over the coming century, the effects will be disproportionately felt across different regions. In Asia, a region which is home to many of the world's most densely populated coastal cities, the forecasts are especially important for long-term planning.

The Global Asia Insurance Partnership (GAIP) and Nanyang Technological University (NTU), in particular, the Earth Observatory of Singapore (EOS), share the common goal of advancing our understanding of rising sea levels and its implications for society.

This first interim report of our GAIP-NTU Living Lab research, developed by EOS in collaboration with NTU's Insurance Risk and Finance Research Centre (IRFRC), represents a significant milestone in our efforts to explore the future impact of sea-level rise on coastal communities, the insurance sector and the wider economy, particularly in Asia.

The findings not only highlight the spatial variability of sea-level rise across Asia but also address the profound challenges this presents to all coastal urban environments, coastal ecosystems, and risk management practices.

At GAIP, we are committed to fostering cross-sector collaboration between academia, the insurance sector, and insurance regulators. This report exemplifies the potential of such partnerships by combining scientific research from EOS with actionable insights for the insurance sector from IRFRC.

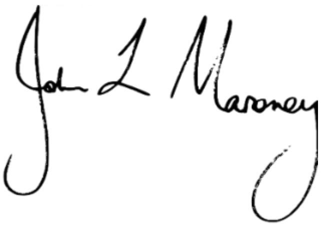
For insurers, this report offers essential guidance to understand regional sea-level projections and the potential impacts of extreme sea-level related events, equipping them to make better informed decisions. As rising sea levels increase the frequency and intensity of extreme weather events and escalate flood risks, insurers should regularly examine the suitability of their risk models, revise pricing and underwriting approaches, and consider broader risk mitigation and prevention strategies.

We extend our deepest appreciation to Dr. Timothy Shaw, the main author of this report, and the team at NTU's IRFRC, particularly Mr. Xu Yanbin, Nanyang Business School PhD student, Assoc. Prof. Wenjun Zhu and Assoc. Prof. Shinichi Kamiya, for their valuable contributions, particularly on the impact of sea-level rise on the insurance sector. We also wish to thank GAIP Partners, whose feedback has been instrumental in shaping this report.

We hope this report serves as a useful initial resource for insurers and policymakers as they navigate the growing risks posed by rising sea levels, particularly in Asia.

Future GAIP research projects will focus on other key aspects of climate-related risks in the Asia Pacific region.

Sincerely,



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Executive Summary

The severity of future sea-level rise depends on greenhouse gas emissions and associated increases to global average temperatures. While global mean sea level (GMSL) will continue to rise over the 21st century, on regional scales in Asia, future sea-level rise will be spatially variable due to a variety of sea-level driving processes related to ocean mass and volume changes and anthropogenic processes such as land subsidence. For example:

Under the very low emissions scenario SSP1-1.9 that raises temperature to ~1.5°C by 2100, GMSL will increase 0.38 m and surpass a 1.0 m milestone by 2287. In Manila, Philippines, however, sea level will increase 0.93 m and surpass a 1.0 m milestone by 2106. Under the very high emissions scenario SSP5-8.5 that raises temperature to ~4.4°C by 2100, GMSL will increase 0.77 m and surpass a 1.0 m milestone by 2122. In Manila, Philippines, however, sea level will increase 1.33 m and surpass a 1.0 m milestone by 2085.

Future sea-level rise could also be exacerbated by extreme sea level events that under a warming climate, will increase in frequency throughout the 21st century. This will pose a significant threat to urban environments and coastal ecosystems where substantial economic assets, populations and services are at risk.

The implications of future sea-level rise on the insurance industry are profound. As regional sea levels rise, the frequency and severity of flooding and vector-borne disease outbreaks will likely increase, leading to potentially higher insurance claims and payouts. Insurers will need to adapt their risk models, pricing, underwriting and product design approaches. This needs to be considered along with risk mitigation and prevention strategies on a broader level, without which, availability and affordability of insurance coverage will become a critical issue, and the protection gap in high-risk areas may widen. Proactive investments in resilient infrastructure and adaptive measures will be crucial to mitigating these escalating risks and ensuring the sustainability of insurance practices in the face of climate change.

Contents

1 Introduction

1.1 Importance to the insurance sector

"It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere, and biosphere have occurred" (IPCC, 2021).

How high will future sea levels rise? Answering this question carries great importance, particularly in low elevation coastal regions which hold high economic, environmental and societal value. From a planning and decision-making perspective, knowing when and by how much sea level will rise is critical in determining what protective measures are needed and to quantify insurance risk.

Over the 21st century, it is virtually certain (99–100% probability) global mean sea level will continue rising. Sea-level rise, however, will not be the same everywhere and its implications will be spatially disproportionate with equatorial and tropical latitudes of Asia facing the greatest impacts.

An overarching goal of the Global Asia Insurance Partnership project on sea-level rise will be to translate sea-level science to inform and quantify insurance risk. This first living lab report therefore serves as an introduction to the topic of sea level, providing an overview of what causes sea level to rise and how and why past and present-day sea level has changed. We then present future sea-level rise projections for case study sites in Asia to illustrate spatial variability that may also be exacerbated by extreme sea level events and discuss the future implications for urban environments, coastal ecosystems and the insurance sector.

1.2 What causes sea level to rise?

Rising sea level reflects the complex interaction between **global**, **regional,** and **local** sea-level driving processes that cause sea level to vary both in time and from place-to-place (Horton et al., 2018). For example, between 1901 and 1990, global ocean volume increases from thermal expansion accounted for 32% of GMSL rise compared to 46% between 1993 and 2018 (Fox-Kemper et al., 2021). Understanding the relative contribution of sea-level driving processes and how they will change in the future forms the basis of sea-level rise projections and why sea-level rise in many regions of Asia will be different from the global mean (Gregory et al., 2019).

- **Global** processes reflect the response of oceans to volume and mass changes as air/ocean temperatures increase and land-based ice from Antarctica, Greenland and glaciers melt.

- **Regional** processes (over distances of tens to hundreds of kilometres) reflect the response of the solid Earth (e.g., mantle) to changes in ice masses and how meltwater input to the oceans is unevenly redistributed around the Earth.

- **Local** processes (over distances of kilometres or less) reflect the response of atmosphere and ocean dynamic changes, vertical land motion from subsidence (natural and anthropogenic) and tectonic earthquakes.

2 Past Sea Level

2.1 Geological reconstructions

Our understanding of past sea level change is derived from geological reconstructions using proxies such as coral reefs and mangrove sediments. Importantly, they inform us how sea level responded to past climate change and provide constraints on future sea-level rise. Compilations of these reconstructions show GMSL rose ~130 m since the last glacial maximum, ~26 thousand years ago (Figure 1). Atmospheric CO_2 concentrations then were between ~188 and ~194 ppm and global mean temperatures cooler (relative to 1850–1900 CE) by 5°–7°C (Fox-Kemper et al., 2021). As atmospheric CO_2 and global climate naturally and gradually warmed over thousands of years, ice sheets that covered large sectors of the northern hemisphere in America and Europe melted and sea level rose. In response, continental shelfs were submerged transforming coastal landscapes and coastlines (Shaw et al., 2023).

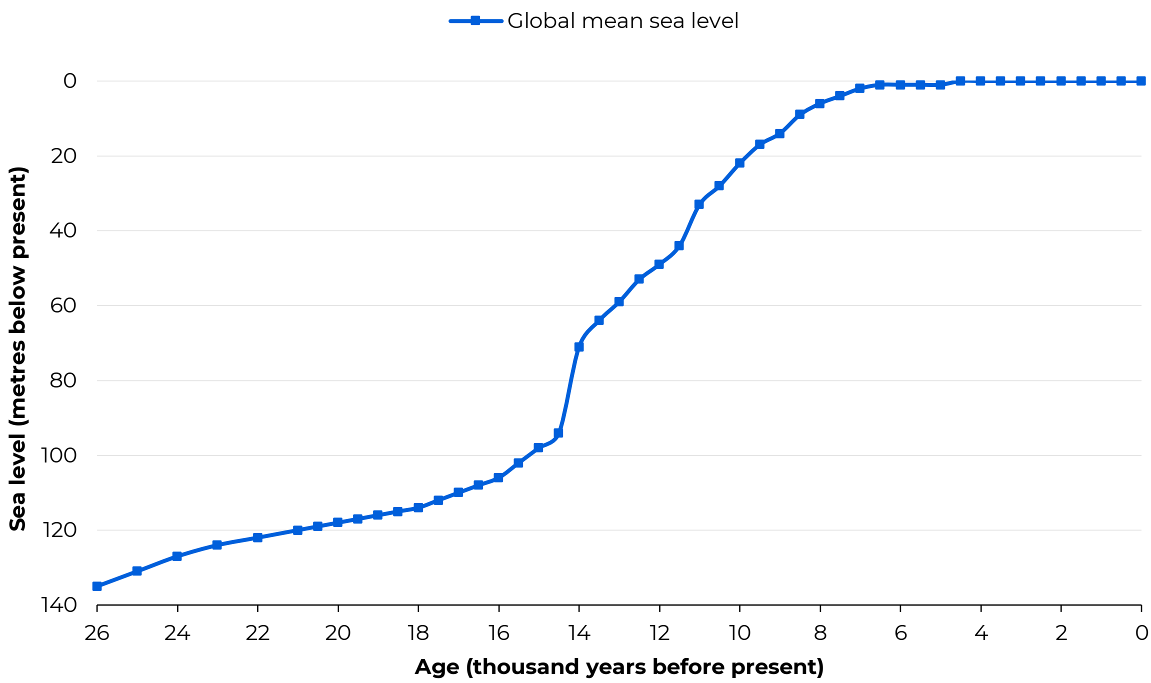

Figure 1: Changes in global mean sea level over the past 26 thousand year from geological reconstructions.

3 Present Sea Level

3.1 Instrumental measurements

Our understanding of present-day sea-level changes are derived through a global network of tide gauge stations providing instrumental measurements that cover changes in Earth's climate driven by anthropogenic forcing. Atmospheric CO_2 concentrations have increased to ~427 ppm which is unprecedented in at least the last two million years and global mean temperatures are ~1.1°C warmer than pre-industrial levels (Fox-Kemper et al., 2021). In response, instrumental measurements show GMSL rose ~0.2 m (Figure 2) and accelerated from ~1.4 mm/yr between 1901 and 1990 to 3.4 mm/yr between 1993 and 2018 as ocean mass and volume increased (Fox-Kemper et al., 2021). In contrast, sea level in Manila, Philippines accelerated at a rate of ~15 mm/yr after ~1960 due to vertical land motion from anthropogenic driven subsidence. In Singapore, however, instrumental measurements are much shorter beginning only in the 1970's and show sea level increasing at a rate of ~2-3 mm/yr (Shaw et al., 2023). These datasets highlight the importance of understanding sea-level rise on different temporal and spatial scales.

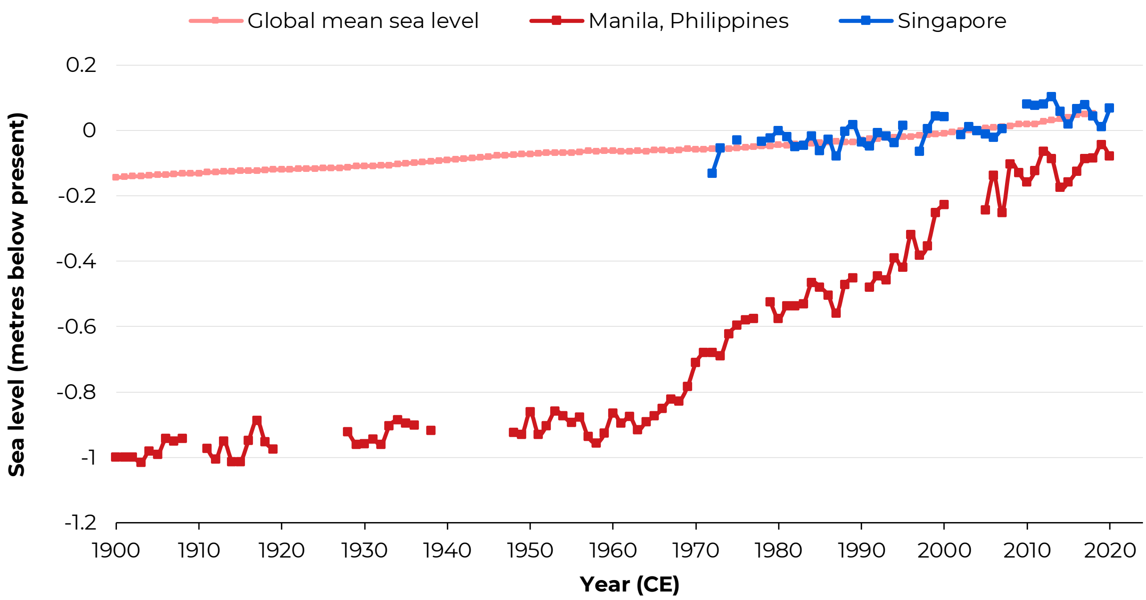

Figure 2: Changes in global mean sea-level compared to Manila, Philippines, and Singapore over the 20th and 21st century from instrumental measurements.

4 Future Sea Level

4.1 Projection methods

Changes in future sea level are characterised by quantifiable and unquantifiable uncertainties (Kopp et al., 2023). Quantifiable uncertainties can be represented by well-defined probability distributions for sea-level driving processes which are well understood (e.g., thermal expansion). Unquantifiable uncertainties, or ambiguity, however, is represented by sea-level driving processes that are difficult-to-quantify and have deep uncertainty (e.g., marine ice sheet processes; DeConto and Pollard, 2016). Ambiguity also arises from socioeconomic factors related to uncertain future emission levels. As a result, sea-level projections in the near-term (e.g., 2050) under low emission scenarios exhibit less ambiguity by comparison to sea-level projections in the long-term (e.g., >2100) under higher emission scenarios (Kopp et al., 2023).

Since the late 1970's and early 1980's, increasing awareness of global climate change and the potential impacts of instability in the West Antarctic Ice Sheet on sea levels gave forth to the first 21st century sea-level rise projections (Garner et al., 2018). Methods of projecting sea-level rise have varied from simple statistical models to more complex approaches that summed individual components as understanding of sea-level driving processes and their uncertainty increased. These have included process-based models, semi-empirical models, and probabilistic assessments (Garner et al., 2018). As an alternative to models, GMSL rise has also been projected by expert judgment surveys (Bamber et al., 2019; Horton et al., 2020).

The sea-level rise projections presented here are derived from the Intergovernmental Panel on Climate Change (IPCC) sixth Annual Report (AR6) which uses the most up-to-date ice sheet and climate model outputs (Fox-Kemper et al., 2021; Garner et al., 2021). They are based on the probabilistic framework developed by Kopp et al (2014) for the global tide gauge network to include local projections aggregating the individual drivers of sea level including ice sheets

(Greenland, West and East Antarctic); glacier and ice cap surface mass balance; thermal expansion and regional ocean steric and dynamic effects; land water storage; and local, non-climatic factors such as vertical land motion from glacial isostatic adjustment, sediment compaction, and tectonics (Kopp et al., 2014, 2017).

