The Physical Climate at 2°C vs 4°C as seen in the UK Earth System Model (UKESM1)

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Motivation

Analyse global warming induced changes in climate and identify regions of significant future climate change that could impact society.

Objectives

(a) Estimate when surface temperature values exceed **Global Warming Levels (GWLs)** such as 2°C or 4°C in Earth System Models .

(b) Analyse regional and seasonal changes in the physical climate **between a 2°C and a 4°C world** to better understand the **impacts of these changes**.

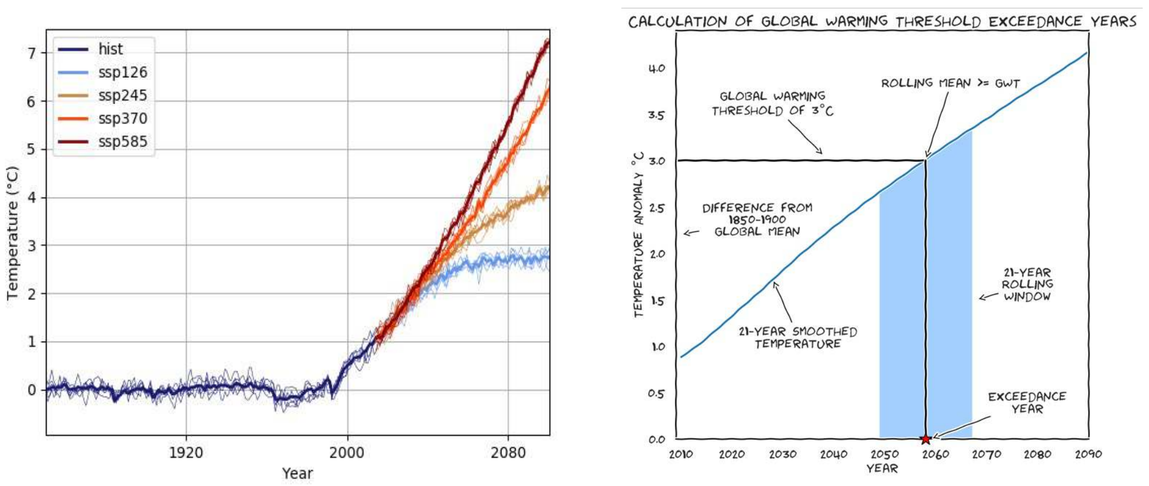

Fig 1. UKESM1 ScenarioMIP atmospheric surface temperature anomalies (left) and GWL exceedance year calculation (right).

Data and Methods

(a) surface temperature data from 32 CMIP6 (Sixth Coupled Model Intercomparison Project) models to calculate GWL exceedance years.

(b) historical, pi-Control and Tier1 ScenarioMIP projections (SSP1-2.6, 2-4.5, 3-7.0 and 5-8.5) .

(c) Surface temperature (tas), precipitation (pr), soil moisture (sm), and precipitation minus evaporation (p-e) from ensemble members (r1-4 ,r8-12, r16-19) i1p1f2 analysed from UK Earth System Model (UKESM1) projections.

(d) ESMValTool (https://www.esmvaltool.org) was used to develop diagnostics.

