**Your SCIPER:**

**Date: 1 February 2023**

**Location: CO 1**

**ENV-410 Science of Climate Change final exam**
**Duration:** 180 minutes, 15:15 – 18:15
**Material allowed:** 1 Din A4 page of notes (back and front) and calculator
**Not allowed:** phones, tablets or computers
**This exam is worth 50 % of your overall grade.**

**Instructions:**
Put your Sciper number on each page. If you need extra paper, ask the supervision team.

Please fill in the feedback form before you hand in your exam.

For multiple choice questions, each correct answer is 0.5 points, while each incorrect answer causes a subtraction of 0.25 points. The number of correct choices per question can vary.

The number of points is indicated for all non-multiple choice questions.

For open questions to be answered with text, respect the line limit. We cannot take into account information that is beyond the line limit.

For figure interpretation, make sure to explicitly refer to any elaboration that you make to a figure (e.g. when you draw on it) on the exam sheet, and make any elaboration very visible.

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## 1. Fundamentals

1.1 Figure 1 shows the global land and ocean annual temperature anomaly between 1880 and 2021. Explain in no more than 7 lines: (i) what “global land and ocean annual temperature anomaly” means, and (ii) why anomalies rather than absolute values are shown. (4 points)

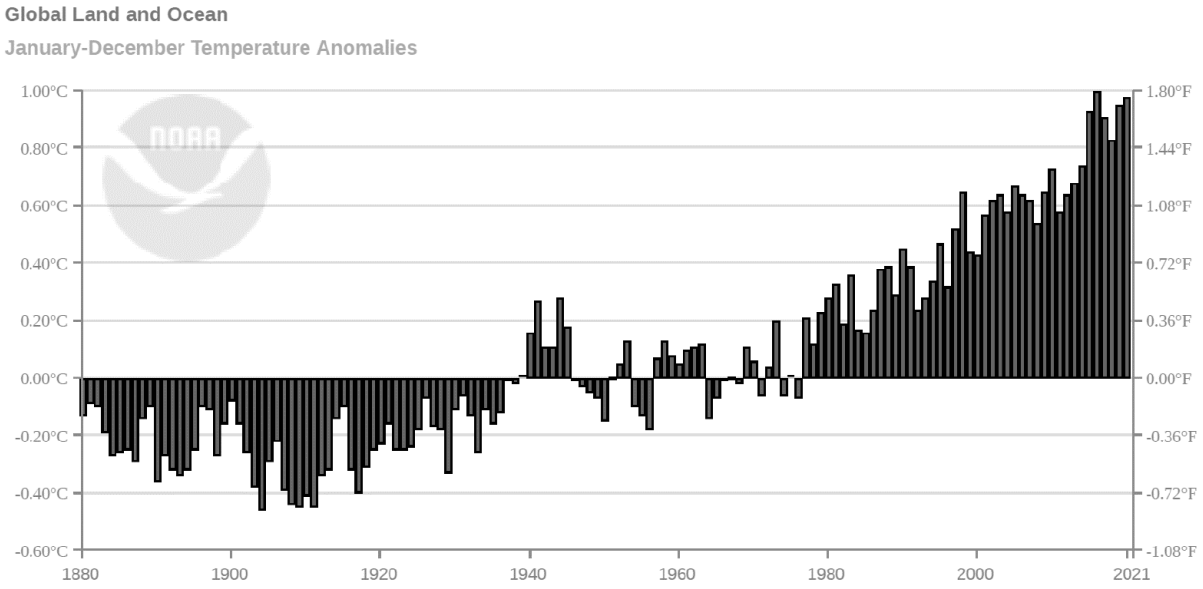


*Figure 1: Global land and ocean temperature anomaly for January through December. Source: https://www.ncdc.noaa.gov/cag/global/time-series/globe/land_ocean/1/1/1880-2021*

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1.2 Which processes force climate?

- ☐ Sahara greening
- ☐ Eccentricity
- ☐ Forest fires
- ☐ Coral bleaching
- ☐ Volcanic eruptions

1.3 Complete below table by choosing the timescale on which each process has a climate impact. Explain why in no more than the space given in the table per item. Time scales to use: seconds, seconds to hours, hours to days, days to weeks, months to years, years to centuries, centuries or longer (5 points)

| | Processes | Timescales |
|---|---|---|
| 1 | longwave radiation effect | |
| 2 | Convection | |
| 3 | Snow/ice albedo | |
| 4 | Air-sea $CO_2$ exchange | |
| 5 | Land ice retreat (e.g., alpine glaciers) | |

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1.4 Figure 2 shows the rate of annual increase of $CO_2$ in the atmosphere as measured at the Mauna Loa observatory. This means concretely (text from website): *The annual mean rate of growth of $CO_2$ in a given year is the difference in concentration between the end of December and the start of January of that year. If used as an average for the globe, it would represent the sum of all $CO_2$ added to, and removed from, the atmosphere during the year by human activities and by natural processes.*

A) Why can we use Mauna Loa as global proxy for atmospheric $CO_2$ increase?

