Radiation Budgets of Deep Convective Systems at the ARM TWP and SGP sites

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Three objectives

1) Studying the similarity and difference of the radiation budgets of Deep Convective Systems (DCS) between the tropics (TWP) and the middle latitudes (SGP).

2) Comparing the observations with the radiative transfer model calculations, especially we want to know under what conditions (i) they agree and (ii) they do not agree

3) What can we contribute to climate models from this study?

Data and methods

Surface data

Downwelling [SW_{sfc}^-] and upwelling [SW_{sfc}^-] SW fluxes measured by PSPs
Cloud-base and -top heights derived from ARM lidar/radar measurements.
Surface data were averaged over a 2-hour period centered at the time of the *Terra* and *Aqua* overpass ARM TWP and SGP sites

Satellite data

CERES SSF cloud-radiation products:
Reflected [SW_{toa}^-] SW fluxes measured by CERES broadband scanner
Downwelling [SW_{toa}^-] is calculated by $1365 \times \mu_0/ES^2$
Effective cloud height/temp, diameter of ice particle, cloud optical depth.
Satellite data were averaged in a $1^o \times 1^o$ box centered on the ARM surface sites.

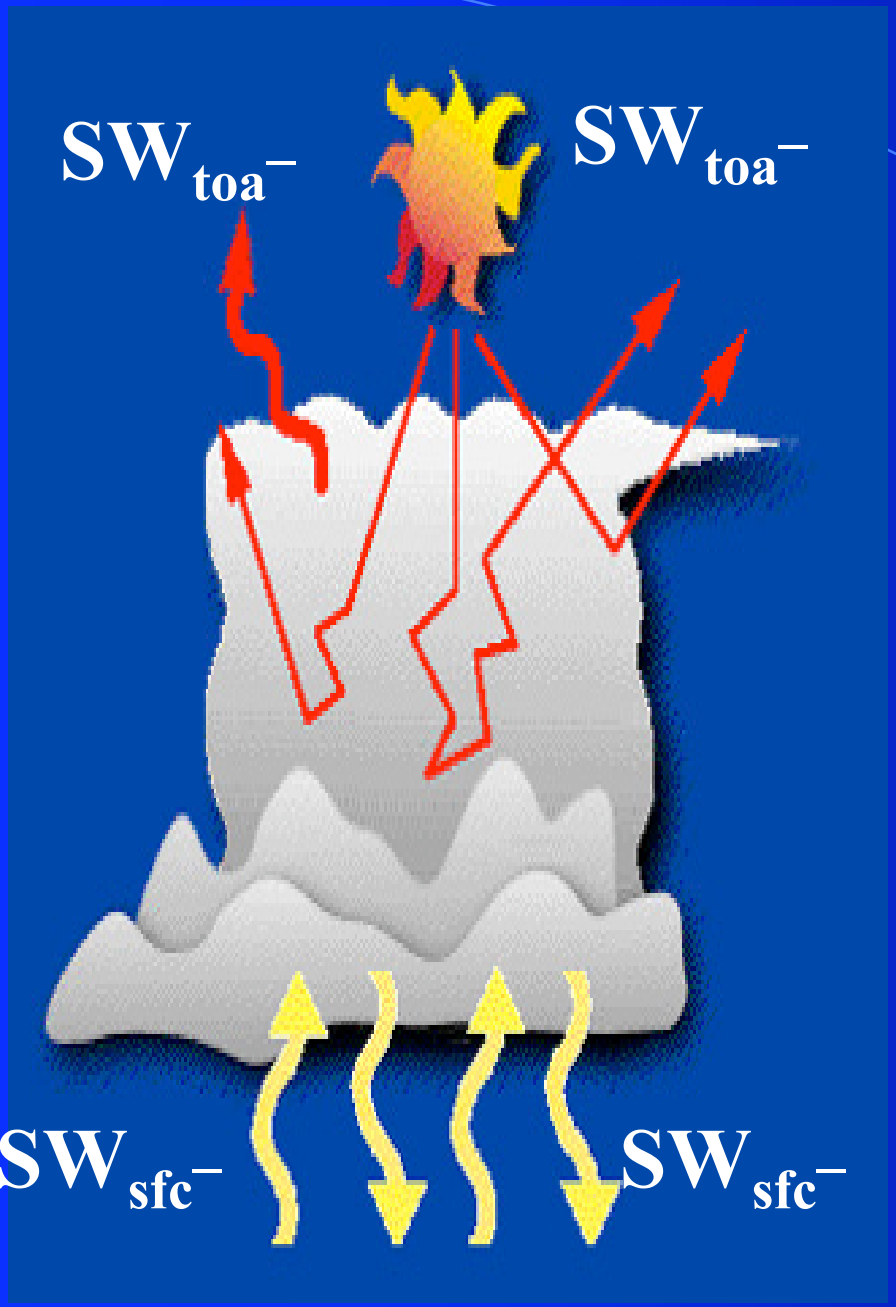
Earth-Atmosphere system: R_{toa}, A_{sfc}, A_{col}

TOA Albedo: $R_{toa} = SW_{toa}^- / SW_{toa}^-$

Surface absorption: $A_{sfc} = [SW_{sfc}^- - SW_{sfc}^-] / SW_{toa}^-$

Atmospheric Absorp: $A_{col} = 1 - R_{toa} - A_{sfc}$

Atmospheric transmittance or surface transmission: $T_{sfc} = SW_{sfc}^- / SW_{toa}^-$
$= A_{sfc}$ when $R_{sfc} = 0$



In this study, we are interested in

- How much SW is reflected back to space?

  $R_{toa}=SW_{toa}^-/SW_{toa}^-$

- How much SW is absorbed at the earth surface?

  $A_{sfc}=(SW_{sfc}^- - SW_{sfc}^-)/SW_{toa}^-$

- How much SW is absorbed by atmospheric column or DCS?

  $A_{col}=1 - R_{toa} - A_{sfc}$

Samples and Time periods

Criteria for selecting cases:

1) _>15, 2) A_{sfc}<0.3, and 3) Cloud-top height > 5 km.

⎝ARM TWP (Manus:2.1° S, 147.4° E; Nauru:0.5° S, 166.9° E)

132 Terra cases from March 2000 to December 2004

97 Aqua cases from July 2002 to December 2004

A total of 229 cases at the TWP sites (It was 10 cases presented in last CERES STM)

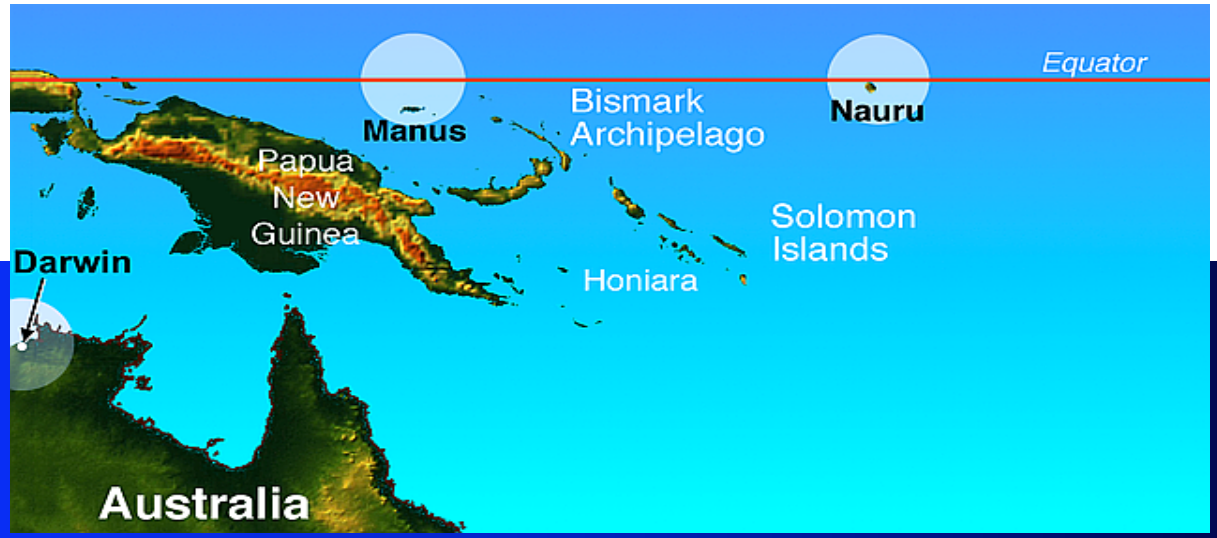
⎝ARM SGP (36.6° N, 97.5° W)

116 Terra cases from March 2000 to July 2004.

66 Aqua cases from July 2002 to July 2004.

A total of 182 cases at the SGP site (It was 30 cases presented in last CERES STM)

