On the use of spectral kernels

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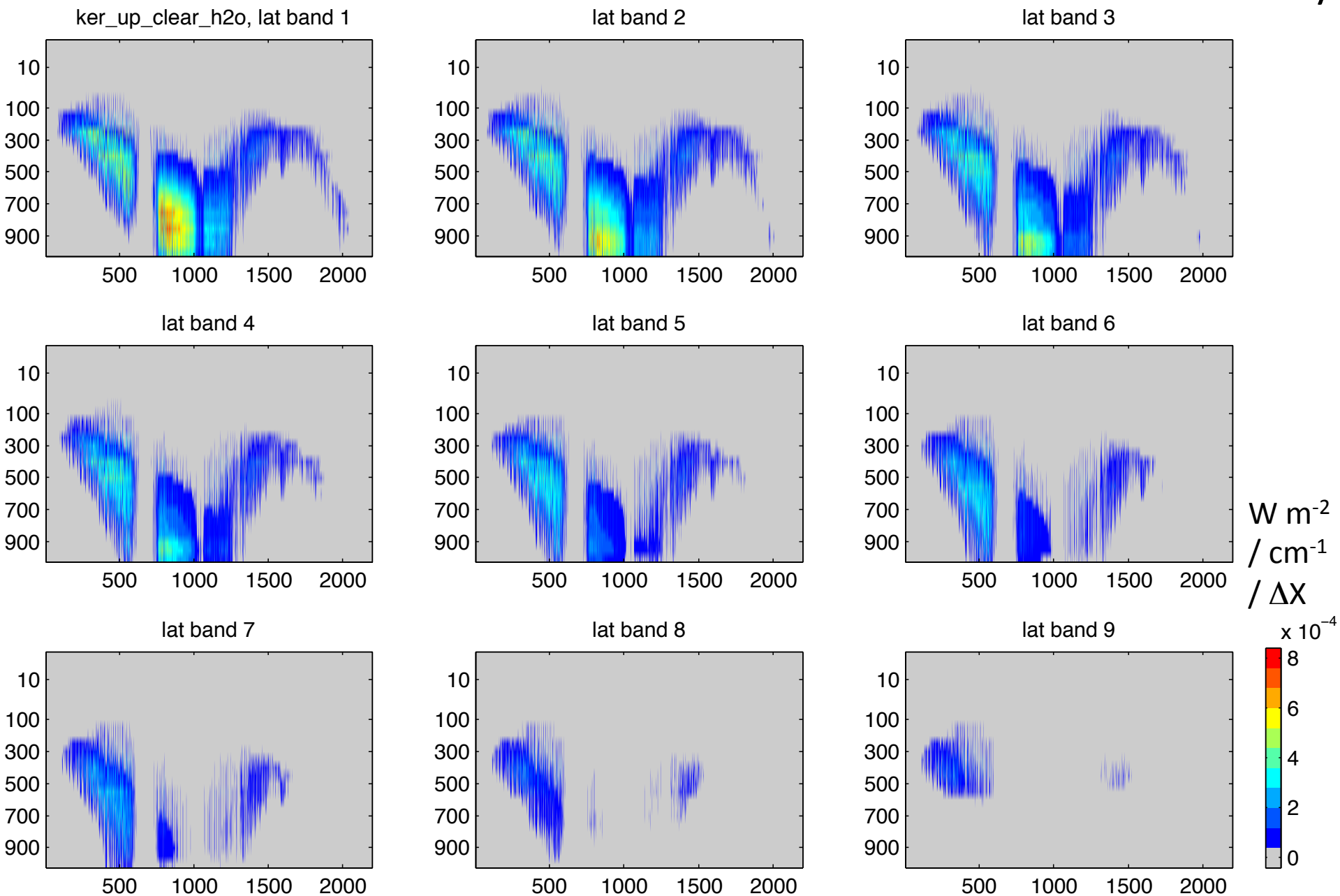
Spectral kernel application

- Kernel (scaling) method
  - Spectral kernels
  - Radiative effect of water vapor
- Implication for radiative forcing in general
  - Curve of growth (spectroscopy) explanation vs. Radiative transfer explanation

Reference
Bani Shahabadi, M., and Y. Huang (2014), Logarithmic radiative effect of water vapor and spectral kernels, J. Geophys. Res. Atmos., 119, 6000–6008, doi:10.1002/2014JD021623.