- ☐ We actually cannot, and the figure is only representative of the North Pacific region.
- ☐ $CO_2$ disperses globally due to its long lifetime. Hence, a remote station like Mauna Loa is representative globally.
- ☐ The data are run through a global atmospheric model simulation to make them representative for the whole planet.

B) Do an eye-ball linear regression on the decadal averages. What is the approximate decadal atmospheric $CO_2$ emission growth rate between the 1960s and 2010s? (2 points)

C) Based on B) and given that we have roughly 420 ppm $CO_2$ atmospheric concentration at the moment, which concentration do we reach in 2100 if the increase in the decadal emission rate does not change? Show your calculation here. (3 points)

D) The current expectation for warming at the end of the century is

- ☐ 1.7 °C
- ☐ 2.0°C
- ☐ 2.3°C
- ☐ 2.8°C
- ☐ 3.5°C

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E) Based on your calculation from C) and Figure 3 with caption, what is the estimated warming in 2100? How does that match the current expectation from D? If there is a difference from the current expectation, why? (3 points, 5 lines)

F) In the lecture, we learned that it always took a crisis to reduce $CO_2$ in the year of crisis compared to the previous year. 2020 was definitely a year of crisis with the global covid-19 pandemic. Why do we still see an increase in $CO_2$ concentration in the year 2020 that is among the highest ever as shown in Figure 2? (1 point, 2 lines)

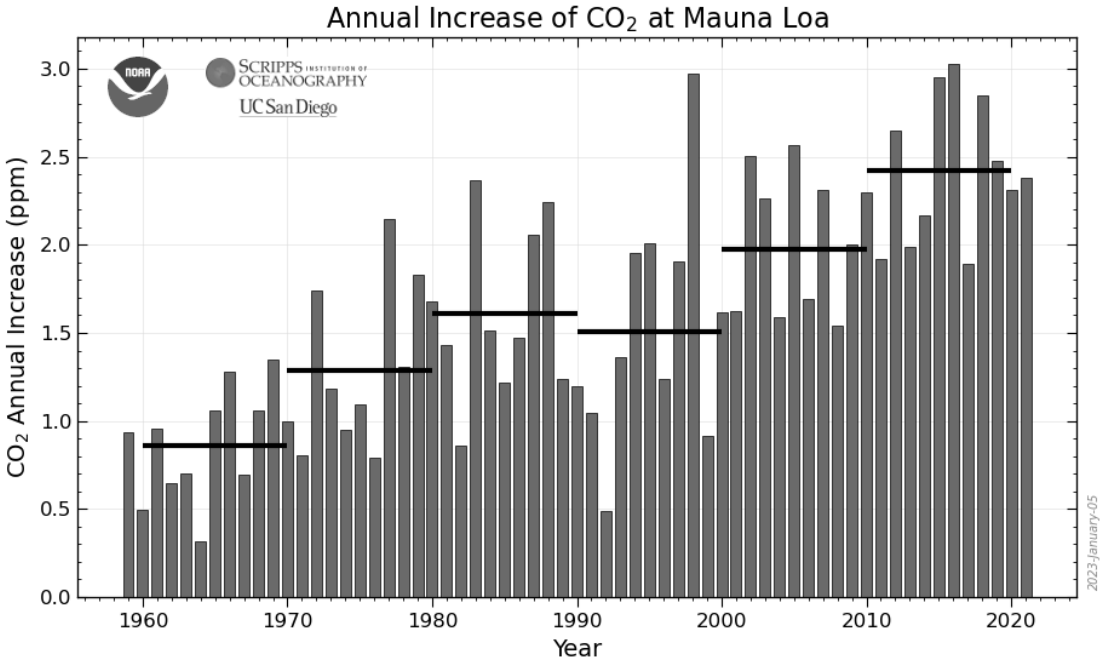


*Figure 2*: Vertical bars indicate annual increase of $CO_2$ at the Mauna Loa observatory. The horizontal bars denote decadal averages. https://gml.noaa.gov/ccgg/trends/gr.html