4.2 Shared socioeconomic pathways

The severity of future sea-level rise depends heavily on societal pathways. Sea-level projections are therefore provided for different shared socioeconomic pathway (SSP) scenarios that reflect changes in socioeconomic conditions, climate driving processes and greenhouse gas emissions:

- **SSP1-1.9** A very strong mitigation scenario. Global emissions reach net zero by 2050 falling below thereafter to limit global temperatures below 1.5°C (above pre-industrial levels) by 2100.
- **SSP1-2.6** A similarly strong 'next best' mitigation scenario but reaches net zero emissions after 2050 and limits global temperatures below 2.0°C by 2100.
- **SSP2-4.5** A intermediate 'middle of the road' scenario. Emissions fall by 2050 but net zero not achieved by 2100. Global average temperatures increase to 2.7°C by 2100.
- **SSP3-7.0** A medium to high reference scenario. Emissions increase and roughly double by 2100. Global temperatures increase to 3.6°C by 2100.
- **SSP5-8.5** A very high reference scenario. Emissions double current levels by 2050 and continue thereafter. Global temperatures increase to 4.4°C by 2100.

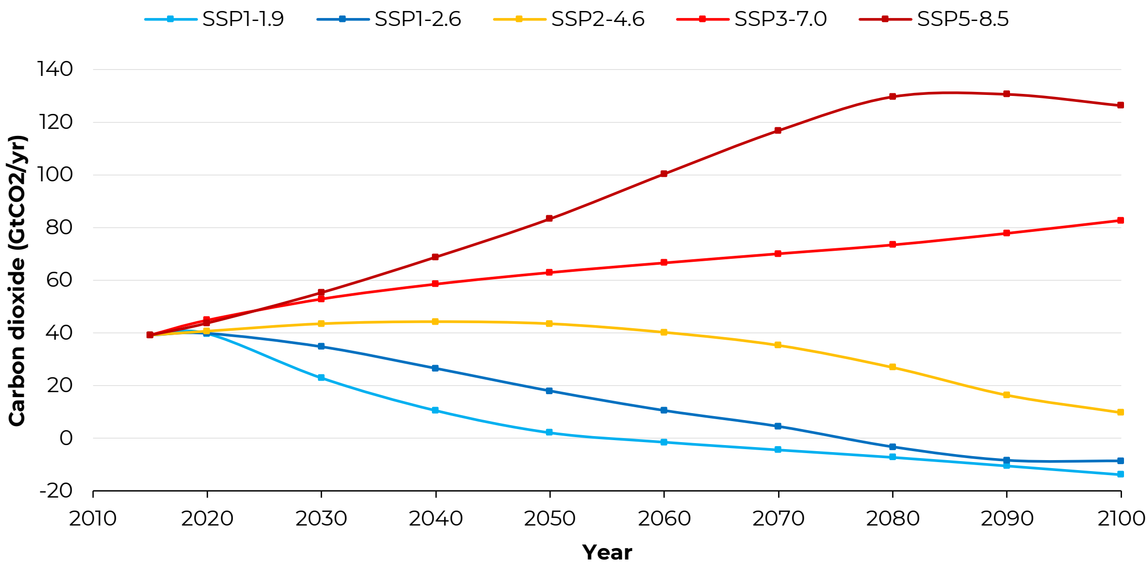

Figure 3: Future annual emissions in carbon dioxide ($GtCO_2/yr$) to 2100 under each SSP scenario.

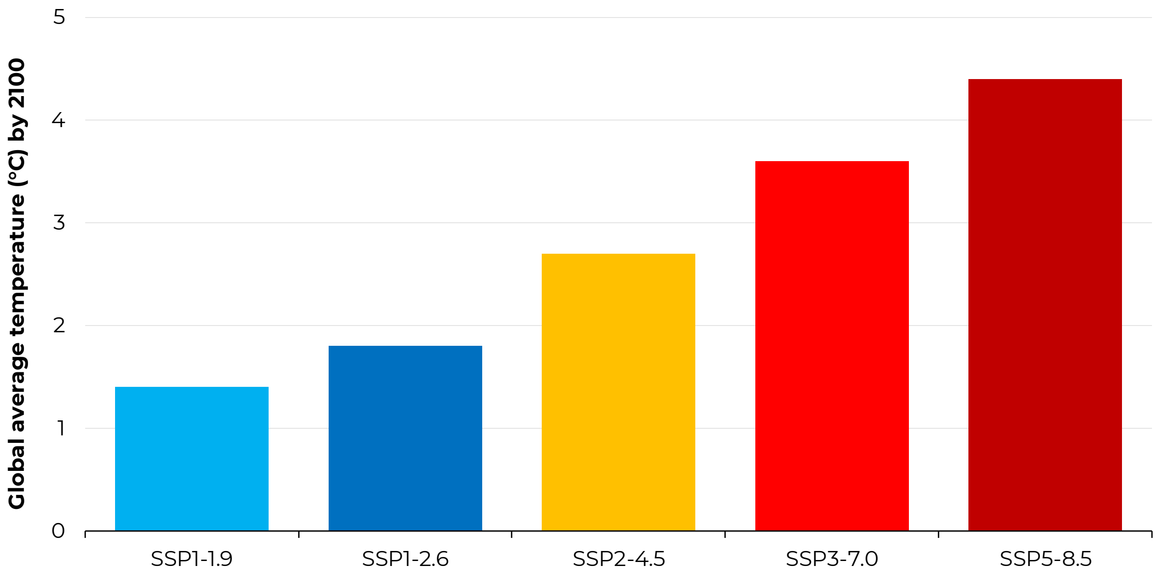

Figure 4: Future changes in global surface temperature to 2100 under each SSP scenario.

4.3 Dataset overview

We present sea-level rise projection datasets on decadal timescales to 2150 for all SSP scenarios and includes sea-level driving processes for which there is at least medium confidence (Fox-Kemper et al., 2021; Garner et al., 2021). Also included is a low-likelihood but high-impact scenario as an indicator of potential high-end sea-level projections that cannot be ruled out (SSP5-8.5 Low Confidence). This scenario considers faster-than-projected disintegration of marine ice shelves and abrupt, widespread onset of marine ice cliff instability and marine ice sheet instability processes in Antarctica and faster-than-projected changes in both the surface mass balance and dynamical ice loss in Greenland (Fox-Kemper et al., 2021).

The sea-level rise projections are relative to a baseline period of between 1995 and 2014 and include median (50th percentile) and likely ranges (17th-83rd percentile) for the following information:

- Sea-level rise magnitudes - how high will sea-level rise reach?
- Sea-level rise rates - how fast will sea-level rise increase?
- Exceedance of sea-level rise milestones - when will sea level rise above…?
- Sea-level rise driving processes - what will cause sea level to rise?

The exceedance of sea-level rise milestones provides an alternative perspective by looking at uncertainty in time of future sea level, providing a year range when thresholds of sea-level rise (e.g., 0.5m, 1.0m and 1.5m) are projected to be crossed.

5 Sea Level Projections

We first present the GMSL projection followed by case study sites in Asia to illustrate spatial variability arising from different contributing sea-level driving processes. These include:

- Singapore
- Manila, Philippines
- Hong Kong
- Phuket, Thailand
- Mumbai, India

As the Global Asia Insurance Partnership project on sea-level rise and insurance evolves, we will be able to include additional sites according to the community's needs and interests.

5.1 Global mean sea level

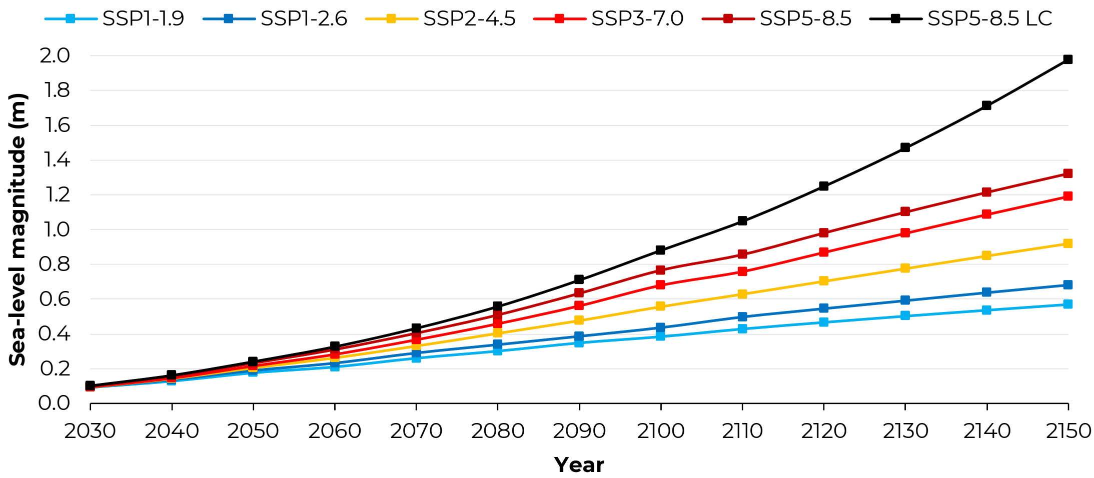

Figure 5: Projected changes in global mean sea-level magnitude under each SSP scenario.

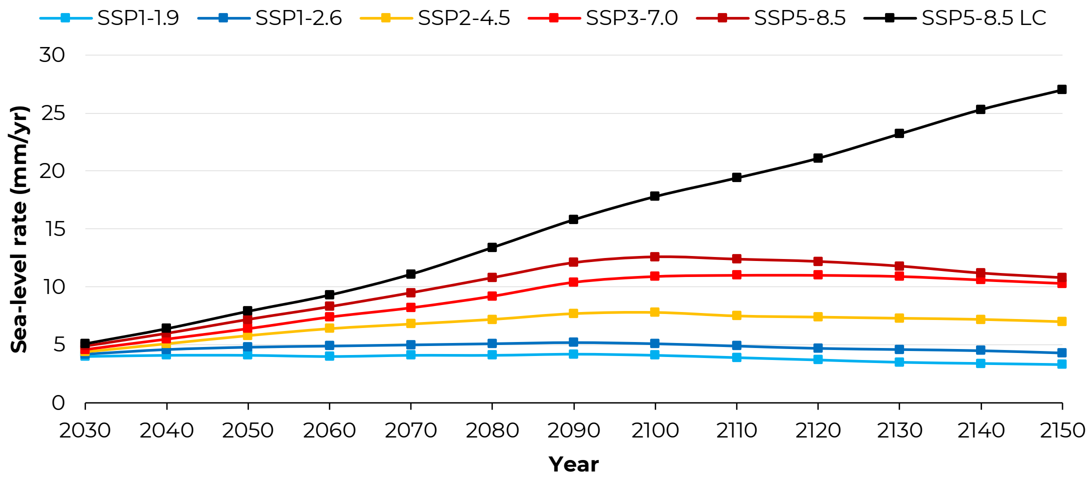

Figure 6: Projected changes in global mean sea-level rate under each SSP scenario.

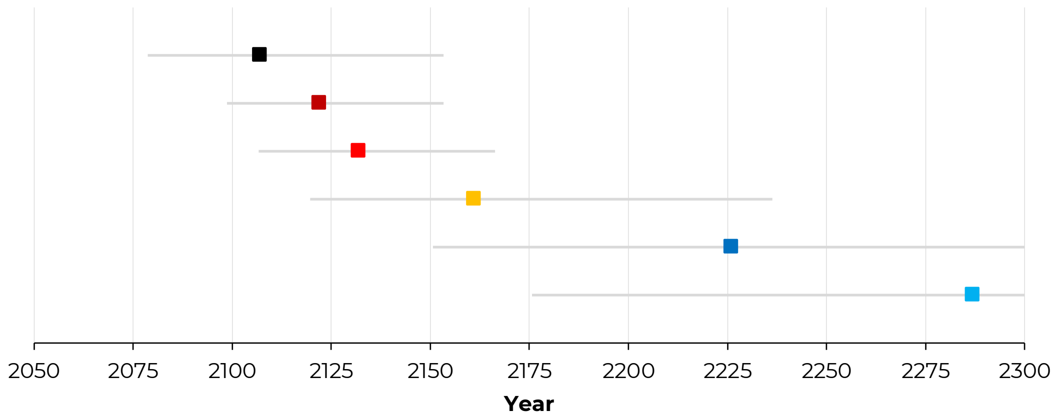

Figure 7: Projected exceedance of a 1.0 m global mean sea-level milestone under each SSP scenario.

- **SSP1-1.9**

Under very low emissions, sea-level rise by 2100 will increase 0.38 m (0.28–0.55 m) at a rate of 4.1 mm/yr (2.3–6.6 mm/yr). By 2150, sea level will increase 0.57 m (0.37–0.86 m) at a rate of 3.3 mm/yr (1.5–5.7 mm/yr) (Figure 5, 6; Table 1, 2).

A 1.0 m sea-level milestone will be crossed by 2287 (2176->2300) (Figure 7; Table 3).

- **SSP2-4.5**

Under intermediate emissions, sea-level rise by 2100 will increase 0.56 m (0.44-0.76 m) at a rate of 7.8 mm/yr (5.2-11.6 mm/yr). By 2150, sea level will increase 0.92 m (0.66-1.33 m) at a rate of 7.0 mm/yr (4.6-10.9 mm/yr).

A 1.0 m sea-level milestone will be crossed by 2161 (2120-2236).

- **SSP5-8.5**

Under very high emissions, sea-level rise by 2100 will increase 0.77 m (0.63–1.01 m) at a rate of 12.6 mm/yr (8.9–18.4 mm/yr). By 2150, sea level will increase 1.32 m (0.98–1.88 m) at a rate of 10.8 mm/yr (7.0–16.4 mm/yr).

A 1.0 m sea-level milestone will be crossed by 2122 (2099-2153).

- **SSP5-8.5 LC**

Under very high emissions that incorporates uncertainty in future ice sheet processes, sea-level rise by 2100 will increase 0.88 m (0.63–1.60 m) at a rate of 17.8 mm/yr (8.9–37.8 mm/yr). By 2150, sea level will increase 1.98 m (0.98–4.82 m) at a rate of 27.0 mm/yr (7.0–99.8 mm/yr).

A 1.0 m sea-level milestone will be crossed by 2107 (2079-2153).

The relative contribution of sea-level driving processes will vary under the different SSP scenarios. Higher temperatures projected under higher emission scenarios will cause oceans to absorb more heat, raising global sea level through thermal expansion while also accelerating melting of glaciers and ice sheets (Figure 8, 9).

