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Climate projections from IPCC models and regression models: A comparison

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Abstract. In this paper, we show that the projected global temperature change from CMIP5 models is remarkably similar to that obtained using simple regression models relating the global temperature to the atmospheric concentrations of CO2. This result is strengthened when we consider the projections obtained using the CMIP6 models.

1 Introduction

General circulation climate (GCM) models are mathematical models based on a system of deterministic differential equations. They are used to simulate the behavior of the main climate variables (temperature and precipitation, for example). In particular, we consider the projections of the global mean temperature obtained using the Coupled Model Intercomparison Project Phase 5 and 6 (CMIP5 and CMIP6) models (Knutti et al. 2013, Eyring et al. 2016).

Climate projections are generally presented for a range of scenarios. A climate scenario is a plausible evolution of greenhouse gases (GHG) and other anthropogenic in influences on climate, such as aerosols.

In the Fifth Assessment Report (AR5) the Intergovernmental Panel on Climate Change (IPCC) uses different scenarios to estimate how the climate could change in the future, known as Representative Concentration Pathways (RCPs). They include a stringent mitigation scenario (RCP2.6), two inter- mediate scenarios (RCP4.5 and RCP6.0), and one scenario with very high GHG emissions (RCP8.5). A detailed scenarios description can be found in Taylor et al. (2012). The projections, starting in 2005, of the global mean temperature presented in the AR5 report are obtained using the CMIP5 models.

The projections from CMIP6 models are based on a set of scenarios known as Shared Socioeconomic Pathways (SSPs). They start in 2015, and include scenarios with high and very high GHG emissions (SSP3-7.0 and SSP5-8.5) and CO_2 emissions that roughly double from current levels by 2100 and 2050, respectively, scenarios with intermediate GHG emissions (SSP2-4.5) and CO_2 emissions remaining around current levels until the middle of the century, and scenarios with very low and low GHG emissions and CO_2 emissions declining to net zero around or after 2050, followed by varying levels of net negative CO_2 emissions (SSP1-2.6). More details can be found in Riahi et al. (2017), Meinshausen et al. (2020) and Tebaldi et al. (2021).

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In this paper, we show that the projected global temperature change from CMIP5 models is remarkably similar to that obtained using simple linear regression models relating the global temperature to the atmospheric concentrations of CO_2. This conclusion is strengthened when we consider the projections obtained using the CMIP6 models.

2 The estimated linear regression models

A long body of research suggests that between the global mean temperature and the logarithm of atmospheric CO_2 concentrations there exists a linear relationship (see, for example, Manabe and Wetherald (1967); Forster et al. (2007)). Thus we have conducted a regression analysis specifying the following simple regression model

$$y = \alpha + \beta x + u, \qquad (1)$$

where y is the global annual land and sea surface temperature, x is the logarithm of atmospheric CO_2 concentrations and u is an error term.

Although we have observations from 1850, we have estimated the model (1) over the periods 1976-2005 and 1976-2014. Our focus on these periods is motivated by the structural break on the year 1976 in the global temperature series (see Mills (2013) and Figure 1). Regression results are reported in Tables 1-2. In formula, we have

$$y = -25.6992 + 4.36311\, x \qquad (2)$$

and

$$y = -21.0664 + 3.57106\, x \qquad (3)$$

The coefficient of our independent variable is significantly different from zero in both regressions. Further, the results of the White's test for heteroskedasticity and the Breusch-Godfrey test for autocorrelation show that the residuals of the models (2) and (3) are homoscedastic and not autocorrelated. Therefore, these models appear to be correctly specified.

3 The comparison

In this section, we compare the projections of global-mean temperature presented in the IPCC AR5 and AR6, with those obtained using model (2) and (3), respectively. Projected future global temperature anomalies under RCP scenarios obtained using the CMIP5 models and the regression model (2) are reported in Figure 2 and Figure 3, respectively.

It is evident that the model (2) predicts very similar responses (in terms of global temperature) to climate change in comparison to the CMIP5 models. Data shown in Tables 3 and 4 also confirm this assessment. Dynamic predicted by linear model (2) is remarkably similar to that obtained using the CMIP5 models. Figure 5-7 show that this result is reinforced when we consider

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the comparison between the projections of global-mean temperature presented in the IPCC AR6, with those obtained using Model (3).

