Climate-Focus-Paper
Global Sea Level Rise

Speed read

- → Global mean sea level (GMSL) rise is one of the main indicators of climate change, and is of major concern for policy and decision makers, as it can have wide ranging impacts including on freshwater resources, agriculture, the incidence of flooding events, and loss of land in coastal areas.
- → Adapting to these impacts is essential but challenging, as there is large uncertainty around how high sea levels may rise, and how fast.
- → GMSL has increased by 0.19 m over the period 1901-2010, and the rate of increase has accelerated during the 20th century, with current rates estimated at 3.2 mm yr^{-1}.
- → GMSL is projected to increase over the 21st century by between 0.28 m and 0.98 m by the year 2100 (IPCC AR5), and the future rate of increase is very likely to exceed the rate observed over the period 1971-2000.
- → Using the IPCC AR5 estimates, it is possible to suggest an upper limit for GMSL of between 1.4 m and 1.6 m by the year 2100.
- → This Climate-Focus-Paper is intended to provide information on various issues associated with GMSL rise, in order to support investment decisions in coastal and low-lying areas.

Background

When planning projects and investments in coastal and low-lying areas the potential impact of sea level rise (SLR) is highly relevant, particularly in the context of feasibility studies. Planners and decision makers may wish to know what a plausible upper limit for sea level rise may be. Establishing an upper limit for sea level rise is extremely challenging, as changes in sea level are the result of a range of different physical processes. At the global scale the chief processes are through thermal expansion as the oceans warm, and through the addition of water from land ice i.e. from melting glaciers and ice sheets. It is estimated that since the early 1970s these two processes account for around 75% of the observed global mean sea level rise[1]. Adapting to the impacts of SLR however, will take place at the local to regional scale, where additional processes related to vertical land movement e.g. subsidence or uplift, sedimentation rates, ocean currents, gravity, and regional variation in temperature and salinity, will also need to be considered in deriving local estimates of sea level change[2]. These factors will be discussed in more detail in a supplementary regional sea level focus paper. Here, the focus is on understanding past and future changes in global mean sea level, and the impacts that SLR has in a range of different economic sectors, illustrated with a detailed analysis of the impacts associated with flooding events. The work presented in this paper draws heavily on the results reported in the recent IPCC Fifth Assessment Report (AR5).

Climate Service Center Germany
Eine Einrichtung des Helmholtz-Zentrums Geesthacht
In cooperation with KFW

Past and present sea level change

Changes in sea level can be measured in both absolute terms and relative to the land surface[2]. Relative sea level is measured with tide gauges, which are distributed sparsely across the Earth's surface. Absolute sea level on the other hand, is measured using satellite technology. When evaluating the impacts of changes in sea level for a given project or investment decision, it is changes in relative sea level that are of most relevance for adaptation and climate risk management.

→ Over the period **1901-2010, global mean sea level is estimated to have risen by 0.19 m**[1] (figure 1).

→ The AR5 Summary for Policymakers (SPM), states there is high confidence that there was a **transition in the rate of sea level rise in the late 19th to early 20th century** from relatively low rates of rise over the preceding two millennia to higher rates of rise, and that it is very *likely* that the mean rate of global mean sea level rise was:

- 1.7 mm yr^{-1} between 1901 and 2010
- 2.0 mm yr^{-1} between 1971 and 2010
- 3.2 mm yr^{-1} between 1993 and 2010

→ The rate of global mean sea level rise has clearly accelerated over the 20th century[3]. The rate of change is crucially important when considering the question how soon a certain amount of sea level rise might be observed, and has clear implications for the amount of time available for adaptation planning and implementation.

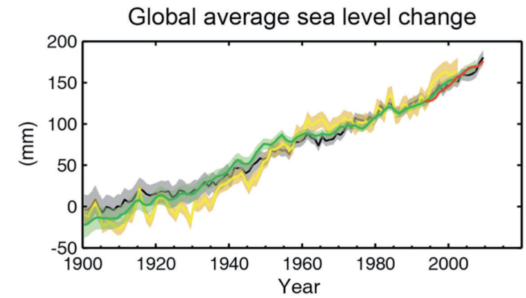


Figure 1. Global mean sea level relative to the 1900–1905 mean of the longest running dataset, and with all datasets aligned to have the same value in 1993, the first year of satellite altimetry data. All time-series (coloured lines indicating different data sets) show annual values, and where assessed, uncertainties are indicated by coloured shading. *Source*: IPCC AR5.

