Trend analysis and empirical estimates of Transient Climate Sensitivity in the CMIP6

Thomas Leirvik, Menghan Yuan

Graduate School of Business, Nord University

May 7, 2020

NORD University

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Background and Research Objectives

Surface solar radiation (SSR) is a fundamental determinant of the Global Energy Balance, a crucial driving force for temperature and hydrological cycles variation.

In this study, we aim to obtain an understanding on the latest updates on

- Historical climate changing from a perspective of SSR and temperature;
- Transient Climate Sensitivity (TCS) estimates to a doubling of atmospheric CO_2 based on an econometric framework are investigated;
- Land-ocean warming ratio, temperature change over land surface compared to the ocean surface.

Data sets in use:

- **Temperature and SSR**:
  - **Simulations**
    The study encompasses 25 members of CMIP6 Global Climate Model (GCM) available up to the time of writing. The first realization for each model is downloaded from the ESGF.
  - **Observations**
    Observational temperature data is from the CRU; SSR data is from the GEBA website.
- CO_2 **equivalent concentrations**:
  Downloaded from the NOAA Annual Greenhouse Gas Index (AGGI) data set.

Time period:

The research focuses on a time period from 1960 to 2014.

Econometric Framework for TCS estimation:

Phillips et al. (2020)[1] constructed an Econometric model for estimating TCS empirically.

The framework relates the three variables $(\bar{T}_t, \bar{R}_t, ln(CO_{2,t}))$ in the linear relation

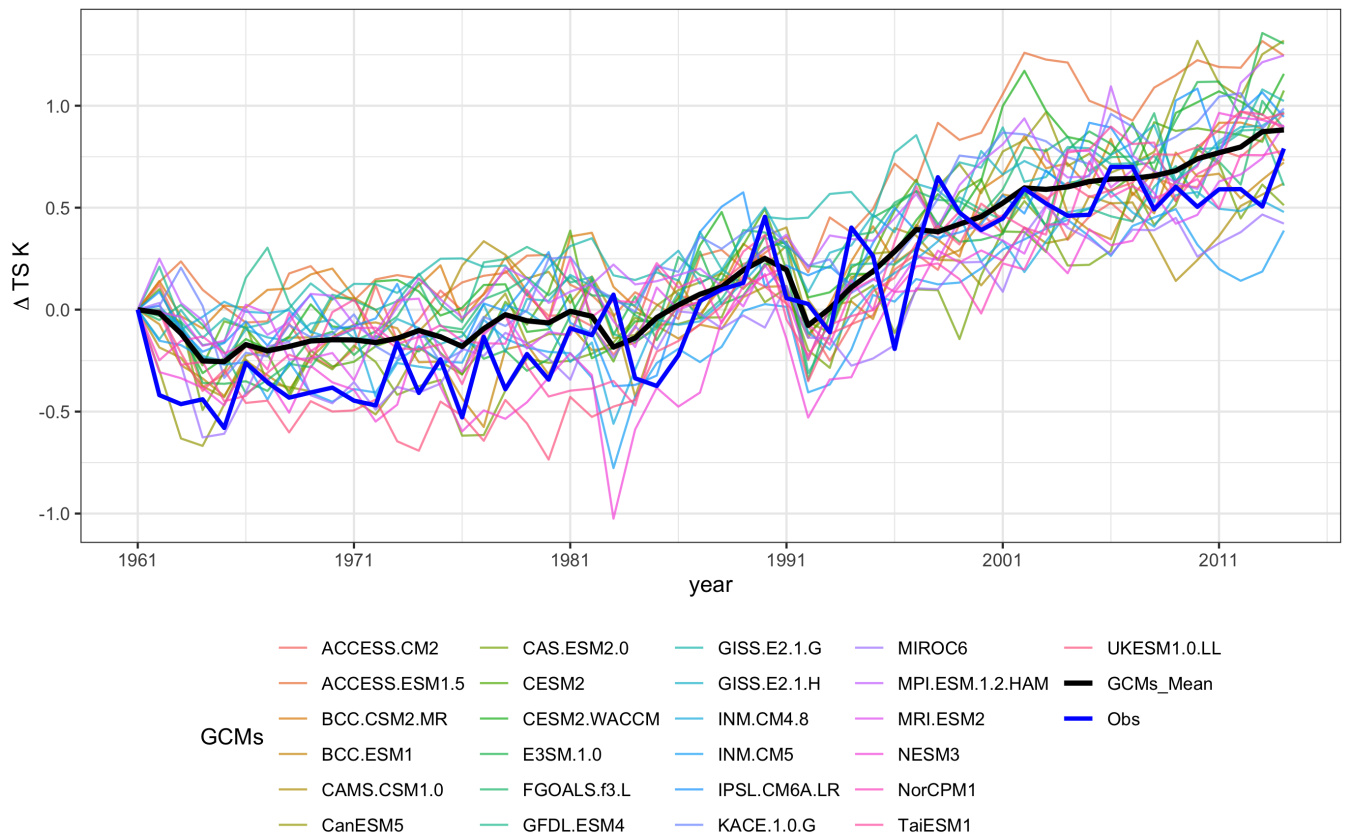
$$\bar{T}_{t+1} = \gamma_0 + \gamma_1 \bar{T}_t + \gamma_2 \bar{R}_t + \gamma_3 ln(CO_{2,t}) + \bar{u}_{.t+1}$$

