Radiative Forcing, Radiative Adjustments, & Radiative Feedbacks in CMIP5

Eui-Seok Chung and Brian Soden

Chung and Soden, 2015a: Radiative Forcing, Radiative Adjustments, and Radiative Feedbacks in CMIP5 Models, J. Climate.

Chung and Soden, 2015b, An assessment of methods for computing radiative forcing in climate models, Env. Res. Lett.

Methodology

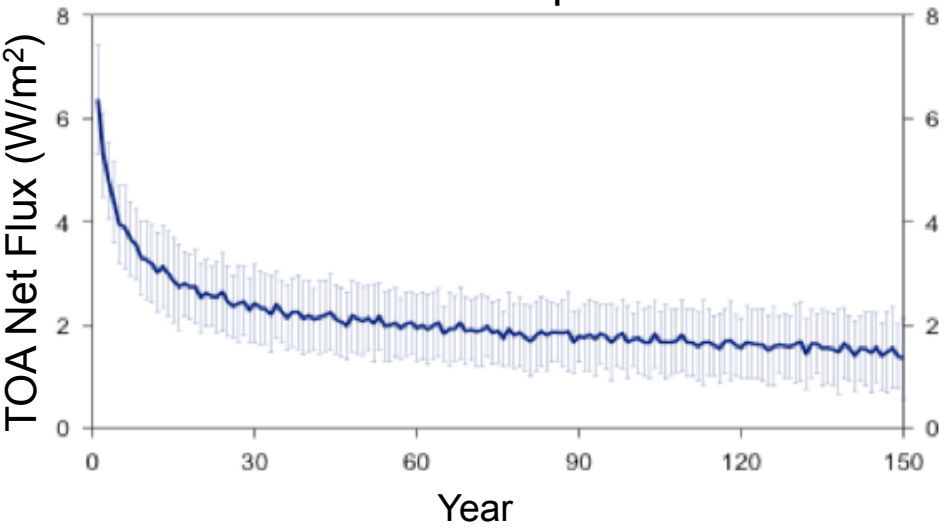
- Decompose changes in radiative flux at TOA into contributions from temperature, water vapor, clouds, ice/snow using kernels.

- 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).

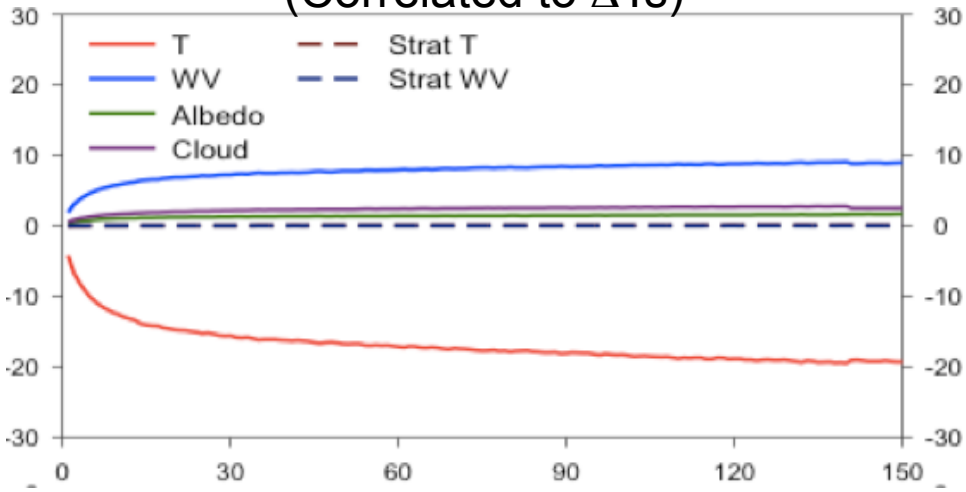
- Use "Abrupt 4xCO2" scenario to de-correlate forcing from surface warming.

- 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 …

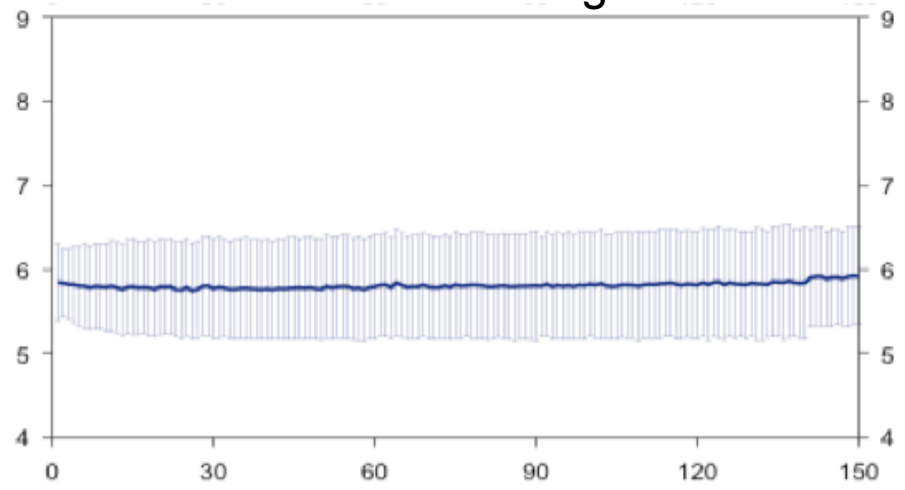
TOA Radiative Flux Imbalance GCM output



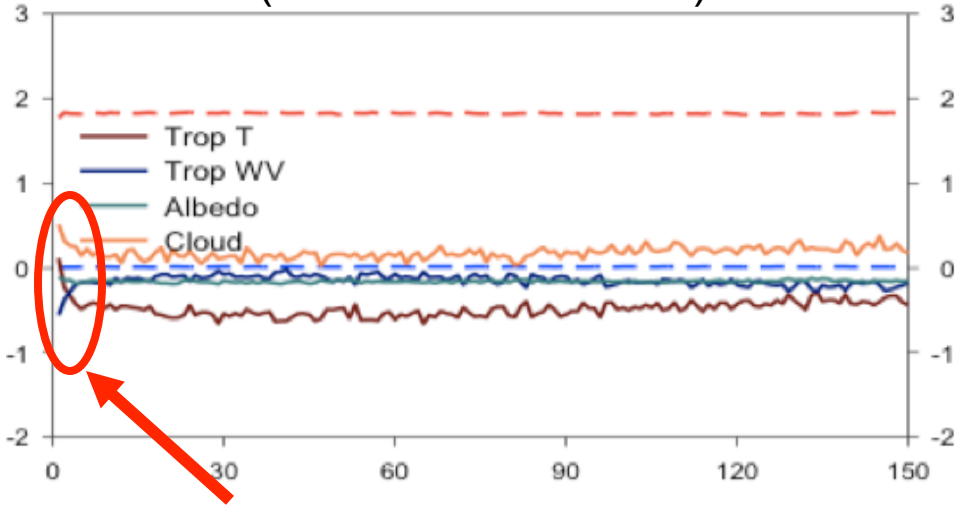
TOA Flux Change due to Feedbacks: Kernel (Correlated to ΔTs)