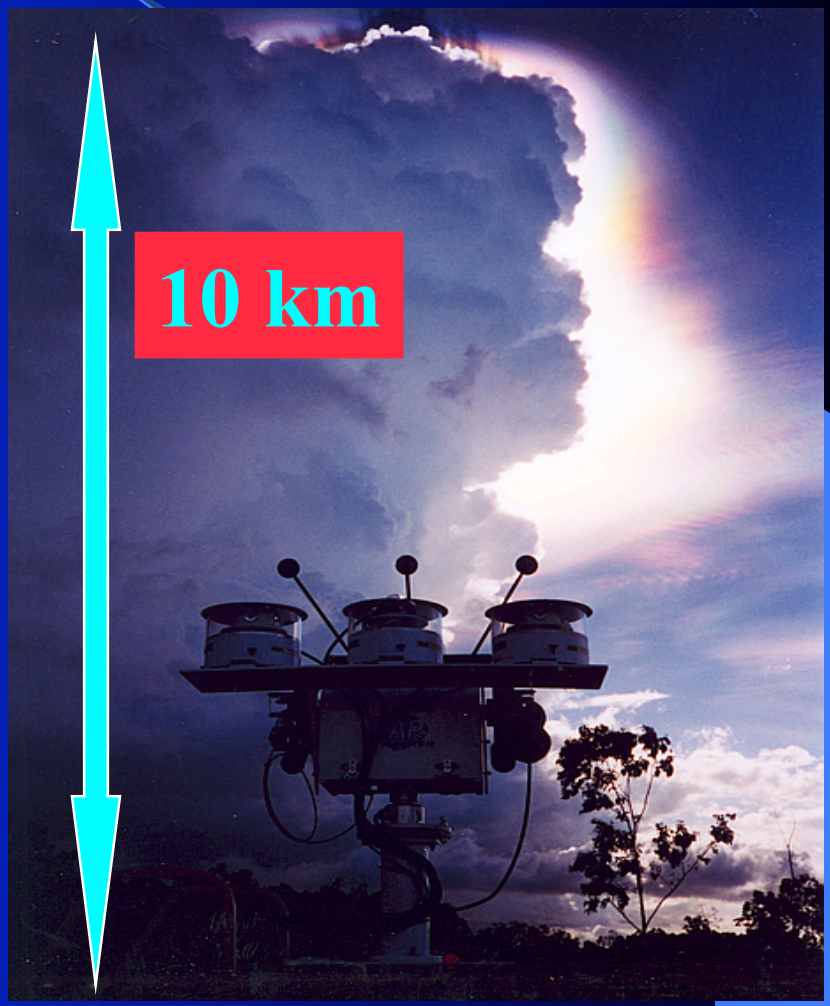
ARM Cloud and Radiation Testbed Sites

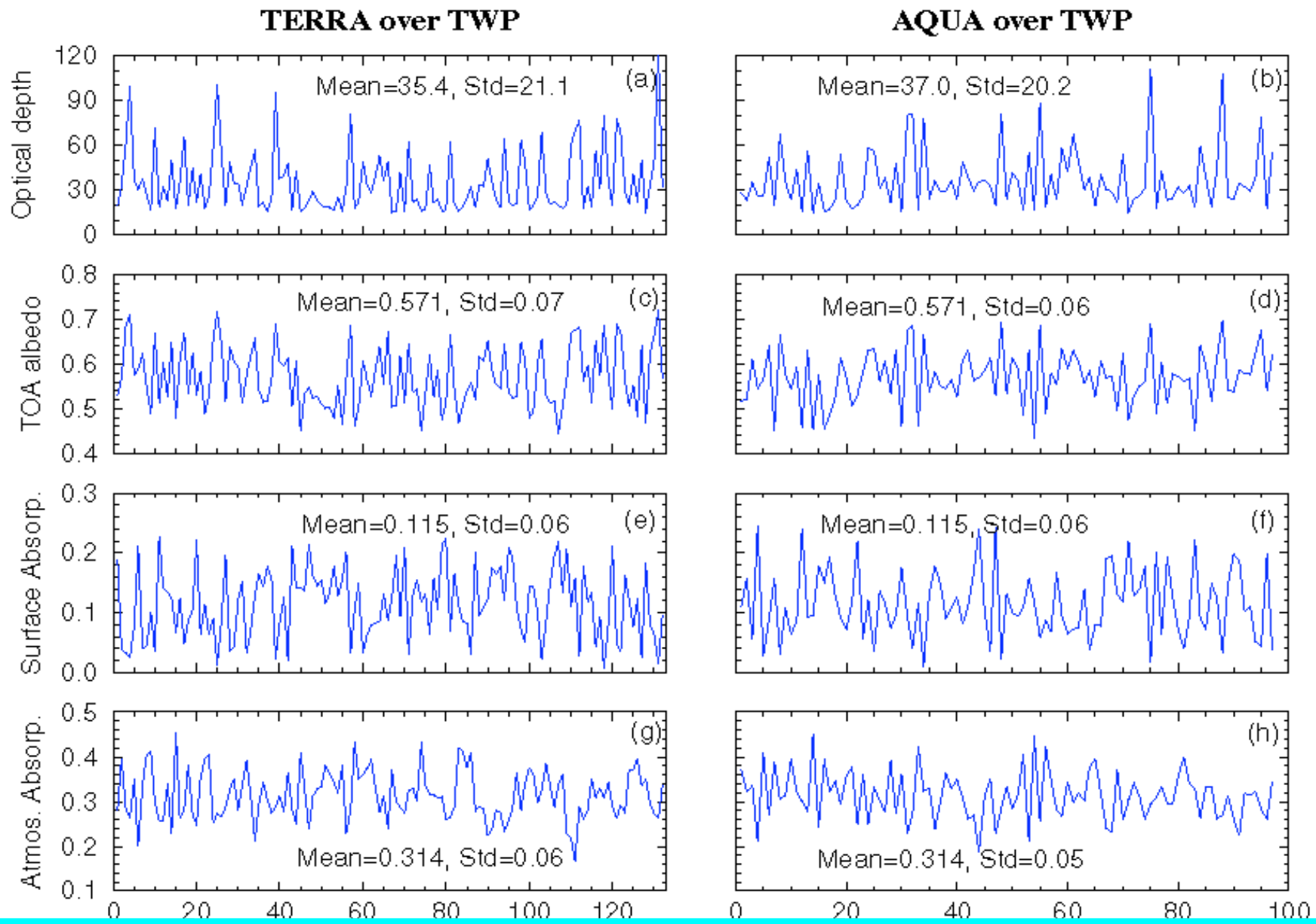


Schematically diagrams

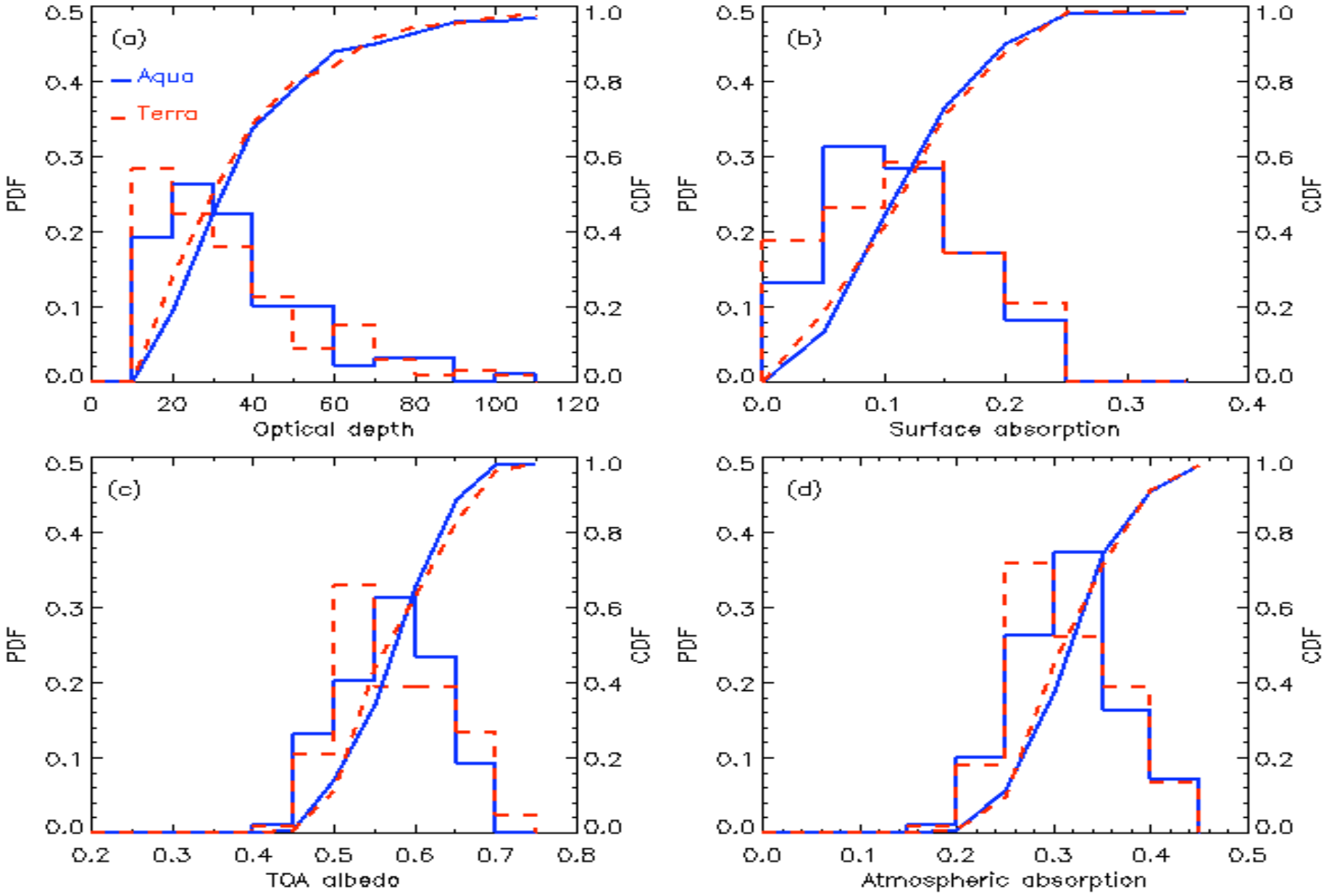
Viewed from satellite

Viewed from surface



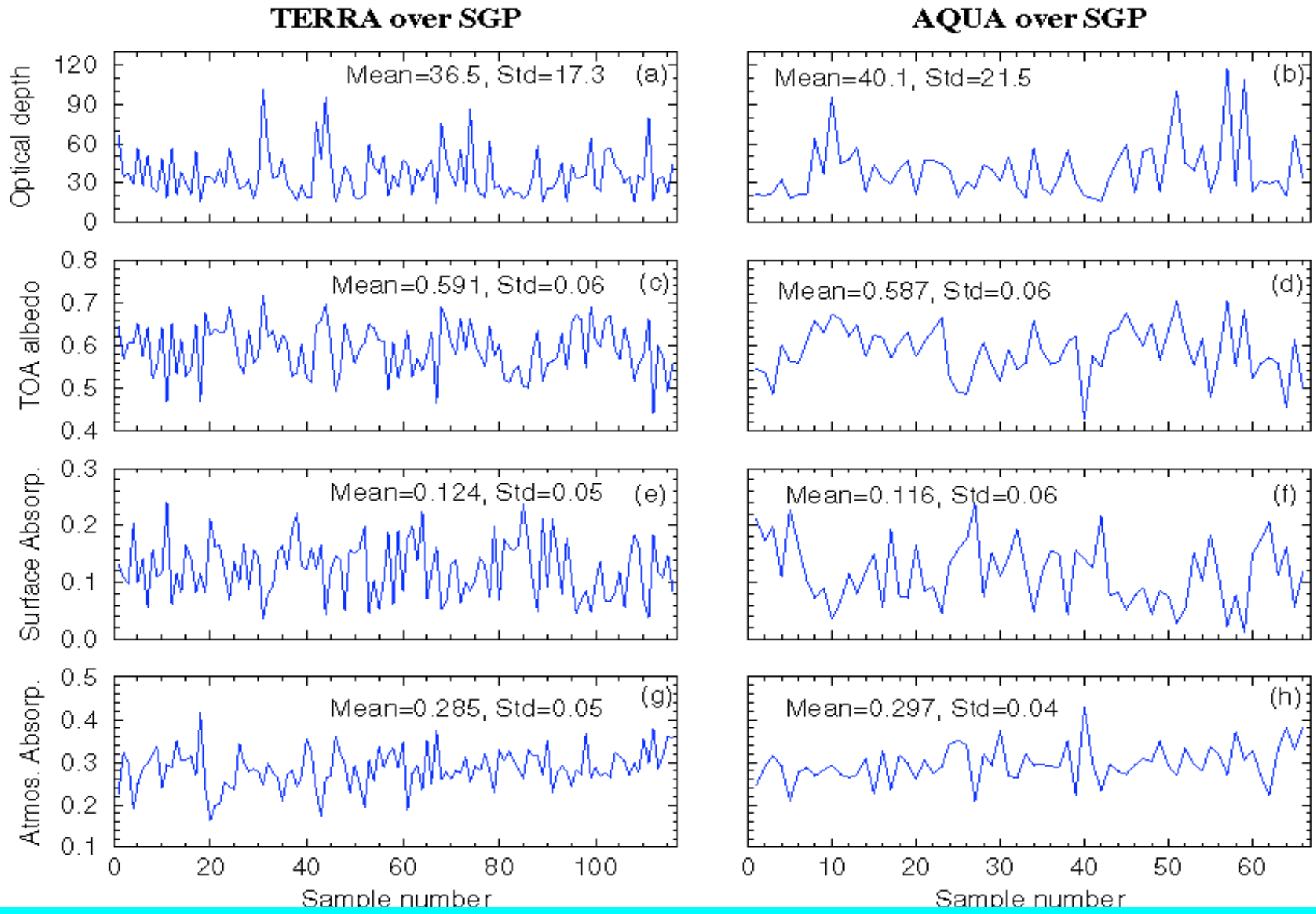


There are NO significant difference and diurnal variation between Terra and Aqua cloud-radiation properties at TWP sites

