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SURGING SEAS in a warming world:

The latest science on present-day impacts and future projections of sea-level rise

United Nations

"Rising seas are a crisis entirely of humanity's making. The world must act, and answer the SOS before it is too late."

António Guterres, United Nations Secretary-General

In 2021, the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) concluded with high confidence that global-mean sea level is rising at rates unprecedented in at least the last 3,000 years due to human-induced global warming. **Since then, emerging research on climate 'tipping points' and ice-sheet dynamics is raising alarm among scientists that future sea-level rise (SLR) could be much larger and occur sooner than previously thought.**

This technical brief provides a summary of the latest science on SLR and its present-day and projected impacts — including coastal flooding — at a global and regional level, with a focus on major coastal cities in the Group of Twenty (G20) countries and on the Pacific Small Island Developing States (Pacific SIDS).

The findings demonstrate that SLR is affecting the lives and livelihoods of coastal communities and low-lying island nations around the world today, and it is accelerating. The climate actions and decisions taken by political leaders and policymakers in the coming months and years will determine how devastating these impacts become and how quickly they worsen.

1. The Current State of Sea-Level Rise

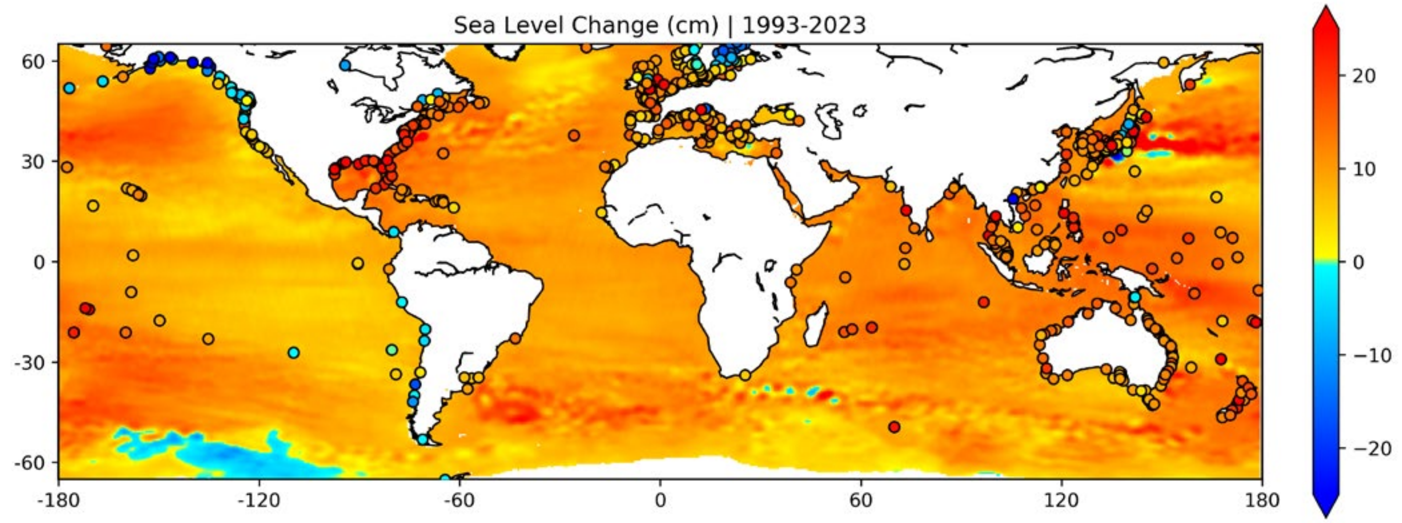


Figure 1. Coastal and regional sea-level change (cm) between 1993 and 2023 (warm colours show where sea levels are rising). The background map shows regional sea-level trends from the NASA Gridded Sea Surface Height Dataset (Fournier et al., 2024). The circles show sea-level change at tide gauges sourced from the Permanent Service for Mean Sea Level with at least 20 years of data. **Source:** NASA Sea Level Change Team (SLCT).

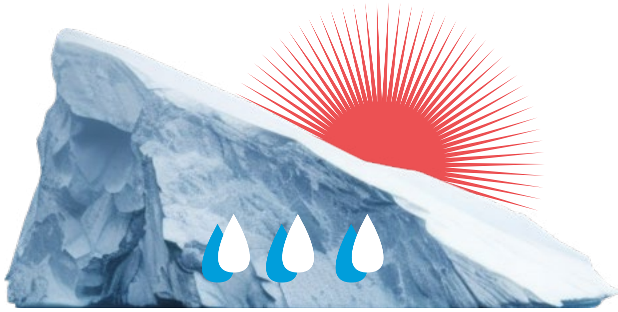
Global-mean sea level is rising and accelerating as a direct consequence of human-induced global warming. This rise in sea level is driven primarily by two factors: the melting of land ice and the expansion of seawater as it warms.[1] Their combined effects have led to mean sea-level rising across most of the world's oceans (Figure 1).

According to the IPCC AR6, between 1901 and 2018, global-mean sea level increased by 20cm [15–25cm uncertainty range]. Between 1993 (the start of the satellite record) and 2018, global-mean sea level increased by 8.1cm [7.2–9.0cm].[2]

More recent data from the United States of America's National Aeronautics and Space Administration (NASA) finds that the change in global-mean sea level in 2023 relative to 1993 reached 9.4cm [+/- 1cm], representing the highest level in the modern observation record that extends back into the 19th century.[3]

Since the start of the 20th century, global-mean sea level has risen faster than over any prior century in at least the last 3,000 years, and the rate of increase is accelerating.[4] The average rate of SLR was 0.13cm [0.06–0.21cm] per year between 1901–1971, increasing to 0.19cm [0.08–0.29cm] per year between 1971–2006, and further increasing to 0.37cm [0.32–0.42cm] per year between 2006–2018.[5] According to the World Meteorological Organization (WMO), **the rate of SLR in the past ten years has more than doubled since the first decade of the satellite record, increasing from 0.21cm per year between 1993–2002 to 0.48cm per year between 2014–2023.**[6]

1 IPCC AR6 WGI Chapter 9 (2021).
2 Ibid.
3 NASA SLCT, 2024.
4 IPCC AR6 WGI Chapter 2, 2021.
5 IPCC AR6 WGI SPM, 2021.
6 WMO State of Global Climate Report, 2023.



