Terra CRS Results and Status

CERES/GERB Science Team Meeting
NCAR, Boulder 29 March 2004

Surface and Atmosphere Radiation Budget (SARB) group:
T. P. Charlock (NASA LaRC)
Fred G. Rose (AS&M)
David A. Rutan (AS&M) – validation and “CAVE” URL
Zhonghai Jin (AS&M) - coupled radiative transfer ***Short Presentation***

Lisa H. Coleman, Thomas E. Caldwell, Scott Zentz (SAIC)
- Data Management Team

Seiji Kato (H.U.) – his Gamma Weighted 2-stream is latest code advance
David Fillmore and Bill Collins (NCAR) - MATCH

Wenying Su (H.U.)- developing surface UV in gridded “SYN” product

Access to CAVE on line surface and CERES validation,
point and click Fu-Liou and COART calculations:
www-cave.larc.nasa.gov/cave/ or goggle “CERES CAVE”

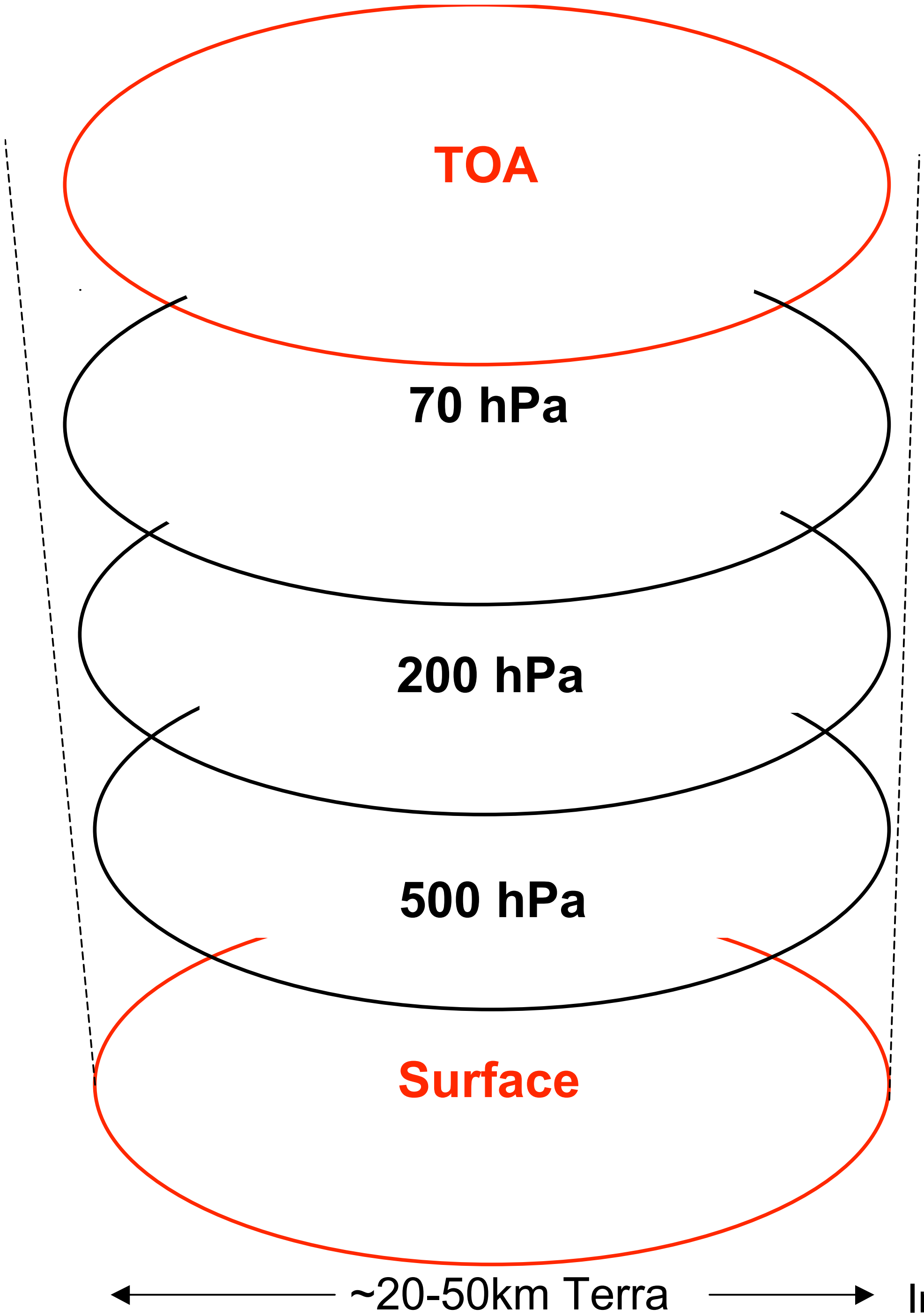
Tuesday: Joint meeting of TISA/SOFA/SARB Working Groups

TISA: Temporal Interpolation and Spatial Averaging (Young)
SOFA: Surface-Only Flux Algorithms (Kratz)
SARB: Surface and Atmosphere Radiation Budget

Agenda: Development of the gridded "SYN" (3-hourly)

Dave Young - TISA input for SYN
Fred Rose - SARB broadband radiative transfer for 3-hourly flux
Wenying Su - New CERES surface UV for bio-medical applications
Zhonghai Jin - Spectral properties of cryosphere
Wenying Su - Ultra-long Duration Balloon (ULDB) report

Reserve - Anand Inamdar on water vapor greenhouse



CERES CRS: Surface and Atmosphere Radiation Budget (SARB) Product

Tuned fluxes at all 5 levels
All-sky & Clear-sky both Up & Down
SW, LW, 8-12.5um non-CERES Window

Surface & TOA also have Untuned fluxes
& Pristine (no aerosol) fluxes for SW&LW
aerosol forcing (includes cloud effect)

Emulated 8-12um CERES Window at TOA

Photosynthetically Active Radiation
(here as 437.5-689.6nm) at surface

Tuning does NOT yield a perfect
match to TOA observations.

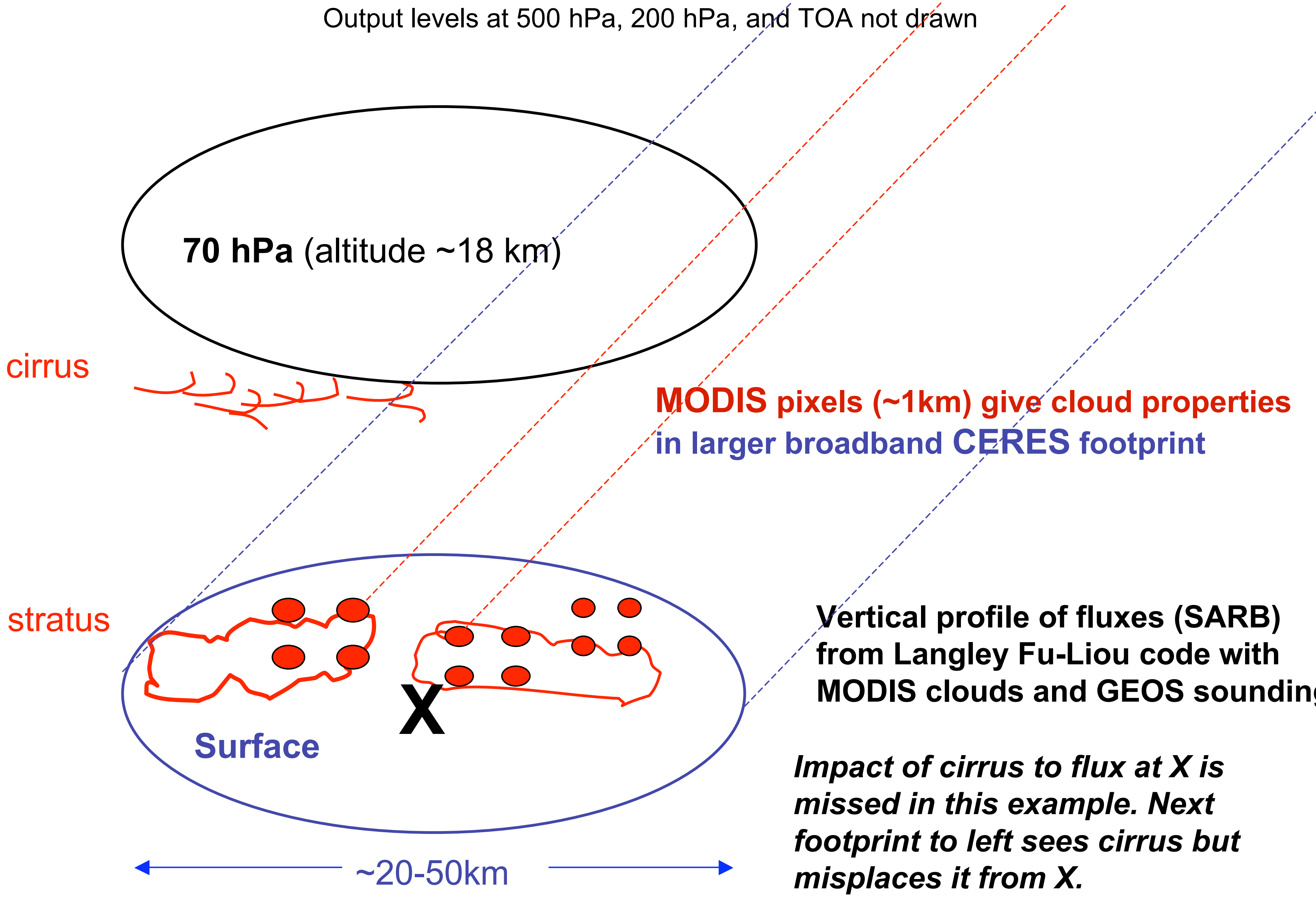
Parameters adjusted when clear:
Skin temperature, aerosol AOT,
lower & upper tropospheric humidity

Parameters adjusted when cloudy:
LWP/IWP, cloud top temperature,
cloud fractional area within footprint

Instantaneous, geolocated at surface, ungridded

Viewing geometry and vertical profile of SARB fluxes

Output levels at 500 hPa, 200 hPa, and TOA not drawn



MODIS pixels (~1km) give cloud properties in larger broadband CERES footprint

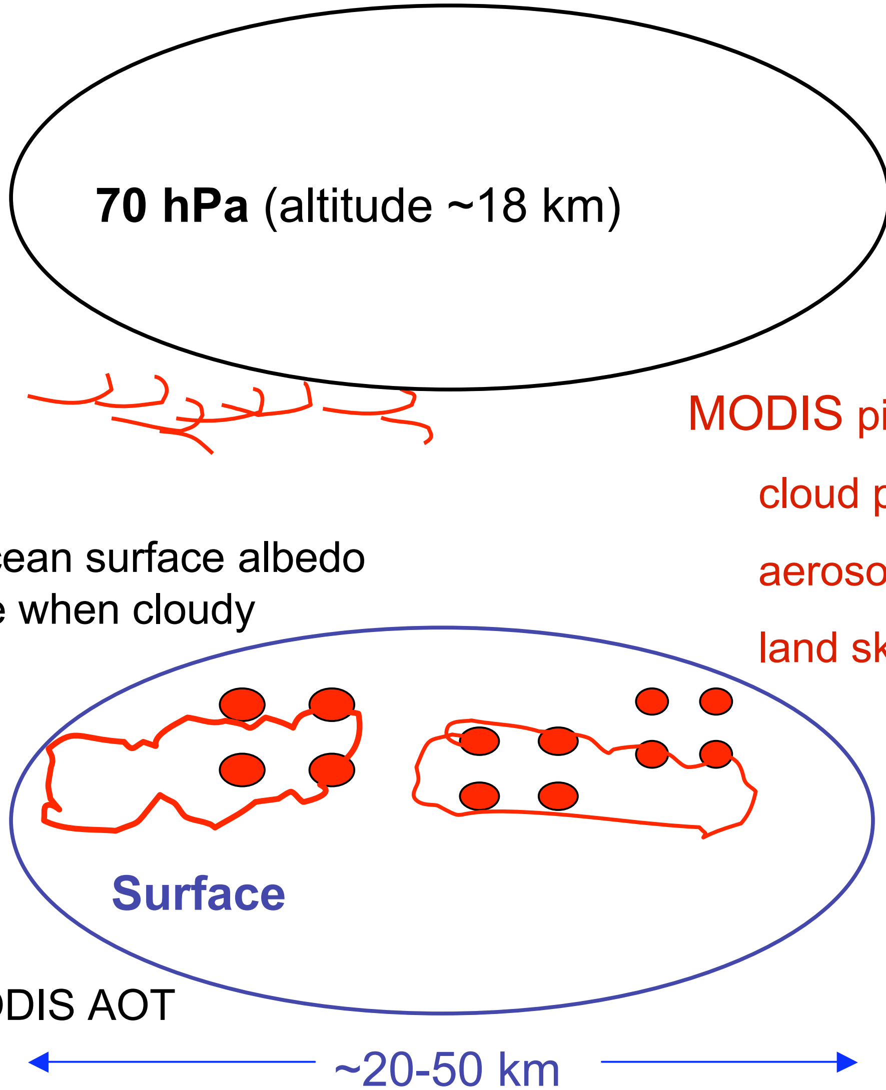
Vertical profile of fluxes (SARB) from Langley Fu-Liou code with MODIS clouds and GEOS sounding

Impact of cirrus to flux at X is missed in this example. Next footprint to left sees cirrus but misplaces it from X.