Results

a. Timing of Global Warming Levels Exceedances

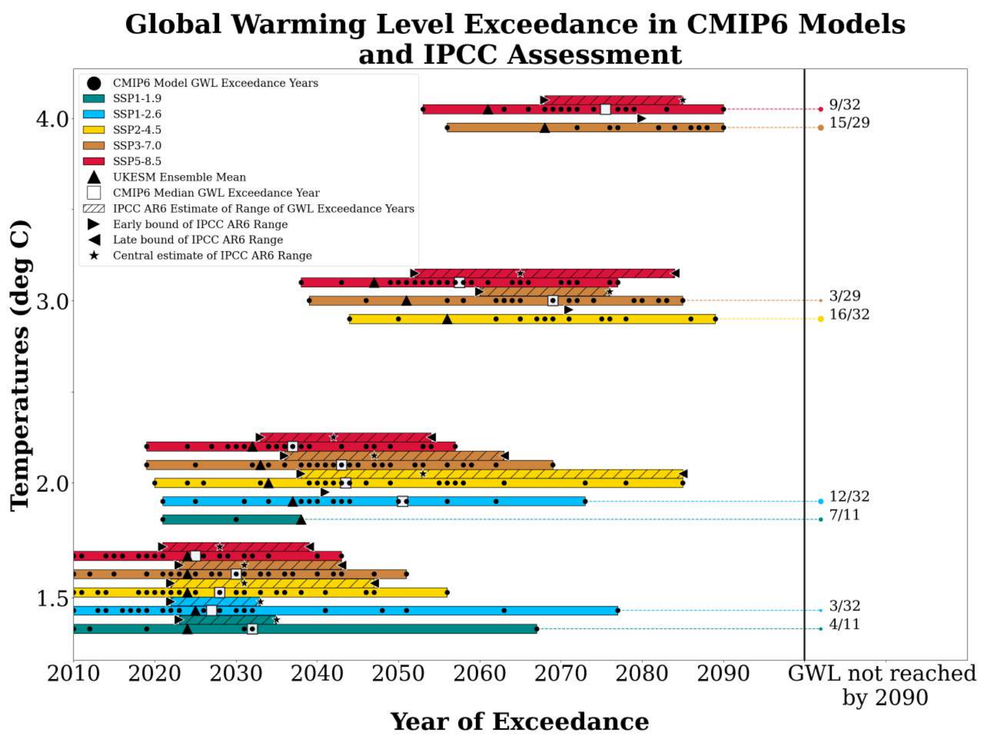

Fig 2. The plain coloured bars show estimates for the range of years when CMIP6 models exceed a given GWL under different SSPs. The number on the right is the count of CMIP6 models that do not exceed a given GWL under a given SSP by the end of the century. For comparison, the IPCC AR6 *"very likely"* range of GWL exceedance years are shown as hatched bars. For each IPCC range, the central estimate as well as early and late bounds are indicated where available on the hatched bars.

b. UKESM1 Changes in surface temperature under SSP3-7.0

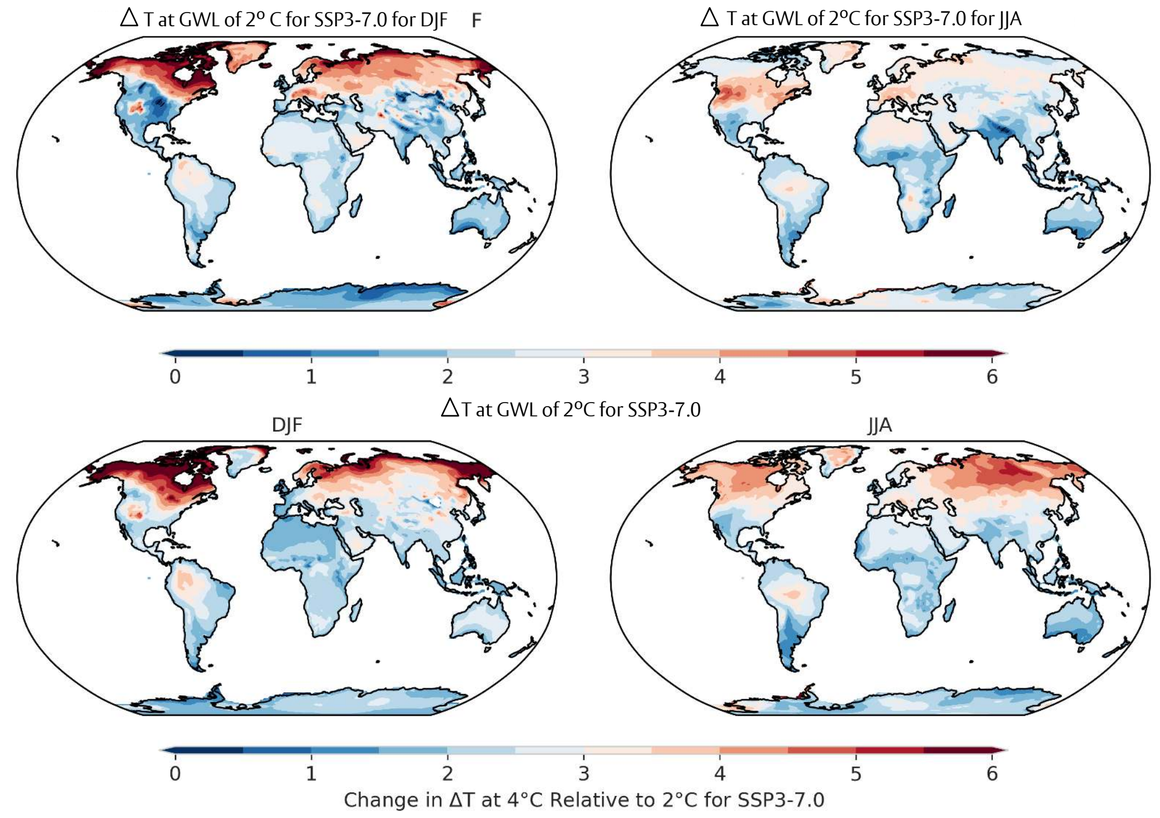

Fig 3. Surface temperature changes contrasted with a doubling from 2°C warming (top) to 4°C (bottom) in northern hemisphere winter (DJF) and summer (JJA).