Since the start of the 20th century, global-mean sea level has risen faster than over any prior century in at least the last 3,000 years, and the rate of increase is accelerating.

Land ice — glaciers and ice sheets — contain a large portion of the Earth's freshwater. As temperatures rise, especially in the polar regions, glaciers and ice sheets are melting, adding water to the oceans. **The recent acceleration in SLR is primarily due to increasing rates of ice loss from the Greenland and Antarctic ice sheets,**[7] which are losing ice mass at average rates of around 270 and 150 billion tonnes per year, respectively.[8] **The seven worst years of ice loss on record all occurred in the last decade.**[9]

At the same time, the ocean has absorbed more than 90% of the excess heat that has accumulated in the Earth system since 1971 due to rising greenhouse-gas emissions.[10] As this heat is absorbed, ocean temperatures increase and water expands, leading to SLR.[11] Ocean-warming rates have shown a particularly strong increase in the past two decades.[12] **In 2023, sea-surface temperatures and ocean-heat content reached their highest levels in the observational records.** It is expected that the upper 2,000 meters of the ocean will continue to warm due to excess heat that has accumulated in the Earth system from global warming — a change that is irreversible on centennial to millennial timescales.[13]

Between 2006 and 2018, melting land ice contributed to around 45% of the observed change in global-mean sea level, while seawater expansion contributed 39%. Additionally, less than 17% came from human-driven changes in land-water storage (such as dam-building or pumping of groundwater into the ocean).[14]

7 IPCC AR6 WGI Chapter 9, 2021.
8 NASA, https://climate.nasa.gov/vital-signs/ice-sheets/?intent=121, accessed 19 Aug 2024.
9 European Space Agency, 2023.
10 Schuckmann, et al., 2020.
11 IPCC AR6 WGI Chapter 9, 2021.
12 Minière et al., 2023.
13 WMO State of Global Climate Report, 2023.
14 IPCC AR6 WGI Chapter 9, 2021, Table 9.5. Note: the cited percentages add up to 101% due to rounding.

2. Projections of Future Sea-Level Rise

The magnitude, timing, and rate of SLR within this century and over the next millennia will depend on the long-term temperature at which global warming will stabilize, as well as on the pathways of greenhouse-gas emissions and associated temperature changes until then.[15]

Even after net-zero emissions are reached, SLR will continue because of the committed ocean warming and land-ice melt that will occur from warming caused by past emissions. **Consequently, sea level is committed to rise for centuries to millennia and will remain elevated for thousands of years.**[16]

Moreover, some amount of SLR is already committed, regardless of future emissions, due to the historical cumulative emissions of long-lived greenhouse gases such as carbon dioxide (CO_2) and the temperature increase that will result from them. According to the IPCC AR6, **historical emissions up to 2016 will likely lead to a committed SLR of 0.7–1.1m up to 2300.**[17] Between 1850 and 2022, cumulative human-made CO_2 emissions totalled around 2,550 billion tonnes ($GtCO_2$), 31% of which came from land-use change and 69% from fossil-fuel production and consumption. However, fossil-fuel emissions have grown significantly since 1960 while land-use changes have not, resulting in the contribution from fossil fuels reaching 88% over the 2013–2022 period.[18]

The Working Group I (WGI) Contribution to the IPCC AR6 assessed future SLR under five different greenhouse-gas emissions and socioeconomic scenarios (see Annex I for further details).[19] **Under the 'Shared Socioeconomic Pathway' SSP1-1.9 (the lowest-emissions scenario resulting in 1.4°C end-of-century warming), global mean SLR is projected to reach 18cm [15–23cm likely range] by 2050 and 38cm [28–55cm] by 2100, relative to 1995–2014. Under SSP5-8.5 (the highest-emissions scenario resulting in 4.4°C end-of-century warming), SLR is projected to reach 23cm [20–29cm] by 2050 and 77cm [63–101cm] by 2100, relative to 1995–2014 (Table 1).**[20]

The above 'likely' (i.e., at least 66% probability) projections only account for processes for which projections can be made with at least medium confidence. However, to be prepared for the worst possible outcomes, processes with relatively low likelihood but potentially high-risk impacts should also be considered. **The timing and spatial extent of ice loss due to ice-sheet instability processes pose the biggest source of uncertainty in projecting the magnitude and rate of future SLR and could lead to higher SLR than the 'likely' range before 2100.**

The AR6 also assessed a low-likelihood, high-impact storyline, which considers faster-than-projected ice loss in Antarctica and Greenland under the SSP5-8.5 highest-emissions scenario. In this case, global mean SLR might exceed well above the 'likely' range before 2100, leading to a 95th-percentile estimate of projected future SLR as high as 2.3m in 2100, relative to 1995-2014.

15 IPCC AR6 WGI Chapter 9, 2021.
16 Ibid; Naughten et al., 2023.
17 IPCC AR6 WGI Chapter 9, 2021; Levermann et al., 2013.
18 Friedlingstein et al., 2023.
19 The IPCC AR6 WGI assessed five different illustrative future scenarios denoted as "SSPx-y", where "x" refers to the Shared Socio-economic Pathway (SSP) describing different underlying socio-economic trends, and "y" refers to the approximate level of radiative forcing (in watts per square metre) resulting from the scenario in the year 2100. The lowest-emissions scenario is associated with end-of-century warming of 1.0°C–1.8°C compared to 1850–1900, and 3.3°C–5.7°C for the highest (See Annex I for details).
20 IPCC AR6 WGI Chapter 9, 2021, Table 9.9.