from which the TCS is estimated as $TCS = \frac{\gamma_3}{1-\gamma_1} \times ln(2)$.

[1] Peter C.B. Phillips, Thomas Leirvik, and Trude Storelvmo. "Econometric estimates of Earth's transient climate sensitivity". In: *Journal of Econometrics* 214.1 (Jan. 2020), pp. 6–32. ISSN: 18726895. DOI: 10.1016/j.jeconom.2019.05.002.

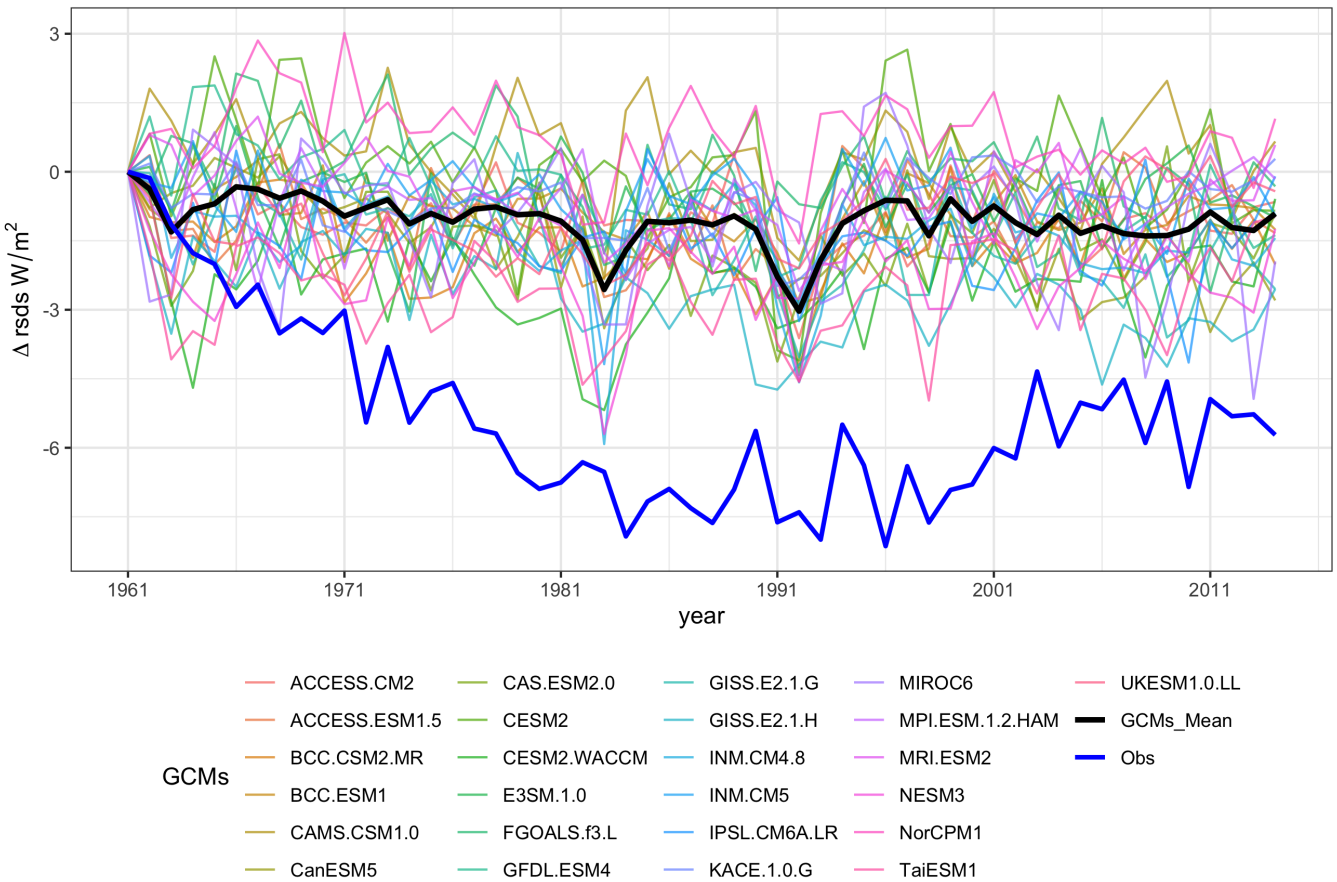
Temperature trends in CMIP6 GCMs and observation

