CERES CLOUD PRODUCTS

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CERES Cloud Products

Provide consistent dataset from *TRMM, Terra, & Aqua* to

- 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

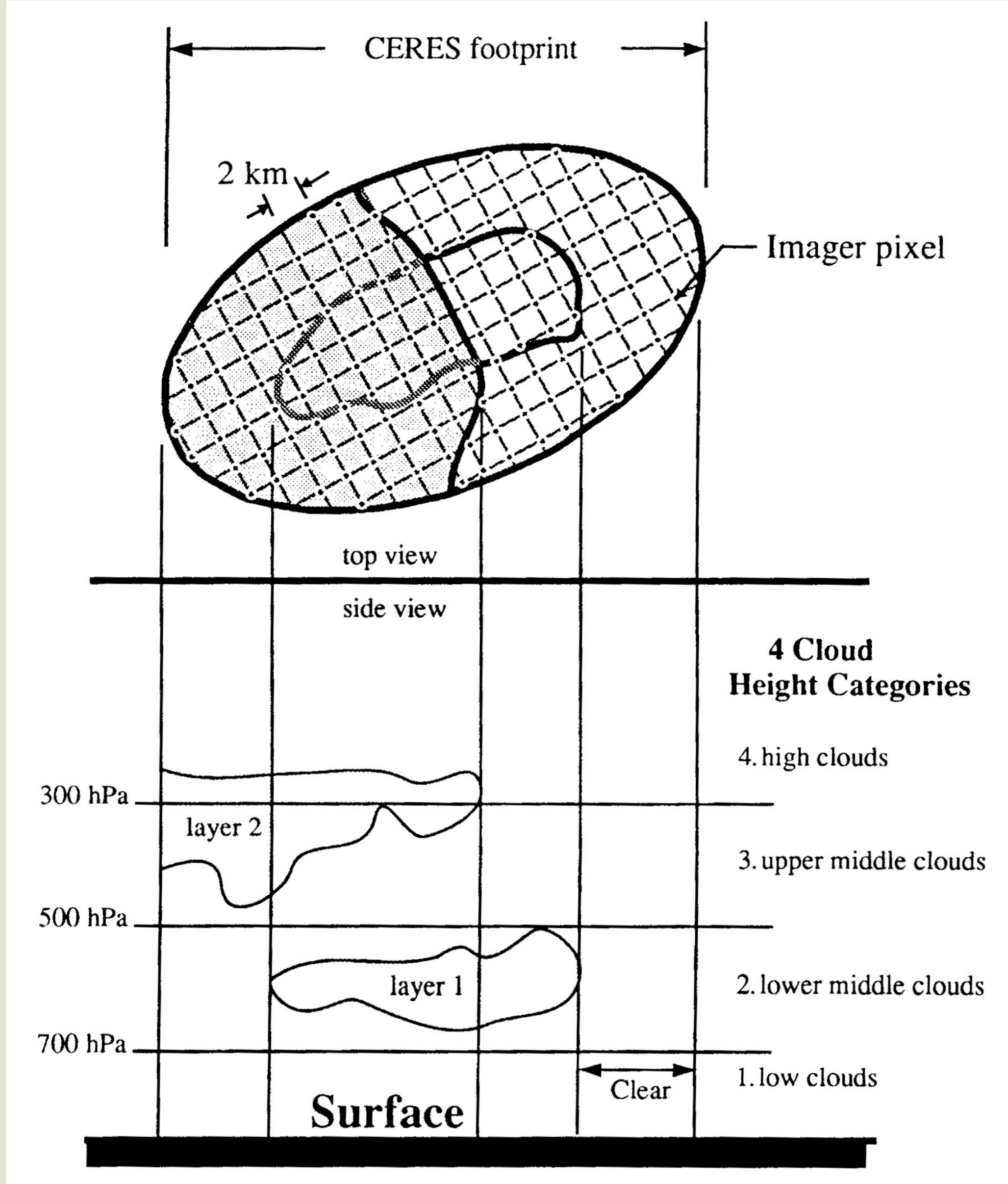
- Provide data to initialize & validate climate & weather prediction models

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 (1/98-7/01)
- MODIS 1-km pixels (sampled to 2 km) Domain: Global
  - 2 overpass/day (night-day), more over poles
- Input
  - 0.65 & 1.6 (2.1) μm reflectances
  - 3.7, 10.8, and 12-μm brightness temperatures
  - GMAO (ECMWF) T(z), q(z), O_3(z) each 6 hr (3-hr skin temps)
  - 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)

  - additional MODIS-team-derived aerosol data included

  (see Ignatov talk)

- SURFACE EMISSIVITY (3.7, 8.5, 11, & 12 μm)

CALIBRATION

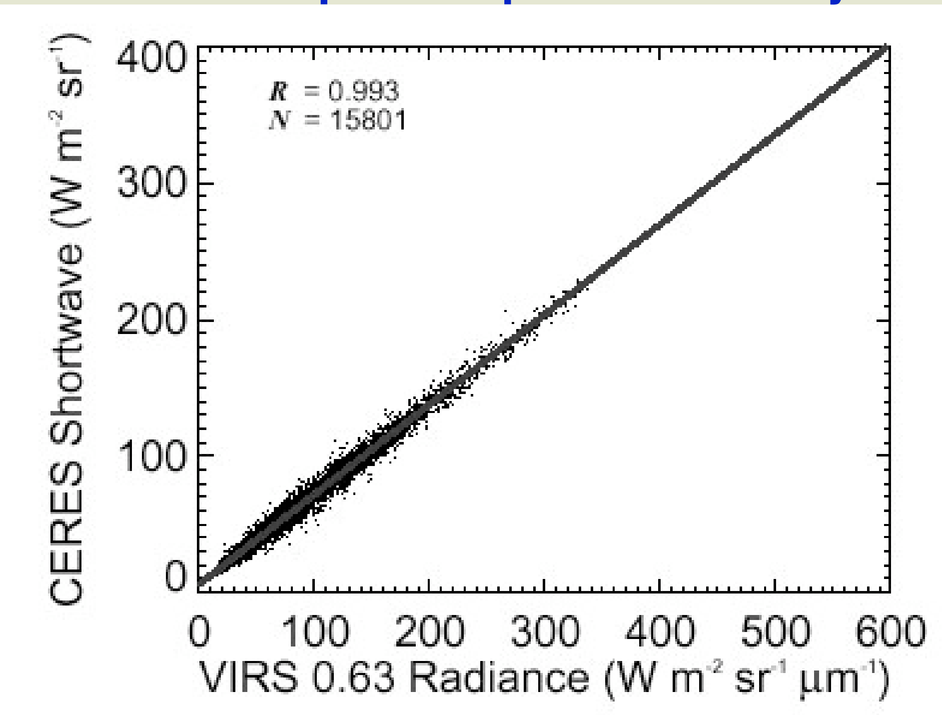
- **Extensive ongoing intercalibration effort**
  - intercalibrate VIRS & MODIS; Terra & Aqua MODIS
  - determine stability by comparing imagers to CERES
  - examine all channels of interest (**0.6, 0.86, 1.6, 3.7-3.9, 10.8, 12 *μ*m**)

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

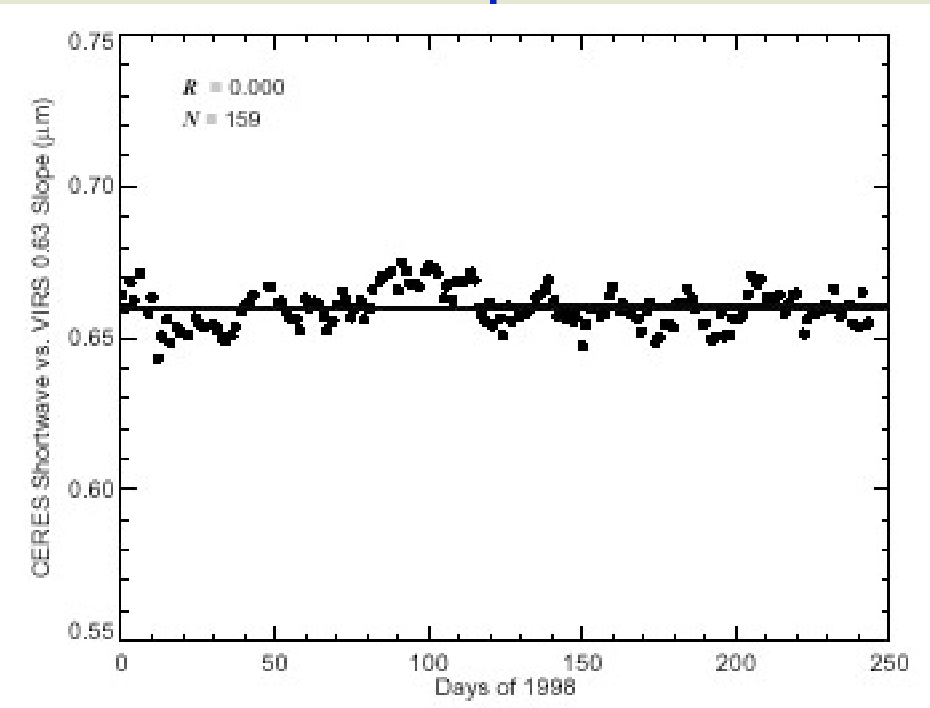
- **Intercalibrate other satellites for CERES & other projects**
  - link all considered satellites to references (VIRS or MODIS)
  - *GOES*-7, 8, 9, 10, 11, 12 (1993 - present)
  - AVHRR: *NOAA*-9,10, 11, 12, 14, 15, 16, 17 (1985 - present)
  - *GMS*-5, *Meteosat*-7 & SEVIRI on *Meteosat-8*

USE CERES BROADBAND TO MONITOR TRENDS IN IMAGER CHANNELS

Compute slope for each day



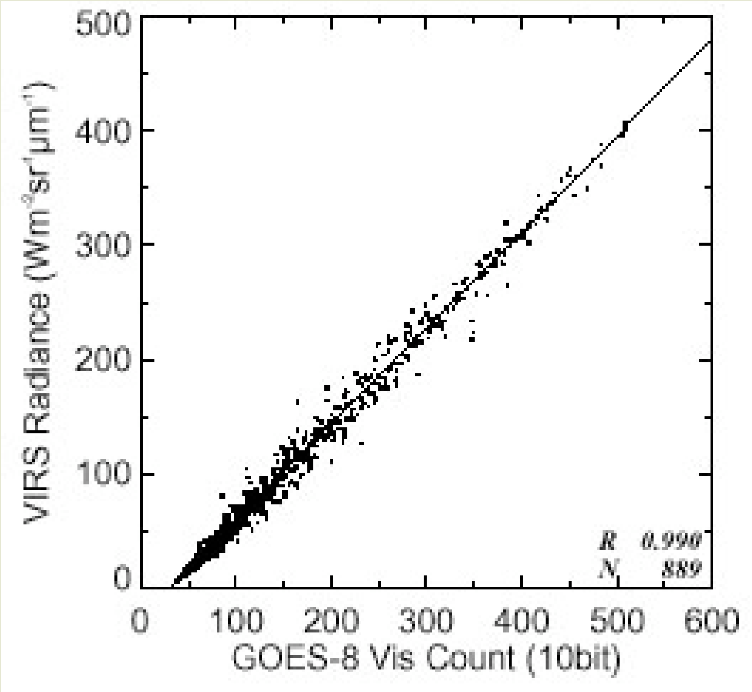
Monitor slope variation



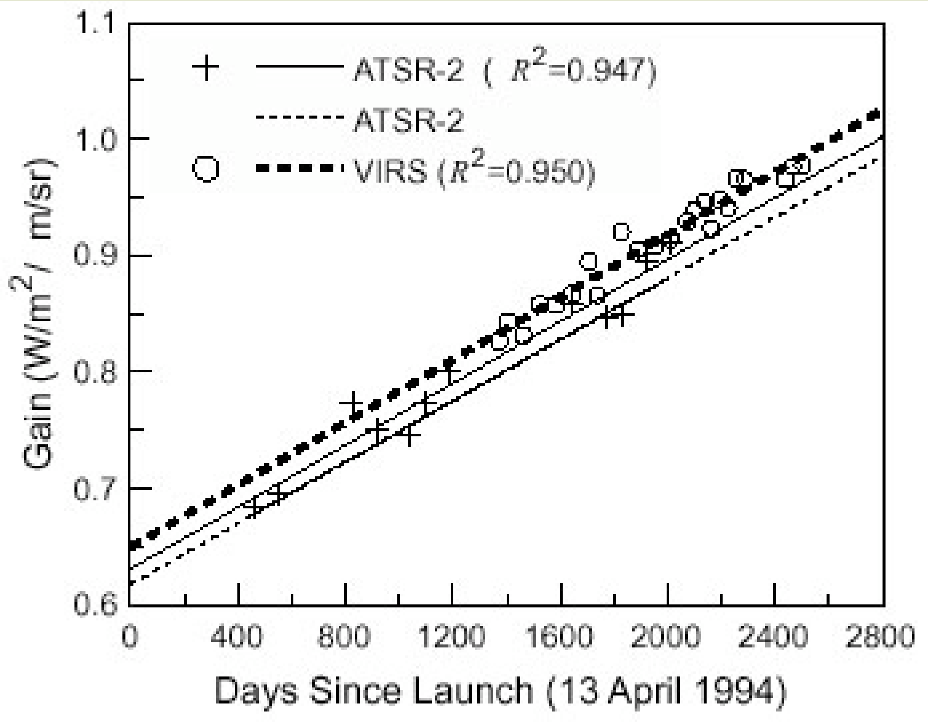
USE STABLE IMAGER AS REFERENCE FOR OTHER IMAGERS

VIRS, ATSR-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, ρ

  - IR, use temperature, T

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

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

CLEAR-SKY REFLECTANCE, SOLAR

- **Estimate overhead-sun albedo, $\alpha_o = \alpha(\mu_o = 1)$**

  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, $\alpha(\mu_o) = \alpha_o\,\delta_o(\mu_o)$**

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

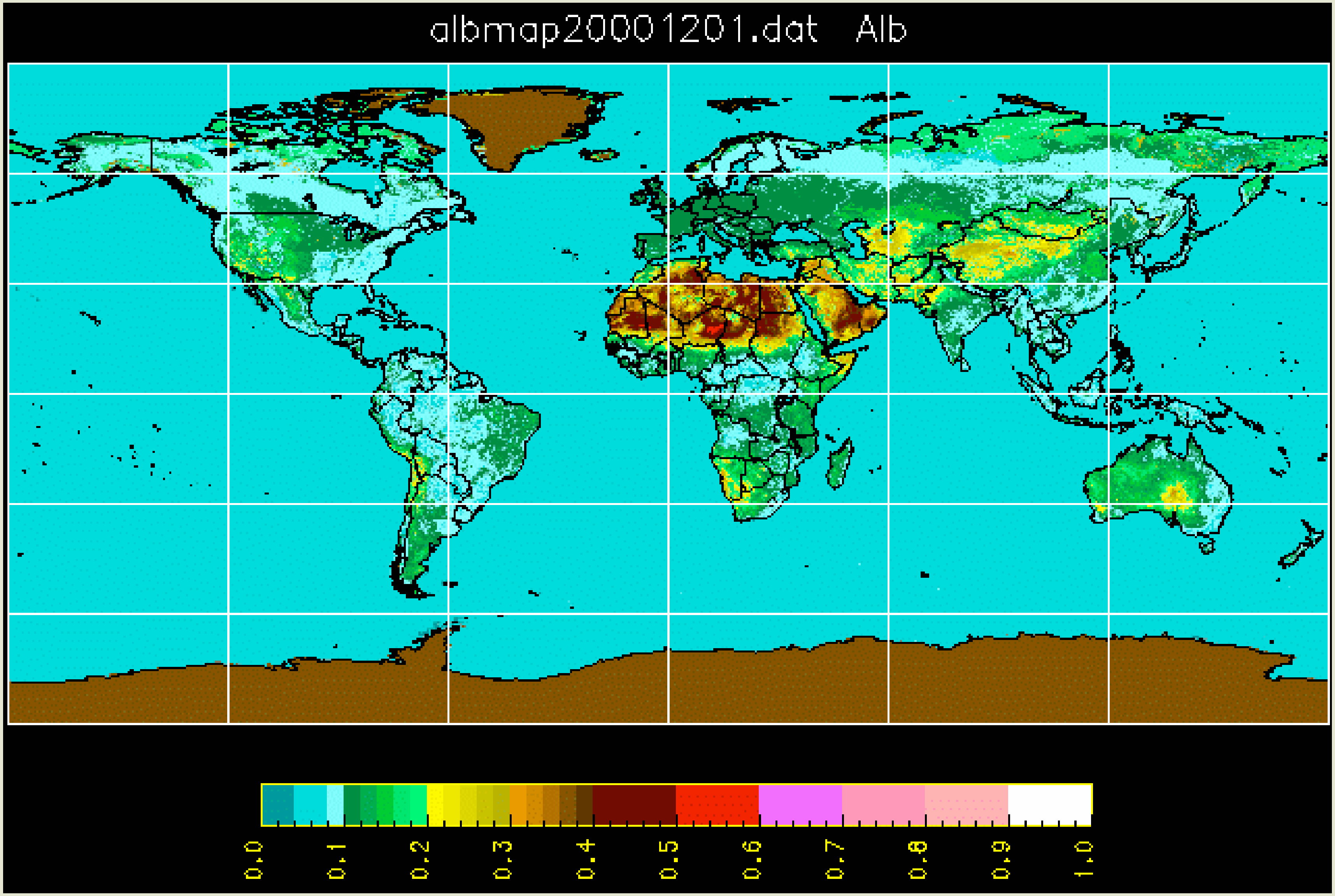
- **Estimate reflectance for given viewing angles, $\rho(\mu_o, \mu, \phi) = \alpha(\mu_o)\,\chi(\mu_o, \mu, \phi)$**