Instantaneous Forcing: Residual

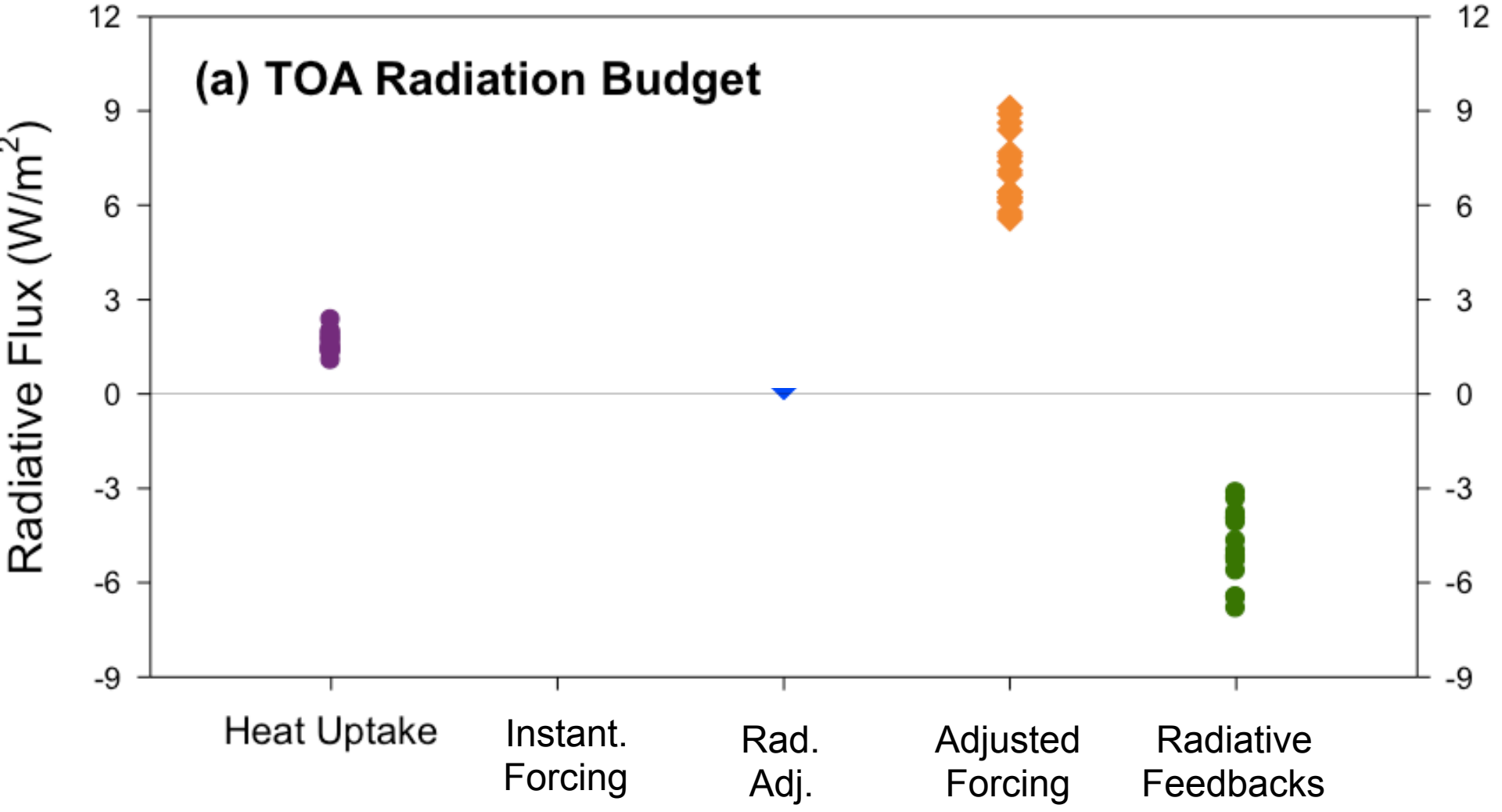


TOA Flux Change due to Adjustments: Kernel (Uncorrelated to ΔTs)

