Direct Aerosol Forcing:
Calculation from Observables and Sensitivities to Inputs

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Objectives:

Determine the uncertainty in forcing as a consequence of uncertainties in the aerosol and surface parameters examined here: optical depth (τ), single scattering albedo (ω_0), asymmetry parameter *(g)*, and surface albedo (α_s).

- **how well can we determine the aerosol Direct Radiative Forcing (DRF)**
- **how well do we need to know DRF for accurate climate predictions**
- **where can improvements in measurement of aerosol and environmental variables be made to best increase accuracy in DRF and climate predictions**
- **do different radiative transfer models have a significant effect on our ability to determine aerosol DRF accurately**

Approach:

Calculate aerosol direct radiative forcing (DRF) based on the radiative forcing efficiency (ε) and a given aerosol optical depth (τ_a)

$$DRF = \varepsilon \tau_a$$

Determine the sensitivity of the DRF to the uncertainty in the property of interest (p_i) and it's measurement uncertainty.

$$S_i = \frac{\partial DRF}{\partial p_i} \Delta p_i$$

Measurement uncertainties

	Δ
τ (550 nm)	0.01
ω_0(550 nm)	0.03
g (550 nm)	0.05
α_s (UV)	0.05
α_s (IR)	0.05

Calculate the total uncertainty in DRF due to the significant properties

$$\Delta DRF = \sum{}^{\oplus} S_i = \sum{}^{\oplus} \frac{\partial DRF}{\partial p_i} \Delta p_i = \sqrt{\left(\frac{\partial DRF}{\partial \tau_a}\Delta\tau\right)^2 + \left(\frac{\partial DRF}{\partial \omega_0}\Delta\omega_0\right)^2 + \left(\frac{\partial DRF}{\partial g}\Delta g\right)^2 + \left(\frac{\partial DRF}{\partial \alpha_s}\Delta\alpha_{UV}\right)^2 + \left(\frac{\partial DRF}{\partial \alpha_s}\Delta\alpha_{IR}\right)^2}$$

Scenarios

S1: integrated over the shortwave and averaged over SZA for the Equinox

S2: at 550 nm averaged over SZA for the Equinox

S3: at 30º, 45º, and 70º SZA integrated over the shortwave for TWP, SGP, and NSA respectively

Base Cases

	TWP	SGP	NSA
τ_a (550 nm)	0.05	0.1	0.05
ω_0(550 nm)	0.97	0.95	0.95
g (550 nm)	0.8	0.6	0.7
α_s (UV)	0.05	0.1	0.9
α_s (IR)	0.05	0.4	0.8
$å_{sp}$	0.5	1.0	1.5
$å_{ap}$	1.0	1.0	1.0

Radiative Transfer Models

SBDART

DISORT

Streams = 8

Spectral range: 0.25 - 4.0 μm

Spectral Resolution: 0.005 μm

Solar spectrum: Gueymard

resolution 0.001 to 1.705 μm

0.005 to 4.0 μm

Aerosol vertical density falls off exponentially

Standard Atmospheric Profiles

RRTM

DISORT

Streams = 8

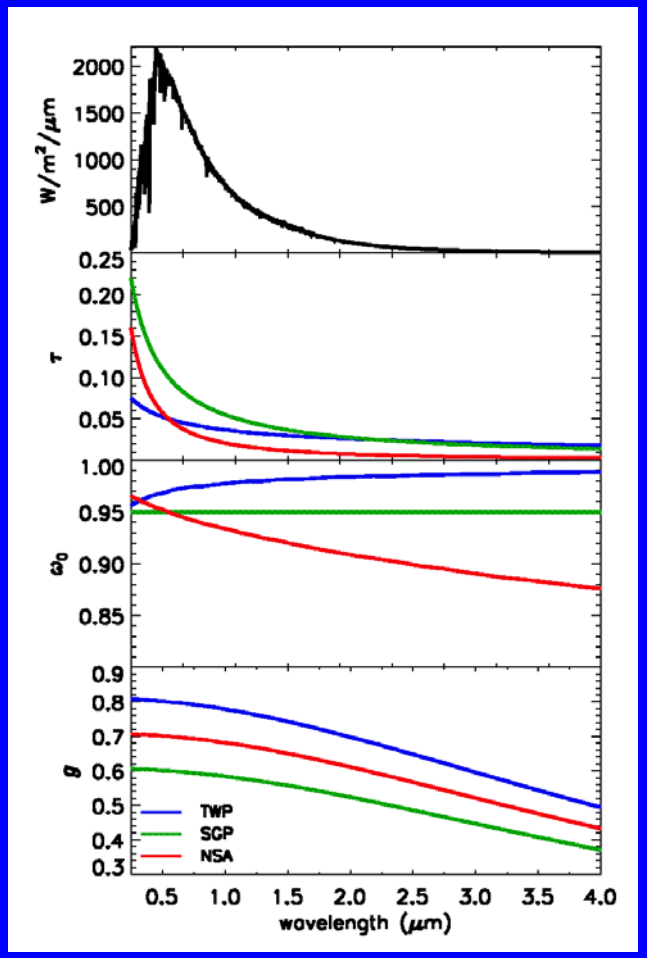
Spectral range: 0.20 - 12.2 μm

Spectral Resolution: 14 bands

Case	Atmosphere	H_2O ($g \cdot cm^{-2}$)	Total O_3 (atm·cm)	Below 10 km O_3 (atm·cm)
TWP	Tropical	4.117	0.253	0.0216
SGP	US62	1.418	0.349	0.0252
NSA	Sub-Arctic Winter	0.418	0.486	0.0340

Wavelength Dependence of Aerosol Properties

Calculated in the wavelength range from 0.25 to 4.0 μm shown for the three base cases

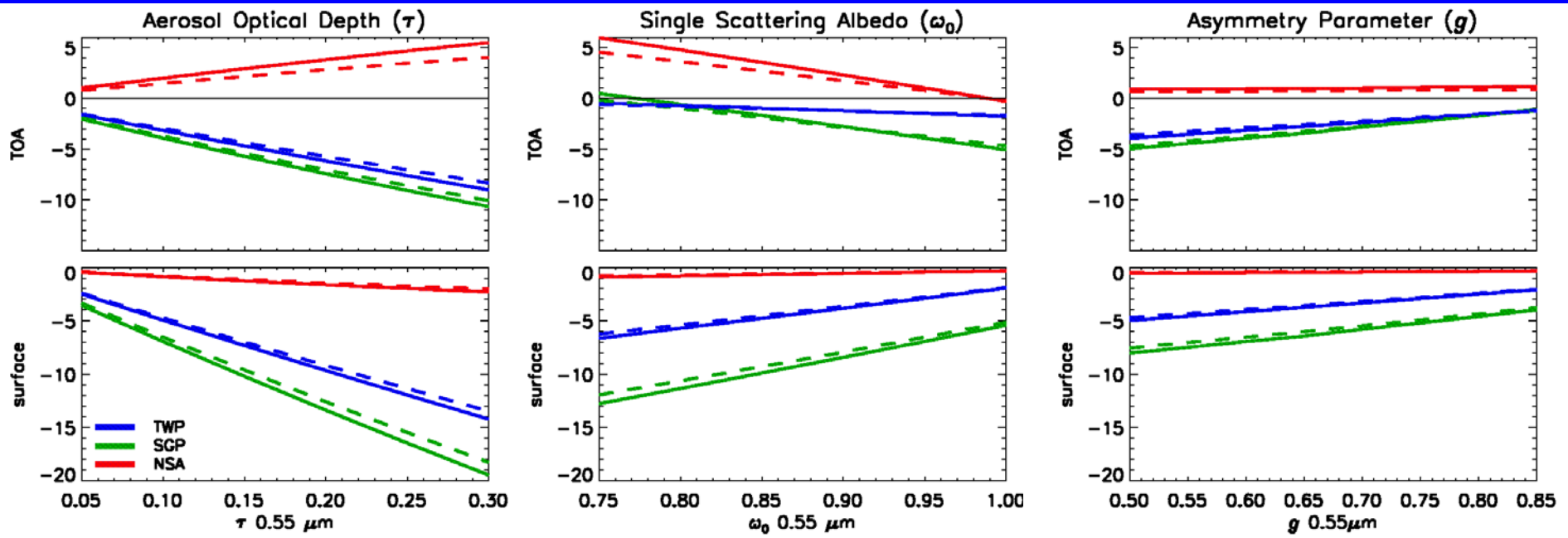


$$\tau_a(\lambda) = \tau_a\left[\omega_0\left(\frac{0.55}{\lambda}\right)^{å_{sp}} + (1-\omega_0)\left(\frac{0.55}{\lambda}\right)^{å_{ap}}\right]$$

$$\omega_0(\lambda) = \frac{\omega_0\left(\frac{0.55}{\lambda}\right)^{å_{sp}}}{\omega_0\left(\frac{0.55}{\lambda}\right)^{å_{sp}} + (1-\omega_0)\left(\frac{0.55}{\lambda}\right)^{å_{ap}}}$$

$$g_{(\lambda)} = g_{(0.55\mu m)}\frac{1+\left(\frac{0.55}{\lambda_g}\right)^2}{1+\left(\frac{\lambda}{\lambda_g}\right)^2}$$