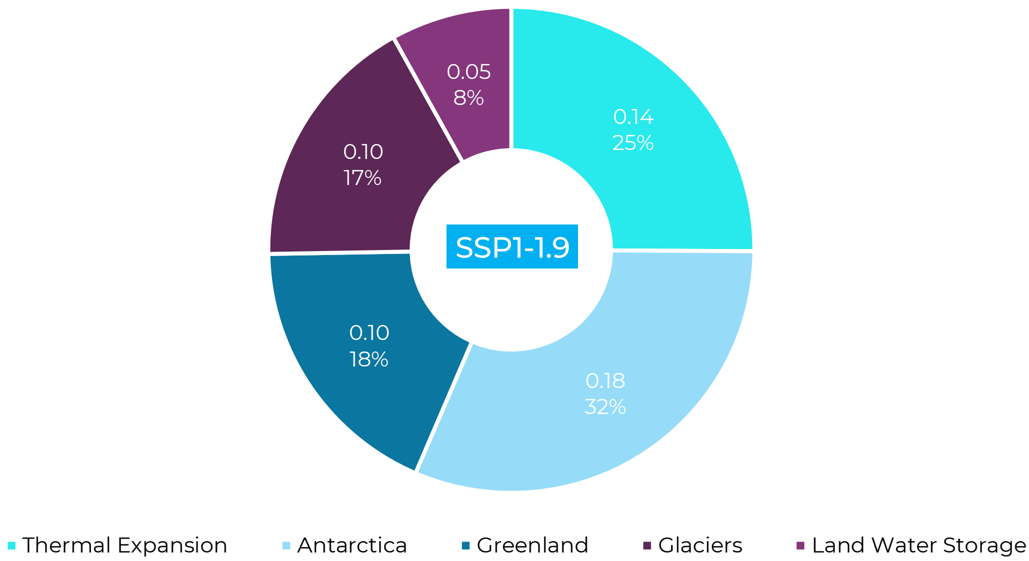

Figure 8: Contribution of processes to global mean sea level by 2150 (50th percentile in metres and relative percentage) under SSP1-1.9.

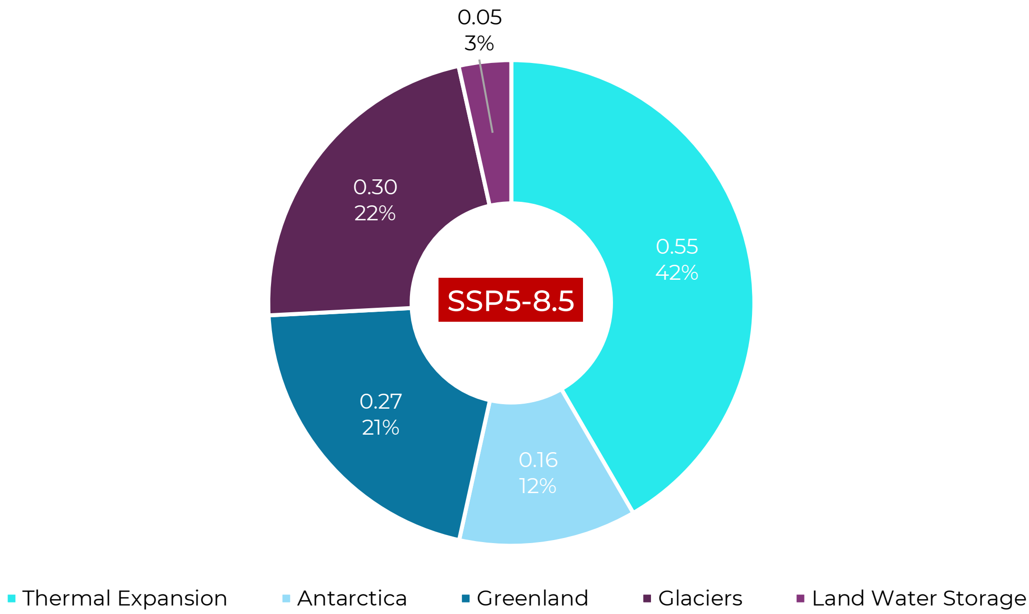

Figure 9: Contribution of processes to global mean sea level by 2150 (50th percentile in metres and relative percentage) under SSP5-8.5.

Table 1: Global mean sea-level rise magnitudes.

	2050		2100		2150	
	Median (m)	Likely range (m)	Median (m)	Likely range (m)	Median (m)	Likely range (m)
SSP1-1.9	0.18	0.15-0.23	0.38	0.28-0.55	0.57	0.37-0.86
SSP1-2.6	0.19	0.16-0.25	0.44	0.32-0.62	0.68	0.46-0.99
SSP2-4.5	0.20	0.17-0.26	0.56	0.44-0.76	0.92	0.66-1.33
SSP3-7.0	0.22	0.18-0.27	0.68	0.55-0.90	1.19	0.89-1.65
SSP5-8.5	0.23	0.20-0.29	0.77	0.63-1.01	1.32	0.98-1.88
SSP5-8.5 LC	0.24	0.20-0.40	0.88	0.63-1.60	1.98	0.98-4.82

Table 2: Global mean sea-level rise rates.

	2050		2100		2150	
	Median (mm/yr)	Likely range (mm/yr)	Median (mm/yr)	Likely range (mm/yr)	Median (mm/yr)	Likely range (mm/yr)
SSP1-1.9	4.1	2.8-6.0	4.1	2.3-6.6	3.3	1.5-5.7
SSP1-2.6	4.8	3.5-6.8	5.1	3.1-8.0	4.3	2.4-7.2
SSP2-4.5	5.8	4.0-7.0	7.8	5.2-11.6	7.0	4.6-10.9
SSP3-7.0	6.4	4.3-7.3	10.9	7.8-15.6	10.3	7.0-14.9
SSP5-8.5	7.2	4.7-8.0	12.6	8.9-18.4	10.8	7.0-16.4
SSP5-8.5 LC	7.9	4.7-12.5	17.8	8.9-37.8	27.0	7.0-99.8

Table 3: Exceedance of global mean sea-level milestones.

	0.5 m		1.0 m		1.5 m	
	Median (year)	Likely range (year)	Median (year)	Likely range (year)	Median (year)	Likely range (year)
SSP1-1.9	2130	2091-2241	2287	2176->2300	>2300	2267->2300
SSP1-2.6	2111	2084-2168	2226	2151->2300	>2300	2223->2300
SSP2-4.5	2093	2076-2117	2161	2120-2236	2243	2166->2300
SSP3-7.0	2086	2072-2101	2132	2107-2166	2182	2140-2253
SSP5-8.5	2081	2069-2094	2122	2099-2153	2167	2127-2240
SSP5-8.5 LC	2076	2056-2094	2107	2079-2153	2131	2097-2240

5.2 Singapore

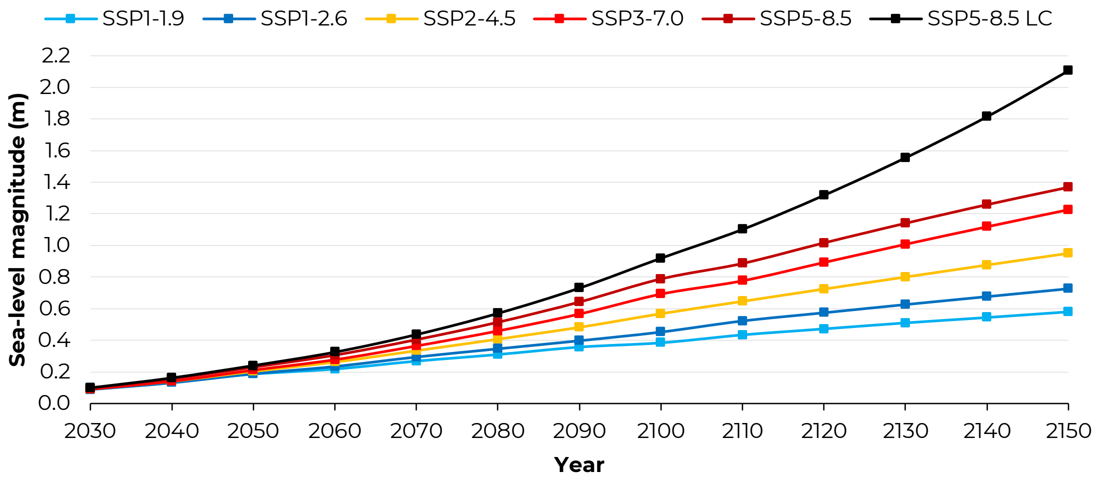

Figure 10: Projected changes in sea-level magnitude in Singapore under each SSP scenario.

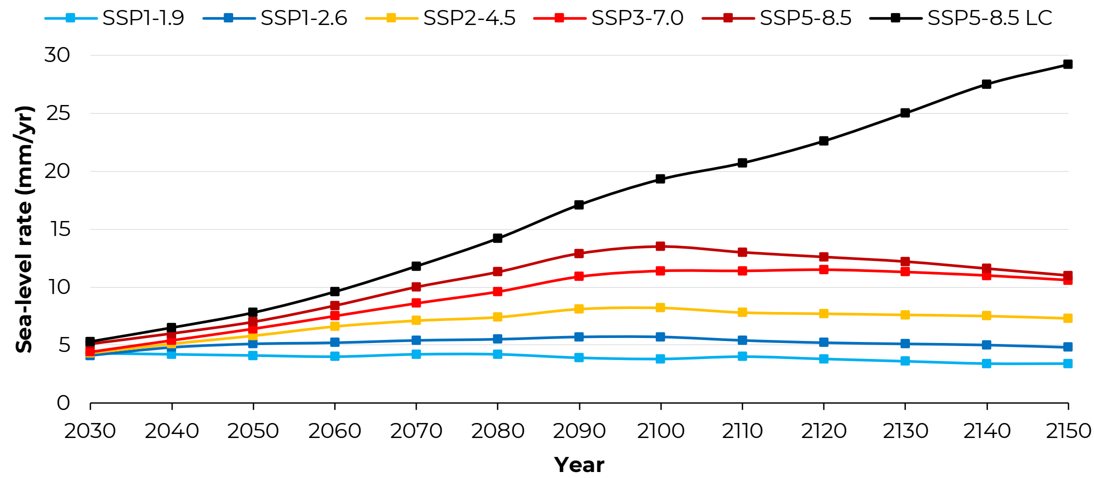

Figure 11: Projected changes in sea-level rate in Singapore under each SSP scenario.

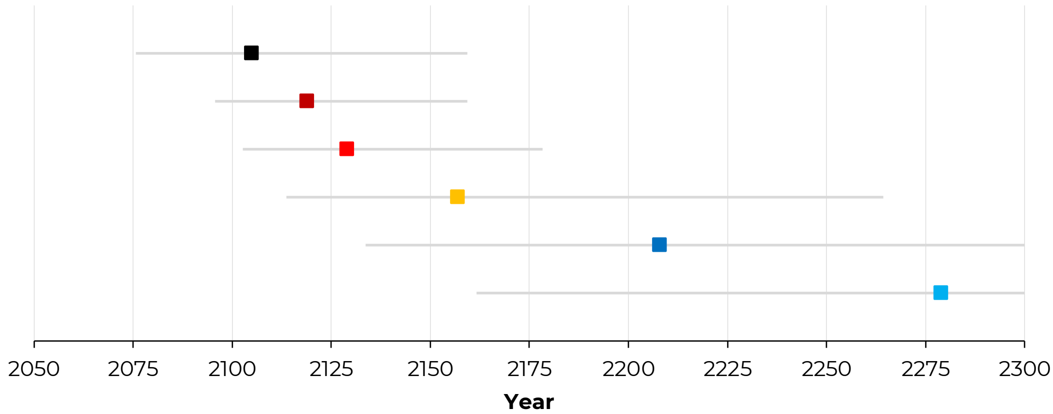

Figure 12: Projected exceedance of a 1.0 m sea- level milestone in Singapore under each SSP scenario.

- **SSP1-1.9**

Under very low emissions, sea-level rise by 2100 will increase 0.38 m (0.23–0.59 m) at a rate of 3.8 mm/yr (1.5–6.7 mm/yr). By 2150, sea level will increase 0.58 m (0.31–0.93 m) at a rate of 3.4 mm/yr (1.2–6.2 mm/yr) (Figure 10, 11; Table 4, 5).

A 1.0 m sea-level milestone will be crossed by 2279 (2162->2300) (Figure 12, Table 6).

- **SSP2-4.5**

Under intermediate emissions, sea-level rise by 2100 will increase 0.57 m (0.40-0.82 m) at a rate of 8.2 mm/yr (5.2-12.4 mm/yr). By 2150, sea level will increase 0.95 m (0.62-1.42 m) at a rate of 7.3 mm/yr (4.4-11.6 mm/yr).

A 1.0 m sea-level milestone will be crossed by 2157 (2114-2264).

- **SSP5-8.5**

Under very high emissions, sea-level rise by 2100 will increase 0.79 m (0.60–1.09 m) at a rate of 13.5 mm/yr (9.0–20.4 mm/yr). By 2150, sea level will increase 1.37 m (0.94–2.02 m) at a rate of 11.0 mm/yr (6.6–17.6 mm/yr).

A 1.0 m sea-level milestone will be crossed by 2119 (2096-2159).

- **SSP5-8.5 LC**

Under very high emissions that incorporates uncertainty in future ice sheet processes, sea-level rise by 2100 will increase 0.92 m (0.60–1.74 m) at a rate of 19.3 mm/yr (9.0-41.7 mm/yr). By 2150, sea level will increase 2.11 m (0.94–5.28 m) at a rate of 29.2 mm/yr (6.6-111.2 mm/yr).

A 1.0 m sea-level milestone will be crossed by 2105 (2076-2159).

Future sea-level rise in Singapore is similar to the global mean and primarily driven by ocean volume and mass increases from rising temperatures and accelerating melting of Antarctica/Greenland ice sheets and glaciers (Figure 13, 14).

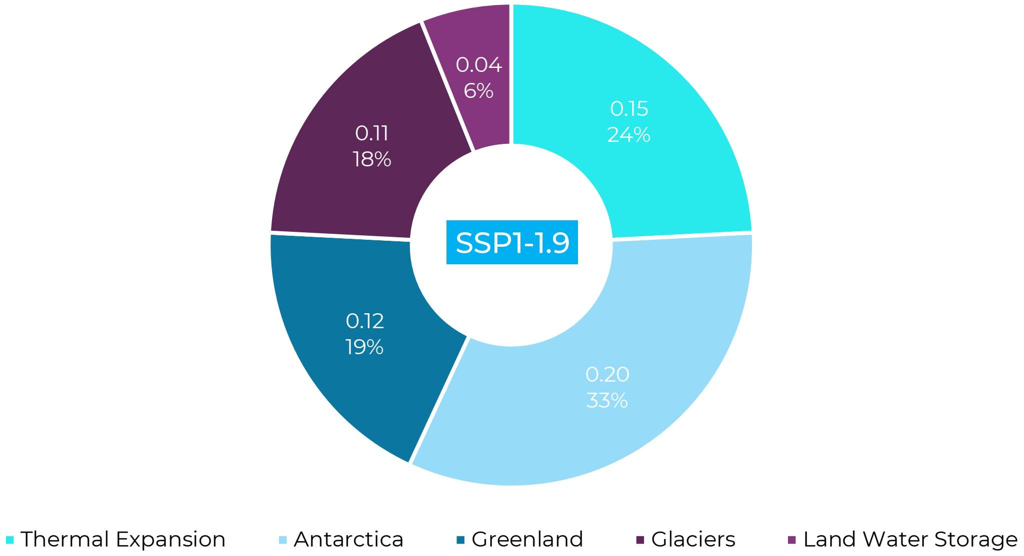

Figure 13: Contribution of processes to sea level in Singapore by 2150 (50th percentile in metres and relative percentage) under SSP1-1.9.

