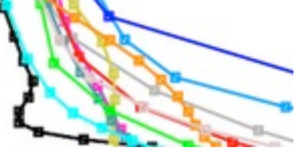

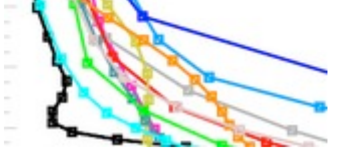

# Intercomparison of shortwave radiative transfer schemes in global aerosol modeling: Results from the AeroCom Radiative Transfer Experiment


**C. A. Randles[1,2], S. Kinne[3], G. Myhre[4], M. Schulz[5], P. Stier[6], J. Fischer[7], L. Doppler[7,8], E. Highwood[9], C. Ryder[9], B. Harris[9], J. Huttunen[10], Y. Ma[11], R. T. Pinker[11], B. Mayer[12], D. Neubauer[13,14], R. Hitzenberger[13,14], L. Oreopoulos[15], D. Lee[15,16], G. Pitari[17], G. Di Genova[17,18], J. Quaas[19], Fred G. Rose[20,21], S. Kato[21], S. T. Rumbold[22], I. Vardavas[23], N. Hatzianastassiou[24], C. Matsoukas[25], H. Yu[26,15], F. Zhang[26], H. Zhang[27], and P. Lu[27]**

[1]GESTAR/Morgan State University, Baltimore, Maryland, USA
[2]NASA Goddard Space Flight Center (GSFC) Atmospheric Chemistry and Dynamics Lab, Greenbelt, MD, USA
[3]Max Plank Institute for Meteorology, Hamburg, Germany
[4]Center for International Climate and Environmental Research-Oslo (CICERO), Oslo, Norway
[5]Meteorologisk Institutt, Oslo, Norway
[6]Department of Physics, University of Oxford, United Kingdom
[7]Institut für Weltraumwissenschaften, Freie Universität, Berlin, Germany
[8]LATMOS-IPSL, Paris, France
[9]Department of Meteorology, University of Reading, United Kingdom
[10]Finnish Meteorological Institute, Kuopio, Finland
[11]Department of Meteorology, University of Maryland College Park, USA
[12]Ludwig-Maximilians-Universitaet, Munich, Germany
[13]Research Platform: ExoLife, University of Vienna, Austria
[14]Faculty of Physics, University of Vienna, Austria
[15]NASA GSFC Climate and Radiation Laboratory, Greenbelt, Maryland, USA
[16]Seoul National University, Republic of Korea
[17]Department of Physical and Chemical Sciences, University of L'Aquila, Italy
[18]Space Academy Foundation, Fucino Space Center, Italy
[19]Universität Leipzig, Germany
[20]SSAI, Hampton, VA, USA
[21]NASA Langley Research Center (LaRC), Hampton, Virginia, USA
[22]UK Met Office (UKMO) Hadley Center, Exeter, United Kingdom
[23]Department of Physics, University of Crete, Greece
[24]Laboratory of Meteorology, Department of Physics, University of Ioannina, Greece
[25]Department of Environment, University of the Aegean, Greece
[26]Earth System Science Interdisciplinary Center (ESSIC), University of Maryland, College Park, Maryland, USA
[27]Laboratory for Climate Studies, CMA, National Climate Center, Beijing, China


GESTAR


Submitted to ACPD 7/31/12 09:30 AM EST


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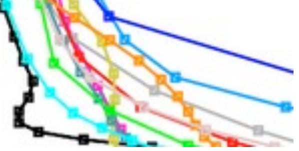
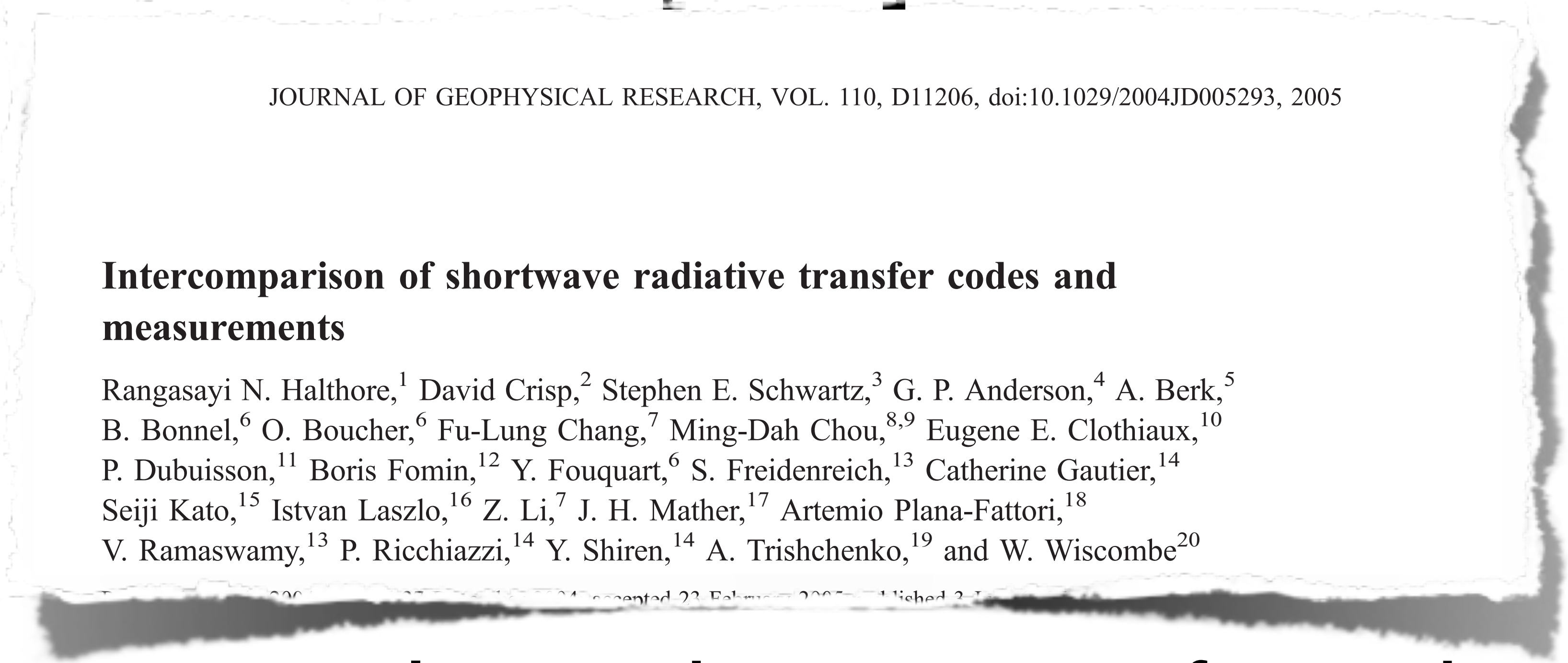