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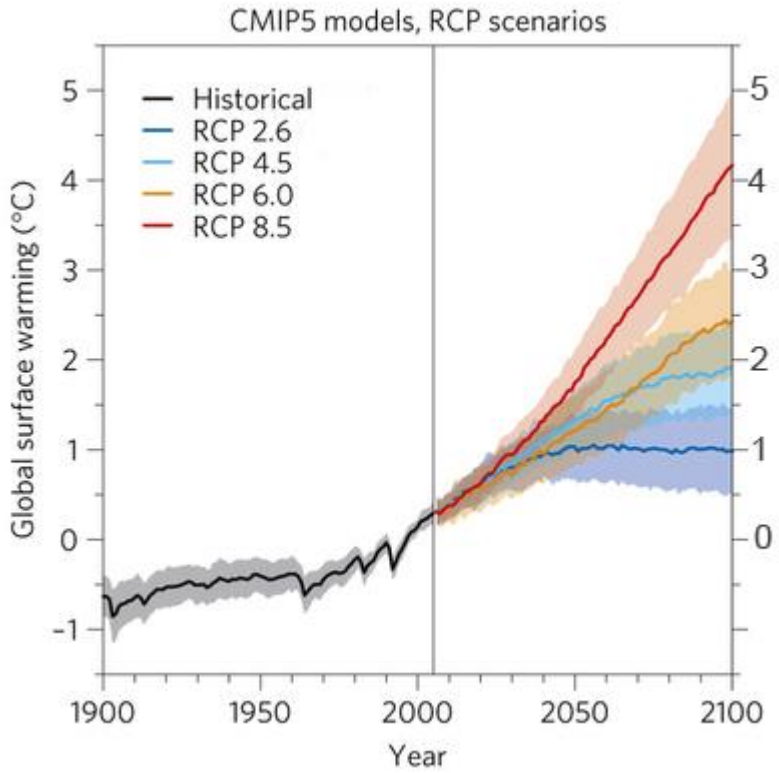


*Figure 3: Estimated temperature outcome in 2100 based on 4 different RCP scenarios. $CO_2$ concentration range per RCP scenario: RCP 2.6 430 – 480 ppm $CO_2$-eq; RPC 4.5 580 – 720 ppm $CO_2$-eq; RCP 6.0 720 – 1000 ppm $CO_2$-eq; RCP 8.5 > 1000 pm $CO_2$-eq*

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## 2. Radiation, Energy budget, Greenhouse Gases

2.1 What is the natural greenhouse effect? Describe the greenhouse gases involved, the physical mechanism and the overall magnitude of the effect. Why is it important? (6 points, 10 lines)

2.2 The atmospheric windows describe:

- ☐ The range of wavelengths that allows solar radiation to pass through to Earth's surface.
- ☐ The range of wavelengths that allows terrestrial radiation to be reflected back by clouds to the Earth surface.
- ☐ The range of wavelengths that allows terrestrial radiation to be re-emitted back by clouds to the Earth surface.
- ☐ The range of wavelengths that allows short-wave radiation to be scattered back into space.
- ☐ The ranges of wavelengths that allow long-wave radiation to be emitted to space.

2.3 The natural and the anthropogenic greenhouse effects are …

- ☐ Different, because there is a difference in the radiation physics.
- ☐ Different, because the altitude of natural $CO_2$ emissions is lower than the altitude of some anthropogenic $CO_2$ emissions, e.g. from aviation.
- ☐ In principle the same, because there is no difference in the physics, but there are some anthropogenic gases which do not occur naturally.

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2.4. The process behind the greenhouse effect consists of these key steps:

- ☐ A) Shortwave radiation warms the surface, B) Earth landmasses emit longwave radiation, C) greenhouse gases absorb the longwave radiation and D) by re-emitting parts downwards decrease the overall amount of longwave radiation escaping to space
- ☐ A) Shortwave and longwave radiation warm the surface, B) Earth emits longwave radiation, C) greenhouse gases absorb the longwave radiation and D) by re-emitting parts downwards decrease the overall amount of longwave radiation escaping to space
- ☐ A) Shortwave and longwave radiation warms the surface, B) Earth emits longwave radiation, C) greenhouse gases scatter the longwave radiation and D) by scattering parts downwards decrease the overall amount of longwave radiation escaping to space

2.5 A) Cloud radiation effects in the Arctic. In Figure 4, draw the paths of shortwave and longwave radiation for locations 1, 2, and 3 with arrows. Make sure to clarify which type of arrow denotes longwave and shortwave. Note, the ocean absorbs about 93% of solar radiation, while sea ice reflects 85% of solar radiation. (6 points)

B) In summer: which net effect (warming or cooling) do clouds have over the open ocean and over the dense pack ice and why? (2 points, 4 lines)

