CERES CLOUD PROPERTY RETRIEVALS

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NASA Clouds and Earth's Radiant Energy System (CERES) Cloud Products

Monitor Earth's radiation budget (ERB) at a higher accuracy with instruments on *TRMM*, *Terra*, & *Aqua*

- Relate cloud properties to the radiation budget

- Develop new bidirectional reflectance models for interpreting broadband radiance measurements

- Derive surface and atmospheric radiation budgets & the top-of-atmosphere ERB

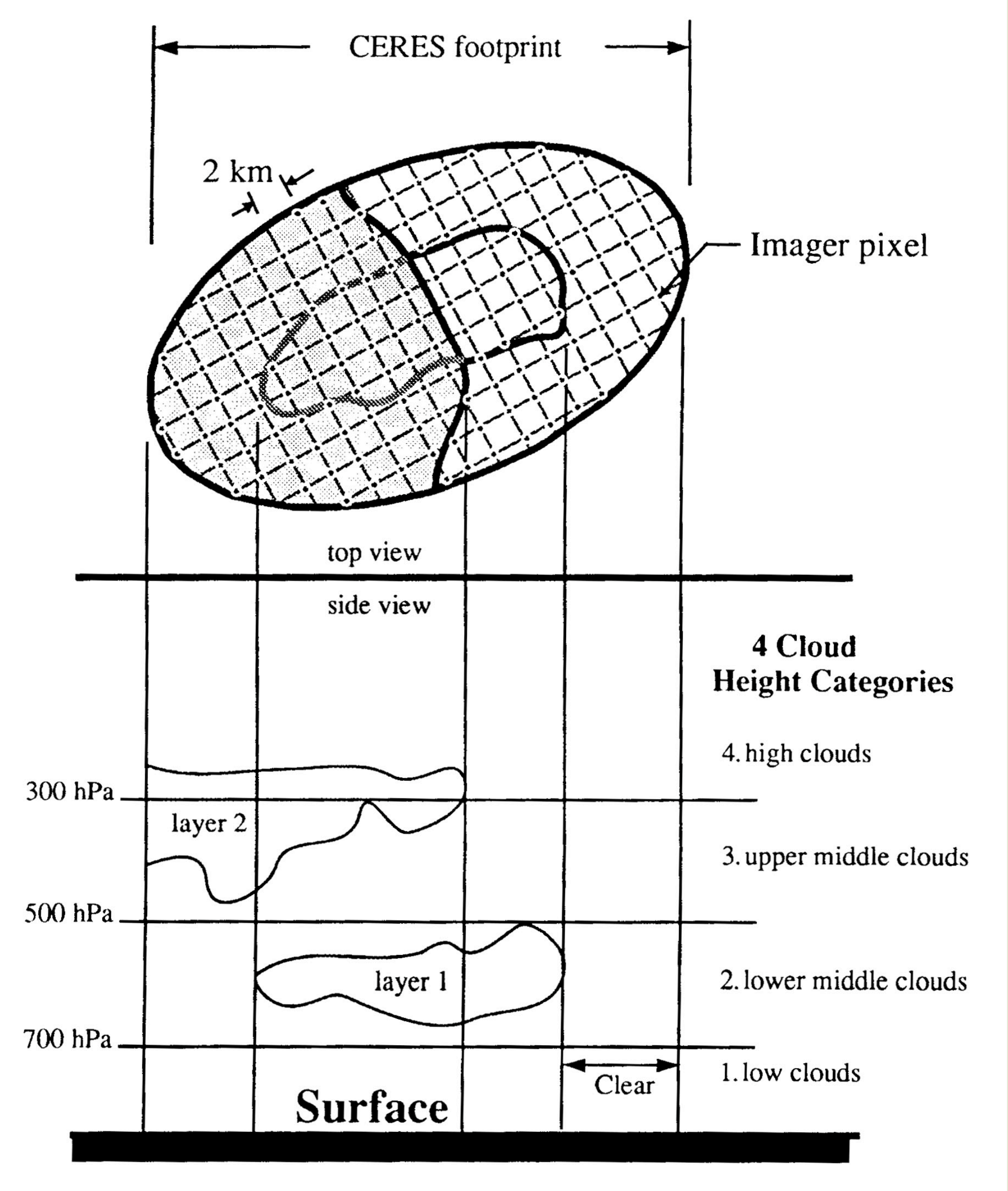
- Provide data to initialize & validate climate & weather prediction models

BASIC APPROACH

CERES Matched Cloud-Radiation Data

• Determine cloud properties from imager data (2 km)

• Convolve & average imager cloud properties into CERES footprints (10 - 50 km)



METHODOLOGY

- **Classify each imager pixel as clear or cloudy**
  - determine the confidence of the classification (good, weak,glint, haze)

- **Retrieve cloud micro- and macrophysical cloud properties**
  - reclassify if no retrievals result (~4% of cloudy pixels)

- **Combine imager cloud properties broadband fluxes from satellite-observed radiances**
  - convolve imager pixel results into CERES sensor footprint
  - select anisotropic correction models
  - compute shortwave & longwave fluxes

DATA

- TRMM VIRS 2-km pixels Domain: 37°S - 37°N
  - 2-30 overpasses per month at all times of daylight
- MODIS 1-km pixels (sampled to 2 km) Domain: Global
  - 2 overpass/day (night-day), more over poles
- Input
  - 0.65 & 1.6 reflectances
  - 3.7, 10.8, and 12-μm brightness temperatures
  - ECMWF T(z), q(z), O_3(z) each 6 hr (3-hr skin temperatures)
  - Elevation, water %, ice/snow, IGBP type
- Results
  - averages on 1.0° grid & individual CERES footprints (~ 10 km)
  - some pixel-level output also available

CERES CLOUD PROPERTIES

1 SSF PIXEL w/CERES FLUXES
(SSF = Single Scanner Footprint)

AMOUNT	F
EFFECTIVE RADIATING TEMP	Tc
EFFECTIVE HEIGHT, PRESSURE	Zc, pc
TOP PRESSURE	p_t
THICKNESS	h
EMISSIVITY	ϵ
PHASE (0 - 2)	P
WATER DROPLET EFFECTIVE RADIUS	re
OPTICAL DEPTH	τ
LIQUID WATER PATH	LWP
ICE EFFECTIVE DIAMETER	De
ICE WATER PATH	IWP

OTHER DERIVED PARAMETERS FROM CLEAR PIXELS

- CLEAR-SKY ALBEDOS (0.6 & 1.6 μm)
- CLEAR-SKY TEMPERATURES (3.7, 11, & 12 μm)
- SKIN TEMPERATURE
- AEROSOL OPTICAL THICKNESS (ocean only)
- SURFACE EMISSIVITY (3.7, 8.5, 11, & 12 μm)

CALIBRATION

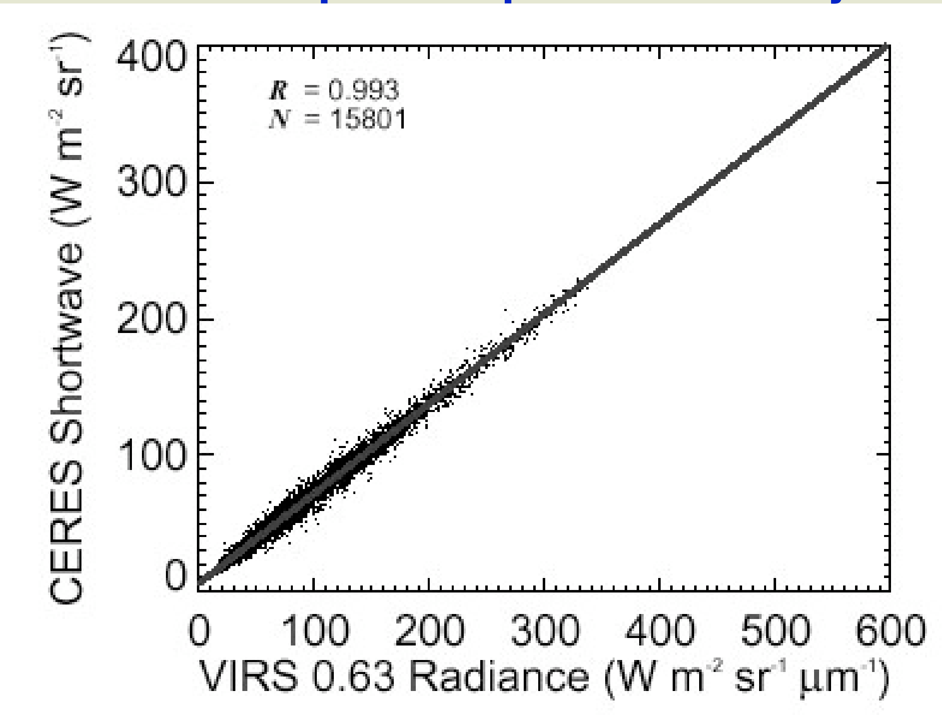
- **Extensive ongoing intercalibration effort**
  - intercalibrate VIRS & MODIS;
  - determine stability by comparing imagers to CERES
  - examine all channels of interest (**0.6, 0.86, 1.6, 3.7-3.9, 10.8, 12 μm**)

    theoretically account for expected inter-satellite spectral differences
  - use statistics to reduce noise and angular/time matching errors

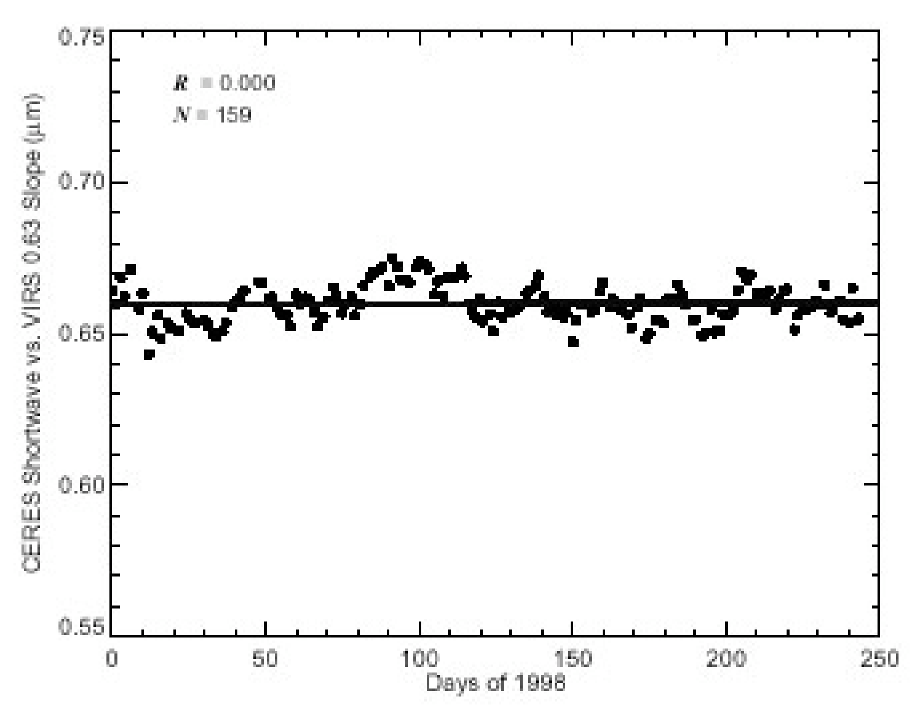
- **Intercalibrate other satellites for CERES & other projects**
  - link all considered satellites to references (VIRS or MODIS)
  - *GOES*-7, 8, 9, 10, 11, 12 (1993 - present)
  - AVHRR: *NOAA*-9,10, 11, 12, 14, 15, 16, 17 (1985 - present)
  - *GMS*-5, *Meteosat*-7

USE CERES BROADBAND TO MONITOR TRENDS IN IMAGER CHANNELS

Compute slope for each day



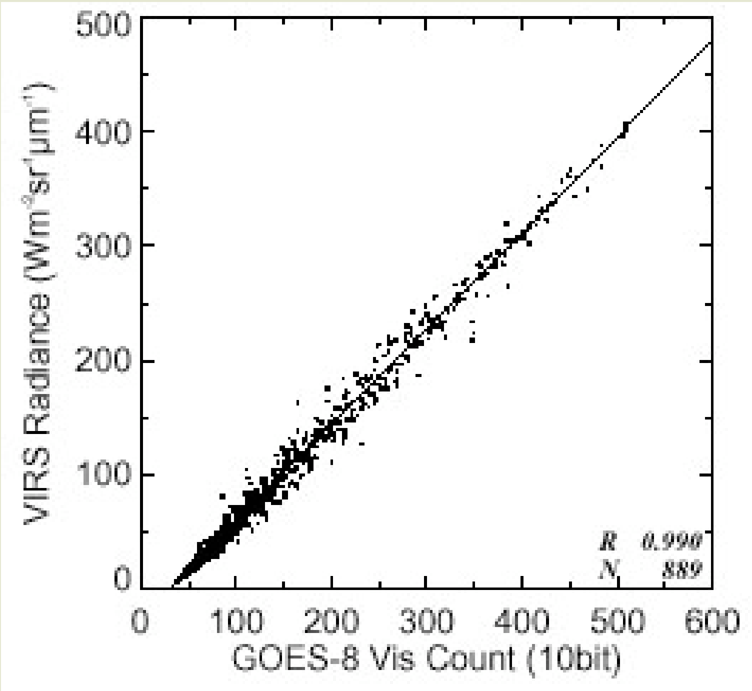
Monitor slope variation



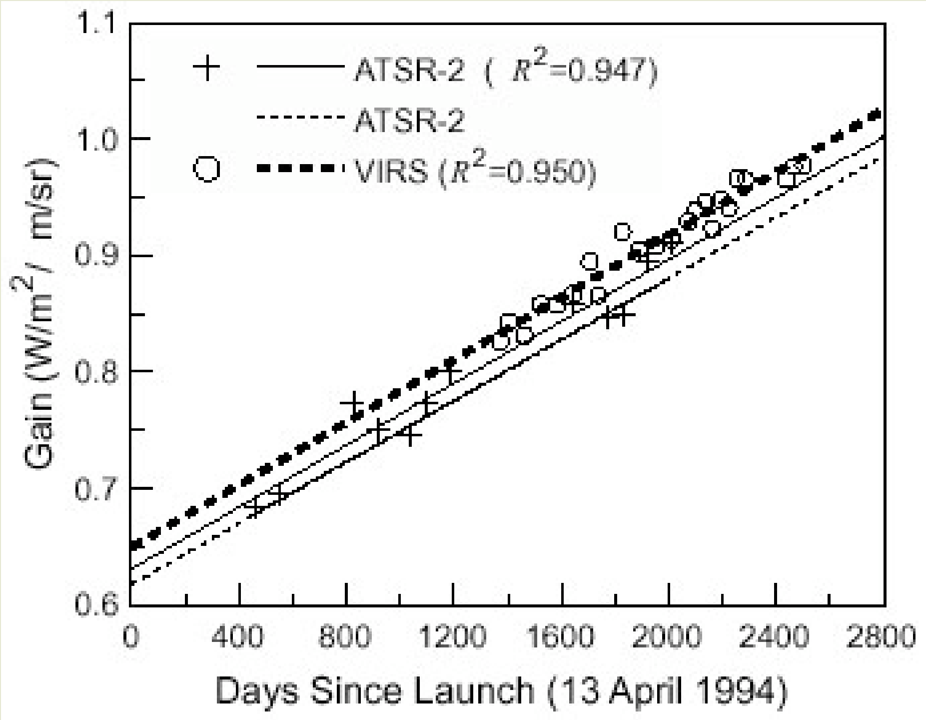
USE STABLE IMAGER AS REFERENCE FOR OTHER IMAGERS

VIRS, ASR-2, MODIS have onboard cal for all channels

Compute gain each month



Derive trend in gain, repeat with other reference platform



CALIBRATION STATUS FOR CERES VIRS/MODIS

- **2.2%/yr degradation in VIRS 1.6-μm relative to *Terra* MODIS**

- ***Terra* MODIS VIS up to 3% greater at high end, 2% less at low end**

  - additional theoretical study needed to warrant changes

  - decreased VIS ocean reflectance model for MODIS

- **Spectral differences will introduce some inconsistencies in the VIRS-MODIS results**

  - cloud emittance models -> ~ 0.5 K difference

  - surface emissivity maps may need some tweaking

- **Trend analyses will continue & include CERES vs MODIS**

- ***Aqua* MODIS intercalibrations to come**

CLOUD MASK

- To detect clouds, the radiances for cloud-free (clear) scene must be known

- Determine clear-sky albedos and surface emissivities after initial processing of data

  - determine means for each surface type to fill in missing areas

- Use ECMWF skin temperatures & profiles to estimate clear-sky brightness temperatures

- Use bidirectional reflectance models to estimate clear-sky reflectance for each pixel

- Estimate thresholds based on uncertainties in models & spatial/temporal variability of the clear radiances

CLEAR-SKY RADIANCE CHARACTERIZATION

- **Predict radiance a given satellite sensor would measure for each channel if no clouds are present**

- **Estimate uncertainty based on spatial & temporal variability & angular model errors**

- **Develop set of spectral thresholds for each channel**

  - Solar, uses reflectance, □

  - IR, use temperature, T

  brightness temperature difference, BTD = $T_{\square 1}$ - $T_{\square 2}$

  typically, BTD(3.7-11) or BTD(11-12)

CLEAR-SKY REFLECTANCE, SOLAR

- **Estimate overhead-sun albedo, $\square_o = \square(\mu_o = 1)$**

  derived empirically with initial runs using ISCCP AVHRR DX
  then updated for each month using VIRS, then Terra MODIS

- **Estimate albedo at given local time, $\square(\mu_o) = \square_o \square_o(\mu_o)$**

  directional reflectance model $\square_o(\mu_o)$ derived for each IGBP type using VIRS

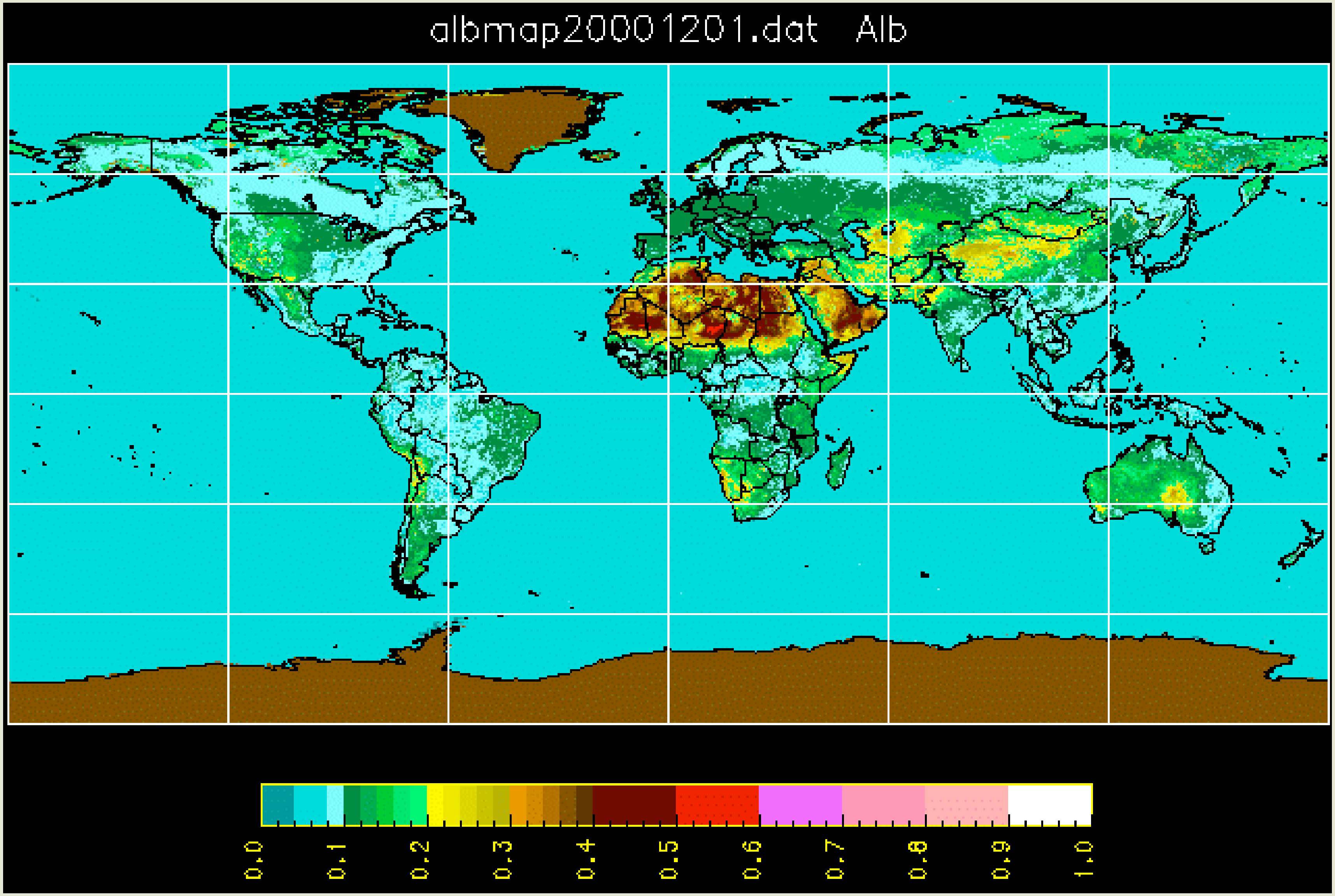
- **Estimate reflectance for given viewing angles, $\square(\mu_o, \mu, \square) = \square(\mu_o)\, \square(\mu_o, \mu, \square)$**

  bidirectional reflectance (BRDF) model $\square$ selected for each IGBP type

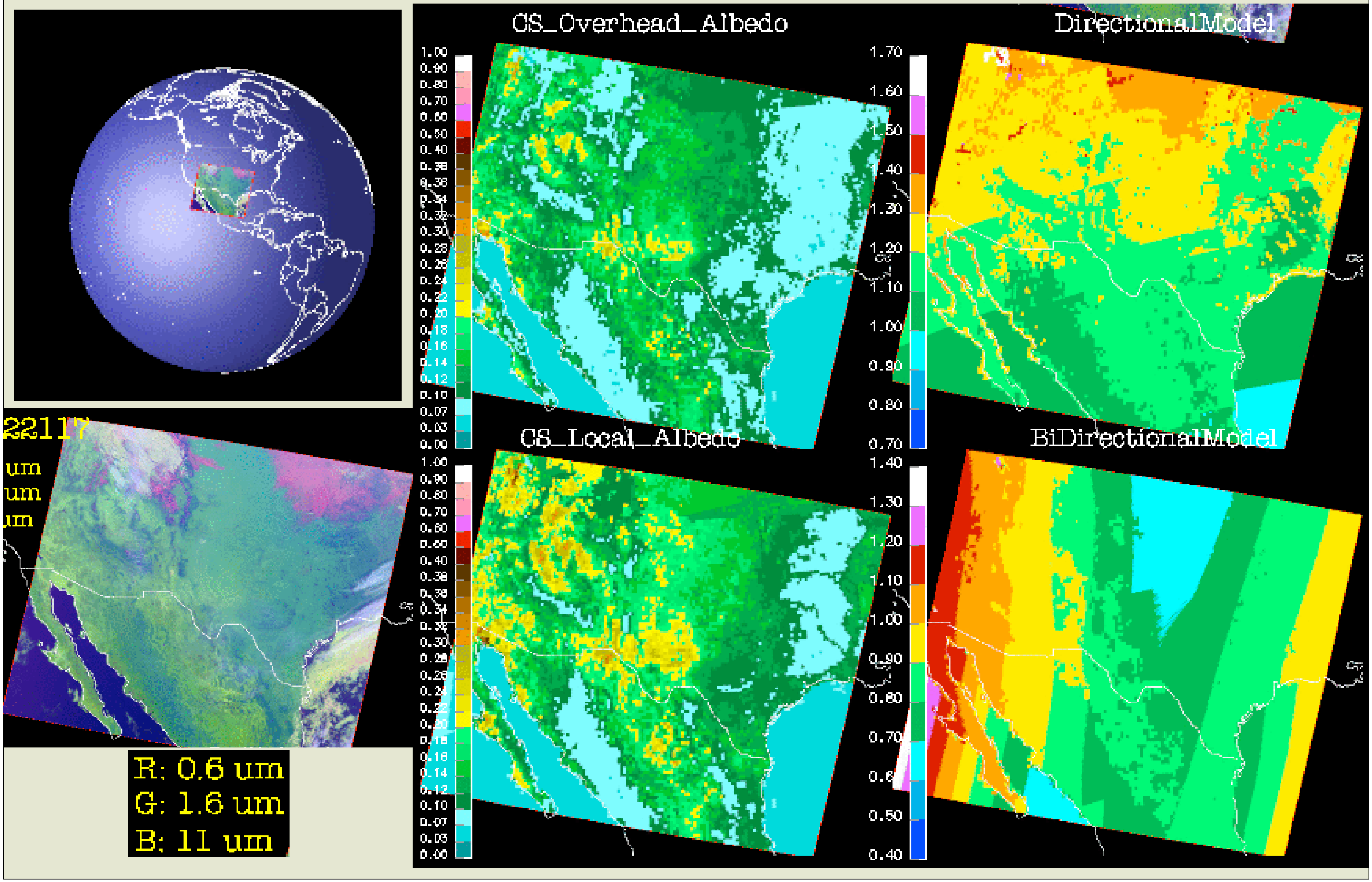
  from Kriebel (1978), Minnis & Harrison (1984), Suttles et al. (1988)

- **Add uncertainty to set reflectance threshold, $\square_T(\mu_o, \mu, \square) = \square + \square\square(\mu_o, \mu, \square)$**

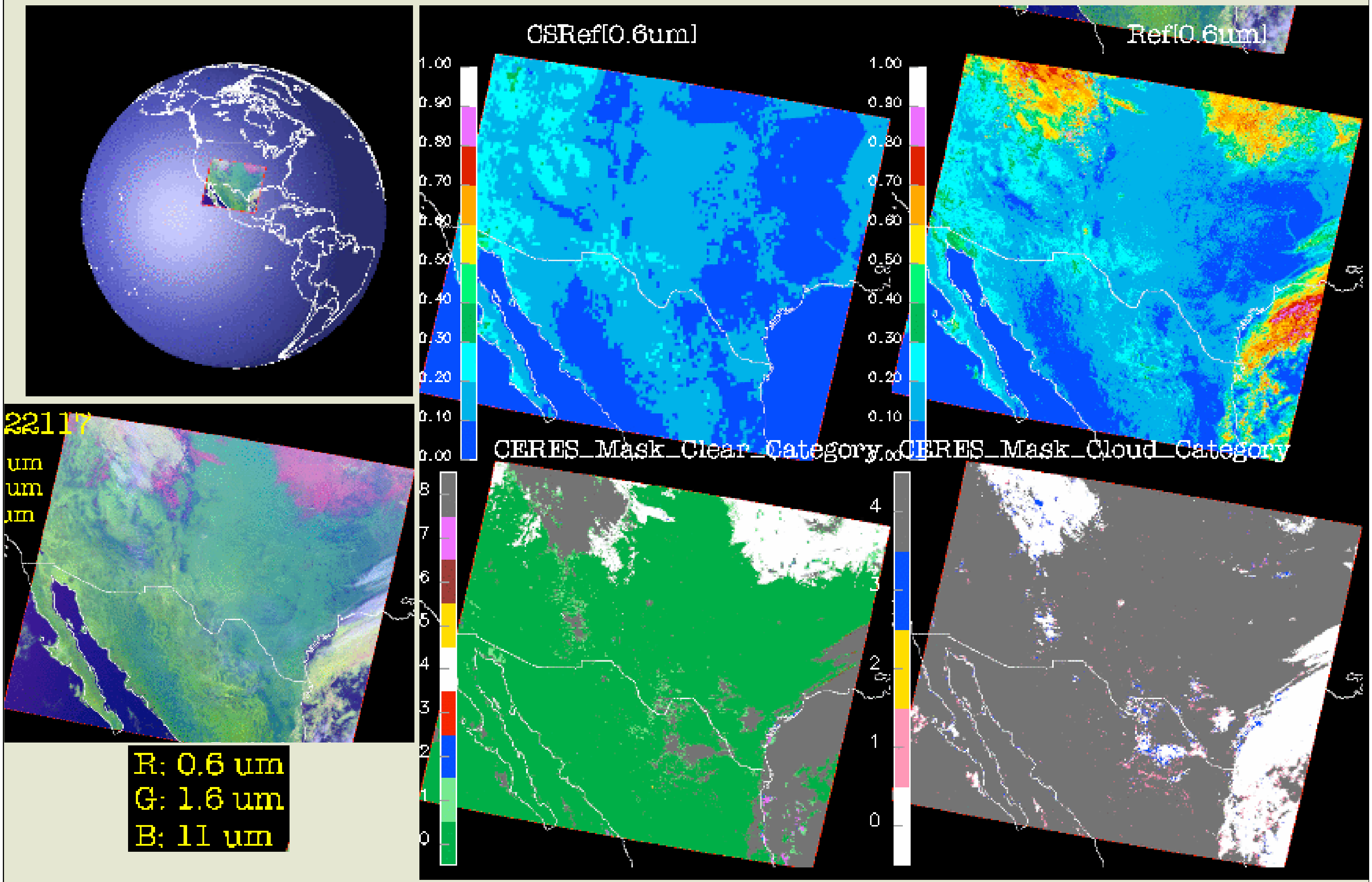
MODIS-BASED OVERHEAD-SUN VIS ALBEDO MAP, 12/1/00



PREDICTED CLEAR-SKY VIS ALBEDO
1700 UTC,12/21/00



PREDICTED CLEAR-SKY & OBSERVED VIS REFLECTANCE & CLOUD MASK
1700 UTC,12/21/00



CLEAR-SKY TEMPERATURE, INFRARED

- **Estimate surface emissivity, $\varepsilon_s(x,y)$**

  derived empirically with initial runs using ISCCP AVHRR DX
  then updated using VIRS, then Terra MODIS; water & snow theoretical

- **Estimate radiance leaving the surface, $L_s = \varepsilon_s B(T_{skin}) + (1-\varepsilon_s)L_{ad}$**

  L_{ad} = downwelling atmo radiation, T_{skin} = skin temperature from model / obs

- **Estimate TOA brightness temperature, $B(T_{cs}) = (1-\varepsilon_a)L_s + \varepsilon_a L_{au}$**

  L_{au} = upwelling atmo radiation, ε_a = effective emissivity of atmo

  layer absorption emission computed using T/RH profile, correlated k-dist

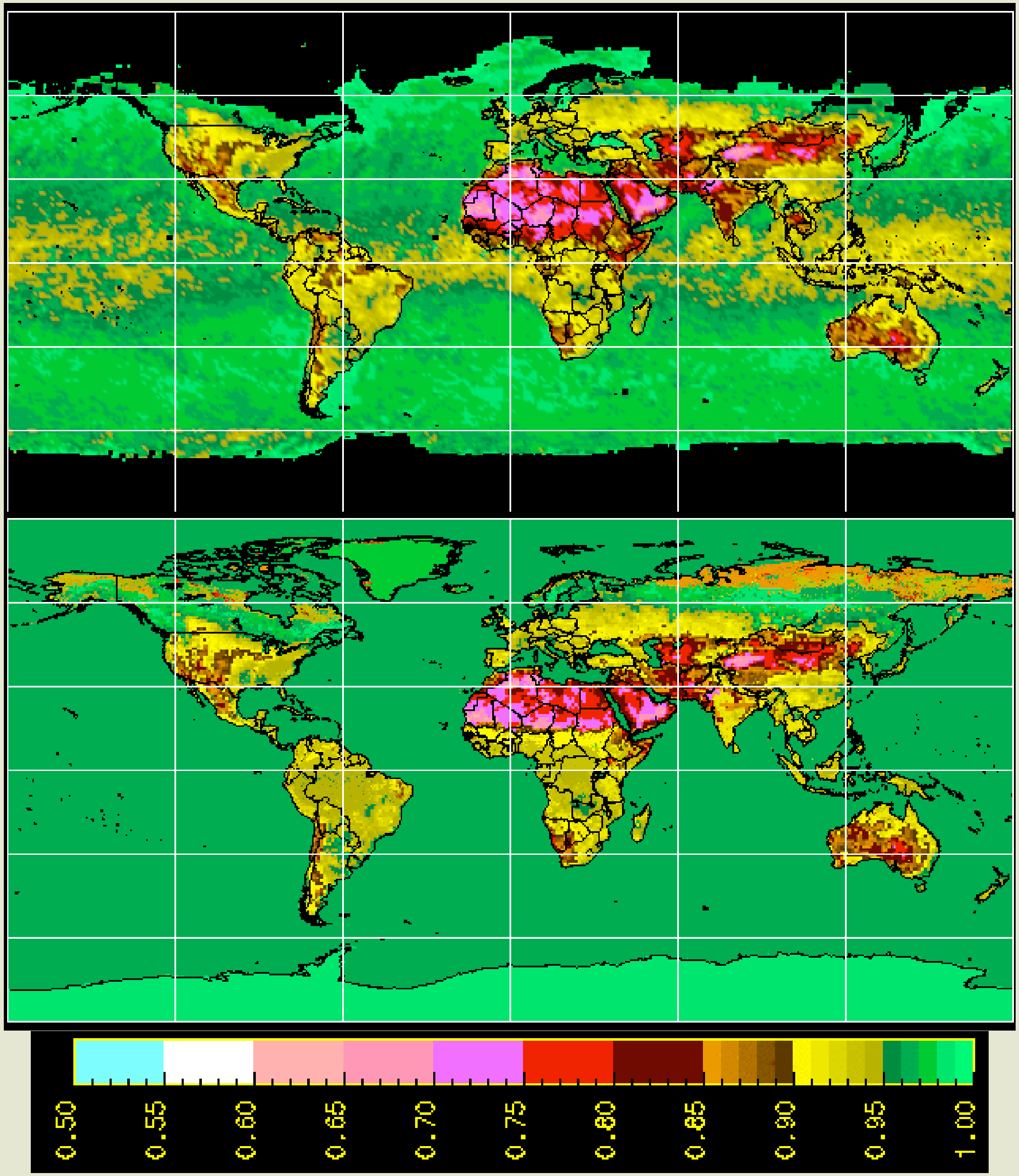
- **Add uncertainty to set T or BTD thresholds, $T_T(\mu) = T_{cs}(\mu) + \Delta T(\mu)$**

  - reflected solar component included in 3.7-4.0 µm estimate

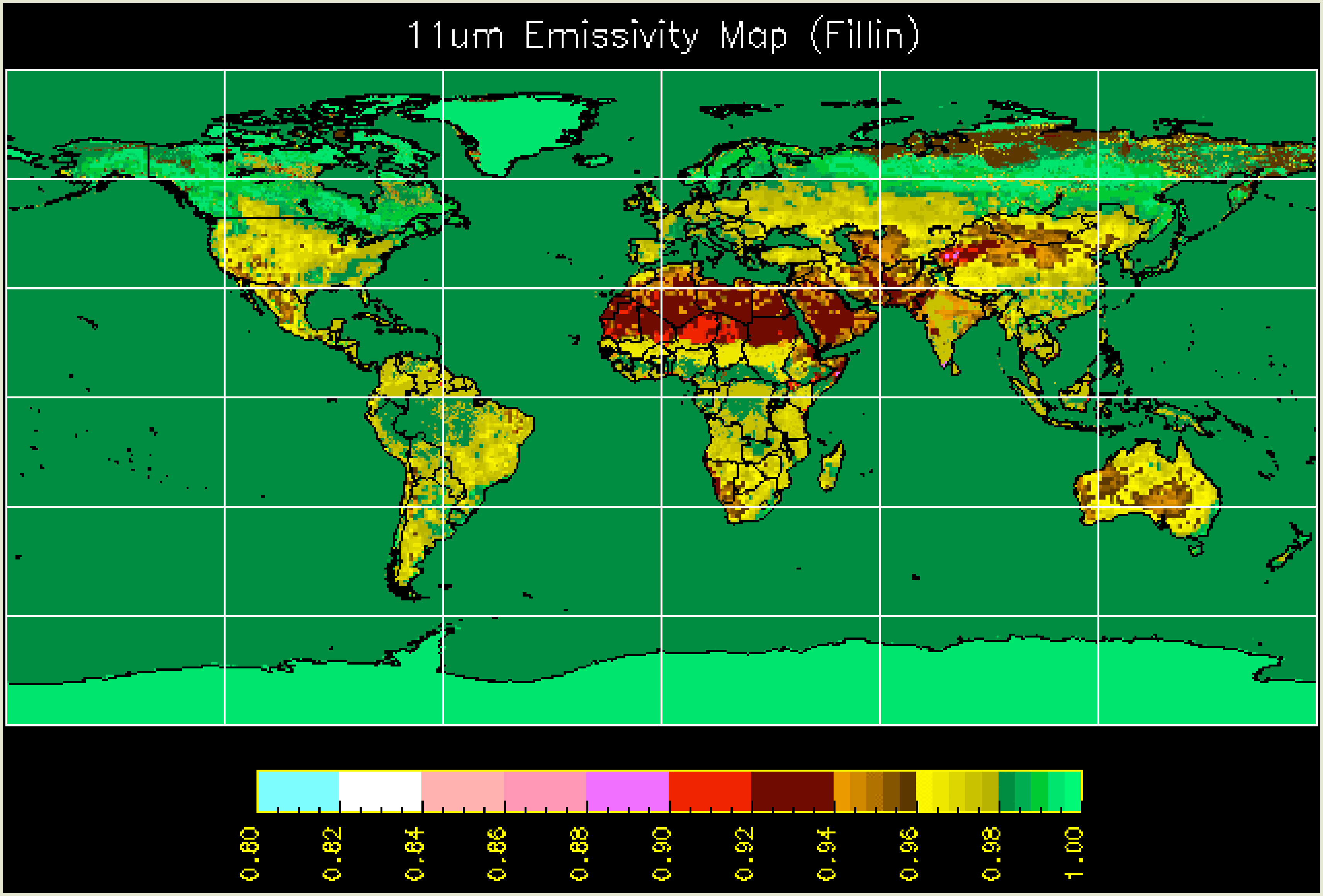
Surface emissivity from *Terra* MODIS, April 2001
3.7 μm

