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The Correlated-k Method for the Gas Absorption in the CERES Ed5 SW Flux Calculations

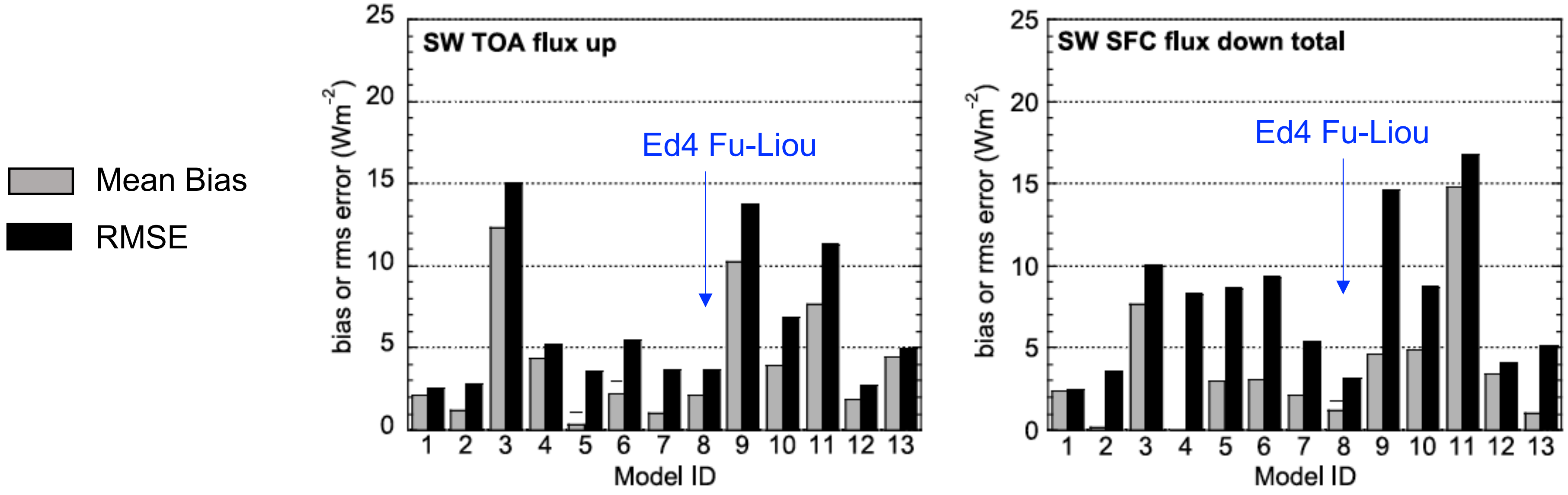
Seung-Hee Ham[1], Fred Rose[1], Seiji Kato[2], and Lusheng Liang[1]

[1]Analytical Mechanics Associates (AMA), Hampton, Virginia
[2]NASA Langley Research Center, Hampton, Virginia

Motivation

- According to the intercomparison study (Oreopoulos et al., 2012), the SW flux error of the Ed4 Fu-Liou model is < 2 W m^{-2} for all skies. However, the gas absorption features in the Ed4 Fu-Liou model (Fu and Liou, 1993; Fu et al., 1997; Kratz and Rose, 1999; Kato et al., 1999, 2005; Rose et al., 2006) is based on HITRAN 1992 database (Rothman 1992). The water vapor continuum features have been continuously updated since then (Mlawer et al. 2012).
- Therefore, it is needed to update the CKD table by using more recent version of LBL database.
- Development of more flexible model in terms of the band structures and CKD table is required for further updates whenever needed.

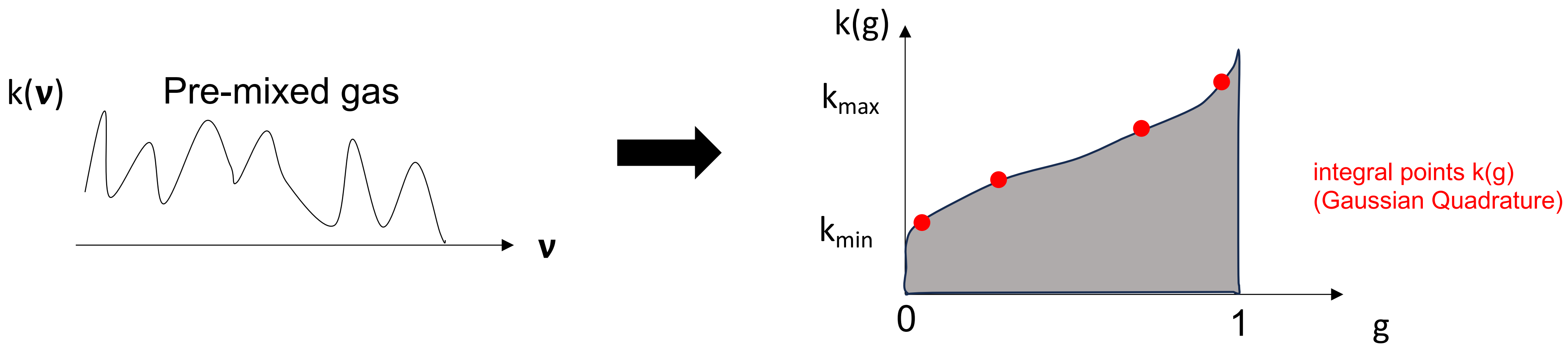
CKD Bias to the LBL Results (Oreopoulos et al. 2012)



Gas Absorption Calculations in Langley Fu-Liou Model

- **Pre-mixed gas method (c.f., multiplicative method)**
  Particular gas species are chosen for the spectral band to get total gas absorption coefficient. For the major gas species, variation of the gas amounts are allowed, while climatological amounts are assumed for the rest gas species.

- **Correlated-k distribution**
  For the given wavelength bound (or narrow band), the gas absorption spectra is re-ordered and the cumulative density function (CDF) (g(k)) of absorption coefficient is calculated. Then the optimal g(k) points are used to integrate the gas absorption spectra for the band.



