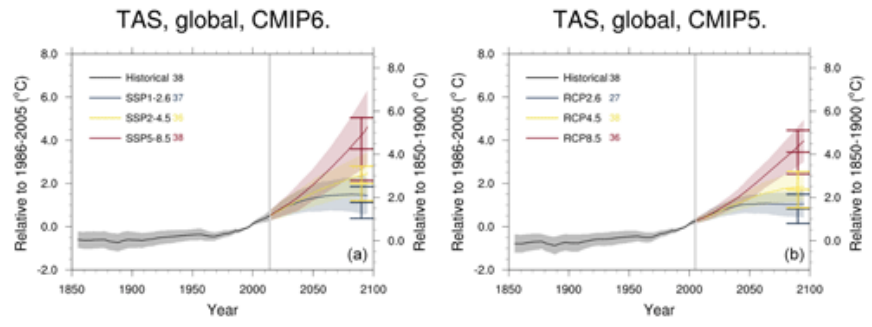


Warmer climate projections in CMIP6: the role of changes in the greenhouse gas concentrations from CMIP5 to CMIP6 in the EC-Earth3-Veg model

**Klaus Wyser, Erik Kjellström, Torben Koenigk, Helena Martins
and Ralf Döscher (2020): Warmer climate projections in EC-
Earth3-Veg: the role of changes in the greenhouse gas
concentrations from CMIP5 to CMIP6, *Env Res Letters*,
<https://doi.org/10.1088/1748-9326/ab81c2>**

CMIP6 projections are warmer than those from CMIP5



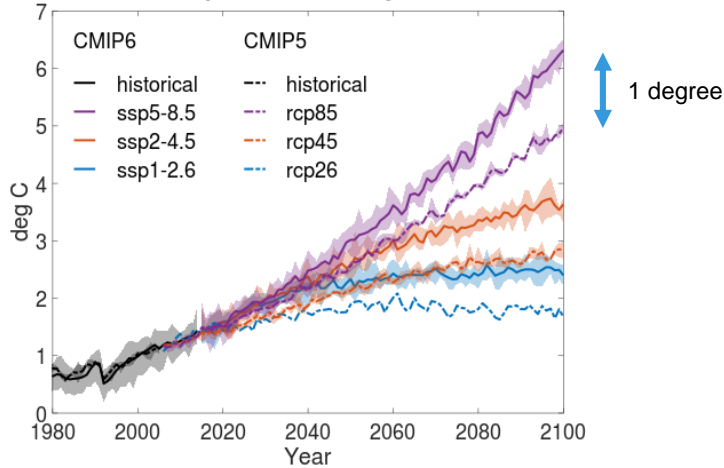
Tebaldi et al (2021): Climate model projections from the Scenario Model Intercomparison Project (ScenarioMIP) of CMIP6

Recent paper by Tebaldi et al. illustrates that CMIP6 future projections are warmer than those from CMIP5.

CMIP6 vs CMIP5 in the EC-Earth model

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Near surface temperature anomaly relative 1850-1870



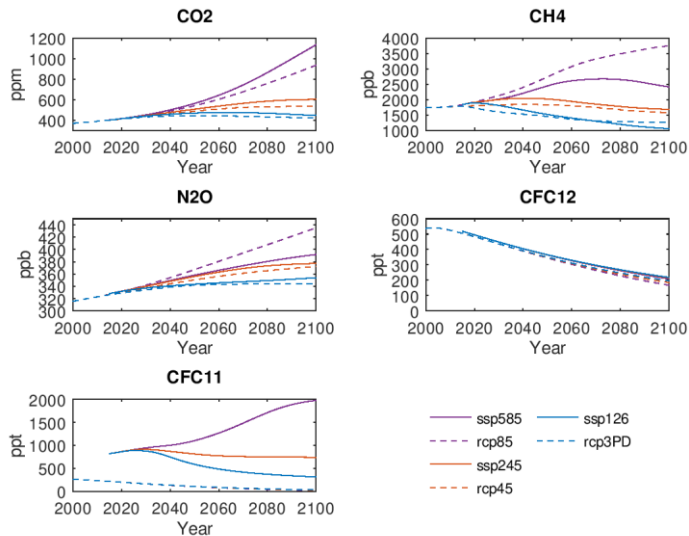
CMIP6: EC-Earth3-Veg, ECS = 4.3
CMIP5: EC-Earth v2.3, ECS=3.3

CMIP6 future projections with the EC-Earth model are warmer than those for CMIP5. One of the reasons is the higher climate sensitivity of EC-Earth3 compared to EC-Earth v2 (4.2 K compared to 3.3 K) that could explain an additional warming in the future scenarios. But is this the end of the story? In addition to model developments and higher resolution there were also changes in the forcing datasets (GHG, aerosols, land use, etc) when going from CMIP5 to CMIP6, and here we will look at the impact from the changes in GHG to see whether or not they also play a role for the additional warming in the CMIP6 simulations.