  bidirectional reflectance (BRDF) model χ selected for each IGBP type

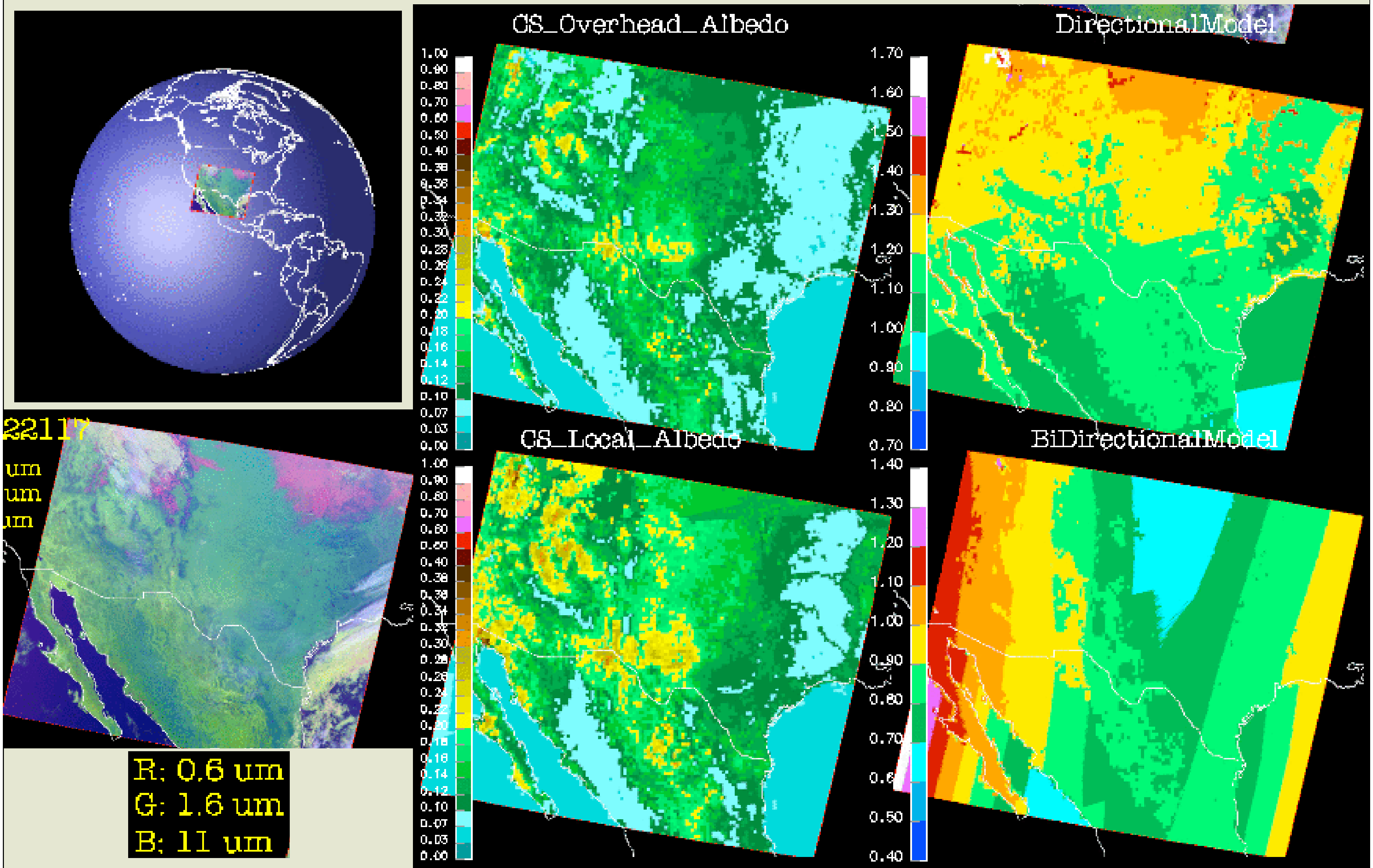
  from Kriebel (1978), Minnis & Harrison (1984), Suttles et al. (1988)

- **Add uncertainty to set reflectance threshold, $\rho_T(\mu_o, \mu, \phi) = \rho + \Delta\rho(\mu_o, \mu, \phi)$**

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

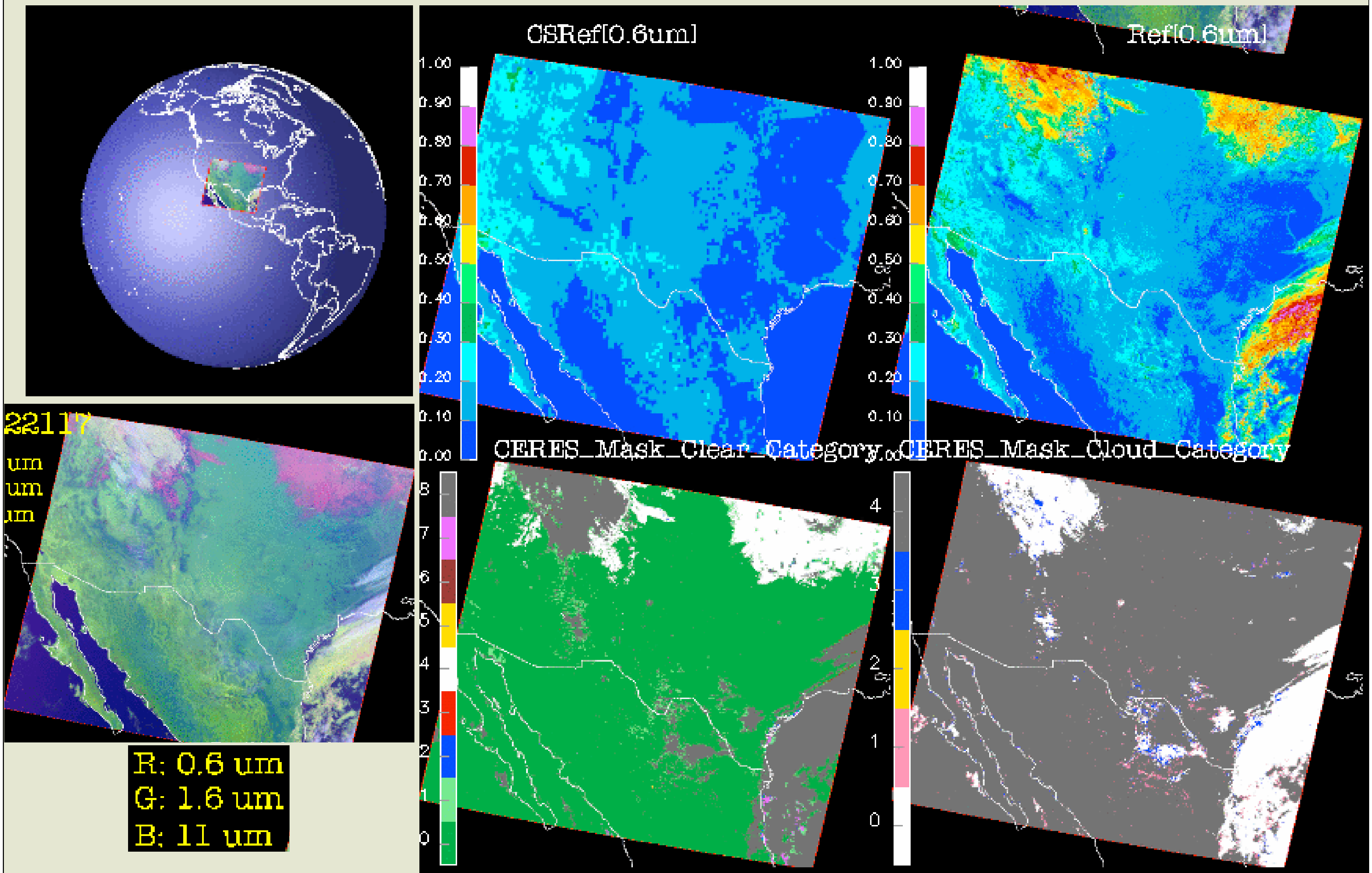


PREDICTED CLEAR-SKY VIS ALBEDO
1700 UTC,12/21/00



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

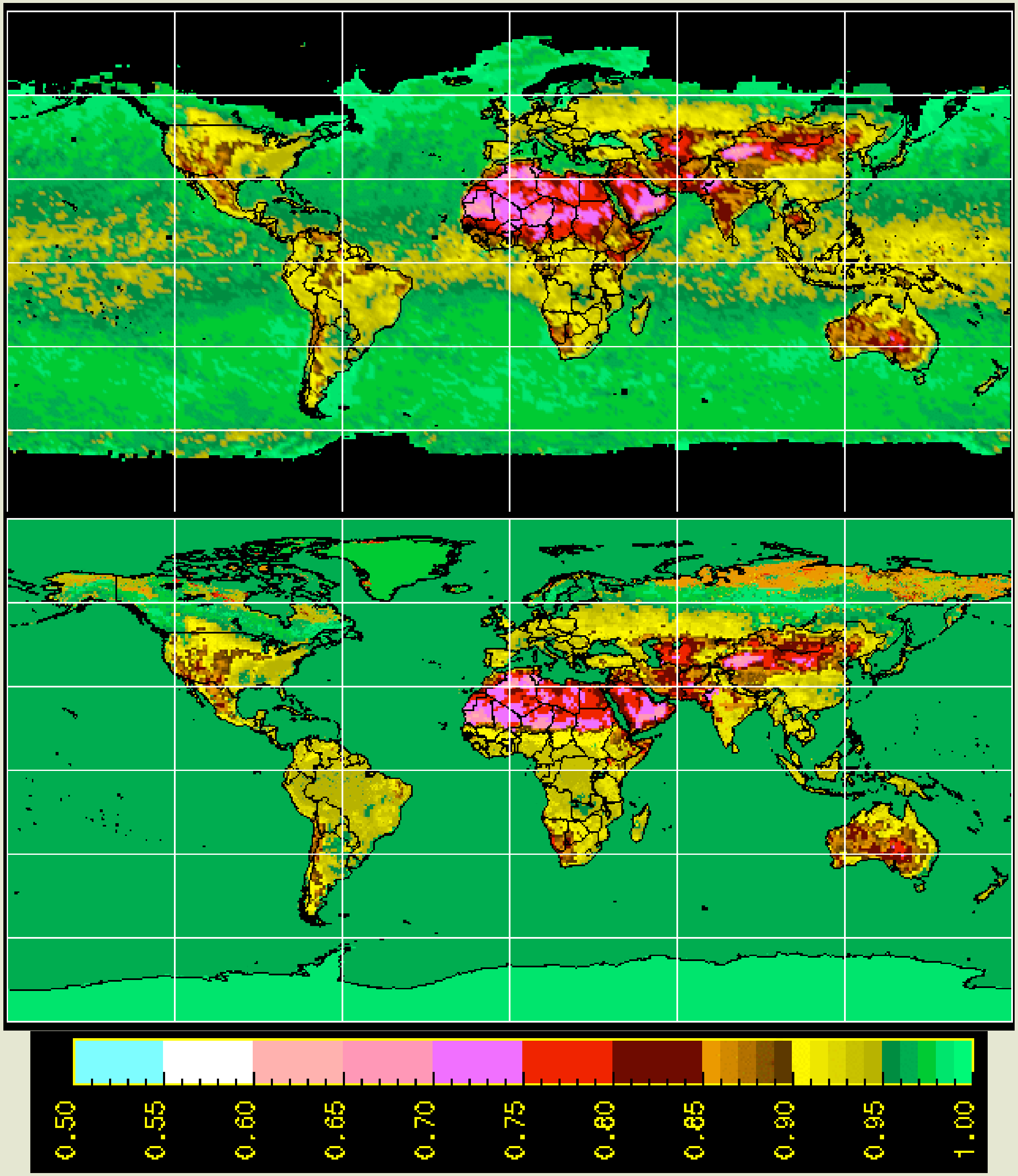
- **Add uncertainty to set T or BTD thresholds, $T_T(\mu) = T_{cs}(\mu) + \Delta T(\mu)$**

  - reflected solar component included in 3.7-4.0 μm estimate

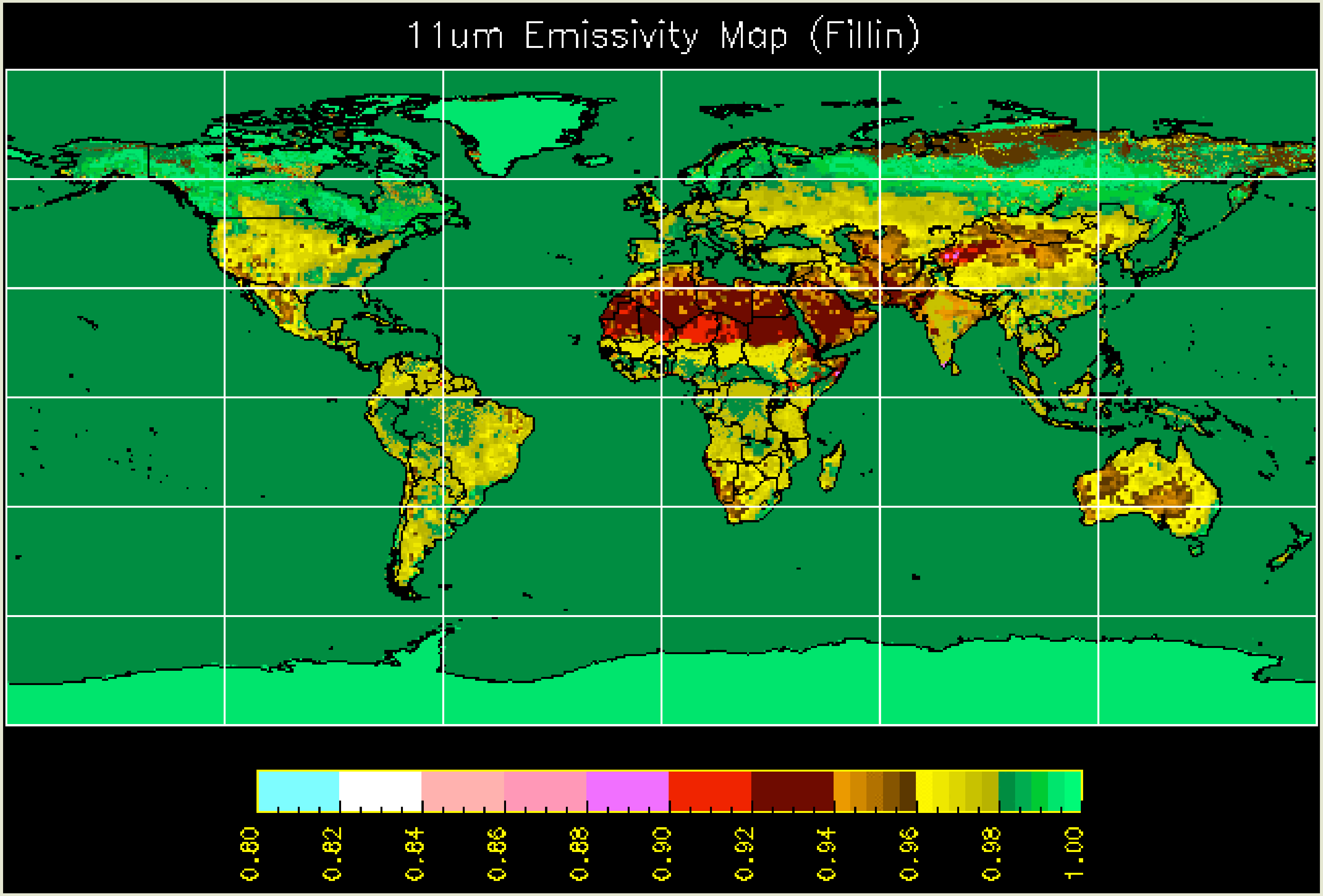
Surface emissivity from *Terra* MODIS, April 2001 3.7 μm