Four Improvements in Gas Absorption Features in the Ed5 Fu-Liou Model (In Progress)

1. More flexibility of Fu-Liou Interface to input correlated-k distribution (CKD) table
2. Inclusion of more recent line-by-line gas absorption database (HITRAN 2012 and MT_CKD 3.2), more gas species (O_3, O_2, CO_2, H_2O, CH_4, N_2O, N_2, CFC1, and. CFC2), and more (18 → 24) narrow bands
3. Variation of CO_2 is newly considered in Ed5, which can be useful in studying radiation process for future climate
4. A better optimization method in determining k(g) points in the CKD method

Flexible Ed5 Fu-Liou Model with One Configuration File

- The Fu-Liou codes were significantly modified and reorganized, even though the core radiative transfer parts (2-stream or 4-stream solver) remain the same.
- The Ed5 Fu-Liou model uses a one configuration HDF file, which describes cloud/aerosol scattering parameters, narrow band structures, Rayleigh scattering, gas absorption, and surface albedo database.
- CKD table, band structure, and k(g) can be modified in this file.

Static parameters

- Narrowband structure
- Incoming solar radiation database
- Gas absorption CKD table
- Rayleigh scattering coefficients
- Surface spectral model (Jin's snow and ocean models)
- Cloud scattering parameter database
- Aerosol scattering parameter database

→ One configuration file → Ed5 Fu-Liou Model

Users can switch gas absorption CKD table, cloud/aerosol scattering parameters, and band structures through this configuration figure.

SW Band Structure (Ed4)

Band	Wavelength (μm)		Gas Species
1	0.18	0.22	O_3
2	0.22	0.24	O_3
3	0.24	0.29	O_3
4	0.29	0.30	O_3
5	0.30	0.32	O_3
6	0.32	0.36	O_3
7	0.36	0.44	O_3
8	0.44	0.50	O_3, H_2O
9	0.50	0.60	O_3 and H_2O
10	0.60	0.69	O_3 and H_2O
11	0.69	0.79	H_2O, O_3 and O_2
12	0.79	0.89	H_2O
13	0.89	1.04	H_2O
14	1.04	1.41	H_2O
15	1.41	1.90	H_2O, CO_2