C) In winter: which net effect (warming or cooling) do clouds have over the open ocean and over the dense pack ice? (2 points, 4 lines)

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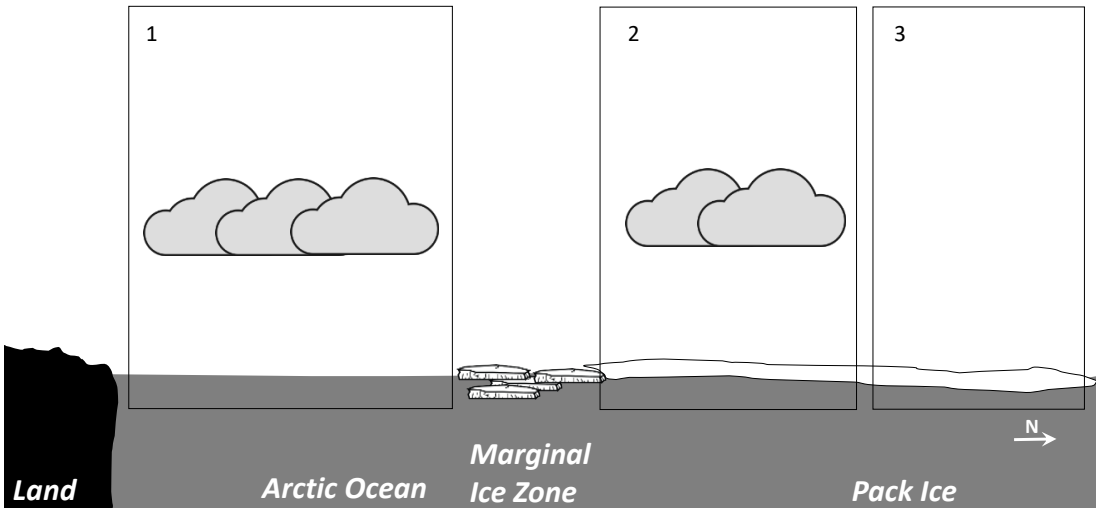


*Figure 4. Clouds over the Arctic Ocean with varying sea ice coverage.*

2.6 One of the solar radiation modification approaches foresees spreading aerosol particles in the stratosphere. What is the radiation process that would occur?

- ☐ Similar to the radiation processes in case of a natural volcanic eruption that reaches the stratosphere.
- ☐ The particles would scatter sunlight.
- ☐ Less shortwave radiation would reach the surface.
- ☐ Clouds would form and cool the surface.

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## 3. Climate Variability, Climate Sensitivity, Climate Feedbacks

3.1 The El Niño Southern Oscillation (ENSO) is one of the most important phenomena driving global climate variability.

A) Briefly explain the global temperature effects of El Niño and La Niña. (3 lines, 1 point)

B) Use Figure 5 to explain why the year 2022 was less warm than it could have been. (3 lines, 1 point)

C) The famous and highly trustworthy scientist James Hansen from Columbia University recently said that the year 2024 could see global warming of 1.5°C. How do you think does it relate to climate variability when looking at Figure 5? (1 point, 3 lines)

D) Why do we care about natural climate variability in general? Answer in max. 3 lines. (2 points)

