How well do integrated assessment models represent non-CO_2 radiative forcing?

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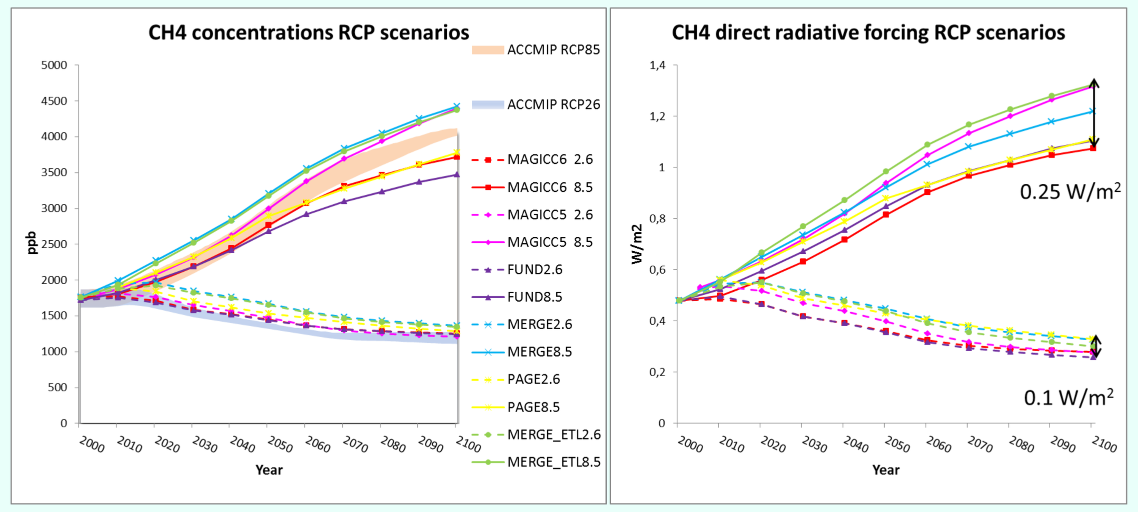
Introduction

This study aims to understand how different Integrated Assessment Models (IAMs) perform in describing the climate forcing by non-CO_2 gases and aerosols. Variations herein play a potentially large role in the choice of a cost-optimal mitigation strategy, given that roughly one third of global warming can be attributed to non-CO_2 forcing.
In order to to so, the outcomes of IAMs have been compared to state-of-the-art atmospheric chemistry models for specific gases and aerosols as well as for overall non-CO_2 forcing effects.

Approach

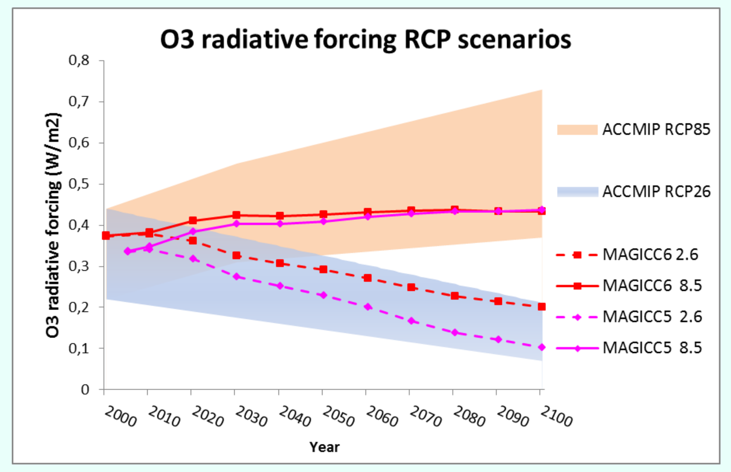
We have included several non-CO_2 forcing representations from IAMs in this analysis: MERGE_ETL, MERGE5.1, FUND3.3, PAGE09 and DICE2013R as well as two versions of MAGICC (5.3 and 6.3), used by most, more detailed IAMs. We refer to all these representations as Simple Climate Models (SCMs). The SCMs have been run with the same pre-descriped anthropogenic emission pathways (the so-called Representative Concentration Pathways, RCPs) and have been compared to the results of analysis by complex atmosperic chemistry and climate models, or earth system models (ESMs), in terms of radiative forcing levels. The RCPs represent a scenario without climate policy (an 8.5 W/m^2 scenario) and a scenario with a stringent two degree climate target in 2100 (a 2.6 W/m^2 scenario). 16 ESMs have been run with precisely the same RCP emissions within the Atmospheric Chemistry and Climate Model Intercomparison Project (ACCMIP).