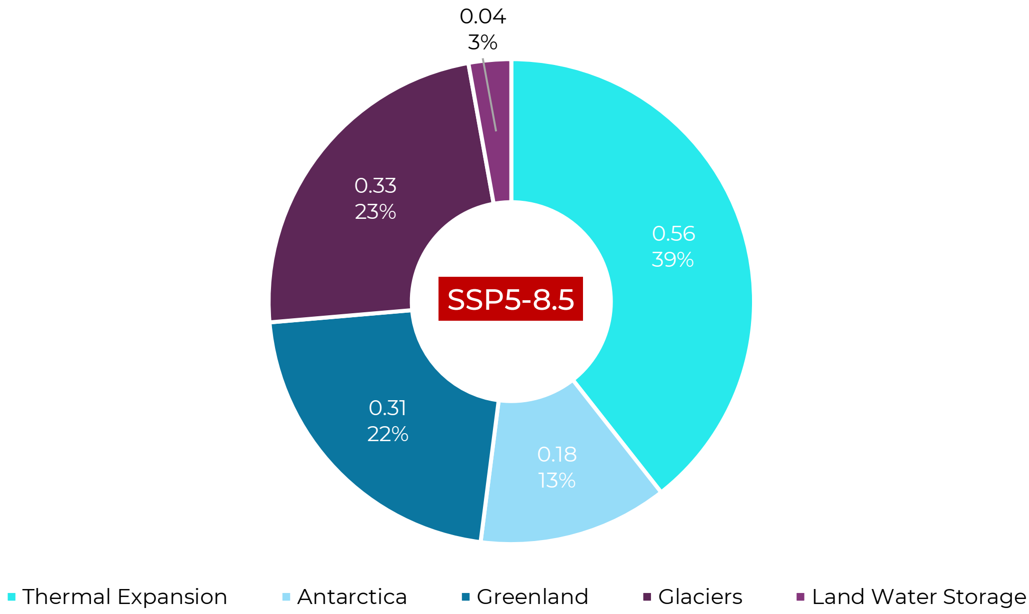

Figure 14: Contribution of processes to sea level in Singapore by 2150 (50th percentile in metres and relative percentage) under SSP5-8.5.

Table 4: Sea-level rise magnitudes in Singapore.

	2050		2100		2150	
	Median (m)	Likely range (m)	Median (m)	Likely range (m)	Median (m)	Likely range (m)
SSP1-1.9	0.19	0.13-0.26	0.38	0.23-0.59	0.58	0.31-0.93
SSP1-2.6	0.19	0.13-0.27	0.45	0.28-0.68	0.73	0.40-1.14
SSP2-4.5	0.20	0.14-0.29	0.57	0.40-0.82	0.95	0.62-1.42
SSP3-7.0	0.21	0.15-0.29	0.69	0.50-0.96	1.23	0.82-1.76
SSP5-8.5	0.23	0.17-0.32	0.79	0.60-1.09	1.37	0.94-2.02
SSP5-8.5 LC	0.24	0.16-0.42	0.92	0.60-1.74	2.11	0.94-5.28

Table 5: Sea-level rise rates in Singapore.

	2050		2100		2150	
	Median (mm/yr)	Likely range (mm/yr)	Median (mm/yr)	Likely range (mm/yr)	Median (mm/yr)	Likely range (mm/yr)
SSP1-1.9	4.1	2.3-6.6	3.8	1.5-6.7	3.4	1.2-6.2
SSP1-2.6	5.1	3.4-7.6	5.7	2.0-10.1	4.8	2.2-8.4
SSP2-4.5	5.8	4.0-8.5	8.2	5.2-12.4	7.3	4.4-11.6
SSP3-7.0	6.4	4.4-8.9	11.4	7.1-17.0	10.6	6.5-16.1
SSP5-8.5	7.0	4.9-9.9	13.5	9.0-20.4	11.0	6.6-17.6
SSP5-8.5 LC	7.8	4.9-17.1	19.3	9.0-41.7	29.2	6.6-111.2

Table 6: Exceedance of sea-level milestones in Singapore.

	0.5 m		1.0 m		1.5 m	
	Median (year)	Likely range (year)	Median (year)	Likely range (year)	Median (year)	Likely range (year)
SSP1-1.9	2127	2084->2300	2279	2162->2300	>2300	2244->2300
SSP1-2.6	2106	2078-2198	2208	2134->2300	>2300	2194->2300
SSP2-4.5	2092	2072-2125	2157	2114-2264	2234	2157->2300
SSP3-7.0	2085	2070-2107	2129	2103-2178	2178	2134-2288
SSP5-8.5	2080	2066-2097	2119	2096-2159	2162	2121-2261
SSP5-8.5 LC	2075	2054-2097	2105	2076-2159	2127	2093-2261

5.3 Manila, Philippines

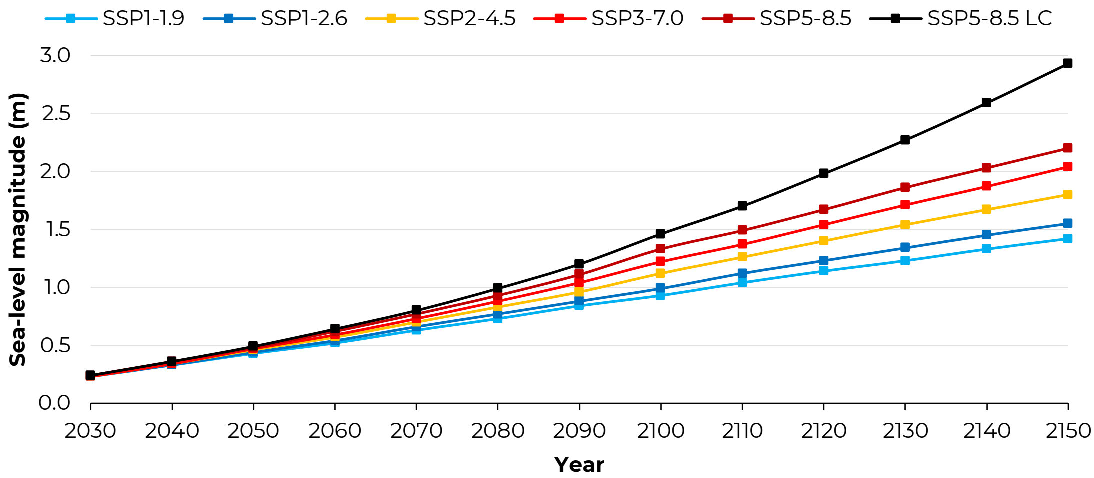

Figure 15: Projected changes in sea-level magnitude in Manila under each SSP scenario.

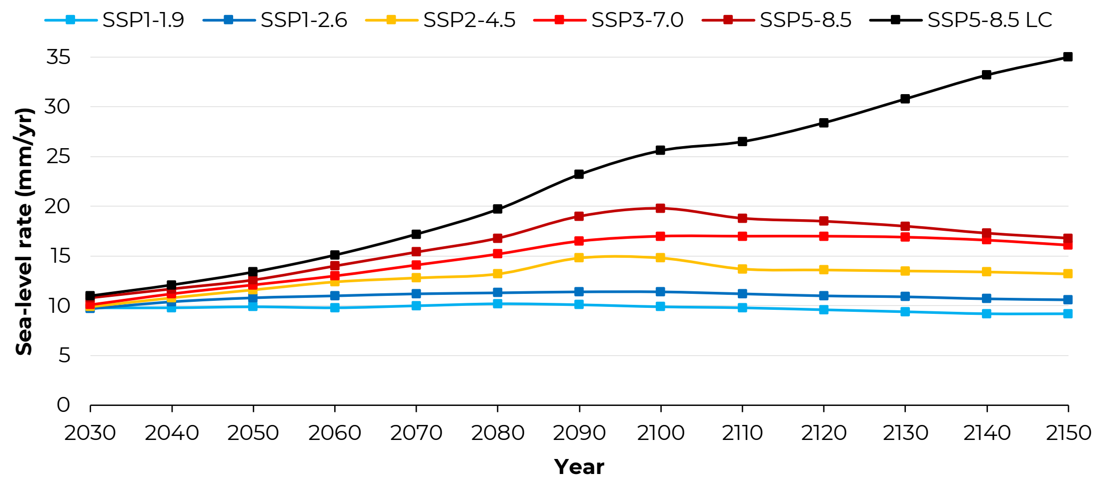

Figure 16: Projected changes in sea-level rate in Manila under each SSP scenario.

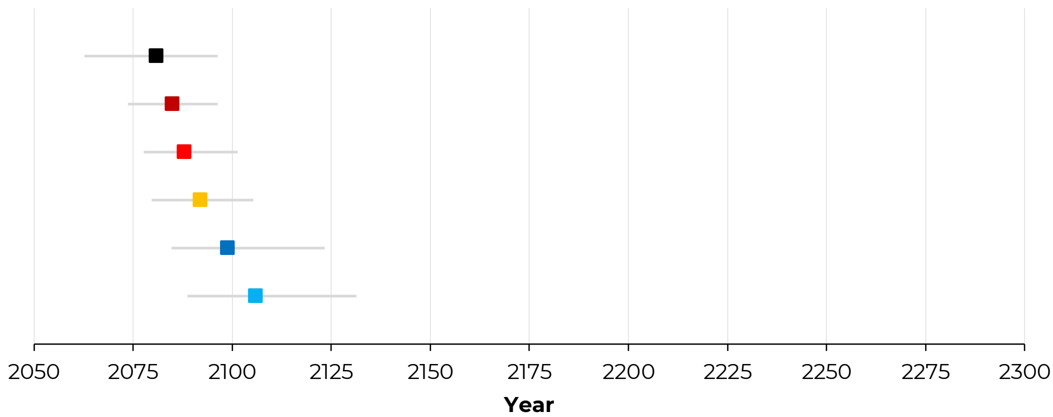

Figure 17: Projected exceedance of a 1.0 m sea-level milestone in Manila under each SSP scenario.

- **SSP1-1.9**

Under very low emissions, sea-level rise by 2100 will increase 0.93 m (0.76–1.15 m) at a rate of 9.9 mm/yr (5.0–15.2 mm/yr). By 2150, sea level will increase 1.42 m (1.44–1.78 m) at a rate of 9.2 mm/yr (7.0–12.0 mm/yr) (Figure 15, 16; Table 7, 8).

A 1.0 m sea-level milestone will be crossed by 2106 (2089-2131) (Figure 17; Table 9).

- **SSP2-4.5**

Under intermediate emissions, sea-level rise by 2100 will increase 1.12 m (0.96-1.37 m) at a rate of 14.8 mm/yr (11.3-19.5 mm/yr). By 2150, sea level will increase 1.80 m (1.48-2.26 m) at a rate of 13.2 mm/yr (10.4-17.4 mm/yr).

A 1.0 m sea-level milestone will be crossed by 2092 (2080-2105).

- **SSP5-8.5**

Under very high emissions, sea-level rise by 2100 will increase 1.33 m (1.13–1.63 m) at a rate of 16.8 mm/yr (12.4–23.4 mm/yr). By 2150, sea level will increase 2.20 m (1.77–2.85 m) at a rate of 16.8 mm/yr (12.4–23.4 mm/yr).

A 1.0 m sea-level milestone will be crossed by 2085 (2074-2096).

- **SSP5-8.5 LC**

Under very high emissions that incorporates uncertainty in future ice sheet processes, sea-level rise by 2100 will increase 1.46 m (1.13-2.30 m) at a rate of 25.6 mm/yr (14.5-48.3 mm/yr). By 2150, sea level will increase 2.93 m (1.77-6.11 m) at a rate of 35.0 mm/yr (12.4-117.0 mm/yr).

A 1.0 m sea-level milestone will be crossed by 2081 (2063-2096).

Future sea-level rise in Manila, Philippines will increase greater than the global mean. While the contribution from ocean volume and mass increases are similar, rising sea level will be exacerbated by vertical land motion (VLM) processes related to anthropogenic subsidence from ground water withdrawal (Figure 18, 19).

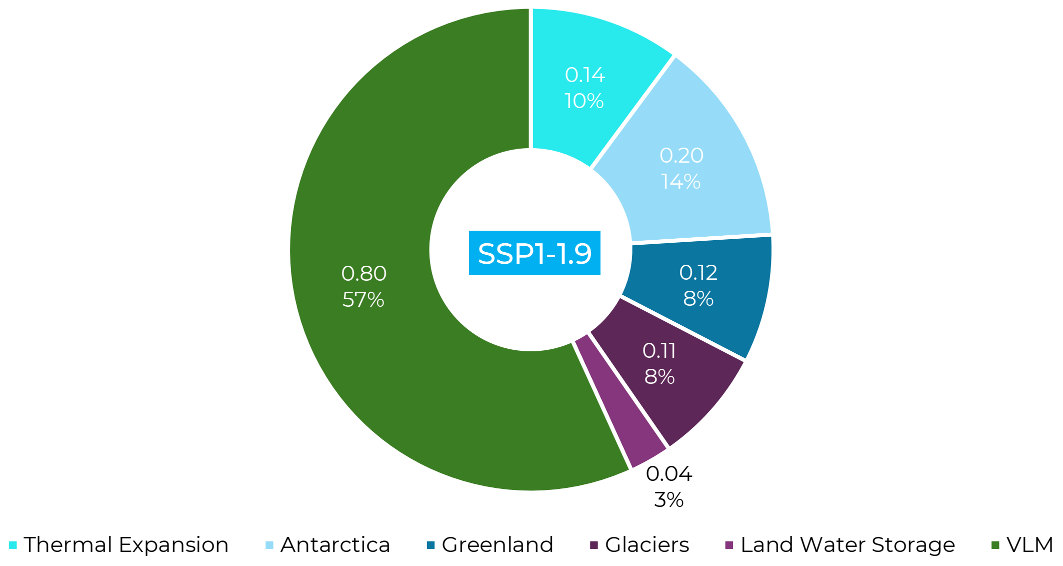

Figure 18: Contribution of processes to sea level in Manila by 2150 (50th percentile in metres and relative percentage) under SSP1-1.9.

