

Supplementary Information for *GIR: a generalised impulse-response model for climate uncertainty and future scenario exploration*

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RCP simulations

Since the RCPs themselves are *concentration* pathways, here we focus on the results of running GIR with concentrations from the RCP database, as was done in the GCMs in CMIP5. We include emissions-driven runs in the Supplementary Information, but these are not fully comparable due to the lack of integration between RCP concentrations and emissions as was planned in Moss et al. (2010). Figure 32 shows diagnosed emissions that are compatible with the RCP concentration series in FaIRv2.0, run with default parameters plus uncertainties as described above. Here we see the large discrepancies between GIR compatible emissions and the RCP database emissions for CH₄ and N₂O, while FaIRv2.0 diagnosed emissions agree well with bottom-up emission estimates to the present-day as expected, since GIR is tuned against a very similar historical concentration series. Figure 3 shows the corresponding radiative forcings compared to those from the RCP database. The updated simple RF formulae described in Etminan et al. (2016) increase the RF of CH₄ and CO₂, while marginally decreasing the N₂O RF. Figure 4 shows historical and future global mean surface temperature ranges (GMST) under the RCP scenarios diagnosed by GIR, alongside historical observed data and future projections from CMIP5. We see that the GIR diagnosed temperatures closely resemble the observed GMST series, but are lower than the CMIP5 ranges. This is due to the default climate response parameter selection in GIR as described above and is discussed in Richardson et al. (2016).

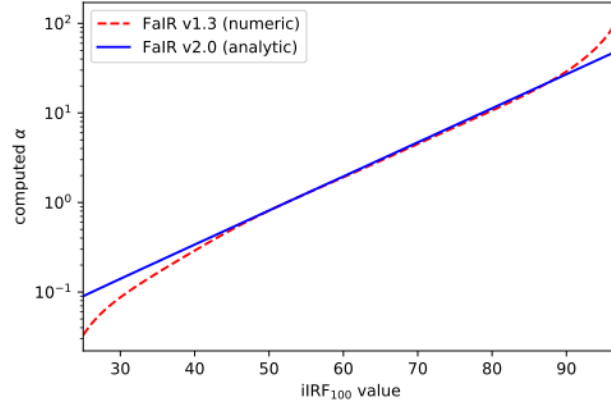


Figure 1. Numerical solution for α in FaIR v1.0 and v1.3 versus analytic solution in GIR. This highlights the reason for the lowered r_0 parameter in GIR compared to FaIR v1.3 (Smith et al., 2017) or v1.0 (Millar et al., 2017), as we see that for pre-industrial α values (0.12 in v1.0 or 0.16 in v1.3), the analytic solution requires a lower $iIRF_{100}$ than the numeric. Despite the marginal difference in shape, we do not find GIR has reduced ability in reproducing historical concentration when compared with FaIR v1.0 or v1.3.

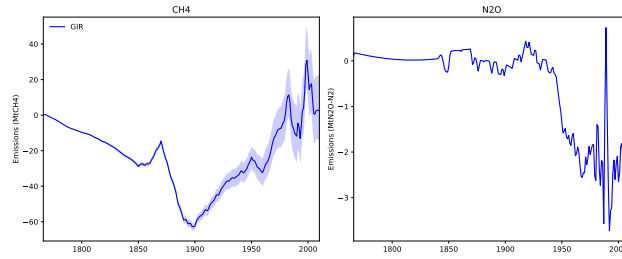


Figure 2. Differences between historical diagnosed emissions in GIR and the RCP database emissions for CH_4 and N_2O . This displays high similarity to the imposed natural emissions in FaIR v1.3 (Figure 2 from Smith et al. (2017)), demonstrating that CH_4 and N_2O cycles in GIR and FaIR v1.3 are not systematically different.

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Code and data availability. The model and code used to produce the figures is publicly available at https://github.com/njleach/FaIR_v2-0, and will be cleaned up and release ready prior to acceptance. All data used in this study is publicly available at the relevant cited sources.

Author contributions. NJL, SJ and MRA conceived the study. NJL and SJ wrote the model code, and BW helped tune model parameters. JT provided CMIP6 response parameters. JL and MC advised on model uses and tested the model. NJL, CJS, ZN, JL and MRA wrote the manuscript.

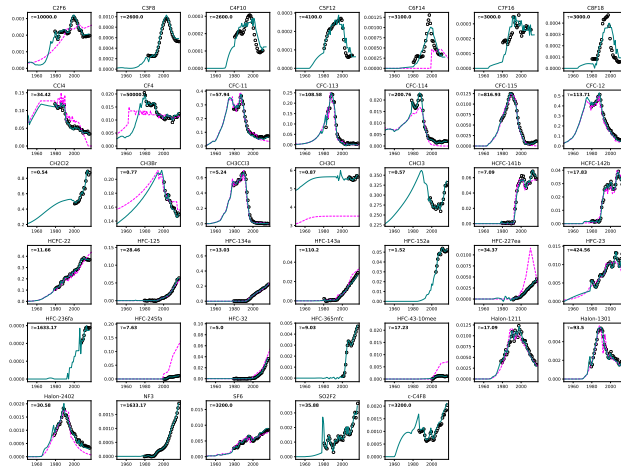


Figure 3. Best-estimate annual emissions from a more complex atmospheric model inversion Rigby et al. (2014), GIR inverse emissions and RCP database emissions. Open black circles show inverse emissions from a 12-box model Cunnold et al. (1994); solid green lines show inverse emissions from GIR with tuned parameters and solid pink lines show emissions from the RCP database. Inset text shows the tuned species lifetime.