Note that the current study focuses on a spatial coverage defined by the GEBA data set. An coverage overlay is conducted on various data sets (CMIP6 GCMs and CRU) to match the GEBA.



SSR trends in CMIP6 GCMs and observation

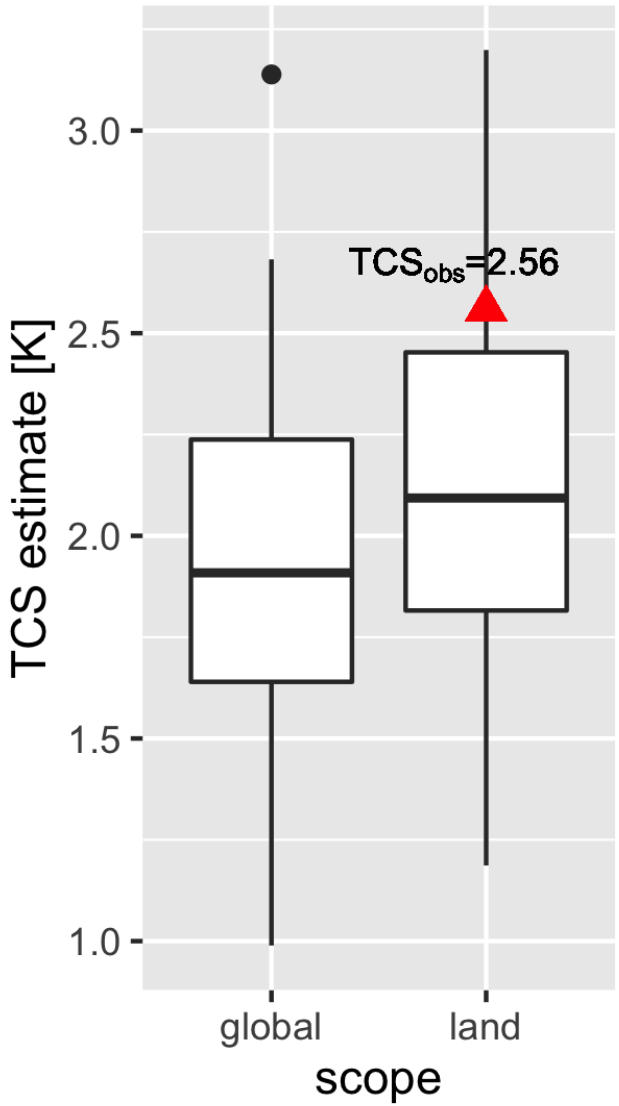
A counterpart figure is obtained for SSR.



