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Radiation: Pathways to Accuracy and Implications for Interpretation

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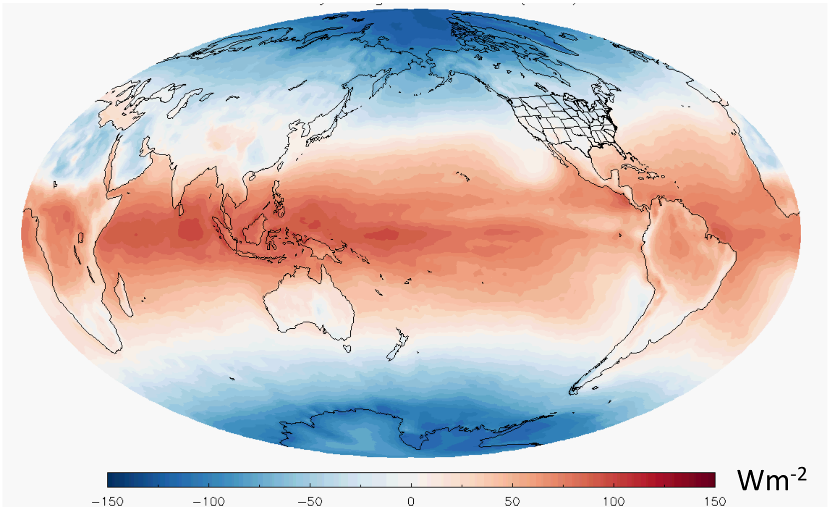
Context

- Radiation is the fundamental driver of weather and climate. Accurate representation is key to weather prediction and climate projection.
- Radiation is on uniquely solid theoretical grounds among physical parameterizations, but balancing computational cost and accuracy have been a challenge
- I'll describe work to improve the representation of radiation in models, assess errors, and determine how those errors impact interpretation of climate simulations

Unpacking radiative transfer

1. Determine optical properties of
   - Gases
   - Clouds
   - Aerosols



2. Compute transport

3. Coupling: use heating rates, surface fluxes to advance the model

Coupling radiation to dynamics

- Radiation is really computational intensive, so we approximate

$$F(x, y, z, t) \approx c(x, y, t) \sum_{g}^{G} w_g F_g(x, y, z, t_{\mathrm{rad}}(t) \mid t_{\mathrm{rad}}(t) - t \leq \Delta t_{\mathrm{rad}})$$

that is we compute radiation fluxes less frequently than other terms and correct for time dependence

