

Climate Change in Data

The Interlocking Signals of CO₂, Temperature, and Sea Level Rise

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1. Introduction

The Earth's climate system is undergoing rapid and measurable change, driven primarily by anthropogenic greenhouse gas emissions. The sustained rise in atmospheric carbon dioxide (CO₂) concentration is the principal factor behind the observed increase in global surface temperature and the rise in global mean sea level. This report analyses three interconnected datasets to examine how these indicators reinforce one another and to project future trends.

2. Results and Analysis

2.1 Atmospheric CO₂ and Global Temperature Anomaly

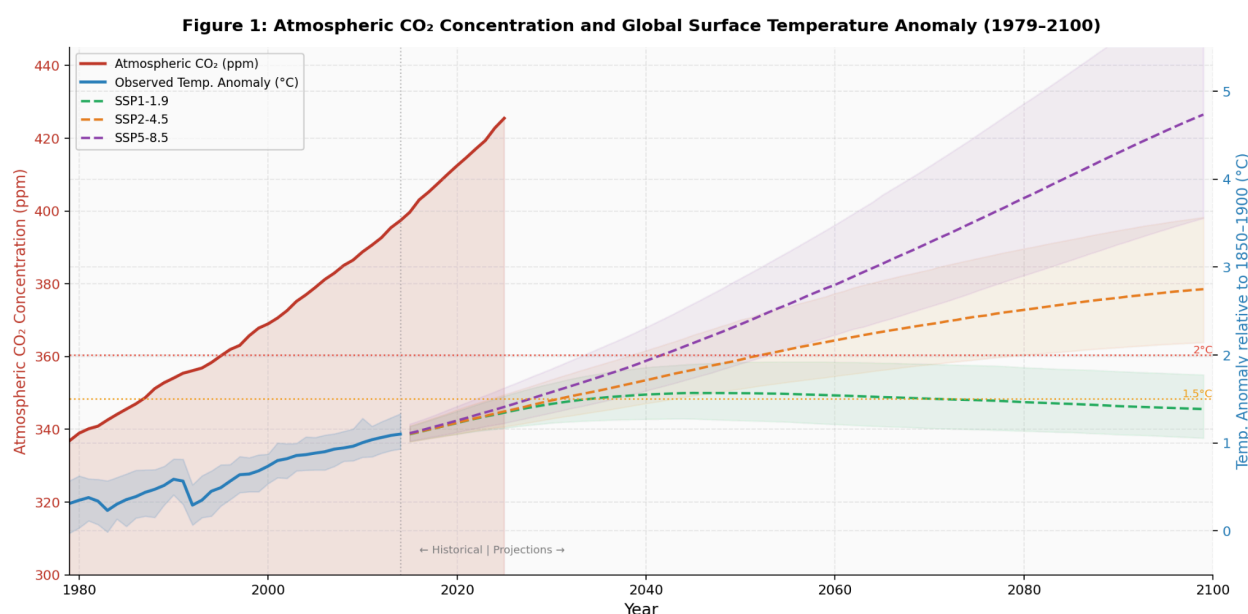


*Figure 1. Atmospheric CO₂ concentration (ppm, left axis, red) measured at the global network and global surface temperature anomaly relative to the 1850–1900 baseline (°C, right axis, blue). Historical temperature ends at 2014; dashed lines show SSP projections to 2100. Shaded bands indicate the 5–95th percentile uncertainty range.

As shown in Figure 1, atmospheric CO₂ concentration and global surface temperature have risen in near-parallel fashion. Since 1979, the global mean CO₂ concentration has increased from approximately 337 ppm to over 425 ppm in 2025, representing a rise of more than 26% over 46 years. This trajectory reflects the cumulative effects of fossil fuel combustion, deforestation, and industrial activity.

Concurrently, the global surface temperature anomaly has risen steadily, from approximately 0.25°C in 1950 to around 1.1°C by 2014, relative to the 1850–1900 pre-industrial baseline. CO₂ and other greenhouse gases absorb outgoing longwave radiation from the Earth's surface, reducing the amount of energy lost to space and thereby warming the lower atmosphere. This enhanced greenhouse effect is the primary physical driver of observed global warming and the rise in surface temperature.