Results - TCS estimates for CMIP6

Table Summary statistics of TCS estimates

	TCS_G	TCS_L
Min.	0.989	1.187
1st Qu.	1.640	1.816
Median	1.909	2.093
Mean	1.903	2.142
3rd Qu.	2.238	2.453
Max.	3.138	3.199
St. dev	0.490	0.514



Results - TCS estimates for CMIP6

Figure Distribution of TCS in CMIP6

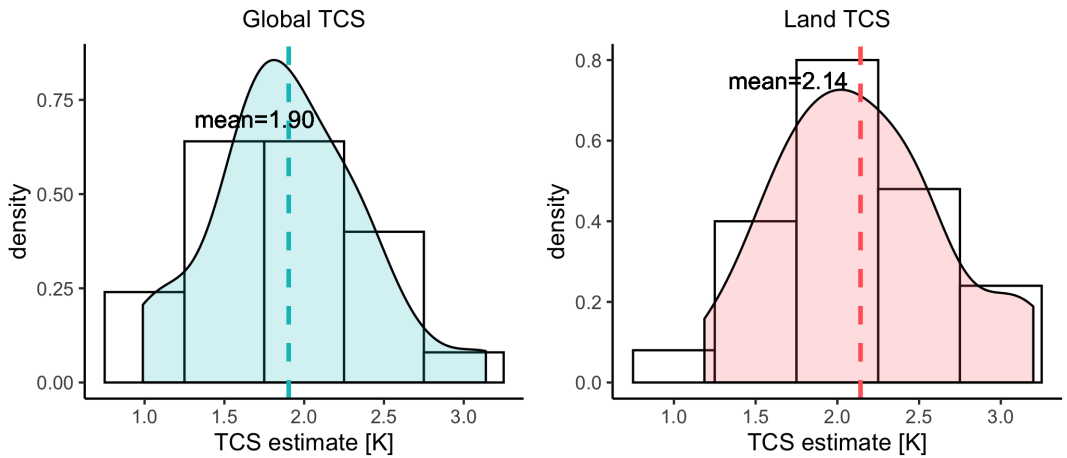
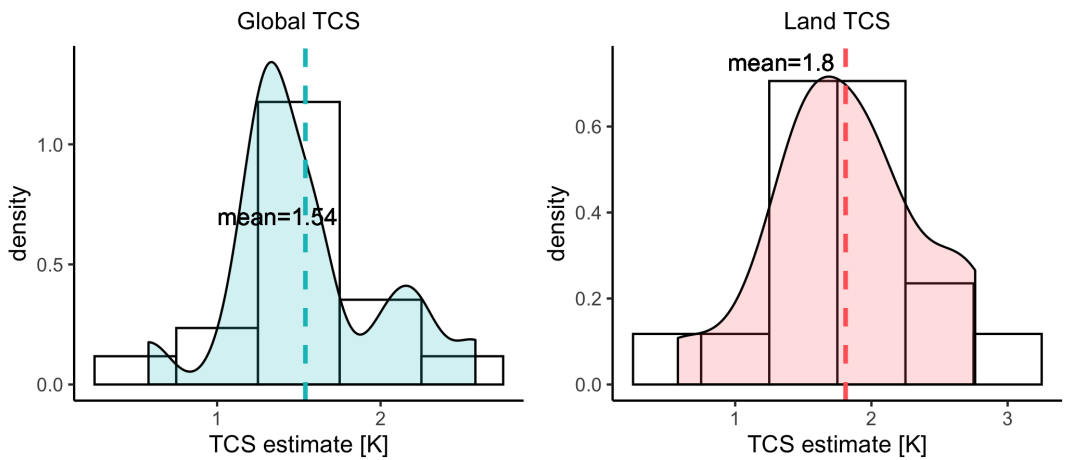


Figure Distribution of TCS in CMIP5 from Phillips et al. (2020)