# Motivation

- Assess solar radiative transfer schemes in AeroCom models
  - Update to Halthore et al. [2005].



JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 110, D11206, doi:10.1029/2004JD005293, 2005

**Intercomparison of shortwave radiative transfer codes and measurements**

Rangasayi N. Halthore,[1] David Crisp,[2] Stephen E. Schwartz,[3] G. P. Anderson,[4] A. Berk,[5] B. Bonnel,[6] O. Boucher,[6] Fu-Lung Chang,[7] Ming-Dah Chou,[8,9] Eugene E. Clothiaux,[10] P. Dubuisson,[11] Boris Fomin,[12] Y. Fouquart,[6] S. Freidenreich,[13] Catherine Gautier,[14] Seiji Kato,[15] Istvan Laszlo,[16] Z. Li,[7] J. H. Mather,[17] Artemio Plana-Fattori,[18] V. Ramaswamy,[13] P. Ricchiazzi,[14] Y. Shiren,[14] A. Trishchenko,[19] and W. Wiscombe[20]

  - Inter-compare solar radiative transfer schemes *without aerosols or clouds* given standard atmospheres ($H_2O$ and $O_3$) and surface albedo.
  - Inter-compare aerosol radiative forcing for *prescribed aerosol optical properties* (scattering and more absorbing aerosols) *and no clouds* with standard atmospheres and surface albedo.

# Experiment Protocol

- Three Radiative Transfer Scheme tests for Rayleigh atmosphere, purely scattering aerosols, and more absorbing aerosols (Table 1). Prescribed aerosol properties and AFGL (SAW and TROP) $O_3$ and $H_2O$ profiles.

- Requested Fields (30° and 75° SZA)
  - Broadband (0.2 - 4.0 µm) total (direct + diffuse) down at surface.
  - Broadband diffuse down at surface.
  - UV-VIS (0.2-0.7 µm) total down at surface.
  - Broadband up at TOA.
  - Near-IR = broadband - UV-VIS

- Compare*:
  - Flux fields
  - Aerosol Direct Radiative Forcing (RF):

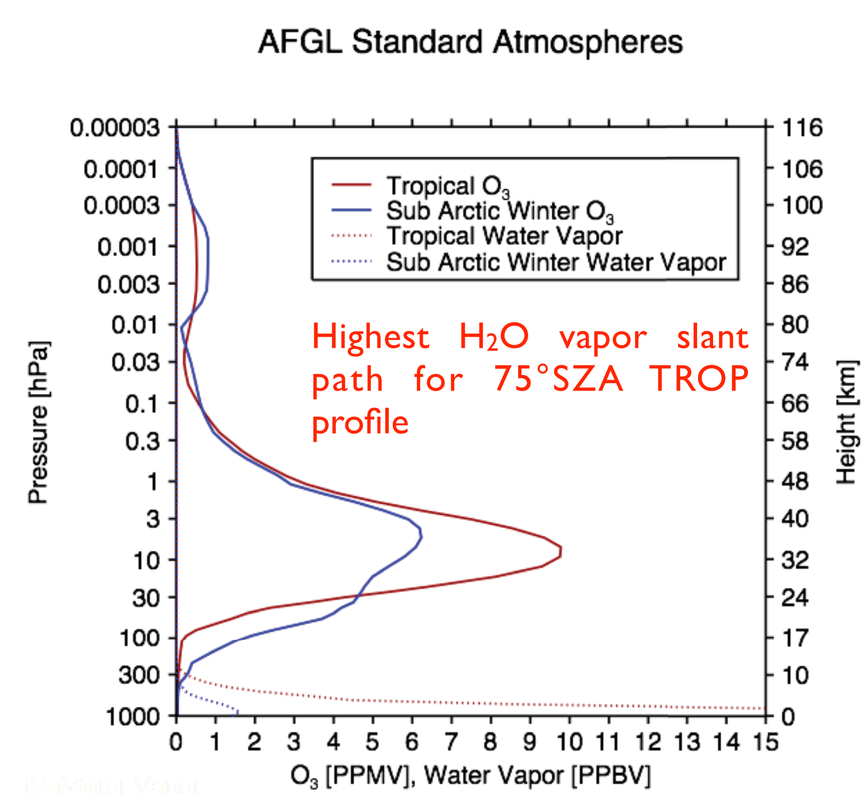
$$RF = (F^{\downarrow} - F^{\uparrow})_{Case\_2} - (F^{\downarrow} - F^{\uparrow})_{Case\_1}$$

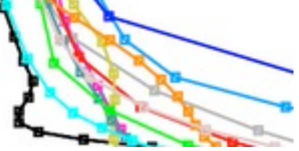
*All fields normalized to model TOA downwards broadband or UV-VIS irradiance; then all results scaled by the same TOA downwards irradiance.