Scenario (and end-of-century warming)	SSP1-1.9 (1.4°C)	SSP1-2.6 (1.8°C)	SSP2-4.5 (2.7°C)	SSP3-7.0 (3.6°C)	SSP5-8.5 (4.4°C)	'Low-likelihood, high-impact' SSP5-8.5
SLR by 2030 (m)	0.09 [0.08–0.12]	0.09 [0.08–0.12]	0.09 [0.08–0.12]	0.09 [0.08–0.12]	0.10 [0.09–0.12]	0.10 [0.09–0.15]
SLR by 2050 (m)	0.18 [0.15–0.23]	0.19 [0.16–0.25]	0.20 [0.17–0.26]	0.22 [0.18–0.27]	0.23 [0.20–0.29]	0.24 [0.20–0.40]
SLR by 2100 (m)	0.38 [0.28–0.55]	0.44 [0.32–0.62]	0.56 [0.44–0.76]	0.68 [0.55–0.90]	0.77 [0.63–1.01]	0.88 [0.63–1.60]
Rate of SLR (2040–2060; mm per year)	4.1 [2.8–6.0]	4.8 [3.5–6.8]	5.8 [4.4–8.0]	6.4 [5.0–8.7]	7.2 [5.6–9.7]	7.9 [5.6–16.1]
Rate of SLR (2080–2100; mm per year)	4.2 [2.4–6.6]	5.2 [3.2–8.0]	7.7 [5.2–11.6]	10.4 [7.4–14.8]	12.1 [8.6–17.6]	15.8 [8.6–30.1]

Table 1. Summary of projected SLR relative to 1995–2014 and rates of SLR for future time periods under different scenarios assessed in the IPCC AR6.[21] Median values (and 'likely' ranges) are shown for all scenarios except for the 'low-likehood, high-impact' one, which shows the 17th-83rd percentile range. The end-of-century 2081–2100 warming shown in brackets for each scenario is estimated relative to 1850–1900. **Source:** IPCC AR6 WGI, Chapter 9, Table 9.9.

Since the publication of the IPCC AR6 WGI in 2021, a growing number of scientific studies on ice-sheet loss are raising alarm among scientists that future SLR could indeed be much larger and occur sooner (see Annex II for list of studies).[22] These recent studies suggest that **long-term warming of 2°C could lead to the eventual loss of nearly all of Greenland, much of West Antarctica, and even vulnerable portions of East Antarctica, triggering inexorable SLR and committing the planet to between 12–20m of SLR over millennia.**[23] Warming of 3°C could further speed up this loss to within the next few centuries, resulting in extensive coastal loss and damage and the loss of livelihoods and assets for many coastal communities around the world.

Additionally, recent scientific studies focused on climate 'tipping points' in the Earth system found that exceeding the long-term temperature threshold of 1.5°C would likely lead to the irreversible collapse of the Greenland Ice Sheet and the West Antarctic Ice Sheet.[24] A study published in August 2024 suggests that **every additional 0.1°C of temporary overshoot above 1.5°C — even if temperatures later decrease — increases the risk of triggering such tipping points.**[25] However, given that the science is still evolving, there are large uncertainties associated with these projections and a lack of consensus among the scientific community on these emerging issues.[26]

21 Ibid.
22 See, e.g., CNN 2024; The Guardian 2023; BBC 2023.
23 The estimated range is based on sea levels at similar CO_2 concentrations and warming levels to those projected in the deep geological past. See, e.g., Dutton et al., 2015; Dumitru et al., 2019; DeConto et al., 2021; Halberstadt et al., 2024 and other studies listed in Annex II.
24 See, e.g., Lenton et al., 2020; Heinze et al., 2021; McKay et al., 2022;
25 Möller et al., 2024.
26 See, e.g., Gomez et al., 2024 and Morlighem et al., 2024.

3. Global Impacts and Implications of Sea-Level Rise

Accelerated SLR has the potential to redefine the coastlines of the 21st century. It can pose major risks to the safety, security, and sustainability of many low-lying islands, populous coastal megacities, large tropical agricultural deltas, and Arctic communities.[27]

The low-elevation coastal zone (LECZ), which comprises continental and island areas connected to the sea no more than 10 meters above mean sea level, **includes a wide diversity of systems, from small islands to megacities, from the Tropics to the Poles, in both the Global North and Global South**. Much of the world's population, economic activities, critical infrastructure, and cultural world heritage sites are concentrated near the sea: **the LECZ generates around 14% of global GDP and hosts almost 11% of the global population (around 900 million people) — a figure projected to increase beyond 1 billion by 2050.**[28]

SLR is a major threat for countries with large coastal populations, especially in developing countries. For Small Island Developing States (SIDS), SLR erodes land, destroys infrastructure, disrupts lives and livelihoods, and threatens habitability due to the concentration of people, assets, and infrastructure in the LECZ. According to one study led by the European Commission's Joint Research Centre, the estimated annual costs of coastal flooding at present already amounts to USD_{2020} 1.64 (0.69–5.15) billion for all SIDS combined.[29] This estimate accounts for direct damage to buildings, infrastructure, and agriculture from coastal flooding.

Relative SLR also threatens dozens of coastal megacities on all continents, including, but not limited to, Bangkok, Buenos Aires, Dhaka, Guangzhou, Jakarta, Lagos, London, Los Angeles, Miami, Mumbai, New Orleans, New York City, Rio de Janeiro, Shanghai, and Tokyo.

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Based on the SLR projections dataset presented in the IPCC AR6, the NASA SLCT developed the "IPCC AR6 Sea-Level Rise Projections Tool" for estimating and visualizing local and regional SLR under five specific values of 2080–2100 warming, ranging from 1.5°C to 5°C.[30] **Table 2 shows the past and projected SLR under a scenario of 3°C warming, which is roughly consistent with a current-policies pathway, for select major cities in the G20 countries.** As Table 2 shows, these cities have already experienced 3–26cm of relative SLR in 2020 relative to 1990.

By 2050, the majority are projected to experience additional SLR of more than 15cm, with six cities (Atlantic City, Boston, New Orleans, New York City, Osaka, and Shanghai) potentially seeing 24–41cm.