Root Mean Square Error (RMSE) is also used to evaluate the distance between the projections of global-mean temperature presented in the IPCC AR5 and AR6, and those obtained using model (2) and (3), respectively. The obtained results are reported in Table 5 and 6. By comparing these tables, we can deduce the following facts.

1. The ability of the regression model to reproduce the IPCC projections increases when the projections based on CMIP6 models are considered.
2. The ability of the regression model to reproduce the ICCP projections increases when the more severe scenarios are considered.

4 Conclusions

Projections of the global temperature obtained using the regression models (2) and (3) are remarkably similar to that obtained using CMIP5 and CMIP6 models, respectively. It seems that through a simple, physically based statistical model, is possible to summarize the complex (and nonlinear), interacting processes needed to simulate the behaviour of the global temperature. We believe that our conclusion is very interesting and should spur additional debate about the suitability of GCMs. If we want to estimate, or predict, the global mean warming due to the increase in the concentration of CO_2, GCMs do not appear to do better than simple regression models. However, this statement refers to the global mean temperature only. It could be interesting to check in which areas GCMs can provide valuable information, skilful predictions that simple regression models cannot provide. For example, can one predict the warming of the climate hot spots (poles, Mediterranean region) with a regression model? Can one explain the vertical profile of global warming using regression models?

Data availability

The data used in this study include:

1. Global annual land and sea surface temperature from HadCRUT4 dataset.
   This data set has been developed by the Climatic Research Unit (University of East Anglia) in conjunction with the Hadley Centre (UK Met Office). Data have been obtained from Met Office Hadley Centre web-
   site: http://www.meto ce.gov.uk/hadobs/hadcrut4/data/current/download.html;

2. Historical atmospheric CO_2 concentrations as well as concentrations for the RCPs (2005-2100) (Meinshausen et al (2011)). Data have been ob-
   tained from website: http://www.pik-potsdam.de/~ mmalte/rcps/index.htm.

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3. CO_2 concentrations for the SSPs (2015-2100). Data are available at: https://doi.org/10.5194/gmd-13-3571-2020-supplement

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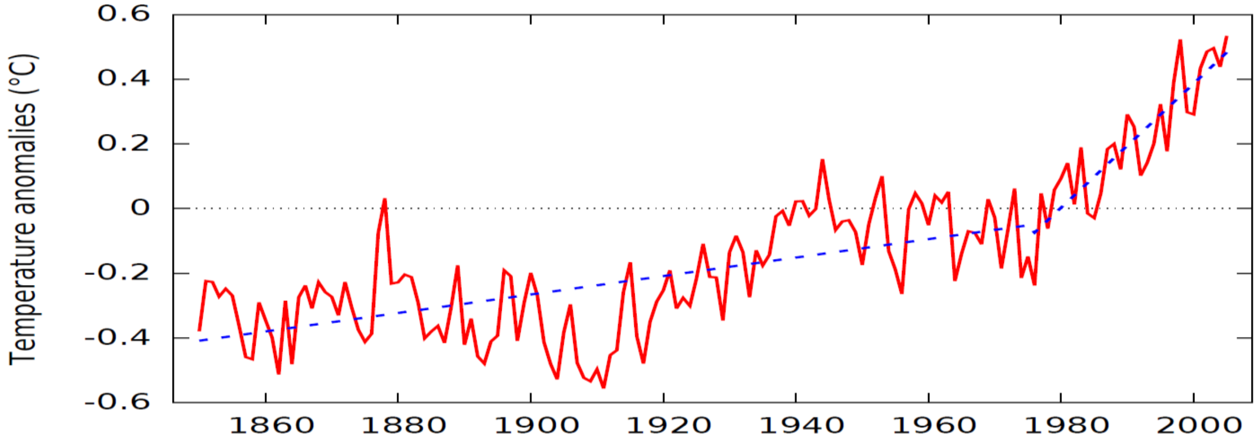
Figure 1: Breaking trend for HADCRUT4 global temperature series.



