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Warmer climate projections in CMIP6: the role of changes in the greenhouse gas concentrations from CMIP5 to CMIP6

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

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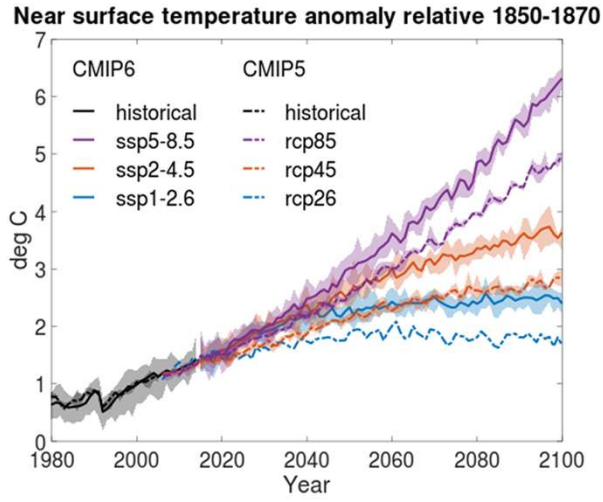
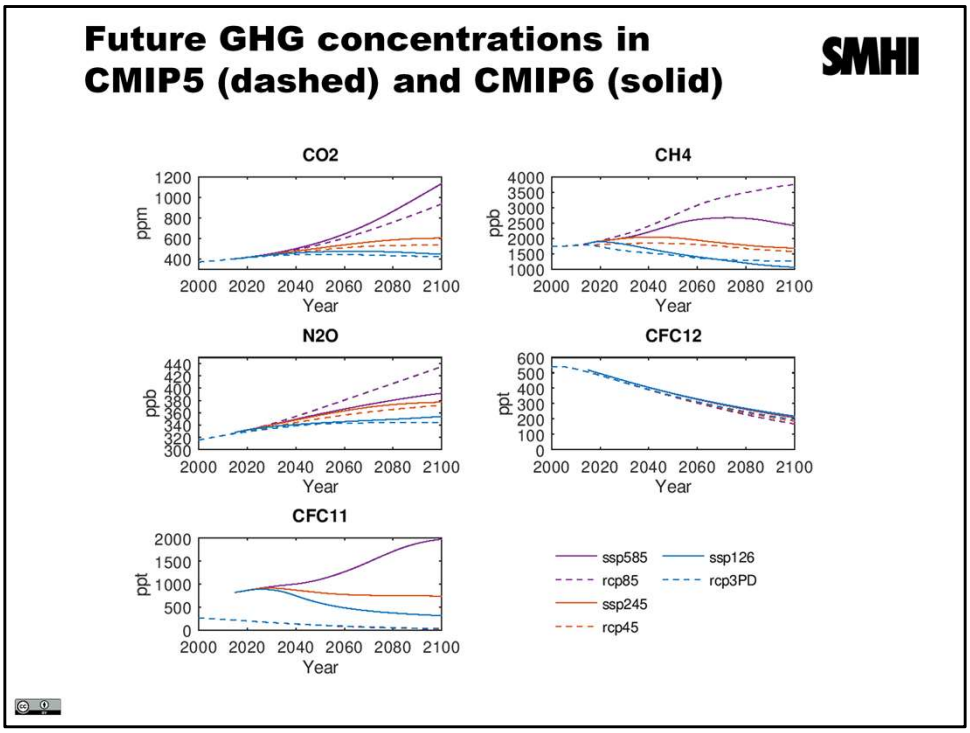


CMIP6: EC-Earth3-Veg (6 members)
CMIP5: EC-Earth v2.3 (3 members for rcp85 and rcp45, 1 member for rcp2.6)

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).