Unfiltered

Filtered &
IGBP filled

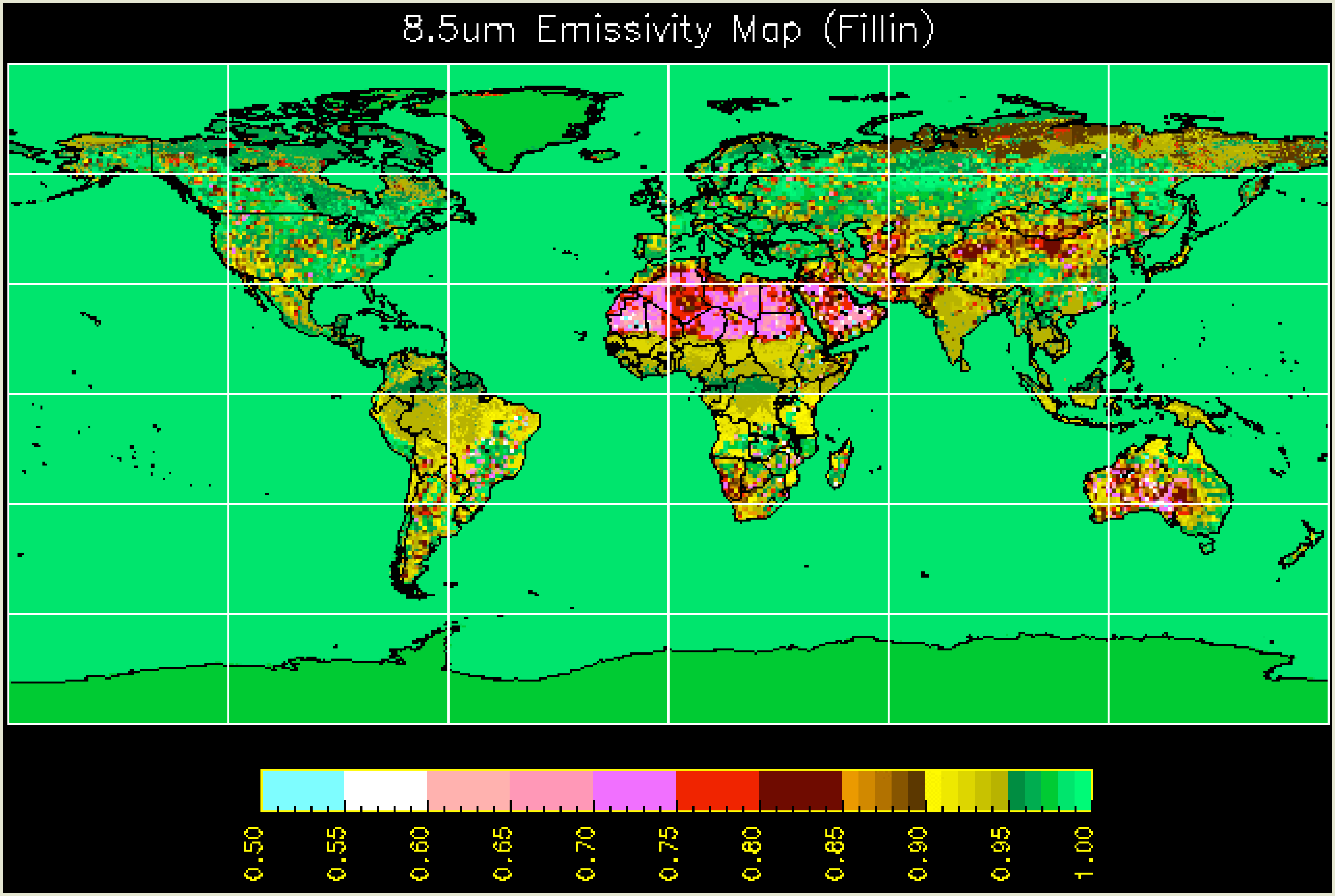


Surface emissivity from *Terra* MODIS, April 2001, 11 μm



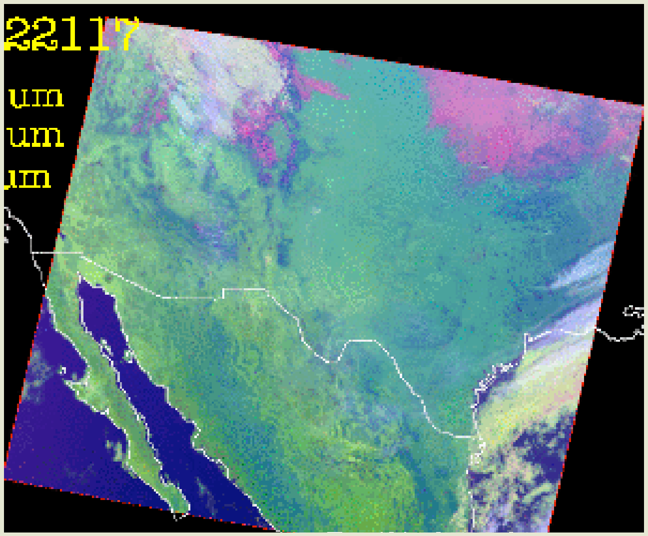
Filtered & IGBP filled

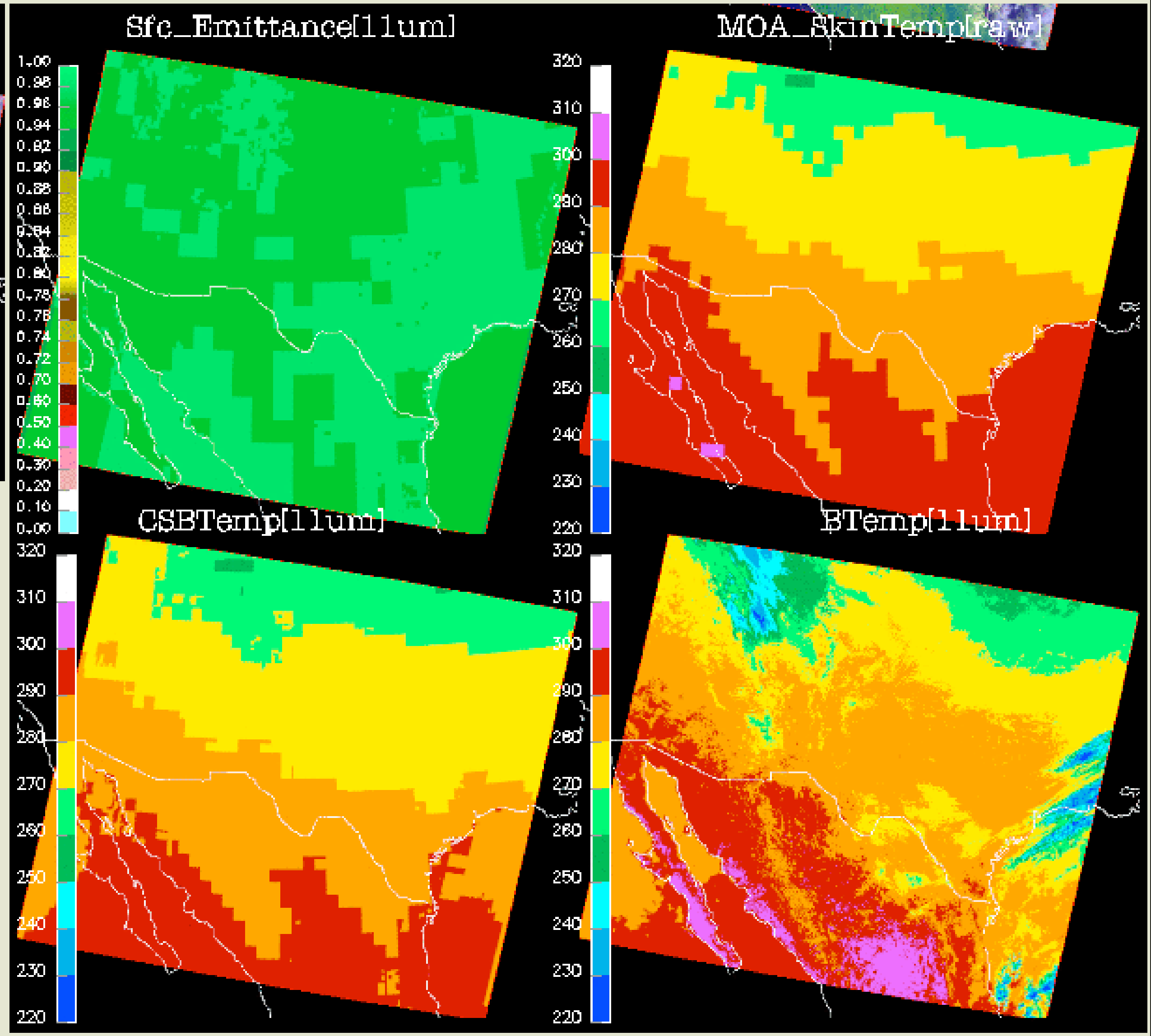
Surface emissivity from *Terra* MODIS, April 2001, 8.5 μm



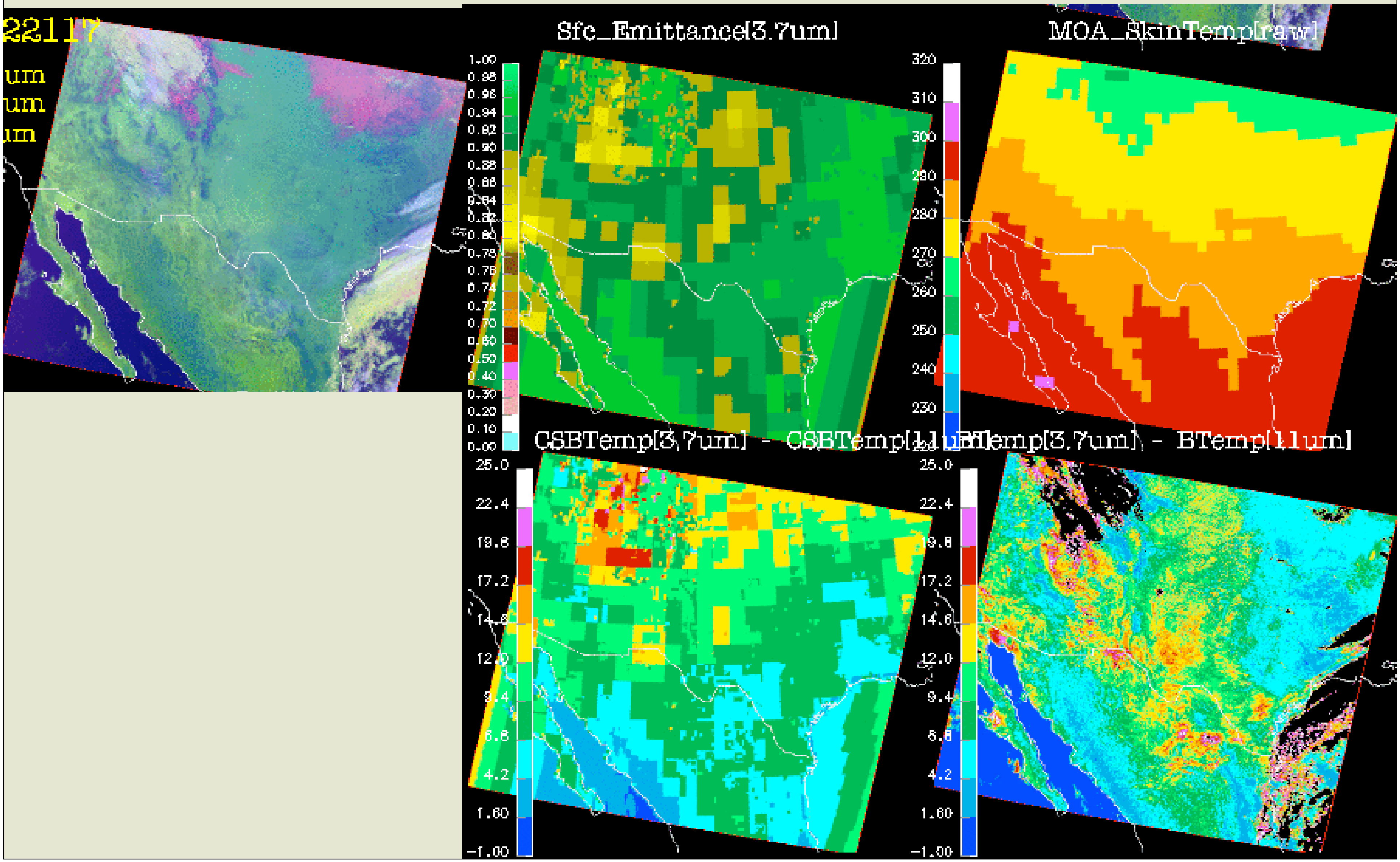
Filtered & IGBP filled

PREDICTED CLEAR-SKY & OBSERVED IR TEMPERATURE
1700 UTC,12/21/00





PREDICTED CLEAR-SKY & OBSERVED BTD (3.7 - 11)
1700 UTC,12/21/00



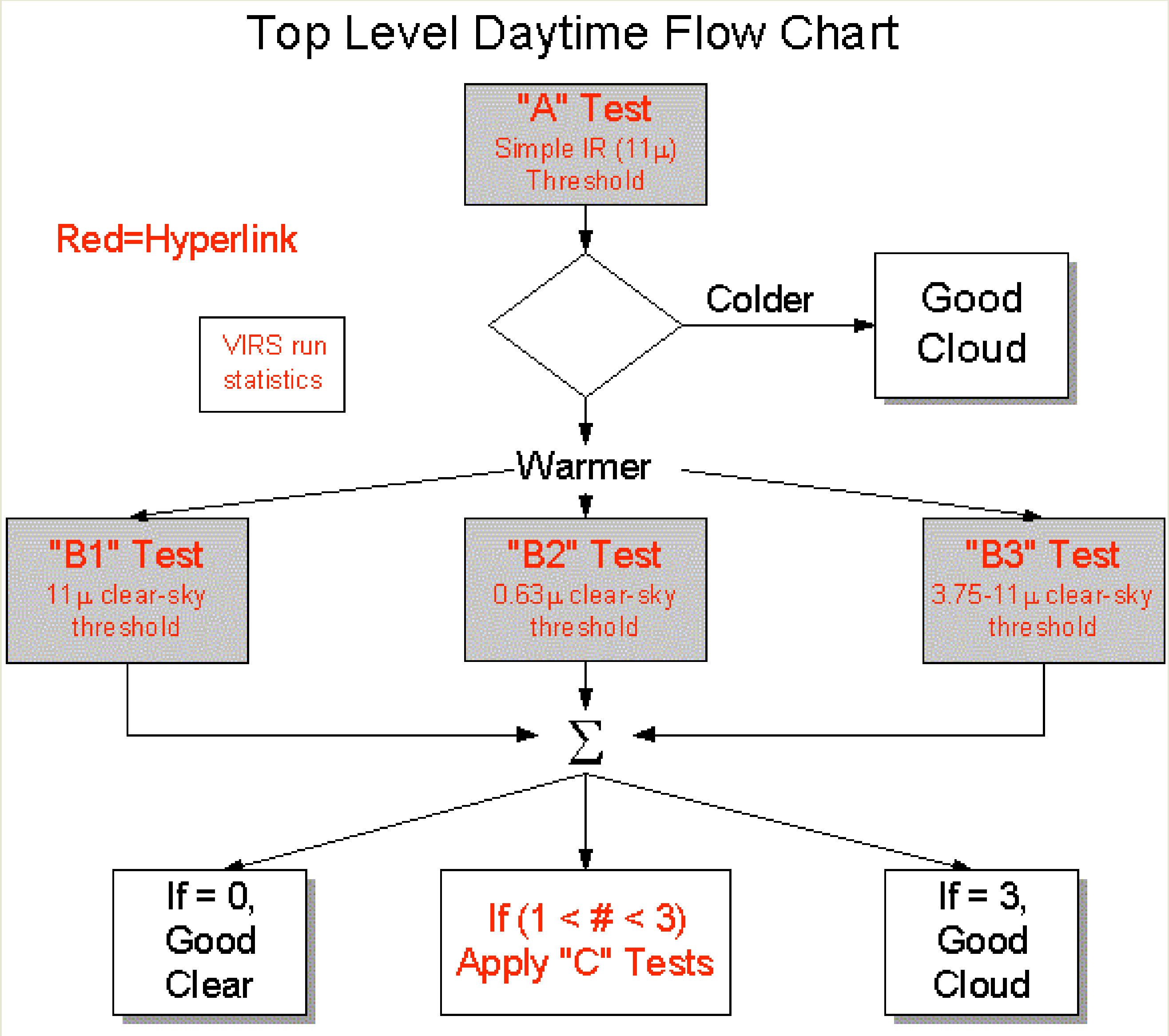
CLOUD MASK

Classify each imager pixel as cloud / clear / bad using multiple cascading thresholds + Welch algo

DAYTIME & POLAR: SZA < 82°, 0.6, 1.6, 3.8, 11, 12 μm

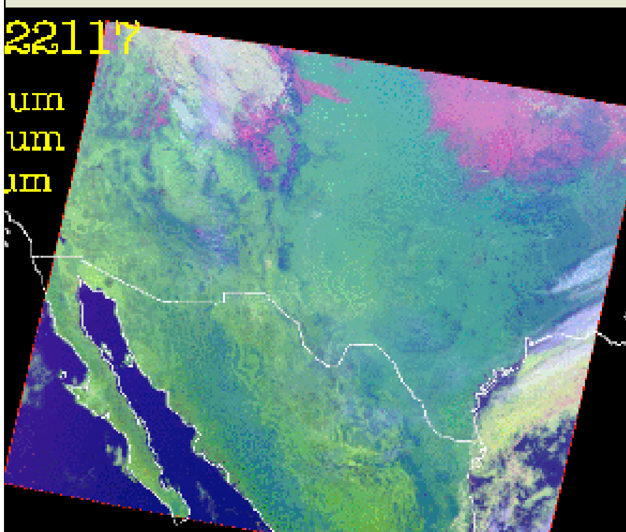
NIGHTTIME & POLAR: 3.8, 11, 12 μm

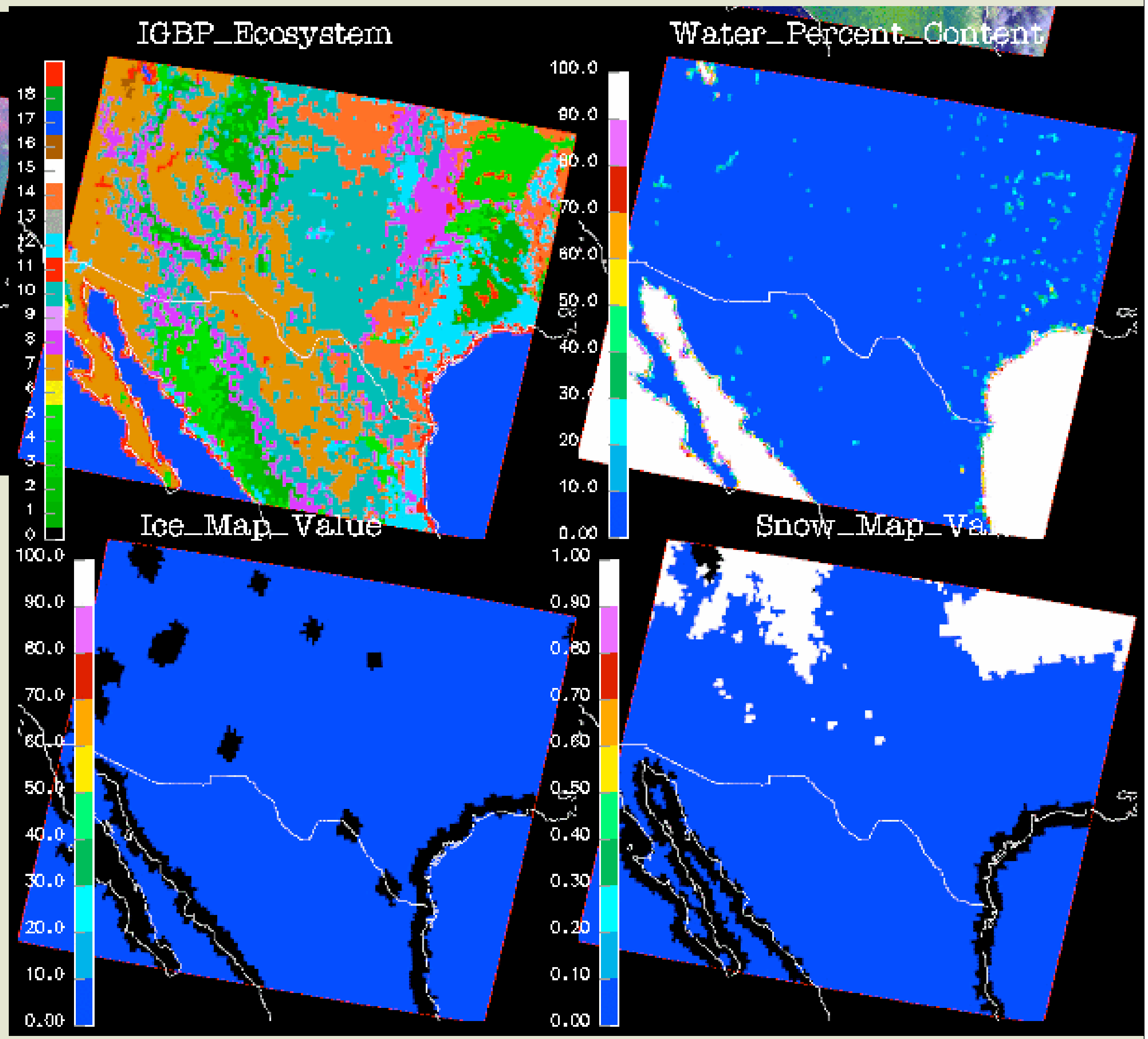
STANDARD DAYTIME MASK ALGORITHM



ANCLILLARY DATA USED IN CLOUD MASK & RETRIEVALS

Snow map used as a guide, snow is determined independently if clear

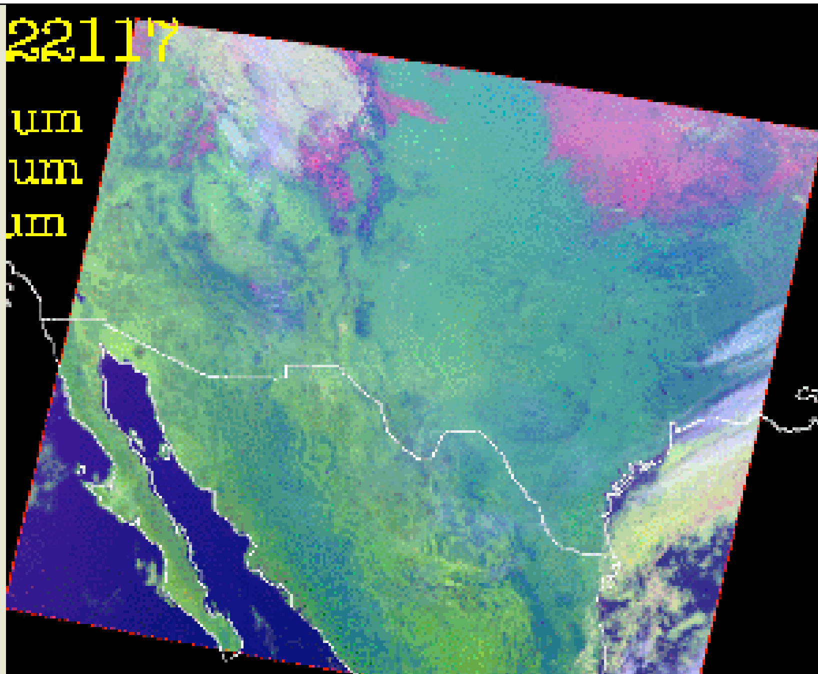




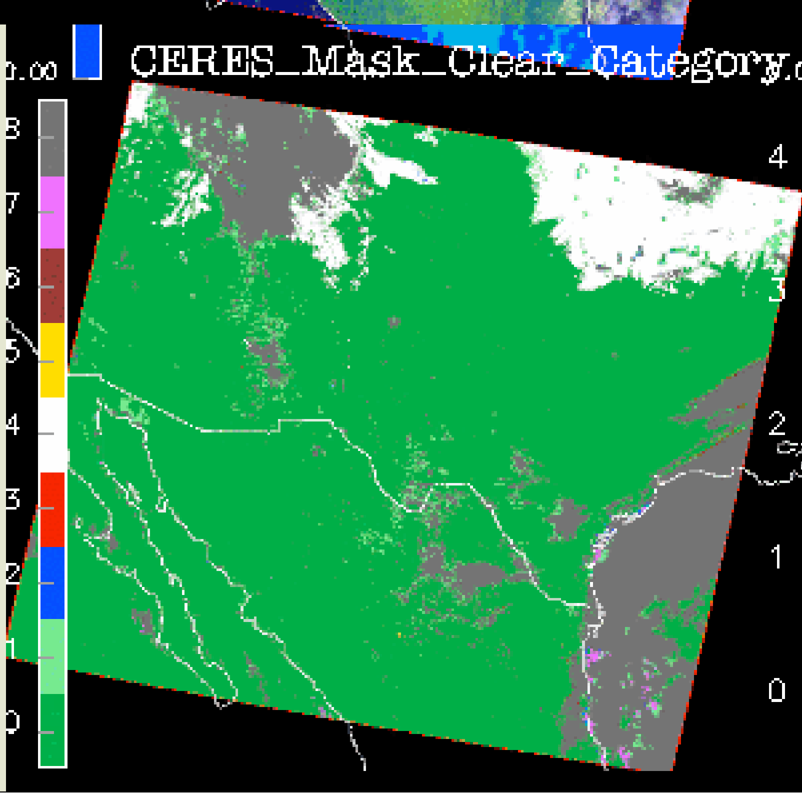
Other

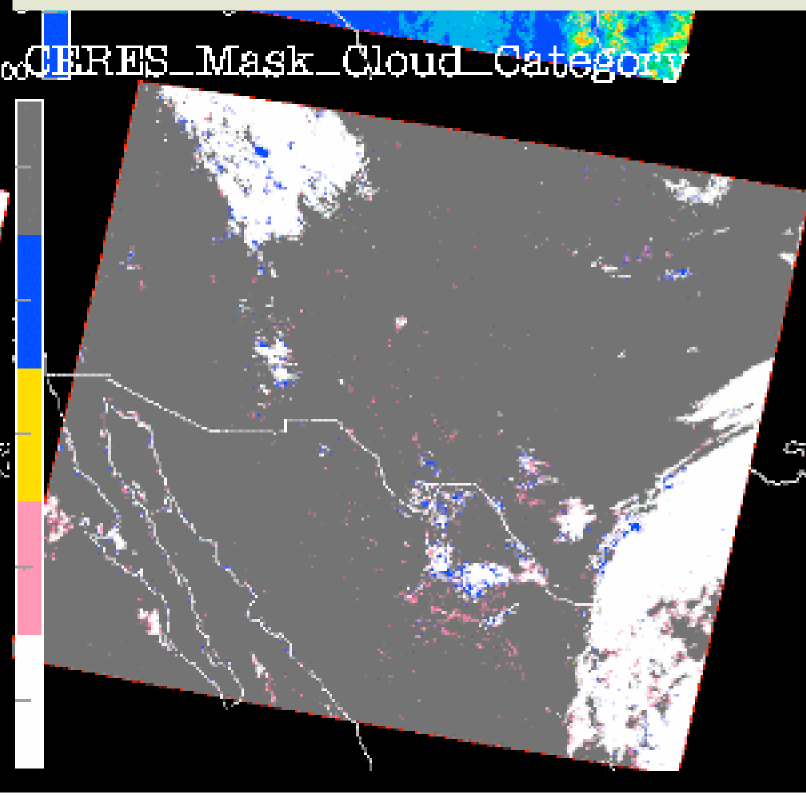
Elevation map (10')

T, q_v, O_3 profiles (1°)

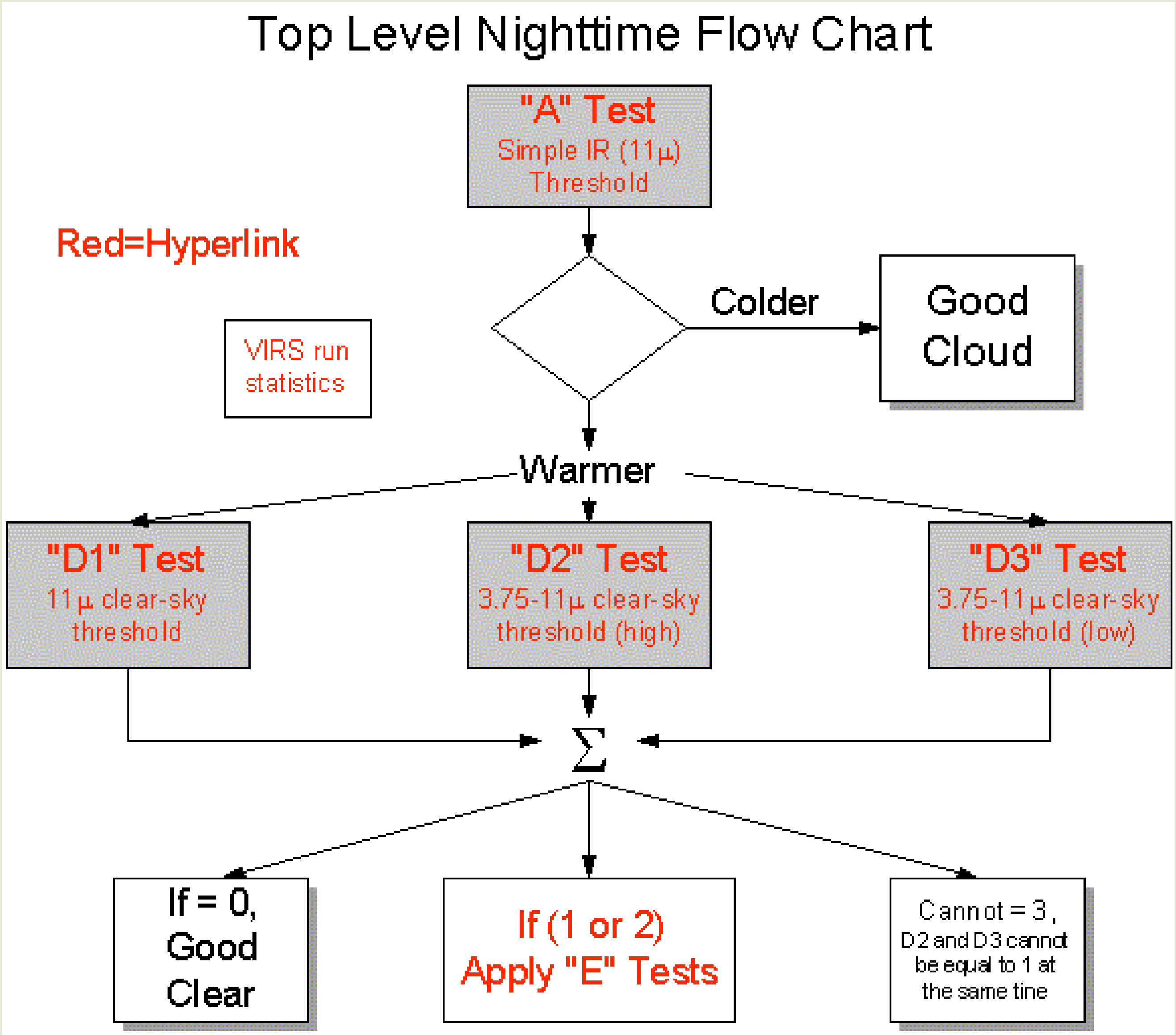


CERES CLOUD MASK 1700 UTC,12/21/00

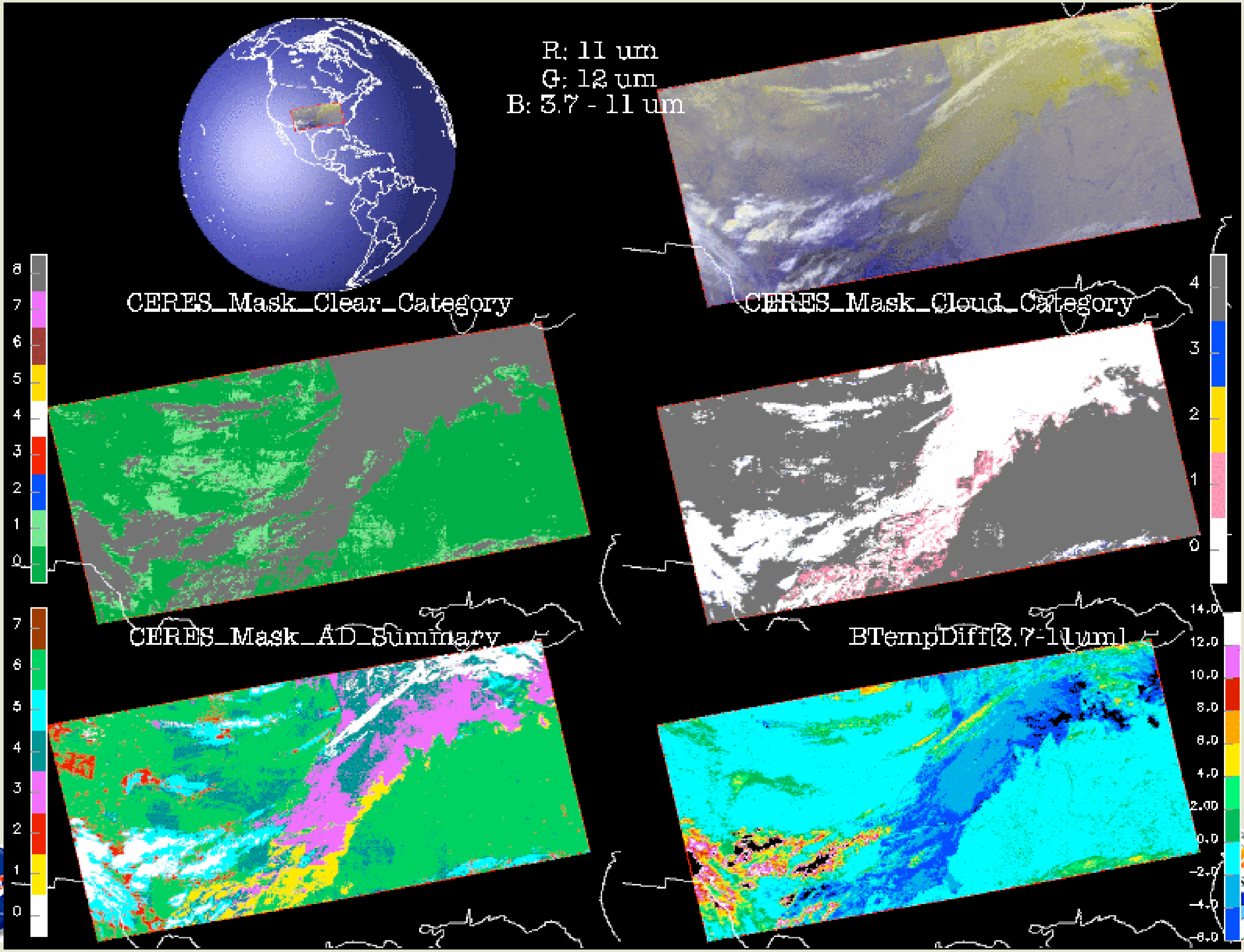




STANDARD NIGHTTIME MASK ALGORITHM



CERES CLOUD MASK & BTD(3.7 - 11) REFLECTANCE 0400 UTC,12/01/00



CLOUD RETRIEVAL METHODOLOGY

- Compute ice & water solution, select most likely based on

  model fits, temperature, LBTM classification, 1.6-μm reflectance

- No retrievals: reclassify as clear or status quo, 3-4%

RETRIEVAL METHODS

DAY: Visible Infrared Solar-Infrared Split-Window Technique (VISST)

see Minnis et al. (1995, 1998)