Input data for computing SARB vertical profile at ~2,000,000 footprints/day

Output levels at 500 hPa, 200 hPa, and TOA not drawn

NCEP O3(z)
Mostly SBUV/2



MODIS pixels (~1km) provide
cloud properties (almost always)
aerosol AOT (sometimes)
land skin temperature (when clear)

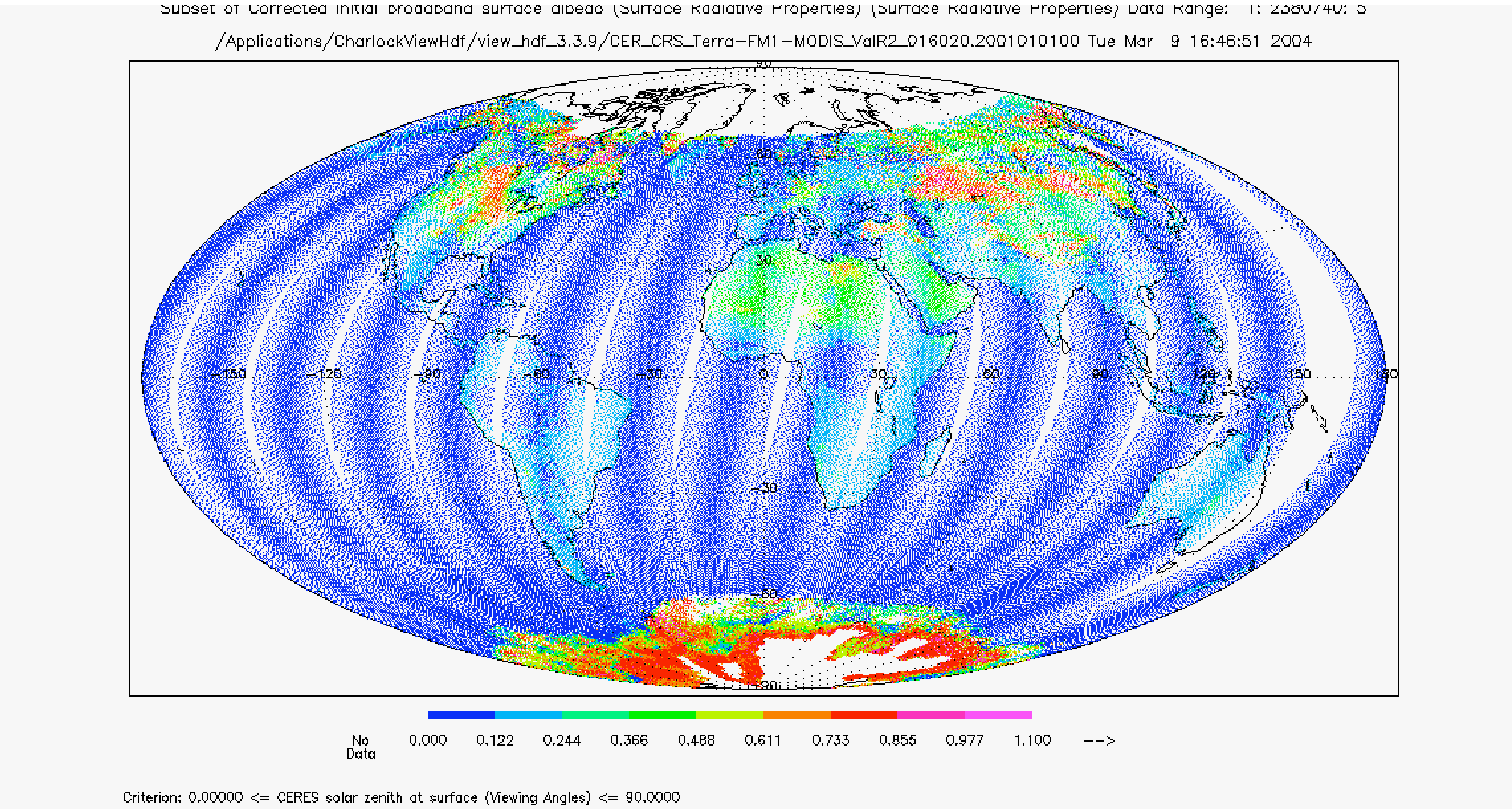
GEOS4 T(z) and q(z)
Wind speed affects ocean surface albedo
Land skin temperature when cloudy

MATCH aerosols
Used for AOT if no MODIS AOT
Always used for SSA

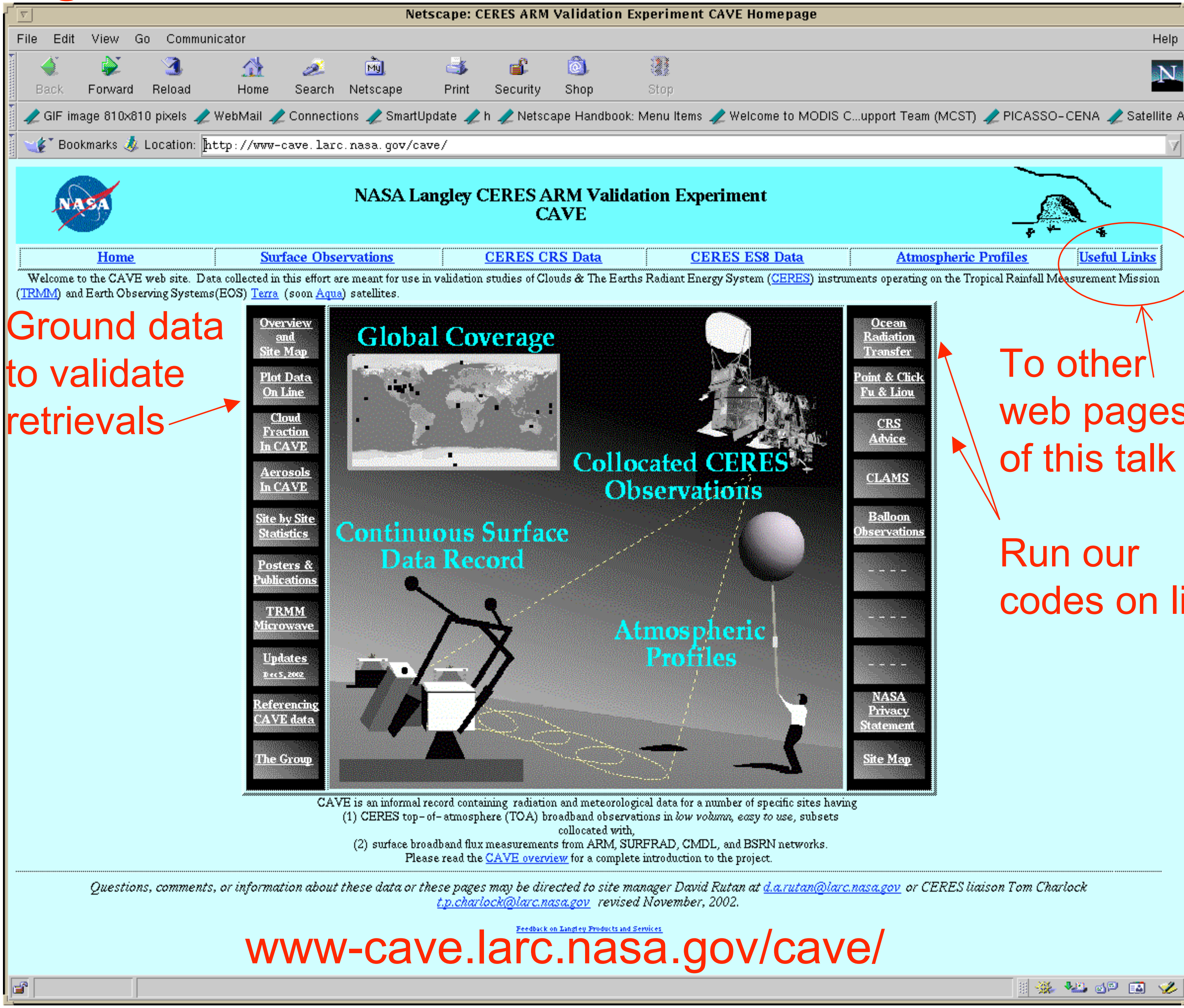
Large CERES footprint (geolocated at surface) for TOA flux

Initial surface albedo for cloudy footprints (1 January 2001).

Land: Based on look up table of the whole month's clear footprints
Ocean: Based on Jin's Coupled Ocean Atmosphere Radiative Transfer



Google “CERES CAVE”: fruitful domain of David Rutan



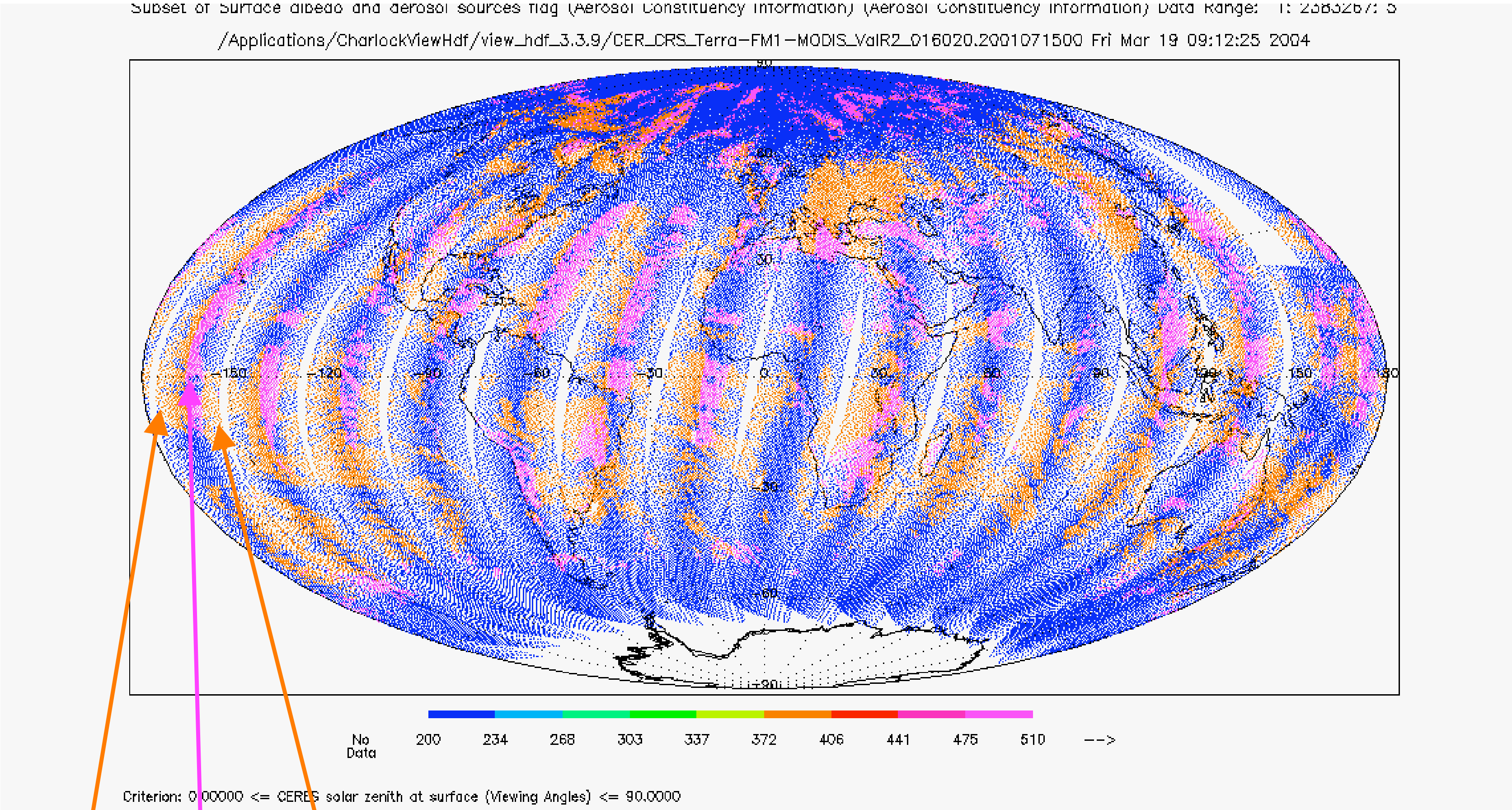
Ground data to validate retrievals

To other web pages of this talk

Run our codes on line

www-cave.larc.nasa.gov/cave/

Sources of Aerosol Optical Thickness (AOT): Daylight on 15 July 2001



ORANGE: Instantaneous MODIS (MOD04) Kaufman algorithm

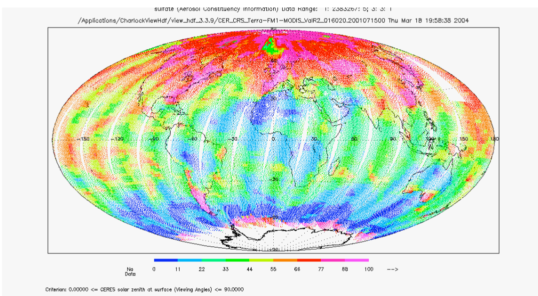
PURPLE: Time interpolation from MODIS Daily Gridded Product

BLUE: MATCH (which uses MODIS as one input)

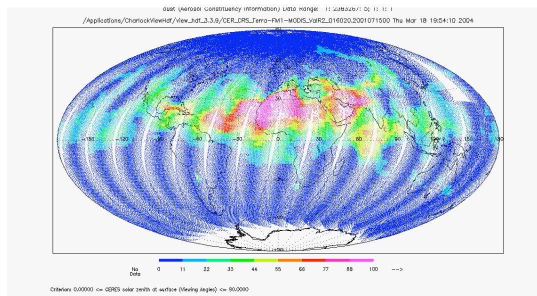
Assignment of aerosol characteristics

MATCH aerosol type	CRS aerosol optics	scale height
dust (0.01-1.0 µm)	1. dust (0.5 µm) Tegen-Lacis	3.0 km
dust (1-10 µm)	2. dust (2.0 µm) Tegen-Lacis	1.0 km
dust (10-20 µm)	2. dust (2.0 µm) Tegen-Lacis	1.0 km
dust (20-50 µm)	2. dust (2.0 µm) Tegen-Lacis	1.0 km
hydrophilic black carbon	3. soot (OPAC)	3.5 km
hydrophobic black carbon	3. soot (OPAC)	3.5 km
hydrophilic organic carbon	4. soluble organic (OPAC)	3.8 km
hydrophobic organic carbon	5. insoluble organic (OPAC)	3.8 km
sulfate	6. sulfate (OPAC)	3.5 km
sea salt	7. sea salt (OPAC)	0.5 km

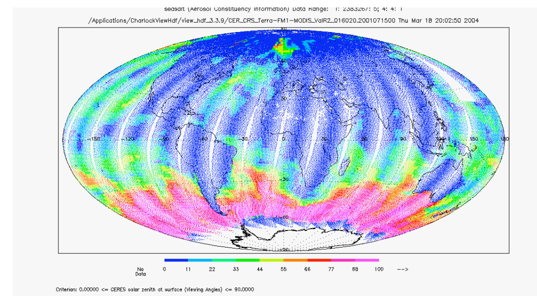
Input from MATCH (Fillmore and Collins) 15 July 2001



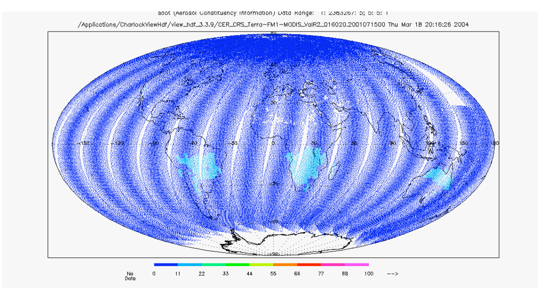
Sulfate (%)



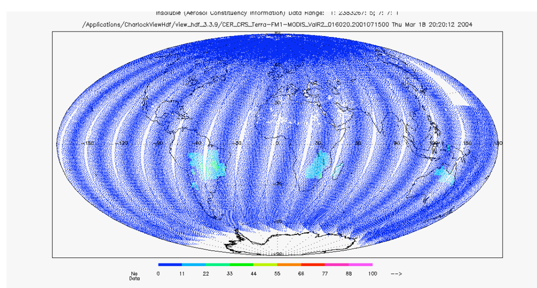
Dust (%)



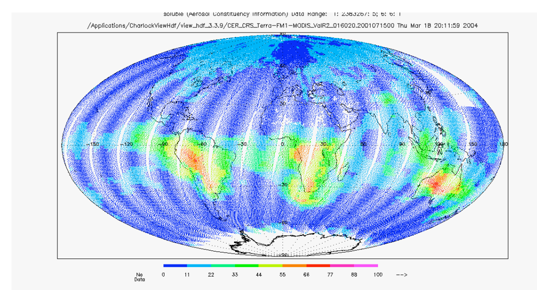
Sea Salt (%)



Soot (%)



Insoluble organic (%)



Soluble organic (%)

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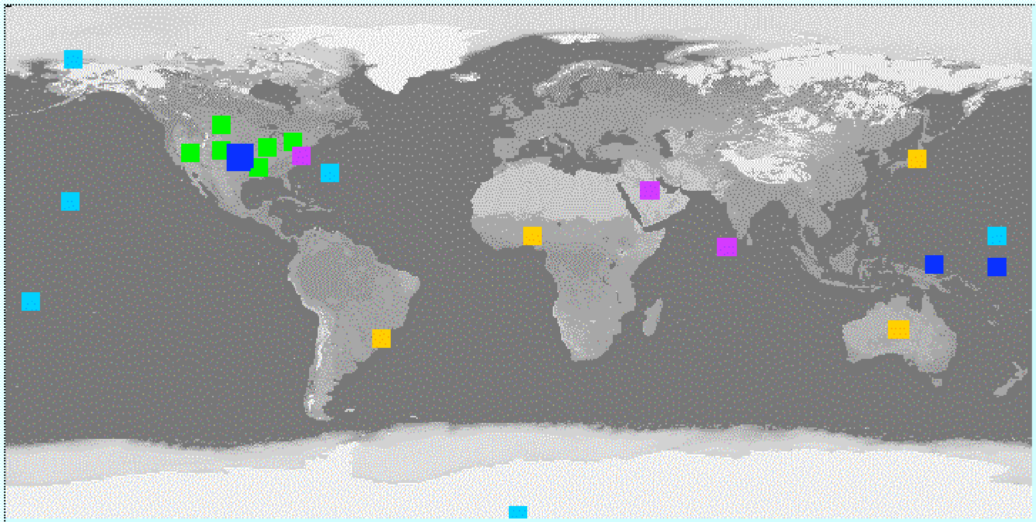
Bookmarks Location: http://www-cave.larc.nasa.gov/cave/cave2.0/Projects.html

Contributing Projects

Home | Surface Observations | CERES CRS Data | CERES ES8 Data | Atmospheric Profiles | Useful Links



ARM – Atmospheric Radiation Measurement

The Department of Energy's Atmospheric Radiation Measurement (ARM) project supplies to CAVE a number of surface observations at 23 different locations. There are 21 sites in and around Kansas and Oklahoma, and two on the islands of Nauru and Manus in the Tropical West Pacific Ocean.