27 IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC), 2019, Chapter 4 and Cross-Chapter Box 9.
28 IPCC AR6 WGII Cross-Chapter Paper 2: Cities and Settlements by the Sea, 2022; Magnan et al., 2022; Marzeion & Levermann (2014).
29 Vousdoukas et al., 2023. See also https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/even-15degc-warming-small-island-developing-states-risk-flooding-sea-level-rise-2023-12-05_en
30 See (1) the NASA/IPCC Sea Level Projections Tool https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool and (2) the NASA SLCT (2023) Assessment of Sea Level Rise and Associated Impacts for Tuvalu, N-SLCT-2023-01 Technical Report, https://zenodo.org/records/8069320 for further details of the methodology.

COUNTRY	CITY	OBSERVED SLR FROM 1990 TO 2020 (cm)	PROJECTED SLR FROM 2020 TO 2050 (cm)
Argentina	Buenos Aires	6	15 [12–19]
Australia	Melbourne	8	13 [11–17]
Australia	Sydney	9	15 [12–20]
Australia	Brisbane	13	15 [12–21]
Australia	Perth	16	16 [15–19]
Brazil	Rio de Janeiro	13	16 [12–21]
Brazil	Atafona	13	16 [12–21]
Canada	Richmond	4	8 [7–12]
Canada	Vancouver	4	8 [7–12]
Canada	Quebec	8	14 [12–17]
China	Shanghai	17	24 [20–29]
China	Guangzhou	11	13 [9–19]
Denmark	Copenhagen	6	17 [13–23]
France	Nice	6	14 [9–19]
France	Marseille	9	15 [11–21]
Germany	Hamburg	7	20 [16–26]
India	Kolkata	10	18 [15–23]
Japan	Tokyo	3	13 [10–18]
Japan	Osaka	13	27 [24–32]
Republic of Korea	Incheon	9	15 [12–20]
South Africa	Cape Town	12	18 [15–23]
South Africa	Durban	8	15 [13–20]
Türkiye	Istanbul	9	16 [12–22]
United Kingdom	London	16	19 [14–26]
United States of America	New York City	14	26 [20–32]
United States of America	Atlantic City	16	28 [24–34]
United States of America	Boston	15	25 [19–32]
United States of America	Miami	20	22 [20–27]
United States of America	New Orleans	26	41 [38–46]
United States of America	San Francisco	6	15 [15–19]
United States of America	Long Beach	6	13 [11–17]

Table 2. Summary of past and future projected SLR (under a scenario of 3°C end-of-century warming) for select major cities in G20 countries. Uncertainty ranges in the 2020 SLR estimates (relative to 1990), driven by instrument error, are all +/- 3 cm. For 2050 SLR projections relative to 2020 the median [and 17th–83rd percentiles] are shown. Source: NASA SLCT.

Notes: (1) The change in SLR between 2020 and 2050 is calculated as: (2050 SLR relative to 1995-2014) – (2020 SLR relative to 1995-2014); (2) Observed global-mean SLR from 1990 to 2020 was around 10cm; (3) Projected global-mean SLR from 2020 to 2050 is 16cm [14–21cm].

Climate-driven coastal hazards and risks come not only from SLR itself but also from its amplification of storm surges, tides, and waves. Coastal-flood hazards and associated risks are also expected to increase as a result of local land sinking (subsidence) because of human activities such as building dams or groundwater and fossil fuel extraction.[31] Their combined effects can lead to infrastructure damage due to coastal flooding, saltwater intrusion into groundwater and rivers, shoreline retreat, and change to or loss of coastal ecosystems and economic sectors.

Such impacts are already or are likely to create risks to livelihoods, settlements, health and well-being, and food and water security.[32] Impacts can also reach far beyond coastal communities. For example, climate-induced, involuntary displacement and migration from coastal areas may lead to population movements to inland areas, while loss of economic activities such as fisheries or agriculture and damage to ports can severely compromise global food systems, supply chains, and maritime trade, with local-to-global geopolitical, economic, and security ramifications.[33]

Small rises in relative sea-level can disproportionately increase coastal flood frequency.[34] According to the United Nations Development Programme (UNDP) and the Climate Impact Lab (CIL), **the extent of coastal flooding has increased over the past 20 years as a result of SLR, meaning 14 million more people worldwide now live in coastal communities with a 1-in-20-year chance of flooding.**[35]

The frequency of present-day, extreme-but-rare sea-level events is projected to increase substantially in most regions. For example, according to the IPCC AR6, in a globally-averaged sense, the 1-in-100-year extreme sea-level event (in terms of total water level) is projected to occur once every 30 years by 2050 and once every 5 years by 2100 under the 'Representative Concentration Pathway' RCP4.5 (an emissions scenario leading to 2.5°C end-of-century warming, see Annex I for details). Such events are projected to occur more than once a year by 2100 under RCP8.5 (4.4°C of warming).[36] Additionally, a recent study projects that minor flooding events that currently occur annually will occur most days per year worldwide under 0.7m of SLR.[37]

The frequency of present-day, extreme-but-rare sea-level events is projected to increase substantially in most regions.

According to one study,[38] the global annual damage from coastal flooding totalled around USD_{2005} 20 billion/year in 2010. Assuming no further protection measures are implemented, this value could increase by a factor of 150 between 2010 and 2080 under RCP4.5. However, structural adaptation investments show high potential to reduce future coastal flood risk and the benefits would exceed the investments and maintenance costs globally and in most regions. In addition, **SLR can hamper the ability of coastal**

31 IPCC AR6 WGI Chapter 9, 2021; Shirzaei et al., 2021; Tay et al., 2022.
32 Magnan et al., 2022.
33 IPCC AR6 WGII Cross-Chapter Paper 2: Cities and Settlements by the Sea, 2022.
34 Taherkhani et al., 2020.
35 UNDP, 2023.
36 IPCC AR6 WGI Chapter 12, 2021; Tebaldi et al., 2021; Kireczi et al., 2020.;
37 Hague et al., 2023.
38 Tiggeloven et al., 2020.