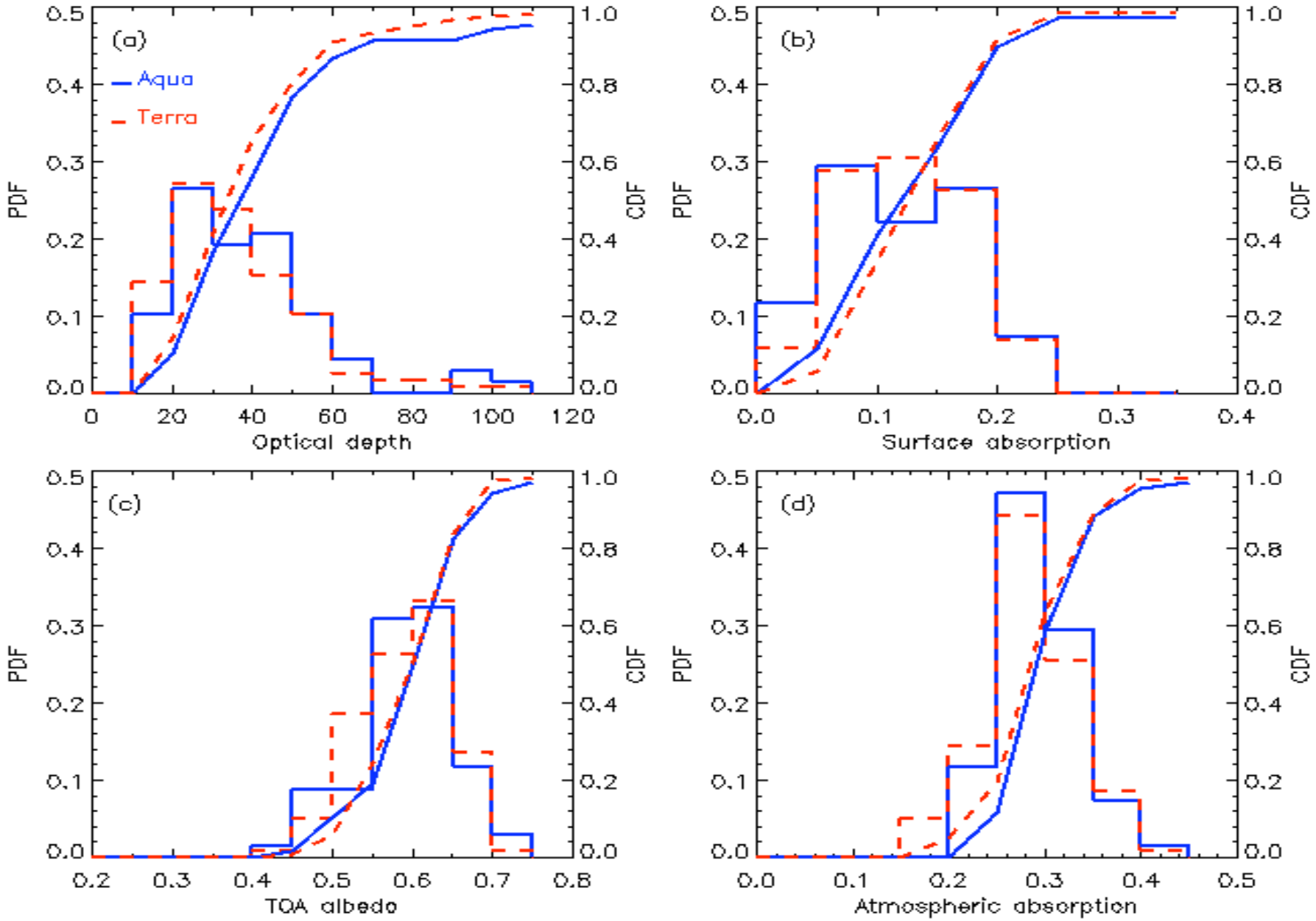


The median and mode values are nearly the same as their mean values

The samples were well distributed (normal distribution) except for optical depth



Similar to the cloud-radiation properties at TWP sites, There is a slightly diurnal variation at SGP site



Very similar to those at TWP sites, well distributed.

TWP sites

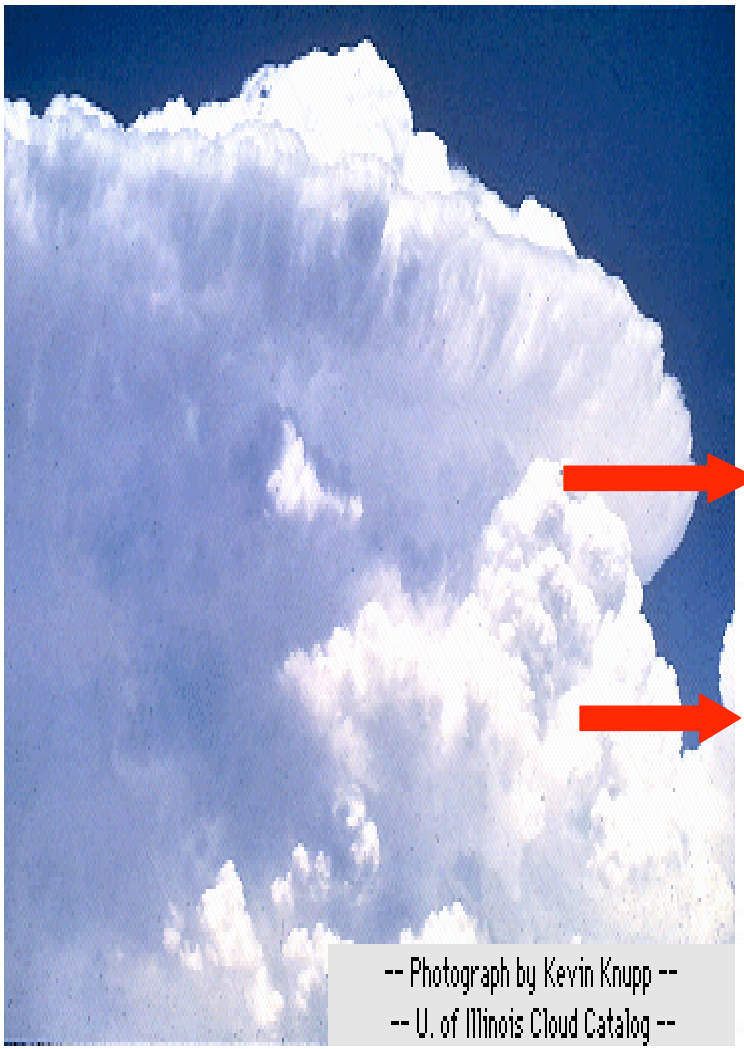
Samples	¶”	R_{TOA}	A_{SFC}	A_{COL}
229 for ¶³15	36	0.571	0.115	0.314
119 for ¶³30	50	0.622	0.084	0.294
70 for ¶³40	61	0.646	0.068	0.287
45 for ¶³50	70	0.663	0.063	0.274
29 for ¶³60	78	0.677	0.046	0.277
17 for ¶³70	88	0.689	0.032	0.279
10 for ¶³80	96	0.697	0.028	0.275

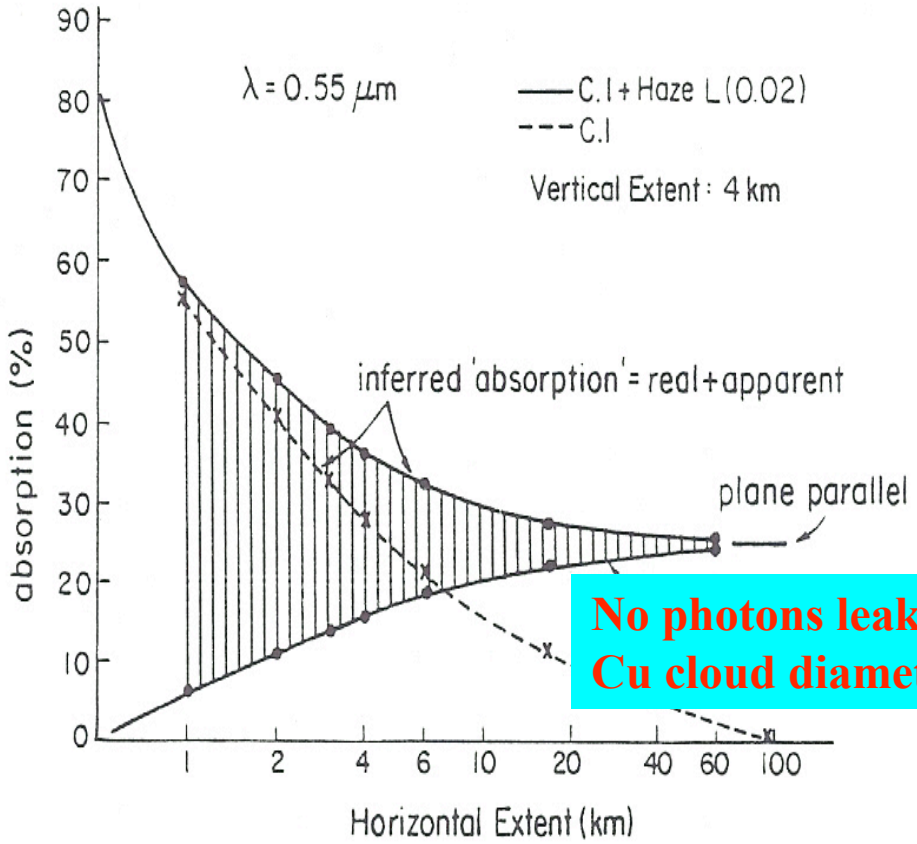
SGP site

Samples	¶”	R_{TOA}	A_{SFC}	A_{COL}
182 for ¶³15	37	0.589	0.121	0.289
108 for ¶³30	48	0.621	0.096	0.283
67 for ¶³40	57	0.637	0.083	0.279
35 for ¶³50	68	0.656	0.064	0.280
16 for ¶³60	82	0.670	0.058	0.272
10 for ¶³70	93	0.684	0.047	0.269
8 for ¶³80	97	0.688	0.037	0.275

A_{COL} is saturated at _>50, the large variation in A_{COL} at TWP is partially due to R_{SFC} varies from 0.08 (ocean) to 0.17 (land).