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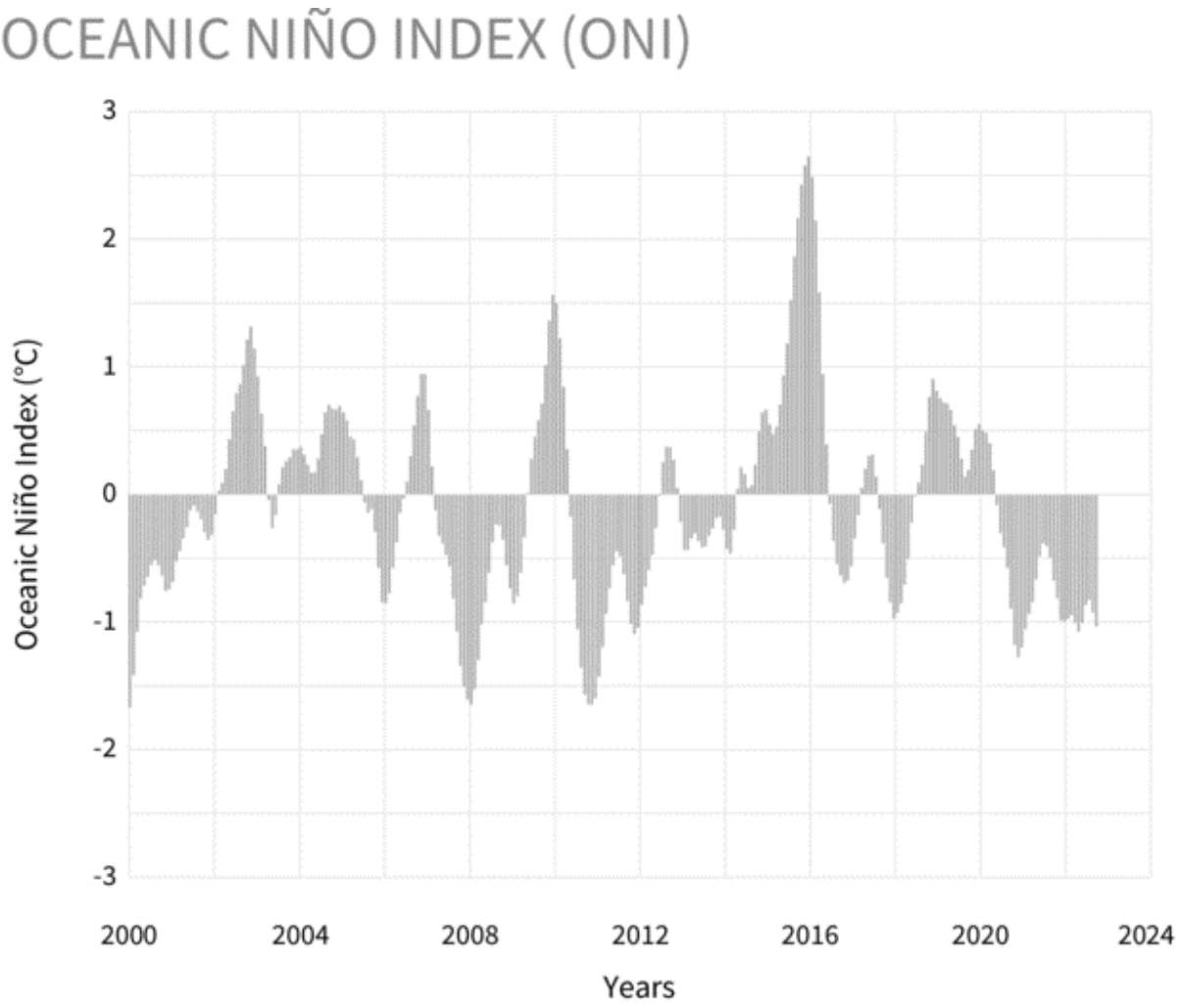


*Figure 5: Oceanic Niño index. Positive indicates El Niño, negative La Niña. Source: https://www.climate.gov/news-features/understanding-climate/climate-variability-oceanic-ni%C3%B1o-index*

3.2 Why are climate scientists so interested in constraining equilibrium climate sensitivity (ECS)?

- ☐ Only with a highly constrained ECS value will we know, how strong Earth reacts to the release of greenhouse gases. And only with this information future temperature projections become more reliable.
- ☐ A better constrained ECS tells us the magnitude of the Planck response, which is still highly uncertain.
- ☐ If we knew the exact value of ECS, we could use it to constrain the strengths of different climate feedbacks.

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3.3 Based on Figure 6, focusing only on the red symbols (denoting the 6th IPCC assessment report results), explain the following:

A) What is the Planck feedback and why is it negative? (2 points, 4 lines)

B) What is the water vapor feedback and why is it positive? (2 points, 4 lines)

C) What is the surface albedo feedback and why is it positive? (2 points, 4 lines)