BSRN – Baseline Surface Radiation Measurement

The BSRN project is an international effort to obtain long–term high–quality surface observations of downwelling broadband radiation. We are downloading data for 4 sites around the globe.

CMDL – Climate Monitoring & Diagnostics Laboratory

The National Oceanic & Atmospheric Association (NOAA) CMDL supplies a high quality data set of primarily downwelling radiation from a number of remote sites about the globe.

SURFRAD – Surface Radiation Budget

SURFRAD supplies a complete set of radiation and surface meteorology from 6 sites located within the US. These sites provide a reliable data set of both upwelling & downwelling radiation, and located in a diverse set of surface vegetation types.

Indpendent Sites

www-cave.larc.nasa.gov/cave/

INDOEX – Indian Ocean Experiment

All-sky Untuned Wm-2: Terra Ed2A (ValR2 for review) and TRMM Ed2B (released)

TRMM (low latitude) Edition 2B instantaneous snapshots

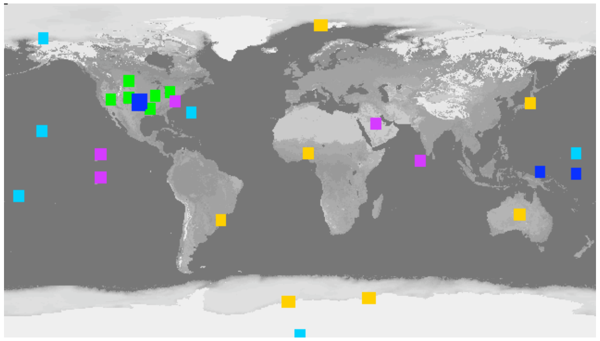
VIRS (sea) and MATCH (uses AVHRR) aerosols

Terra (global) Edition 2A instantaneous snapshots

MODIS (sea and land) and MATCH aerosols; better SW code

Surface (SFC) observations as 30-minute (half hour) intervals

~40 CAVE sites (ARM, BSRN, SURFRAD, COVE)



	Terra			TRMM		
	Observed (Wm-2)	N	Bias (Wm-2)	Observed (Wm-2)	N	Bias (Wm-2)
LW down SFC	290	7727	-5	358	5571	-2
LW up SFC	360	5556	-3	425	3992	-3
SW down SFC	488	3939	9	451	3244	29
SW up SFC	114	2756	-20	92	2348	-13
LW up TOA	222	8028	1	253	6122	-2
SW up TOA	271	3879	2	215	3355	-6

Terra here 6 months in 2001 TRMM here 8 months in 1998

All-sky Untuned Wm-2: Terra Ed2A (ValR2 for review) and TRMM Ed2B (released)

- TRMM (low latitude) Edition 2B instantaneous snapshots
  - VIRS (sea) and MATCH (uses AVHRR) aerosols
- Terra (global) Edition 2A instantaneous snapshots
  - MODIS (sea and land) and MATCH aerosols; better SW code
- Surface (SFC) observations as 30-minute (half hour) intervals
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Surface insolation bias for new Terra (9 Wm-2) is much better than old TRMM (29 Wm-2).

But surface reflection is highly biased in Terra and TRMM.

Terra Ed2A (ValR2 for review) Untuned Bias/RMS for All sky and Clear sky

January, February, March, April, July and October 2001

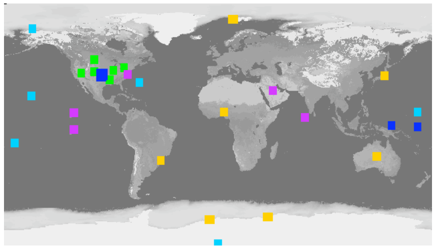
Bias = Mean (Calculation - Observation)

RMS = (1/N)*(SQRT **Σ**(Calculation – Observation)**2)

Surface (SFC) observations as 30-minute (half hour) intervals

~40 CAVE sites (ARM, BSRN, SURFRAD, COVE)

	All sky		Clear sky	
	Bias (Wm-2)	RMS (Wm-2)	Bias (Wm-2)	RMS (Wm-2)
LW down SFC	-5	22	-9	15
LW up SFC	-3	24	1	19
SW down SFC	9	82	0	25
SW up SFC	-20	51	-20	33
LW up TOA	1	9	0	5
SW up TOA	2	28	1	6



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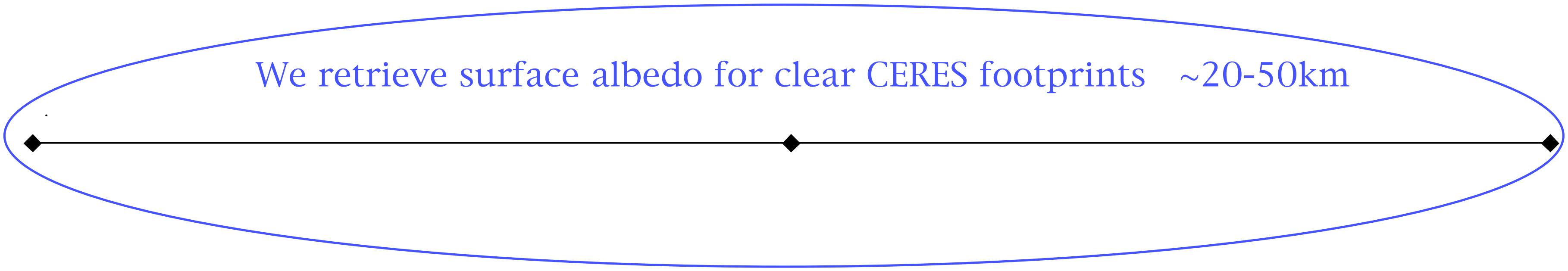
SW up TOA	2	28	1	6

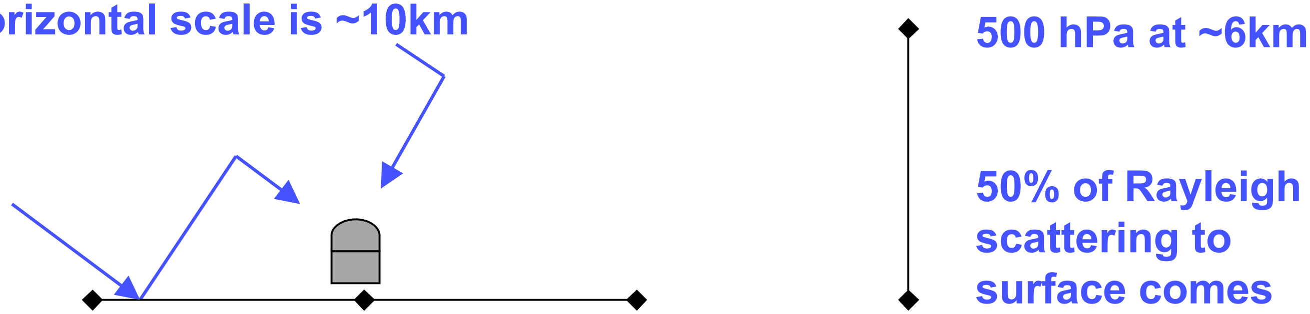
RMS is huge (82 Wm-2) for all-sky SW downwelling at the surface. The surface radiometer is located at a single point in the big ~20-50km footprint. The distance to the centroid (relative position of the surface radiometer) changes every day; so does the footprint size and viewing geometry.

Mismatch of surface albedo and surface insolation in SARB.



Surface insolation measured at a point is affected by surface albedo.

Clear sky: surface albedo impact on insolation is small.
Relevant albedo horizontal scale is ~10km

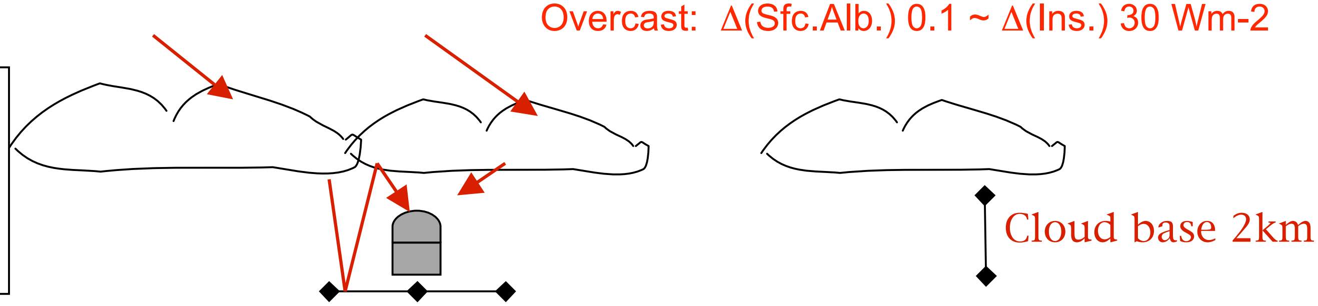


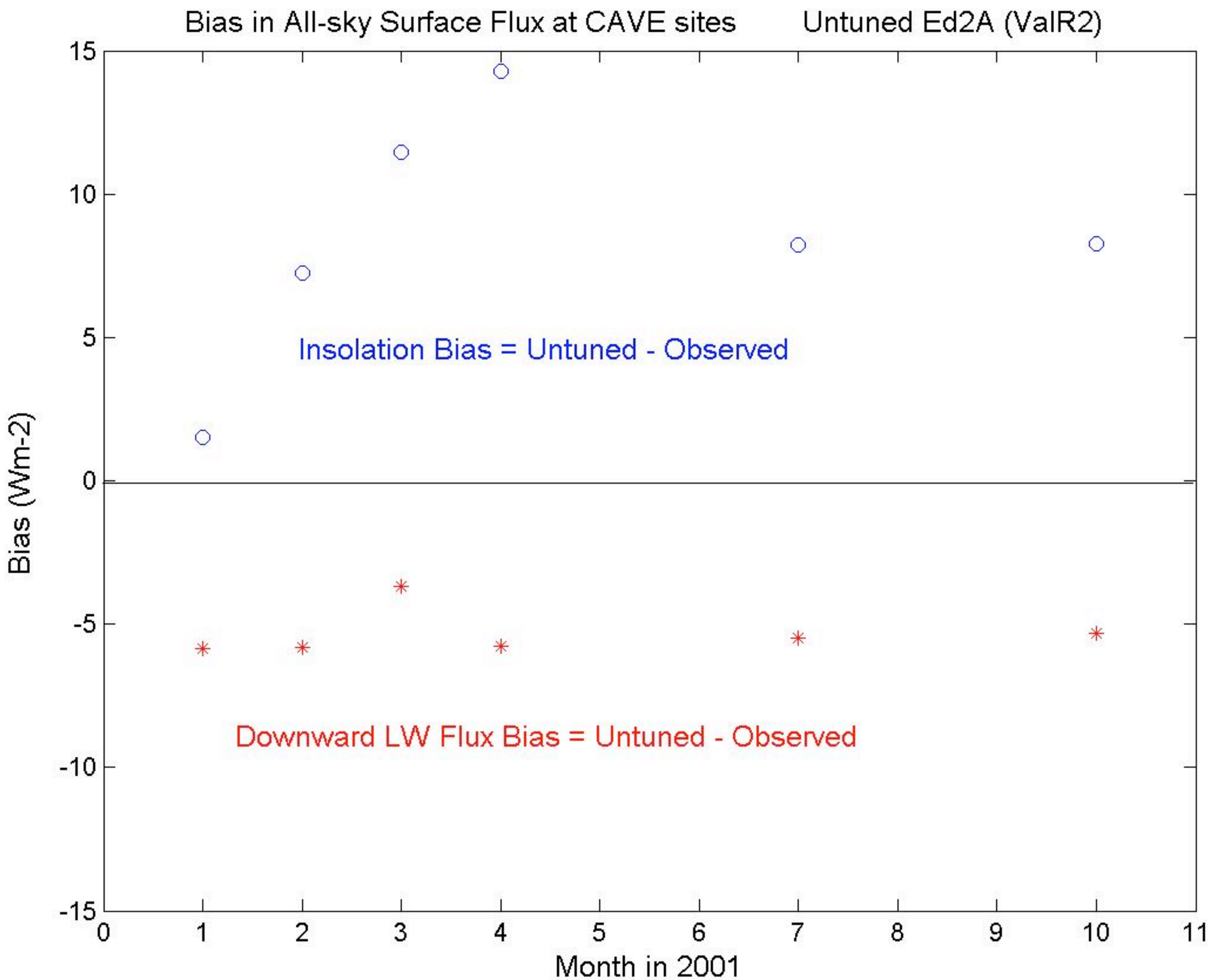
50% of Rayleigh scattering to surface comes from above 5 km

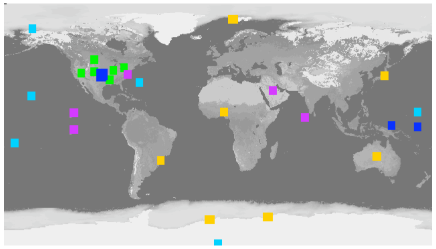
Cloudy sky: surface albedo impact on insolation can be large. Relevant albedo scale is ~twice cloud base height.