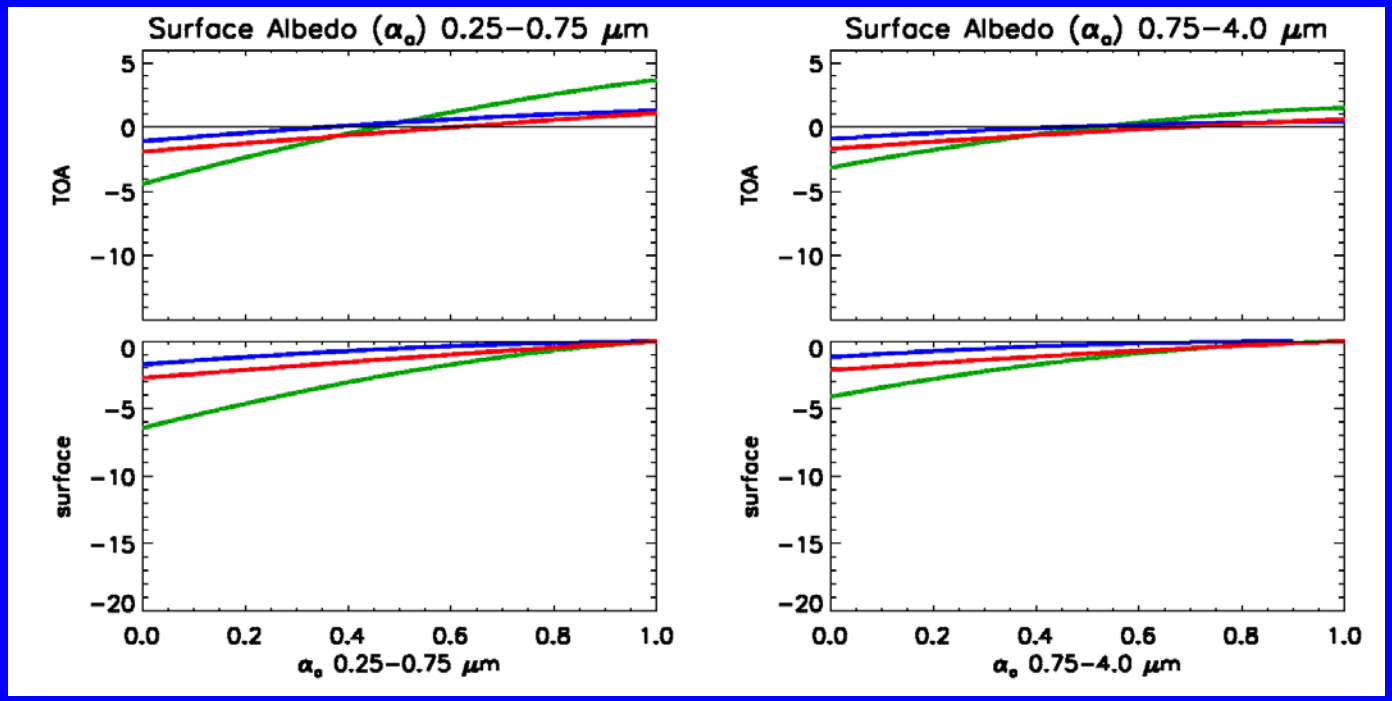
DRF: Integrated over wavelength, averaged over Equinox SZA



SBDART - solid lines

RRTM - dashed lines

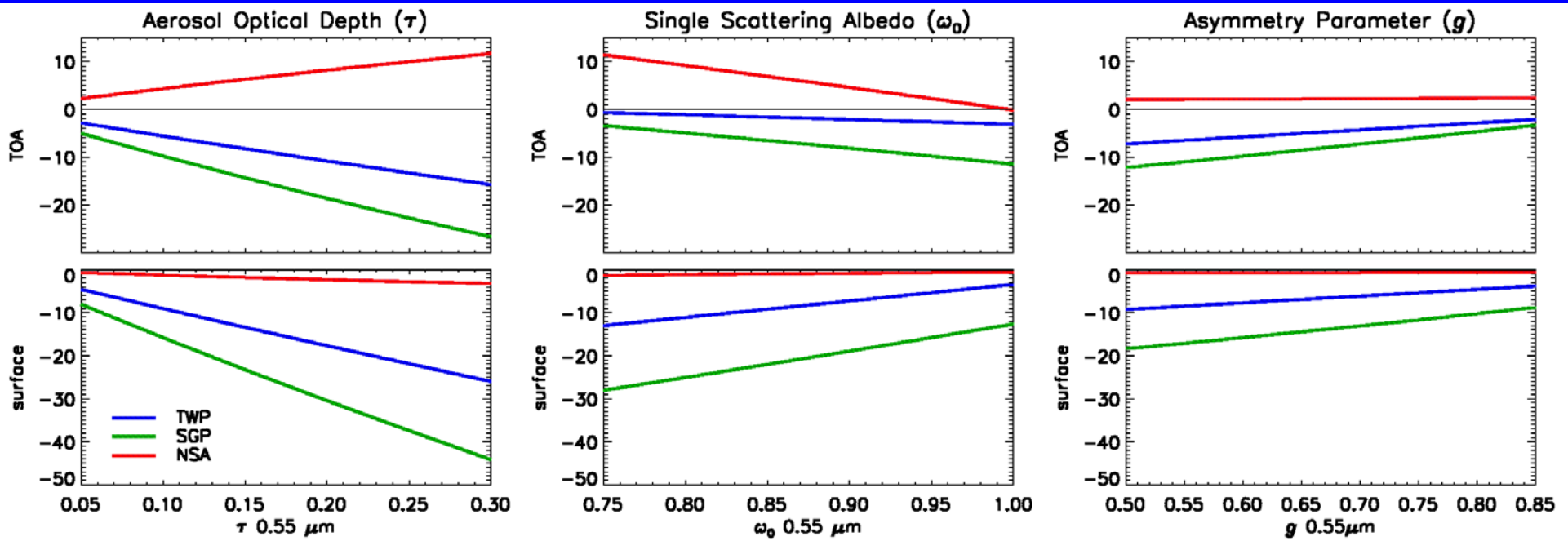
DRF: Integrated over wavelength, averaged over Equinox SZA



