accuracy of Radiative Transfer Schemes in global modeling

the AeroCom A2 TROP/ARCTIC experiment

an update

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Participating Models

- **many thanks to the contributing models** /partners … thus far:

- **GENLN2-DISORT LBL** (CICERO; G.Myhre) **benchmark Line-to-line**
- **DISORT** (CICERO; Gunnar Myhre)
- **libRadtran** (Finnish Meteorological Institute; Jani Huttunen)
- **RRTMG-SW** (GSFC; L.Oreopoulos and D. Lee, Seoul Nat University)
- **Edwards and Slingo 96** (U. Reading; C. Ryder, E.Highwood, B. Harris)
- **RFM DISORT (line by line)** (U. Read.; C.Ryder, E. Highwood, B. Harris)
- **HadGEM2 GCM** (Steven Rumbold, UK Met Office)

- ***there's still room for more results if you would like to contribute! we'd like to close contributions by DATE***

Motivation

- **assess solar radiative transfer schemes** in AeroCom global models

- inter-compare AeroCom model solar radiative transfer schemes ***without aerosols or clouds*** given standard atmospheres and surface albedo.

- useful to see how each model treats (1) **Rayleigh** scattering, (2) **ozone** absorption, and (3) **water vapor** absorption.

- will facilitate analysis of AeroCom forcing experiments (i.e. **A2 CTRL** & **A2 PRE**) and prescribed aerosol field forcing (i.e. **AERpre 1** and **AERpre 0**) *… see P.Stier's presentation*

- we encourage all global models with shortwave radtiave transfer scheme and off-line codes … to participate

participate ! NOW.

Case 1 Setup: Rayleigh Atmos.

- use the same GCM/CTM as set up for the AeroCom **A2-ZERO** experiment, or standalone radiation codes.
- prescribe **ozone-profiles** and **water vapor profiles** from provided AFGL standard atmospheres.
- prescribe **surface albedo** at 0.2 globally.
- run ***2*** one-day ***(01 Jan 2006)*** simulations at **one** model time-step *(so you do not have to pull the code out of your mode environment)* for
  - **tropical** AFGL standard atmosphere
  - **sub-arctic** Winter AFGL standard atmosphere
- compare solar broadband (0.3-4.0um) and visible (0.2-0.7um) downw. rad. fluxes to the surface (normalized by top-of-the atmosphere flux)
  - at a solar zenith angle of **30 degree** (or sun-elevation of 60 degree)
  - at a solar zenith angle of **75 degree** (or sun-elevation of 25 degree)

Case 2 Setup: Prescribe aerosols

include in addition aerosol

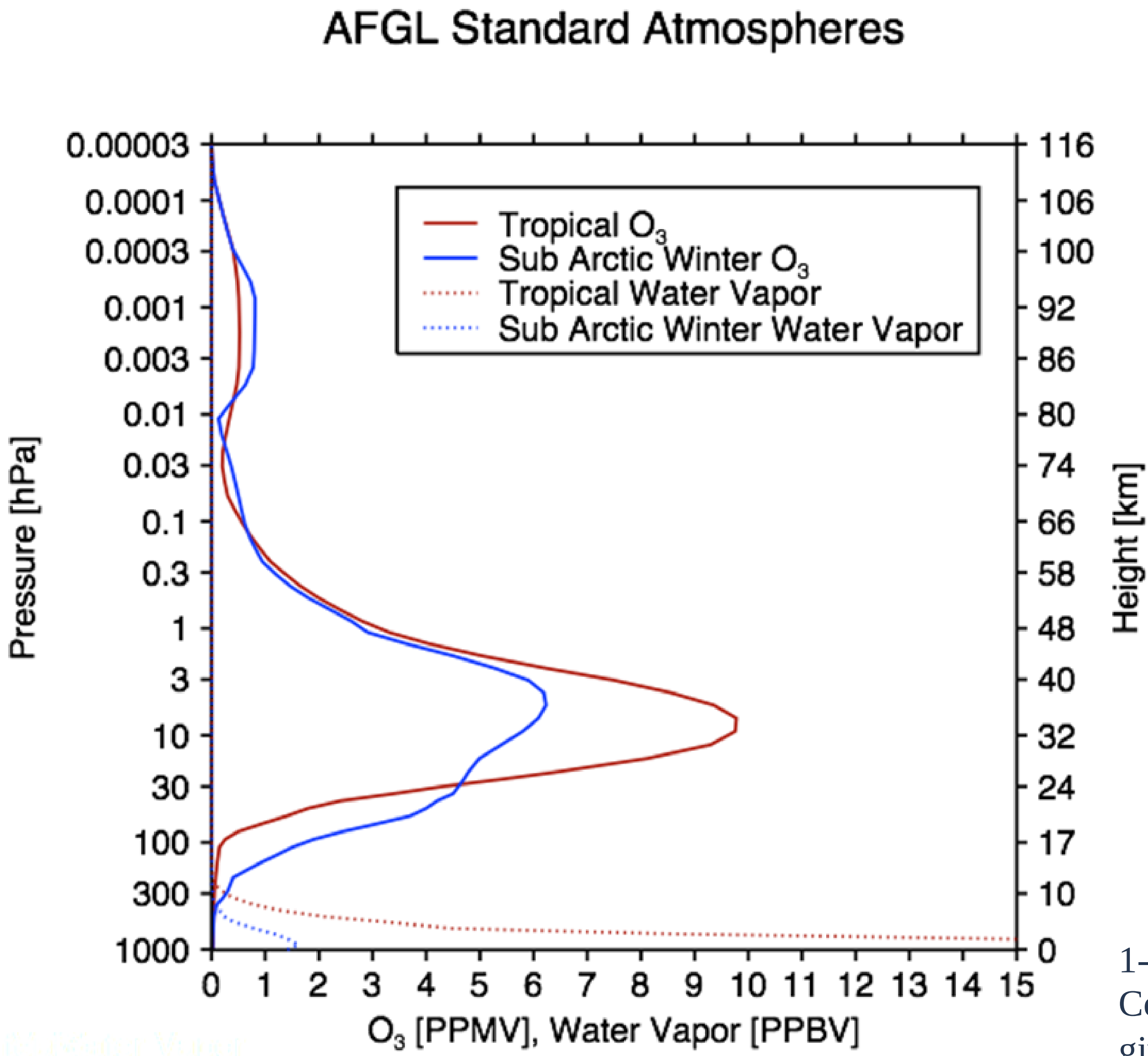
- **AOD = 0.2** at 550 nm (lowest 2 km) **two cases**
  - solar wavelength independent (AER_prescribed 0)
  - Ångstrøm Exponent of 1.0 (spectrally dependent)

- **asymmetry factor (*g*) = 0.7** (solar wavelength independent)

- solar absorption **two cases**
  - NO **single scattering albedo ω_0 = 1.0** (wavelength independent)
  - YES **single scattering albedo ω_0 = 0.8** (wavelength independent)

- *… again for **solar zenith angles of 30 and 75 degrees***
- *… again for **tropics and sub-arctic** atmospheric profiles*

AFGL Profiles



1-km Resolution: 0-120 km
Corresponding pressure levels also given.

Diagnostics

- **6** diagnostic fields for each case:
  - **shortwave** (0.2-4um) **downwelling** (*direct* + *diffuse*) flux **at top of atm**. no clouds
  - **shortwave** (0.2-4um) **downwelling** (*direct* + *diffuse*) **surface** flux, no clouds
  - **shortwave** (0.2-4um) **downwelling** *diffuse* **surface** flux, no clouds
  - **visible** (0.2-0.7um) **downwelling** (*direct* + *diffuse)* flux **at top of atm**. no clouds
  - **visible** (0.2-0.7um) **downwelling** (*direct* + *diffuse*) **surface** flux, no clouds
  - **shortwave** (0.2-4um) **upwelling** flux at **top of the atmosphere**, no clouds
- diagnostics should be instantaneous at **one** model time-step.
  - This could be the first time step, but at noon UTC is preferred.
- data should be in netCDF format following the CF convention
  - follow AeroCom website summary under DIRECT FORCING diagnostics package (http://nansen.ipsl.jussieu.fr/AEROCOM/AEROCOM_diagnostics.xls)
  - CMOR rewriting tool (http://www-pcmdi.llnl.gov/software-portal/cmor/)
  - AeroCom A2 Exp. CMOR tables (http://www-lscedods.cea.fr/aerocom/CMOR)
- in total, **report only on 36 numbers**! (a couple of more for AOD fixed)

Analysis

- follow the *Halthore et al. (2005)* effort on Intercomparison of shortwave radiative transfer codes and measurements (*J. Geophys. Res.*, *110,* D11206, doi:10.1029/2004JD005293)
- will examine provided global results at two chosen sun elevations (solar zenith angles of 30° and 75°) for each of the two standard atmospheres.
  - **because not all models use the same wavelength bands, we normalize all results by the TOA downwards flux for the bands provided, and we compare results normalized to a common TOA downward flux**
- interest from DOE ARM program to archive these results along with the *Halthore et al.* [2005] results as well as other model inter-comparison results (Warren Wiscombe and Alice Cialella, ARM EXternal Data Center (XDC), *personal communication*)
- time frame for submission: **as soon as you can**!

Case 1: Clear-Sky (1)

absolute mean and **std dev** (excl. GENLN2-DISORT benchmark in brackets) **in W m^{-2}**
blue numbers indicate problems (values outside ±1 Standard Deviation of the Mean)

flux	SZA	SAW	TROP
↓Broadband SFC	30	992.5 ± 25.6 (1006.3)	904.9 ± 10.2 (896.9)
	75	253.6 ± 2.7 (254.0)	**223.0 ± 5.3** (210.3)
↓Diffuse SFC	30	61.8 ± 3.1 (64.4)	61.7 ± 3.0 (63.8)
	75	36.7 ± 1.3 (37.3)	36.6 ± 1.3 (36.7)
↓ VIS SFC	30	**474.6 ± 5.3** (480.5)	478.8 ± 5.2 (481.8)
	75	113.7 ± 2.5 (115.0)	114.1 ± 2.2 (113.6)
↑ Broadband TOA	30	225.7 ± 3.9 (228.4)	**206.2 ± 0.6** (201.6)
	75	82.3 ± 0.8 (83.0)	**76.4 ± 0.8** (73.8)

Case 1: Clear-Sky (2)

MEAN BIAS (as a % difference rel. to GENLN2-DISORT) **± Standard Deviation of Bias**
BLUE (**RED**) indicate intermodel mean is **bias**ed **low** (**high**) relative to GENLN2-DISORT

flux	SZA	SAW	TROP
↓Broadband SFC	30	-1.4 ± 2.5%	+0.9 ± 1.1%
	75	-0.1 ± 1.1%	+6.0 ± 2.5%
↓Diffuse SFC	30	-4.1 ± 4.7%	-3.3 ± 4.7%
	75	-1.7 ± 3.4%	-0.3 ± 3.5%
↓ VIS SFC	30	-1.2 ± 1.1%	-0.6 ± 1.1%
	75	-1.2 ± 2.2%	+0.4 ± 2.0%
↑ Broadband TOA	30	-1.2 ± 1.7%	+2.3 ± 0.3%
	75	-0.8 ± 0.9%	+3.5 ± 1.1%