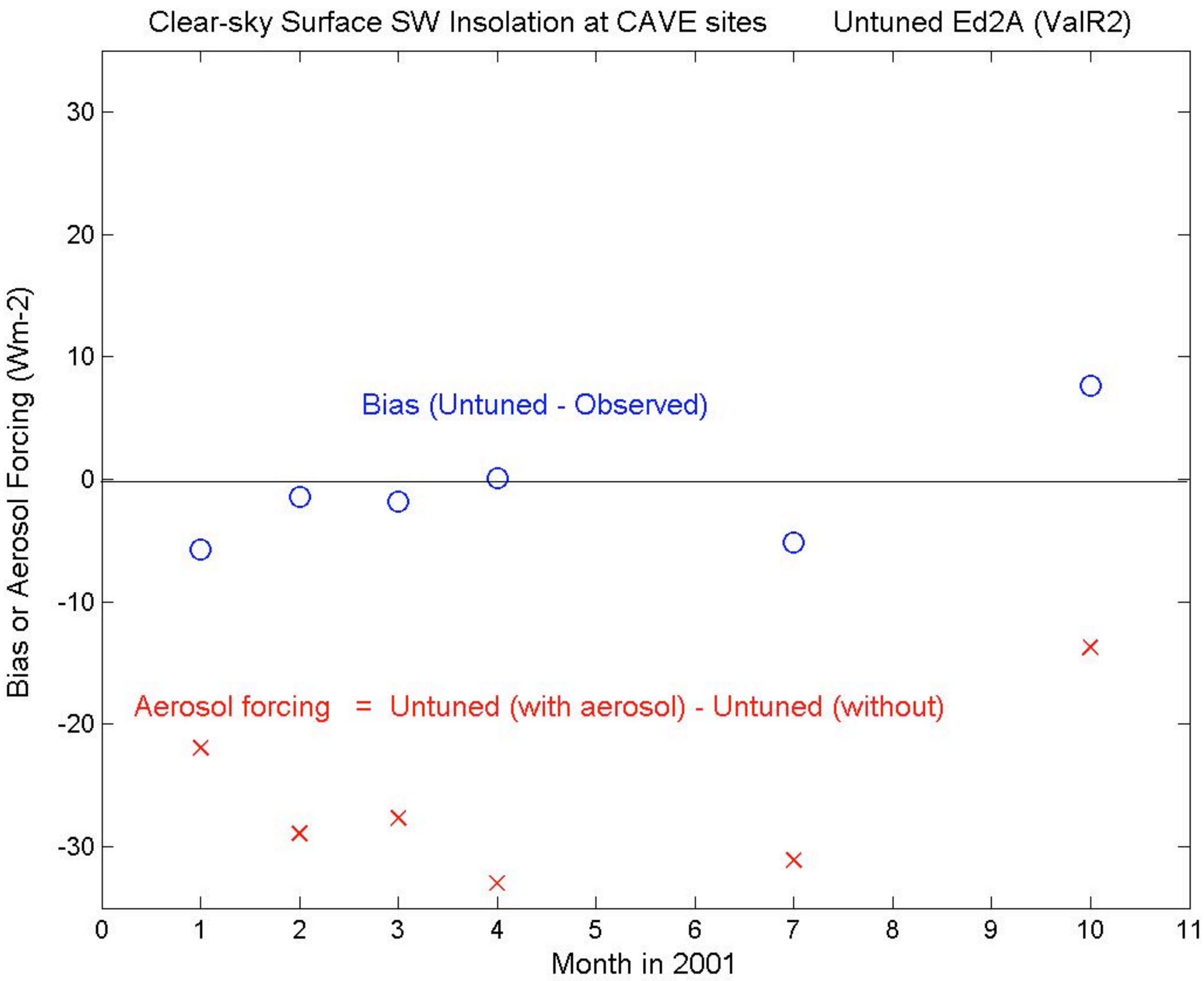
Overcast: Δ(Sfc.Alb.) 0.1 ~ Δ(Ins.) 30 Wm-2

Not a problem at COVE sea platform, where we know the surface albedo.

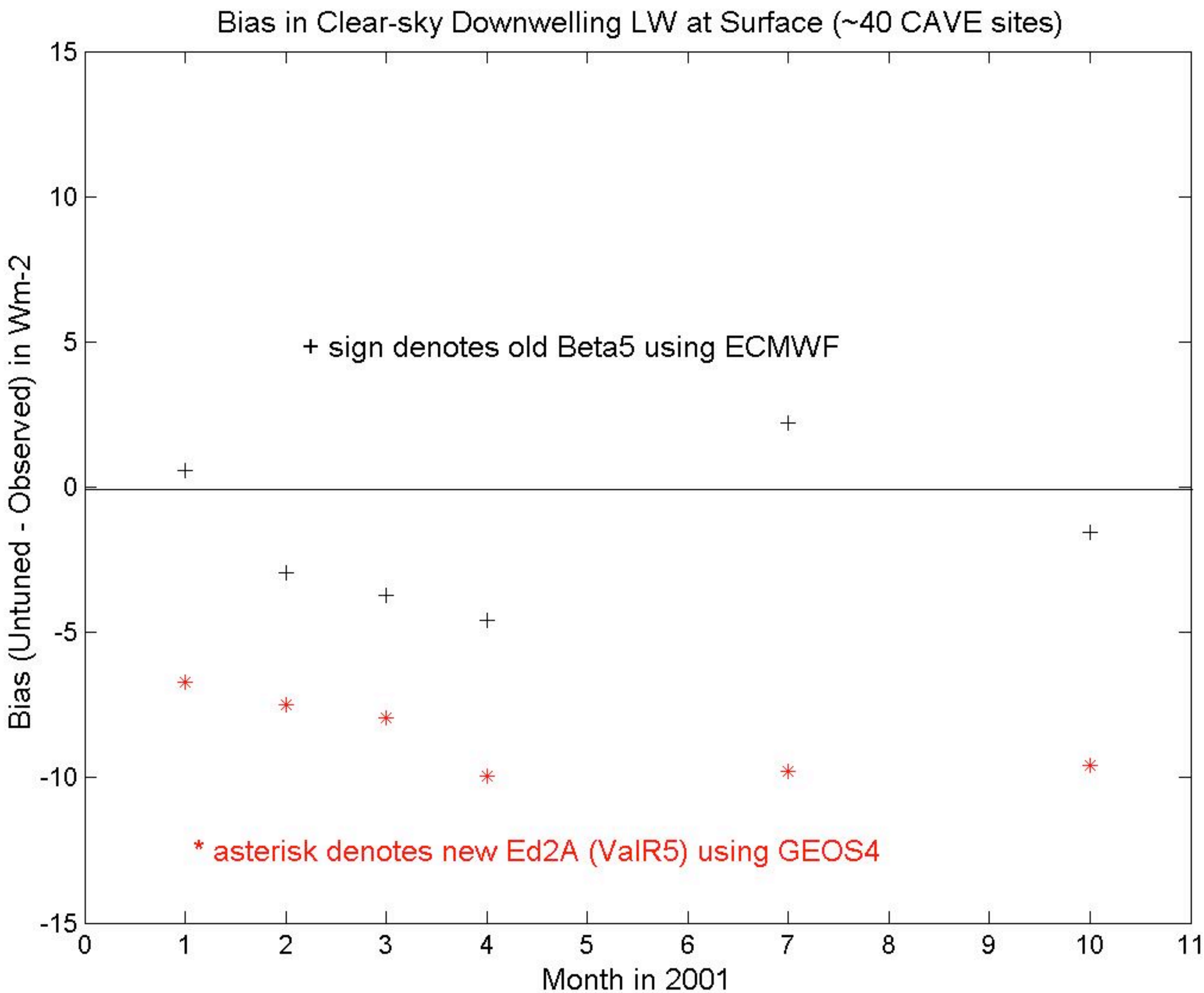



Bias in All-sky Surface Flux at CAVE sites
Untuned Ed2A (ValR2)
Insolation Bias = Untuned - Observed
Downward LW Flux Bias = Untuned - Observed
Bias (Wm-2)
Month in 2001
15
10
5
0
-5
-10
-15
0
1
2
3
4
5
6
7
8
9
10
11

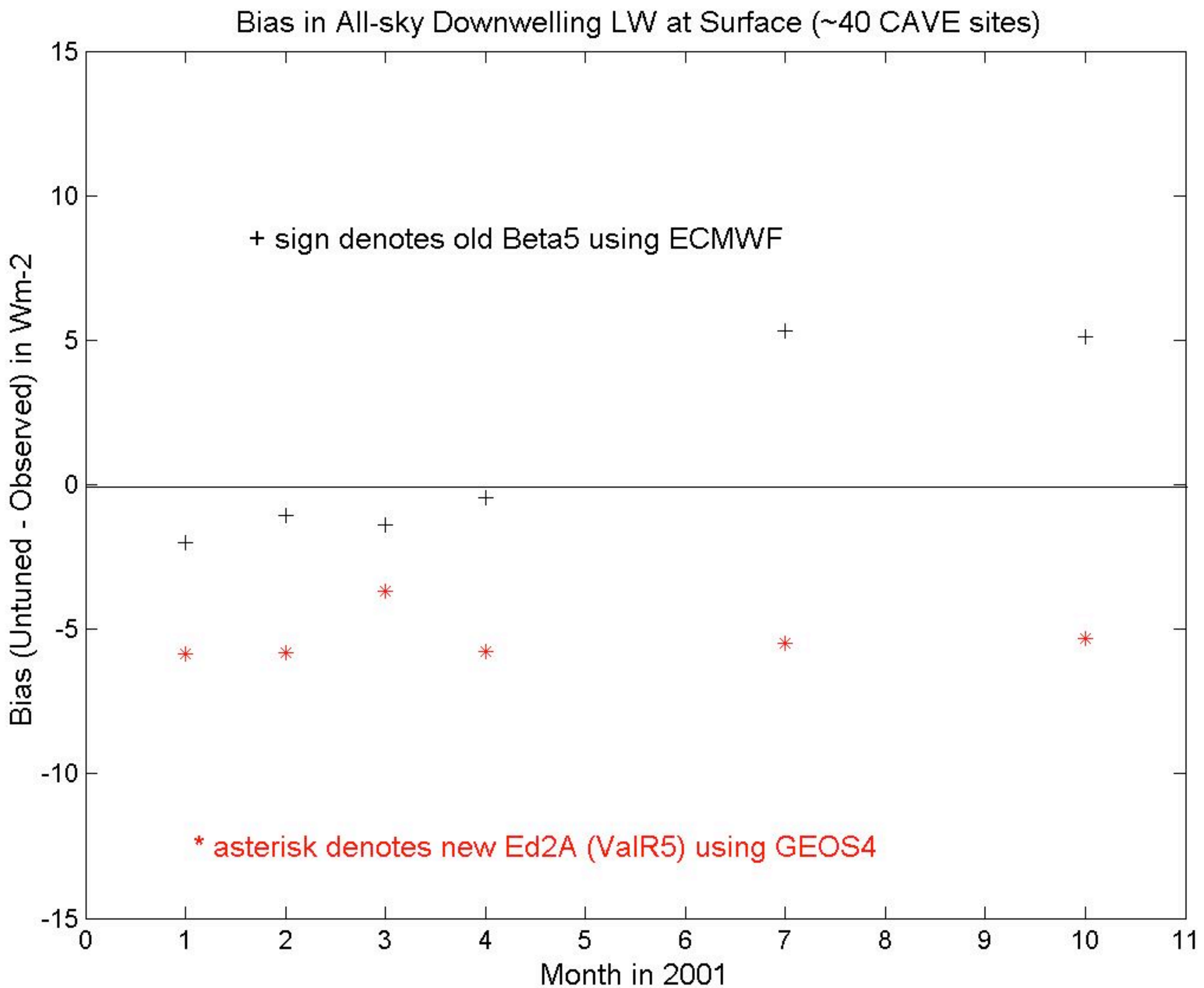




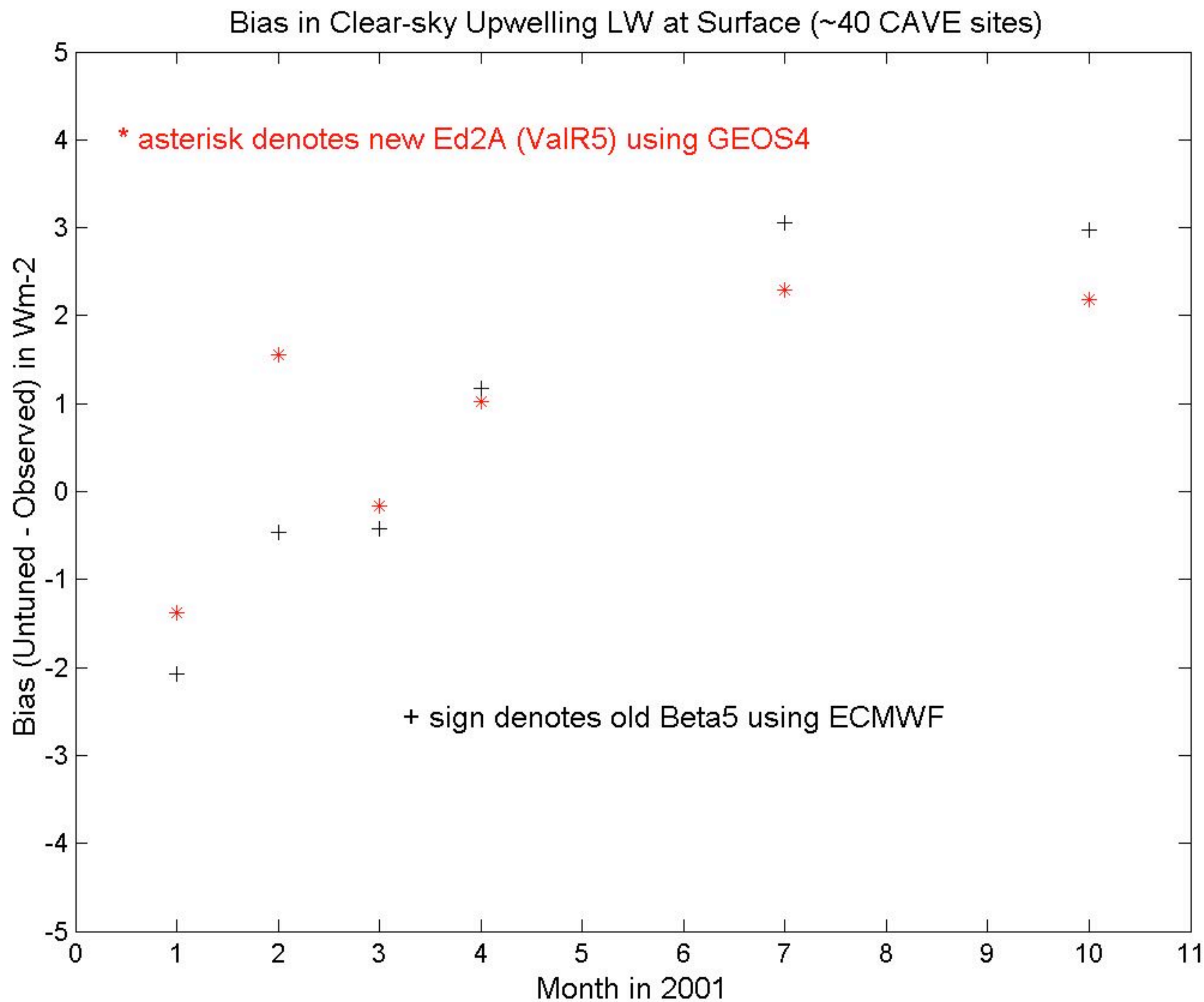
Bias for untuned clear-sky surface insolation is very small when averaged over 40 sites for 6 months. RMS error is 25 Wm-2. Mean aerosol forcing to insolation is -25 Wm-2.