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 (ERF)

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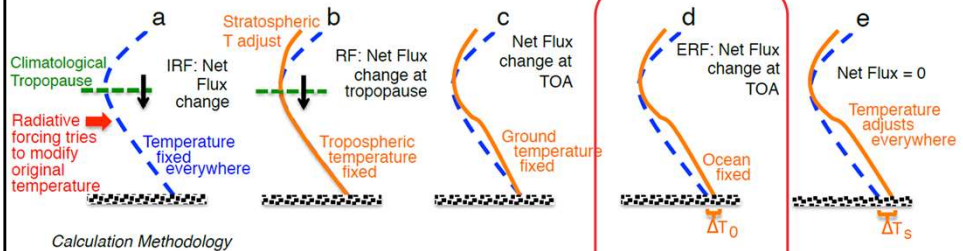

Calculation Methodology

Online or offline pair of radiative transfer calculations within one simulation	Difference between two offline radiative transfer calculations with prescribed surface and tropospheric conditions allowing stratospheric temperature to adjust	Difference between two full atmospheric model simulations with prescribed surface conditions everywhere or estimate based on regression of response in full coupled atmosphere-ocean simulation	Difference between two full atmospheric model simulations with prescribed ocean conditions (SSTs and sea ice) **ERF**	Difference between two full coupled atmosphere-ocean model simulations

From IPCC WG1 AR5 (p.669)

Effective radiative forcing

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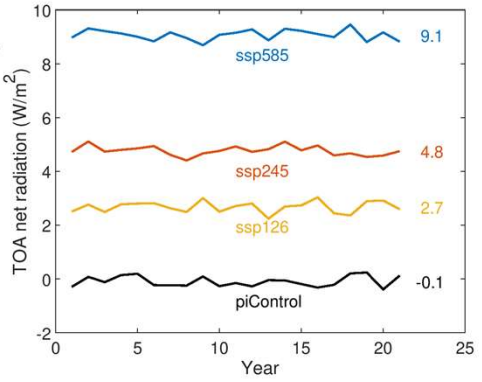
Not (easily) possible to measure radiative forcing (RF) with climate model

Effective radiative forcing (ERF) is a measure for the radiative forcing including all feedbacks from the atmosphere

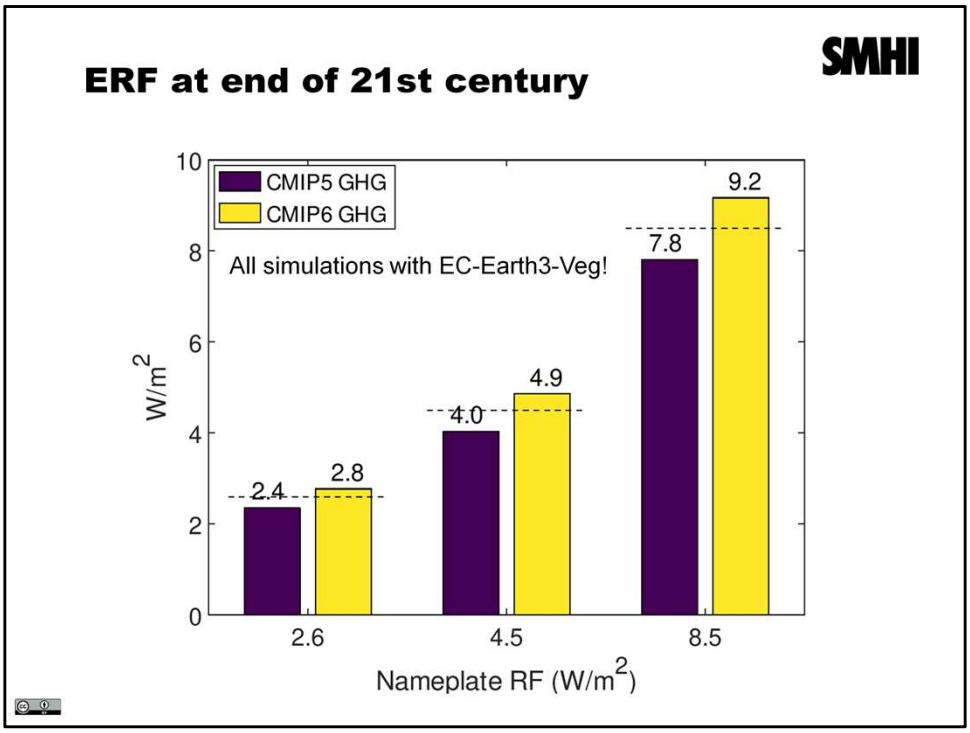
ERF is obtained from short (10-30 yr) long atmosphere-only simulations with climatological SST



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) atmopshere-only simulations with the EC-Earth3 model with prescribed climatological SST (from the piControl simulation) and all forcings (GHG, aerosols, startospheric ozone) from the SSPs. ERF is the resulting top of the atmosphere net radiation imbalance for each scenario.