Case 1: Clear-Sky (3)

- inter-model variability is greatest for downward broadband surface fluxes
- for most fields, the benchmark Line-to-Line code …

  … is within ±1 standard deviation of the inter-model mean.
- there is more inter-model variability at the lower sun-elevation angle
- there is more inter-model variability for the ARCTIC winter profile
- **most** fields are **within 2% of the GENLN2-DISORT benchmark, *except***
- Arctic, high sun-elevation: Downwards diffuse flux at the surface
- tropic, low sun-elevation: Downwards broadband flux at the surface
- tropic, low sun-elevation: Upwards broadband flux at TOA

TOA Aerosol Radiative Forcing *in W m^{-2}* with scattering aerosols (case 2)

(Number in parenthesis is a% change in magnitude relative to GENLN2_DISORT)

Model	SAW 30	SAW 75	TROP 30	TROP 75
LBL GENLN2_DISORT	**- 8.8**	**- 20.6**	**- 8.2**	**- 17.7**
ES96 (220 bands delta)	-11.5	-16.9	-11.0	-15.5
ES96 (6 bands delta)	-11.1	-16.8	-10.6	-15.3
RFMD	-8.4	-19.7	-8.2	-18.2
DISORT	-7.7	-20.0	-7.6	-19.2
libRadtran	-8.9	-21.2	-8.4	-19.0
RRTMG-SW	-10.8	-17.3	-10.3	-15.8
HadGEM2_GCM	-11.6	-17.6	-10.9	-16.0
MEAN	**- 10.0** ***(14%)***	**- 18.5** ***(10%)***	**- 9.6** ***(17%)***	**- 17.0** ***(4%)***
MEDIAN	**- 10.8**	**- 17.6**	**- 10.3**	**- 15.9**
STDDEV	**1.6**	**1.8**	**1.4**	**1.7**

TOA Aerosol Radiative Forcing *in W m^{-2}* absorbing aerosols (case 2)

(Number in parenthesis is % change in magnitude relative to GENLN2_DISORT)

Model	SAW 30	SAW 75	TROP 30	TROP 75
LBL GENLN2_DISORT	**11.6**	**- 7.1**	**10.1**	**- 6.2**
ES96 (220 bands delta-r)	9.1	-5.4	8.2	-5.1
ES96 (6 bands delta-r)	8.8	-5.4	7.9	-5.1
RFMD	11.4	-7.2	10.4	-6.7
DISORT	10.6	-7.1	10.0	-6.9
libRadtran	11.8	-7.4	10.5	-6.6
RRTMG-SW	9.7	-5.9	8.7	-5.5
HadGEM2_GCM	9.1	-5.7	8.2	-5.3
MEAN	**10.1** ***(13%)***	**- 6.3** ***(11%)***	**9.1** ***(10%)***	**- 5.9** ***(5%)***
MEDIAN	**9.7**	**-5.9**	**8.7**	**-5.5**
STDDEV	**1.2**	**0.9**	**1.1**	**0.8**

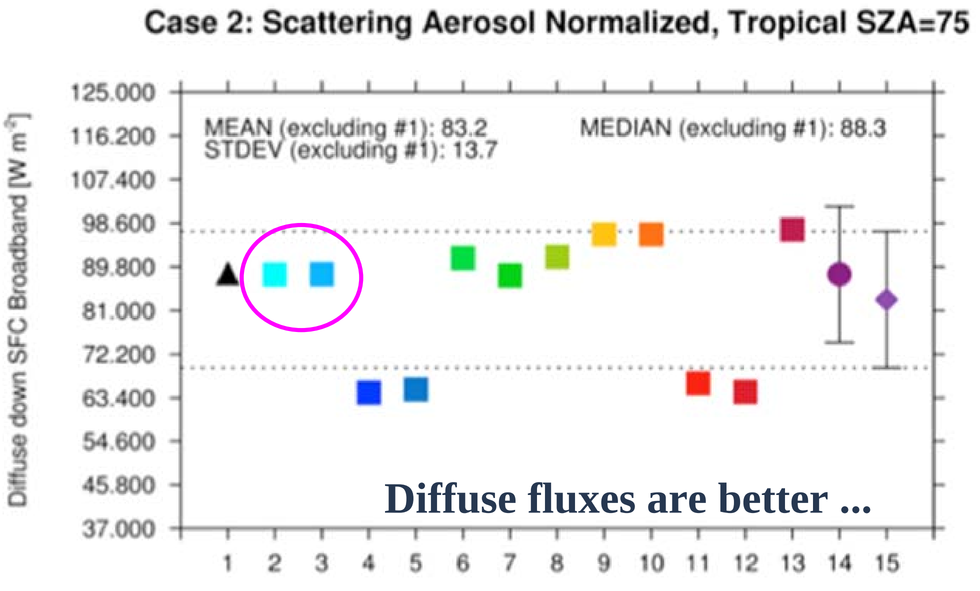
Case 2: cases with aerosols

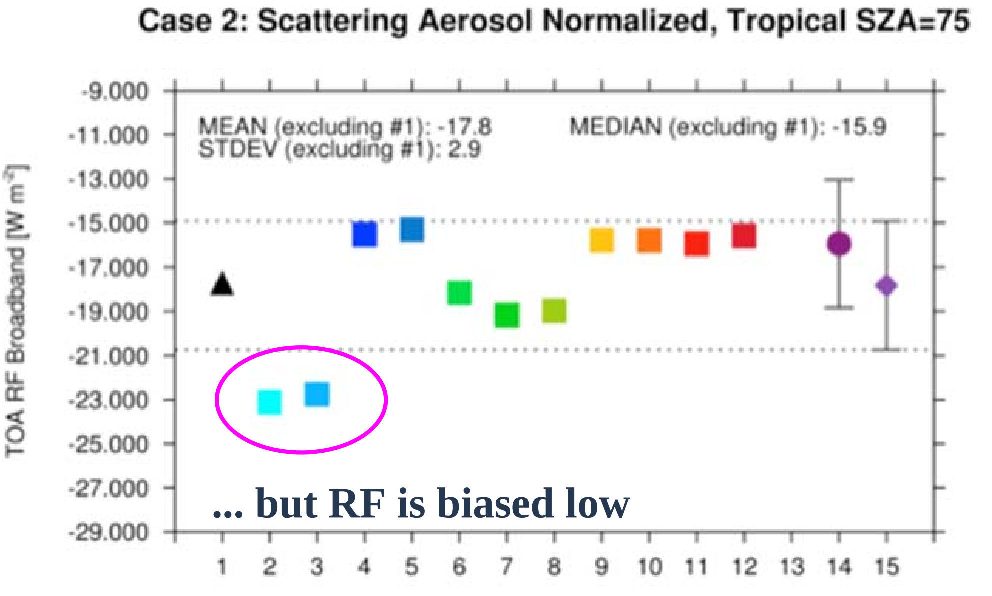
- Inter-model variability is greatest for downwards diffuse flux at the surface.
- for most flux fields, benchmark line-to-line code is within ±1 standard deviation of the inter-model mean.
- generally, there is **more inter-model variability at lower zenith angels** for both profiles, and there is **more inter-model variability for the SAW profile** relative to the TROP profile (especially for the downwards broadband flux and downwards broadband diffuse flux at the surface).
- With the exception of Downward diffuse flux at the surface, **the inter-model averages are within about 3% of the GENLN2-DISORT benchmark** (TROP SZA=75 Broadband down at the surface is 8.7% higher)
- **diffuse fluxes down at the surface are low compared to GENLN2-DISORT by 15-20% !**

potential issues:
diff. fluxes & Δ scale

Note: pink below NOT included in previous previous results because a duplication of included models.

- U. Reading provides results with delta rescaling switched on and off; (prev.results were switched on (#4 and #5, right).
- with delta rescaling switched off (below left, #2 and #3), diffuse fluxes are improved; but TOA RF is made worse!
- could something similar be going on in other models?





Summary

- This simple experiment shows that there is (un-needed) diversity in solar radiative transfer codes *even in the clear sky* *(though the difference relative to the LBL code is generally within 3%).*

- This diversity typically increases as aerosols are included, and as the solar zenith angle increases.

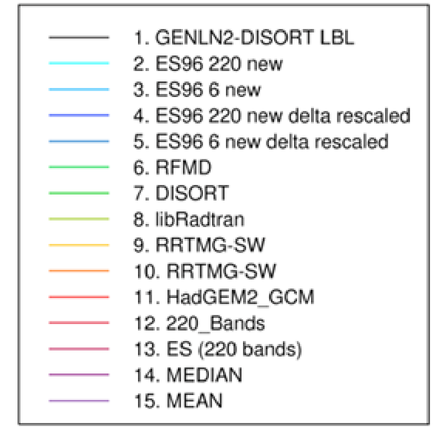
- This, of course, has consequences for calculations of aerosol direct radiative forcing.

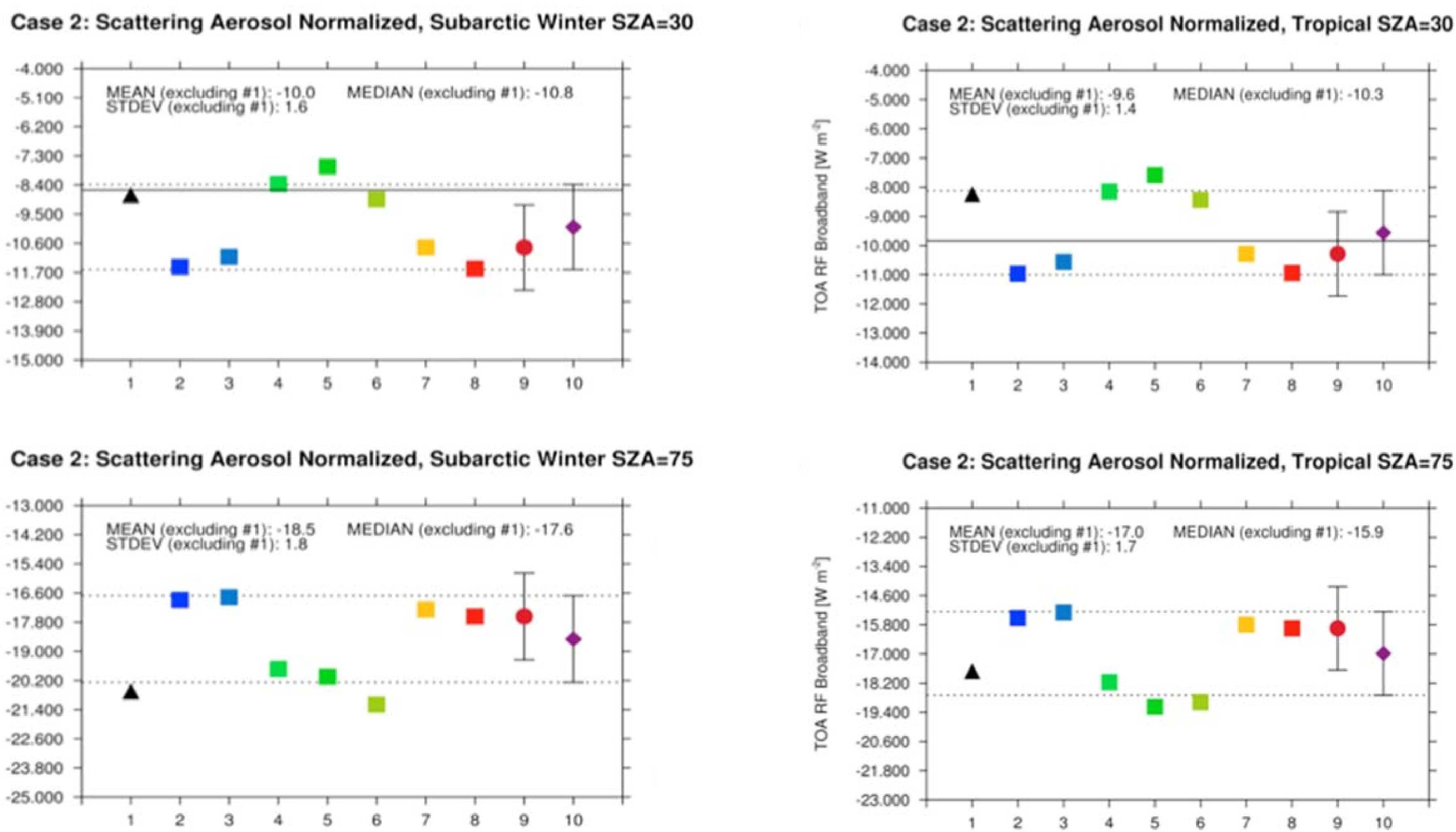
many thanks to the contributing groups/models thus far!