NIGHT: Solar-infrared Infrared Split-Window Technique (SIST)

see Minnis et al. (1995, 1998)

SNOW (DAY): Solar-Infrared Infrared Near-Infrared Technique (SINT)

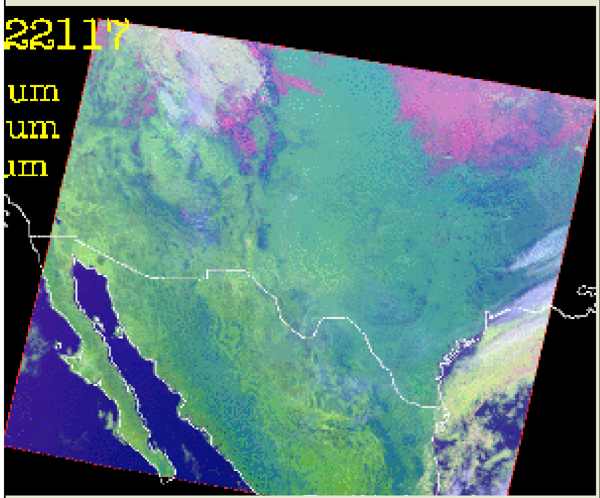
MODIS only *see Platnick (JGR, 2001)*

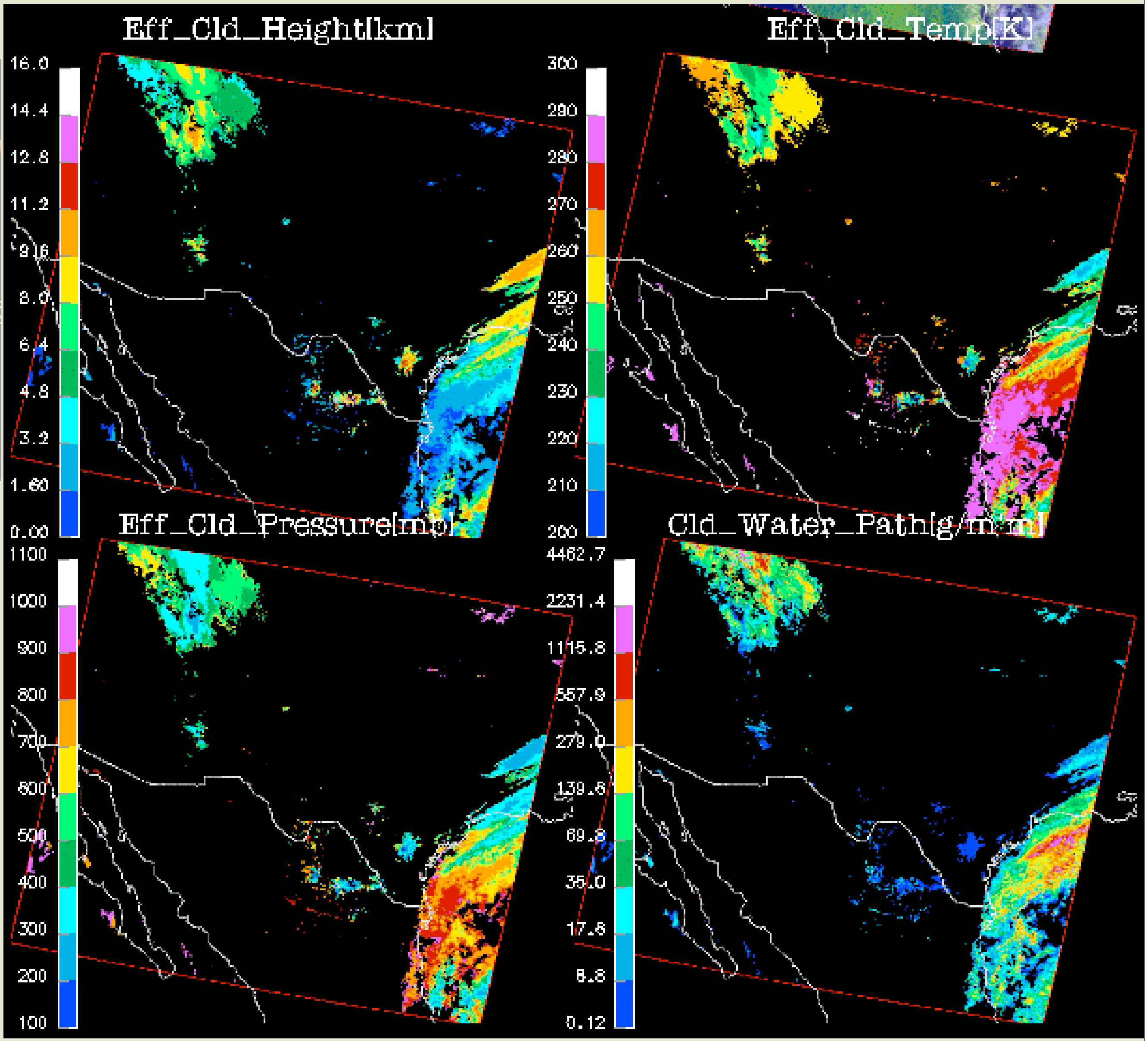
CERES CLOUD PROPERTIES

1 SSF PIXEL w/CERES FLUXES

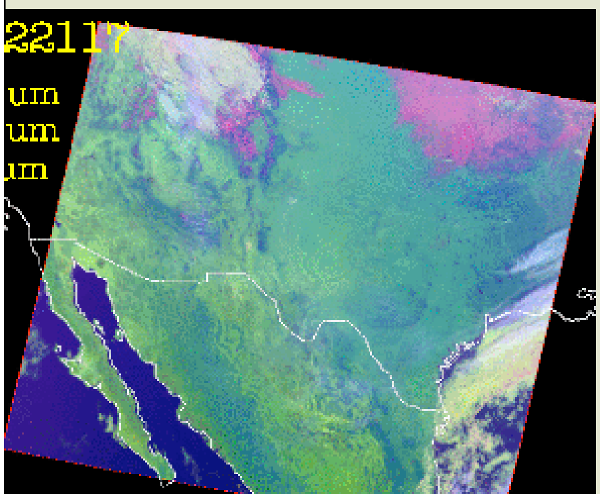
AMOUNT	F
EFFECTIVE RADIATING TEMP	Tc
EFFECTIVE HEIGHT, PRESSURE	Zc, pc
TOP PRESSURE	p_t
THICKNESS	h
EMISSIVITY	□
PHASE (0 - 2)	P
WATER DROPLET EFFECTIVE RADIUS	re
OPTICAL DEPTH	□
LIQUID WATER PATH	LWP
ICE EFFECTIVE DIAMETER	De
ICE WATER PATH	IWP

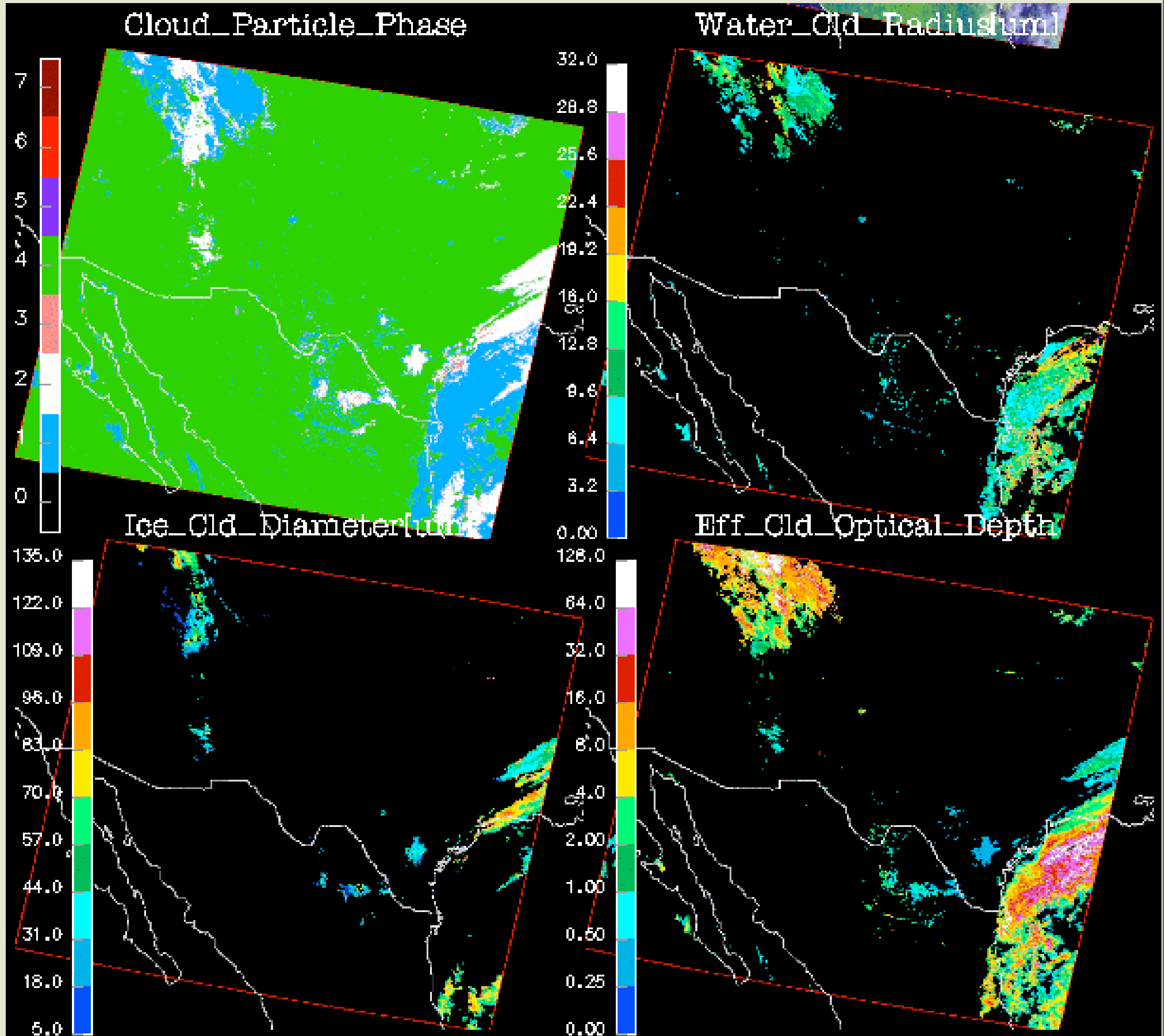
CERES CLOUD MACROPHYSICAL PROPERTIES
1700 UTC, 12/21/00





CERES CLOUD MICROPHYSICAL PROPERTIES 1700 UTC, 12/21/00

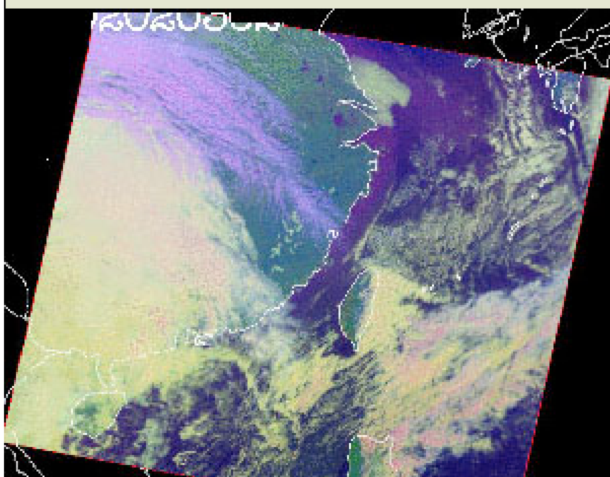




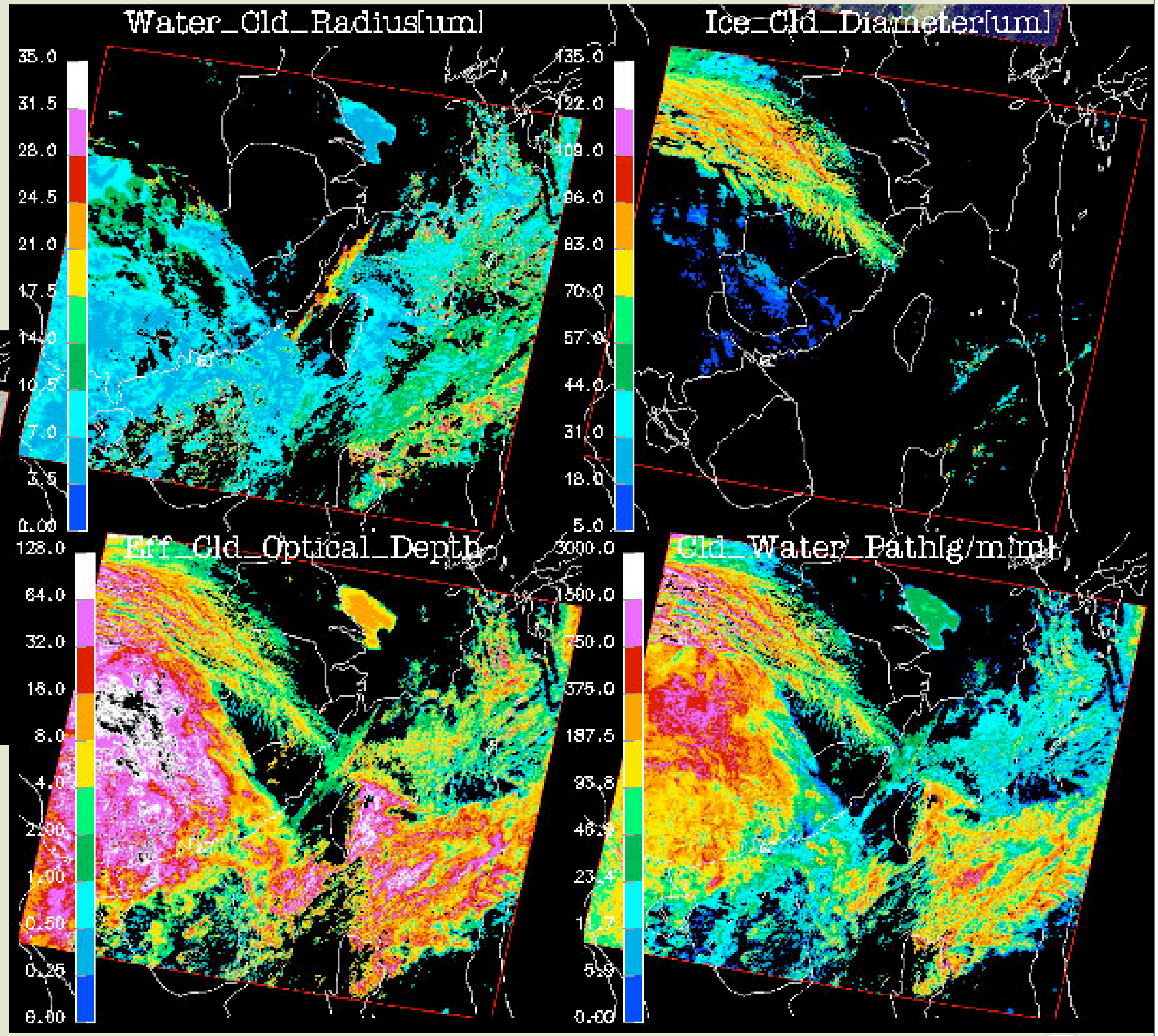
CERES Cloud Microphysical Properties

Eastern China

0002 UTC, 2/03/02



R: 0.6 um
G: 1.6 um
B: 11 um

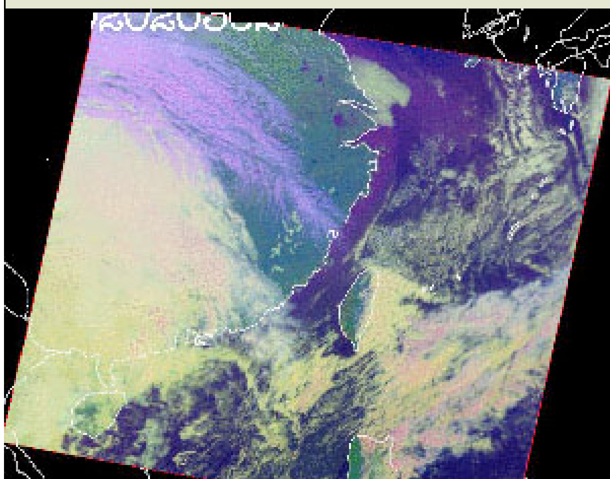


Terra MODIS

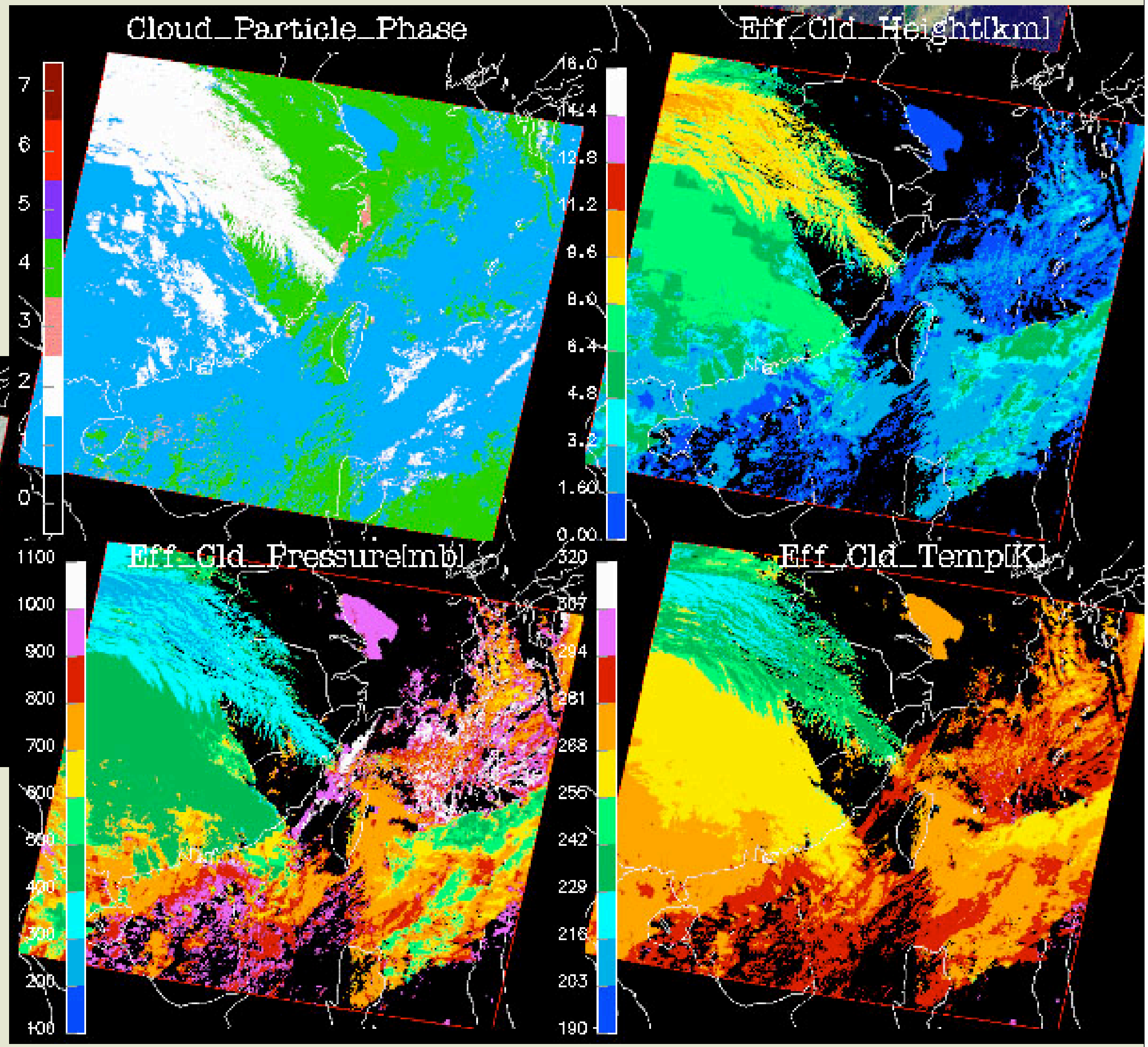
CERES Cloud Macrophysical Properties

Eastern China

0002 UTC, 2/03/02



R: 0.6 um
G: 1.6 um
B: 11 um



Terra **MODIS**

Comparison of Optical Depths (OD) from VISST & SINT, *Terra* MODIS

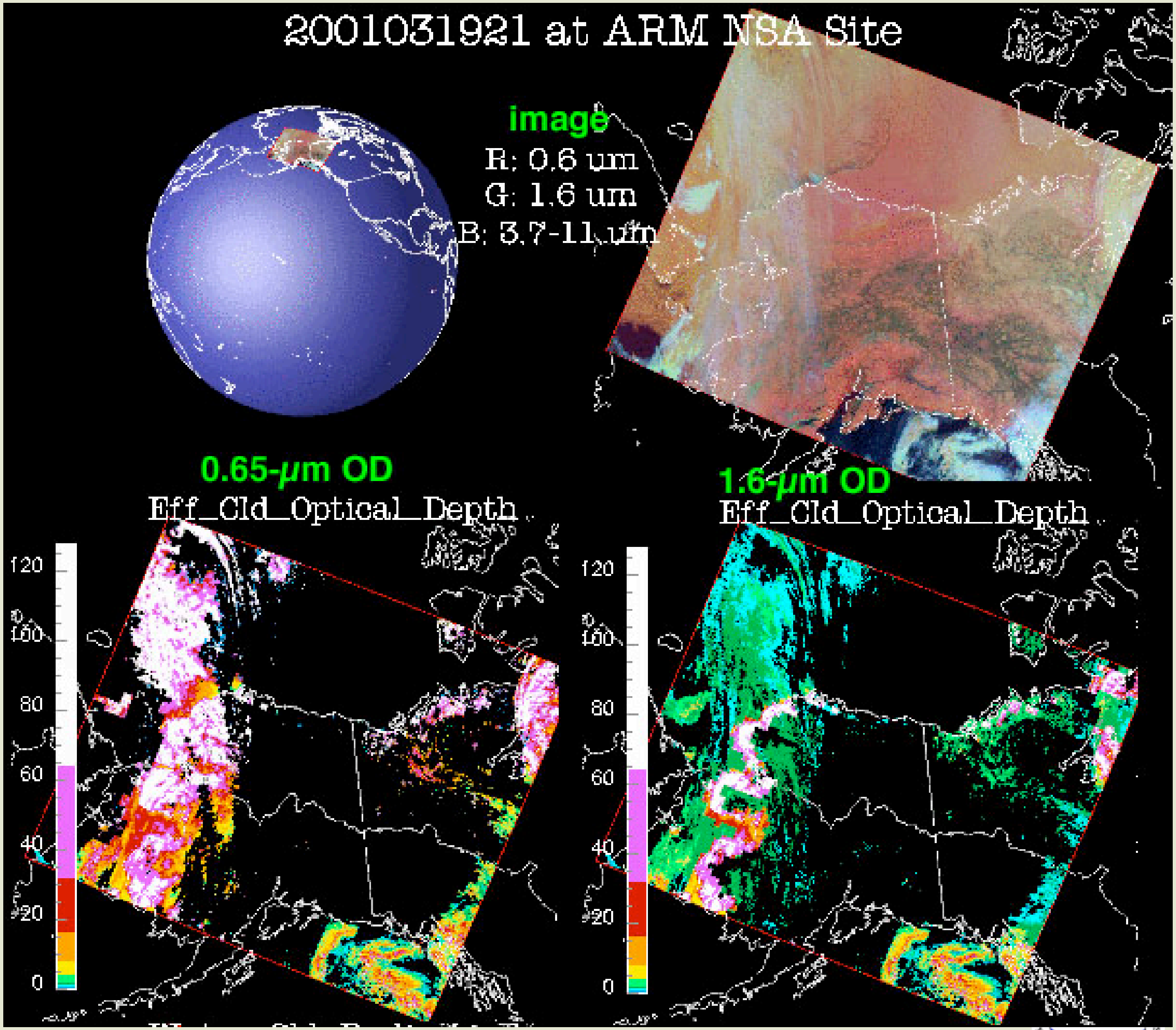
Northern Alaska

March 3, 2001

2100 UTC

Visible channel overestimates OD over snow & ice

1.6-μm yields more realistic value for OD



RESULT EXAMPLES

CLOUD MASK CLEAR STATISTICS, DECEMBER 2000

Day: csz > 0.1

	Ocean	Land	Desert	Total
Clr Good	0.920	0.759	0.971	0.853
Clr Weak	0.009	0.010	0.015	0.009
Clr Smoke	0.001	0.000	0.000	0.001
Clr Fire	0.000	0.000	0.000	0.000
Clr Snow	0.017	0.228	0.009	0.108
Clr Glint	0.052	0.001	0.000	0.028
Clr Shadow	0.000	0.001	0.005	0.001
Clr Aerosol	0.002	0.000	0.000	0.001
Total	1.000	1.000	1.000	1.000

Night: csz < 0.1

	Ocean	Land	Desert	Total
Clr Good	0.704	0.661	0.717	0.687
Clr Weak	0.076	0.032	0.211	0.062
Clr Snow	0.220	0.307	0.072	0.251
Total	1.000	1.000	1.000	1.000

CLOUD MASK CLOUD STATISTICS, DECEMBER 2000

Day: csz > 0.1

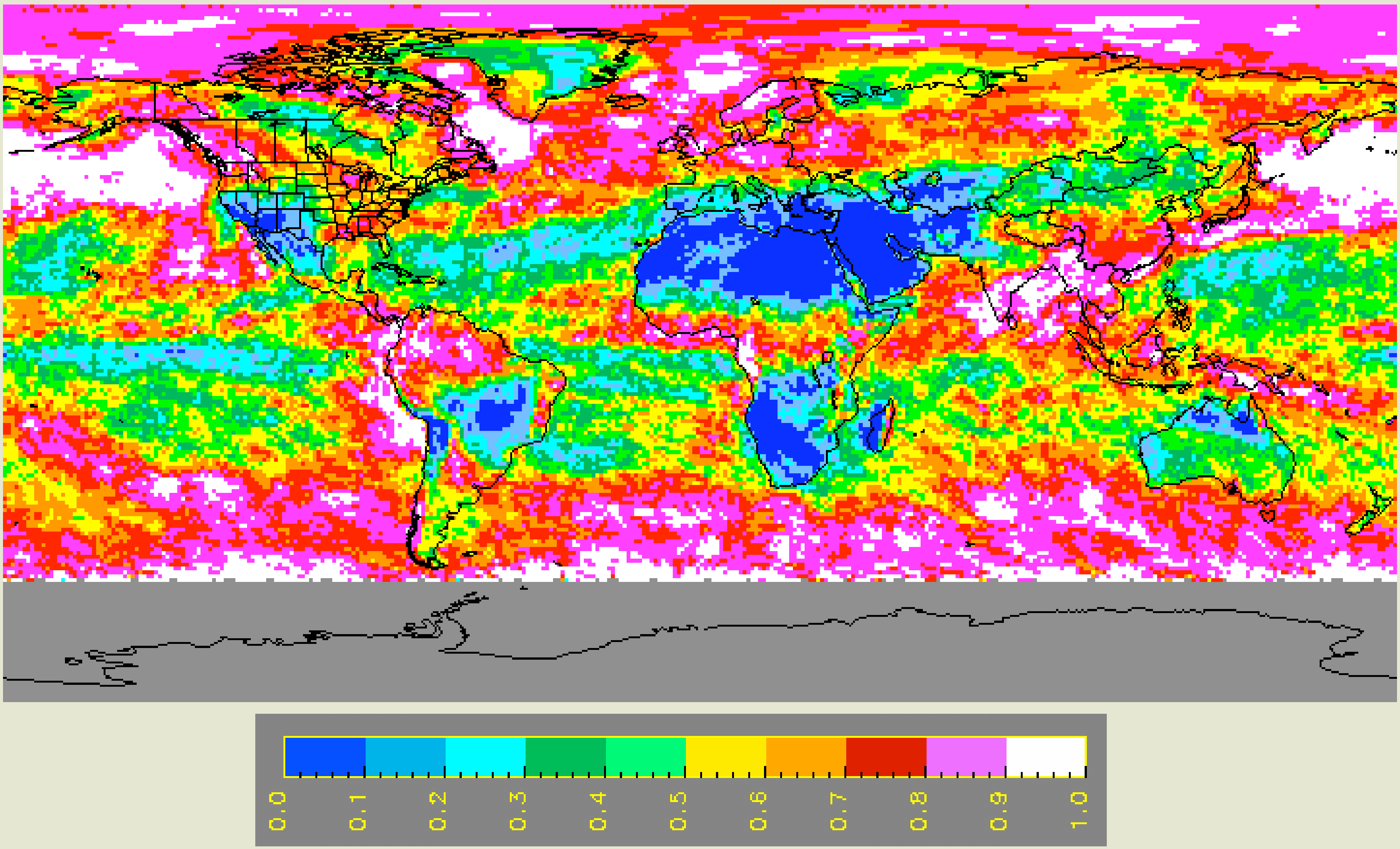
	Ocean	Land	Desert	Total
Cld Good	0.940	0.855	0.662	0.912
Cld Weak	0.038	0.042	0.088	0.047
Cld Glint	0.009	0.001	0.000	0.007
Cld N/R	0.030	0.068	0.250	0.042
Total	1.000	1.000	1.000	1.000

Night: csz < 0.1

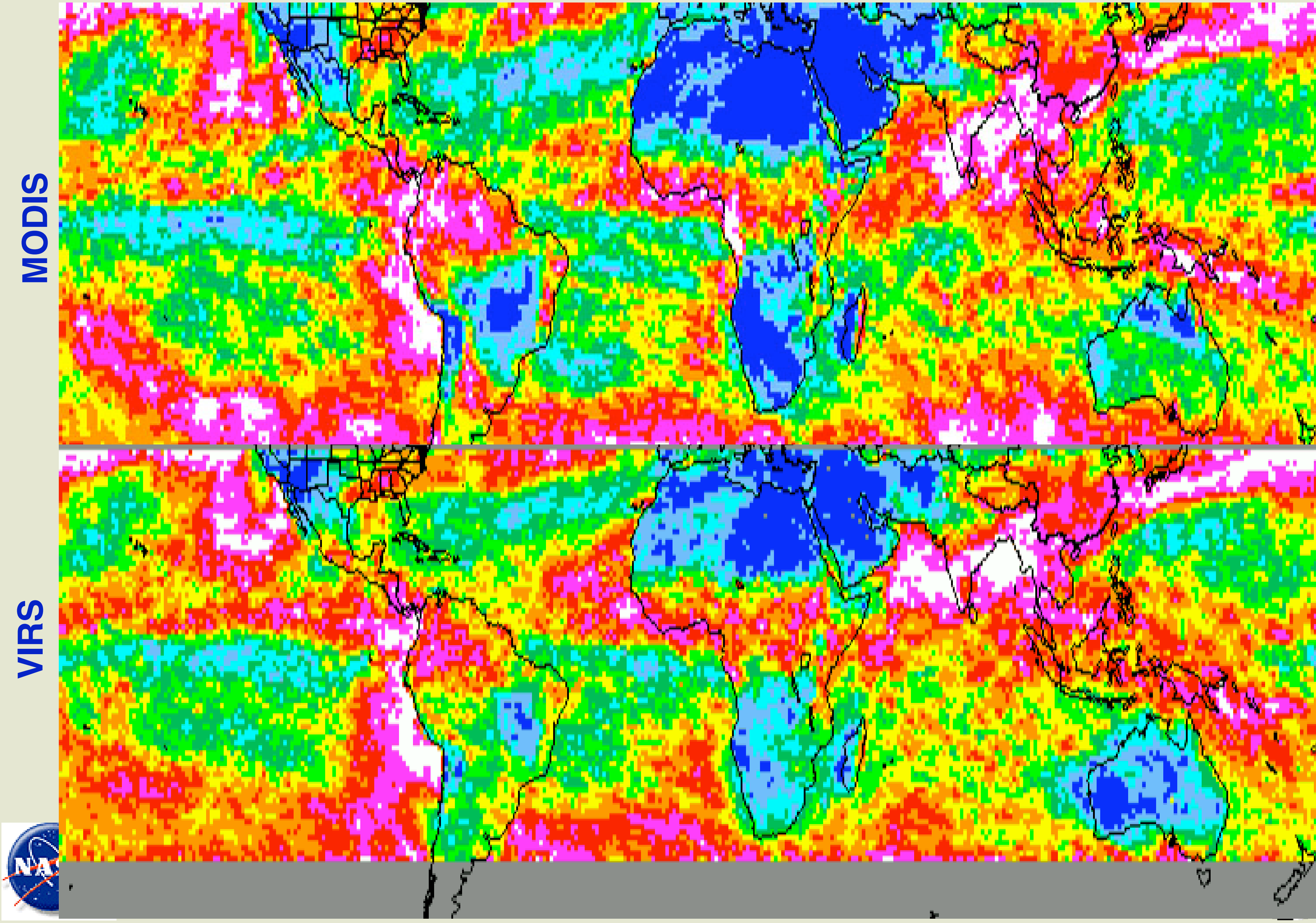
	Ocean	Land	Desert	Total
Cld Good	0.909	0.906	0.909	0.908
Cld Weak	0.084	0.084	0.038	0.084
Cld N/R	0.007	0.009	0.053	0.014
Total	1.000	1.000	1.000	1.000