Photon leak on the edges of deep Cu clouds





Real and apparent 0·55 μm absorption as a function of the horizontal extent for two clouds of different composition and normal irradiance (after Newiger and Bähnke 1981).

No photons leak for Cu cloud diameter>60 km

Most of DCS (radius) range from 100 and 200 km in the tropics (Bin et al. 2005). Therefore, it is possible to have photon leak, BUT not significant in this study.

Comparison with Fu-Liou calculations

***A total of 24 cases selected at TWP sites*:**

With strict restriction

(1) $\tau \geq 50$, and inhomogeneiety factor, $(\tau_{mean} / \tau_{std})^2$, >10

(2) The ratio of standard derivation of A_{sfc} to the 30-minute averaged $A_{sfc} \leq 25\%$

Closely matched

Surface data were averaged over a 0.5-hour period centered at the time of the *Terra* /*Aqua* overpass

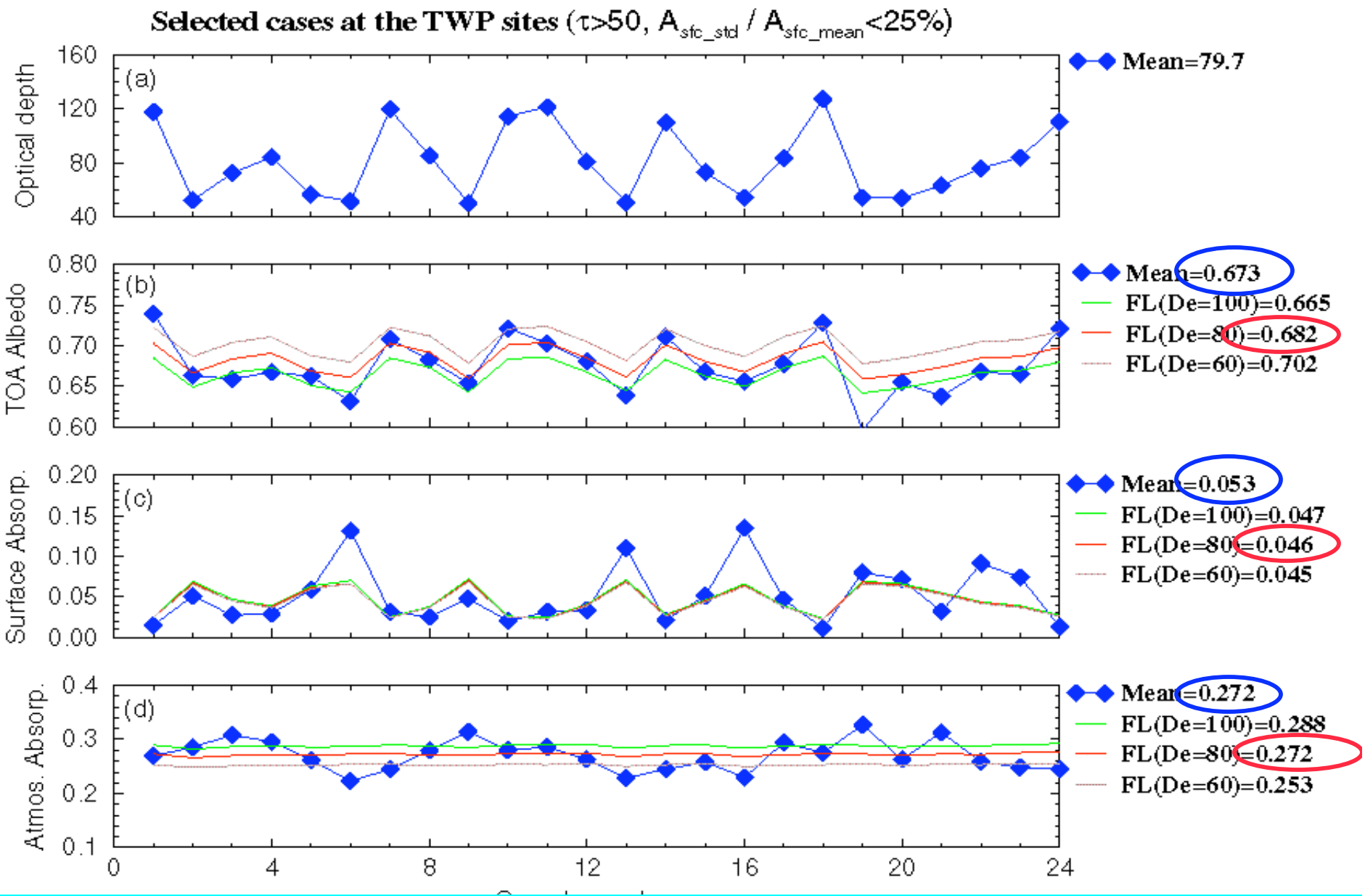
CERES cloud and radiation properties were averaged in a 20km x 20km box centered on the ARM surface sites

Inputs of Fu_Liou code

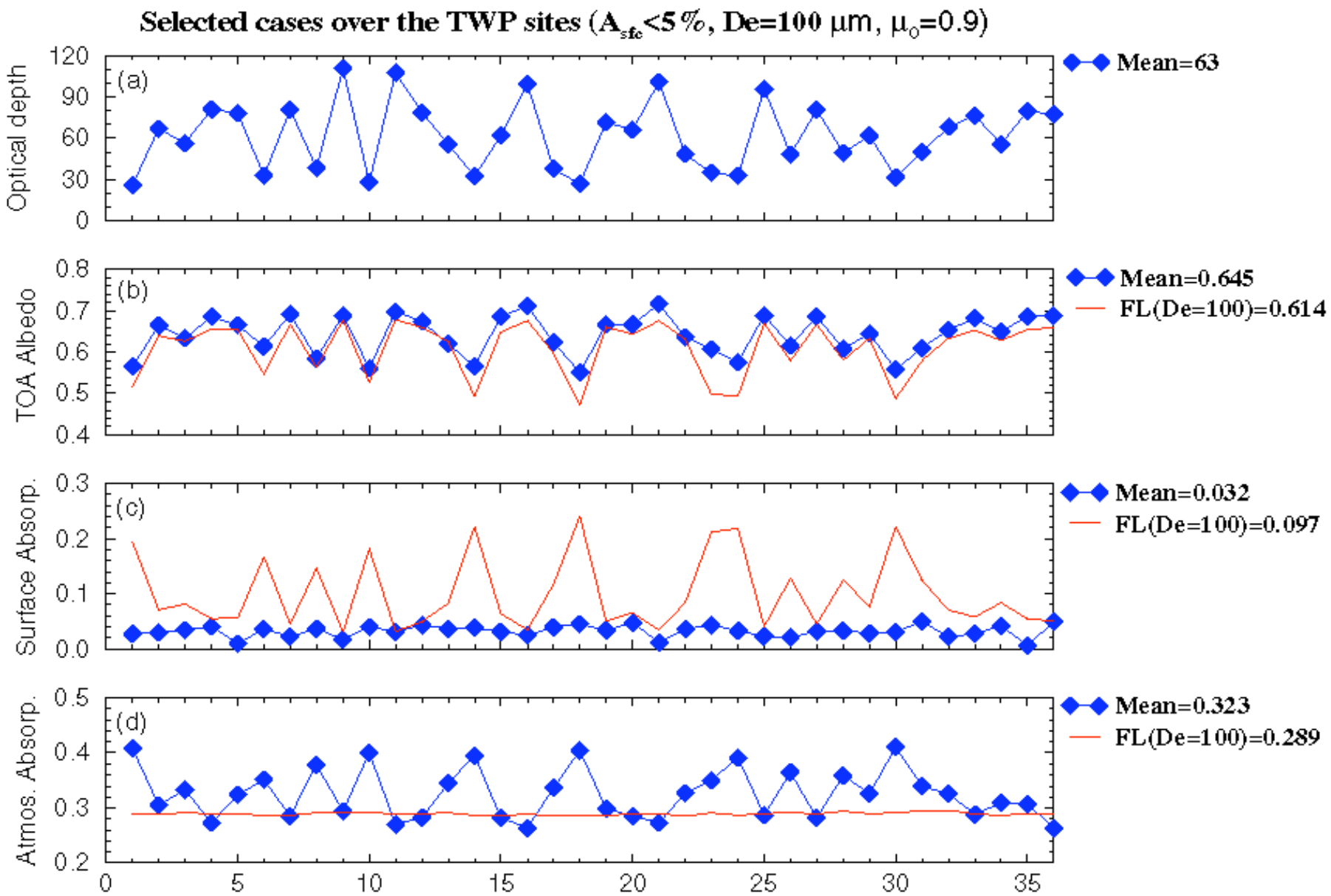
Retrieved effective heights and optical depths with De=60/80/100μm

Fixed R_{sfc}=0.15, μ_0=0.9, $\_{aerosol}$=0.2, and standard tropical sounding

MODIS retrieved De=67 μm at 3.7 μm; De=100 μm at 1.6 or 2.1 μm.



For De = 60\100 μm, the R_{toa} difference between model and data is less than 3%, A_{sfc} difference is less than 1%, and A_{col} difference is less than 2%.