16	1.90	2.50	H_2O, CO_2, CH_4
17	2.50	3.51	H_2O, CO_2, O_3 and CH_4
18	3.51	4	H_2O, CO_2, CH_4

SW Band Structure (Ed5)

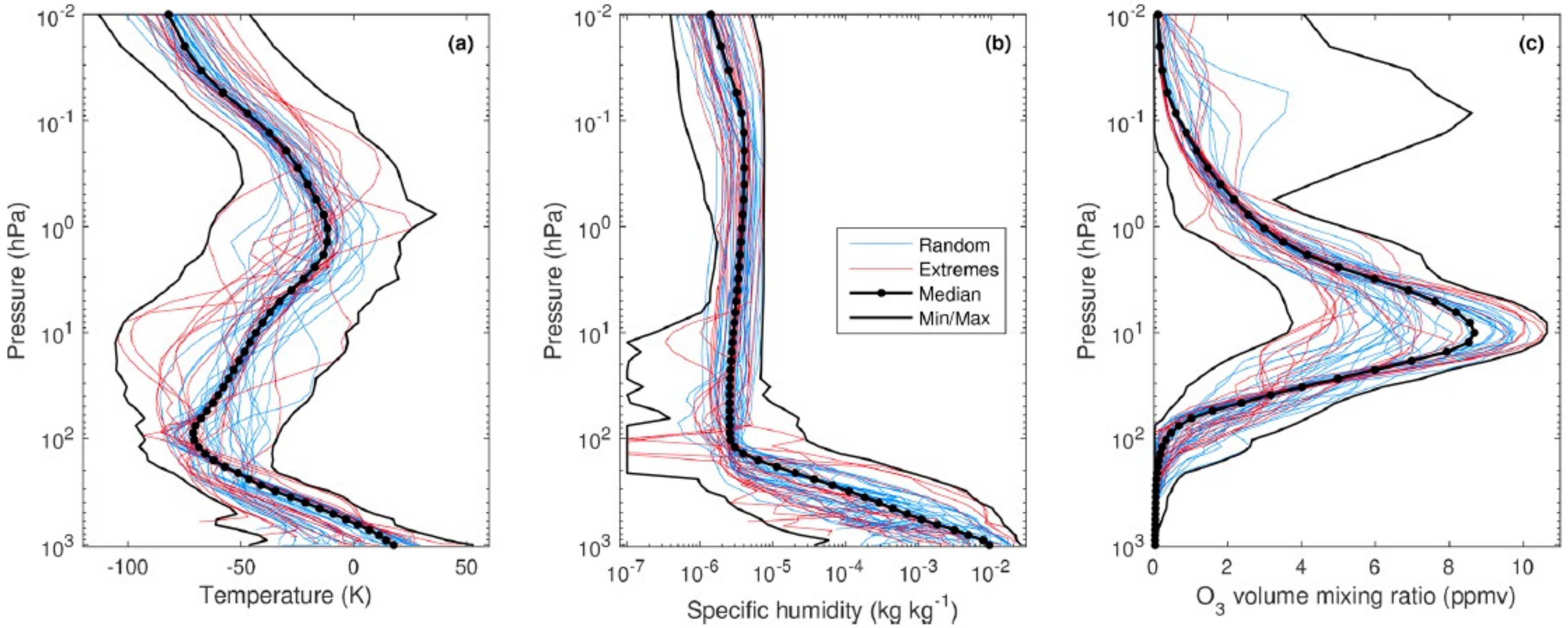
Band	Wavelength (μm)		Gas Species (Variable)	Gas Species (Fixed)
1	0.18	0.22	O_3	O_2, CO_2, H_2O, CH_4, N_2O, N_2, CFC1, and. CFC2
2	0.22	0.24	O_3	O_2, CO_2, H_2O, CH_4, N_2O, N_2, CFC1, and. CFC2
3	0.24	0.29	O_3	O_2, CO_2, H_2O, CH_4, N_2O, N_2, CFC1, and. CFC2
4	0.29	0.30	O_3	O_2, CO_2, H_2O, CH_4, N_2O, N_2, CFC1, and. CFC2
5	0.30	0.32	O_3	O_2, CO_2, H_2O, CH_4, N_2O, N_2, CFC1, and. CFC2
6	0.32	0.36	O_3	O_2, CO_2, H_2O, CH_4, N_2O, N_2, CFC1, and. CFC2
7	0.36	0.44	O_3	O_2, CO_2, H_2O, CH_4, N_2O, N_2, CFC1, and. CFC2
8	0.44	0.50	O_3 and H_2O	O_2, CO_2, CH_4, N_2O, N_2, CFC1, and. CFC2
9	0.50	0.56	O_3 and H_2O	O_2, CO_2, CH_4, N_2O, N_2, CFC1, and. CFC2
10	0.56	0.60	O_3 and H_2O	O_2, CO_2, CH_4, N_2O, N_2, CFC1, and. CFC2
11	0.60	0.63	O_3 and H_2O	O_2, CO_2, CH_4, N_2O, N_2, CFC1, and. CFC2
12	0.63	0.69	O_3 and H_2O	O_2, CO_2, CH_4, N_2O, N_2, CFC1, and. CFC2
13	0.69	0.74	O_3 and H_2O	O_2, CO_2, CH_4, N_2O, N_2, CFC1, and. CFC2
14	0.74	0.79	O_3 and H_2O	O_2, CO_2, CH_4, N_2O, N_2, CFC1, and. CFC2
15	0.79	0.89	H_2O	O_3, O_2, CO_2, CH_4, N_2O, N_2, CFC1, and. CFC2
16	0.89	1.04	H_2O	O_3, O_2, CO_2, CH_4, N_2O, N_2, CFC1, and. CFC2
17	1.04	1.41	H_2O	O_3, O_2, CO_2, CH_4, N_2O, N_2, CFC1, and. CFC2
18	1.41	1.90	H_2O and CO_2	O_3, O_2, CH_4, N_2O, N_2, CFC1, and. CFC2
19	1.90	2.30	H_2O and CO_2	O_3, O_2, CH_4, N_2O, N_2, CFC1, and. CFC2
20	2.30	2.50	H_2O and CO_2	O_3, O_2, CH_4, N_2O, N_2, CFC1, and. CFC2
21	2.50	3.51	H_2O and CO_2	O_3, O_2, CH_4, N_2O, N_2, CFC1, and. CFC2
22	3.51	4.00	H_2O and CO_2	O_3, O_2, CH_4, N_2O, N_2, CFC1, and. CFC2
23	4.00	5.00	H_2O and CO_2	O_3, O_2, CH_4, N_2O, N_2, CFC1, and. CFC2
24	5.0.	12.50	O_3 and H_2O	O_2, CO_2, CH_4, N_2O, N_2, CFC1, and. CFC2