SBDART - solid lines

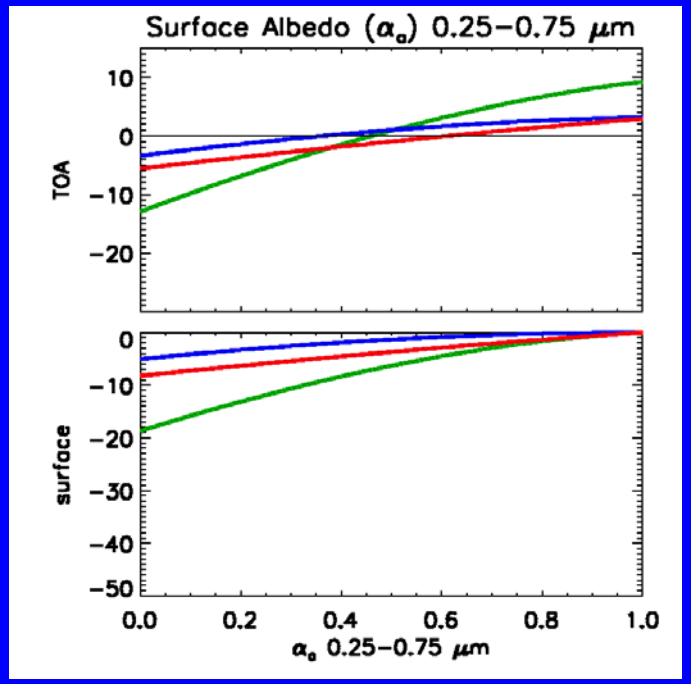
RRTM - dashed lines

DRF: 500 nm, averaged over Equinox SZA



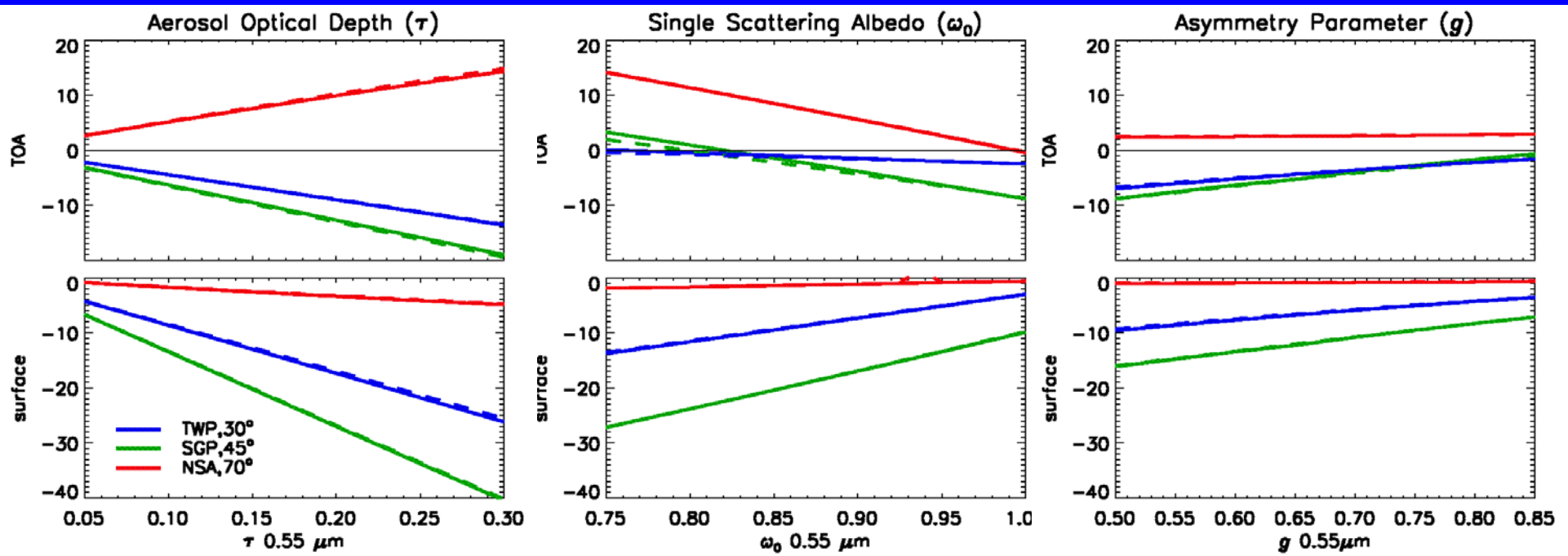
SBDART - solid lines

DRF: 500 nm, averaged over Equinox SZA



SBDART - solid lines

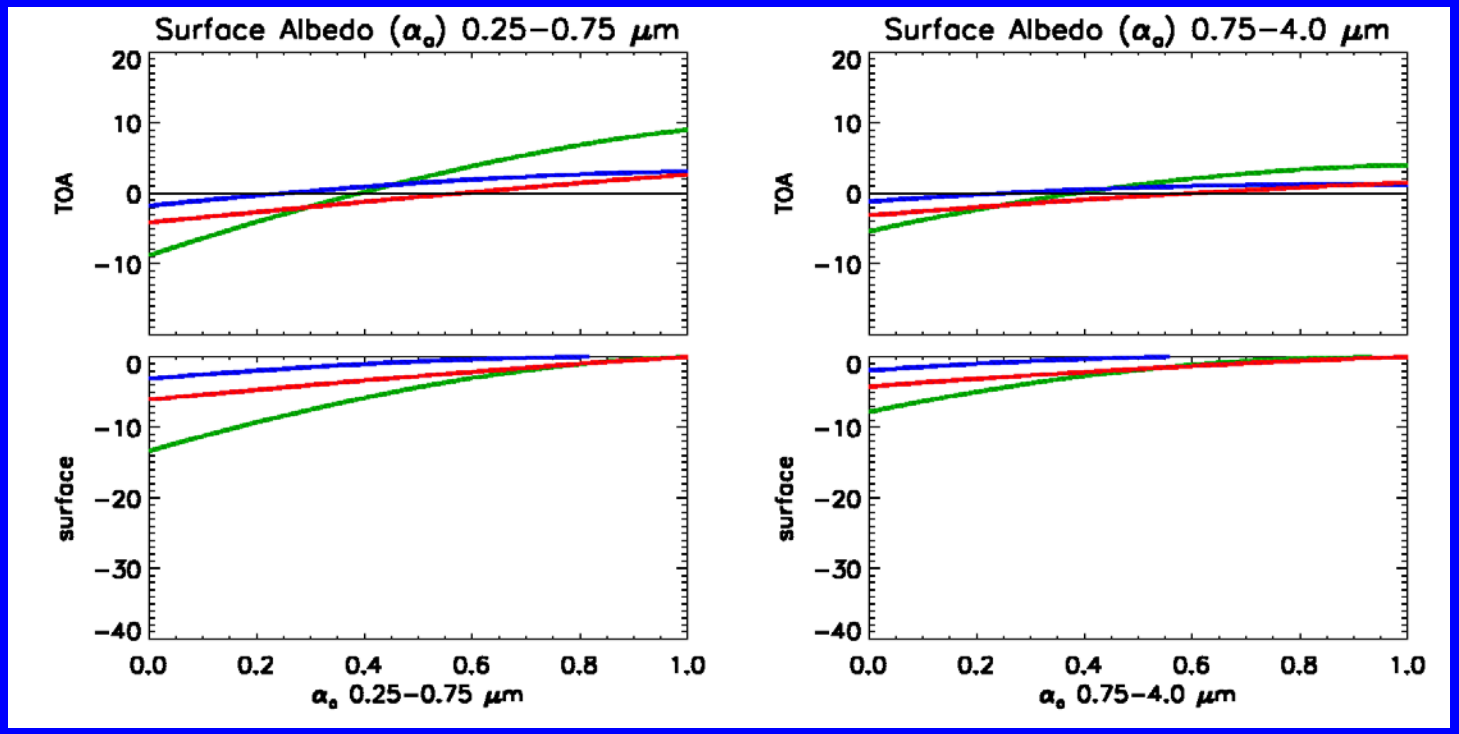
DRF: Integrated over wavelength, 30º, 45º, 70º SZA