Mean bias for untuned clear-sky downwelling LW at the surface is -8.70 Wm-2 in the new Terra Ed2A (ValR2) using GEOS4. The old Terra Beta5 using ECMWF was better for downwelling LW.



The bias in downwelling LW at the surface is reduced for all-sky conditions in the new Terra Ed2A (ValR2) using GEOS4, but the earlier version (Beta5 using ECMWF) was slightly better. Is GEOS4 too moist near the surface?



Both the new Ed2A (ValR2) using GEOS4 and the old Beta5 using ECMWF have small biases for clear-sky upwelling LW at the surface. Over land, the skin temperature for clear footprints is taken from the Cloud WG, which uses MODIS.

Impact of Constrainment (Tuning) at TOA for Terra Ed2A (ValR2)

January, February, March, April, July and October 2001

Bias = Mean (Calculation - Observation)

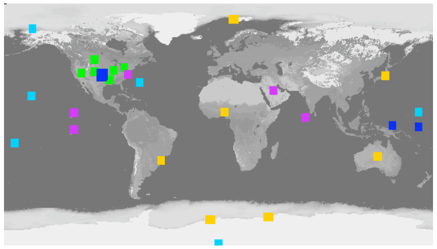
RMS = (1/N)*(SQRT Σ(Calculation – Observation)**2)

Surface (SFC) observations as 30-minute (half hour) intervals

~40 CAVE sites (ARM, BSRN, SURFRAD, COVE)

All sky fluxes	**Untuned** Bias (Wm-2)	**Untuned** RMS (Wm-2)	**Tuned** (Constrained) Bias (Wm-2)	**Tuned** (Constrained) RMS (Wm-2)
LW down SFC	-5	22	-5	21
LW up SFC	-3	24	-3	23
SW down SFC	9	82	10	85
SW up SFC	-20	51	-19	51
LW up TOA	1	9	1	5
SW up TOA	2	28	1	13

Clear tuning: Adjust PW, UTH, skin temperature, land albedo/ocean AOT
Cloudy tuning: Adjust cloud fraction, optical depth, altitude



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By design, constrainment (or tuning) reduces the RMS error, and generally the bias, with respect to TOA observations. It has little impact on the mean bias at the surface. The comparison with surface radiometric data is a totally "cold" test for CERES SARB.

Gross, global scale evaluation at TOA only

Table of raw mean TOA parameters for CRS Terra Edition 2

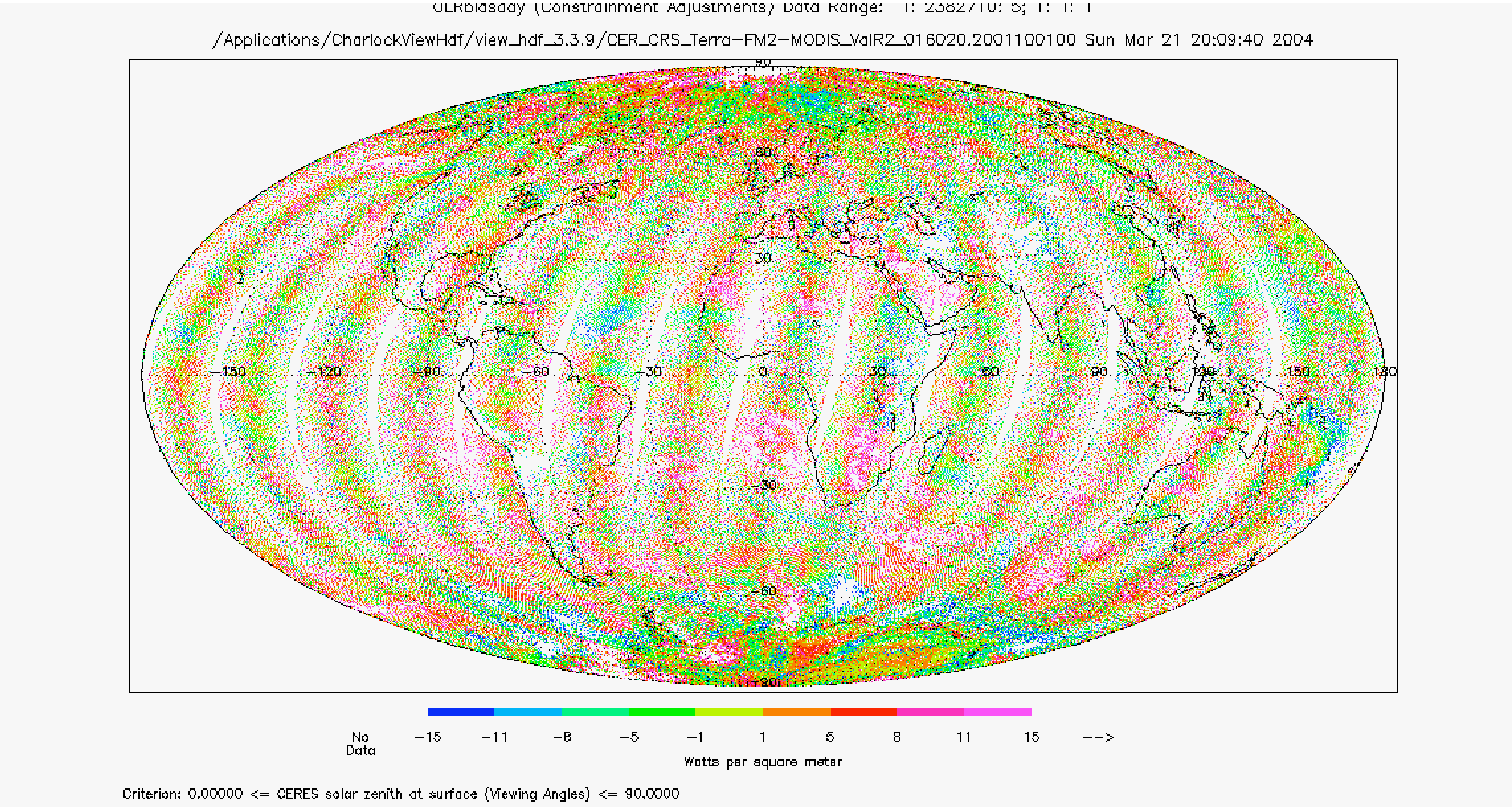
SW statistics are daylight-only means

Other statistics are 24-hour means

	January 2001	April 2001	July 2001	October 2001
SW reflected in Wm-2	252.6	239.7	223.4	243.8
Untuned bias (std. dev.)	7.3 (23.2)	5.0 (23.0)	5.7 (22.4)	6.1 (23.8)
Tuned bias (std. dev.)	1.1 (10.9)	0.6 (10.6)	2.0 (10.4)	0.6 (10.3)
OLR in Wm-2	223.1	222.0	229.1	222.7
Untuned bias (std. dev.)	0.1 (8.0)	0.4 (8.7)	0.2 (8.1)	0.3 (8.5)
Tuned bias (std. dev.)	0.2 (4.5)	0.5 (4.8)	0.2 (4.3)	0.4 (4.5)
Window 8-12μm in Wm-2	57.3	57.6	61.1	58.1
Untuned bias (std. dev.)	0.7 (3.6)	0.6 (3.7)	0.6 (3.8)	0.5 (3.5)
Tuned bias (std. dev.)	0.7 (2.3)	0.6 (2.6)	0.6 (2.4)	0.5 (2.4)
LW broadband radiance in Wm-2sr-1	72.9	72.6	75.0	72.8
Untuned bias (std. dev.)	-0.2 (2.6)	-0.1 (2.8)	-0.1 (2.6)	-0.1 (2.8)
Tuned bias (std. dev.)	-0.2 (1.5)	-0.0 (1.6)	-0.1 (1.4)	-0.1 (1.5)

Bias in Daytime OLR (Untuned calculation - Observed)   1 October 2001

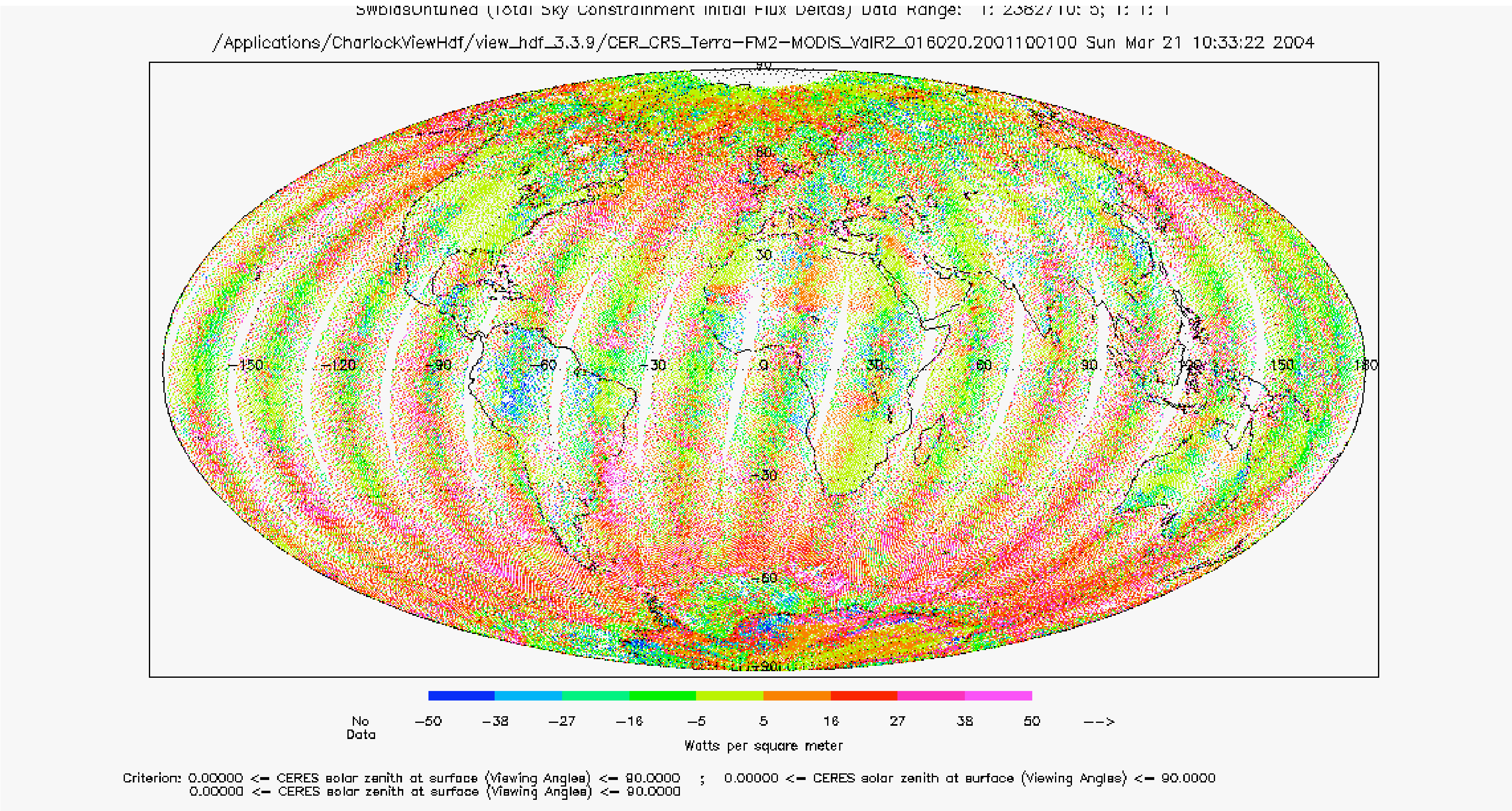
scale -15 to +15 Wm-2



Bias for 24-hour OLR is 0.53 Wm-2 (1.14 Wm-2 for footprints with less than 5% cloud)

Bias in Reflected SW at TOA (Untuned calculation - Observed)   1 October 2001

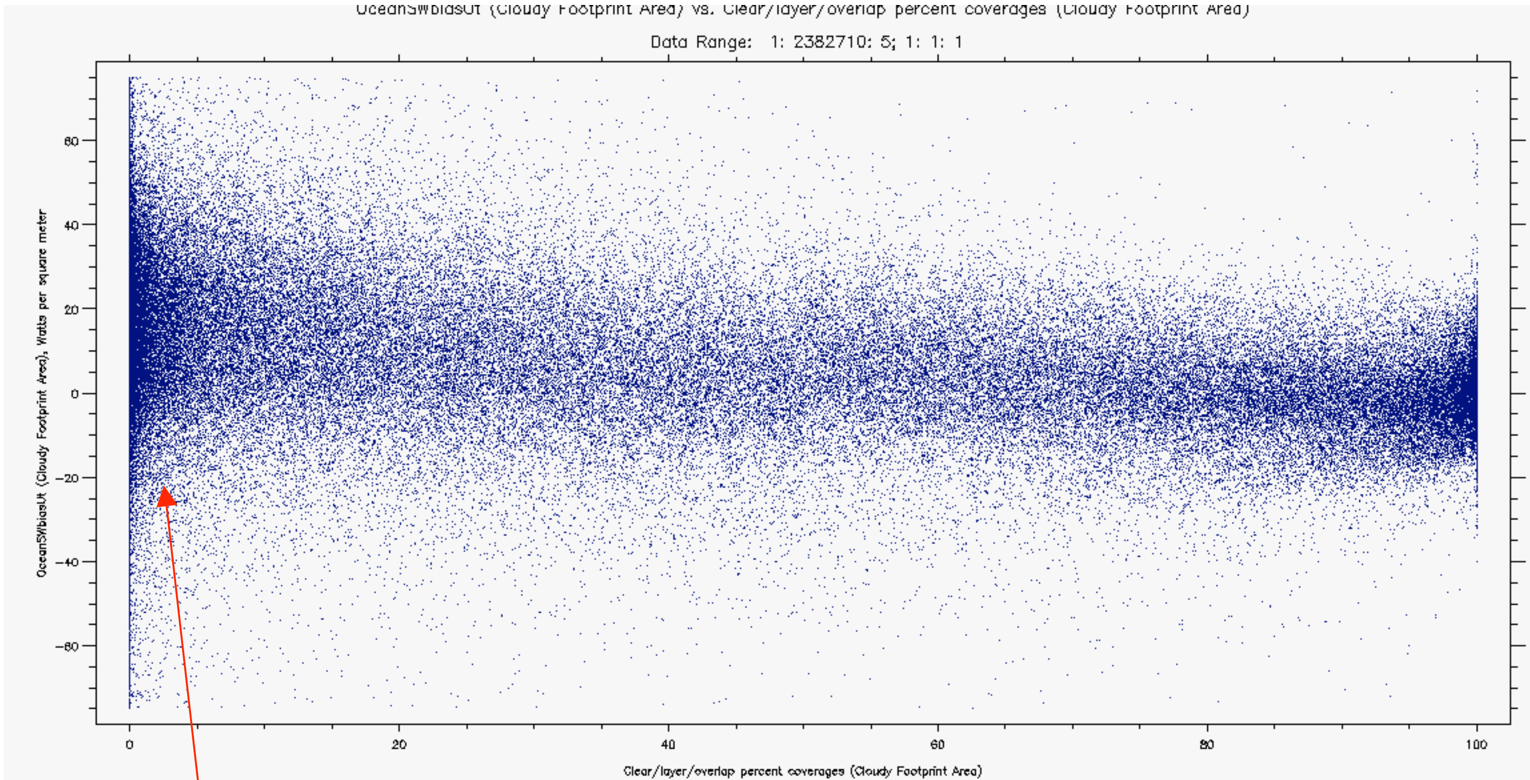
scale -50 to +50 Wm-2



Biases over the ocean: Overcast (10.4 Wm-2) Partly cloudy (5.1 Wm-2) Clear (0.1 Wm-2)