Methane



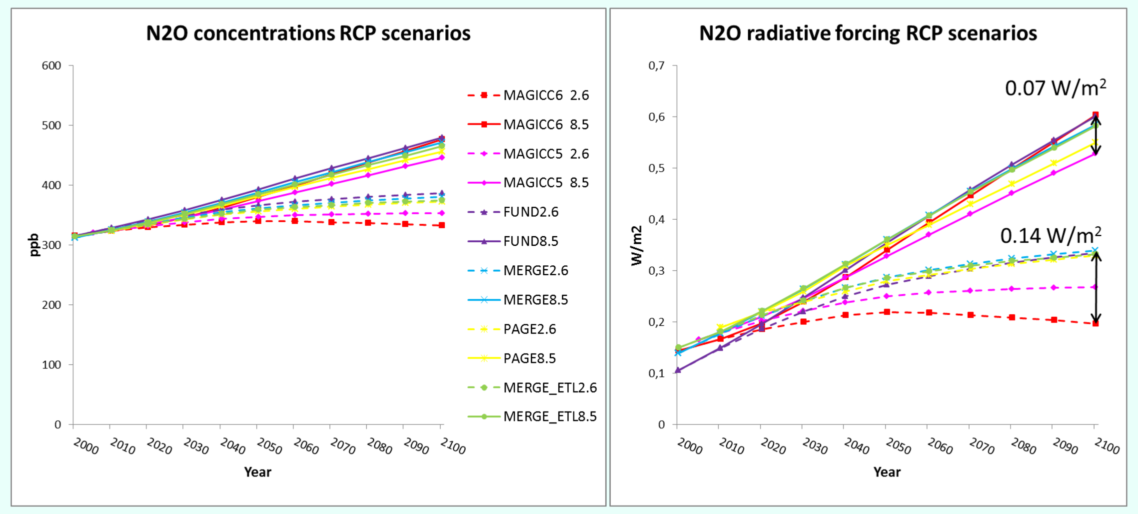
For methane, all models use a very similar way to translate concentration (left) into forcing (right). Models differ in calculating concentrations from emissions, resulting in a significant spread in concentrations (and therefore in radiative forcing), particularly in RCP8.5.

Ozone



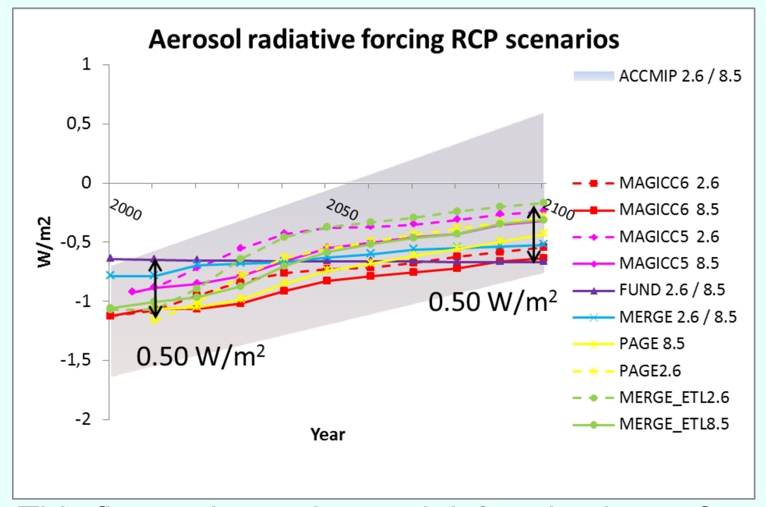
Of the SCMs, only MAGICC includes ozone radiative forcing. This results in an underestimation of forcing by other models. Both MAGICC versions are within the expert model range, but might slightly underestimate forcing in the RCP8.5 scenario because of omission of a temperature feedback effect.