SBDART - solid lines

RRTM - dashed lines

DRF: Integrated over wavelength, 30º, 45º, 70º SZA

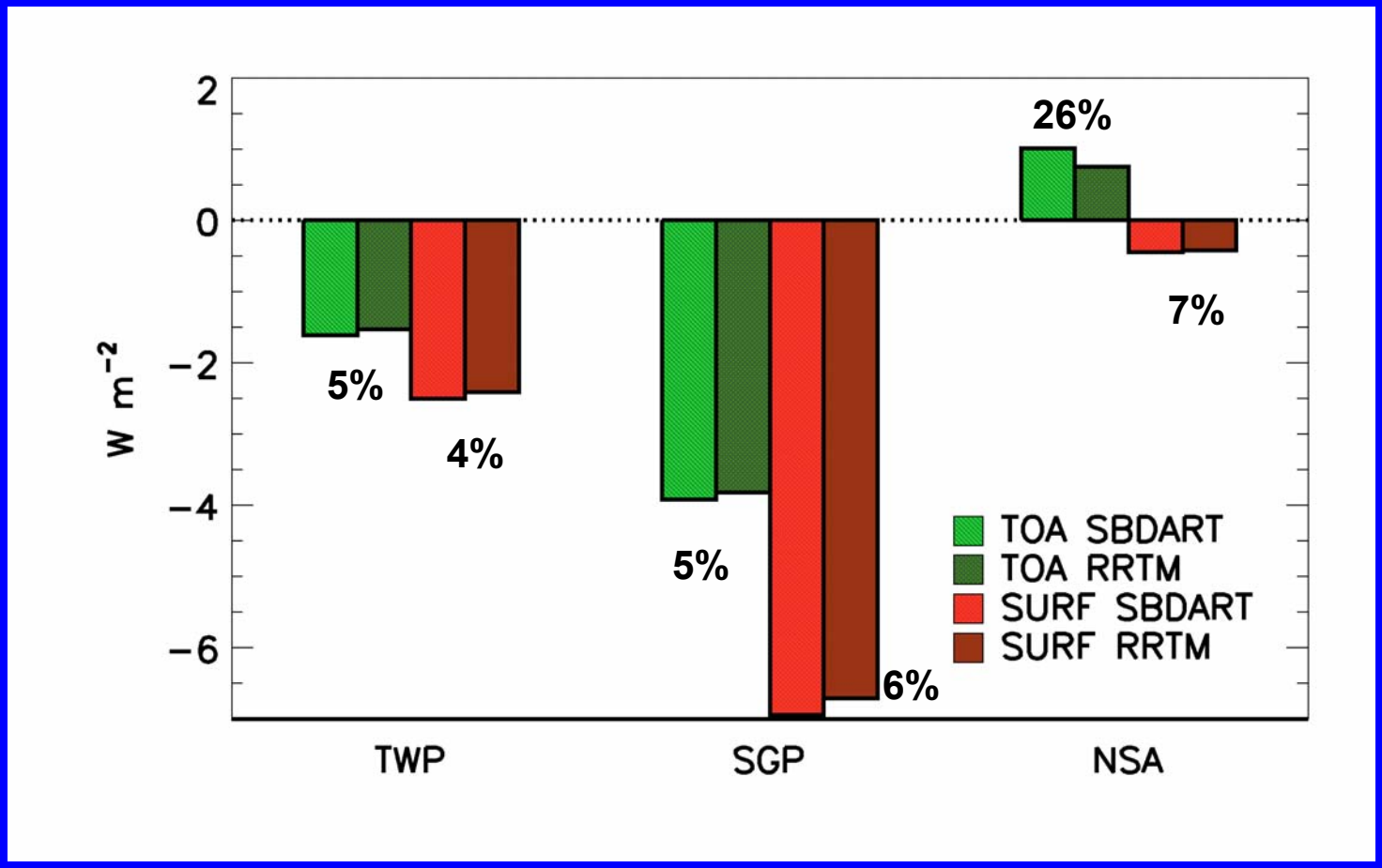


SBDART - solid lines

RRTM - dashed lines

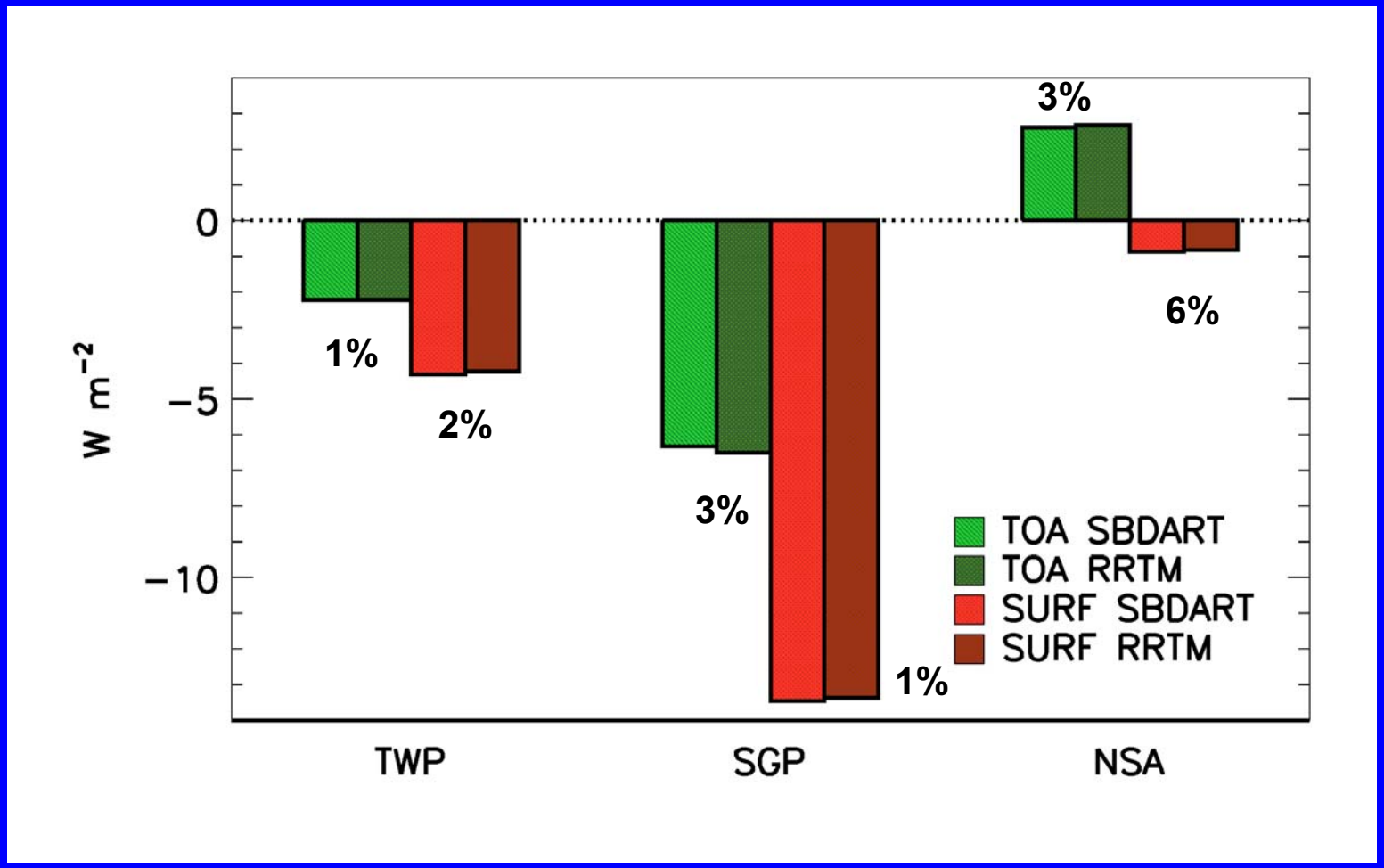
Scenario 1: Averaged over shortwave and SZA

DRF Model Comparison (Base Cases)