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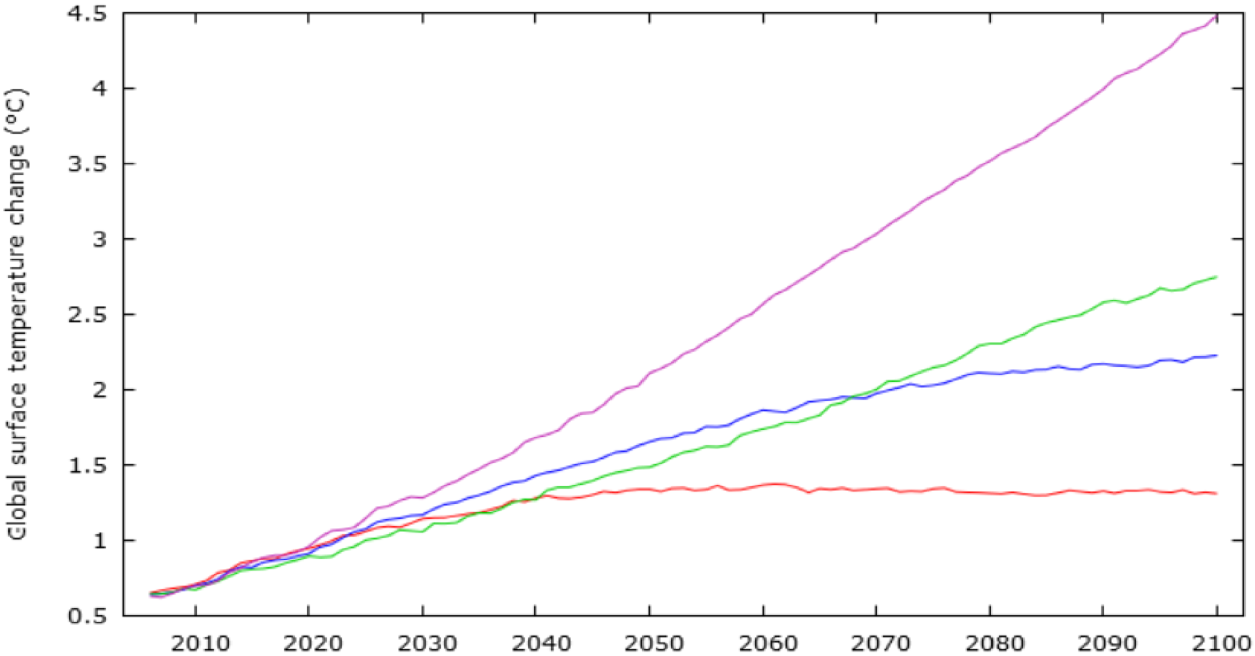

Figure 2: Global mean temperature change averaged across all Coupled Model Intercomparison Project Phase 5 (CMIP5) models (expressed relative to the 1986-2005 reference period) for the four Representative Concentration Pathway (RCP) scenarios: RCP2.6 (red), RCP4.5 (blue), RCP6.0 (green) and RCP8.5 (violet).