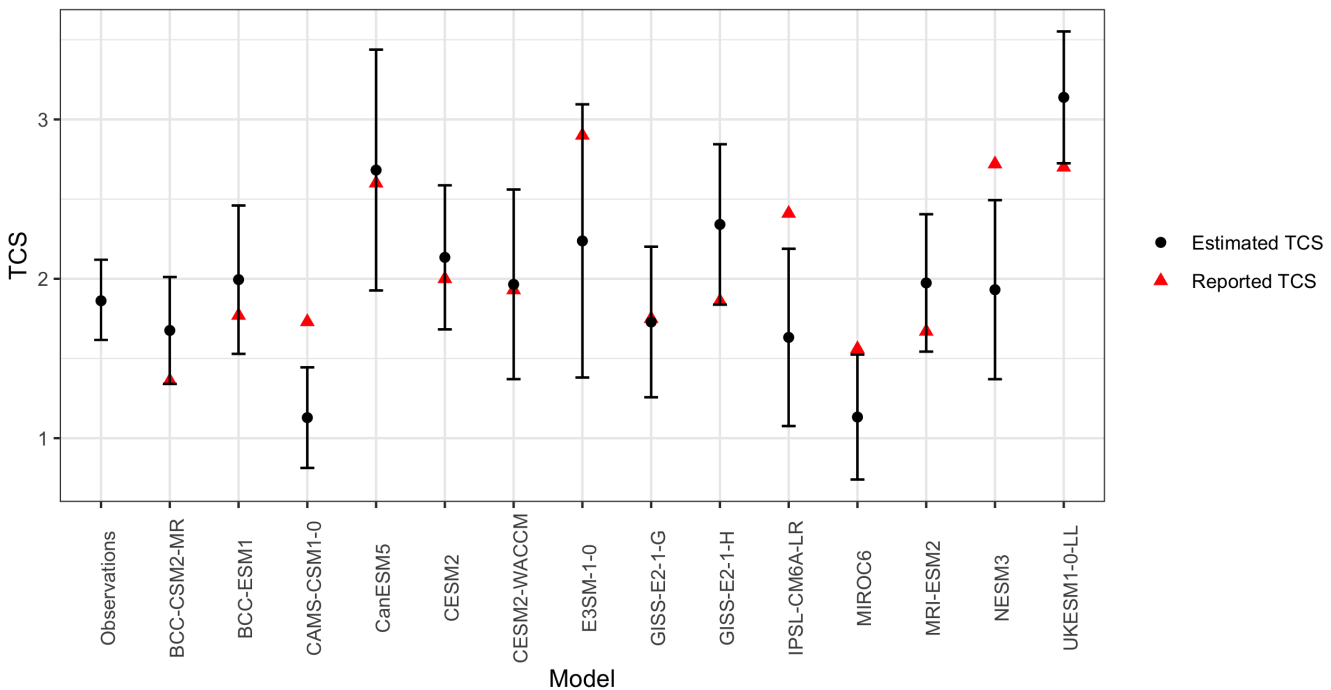


A t-test on global TCS for CMIP5 agaist CMIP6: $t(34.93) = 2.38, p = 0.023$.

Results - TCS estimates for CMIP6

Model	Scope	TCS	St. dev.	$CI_{L,.95}$	$CI_{U,.95}$
NorCPM1	global	0.99	0.19	0.63	1.35
	land	1.41	0.26	0.91	1.92
CAS-ESM2-0	global	1.52	0.29	0.96	2.09
	land	1.85	0.30	1.25	2.45
INM-CM4-8	global	1.74	0.12	1.51	1.98
	land	1.65	0.19	1.28	2.02
FGOALS-f3-L	global	1.91	0.19	1.53	2.29
	land	2.23	0.17	1.89	2.56
NESM3	global	1.93	0.29	1.37	2.49
	land	2.20	0.32	1.58	2.82
MRI-ESM2	global	1.97	0.22	1.54	2.40
	land	2.00	0.29	1.43	2.57
E3SM-1-0	global	2.24	0.44	1.38	3.09
	land	3.00	0.41	2.20	3.81
KACE-1-0-G	global	2.42	0.12	2.18	2.65
	land	2.57	0.19	2.19	2.94
CanESM5	global	2.68	0.39	1.93	3.44
	land	3.10	0.46	2.20	4.00
UKESM1-0-LL	global	3.14	0.21	2.73	3.55
	land	3.20	0.18	2.84	3.56

Comparison of estimated global TCS with reported global TCS



Land-ocean warming ratio

The land-ocean warming ratio (WR) is defined as the warming rate over land surface, W_L, divided by the warming rate over ocean surface, W_O. In particular,

$$
\begin{aligned}
Temp_{t,L} &= Temp_{0,L} + W_L \times t \\
Temp_{t,O} &= Temp_{0,O} + W_O \times t \\
WR &= \frac{W_L}{W_O}
\end{aligned}
$$

where t indicates for year.