| Experiment | Case 1 | Case 2a | Case 2b |
|---|---|---|---|
| Aerosol | None (Rayleigh) | Fixed | Fixed |
| AOD (0.55 $\mu$m) | 0 | 0.2 | 0.2 |
| Ångström Parameter | Spectral dependence of AOD: AOD = exp(-1.0 × ln($\lambda$/0.55)+ln(0.2)) | | |
| Asymmetry ($g$) Parameter[a] | N/A | 0.7 | 0.7 |
| SSA[a] | N/A | 1.0 | 0.8 |
| Surface Albedo[a] | 0.2, globally, spectrally uniform | | |
| Atmosphere[b] | AFGL "Tropical" (TROP) and "Sub-Arctic Winter" (SAW) ($O_3$ and $H_2O$ profiles w/1-km resolution) | | |
| Clouds | NONE | | |
| Solar Zenith Angle | 30°, 75° for each atmosphere | | |

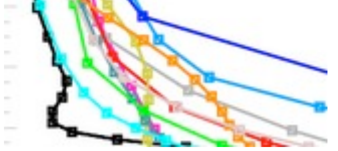
[a] Solar-spectrally invariant.

[b] TROP has higher humidity ($H_2O$ mixing ration) and ozone (see Fig. 1).





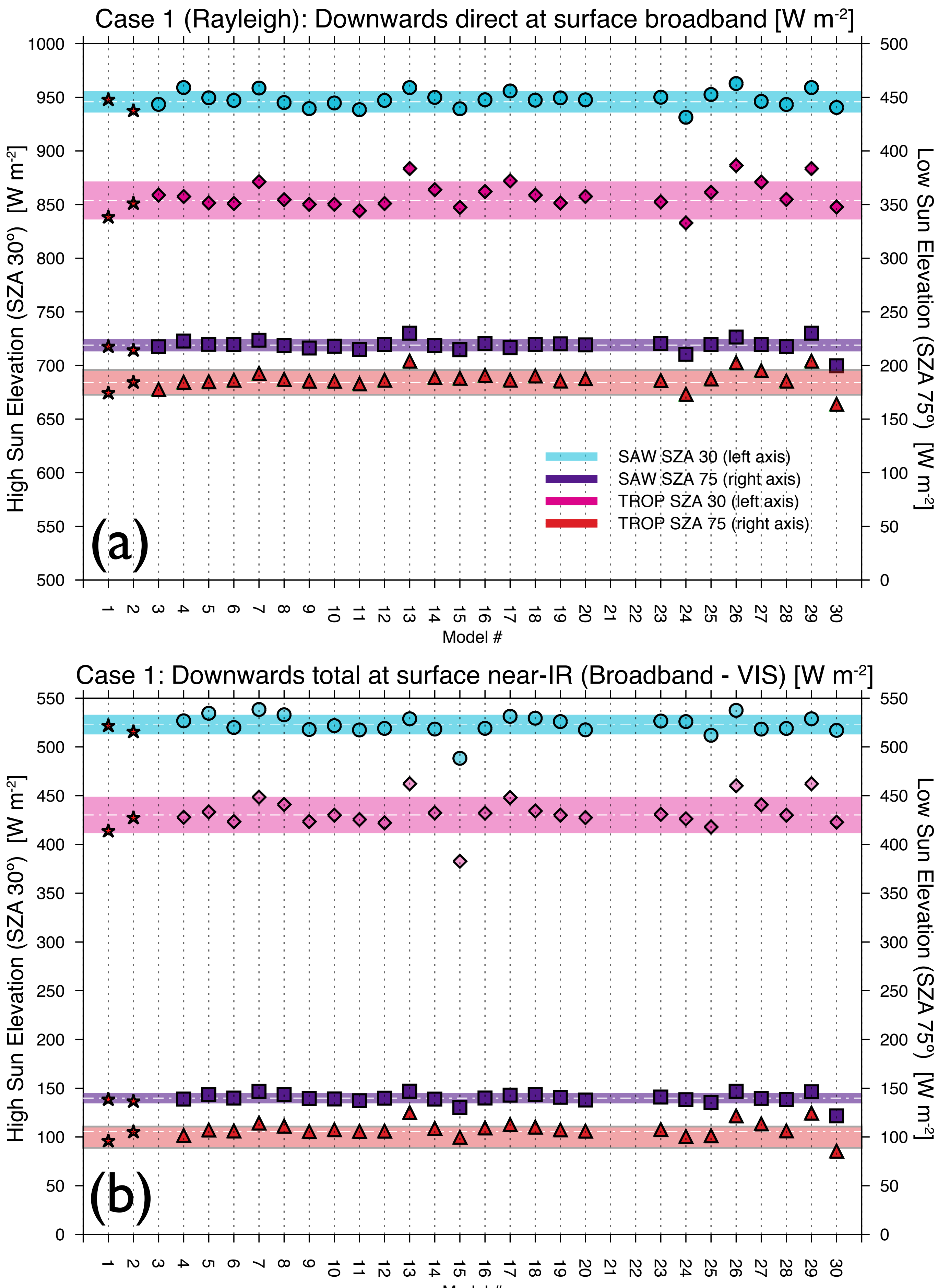
# Participating Models



| Model | Name | Multiple-Scattering | Gaseous Transmission | Prescribed (P) or Direct Effect (D) AeroCom Experiment? |
|---|---|---|---|---|
| 1 | **GENLN2-DISORT** | **16-stream DISORT** | **Line-by-line, 0.02 cm$^{-2}$** | |
| 2 | **RFM DISORT (RFMD)** | **4-stream DISORT** | **Line-by-line, 1 cm$^{-2}$** | |
| 3 | Oslo-DISORT | 8-stream DISORT | ESFT | P, D |
| 4 | UNIVIE-Streamer | 8-stream DISORT | ESFT | |
| 5 | FMI-libRadtran | 8-stream DISORT2 + δ-M scaling | ESFT | |
| 6 | LMU-libRadtran | 6-stream DISORT | ESFT | |
| 7 | GSFC-FLG | 4-stream δ-Eddington | correlated-*k* | |
| 8 | CAR-FLG | 4-stream δ-Eddington | correlated-*k* | |
| 9 | LaRC-FL | 2-stream δ-Eddington | correlated-*k* | |
| 10 | CAR-RRTMG | 2-stream δ-Eddington | correlated-*k* | P, D |
| 11 | RRTMG-SW | 2-stream δ-Eddington | correlated-*k* | P, D |
| 12 | LMU-2stream | 2-stream δ-Eddington | correlated-*k* | |
| 12 | MIP-2stream | 2-stream δ-Eddington | correlated-*k* | P |