Zonal mean (equa. to pole) spectral kernels

Water vapor
clear-sky



Zonal mean (equa. to pole) spectral kernels

Water vapor
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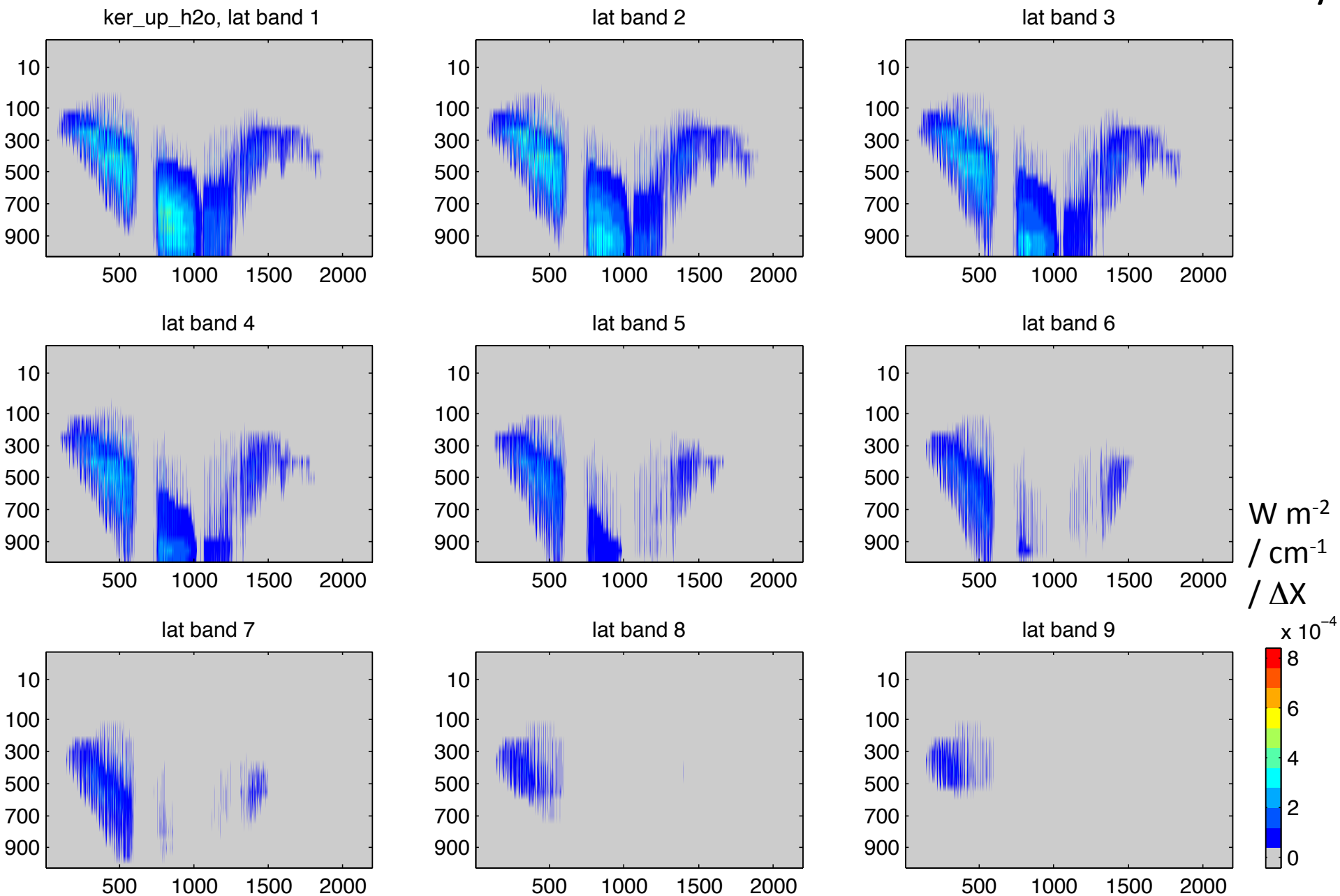
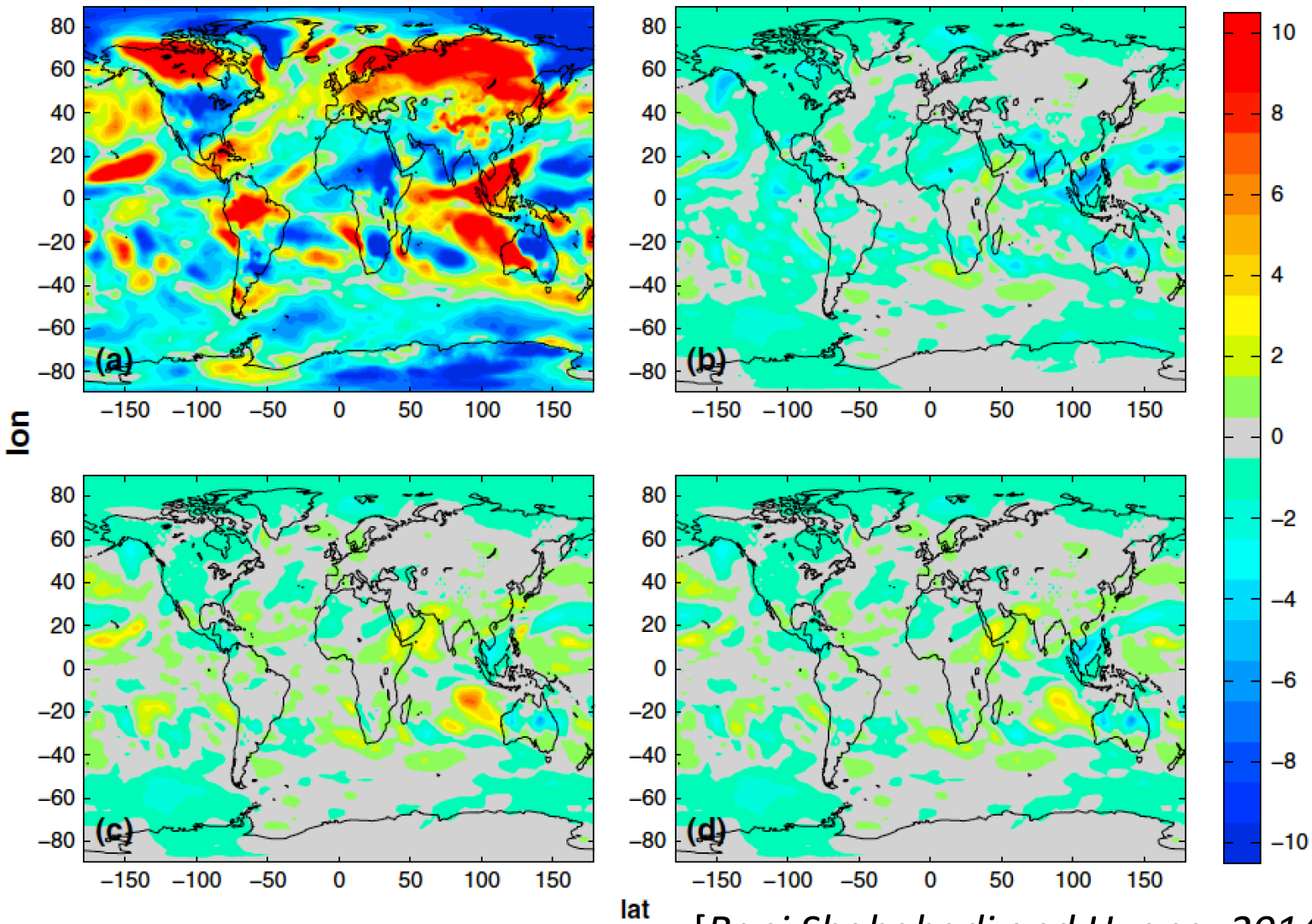