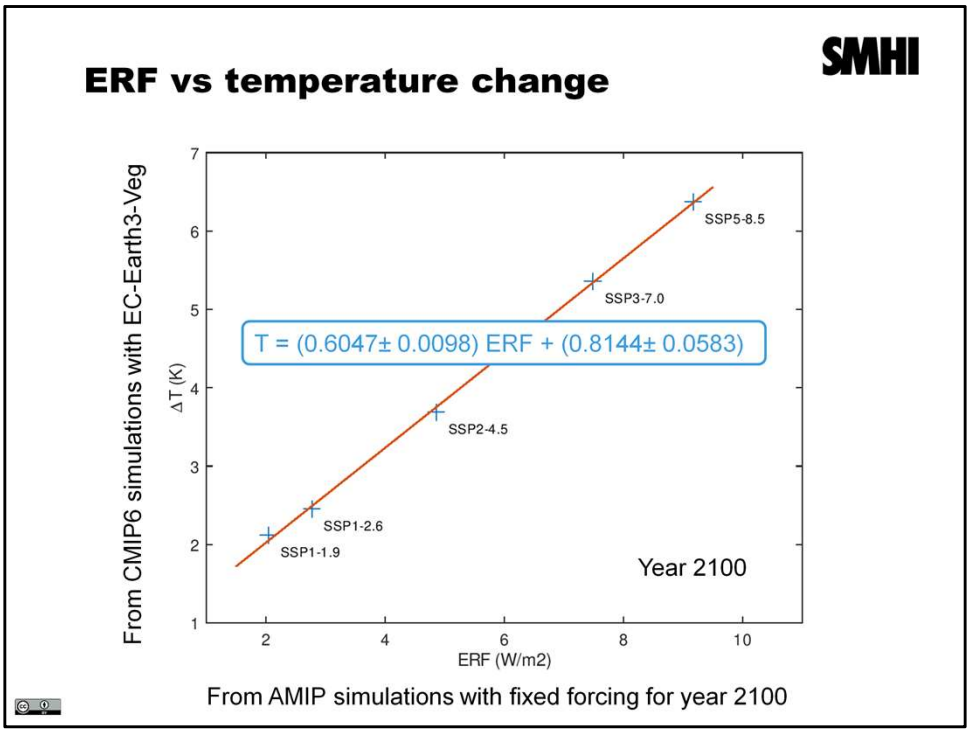
We then repeat the atmosphere-only experiments but replace the GHG concentrations from CMIP6 by those from CMIP5, everything else being the same.

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



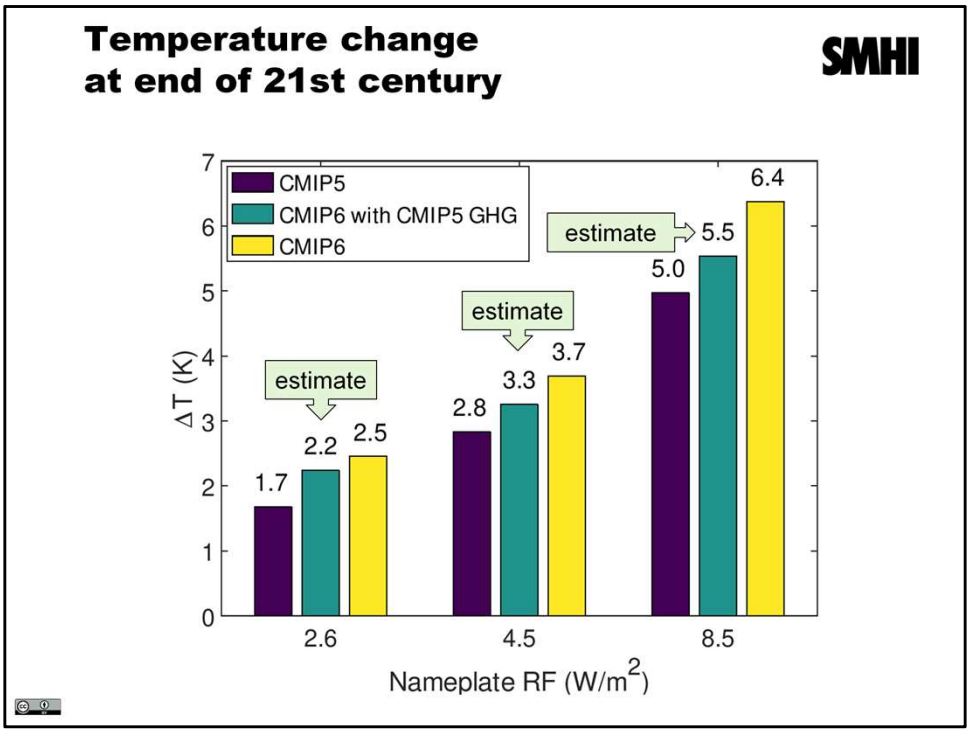
The results show that ERF with all CMIP6 forcings is larger than the RF, e.g. 9.2 W/m2 for the SSP with RF=8.5 W/m2. This is not a problem: ERF and RF can be different because ERF includes all feedbacks (except those from the ocean).