communities to adapt to climate impacts through its destruction of natural coastal defenses and ecosystems. Mangroves, corals, saltmarshes, and seagrass meadows currently protect hundreds of millions of people worldwide against storm surges and waves. Under RCP8.5, a 1m loss in coral reef height is projected to more than double the global area flooded during a 100-year event in 2100.[39]

The IPCC AR6 has also highlighted that as sea levels rise and extreme events intensify, “coastal communities face limits due to financial, institutional, and socioeconomic constraints and a short timeline for adaptation implementation, reducing the efficacy of coastal protection and accommodation approaches and resulting in loss of life and economic damages”**. For coastal communities reliant on nature-based coastal protection, ‘limits to adaptation’ are projected to begin at 1.5°C of warming.**[40] **In Arctic human communities without rapid land uplift, and in urban atoll islands, risks to reaching adaptation limits are projected to be moderate to high even under a low-emissions scenario associated with 1.6°C of warming (RCP2.6).**[41]

“Around the world, rising seas have unparallelled power to cause havoc to coastal cities and ravage coastal economies.”

António Guterres, United Nations Secretary-General

39 Magnan et al., 2022.
40 IPCC AR6 WGII Technical Summary, 2022, pp. 84–85.
41 IPCC SROCC SPM, 2019.

4. Impacts and Implications of Sea-Level Rise for the Pacific Small Island Developing States

UN Secretary-General António Guterres (left) meets a community member from Lalomanu in Samoa which, like many Small Island Developing States, is already facing severe and disproportionate impacts from sea-level rise. **Photo:** United Nations/Kiara Worth.

The Pacific SIDS are on the frontline of the climate crisis, facing severe and disproportionate impacts from SLR.

Local and regional sea level changes can be larger or smaller than the global average due to many factors.[42] **While the change in global-mean sea level from 1993 to 2023 was 9.4cm [+/- 1cm], sea level change in the South-West Pacific over the same period was greater than 15cm [+/- 3cm] in some locations.**[43] According to one recent study, under RCP4.5, **most of the Pacific SIDS are located in a region where relative SLR is projected to be 10–30% higher than the global-mean SLR arising from Antarctic melt in 2100 relative to 2000.**[44]

According to analysis by the NASA SLCT,[45] under a scenario of 3°C warming, which is roughly consistent with a current-policies pathway, **all locations across the Pacific region can expect to see at least another 15cm of additional SLR between 2020 and 2050 (Table 3). Between 2005 and 2100, the median SLR for the Pacific region ranges from 50–97cm across the five warming scenarios assessed, ranging from 1.5°C to 5°C.** Under a 5°C 'low-likelihood, high-impact' storyline accounting for potentially rapid ice sheet loss, the worst-case regional estimate approaches 2m. **The 1.5°C and 3°C scenarios have median values of 50cm and 68cm, respectively.** At the individual island-level, projections are similar to this regional average with variations of less than 10cm under 3°C, except for Samoa with moderately higher projected SLR.[46]

42 Higher sea level in the western tropical Pacific region is driven by a combination of ocean warming, dynamic ocean changes, and ice melt. In a given region, local SLR may be more or less due to many factors such as land subsidence and erosion.
43 Fournier et al., 2022.
44 Sadai et al., 2022.
45 See Footnote #30.
46 It is important to note that these IPCC AR6 projections do not adequately represent the high rates of subsidence that are observed in Tonga and Samoa. These rates are expected to persist until mid-century. The projections for these islands should thus be used with caution and should be treated as conservative or low.

Country	Tide Gauge Name	Observed SLR from 1990 to 2020 (cm)	Projected SLR from 2020 to 2050 (cm)	Average Flooding Days/Year, 1980s	Average Flooding Days/Year, 2010s	Projected "Average-year" Flooding Days/ Year, 2050s	Projected "Worst-year" Flooding Days/ Year, 2050s
Cook Islands	Penrhyn	9	17 [14–23]	<5	<5	50	155
Cook Islands	Rarotonga	14	17 [13–23]	<5	<5	75	145
Fiji	Suva-B	29	18 [15–23]	<5	<5	25	65
Fiji	Lautoka	13	18 [15–23]	<5	<5	35	60
Micronesia	Kapingamarangi	15	18 [14–24]	<5	<5	15	50
Micronesia	Pohnpei	20	20 [18–24]	<5	<5	30	85
Micronesia	Yap-B	19	17 [16–20]	<5	<5	5	55
Kiribati	Betio, Tarawa	13	19 [17–23]	<5	<5	20	45
Kiribati	Kanton	9	17 [13–22]	<5	5	30	80
Kiribati	Kiritimati	5	18 [14–24]	<5	<5	65	165
Marshall Islands	Kwajalein	11	19 [17–22]	<5	5	45	90
Marshall Islands	Majuro	10	19 [17–22]	<5	<5	30	60
Nauru	Nauru-B	16	19 [14–25]	<5	<5	10	30
Palau	Malakal-B	15	17 [16–20]	<5	<5	30	100
Samoa	Apia	31	23 [20–28]	<5	5	35	90
Tonga	Nuku'alofa	21	18 [15–23]	<5	<5	35	70
Tuvalu	Funafuti	14	19 [15–26]	<5	<5	25	50

Table 3. Summary of past and future projected SLR and flood frequencies (under a scenario of 3°C end-of-century warming) for some of the Pacific SIDS. For 2050 SLR projections relative to 2020, the median [and 17th–83rd percentiles] are shown. Estimates and projections of average number of "flooding" days per year are evaluated as exceedances of the 2-year flood threshold from the tide gauge record in each location. The term "flooding" as used here corresponds to any water level above this threshold, but this water level may or may not correspond to tangible impacts. Average flooding days per year for the specified decade are rounded to the nearest five. Within a given decade, some years will experience more or less flooding than this average, driven by tidal variability and natural ocean variability. The data contained in the last column corresponds to the projected "worst year" of flooding that could occur during the 2050s. **Source:** NASA SLCT.