Combined in Ed4

Added (split) bands compared to Ed4

Evaluation of the CKD Method Using Realistic Gas Amount Profiles

- Two sets of 50 realistic scenarios of T(z), q(z), p(z), and gas amount profiles are from the intercomparison study of Hogan et al. (2020) (33 randomly selected profiles from NWP-SAF and 17 profiles as extreme and min/mean/max cases). The dataset also includes gas optical depth profile, flux profiles from the LBL calculations.

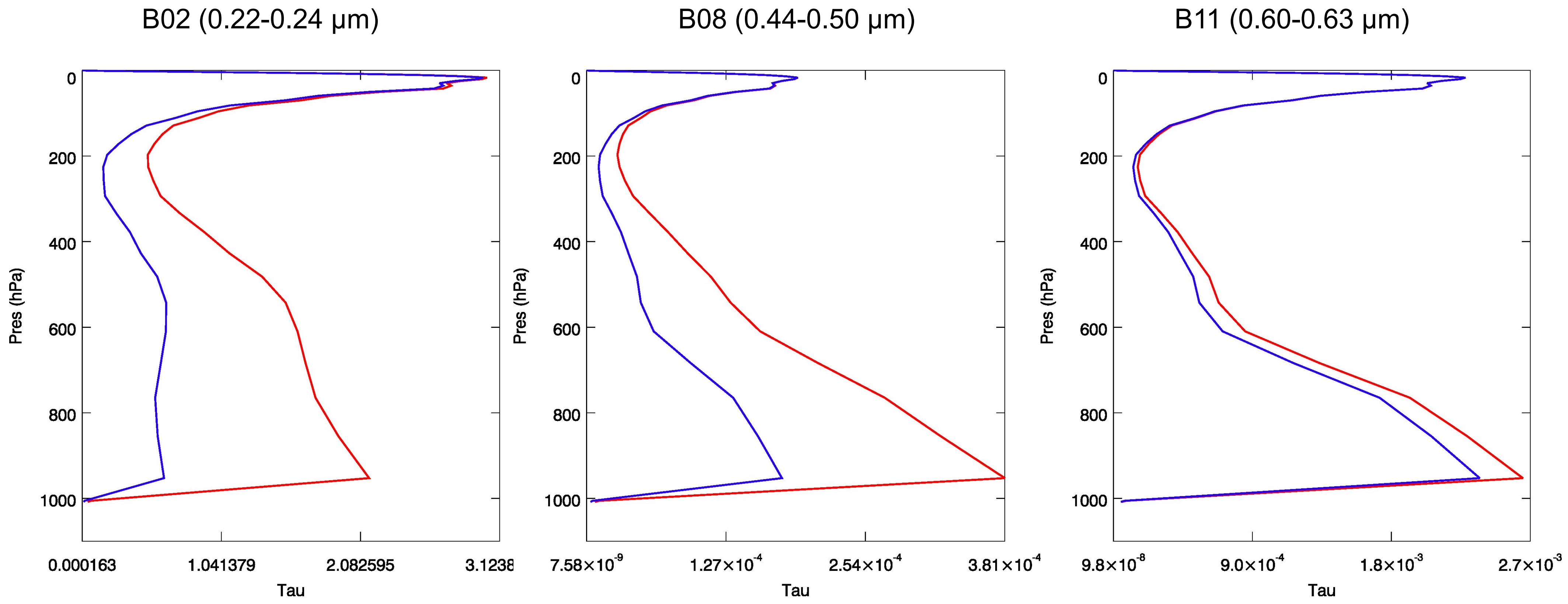


(Hogan et al. 2020)

Impact of Inclusion of More Gas Species on Gas Optical Depth

- Oxygen (O_2) was ignored in many narrow bands of the Ed4 model, underestimating the gas optical depths.

case 1 evaluation 1

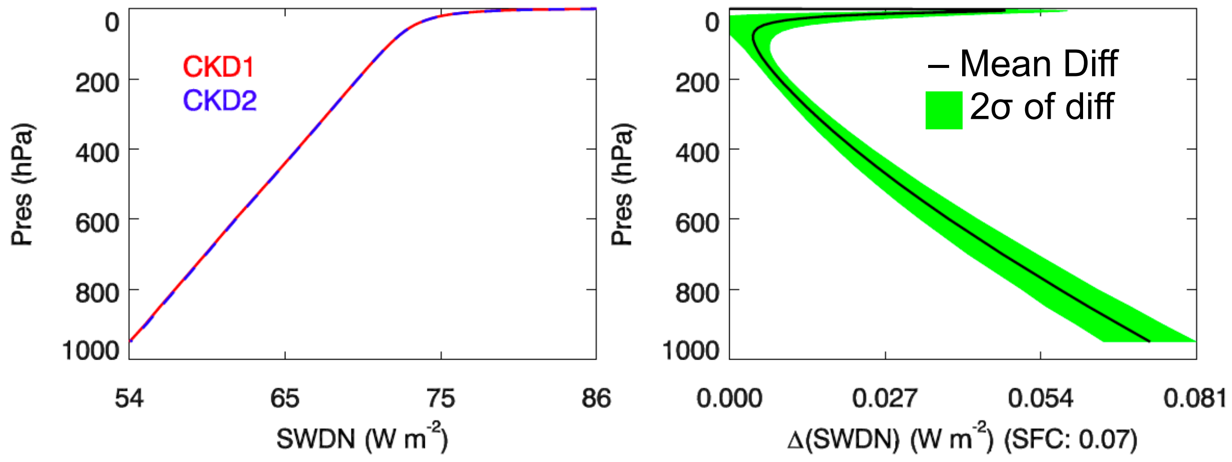


O_2 included (9 gas species)

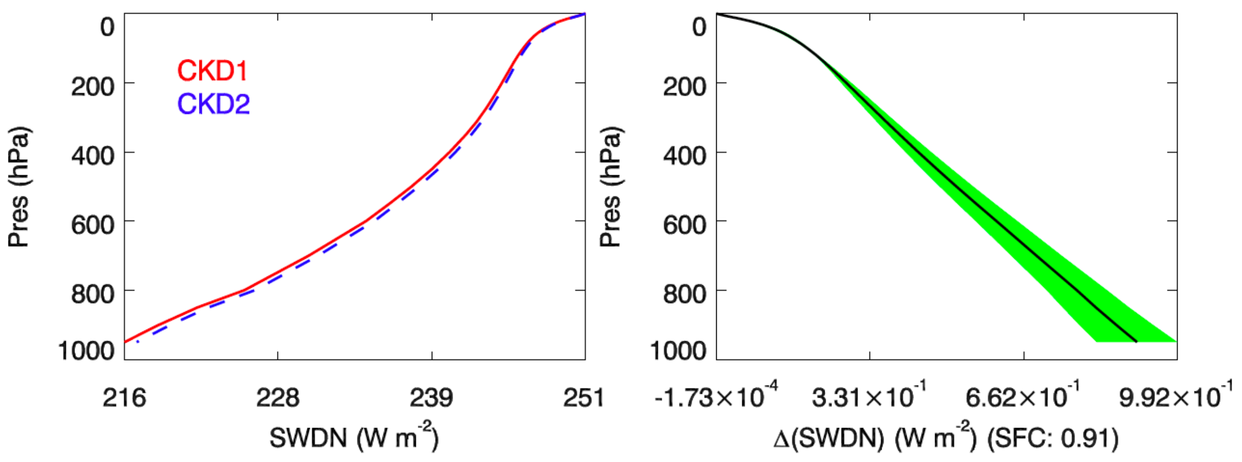
O_2 not included (major gas species only)

Impact of Inclusion of More Gas Species on the SW Fluxes

UV Spectral Bands
B01-07 (0.18-0.44 µm)



Visible Bands
B09–12 (0.50-0.69 µm)