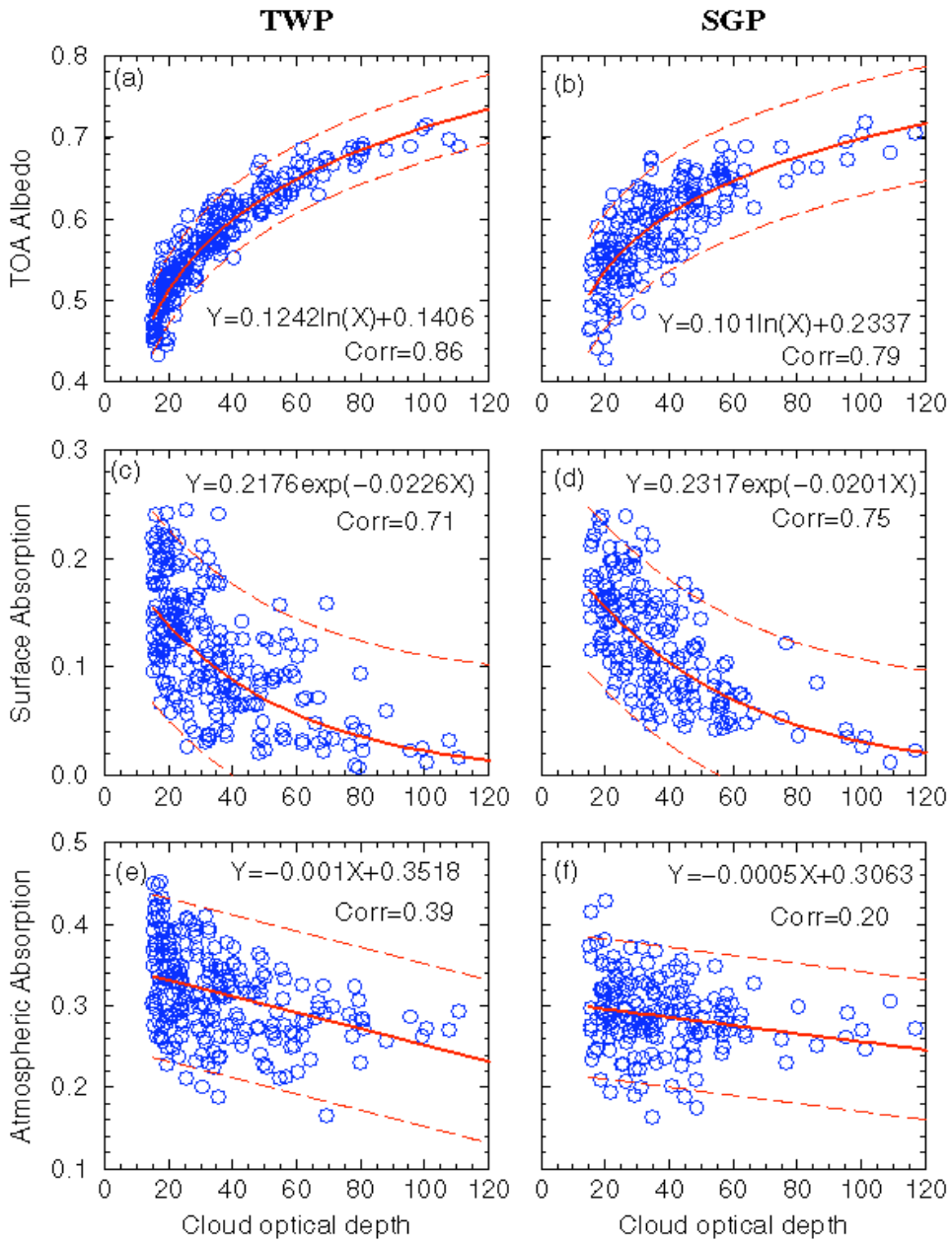


Fu_Liou calculated R_{toa} and A_{col} are 3% lower, but A_{sfc} is 6% higher than data for De=100 μm.

1) Most of points fall in the range of ±2 standard deviations (95% confidence intervals).

2) Correlations between _ and R_{toa} are better than those between _ and A_{sfc}, which may represent the mismatch spatial averages (_, R_{toa}) and temporal averages (A_{sfc}).

Correlations between _ and A_{col} are even worse because $A_{col} = 1 - R_{toa} - A_{sfc}$

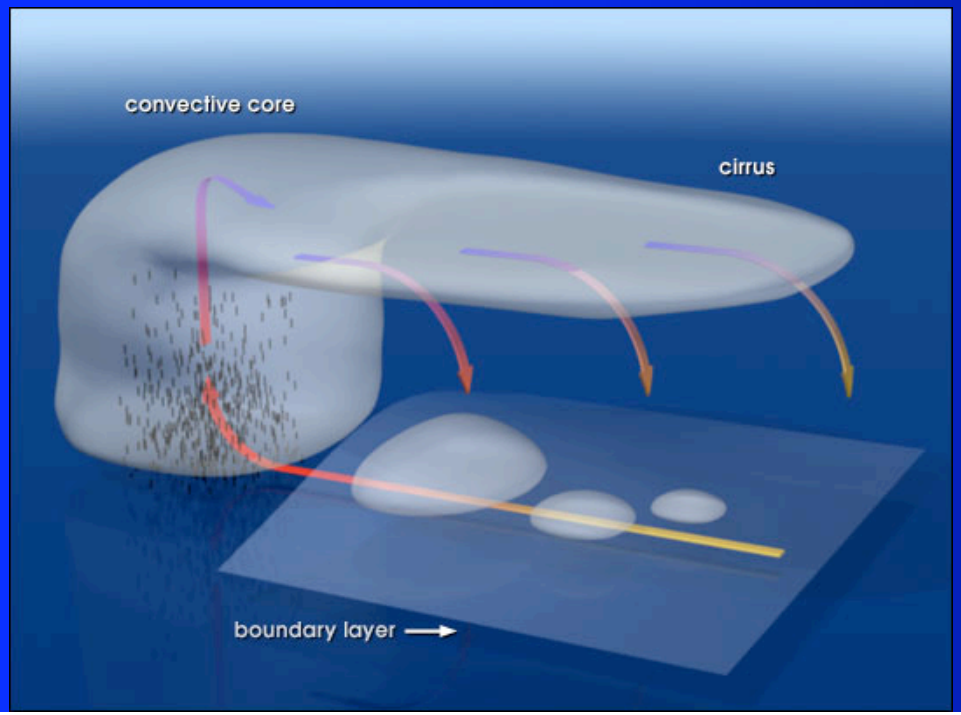


Why TWP is less noise than at SGP?

TWP Sites (tropics)

1) Convective core is always associated with more extensive and uniform horizontal anvils

2) DCS can often be a forest canopy



SGP (middle latitudes)

1) Individual convective elements, or a frontal band

Cess et al. 1995 Science

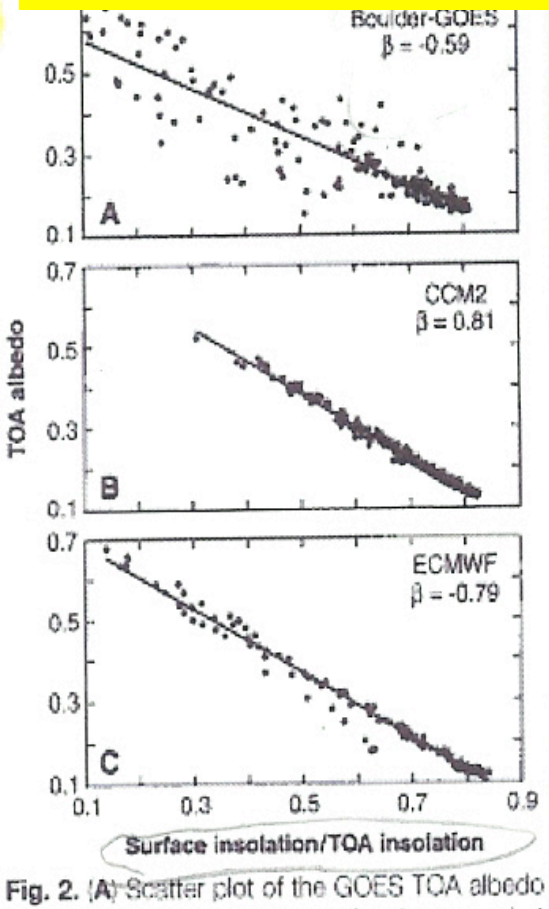
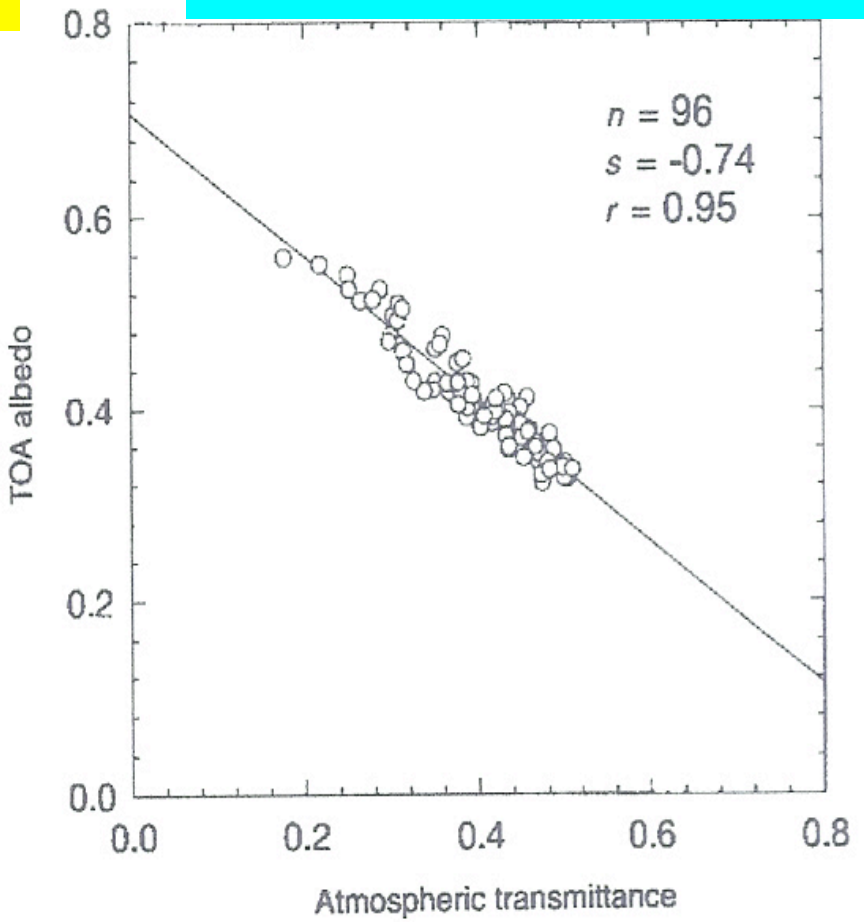