Notes: (1) Uncertainty ranges in the 1990–2020 SLR estimates, driven by instrument error, are all +/- 3 cm. (2) The change in SLR between 2020 and 2050 is calculated as: (2050 SLR relative to 1995-2014) – (2020 SLR relative to 1995-2014). (3) The "flooding" estimates shown here do not take into consideration directly-modelled wave action, the primary driver of coastal flooding in the Pacific. Also, the definition of "flooding" used here is based on water levels exceeding those compared to a 2-year flood threshold, which is used as a common threshold to capture the relative increase between past, present, and future flooding. In many locations, such as Kiribati and Tuvalu, flooding is currently being experienced at every high tide.[47]

47 COSPPac Climate change in the Pacific 2022 report; Wandres et al., 2024.

As also shown in Table 3, future SLR is projected to cause a large increase in the frequency and severity of episodic flooding in almost all locations in the Pacific SIDS in the coming decades. Across all future scenarios and under the assumption of no additional protections, all islands may see an order-of-magnitude increase in potential "flooding" days per year by mid-century, relative to what has been seen in the past decade.[48]

In the 1980s, all Pacific SIDS had fewer than 5 flooding days per year on average. **It is projected that for Nuku'alofa and Apia, the capital cities of Tonga and Samoa respectively, the number of flooding days will increase to 35 days per year during the 2050s for an average year. For a projected "worst year" of flooding, the estimates increase to 70 and 90 days per year for Nuku'alofa and Apia, respectively.** Under the "worst-year" projections, **some locations in the Pacific SIDS could experience floodings for almost half of the entire year**; for instance, Kiribati's Kiritimati atoll could see up to 165 flooding days per year in the 2050s.

The Pacific SIDS, especially those in the western tropical Pacific (e.g., Kiribati, Tuvalu, and the Republic of the Marshall Islands), are particularly vulnerable to SLR because of: (i) high exposure to tropical cyclones and other tropical storms; (ii) high shoreline-to-land area ratios; (iii) high sensitivity to changes in sea level, waves, and currents; and (iv) its many low-lying coral atolls or volcanically-composed islands. Many Pacific islands are atolls fringed with coral reefs and have maximum elevations of 3–5m above sea level, with mean elevations of 1–2m above sea level.[49]

Many Pacific and other SIDS — home to 70 million people combined — are already experiencing loss of human life and significant economic damages, particularly from tropical cyclones and increases in SLR.[50] In the Solomon Islands, 50% of homes have already been lost, along with individual islands, to SLR and coastal erosion.[51] **Tropical cyclones (TCs) account for 76% of disasters in the Pacific Island region and bring extreme winds, waves, intense storm surge, prolonged rainfall, and coastal flooding.** For example, TC Tomas (March 2010) generated water levels associated with wave run-up and storm surge of 7m above mean sea level around the Lau Island Group in Fiji.[52] In 2015, Category-5 TC Pam devastated Vanuatu with USD 449.4 million in losses for an economy with a GDP of USD 758 million. In 2016, TC Winston caused 43 deaths in Fiji and losses of more than one third of the GDP. In 2018, Category-4 TC Gita impacted 80% of Tonga's population through destruction of buildings, crops, and infrastructure, resulting in USD 165 million of damages for a country with a national GDP of USD 461 million.[53] **Effective early warning systems meant that there was no loss of life in Tonga for TC Gita in 2018, and such systems helped to reduce the loss of life in the tsunami that accompanied the Hunga Tonga–Hunga Ha'apai volcanic eruption in 2022.**[54]

Many Pacific SIDS are already experiencing loss of human life and significant economic damages from tropical cyclones and increases in sea-level rise.

SLR poses an alarming threat to human life and socio-economic livelihoods and the implications for adaptation and loss and damage are profound and far-reaching. Severely accelerated SLR from

48 See Table 3 notes for definitions and Thompson et al., 2021 for detailed methodology of the NASA Flooding Analysis Tool.
49 USGS, https://cmgds.marine.usgs.gov/data/walrus/atolls/overview.html, accessed 19 Aug 2024.
50 Vousdoukas et al., 2023; IPCC SROCC, 2019, Cross-Chapter Box 9.
51 Martyr-Koller et al., 2021.
52 ADB, 2022.
53 IPCC SROCC, 2019, Cross-Chapter Box 9, pp. 663 and references therein.
54 GFDRR, 2018; NOAA, 2024.

rapid ice-sheet loss could bring impacts forward by decades, and adaptation would need to occur much faster and on a much greater scale than ever performed in the past.[55] **An estimated 90% of Pacific Islanders live within 5km of the coastlines.** In the Solomon Islands and Vanuatu, over 60% of the populations live within 1km of the coast. **Most Pacific islands have over 50% of their infrastructure within 500m of the coast.** In Kiribati, the Republic of the Marshall Islands, and Tuvalu, over 95% of the infrastructure is in the LECZ.[56]

As global warming intensifies, especially under high-emissions scenarios, loss and damage can lead to an 'unvirtuous cycle' of climate-induced erosion of sustainable development and climate resilience. **The cascading and cumulative impacts of extreme events experienced in Pacific and Caribbean SIDS exemplify that this cycle may already be in effect.**[57, 58]

"If we save the Pacific, we also save ourselves."

António Guterres, United Nations Secretary-General

55 IPCC AR6 Synthesis Report, 2023.
56 IPCC AR6 WGII Chapter 15, 2021.
57 IPCC AR6 WGII Chapter 15, 2021, Box 15.2; Benjamin & Thomas, 2023.
58 IPCC SROCC, 2019, Cross-Chapter Box 9.

5. Surging Seas in a Warming World: The Urgency of Action

Projecting future SLR and quantifying the associated impacts and damages remain a complex challenge involving many geophysical and socioeconomic uncertainties, as our understanding of ice-sheet dynamics and coastal flood risks, and changes in urban coastal development and protection measures, continues to evolve. **Nevertheless, one certainty that can be taken away from the latest research is that the climate crisis and SLR are no longer distant threats, especially for the Pacific SIDS.**

Deep, rapid, and sustained cuts in global greenhouse gas emissions are needed NOW to stay within a 1.5°C long-term warming trajectory. At the same time, effective coastal adaptation and investment in resilience and implementation must be scaled up worldwide, especially in the SIDS, to minimize growing SLR impacts and risks. For example, from 2005 to 2100, the Pacific SIDS could see around 18cm higher SLR on average under a current-policies (3°C) pathway instead of a 1.5°C-aligned pathway, with consequential impacts and risks.