SW bias (Untuned - Observed) for **Ocean Only** versus Clear Percentage (1 Oct 2001)

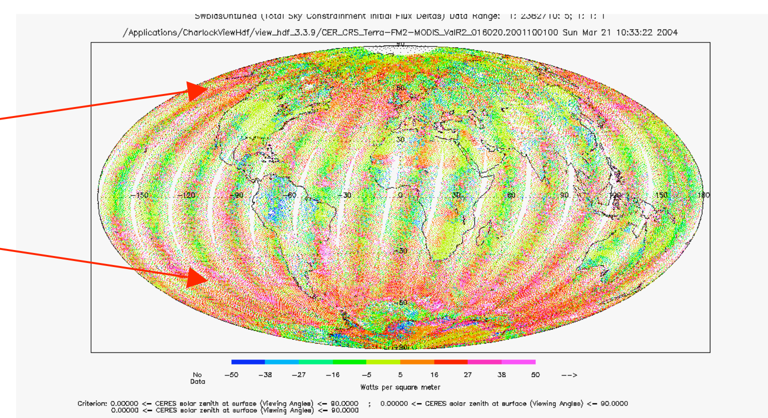
Bias (Wm-2)



Clear Percentage of Footprint (%)

Lots of overcast

and bias

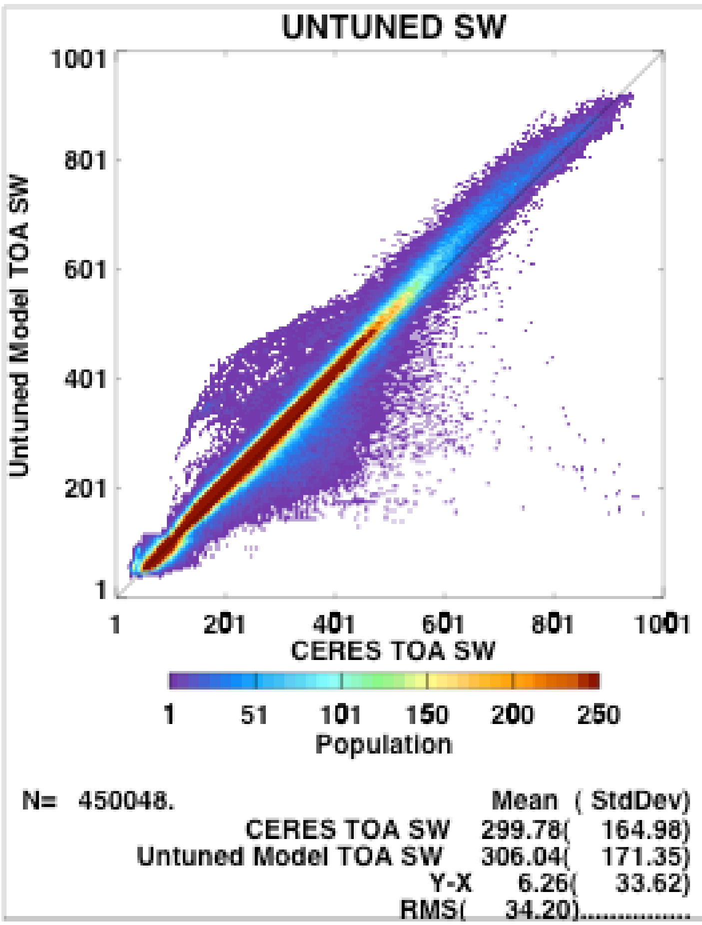


Overcast Ocean: Untuned SW (y) vs. Observed SW (x) for 15 July 2001

Seiji's Gamma weighted 2-stream reduces RMS error:

Beta 5 (old SW code)

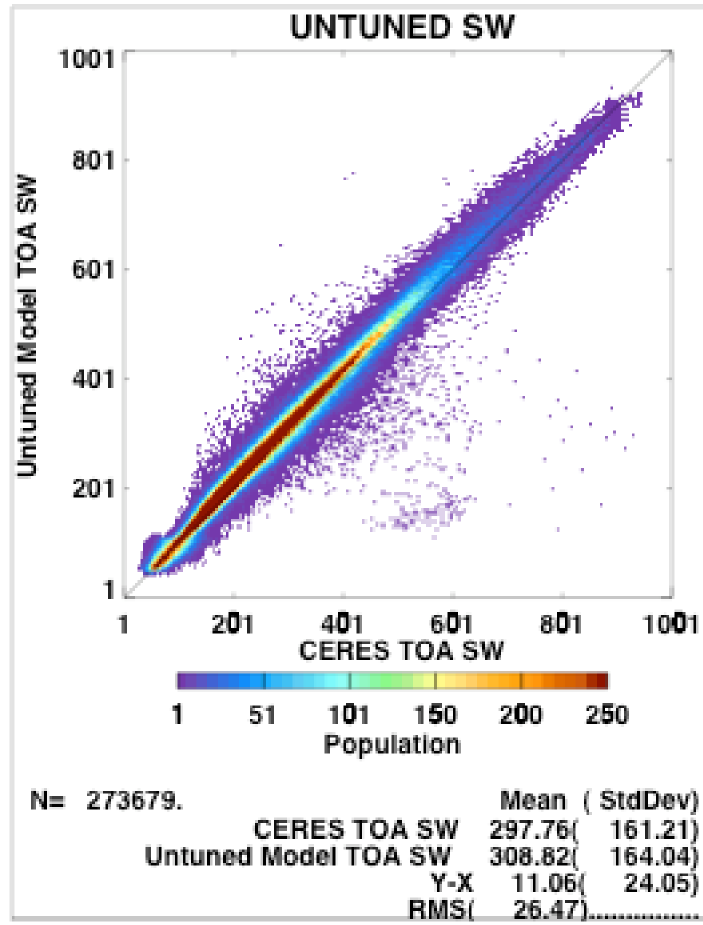
bias/rms = 6/34 Wm-2



Tuned bias/rms = 0/14 Wm-2

ValR2/Ed2a (new SW code)

bias/rms = 11/26 Wm-2



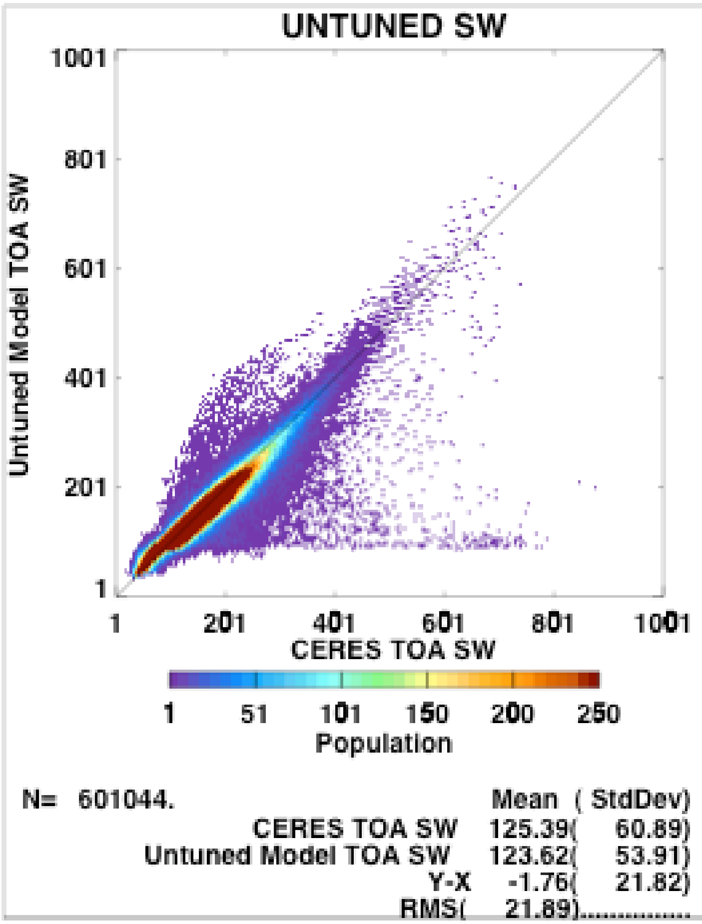
Tuned bias/rms = 2/10 Wm-2

1.2
4.12 4.98

Partly Cloudy Ocean: Untuned SW (y) vs. Observed SW (x) for 15 July 2001

Beta 5 (old SW code)

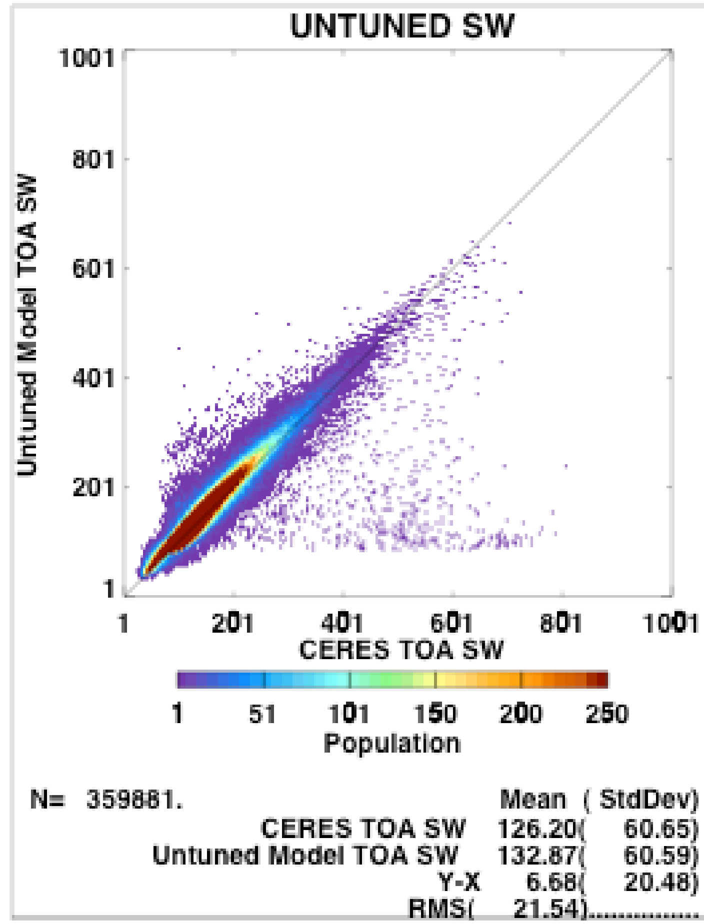
bias/rms = -2/22 Wm-2



Tuned bias/rms = 1/11 Wm-2

ValR2/Ed2a (new SW code)

bias/rms = 7/22 Wm-2

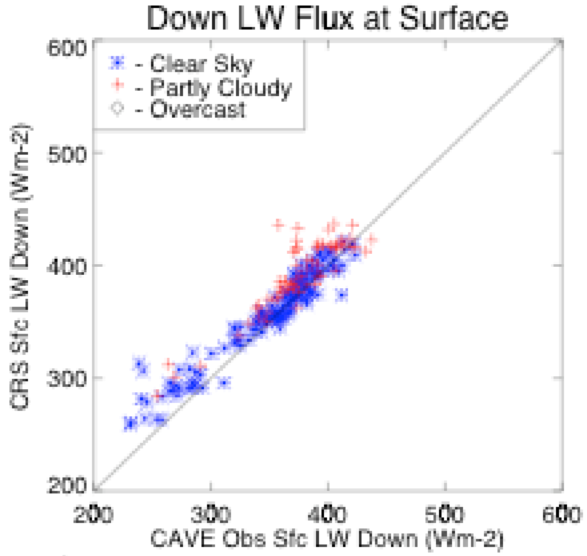


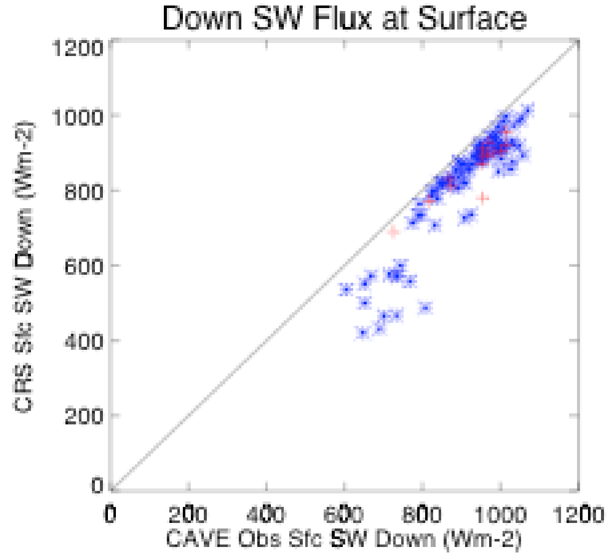
Tuned bias/rms = 4/11 Wm-2

1.2
4.12 4.98

Assumed single scattering albedo for dust is too small. This causes huge biaes for SW over deserts.