Fig. 2. (A) Scatter plot of the GOES TOA albedo

Li et al. 1995 Nature

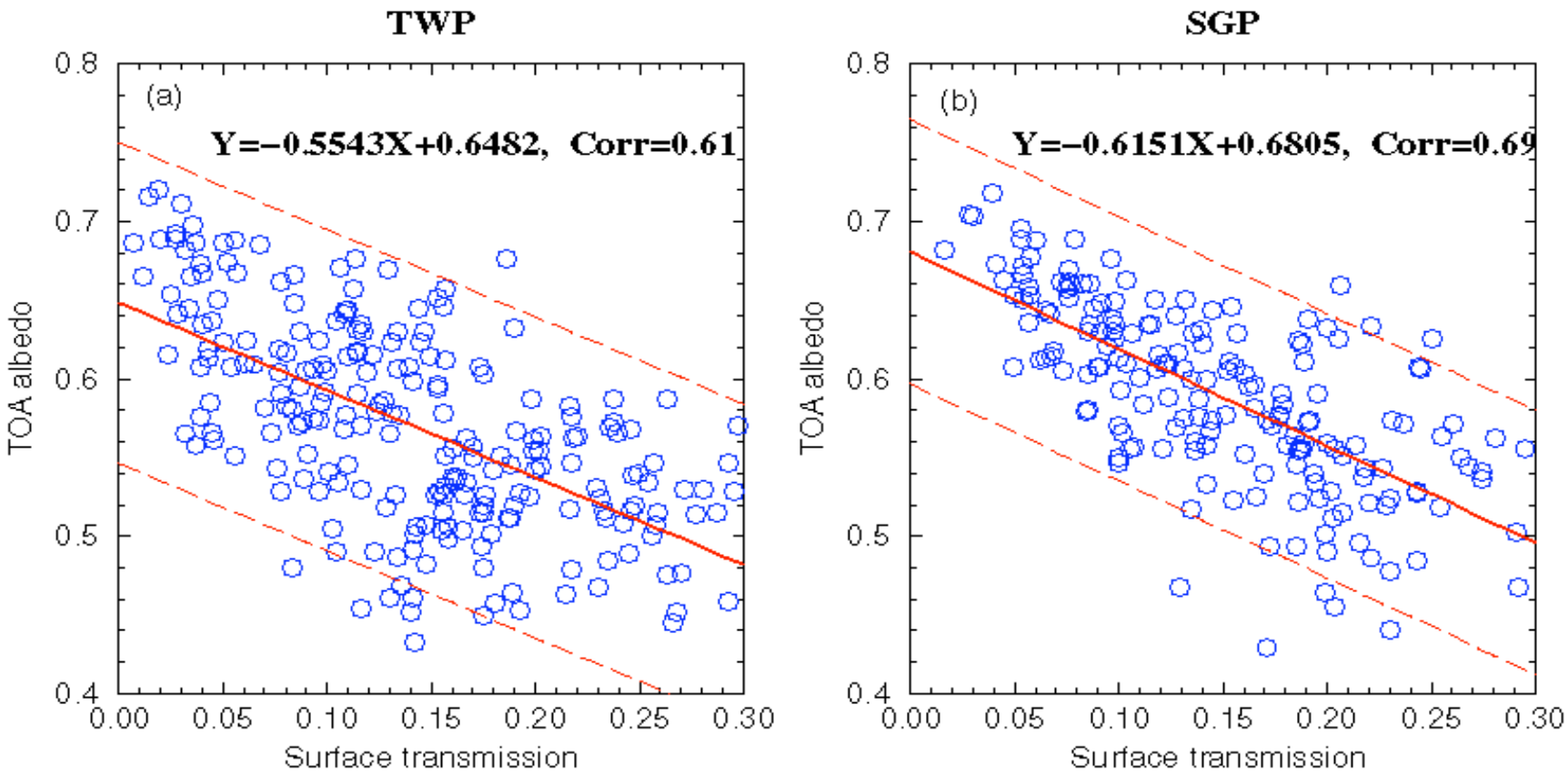


Atmospheric column absorption $A=(1-R_{sfc})/slope$, $R_{sfc}=0.17$

Model: Slope=0.8, A=1.04

Cess: Slope=0.59, A=1.4 — **More absorption than model**

Li: Slope=0.74, A=1.12 — **Nearly the same as model**



Atmospheric column absorption $A=(1-R_{sfc})/slope$, $R_{sfc}= 0.17$

At TWP: Slope=0.5543, A=1.50; At SGP: Slope=0.6151, A=1.35

(1)There is NO significant difference in atmospheric column SW absorption between tropics and middle latitudes, same as our tables

(2) Our slopes are close to the Cess study, but we have good agreement between data and model

Conclusions

1) There are NO strong diurnal variations of radiation budget at both TWP and SGP sites.

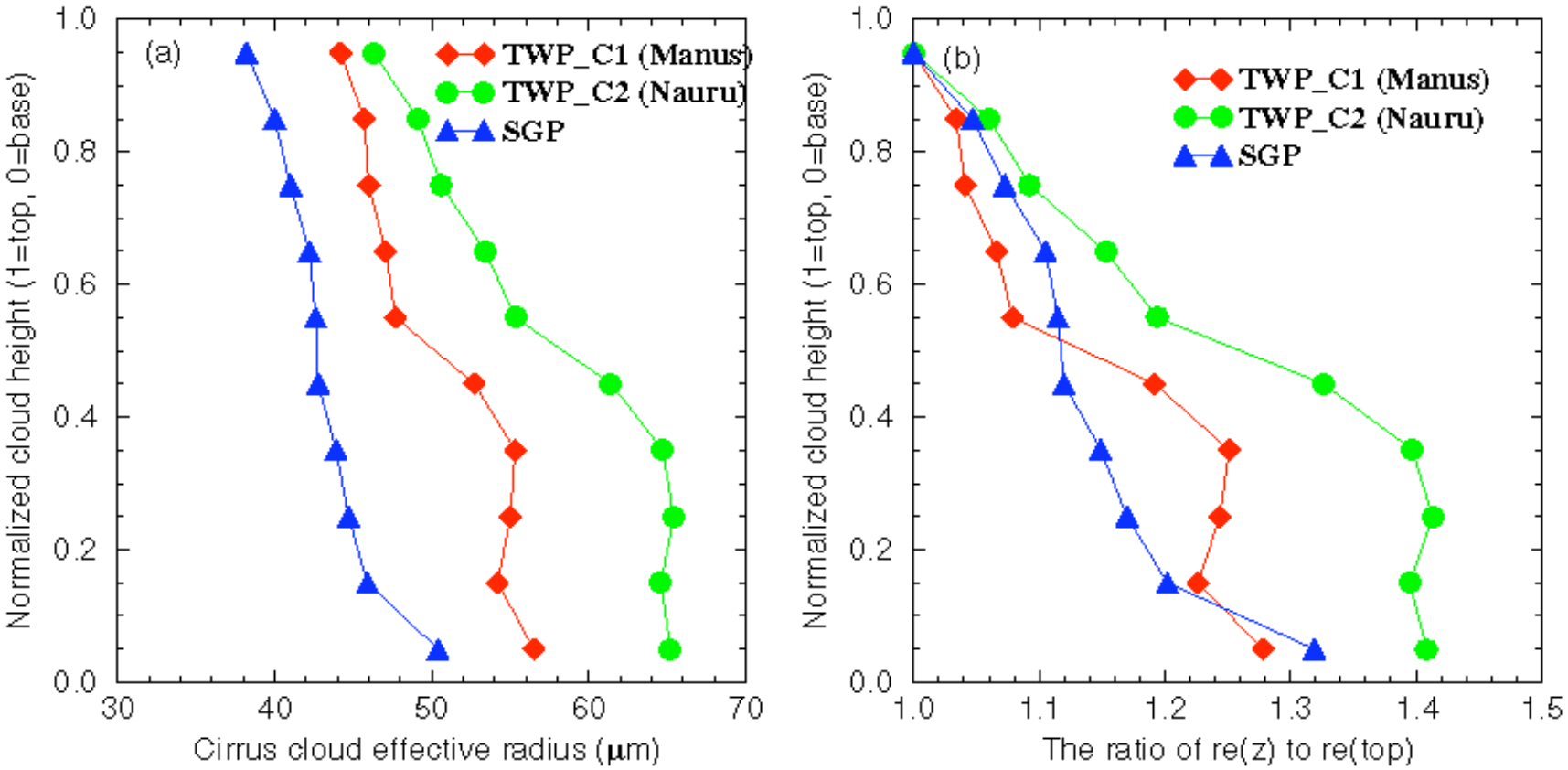
2) There is more atmospheric column SW absorption (~2.5%) in the tropics than in the middle latitudes, but this difference is NOT significant and disappears for _ > 50.

3) For the selected 24 cases, De=60\100 μm, the averaged R_{toa} difference between model and data is less than 3%; A_{sfc} difference is less than 1%; and A_{col} difference is less 2%.