  - Consistent with slow forcing by radiation
  - We ~~assume~~ hope this works

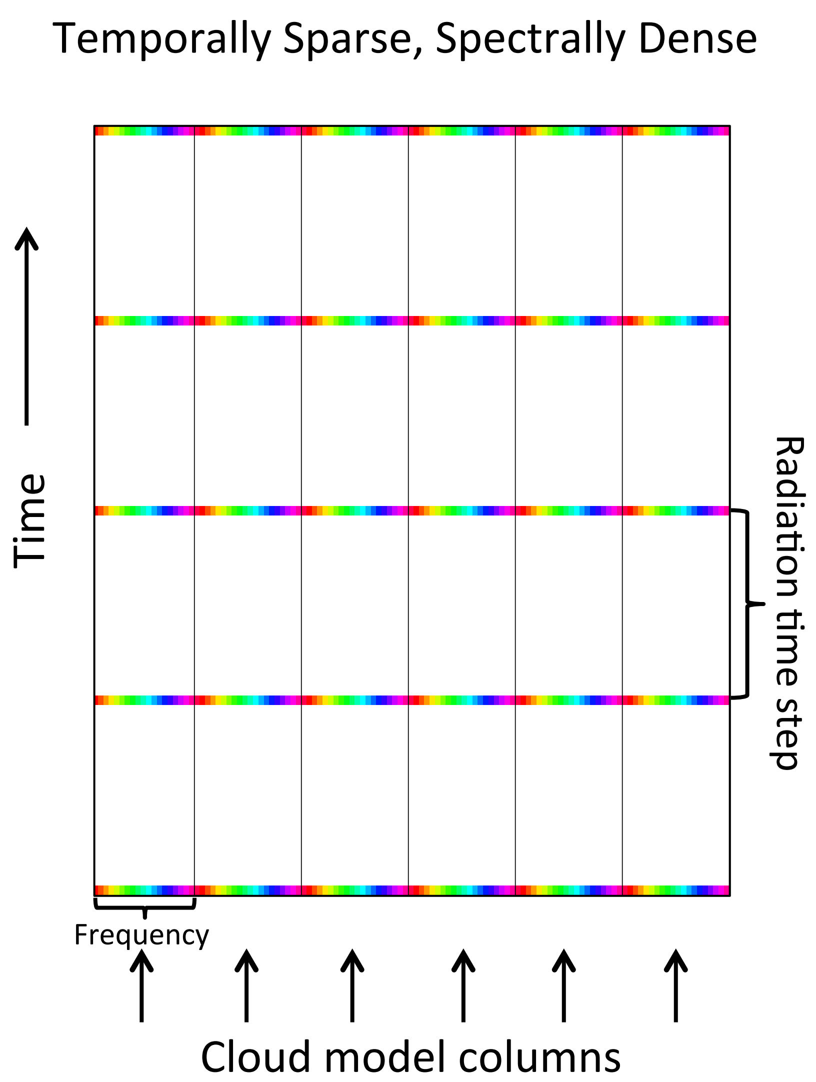
Coupling radiation to dynamics

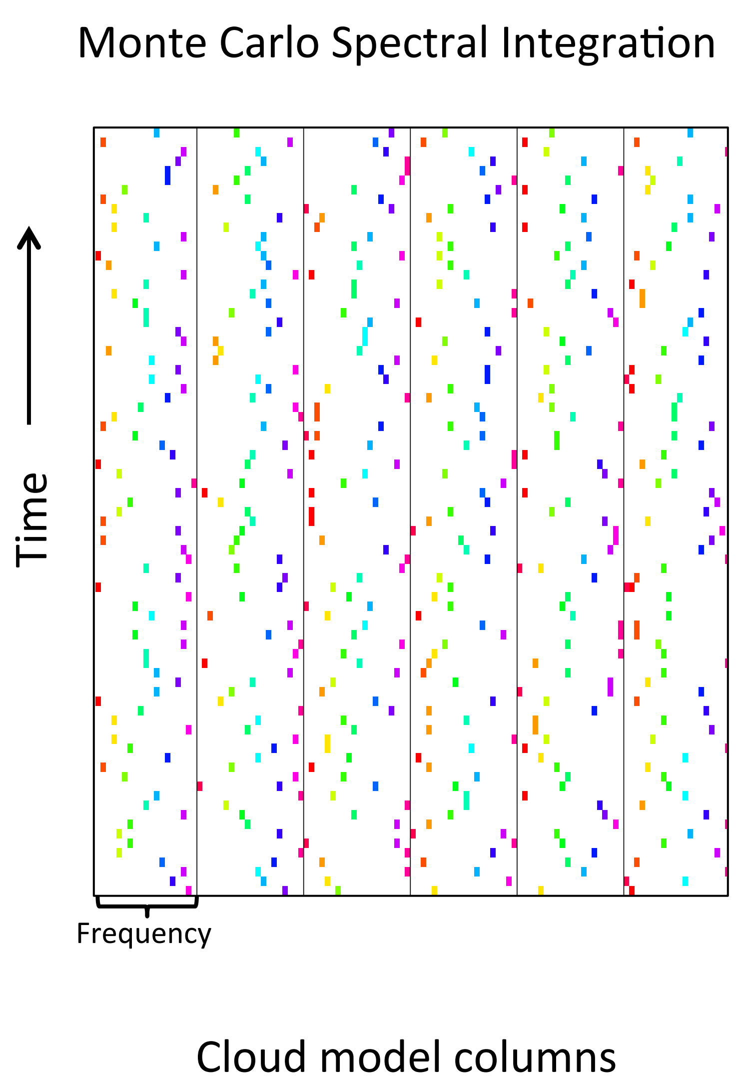
Insight: Frequent randomly-chosen subsets of the spectral integration are an unbiased estimate of the full calculation

$$F(x,y,z,t) \approx \frac{G}{G'} \sum_{g(i \in [1..G])}^{G'} w_g F_g(s'; x, y, z, t)$$

Why is this useful?