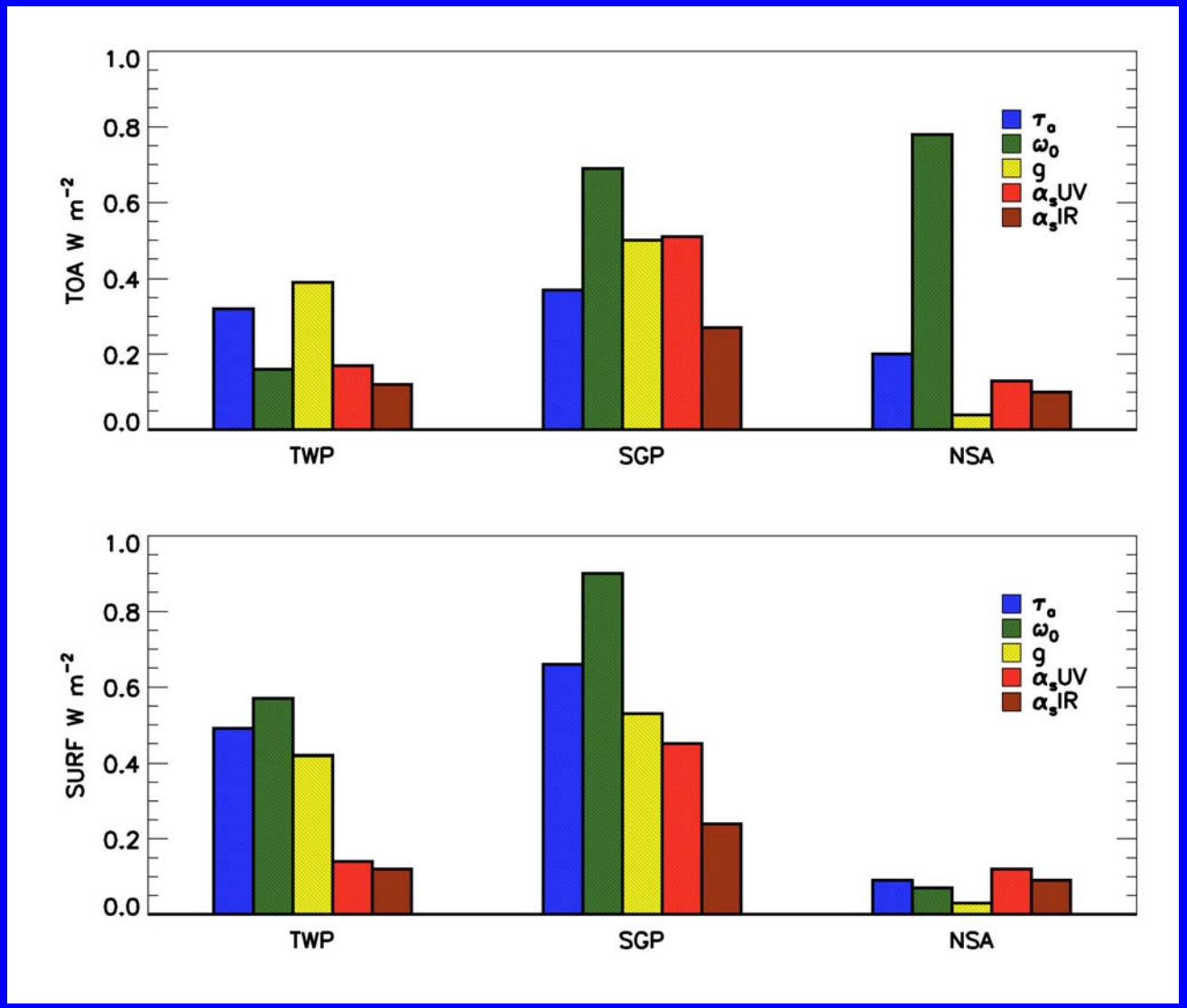
Scenario 3: Averaged over shortwave at 30°, 45 °, and 70 ° SZA

DRF Model Comparison (Base Cases)



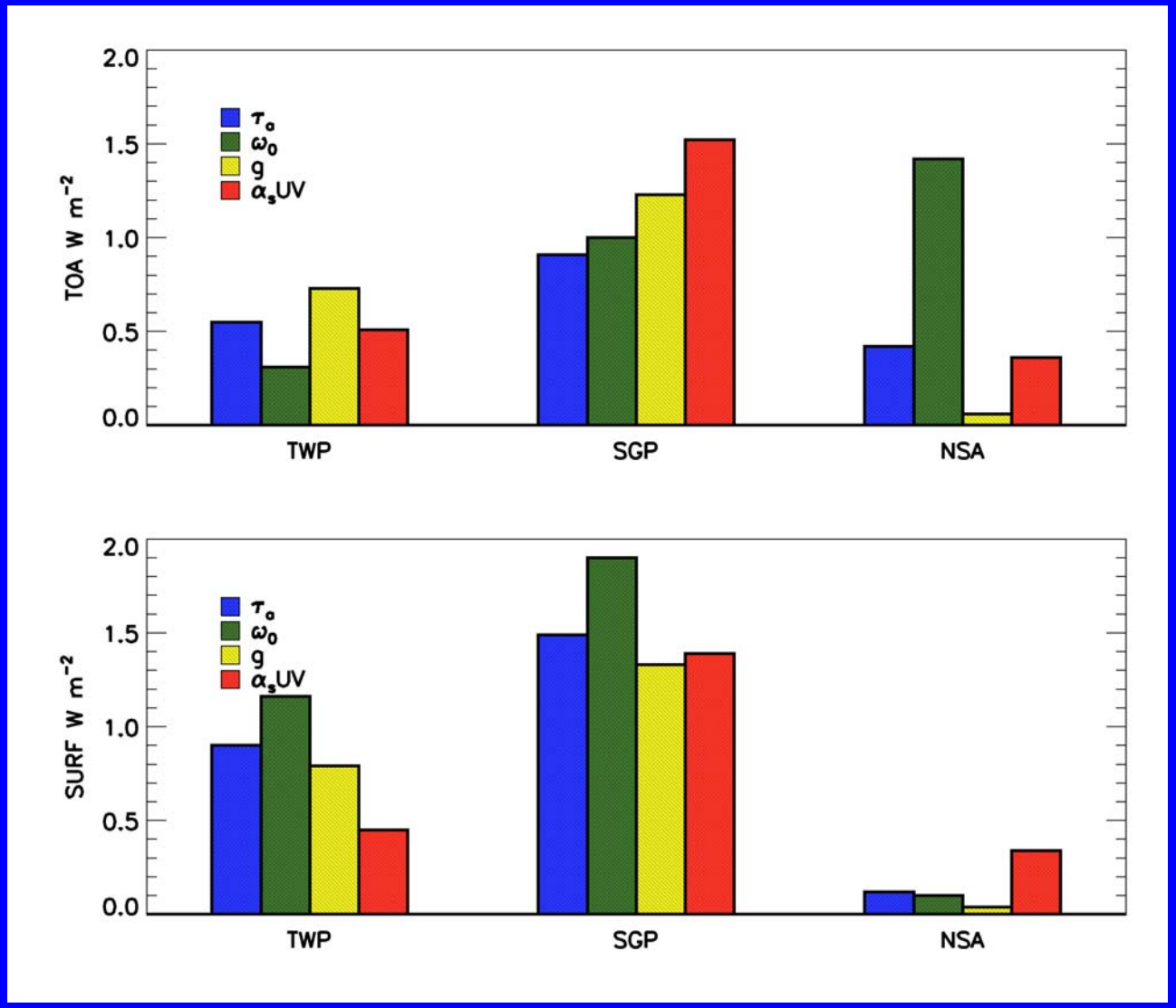
Scenario 1: Averaged over shortwave and SZA