Unfiltered

Filtered & IGBP filled

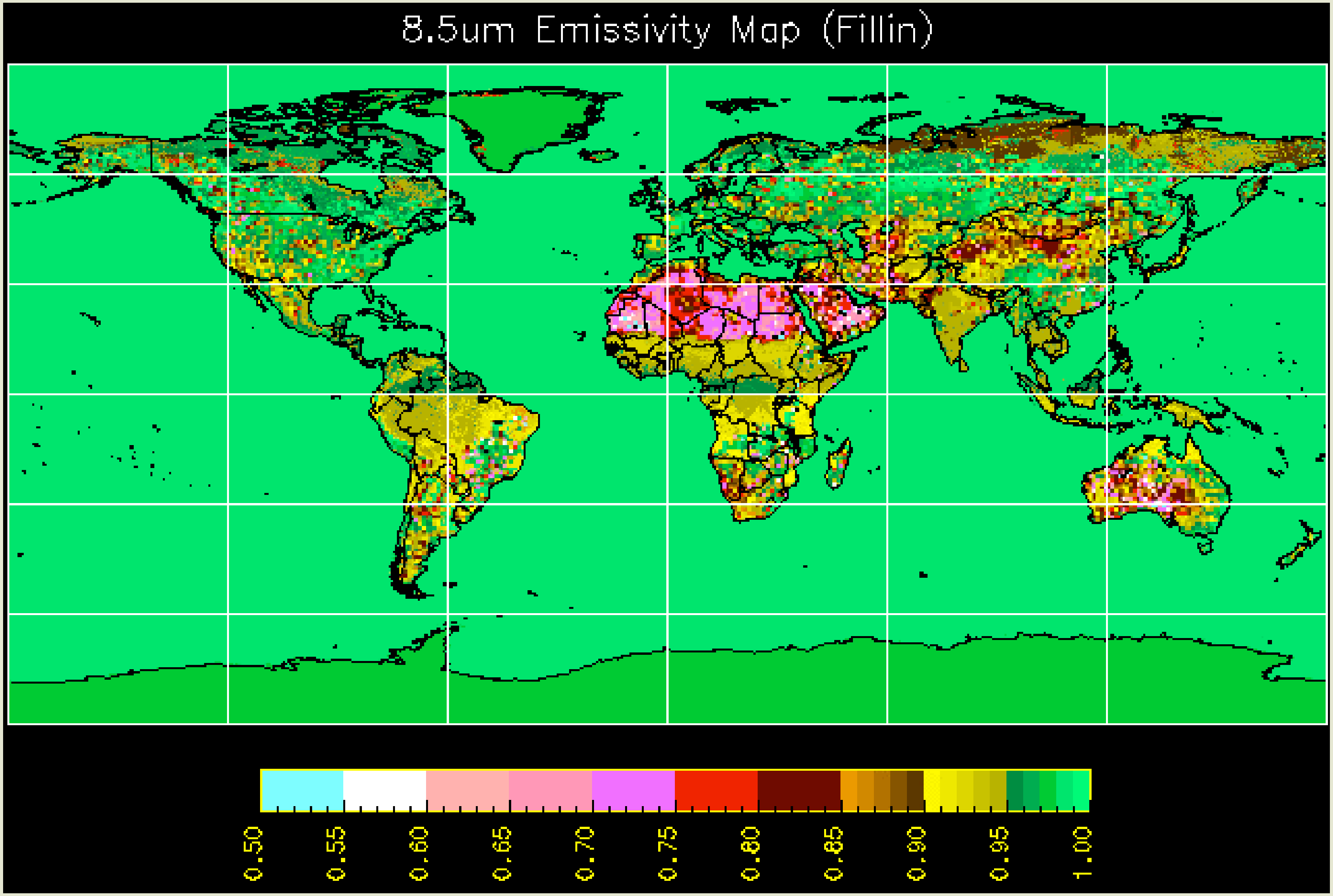


Surface emissivity from *Terra* MODIS, April 2001, 11 μm



Filtered & IGBP filled

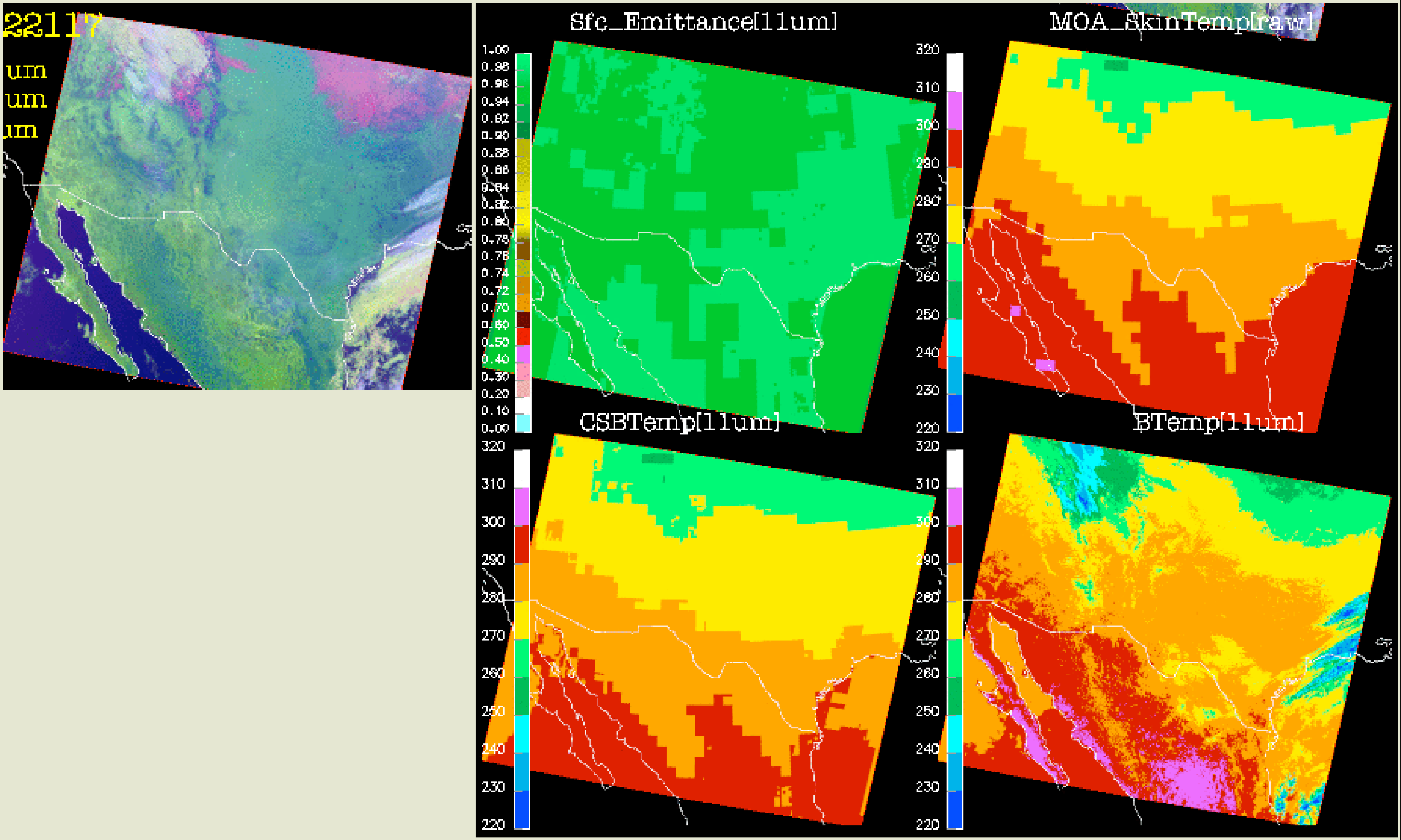
Surface emissivity from *Terra* MODIS, April 2001, 8.5 μm



Filtered & IGBP filled

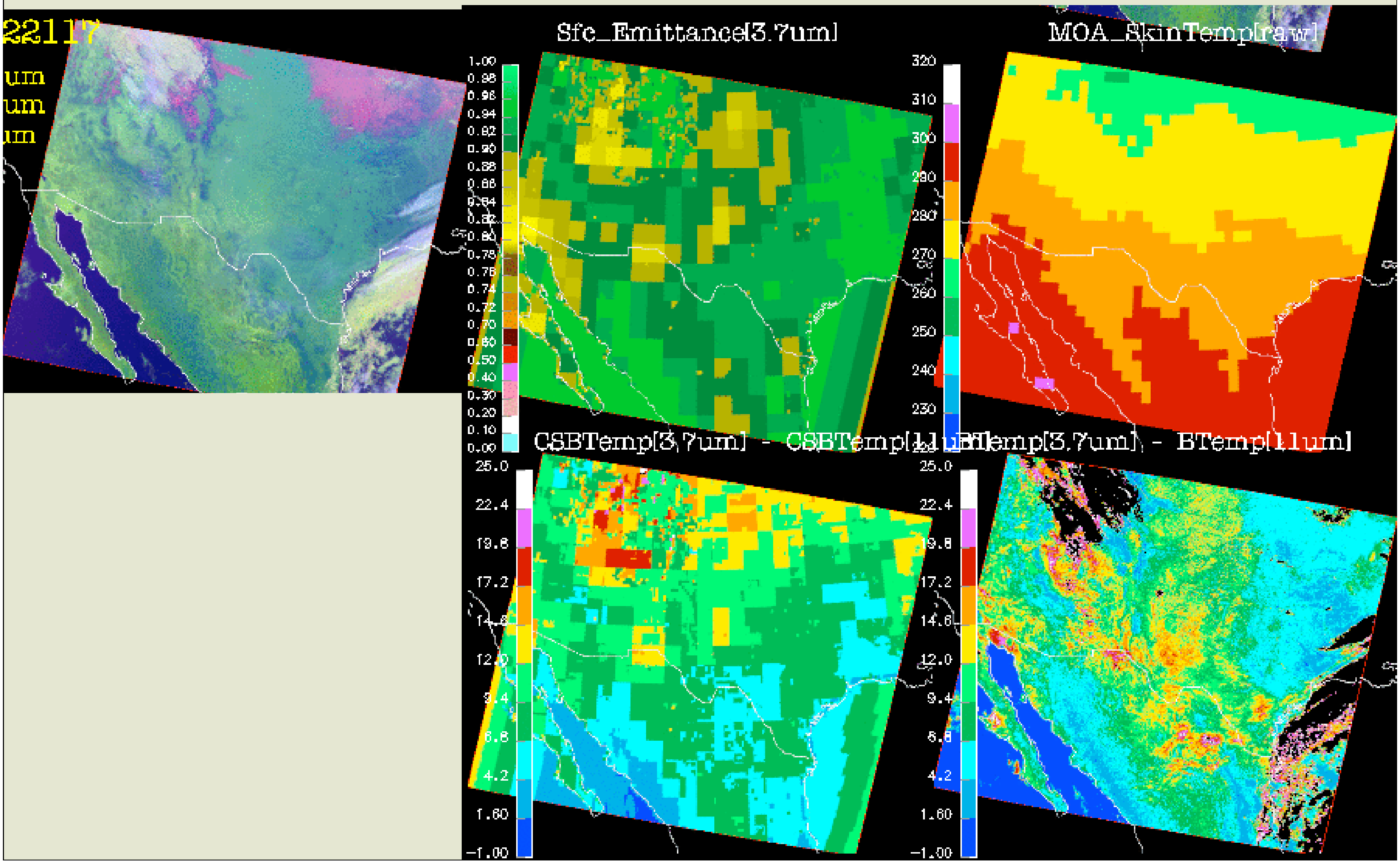
PREDICTED CLEAR-SKY & OBSERVED IR TEMPERATURE

1700 UTC,12/21/00



PREDICTED CLEAR-SKY & OBSERVED BTD (3.7 - 11)