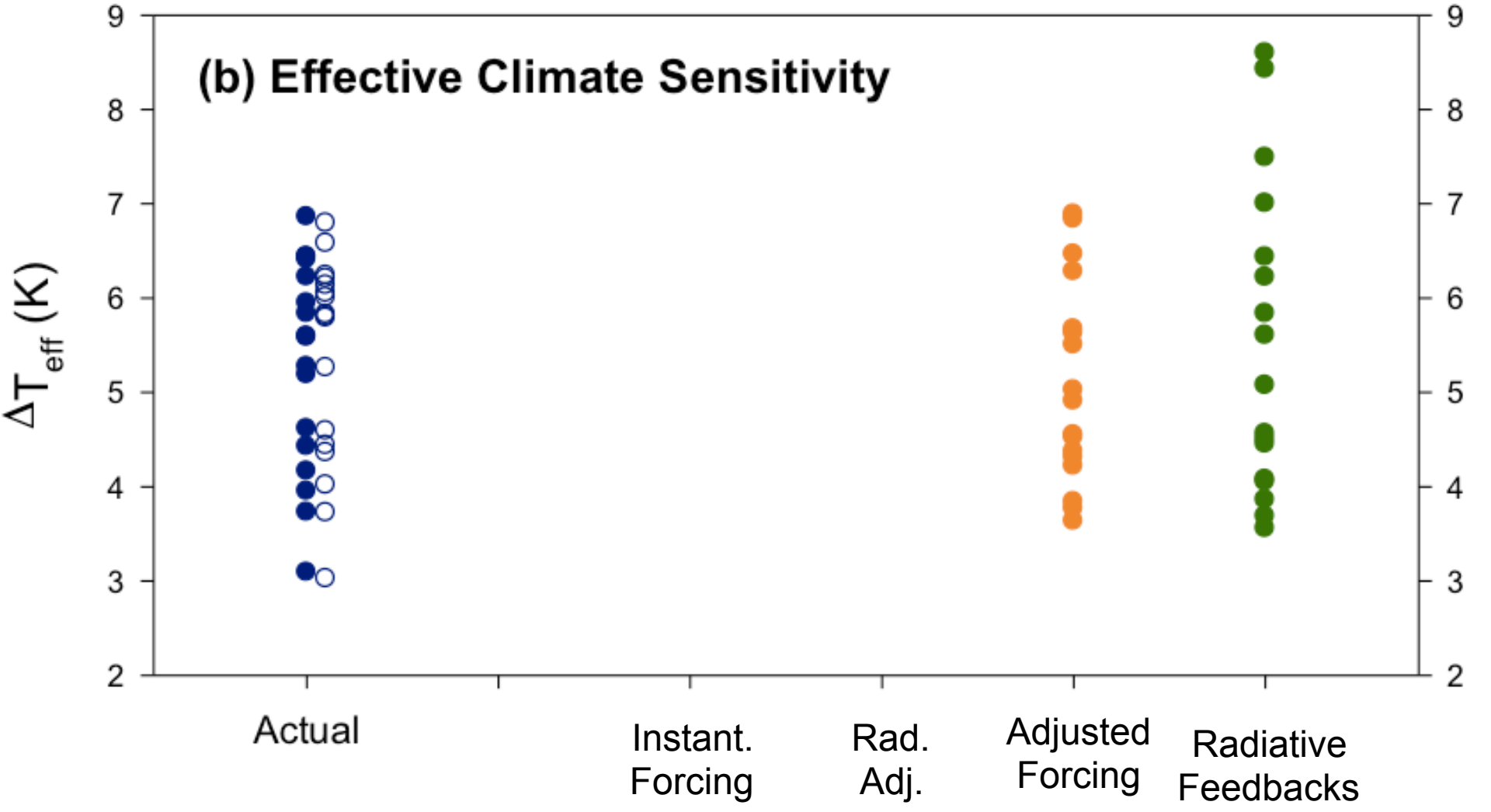


Not “true” adjustments, but artifacts of spatial variations in warming

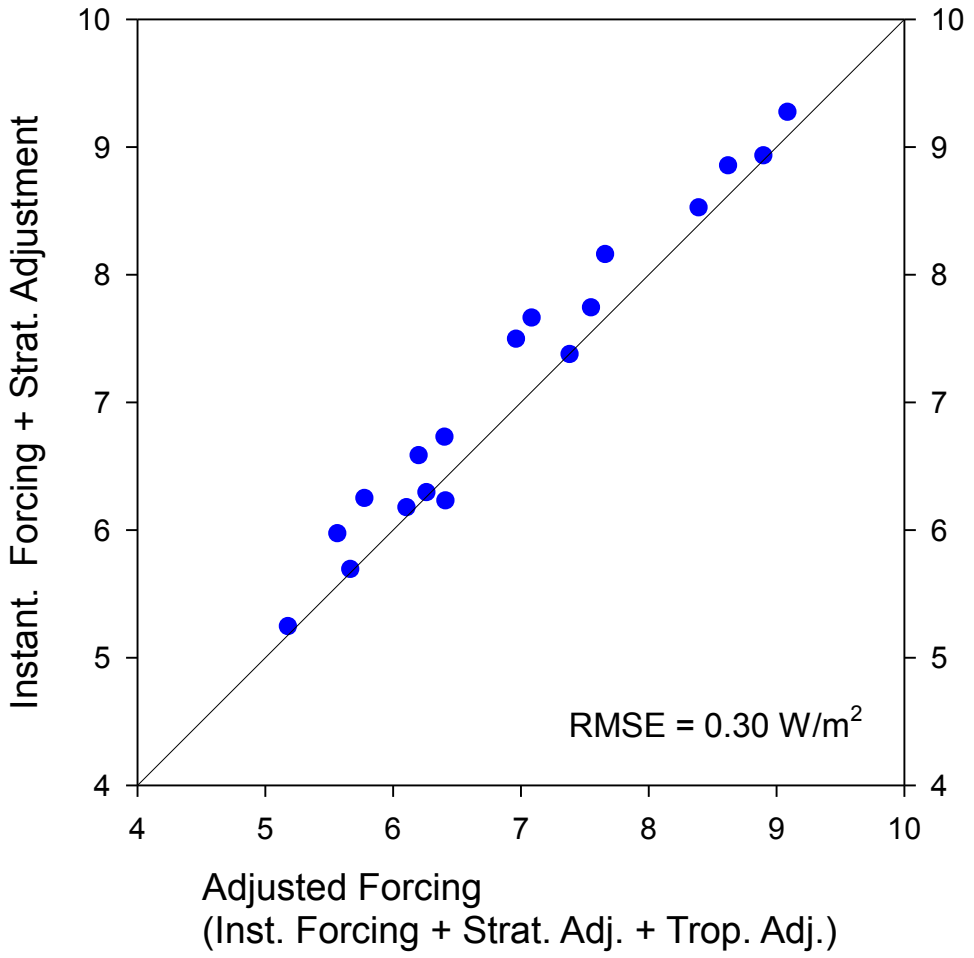
Contributions to Intermodel Spread in TOA Flux



Contributions to Intermodel Spread in ECS



Intermodel Spread in 4xCO2 Forcing

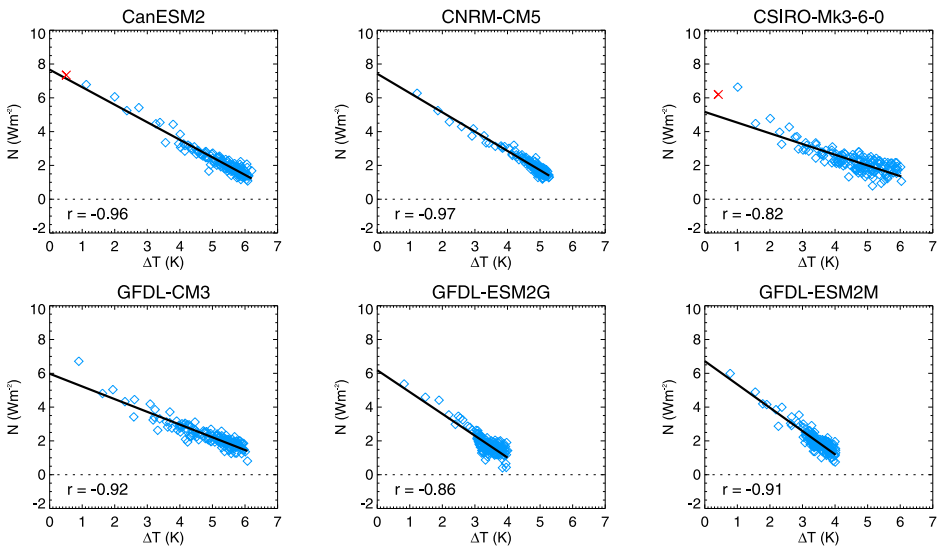


Spread is primarily due to IF and stratospheric cooling (i.e. radiative transfer)