Countries' next nationally determined contributions (NDCs) under the Paris Agreement, due in 2025, present an unprecedented opportunity for countries to rally cross-government and non-state actors to take immediate action to cut emissions, chart out 1.5°C-aligned decarbonization pathways, and build resilience to climate impacts. Similarly, the national adaptation plan (NAP) process presents an opportunity for whole-of-economy comprehensive risk management, including actions to prepare for and manage the impacts of sea-level rise.

The outcome of the first global stocktake (GST) under the Paris Agreement — adopted by Parties at the 28th United Nations Climate Change Conference (UNFCCC COP28) — **provides clear guidance that Parties' next NDCs should be 1.5°C-aligned and economy-wide, covering all greenhouse gases and all sectors.**[59] Ambitious, absolute emissions reduction targets for 2030 and 2035 should be supported by credible decarbonization and just transition sectoral pathways and policies. These plans should also detail adaptation priorities, as well as financing and other implementation needs for both mitigation and adaptation. **In particular, countries should clearly demonstrate how they intend to contribute to the global goals of halting and reversing deforestation and forest degradation, tripling renewable energy capacity, and doubling the average rate of energy efficiency improvements, by 2030, and accelerating the transition away from fossil fuels in energy systems in this critical decade.**

Based on global mitigation scenarios assessed in the IPCC AR6 and developed by the International Energy Agency (IEA), **a 1.5°C-aligned transition away from fossil fuels entails: (i) no new coal mines and coal plants, and no new upstream oil and gas projects, as of 2021; (ii) cutting global fossil fuel production and consumption by at least 30% by 2030, and by 40% by 2035, relative to 2019 levels; and (iii) phasing out unabated coal power by 2030 in advanced economies and by 2040 worldwide.**[60]

The first GST also called for countries to have in place their national adaptation plans, policies, and planning processes by 2025, and to have

59 Para 39, Decision 1/CMA.5 Outcome of the First Global Stocktake FCCC/PA/CMA/2023/16/Add.1.
60 IEA Net-Zero by 2050 Roadmap, 2023; UNEP Production Gap Report, 2023; Achakulwisut et al., 2023.

progressed in implementing them by 2030. The Global Goal on Adaptation, adopted at COP28, also provides a framework to help countries build up adaptation capacities, including protection against coastal flooding and other extreme sea-level events.

At the same time, we must improve foresight and early warnings to prepare and protect vulnerable communities, so that every person on Earth will be protected with an effective early warning system by 2027, as per the United Nations Secretary-General's Early Warnings for All (EW4All) initiative launched in 2022.[61] This requires sustained investments and capacity-building in local climate data services and knowledge, so that localized SLR-driven risks and impacts can help to inform early warning systems and longer-term adaptation strategies.

Finance is critical to implement ambitious mitigation actions and enhanced adaptation measures. At the upcoming UNFCCC COP29, countries are expected to decide on a new collective quantified goal (NCQG) to succeed the USD 100 billion climate finance goal. This year's G20 and COP29 must deliver outcomes that build trust and confidence, catalyze the trillions of dollars needed, and generate momentum for reform of the international financial architecture.

Long-term global warming is closely proportional to cumulative net CO_2 emissions from human activities.[62] As of January 2024, the remaining global carbon budget for limiting long-term warming to 1.5°C with a 50% chance was approximately 200 $GtCO_2$.[63] In 2023, global CO_2 emissions from fossil fuels reached a record high of 37 $GtCO_2$, and a total of 41 $GtCO_2$ when also accounting for net land-use emissions.[64] **At this current level, the remaining carbon budget will be depleted in approximately five years from now. We have no time to lose.**

"Global leaders must step up: To drastically slash global emissions; To lead a fast and fair phase-out of fossil fuels; And to massively boost climate adaptation investments, to protect people from present and future risks."

António Guterres, United Nations Secretary-General

61 https://earlywarningsforall.org
62 IPCC AR6 WGI SPM, 2021.
63 Forster et al., 2024.
64 Friedlingstein et al., 2023.

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Annex I: Emissions and socioeconomic scenarios assessed in the IPCC reports

This briefing draws on several IPCC reports which assessed two different sets of future greenhouse-gas emissions and socioeconomic scenarios. The tables below show the different scenarios and associated long-term global warming outcomes assessed in the Sixth Assessment Report and in the Fifth Assessment Report.

	Near term, 2021–2040		Mid-term, 2041–2060		Long term, 2081–2100	
Scenario	**Best estimate (°C)**	**Very likely range (°C)**	**Best estimate (°C)**	**Very likely range (°C)**	**Best estimate (°C)**	**Very likely range (°C)**
SSP1-1.9	1.5	1.2 to 1.7	1.6	1.2 to 2.0	1.4	1.0 to 1.8
SSP1-2.6	1.5	1.2 to 1.8	1.7	1.3 to 2.2	1.8	1.3 to 2.4
SSP2-4.5	1.5	1.2 to 1.8	2.0	1.6 to 2.5	2.7	2.1 to 3.5
SSP3-7.0	1.5	1.2 to 1.8	2.1	1.7 to 2.6	3.6	2.8 to 4.6
SSP5-8.5	1.6	1.3 to 1.9	2.4	1.9 to 3.0	4.4	3.3 to 5.7

Table A.1. Changes in global surface temperature, which are assessed based on multiple lines of evidence, for selected 20-year time periods and each of the five illustrative scenarios assessed in the AR6. Temperature differences relative to the average global surface temperature of the period 1850–1900 are reported in °C. This includes the revised assessment of observed historical warming for the AR5 reference period 1986–2005, which in AR6 is higher by 0.08 [–0.01 to +0.12] °C than in AR5 (see footnote 10). Changes relative to the recent reference period 1995–2014 may be calculated approximately by subtracting 0.85°C, the best estimate of the observed warming from 1850–1900 to 1995–2014. Source: IPCC AR6 WGI SPM, 2021, Table SPM.1.