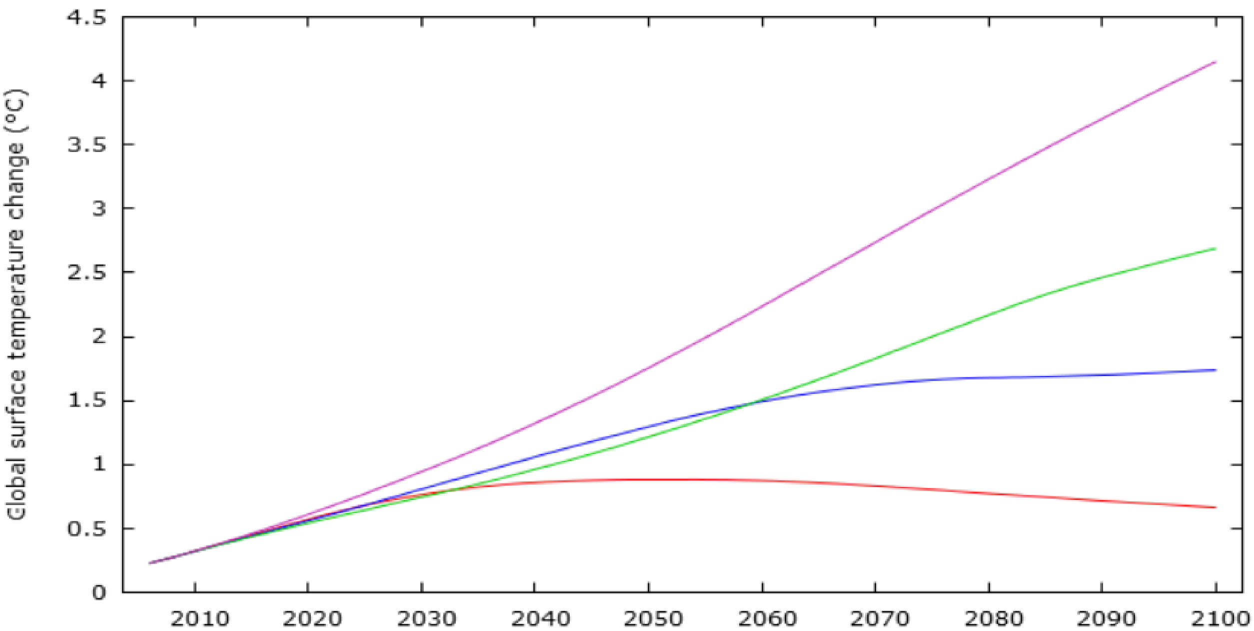

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Figure 3: Global mean temperature change (relative to 1986-2005 reference period) obtained using the regression model (2), for the four Representative Concentration Pathway (RCP) scenarios: RCP2.6 (red), RCP4.5 (blue), RCP6.0 (green) and RCP8.5 (violet).