| 14 | CAR-GSFC | 2-stream δ-Eddington + adding | correlated-*k* | P, D |
| 15 | BCC-RAD | 2-stream δ-Eddington | correlated-*k* | D |
| 16 | CAR-CCCMA | 2-stream δ-Eddington + adding | correlated-*k* | |
| 17 | ECHAM5.5 | 2-stream δ-Eddington | Padé approximation | P, D |
| 18 | UMD-SRB | 2-stream δ-Eddington | correlated-*k* | |
| 19 | ES96-6 | 2-stream PIFM | correlated-*k* | |
| 20 | ES96-220 | 2-stream PIFM | correlated-*k* | |
| 21 | ES96-6-D | 2-stream PIFM w/δ-rescaling | correlated-*k* | |
| 22 | ES96-220-D | 2-stream PIFM w/δ-rescaling | correlated-*k* | |
| 23 | UKMO-HadGEM2 | 2-stream PIFM w/δ-rescaling | correlated-*k* | D |
| 24 | CAR-CAWCR | 2-stream δ-Eddington | ESFT | |
| 25 | CAR-CAM | 2-stream δ-Eddington | ESFT | |
| 26 | ULAQ | 2-stream δ-Eddington | ESFT | |
| 27 | FORTH | 2-stream δ-Eddington | ESFT | |
| 28 | CAR-GFDL | 2-stream δ-Eddington + adding | ESFT | |
| 29 | MPI-MOM | 10-stream Matrix-Operator adding-doubling | correlated-k | |
| 30 | MOMO | Matrix-Operator adding-doubling | non-correlated-*k* | |

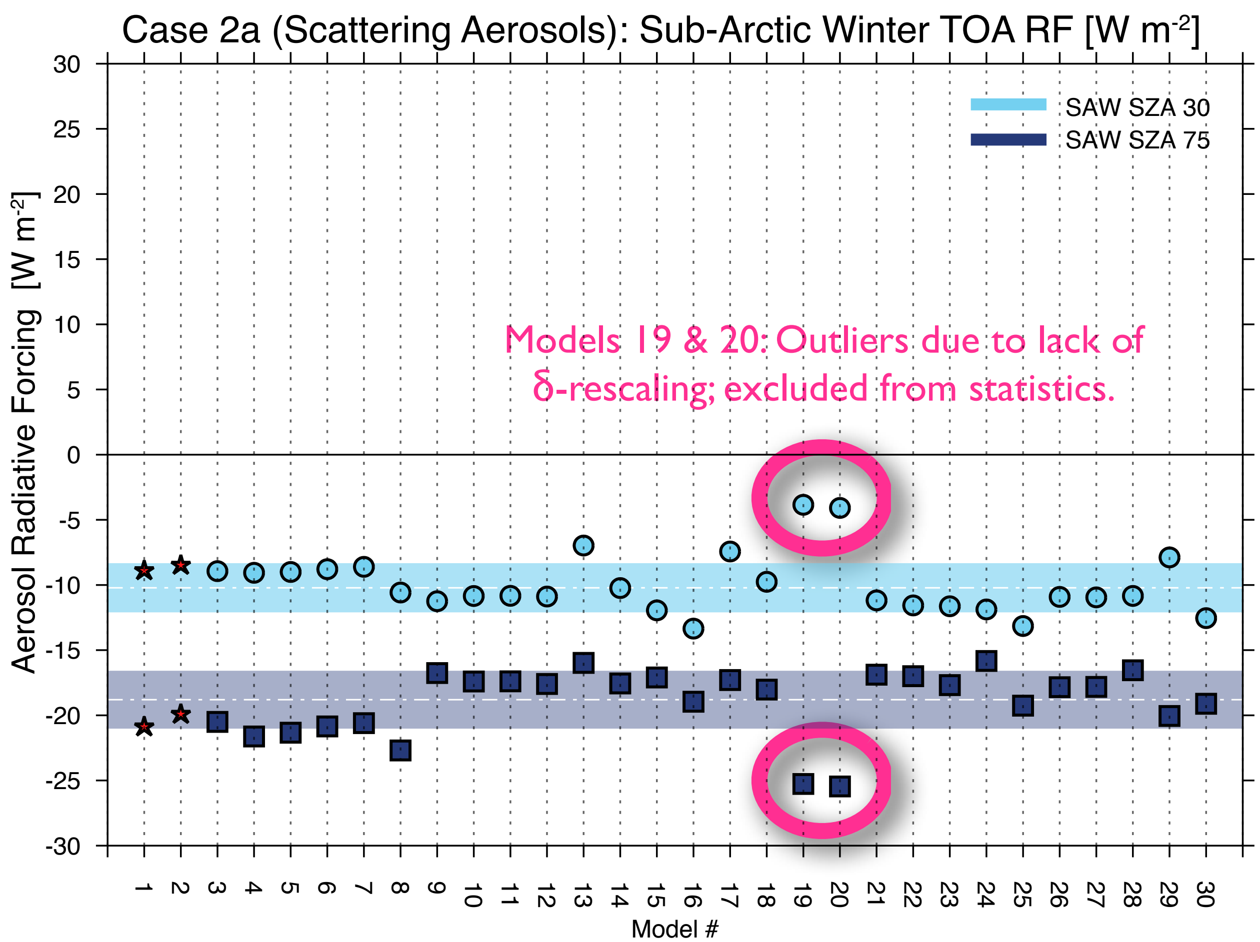
- <u>31 Participating models!!!</u>
  - 2 line-by-line (LBL) benchmarks
  - <u>Multiple Scattering:</u>
    - 10 codes (including LBL) have > 2 streams
    - 6 codes use discrete ordinate method (DISORT)
    - 21 use some variant of delta Eddington (δ-Eddington)
    - 2 use matrix operator method (MOM)
  - <u>Gaseous Transmission:</u>
    - 9 codes use exponential sum fit transmission (ESFT)
    - 16 use correlated-k
    - 1 uses non-correlated k
    - 1 uses Padé approximation
- Relationship to other AeroCom experiments:
  - 6 codes also used in AeroCom Prescribed Experiment (Stier et al., 2012)
  - 6 codes also used in AeroCom Direct Effect Experiment (Myhre et al., 2012)