The SSP projection lines diverge markedly beyond 2014, illustrating the profound influence of future emission choices. Under the most ambitious mitigation pathway (SSP1-1.9, green dashed line), warming stabilises at close to 1.5°C, consistent with the aspirational target of the Paris Agreement. The moderate scenario (SSP2-4.5, orange dashed line) stabilises at approximately 2.7°C, while the

high-emission scenario (SSP5-8.5, purple dashed line) projects warming exceeding 4.5°C by 2100. These projections demonstrate that the choices made by society can fundamentally alter the future trajectory of global temperature rise.

2.2 Global Mean Sea Level Rise

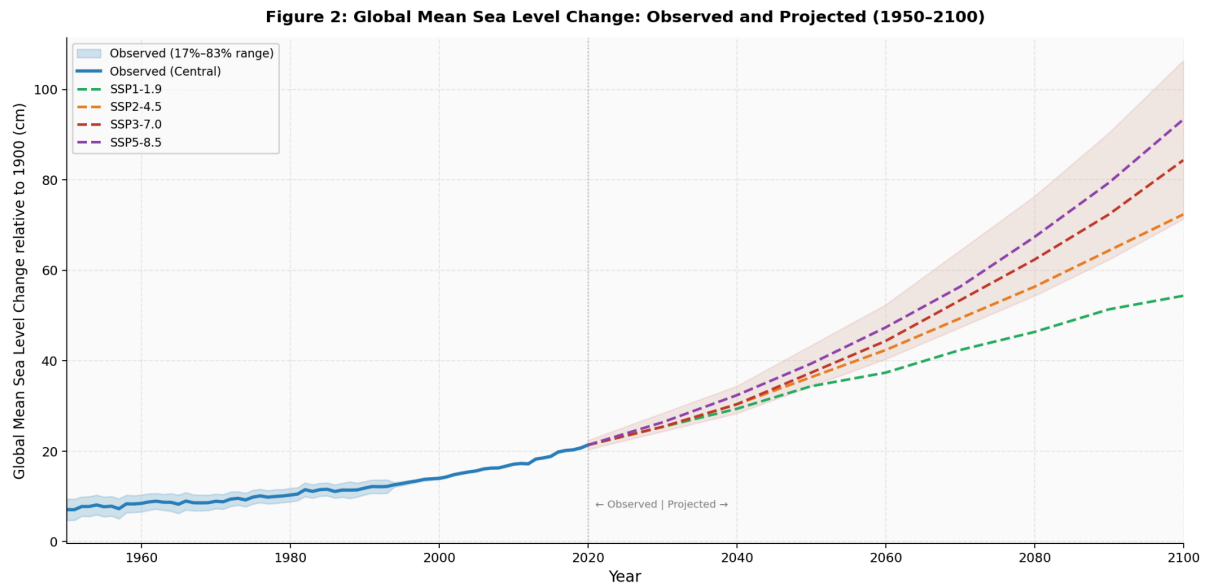


*Figure 2. Global mean sea level change relative to 1900 (cm). Blue solid line = observed central estimate; shaded band is 17–83% confidence interval. Dashed coloured lines show projected sea level under four SSP scenarios from 2020 to 2100.

Figure 2 presents the observed and projected changes in global mean sea level. Relative to 1900, global mean sea level has already risen by approximately 20 cm, with the rate of rise accelerating noticeably from the 1990s onward. This acceleration is primarily attributed to the thermal expansion of the upper ocean and the melting of land-based glaciers and ice sheets.

The projected trajectories from 2020 to 2100 span a wide range depending on the emission scenario. Under SSP1-1.9, sea level is projected to rise a further 20–30 cm above current levels by 2100. In contrast, under SSP5-8.5, the central estimate approaches an additional rise of approximately 90 cm by century's end.

3. Discussion: Implications and Course Connections

3.1 Radiative Forcing and the Greenhouse Effect

The near-parallel upward trends in CO₂ and temperature presented in Figure 1 directly illustrate the concept of radiative forcing. Since the Industrial Revolution, large-scale fossil fuel combustion has driven atmospheric CO₂ from a pre-industrial level of approximately 280 ppm to over 425 ppm in 2025. The carbon released through fossil fuel combustion represents carbon stocks accumulated over millions of years through natural processes; by releasing this carbon within a matter of decades, human activity has fundamentally disrupted the natural carbon cycle balance. CO₂ and other greenhouse gases absorb the longwave radiation emitted by the Earth's surface, reducing the energy lost to outer space and imposing a sustained positive radiative forcing on the climate system, which in turn drives the continuous rise in atmospheric and surface temperatures.