… and we are anticipating more group/models to participate

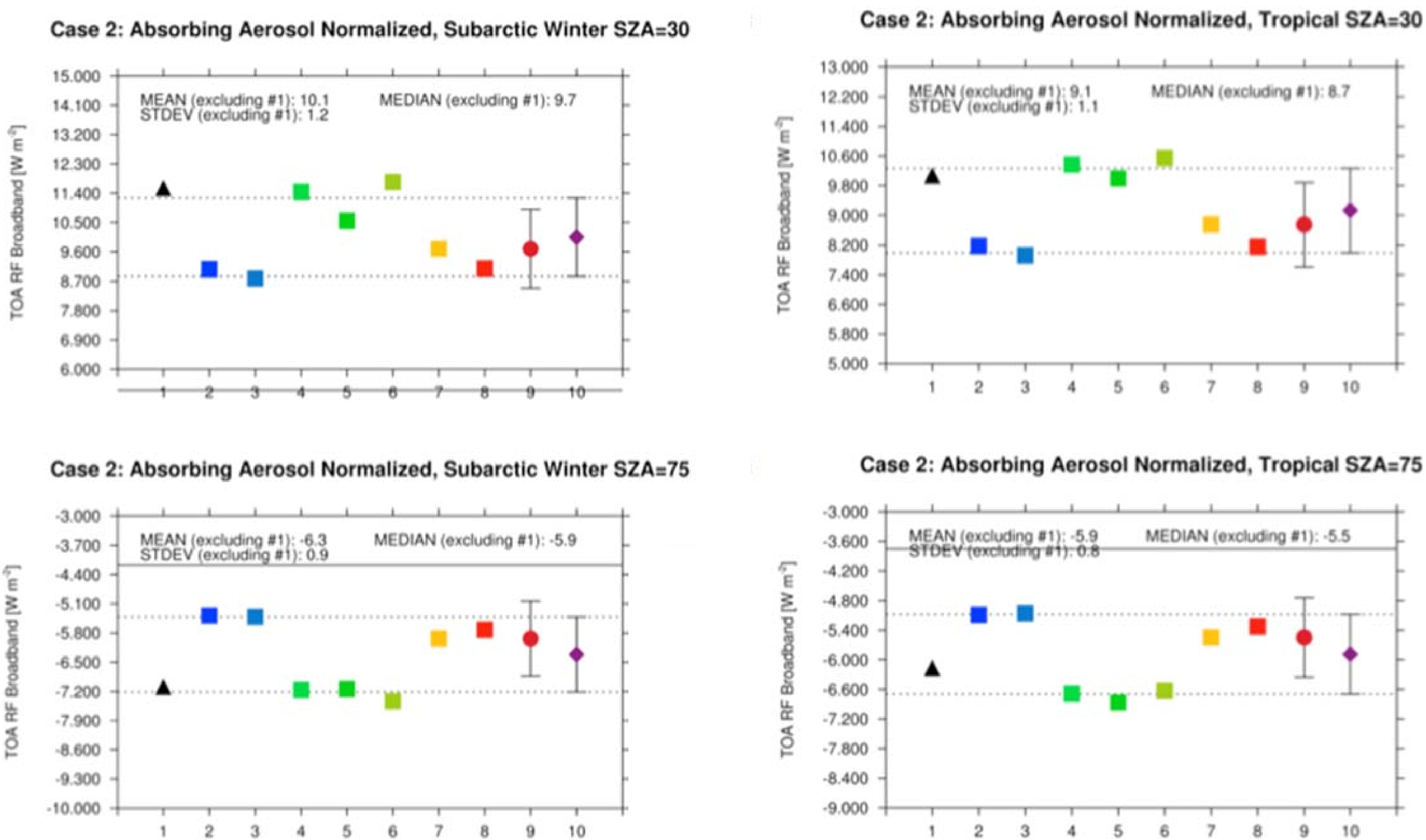
Additional Slides

Case 2: Scattering Aerosols TOA RF





Case 2: Absorbing Aerosols TOA RF



Case 2: Scattering Aerosol (1)

Absolute Mean and Standard Deviation (excluding GENLN2-DISORT benchmark) in W m^{-2}; GENLN2-DISORT results given in parenthesis.
Bold numbers indicate that the GENLN2-DISORT Flux is NOT within ±1 Standard Deviation of the of the Mean

Flux	SZA	SAW	TROP
↓Broadband SFC	30	979.0 ± 24.1 (993.8)	891.6 ± 8.9 (884.0)
	75	230.0 ± 4.5 (226.5)	**201.8 ± 5.1** (186.8)
↓Diffuse SFC	30	166.5 ± 37.5 (203.8)	159.9 ± 35.2 (191.5)
	75	85.5 ± 16.3 (98.8)	80.5 ± 14.4 (88.5)
↓ VIS SFC	30	**465.4 ± 4.9** (471.9)	469.4 ± 4.9 (473.0)
	75	101.3 ± 3.0 (100.7)	101.8 ± 2.8 (99.6)
↑ Broadband TOA	30	235.7 ± 5.2 (237.2)	**215.8 ± 1.8** (209.8)
	75	**100.8 ± 1.7** (103.6)	93.4 ± 2.2 (91.5)

Case 2: Scattering Aerosol (2)

Mean Bias (expressed as a % Difference relative to GENLN2-DISORT)
± Standard Deviation of Bias
Blue (red) indicates that the inter-model mean is biased low (high) relative to GENLN2-DISORT

Flux	SZA	SAW	TROP
↓Broadband SFC	30	-1.5 ± 2.4%	+0.9 ± 1.0%
	75	1.5 ± 2.0%	+8.0 ± 2.7%
↓Diffuse SFC	30	-18.3 ± 18.4%	-16.5 ± 18.4%
	75	-13.4 ± 16.5%	-9.1 ± 16.3%
↓ VIS SFC	30	-1.4 ± 1.0%	-0.8 ± 1.0%
	75	+0.6 ± 3.0%	+2.2 ± 2.8%
↑ Broadband TOA	30	-0.6 ± 2.2%	+2.9 ± 0.9%
	75	-2.7 ± 1.7%	+2.1 ± 2.4%

Case 2: Absorbing Aerosol (1)

Absolute Mean and Standard Deviation (excluding GENLN2-DISORT benchmark) in W m^{-2}; GENLN2-DISORT results given in parenthesis.
Bold numbers indicate that the GENLN2-DISORT Flux is NOT within ±1 Standard Deviation of the of the Mean

Flux	SZA	SAW	TROP
↓Broadband SFC	30	941.4 ± 22.8 (953.4)	**855.7 ± 7.9** (846.2)
	75	210.1 ± 4.4 (206.1)	**183.5 ± 5.4** (168.8)
↓Diffuse SFC	30	135.1 ± 28.7 (163.3)	129.9 ± 26.9 (153.7)
	75	69.2 ± 12.0 (78.4)	65.4 ± 10.6 (70.6)
↓ VIS SFC	30	439.1 ± 5.6 (444.3)	442.9 ± 5.4 (445.3)
	75	89.3 ± 3.0 (88.3)	89.7 ± 2.8 (87.3)
↑ Broadband TOA	30	215.7 ± 4.4 (216.8)	**197.1 ± 1.5** (191.5)
	75	**88.6 ± 0.9** (90.1)	**82.3 ± 1.4** (80.0)

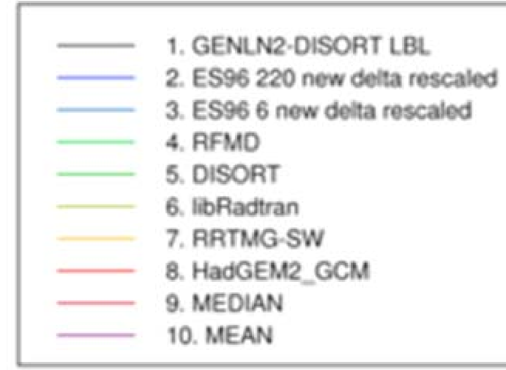
Case 2: Absorbing Aerosol (2)

Mean Bias (expressed as a % Difference relative to GENLN2-DISORT)
± Standard Deviation of Bias
Blue (red) indicates that the inter-model mean is biased low (high) relative to GENLN2-DISORT

Flux	SZA	SAW	TROP
↓Broadband SFC	30	-1.3 ± 2.4%	+1.1 ± 0.9%
	75	+1.9 ± 2.1%	+8.7 ± 3.2%
↓Diffuse SFC	30	-17.2 ± 17.6%	-15.5 ± 17.5%
	75	-11.7 ± 15.3%	-7.4 ± 15.0%
↓ VIS SFC	30	-1.2 ± 1.3%	-0.5 ± 1.2%
	75	+1.1 ± 3.4%	+2.8 ± 3.2%
↑ Broadband TOA	30	-0.5 ± 2.0%	+2.9 ± 0.8%
	75	-1.6 ± 1.0%	+2.9 ± 1.7%