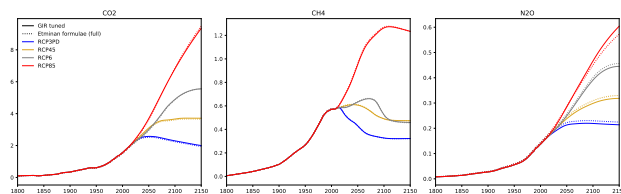


Figure 4. Comparison of the effective radiative forcings calculated in GIR versus the simple formulae derived from spectral measurements given in Etminan et al. (2016).

Competing interests. We declare that we have no competing interests.

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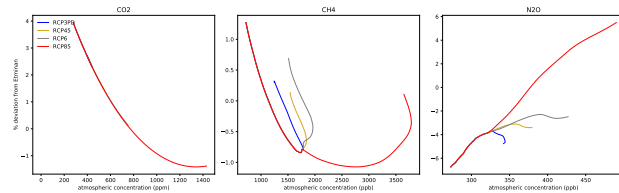


Figure 5. Corresponding deviations of FaIR v2.0 from Etminan et al. (2016) formulae for the RCPs. These are plotted as % deviations against gas concentration (so absolute deviations are considerably lower at low concentrations than high concentrations).

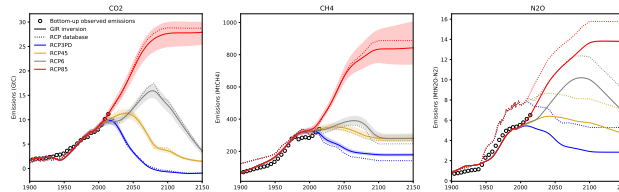


Figure 6. Diagnosed emissions corresponding to the RCPs. Solid lines show best-estimate GIR diagnosed inverse emissions, with associated 5-95% plumes. Dotted lines show emissions directly from the RCP database. Unfilled black circles show bottom-up emission estimates from GCP and PRIMAP-histTP (Qu  r   et al., 2018; G  tschow et al., 2016), smoothed with a 5-yearly running mean.

25 References

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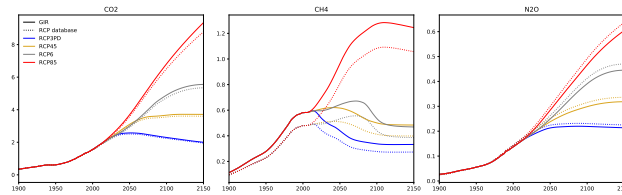


Figure 7. Radiative forcing as computed from the RCP database concentrations using GIR, and corresponding forcings diagnosed by MAG-ICC from the database.

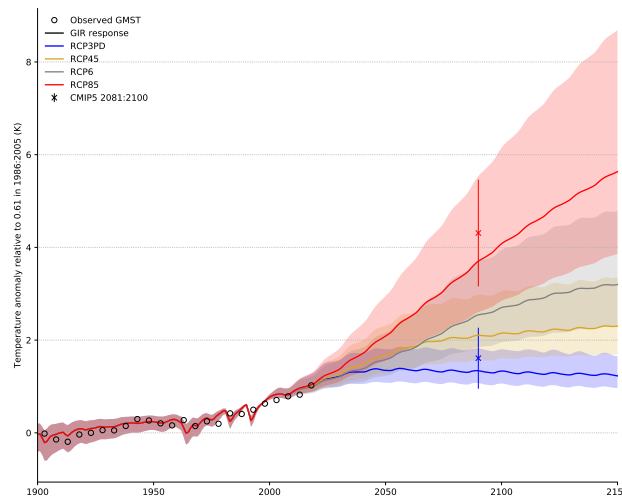


Figure 8. RCP temperature anomalies computed by GIR, and ranges from the CMIP5 ensemble. Solid lines and plumes show best-estimate and 5-95% range temperature anomaly simulated in GIR. Unfilled black circles show observed GMST as the mean of 4 temperature datasets (Vose et al., 2012; Cowtan and Way, 2014; Lenssen et al., 2019; Morice et al., 2011), smoothed with a 5-yearly running mean. Error bars in 2090 show CMIP5 projected 2081:2100 mean temperature anomalies (Collins et al., 2013).

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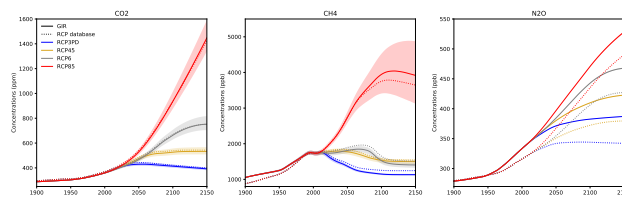


Figure 9. Simulated concentrations when RCP database emissions and other forcings drive GIR, compared to original RCPs.

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