MEAN CLOUD COVER, MODIS, June 2001

Day

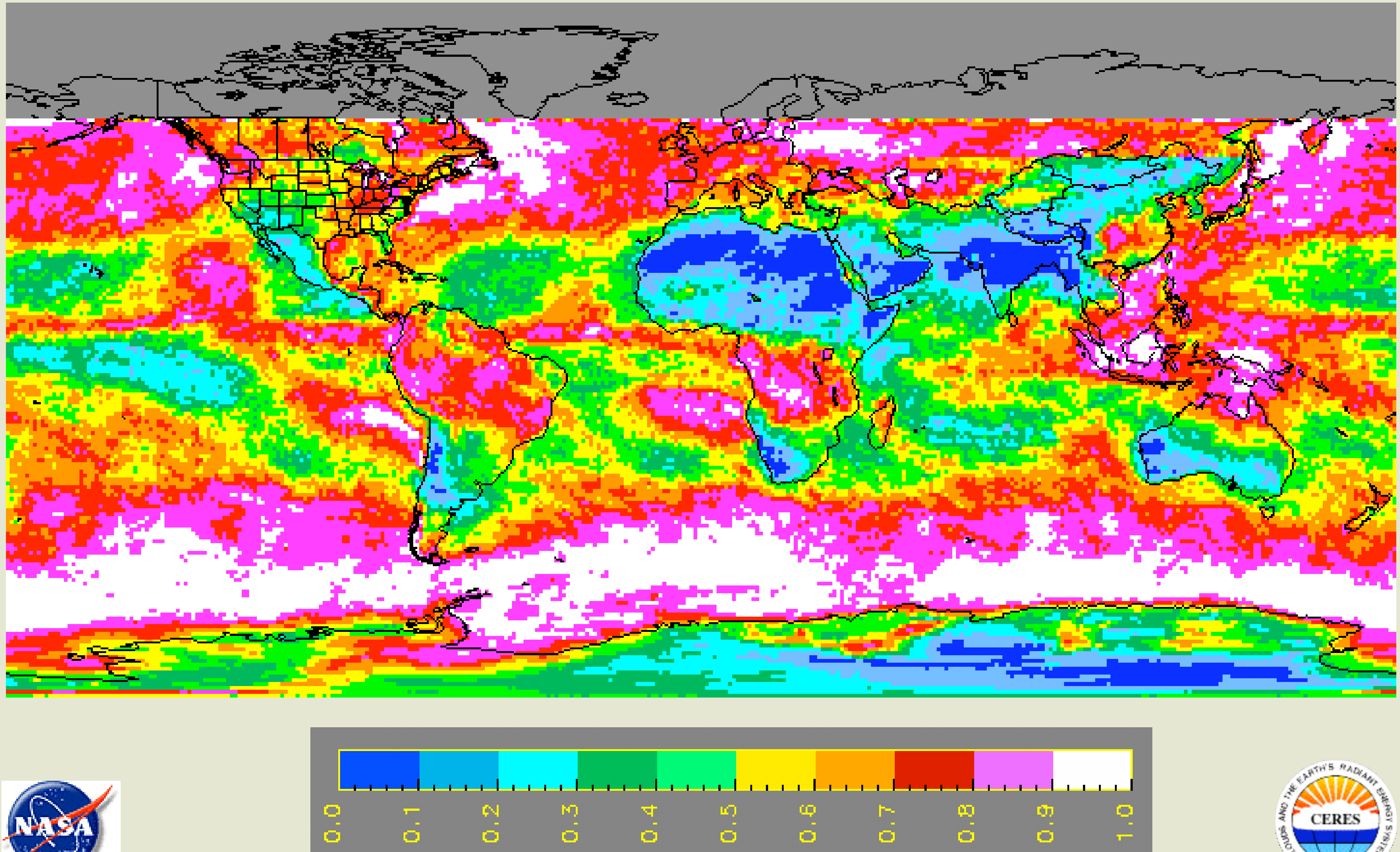


DAYTIME CLOUD FRACTION
MODIS (15 days) & VIRS, JUNE 2001



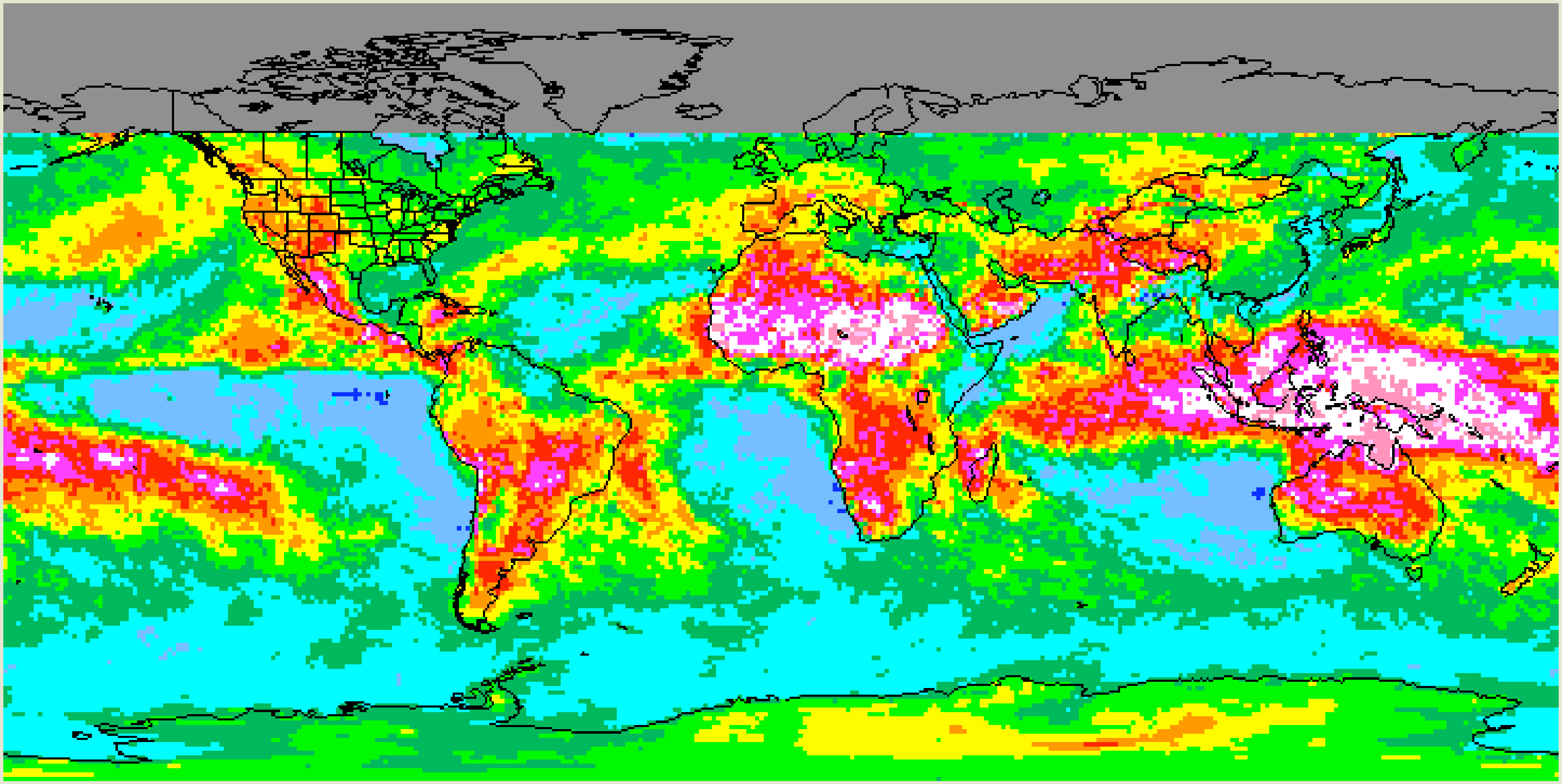
MEAN CLOUD COVER, MODIS, DEC 2000

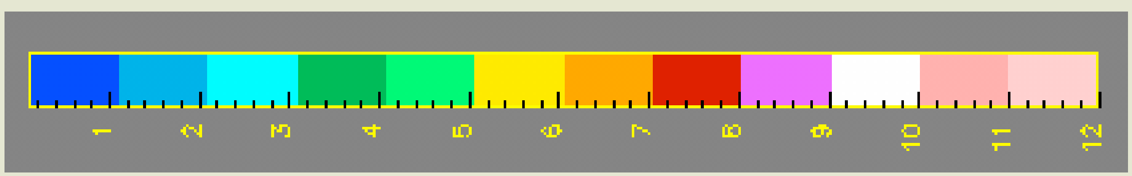
DAYTIME



MEAN EFFECTIVE CLOUD HEIGHT, MODIS, DEC 2000

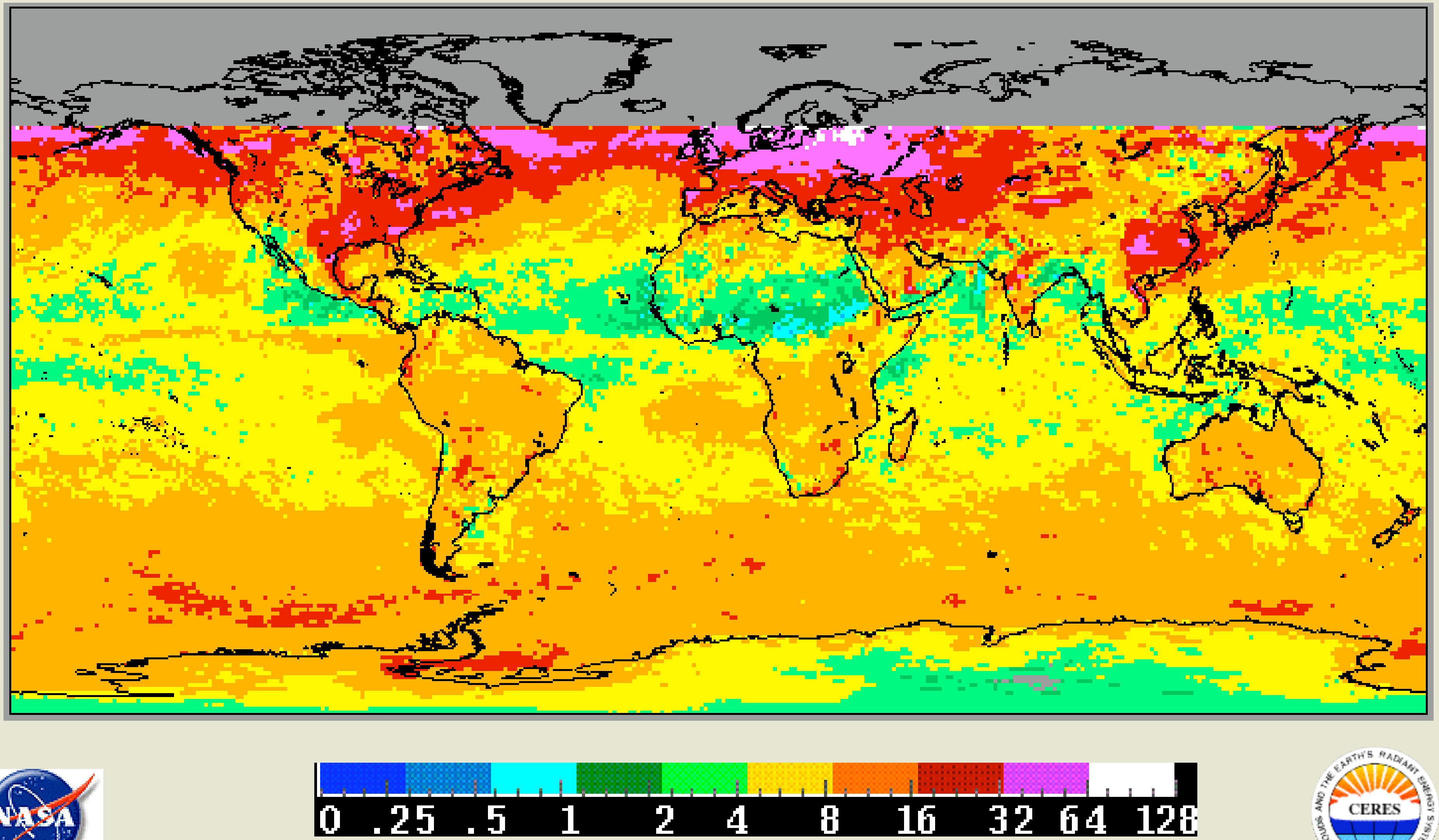
DAYTIME





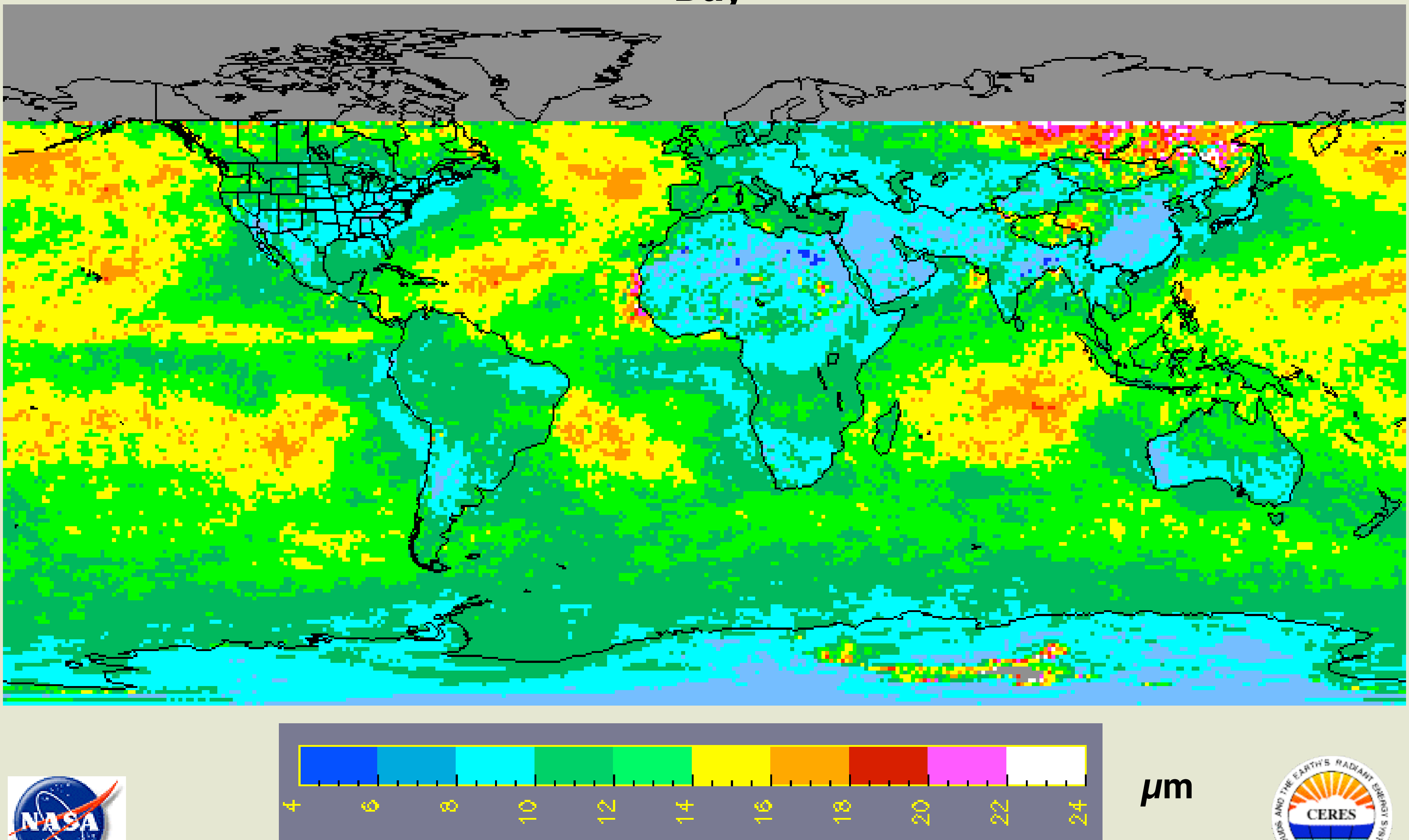
km

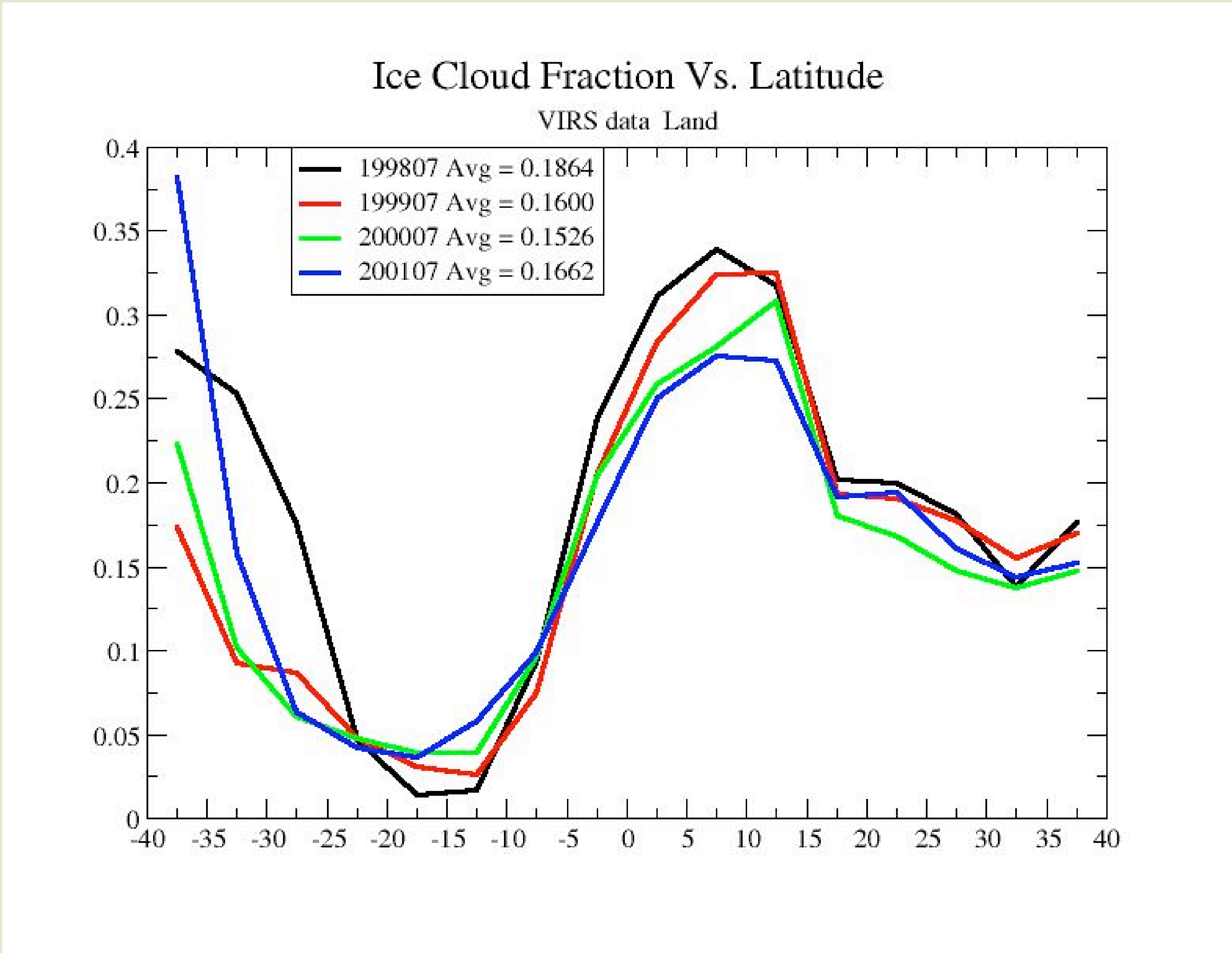
MEAN WATER CLOUD OPTICAL DEPTH, MODIS, DEC 2000, DAY

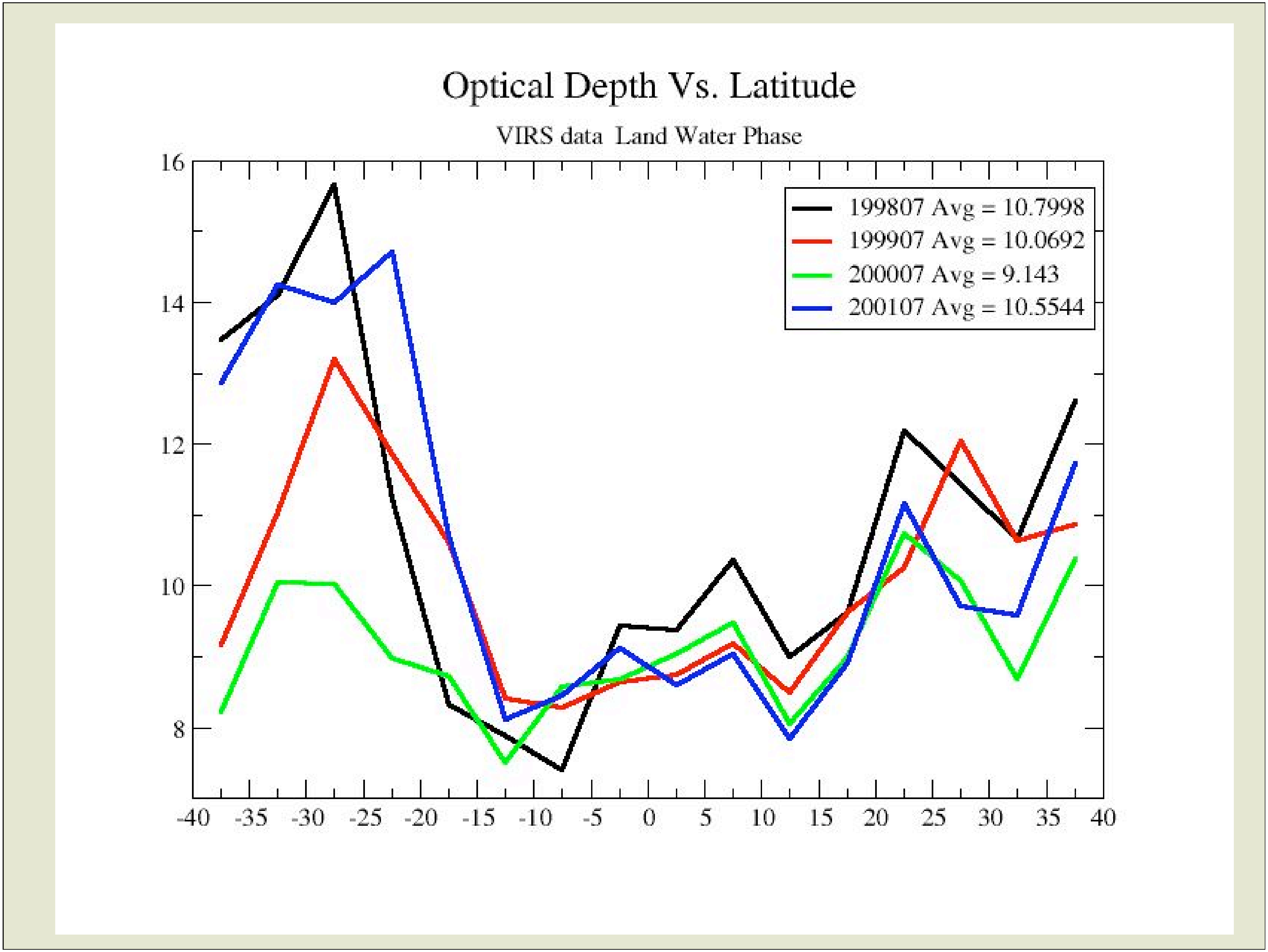


MEAN EFFECTIVE DROPLET RADIUS, MODIS, DEC 2000

Day

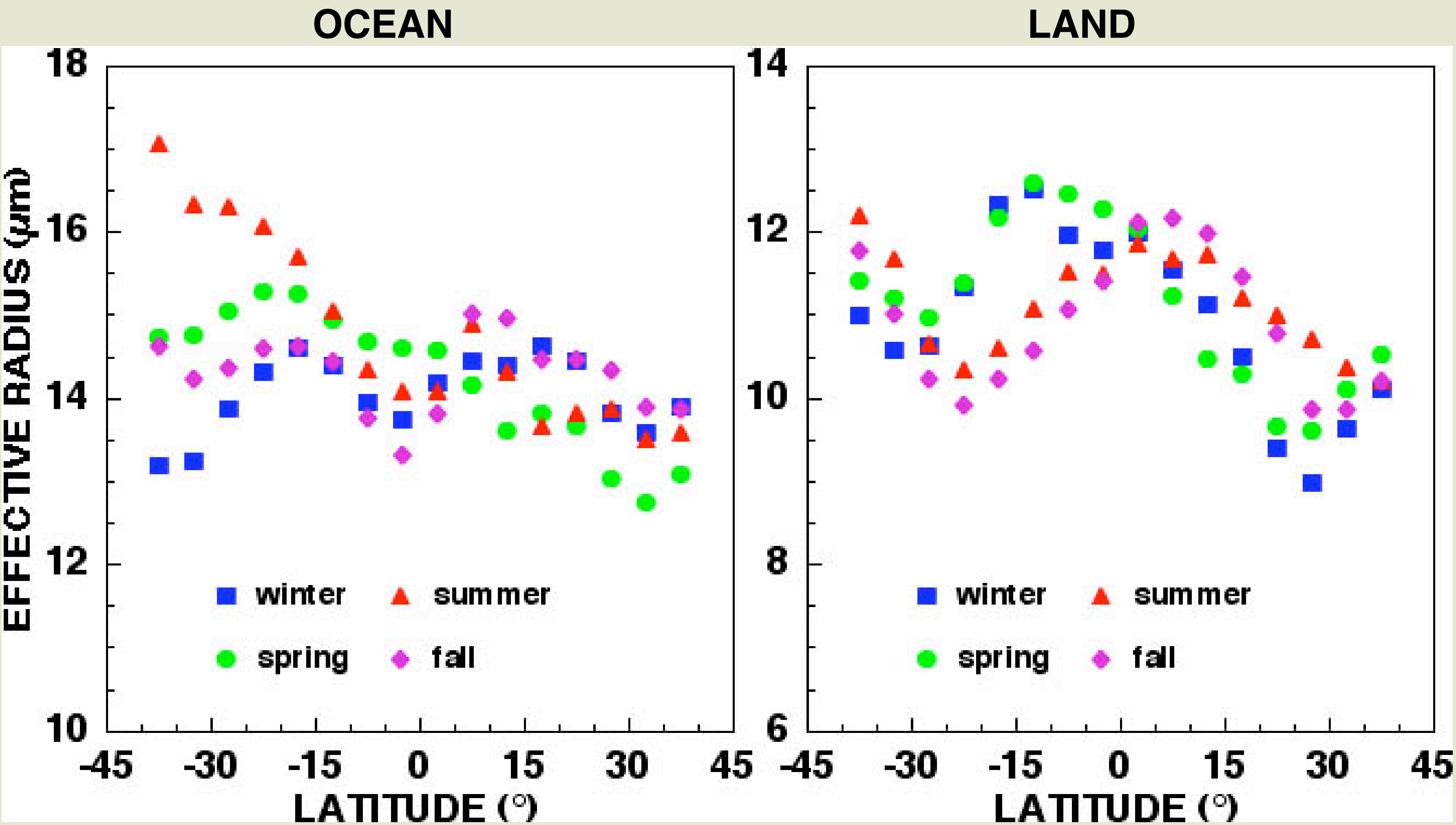



Ice Cloud Fraction Vs. Latitude
VIRS data Land
199807 Avg = 0.1864
199907 Avg = 0.1600
200007 Avg = 0.1526
200107 Avg = 0.1662
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-40
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35
40


Optical Depth Vs. Latitude
VIRS data Land Water Phase
199807 Avg = 10.7998
199907 Avg = 10.0692
200007 Avg = 9.143
200107 Avg = 10.5544
16
14
12
10
8
-40
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35
40

