PCIC PRIMER: UNDERSTANDING FUTURE CLIMATE SCENARIOS

Learning Objectives

After reviewing this Primer, readers should understand:

- What an emissions scenario is and its purpose.
- The two types of emissions scenario frameworks in current use and their differences.

1 Introduction: Climate Change and Future Scenarios

The Earth's climate is changing under human influence, primarily due to the release of greenhouse gases (GHGs) and aerosols from fossil-fuel use. Over the past century, these emissions have raised atmospheric GHG concentrations well above their preindustrial levels, warming the Earth's surface.

The amount of global warming caused by these emissions has been shown to be directly proportional to the total amount of GHGs emitted since the beginning of the industrial era. This and multiple other lines of reasoning indicate that the extent of further warming depends on how how much more we emit in the future. As future societal conditions affecting GHG emissions are difficult to predict, we need to consider a range of plausible socioeconomic futures, or scenarios, in order to plan for the impacts of future GHG-induced climate change.

Given these scenarios and their associated emissions, climate scientists use computer models of the entire Earth system, called global climate models (GCMs), to simulate Earth's climate in great detail. GCMs of steadily increasing complexity have been used over the past fifty years, and have been carefully evaluated via an immense volume of peer-reviewed research, including a series of Coupled Model Intercomparison Projects (CMIPs). The most recent of these are known as CMIP5 (circa 2013) and CMIP6 (circa 2021). The results of these intercomparison projects, along with a vast amount of scientific knowledge regarding the climate system, are assessed in the Intergovernmental Panel on Climate Change's Fifth Assessment Report (2013) and Sixth Assessment Report (2021). The scenarios used to drive these models are termed Representative Concentration Pathways (RCPs) in the Fifth Assessment and Shared Socioeconomic Pathways (SSPs) in the Sixth Assessment.

2 Emissions Scenarios: Representative Concentration Pathways (RCPs)

The RCPs used in CMIP5 describe emissions pathways leading to different levels of warming by the end of this century. Each RCP begins with the historical record of GHG emissions up to the year 2005, followed by four distinct emissions scenarios: a low emissions scenario (RCP2.6), two intermediate scenarios (RCPs 4.5 and 6.0), and one high emissions scenario (RCP8.5). **Figure 1** shows the relationship between GHG emissions, concentrations and radiative forcing (which determines how much global warming occurs; see **Box**) under each RCP. Although the RCPs reflect separate narratives of future industrial development, they are not derived from specific socioeconomic scenarios, which were developed later (i.e. the SSPs).

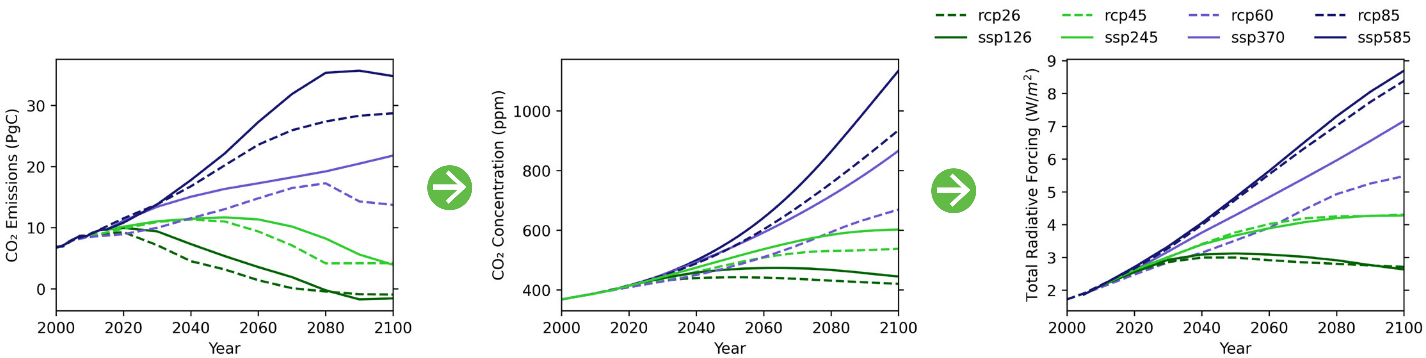

Figure 1: The emission of GHGs such as carbon dioxide (CO_2) into the atmosphere (left) alters their global mean concentrations (centre), which results in a net radiative forcing (right; Box). The magnitude of the radiative forcing, along with various feedback processes, determines how much the climate will change. This figure shows results for the Representative Concentration Pathways (RCPs, dashed lines) of CMIP5 and Shared Socioeconomic Pathways (SSPs, solid lines) of CMIP6. After O'Neill et al. (2016).