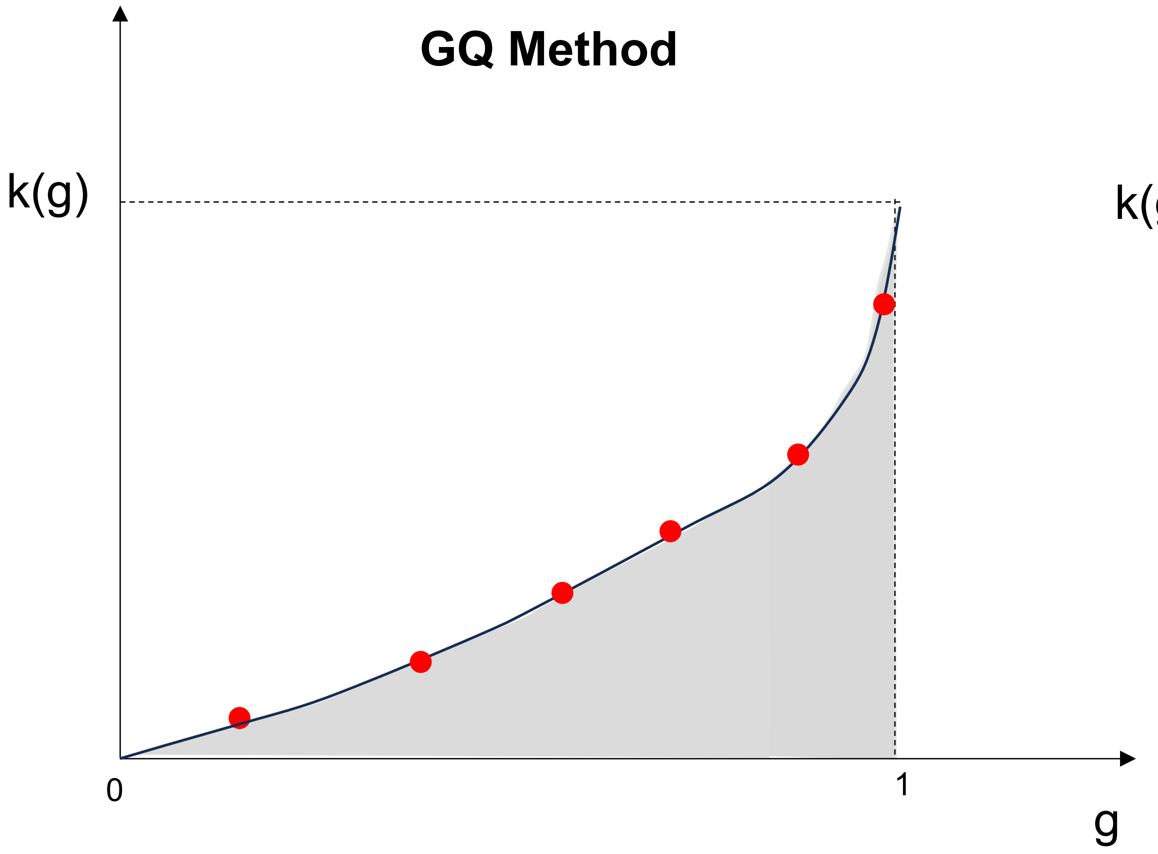
- For UV bands, the impact is small since the solar radiation is mostly absorbed in the stratosphere.
- The impact of missing O_2 is noticeable near surface in the visible bands (0.50 – 0.69 µm). The difference in surface downward fluxes can change by 0.9 W m^{-2}.

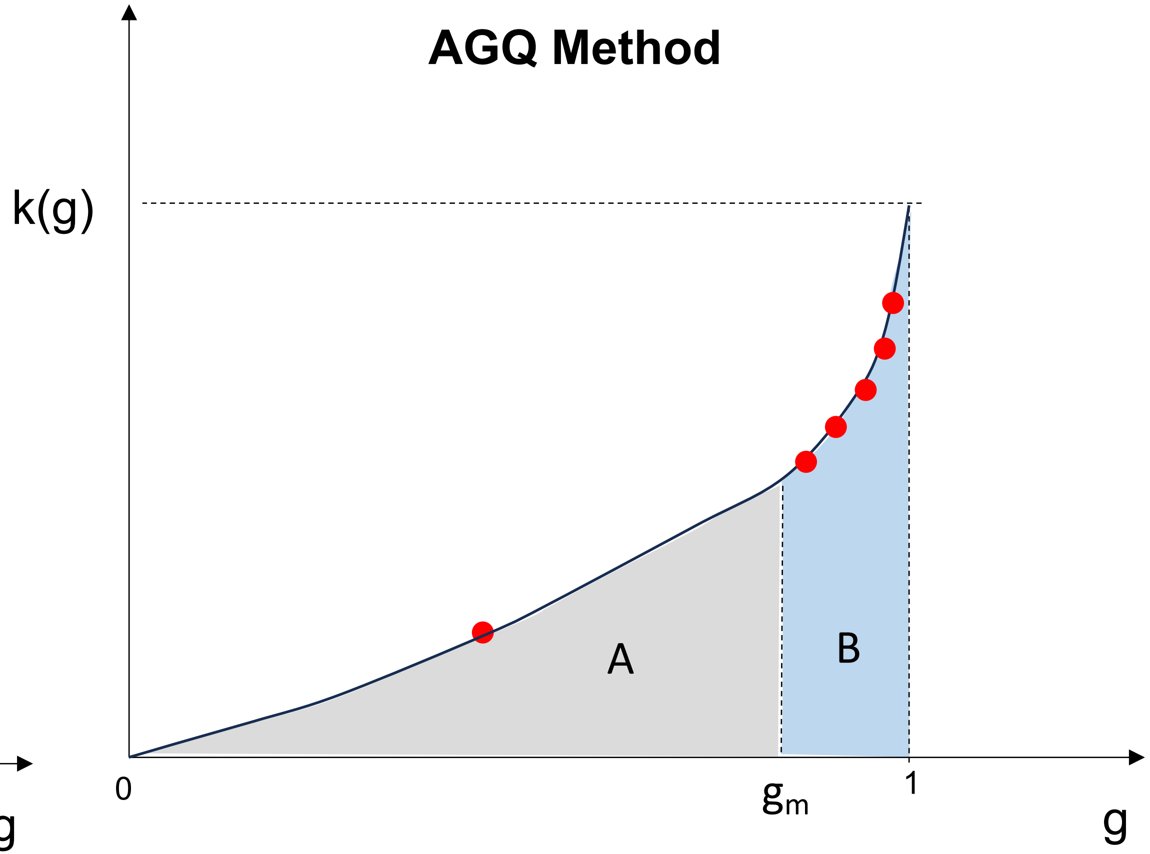
O_2 included (9 gas species)

O_2 not included (major gas species only)

Gaussian Quadrature (GQ) versus Adaptive Gaussian Quadrature (AGQ)

- Gaussian Quadrature: # of GQ points are determined between g=0 and g=1.
- Adaptive Gaussian Quadrature (AGQ): The g-interval of [0,1] is broken into two intervals, and then GQ integral points are separately assigned for each interval.