Saudi Solar Village, (NREL) Untuned CRS 2001





All Sky

	Obs Mean	N	Bias CRS-Obs	Std Dev	RMS	Obs Frc All-Clr	Mod Frc All-Clr	Forcing RMS
LW Dn Sfc	357.00	195.00	10.71	16.06	19.27	-7.76	2.96	19.27
LW Up Sfc	494.83	194.00	4.13	21.05	21.40	--------	--------	--------
SW Dn Sfc	907.17	103.00	-82.48	59.63	101.60	81.00	-1.48	101.60
SW Up Sfc	242.39	30.00	-31.86	30.60	43.82	--------	--------	--------
LW Up TOA	310.36	195.00	-10.71	12.39	16.35	8.18	-2.53	16.35
SW Up TOA	317.80	103.00	5.74	31.04	31.42	-4.27	1.48	31.42

Clear Sky MODIS

	Obs Mean	N	Bias CRS-Obs	Std Dev	RMS	Dir Bias CRS-Obs	Dif Bias CRS-Obs	AOT Frc Clr-Prs
LW Dn Sfc	348.28	130.00	7.68	14.72	16.55	--------	--------	27.30
LW Up Sfc	499.18	129.00	12.80	19.66	23.40	--------	--------	--------
SW Dn Sfc	903.36	89.00	-84.34	62.46	104.74	--------	--------	-135.50
SW Up Sfc	233.63	24.00	-30.73	33.75	45.12	--------	--------	--------
LW Up TOA	318.04	130.00	-13.15	12.40	18.04	--------	--------	-13.65
SW Up TOA	314.64	89.00	16.98	8.65	19.04	--------	--------	-44.25

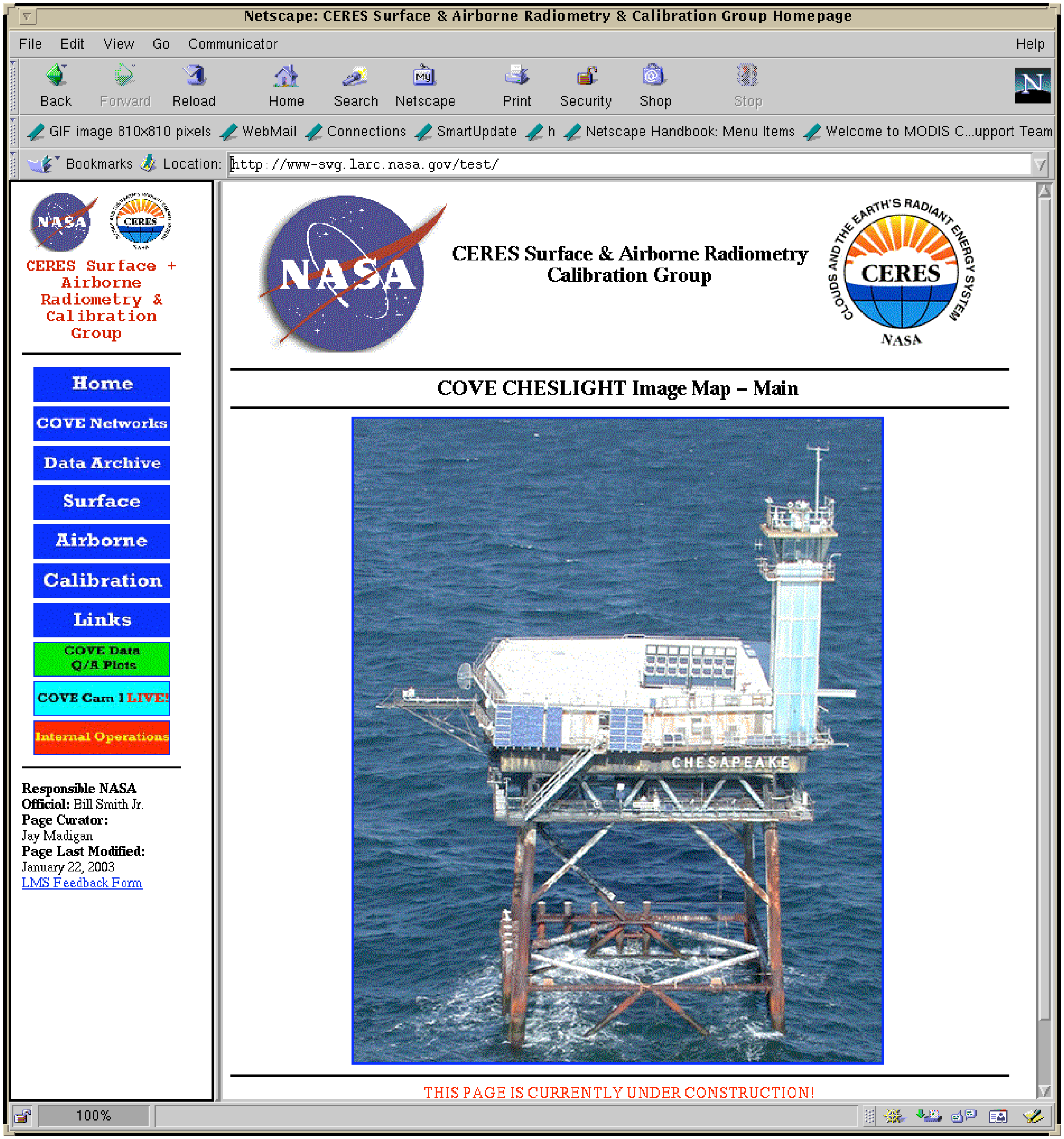
COVE Ken Rutledge

CERES Ocean
Validation Experiment

Rigid sea platform
Continuous
Long-term
Well calibrated
AERONET aerosol
NOAA wind and waves
BSRN surface radiation
looks DOWN at sea

At COVE:
SW up (time mean)
approximately equals
SW up (space mean)

Various short/medium
term measurements:
SP1A for upwelling
SW spectral radiance
Ocean optics (ODU)

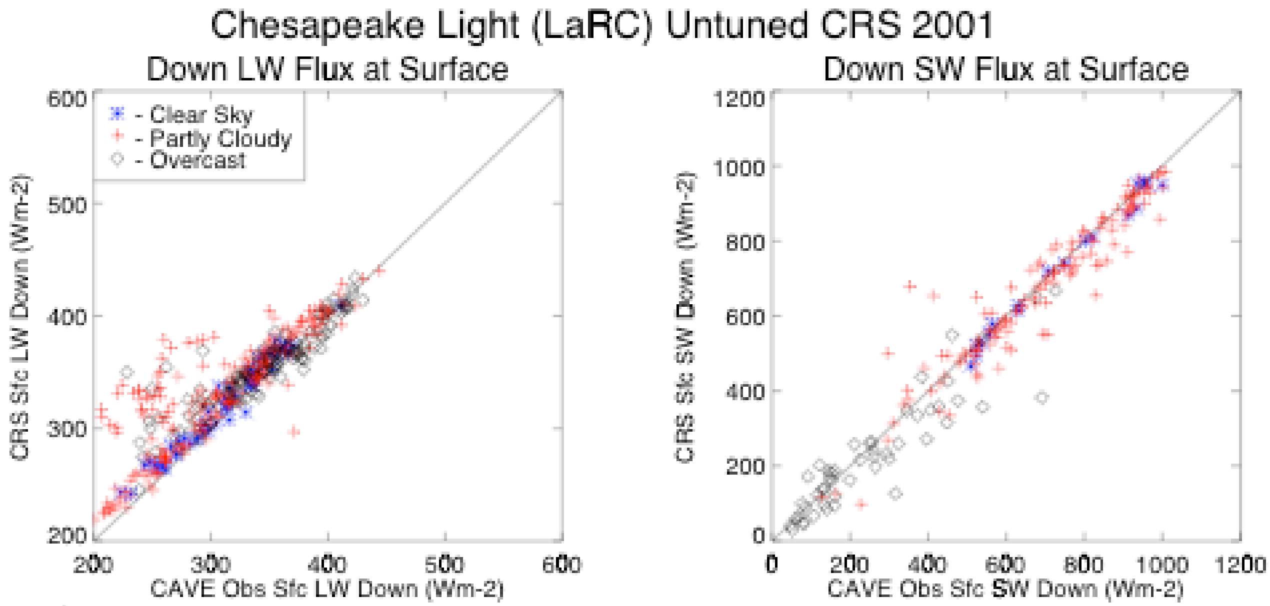


SW for all-sky conditions of CERES multi-angle Field of View (FOV) Terra overpasses at COVE from 7.8.01 to 8.2.01.
Observations, model biases, and modeled forcings.

CERES FOV Average **(several snapshots on each of 18 days)**	N FOVs	TOA Wm-2	Surface Wm-2	Direct Wm-2	Diffuse Wm-2
Observations	282	180	812	546	267
Model (MODIS τ)					
Model-Observations	282	-1	-3	-20	17
RMS error	282	21	61	101	73
Model (AERONET τ)					
Model-Observations	282	-1	1	2	-1
RMS error	282	20	75	115	72
Day Average *(1 sample = mean of snapshots during 1 day)*	*N days*				
Observations	*18*	*166*	*821*	*555*	*266*
Model (MODIS τ)					
Model-Observations	*18*	*-1*	*-4*	*-23*	*20*
RMS error	*18*	*16*	*68*	*115*	*75*
Model Forcings (MODIS τ)					
Cloud forcing	*18*	*82*	*-94*	*-212*	*118*
Aerosol forcing to clear sky	*18*	*10*	*-32*	*-148*	*115*
Aerosol forcing to all sky	*18*	*8*	*-31*	*-106*	*74*

This off line test uses CERES Programmed Azimuth Pattern for Scan.

This routine production uses along-track CERES scans. SW biases are large. Is this due to sunglint? LW is biased because of the SST and sounding reported over this coastal site.



All Sky

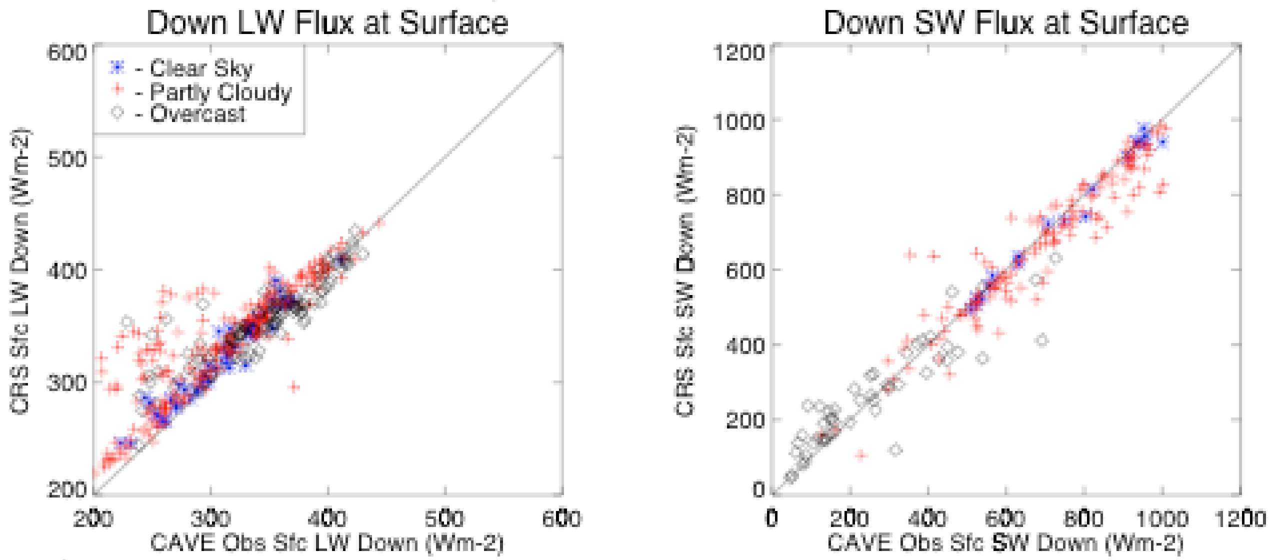
	Obs Mean	N	Bias CRS-Obs	Std Dev	RMS	Obs Frc All-Clr	Mod Frc All-Clr	Forcing RMS
LW Dn Sfc	318.64	395.00	18.69	26.74	32.59	6.87	25.56	32.59
LW Up Sfc	370.17	228.00	37.56	30.35	48.24	--------	--------	--------
SW Dn Sfc	588.06	204.00	-17.24	62.86	65.03	-126.10	-143.34	65.03
SW Up Sfc	28.23	203.00	-2.16	16.00	16.11	--------	--------	--------
LW Up TOA	239.60	401.00	2.87	8.76	9.21	-31.61	-28.75	9.21
SW Up TOA	211.77	206.00	7.83	25.64	26.75	119.99	127.83	26.75

Clear Sky MODIS

	Obs Mean	N	Bias CRS-Obs	Std Dev	RMS	Dir Bias CRS-Obs	Dif Bias CRS-Obs	AOT Frc Clr-Prs
LW Dn Sfc	310.28	52.00	9.44	8.60	12.71	--------	--------	1.45
LW Up Sfc	397.42	23.00	15.38	28.33	31.69	--------	--------	--------
SW Dn Sfc	747.85	19.00	-12.80	21.10	24.19	--------	--------	-27.71
SW Up Sfc	34.21	19.00	-3.45	8.70	9.14	--------	--------	--------
LW Up TOA	274.26	52.00	4.09	6.68	7.78	--------	--------	-0.65
SW Up TOA	79.07	19.00	12.40	12.71	17.51	--------	--------	10.78

Tuning over COVE does reduce the bias for surface insolation.

Chesapeake Light (LaRC) Tuned CRS 2001



All Sky

	Obs Mean	N	Bias CRS-Obs	Std Dev	RMS	Obs Frc All-Clr	Mod Frc All-Clr	Forcing RMS
LW Dn Sfc	318.64	395.00	19.81	27.08	33.52	5.47	25.28	33.52
LW Up Sfc	370.17	228.00	35.09	29.89	46.05	--------	--------	--------
SW Dn Sfc	588.06	204.00	-14.51	65.99	67.40	-122.10	-136.61	67.40
SW Up Sfc	28.23	203.00	-1.94	16.01	16.09	--------	--------	--------
LW Up TOA	239.60	401.00	2.14	5.24	5.65	-30.69	-28.55	5.65
SW Up TOA	211.77	206.00	2.97	10.16	10.56	119.39	122.36	10.56

Clear Sky MODIS

	Obs Mean	N	Bias CRS-Obs	Std Dev	RMS	Dir Bias CRS-Obs	Dif Bias CRS-Obs	AOT Frc Clr-Prs
LW Dn Sfc	310.28	52.00	12.77	10.71	16.60	--------	--------	1.11
LW Up Sfc	397.42	23.00	6.54	17.18	18.03	--------	--------	--------
SW Dn Sfc	747.85	19.00	-9.01	22.69	23.85	-17.52	12.25	-19.30
SW Up Sfc	34.21	19.00	-3.90	8.37	9.03	--------	--------	--------
LW Up TOA	274.26	52.00	1.82	3.23	3.68	--------	--------	-0.55
SW Up TOA	79.07	19.00	7.24	6.05	9.33	--------	--------	6.48