3.2 SSP Scenarios and the Importance of Policy Choices

The clear divergence of the three SSP projection lines after 2014 in Figure 1 highlights the critical role of energy transition and climate policy instruments, as discussed in Lecture 12. SSP1-1.9 represents the most aggressive mitigation pathway, assuming a rapid and large-scale expansion of renewable energy, substantial improvements in energy efficiency, and the eventual achievement of net-negative emissions, keeping warming close to the 1.5°C Paris Agreement target. By contrast, SSP5-8.5 assumes continued dependence on fossil fuels, with warming potentially exceeding 4.5°C by 2100. This divergence makes clear that future climate change is not predetermined, it is a direct function of the collective choices societies make regarding energy policy, carbon pricing, and investment in renewable technologies. Decarbonising electricity generation, electrifying transportation, and improving energy efficiency are the key levers for narrowing the gap between these scenarios, while policy tools such as carbon taxes, emissions trading schemes, and renewable energy subsidies will directly shape which emissions pathway the world follows.

3.3 Climate Inertia and Committed Warming

The sea level rise trends shown in Figure 2 reflect a fundamental property of the climate system known as climate inertia. Even if all greenhouse gas emissions were to cease immediately, a certain degree of additional sea level rise is already locked in, because large amounts of heat have already been absorbed and stored in the deep ocean, and the melting of the Greenland and Antarctic ice sheets will continue to unfold over decades to centuries. This concept is referred to as committed warming. The 20 cm of sea level rise already observed today represents only a partial expression of the impacts set in motion by past emissions; the full extent of future rise will far exceed current observations. This underscores the urgency of early and decisive climate action, the longer mitigation is delayed, the greater the irreversible impacts that become committed, and the less adaptation space is left for future generations.

3.4 Climate Justice and Unequal Impacts

Beyond the physical science, the data presented in this report compels us to confront the issue of climate justice, as examined in Lecture 14. According to global carbon budget data, the United States alone has been responsible for approximately 24% of cumulative global CO₂ emissions since 1750, with major European industrial nations accounting for a further substantial share. Yet the most severe consequences of climate change disproportionately fall upon low-income countries and small island states that have contributed almost nothing to historical emissions. Taking the SSP5-8.5 scenario in Figure 2 as an example, if warming reaches the levels projected under this high-emission pathway, low-lying Pacific island nations such as the Maldives and Tuvalu, with average elevations of less than one to two metres above sea level, face the existential threat of near-total inundation, despite their negligible contribution to global cumulative emissions. This exemplifies the problem of intragenerational justice: within the current generation, there exists a profound mismatch between emission responsibility and the burden of climate risk. Furthermore, the concept of intergenerational justice is equally at stake, today's emission decisions will profoundly shape the climate conditions inherited by future generations, who have no voice in current policy deliberations. Reducing greenhouse gas emissions is therefore not only a scientific and technological challenge, but fundamentally a question of fairness and moral responsibility.

4. Conclusion

This report has analysed three interconnected datasets and confirmed three robust, mutually reinforcing long-term trends. Atmospheric CO₂ concentration has risen continuously from 337 ppm in 1979 to over 425 ppm in 2025; global surface temperature has increased by approximately 1.1°C above the pre-industrial baseline; and global mean sea level has risen by around 20 cm since 1900, with the rate of rise accelerating in recent decades. The SSP projection data clearly demonstrate that future warming trajectories and the extent of sea level rise are strongly dependent on the emission pathways that governments and societies choose to pursue, the difference between ambitious mitigation and a high-emission scenario could amount to more than 3°C of additional warming and tens of centimetres of additional sea level rise by the end of this century. The inertia inherent in the climate system further reminds us that the costs of delayed action will ultimately be borne by future generations. Addressing climate change therefore requires not only advances in science and technology, but also the establishment of fair and effective international cooperation mechanisms that hold historically high-emitting nations accountable for their proportionate obligations in emissions reduction and climate finance, so as to protect the most vulnerable communities and regions from the worst impacts of climate change.

*AI tools were used to assist with language refinement and grammar checks.