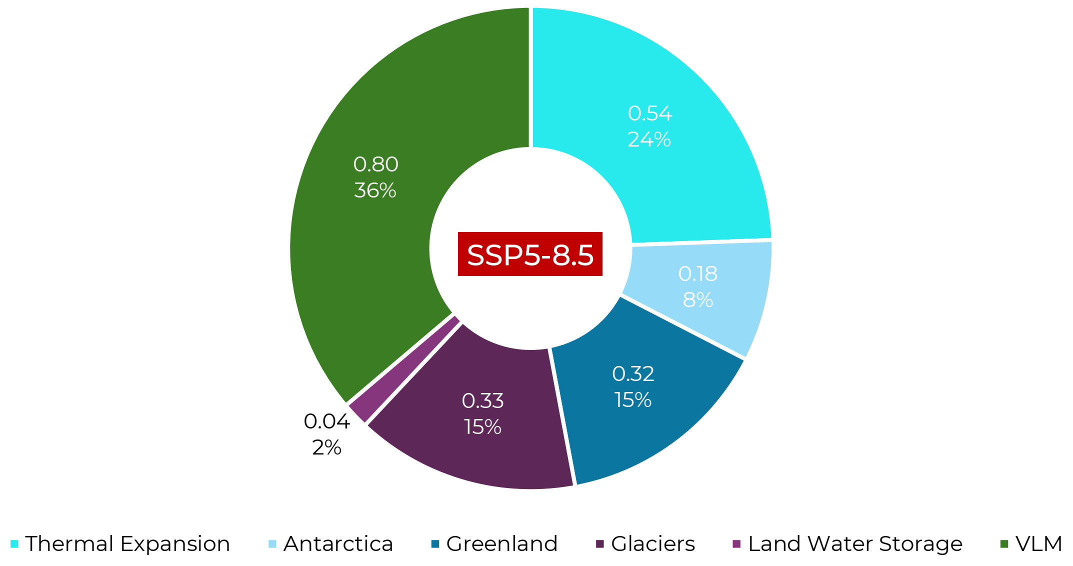

Figure 19: Contribution of processes to sea level in Manila by 2150 (50th percentile in metres and relative percentage) under SSP5-8.5.

Table 7: Sea-level rise magnitudes in Manila.

	2050		2100		2150	
	Median (m)	Likely range (m)	Median (m)	Likely range (m)	Median (m)	Likely range (m)
SSP1-1.9	0.43	0.39-0.50	0.93	0.76-1.15	1.42	1.14-1.78
SSP1-2.6	0.44	0.39-0.51	0.99	0.81-1.22	1.55	1.21-1.98
SSP2-4.5	0.46	0.40-0.53	1.12	0.96-1.37	1.80	1.48-2.26
SSP3-7.0	0.47	0.41-0.54	1.22	1.04-1.49	2.04	1.64-2.57
SSP5-8.5	0.48	0.43-0.57	1.33	1.13-1.63	2.20	1.77-2.85
SSP5-8.5 LC	0.49	0.42-0.68	1.46	1.13-2.30	2.93	1.77-6.11

Table 8: Sea-level rise rates in Manila.

	2050		2100		2150	
	Median (mm/yr)	Likely range (mm/yr)	Median (mm/yr)	Likely range (mm/yr)	Median (mm/yr)	Likely range (mm/yr)
SSP1-1.9	9.9	8.3-12.1	9.9	5.0-15.2	9.2	7.0-12.0
SSP1-2.6	10.8	9.4-13.0	11.4	5.8-17.3	10.6	7.6-14.4
SSP2-4.5	11.6	10.0-14.1	14.8	11.3-19.5	13.2	10.4-17.4
SSP3-7.0	12.1	10.2-14.6	17.0	12.4-22.8	16.1	12.1-21.6
SSP5-8.5	12.6	10.8-15.4	19.8	14.5-27.0	16.8	12.4-23.4
SSP5-8.5 LC	13.4	10.8-23.0	25.6	14.5-48.3	35.0	12.4-117.0

Table 9: Exceedance of sea-level milestones in Manila.

	0.5 m		1.0 m		1.5 m	
	Median (year)	Likely range (year)	Median (year)	Likely range (year)	Median (year)	Likely range (year)
SSP1-1.9	2056	2049-2064	2106	2089-2131	2159	2127-2203
SSP1-2.6	2055	2048-2062	2099	2085-2123	2145	2117-2189
SSP2-4.5	2054	2047-2060	2092	2080-2105	2127	2107-2152
SSP3-7.0	2053	2047-2060	2088	2078-2101	2118	2101-2139
SSP5-8.5	2052	2046-2058	2085	2074-2096	2110	2095-2130
SSP5-8.5 LC	2051	2041-2058	2081	2063-2096	2102	2079-2130

5.4 Hong Kong

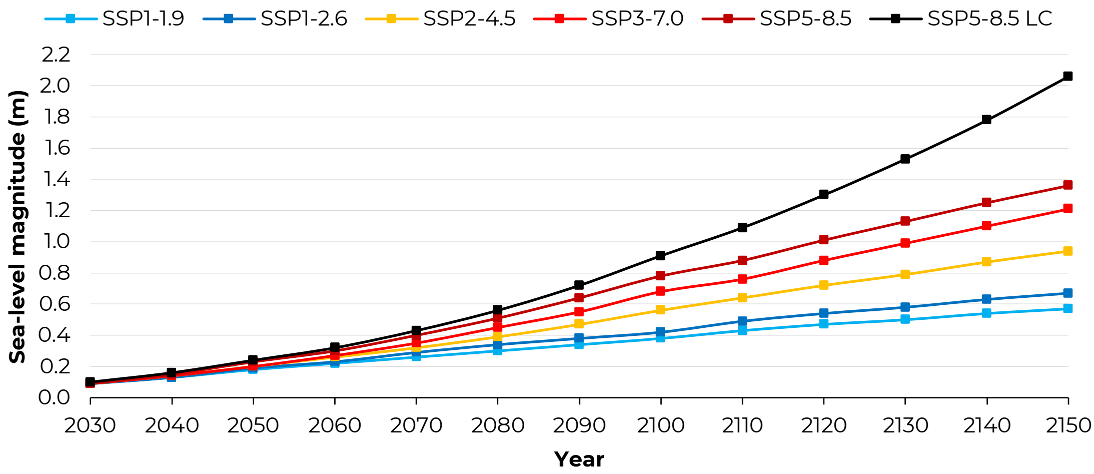

Figure 20: Projected changes in sea-level magnitude in Hong Kong under each SSP scenario.

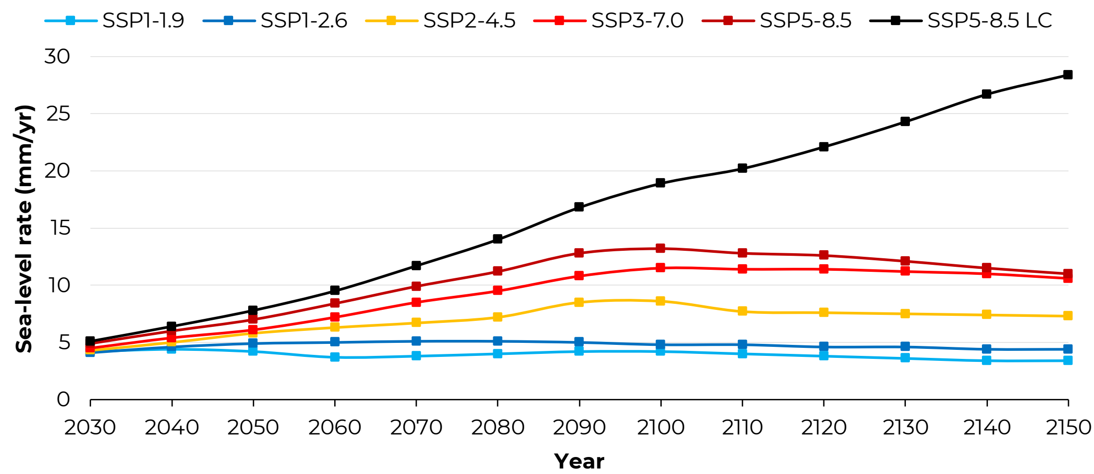

Figure 21: Projected changes in sea-level rate in Hong Kong under each SSP scenario.

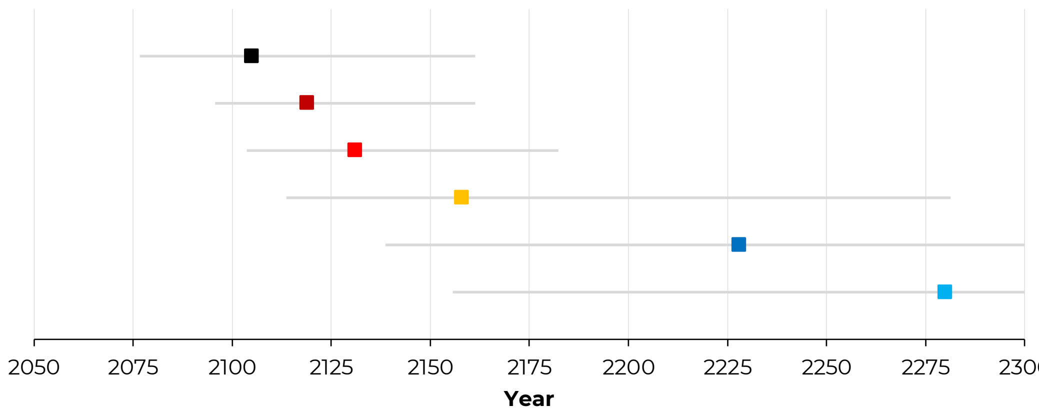

Figure 22: Projected exceedance of a 1.0 m sea-level milestone in Hong Kong under each SSP scenario.

- **SSP1-1.9**

Under very low emissions, sea-level rise by 2100 will increase 0.38 m (0.18-0.61 m) at a rate of 4.2 mm/yr (-0.2-9.1 mm/yr). By 2150, sea level will increase 0.57 m (0.25-0.96 m) at a rate of 3.4 mm/yr (0.9-6.4 mm/yr) (Figure 20, 21; Table 10, 11).

A 1.0 m sea-level milestone will be crossed by 2280 (2156->2300) (Figure 22; Table 12).

- **SSP2-4.5**

Under intermediate emissions, sea-level rise by 2100 will increase 0.56 m (0.37-0.82 m) at a rate of 8.6 mm/yr (5.2-13.0 mm/yr). By 2150, sea level will increase 0.94 m (0.58-1.41 m) at a rate of 7.3 mm/yr (4.2-11.4 mm/yr).

A 1.0 m sea-level milestone will be crossed by 2158 (2114-2281).

- **SSP5-8.5**

Under very high emissions, sea-level rise by 2100 will increase 0.78 m (0.57-1.08 m) at a rate of 13.2 mm/yr (9.0-19.8 mm/yr). By 2150, sea level will increase 1.36 m (0.92-1.99 m) at a rate of 11.0 mm/yr (6.8-17.4 mm/yr).

A 1.0 m sea-level milestone will be crossed by 2119 (2096-2161).

- **SSP5-8.5 LC**

Under very high emissions that incorporates uncertainty in future ice sheet processes, sea-level rise by 2100 will increase 0.91 m (0.57-1.72 m) at a rate of 18.9 mm/yr (9.0-40.8 mm/yr). By 2150, sea level will increase 2.06 m (0.92–5.19 m) at a rate of 28.4 mm/yr (6.8-106.8 mm/yr).

A 1.0 m sea-level milestone will be crossed by 2105 (2077-2161).

Future sea-level rise in Hong Kong will primarily be driven by ocean volume and mass increases from rising temperatures and accelerating melting of Antarctica/Greenland ice sheets and glaciers. The impacts from vertical land motion and land water storage are negligible (Figure 23, 24).

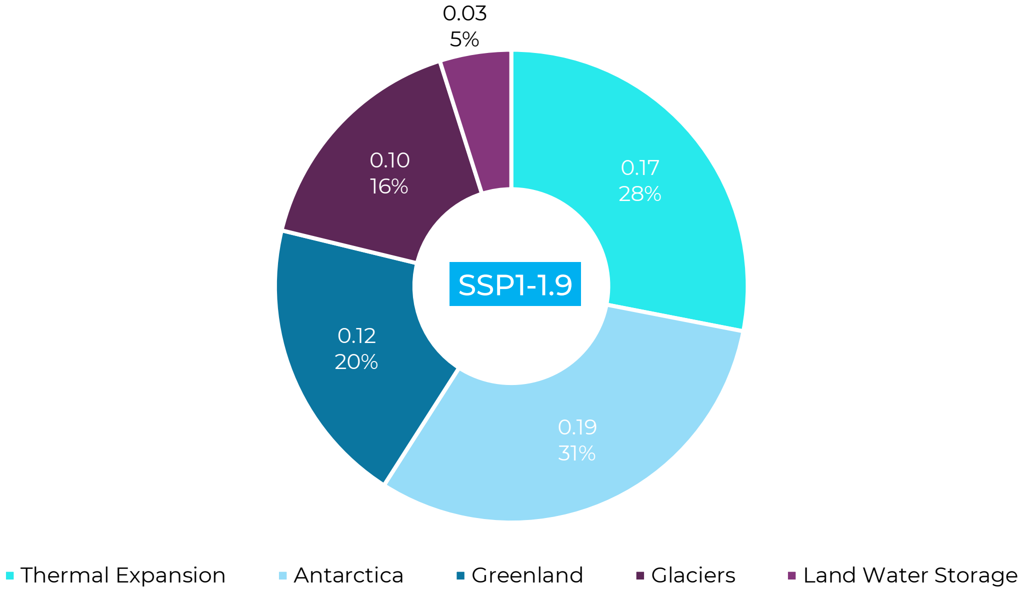

Figure 23: Contribution of processes to sea level in Hong Kong by 2150 (50th percentile in metres and relative percentage) under SSP1-1.9.

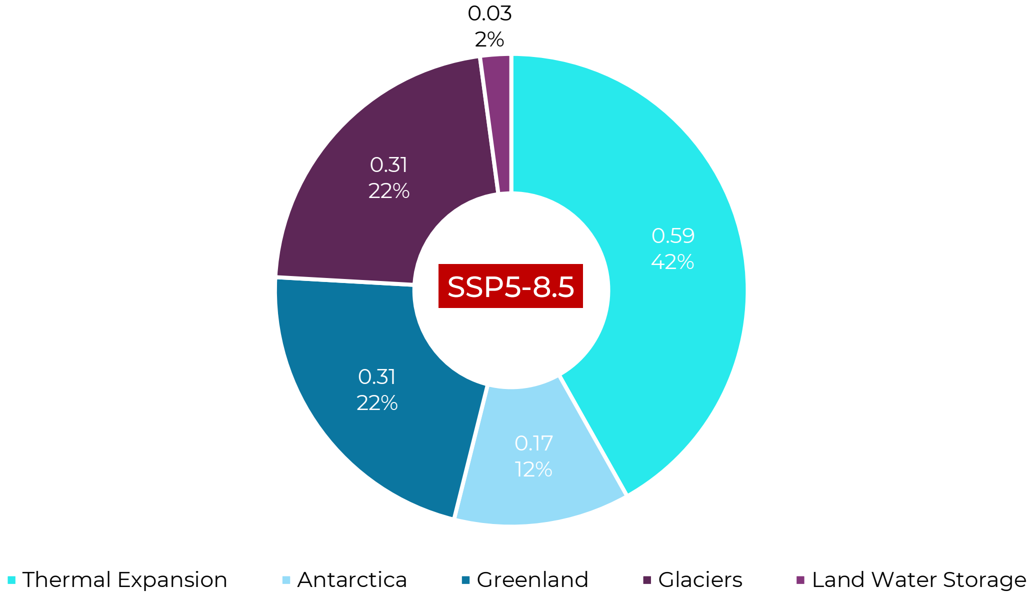

Figure 24: Contribution of processes to sea level in Hong Kong by 2150 (50th percentile in metres and relative percentage) under SSP5-8.5.