Model-simulated vs. Kernel-analyzed dOLR



- Example: Interannual variation
- kernel method

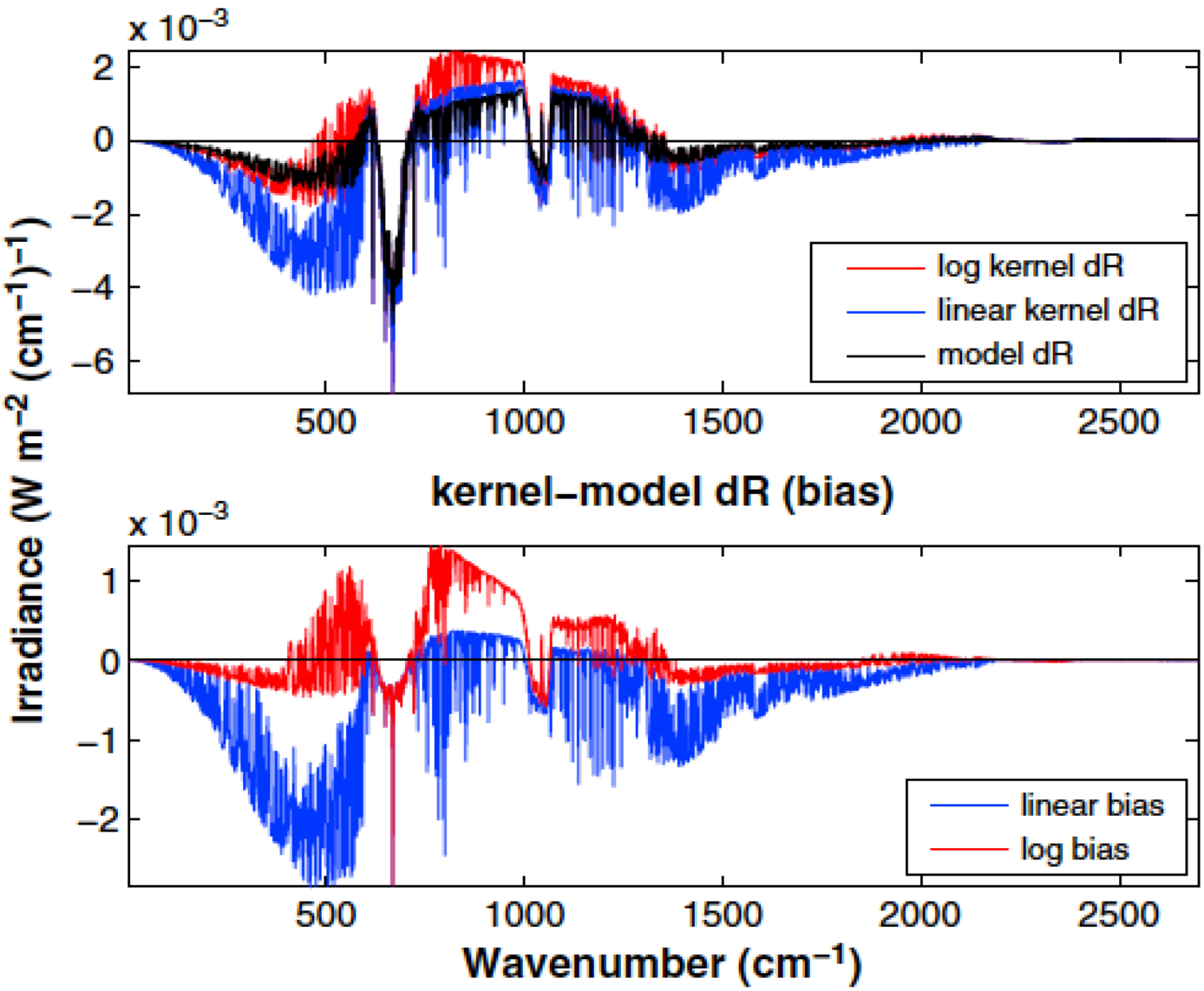
$\Delta R_X = (dR/dX)\Delta X$

Truth Simul.	Bias K_{LINEAR}
Bias K_{LOG}	Bias Hybrid

W m^{-2}

[*Bani Shahabadi and Huang, 2014, J.G.R.-Atmos.*]

Model-simulated vs. Kernel-analyzed spectral dOLR



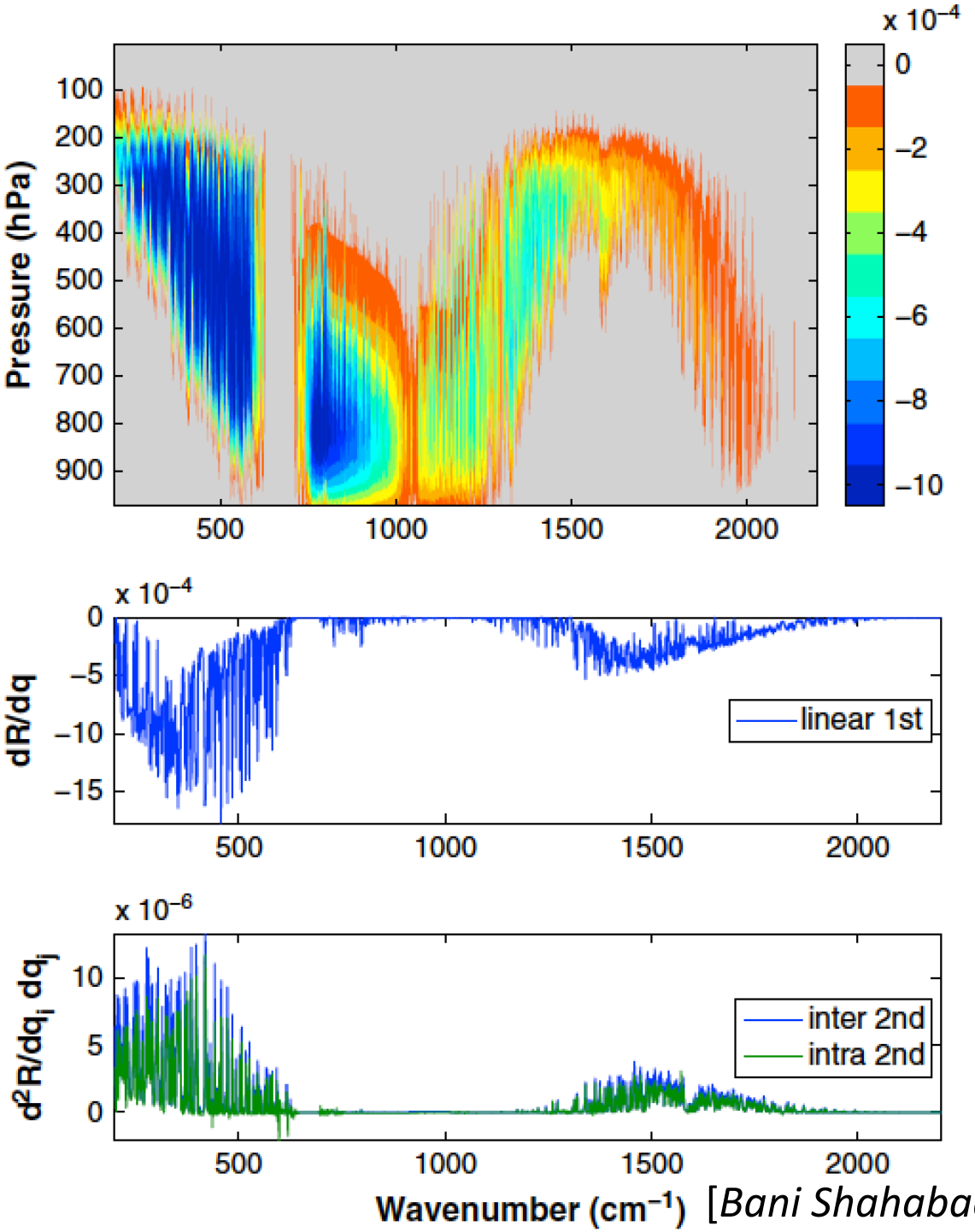
- Interannual tropical mean change
- kernel method