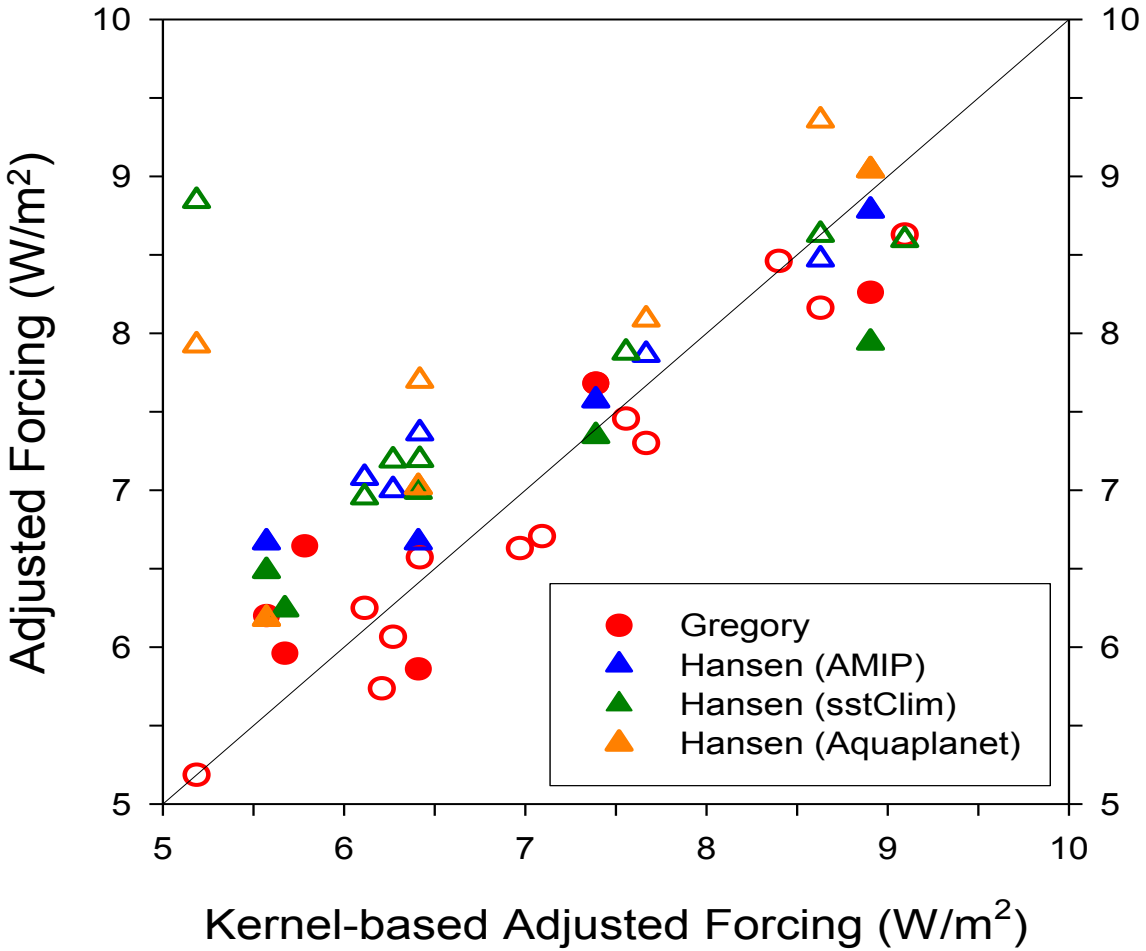
Evaluating Radiative Forcing from Kernels

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 ($\Delta T=0$) 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 →
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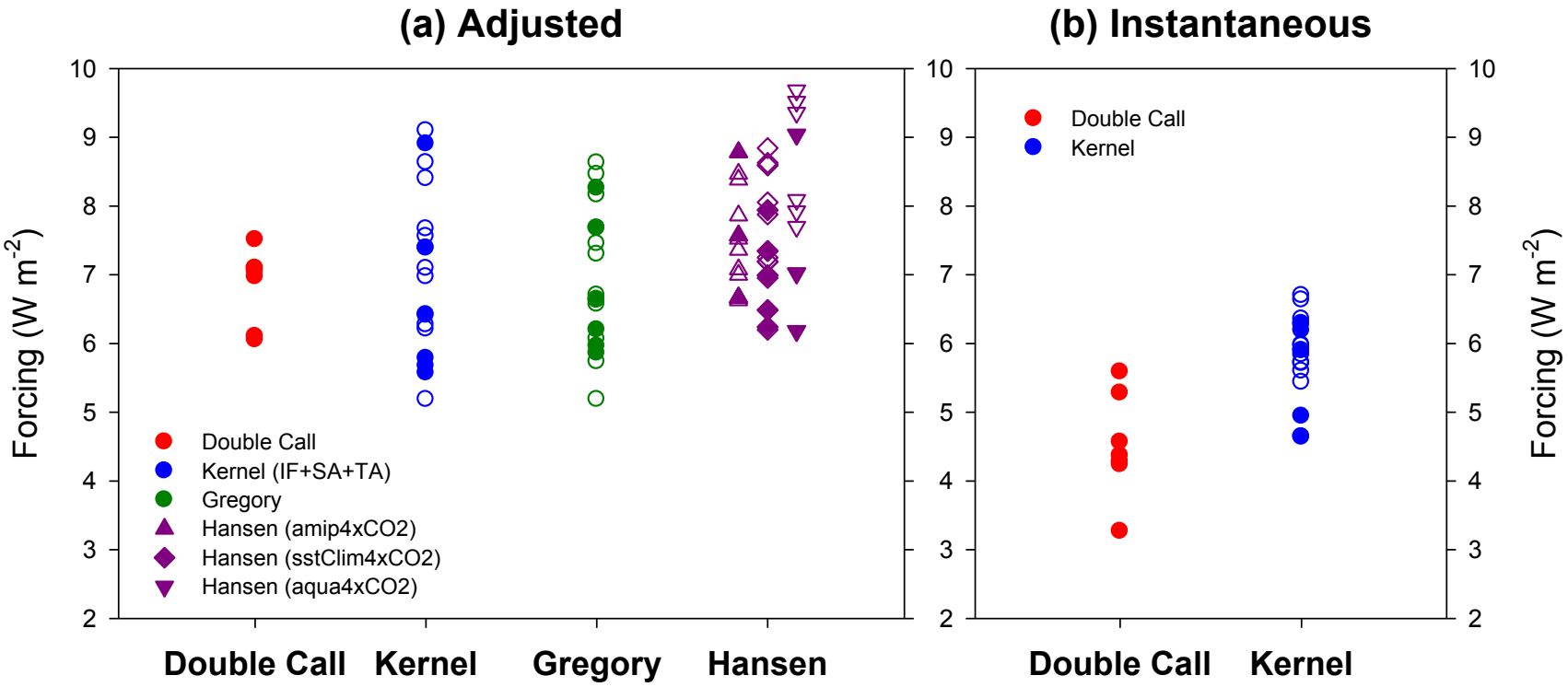
   ii. **Fixed SST "Hansen" Method (AMIP 4xCO2)**
   Increase CO2 while holding SSTs fixed to suppress feedbacks