Land-ocean Warming Ratio

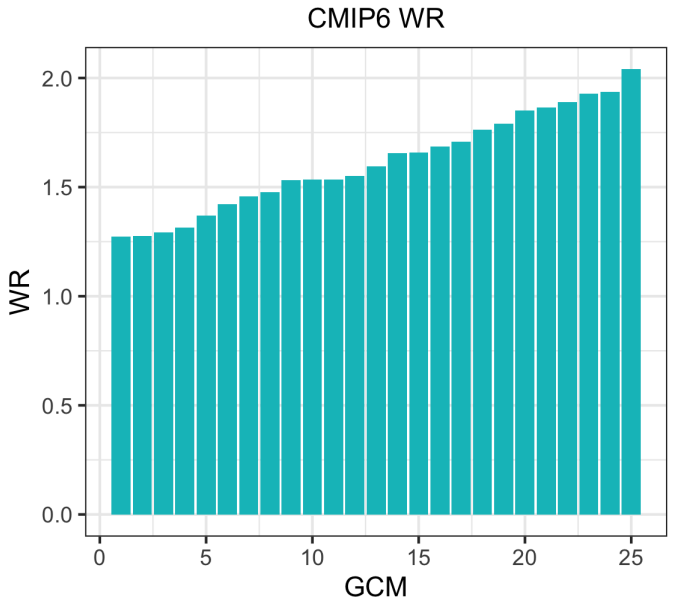
Table Summary statistics of WR

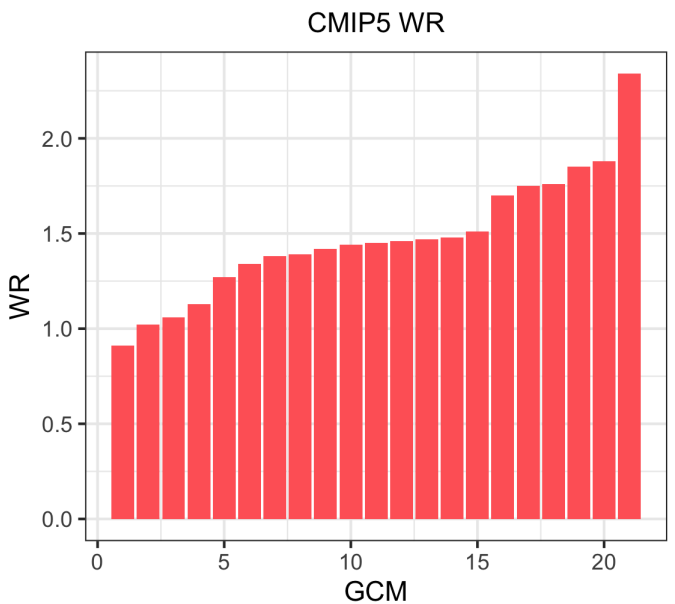
	CMIP6	CMIP5
Min.	1.27	0.91
1st Qu.	1.46	1.34
Median	1.60	1.45
Mean	1.62	1.48
3rd Qu.	1.79	1.70
Max.	2.04	2.34
St. dev	0.23	0.33

CMIP5 WR is from Wallace and Joshi 2018[a].

A Welch two-sample t-test shows that:

$t(34.59) = 1.64, p = 0.109$





[a] C J J Wallace and M Joshi. "Comparison of land-ocean warming climate models Comparison of land-ocean warming ratios in updated In: *Environmental Research Letters* 13 (2018), p. 114011. DOI: 10.1(https://doi.org/10.1088/1748-9326/aae46f.