

Interactive comment on “The Radiative Forcing Model Intercomparison Project (RFMIP): Experimental Protocol for CMIP6” by Robert Pincus et al.

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Dear Johannes -

Thanks very much for your detailed and helpful suggestions. We've followed nearly all of them. We have corrected all the typographic errors you found but don't bother listing them below.

Major comments

The paper only occasionally indicates which model diagnostics (output) is to be produced and analysed. One could only assume that the different contributions of top-of-atmosphere (also surface?) radiation flux densities (solar and terrestrial, all-sky and

C1

clear-sky) are to be determined. What about cloud quantities?

Consistent with other MIP manuscripts we note at the end of section 1:

“We provide brief summaries of requested output but the definitive and detailed specification is documented in the CMIP6 data request available at <https://earthsystemcog.org/projects/wip/CMIP6DataRequest>.”

We have also added further detail. For the ERF simulations the most important diagnostics are top of atmosphere energy budget changes. These are simple to produce and we want to encourage as many groups to produce these and participate. Surface energy budget data and cloud data allow much more interesting analyses. In the protocols we ask for ISCCP cloud simulator data, but not all groups can provide this, so we do not want to sound as if they are vital in this overview paper. These diagnostics are now mentioned explicitly. We have added text here at the start to be more explicit:

“The main diagnostics are the top of atmosphere energy budget terms required to estimate ERF. Diagnostics of atmospheric state, including temperature, water vapor, cloud and aerosol information, are requested to allow for detailed diagnosis of rapid adjustments. A few daily variables related to temperature and precipitation are requested in conjunction with DAMIP to help distinguish direct effects of external forcing and air-sea interaction effects on historical changes in extreme indices (e.g., extreme precipitation).”

When it comes to the aerosol ERF it has been shown that it is useful to on-line diagnose components of the forcing. This in particular involves a triple-call to the radiation, allowing to diagnose the radiative forcing due to aerosol-radiation- and due to aerosol-cloud interactions (Ghan, Atmos Chem Phys 2013; doi:10.5194/acp-13-9971-2013). Would it not be useful to request such a diagnostics?

We agree this is useful. However, as not all models have this capability and as there is no clear protocol for how to employ the methodology beyond greenhouse gas and

C2

aerosol changes we have chosen not to make it part of the official request. We have added text asking for these calculations if they are available.

“We are also interested in comparing IRP and cloud adjustments estimated from the kernel method with those that have been explicitly calculated in models that employ the triple radiation call approach of Ghan (2013) to diagnose instantaneous forcings and cloud adjustments. As this method is time-consuming and not implemented by all models we do not include this request as part of the protocol but models implementing triple radiation calls are encouraged to contact us. ”

For the transient ERF, more specifications are necessary how to compute it. Are multiple ensemble members necessary? Or are time slices computed? Or else is a noisy signal accepted? What about the strong deviation from the pre-industrial base state at least in the future scenarios at least in the Arctic?

We agree and have added details. We also refer to the Forster et al. 2016 study which expands in more detail. We also add more details on the ERF time slice error for consistency. The modified text reads

“Transient simulations (Table 2) in which forcing agent concentrations evolve over time are designed to give a complete picture of the CMIP6 Historical transient ERF and possible future radiative forcing. Transient ERFs will be computed by differencing top of atmosphere energy diagnostics from three ensemble members employing time varying forcing changes with the energy budget diagnostics from the Tier 1 30-year control simulation. These integrations will use the same prescribed preindustrial climatology of SST and-sea-ice as in the time-slice ERF experiments. AerChemMIP employs a more complex method of prescribing SSTs and sea-ice that allows for base climate changes through time. Offline tests found that such complexity was unnecessary as ERF was only weakly dependent of base-state with small differences in the future confined to sea-ice edges (Forster et al. 2016). Therefore RFMIP adopts the same base climatology in all experiments for ease of implementation. Tests also found that the transient

C3

ERF fields suffer from year-to-year random noise, so ten-year averages of the three ensembles would be needed to quantify ERF to within 0.05 W/m² (Forster et al. 2016)”

For the IRF study, the paper should be structured more clearly to clarify the two aspects (CO₂ and aerosols) to this, which use two very distinct approaches.