- Samples temporal variability
- Can save computation time
- Converges properly


Temporally Sparse, Spectrally Dense
Time
Radiation time step
Frequency
Cloud model columns


Monte Carlo Spectral Integration
Time
Frequency
Cloud model columns

Monte Carlo Spectral Integration: impacts

- Understanding why this works helped us better understand the coupling of radiation and cloud dynamics
- MCSI *enabled* realistic radiation in large-eddy simulations

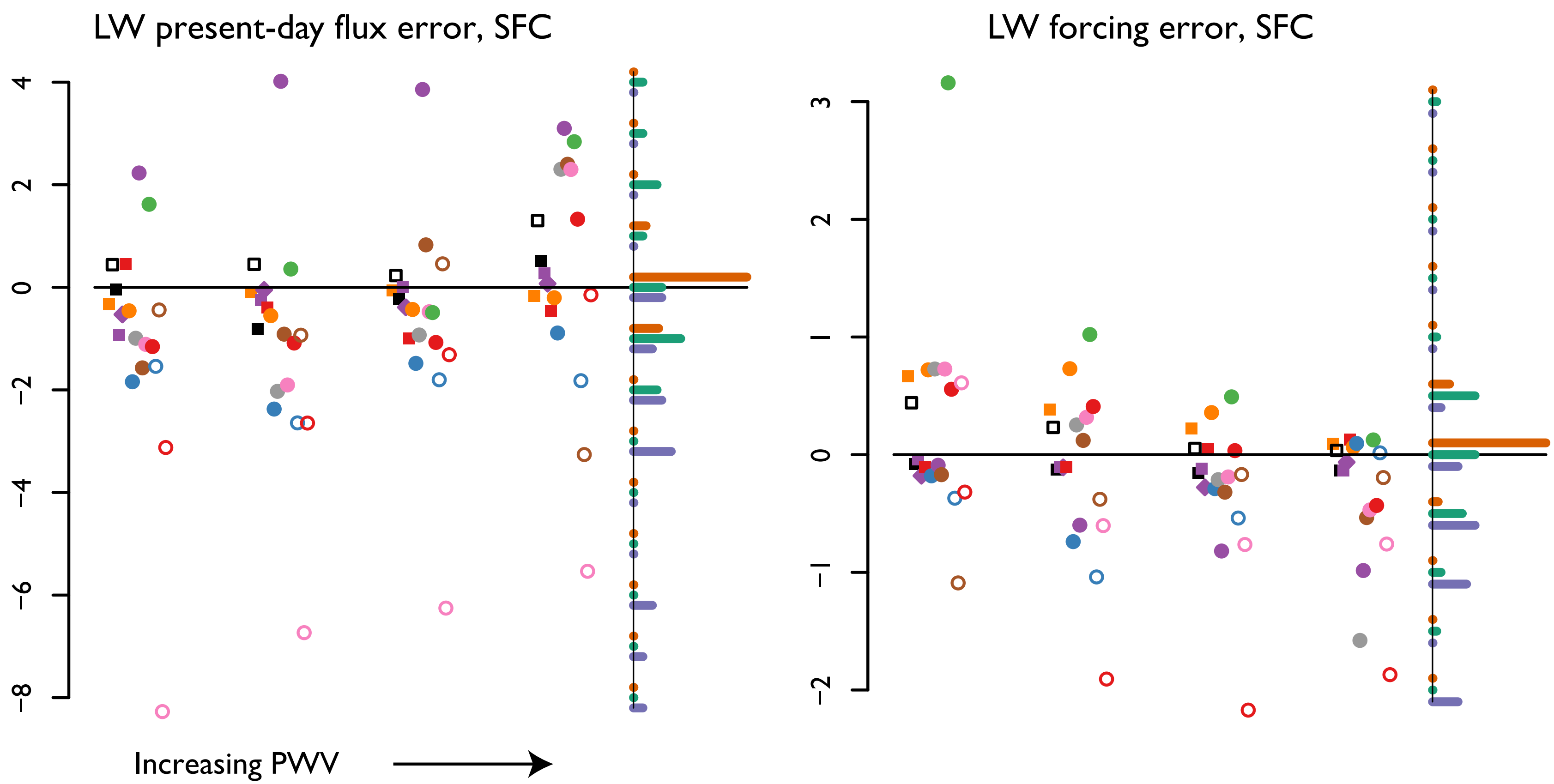
  …leading to new insights into cold pool/cloud dynamics, aerosol cloud interactions…