c. UKESM1 Water cycle variable changes under SSP3-7.0

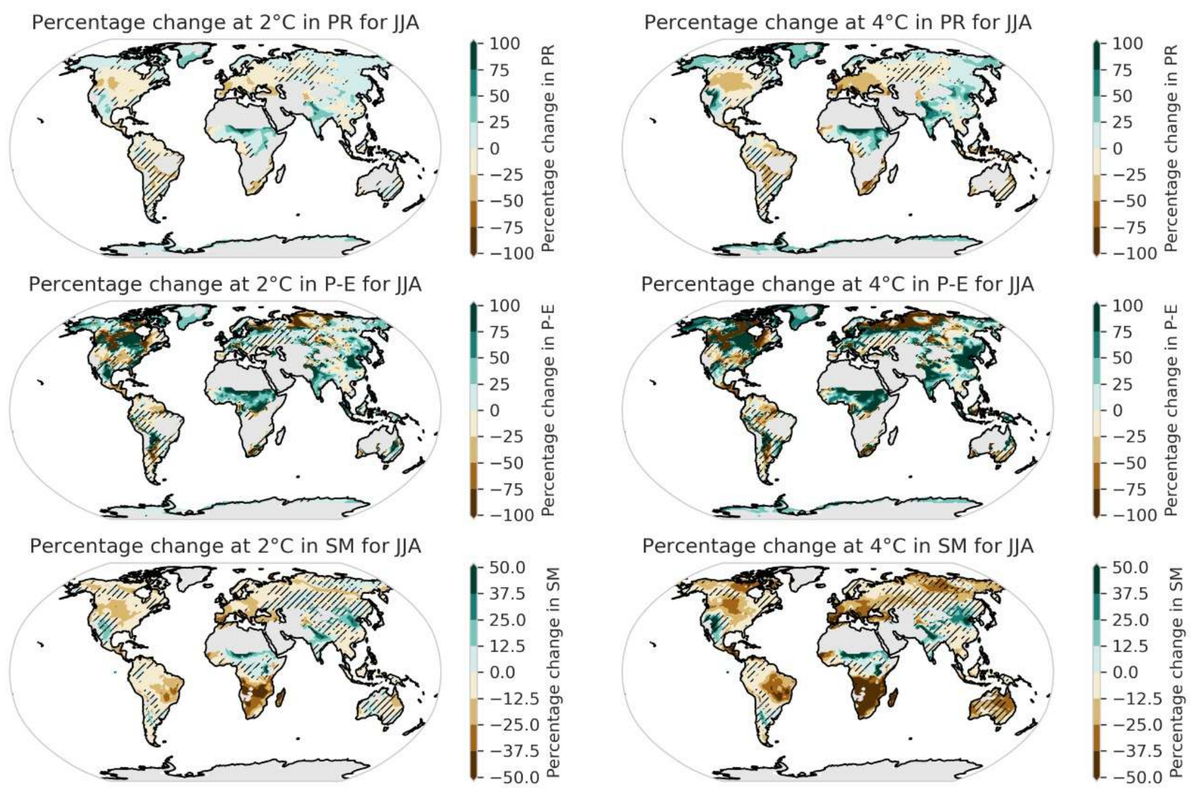

Fig 4. Changes in precipitation (PR), precipitation minus evaporation (P-E) and soil moisture (SM) at 2°C warming vs 4°C warming for the northern hemisphere summer (JJA) season. Hatched regions are where the magnitude of change is less than natural variability.

Conclusions

- **20 (out of 32) CMIP6 models exceed the 2°C GWL** by 2075 under SSP1-2.6 and **14 (out of 29) and 23 (out of 32) models exceed 4°C GWL** by the end of the century under SSP3-7.0 and SSP5-8.5 respectively.
- **Arctic amplification could exceed 2-2.5 times global mean temperature** changes in the DJF season and 1.5 times in JJA, risking the release of carbon by thawing out permafrost.
- **Mediterranean precipitation in JJA reduces** by 20-25% at 2°C warming and by double that with a 4°C warming. Soil moisture shows a similar decrease and could cause extreme water stress in the region.
- **Indian monsoons intensify** with a doubling in warming and will require adequate planning and measures for flood management.
- Not all regional changes scale uniformly with doubling in warming.

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