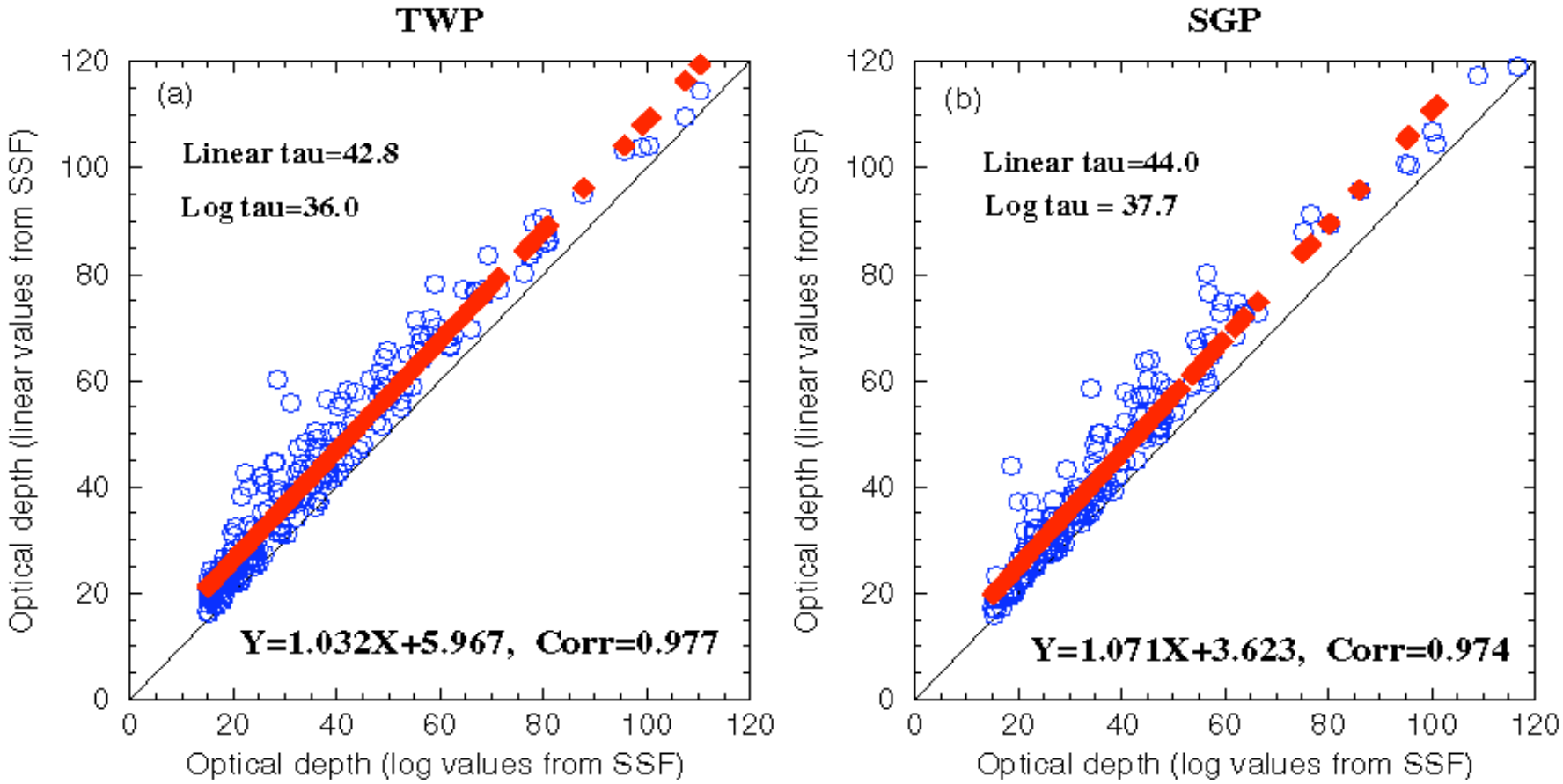

DCS is a very important topic.
This is why we are working on it

Backup slipes

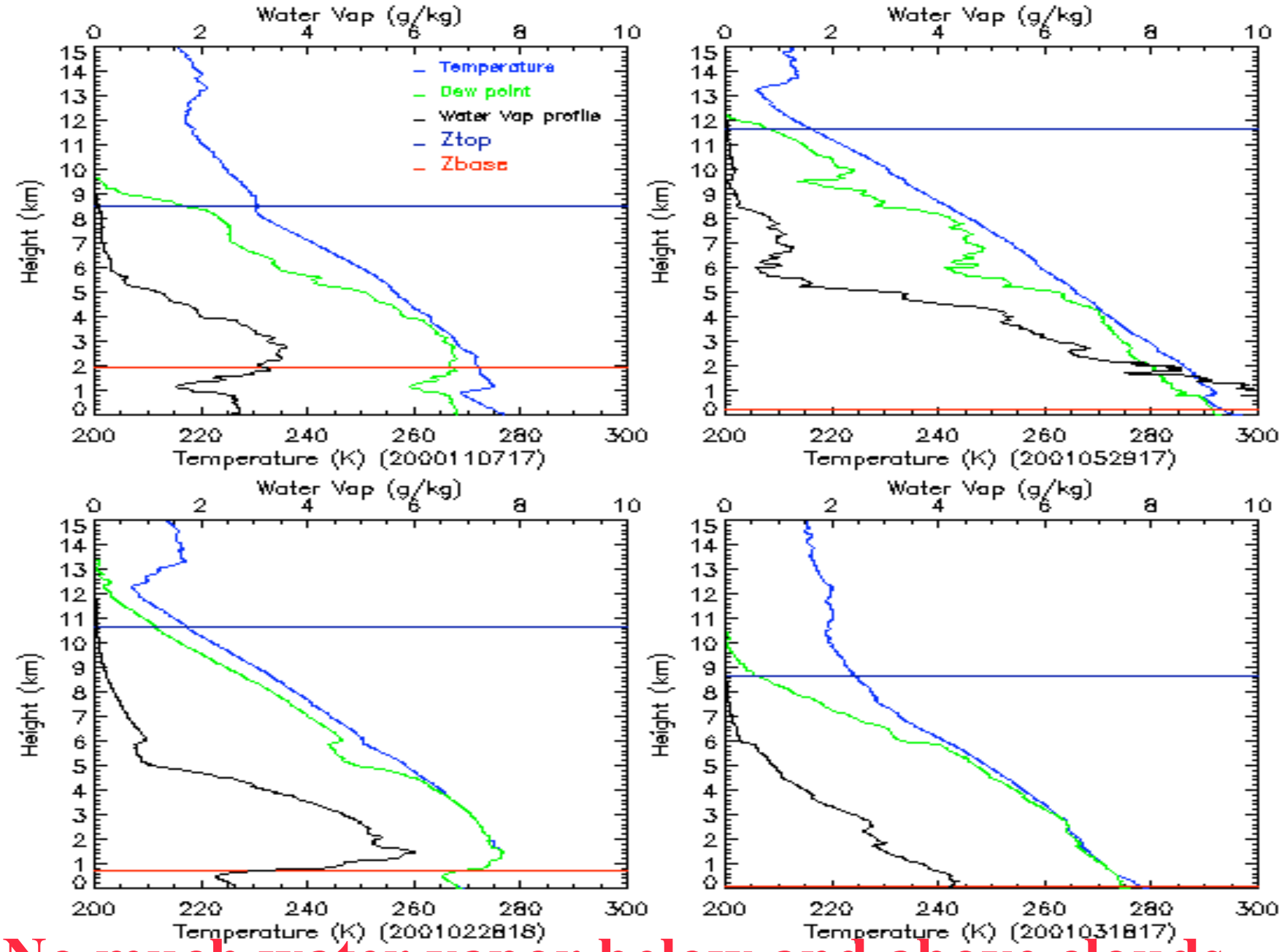
Vertical profiles of cirrus cloud effective radius at ARM TWP and SGP sites



Deng and Mace, 2005 JAM



There are linear (_) and log tau (_*) in CERES SSF products.
For the 1x1 degree average, we used (1) sum of all ln (_), then to have an average (Y-axis); (2) sum of all _*, then have an average (X-axis).



No much water vapor below and above clouds

Table 3. Mean values of cloud-radiative properties at the TWP and SGP sites

Parameters	TWP		SGP	
	TERRA	AQUA	TERRA	AQUA
Z_{base}, km	1.011	1.017	1.116	1.042
Z_{top}, km	10.01	9.585	9.034	8.890
ΔZ, km	9.0	8.568	7.917	7.848
Z_{eff}, km	12.368	12.480	7.473	7.726
T_{eff}, K	226.9	224.4	248.3	251.7
De, µm	67.4	65.1	52.3	52.5
LWP, gm^{-2}	5245	4403	744	1154
$SW_{sfc}^{\downarrow\downarrow}$, Wm^{-2}	169.4	168.2	152.6	143.3
$SW_{sfc}^{\uparrow}$, Wm^{-2}	30.1	29.7	27.0	26.0
$SW_{toa}^{\downarrow\downarrow}$, Wm^{-2}	1209.5	1201.5	997.5	994.8
$SW_{toa}^{\uparrow}$, Wm^{-2}	689.7	685.2	585.3	580.4
Atmospheric Absorp, Wm^{-2}	380.5	377.8	286.6	297.1

TABLE 4. Seasonal and annual averages of cloud properties at the ARM TWP sites

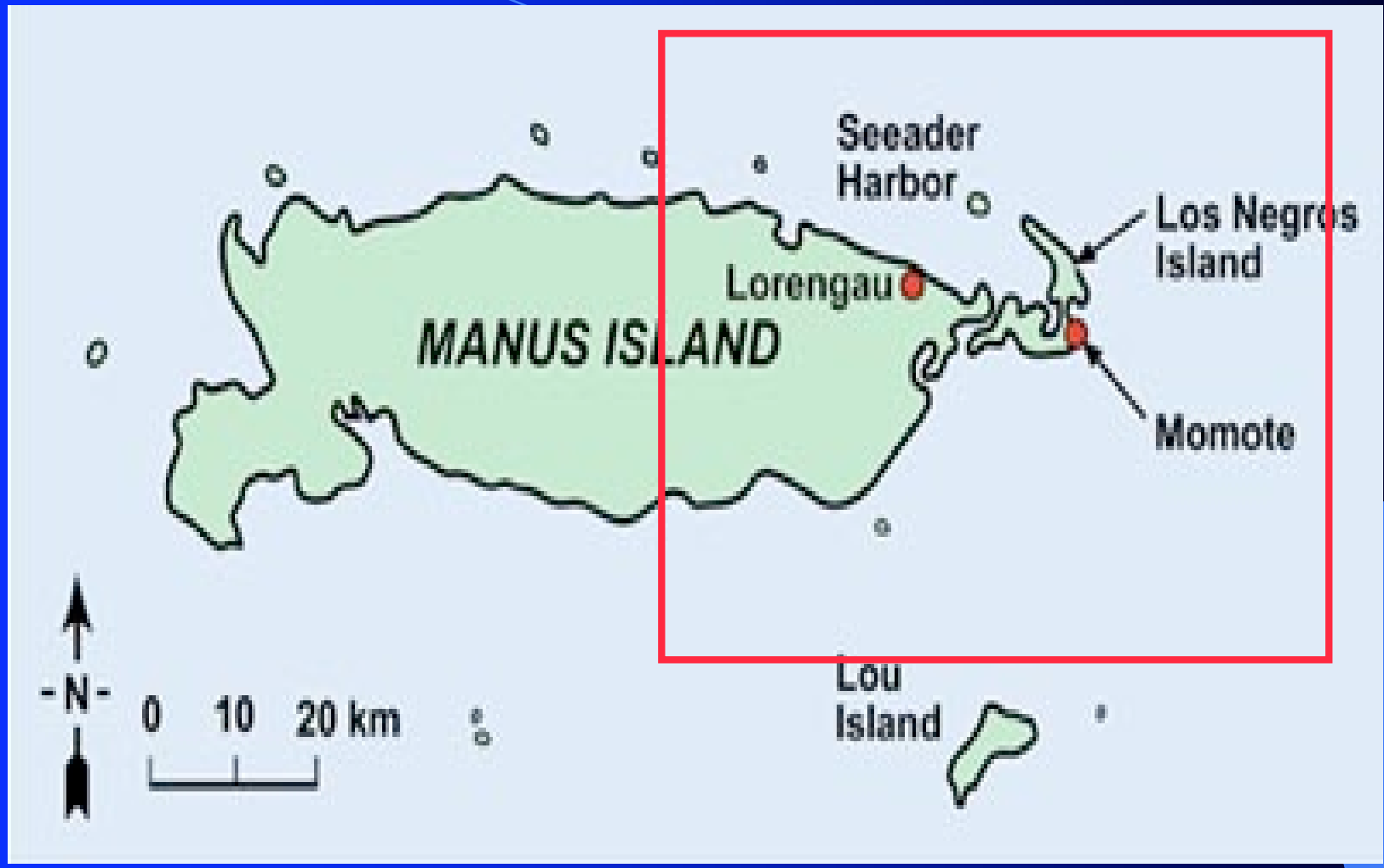
Parameter, # of sample	Winter	Spring	Summer	Autumn	Annual
	N=55	N=42	N=67	N=65	N=229
Z_{eff}, km	12.35 / 1.40	12.53 / 1.16	12.32 / 1.31	12.50 / 1.16	12.42 / 1.26
T_{eff}, K	226.5 / 17.5	226.0 / 14.9	226.3 / 16.4	224.7 / 14.3	225.8 / 15.8
De, µm	61.1 / 11.8	68.4 / 11.4	67.6 / 9.2	67.7 / 11.1	66.3 / 11.1
¶”	34.7 / 19.9	35.3 / 21.1	37.2 / 21.9	36.4 / 20.3	36.0 / 20.7
LWP, gm^{-2}	5078 / 4478	6028 / 6126	4714 / 4346	4971 / 4505	5112 / 4771
R_{sfc}	0.167 / 0.022	0.168 / 0.026	0.172 / 0.021	0.168 / 0.017	0.169 / 0.021
R_{toa}	0.569 / 0.068	0.564 / 0.070	0.574 / 0.066	0.574 / 0.059	0.571 / 0.065
A_{sfc}	0.116 / 0.052	0.112 / 0.059	0.120 / 0.060	0.111 / 0.060	0.115 / 0.058
A_{col}	0.315 / 0.061	0.324 / 0.053	0.307 / 0.055	0.315 / 0.050	0.314 / 0.055
SW_{sfc} °˝, $W\ m^{-2}$	174.6 / 81.7	168.4 / 92.3	167.2 / 86.8	165.9 / 93.0	168.8 / 87.9
SW_{sfc} °›, $W\ m^{-2}$	30.6 / 15.4	29.8 / 17.9	30.0 / 16.8	29.2 / 17.7	29.9 / 16.8
SW_{toa} °˝, $W\ m^{-2}$	1233.8/ 51.9	1233.5/ 70.3	1141.7/ 67.7	1231.4/ 59.3	1206.1/ 74.6
SW_{toa} °›, $W\ m^{-2}$	700.6 / 82.0	695.8 / 93.8	654.1 / 76.9	706.6 / 79.6	687.8 / 94.6
A_{col}, $W\ m^{-2}$	389.2	399.1	350.4	388.1	379.4