Table 10: Sea-level rise magnitudes in Hong Kong.

	2050		2100		2150	
	Median (m)	Likely range (m)	Median (m)	Likely range (m)	Median (m)	Likely range (m)
SSP1-1.9	0.18	0.11-0.27	0.38	0.18-0.61	0.57	0.25-0.96
SSP1-2.6	0.19	0.12-0.27	0.42	0.24-0.66	0.67	0.33-1.08
SSP2-4.5	0.20	0.13-0.28	0.56	0.37-0.82	0.94	0.58-1.41
SSP3-7.0	0.20	0.13-0.29	0.68	0.47-0.95	1.21	0.80-1.74
SSP5-8.5	0.23	0.16-0.32	0.78	0.57-1.08	1.36	0.92-1.99
SSP5-8.5 LC	0.24	0.15-0.42	0.91	0.57-1.72	2.06	0.92-5.10

Table 11: Sea-level rise rates in Hong Kong.

	2050		2100		2150	
	Median (mm/yr)	Likely range (mm/yr)	Median (mm/yr)	Likely range (mm/yr)	Median (mm/yr)	Likely range (mm/yr)
SSP1-1.9	4.2	2.3-6.7	4.2	-0.2-9.1	3.4	0.9-6.4
SSP1-2.6	4.9	3.0-7.4	4.8	1.2-9.0	4.4	1.5-7.8
SSP2-4.5	5.8	3.8-8.4	8.6	5.2-13.0	7.3	4.2-11.4
SSP3-7.0	6.1	4.0-8.7	11.5	7.2-16.9	10.6	6.6-15.8
SSP5-8.5	7.0	4.9-10.0	13.2	9.0-19.8	11.0	6.8-17.4
SSP5-8.5 LC	7.8	4.9-17.0	18.9	9.0-40.8	28.4	6.8-106.8

Table 12: Exceedance of sea-level milestones in Hong Kong.

	0.5 m		1.0 m		1.5 m	
	Median (year)	Likely range (year)	Median (year)	Likely range (year)	Median (year)	Likely range (year)
SSP1-1.9	2129	2084->2300	2280	2156->2300	>2300	2236->2300
SSP1-2.6	2112	2079-2274	2228	2139->2300	>2300	2205->2300
SSP2-4.5	2093	2073-2131	2158	2114-2281	2237	2158->2300
SSP3-7.0	2087	2071-2110	2131	2104-2182	2179	2135-2290
SSP5-8.5	2080	2066-2099	2119	2096-2161	2163	2122-2258
SSP5-8.5 LC	2076	2055-2099	2105	2077-2161	2128	2093-2258

5.5 Phuket, Thailand

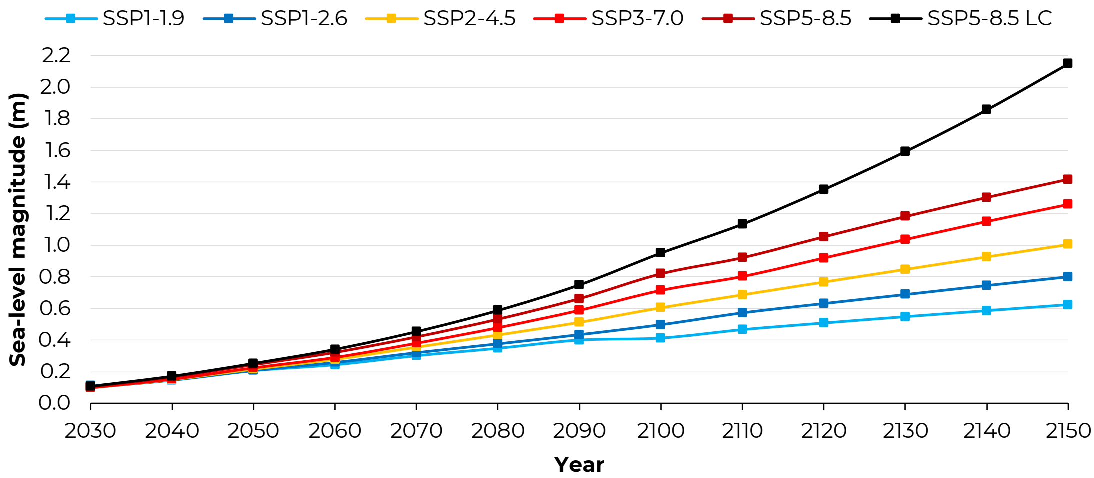

Figure 25: Projected changes in sea-level magnitude in Phuket under each SSP scenario.

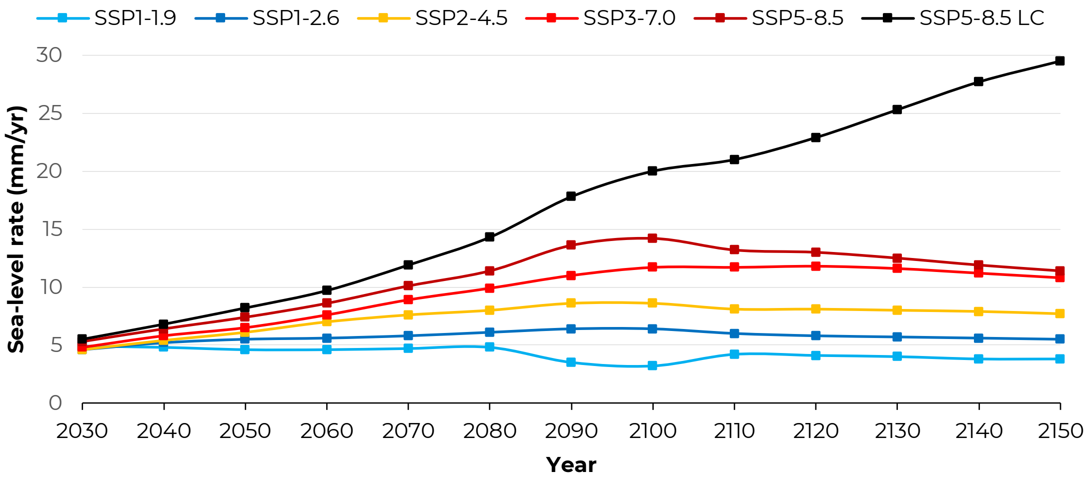

Figure 26: Projected changes in sea-level rate in Phuket under each SSP scenario.

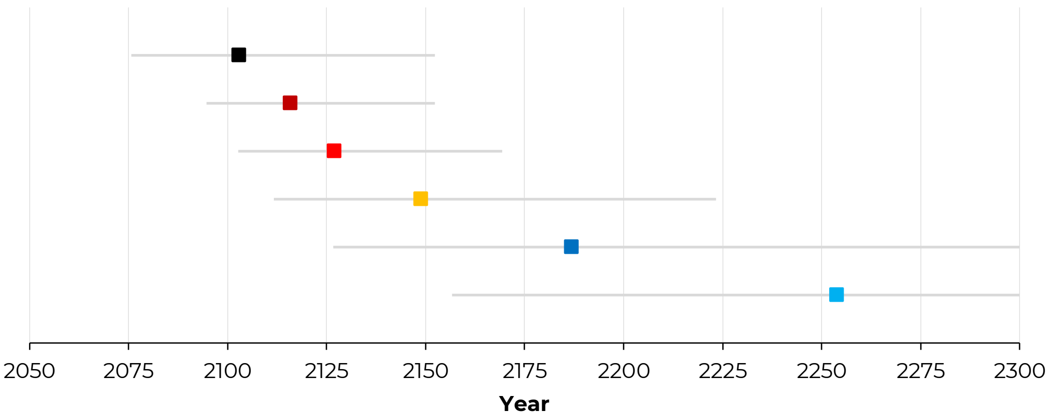

Figure 27: Projected exceedance of a 1.0 m sea-level milestone in Phuket under each SSP scenario.

- **SSP1-1.9**

Under very low emissions, sea-level rise by 2100 will increase 0.41 m (0.27-0.61 m) at a rate of 3.2 mm/yr (0.6-6.4 mm/yr). By 2150, sea level will increase 0.62 m (0.38-0.95 m) at a rate of 3.8 mm/yr (1.7-6.4 mm/yr) (Figure 25, 26; Table 13, 14).

A 1.0 m sea-level milestone will be crossed by 2254 (2157->2300) (Figure 27; Table 15).

- **SSP2-4.5**

Under intermediate emissions, sea-level rise by 2100 will increase 0.60 m (0.45-0.84 m) at a rate of 8.6 mm/yr (5.1-13.2 mm/yr). By 2150, sea level will increase 1.00 m (0.69-1.21 m) at a rate of 7.7 mm/yr (4.8-11.9 mm/yr).

A 1.0 m sea-level milestone will be crossed by 2149 (2112-2223).

- **SSP5-8.5**

Under very high emissions, sea-level rise by 2100 will increase 0.82 m (0.62-1.12 m) at a rate of 14.2 mm/yr (8.9-21.4 mm/yr). By 2150, sea level will increase 1.42 m (0.99-2.06 m) at a rate of 11.4 mm/yr (6.8-16.3 mm/yr).

A 1.0 m sea-level milestone will be crossed by 2116 (2095-2152).

- **SSP5-8.5 LC**

Under very high emissions that incorporates uncertainty in future ice sheet processes, sea-level rise by 2100 will increase 0.95 m (0.62–1.77 m) at a rate of 20.0 mm/yr (8.9–42.3 mm/yr). By 2150, sea level will increase 2.15 m (0.99-5.30 m) at a rate of 29.5 mm/yr (7.0–111.0 mm/yr).

A 1.0 m sea-level milestone will be crossed by 2103 (2076-2152).

Future sea-level rise in Phuket, Thailand will primarily be driven by ocean volume and mass increases from rising temperatures and accelerating melting of Antarctica/Greenland ice sheets and glaciers (Figure 28, 29).

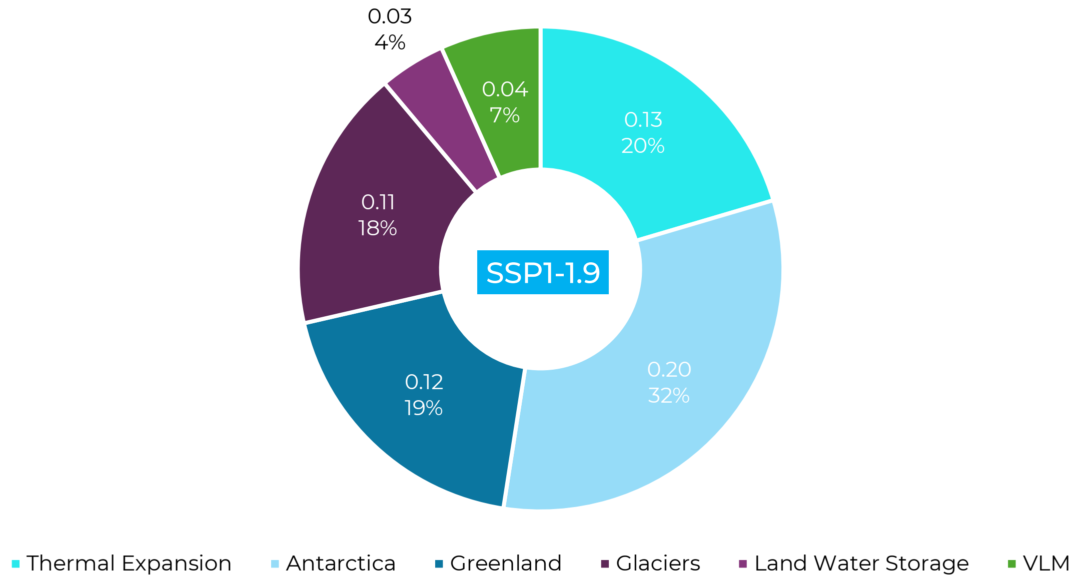

Figure 28: Contribution of processes to sea level in Phuket by 2150 (50th percentile in metres and relative percentage) under SSP1-1.9.

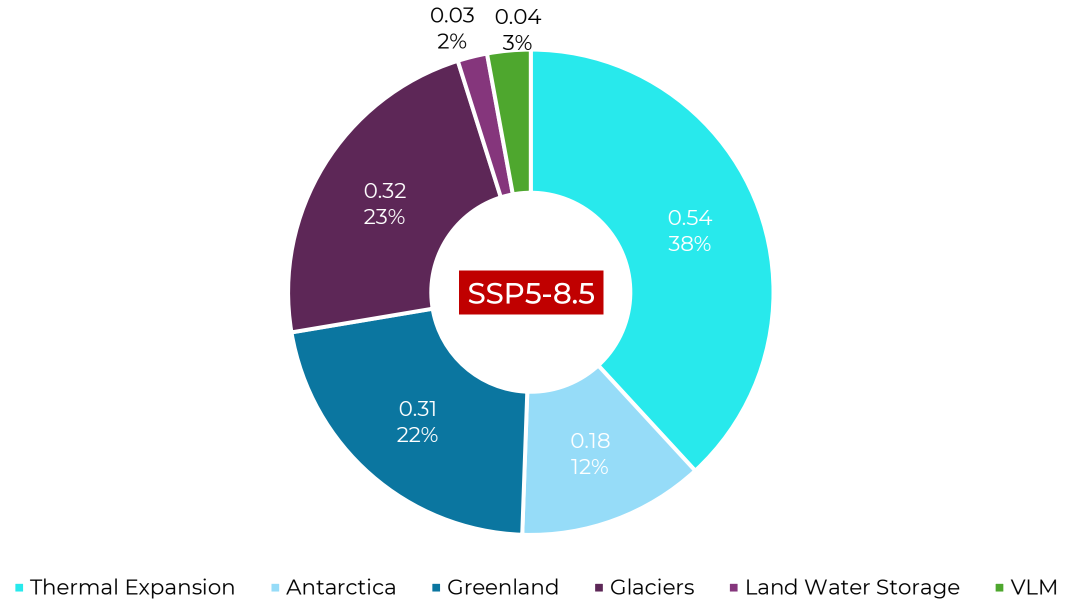

Figure 29: Contribution of processes to sea level in Phuket by 2150 (50th percentile in metres and relative percentage) under SSP5-8.5.

Table 13: Sea-level rise magnitudes in Phuket.

	2050		2100		2150	
	Median (m)	Likely range (m)	Median (m)	Likely range (m)	Median (m)	Likely range (m)
SSP1-1.9	0.21	0.16-0.28	0.41	0.27-0.61	0.62	0.38-0.95
SSP1-2.6	0.21	0.16-0.28	0.50	0.33-0.72	0.80	0.48-1.21
SSP2-4.5	0.22	0.16-0.29	0.60	0.45-0.84	1.00	0.69-1.21
SSP3-7.0	0.22	0.17-0.30	0.71	0.54-0.98	1.26	0.87-1.78
SSP5-8.5	0.24	0.19-0.32	0.82	0.62-1.12	1.42	0.99-2.06
SSP5-8.5 LC	0.25	0.19-0.43	0.95	0.62-1.77	2.15	0.99-5.30

Table 14: Sea-level rise rates in Phuket.