N_2O



As with methane, N_2O concentration-to-forcing calulations are similar across models. Differences in forcing projections occur because of different emission-to-concentration representations.

Aerosols



This figure shows the models´ projections of total aerosol forcing (direct and indirect). Aerosol forcing is very uncertain, which is reflected in a large expert model range as well as a large spread in model outcomes. All models are within the expert model range in 2100, but are also below the 2100 mean value (0.12 W/m^2). This means they might overestimate the negative forcing resulting from aerosol emissions.

Conclusions

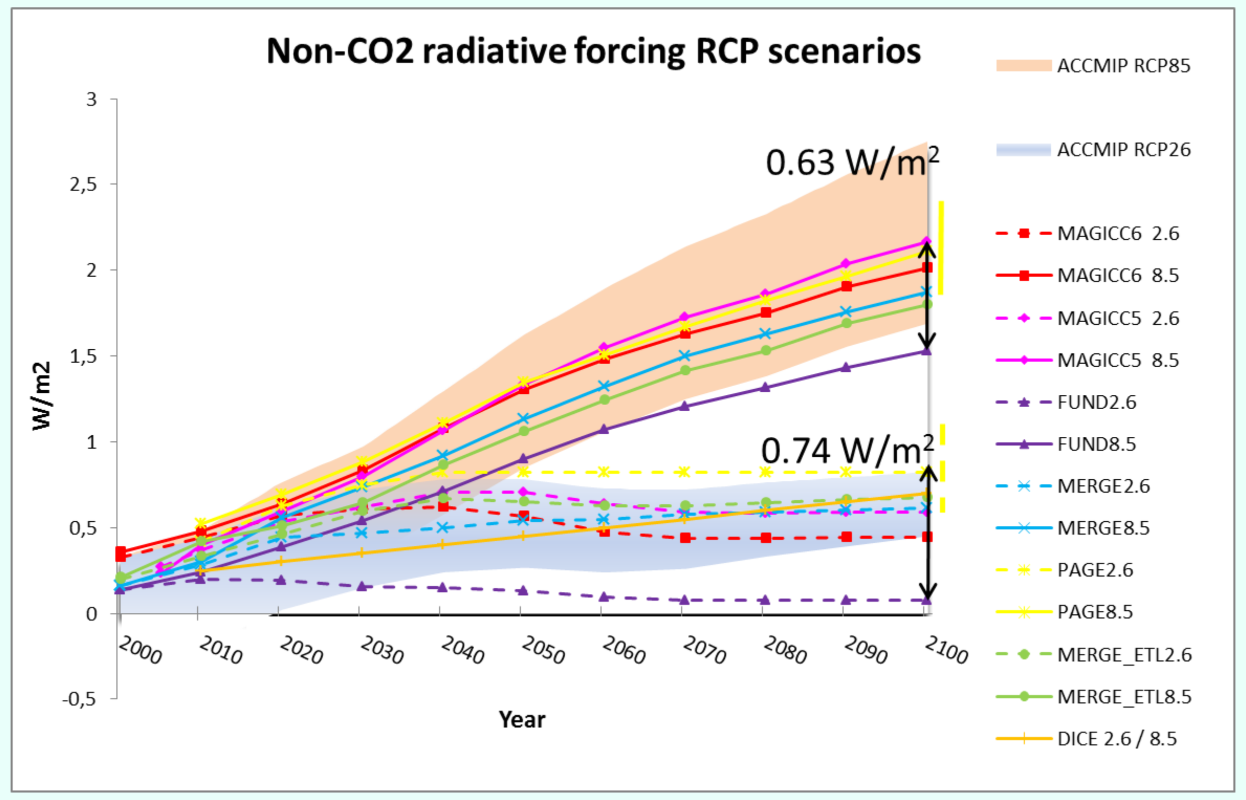
Overall, it can be concluded that the overall behaviour of non-CO_2 gases and aerosols seems to be reasonably captured by most models, given that most overall non-CO_2 radiative forcing projections are found within the expert model range.