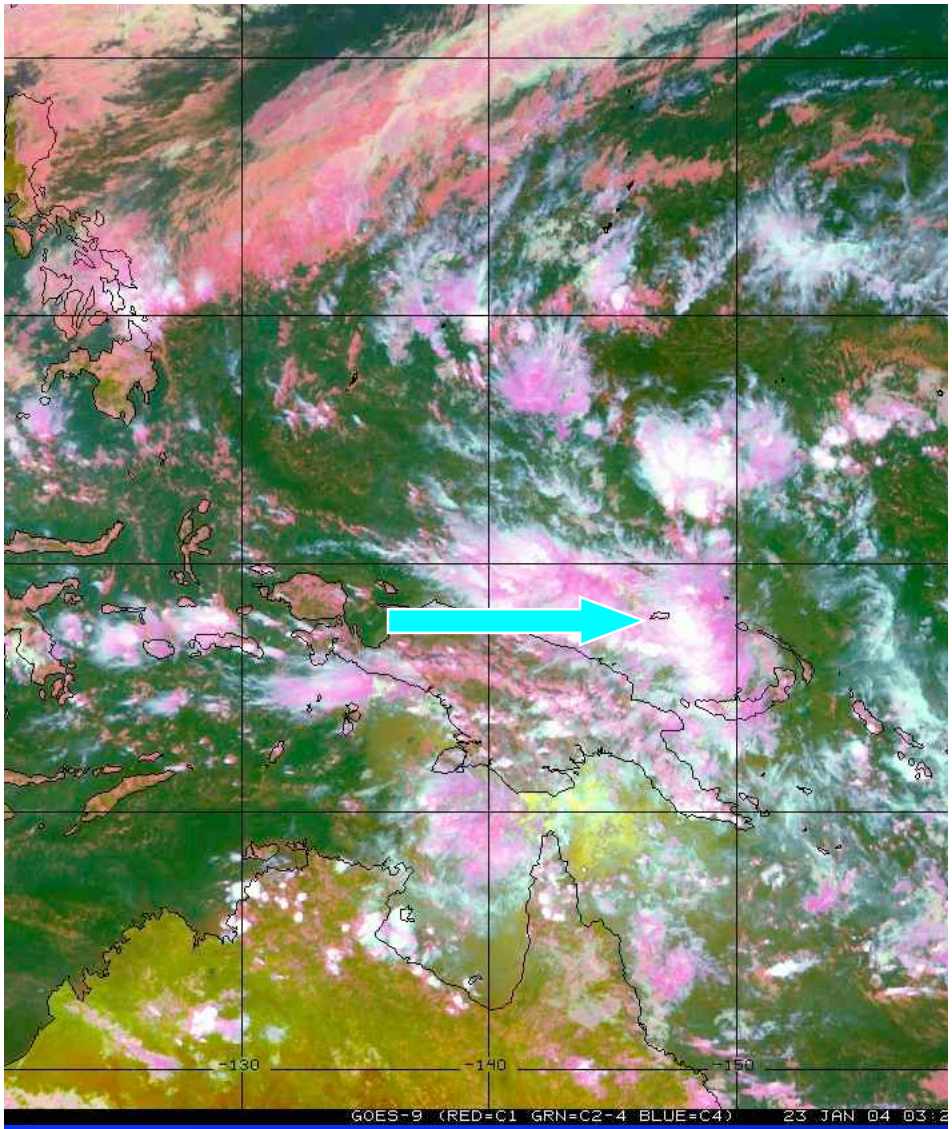
TABLE 5. Seasonal and annual averages of cloud-radiation properties at the ARM SGP site

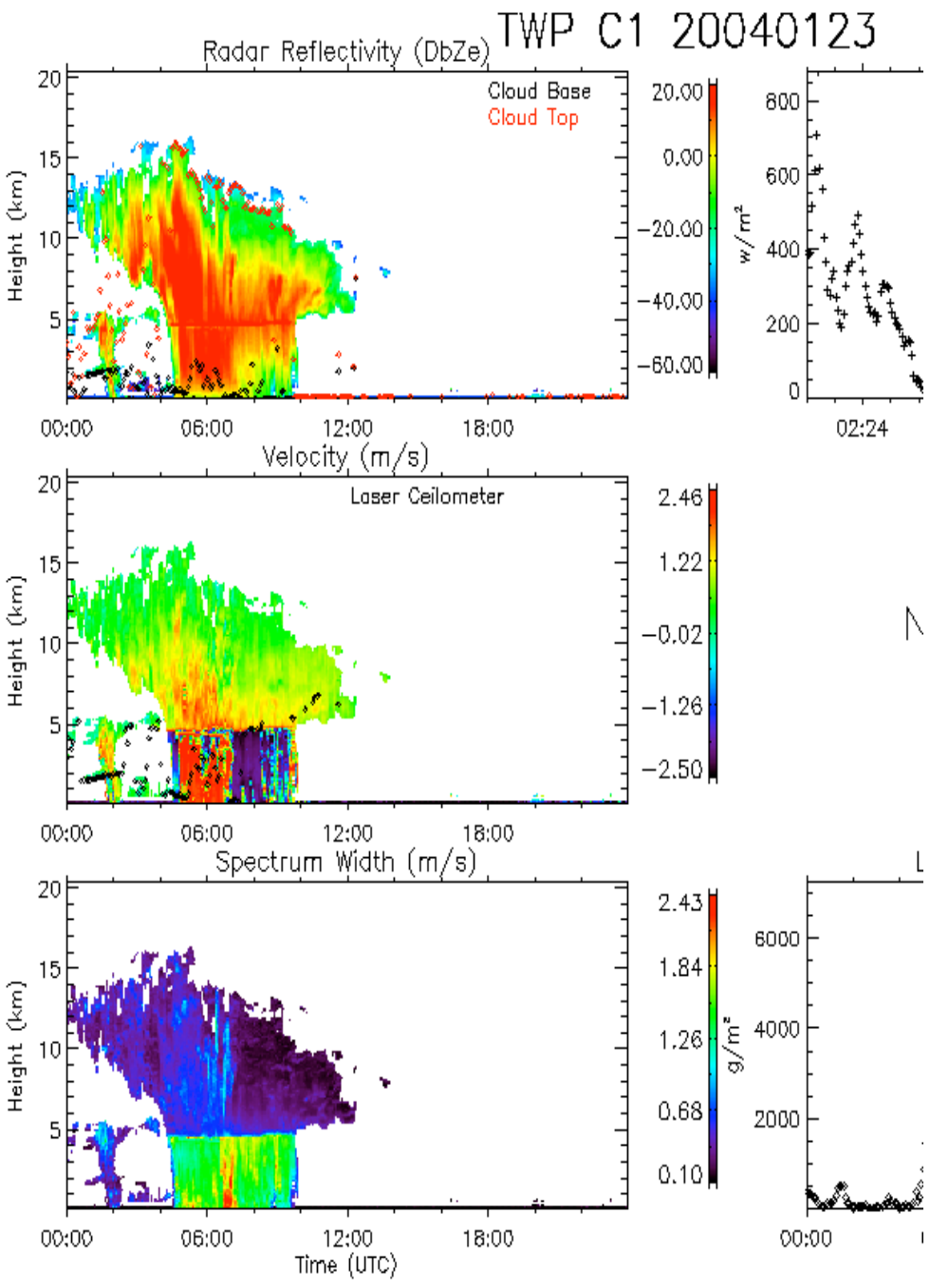
Parameter, # of sample	Winter	Spring	Summer	Autumn	Annual
	N=43	N=64	N=27	N=48	N=182
Z_{eff}, km	7.20 / 2.47	7.50 / 2.90	8.99 / 2.45	7.18 / 2.42	7.57 / 2.66
T_{eff}, K	245.2 / 15.2	248.5 / 21.3	252.2 / 18.0	253.2 / 16.6	249.5 / 18.4
De, µm	55.5 / 18.5	49.1 / 21.2	45.9 / 21.0	57.1 / 19.9	52.2 / 20.5
¶”	39.5 / 18.3	38.9 / 18.6	38.6 / 23.5	34.4 / 17.2	37.8 / 18.9
LWP, Gm^{-2}	600 / 675	718 / 953	1154 / 1546	1560 / 2148	969 / 1441
R_{sfc}	0.163 / 0.032	0.175 / 0.027	0.187 / 0.020	0.158 / 0.027	0.169 / 0.029
R_{toa}	0.619 / 0.044	0.584 / 0.056	0.559 / 0.062	0.588 / 0.060	0.589 / 0.058
A_{sfc}	0.100 / 0.043	0.126 / 0.053	0.132 / 0.055	0.127 / 0.052	0.121 / 0.052
A_{col}	0.281 / 0.035	0.290 / 0.043	0.309 / 0.045	0.285 / 0.051	0.289 / 0.045
$SW_{sfc}^{\circ\prime\prime}$, $W\ m^{-2}$	92.8 / 43.0	177.0 / 81.0	201.2 / 83.3	133.4 / 61.8	149.2 / 78.7
$SW_{sfc}^{\circ\cdot}$, $W\ m^{-2}$	15.8 / 8.6	32.3 / 16.7	38.3 / 17.3	22.3 / 12.6	26.6 / 16.2
$SW_{toa}^{\circ\prime\prime}$, $W\ m^{-2}$	773.8 / 110.6	1135.6/ 95.5	1236.6/ 39.0	875.6 / 124.7	996.5 / 203.4
$SW_{toa}^{\circ\cdot}$, $W\ m^{-2}$	478.2 / 72.5	661.4 / 70.2	691.3 / 83.1	513.4 / 80.2	583.5 / 115.8
A_{col}, $W\ m^{-2}$	218.6	329.5	382.4	251.1	290.4

Winter Storm cases at ARM SGP

Samples	*Optical depth*	*slope*	*intercept*
43 for tau>15	39.5	-0.57	0.69
32 for tau>25	45.8	-0.6	0.7
31 for tau>15, ICE	39.5	-0.56	0.69
23 for tau >25, ICE	46.2	-0.55	0.7
9 for tau >50, ICE	62.7	-0.58	0.71


Seeader
Harbor
Los Negros
Island
Lorengau
MANUS ISLAND
Momote
Lou
Island
- N -
0 10 20 km


-130
-140
-150
GOES-9 (RED=C1 GRN=C2-4 BLUE=C4)
23 JAN 04 03:2


TWP C1 20040123
Radar Reflectivity (DbZe)
Cloud Base
Cloud Top
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0.00
-20.00
-40.00
-60.00
w/m²
00:00
06:00
12:00
18:00
02:24
Velocity (m/s)
Laser Ceilometer
2.46
1.22
-0.02
-1.26
-2.50
Spectrum Width (m/s)
2.43
1.84
1.26
0.68
0.10
g/m²
Time (UTC)