	2050		2100		2150	
	Median (mm/yr)	Likely range (mm/yr)	Median (mm/yr)	Likely range (mm/yr)	Median (mm/yr)	Likely range (mm/yr)
SSP1-1.9	4.6	2.9-6.9	3.2	0.6-6.4	3.8	1.7-6.4
SSP1-2.6	5.5	4.0-7.9	6.4	1.4-11.8	5.5	2.6-9.1
SSP2-4.5	6.1	4.4-8.6	8.6	5.1-13.2	7.7	4.8-11.9
SSP3-7.0	6.5	4.8-8.9	11.7	7.2-17.2	10.8	6.8-16.3
SSP5-8.5	7.4	5.6-10.1	14.2	8.9-21.4	11.4	6.8-16.3
SSP5-8.5 LC	8.2	5.6-17.4	20.0	8.9-42.3	29.5	7.0-111.0

Table 15: Exceedance of sea-level milestones in Phuket.

	0.5 m		1.0 m		1.5 m	
	Median (year)	Likely range (year)	Median (year)	Likely range (year)	Median (year)	Likely range (year)
SSP1-1.9	2118	2080-2226	2254	2157->2300	>2300	2236->2300
SSP1-2.6	2098	2076-2159	2187	2127->2300	2284	2182->2300
SSP2-4.5	2088	2071-2114	2149	2112-2223	2220	2153->2300
SSP3-7.0	2083	2070-2102	2127	2103-2169	2173	2133-2268
SSP5-8.5	2078	2066-2094	2116	2095-2152	2157	2120-2238
SSP5-8.5 LC	2074	2054-2094	2103	2076-2152	2126	2092-2238

5.6 Mumbai, India

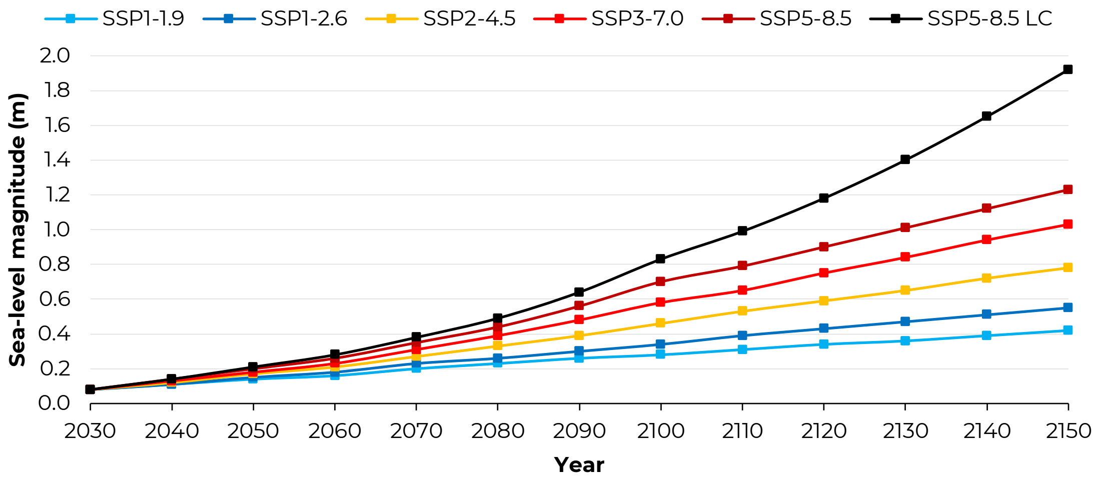

Figure 30: Projected changes in sea-level magnitude in Mumbai under each SSP scenario.

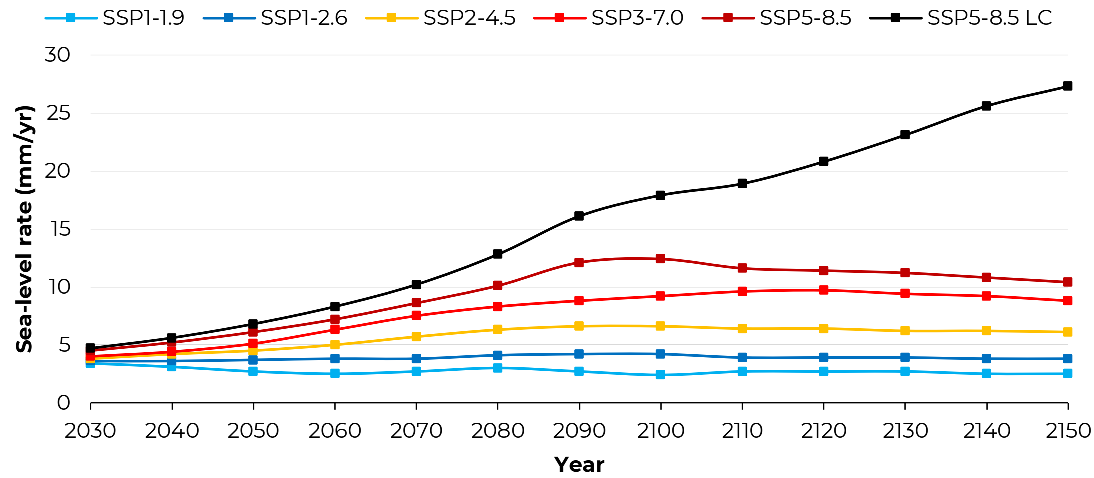

Figure 31: Projected changes in sea-level rate in Mumbai under each SSP scenario.

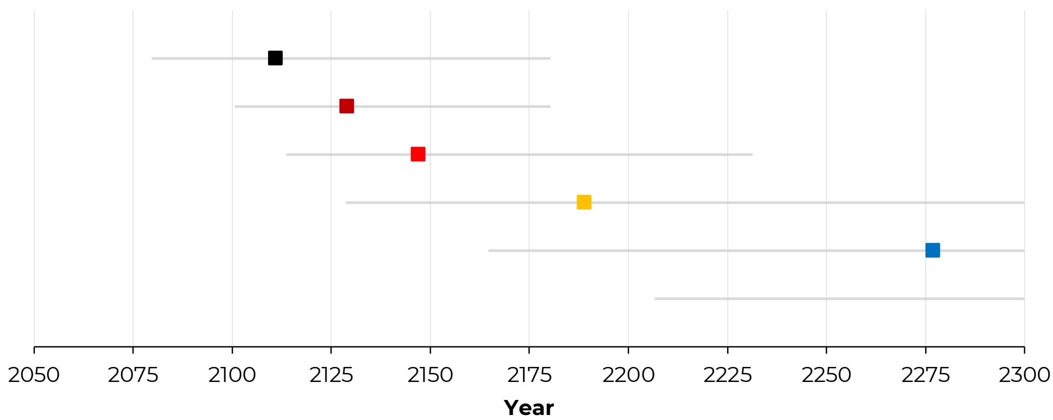

Figure 32: Projected exceedance of a 1.0 m sea-level milestone in Mumbai under each SSP scenario.

- **SSP1-1.9**

Under very low emissions, sea-level rise by 2100 will increase 0.28 m (0.16-0.45 m) at a rate of 2.4 mm/yr (0.4-5.0 mm/yr). By 2150, sea level will increase 0.42 m (0.20-0.72 m) at a rate of 2.5 mm/yr (0.7-5.0 mm/yr) (Figure 30, 31; Table 16, 17).

A 1.0 m sea-level milestone will be crossed by after 2300 (2207->2300) (Figure 32; Table 18).

- **SSP2-4.5**

Under intermediate emissions, sea-level rise by 2100 will increase 0.46 m (0.32-0.68 m) at a rate of 6.6 mm/yr (4.0-10.7 mm/yr). By 2150, sea level will increase 0.78 m (0.49-1.21 m) at a rate of 6.1 mm/yr (3.4-10.0 mm/yr).

A 1.0 m sea-level milestone will be crossed by 2189 (2129->2300).

- **SSP5-8.5**

Under very high emissions, sea-level rise by 2100 will increase 0.70 m (0.52-0.99 m) at a rate of 12.4 mm/yr (7.4-19.2 mm/yr). By 2150, sea level will increase 1.23 m (0.82-1.85 m) at a rate of 10.4 mm/yr (6.2-16.5 mm/yr).

A 1.0 m sea-level milestone will be crossed by 2129 (2101-2180).

- **SSP5-8.5 LC**

Under very high emissions that incorporates uncertainty in future ice sheet processes, sea-level rise by 2100 will increase 0.83 m (0.52-1.59 m) at a rate of 17.9 mm/yr (7.4-39.3 mm/yr). By 2150, sea level will increase 1.92 m (0.82-4.89 m) at a rate of 27.3 mm/yr (6.2-104.0 mm/yr).

A 1.0 m sea-level milestone will be crossed by 2111 (2080-2180).

Future sea-level rise in Mumbai, India will primarily be driven by ocean volume and mass increases from rising temperatures and accelerating melting of Antarctica/Greenland ice sheets and glaciers (Figure 33, 34).

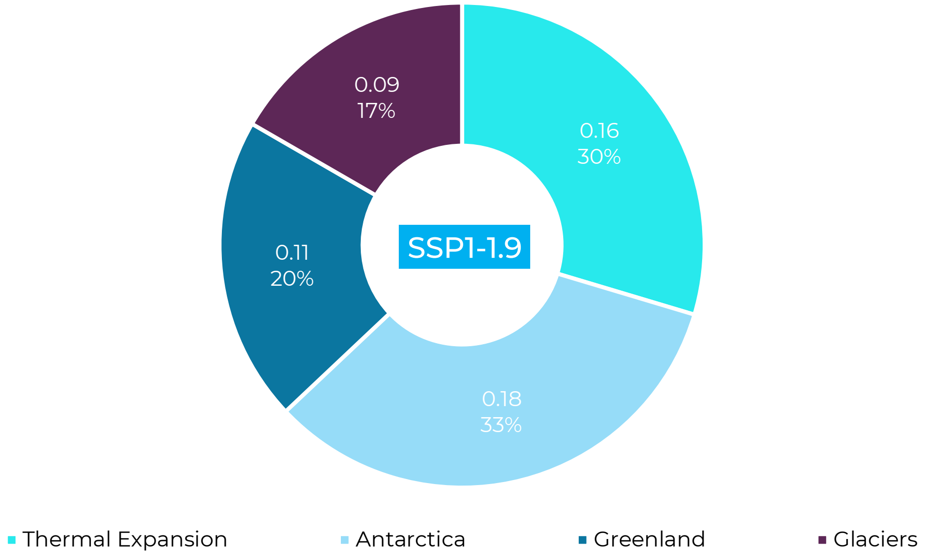

Figure 33: Contribution of processes to sea level in Mumbai by 2150 (50th percentile in metres and relative percentage) under SSP1-1.9.

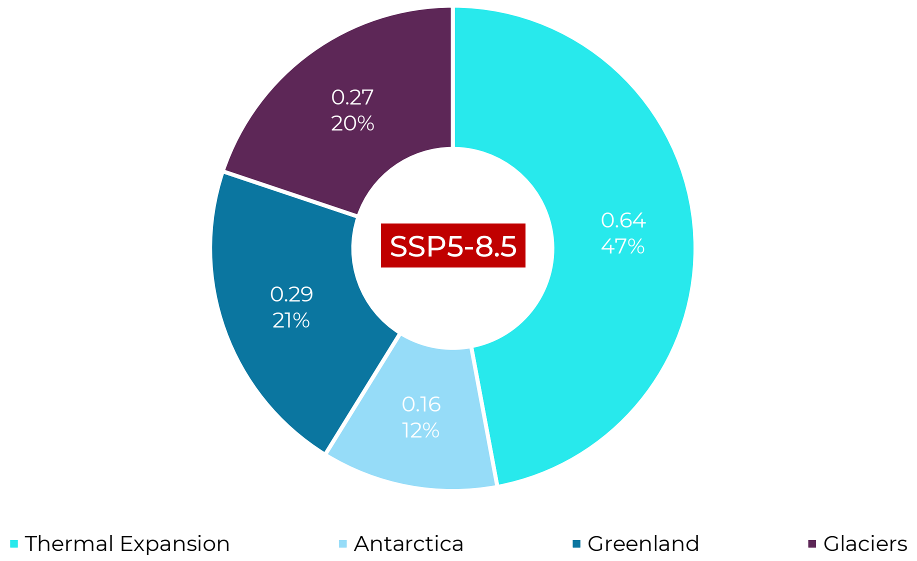

Figure 34: Contribution of processes to sea level in Mumbai by 2150 (50th percentile in metres and relative percentage) under SSP5-8.5.

Table 16: Sea-level rise magnitudes in Mumbai.

	2050		2100		2150	
	Median (m)	Likely range (m)	Median (m)	Likely range (m)	Median (m)	Likely range (m)
SSP1-1.9	0.14	0.11-0.20	0.28	0.16-0.45	0.42	0.20-0.72
SSP1-2.6	0.15	0.10-0.22	0.34	0.21-0.53	0.55	0.29-0.90
SSP2-4.5	0.17	0.12-0.24	0.46	0.32-0.68	0.78	0.49-1.21
SSP3-7.0	0.18	0.13-0.25	0.58	0.42-0.83	1.03	0.68-1.52
SSP5-8.5	0.20	0.15-0.27	0.70	0.52-0.99	1.23	0.82-1.85
SSP5-8.5 LC	0.21	0.15-0.37	0.83	0.52-1.59	1.92	0.82-4.89

Table 17: Sea-level rise rates in Mumbai.

	2050		2100		2150	
	Median (mm/yr)	Likely range (mm/yr)	Median (mm/yr)	Likely range (mm/yr)	Median (mm/yr)	Likely range (mm/yr)
SSP1-1.9	2.7	1.2-4.9	2.4	0.4-5.0	2.5	0.7-5.0
SSP1-2.6	3.7	2.2-5.9	4.2	1.5-7.6	3.8	1.6-6.8
SSP2-4.5	4.5	2.9-7.0	6.6	4.0-10.7	6.1	3.4-10.0
SSP3-7.0	5.1	3.2-7.6	9.2	5.8-14.0	8.8	5.2-13.8
SSP5-8.5	6.1	4.1-8.9	12.4	7.4-19.2	10.4	6.2-16.5
SSP5-8.5 LC	6.8	4.1-15.5	17.9	7.4-39.3	27.3	6.2-104.0

Table 18: Exceedance of sea-level milestones in Mumbai.

	0.5 m		1.0 m		1.5 m	
	Median (year)	Likely range (year)	Median (year)	Likely range (year)	Median (year)	Likely range (year)
SSP1-1.9	2184	2107->2300	>2300	2207->2300	>2300	>2300->2300
SSP1-2.6	2138	2093->2300	2277	2165->2300	>2300	2240->2300
SSP2-4.5	2106	2081-2153	2189	2129->2300	>2300	2180->2300
SSP3-7.0	2094	2077-2120	2147	2114-2231	2212	2149->2300
SSP5-8.5	2086	2071-2106	2129	2101-2180	2178	2129->2300
SSP5-8.5 LC	2081	2058-2106	2111	2080-2180	2134	2097->2300

6 Extreme Sea Levels

6.1 Compounding events

Superimposed on baseline projections of sea-level rise are the potential compounding effects of extreme sea level (ESL) events. An ESL refers to the occurrence of exceptionally high or low local sea surface height driven by a combination of tides, storm surges, and waves (Gregory et al., 2019). Increased global warming is expected to drive ESL events and flood risk along coastlines and their impacts in tropical latitudes could be exacerbated by future changes in tropical cyclone activity through intensified wind-waves, storm surges and heavy rainfall. For example, the present-day 100-year return period for ESL will occur at least once a year, even under a low-end scenario of 1.5 °C warming by 2100 along global coastlines and possibly even earlier in the tropics (Tebaldi et al., 2021; Jevrejeva et al., 2023).