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

Comparison of Direct and Adjusted Forcing



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)**
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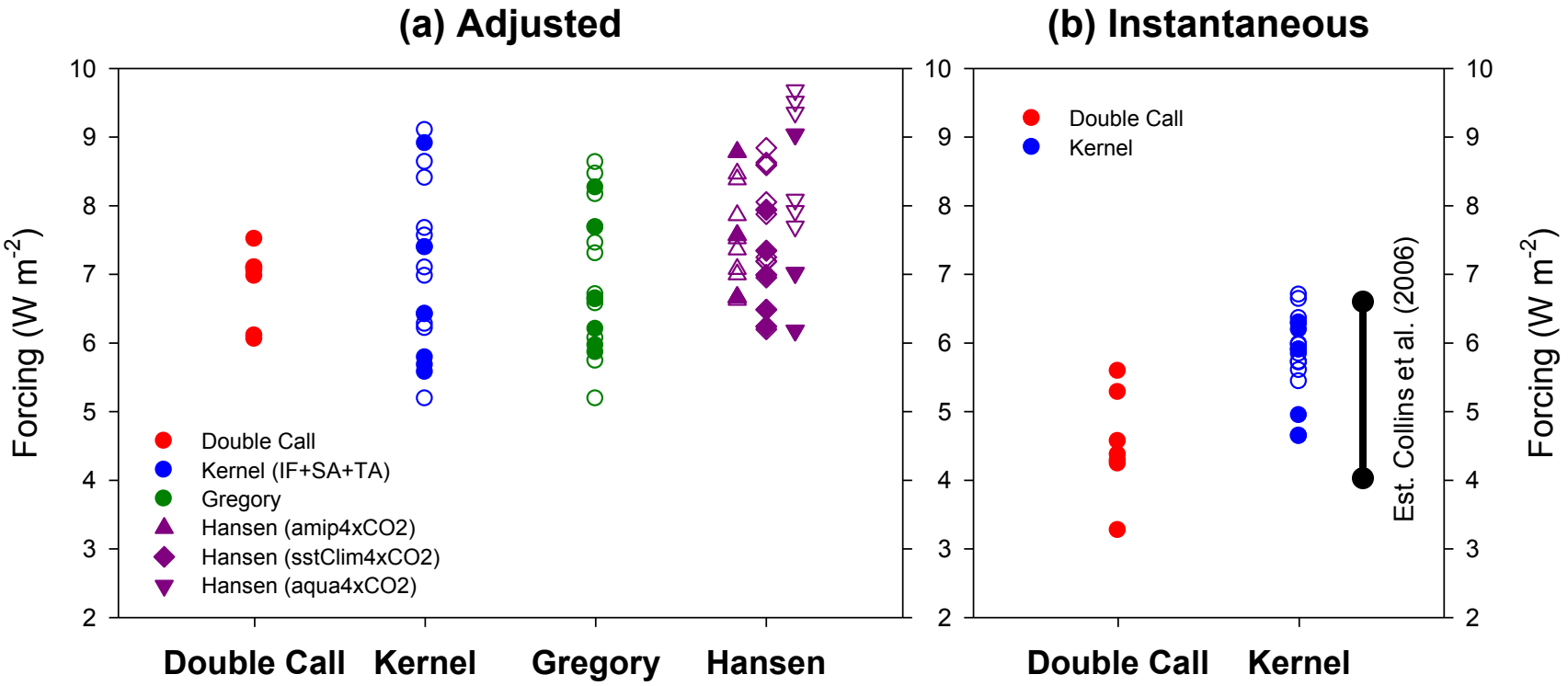
   Increase CO2 while holding SSTs fixed to suppress feedbacks