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3 Socioeconomic Scenarios: Shared Socioeconomic Pathways (SSPs)

The SSPs used in CMIP6 are a set of five socioeconomic pathways (SSP1 through SSP5) that illustrate different ways in which global societies may develop. Like the RCPs, the SSPs follow historical emissions (ending in 2014 in this case) before diverging onto several possible future scenarios for each primary pathway (that is, a given SSP can result in a range of emissions scenarios). For CMIP6, modelling centers were encouraged to run particular scenarios that were more or less aligned with the CMIP5 RCPs, to allow for ready comparisons. The SSPs differ from the RCPs in that they were developed by considering a number of socioeconomic factors, such as future population growth, economic development, changes to lifestyles, policies and institutions, advances in technology, and management of the global environment and natural resources. Knowledge of these factors was used to develop country-level estimates of quantities such as Gross Domestic Product, degree of urbanization, etc. leading to corresponding projections of GHG and aerosol emissions. An example of different GCM projections of global temperature resulting from four SSPs is shown in **Figure 2**.

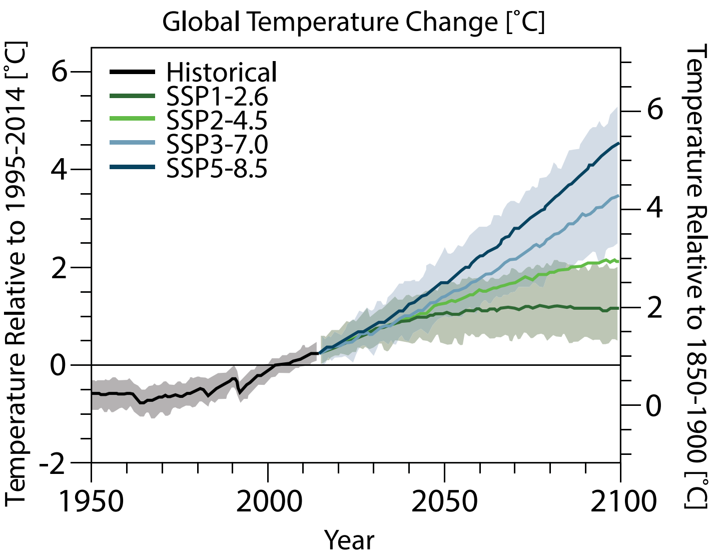

Figure 2: Change in global mean temperature simulated by CMIP6 GCMs over the historical period (black line) and in the future (coloured lines, as denoted in legend) driven by the four SSPs from Fig. 1. Note that increasing concentrations in each of the SSPs result in proportionally larger temperature changes by the end of the century. The shading surrounding the mean curves for the historical period and SSP1-2.6 and SSP3-7.0 scenarios reflects the range of different climate model responses to a given forcing along with natural climate variability (as simulated by the models). After Figure 4.2 in Lee et al. (2021).

Box: Radiative Forcing

Radiative forcing (often abbreviated to just "forcing") is the difference between the solar radiation absorbed by the Earth and the energy radiated back to space, mainly in the form of heat, expressed in Watts per square metre (Wm^{-2}). Just prior to the Industrial Revolution, Earth's radiative forcing was roughly zero. The increase in GHG concentrations and aerosols since that time have resulted in a net positive radiative forcing of approximately 1.6 Wm^{-2}. A positive radiative forcing indicates that the Earth system is not shedding as much energy to space as it is receiving from the Sun, and as a result, the planet warms, as has been observed.

The RCPs each lead to a specified level of radiative forcing by the year 2100, and are named for those 2100 forcing values. For example, the least emissions intensive scenario in CMIP5 (RCP2.6) corresponds to a year 2100 forcing level of about 2.6 Wm^{-2}.

4 Conclusion

The RCPs and SSPs each provide multiple emissions scenarios that are used in climate models to simulate the amount of future climate change that could occur throughout this century.

Which scenario, if any, is the world following? As of 2019, estimated global, annual CO_2 emissions (33.4 Gt CO_2) fall between the low (RCP 2.6/SSP1-2.6) and medium (RCP 4.5/SSP2-4.5) scenarios—but this is merely a snapshot of the recent situation. Whether one employs the RCPs or SSPs, the role of scenarios is to not to predict the future, but rather to illustrate the various GHG emission outcomes resulting from a range of future societal and economic circumstances.

Further Reading

Introductory web resources on the RCPs and SSPs:

Hausfather, Z., 2018: *How Shared Socioeconomic Pathways Explore Future Climate Change*, Accessed 10 March 2021, https://www.carbonbrief.org/explainer-how-shared-socioeconomic-pathways-explore-future-climate-change.

Wayne, G.P., 2013: *The Beginner's Guide to Representative Concentration Pathways*. Accessed 10 March 2021, https://skepticalscience.com/rcp.php.

On the RCPs and SSPs:

van Vuuren, D.P., et al., 2011: The Representative Concentration Pathways: An Overview. *Climatic Change*, **109**, 1-2, 5-31, doi:10.1007/s10584-011-0148-z.

Lee, J. Y. et al., 2021: Future Global Climate: Scenario Based Projections and Near-Term Information. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V. et al. (eds.)]. Cambridge University Press. In Press.

O'Neill, B.C. et al., 2016: The Scenario Model Intercomparison Project (ScenarioMIP) for CMIP6. *Geoscientific Model Development*, **9**, 3461–3482, doi:10.5194/gmd-9-3461-2016.

O'Neill, B.C. et al., 2017: The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. *Global Environmental Change*, **42**, 169-180, doi: 10.1016/j.gloenvcha.2015.01.004.

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