The significant population densities, ecosystems and critical infrastructure in coastal regions of Asia are therefore vulnerable to the impacts of ESL when natural and/or engineered defences are breached.

Understanding and quantifying ESL is particularly important to the insurance sector due to the increased coastal flood risk and disruption to key services. As we progress with providing sea-level projections for additional sites throughout the Asia region, we will also be exploring the compounding impacts from ESL.

7 Future Implications

7.1 Urban environments

Rising sea level poses an existential threat to low-lying regions where highly developed coastlines support substantial economic and societal value. Of the global land area less than 2 m above present-day sea level, 31% is in tropical latitudes of Asia where an estimated ~157 million people currently live (Hooijer and Vernimmen, 2021). Over the 21st century and beyond, future sea-level rise would significantly increase the susceptibility of coastal populations in Asia living in projected sea- and flood-levels (Kulp and Strauss, 2019; Strauss et al., 2021). Many coastal cities in Asia are also experiencing non-climatic factors related to land subsidence from anthropogenic activities (e.g., resource extraction) that exacerbates sea-level rise (Tay et al., 2022; Ao et al., 2024). For example, by 2120, the combined effects of land subsidence and sea-level rise will cause 22 to 26% of China's coastal lands to have a relative elevation lower than sea level (Ao et al., 2024).

As socioeconomic developments increase coastal population and value of assets, the economic cost of sea-level rise and flooding are expected to increase during the 21st century (Hinkel et al., 2014). A global assessment of the economic impacts shows regions of Asia will experience the highest costs (Anthoff et al., 2010) through the loss of land, infrastructure and physical and social, additional costs from ESL events, and increased costs for coastal defence (Asuncion and Lee, 2017). Furthermore, new global elevation and population data shows at least 50 major cities, mostly in Asia, would need to defend against globally unprecedented levels of exposure or face partial to near-total extant area losses from rising sea level under high emissions scenarios (Strauss et al., 2021). While accurate projections are undoubtedly needed to implement appropriate adaptation and mitigation measures, a global survey of coastal practitioners, however, shows there is currently a limited consensus on what sea-level rise projections are used (Hirschfeld et al., 2023).

7.2 Coastal ecosystems

The Asia Pacific region supports a wide array of costal ecosystems including tidal marshes, intertidal mudflats, seagrasses, coral islands and reefs and mangrove forests. Indeed, nearly two thirds of the world's most ecologically diverse mangrove forests are found in Asia alone. These ecosystems provide many essential services to local communities and the global environment including promoting biodiversity for fauna and flora, nutrient cycling and water treatment, as well as tourism and recreational activities. Furthermore, they provide a natural defence reducing the impact of wave energy to limit coastal erosion and protect coastlines from sea-level rise and ESL events. More recently, the coastal realm has also been recognised as an important carbon sink providing natural sequestration to offset and mitigate rising CO_2. For example, mangrove forests have shown to sequestrate five times more organic carbon as tropical rainforests (Donato et al., 2011).

The productivity and survival of coastal ecosystems, however, is under threat from a warming climate and rising seas (Perry et al., 2018). While there are positive feedback mechanisms from higher CO_2 levels, such as enhanced plant growth and productivity, overwhelmingly the effect will be negative (Friess et al., 2022). The geological past tells us these ecosystems have 'tipping points' and when sea-level rise exceeds their capacity to adapt, they died (Saintilan et al., 2023). For example, geological reconstructions and modern monitoring studies show when rates of sea-level rise exceeded ~7 mm/yr, similar to those projected under moderate emissions scenario by 2100, their probability of survival dramatically decreases (Saintilan et al., 2023). This can be further compounded by other anthropogenic pressures, where landward migration is impeded, sediment supply is diminished, water quality/turbidity decreases/increases and ocean warming and acidification. Careful management and intervention will therefore be essential to ensure the long-term survival of coastal ecosystems as temperatures increase and sea level rises.

7.3 The insurance sector

Rising sea levels have implications for urban environments, with regions of Asia potentially experiencing the highest costs through the loss of land and infrastructure, additional physical and social costs from ESL events, and increased costs for coastal defence. The implications for coastal ecosystems and communities were also briefly discussed. These expected impacts have amplified the complexity of risk assessment for the non-life and life insurance sectors.

7.3.1 Risk modelling and data

Rising sea levels are reshaping the risk landscape for both non-life and life & health insurance sectors.

For the non-life insurance sector, the increasing uncertainties regarding risk events such as floods and cyclones, especially with the potential threats of ESL events, suggest that prevailing catastrophe risk underwriting and modelling techniques concluded from past experience may no longer be adequate. This is especially critical for areas susceptible to rising sea levels. While the potential impacts of sea-level rise vary, the direct emerging risks include changes in the frequency and severity of loss distributions for:

- Coastal flooding: Public, commercial, and residential properties are densely placed in coastal areas in Southeast Asia (SEA), which are more likely to be affected by rising sea level;
- Agricultural damages: Coastal farms are susceptible to flooding and seawater, potentially leading to the permanent closure of farmlands;
- Offshore projects: Offshore wind power farms, for instance, are vulnerable to tropical cyclones and rising sea levels, causing higher costs and challenges in installation, maintenance, and carbon credits.

For the life and health insurance sectors, where geographical specifics were of less importance traditionally, the socio-economic impacts of rising sea levels in susceptible geographical regions, as well as the potential displacement and migration of populations from affected coastal areas, will have implications on the mortality and morbidity risks of people in those regions. Further, rising sea levels can affect human health and life expectancy, particularly in the context of SEA, through several key pathways, including:

- Vector-borne diseases: Rising sea levels can alter the habitats of various vectors, such as mosquitoes and ticks, leading to the spread of vector-borne diseases such as malaria and dengue fever. Epidemic outbreaks can be more frequent and severe than before.
- Increased flooding: Significant populations in SEA are exposed to flood risks. As sea levels rise, coastal communities face increased risk of flooding, which can lead to immediate health hazards. Evidence also shows that flood risk can lead to long-term health problems due to its threat to the drinking water supply.
- Food security: Rising sea levels can lead to the contamination of groundwater and soil, affecting agricultural productivity and fisheries. This can threaten food security and create health problems. As a developing region, SEA has many vulnerable populations, and the food security issue may be particularly severe for them.

For both sectors, this means that traditional methods, which often rely on historical data to predict future risks, may not be sufficient in accurately forecasting the heightened risks associated with climate change and its effects on sea levels. In addition, there may be a need to consider variables beyond the traditional underwriting and risk modelling variables. For example, in the life and health insurance sector, factors such as more precise geographical and property information to assess exposures to health risks arising from floods and vector-borne diseases, as well as travel patterns and engagement in outdoor activities that may increase exposure to health risks in the face of rising sea levels, may be factors to consider in the future.

Moreover, insurers face significant challenges in obtaining accurate visibility of current risk exposures, particularly in flood modelling, due to the lack of standardized flood models in the region. This inconsistency in risk assessment complicates insurers' ability to make informed decisions about coverage and pricing. Developing a standardized approach for catastrophe risk modelling, with common benchmarks, could help reduce variability in risk assessments and promote more accurate and consistent insurance practices.

Notwithstanding the increasing exposures to climate change and sea-level rise risks, the parallel risk of biodiversity loss and its associated impacts is becoming just as significant. Biodiversity loss, along with land use changes and ecosystem damage, directly affects insurers' risk profiles. For example, deforestation leads to increased flooding, heightening physical risks for insurers by causing more damage to properties and infrastructure. Similarly, water scarcity and soil erosion reduce food production, escalating risks for crop yield insurance and threatening the stability of agricultural markets. Additionally, land use changes and pollution contribute to rising mortality and morbidity rates, which directly impact the life and health insurance sectors (Dong and Klug, 2022). As ecosystems degrade, the insurance industry faces amplified risks that require more proactive measures in underwriting and risk management.

The insurance sector has the opportunity to reduce its environmental impact and drive a green, fast, and fair transition. Taking action on climate and biodiversity aligns with its long-term interests, as rising risks threaten insurability. WWF (2022) recommends aligning underwriting policies with global climate and biodiversity goals, supported by measurable transition plans. Engaging clients and brokers to promote green choices, such as renewable energy projects and nature-based solutions, can also help.

7.3.2 Risk management

Risk management in the insurance sector includes considerations of exposure concentrations and comprehensive scenario analyses or stress tests.

Although this report is primarily focused on future time horizons, it is worth acknowledging the shorter and present-day effects of climate change. Research indicates that ESL events have already increased significantly in recent decades (e.g., Zheng et al., 2023). This underscores the importance of considering current trends when assessing risk. Many risk models assume a stationary climate, which may underestimate present-day risks. Incorporating these trends into models would enhance our understanding of both immediate and long-term impacts of climate change on low-elevation coastal areas.

The non-life insurance sector is expected to be more significantly affected as rising sea level risk emerges. However, exposures and consequent hazards are disproportionally distributed around the world. This can lead to diverse impacts across geographical regions, necessitating region-specific risk assessments to determine exposures and thereby assess concentrations of exposures. Non-life insurers may need to assess their concentration risk and plan their portfolio's geographical distribution accordingly to optimise their risk exposure and profitability.

Additionally, non-life insurance contracts typically have a 12-month duration, which does not adequately align with the long-term risks posed by climate change and rising sea levels. This short-term focus can create a form of industry myopia, where gradual changes are overlooked until they lead to significant harmful outcomes. Consideration of the longer-term implications of climate change, and more importantly, the timeline for realising the benefits of risk adaptation, mitigation and prevention measures, are areas for the insurance sector to adopt within their product design, underwriting and pricing approaches. Such considerations could enable insurers and their clients to manage risks more effectively over the long term, fostering a proactive approach to climate-related challenges.

Further research and discussions within both academic and industry circles are required to extend our understanding of how to adapt existing models or develop new approaches that incorporate rising sea levels and other climate-related challenges into the insurance sector's pricing, valuation, and capital planning approaches. Nonetheless, it is still worthwhile to highlight that scenario analyses will be useful for quantifying and assessing the risks associated with sea-level rise in different regions. Moreover, climate modelling is advancing rapidly. For example, the recently proposed NeuralGCM model by Kochkov et al. (2024) combines machine learning with traditional general circulation models (GCMs), enabling more accurate and computationally efficient forecasts for both weather and climate.

One approach is based on SSP scenarios, which outline a range of future scenarios based on varying levels of greenhouse gas emissions, socioeconomic conditions, and mitigation and adaptation strategies. This can potentially provide a structured framework for the insurance sector to be better prepared for the potential impacts of climate change.

7.3.3 Protection gaps

Rising sea levels and other climate change-related risks are progressively increasing potential economic losses that can arise from risk events, such as natural catastrophes like floods and cyclones, and increased mortality and morbidity risks, as mentioned above. This will lead to a widening of protection gaps, broadly defined as the gap between total economic losses arising from risk events and the losses for those events covered by insurance and other forms of financial protection.

On the supply side, increasing uncertainties and risk exposures will likely increase risk costs to the insurance sector, leading to increased premiums or reduced coverage, depending on (re)insurers' risk appetites. This will create issues relating to the affordability and availability of insurance, particularly for those who need it most. In the context of rising sea levels, communities in low-lying coastal regions may face increased insurance premiums or a reduction of insurance coverage supply. However, in some parts of SEA, there are also vulnerable communities that may struggle to afford insurance coverage. This potential issue of availability and affordability of insurance will further exacerbate the protection gaps. Addressing protection gaps will require a holistic, multi-stakeholder approach that encompasses:

- Risk reduction via prevention, mitigation, and adaptation.
- Increasing insurance penetration.

- Fiscal risk financing. Doing so will require the public and private sectors to collaborate and implement complementary policies and solutions.

8 Future Research

We have outlined future research projects that will focus on several key aspects of climate-related risks in the Asia Pacific region including:

- **Cyclones in the Asia Pacific: A view to future risk**. This project will explore future cyclone risks in the region, with deliverables including a detailed report, technical workshop, and supporting data, enhancing methodologies for projecting cyclone impacts.
- **Coastal Risk Profiles for Port Infrastructure.** Focusing on the vulnerabilities of port infrastructure, this study will generate insights into coastal risks, supplemented by a robust data repository and methodological framework.
- **Volcanic Tsunami Risk.** This project addresses the largely underestimated hazard of volcanic tsunamis. It will produce a comprehensive report and database to assess these risks.
- **Future Cyclone Risk in the South China Sea and Bay of Bengal.** Furthering cyclone risk research, this project will provide region-specific insights, supported by workshops and technical notes for enhanced modelling accuracy.
- **Integrated Coastal Risk Report.** The final phase will synthesise findings from earlier projects, offering an overarching perspective on coastal risks in Asia, complete with regulators' engagement to guide resilient infrastructure planning and policy making.

9 Summary

Over the 21st century, continuing sea-level rise poses an existential threat to low-lying regions around the world. The implications of rising sea level, however, will be spatially disproportionate with equatorial and tropical latitudes of the Asia Pacific facing the greatest impacts where substantial population densities, economical assets, services and vulnerable coastal ecosystems are within and/or below projected sea- and flood-levels.

While changes in sea level have been an integral part of Earth's geologic history, present day changes reflect the unprecedented rate of increase in atmospheric CO_2 concentrations and temperature from anthropogenic forcing. Nonetheless, determining past and present changes in sea level and its drivers help us understand and predict how sea level will change in the future. At the global scale, sea level responds to changes in ocean mass and volume from a warming climate and melting ice. At regional and local scales, however, sea-level changes are more complex reflecting the interaction of multiple processes such as the response of the solid earth, atmosphere and ocean dynamic changes and tectonics that causes significant spatial variability. Furthermore, non-climatic processes such as land subsidence also exacerbates present-day sea-level rise in many coastal regions of Asia.

These sea-level driving processes also cause spatially variability in projections of future sea level and are characterised by both quantifiable and unquantifiable uncertainties that increases with time. This is primarily due to hard-to-quantity sea-level driving processes related to ice-sheet dynamics and land subsidence and uncertain emission futures beyond 2050. Superimposed on future sea-level rise will be the compounding impacts of ESL events that may also increase in frequency throughout the 21st century as global climate warms.

Consequently, the implications for the insurance industry are profound, with increased risks of flooding and coverage gaps in high-risk areas. Insurers must reassess risk models and invest in resilient infrastructure and adaptive measures to sustain insurance practices and manage these escalating risks effectively. Transparent and effective communication of sea-level science into usable information that can inform long-term insurance risk will therefore be a key goal of Global Asia Insurance Partnership project on sea level moving forward.

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