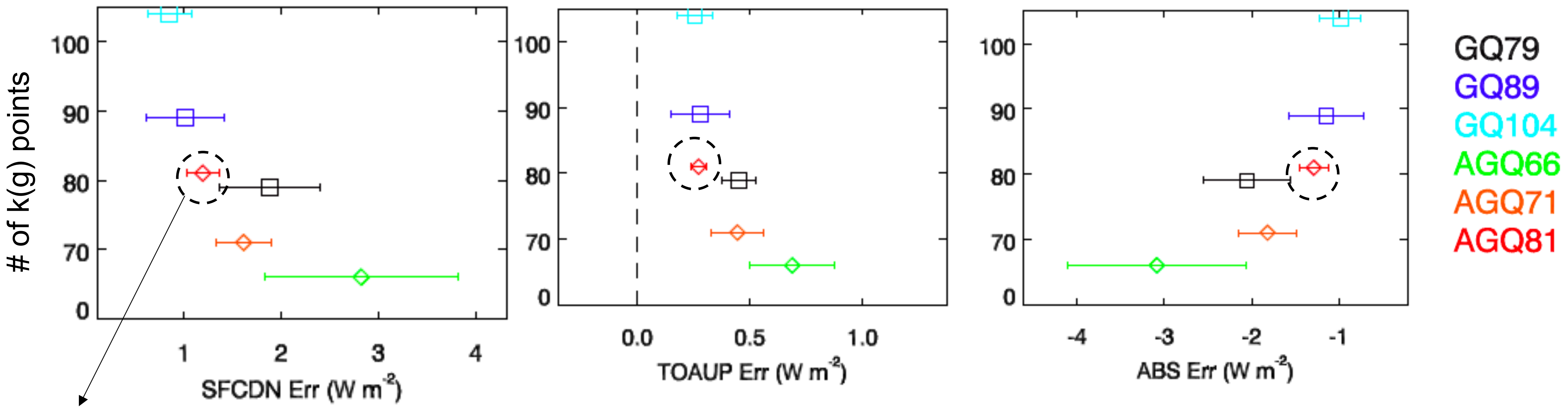




Accuracy of TOA Upward, Surface Downward, and Atmosphere-Absorbed SW Fluxes Depending on the Choice of k(g) Points

- The reference fluxes are obtained using 960 k points since the results mostly converge as the k number > 480.
- Compared to the GQ approach, the AGQ approach gives a better accuracy of fluxes for the given similar k(g) points.
- The choice of optimal k(g) changes surface fluxes by 4 W m^{-2}, TOA fluxes by 1 W m^{-2}.