After replacing the CMIP6 GHG concentrations by those from CMIP5 the ERF drops considerably, e.g. by 1.4 W/m2 for the 8.5 W/m2 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!



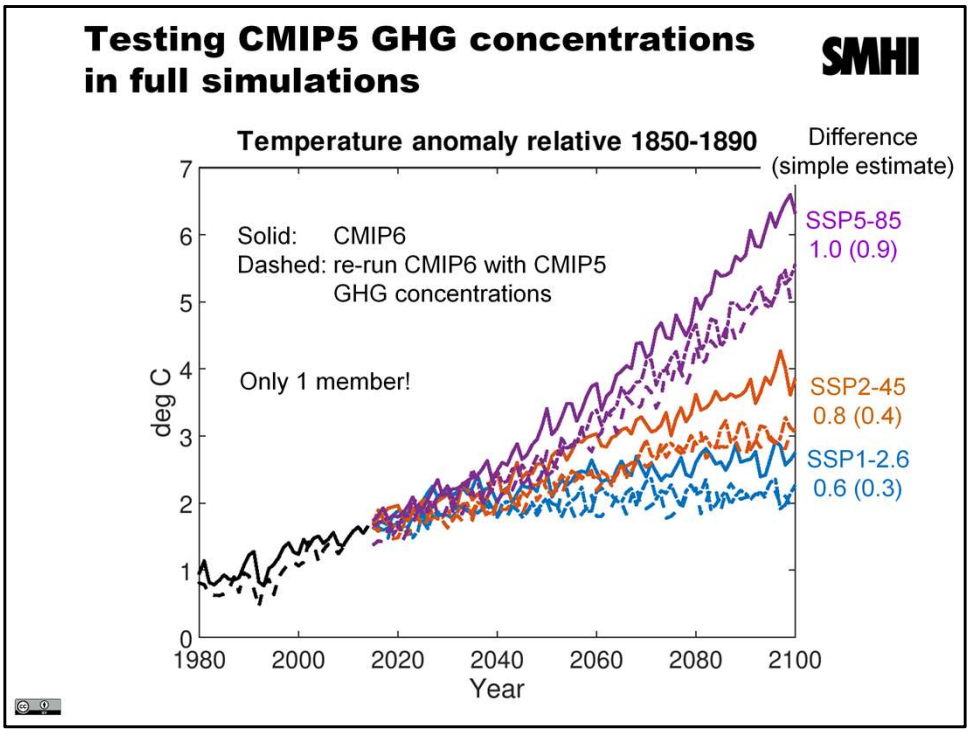
Can we translate the change in ERF to a change in the temperature? In other words: can we estimate how warm our model would be if we'd make the scenarios with GHG concentrations from CMIP5 instead?