1700 UTC,12/21/00



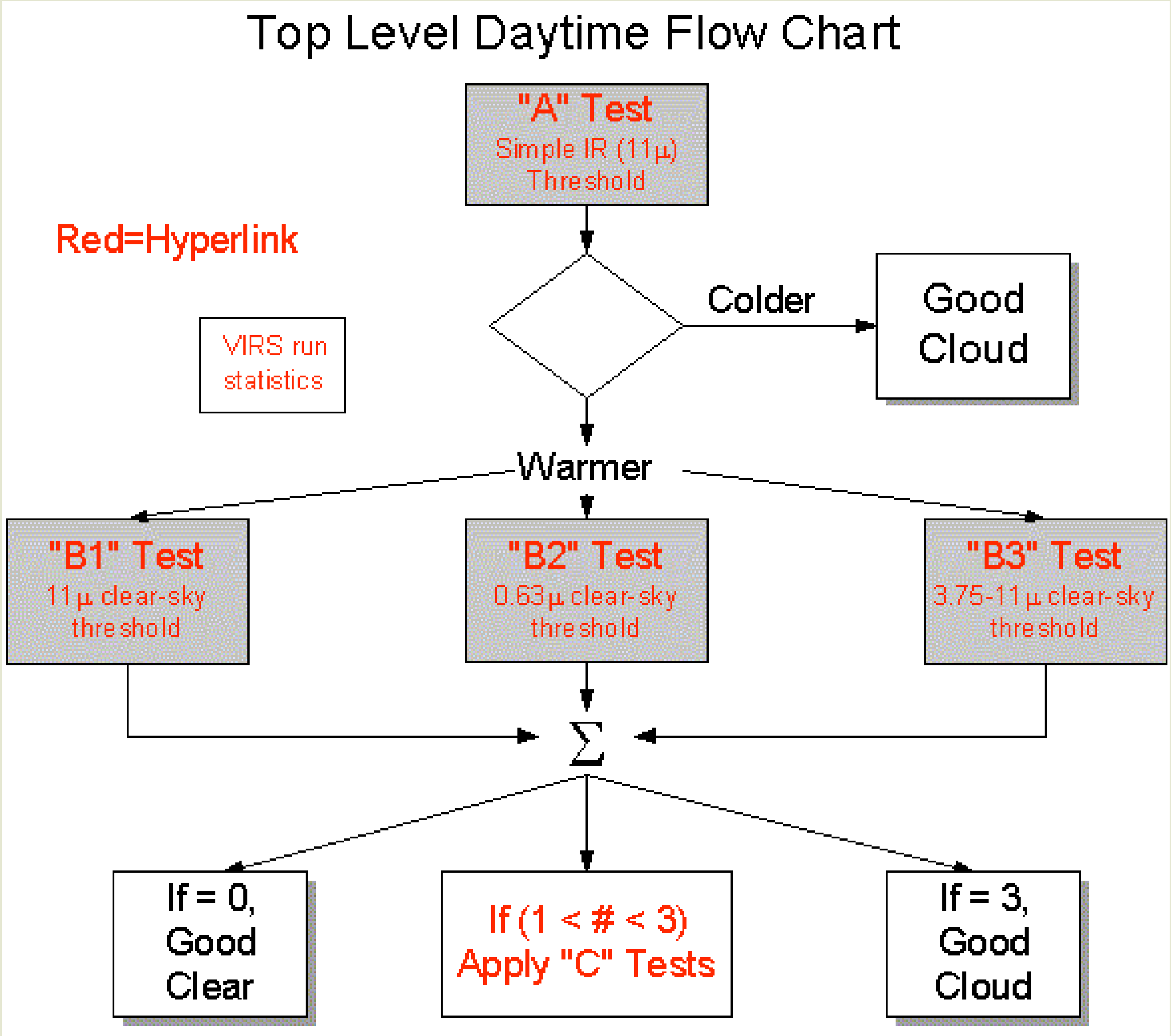
CLOUD MASK

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

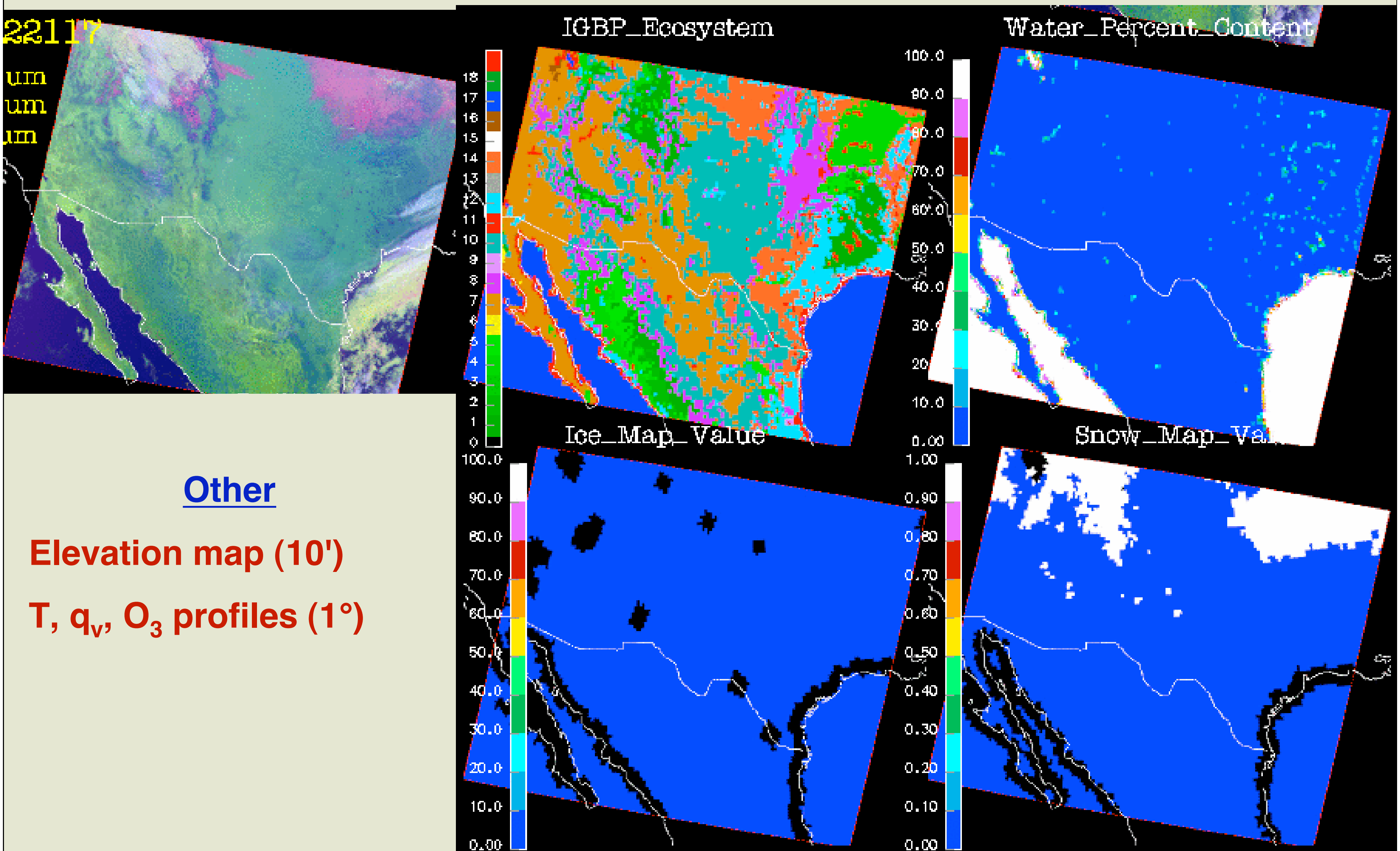
NIGHTTIME & POLAR: 3.8, 11, 12 μm

STANDARD DAYTIME MASK ALGORITHM



ANCLILLARY DATA USED IN CLOUD MASK & RETRIEVALS

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

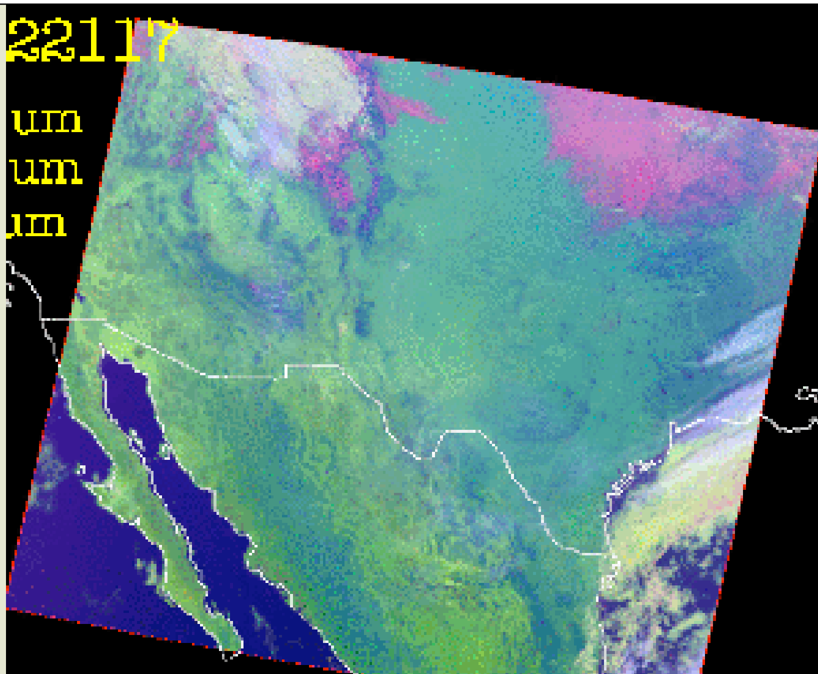


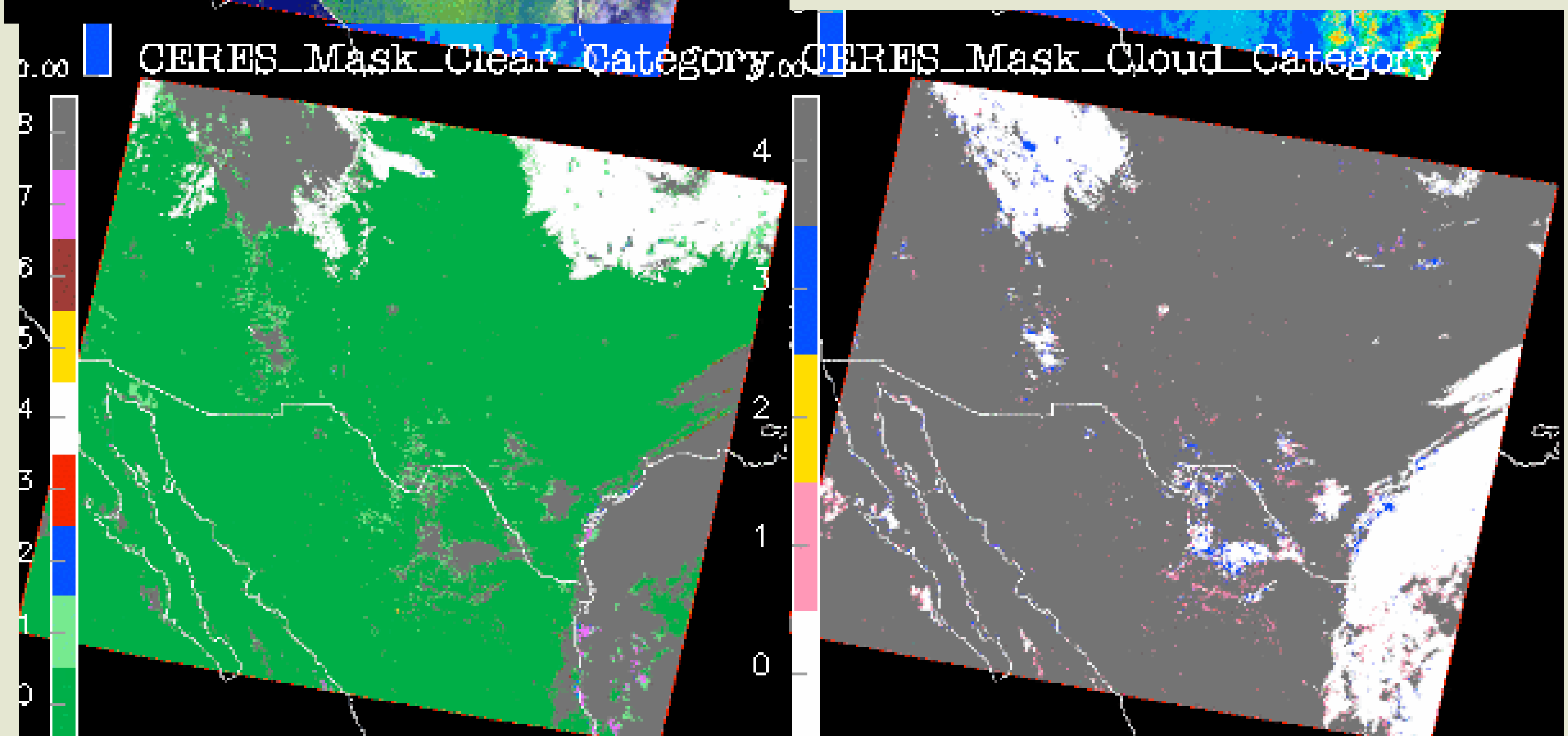
Other

Elevation map (10')

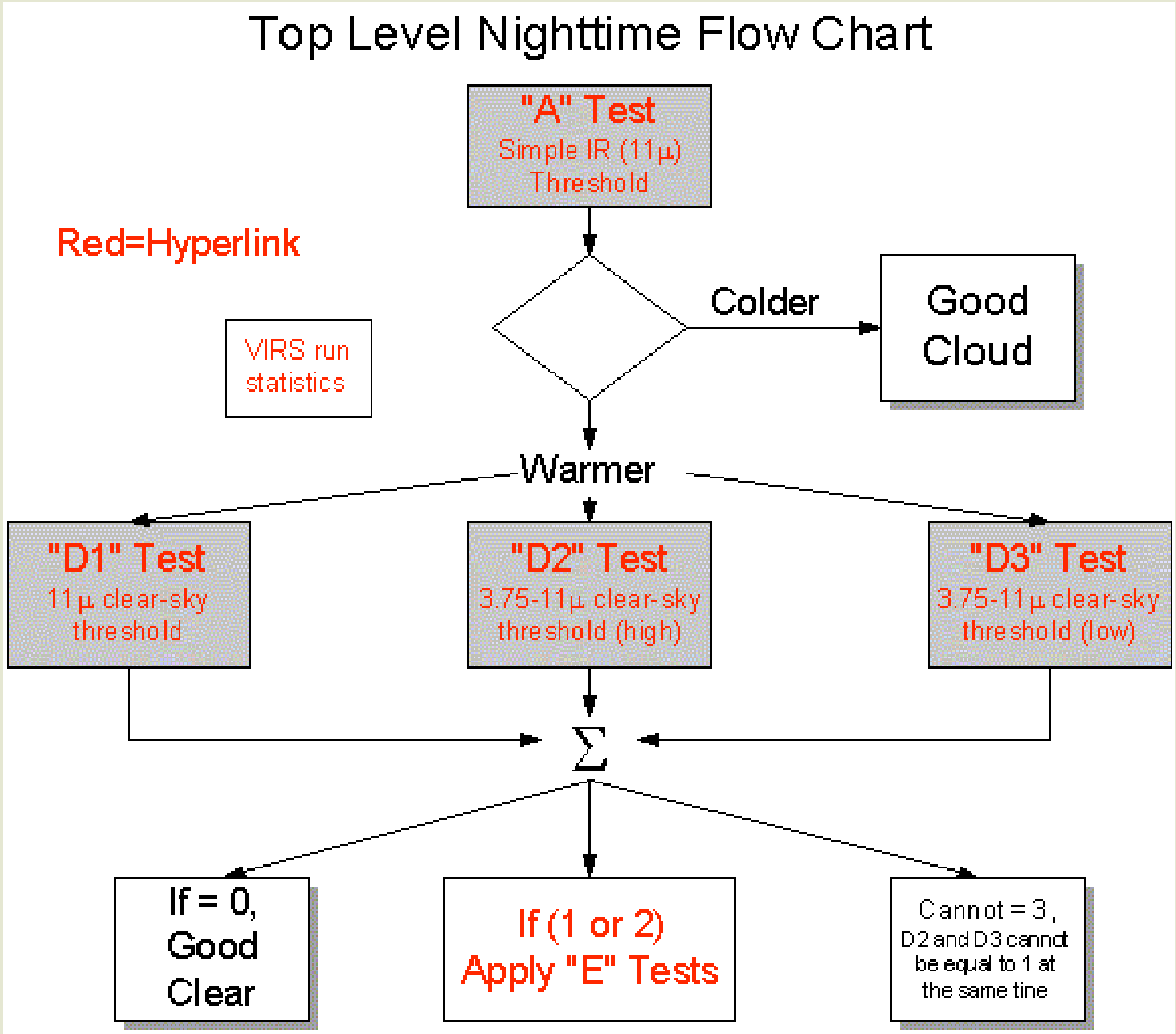
T, q_v, O_3 profiles (1°)

CERES CLOUD MASK 1700 UTC,12/21/00

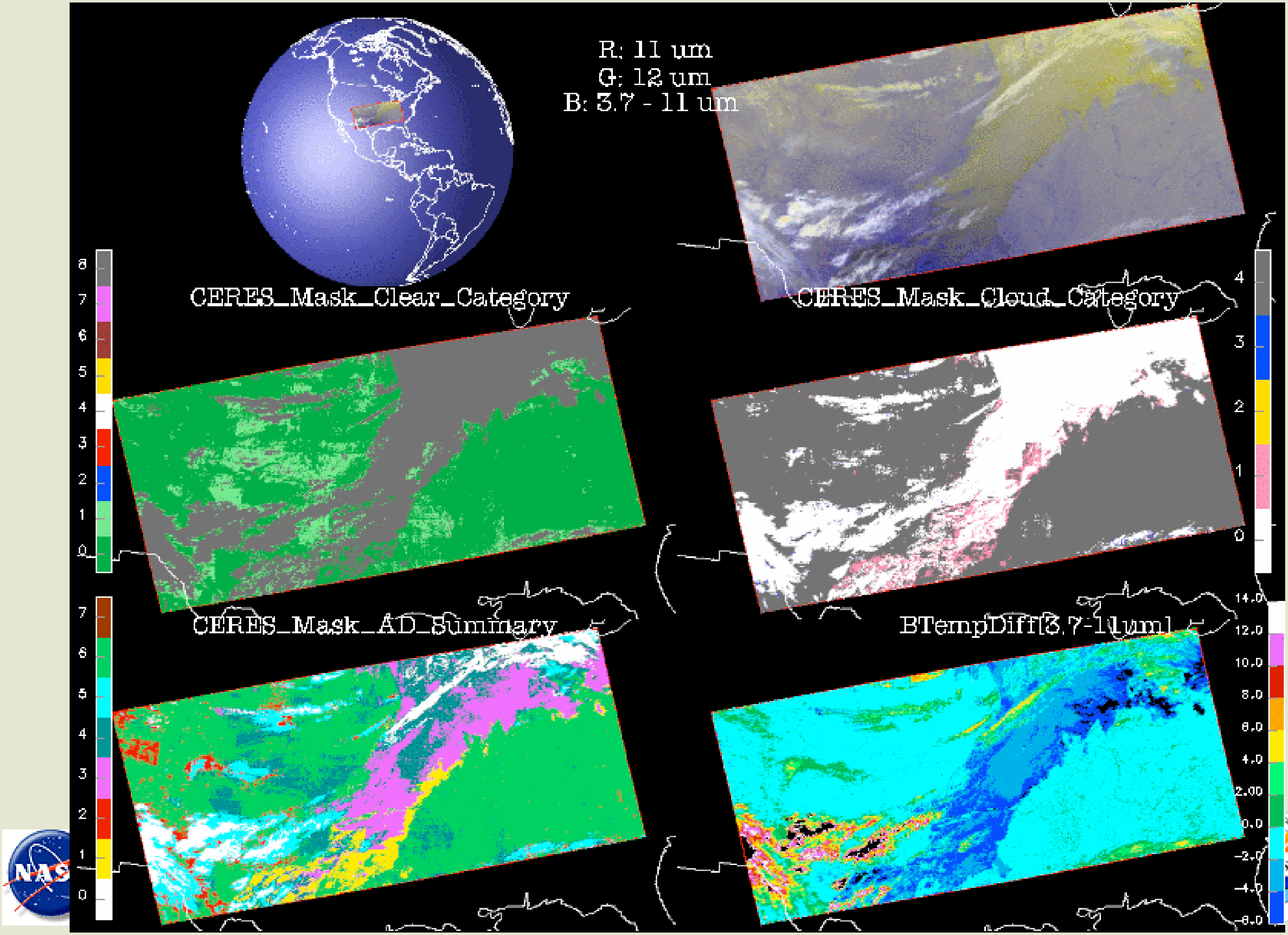




STANDARD NIGHTTIME MASK ALGORITHM



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	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