Case 1: Clear-Sky

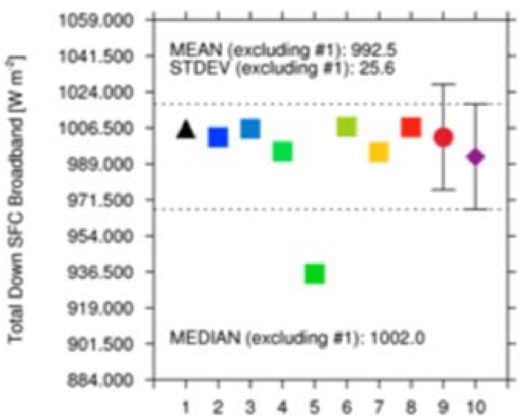
Broadband Total Down at Surface

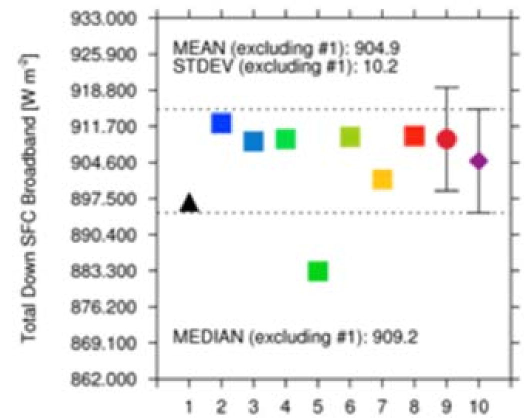


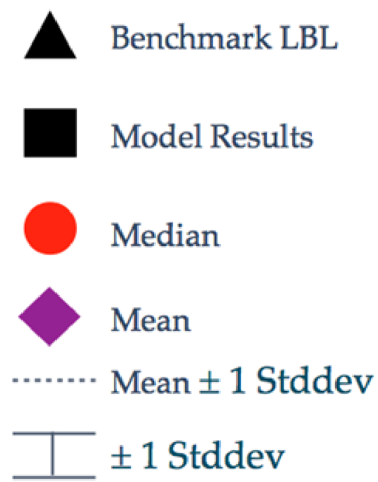
SAW

TROP

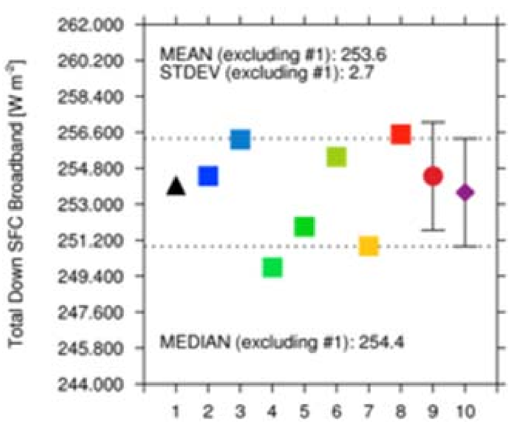
SZA = 30

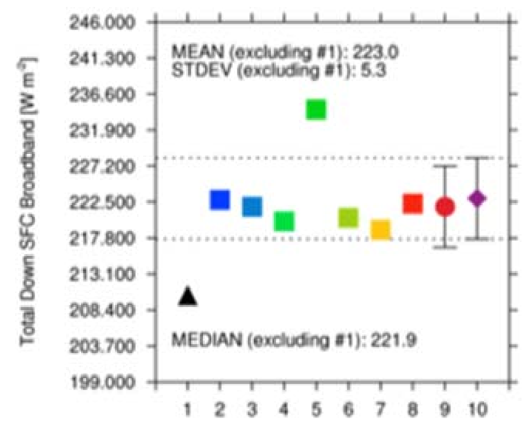






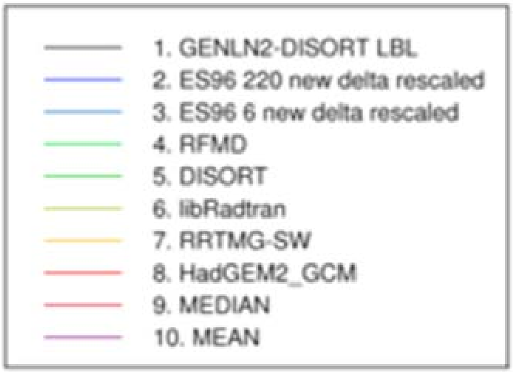
SZA = 75





Case 1: Clear-Sky

Broadband Diffuse Down at Surface

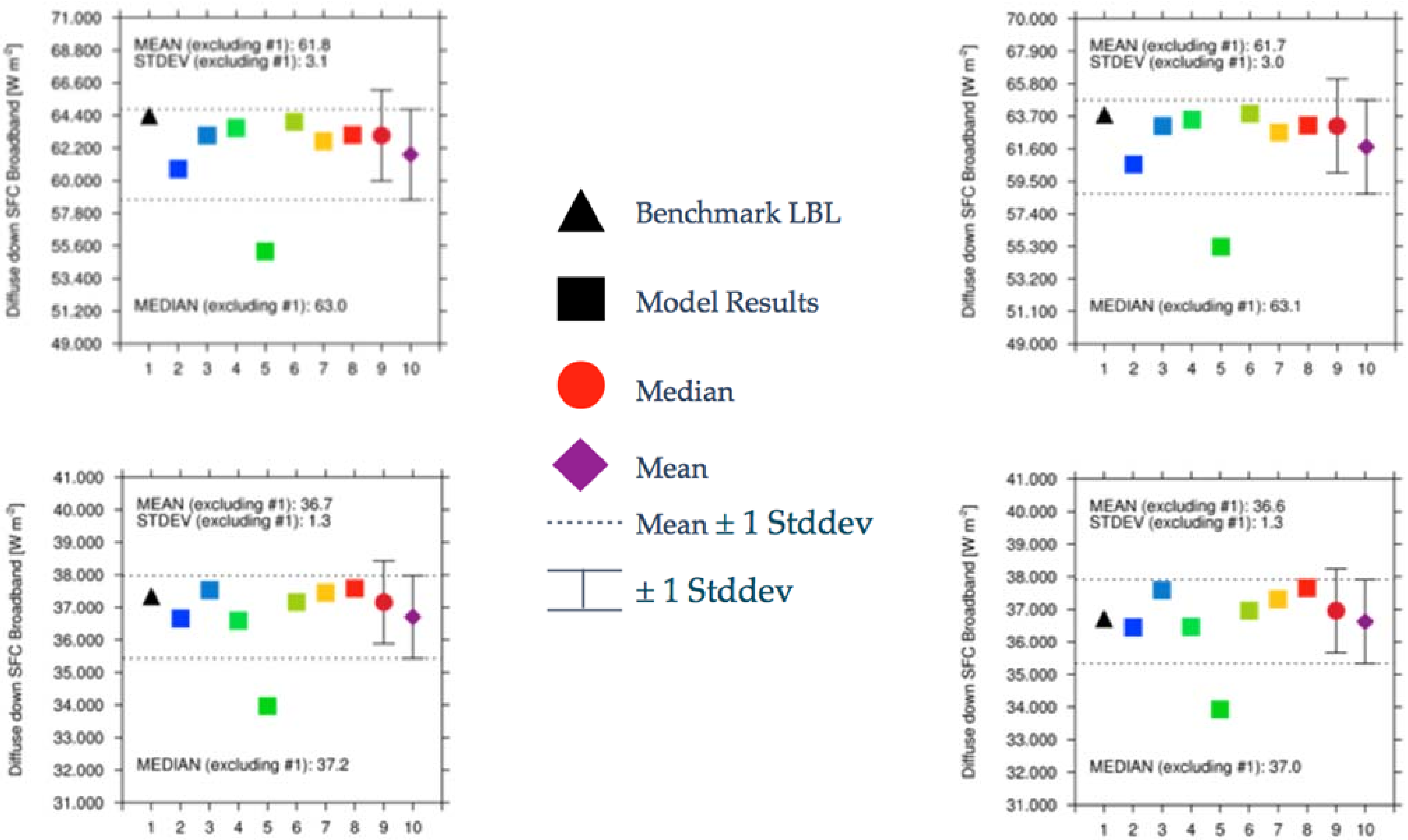


SAW

TROP

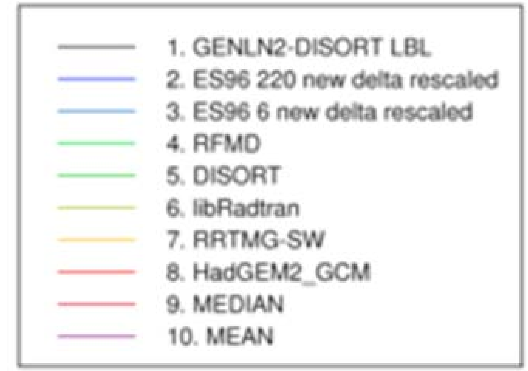
SZA = 30

SZA = 75



Case 1: Clear-Sky

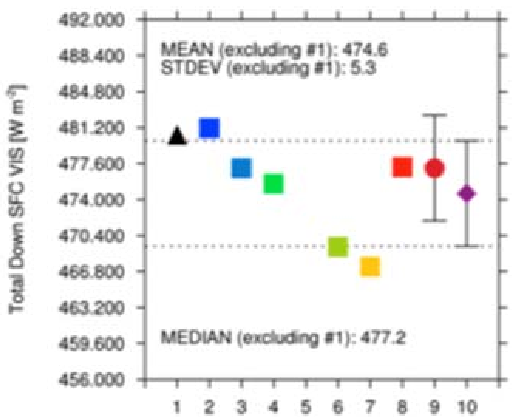
Visible Down at Surface