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

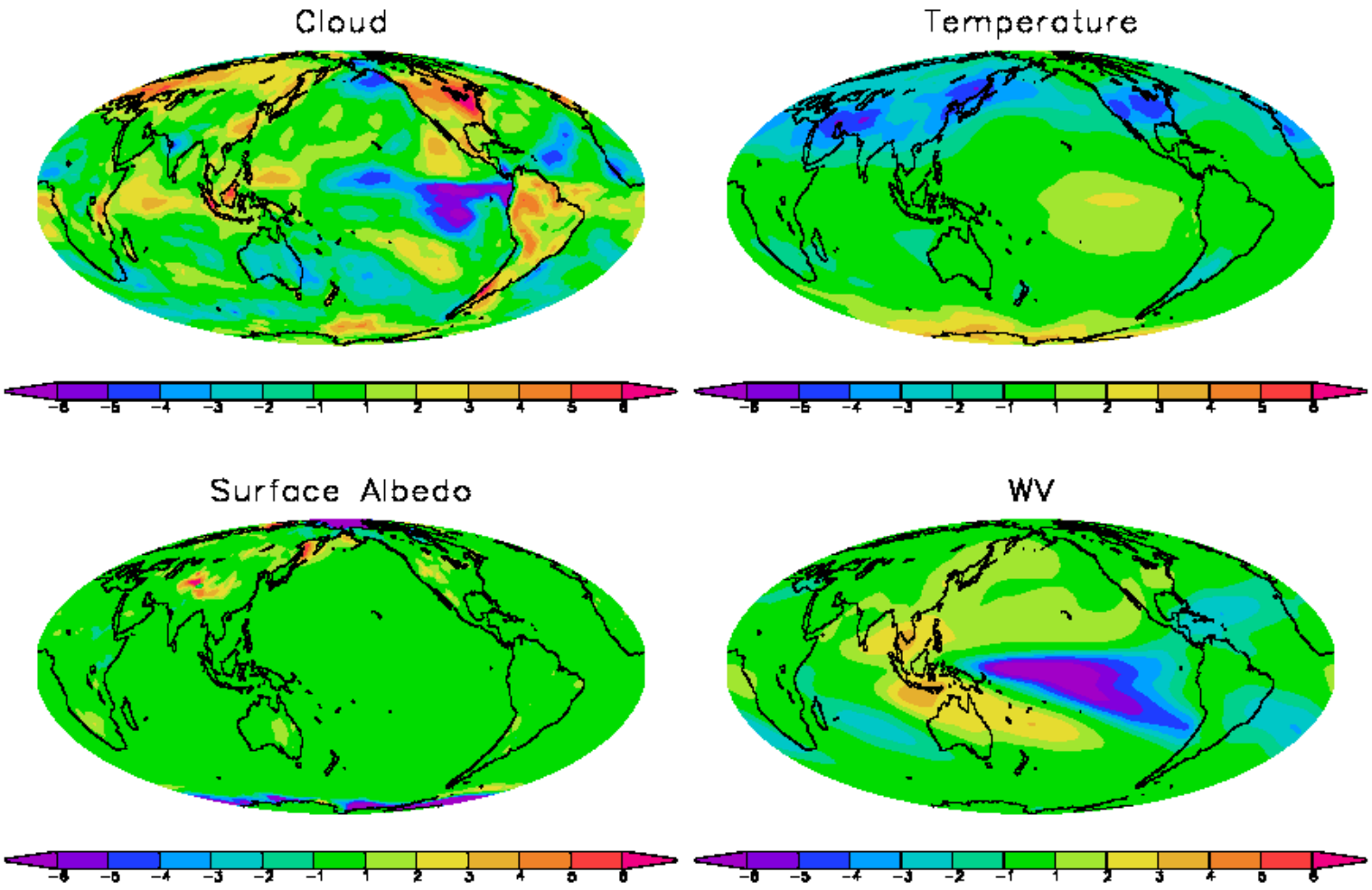


Kernel estimates of inst. forcing are consistent with those of Collins et al. (2006)

Conclusion

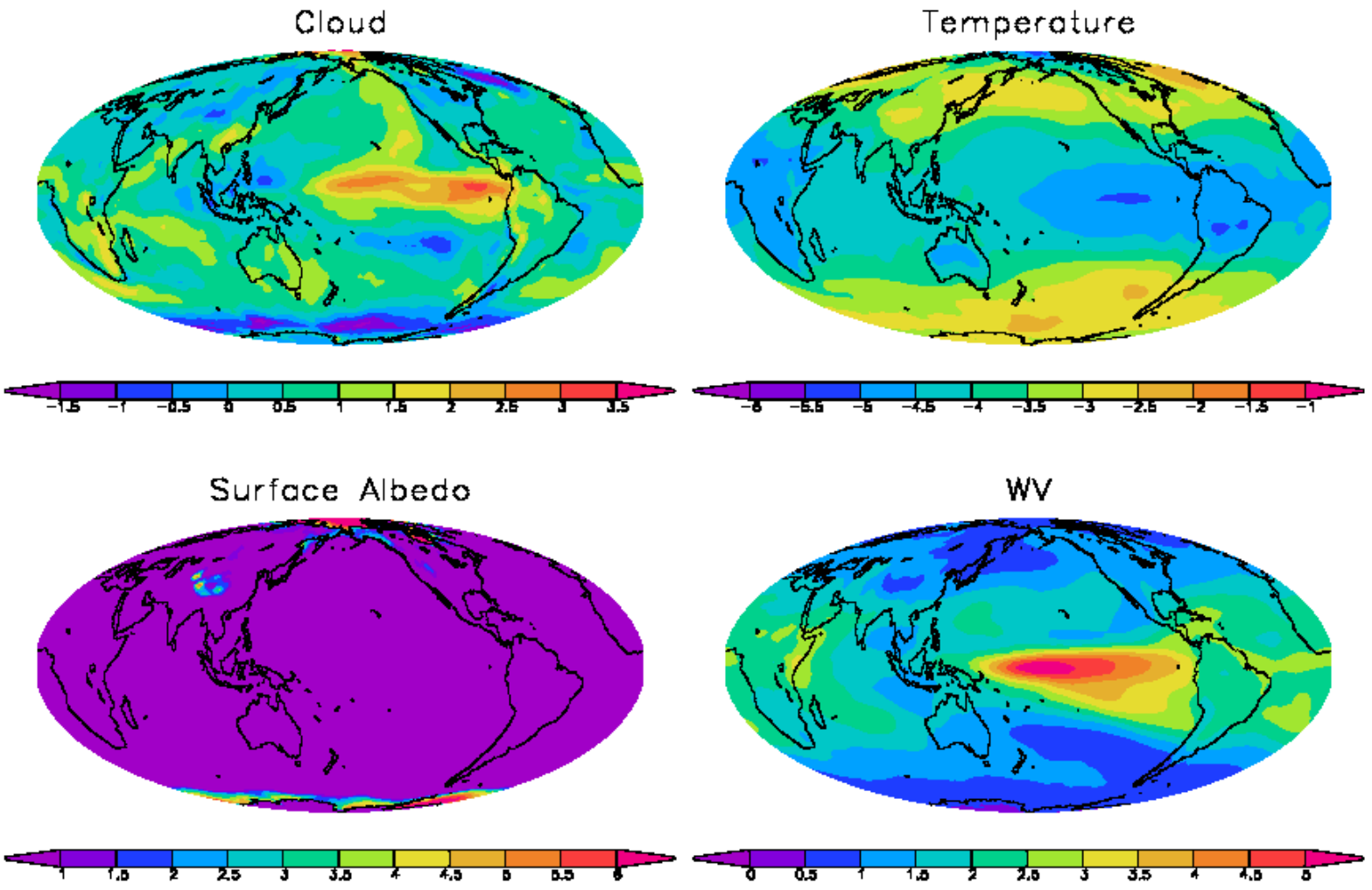
Double Call calculations of IF should be mandatory for each emission scenario in CMIP6