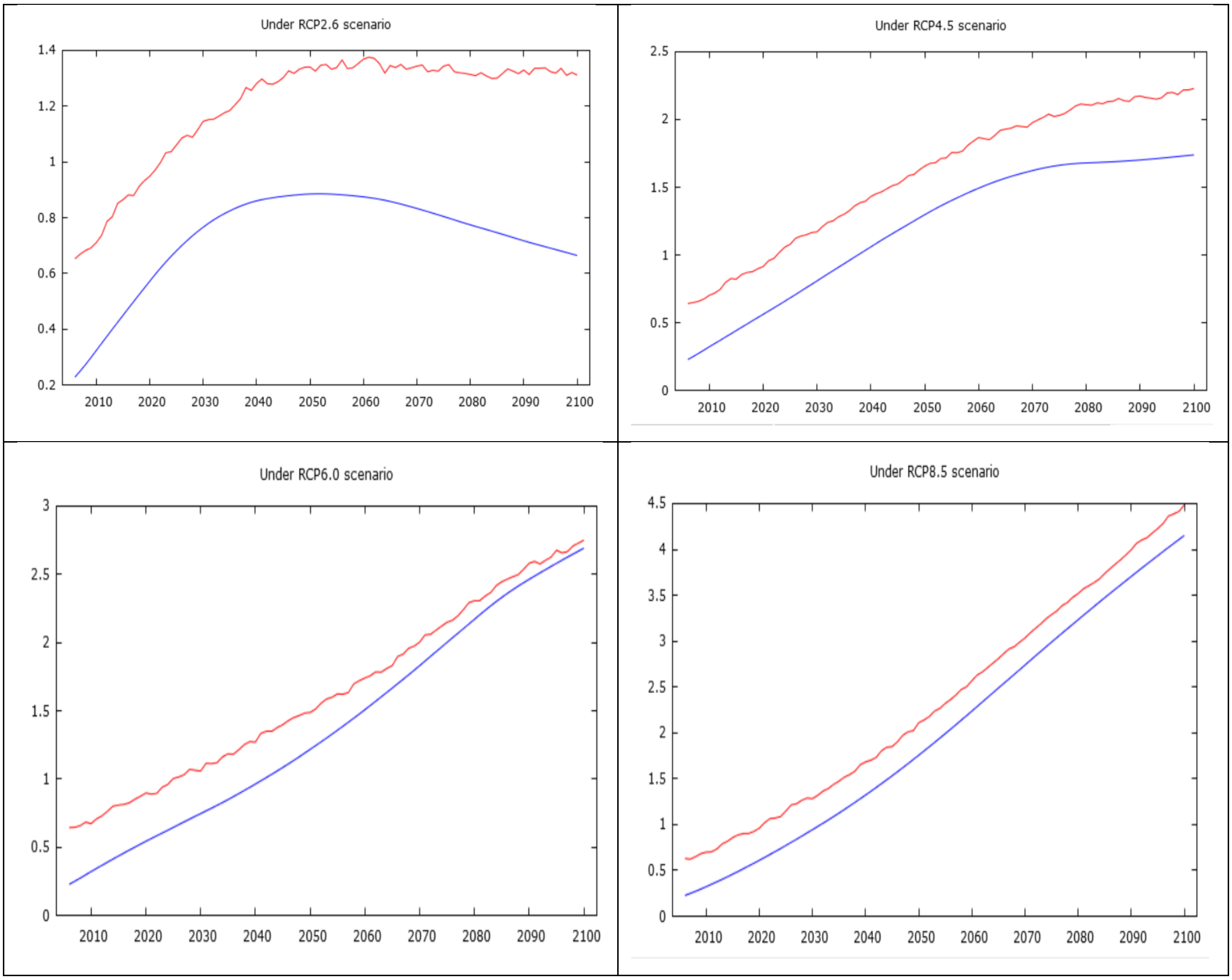

Figure 4: Global mean temperature change averaged across all Coupled Model Intercomparison Project Phase 5 (CMIP5) models (expressed relative to the 1986-2005 reference period) (red). Global mean temperature change (relative to 1986 2005 reference period) obtained using the regression model (2) (blue). The two projections are compared under each scenario.

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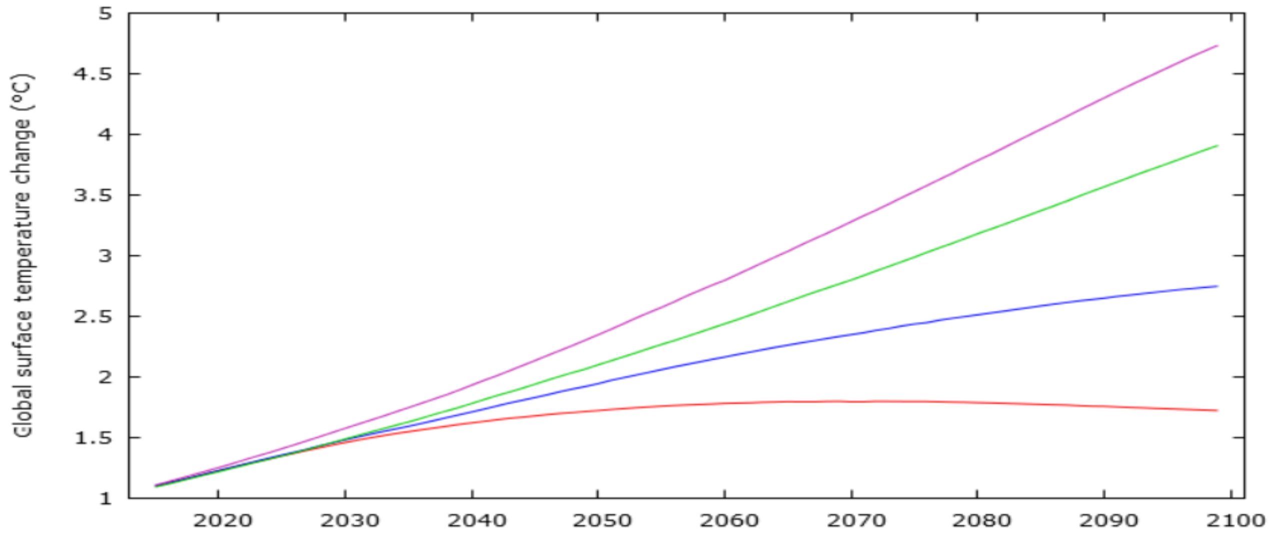

Figure 5: Global mean temperature change averaged across all Coupled Model Intercomparison Project Phase 6 (CMIP6) models (expressed relative to the 1850-1900 reference period) for four Shared Socioeconomic Pathway (SSP) scenarios: SSP1-2.6 (red), SSP2-4.5 (blue), SSP3-7.0 (green) and SSP5-8.5 (violet).