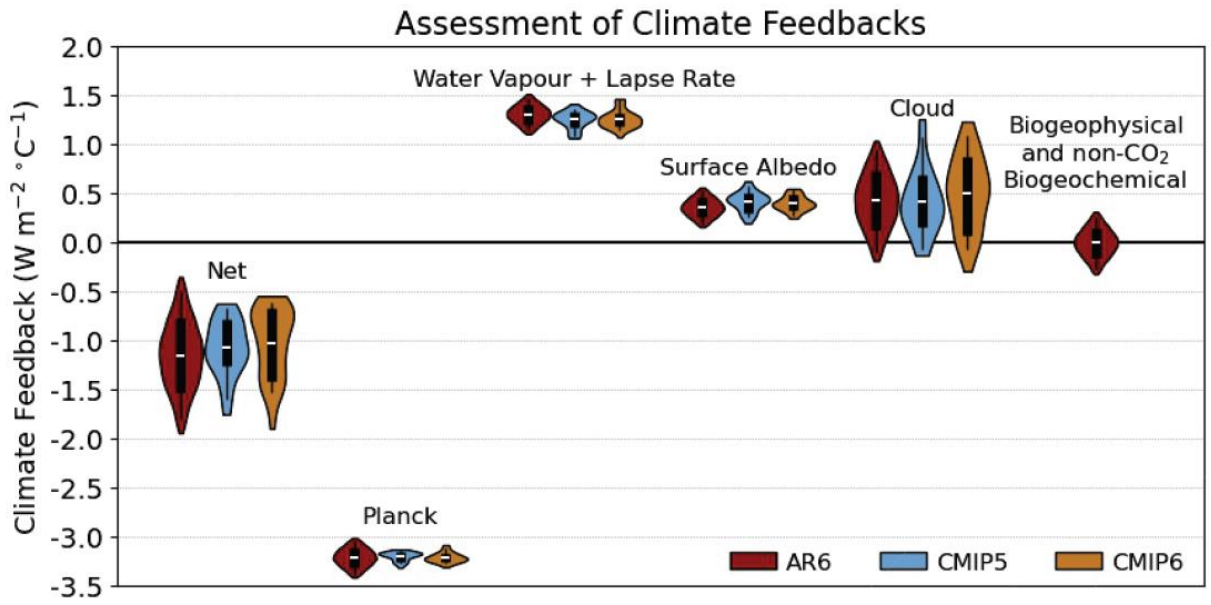


*Figure 6: Global-mean climate feedbacks estimated in abrupt 4x $CO_2$ simulations of 29 CMIP5 models (light 4 blue) and 49 CMIP6 models (orange), compared with those assessed in this Report (red). Individual feedbacks for CMIP models are averaged across six radiative kernels as computed in Zelinka et al. (2020). The white line, black box and vertical line indicate the mean, 66% and 90% ranges, respectively. The shading represents the probability distribution across the full range of GCM/ESM values and for the 2.5–97.5 percentile range of the AR6 normal distribution. The unit is W m–2 °C–1. Feedbacks associated with biogeophysical and non- $CO_2$ biogeochemical processes are assessed in AR6, but they are not explicitly estimated from GCMs/ESMs in CMIP5 and CMIP6. Figure from IPCC AR6, Ch. 7. CMIP means couple model intercomparions project. GCM means general circulation model. ESM means Earth System Model.*

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## 4. Climate change scenarios, carbon budget, extremes

4.1 Use Figure 7 to describe how our $CO_2$ emissions need to change over the course of the century to meet the Paris Agreement goal of 1.5°C global warming. Answer the following questions.

A) Which of the two displayed scenarios (no or limited overshoot, higher overshoot) seems the more likely and why? (1 point, 1 line)

B) By when do we need to reach net-zero emission approximately and what does net-zero emissions mean? (2 points, 3 lines).

C) What needs to happen in the second half of this century? (1 point, 2 lines)

D) Which is the largest challenge you anticipate for the time 2023 – 2050 and which is the largest challenge after 2050 to ensure we achieve to the 1.5°C goal. Why are these the largest challenges in your view? (2 points, 6 lines)