Differences between global and regional sea level change

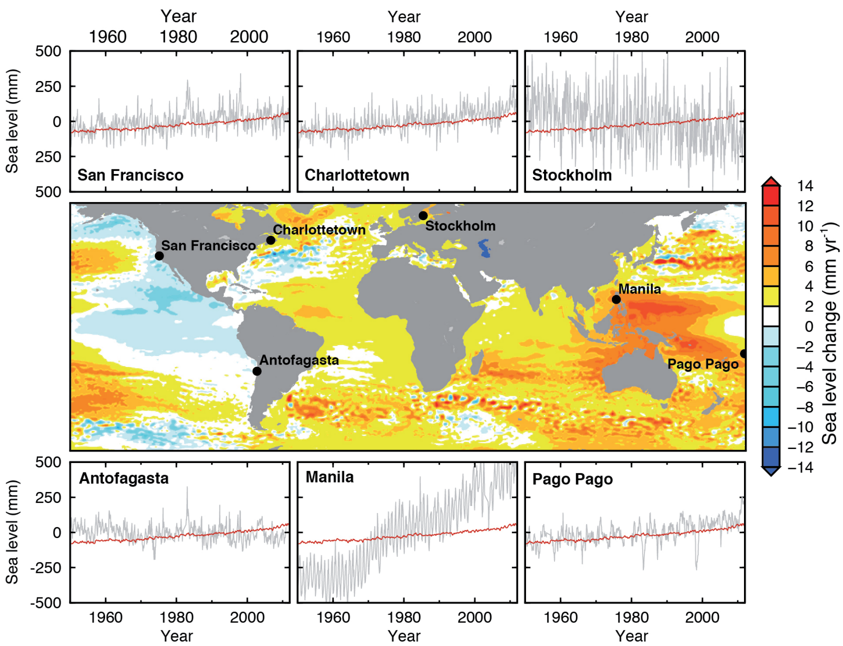
Because of the relative importance of the various processes at the global and regional scale, there is **large geographical variation in sea levels, and rates of sea level change** (figure 2). The map in figure 2 shows changes in absolute (geocentric) sea level for the period 1993-2012.

→ Some areas of the world have experienced a rise in sea level e.g. south east Asia, whereas others have seen a fall in sea level over this period e.g. the west coast of North America.

The graphs in figure 2 compare changes in relative sea level (the grey lines) to the GMSL rise, at 6 different locations.

→ Regional sea level varies at the interannual timescale due to natural climate variability, with some places experiencing a larger increase than the global mean e.g. Manilla, and some places e.g. Stockholm, show a falling trend in sea level, which is due to local scale land uplift.

Figure 2. Map of rates of change in sea surface height (geocentric sea level) for the period 1993–2012 from satellite altimetry. Also shown are relative sea level changes (grey lines) from selected tide gauge stations for the period 1950–2012. For comparison, an estimate of global mean sea level change is also shown (red lines) with each tide gauge time series. The relatively large, short-term oscillations in local sea level (grey lines) are due to the natural climate variability. For example, the large, regular deviations at Pago Pago are associated with the El Niño-Southern Oscillation. *Source:* IPCC AR5.



Future sea level change

Clearly, project and investment decisions that will be effective for many years into the future, will need to consider possible future changes in GMSL. The temporal evolution of global mean sea level from the AR5 projections is shown in figure 3, and figure 4 shows the modelled mean change in sea level under the four representative concentration pathways (RCP) emissions scenarios[4] (box 1). All changes in GMSL reported below are relative to the period 1986-2005.