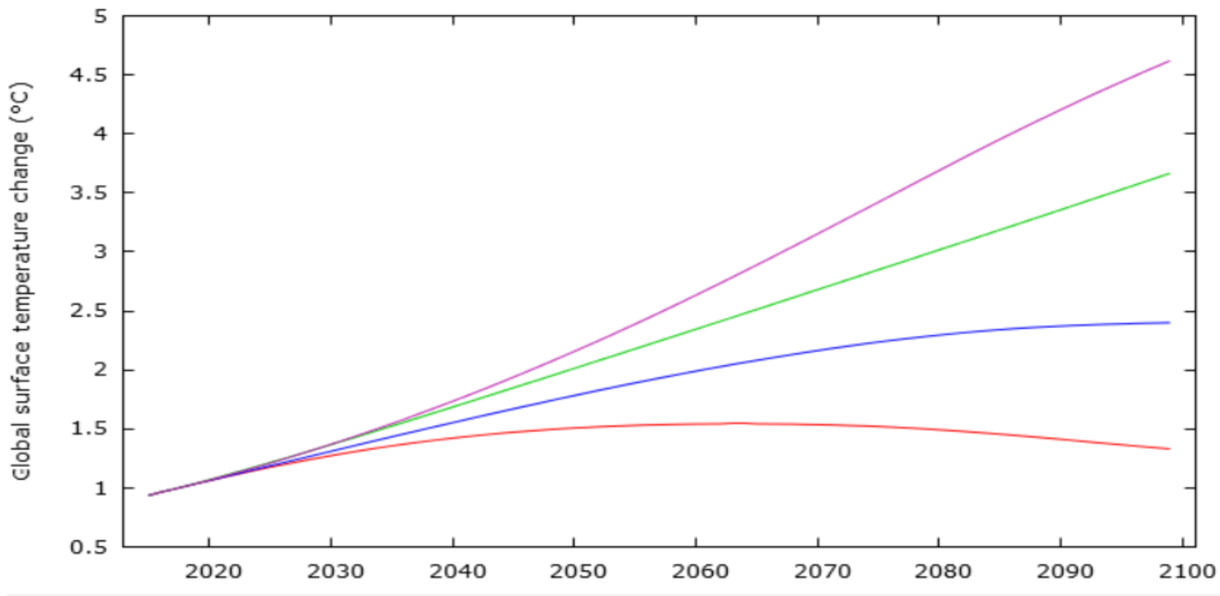

Figure 6: Global mean temperature change (relative to the 1850-1900 reference period) obtained using the regression model (3) for four Shared Socioeconomic Pathway (SSP) scenarios: SSP1-2.6 (red), SSP2-4.5 (blue), SSP3-7.0 (green) and SSP5-8.5 (violet).