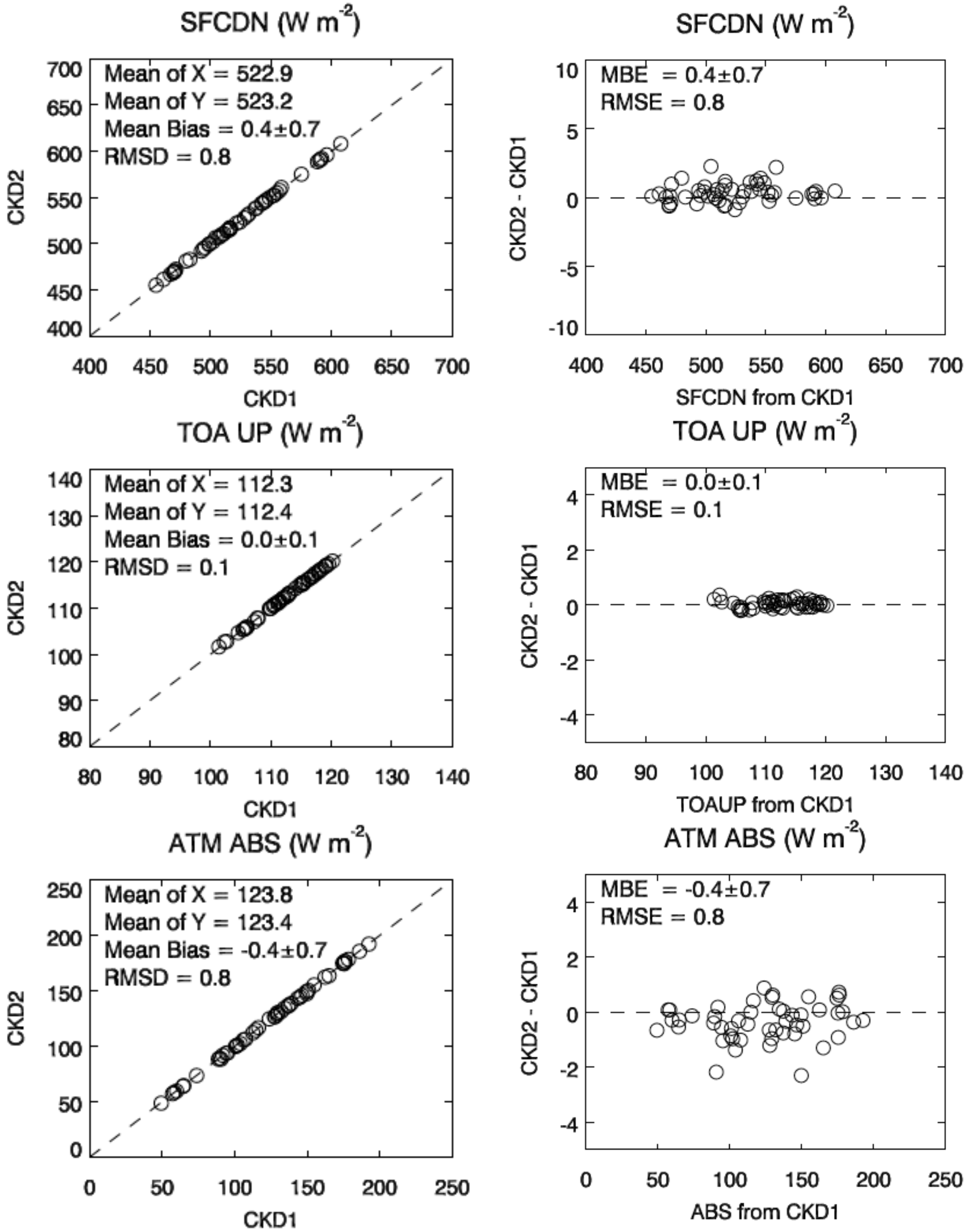
GQ versus AGQ Approach



Our best pick for now is AGQ with 81 k points, since it gives small σ and bias for the similar k points. However, it still shows 1 W m^{-2} errors in SFCDN and absorption. Further improvement can be made by adjusting band structure and increasing k numbers.

Comparison between Ed4 and Ed5 for the 50 Cases of Hogan et al. (2020)

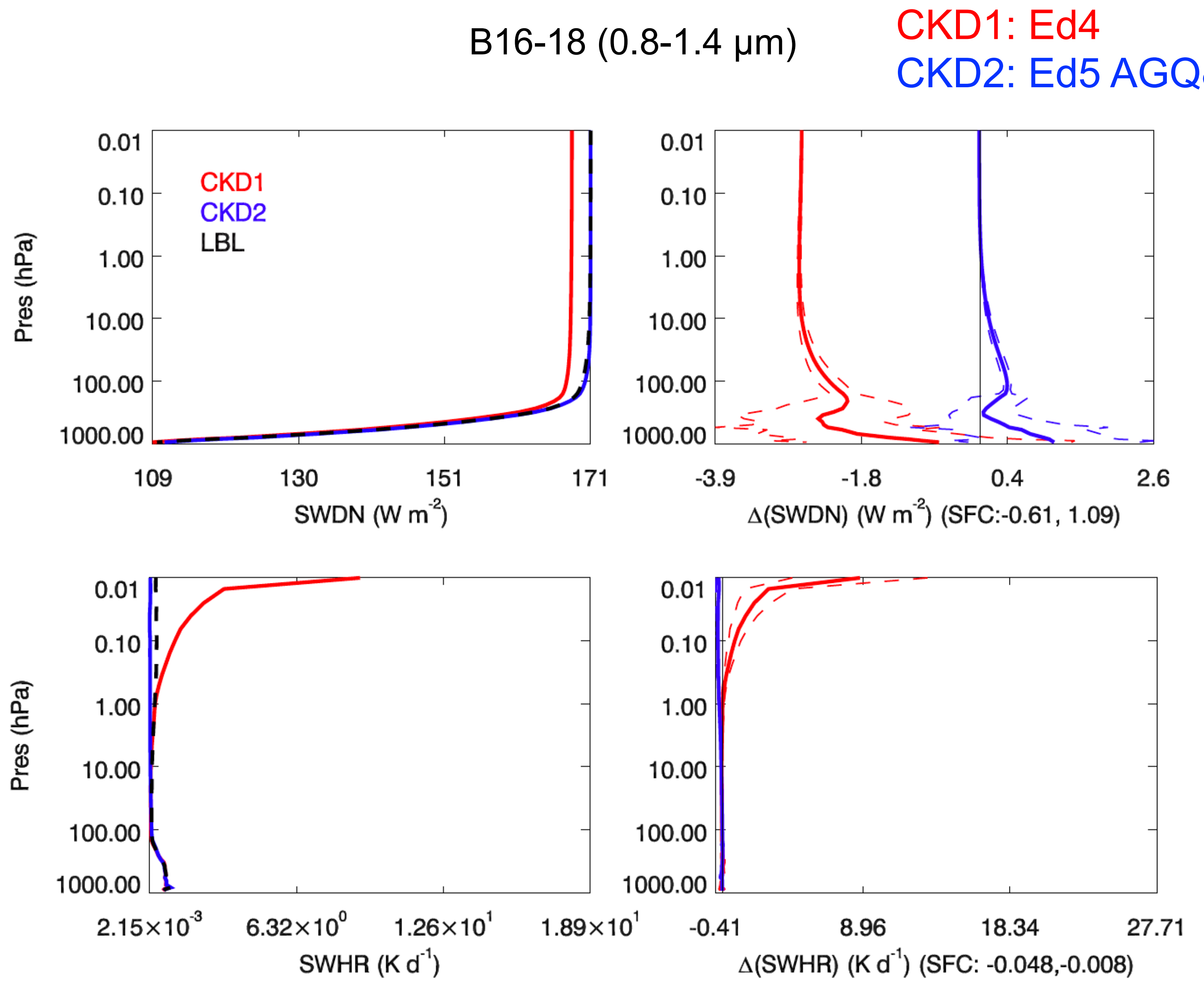
CKD1: Ed4 GQ70
CKD2: Ed5 AGQ81



- Ed4 and Ed5 CKD surprisingly give similar results, and difference in SFCDN and absorption is 0.4 W m^{-2}.
- Specifically, Ed5 absorption is smaller than Ed5 absorption by 0.4 W m^{-2}.
- Inclusion of more gas species in Ed5 should gives larger absorption. Why the opposite result happens?