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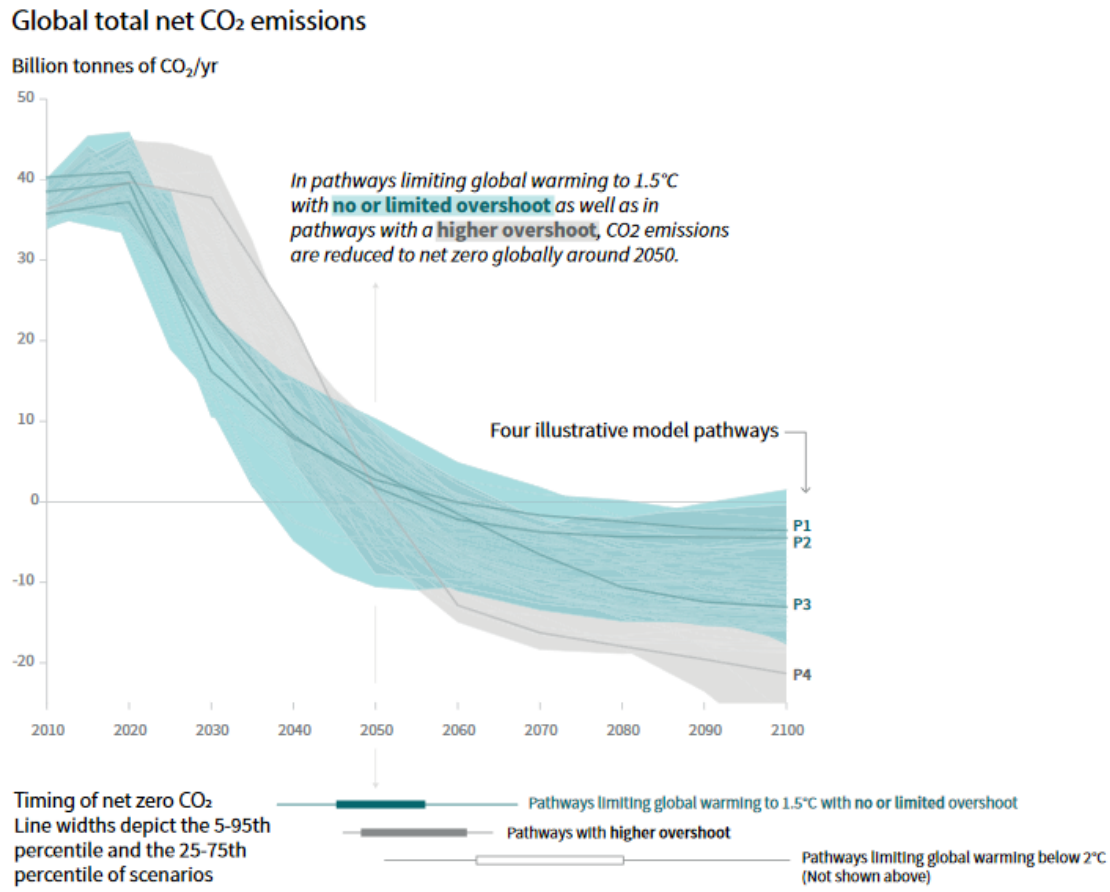


*Figure 7: Global net $CO_2$ emission pathways to keep global warming to 1.5°C. From IPCC SP 1.5°, 2019*

4.2 Why is it not exaggerated to speak of a climate emergency?
Imagine for your answer that you have only 30 seconds in an elevator to convince a powerful policy maker. Ensure that you mention at least three key arguments for the emergency and remember that an emergency is urgent. Note, as rule of thumb, 130 words can be spoken without haste in 1 minute. You need to use full and coherent sentences. 5 lines (6 points)

4.3 What does “2.6” stand for in RCP2.6?

- ☐ By 2100 there will be 2.6 times the $CO_2$ emissions compared to 1850.
- ☐ It is just a random number assigned to a specific representative concentration pathway.
- ☐ The radiative forcing according to this RCP scenario will be 2.6 W m-2 at the end of the century.
- ☐ The temperature will be 2.6 °C above pre-industrial levels by the end of the century according to this RCP scenario.

4.4 What are shared socio-economic pathways (SSPs)?

- ☐ SSPs are pure qualitative descriptions of potential future emission scenarios.
- ☐ SSPs are pure quantitative descriptions of potential future emission scenarios.
- ☐ SSPs replace RCPs.
- ☐ SSPs are narratives describing alternative socio-economic development.
- ☐ SSPs contain information on air pollution, population growth and greenhouse gases.

4.5 How many SSPs are there?

- ☐ 3
- ☐ 6
- ☐ 7
- ☐ It depends on the scientific question.
- ☐ None of the above.

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4.6 Extreme events become more frequent with climate change.
a) Draw the probability density distribution of annual daily temperatures for a random location on Earth. Indicate the cold and hot extremes and explain how you defined them. (3 points, 3 lines, 1 plot)

b) Then draw a second probability density distribution of annual daily temperatures for the same random location on Earth, but for a future climate. Explain what changes and how. Indicate the hot and cold extremes and how you defined them. (4 points, 5 lines, 1 plot)

4.7 Which of the following are not tipping elements?

- ☐ Loss of the Amazon rain forest.
- ☐ Loss of Greenland ice.
- ☐ Loss of coral reefs.
- ☐ Sahara greening.
- ☐ Arctic greening.

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## 5. Climate change misconceptions and skepticism

5.1 A hypothetical 13 year old relative of yours is super eager to learn English and recently read an article in the Forbes magazine of which you see an excerpt below.

*Forbes, 21 March 2022: In an exclusive interview Monday on Fox Business Network's Varney & Company Monday, Donald Trump told host Stuart Varney that climate change is "a hoax." The former president said "in my opinion, you have a thing called weather, and you go up, and you go down," he said. "If you look into the 1920s, they were talking about a global freezing, okay? In other words, the globe was going to freeze."*
*"And then they go global warming," Trump continued. "Then they couldn't use that because the temperatures were actually quite cool. And many different things. So now they just talk about climate change. The climate's always been changing."*
https://www.forbes.com/sites/markjoyella/2022/03/21/on-fox-donald-trump-calls-climate-change-a-hoax-in-the-1920s-they-were-talking-about-global-freezing/?sh=4500a3f63787

The content of the articles contradicts what your relative learned in school the other day. Knowing that you take the class "science of climate change", your relative approaches you and asks the following questions.