We have followed the suggestion below of isolating each of these efforts in its own subsection.

For the imposed aerosol forcing, it would be good to indicate what the implied ERF due to aerosol-radiation-interactions and what the ERF due to aerosol-cloud-interactions are for e.g. year 2011.

As described below we have provided more detail on the MACv2-SP climatology, including that the all-sky ERF for 2005 is -0.7 W/m² in one CMIP6 model.

Minor comments

page 1

119 the “roughly” might merit a sentence of explanation, or a reference.

We have changed this phrasing:

“... can induce a radiative perturbation loosely called a *radiative forcing*”

is it worth mentioning that Eq. (1) actually defines the radiative forcing, and that the usefulness of F is linked to the degree to which α is independent on the exact nature of the process that generates F, so that comparing different F is sufficient to predict different ΔT for a given α (i.e. given model)?

We considered changes along these lines but decided against them as we could not find a way to express these points without distracting readers away from our focus on the radiative forcing itself.

Page 2

C4

L20: If sticking to the acronym “IRP” this should probably be spelled out “instantaneous radiative flux perturbation” (assuming the “R” represents “radiative”)

We have removed the use of the IRP acronym. In a few places we use the acronym IRF for instantaneous radiative forcing, as per the fifth IPCC report, but in general we have tried to distinguish carefully between forcing (i.e. a change in physical or chemical state); radiative perturbations including IRF; and effective radiative forcing.

L30: this sentence in my opinion is not understandable to somebody not experienced in the topic. The point is about efficacy, and so I'd propose to write “...suggests that IRP due to different forcing agents is not, in practice, a very good predictor for changes in surface temperature assuming constant climate feedback parameters, a point...”

We have revised this text in a way we hope will be more clear without bringing in the concept of efficacy.

“Equation 1 is a diagnostic framework, useful in interpreting observations and comprehensive models of the climate system. Experience with models (in which all terms can be determined precisely) suggests that IRF is not, in practice, related very closely to changes in surface temperature, a point highlighted . . .”

Page 3

l2 “accurate diagnosis”, or rather diagnosis at all?

We chose not to change this text as forcing can also be diagnosed from historical and 1%/year runs following Taylor and Forster, 2006, doi:10.1175/JCLI3974.1.

L5 Reference Hansen et al. (2005): I think it would be appropriate to also cite Rotstayn and Penner (J Climate 2012, 14, 2960-2975) who introduced the concept several years before Hansen

Reference has been added.

l6 “fullness of the model response” to be precise, perhaps “fullness of the rapid model

C5

response”

We chose not to change this text as timescale is not the essential difference between feedbacks and adjustments.

page 4: l2 “concentration or emission changes”, since at least some models computed carbon- and aerosol cycles interactively

Agreed, and changed accordingly.

l15 One would expect a reference corroborating the sentence, rather than – once more – introducing the regression concept (Gregory).

We've amplified this point:

“The “fixed-SST” method has important advantages compared to regressions of top-of-atmosphere imbalance against surface temperature change (?). The first is better error characteristics (Forster et al. 2016): thirty years of simulation using only the atmospheric and land components of an earth system model can diagnose global ERF to better than 0.05 W/m² standard error, such that a 2xCO₂ forcing of 3.7 W/m² is larger than its standard error over 70% of the globe. Achieving similarly small errors from regression requires ensembles of coupled model integrations and therefore many centuries of simulation.”

L19 The sentence is not straightforward to understand. For both methods, only a given perturbation can be diagnosed, and this can be done for either approach. L22 It would be useful to specify as clearly as possible the simulation. I'd suggest to clarify the following things: (i) it is one annual cycle consisting of 12 geographical distributions of sea surface temperatures and sea ice fractional coverage; (ii) from how many years should the fields be derived? Average over any 30 years of the piControl run? (iii) should the monthly means be linearly interpolated to the individual time step, or abruptly change on the first of each month, 0 UTC?