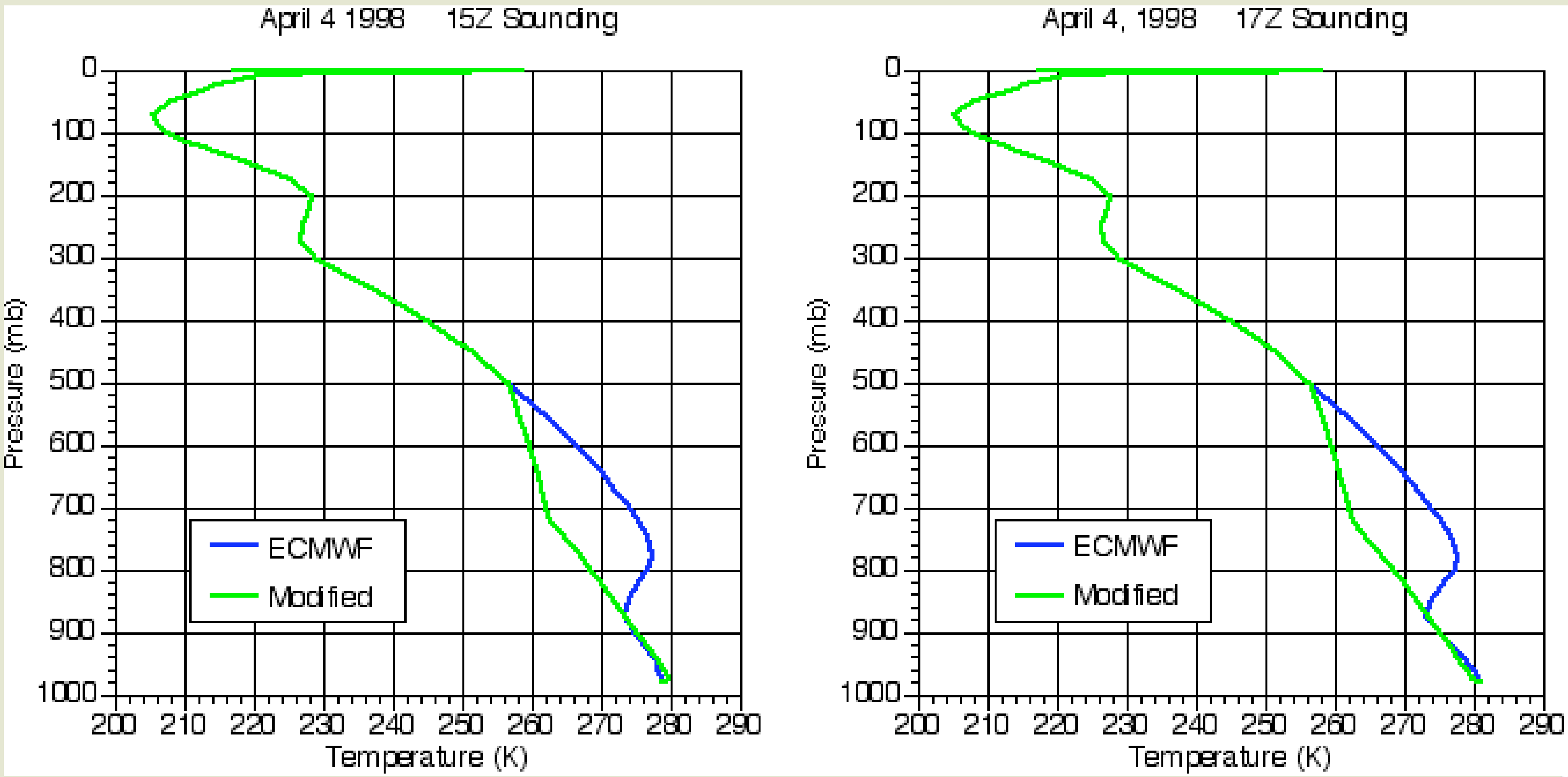
CLOUD HEIGHT ESTIMATION

- Cloud radiating temperature, Tcld
  - optically thin, corrected for semi-transparency
  - optically thick, T11 corrected for atmos attenuation
- Zcld = Z(Tcld)
  - boundary layer uses lapse rate method over ocean & land
  - 700 hPa and lower pressure, use T(z) from GMAO
- Ztop = empirical function of Z(Tcld), phase, Tcld, τ
- Thickness = empirical function of phase, Tcld, τ
- Zbase = Ztop - Thickness

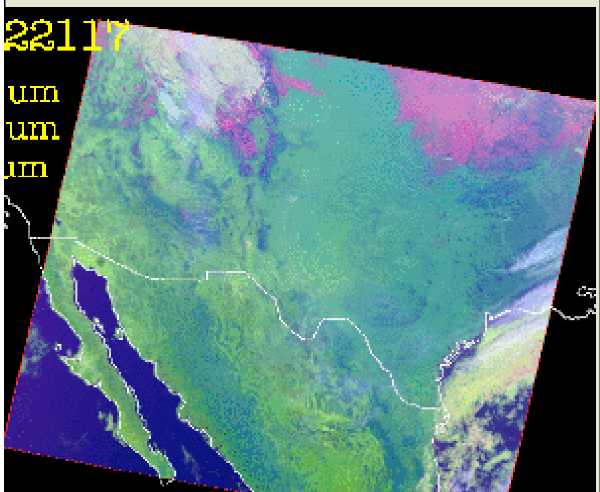
LAPSE RATE METHOD

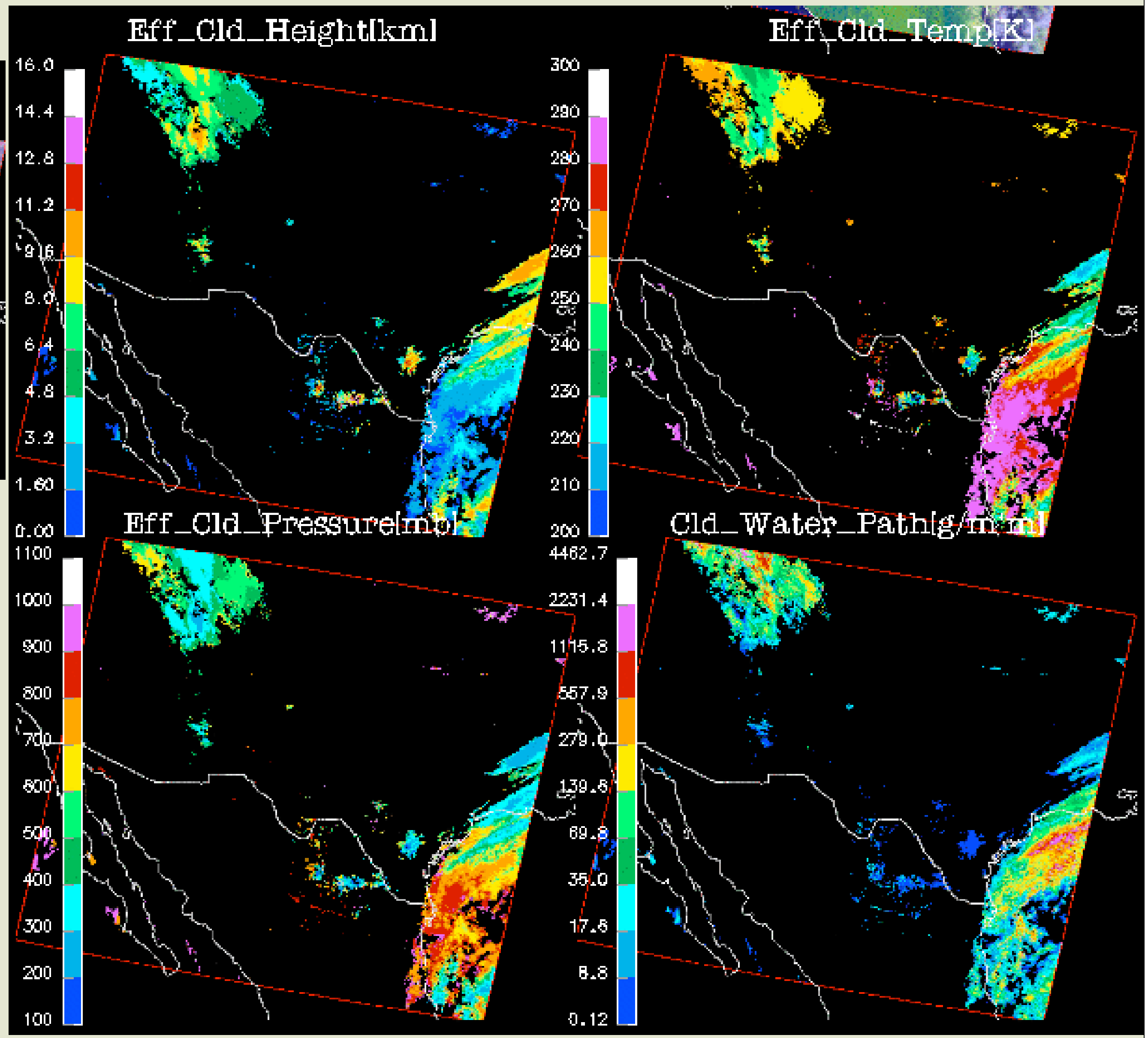
- OCEAN: Use SST as anchor for -7.1 K/ km lapse rate
- LAND: Use 24-hr running mean for anchor
- Blend at 500 hPa