	Near-term: 2031–2050		End-of-century: 2081–2100	
Scenario	**(Mean °C)**	**Likely range (°C)**	**(Mean °C)**	**Likely range (°C)**
RCP2.6	1.6	1.1 to 2.0	1.6	0.9 to 2.4
RCP4.5	1.7	1.3 to 2.2	2.5	1.7 to 3.3
RCP6.0	1.6	1.2 to 2.0	2.9	2.0 to 3.8
RCP8.5	2.0	1.5 to 2.4	4.3	3.2 to 5.4

Table A.2. Projected global mean surface temperature change relative to 1850–1900 for two time periods under four Representative Concentration Pathways (RCPs) assessed in the AR5 and other report. Source: IPCC SROCC SPM, 2019, Table SPM.1.

Annex II: Compilation of scientific studies published after the IPCC AR6 suggesting sooner and higher ice-sheet loss and SLR

Antarctica:

Rignot, E. et al. (2024). Widespread seawater intrusions beneath the grounded ice of Thwaites Glacier, West Antarctica. Proceedings of the National Academy of Sciences, 121(22), p.e2404766121. **https://www.pnas.org/doi/abs/10.1073/pnas.2404766121**

Naughten, K.A. et al. (2023). Unavoidable future increase in West Antarctic ice-shelf melting over the twenty-first century. Nature Climate Change, 13, 1222–1228. **https://doi.org/10.1038/s41558-023-01818-x**

Batchelor, C.L. et al. (2023). Rapid, buoyancy-driven ice-sheet retreat of hundreds of metres per day. Nature 617, 105–110. **https://doi.org/10.1038/s41586-023-05876-1**

Bradley, A. T., and Hewitt, I. J. (2024). Tipping point in ice-sheet grounding-zone melting due to ocean water intrusion. Nature Geoscience, v. 17, no, 7, 631-637. **https://doi.org/10.1038/s41561-024-01465-7**

Bett, D. T. et al. (2024). Coupled ice–ocean interactions during future retreat of West Antarctic ice streams in the Amundsen Sea sector. The Cryosphere, 18(6), 2653-2675. **https://doi.org/10.5194/tc-18-2653-2024.**

Christie, F.D.W. et al. (2022). Antarctic ice-shelf advance driven by anomalous atmospheric and sea-ice circulation. Nat. Geosci. 15, 356–362. **https://doi.org/10.1038/s41561-022-00938-x**

Lau, S. C. Y. et al. (2023). Genomic evidence for West Antarctic Ice Sheet collapse during the Last Interglacial. Science, v. 382, no, 6677, 1384-1389. **https://doi.org/doi:10.1126/science.ade0664.**

Yidongfang Si et al. (2024). Antarctic Slope Undercurrent and onshore heat transport driven by ice shelf melting. Science Advances 10. **https://doi.org/10.1126/sciadv.adl0601**

Li, Q. et al. (2023). Abyssal ocean overturning slowdown and warming driven by Antarctic meltwater. Nature 615, 841–847. **https://doi.org/10.1038/s41586-023-05762-w**

Davis, P.E.D. et al. (2023). Suppressed basal melting in the eastern Thwaites Glacier grounding zone. Nature 614, 479–485. **https://doi.org/10.1038/s41586-022-05586-0**

Park, JY. et al. (2023). Future sea-level projections with a coupled atmosphere-ocean-ice-sheet model. Nature Communications 14, 636. **https://doi.org/10.1038/s41467-023-36051-9**

Purich, A., and Doddridge, E.W. (2023). Record low Antarctic sea ice coverage indicates a new sea ice state. Commun Earth Environ 4, 314. **https://doi.org/10.1038/s43247-023-00961-9**

Graham, A.G.C. et al. (2022). Rapid retreat of Thwaites Glacier in the pre-satellite era. Nature Geoscience. 15, 706–713. **https://doi.org/10.1038/s41561-022-01019-9**

Stokes, C.R., et al. (2022). Response of the East Antarctic Ice Sheet to past and future climate change. Nature 608, 275–286. **https://doi.org/10.1038/s41586-022-04946-0**

Miles, B. W. J., and Bingham, R. G. (2024). Progressive unanchoring of Antarctic ice shelves since 1973. Nature, v. 626, no, 8000, 785-791. **https://doi.org/10.1038/s41586-024-07049-0**

Pelle, T. et al. (2023). Subglacial discharge accelerates future retreat of Denman and Scott Glaciers, East Antarctica. Science Advances, v. 9, no, 43, eadi9014. **https://doi.org/doi:10.1126/sciadv.adi9014**

Gomez, N., et al. (2024). The influence of realistic 3D mantle viscosity on Antarctica's contribution to future global sea levels. Science Advances, v. 10(31), eadn1470. **https://doi.org/doi:10.1126/sciadv.adn1470**

Greenland:

Greene, C. A. et al. (2024). Ubiquitous acceleration in Greenland Ice Sheet calving from 1985 to 2022. Nature, v. 625, no, 7995, 523-528. **https://doi.org/10.1038/s41586-023-06863-2**

Christ, A.J. et al. (2023). Deglaciation of northwestern Greenland during Marine Isotope Stage 11. Science, 381(6655), 330-335. **https://doi.org/10.1126/science.ade4248**

Otosaka, I. N. et al. (2023). Mass balance of the Greenland and Antarctic ice sheets from 1992 to 2020, Earth Syst. Sci. Data, 15, 1597–1616. **https://doi.org/10.5194/essd-15-1597-2023**

Bierman, P. R. et al. (2024). Plant, insect, and fungi fossils under the center of Greenland's ice sheet are evidence of ice-free times. PNAS. **https://doi.org/10.1073/pnas.2407465121**