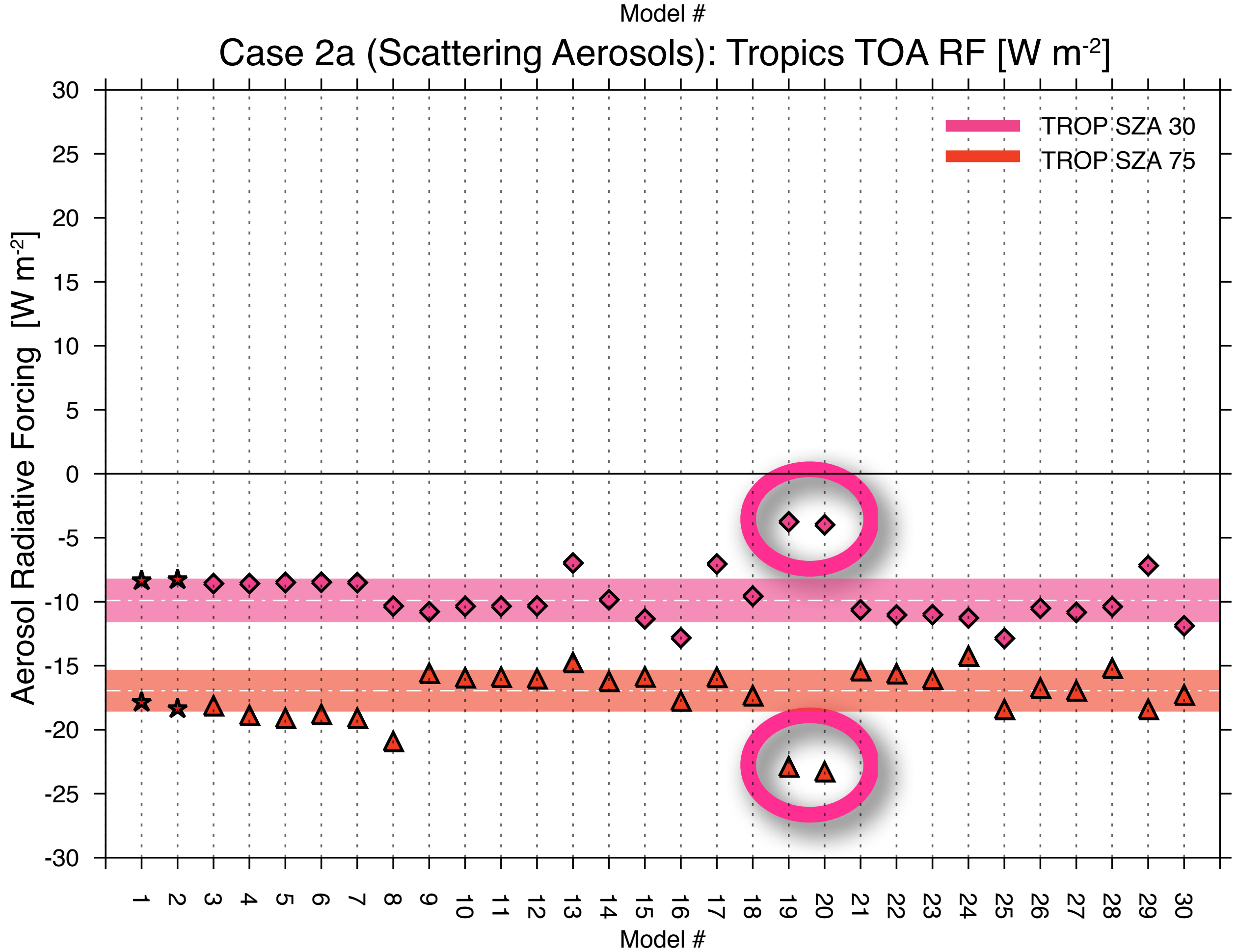
# Results: Rayleigh Atmosphere (Case 1)




- Fig 1a: Model bias relative to LBL for broadband direct downwards flux at surface <2%. Exception: TROP 75 (Bias 4%). Diversity (standard deviation as % of mean; STDVM) ranges 1-5%.
- Fig 1b: Bias in total near-IR flux down to surface <3% except for TROP SZA 75° (7%). Diversity ranges 2-8%. Note: near-IR = broadband - UV/VIS.
- Broadband diffuse fluxes under- or overestimate relative to LBL mean at high and low sun elevation, respectively (up to +3% TROP 75).
- With exception of diffuse fluxes, both inter-model diversity and bias relative to benchmark LBL codes increase with solar zenith angle (or, increase with decreased sun elevation) and with the amount of water vapor (i.e. higher for TROP). <u>Thus, the highest errors and disagreement occur when the slant path of water vapor increases.</u>