Sensitivity Values



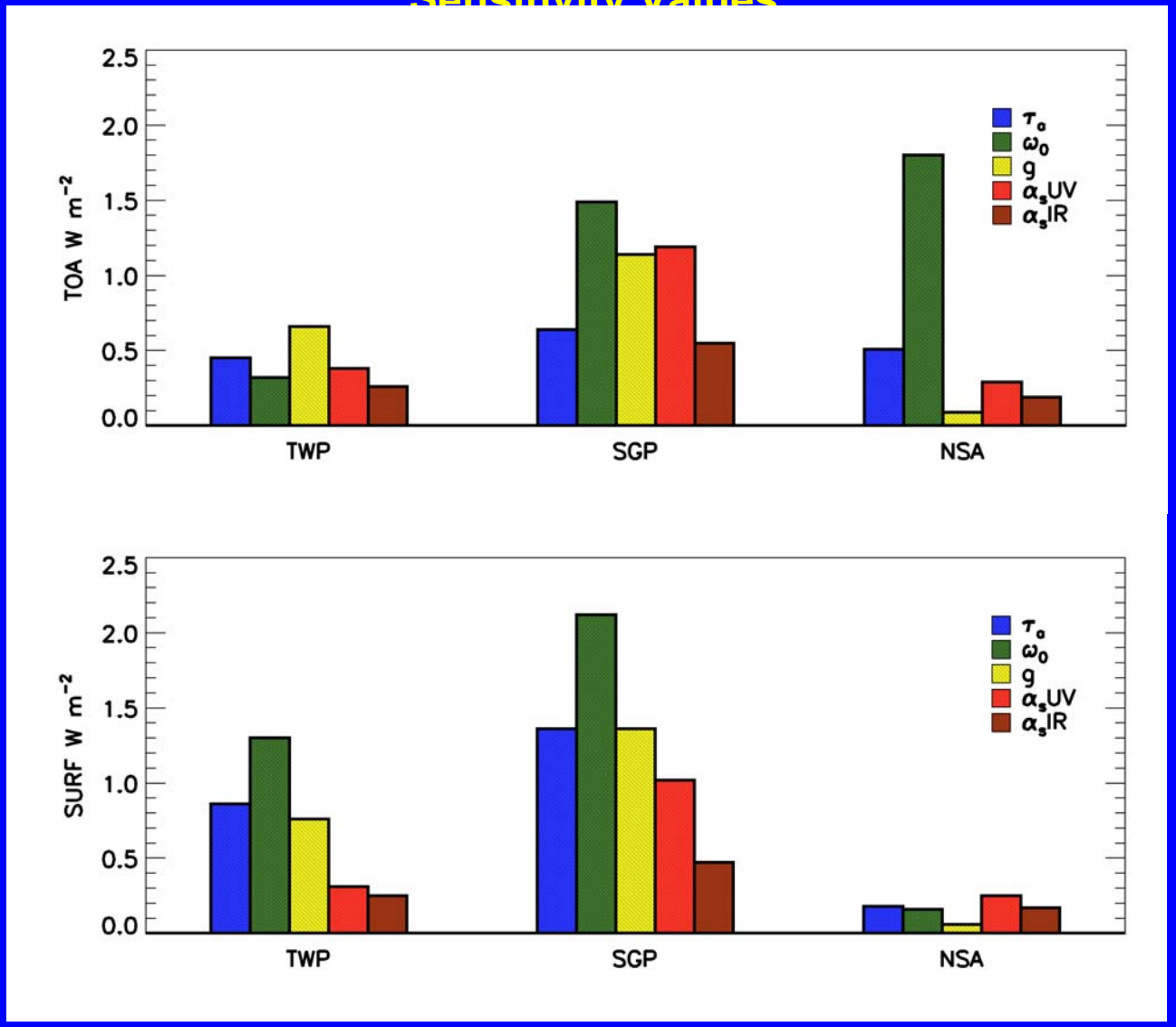
Scenario 2: 500 nm, Averaged over SZA

Sensitivity Values



Scenario 3: Averaged over shortwave, at 30º, 45º, 70º SZA

Sensitivity Values



Additional Slides

Scenario 1 Sensitivity

		TWP	SGP	NSA
	$W \cdot m^{-2}$			
$\Delta\tau_a$=0.01				
	TOA	0.02	0.04	0.01
	SURF	0.02	0.07	0.00
$\Delta\omega_0$=0.03				
	TOA	0.16	0.69	0.78
	SURF	0.65	1.61	0.37
Δg=0.05				
	TOA	0.39	0.50	0.04
	SURF	0.85	2.02	0.76
ΔαUV=0.05				
	TOA	0.17	0.51	0.13
	SURF	0.14	0.45	0.12
ΔαIR=0.05				
	TOA	0.12	0.27	0.10
	SURF	0.12	0.24	0.09