$\Delta R_X=(dR/dX)\Delta X$

Concerning H2O:
Linear scaling:
$\Delta X=\Delta(q)$

Log-scaling:
$\Delta X=\Delta(\log(q))$

[*Bani Shahabadi and Huang, 2014, J.G.R.-Atmos.*]

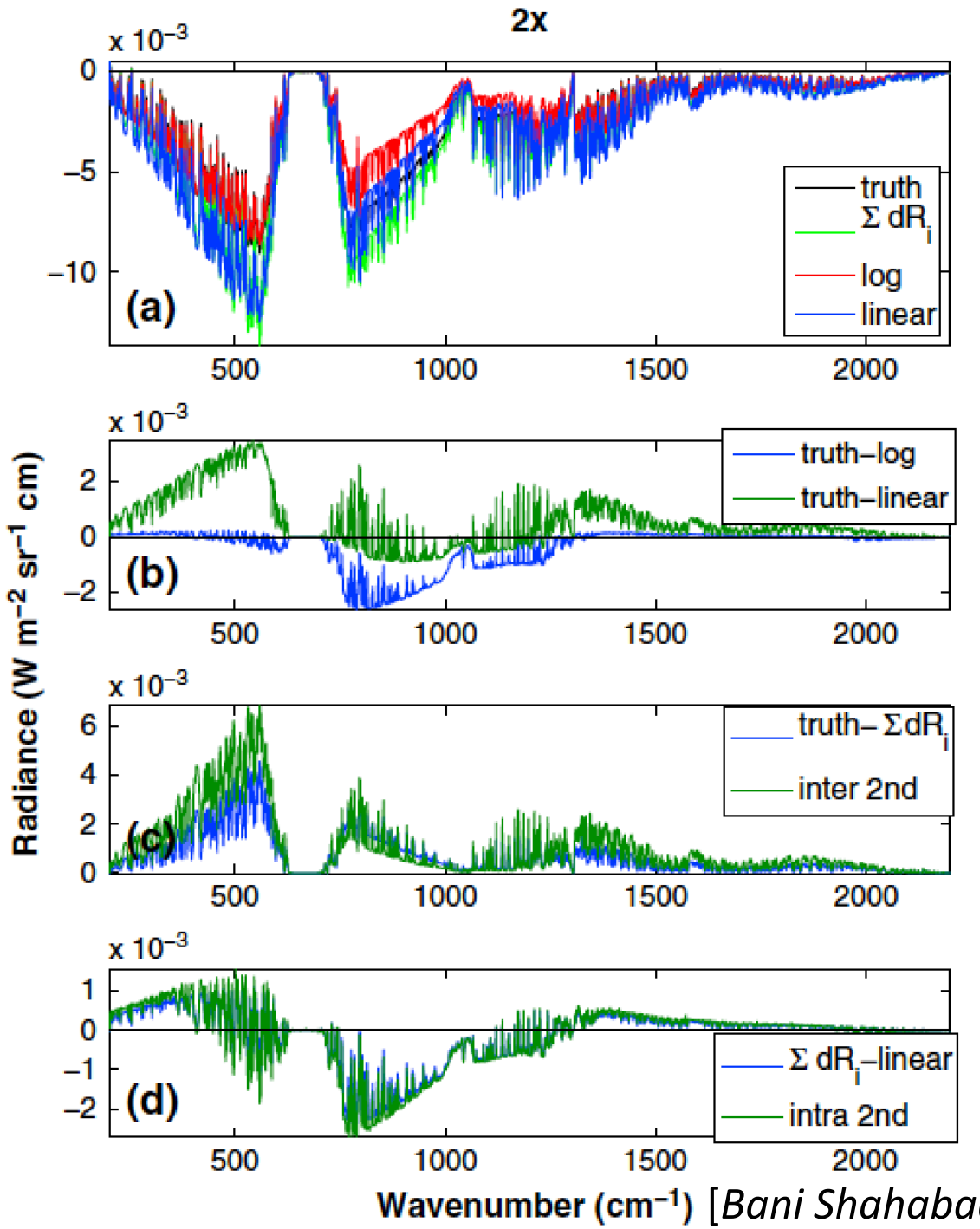


1st vs. 2nd-order kernel

- Log behaviour, i.e., reduced sensitivity, can be understood as inter-layer and intra-layer effects.

$$\Delta R = \sum_i \frac{\partial R}{\partial q^i} \Delta q^i + \frac{1}{2} \sum_i \frac{\partial^2 R}{\partial q^i \partial q^i} (\Delta q^i)^2 + \sum_{i \neq j} \frac{\partial^2 R}{\partial q^i \partial q^j} \Delta q^i \Delta q^j$$

[*Bani Shahabadi and Huang, 2014, J.G.R.-Atmos.*]



1st vs. 2nd-order kernel

- Case: uniform 2xH2O
- Inter-layer > intra-layer for H2O band
- Inter-layer offsets intra-layer

$$\Delta R = \sum_i \frac{\partial R}{\partial q^i} \Delta q^i + \frac{1}{2} \sum_i \frac{\partial^2 R}{\partial q^i \partial q^i} (\Delta q^i)^2 + \sum_{i \neq j} \frac{\partial^2 R}{\partial q^i \partial q^j} \Delta q^i \Delta q^j$$

