Sparse, Empirically Optimized Quadrature for Broadband Radiative Fluxes and Heating Rates

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Calculating Radiative Quantities

- Physics of radiative transfer is well-known
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- Direct spectral integration, and even parameterization, is computationally expensive
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Aim: create an alternative method that is easy to understand and customizable to different problems
Proposed Approach

• Can we sparsely sample the spectrum instead?

\[ F_{int} = \int F_{\nu} \, d\nu \approx \sum_i F_{\nu_i} \Delta \nu_i \]
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• Method: approximate the broadband integral with a weighted sum of a subset of monochromatic fluxes

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\approx \sum_{\nu \in S} w_\nu F_\nu
\]
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\[ \approx \sum_{\nu \in S} w_{\nu} F_{\nu} \]

• Two parts of the problem:
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  • Predict the total flux with linear weights
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\]

• Two parts of the problem:
  • Predict the total flux with linear weights
  • Optimize the subset using simulated annealing
Training and Testing Data

• CKDMIP: high-resolution spectral fluxes and broadband reference calculations
  • Two independent datasets, 50 atmospheric profiles, 55 vertical levels, 7 million wavenumbers

• Here – present-day clear-sky longwave fluxes
  → Variation only in water vapor, temperature, and ozone
Flux Profiles

\[ C = \|H_{est} - H_{ref}\| + f\|F_{est} - F_{ref}\| \]
Flux Profiles

\[ C = \| H_{est} - H_{ref} \| + f \| F_{est} - F_{ref} \| \]

\[ H_{est} = -\frac{g}{c_p} \frac{dF_{est}}{dp} \]

\[ F_{est} = w F_{v \in S} \]
Flux Profiles

\[ C = ||H_{est} - H_{ref}|| + f ||F_{est} - F_{ref}|| \]

RMS error in net flux (W/m²)

- Training
  - 64
  - 32
  - 16
  - 8
  - 4
  - eeCKD
  - RRTMGP

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  - 64
  - 32
  - 16
  - 8
  - 4

Pressure (hPa)
Heating Rates

\[ C = \| H_{est} - H_{ref} \| + f \| F_{est} - F_{ref} \| \]
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Limitations – Tied to Training Data

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\[ H_{est} = -\frac{g}{c_p} \frac{dF_{est}}{dp} \]

\[ F_{est} = \omega F_{\nu \in S} \]
Limitations – Tied to Training Data
Forcing by CO$_2$

\[ C = \|H_{est} - H_{ref}\| + f \|F_{est} - F_{ref}\| + \|F_{est} - F_{ref}\| \]
Forcing by CO$_2$

\[ C = \| H_{est} - H_{ref} \| + f \| F_{est} - F_{ref} \| + \| \mathcal{F}_{est} - \mathcal{F}_{ref} \| \]

\[ \mathcal{F}_{est} = \text{OLR}^{\text{present}}_{est} - \text{OLR}^{\text{perturbed}}_{est} \]
Forcing by CO$_2$:

\[ C = \| H_{est} - H_{ref} \| + f \| F_{est} - F_{ref} \| + \| \mathcal{F}_{est} - \mathcal{F}_{ref} \| \]

\[ \mathcal{F}_{est} = OLR_{est}^{\text{present}} - OLR_{est}^{\text{perturbed}} \]

8 x CO$_2$
Forcing by CO$_2$

\[ C = \|H_{est} - H_{ref}\| + f\|F_{est} - F_{ref}\| + \|\mathcal{F}_{est} - \mathcal{F}_{ref}\| \]
Forcing by CO₂

\[ C = \| H_{est} - H_{ref} \| + f \| F_{est} - F_{ref} \| + \| F_{est} - F_{ref} \| \]

Sparse, Empirically Optimized Quadrature for Broadband Spectral Spectral Integration

Paulina Czarnecki, Lorenzo Polvani, Robert Pincus

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Implementation in a Simple Model

With Stefan Buehler (UHH), Manfred Brath (UHH), Richard Larsson (UHH), and Lukas Kluft (MPI)
Implementation in a Simple Model

Single-column RCE model developed by Lukas Kluft et al. at MPI, Hamburg
Implementation in a Simple Model

konrad

Single-column RCE model developed by Lukas Kluft et al. at MPI, Hamburg

Line-by-Line radiation code developed by Stefan Buehler et al. at Uni. Hamburg

ARTS
Implementation in a Simple Model

ARTS calculates monochromatic fluxes

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konrad
Implementation in a Simple Model

ARTS calculates monochromatic fluxes

Quadrature scheme computes fluxes + heating rates, and feeds back into atmospheric state

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Implementation in a Simple Model

ARTS

Konrad

Quadrature scheme
- Quadrature scheme computes fluxes + heating rates, and feeds back into atmospheric state

ARTS calculates monochromatic fluxes
- Includes longwave and shortwave clear-sky schemes that can handle present-day variations + perturbations in CO2

Single-column RCE model developed by Lukas Kluft et al. at MPI, Hamburg

Line-by-Line radiation code developed by Stefan Buehler et al. at Uni. Hamburg
Conclusions

• The quadrature scheme is more flexible than leading models
  • Our computational cost/accuracy are competitive
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• The scheme works well in a simple model in present-day, clear-sky conditions
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  • Our computational cost/accuracy are competitive
• The scheme works well in a simple model in present-day, clear-sky conditions

• Further challenges:
  • Clouds
  • Variation in a wider set of gases
Thank you!
Important quantities can + should be added to the cost function