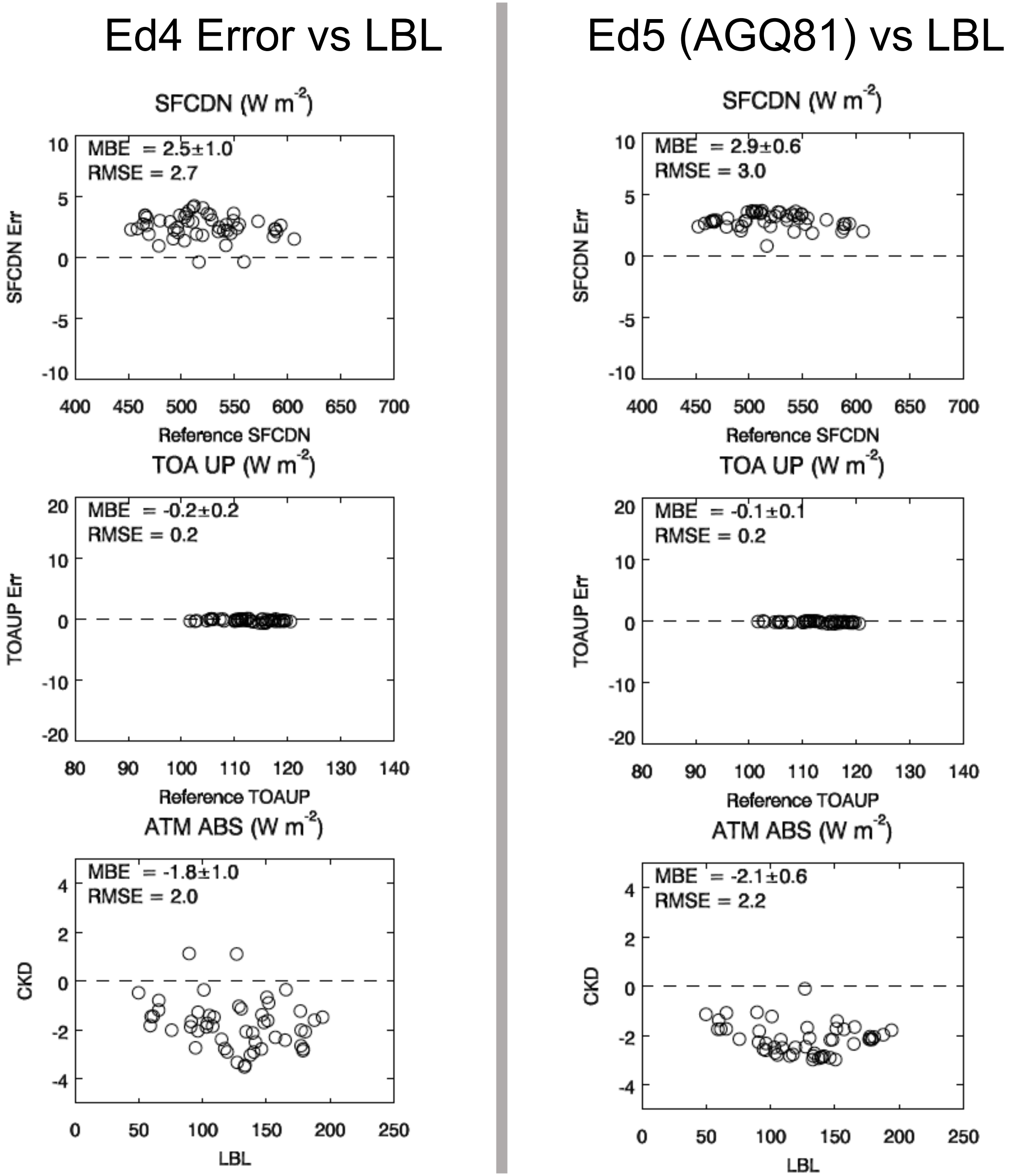
50 cases in evaluation-1, cos(SZA)=0.5

Larger Absorption in Ed4, Compared to Ed5 for the NIR Spectral Region



- The absorption in Ed4 is larger than Ed5, which may be related to the different LBL database or different bins used in the CKD.
- The Ed5 shows much closer results to the LBL results, while the absorption seems to be overestimated in the mesosphere (1< p < 0.01 hPa), compared to the LBL results.
- The impact of the overestimation of the absorption for the NIR bands is cancelled with the underestimation of the oxygen gas absorption in the visible bands, in computing SW BB flux.

Compared of the TOA and SFC Fluxes to the LBL results



- Both Ed4 and Ed5 SFCDN fluxes are positively biased to the LBL results by 2.5 and 2.9 W m^{-2}, respectively.
- Note that the LBL results of Hogan et al. (2020) were computed using different Rayleigh scattering and two-stream model. Our Fu-Liou results from the four-stream model. Therefore, different radiative scheme and Rayleigh scattering partly contributed the biases in the CKD.
- Existing problems for Ed4 and Ed5 are underestimation of CO_2 absorption in the mesosphere and strong WV absorption near surface. This can be improved by considering a better band structure, better optimized k(g) points, and increasing k(g) numbers.

Summary

- The Ed5 gas absorption module is developed to have more flexibility, more gas species, and more narrow bands, based on more recent LBL database.
- The Ed4 CKD did not consider oxygen absorption in most bands, underestimating gas absorption for UV and visible spectral region.
- However, WV absorption from the Ed4 CKD is larger than Ed5, and the differences between Ed4 and Ed5 are largely cancelled in the broadband computations.
- SFCDN and atmospheric absorption fluxes from Ed4 and Ed5 differ by 0.4 W m^{-2}, and these are linearly well correlated.
- Both the absorption in the Ed4 and Ed5 is underestimated compared to the LBL results, which are partly explained by the different radiative scheme. Further improvement can be made in the CKD calculations by considering better band structure and optimization method of k(g) points.
- This study mainly focused SW calculations, but it will be expanded to the LW CKD table in the future.

Thank you for your attention!

Please contact to seung-hee.ham@nasa.gov if you have any questions.