- Interactive land surface makes this problem harder

  Experiments in weather and climate contexts show no obvious advantage but the jury is still out

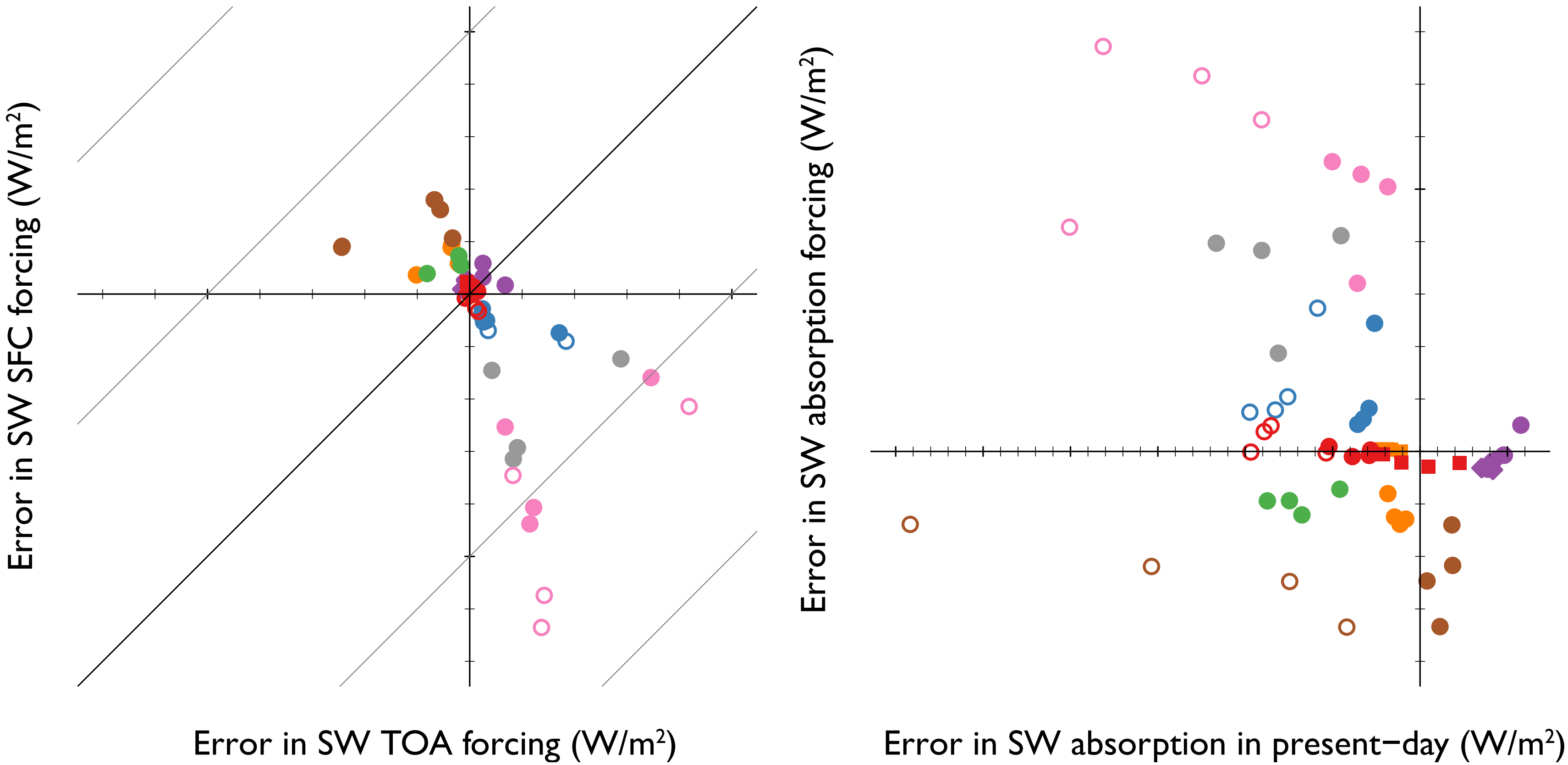
Schlemmer and Hohenegger, 2014; Seifert et al, 2015