Regional Distribution of Tropospheric Adjustments



Large regional variations in tropospheric adjustments

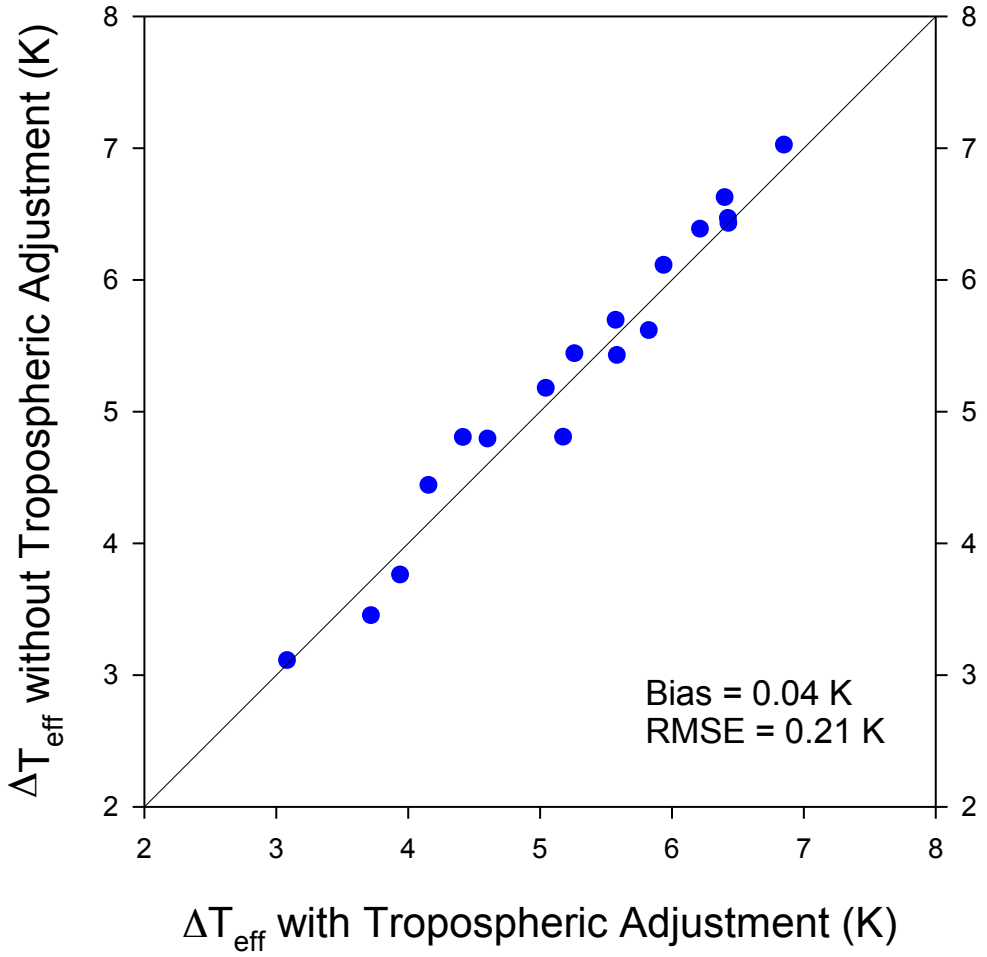
Regional Distribution of Tropospheric Feedbacks



Regional variations in adjustments tend to oppose the corresponding feedback

Adjustment or Feedback: Does it Matter?

Everything in troposphere is a feedback



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. Zhong[18]

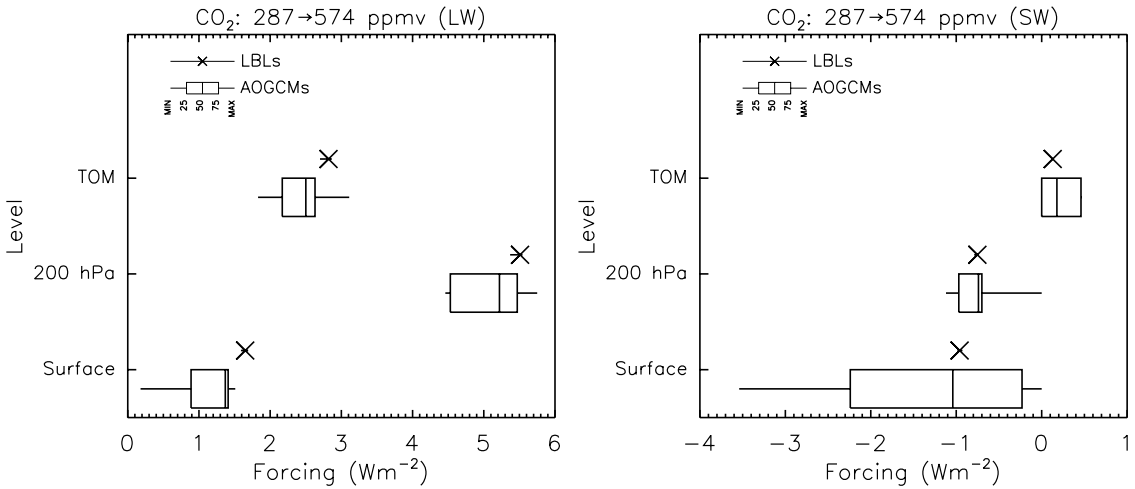
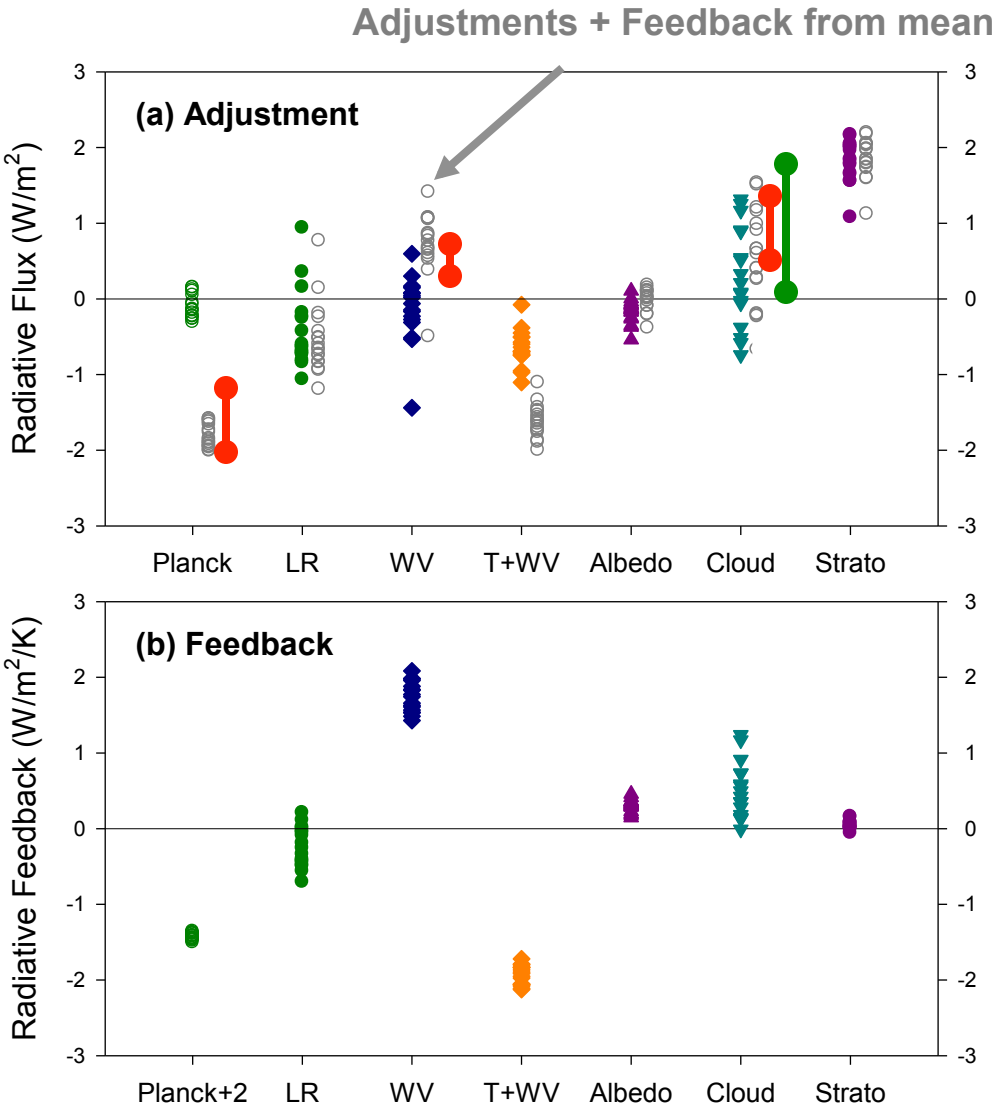