Example: ARM SGP

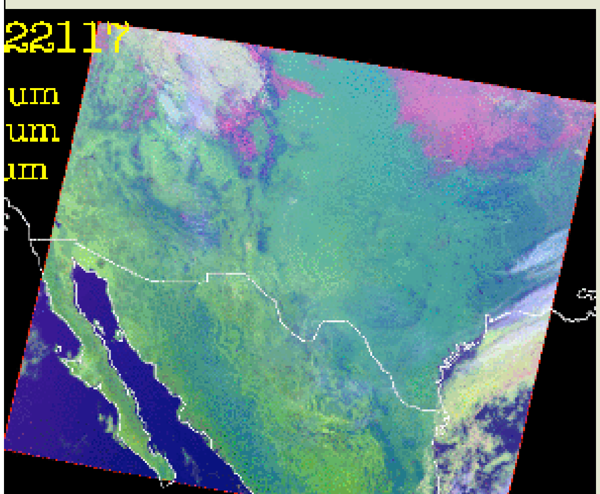


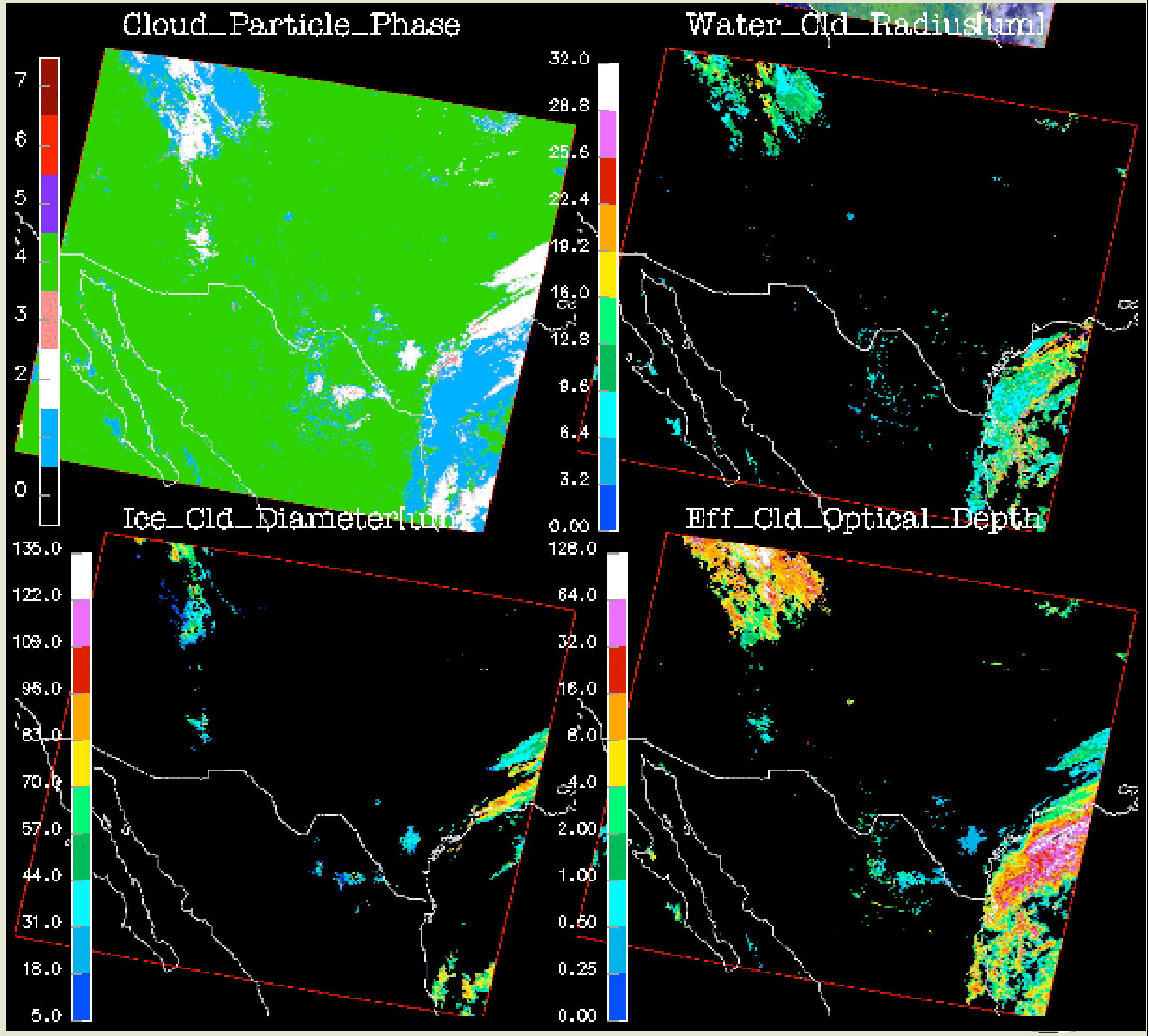
CERES CLOUD MACROPHYSICAL PROPERTIES
1700 UTC, 12/21/00





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

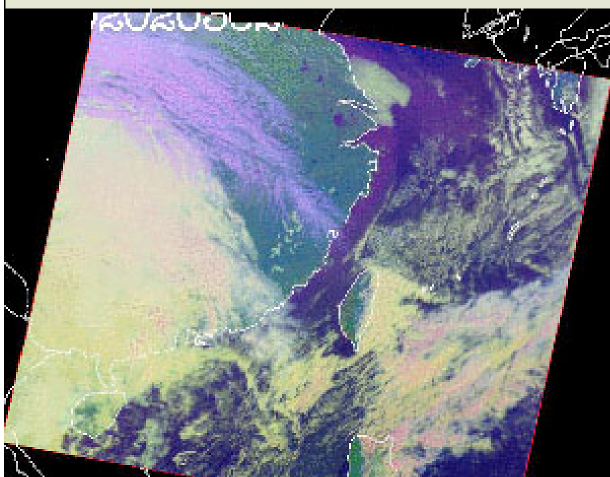




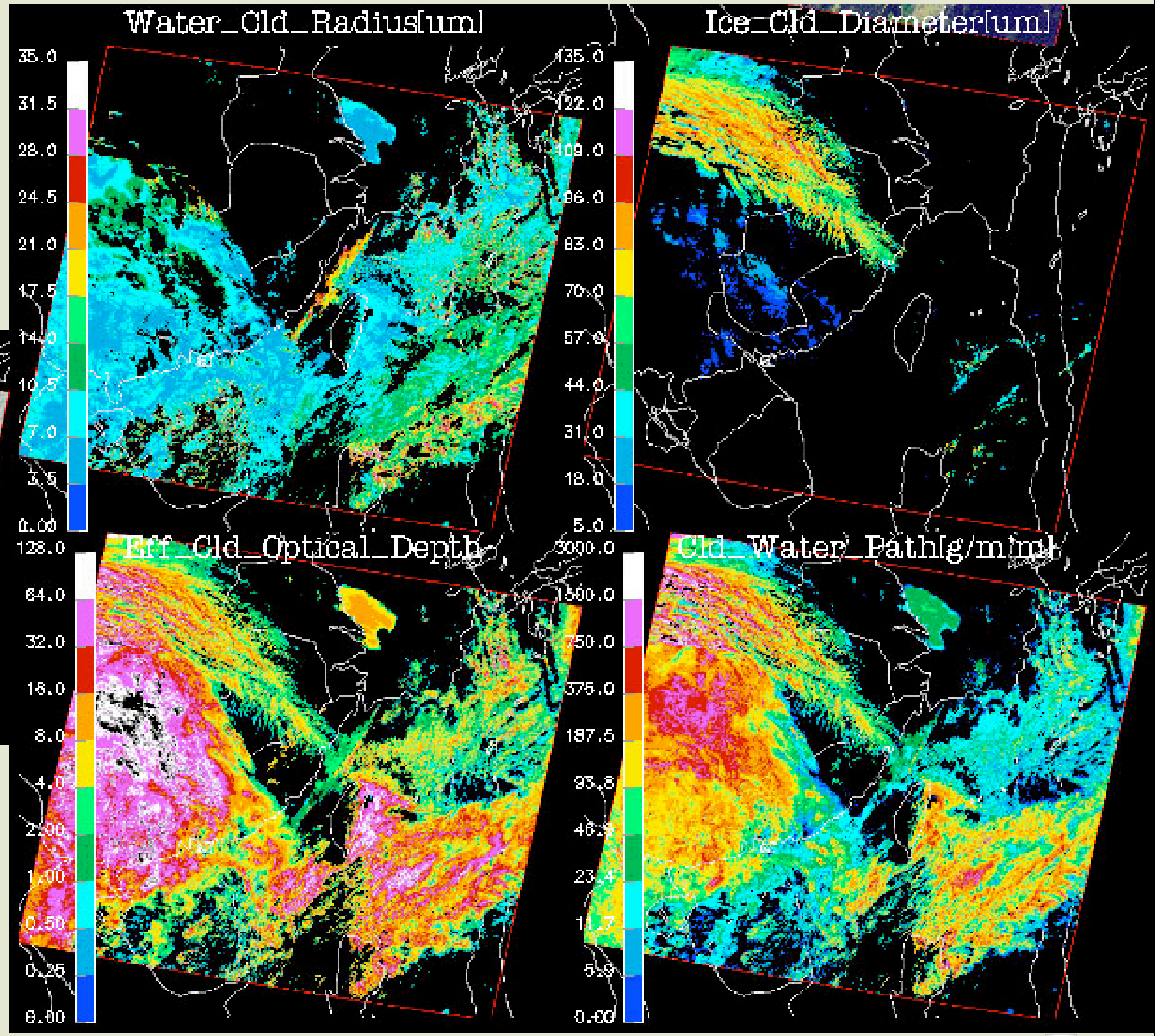
CERES Cloud Microphysical Properties

Eastern China

0002 UTC, 2/03/02



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

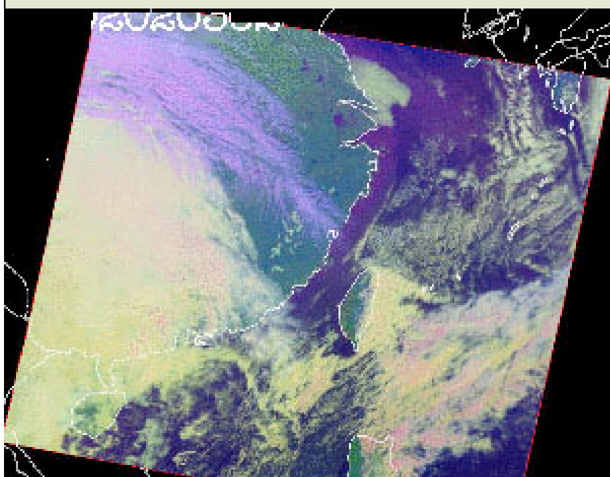


Terra MODIS

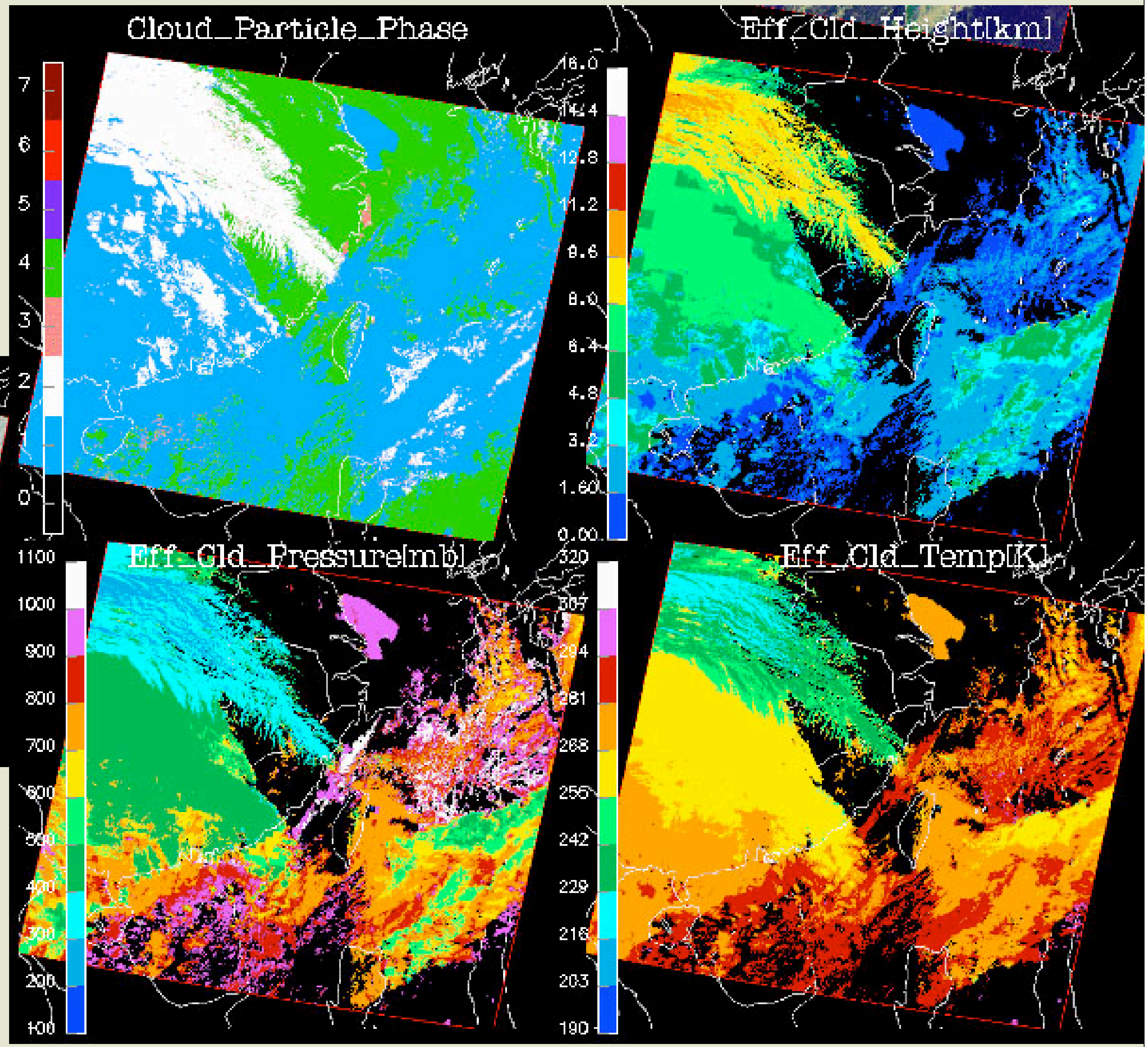
CERES Cloud Macrophysical Properties

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

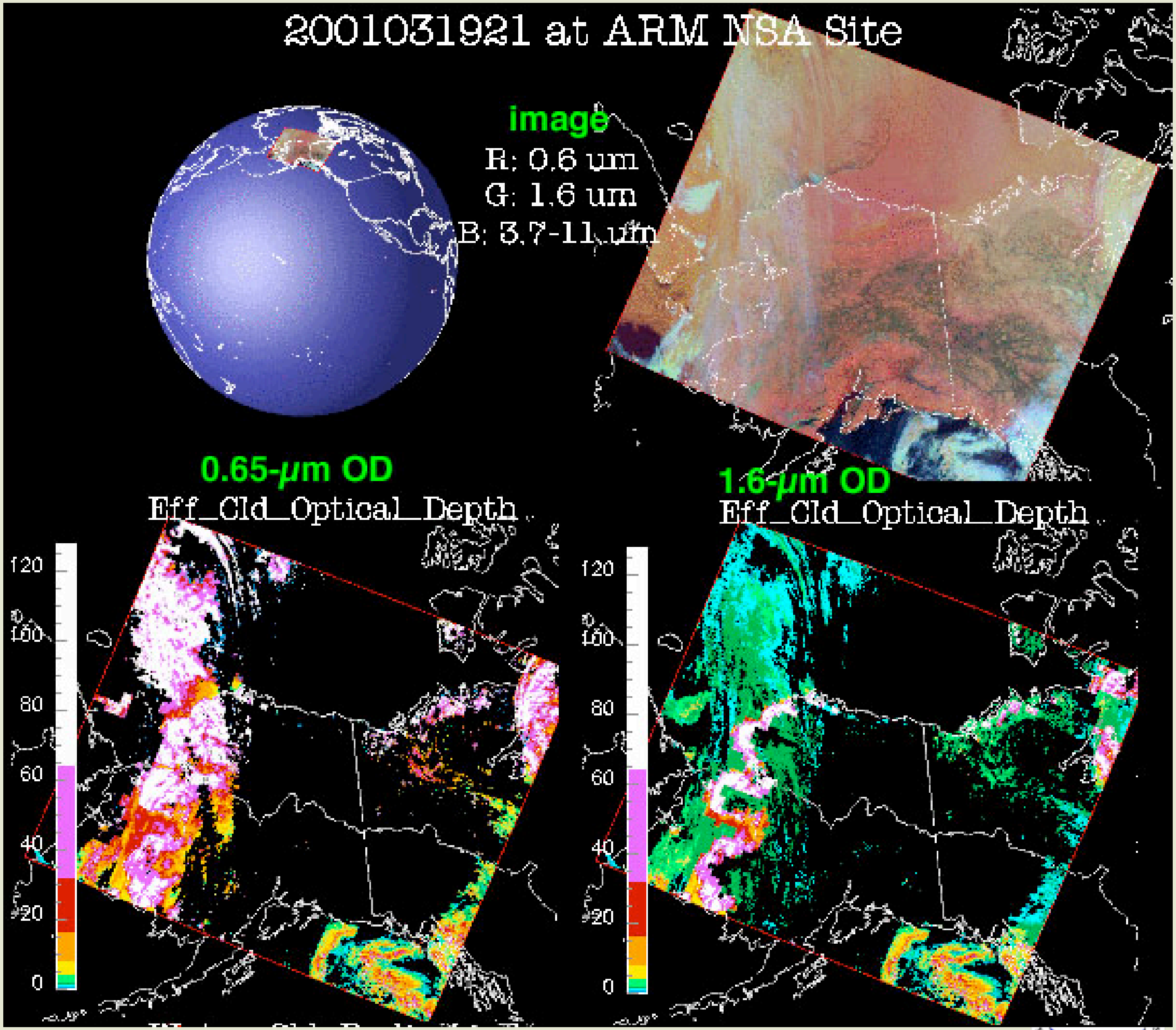
Northern Alaska

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

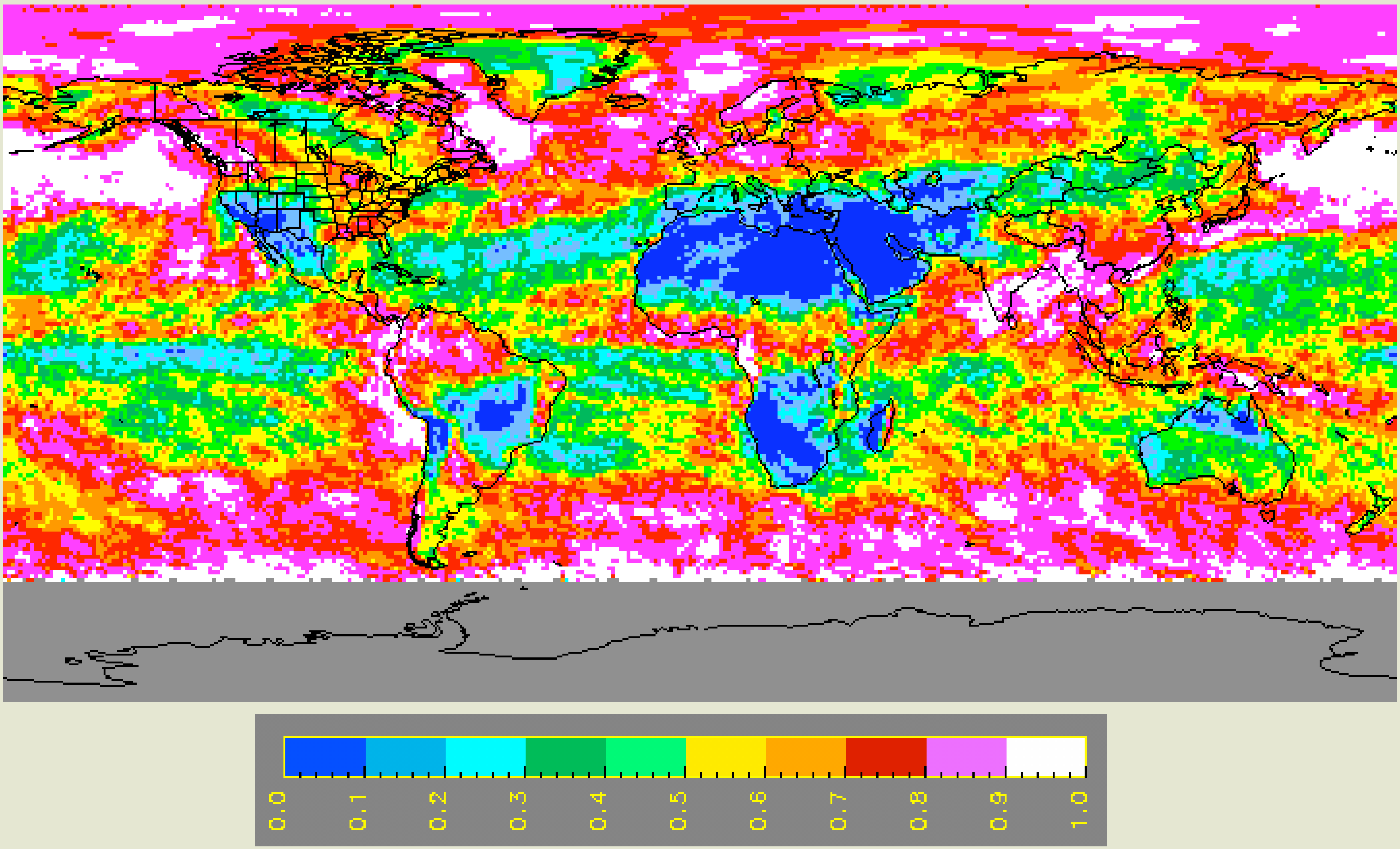
	Ocean	Land	Desert	Total
Cld Good	0.940	0.855	0.662	0.912
Cld Weak	0.038	0.042	0.088	0.047
Cld Glint	0.009	0.001	0.000	0.007
Cld N/R	0.030	0.068	0.250	0.042
Total	1.000	1.000	1.000	1.000