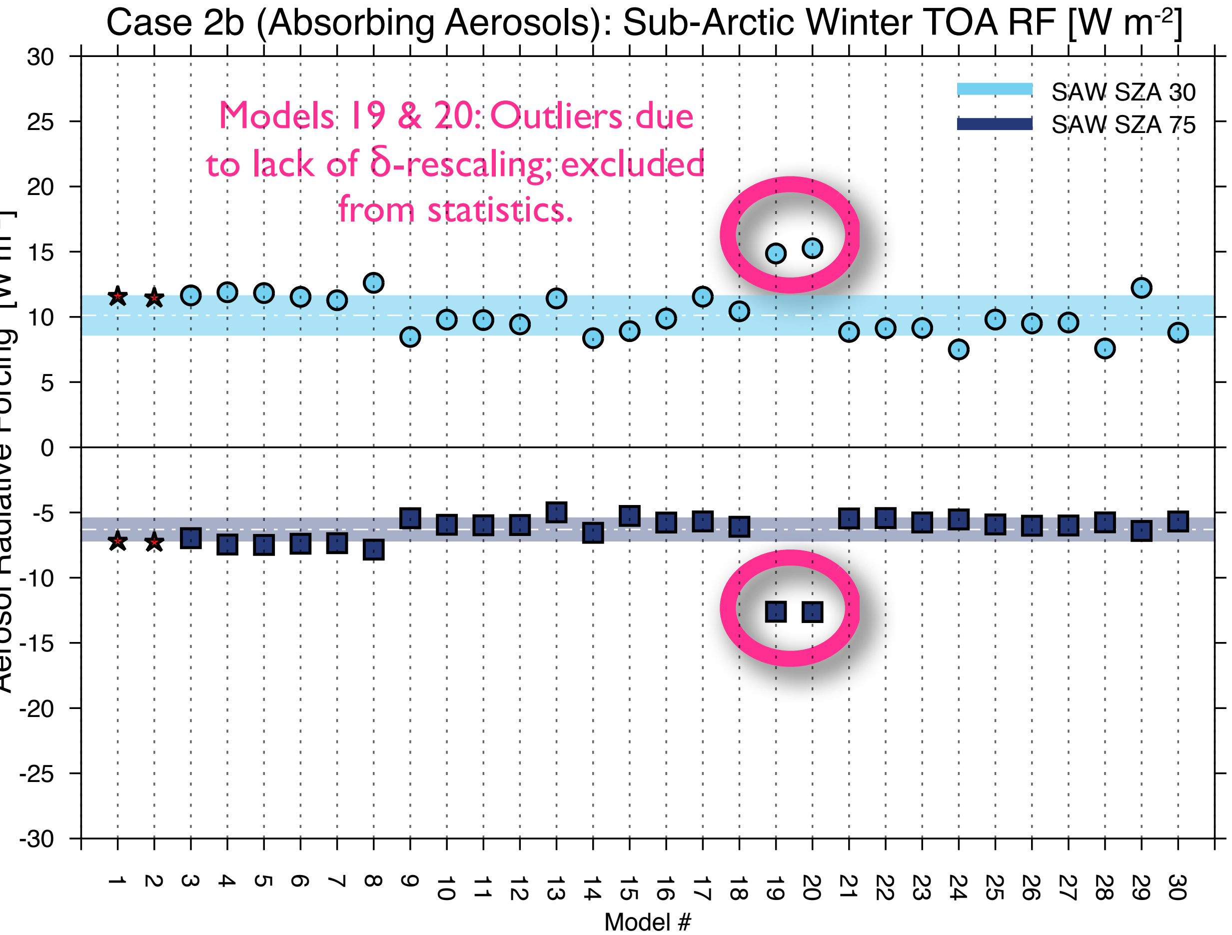
# Results: Scattering Aerosol TOA Radiative Forcing (RF)