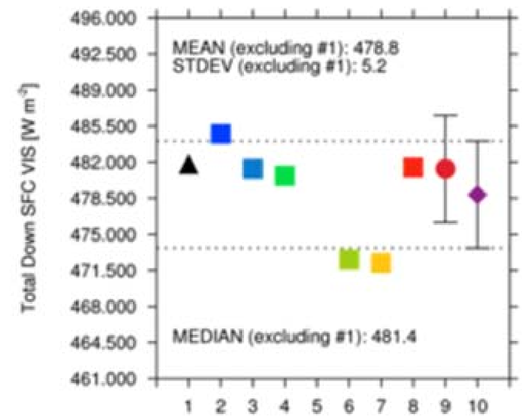


SAW

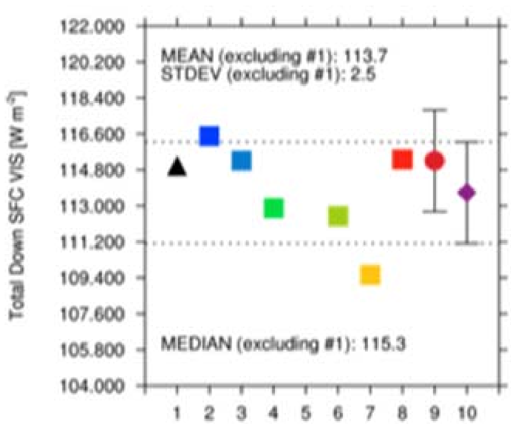
TROP

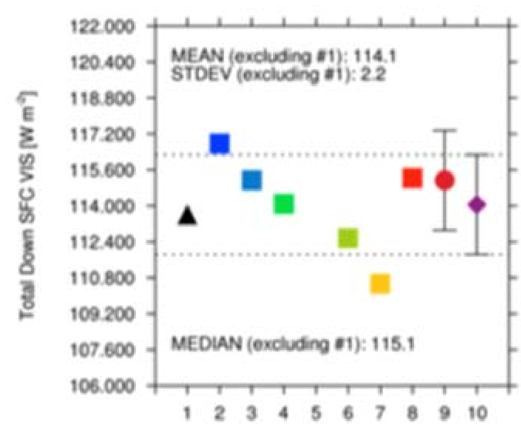
SZA = 30





SZA = 75





▲ Benchmark LBL

■ Model Results

● Median

◆ Mean

Mean ± 1 Stddev

± 1 Stddev

Case 1: Clear-Sky

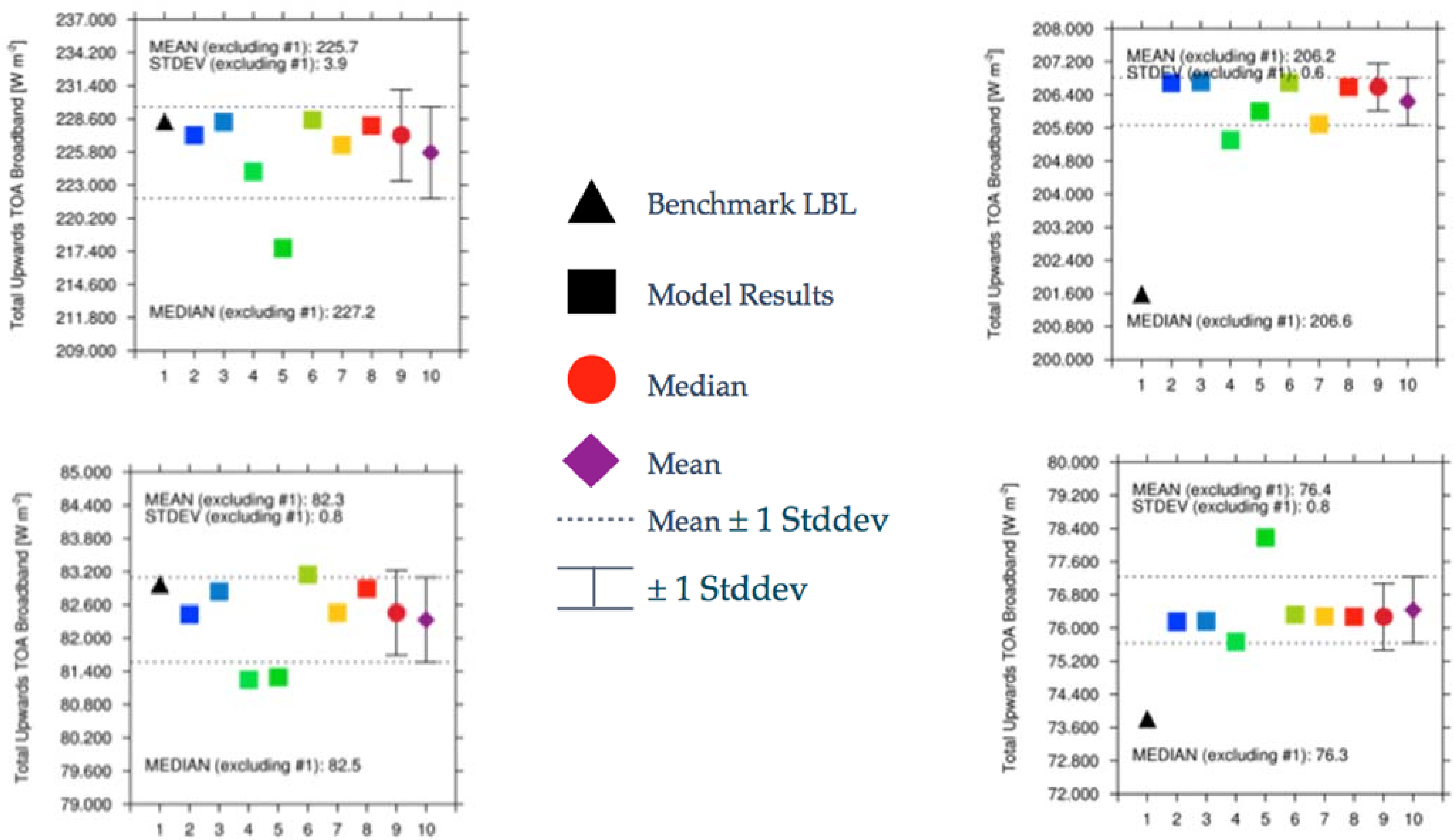
Broadband Up at TOA

SAW

TROP

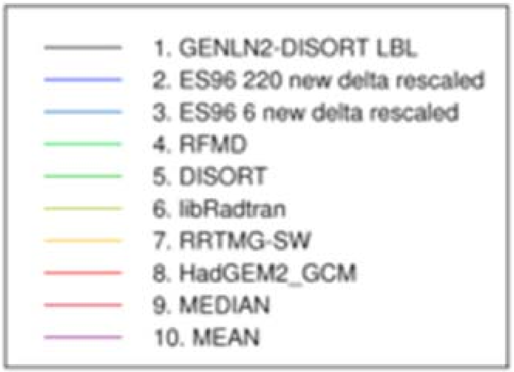
SZA = 30

SZA = 75



Case 2: Scattering Aerosol

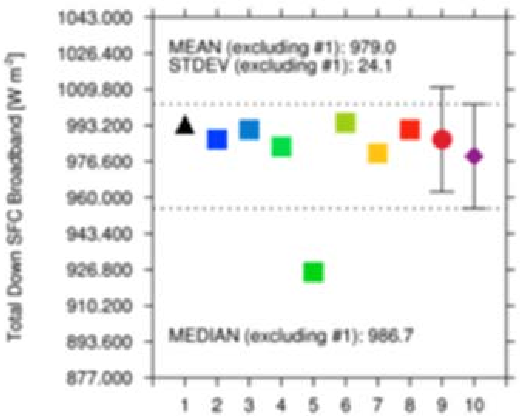
Broadband Total Down at Surface

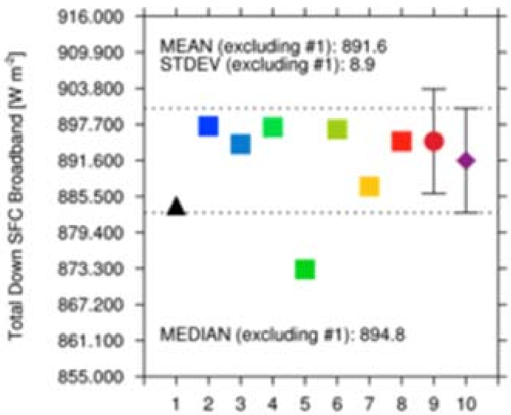


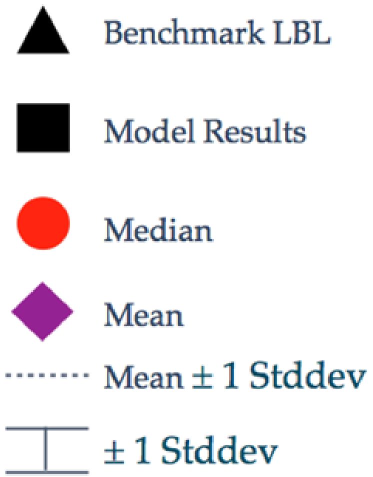