We've added some detail:

C6

“The protocol for RFMIP fixed-SST integrations is to use a monthly-averaged model-specific climatology of SST and sea-ice based on the model’s preindustrial DECK integration (Eyring et al. 2016). Applying a climatology limits variability and improves the diagnoses of small ERF differences. The same climatology will be used for all ERF integrations. We request that distributions from a monthly averaged climatology of SST and sea-ice fractional coverage covering the annual cycle be generated from at least a 30 year segment of a preindustrial control integration. These should be prescribed according to the AMIP protocols, whereby interpolated daily data is generated preserving the prescribed monthly averaged fields. Because ERF is weakly dependent on background state (Forster et al. 2016) the exact choice of background SST and sea-ice has little impact on the forcing estimate in the historic period and has only a small effect in future climates (see below). We hope that a simple approach will encourage model centers to participate.

Time-slice simulations (Table 2), in which forcing agents are held constant at present-day or 4xCO₂ values, provide estimates of present-day and 4xCO₂ ERF. Present-day estimates provide a direct comparison between the estimates of ERF in the model with other estimates e.g. in assessment reports (Myhre et al. 2103). Estimate of ERF will also let us understand basic aspects of each model’s temperature and other climate responses in the Historical and 4xCO₂ DECK simulations. ”

L26 “without compromising accuracy” - I don’t understand what is meant in this context.

Text now deleted as paragraph reworded.

L27 “present-day” needs clarification. Is this year 2011 as in CMIP5, or 2005 as in CMIP3? It would also be good this time to have the date consistent with the end of the DECK historical simulation. and also your points Table 1 “Present-day” is not specified. Is this intended? and RFMIP-ERF-GHG Experiment description: It should be made very clear whether ozone (tropospheric? Stratospheric?) is considered a

C7

(greenhouse) “gas”. Can one not be specific by writing “CO₂, CH₄, N₂O, Halocarbons, and O₃ and CO precursor gases?”

We have clarified that RFMIP follows CMIP6 protocols that define these quantities:

“RFMIP follows CMIP6 protocols, so that *present-day* is interpreted as 2015 and *greenhouse gases* refer to those specified by Meinshausen et al. (2016), i.e. CO₂, CH₄, N₂O, and some or all of a long list of halocarbons or equivalent concentrations. Ozone concentrations are specified separately. ”

The Tier-2 experiments need to be motivated. Is a signal from 0.1 Aer really detectable over the noise in a 30-year fixed-SST framework? Why a factor of 0.1 and not a factor of 0.5? Or why not – probably even more useful in interpreting the historical simulations – a year 1985 simulation?

We have omitted these experiments from the protocol.

Page 5:

l2 Forster et al. (the cited JGR paper) say 30 years of integration time are necessary to characterize ERF. How is this done here? By 30 ensemble members and they reporting the forcing every year of the simulation? Or is a much greater transient uncertainty simply accepted if a single ensemble is run?

Text now added to better describe transient ERF estimates – see additions above

It seems Forster et al. (JGR) claim the base state does not matter much so a pre-industrial SST and SIC distribution is good enough. But is this not a main uncertainty when integrating into the future? How meaningful is a forcing diagnostics in the second half of the 21st century in the Arctic when pre-industrial sea ice cover is prescribed?

We show in Forster et al, submitted JGR that this is in fact only a small effect around sea-ice edges. Text has been clarified and expanded (see above)

Page 6

C8

L14: "both greenhouse gases and aerosols": It is quite unclear from Table 3 how the greenhouse gases beyond CO₂, and aerosols are to be prescribed, in both the control and perturbed simulations. Only at some point in the text, it appears the atmospheric profiles should be not only cloud-free, but also aerosol-free. I didn't find any information about greenhouse gases beyond CO₂.

This has been addressed by clarifying that RFMIP follows the CMIP6 protocols, as above.

Page 7

L1 Why not provide the selected profiles as supplementary material? It would be useful to specify in the paper the exact way the profiles are introduced. Is the vertical discretisation the model's one? Or is a common vertical grid chosen? and also L8 "when finalized" why not put this up for review here as well?

We have amplified the description of the selected profiles including specifying that all radiation models are meant to solve the same problem i.e. operate on the same vertical grid.