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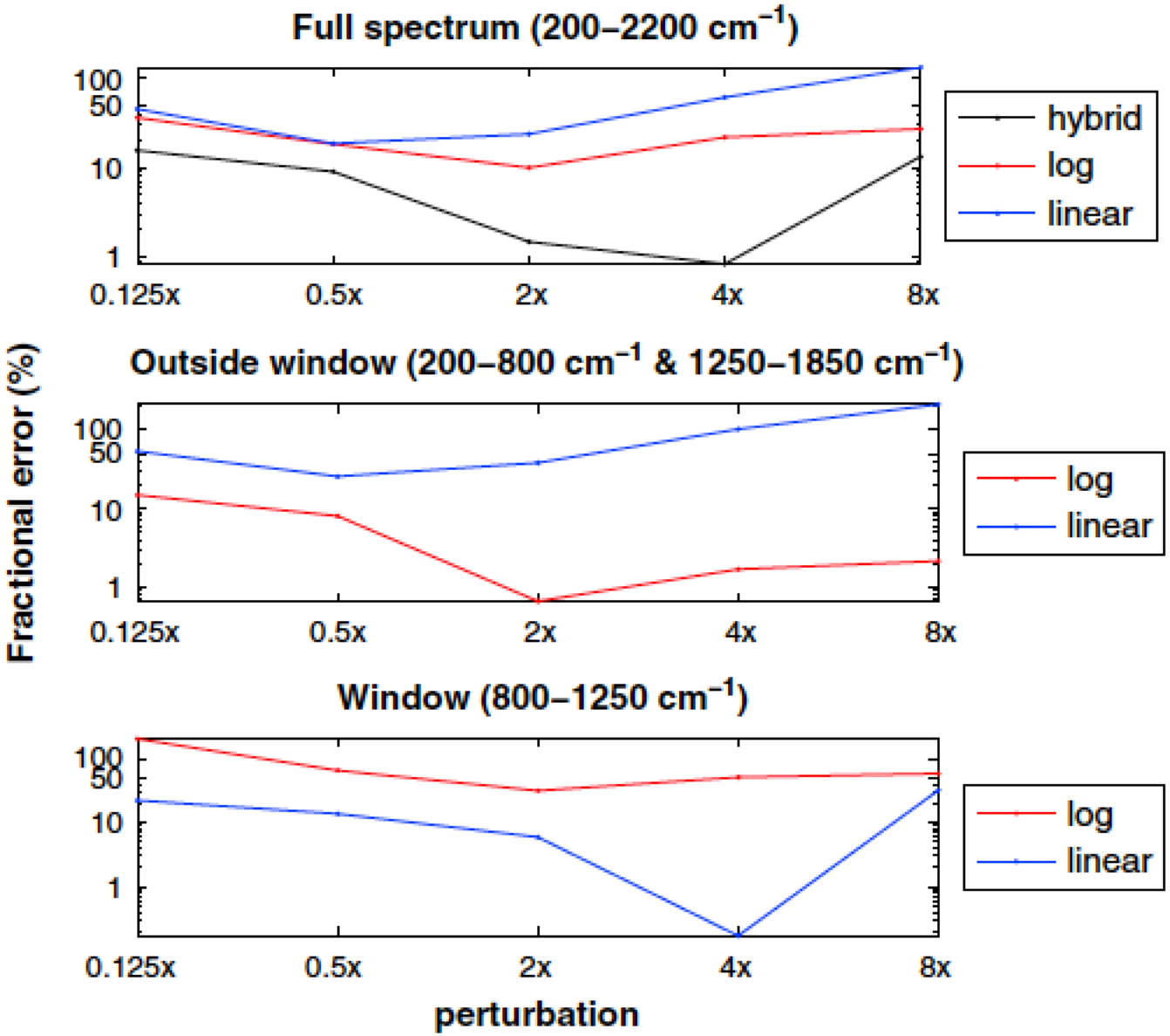


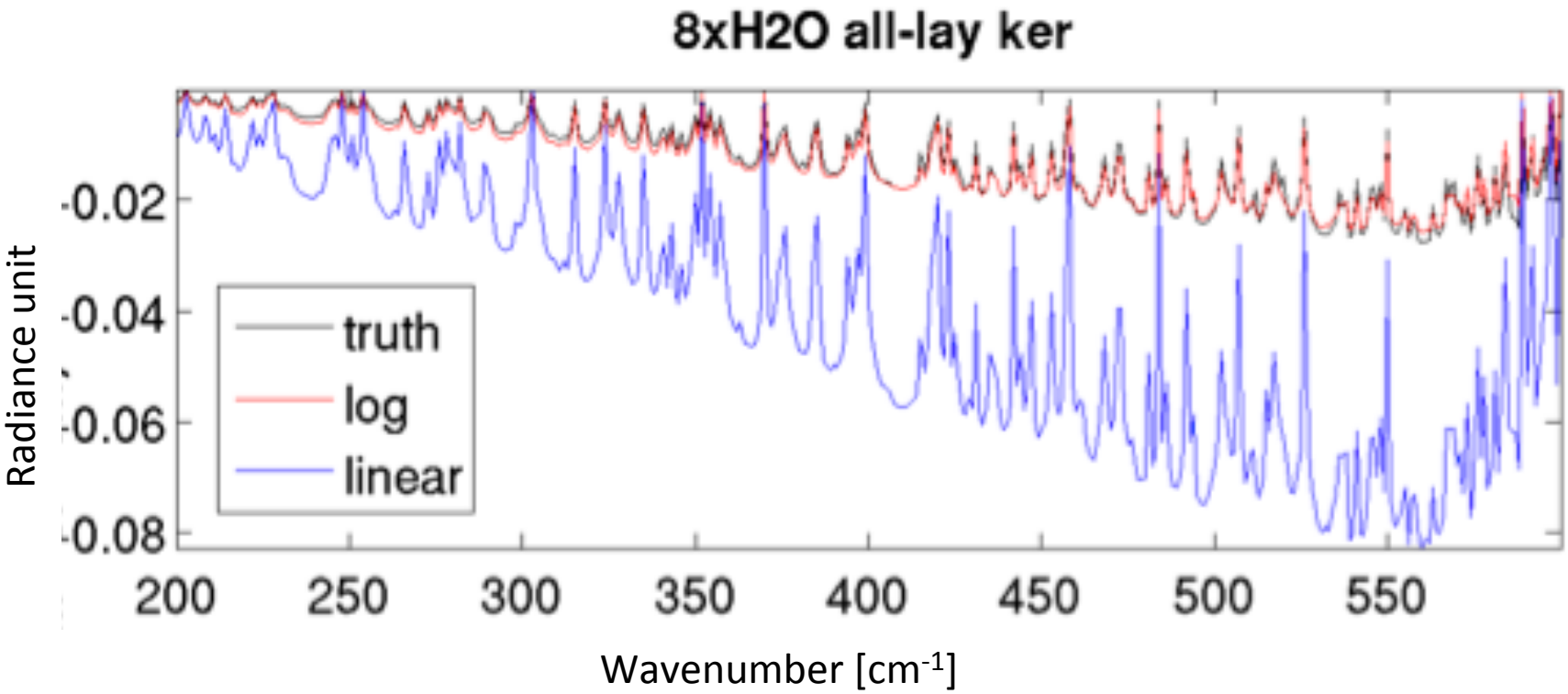
Hybrid scaling

Best performance can be obtained through:

- Absorption band: log-scaling
- Window: linear-scaling

[*Bani Shahabadi and Huang, 2014, J.G.R.-Atmos.*]

Logarithmic relationship holds even for monochromatic radiance!