SAW

TROP

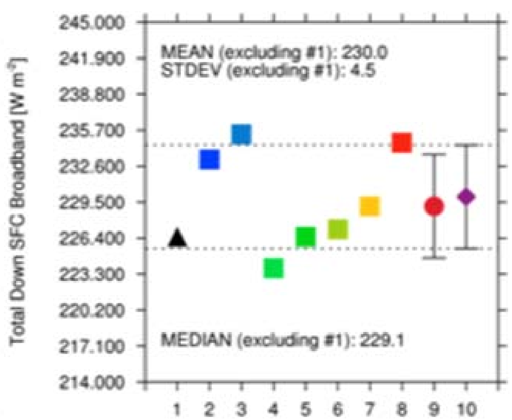
SZA = 30

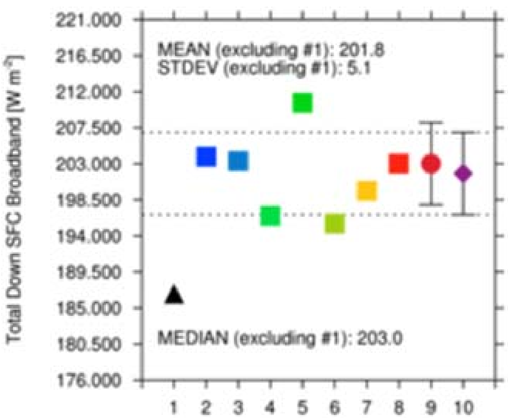






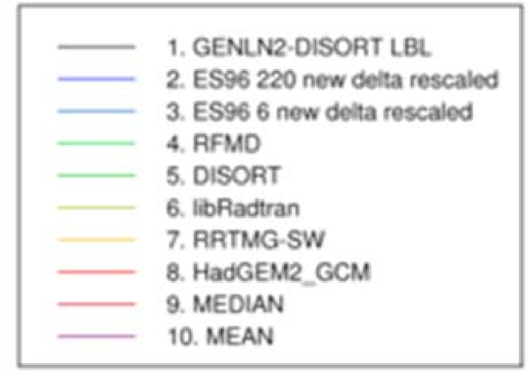
SZA = 75





Case 2: Scattering Aerosol

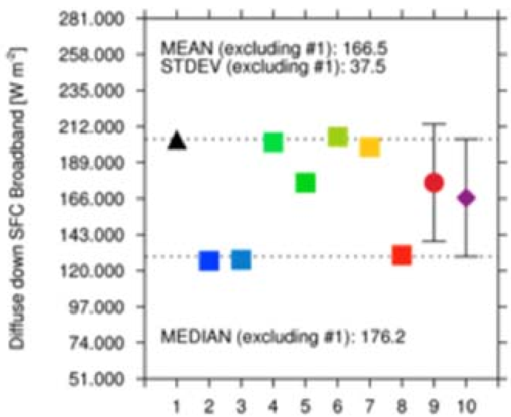
Broadband Diffuse Down at Surface

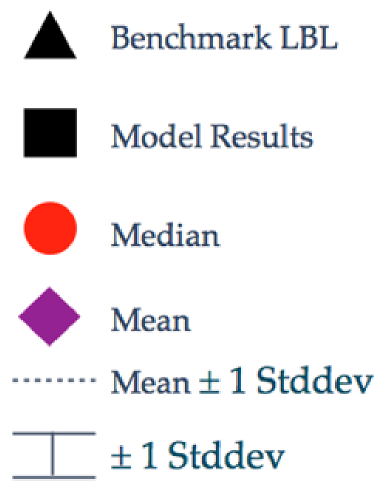


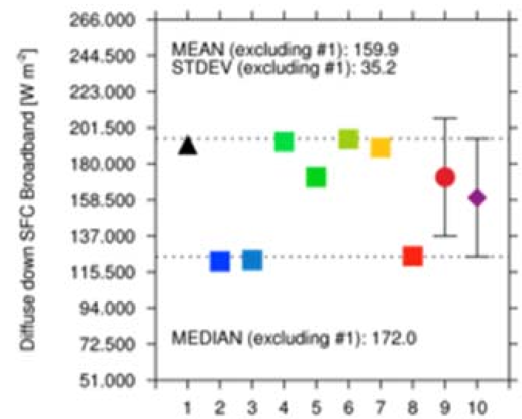
SAW

TROP

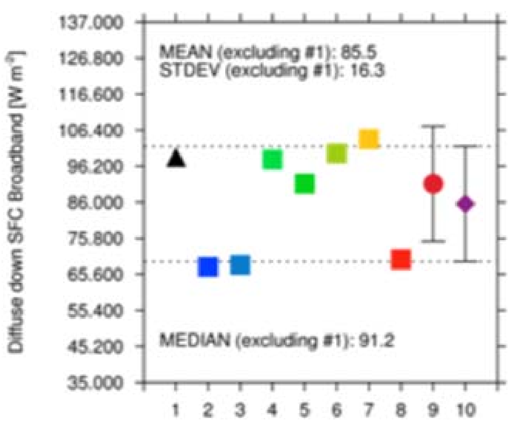
SZA = 30

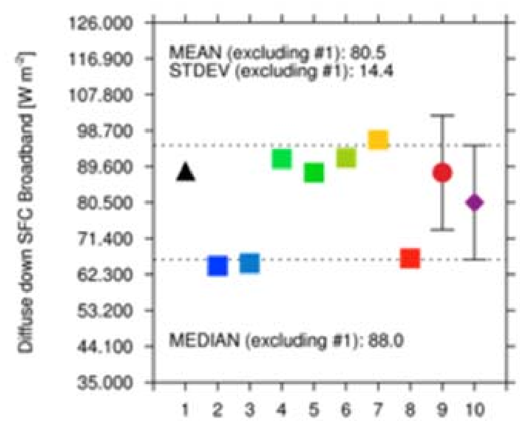






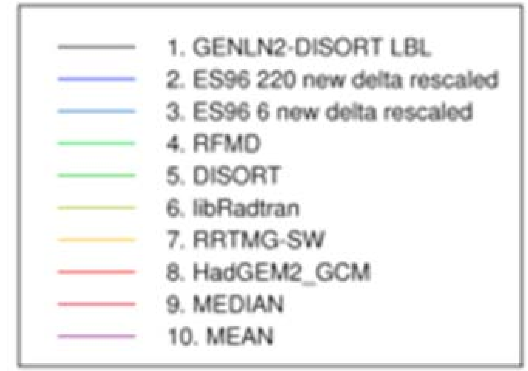
SZA = 75





Case 2: Scattering Aerosol

Visible Down at Surface