SEASONAL VARIATION OF EFFECTIVE DROPLET RADIUS

VIRS, 1998 - 2001

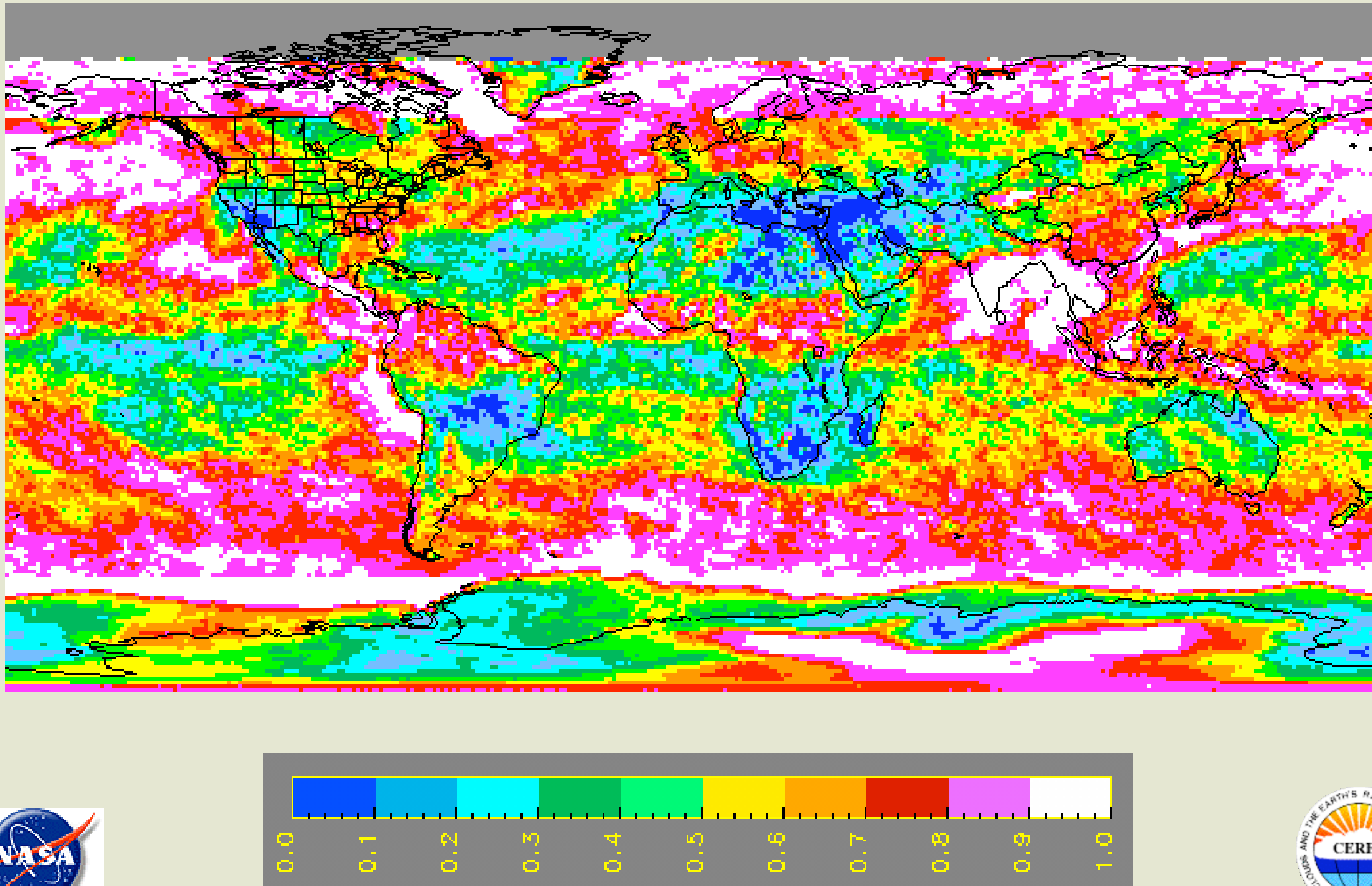


Range in southern ocean is 2 - 4 μm
1 - 2 μm elsewhere

Range over tropical land 1 - 2 μm

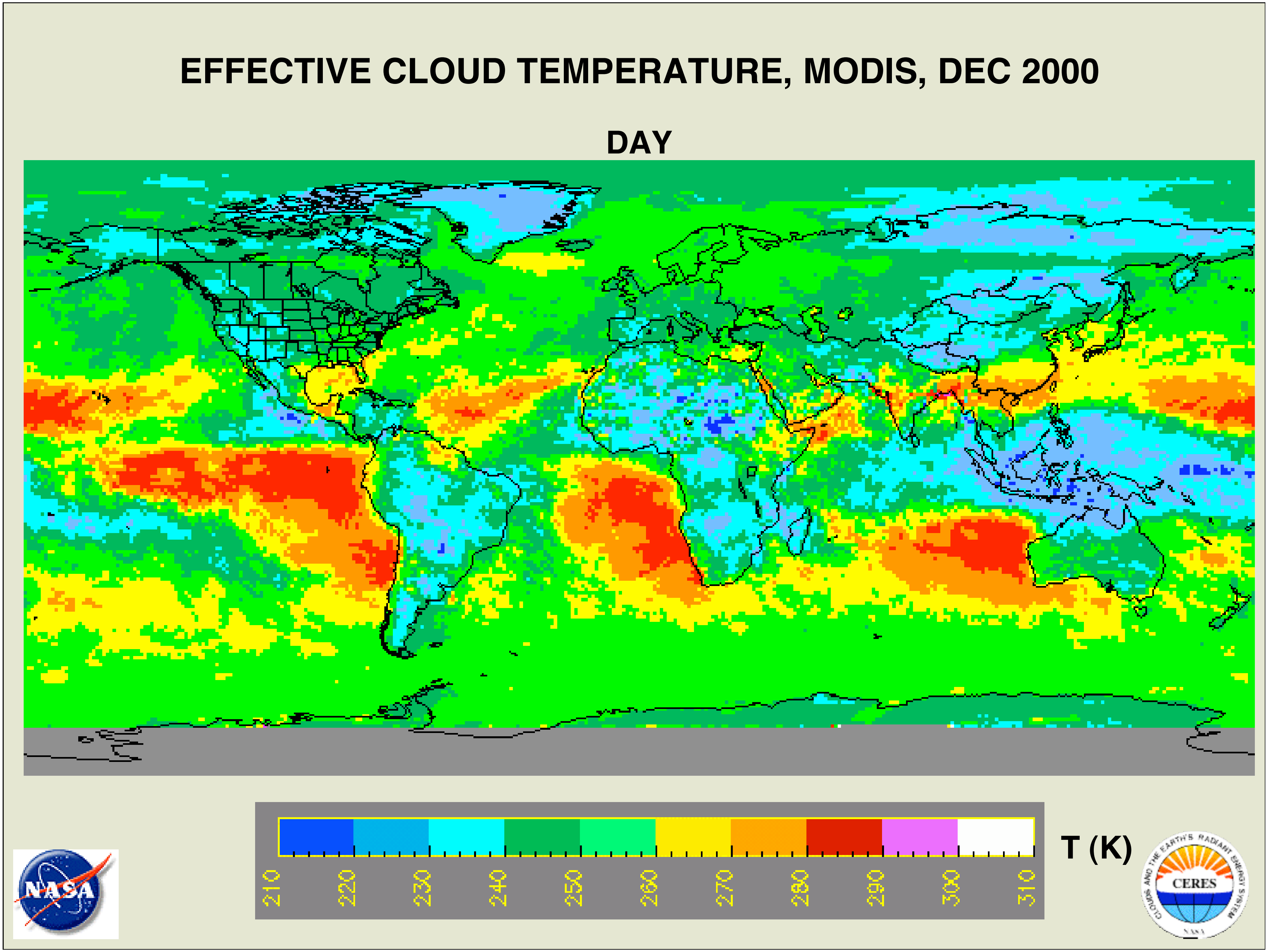
MEAN CLOUD COVER, MODIS, June 2001

night



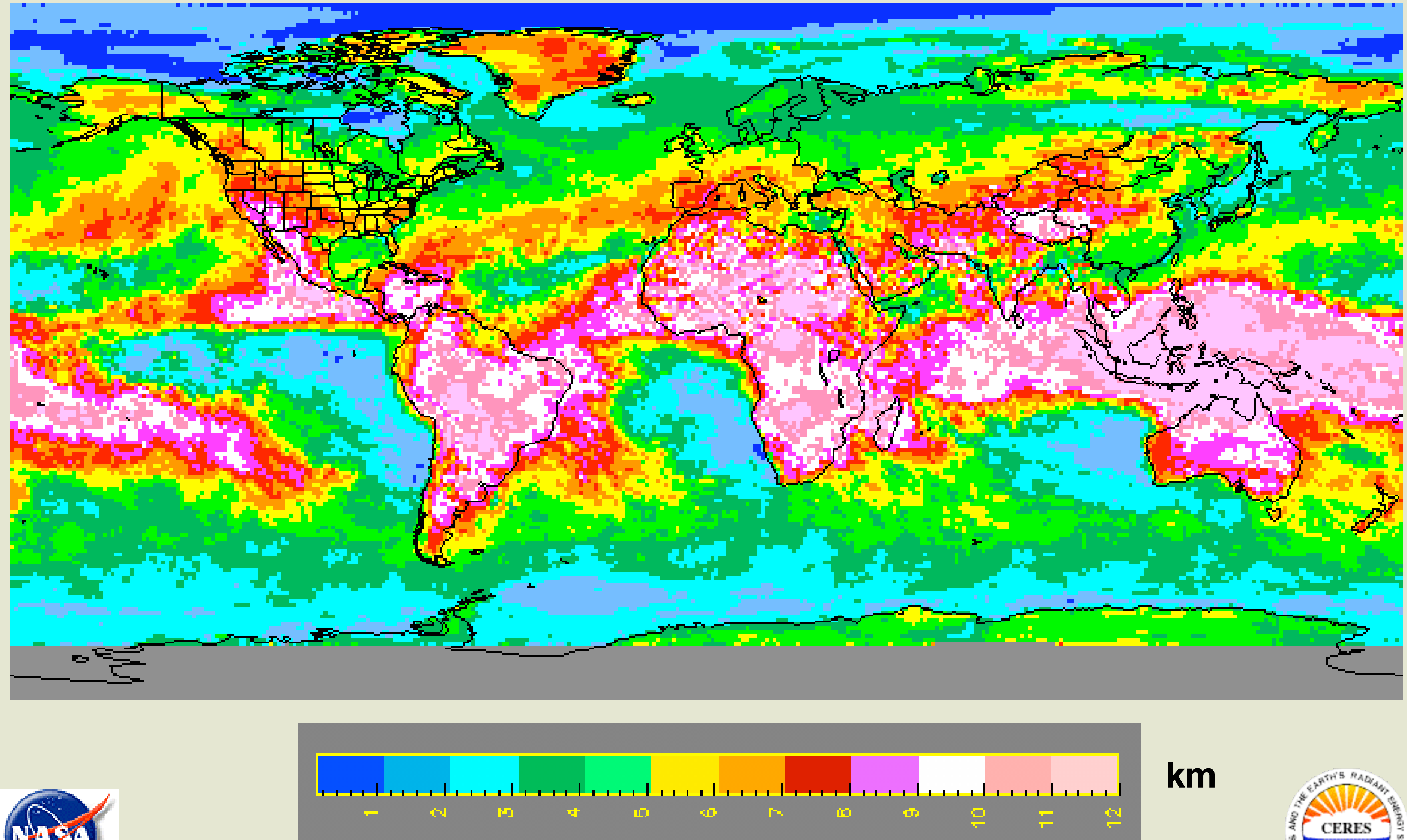
EFFECTIVE CLOUD TEMPERATURE, MODIS, DEC 2000

DAY



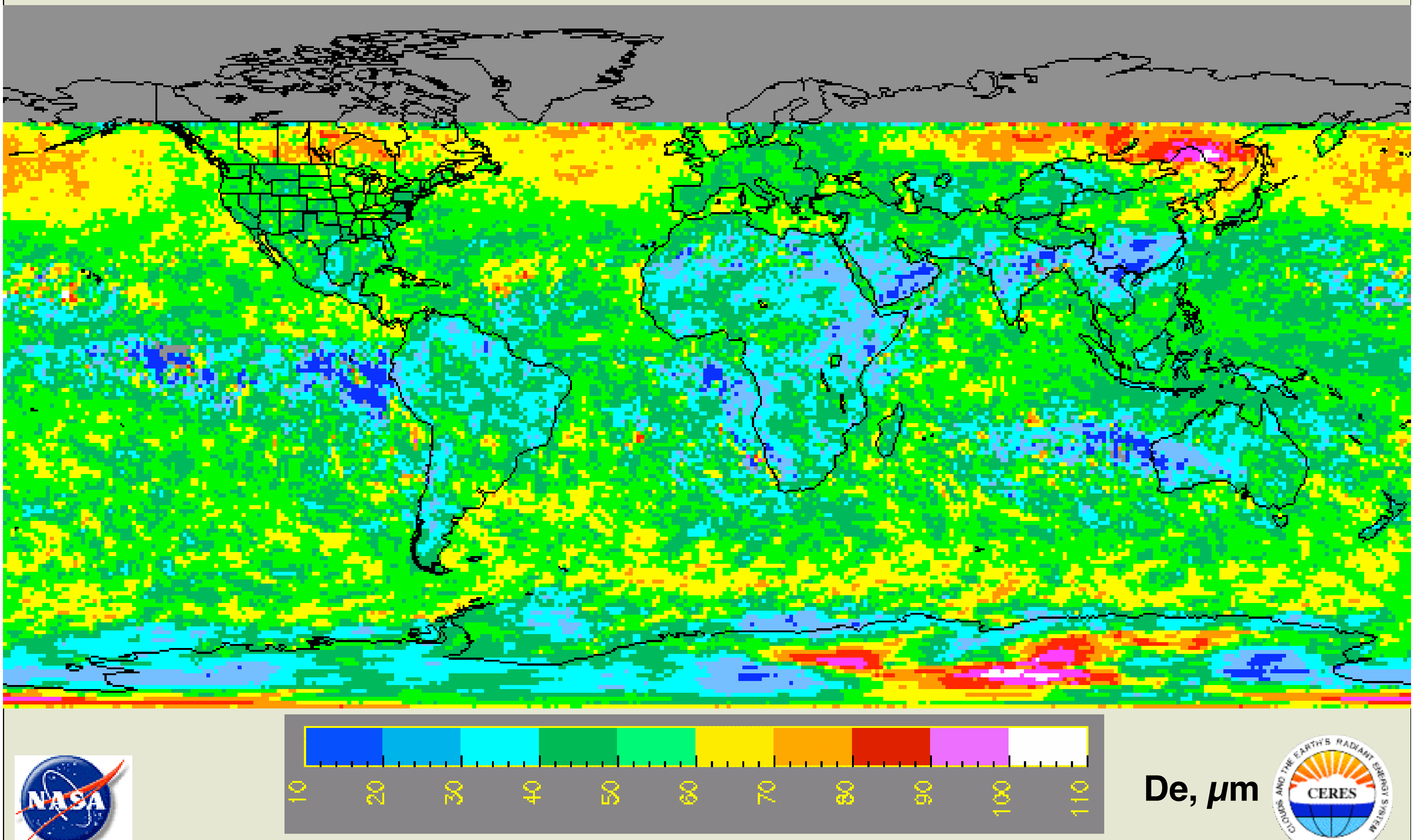
MEAN EFFECTIVE CLOUD HEIGHT, MODIS, DEC 2000

NIGHT



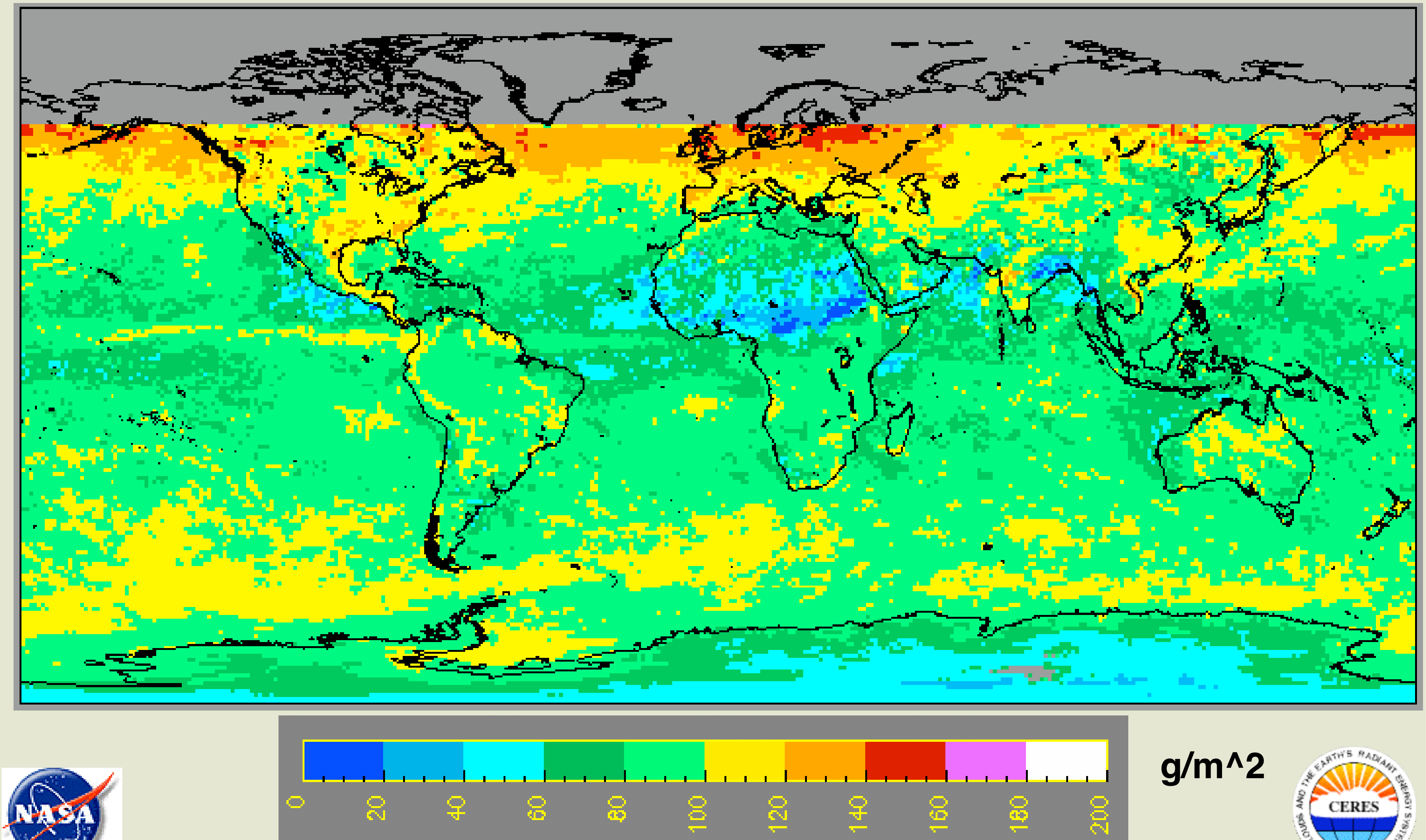
MEAN EFFECTIVE ICE CRYSTAL DIAMETER , MODIS, DEC 2000

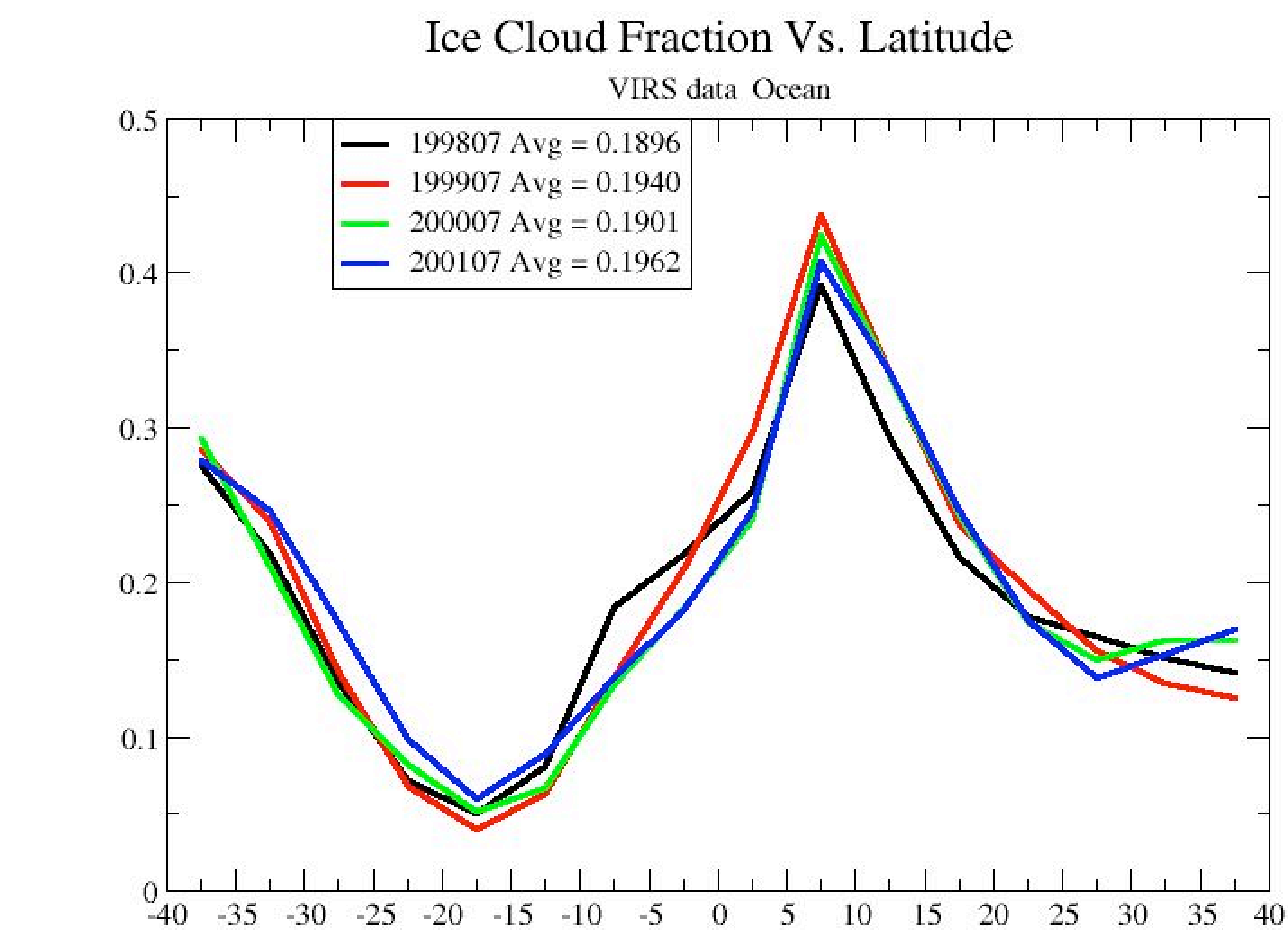
DAYTIME



MEAN CLOUD LIQUID WATER PATH, MODIS DEC 2000

Daytime

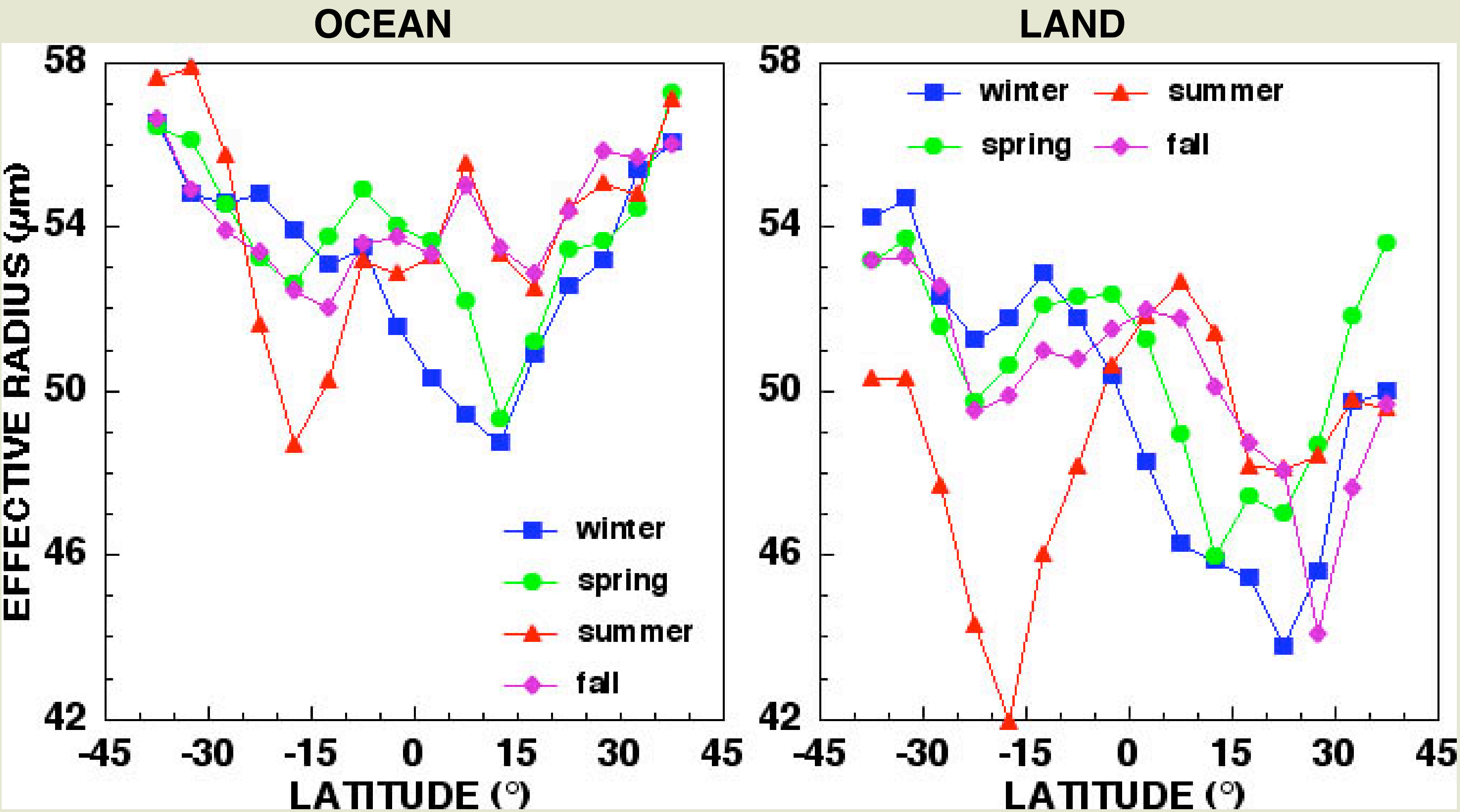




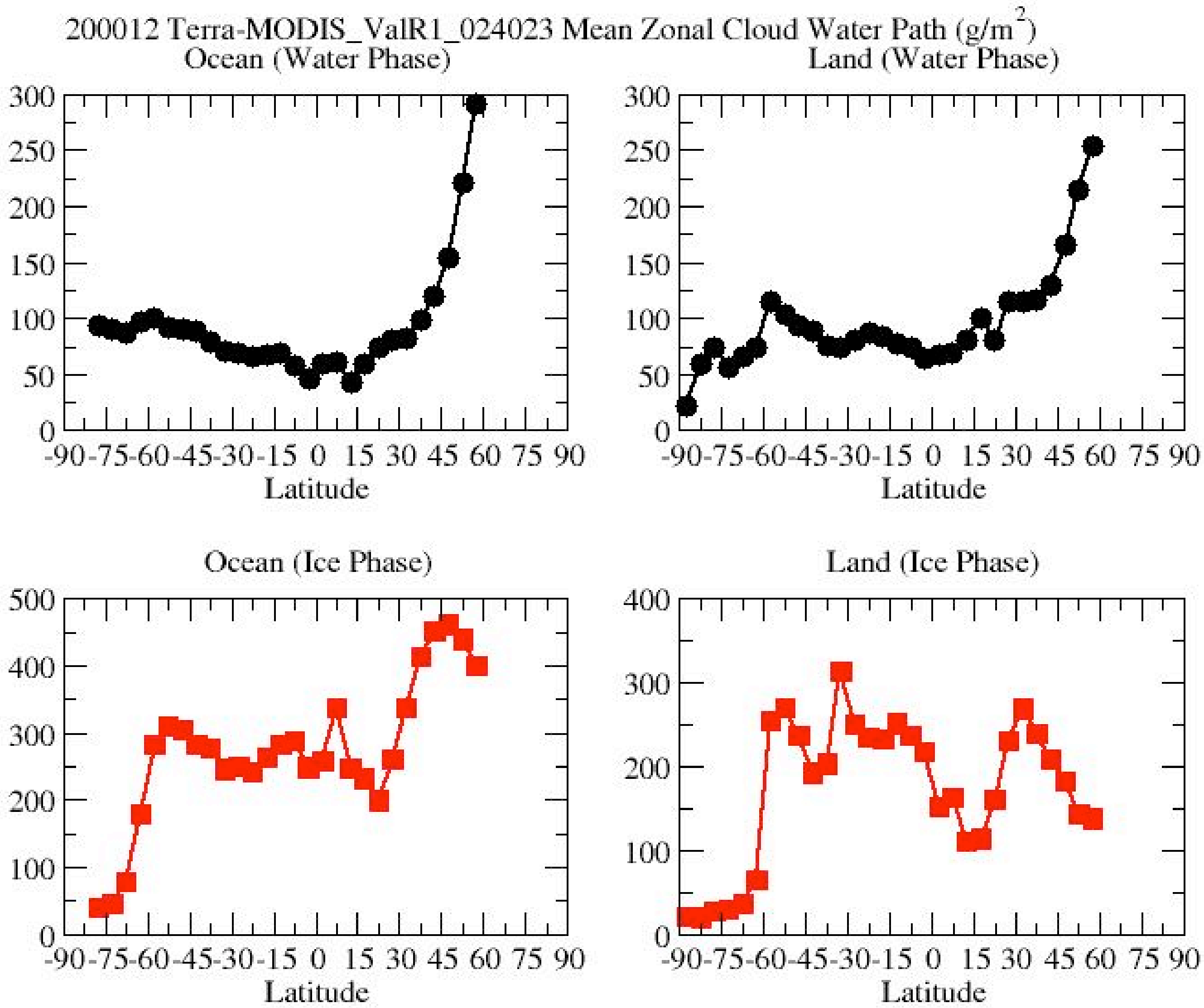
Ice Cloud Fraction Vs. Latitude
VIRS data Ocean
199807 Avg = 0.1896
199907 Avg = 0.1940
200007 Avg = 0.1901
200107 Avg = 0.1962
0.5
0.4
0.3
0.2
0.1
0
-40
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35
40

SEASONAL VARIATION OF EFFECTIVE ICE CRYSTAL DIAMETER

VIRS, 1998 - 2001



MEAN WATER PATH, MODIS, DEC 2000, DAY

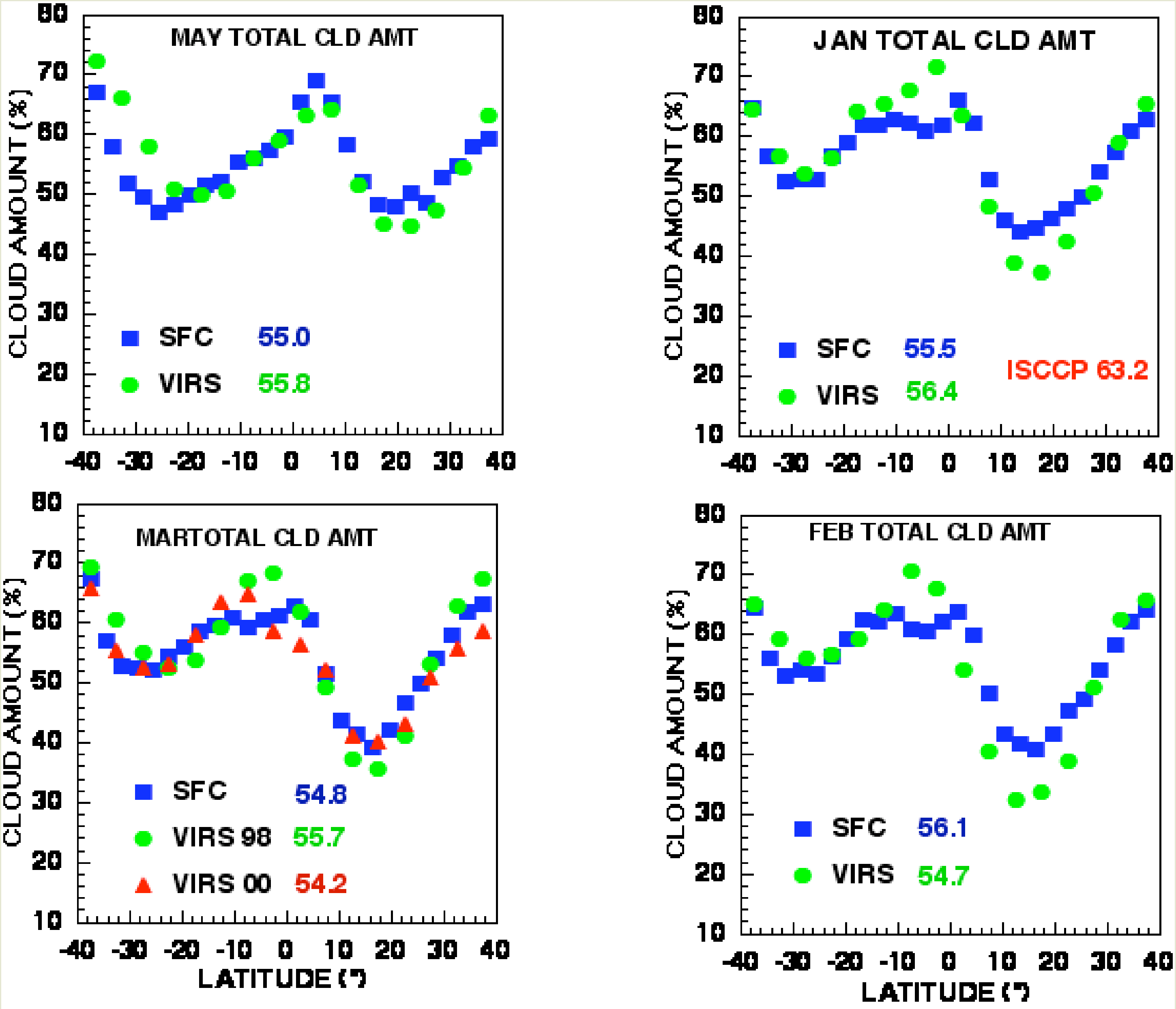


VALIDATION (COMPARISONS)

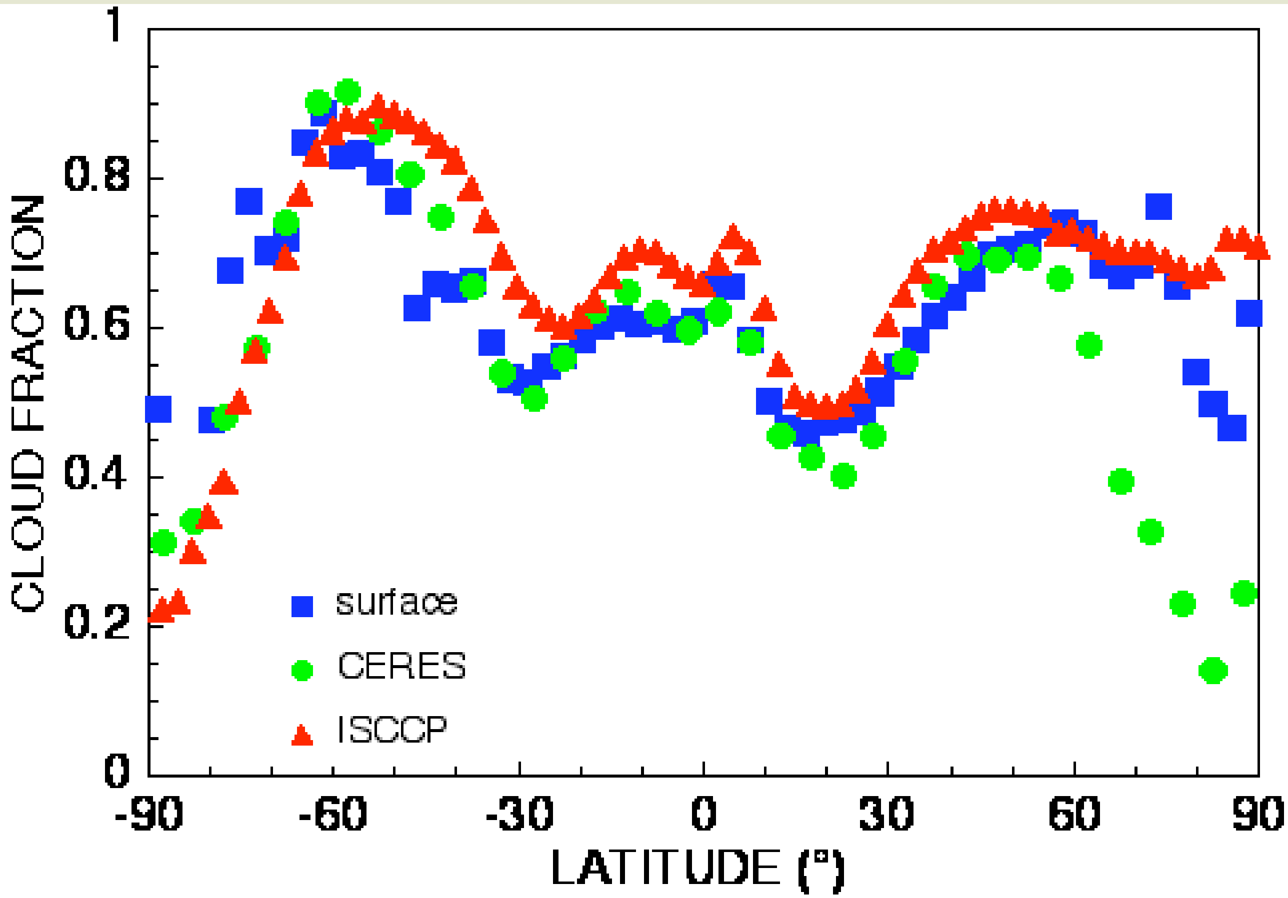
- with climatological datasets (surface, ISCCP)
  - cloud amount, optical depth
- with surface-based retrievals
  - LWP, r_e, Z_c, T_c, □ from radiometers, radar, lidar
- with aircraft measurements
  - in situ microphysics
  - remotely sensed macrophysics, radiation
- with other satellite measurements
  - different type of retrievals (e.g., LWP from μ-wave)
  - dual angle retrievals (phase function, phase, □)
  - intersatellite consistency
- with theoretical calculations (consistency)
  - TOA fluxes (e.g., SARB results from Charlock)
  - angular variations (e.g., ADMs from Loeb)

COMPARISON OF TOTAL CLOUD AMOUNTS

SURFACE (1971-1996) VIRS (1998) ISCCP (1984 - 1991)

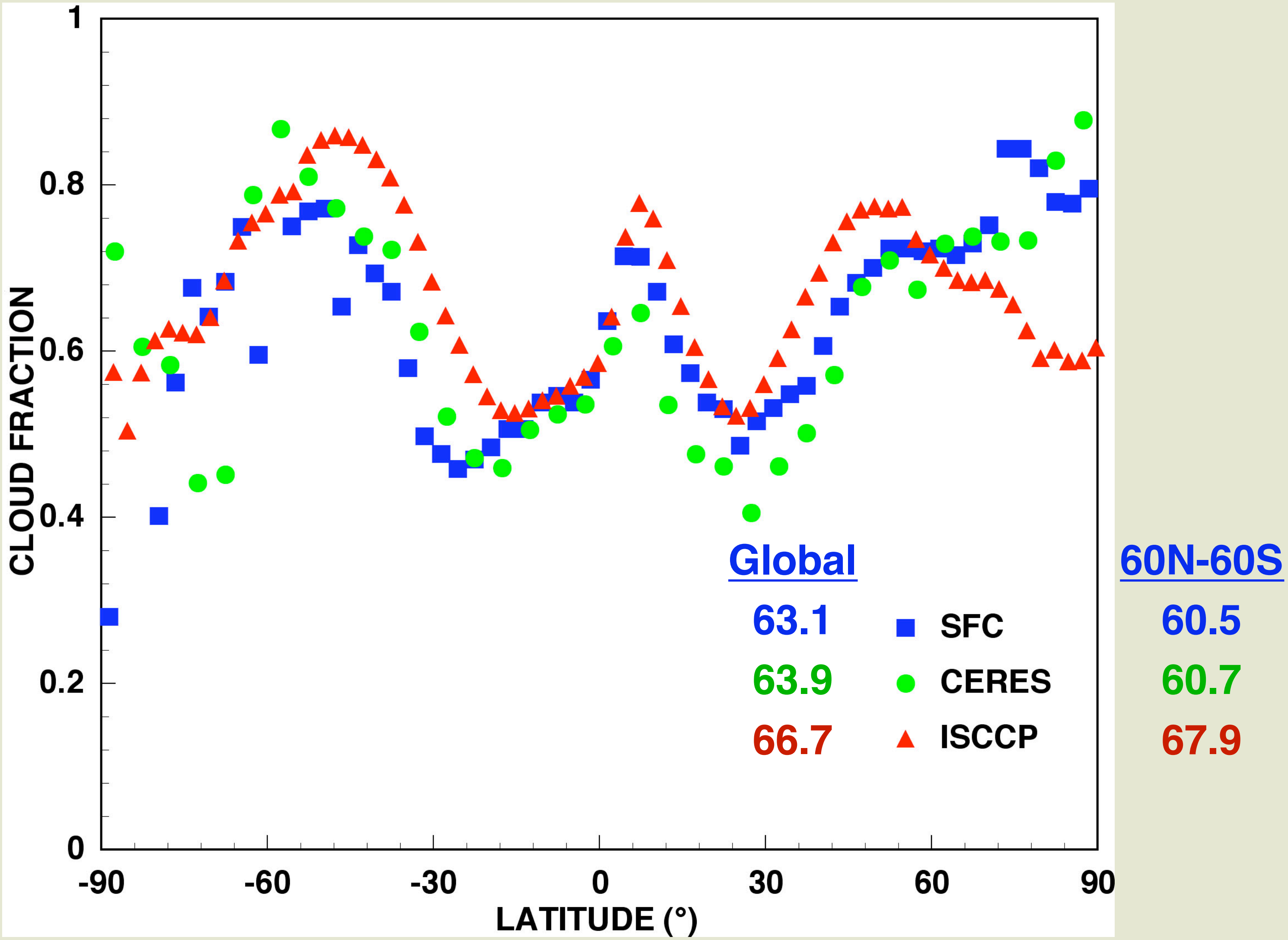


MEAN CLOUD FRACTION, DEC



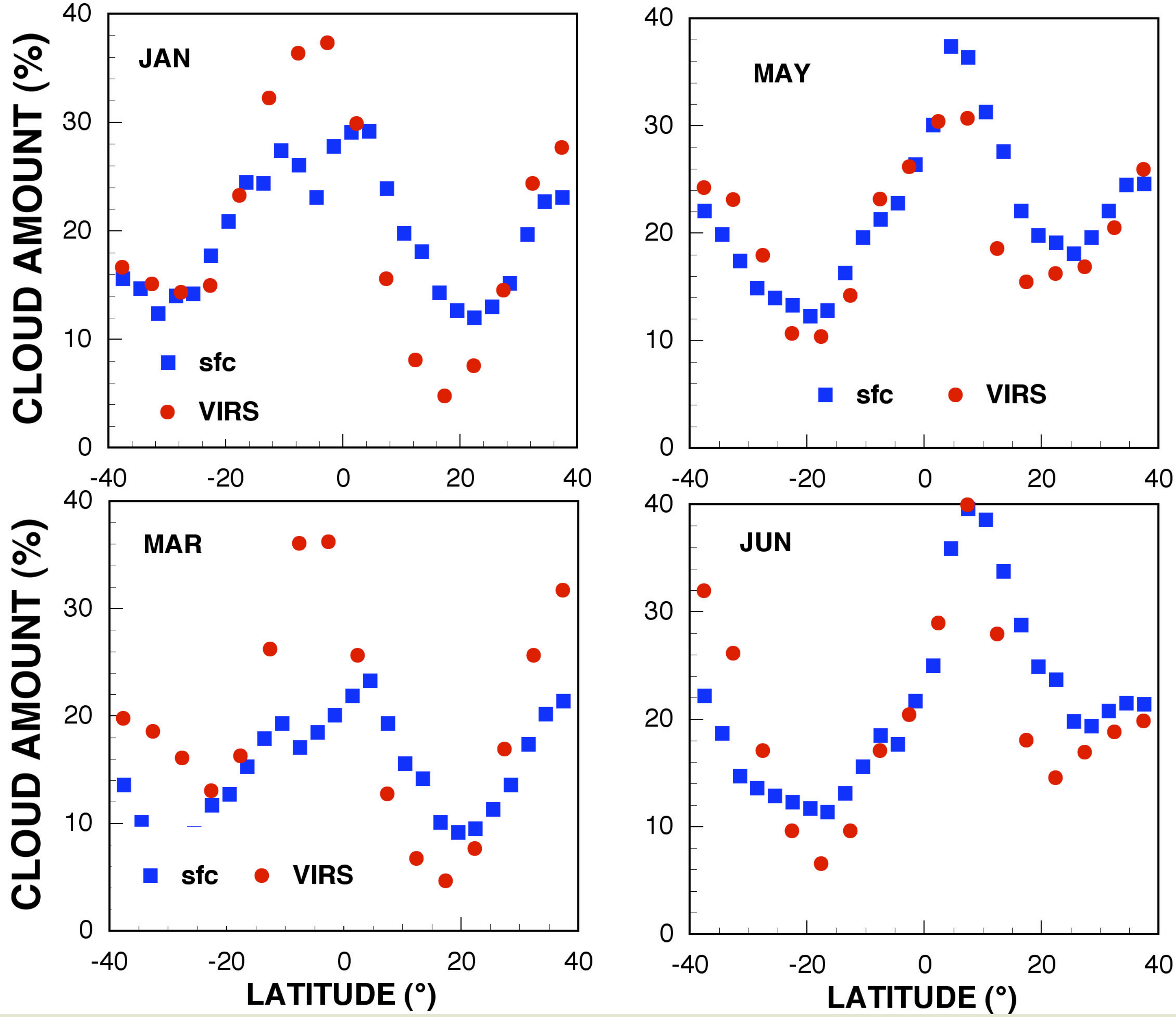
	SURFACE	CERES	ISCCP
ALL	0.632	0.563	0.669
60N - 60S	0.606	0.625	0.696
YEAR	71-96	00	84-94

COMPARISON OF JUNE CLOUD AMOUNTS

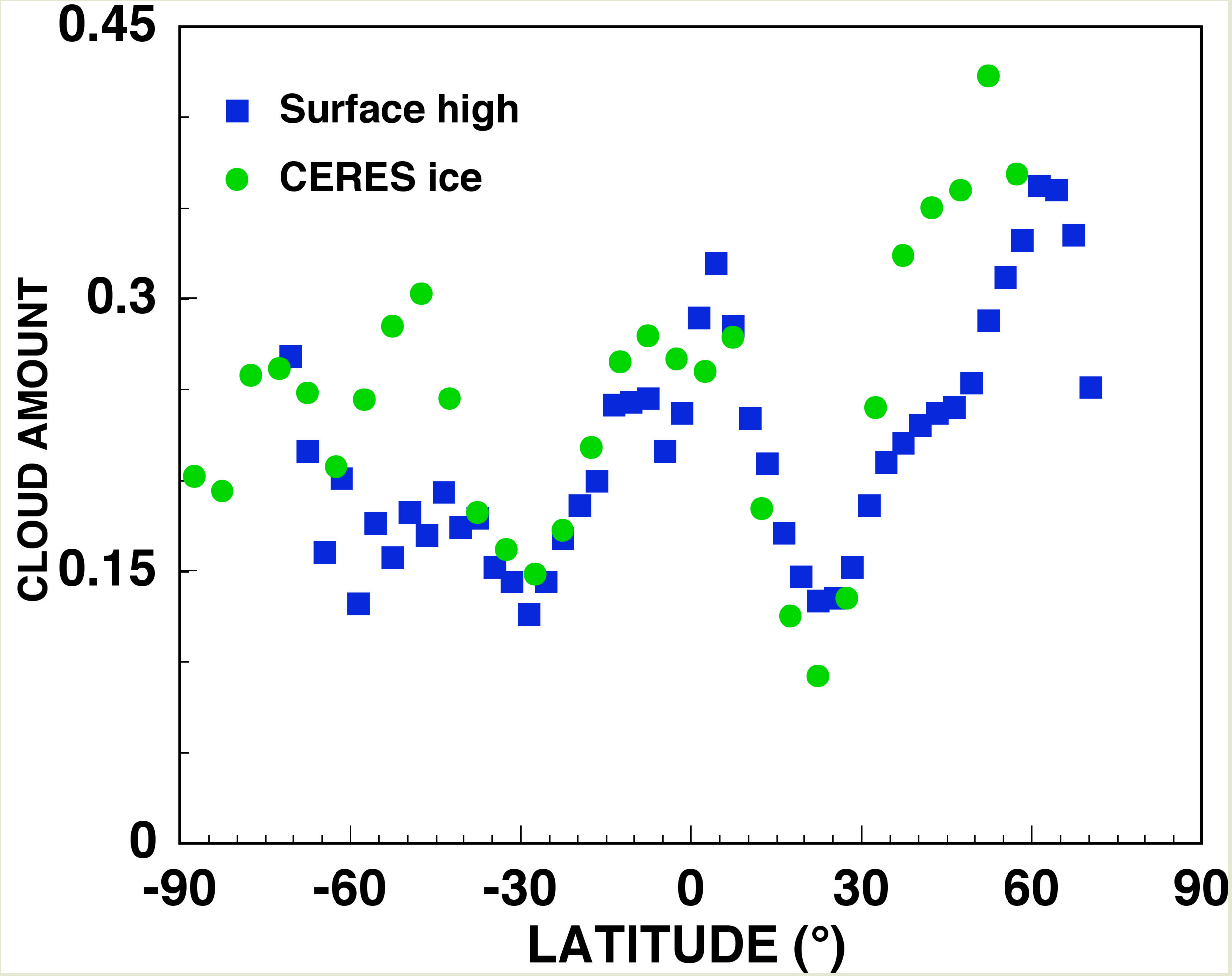


ISCCP: lower resolution => more cloud cover?