"Modeling centers are asked to use the vertical grid provided."

As the column selection is somewhat involved full details will be described elsewhere; our intent here is to describe the protocol.

L4 "aerosol-free": What about greenhouse gases?

We couldn't figure out how to make this more clear. The columns are chosen to optimize a forcing calculation for greenhouse gases so indeed those gases (at both pre-industrial and present-day concentrations) are part of the calculation on which the column selection is based.

L12: It would be good to make clear at the beginning of section 3 that there are two distinct and very different approaches to characterize greenhouse gas- and aerosol

C9

forcing. It would be also useful to split these two into to sub-sections, one on greenhouse gases, and one on aerosols.

We've followed this suggestion.

L14: "radiative perturbations": does this imply a double radiation call, one with the current aerosol and a second one with all aerosol set to zero? The exact definition should be clarified, and also the necessary output. Is this requested for the top of the atmosphere, or vertically resolved? Broadband in the solar spectrum, or spectrally resolved? Why not both, the clear-sky and the clean-sky flux?

We've substantially expanded the discussion of the protocol in this section:

"RFMIP is developing a compact (roughly 100) sample of atmospheric conditions (profiles of pressure, temperature, humidity, greenhouse gas concentrations, surface properties) and radiative transfer boundary conditions (solar geometry and solar constant) that, when weighted appropriately, can be used to estimate time-averaged global-mean fluxes . . . Present-day atmospheric and surface conditions are sampled from reanalysis while greenhouse gas concentrations follow the CMIP6 protocol, using 2015 values provided by Meinshausen et al. 2016. Aerosols are not included. Perturbations to these states allow for the calculation of instantaneous radiative perturbation as the difference in flux between a perturbed state and present-day conditions and concentrations. Some perturbed states (see Table 3) represent changes in conditions tied to CMIP DECK or Historical simulations. The more idealized perturbations described in Table 4 are aimed at exposing model errors with global impacts, especially in present-day forcing by specific greenhouse gases. This set of conditions will be distributed on the Earth System Grid as a single file.

The sample is constructed to minimize the sampling error in annual-mean, present-day clear-sky, aerosol-free forcing by greenhouse gases (i.e. the difference in fluxes using present-day and pre-industrial gas concentrations). The sampling error, even with as few as 50 distinct conditions, is several orders of magnitude smaller than the

C10

forcing; forcing errors for other composition changes are larger but still small relative to the change in flux. Further details on the selection of these columns will be reported separately.

Modeling centers are asked to compute broadband (spectrally-integrated) fluxes for the full range of conditions and all perturbations using off-line versions of their radiative transfer parameterizations (or using any work flow that computes fluxes as the host model does using precisely the specified conditions). Modeling centers are asked to use the vertical grid provided and to omit aerosols. The representation of greenhouse gases, and particularly the choice of using a subset of gases or one of the equivalent concentrations provided by Meinshausen et al. 2016, should follow used in other integrations made for CMIP6 and related activities. "

117: It would be good to be exhaustive in the request list, i.e. to also include which other parameters (temperature, pressure, specific humidity? gases?) to provide.

We have slightly expanded the list and also note that the full specification provided in the file is complete.

L24: Maybe would it be possible to write why multiple reference models are advantageous? Is it expected that their results differ?

We decided not to address this point because it is a bit subtle but mostly irrelevant to the protocol. We did amplify the role of the reference models:

"We anticipate that reference models may also be used to assess the impact of choices made in the CMIP6 specification for greenhouse gas concentrations (Meinshausen et al., 2016) including the use of equivalent concentrations to reduce the number of greenhouse gases considered, the neglect of species like CO that are not well mixed, and the specification of latitudinal and vertically-varying concentrations for well-mixed gases. "

Page 8:

C11

16 Another substantial contributor is the diversity in simulated cloud distributions (Perner et al., Atmos Chem Phys 2006 doi:10.5194/acp-6-3391-2006; Stier et al., Atmos Chem Phys 2013, doi:10.5194/acp-13-3245-2013)

We have added these citations after new text: "further modulated by varying distributions of clouds"

19: 20th century: rather a balance of sulfate and greenhouse gases; L12: To be more precise: the continents adjacent to the North Atlantic; 117: "commensurately large", or why "larger" (than the emission changes?)