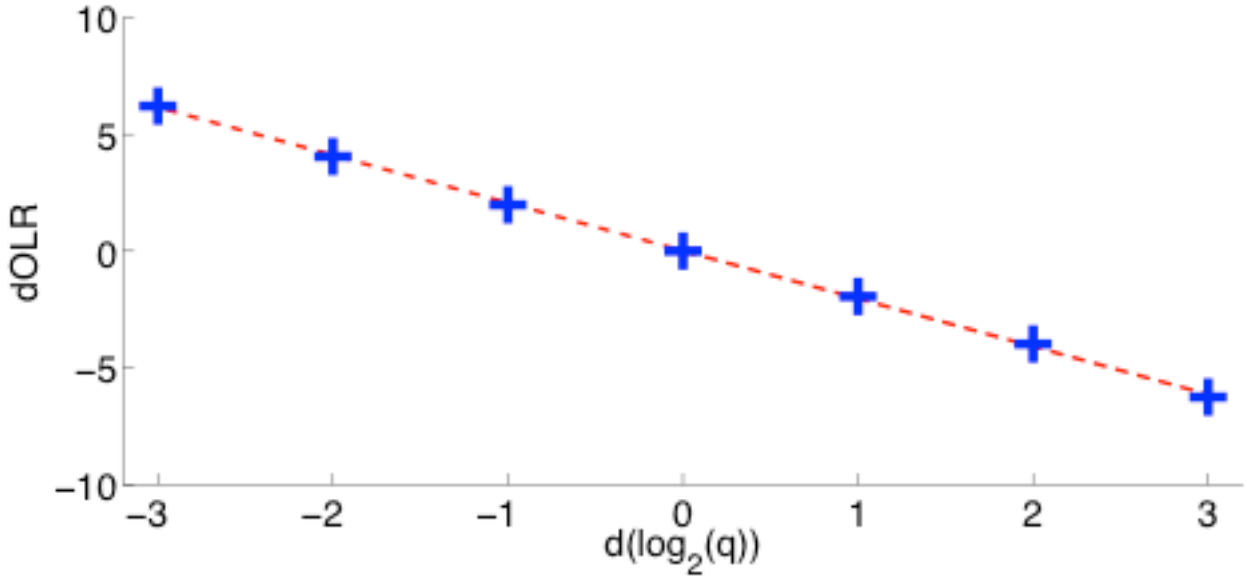
Monochromatic!

Truth:
$\Delta R(8x) = R(8x) - R(1x)$
Calculated using LBL RT model

Log scaling:
$\Delta R(8x) = \Delta R(1.1x) * \log(8)/\log(1.1)$

Linear scaling:
$\Delta R(8x) = \Delta R(1.1x) * (8-1)/0.1$

Logarithmic relationship

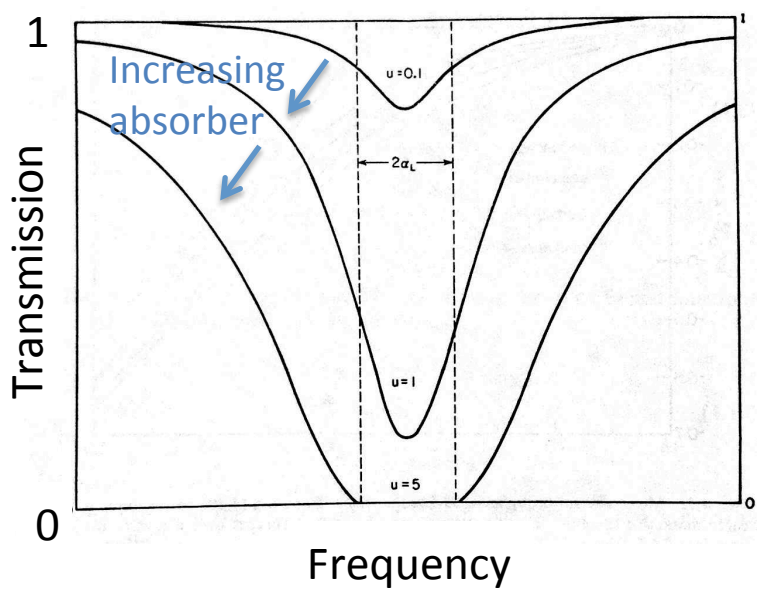


Radiative forcing [W m^{-2}] calculated using R.T. model by perturbing atmospheric CO_2 concentration (q).

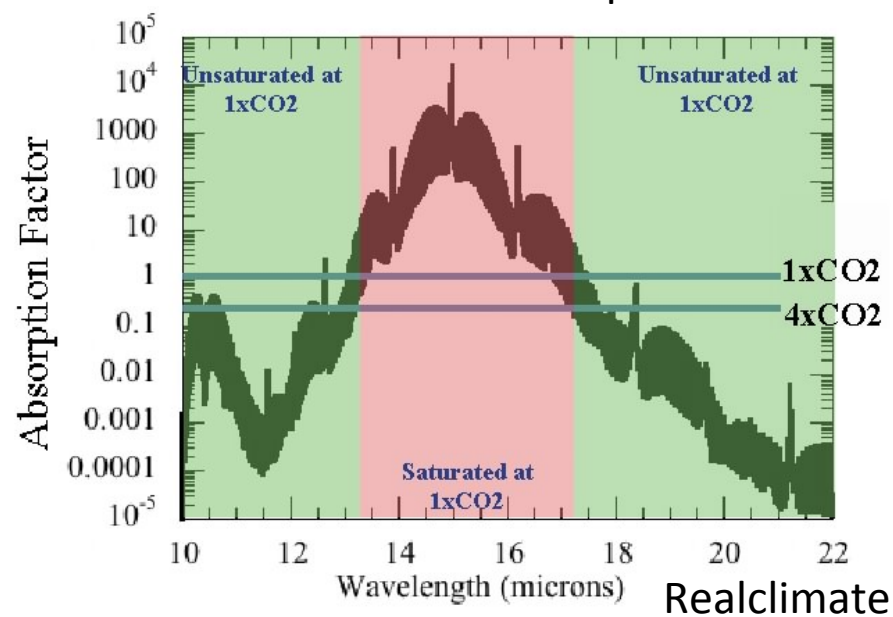
- Log relationship can be verified with any RT model
- Log estimation formula widely adopted
  - $F = F_0 \log(q/q_0)$
  [IPCC AR1,2,3,…; Wikipedia, …]