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

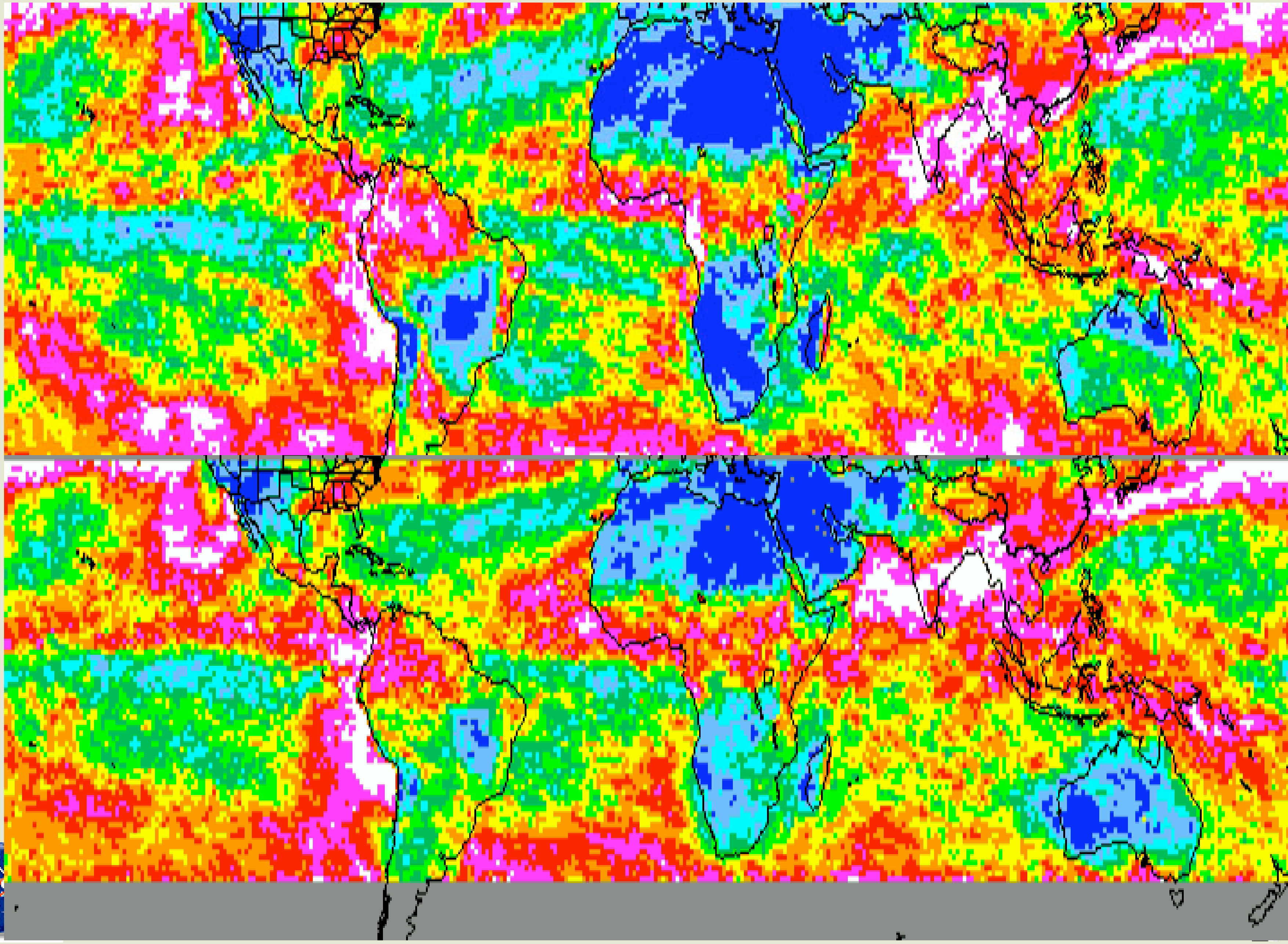
Day



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

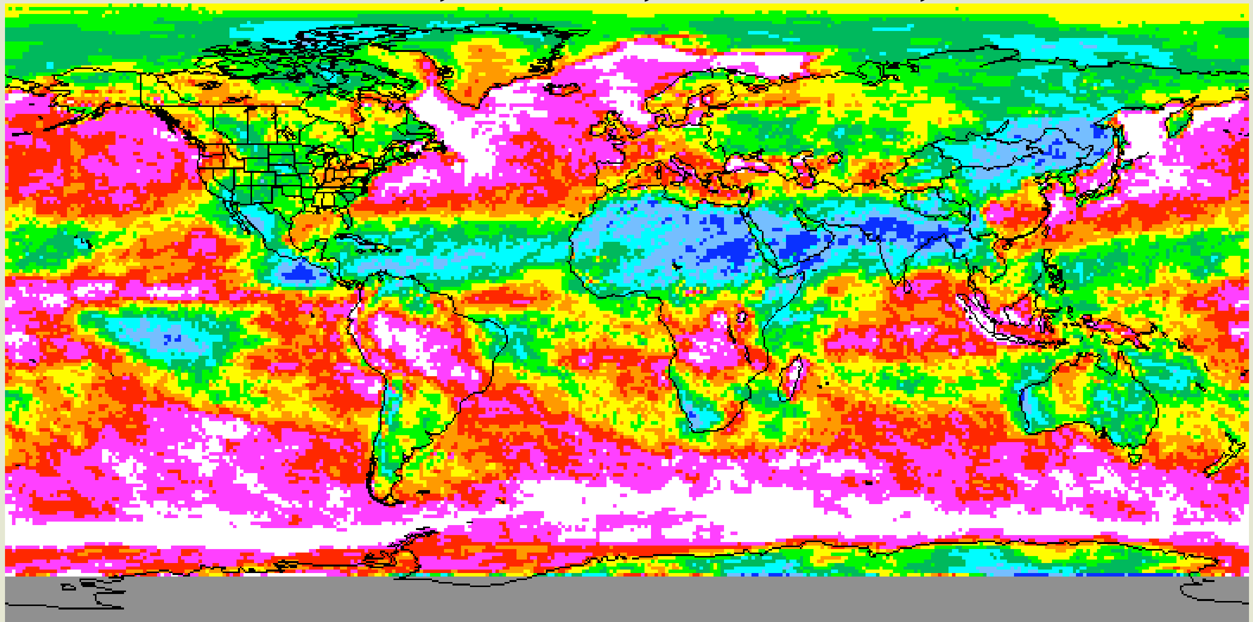
MODIS

VIRS

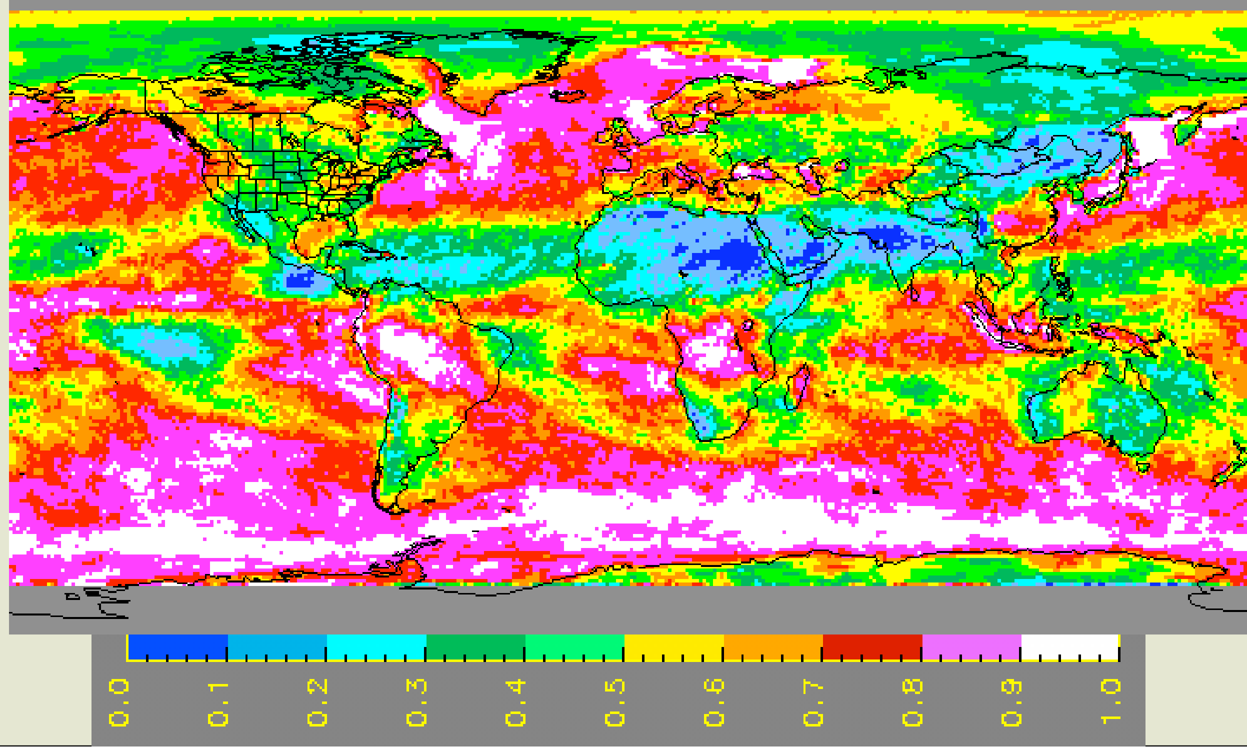


MEAN CLOUD COVER, MODIS, DEC 2002, NIGHT

Terra



Aqua

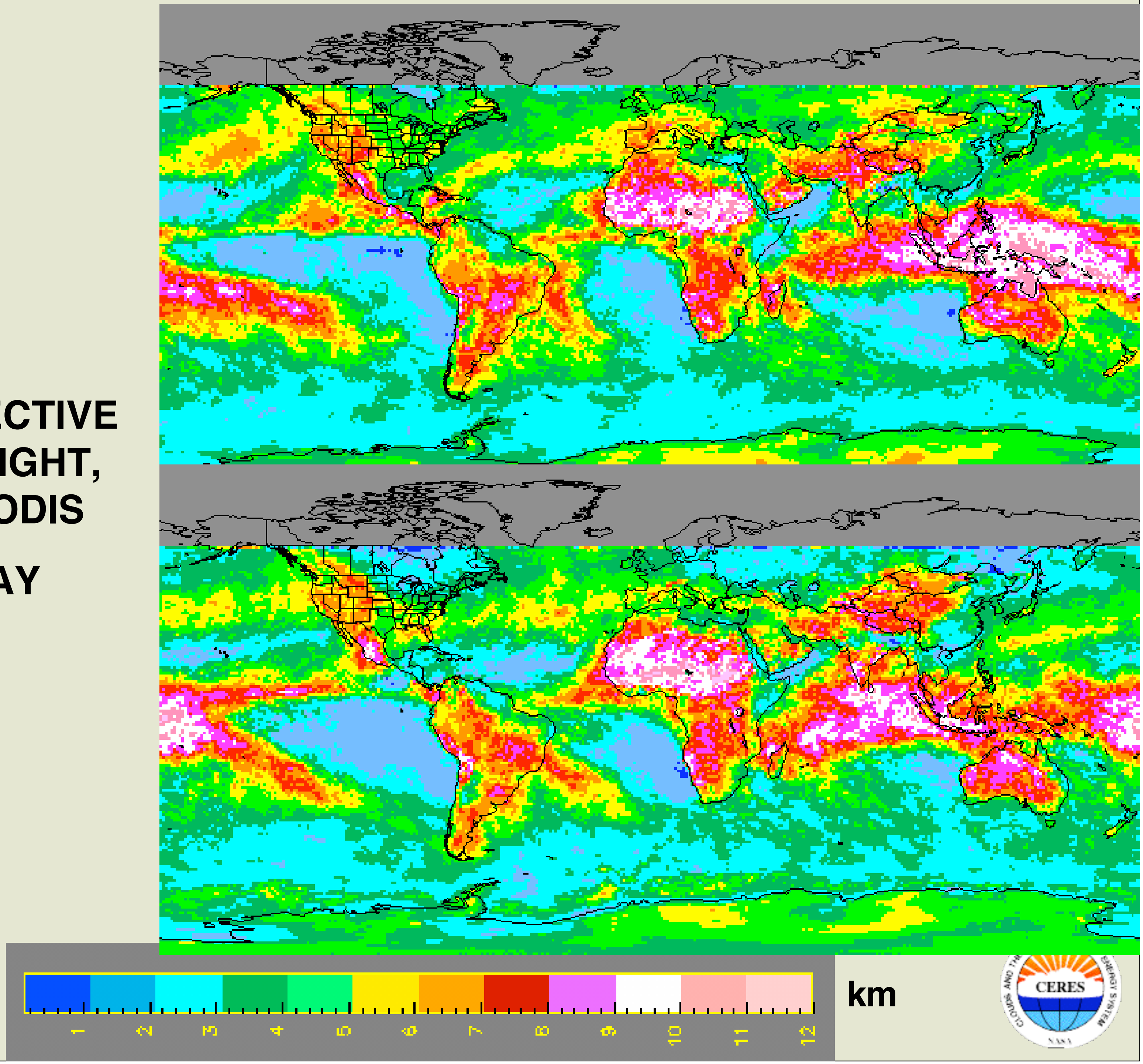


2000

MEAN EFFECTIVE CLOUD HEIGHT, TERRA MODIS

DEC, DAY

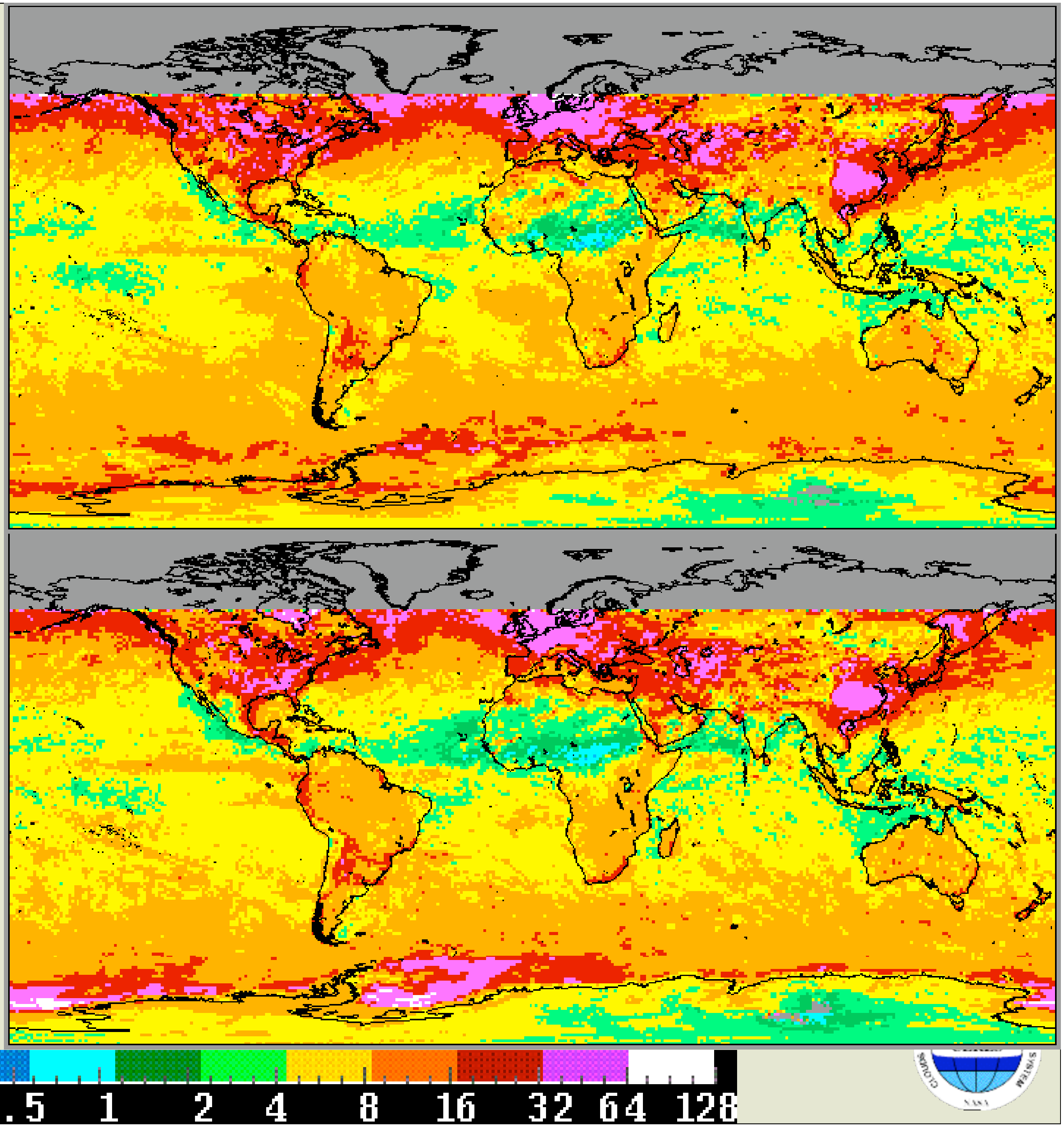
2002



Terra

MEAN WATER CLOUD OPTICAL DEPTH, MODIS, DEC 2002, DAY