There is a very large spread between the SCMs for the same emission-driven mitigation scenario (0.74 W/m^2 for RCP2.6). This implies that the choice of a climate model has large implications for determining the mitigation strategies in terms of CO_2 reduction and associated policy costs. Models may want to move closer to the median of the expert model range. Differences in aerosol assumptions (notably indirect, cloud forming effects) account for the largest spread in forcing projections. Variations in N_2O, halogenated gas and exogenous forcing assumptions also play a large role in the spread in forcing outcomes. For N_2O as well as for CH_4, model differences mainly occur in calculation of concentrations while models show consistency in deriving forcing levels from concentrations.

Compared to expert models, many IAMs seem to show a less rapid decline of negative aerosol forcing and could in that sense be improved. MAGICC6.3, which has a particularly negative forcing projection in 2100, could benefit from compensating for differences in indirect forcing effects of specific aerosols. For well-mixed greenhouse gases, forcing estimates are possibly too high across several models, yet further comparison with expert models is needed.

Because most SCMs generally do not include important forcers such as O_3, BC and stratospheric vapour from CH_4, they run the risk of underestimating forcing differences between baseline and mitigation scenarios.

Combined effect all non-CO2 forcers



This figure depicts the combined forcing effect of all non-CO_2 gases and aerosols in the different models. In general, most IAMs (except FUND and DICE in RCP8.5) are within the ACCMIP exper model range, although most models show somewhat low projections in the RCP8.5 scenario. Overall, MAGICC5.3 is well within the range and MAGICC6.3 is slighly low, also due to a low aerosol forcing projection. FUND is well outside the range for the same reason. DICE makes use of an exogenous scenario-independent radiative forcing factor which makes it unsuited for a RCP8.5 baseline scenario.

RCP8.5	ACCMIP	MAGICC6.3	MAGICC5.3	MERGE_ETL	MERGE 5.1	FUND3.3	PAGE09	DICE 2013R
WMGHGs (excl CO2) *	1.78	1.97	2.05	2.00	2.15	1.76	1.98	0
Aerosols	-0.12	-0.58	-0.32	-0.31	-0.52	-0.67	-0.43	0
Other **	0.55	0.62	0.44	0.12	0.00	0.44	0.57	0.70
Total non CO2	***2.21***	***2.01***	***2.17***	***1.81***	***1.62***	***1.53***	***2.11***	***0.70***
RCP2.6								
WMGHGs (excl CO2) *	0.61	0.70	0.73	0.72	1.00	0.64	0.98	0
Aerosols	-0.12	-0.50	-0.24	-0.17	-0.52	-0.67	-0.29	0
Other **	0.14	0.25	0.10	0.12	0.00	0.10	0.13	0.70
Total non CO2	***0.63***	***0.44***	***0.60***	***0.68***	***0.48***	***0.08***	***0.82***	***0.70***
Difference 8.5 /2.6								
WMGHGs (excl CO2) *	1.17	1.27	1.32	1.27	1.15	1.11	1.00	0
Aerosols	0	-0.08	-0.08	-0.15	0	0	-0.15	0
Other **	0.41	0.37	0.33	0.00	0.00	0.34	0.43	0
Total non CO2	***1.58***	***1.56***	***1.58***	***1.13***	***1.15***	***1.45***	***1.29***	***0***

* Well mixed greenhouse gases: CO_2, methane, N_2O, halogenated gases
** Other = Tropospheric Ozone, indirect methane effect (stratospheric vapour)

- Compared to expert models, SCMs show high forcing levels for well-mixed greenhouse gases (WMGHGs: methane, N_2O and halogenated gasess), and low forcing levels for aerosols. This needs to be further researched.

- For both MAGICC versions, the difference in total non-CO_2 forcing levels between RCP2.6 and RCP8.5 is comparable to ACCMIP, while for most SCMs the difference is much smaller because these do not capture ozone forcing.

- PAGE, MERGE, and MERGE_ETL display relatively small differences in non-CO2 foricng between RCP2.6 and RCP8.5. This indicates that they are less sensitive to emission changes.

Acknowledgements
The research leading to these results has received funding from the European Union's Seventh Framework Programme FP7/2010 under grant agreement n°265139 (AMPERE). We appreciate the comments from colleagues in the AMPERE project at various stages of the project. Special thanks also goes out to David Anthoff who helped considerably with interpreting the FUND model