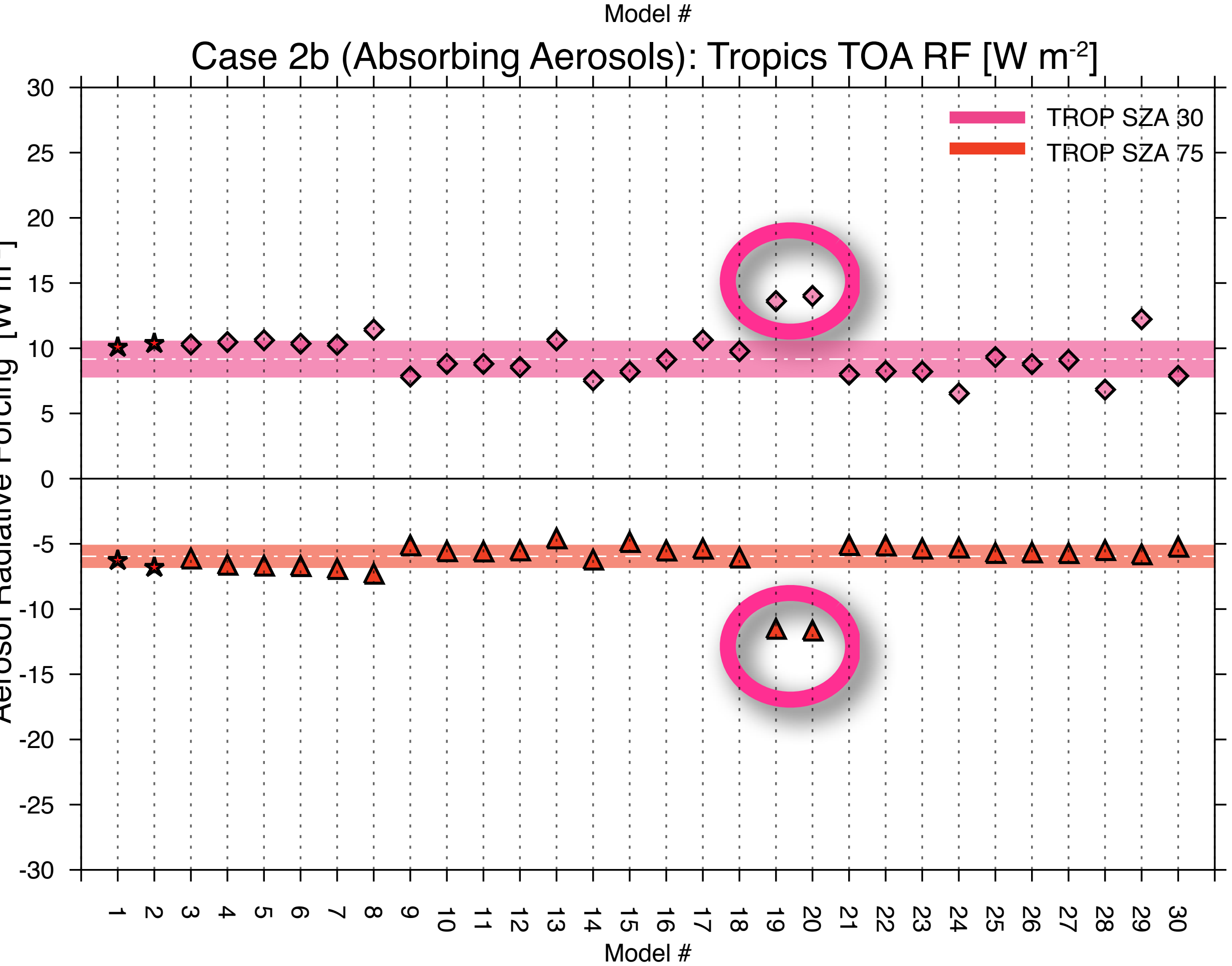



- Average bias relative to LBL ~ -20% at SZA 30° (underestimate) and +8% at SZA 75° (overestimate).
- Diversity is ~13% at SZA 30° and 10% at SZA 75° for both atmospheres.
- Bias and diversity similar for surface forcing (not shown).
- Multi-stream models (#3-8) generally in good agreement with LBL benchmark.
- <u>Aerosol RF more sensitive to sun elevation than to prescribed gaseous absorbers</u>, (i.e. prescribed atmosphere) as expected.

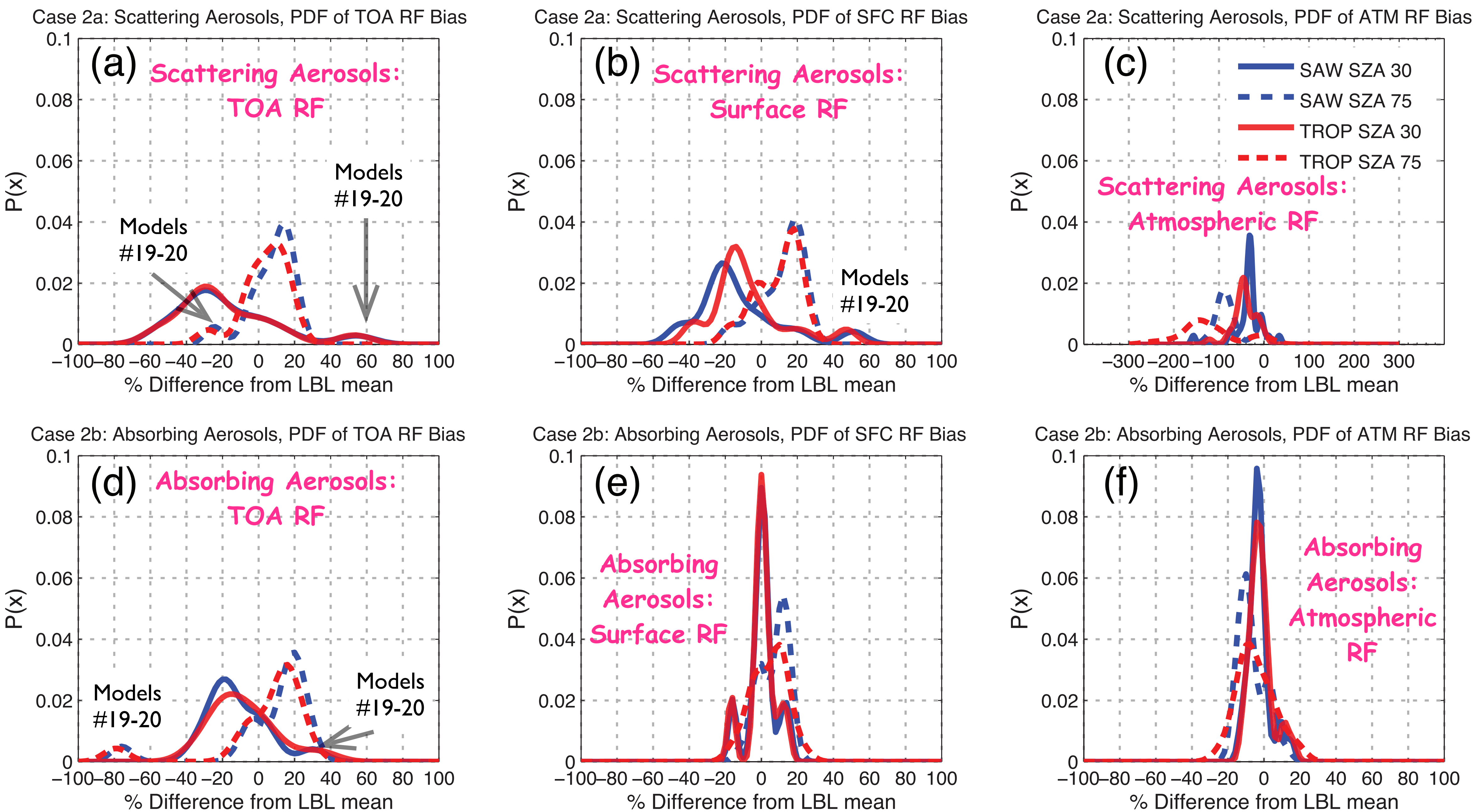
# Results: Absorbing Aerosol TOA Radiative Forcing (RF)