→ Depending on the path along which global emissions of greenhouse gases develop **GMSL could rise between 0.28 m and 0.98 m by 2100**. These projections are considerably higher than those reported in the IPCC Fourth Assessment Report (AR4), which projected a range of 0.18 m to 0.59 m by the end of the 21st century.

→ Under **RCP2.6, a stringent mitigation scenario, the median projection is for a rise of 0.43 m by 2100**, with a *likely* range of 0.28 m to 0.60 m.

→ Under the **"business as usual" RCP8.5, the median projection is a rise of 0.73 m by 2100**, with a *likely* range of 0.53 m to 0.98 m.

→ By the end of the 21st century under a RCP8.5 pathway, **rates of GMSL rise may increase to as much as 15.5 mm yr-1, or almost 16cm per decade**. The implication being that **the task of adapting to rapidly rising global sea level would be even more challenging**.

→ **GMSL** will **continue to rise over the next century**, by how much, will in large part be determined by our actions to reduce carbon emissions. In addition, **GMSL rise** is a **very long term issue**, with AR5 projections of GMSL **rise by the year 2300 of between 0.92 m and more than 3 m**.

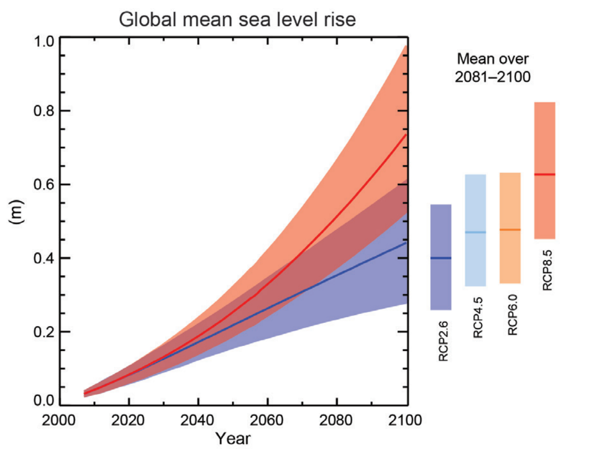


Figure 3. Projections of global mean sea level rise over the 21st century relative to 1986–2005 from the combination of the CMIP5 ensemble with process-based models, for RCP2.6 and RCP8.5. The assessed likely range is shown as a shaded band. The assessed likely ranges for the mean over the period 2081–2100 for all RCP scenarios are given as coloured vertical bars, with the corresponding median value given as a horizontal line. *Source:* IPCC AR5.

Box 1.

Representative concentration pathways (RCPs)

Future climate change will depend on the balance between incoming and outgoing radiation to the atmosphere, which is known as the radiative forcing. This radiative forcing is determined by changes in the output of the sun, and the concentration of greenhouse gases (GHGs), and aerosols in the atmosphere. The concentration of these atmospheric constituents will be influenced by human activities. To make projections of future climate, assumptions need to be made about the way in which human society may develop. For the AR5 climate model projections, the representative concentration pathways (RCPs) were used, which permit a wide range of different development pathways for human society, consistent with a given level of radiative forcing. There are four RCPs, each of which describes a possible future evolution of atmospheric composition. RCP2.6 represents a pathway where stringent climate mitigation is undertaken, RCP4.5 and RCP6.0 represent pathways where there is mitigation leading to intermediate and high levels of radiative forcing, respectively, and RCP8.5 represents a case of "business as usual", where emissions continue to rise through the 21st century.