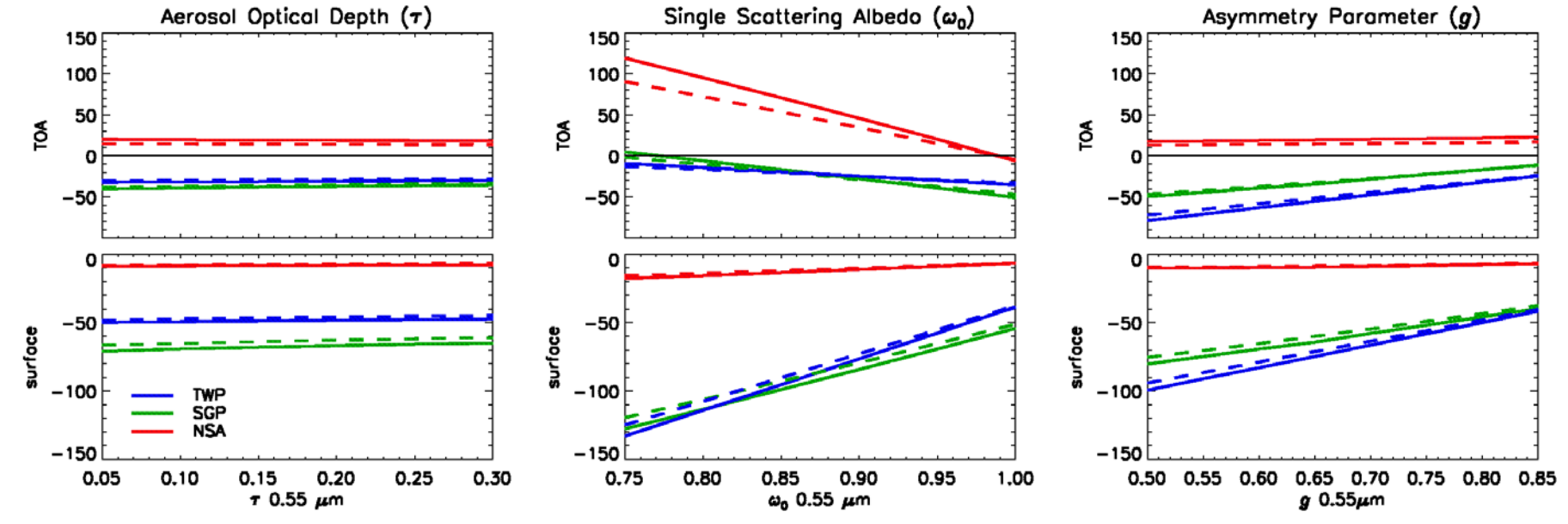
Scenario 2 Sensitivity

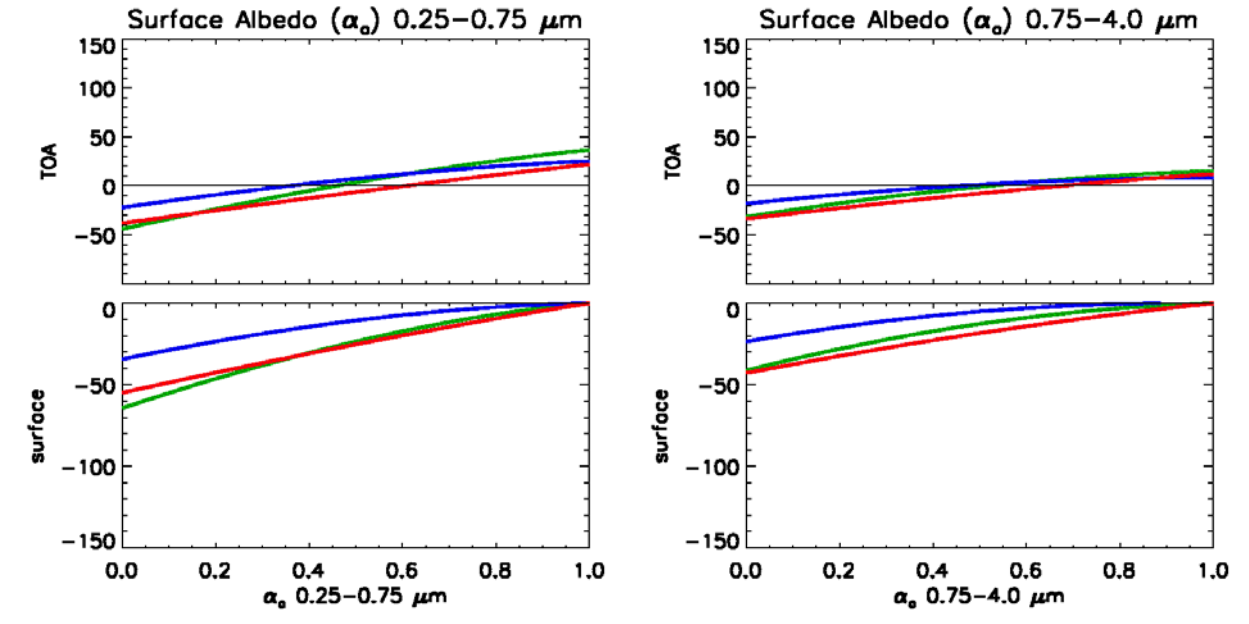
$W \cdot m^{-2} \cdot um^{-1}$	TWP	SGP	NSA
$\Delta\tau_a$=0.01			
TOA	0.03	0.10	0.02
SURF	0.05	0.16	0.01
$\Delta\omega_0$=0.03			
TOA	0.31	1.00	1.42
SURF	1.29	3.44	0.78
Δg=0.05			
TOA	0.73	1.23	0.06
SURF	1.63	4.29	1.49
ΔαUV=0.05			
TOA	0.51	1.52	7.27
SURF	0.45	1.39	6.81
ΔαIR=0.05			
TOA	------	------	------
SURF	------	------	------

Scenario 3 Sensitivity

$W \cdot m^{-2}$	TWP	SGP	NSA
$\Delta\tau_a$=0.01			
TOA	0.02	0.06	0.03
SURF	0.04	0.13	0.01
$\Delta\omega_0$=0.03			
TOA	0.32	1.49	1.80
SURF	1.53	3.86	0.91
Δg=0.05			
TOA	0.66	1.14	0.09
SURF	1.75	4.74	1.82
ΔαUV=0.05			
TOA	0.38	1.19	0.29
SURF	0.31	1.02	0.25
ΔαIR=0.05			
TOA	0.26	0.55	0.19
SURF	0.25	0.47	0.17

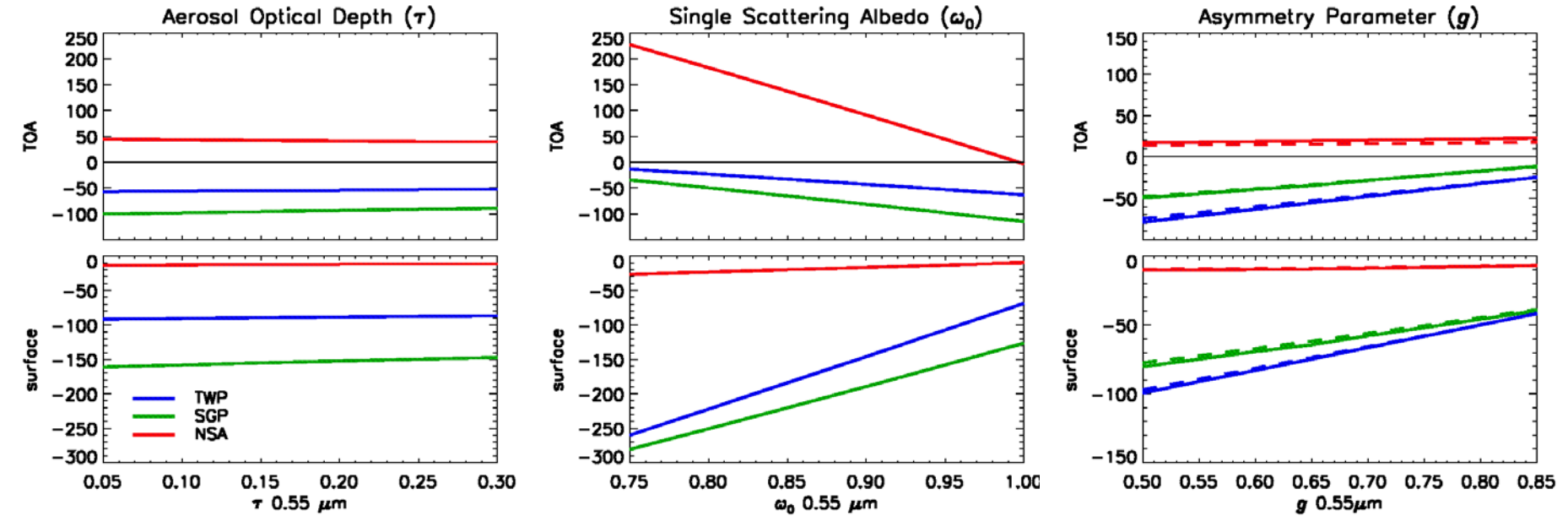
RFE: Integrated over wavelength, averaged over Equinox SZA

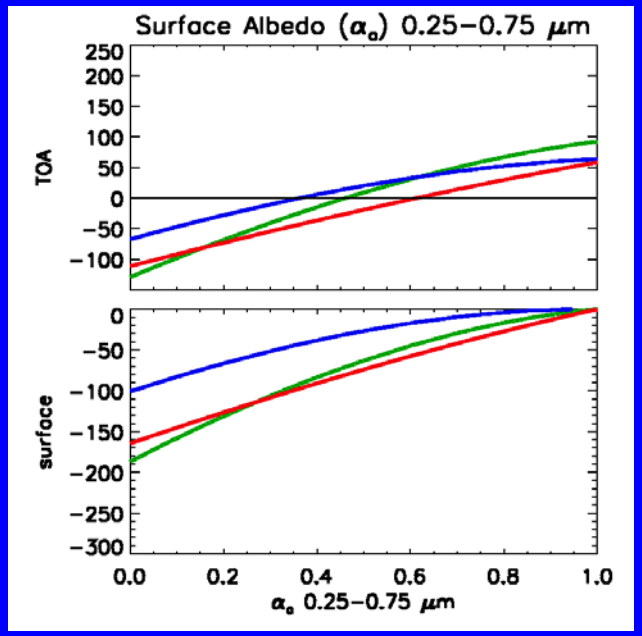




	TWP	SGP	NSA
Δτ=0.01			
TOA	0.32	0.39	0.20
SURF	0.50	0.69	0.09
$\Delta\omega_0$=0.03			
TOA	3.23	6.86	15.51
SURF	12.98	16.10	7.41
Δg=0.05			
TOA	7.74	5.00	0.84
SURF	16.90	20.15	15.24
ΔαUV=0.05			
TOA	3.31	5.31	2.70
SURF	2.80	4.51	2.37
ΔαIR=0.05			
TOA	2.42	2.66	1.96
SURF	2.35	2.41	1.77