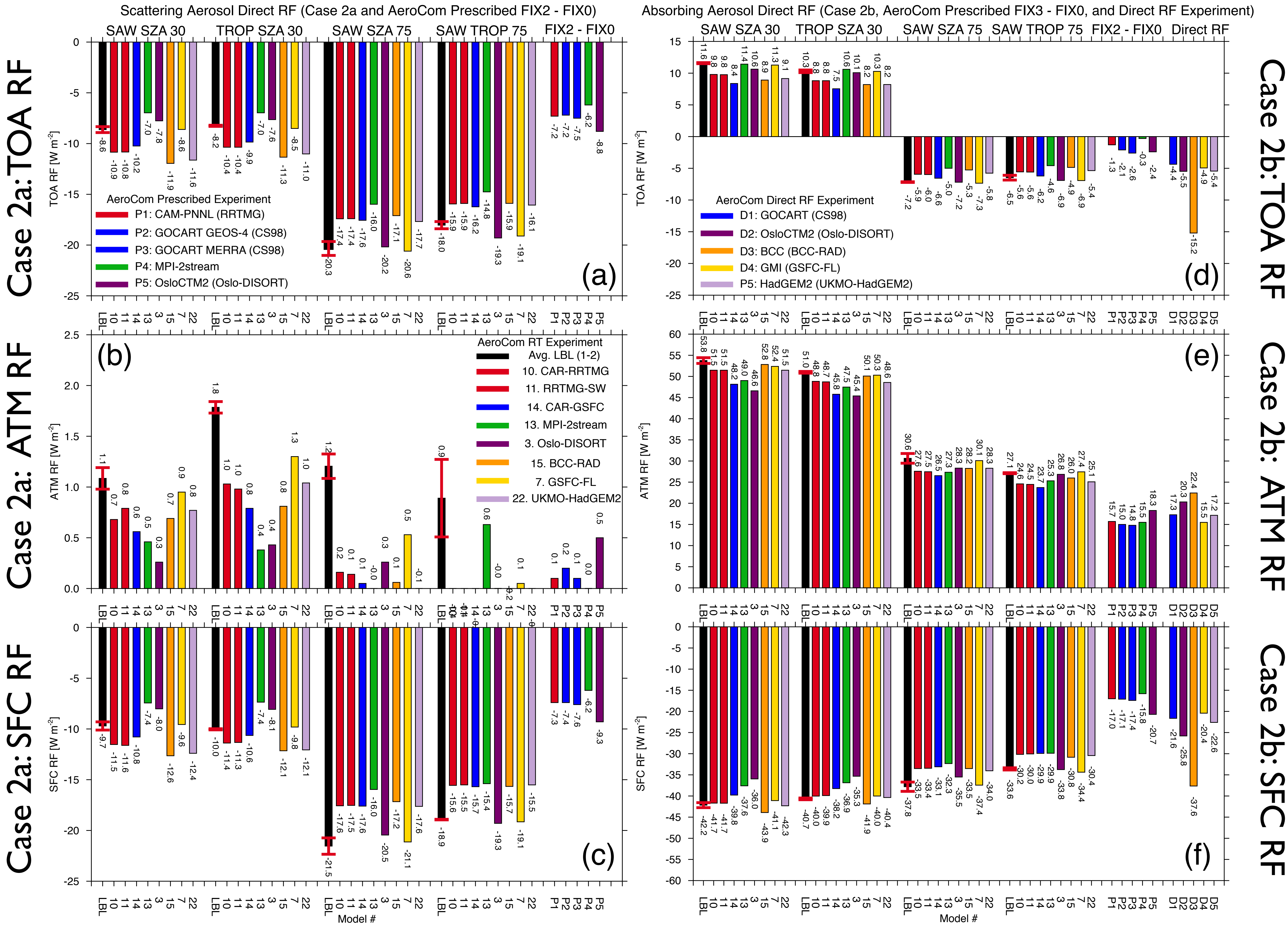

- Average bias relative to LBL ~ -13% at SZA 30° (underestimate) and +12% at SZA 75° (overestimate) -- less bias than scattering aerosol case.
- Diversity is ~14% at SZA 30° and 12% at SZA 75° (slightly more diversity than scattering aerosol case).
- Bias in atmospheric forcing (not shown) bias ranges 0 to -7% and diversity ranges 6-10%.
- For both absorbing and especially for scattering aerosols, bias and diversity increase as sun elevation increases (or, increase as solar zenith angle decreases) -- role of multiple scattering.

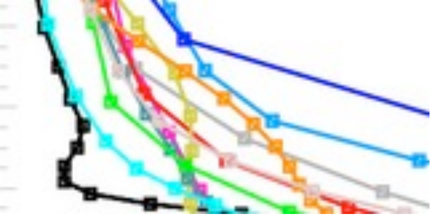
# PDFs of Aerosol RF bias relative to benchmark LBL Results




- Strong dependence of bias (and diversity!) on sun elevation.
- Bias decreases as:
  - Sun elevation decreases (SZA increases)
  - Aerosol absorption increases
- Treatment of multiple-scattering leads to increased inter-model diversity.
- Biases at specific SZA may be important for regional aerosol forcing and climate impacts.

# Relationship to AeroCom Prescribed and Direct RF





# AeroCom Current and Future Activities

- Companion AeroCom papers:
  - Aerosol Direct Effect in global models:

    Myhre et al., Radiative forcing of the direct aerosol effect from AeroCom Phase II simulations, *submitted to ACPD,* 2012.
  - Prescribed aerosol properties the same as in this study, but in global models with varying surface albedos, gaseous absorbers, and including clouds:

    Stier, P. et al., Host model Uncertainties in Aerosol Forcing Estimates: REsults from the AeroCom Prescribed Intercomparison Study, *submitted to ACPD,* 2012.
- Data hosting via the AeroCom web server:

  http://aerocom.met.no/data.html
- Interest from DOE ARM program to archive results along with Halthore et al. [2005] results (Warren Wiscombe and Alice Cialella, ARM EXternal Data Center (XDC), *personal communication).*
- Paper coming soon to ACPD!!!
  - Randles et al., Intercomparison of shortwave radiative transfer schemes in global aerosol modeling: Results from the AeroCom Radiative Transfer Experiment, *submitted to ACPD*, 2012.