COMPARISON OF SFC-OBSERVED HIGH CLOUD AMOUNTS (1971-1996) AND VIRS-DERIVED COVERAGE BY ICE CLOUDS



SURFACE-OBSERVED HIGH CLOUD AMOUNTS (JUNE 1971-95) VS CERES-MODIS ICE CLOUD COVER (JUNE 2001)

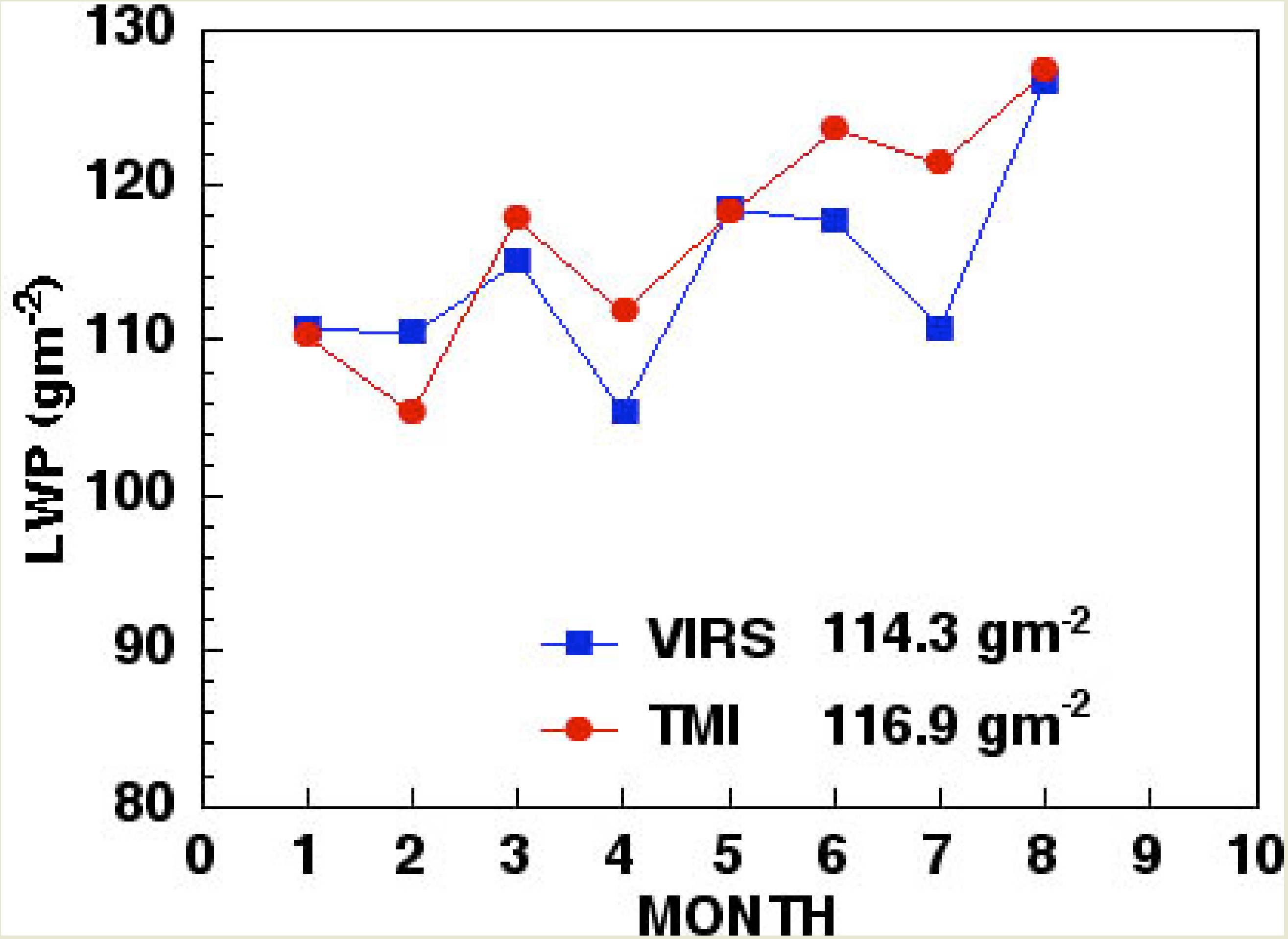


Agreement in low latitudes consistent with VIRS

- discrepancy in midlatitudes due to definition of high?

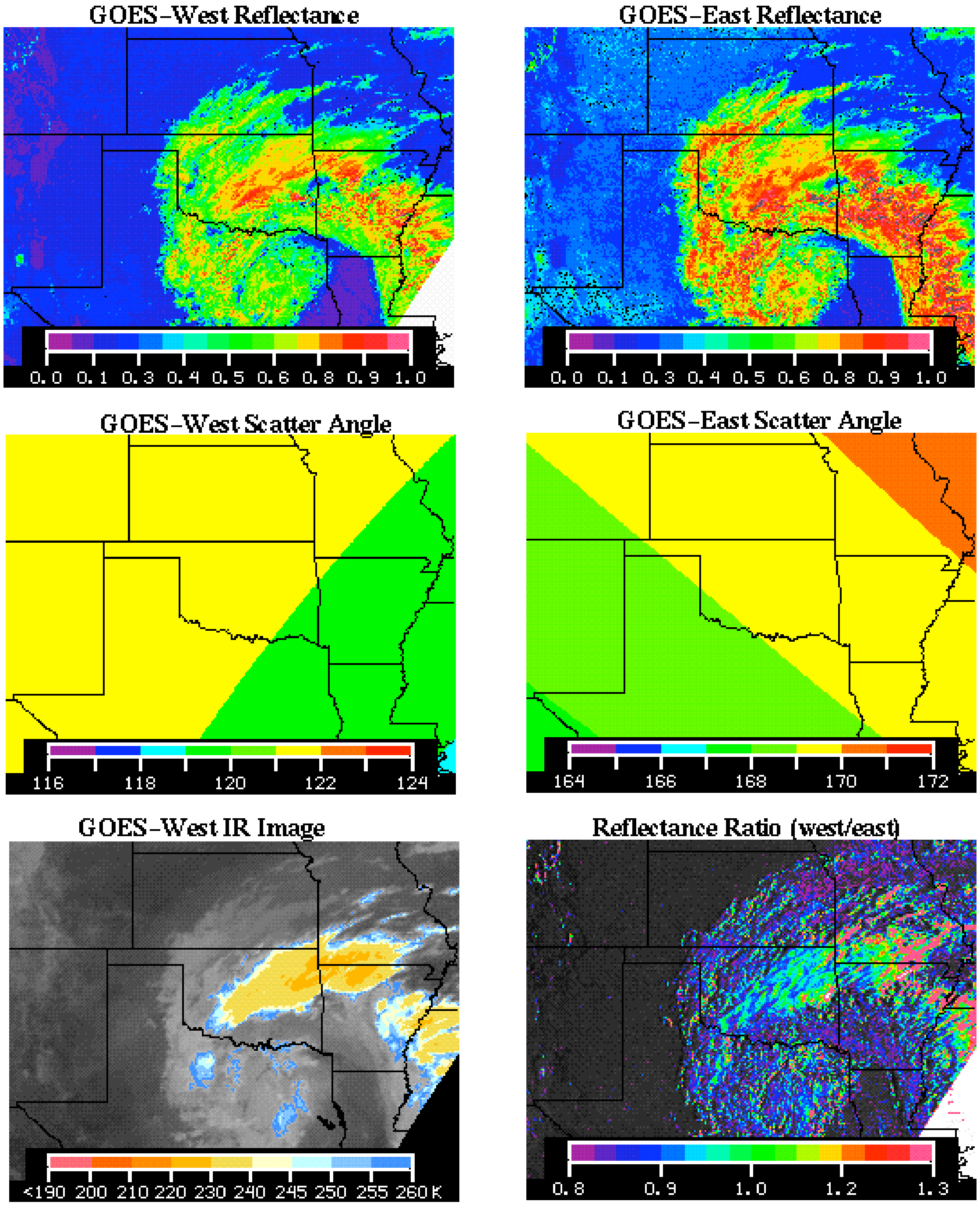
MONTHLY MEAN CLOUD LWP FROM VIRS & TMI OVER OCEANS

overcast, water cloud only, Tc > 273 K, SZA < 78°, no sunglint



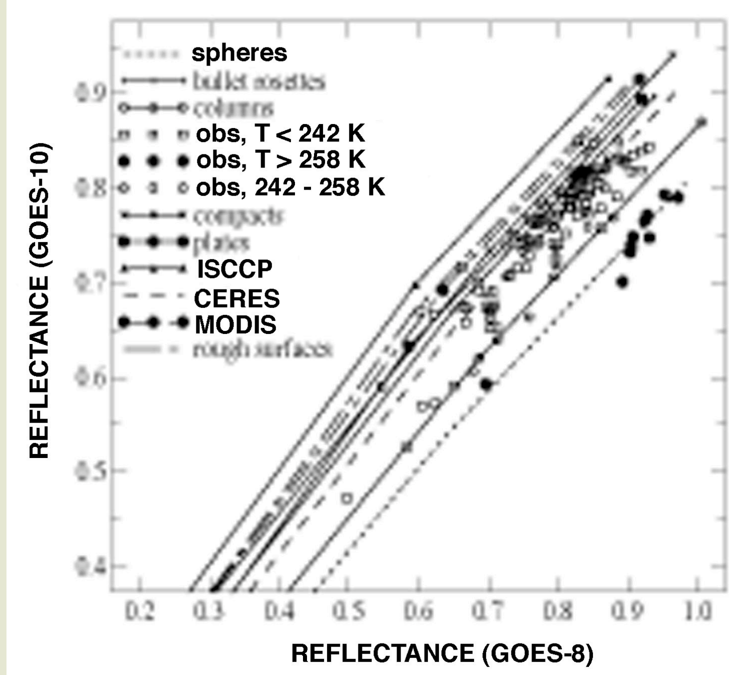
TMI - TRMM Microwave Imager, LWP from method of *Lin et al., JGR, 1998*

October 31, 1999 17:00 & 17:02 UTC



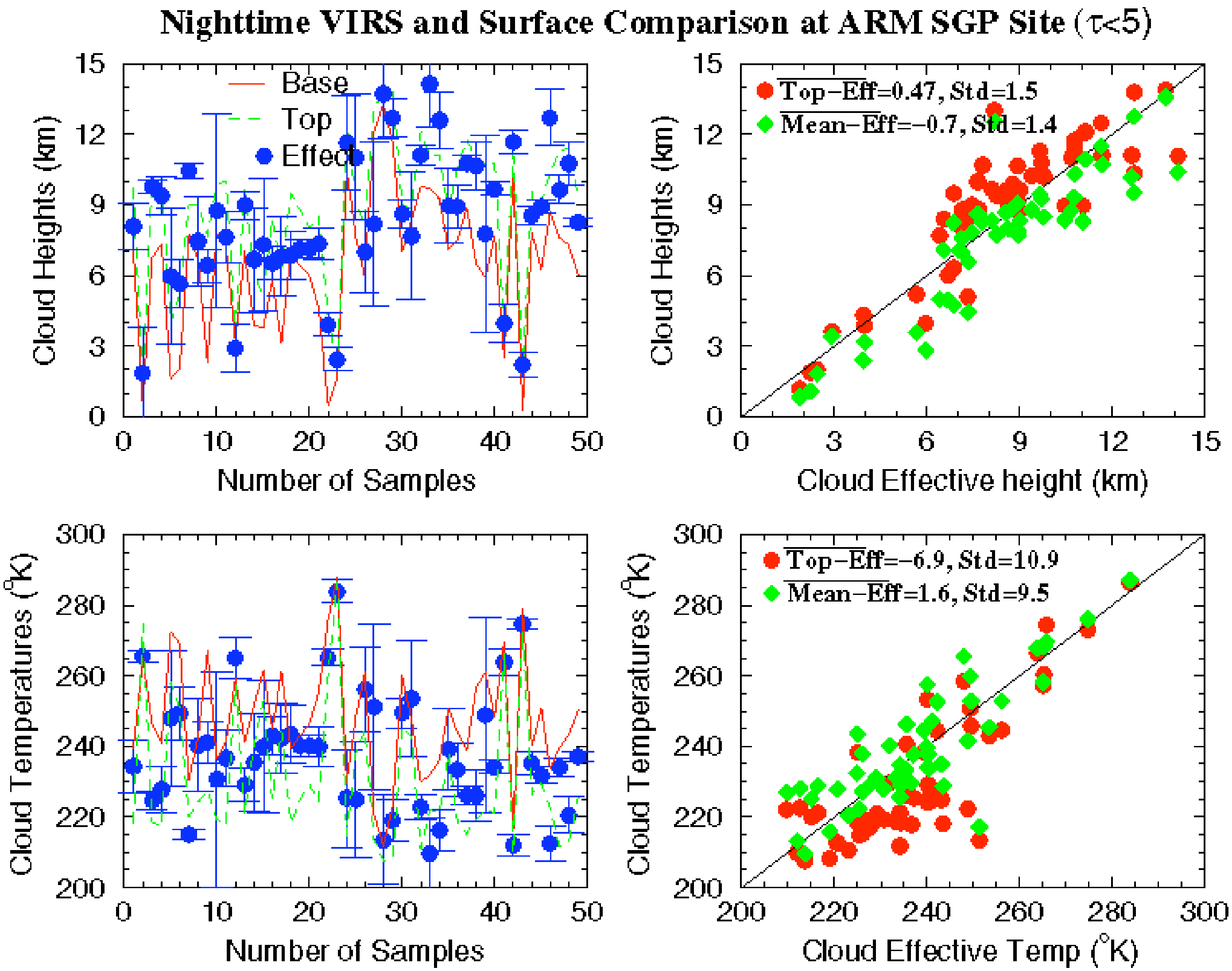
DUAL-ANGLE RETRIEVAL TO TEST PHASE FUNCTION

For a pair of reflectances, the matched observations should coincide with a particular reflectance-pair line for a given phase function



Chepfer et al. **(JGR, 2002) found that CERES ice phase function explains observed reflectances as often or more so as any others tested.**

Validation of Cloud Height over ARM SGP, VIRS 1998

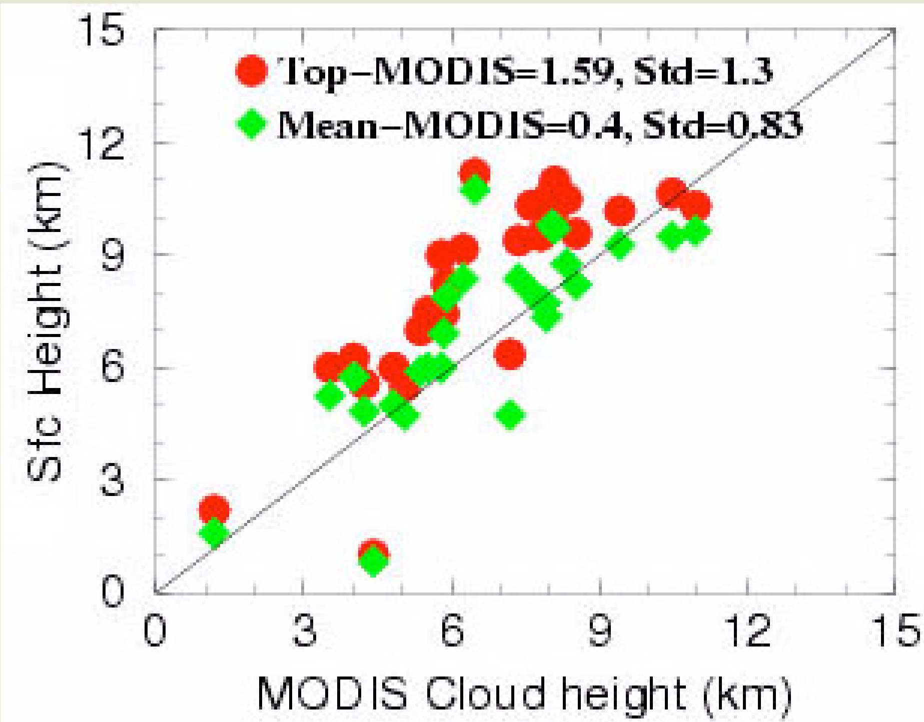


Nighttime thin: 4 Ci too high, 1 too low; best agreement

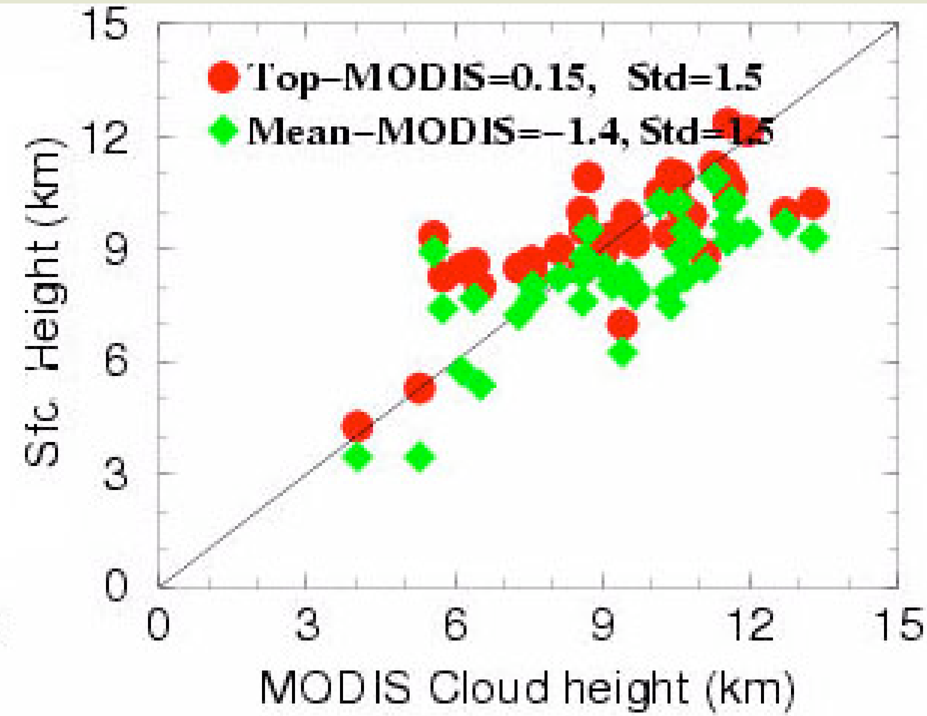
Dong et al. (submitted JAS 2002)

Validation of Thin (□< 5) Cloud Height over ARM SGP, MODIS 2001

Daytime



Nighttime

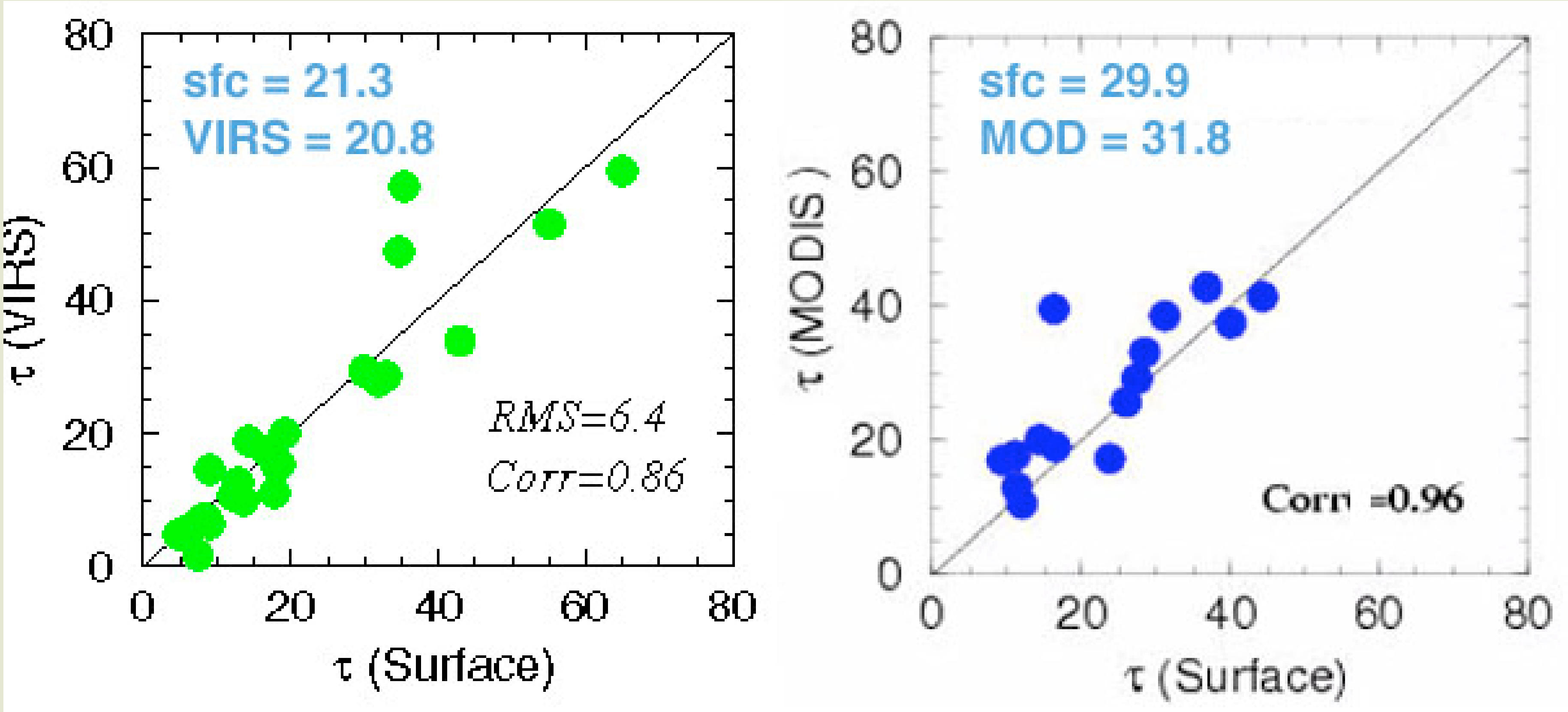


Nearly all thin cloud heights are within boundaries of cloud:

- **Clouds higher at night due to greater errors in skin temperature**
- **Boundary-layer cloud heights sometimes too high due to inversions**
- **Implies cirrus optical depths are quite reasonable**

Validation of CERES Cloud Optical Depth (Stratus)

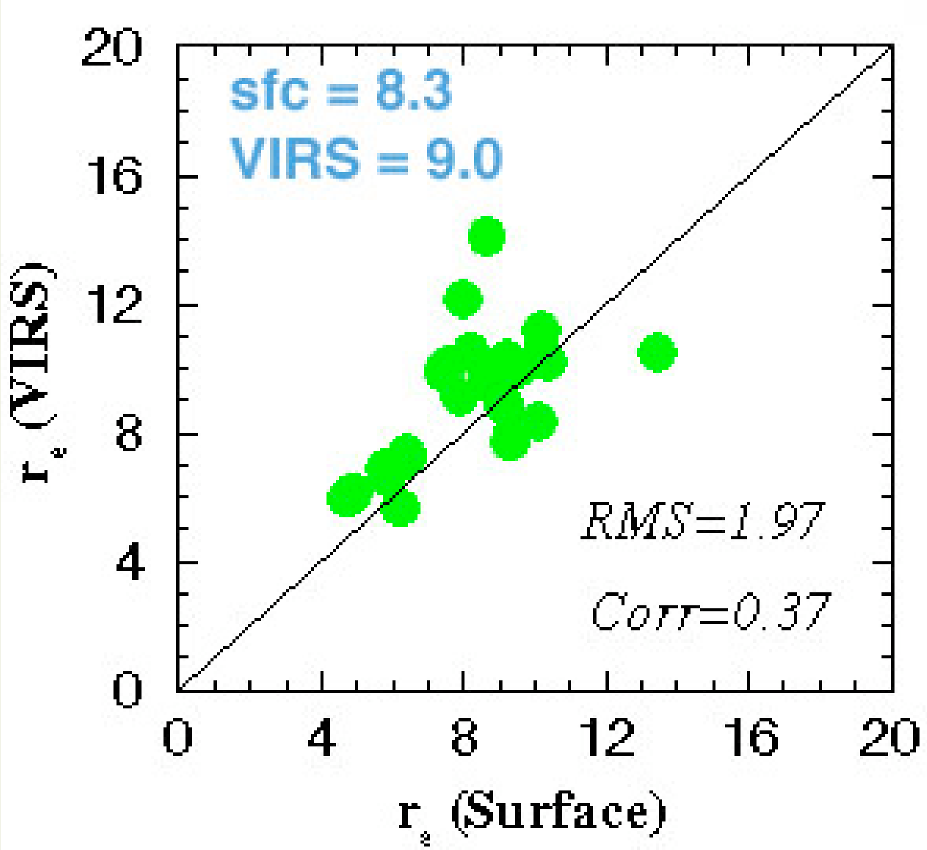
ARM SGP, VIRS 1998; MODIS 2001

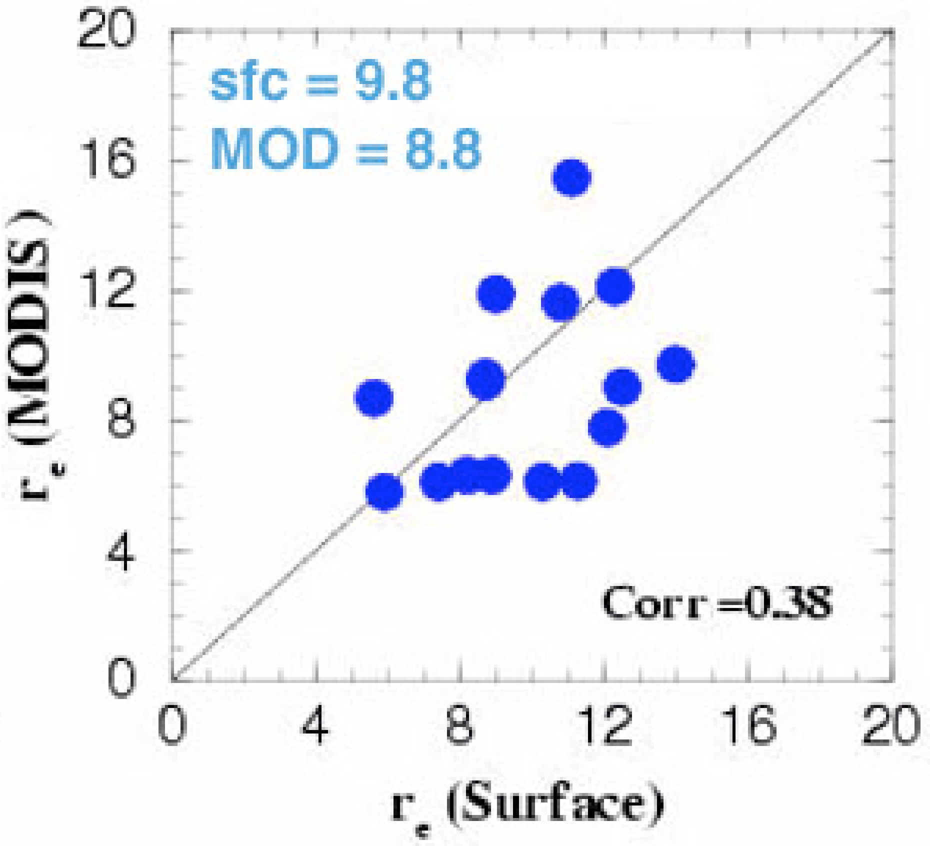


Excellent correspondence between CERES and surface-derived optical depths over ARM SGP site

Validation of CERES Cloud Droplet Size (Stratus)

ARM SGP, VIRS 1998; MODIS 2001

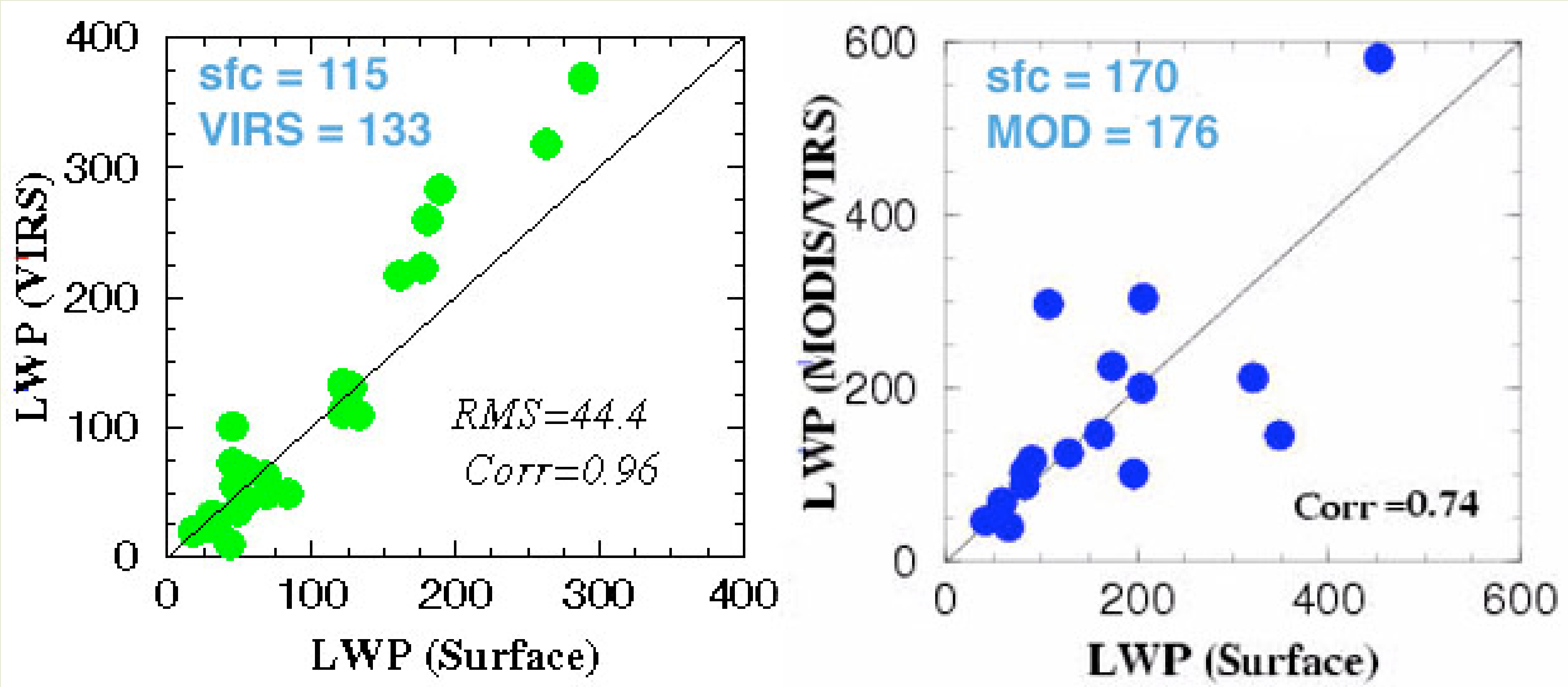




CERES average droplet sizes within $\pm$ 1 µm of surface-based values over ARM SGP site

Validation of CERES Cloud Droplet Size (Stratus)

ARM SGP, VIRS 1998; MODIS 2001



CERES LWP slightly greater than surface-based values over ARM SGP site

COMPARISON OF CERES VIRS & SURFACE-DERIVED CLOUD PROPERTIES

ARM SGP JAN - AUG 1998 DAYTIME

Parameter	VIRS-sfc	std dev	SD(%)	N
Thin Tc vs mean	-11.8 K	11.7 K	-	18
Thick Tc vs mean	-6.8 K	8.2 K	-	41
Thin Zc vs. mean	-1.1 km	1.7 km	-	18
Thin Zc vs. top	-2.1 km	2.0 km	-	18
Thick Zc vs. mean	0.4 km	1.3 km	-	41
Thick Zc vs. top	-0.4 km	1.6 km	-	41
Stratus □	-1.5	6.2	21	25
Stratus re (μm)	0.7	1.8 □	20	25
LWP (gm^{-2})	-18	41	35	25
Cirrus □	0.7	1.3	38	7
Cirrus De (μm)	0.5	17.0	72	7
IWP (gm^{-2})	4.3	18.3	49	7

COMPARISON OF CERES VIRS & SURFACE-DERIVED CLOUD PROPERTIES

ARM SGP JAN - AUG 1998 NIGHTTIME

Parameter	VIRS-sfc	std dev	SD(%)	N
Thin Tc vs mean	-1.6 K	9.5 K	-	49
Thick Tc vs mean	-6.4 K	7.3 K	-	31
Thin Zc vs. mean	0.7 km	1.4 km	-	49
Thin Zc vs. top	-0.5 km	1.5 km	-	31
Thick Zc vs. mean	1.6 km	1.1 km	-	49
Thick Zc vs. top	-0.4 km	1.6 km	-	49
Cirrus □	0.6	1.1	78	16
Cirrus De (μm)	-16.8	17.0	32	16
IWP (gm^{-2})	2.0	27.5	97	16