It turns out that there is a nice linear relationship between the warming at the end of the 21st century (obtained from the CMIP6 simulations) and the ERF (obtained from the atmosphere-only simulations with fixed forcing). We can then use this relationship to get an estimate for the warming of a simulation with CMIP5 GHG given their ERF.



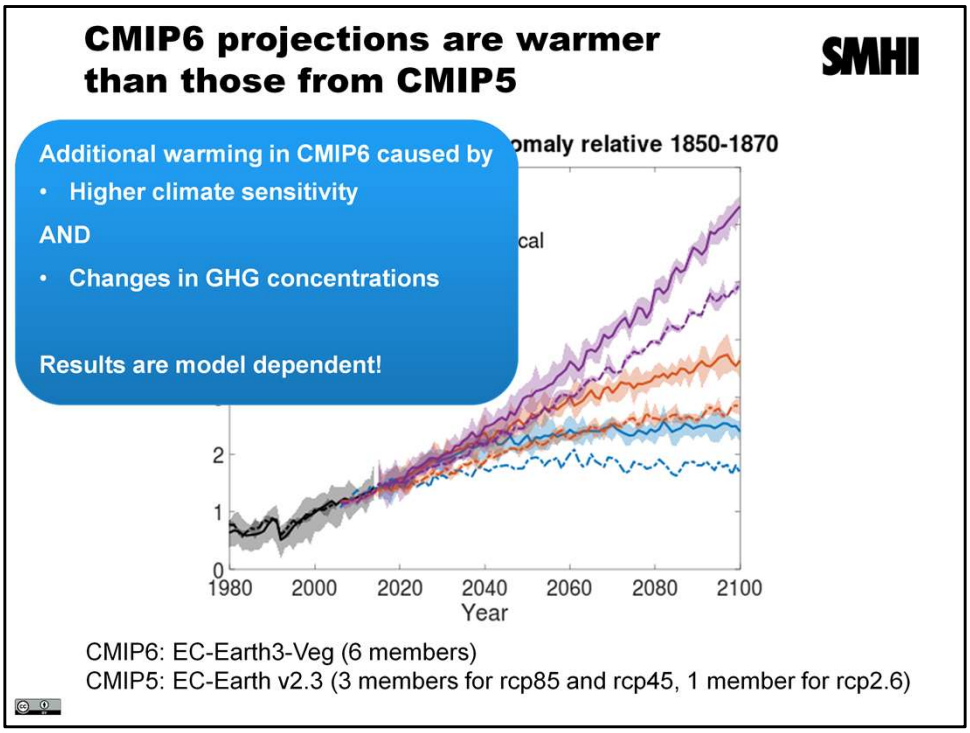
The plot shows the warming (relative pre-industrial) in our CMIP5 and CMIP6 simulations. It also shows the _estimated_ warming computed from the ERF of the runs with CMIP5 GHGs and the linear relationship from the previous slide.

The estimated warming of the simulations with CMIP5 GHGs is larger than what we got from CMIP5 which is expected because the climate sensitivity of the new model version is higher. But the estimated warming is substantially lower than what we have got for CMIP6, indicating that the change in GHG concentrations also plays an important role to explain the additional warming between CMIP5 and CMIP6 simulations. Roughly speaking about half of the additional warming comes from the changes in the prescribed GHG forcing.



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 historial simulation followed by scenarios (dahsed), 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 maily 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 paranthesis 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.



We conclude that the warmer projections in CMIP6 are caused by two reasons:
1) There are changes in the model (higher resolution, imporved parameterisations, more processes) that lead to a higher climate sensitivity.
2) The forcing datasets have changed from CMIP5 to CMIP6. Here we have looked only at the impact of the changes in the GHG concentrations as one of the major drivers of climate change.

The change in GHG concentrations explains 50% or more of the additional warming in CMIP6 compared to CMIP5. However, this result is strongly model dependent: both the climate sensitivity and the effective radiative forcing are different for different models, and therefore the results presented here cannot easily be generalised. We encourage other modeling groups to make similar experiments - atmosphere-only to assess ERF or fully coupled to assess the full impact of chnages in the GHG concentrations. For future CMIP phases we would also recommend to be careful with the mix of model improvements and updates of the forcing datasets to ensure traceability, one possible solution could be experiments with the new models but with previous forcing datasets.