Cause of logarithmic relationship
Answer 1: it is due to spectroscopy

Saturation of an absorption line



Saturation of an absorption band

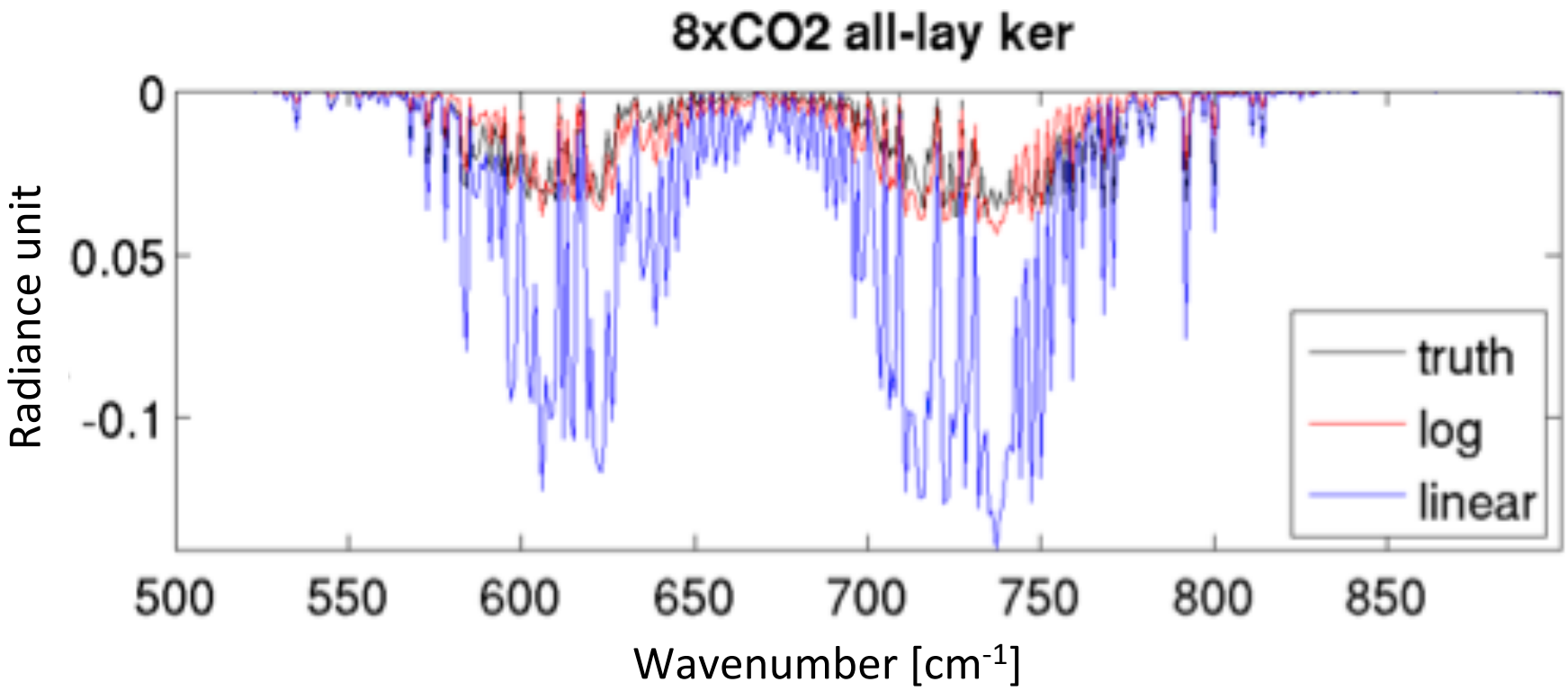


Realclimate.org

Radiative forcing ∝ increased absorption ∝ saturation from line center to wing: "curve of growth" theorem [Goody&Yung 1989]; from band center to wing [Pierrehumbert 2010]

The log relationship applies to spectrally integrated (broadband) radiation flux.

Counterevidence: Logarithmic relationship holds even for monochromatic radiance!



CO_2 case.

Truth:
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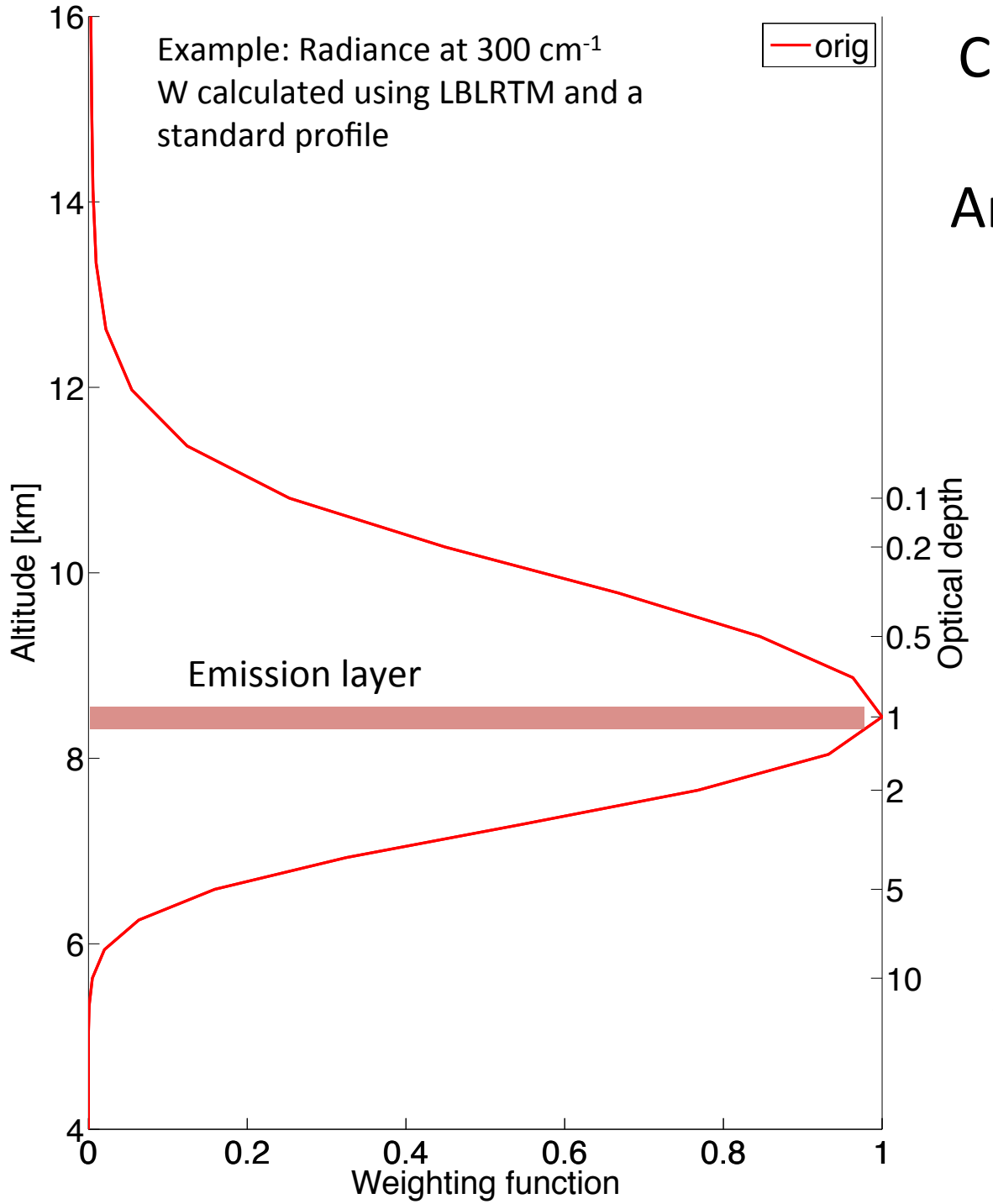