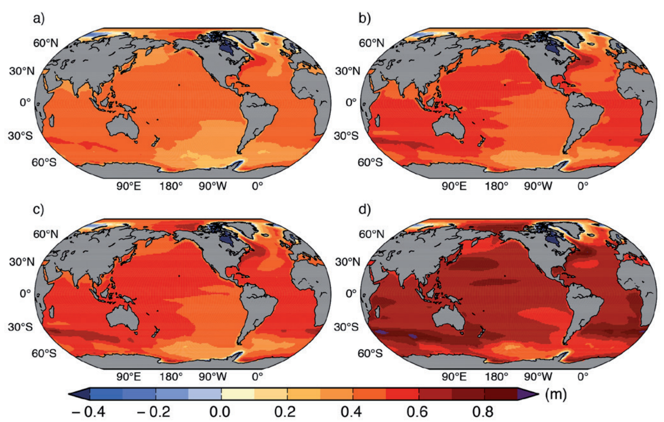


Figure 4. Ensemble mean regional relative sea level change (metres) evaluated from 21 CMIP5 models for the RCP scenarios (a) 2.6, (b) 4.5, (c) 6.0 and (d) 8.5 between 1986–2005 and 2081–2100. Each map includes effects of atmospheric loading, plus land-ice, GIA and terrestrial water sources. *Source:* IPCC AR5.

A note on IPCC likelihood statements

The IPCC provide an assessment of the likelihood of an outcome, and in this paper the terms *likely* and *very likely* are encountered, where very likely means 90–100% probability, and likely 66–100% probability.

Do the IPCC AR5 sea level projections represent an upper limit of sea level rise?

When planning projects and investment decisions, a key concern will be to try and establish a plausible upper limit for GMSL rise. Projections of GMSL from the AR5 do not represent an upper limit. While the AR5 projections of GMSL are higher than those in the AR4 they still only represent a *likely* range. A chief source of uncertainty in the projections for the 21st century is the potential for a significant contribution of ice mass from parts of the West Antarctic Ice Sheet. The AR5 states that it is not possible to establish a robust probability for this event, but that there is *medium confidence* that in the event of a collapse, this would not contribute more than several tenths of a metre during the 21st century. Using this information, we may calculate a plausible upper limit for GMSL rise by the end of the 21st century. If we take the highest value from the AR5 of 0.98 m and add several tenths of a metre to this, we may end up with **a plausible upper limit of between 1.4 m and 1.6 m of sea level rise by 2100**.

Impacts of sea level rise

Rising sea levels pose a major problem for a range of activities in coastal and low-lying areas, including effects on flooding, freshwater supplies, agriculture, tourism, biodiversity, wetlands, erosion rates, and loss of land[5]. Table 1 summarizes some estimates of impacts for 84 coastal developing countries associated with a global mean sea level rise of 1 and 2 metres, based on the analysis by Dasgupta *et al.*[6] Overall, the analysis carried out by Dasgupta *et al.* highlighted Vietnam, Egypt, and Suriname as being particularly vulnerable to the impacts of sea level rise.

Costing the impacts of GMSL rise

According to the UNFCCC, sea level rise is one of the major drivers of "loss and damage" worldwide, including economic losses as well as non-economic losses such as human casualties, or loss of livelihoods. Clearly, with increasing sea levels, the incidence of flooding events and associated infrastructure damage, and human suffering may increase. **The IPCC SREX report states that it is very likely that changes in mean sea level will contribute to an increase in future sea level extremes**[7]. This may focus attention on the need to plan better flood defences and/or modify planning strategies. This will be particularly concerning for cities that are already under threat from coastal flooding.

In addition, any increase in the incidence of extreme water levels in a given location, may be accompanied by trends in socio-economic factors, such as rapid population growth, which is expected in many developing nation cities, resulting in more people being exposed to these climate risks.

Table 1. Estimates of the impacts of global mean sea level rise of 1 m and 2 m, for a range of indicators, in 84 coastal developing countries. All areas are given in units of square kilometres. *Source*: Dasgupta *et al.*[6]

Impact	1 m	2 m
Land area % of total area	194,309 0.31	305,036 0.48
Population % of total population	56,344,110 1.28	89,640,441 2.03
GDP (USD) % of total GDP	219,181 1.30	357,401 2.12
Urban areas % of total area	14,646 1.02	23,497 1.64
Agricultural land % of total area	70,671 0.39	124,247 0.69
Wetlands area % of total area	88,224 1.86	140,355 2.96

To illustrate the effect that sea level rise may have on exposure to flooding, and the associated economic losses, we use the results presented in a recent analysis by Hallegatte *et al.*[8] Their analysis includes the effects of changes in socio-economics, subsidence, and sea level, for the world's 136 largest coastal cities. This is a key feature of this analysis, because as cities grow in size more value may be at risk, and changes in sea levels are caused by both climatic and non-climatic factors. As such, consideration of subsidence is crucially important, as particularly in delta cities, changes in sea level may be driven more by the sinking of land relative to sea level, than changes in the total volume of water.