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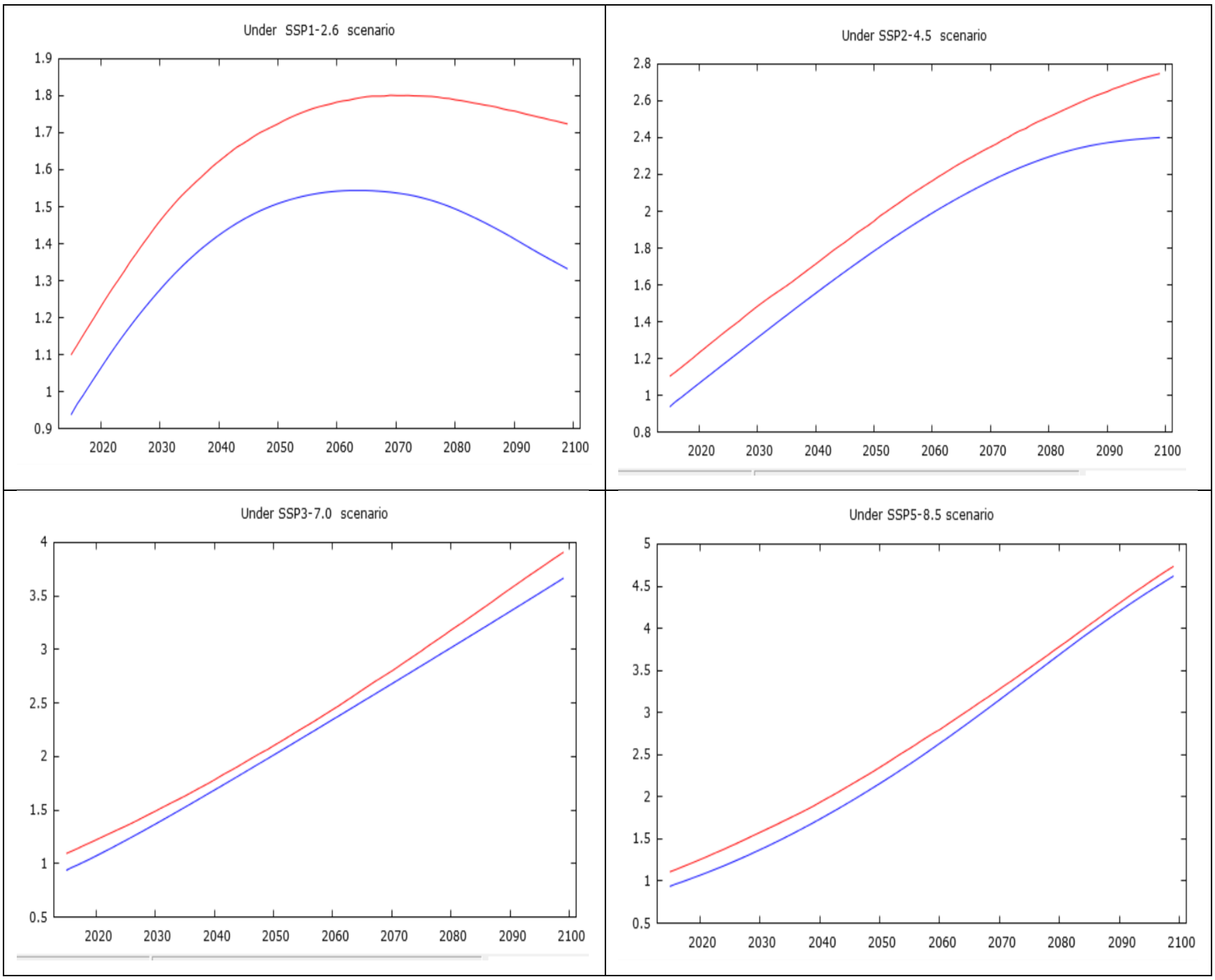

Figure 7: Global mean temperature change averaged across all Coupled Model Intercomparison Project Phase 5 (CMIP6) models (expressed relative to the 1850-1900 reference period) (red). Global mean temperature change (relative to 1850-1900 reference period) obtained using the regression model (3) (blue). The two projections are compared under each scenario.

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Table 1. Estimated model: OLS, using observations 1976-2005, dependent variable: y

	Coefficient	Std. Error	t-ratio	p-value
const	-25.0664	2.54068	-10.12	0.0000
x	4.36311	0.43289	10.08	0.0000

Table 2. Estimated model: OLS, using observations 1976-2014, dependent variable: y

	Coefficient	Std. Error	t-ratio	p-value
const	-21.0664	1.66141	-12.68	0.0000
x	3.57106	0.28192	12.67	0.0000

Table 3: CMIP5 model projections. Global annual mean temperature changes (ΔT in °C) above 1986- 2005 for selected time periods of each RCP scenario.

Scenario	ΔT 2046-2065	ΔT 2081-2100
RCP2.6	1.0	1.0
RCP4.5	1.4	1.8
RCP6	1.3	2.2
RCP8.5	2.0	3.7

Table 4: Linear regression model projections. Global annual temperature changes (ΔT in °C) above 1986-2005 for selected time periods of each RCP scenario.

Scenario	ΔT 2046-2065	ΔT 2081-2100
RCP2.6	0.870	0.715
RCP4.5	1.402	1.705
RCP6	1.378	2.465
RCP8.5	2.022	3.723

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Table 5: Distance between CMIP5 model projections and those obtained using model (2), for each RCP scenario.

Scenario	RMSE
RCP2.6	0.479
RCP4.5	0.391
RCP6	0.265
RCP8.5	0.334

6: Distance between CMIP6 model projections and those obtained using model (3), for each RCP scenario.

Scenario	RMSE
SSP1-2.6	0.255
SSP2-4.5	0.204
SSP3-7.0	0.144
SSP5-8.5	0.162