A) What is the difference between weather and climate? (3 lines, 1 point)

B) Did they really speak about global freezing back then?
Use Figure 8 from the IPCC report to explain what Trump might have refered to. How would you explain the temperature curve at the beginning at the 20$^{th}$ century? (1 point, 3 lines)

C) It's true that the climate has always been changing, so why is it different now?
Give at least 3 arguments. (3 points, 6 lines)

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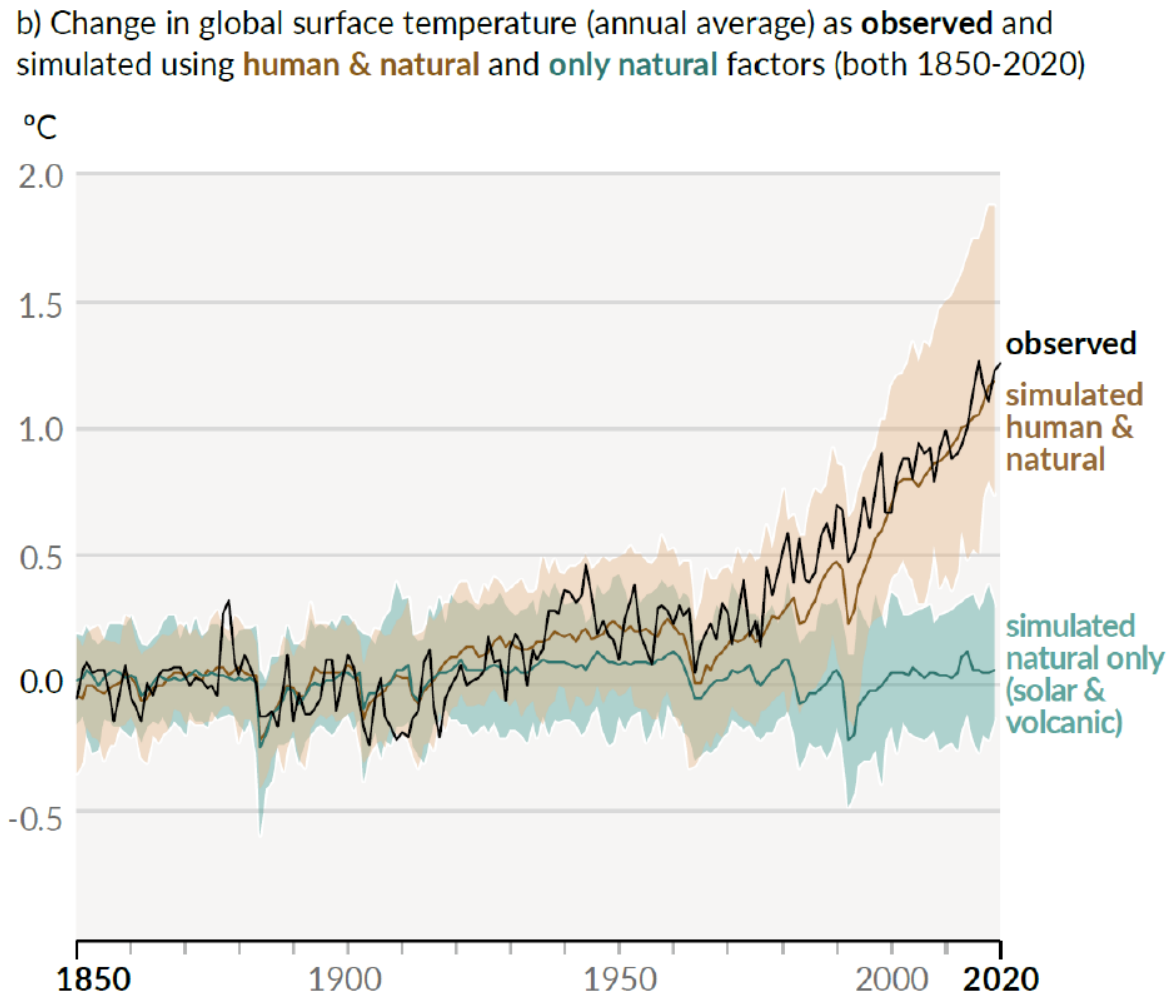


*Figure 8: Observed and simulated temperature time series. This is figure 1 from the IPCC SPM, 2021.*