→ Table 2 powerfully illustrates that **with adaptation that maintains present day defence standards, the associated economic losses can be reduced dramatically**, this is true across all scenarios, but is particularly striking under a pessimistic scenario of 70 cm of rise by 2070.

→ The **global average economic losses associated with no adaptation are colossal**.

In order to provide a first pass assessment of the potentially most vulnerable cities to suffering economic losses associated with increased flood exposure, table 3 provides a ranking of the ten most vulnerable coastal cities in developing countries. This ranking is determined on the basis of the relative proportion of a city's GDP that the economic losses would represent.

→ Table 3 shows quite clearly that **cities in East Asia could be particularly vulnerable**, and figure 5 complements this table by showing the distribution of cities where losses are greater than 0.1% of GDP under the pessimistic scenario in 2050. East Asia is highlighted as a potential hotspot, but **also areas in South America, Africa, and the Indian sub-continent**.

→ A separate analysis for the country of **Samoa**, has shown that the annual **damages in the year 2030 may amount to 8.5% of GDP**, under a worst case scenario of 26 cm of sea level rise[9].

A note on the Hallegatte *et al.* analysis

It is important to state that the figures presented in tables 2 and 3 are not predictions. Rather, they provide an indication of the level of economic losses that may be associated with sea level rise, and highlight the need for investment in adaptation. It is also important to state that this analysis does not cover all cities, such that other cities and areas of the world could be equally as exposed to the impacts of flooding events, and not just those reported in table 3 and shown in figure 5. In addition, this analysis only focuses on financial losses, and not aspects relating to human suffering, which are equally as important.

Table 2. Aggregated annual losses (million US$), with and without adaptation in the year 2030, 2050, and 2070 for the 136 cities analysed in the Hallegatte *et al.*[8] study, under two different sea level rise scenarios. These two scenarios both include changes in socio-economics, and subsidence effects. For comparison, current losses (as of 2005) are estimated at 5,744 US$ million per year.

	Optimistic Sea Level Rise			Pessimistic Sea Level Rise		
Adaptation option	2030 (10 cm)	2050 (20 cm)	2070 (30 cm)	2030 (20 cm)	2050 (40 cm)	2070 (70 cm)
No adaptation	272,812	1,192,785	2,502,195	459,885	1,566,856	4,024,604
Maintain present defence standards	26,117	59,767	118,555	27,026	63,273	131,788

Table 3. Top 10 cities in developing countries, ranked by highest average annual loss (AAL) in 2050 as a percentage of the city GDP. Results are presented for two sea-level rise scenarios, and assuming adaptation that maintains flood probability. Data are from Hallegatte *et al.*[8]

	Optimistic Sea Level Rise (20 cm)		Pessimistic Sea Level Rise (40 cm)	
Urban agglomeration	AAL (US$ million)	AAL (% of city GDP)	AAL (US$ million)	AAL (% of city GDP)
Guangzhou, China	13,200	1.46	13,537	1.49
Guayaquil, Ecuador	3,189	1.08	3,278	1.11
Abidjan, Ivory Coast	1,023	0.89	1,187	1.03
Ho Chi Minh City, Vietnam	1,953	0.83	2,032	0.86
Khulna, Bangladesh	409	0.60	459	0.67
Zhanjiang, China	891	0.55	926	0.57
Mumbai, India	6,414	0.49	6,664	0.51
Palembang, Indonesia	506	0.48	526	0.49
Hai Phòng, Vietnam	383	0.44	418	0.48
Shenzen, China	3,136	0.40	3,338	*0.43*