Cause of logarithmic relationship

Answer 2: it is due to radiative transfer

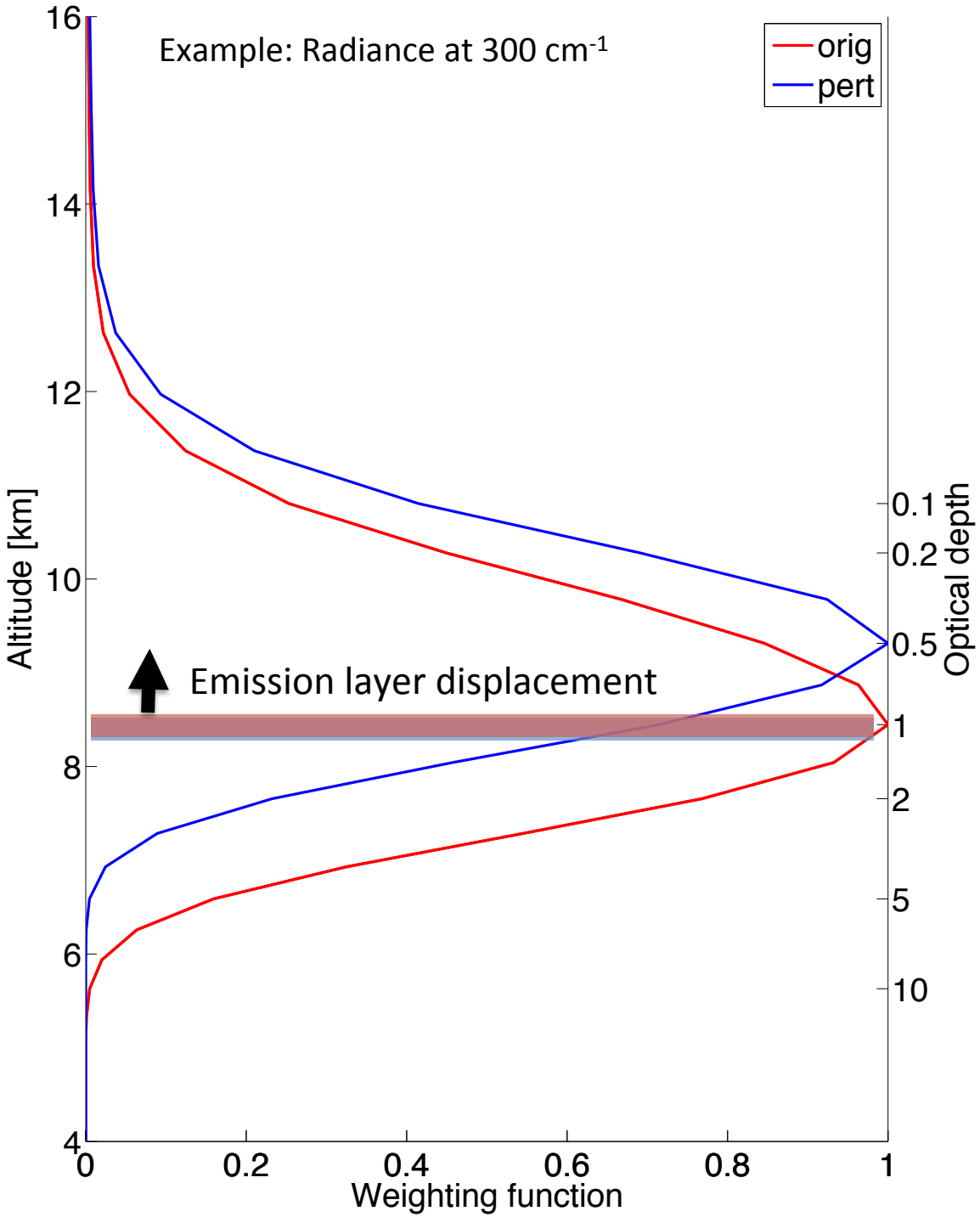
- Emission layer displacement model

Solution to non-scattering R.T. Eq. can be generalized as:

$R = \Sigma\{W_i * B_i\}$

W_i: weighting function for layer i, a function of optical depth τ measured from TOA to layer i.

B_i: Planck function of layer tempreature (T_i)



Emission layer displacement model

Solution to non-scattering R.T. Eq. can be generalized as:
$R = \Sigma\{W_i * B_i\}$

Perturbation of absorber amount (α x q) equivalently displaces all the contributing layers to higher altitudes.

As $W = W(\tau)$ and $\tau \propto q$, each emission layer is displaced from τ to $\tau' = \tau/\alpha$.

Given $T=T_0-z*\Gamma$, it can be shown $B \propto \log(\tau)$, and thus $B(\tau')-B(\tau) \propto \log(\alpha)$

[Huang and Bani Shahabadi, *J. Atm. Sci.*, under review]

Summary

- Spectral kernels are developed and ready for climate diagnoses
  - Log- and linear-scaling suit different spectral regions
  - Wise to apply hybrid scaling

- Why logarithmic in the absorption band?

  Log-dependence:
  - Holds for monochromatic radiance (not only broadband flux)
  - Results from radiative transfer (not only spectroscopy)

    "Emission layer displacement model"

    Key conditions:

    saturated absorption;

    lapse rate;

    coherent dX -> fingerprint configuration