Concluding remarks on Terra Edition 2A / ValR2

CRS Terra ValR2 is acceptable for release as Terra Edition 2A

Bias in surface insolation is much reduced from 1998 TRMM Edition 2B

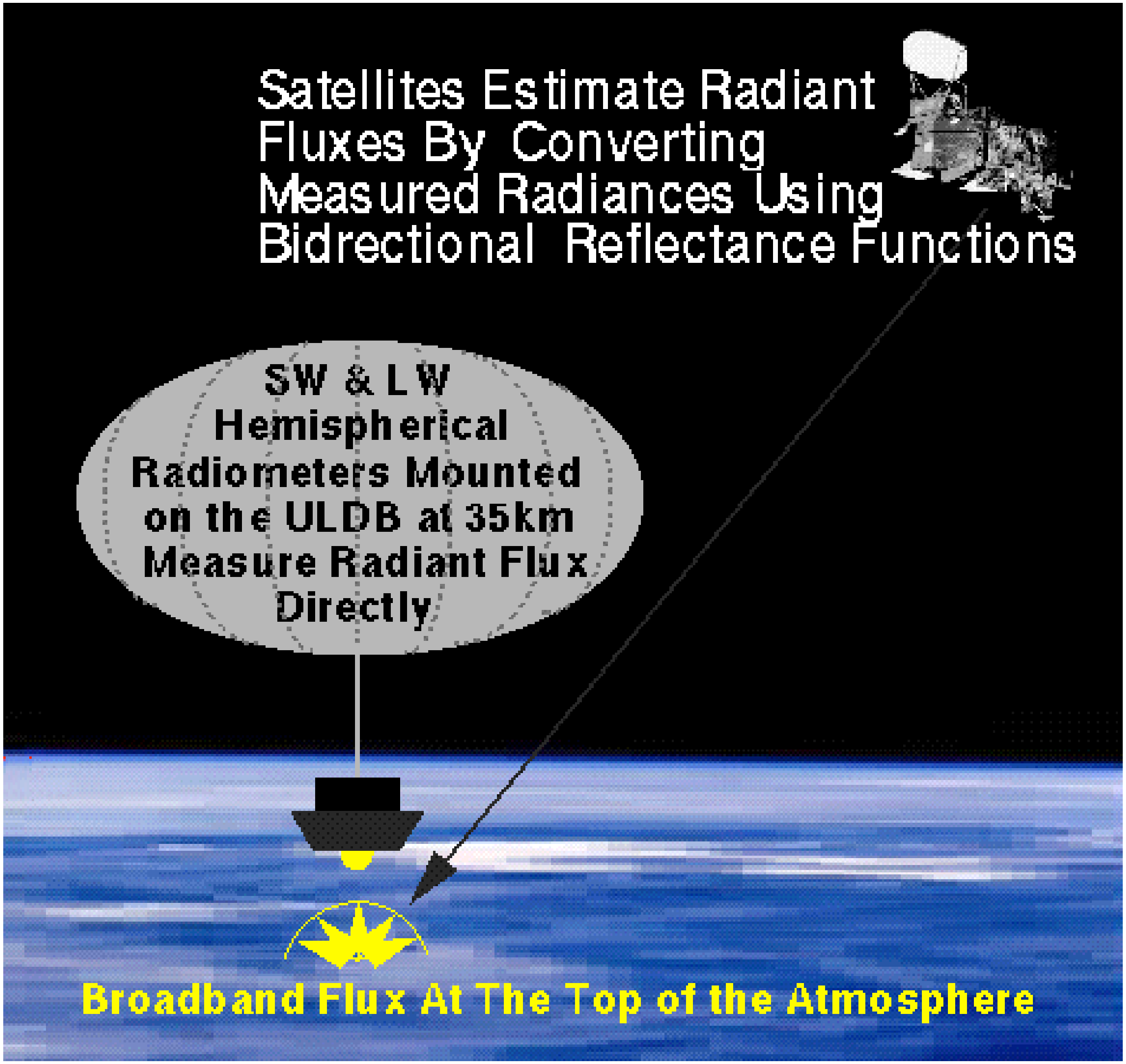
While aerosol forcing is generally interesting, it’s a disaster with dust.
Our dust absorbs too much. Our retrieved surface albedo over desert is not realistic. Dust absorption will be reduced in the next version.

TOA SW bias is slightly higher than TRMM because Terra covers the overcast-laden baroclinic zones.

Bias for surface downwelling LW is larger than TRMM. This may be due to GEOS4 soundings (vs. ECMWF in TRMM).

Click “Balloon” from CAVE URL

Wenying Su’s deployement of Haeffelin modified radiometers



Launch #1 (from Alice Springs) crashed. We prepare for # 2.

NCAR Colleagues: TRMM CRS Edition 2B (Surface and Atmosphere Radiation Budget SARB) is already available for Jan-Aug 1998.

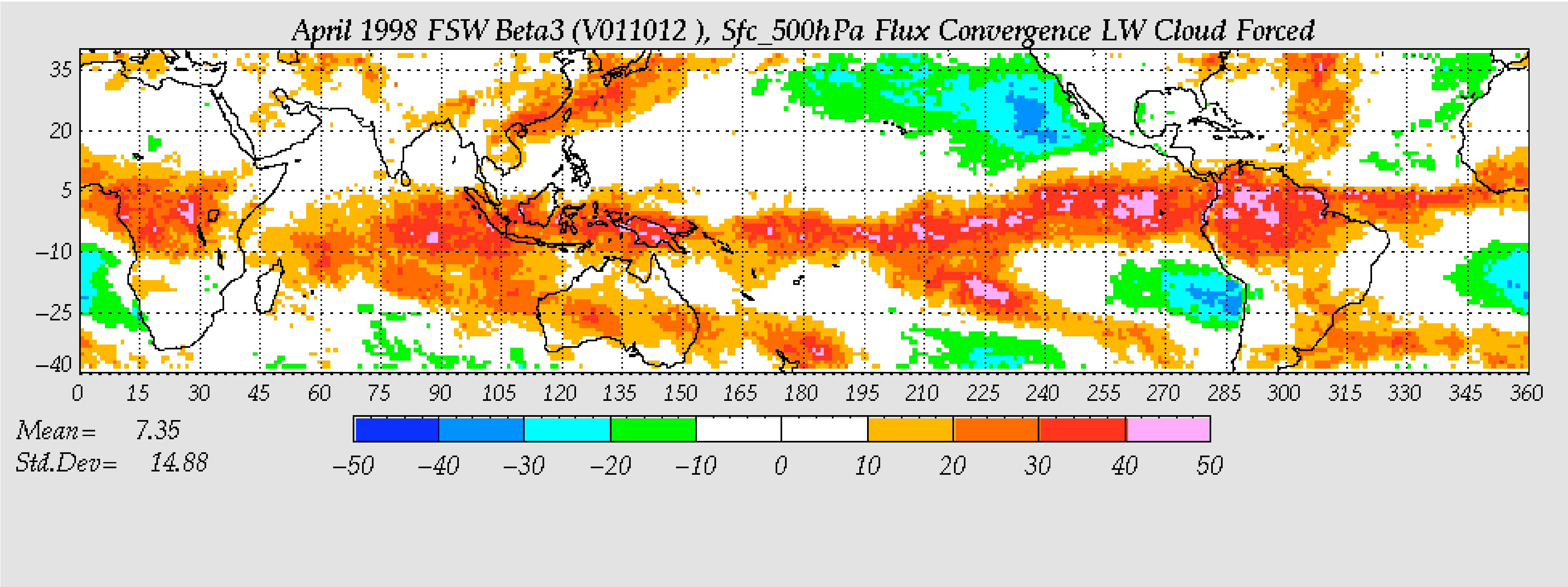
This slide and next show what can be done with TRMM SARB.

Cloud forcing to LW "convergence" (Surface to 500hPa) April 1998

All sky LW convergence is generally negative.

Gridded "FSW Beta3"= hourly mean of ungridded "CRS Ed2B"

Gridding here does not account for diurnal effects, but should give reasonable estimate for LW during this month.



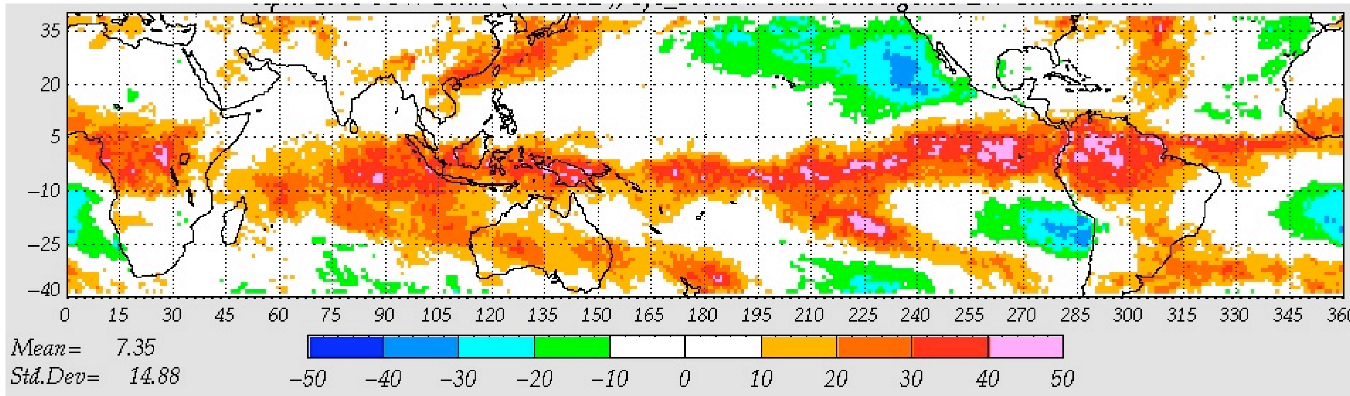
Cloud Forcing to

LW Convergence

(Surface-500hPa)

crude mean = 7 Wm-2

range -50 to +50 Wm-2



Much of the LW cooling occurs in the lower troposphere.

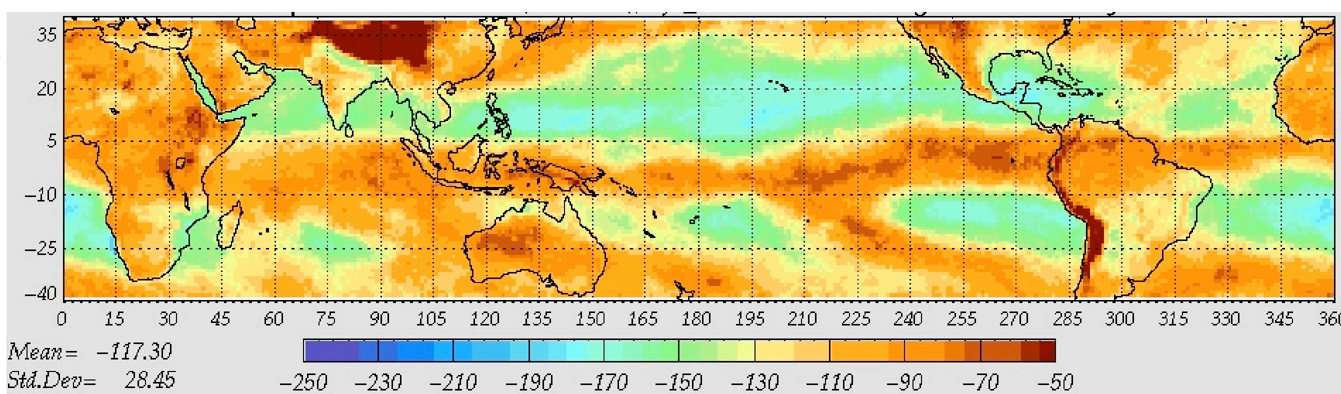
Clouds (above) account for little of the gross mean cooling (the all-sky convergence below), but clouds strongly affect the geographical variation.

Relationship to dynamics and latent heating on the next page…

All Sky LW Convergence (Surface-500hPa)

crude mean = -117 Wm-2

range -170 to -70 m-2

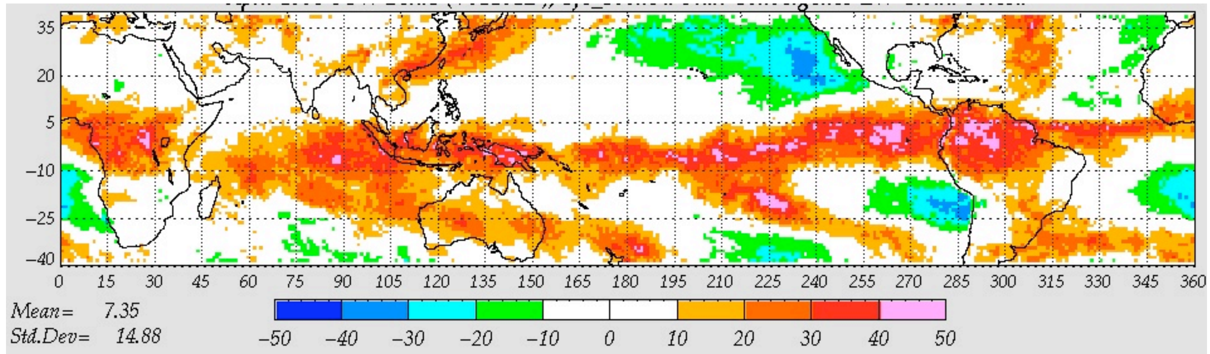


Cloud Forcing

LW Conv Sfc-500hPa

crude mean = 7 Wm-2

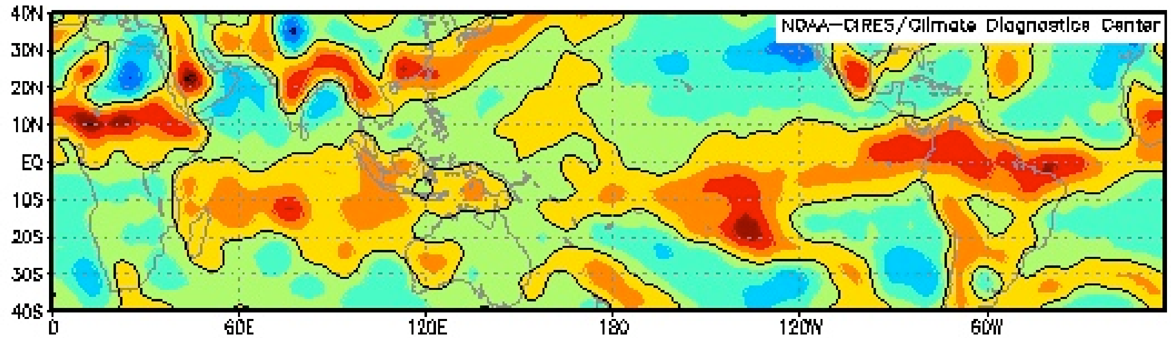
range -50 to +50 Wm-2



Omega at 700 hPa

red = ascent

NCEP/NCAR April 98

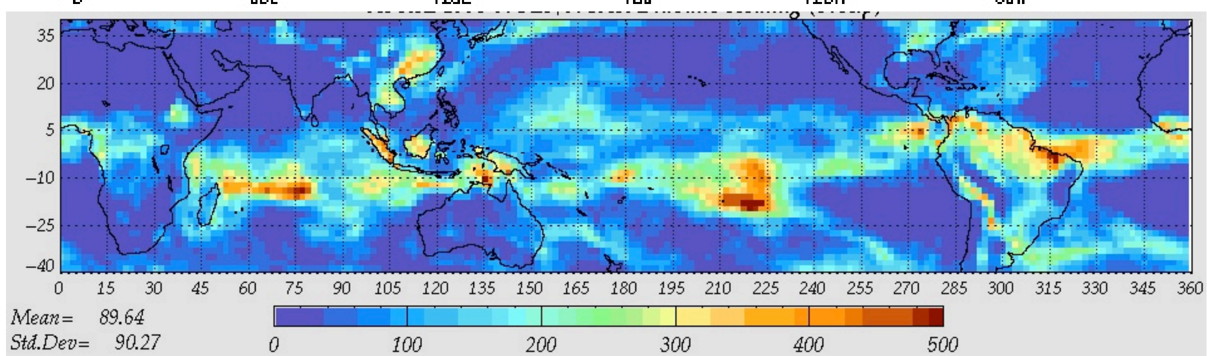


Precipitation expressed

as Diabatic Heating

mean = 89 Wm-2

range 0 to 500 Wm-2



All Sky

LW Conv Sfc-500hPa

crude mean = -117 Wm-2

range -170 to -70 m-2