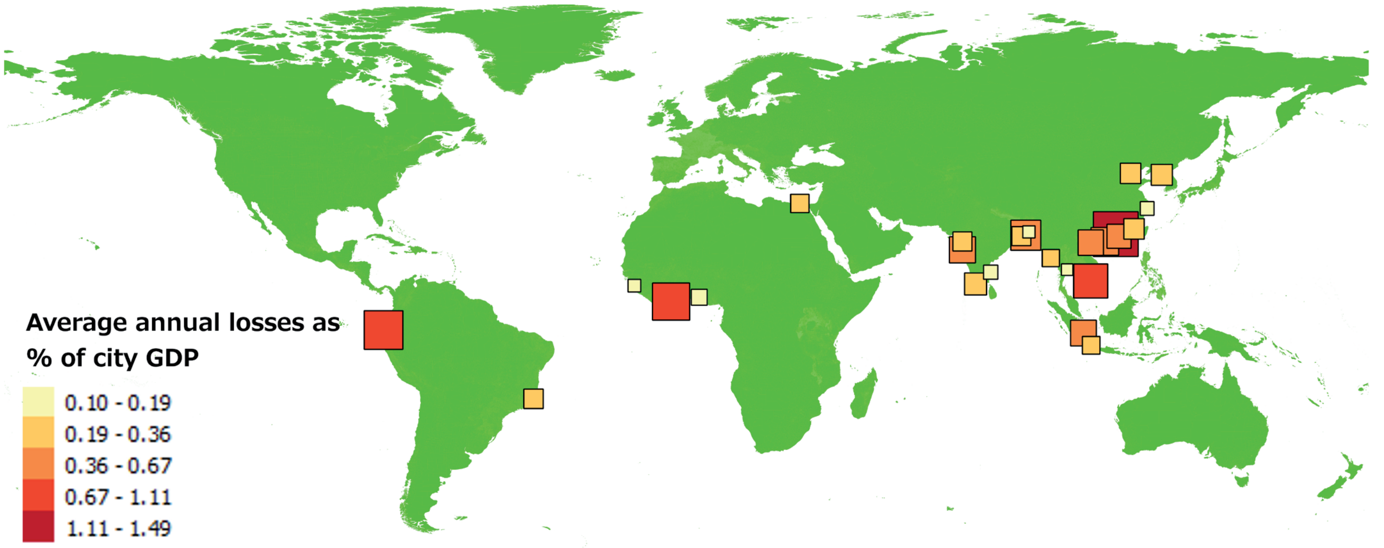


Figure 5. Cities in the developing world with at least 0.1% GDP average annual losses in 2050 under a pessimistic scenario of 40 cm of sea level rise (source data from Hallegatte *et al.*[8]).

References

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More on the web

→ **NOAA Laboratory for Satellite Altimetry:** maps and data on global and regional trends in sea level **http://goo.gl/HH5bp3**
→ **University of Colorado Sea Level Research Group:** range of data, useful background information and FAQ on sea level change **http://goo.gl/vKmOCw**
→ **CSIRO Australia:** excellent background and useful links on sea level change, from observations, to projections and impacts **http://goo.gl/Hriztm**
→ **Permanent Service for Mean Sea Level (PMSL):** provides access to global tide gauge data, and trends in sea level **http://www.psmsl.org/**
→ **Centre for Remote Sensing of Ice Sheets, Haskell Indian Nations University:** exploratory inundation maps for a range of different increases in sea level **http://goo.gl/o7uSRL**

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December 2015

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The Climate Service Center was founded in 2009 by the German Federal Ministry of Education and Research. Starting in June 2014, the center was institutionalized in the Helmholtz Association. Since July 20th 2015 the center is renamed in Climate Service Center Germany (GERICS).

GERICS offers in a scientifically sound manner products, advisory services and decision-relevant information to support government, administration and business in their efforts to adapt to climate change. One of the main tasks is to investigate the need for advice with regard to the climate change. GERICS aims to be a link between climate-researchers and climate-advisors. GERICS addresses therefore the needs of scientists as well as of practitioners and offers customer-oriented services and products, amongst others (raw) data as well as processed data-sets, e.g. Climate-Focus-Papers.

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