Figure 4. (left) Longwave forcings at TOM, 200 hPa, and the surface for increasing CO_2 from 287 to 574 ppmv (case 2b-1a, Table 2; same symbols as Figure 3). (right) Corresponding shortwave forcings.

Spread in 2xCO2 forcing for MLS Profiles: LW =1.2 W/m^2 SW=0.25 W/m^2

Intermodel Spread in Adjustments and Feedbacks



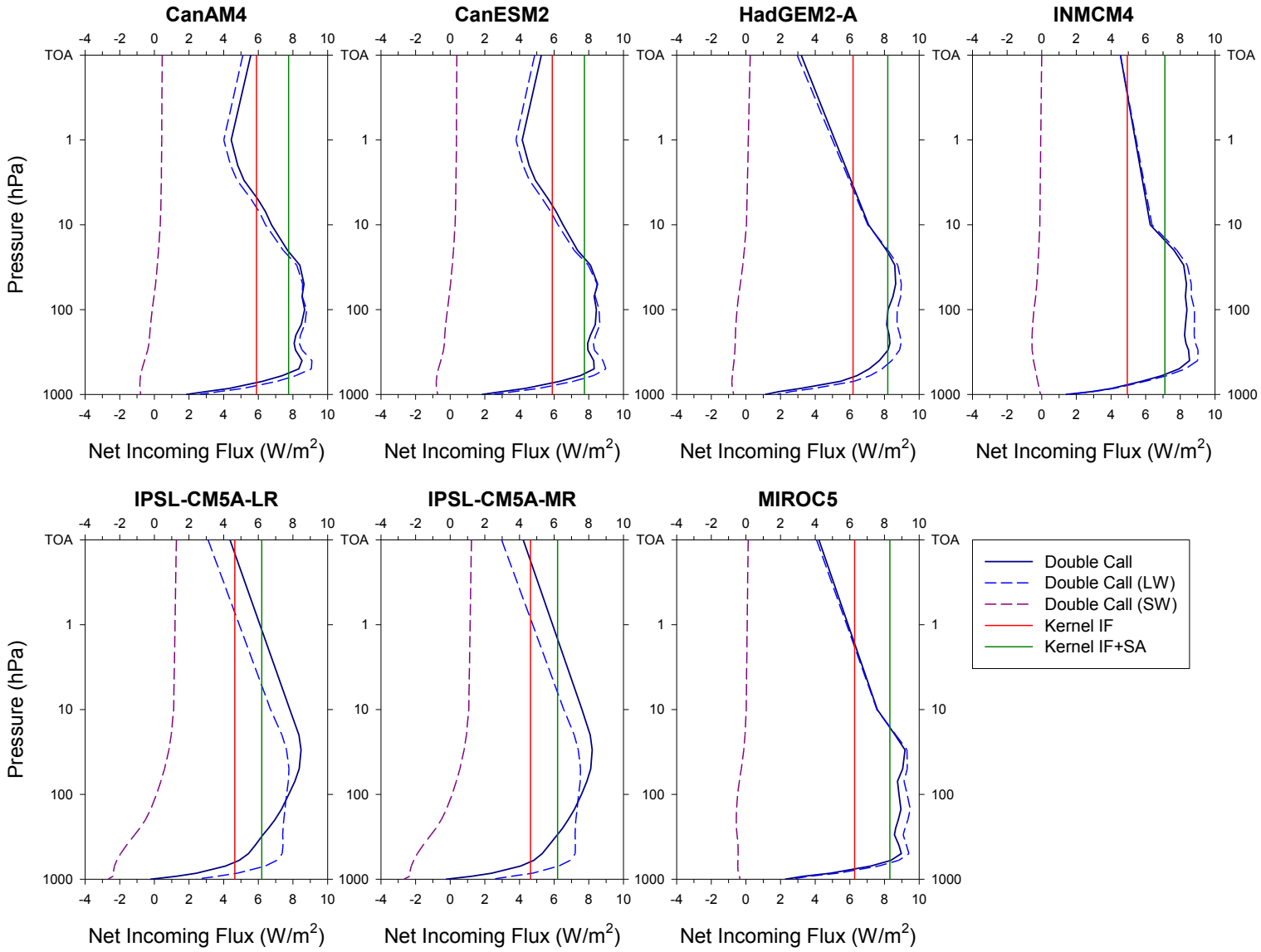
Vial et al. (2013) estimates of adjustments larger and have less spread.

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)

Profiles of Instantaneous Radiative Forcing



AR5 Radiative Forcing Scenarios from Radiative Kernels