CONSISTENCY WITH RADIATIVE TRANSFER CALCULATIONS

- MEASURE BROADBAND RADIANCE AT ONE ANGLE & CONVERT TO FLUX

- DETERMINE CLOUD PROPERTIES FROM ANOTHER ANGLE & COMPUTE FLUX USING CLOUD PROPERTIES AS INPUT TO RADIATIVE TRANSFER MODEL

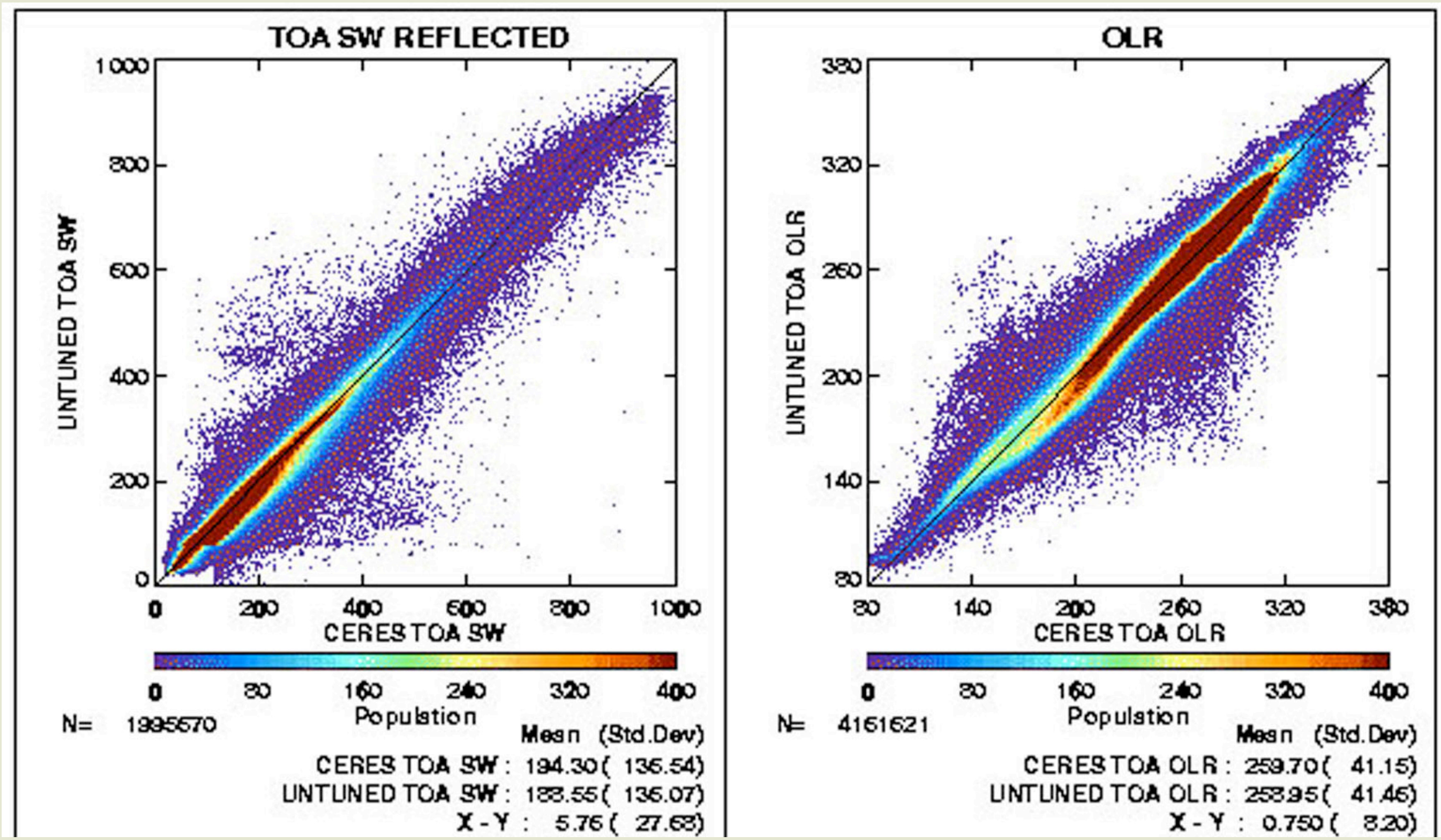
(*Fu and Liou, 1993*)

- DIFFERENCE IS MEASURE OF UNCERTAINTY IN PHASE FUNCTION USED TO RETRIEVE CLOUD PROPERTIES, CLOUD DETECTION, BIDIRECTIONAL REFLECTANCE MODEL, SURFACE & ATMOSPHERIC PROPERTIES

- UNCERTAINTY TELLS US HOW ACCURATE A CLIMATE OR WEATHER MODEL SHOULD COMPUTE THE INSTANTANEOUS FLUX IF THE CLOUD PROPERTIES ARE PROPERLY COMPUTED IN THE MODEL

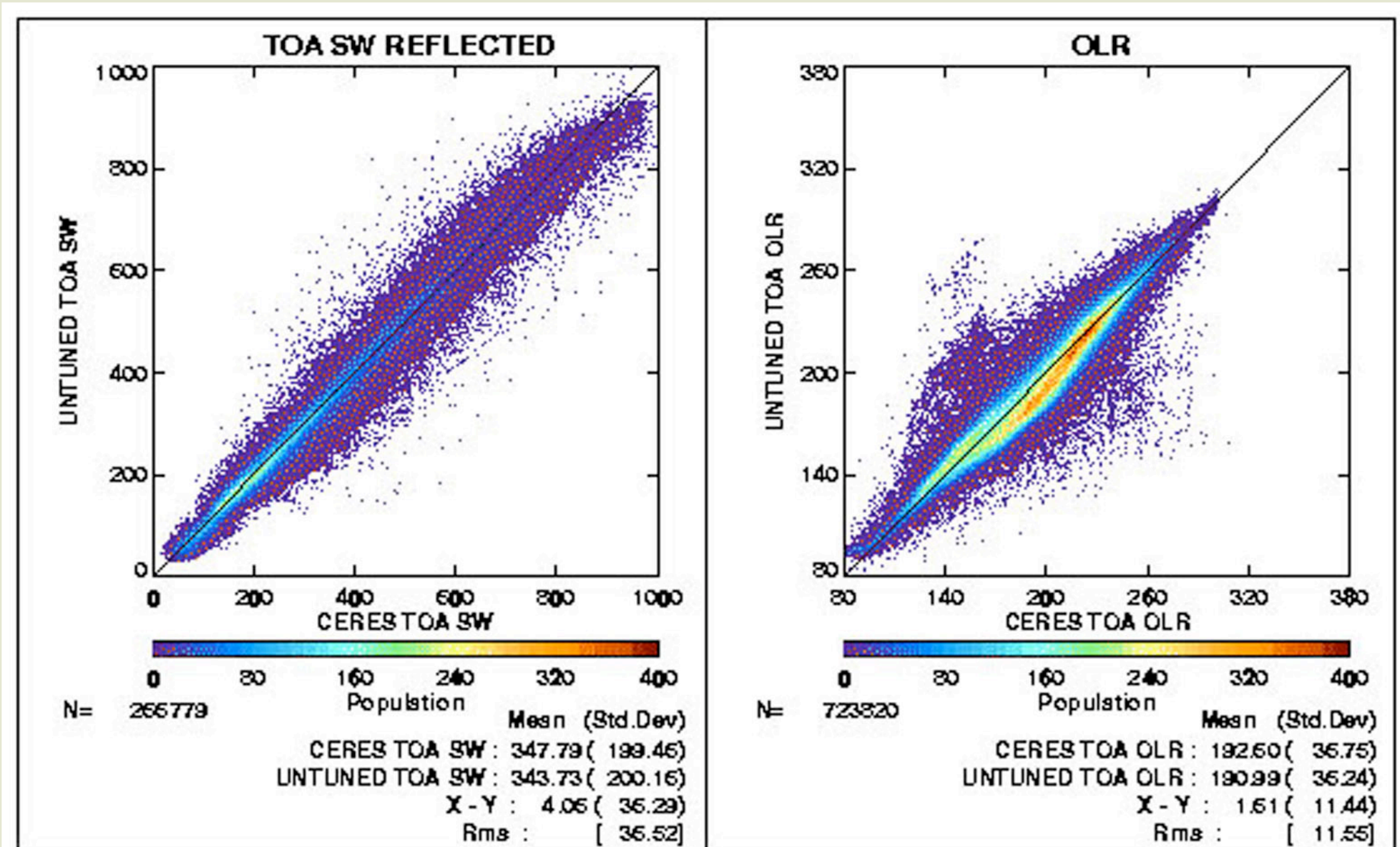
COMPARISON OF OBSERVED & COMPUTED SW & LW FLUXES
ALL SCENE TYPES, TRMM VIRS/CERES, APRIL 18, 1998

ΔSW = 5.8 ± 28 Wm^{-2} (14%) **ΔLW = 0.7 ± 8 Wm^{-2} (3%)**



COMPARISON OF OBSERVED & COMPUTED SW & LW FLUXES
ICE CLOUDS ONLY TRMM VIRS/CERES, APRIL 18, 1998

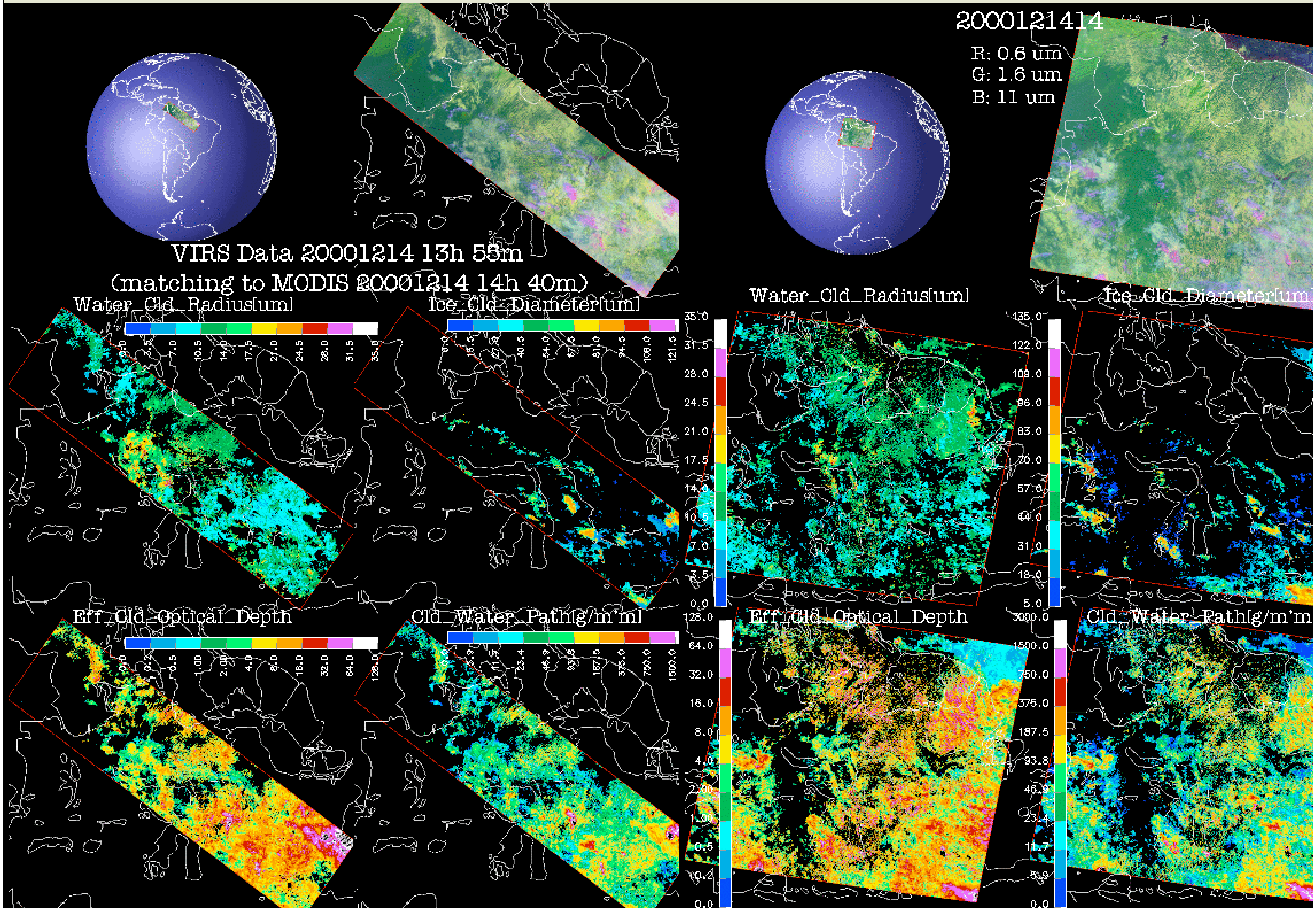
□SW = 4.1 $\pm$ 36 Wm^{-2} (10%) **□SW = 1.6 $\pm$ 11 Wm^{-2} (6%)**



CERES-DERIVED CLOUD PROPERTIES

YIELD EXCELLENT AGREEMENT BETWEEN FLUX OBSERVATIONS & RADIATIVE TRANSFER MODELS

CONSISTENCY WITH VIRS



VIRS Data 20001214 13h 55m
(matching to MODIS 20001214 14h 40m)
2000121414
R: 0.6 um
G: 1.6 um
B: 11 um
Water_Cld_Radius[um]
Ice_Cld_Diameter[um]
Eff_Cld_Optical_Depth
Cld_Water_Path[g/m'm]
Water_Cld_Radius[um]
Ice_Cld_Diameter[um]
Eff_Cld_Optical_Depth
Cld_Water_Path[g/m'm]

Scatter Plots for MODIS and VIRS Matchup

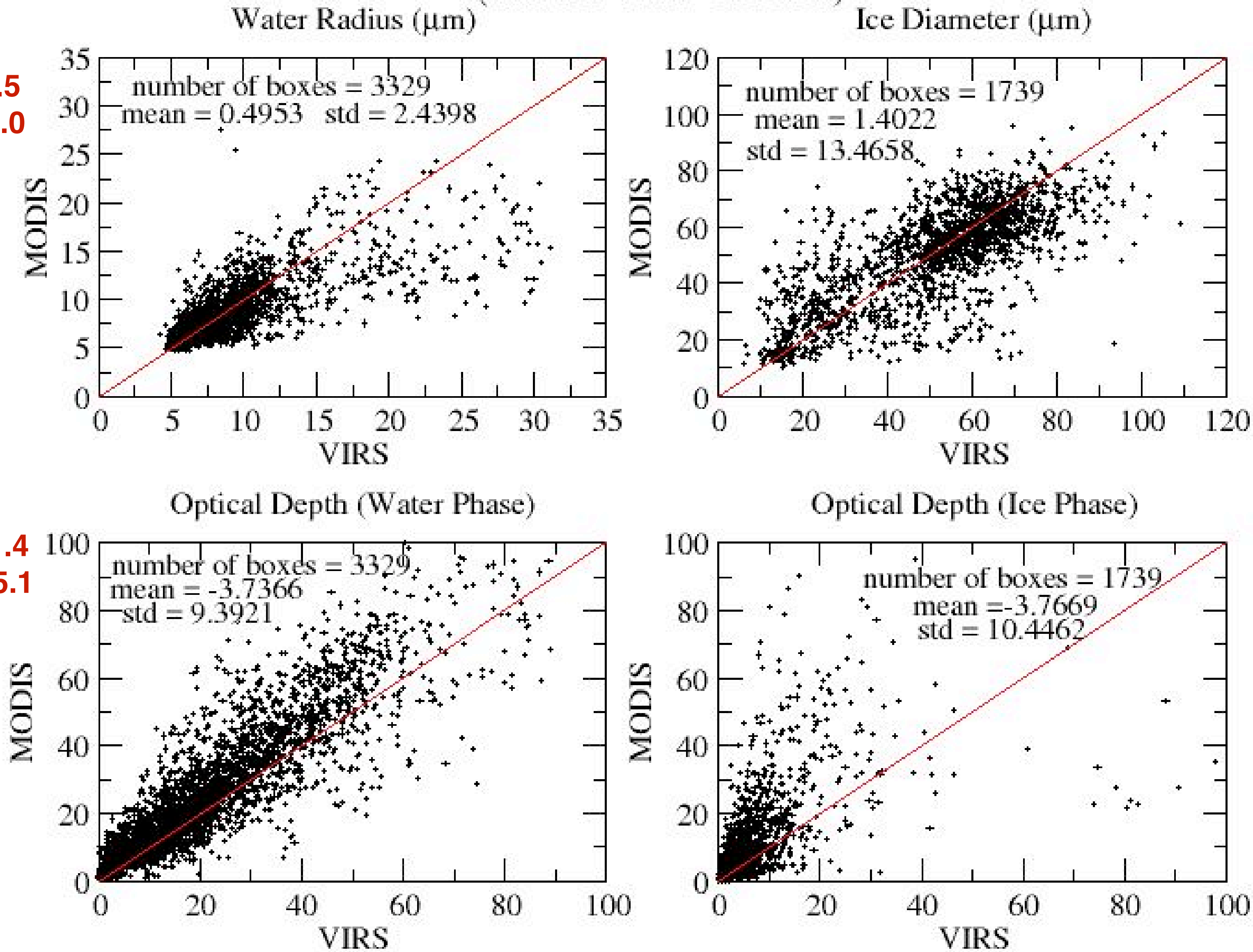
MODIS (200012021725) and VIRS (200012021654)

(stats for VIRS - MODIS)

Δt = 31 min

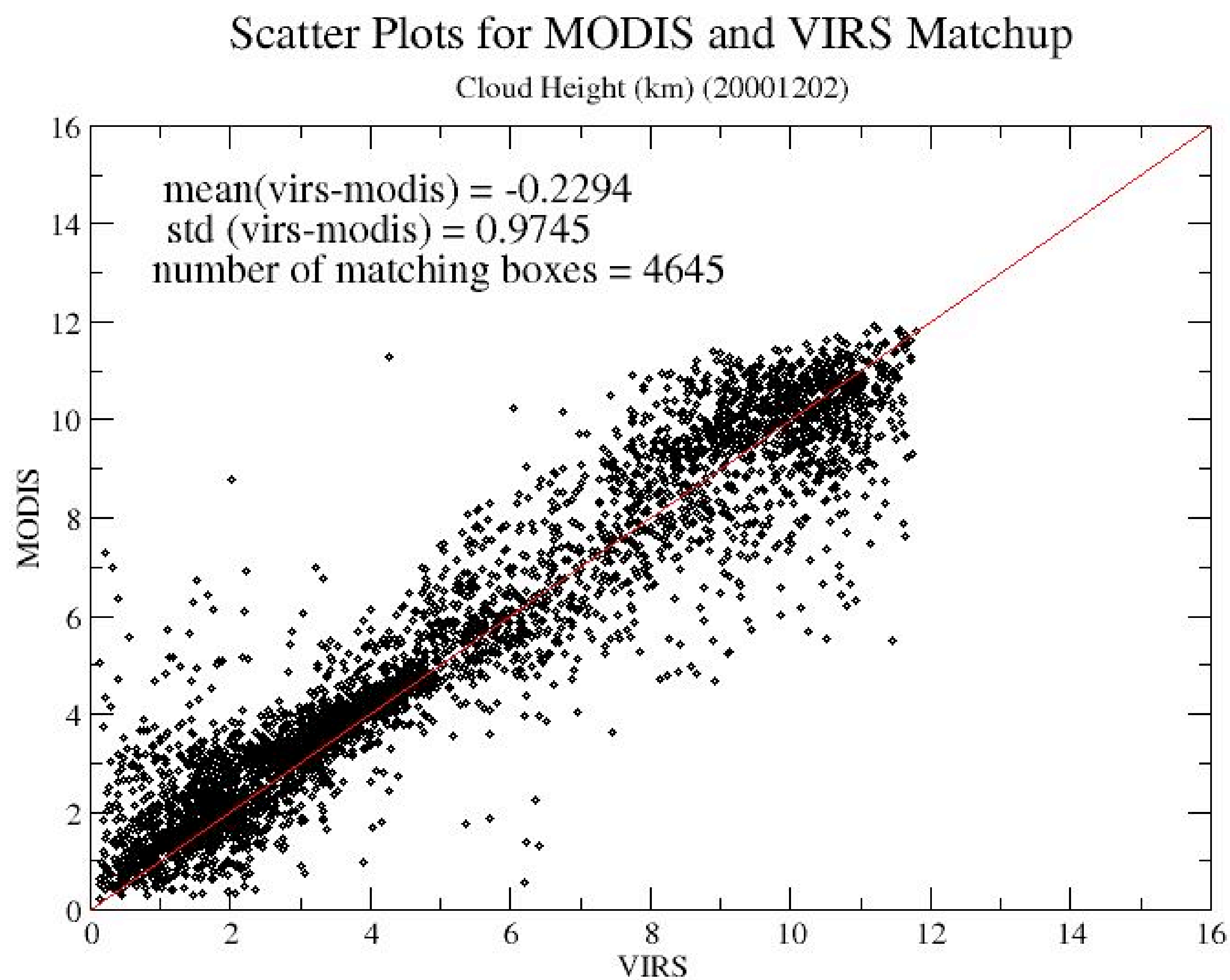
V= 8.5
M= 8.0

V=50.8
M=49.4



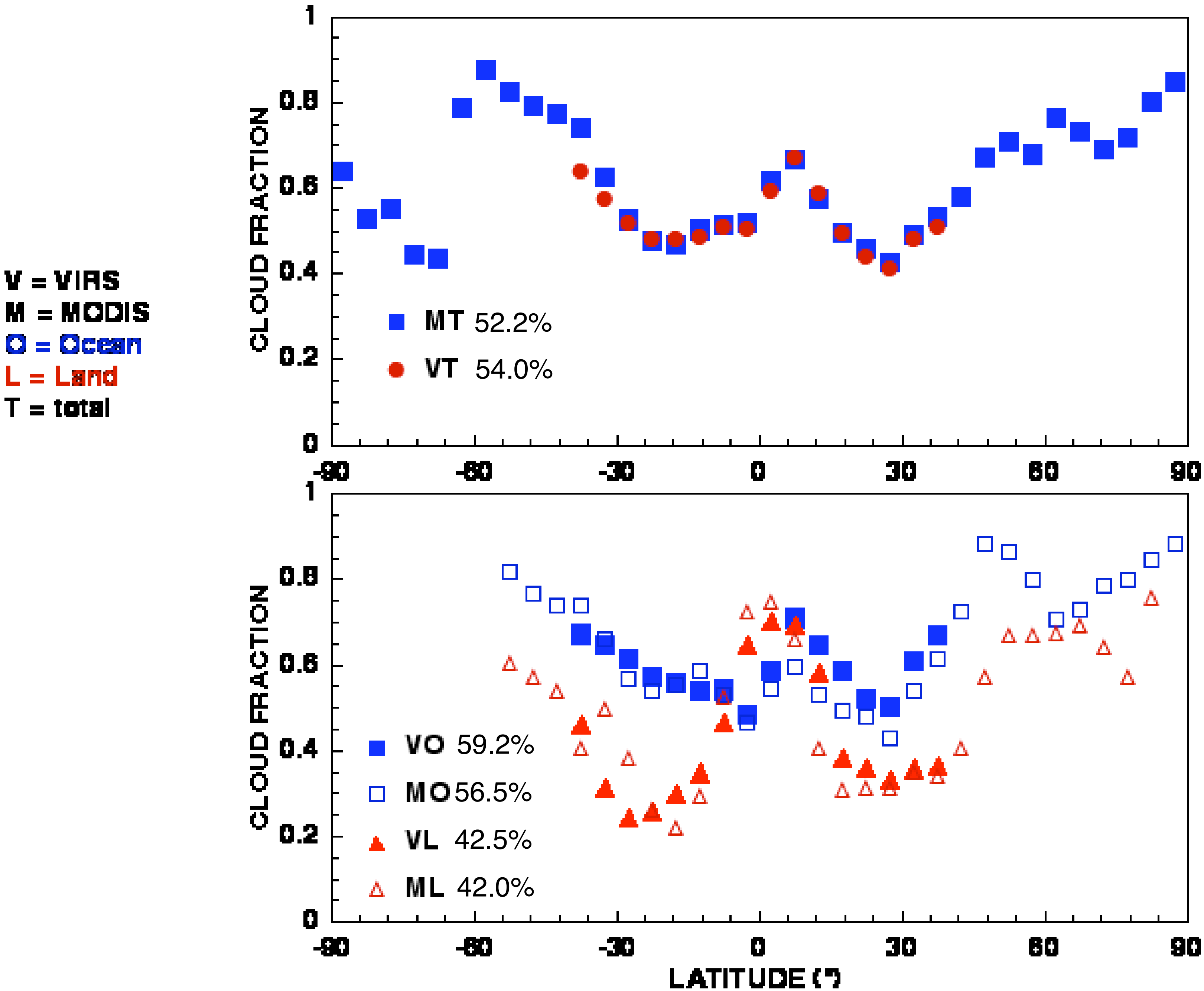
V=21.4
M=25.1

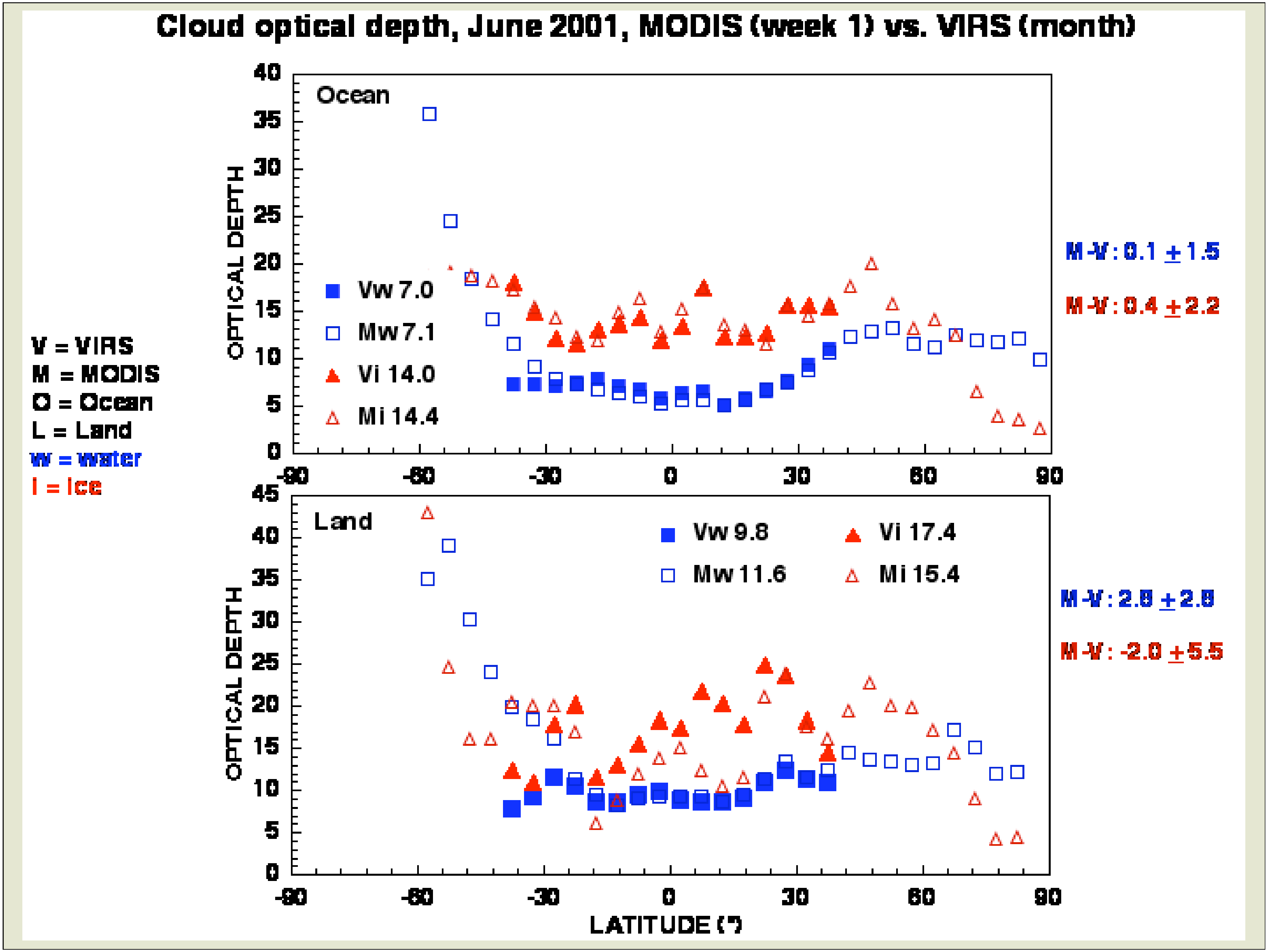
V= 6.1
M=9.8



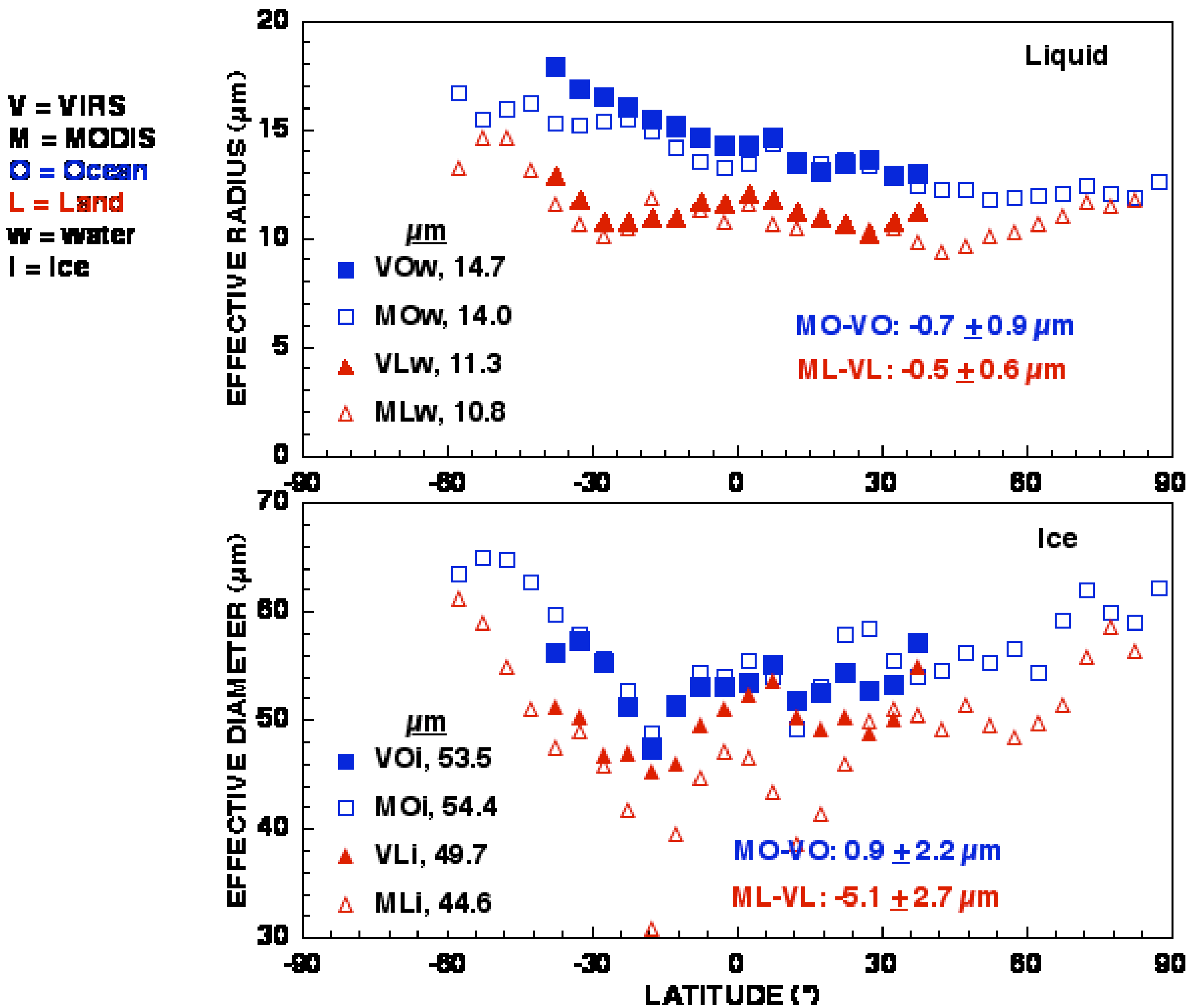
Scatter Plots for MODIS and VIRS Matchup
Cloud Height (km) (20001202)
mean(virs-modis) = -0.2294
std (virs-modis) = 0.9745
number of matching boxes = 4645
MODIS
VIRS
0
2
4
6
8
10
12
14
16

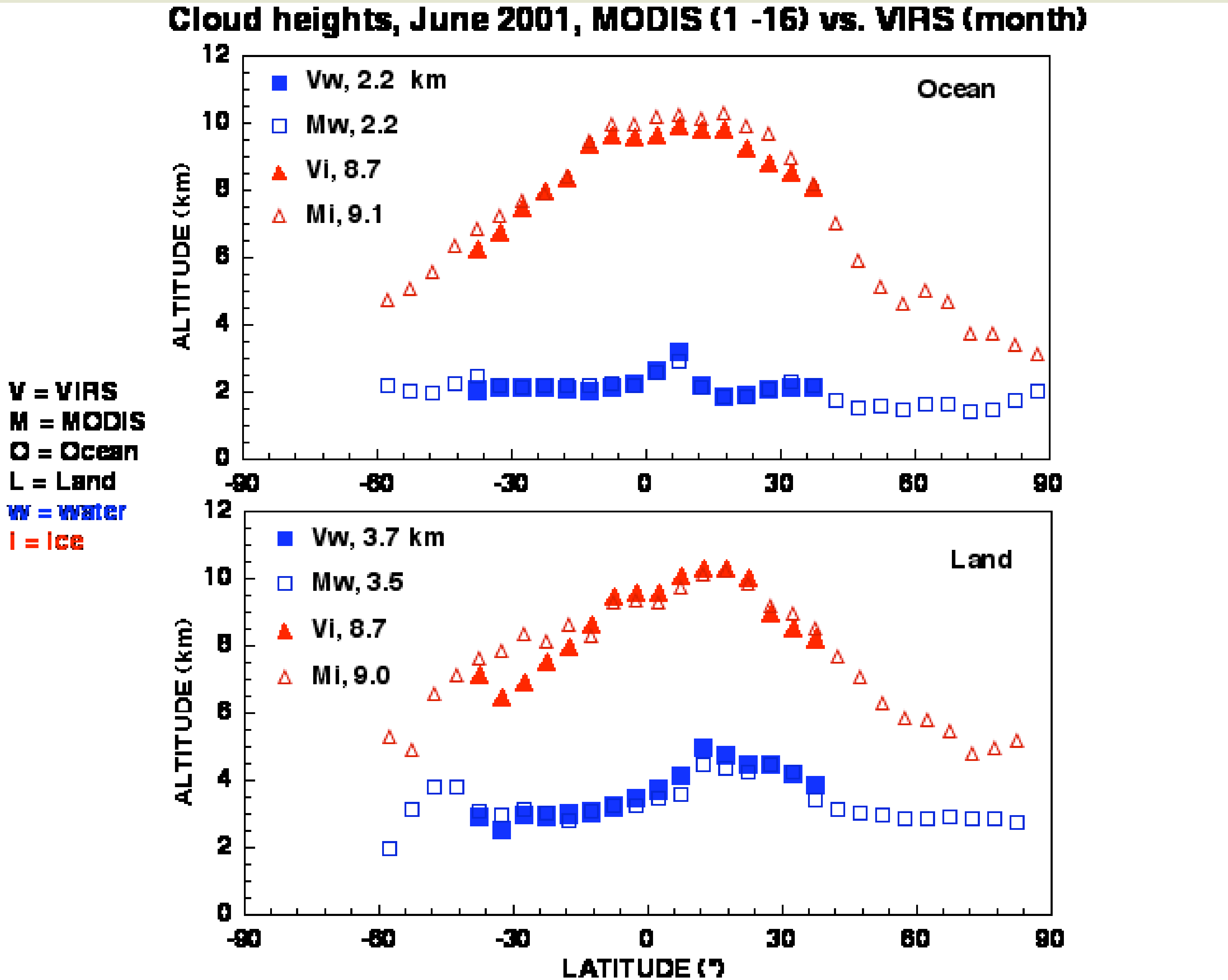
Cloud fraction, June 2001, MODIS (day 1 - 16) vs. VIRS (month)