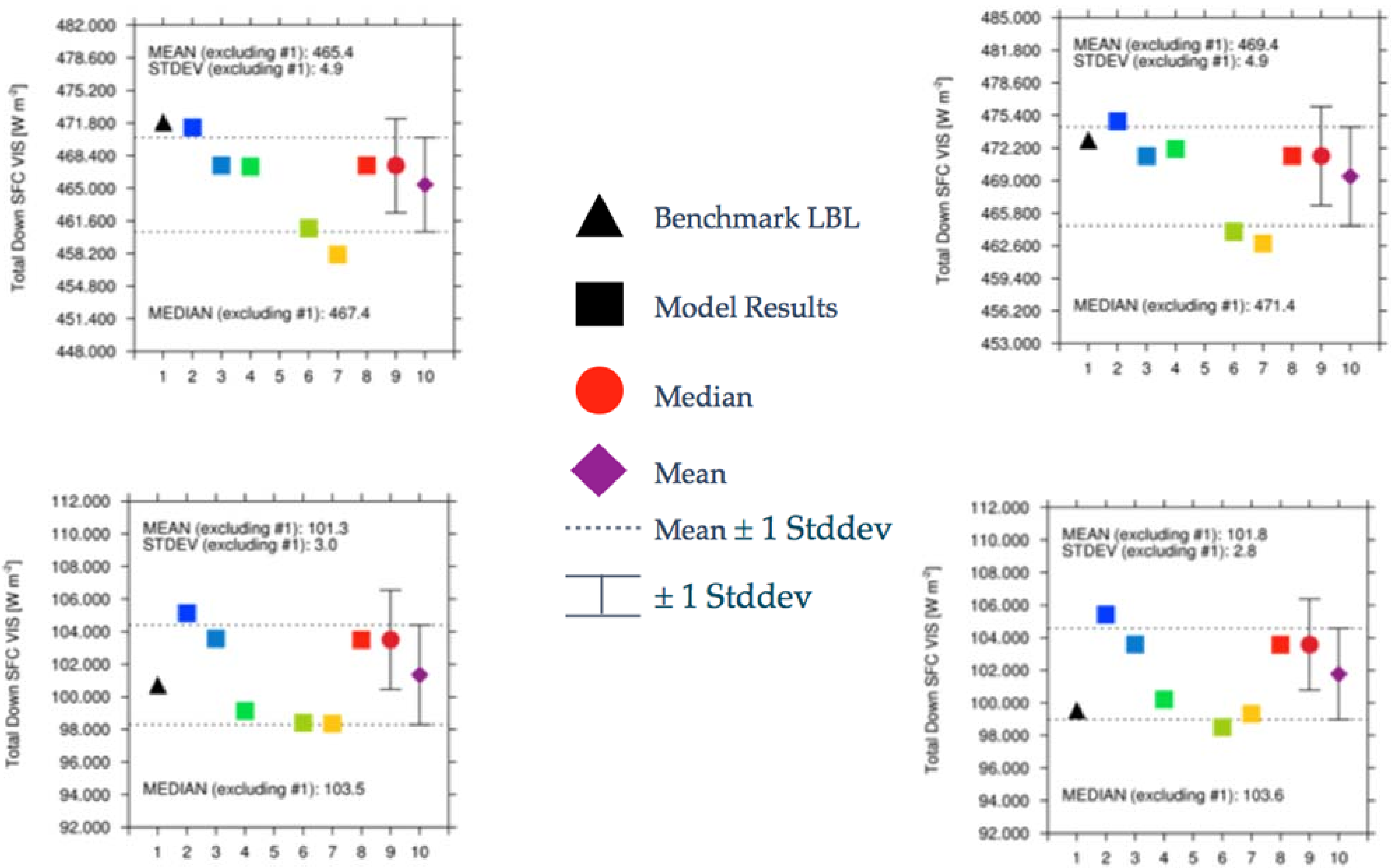


SAW

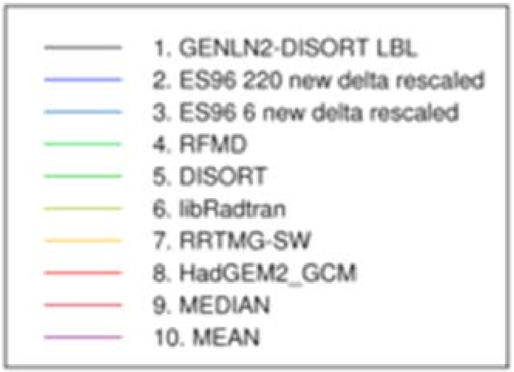
TROP

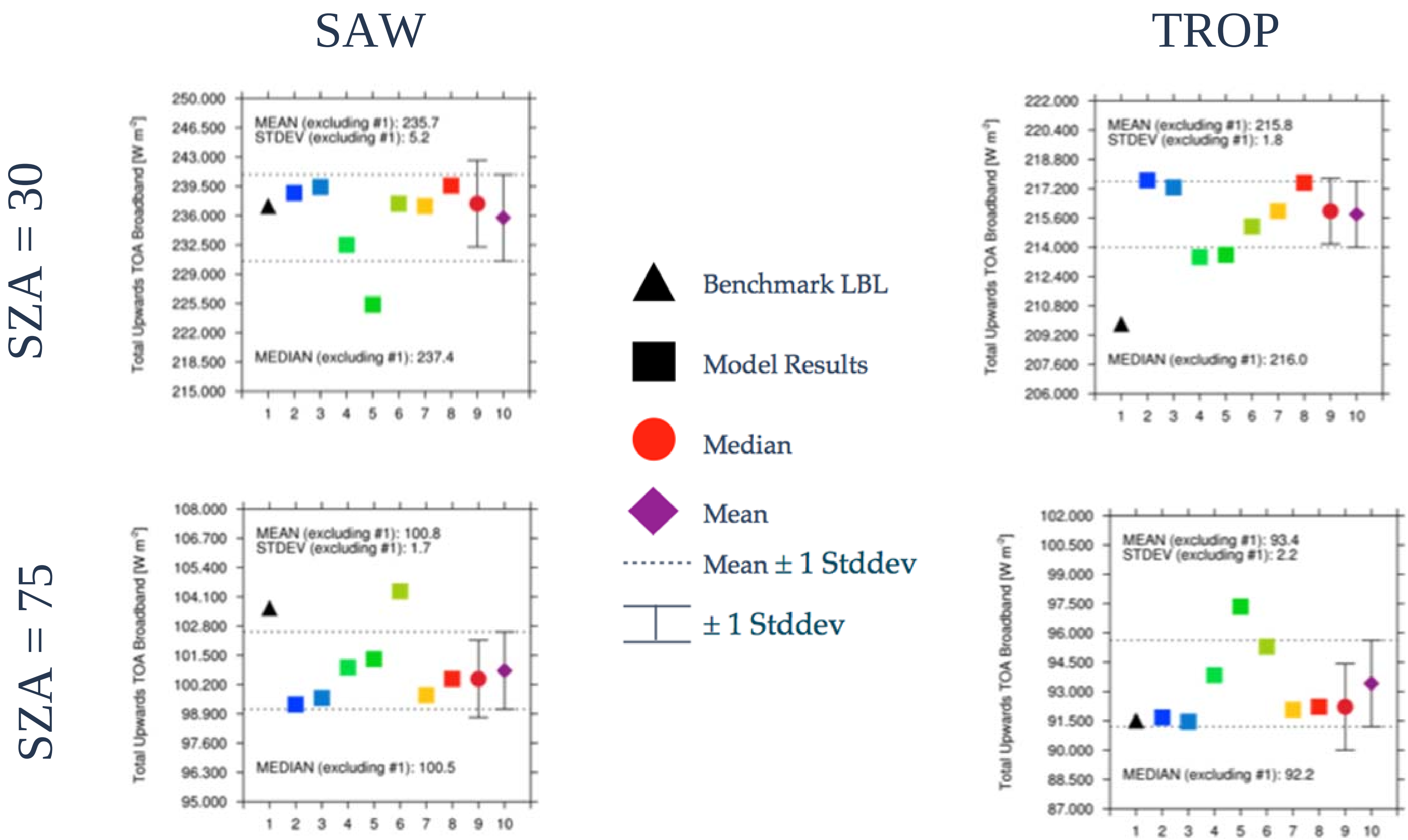
SZA = 30

SZA = 75

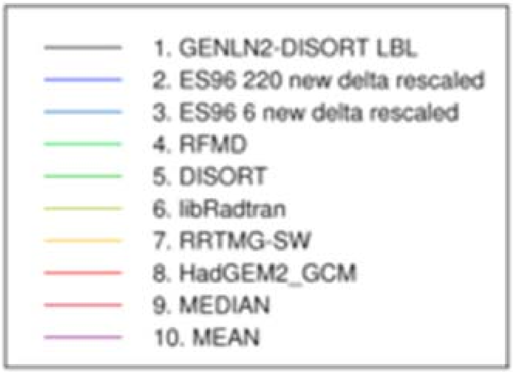


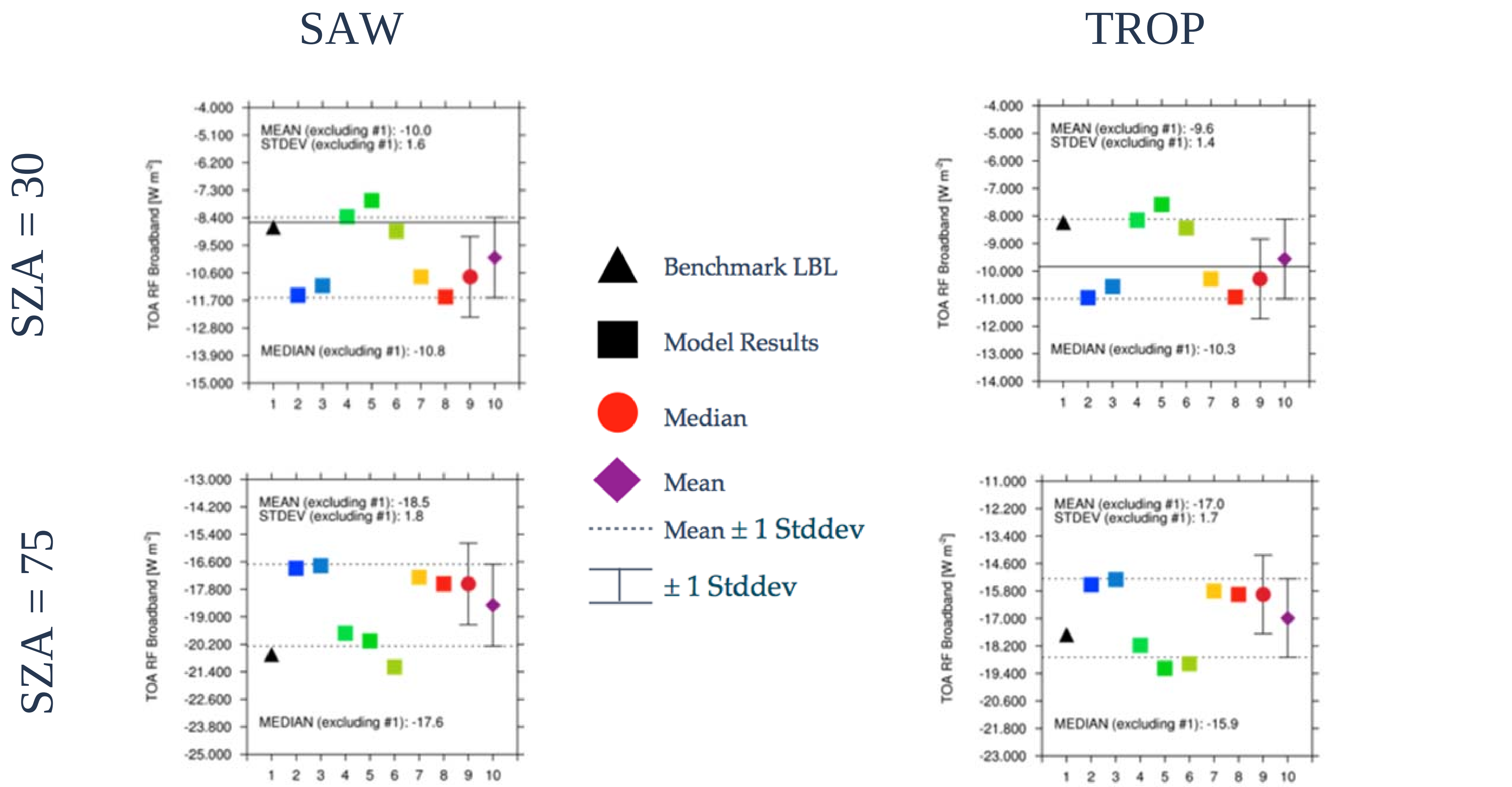
Case 2: Scattering Aerosol
Broadband Total Up at TOA





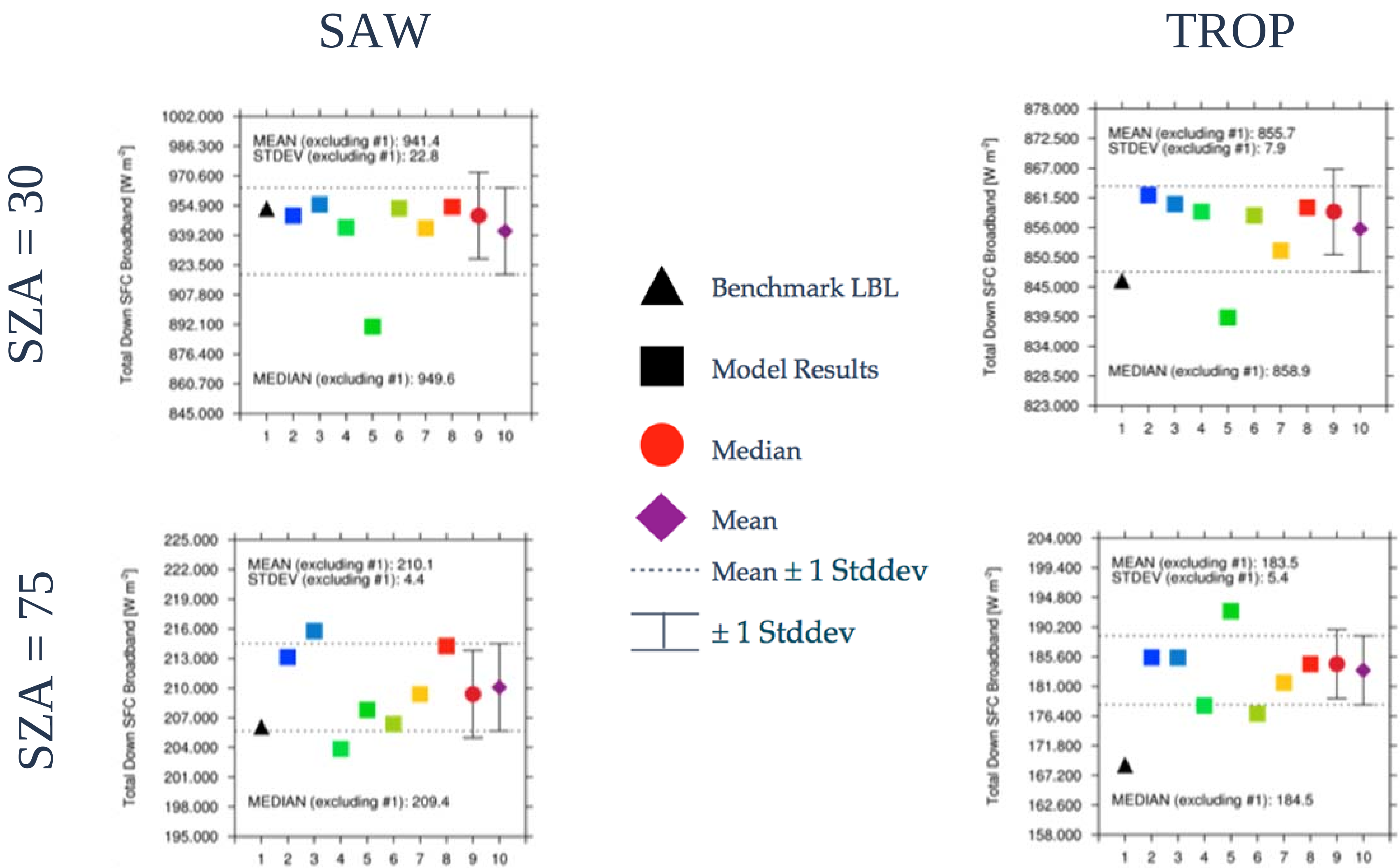
Case 2: Scattering Aerosol
Broadband TOA RF





Case 2: Absorbing Aerosol

Broadband Total Down at Surface

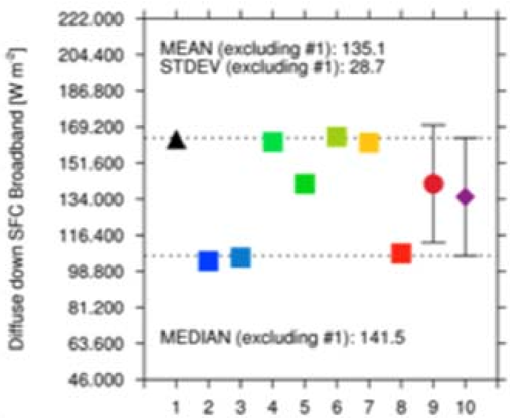


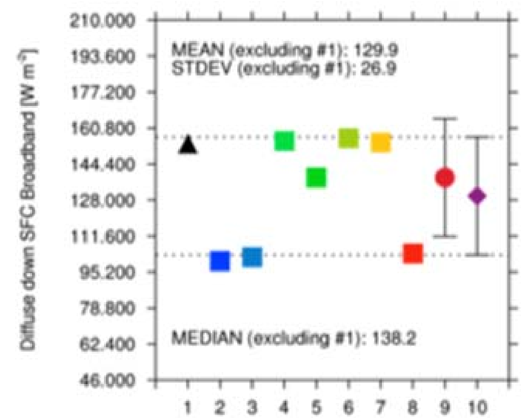
Case 2: Absorbing Aerosol
Broadband Diffuse Down at Surface