Coupling strategies aside, the accuracy of radiation parameterizations can be assessed…

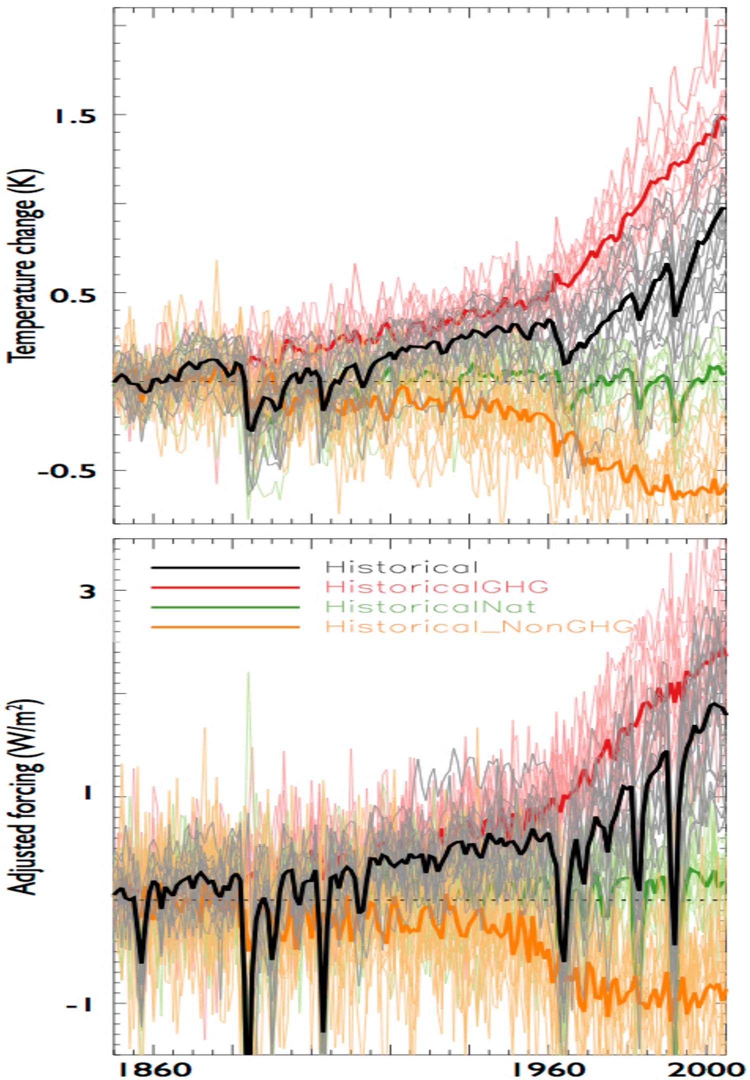


Pincus et al., 2015

… and are getting better, but still show a surprising range of skills especially in forcing calculations



Pincus et al., 2015



Even in "controlled" experiments each GCM is subject to different radiative forcing. This diversity arises from *errors*, loose specifications, and specific aspects of the model that modify the instantaneous forcing.

We can't understand diversity in response without quantifying the diversity in forcing and understanding how much of that diversity is plausible.

Forster et al., 2013

Radiative Forcing (RF) model intercomparison project

- Motivation
  - Disentangle variability in forcing from variability in response across models
- Approach
  - Characterize and assess radiative forcing for each model
  - Coordinate simulations in which RF is tightly specified
- Components
  - Offline assessment of parameterizations (Pincus)
  - Online diagnosis of effective radiative forcing (Forster)
  - Integrations with tightly-controlled RF (Stevens)

Summary

We are making models better by

- improving radiation parameterizations for weather and climate applications
- exploring radical new coupling strategies

We are leading an international effort to understand how relationships between forcing and climate response past, present, and future. This is key to interpreting projections, and to detection and attribution.

- Feeds directly into climate assessments such as IPCC AR6.