This paragraph has been substantially revised.

"In the 20th Century sulfate is thought to have contributed substantially to the net radiative forcing, although the magnitude and mechanisms are disputed (Stevens,2015). What is not disputed is that precursor SO₂ emissions increased greatly, and that these emissions were concentrated over a relatively small portion of the planet. Consistent with other studies, Carslaw et al. 2013 estimate that SO₂ emissions, to which the dominant component of the aerosol contribution to ERF are attributed, increased three-fold through the first hundred years of industrialization. Smith et al., 2011 pinpoint these changes to changes in the North Atlantic sector – a region covering about a tenth of Earth's surface. Beginning in the 1970s air quality controls began to reduce emissions in Western Europe and North America. Present Western European emissions are now estimated to be a fifth, and North American emissions a half, of what they were in the early 1970s. As emissions over the Atlantic sector declined, emissions over South and East Asia increased so that globally anthropogenic SO₂ emissions remained roughly constant. The short life-time of sulfate implies that the regional concentration of emissions would lead to strong regionality in forcing. So, to the extent that sulfate forcing is important globally, regional signals should be readily identifiable and may help bound the overall radiative forcing attributable to anthropogenic SO₂ emissions."

126: "reducing temperature" may be misunderstood (the GHG effect mostly is domi-

C12

nant), why not – pertinent to the paper – say that they introduce a negative effective radiative forcing?

We have qualified the sentence to read “reducing global mean temperature,” but we wish to stress the ultimate impact of aerosols on climate (temperature) rather than the intermediate step of radiative forcing.

I23 Why citing Eyring here?

The reference for MACv2-SP is now available and has replaced this reference.

L23: The sentence in brackets is difficult to understand and should be explained better. Page 10

We have omitted the sentence.

I33: But does the MACv2-SP provide a forcing more negative than -1 Wm⁻² in 2011?

No, and we have amplified this point:

“In a version of the Max Planck Institute Earth System Model (MPI-ESM; see Giorgetta et al., 2013; Stevens et al. 2013) using an updated atmospheric component the clear-sky ERF for this aerosol description is -0.8 W/m², evaluated over the time period 2000-2011 using aerosols at 2005 values. The corresponding all-sky ERF is -0.685 W/m². In other models the latter value, especially, will depend on the model’s distribution of cloudiness. ”

I21: “quite useful” for what?

From the context we think this point is clear: output from the ISCCP simulator will be useful in studying cloud adjustments. RFMIP’s use of the data is described in detail in section 2.2, referred to in the sentence.

CMIP6 label/experiment id: can the dashes be omitted? I think having just words helps in some scripts, and this was common practice in CMIP5.

C13

We have not received this feedback from the CMIP or WGCM infrastructure panels. As our names are quite long we will retain the dashes at this time.

RFMIP-ERF-AerO3: Experiment description: How is O3 perturbed for models that include atmospheric chemistry, i.e. that require emission, rather than concentration, perturbations? Is this tropospheric ozone only?

Text has been added to better describe transient ERF estimates – see additions above
RFMIP-ERF-LU Experiment description: gases or land-use?

This was an error: we mean changes in vegetation types and corresponding changes in surface albedo, roughness length and transpiration but not changes in gases.

RFMIP-ERF-4xCO2: Does this require another control simulation for models with an interactive carbon cycle (namely a simulation with pre-industrial CO2 concentrations, rather than emissions)?

Interactive carbon cycle models are not used here

RFMIP-ERF-HistNat Experiment description: I think “etc.” is very bad to use in such a protocol. It is necessary to very precisely say what should be varied. What could and should be thought of besides solar activity and volcanic eruptions?

Yes. We removed etc. and specify that variability is to include any spectral variation

RFMIP-ERF-HistAer Experiment description: What about ozone?

The title and experiment_id have been changed to indicate that ozone and aerosols are always treated together.

Interactive comment on Geosci. Model Dev. Discuss., doi:10.5194/gmd-2016-88, 2016.

C14