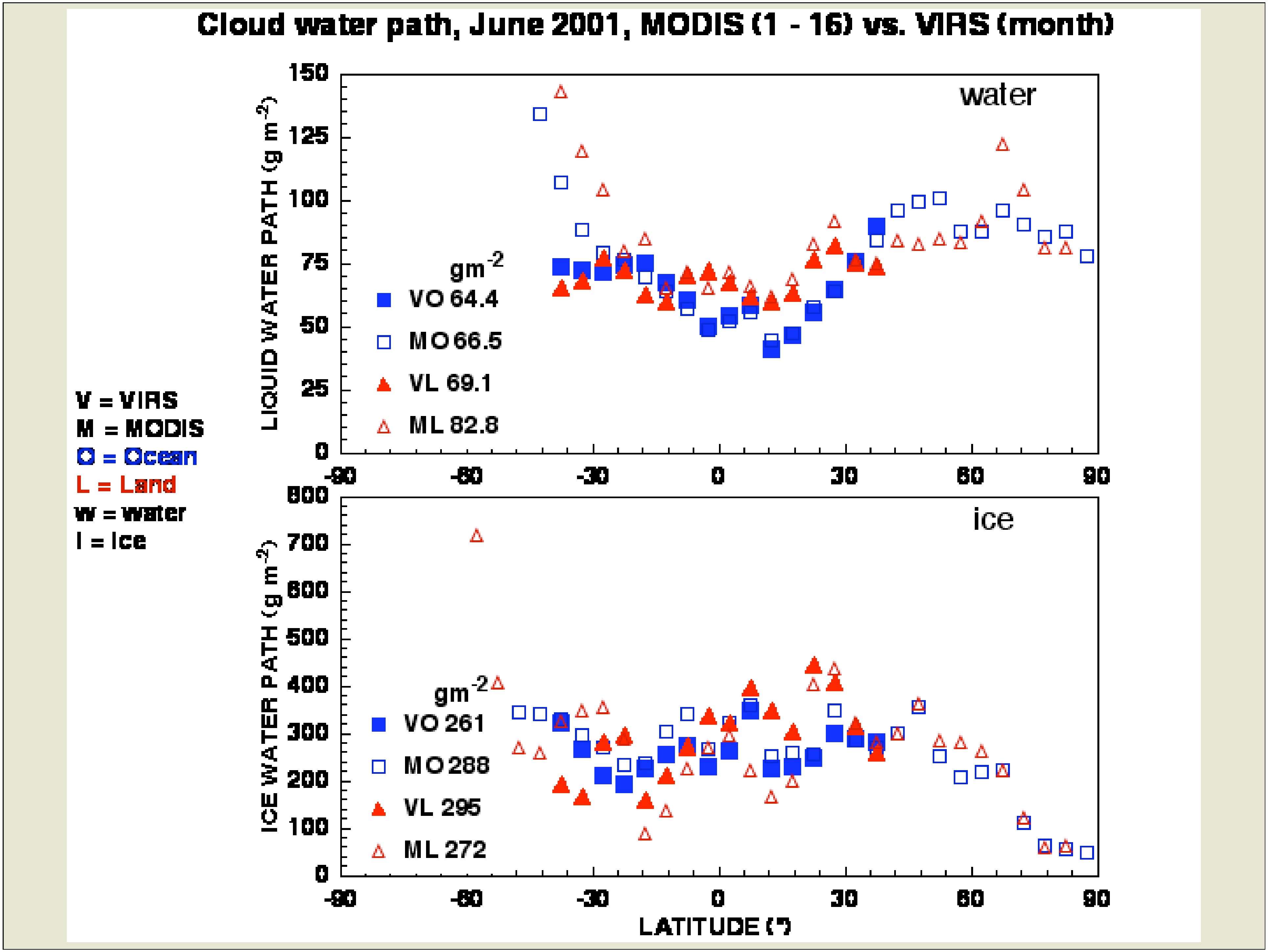



Cloud optical depth, June 2001, MODIS (week 1) vs. VIRS (month)
Ocean
Vw 7.0
Mw 7.1
Vi 14.0
Mi 14.4
M-V: 0.1 ± 1.5
M-V: 0.4 ± 2.2
OPTICAL DEPTH
V = VIRS
M = MODIS
O = Ocean
L = Land
w = water
I = Ice
Land
Vw 9.8
Mw 11.6
Vi 17.4
Mi 15.4
M-V: 2.8 ± 2.8
M-V: -2.0 ± 5.5
LATITUDE (°)

Cloud particle sizes, June 2001, MODIS (week 1) vs. VIRS (month)




Cloud heights, June 2001, MODIS (1 -16) vs. VIRS (month)
Vw, 2.2 km
Mw, 2.2
Vi, 8.7
Mi, 9.1
Ocean
Vw, 3.7 km
Mw, 3.5
Vi, 8.7
Mi, 9.0
Land
ALTITUDE (km)
LATITUDE (°)
V = VIRS
M = MODIS
O = Ocean
L = Land
w = water
I = Ice



Cloud water path, June 2001, MODIS (1 - 16) vs. VIRS (month)
water
LIQUID WATER PATH (g m-2)
gm-2
VO 64.4
MO 66.5
VL 69.1
ML 82.8
ice
ICE WATER PATH (g m-2)
gm-2
VO 261
MO 288
VL 295
ML 272
LATITUDE (°)
V = VIRS
M = MODIS
O = Ocean
L = Land
w = water
I = Ice

SUMMARY OF ZONAL DIFFERENCES, JUNE 2001

Edition 1a

PARAMETER	MODIS (2 week) - VIRS (1 month)	
	ocean	land
Cld amt	-0.028	-0.005
Ice height (km)	0.4	0.3
Water height (km)	0.0	-0.2
Ice tau	2.8	-2.0 ($\pm$ 5.5)
Water tau	0.1 ($\pm$ 1.5)	0.4 ($\pm$ 2.8)
r_e (μm)	-0.7 ($\pm$ 0.9)	-0.5 ($\pm$ 0.6)
D_e (μm)	0.9 ($\pm$ 2.2)	-5.1 ($\pm$ 2.7)
LWP (gm^{-2})	2.1	13.7 (SH sampling)
IWP (gm^{-2})	17, *7%*	-23, *8%*

SUMMARY

- Cloud amount: **VIRS detects more cloud cover**

  - orbit times (MODIS designed for clear sky)

  - resolution differences, slight mask differences

- Optical depth: **VIRS has variable agreement with MODIS**

  - MODIS slightly greater on average (calibration, resolution), < 10% mean diff

- Effective size: **VIRS generally larger than MODIS (ice over land greatest)**

  - 0.5K difference in 3.7-μm cal => 0.5 μm □r_e (< 10% bias)

  - Need updated 3.7-μm emissivity maps for thin clouds

- Water path: **Mixed results, < 10% difference on average, sampling differences**

- Heights: **Small differences on average, -0.2 km to 0.4 km (ice)**

- **Future: examine calibration differences more closely & impact of cloud emittance models & surface emissivity data**

Some Caveats!

- Everything is retrieved: ice over water/ mixed phase ->

  if overlap, large re (1-2 μm overestimate) or small De (3-5 μm under)

  Zc may be underestimated

- IWP overestimated when water cloud under ice

- Don't use cloud properties for thick clouds at night (τ > 8)

- Nighttime polar cloud amounts underestimated

  Look for discontinuities at 60° latitude

- Nighttime ice cloud heights somewhat greater (~ 0.5 km for ice)

- Cloud temperature better than height for low clouds over land

  (missing inversions in profiles)

- Others, see Data Quality Summary

CONCLUDING REMARKS

- CERES archived cloud/radiation data now available
  - VIRS Edition 2 Jan 1998 - August 2001, continuing
    CERES fluxes only for Jan-Aug 98, March 2000
  - Terra MODIS Edition 1a: Nov 2000 -
- Validation so far indicates very reasonable values for results
  - Validation continues
  - MODIS & VIRS results very consistent
- Use the dataset you'll like it
  - Read caveats!

SUMMARY OF PRELIMINARY AQUA MODIS ANALYSES

- MODIS CHANNELS LOOK CLEAN EXCEPT FOR 1.6 μm
    - SELECT OTHER CHANNEL (2.13 μm)
    - NEW MODELS DEVELOPED FOR 2.13 μm

- ALGORITHMS WORK WITH NO SIGNIFICANT PROBLEMS
    - NEED TO VERIFY CALIBRATIONS

- FIRST BETA RESULTS WILL BE OUT SOON

FUTURE RESEARCH

- **multilayer cloud detection & interpretation**

  - combined microwave / VISST over ocean
  - secondary processing using info on BTD(11-12), τ, D_e/r_e

    => improved IWP assessment

- **improvement of nighttime/twilight everywhere including poles**

  - revise thresholds,include VIS in twilight, include 8.5 μm
  - improve surface emissivities

- **continued validation**

  - more continuous assessment at ARM sites
  - CALIPSO cloud height/amt global comparison
  - additional multiangle studies including MSG & GOES
  - in situ icing / microphysics field programs

- **subpixel cloud amounts**

  - combine hi-res VIS with lo-res multispectral (MODIS)

DATA AVAILABILITY

- **VIRS (Edition 2)**

With CERES fluxes:	***Jan - Aug 1998, March 2000***
With no fluxes:	***Sept 1998 - July 2001***

- ***Terra* MODIS (Edition 1a)**

March & April 2000

November, December 2000

January - September 2001

REFERENCES

List of references and pdfs given on the following web page.

http://www-pm.larc.nasa.gov/ceres/ceres-ref.html

Only imagery and summaries are available for CERES at the Cloud Working Web Page

http://lposun.larc.nasa.gov/~cwg/

Digital data avaialble at the LaRC DAAC

http://eosweb.larc.nasa.gov/HPDOCS/

TERRA/AQUA SSF AEROSOLS

LAND: 1 Product

- MODIS (Kaufman et al. *JGR* 1997)

OCEAN: 2 Products

- MODIS (Tanre et al. *JGR* 1997)
- VIRS-like (Ignatov Stowe *JAM* 2000; *JAS* 2002)

MOTIVATION FOR "VIRS-like"

1) LEARN BY COMPARISON
2) HEREDITARY: NOAA/AVHRR & TRMM/VIRS
3) MULTI-SPECTRAL IMPROVEMENTS

Cloud Screening

MODIS (Ref?): Done by MODIS Team

VIRS-like (Minnis et al): Consistent w/ TRMM/VIRS

Sampling

MODIS: Beyond 40° glint

VIRS-like: Beyond 40° glint & Anti-solar side of Orbit

Aerosol Retrievals

MODIS (Tanre et al. 1997)

- **Spectral:** 6 bands from 0.55-2.13 μm
- **Aerosol:** Var Bi-LogNormal (Mode Location/Ratio)
- **Surface:** Fresnel (V=7 m/s) + Black (except 0.55 μm)
- **RT Model:** Ahmad-Fraser (JAS 1981)

VIRS-like (Ignatov Stowe 2000, 2002)

- **Spectral:** Single-Channel: 0.659 & 1.640 μm
- **Aerosol:** Prescribed (Fixed) Mono-LogNormal
- **Surface:** Fresnel (V=1 m/s) + Small Diff.Ref.
- **RT Model:** Vermote et al. 6S (IEEE/TGARS 1997)

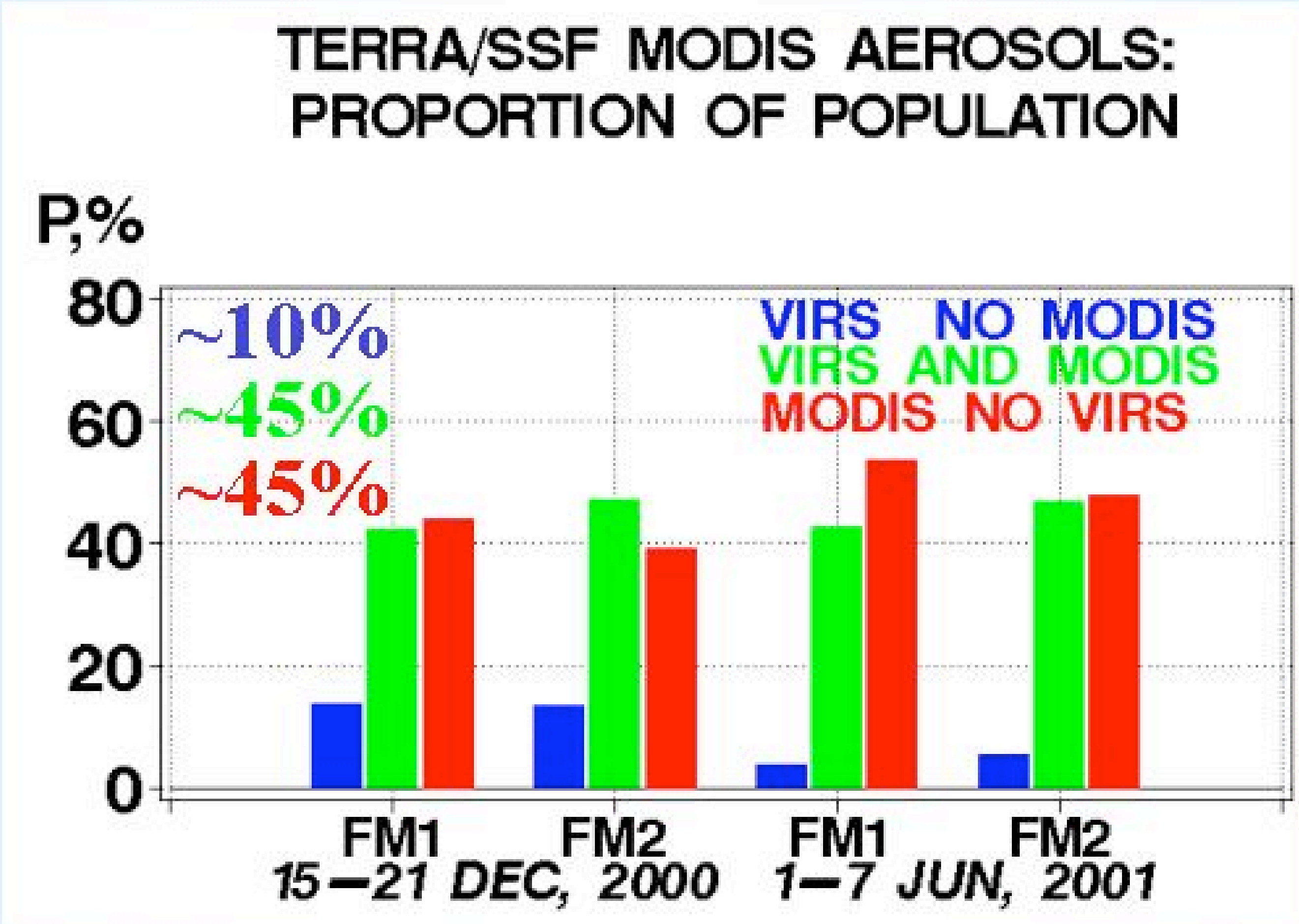
OF AEROSOL FOOTPRINTS

VIRS-like

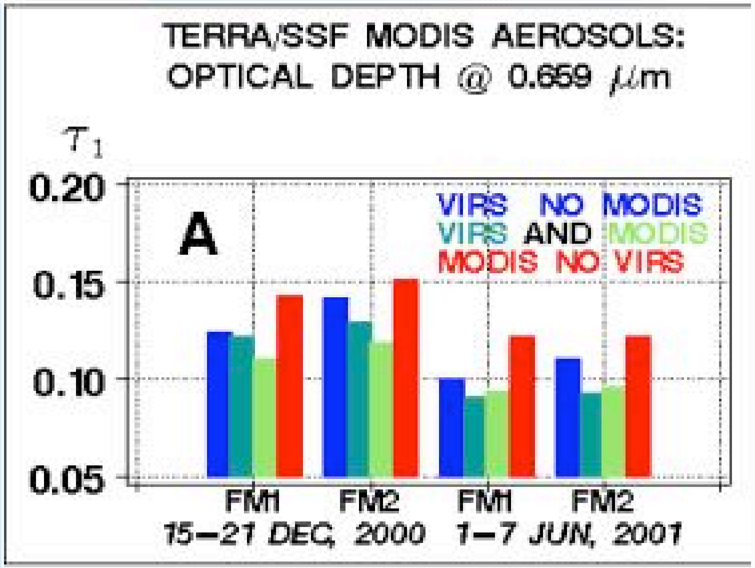
DEC 15-21 2000 FM1	DEC 15-21 2000 FM2	JUN 1-7 2001 FM1	JUN 1-7 2001 FM2
14%	14%	4%	5%
42%	47%	43%	47%
44%	39%	53%	48%
M⊕V=100% N=2,268,474	M⊕V=100% N=2,217,566	M⊕V=100% N=2,652,508	M⊕V=100% N=2,542,214

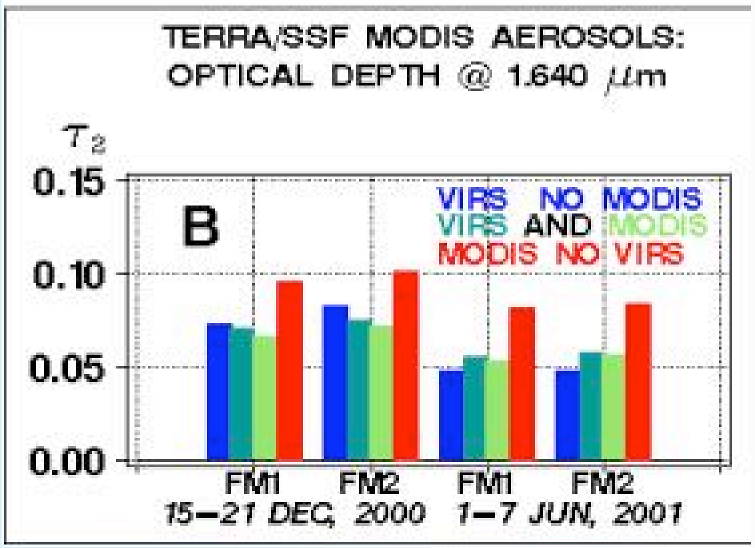
MODIS

SUB-SAMPLES: POPULATION



τ-RETRIEVALS



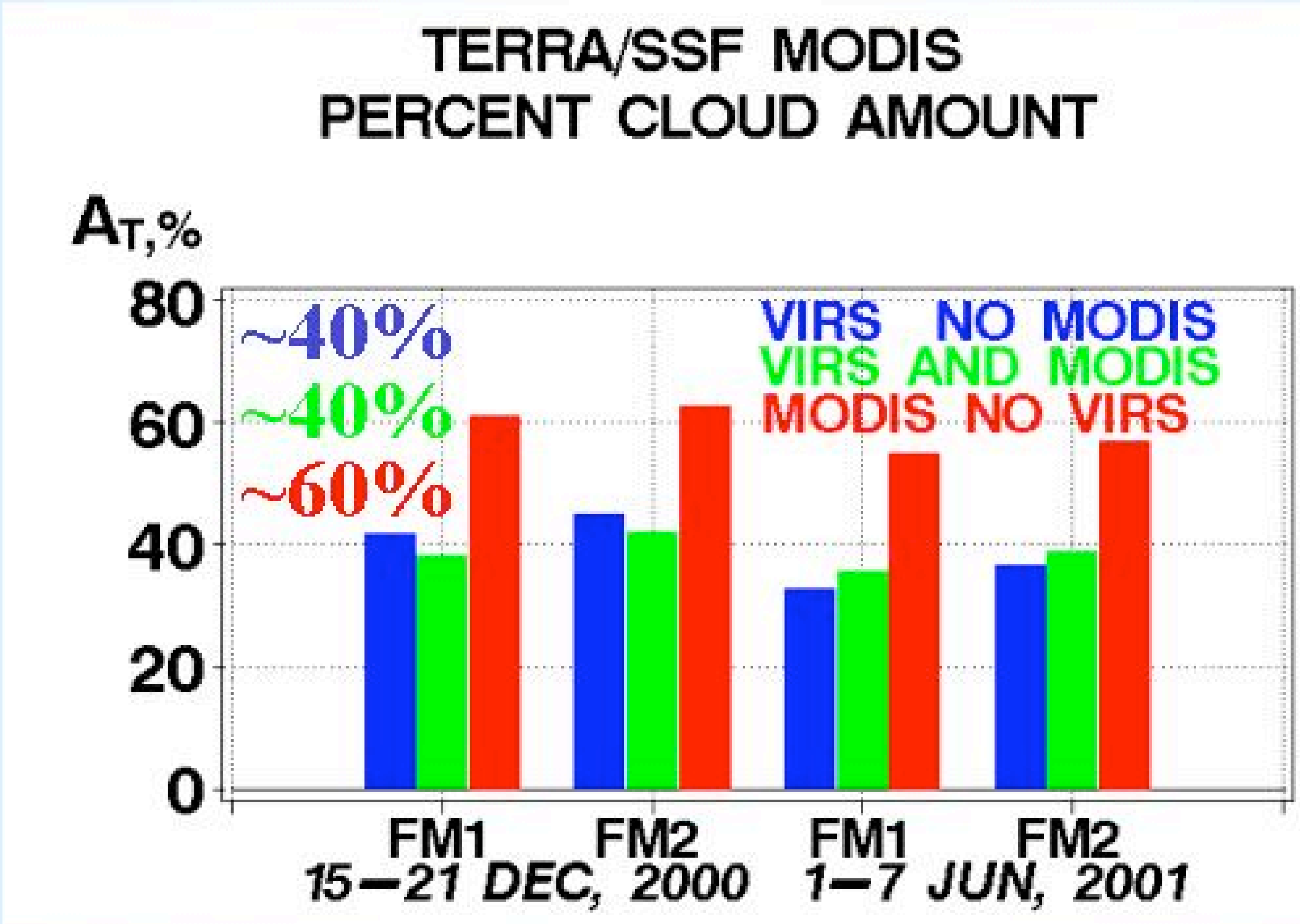


- **VIRS – MODIS ($\delta\tau_1$~0.004; $\delta\tau_2$~0.003)**
  - **Lat/Lon Domain: Identical**
  - **Sun/View/Scatter/Glint: Identical**
  - **Cloud Condition/Sampling: Close**
  - **Aerosol Algorithm: DIFFER**

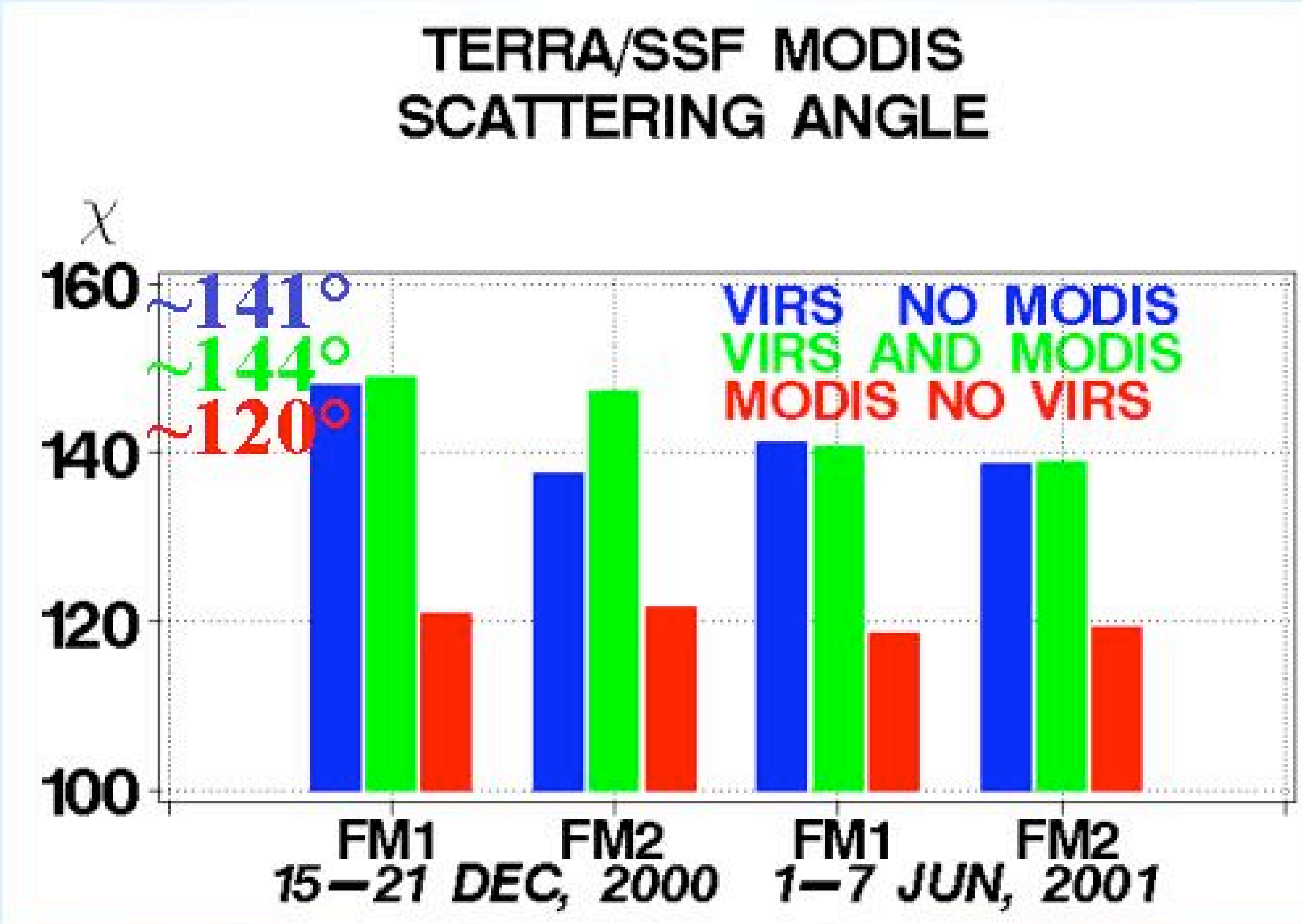
- **VIRS – VIRS ($\delta\tau_1$~0.01; $\delta\tau_2$~0.002)**
  - **Lat/Lon Domain: DIFFER?**
  - **Cloud Condition: DIFFER?**
  - **Sun/View/Scatter/Glint: DIFFER?**
  - **Aerosol Algorithm: Identical**

- **MODIS – MODIS ($\delta\tau_1$~0.03; $\delta\tau_2$~0.03)**
  - **Lat/Lon Domain: DIFFER?**
  - **Cloud Condition: DIFFER?**
  - **Sun/View/Scatter/Glint: DIFFER?**
  - **Aerosol Algorithm: Identical**

CLOUD AMOUNT



SCATTER ANGLE



CONCLUSION TO MODIS

Cloud/Sampling

VIRS-like NO MODIS: ~10%

VIRS-like AND MODIS: ~45%

MODIS NO VIRS-like: ~45%

τ -Retrievals:

- VIRS-like compares to MODIS

(Aerosol algorithm: Effect Small)

- MODIS differ from MODIS

(Cloud/Scat Angle Differ)

Paper to *JAS-2003* in preparation

TRMM/VIRS AEROSOLS

AVHRR: λ_1=0.63 µm λ_2=0.83 µm (λ_{3A}=1.61 µm)
NOAA: 1981- pr; 70°S-70°N; ~1:30 pm; H=870 km; 9 lays

VIRS: λ_1=0.63 µm λ_2=1.61 µm
TRMM: 1997- pr; 40°S-40°N; full day; H=350 km; 45 day

Cloud Screening: Accurate / Different

Ignatov Stowe *JAS* 2002:

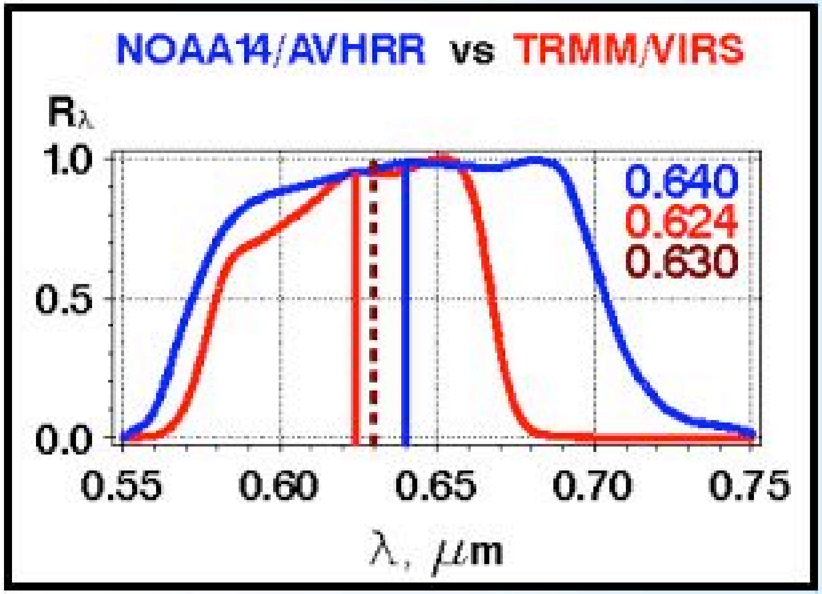
τ_1: 6S-based (Vermote et al. *IEEE* 1997)
single-channel (scaled to 0.63 µm)

Atmosphere

Aerosol: Log-Normal R_m=0.1 µm, σ=2.03; n=1.4-0*i*
(Empirical Phase Function; Ignatov *JAM* 1997)
Rayleigh/Gas: Mid-Latitude Summer

Surface

Lambertian: ρ_{sfc}=0.002 (0.2%)
Bi-directional: Cox-Munk V=1 ms^{-1}



Why Single-Channel?

$$\rho \equiv \frac{\pi L}{F\mu_S}; \qquad \rho = \frac{P^R(\chi)\tau^R}{4\mu_S\mu_V} + \frac{\omega_0 P^A(\chi)\tau}{4\mu_S\mu_V}$$

Single-Channel: τ

- $\omega_0 P^A$: fixed globally non-variable
  (average aerosol type $\pm$30%)

Two-Channel: (τ, α) (Def: $\tau(\lambda) = \tau_0 \times \lambda^{-\alpha}$)

- $\omega_0 P^A$: adjusted coherently with retrieved α
  (as accurate as α)

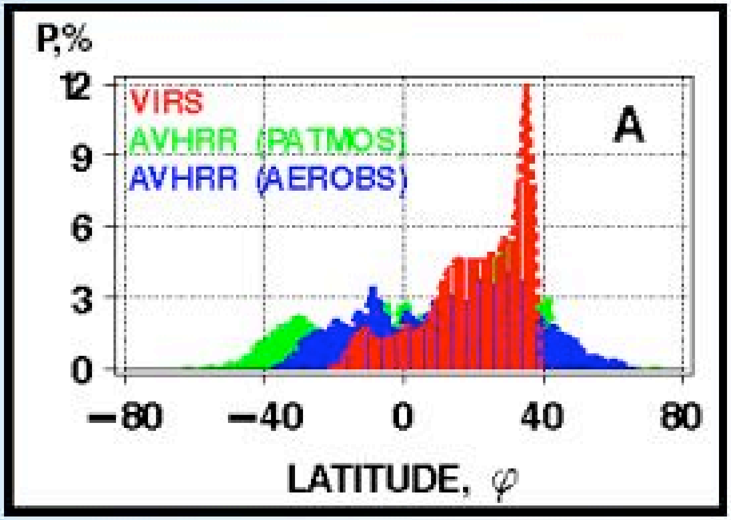
Information Content/Signal-To-Noise Ratio: $\eta = \sigma_{\alpha_0}/\sigma_\alpha$

(Westwater Strand *JAS* 1968; Rogers *RGSP* 1976)

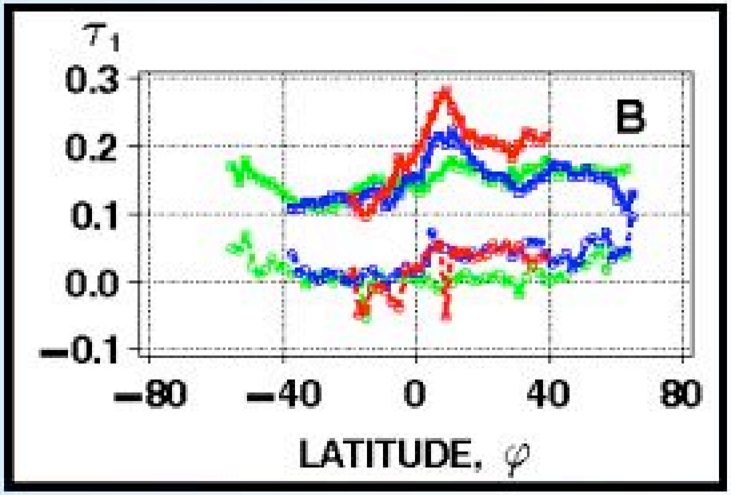
- $\sigma_{\alpha_0} \sim 0.3$; $\sigma_\alpha \sim k/\tau$ (Ignatov et al. *ASR* 1997; Ignatov Stowe *JAS* 2002)
- $\eta = \tau/\tau_0$; $\eta \sim 1$ at $\tau \sim \tau_0$

- AVHRR/AEROBS	$(8\ \text{km})^2$	$\tau_0 \sim 0.18$	(Ignatov Stowe *JAS* 2002)
- AVHRR/PATMOS	$(110\ \text{km})^2$	$\tau_0 \sim 0.11$	(Ignatov Nalli *JTech* 2002)
- TRMM/VIRS	$(>10\ \text{km})^2$	$\tau_0 \sim ?$	(Thermal Leak)

LATITUDE

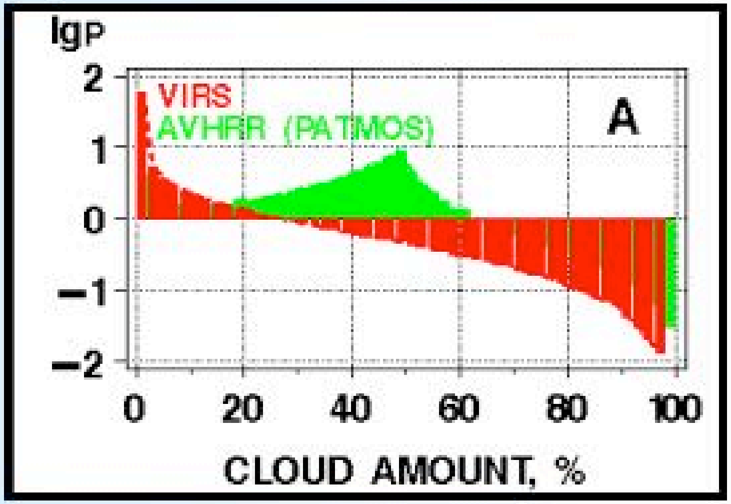


- VIRS: 20°S - 40°N
- AVHRR: 40°S - 60°N
- AVHRR: 60°S - 60°N

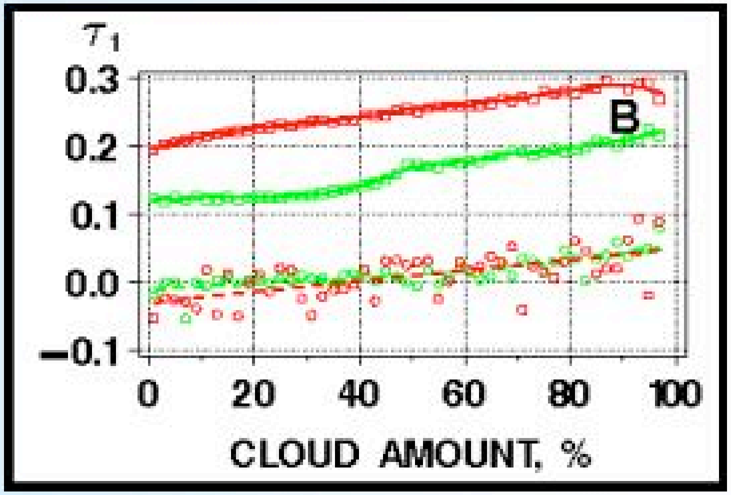


- Minimum
  - VIRS noisier (drop-outs)
  - Min(VIRS) ~ min(AVHRR): No Cal Error?
- Average
  - AVHRR-AVHRR: + Anomaly Apr98 (0-20°S)
  - VIRS: anomaly exaggerated

CLOUD AMOUNT



- VIRS: ~15%
- AVHRR: ~40%



- Average
  - reproducible pattern for 2 datasets
  - increasing trend with cloud amount
- Minimum
  - Increasing trend (residual cloud?)

CONCLUSION TO VIRS

τ_1 0.63 μm: Biased w/t to AVHRR by ~+0.04

τ_2 1.61 μm: Bad (thermal leak).
Recommend against using.

α Bad (thermal leak in τ_2).

Paper to *JAM-2003* in preparation