Radiative Forcing, Radiative Adjustments, & Radiative Feedbacks in CMIP5

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Methodology

- Decompose changes in radiative flux at TOA into contributions from temperature, water vapor, clouds, ice/snow using kernels.

- Separate feedbacks from forcings by regressing state variables (T, WV, etc.) against global mean surface temperature.
  - “Radiative Feedbacks” are correlated to temperature.
  - “Radiative Adjustments” are not (e.g., stratospheric cooling).

- Use “Abrupt 4xCO2” scenario to de-correlate forcing from surface warming.

- Many other studies on this topic: Andrews et al. 2012, Block and Mauritsen 2013, Huang 2013, Vial et al. 2013, Zelinka et al. 2013, and others …
TOA Radiative Flux Imbalance
GCM output

Instantaneous Forcing: Residual

Not “true” adjustments, but artifacts of spatial variations in warming
Contributions to Intermodel Spread in TOA Flux

(a) TOA Radiation Budget

Radiative Flux (W/m^2)

Heat Uptake  Instant. Forcing  Rad. Adj.  Adjusted Forcing  Radiative Feedbacks
Contributions to Intermodel Spread in ECS

(b) Effective Climate Sensitivity
Intermodel Spread in 4xCO2 Forcing

Spread is primarily due to IF and stratospheric cooling (i.e. radiative transfer)
Evaluating Radiative Forcing from Kernels

1) Compare Adjusted Forcing with other methods from CMIP5
   i. Regression (“Gregory”) Method
      - Regress net TOA flux vs surface temperature
      - Slope is sensitivity and intercept (ΔT=0) is forcing

   ii. Fixed SST (“Hansen”) Method
      - Increase CO2 while holding SSTs fixed to suppress feedbacks
Comparison of Adjusted Forcing

Kernel estimates of adjusted forcing agree well (~0.5 W/m$^2$) with other methods.
Evaluating Radiative Forcing from Kernels

1) Compare Adjusted Forcing with other methods from CMIP5

   i. Regression “Gregory” Method (Abrupt 4xCO2)
      Regress TOA net flux vs surface temperature →
      Slope is sensitivity and intercept \((\Delta T=0)\) is forcing

   ii. Fixed SST “Hansen” Method (AMIP 4xCO2)
       Increase CO2 while holding SSTs fixed to suppress feedbacks

2) Compare to Double Call calculations from CMIP5 (Abrupt 4xCO2)
There is a ~2.5 W/m² spread in both Kernel and “Double Call” estimates of IF.
Evaluating Radiative Forcing from Kernels

1) Compare Adjusted Forcing with other methods from CMIP5
   
   i. Regression “Gregory” Method (Abrupt 4xCO2)
      Regress TOA net flux vs surface temperature \( \rightarrow \)
      Slope is sensitivity and intercept (\( \Delta T = 0 \)) is forcing

   ii. Fixed SST “Hansen” Method (AMIP 4xCO2)
       Increase CO2 while holding SSTs fixed to suppress feedbacks

2) Compare to Double Call calculations from CMIP5 (Abrupt 4xCO2)

3) Compare to RTMIP forcing calculations for 2xCO2 (Collins et al 2006)
Comparison of Direct and Adjusted Forcing

Kernel estimates of inst. forcing are consistent with those of Collins et al. (2006)
Conclusion

Double Call calculations of IF should be mandatory for each emission scenario in CMIP6
Regional Distribution of Tropospheric Adjustments

Large regional variations in tropospheric adjustments
Regional Distribution of Tropospheric Feedbacks

Regional variations in adjustments tend to oppose the corresponding feedback
Everything in troposphere is a feedback

Adjustment or Feedback: Does it Matter?

Separate Feedbacks from Adjustments
Conclusions

- The intermodel spread in adjusted forcing from CO$_2$ is nearly as large as the spread in climate sensitivity.

- Instantaneous forcing and stratospheric adjustment are the dominant contributors to this spread.

- This is largely an RT modeling issue → “Low hanging Fruit”

- Tropospheric “adjustments” to CO$_2$ are strongly tied to regional variations in surface warming and, to some extent, are artifacts of methodology.

- Ignoring tropospheric adjustments to CO$_2$ introduces little uncertainty in estimates of climate sensitivity.
Extra Slides
Radiative forcing by well-mixed greenhouse gases: Estimates from climate models in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4)

W. D. Collins,1 V. Ramaswamy,2 M. D. Schwarzkopf,2 Y. Sun,3 R. W. Portmann,4 Q. Fu,5 S. E. B. Casanova,6 J.-L. Dufresne,7 D. W. Fillmore,8 P. M. D. Forster,9 V. Y. Galin,10 L. K. Gohar,6 W. J. Ingram,11 D. P. Kratz,12 M.-P. Lefebvre,7 J. Li,13 P. Marquet,14 V. Oinas,15 Y. Tsushima,16 T. Uchiyama,17 and W. Y. Zhong18

Figure 4. (left) Longwave forcings at TOM, 200 hPa, and the surface for increasing CO2 from 287 to 574 ppmv (case 2b-1a, Table 2; same symbols as Figure 3). (right) Corresponding shortwave forcings.
Intermodel Spread in Adjustments and Feedbacks

(a) Adjustment

Radiative Flux (W/m²)

(b) Feedback

Radiative Feedback (W/m²/K)

Vial et al. (2013) estimates of adjustments larger and have less spread.

The bias is due to aliasing of feedbacks into adjustment due to mean warming of ~0.5 K in fixed SST experiments.

Zelinka et al. (2013) also used fixed SST and has positive cloud adj. (w larger spread)

(Chung and Soden 2015)
AR5 Radiative Forcing Scenarios from Radiative Kernels

- **1%CO2**
- **Abrupt 4xCO2**
- **RCP2.6**
- **RCP4.5**
- **RCP8.5**
- **Historical**

The images depict radiative forcing scenarios over time, with years and radiative forcing (W/m²) axes.