The SSP and RCP forcings are marked with their RF (radiative forcing) at the end of the 21st century, e.g. RCP85 stands for the RCP with 8.5 W/m² forcing at year 2100. In principle we would expect the same forcing for RCP and SSP with the same RF, and thus similar warming (apart from the contribution from changes in the climate sensitivity).

Future GHG concentrations in CMIP5 (dashed) and CMIP6 (solid)

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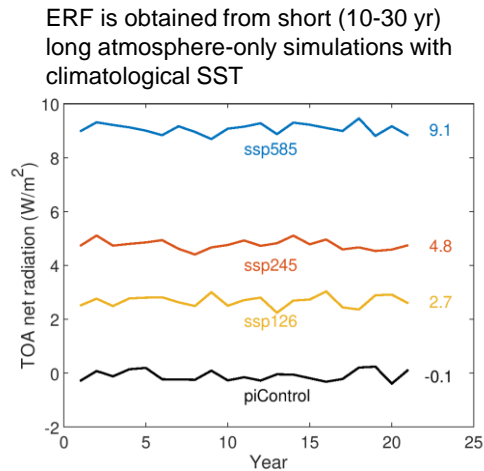
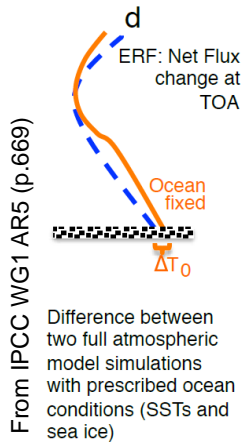


The EC-Earth model is concentration driven with these 5 major GHG concentrations as input. The concentrations shown here are part the official forcing datasets for CMIP5 and CMIP6. There are clear differences between SSPs (used in CMIP6) and RCPs (used in CMIP5). Some of the changes from CMIP5 to CMIP6 may compensate each other, e.g. the increase of CO₂ in the 8.5 scenarios could be compensated by the decrease of methane.

The big question is what do the changes in GHG concentrations mean for the RF. The providers of the forcing datasets state that the radiative forcing of the scenarios is the given by the name of the scenario, e.g. 8.5 W/m² for the SSP5-8.5 scenario. Can we check these RF values?

Effective radiative forcing

Not (easily) possible to measure radiative forcing (RF) with climate model -> Effective Radiative Forcing (ERF) is easy to assess (but model dependent because of feedbacks)



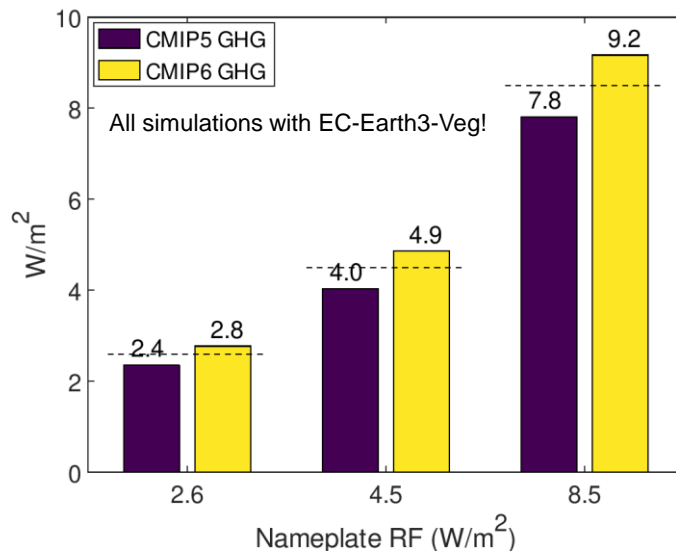
Unfortunately it's not easy to measure the RF of the forcing datasets. As an alternative to the instantaneous RF we could look at the effective radiative forcing (ERF) which is easier to determine. The major difference to RF is that ERF measures the imbalance in the net radiation with all feedbacks in the atmosphere included (for a discussion of the different measures of the radiative forcing please see definition in IPCC WG1 AR5 p.696). To get the ERF of the different scenarios we make short (21 yr long) atmosphere-only simulations with the EC-Earth3 model with prescribed climatological SST (from the piControl simulation) and all forcings (GHG, aerosols, stratospheric ozone) from the SSPs. ERF is the resulting top of the atmosphere net radiation imbalance for each scenario.