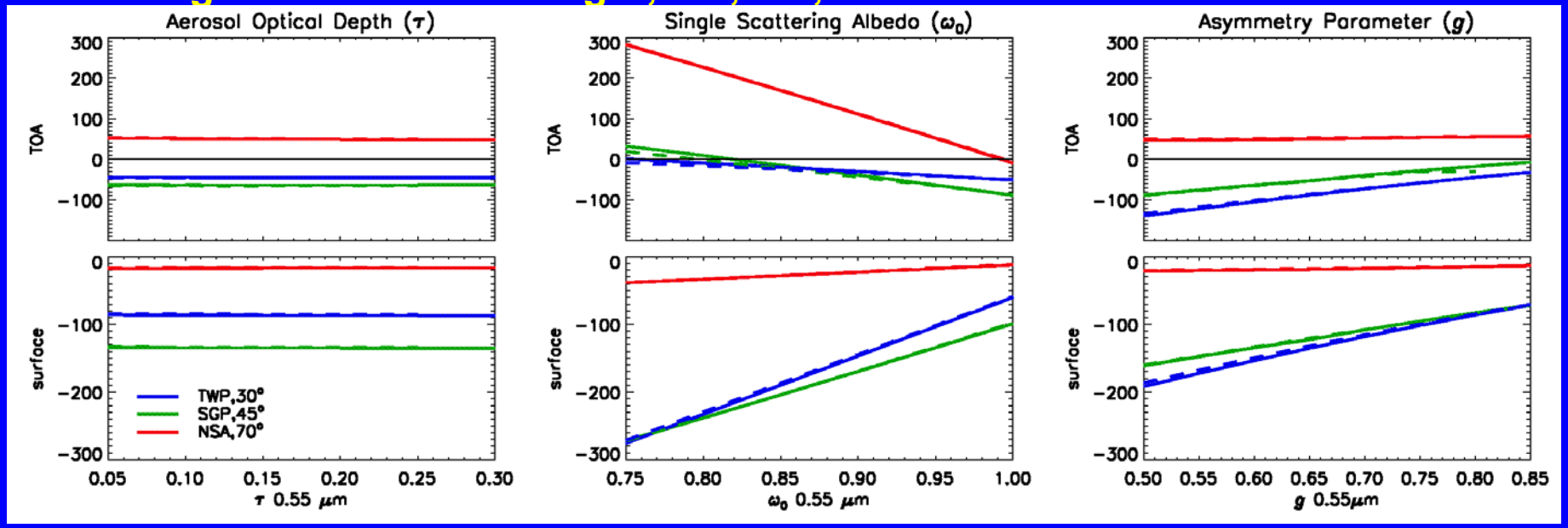
RFE: 500 nm, averaged over Equinox SZA

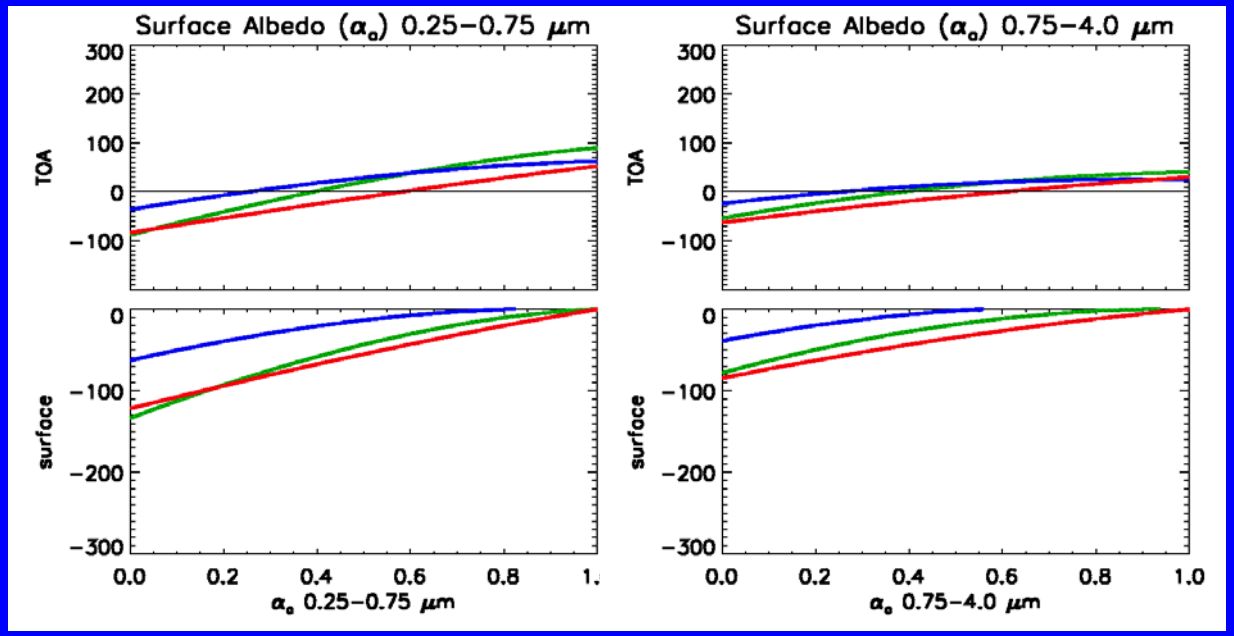




	TWP	SGP	NSA
Δτ=0.01			
TOA	0.57	0.98	0.44
SURF	0.92	1.58	0.13
$\Delta\omega_0$=0.03			
TOA	6.14	10.04	28.38
SURF	25.86	34.43	15.54
Δ*g*=0.05			
TOA	14.69	12.33	1.17
SURF	32.67	42.85	29.74
ΔαUV=0.05			
TOA	10.19	15.20	0.36
SURF	8.99	13.90	0.34
ΔαIR=0.05			
TOA	------	------	------
SURF	------	------	------

RFE: Integrated over wavelength, 30º, 45º, 70º SZA





	TWP	SGP	NSA
Δτ=0.01			
TOA	0.44	0.63	0.52
SURF	0.86	1.35	0.18
$\Delta\omega_0$=0.03			
TOA	6.41	14.95	36.00
SURF	30.65	38.65	18.20
Δ*g*=0.05			
TOA	13.25	11.35	1.70
SURF	35.04	47.45	36.30
ΔαUV=0.05			
TOA	7.52	11.89	5.90
SURF	6.2	10.16	5.00
ΔαIR=0.05			
TOA	5.26	5.50	3.80
SURF	4.99	4.70	3.30

Model Intercomparisons: SBDART and RRTM

Difference between SBDART and RRTM base case runs for DRF and RFE and sensitivity values in Wm-2 and (% difference) (SBDART-RRTM/SBDART) for scenario 1.

	TWP	SGP	NSA
DRF			
τ, ω_0, g			
TOA	-0.03 (2%)	-0.10 (3%)	0.20 (20%)
SURF	-0.01 (0%)	-0.23 (3%)	-0.03 (6%)
RFE			
τ, ω_0, g			
TOA	-0.57 (2%)	-1.00 (3%)	4.12 (20%)
SURF	-0.10 (0%)	-2.24 (3%)	-0.46 (5%)
DRF Sensitivity			
$\Delta\tau = 0.01$			
TOA	0.0 (0%)	0.0 (0%)	0.0 (0%)
SURF	0.0 (0%)	0.0 (0%)	0.0 (0%)
$\Delta\omega_0 = 0.03$			
TOA	-0.02 (13%)	-0.11 (16%)	-0.16 (21%)
SURF	0.04 (7%)	0.04 (4%)	0.01 (14%)
$\Delta g = 0.05$			
TOA	0.03 (8%)	0.0 (0%)	0.01 (25%)
SURF	0.02 (5%)	0.0 (0%)	0.01 (33%)

Difference between SBDART and RRTM base case runs for DRF and RFE and sensitivity values in Wm-2 and (% difference) (SBDART-RRTM/SBDART) for scenario 3.

	TWP	SGP	NSA
DRF			
τ, ω_0, g			
TOA	0.11 (5%)	0.36 (6%)	-0.17 (7%)
SURF	0.10 (2%)	0.26 (2%)	-0.03 (4%)
RFE			
τ, ω_0, g			
TOA	2.25 (5%)	3.61 (6%)	-3.43 (7%)
SURF	1.86 (2%)	2.62 (2%)	-0.63 (4%)
DRF Sensitivity			
$\Delta\tau = 0.01$			
TOA	0.0 (0%)	0.01 (17%)	0.0 (0%)
SURF	0.0 (0%)	0.01 (8%)	0.0 (0%)
$\Delta\omega_0 = 0.03$			
TOA	-0.06 (19%)	-0.14 (9%)	0.05 (3%)
SURF	-0.02 (2%)	-0.08 (4%)	-0.02 (13%)
$\Delta g = 0.05$			
TOA	-0.06 (19%)	-0.14 (9%)	0.05 (3%)
SURF	-0.02 (2%)	-0.08 (4%)	-0.02 (13%)

Range of calculations

	range
τ (550 nm)	0.0-0.03
ω_0(550 nm)	0.75-1.00
g (550 nm)	0.50-0.75
α_s (UV)	0.0-1.0
α_s (IR)	0.0-1.0