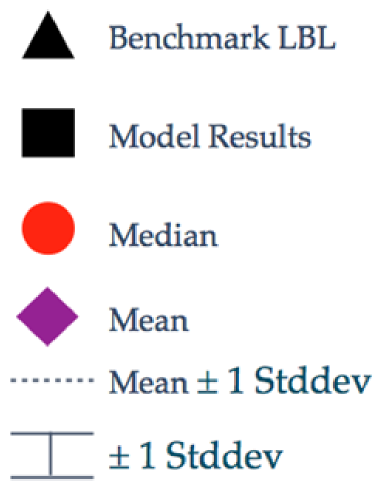
SAW

TROP

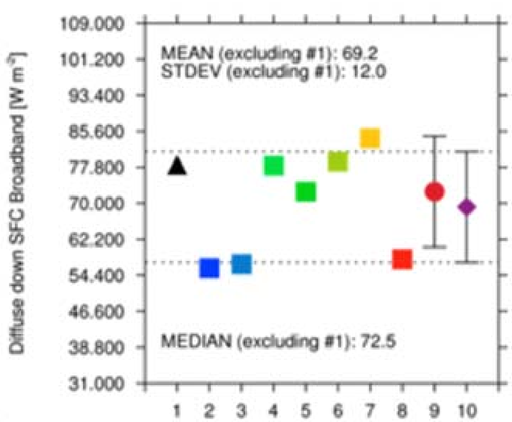
SZA = 30

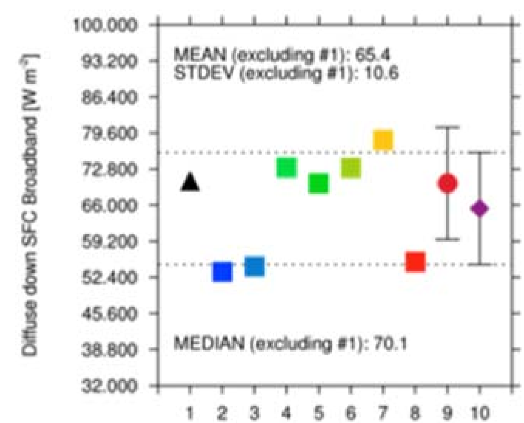




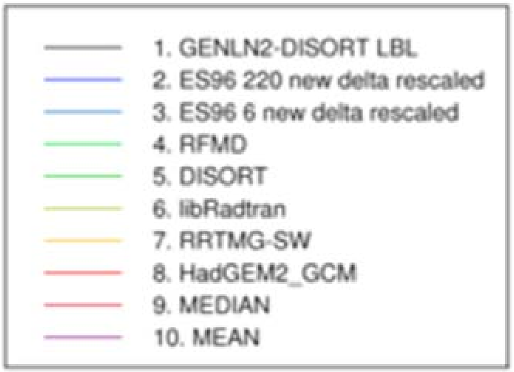


SZA = 75





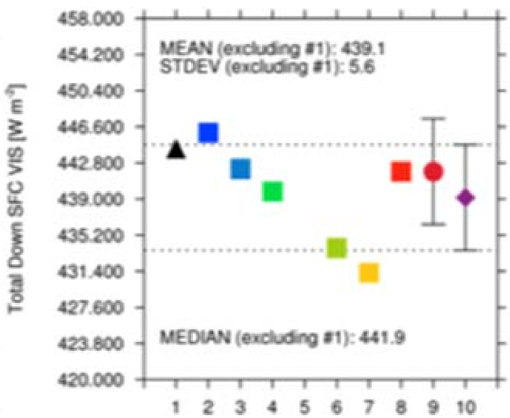
Case 2: Absorbing Aerosol
Visible Down at Surface

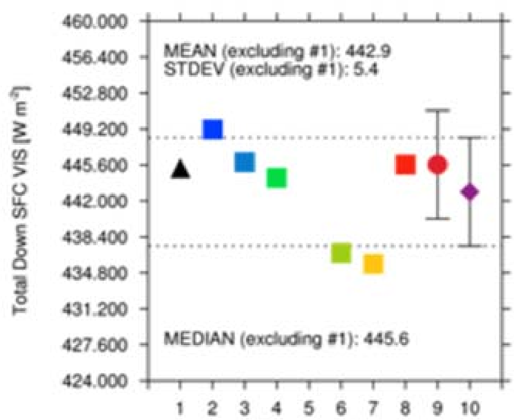


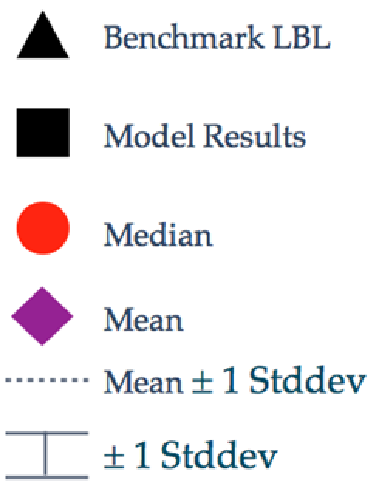
SAW

TROP

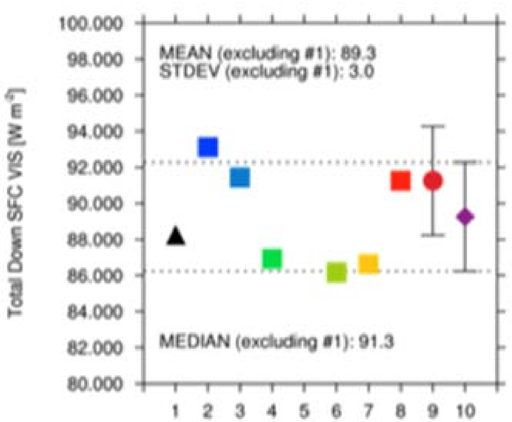
SZA = 30

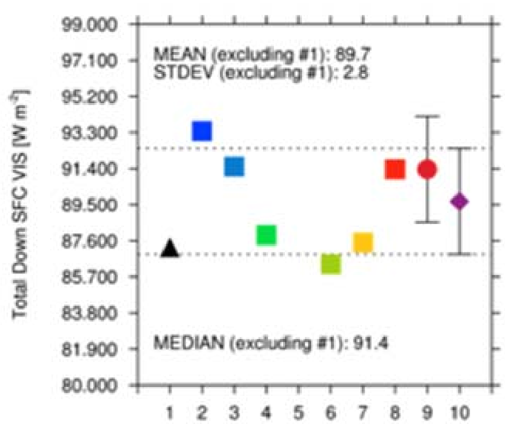




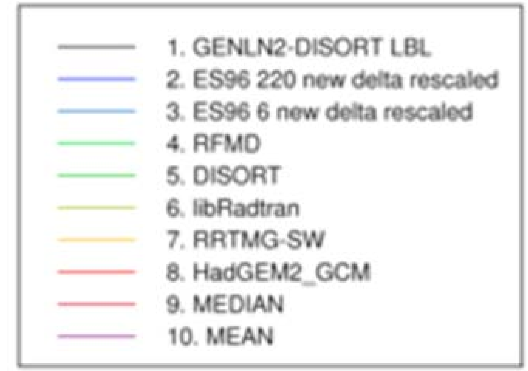


SZA = 75





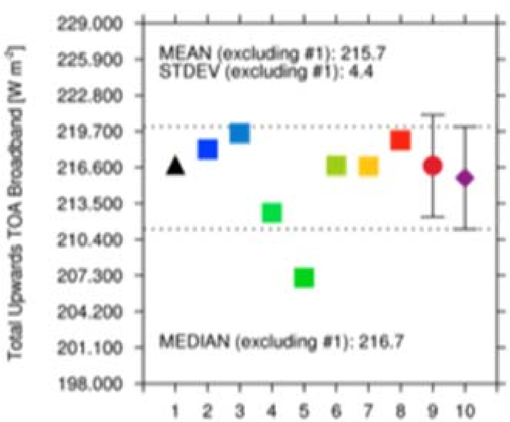
Case 2: Absorbing Aerosol
Broadband Total Up at TOA

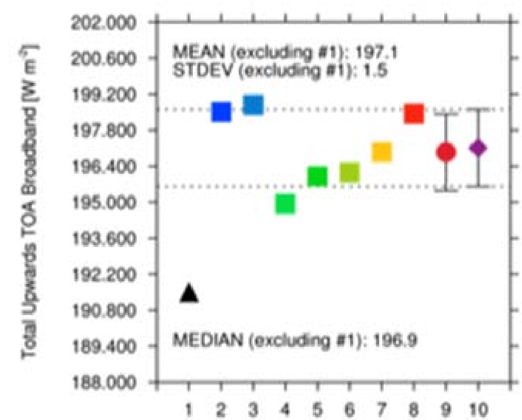


SAW

TROP

SZA = 30





Benchmark LBL

Model Results

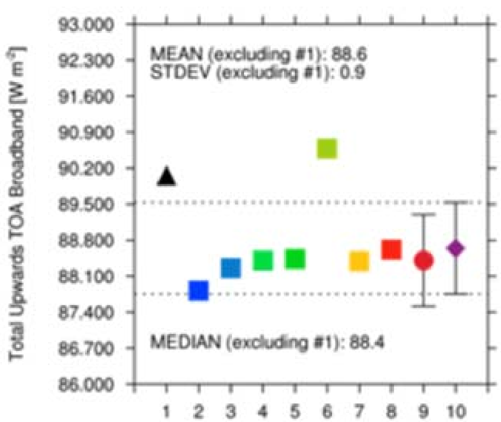
Median

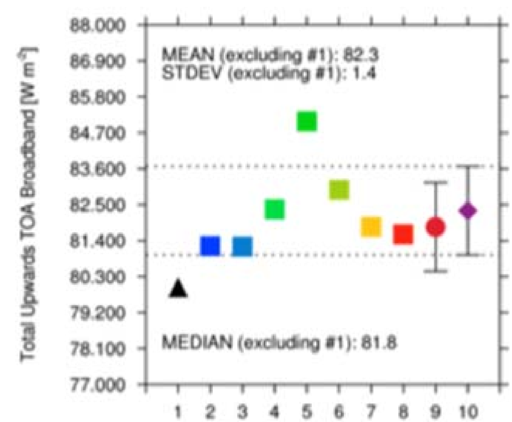
Mean

Mean ± 1 Stddev

± 1 Stddev

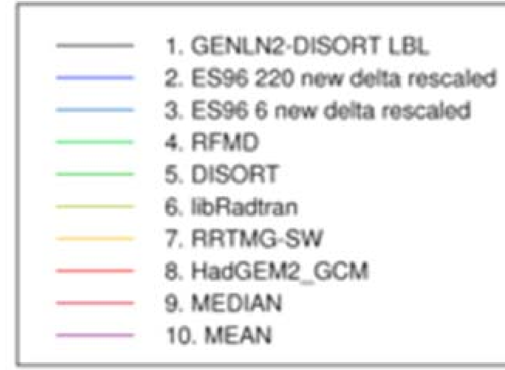
SZA = 75





Case 2: Absorbing Aerosol

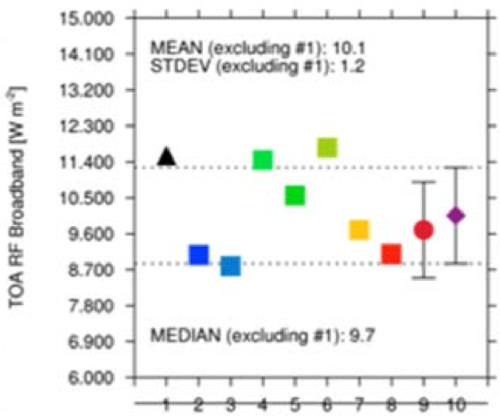
Broadband TOA RF

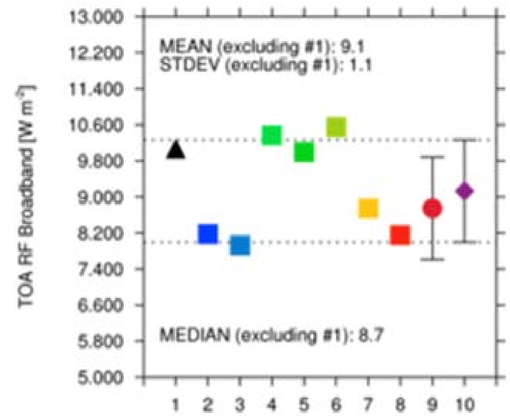


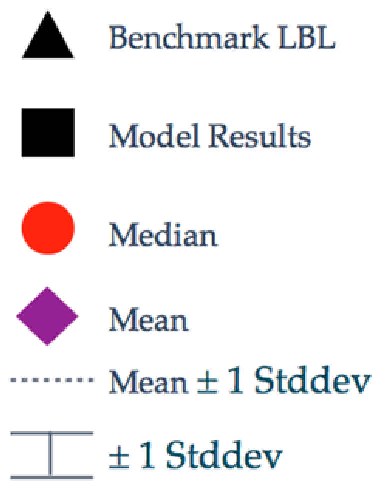
SAW

TROP

SZA = 30







SZA = 75