We then repeat the atmosphere-only experiments but replace the GHG concentrations from CMIP6 by those from CMIP5, everything else being the same.

Note that the ERF methodology is widely used by RFMIP to assess various contributions to the radiative forcing.

ERF at end of 21st century

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The results show that ERF with all CMIP6 forcings is larger than the RF, e.g. $9.2 W/m^2$ for the SSP with $RF=8.5 W/m^2$. This is not a problem: ERF and RF can be different because ERF includes all feedbacks (except those from the ocean).

After replacing the CMIP6 GHG concentrations by those from CMIP5 the ERF drops considerably, e.g. by $1.4 W/m^2$ for the $8.5 W/m^2$ scenario. It is important to note that this result has been obtained with the same model (i.e. our CMIP6 model) with the very same climate sensitivity. The change in ERF is thus caused solely by the change in GHG concentrations!

Testing CMIP5 GHG concentrations in full simulations

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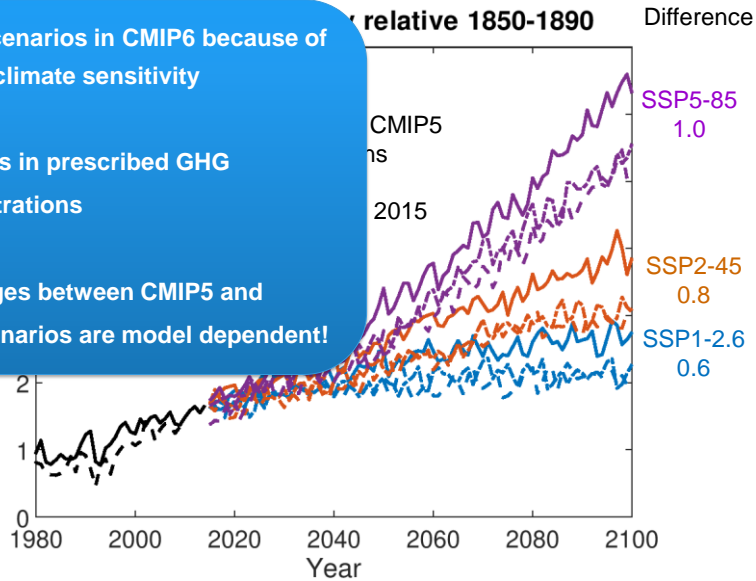
Warmer scenarios in CMIP6 because of

- Higher climate sensitivity

AND

- Changes in prescribed GHG concentrations

NB: Changes between CMIP5 and CMIP6 scenarios are model dependent!



To test the impact of the changes in the GHG forcing datasets we have repeated fully coupled CMIP6 experiments but with the GHG concentrations from CMIP5 (all other forcings are from CMIP6). There are 2 different experiments: one that starts from 1850 with a historical simulation followed by scenarios (dashed), and the other that starts from initial conditions from the original CMIP6 historical runs in 2015 (dashed-dotted). Both experiments yield similar results during the 21st century, clearly less warm than the CMIP6 simulations. We also see that the differences during the historical period are small, telling us that the differences at the end of the 21st century are mainly caused by the changes from RCPs to SSPs in the scenarios.

The numbers to the right of the plot are the temperature differences between the CMIP6 simulation and the new experiment with CMIP5 GHGs. The numbers in parenthesis are the estimates for the change in the warming obtained with the linear relationship between ERF and warming. We see that the warming in the real experiment exceeds the estimate telling us that the estimate is probably rather conservative. But we should also keep in mind that the estimates for the warming are based on ensembles with several members whereas the sensitivity experiment shown here is for a single member and we can therefore expect some variability.