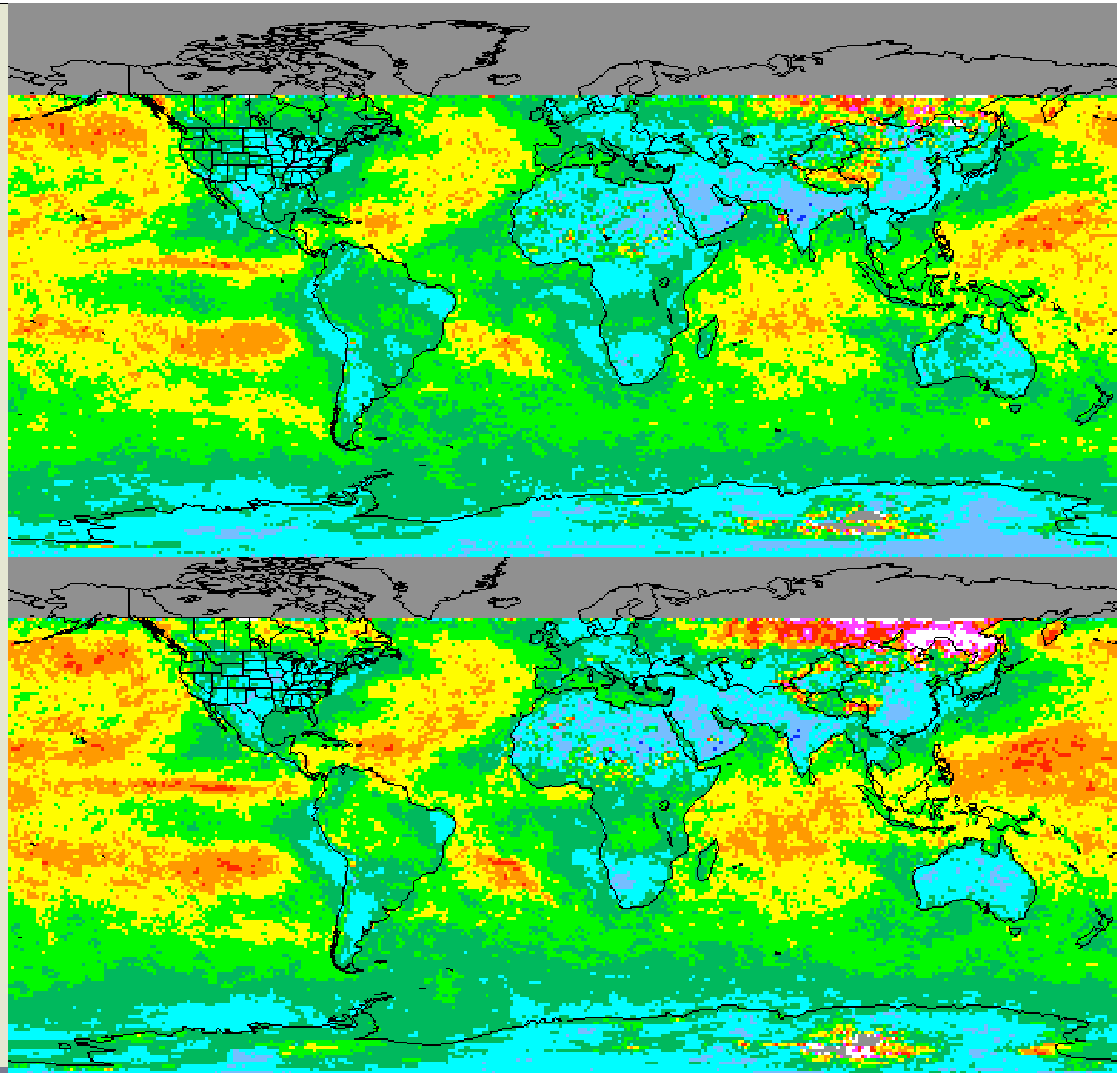
Aqua

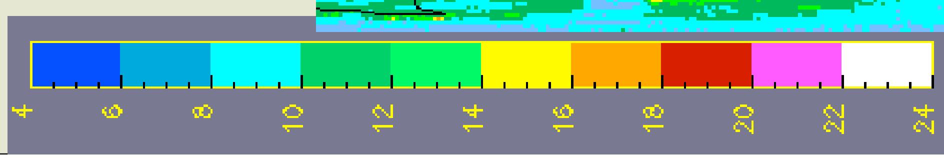


Terra

MEAN EFFECTIVE DROPLET RADIUS, MODIS, DEC 2002

Aqua

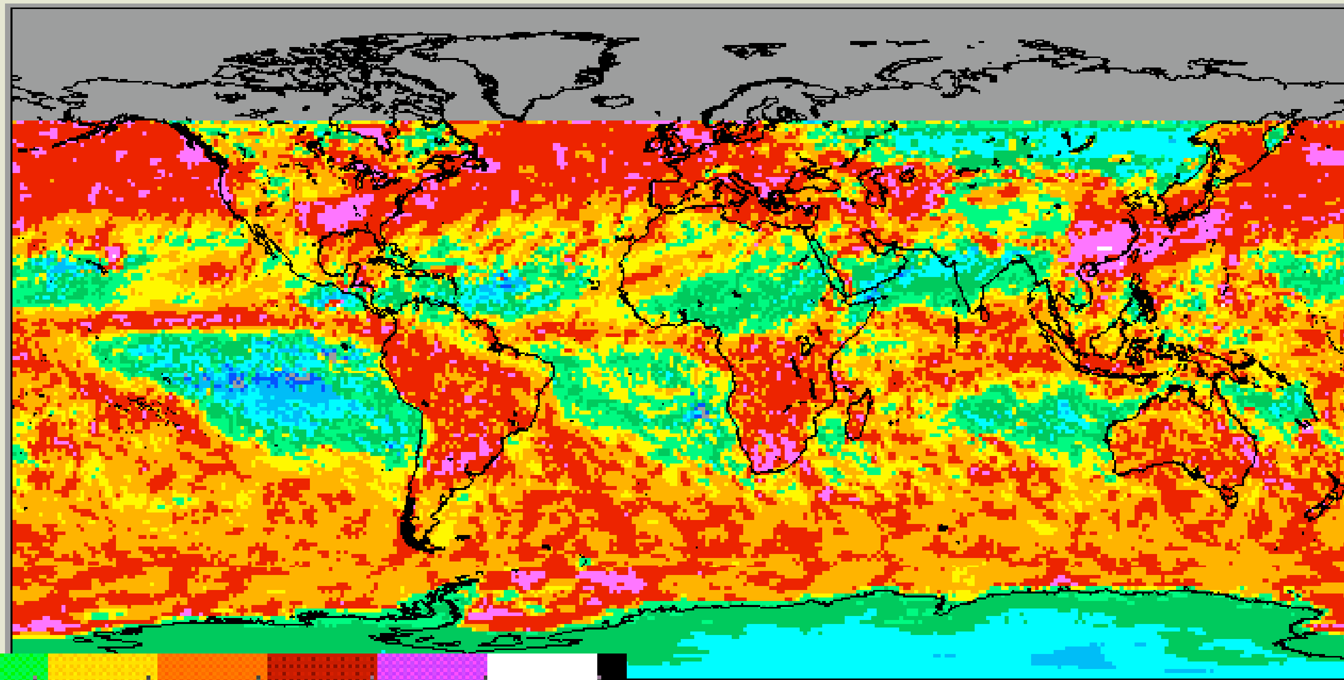


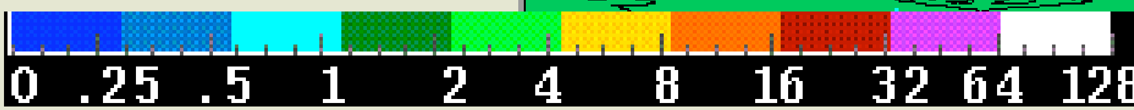


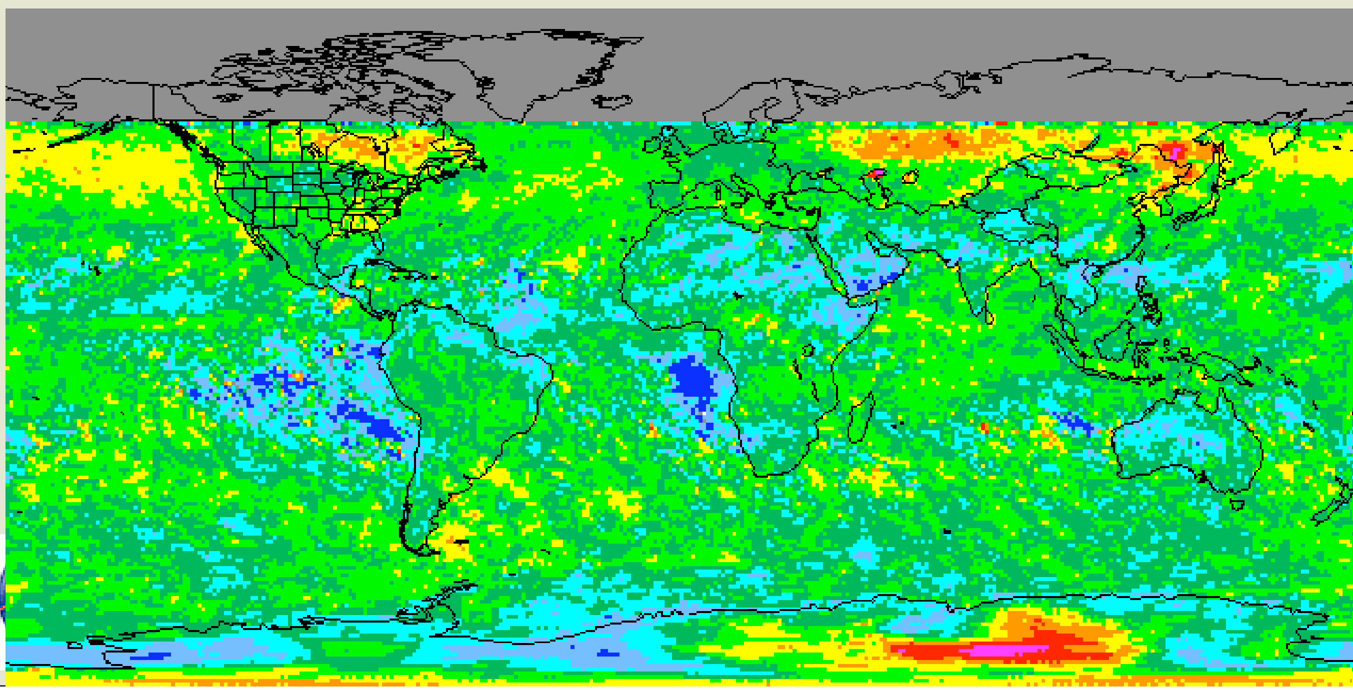
µm

Ice Cloud OD

Aqua Dec 2002





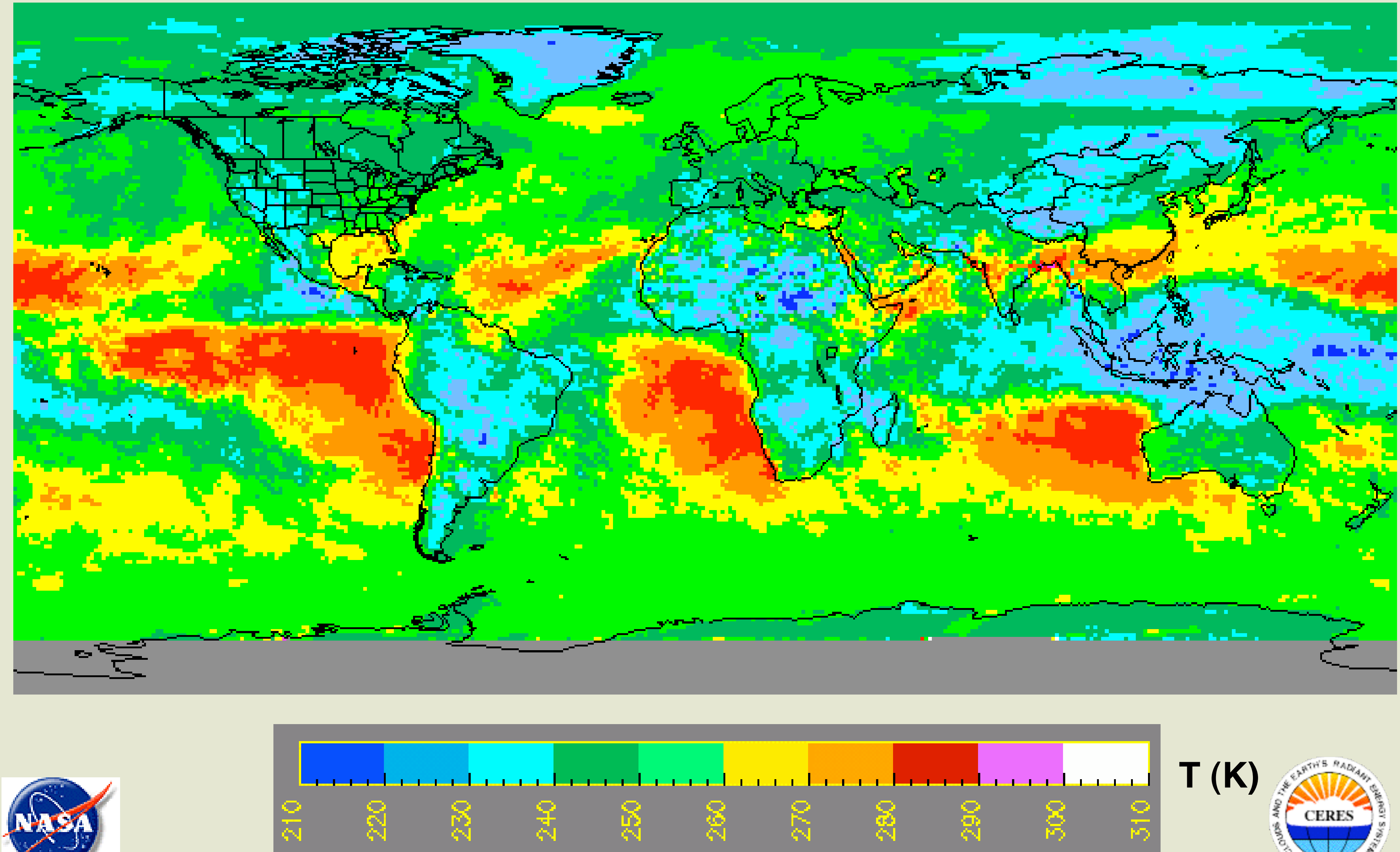


Ice Cloud De

Aqua Dec 2002

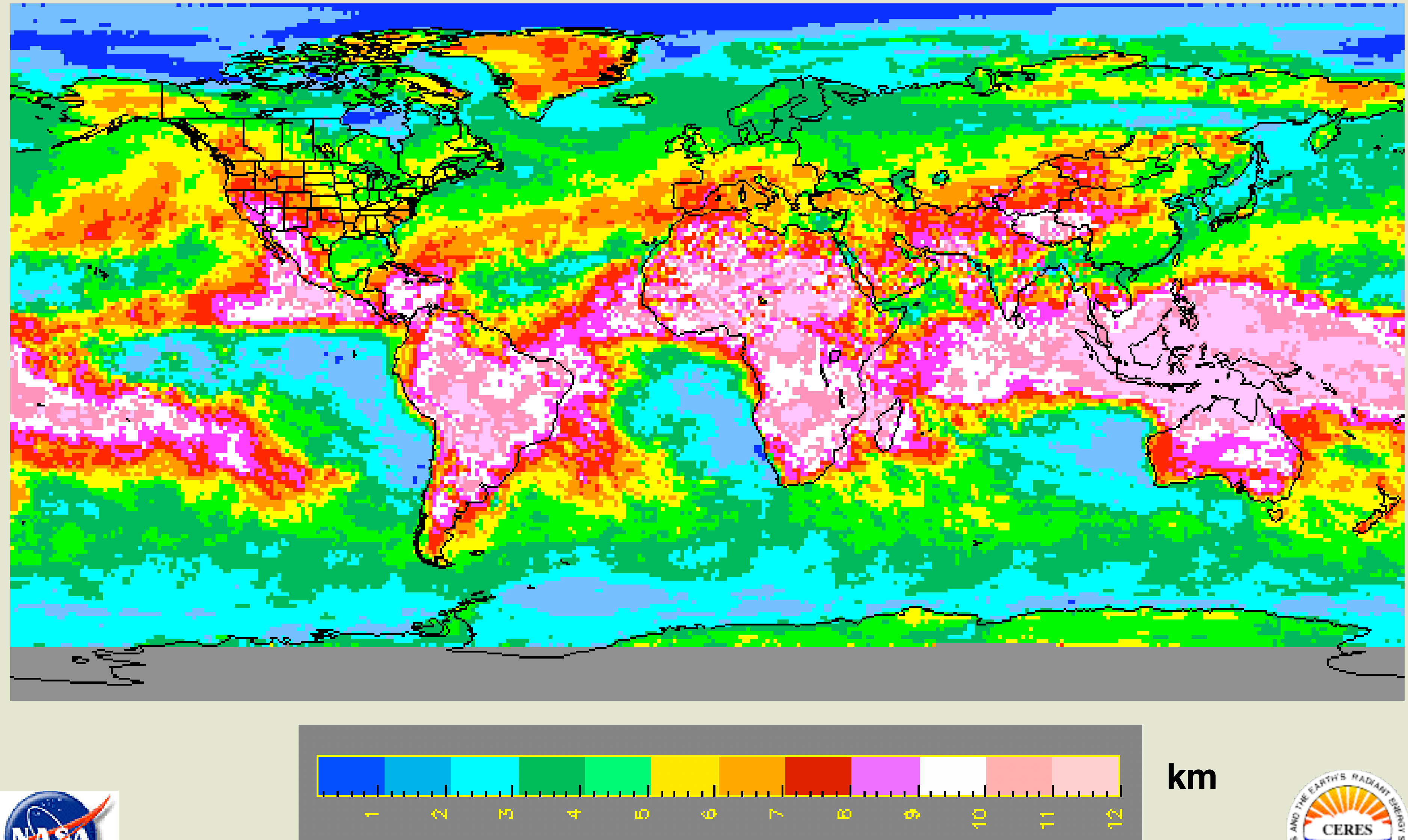
EFFECTIVE CLOUD TEMPERATURE, MODIS, DEC 2000

DAY



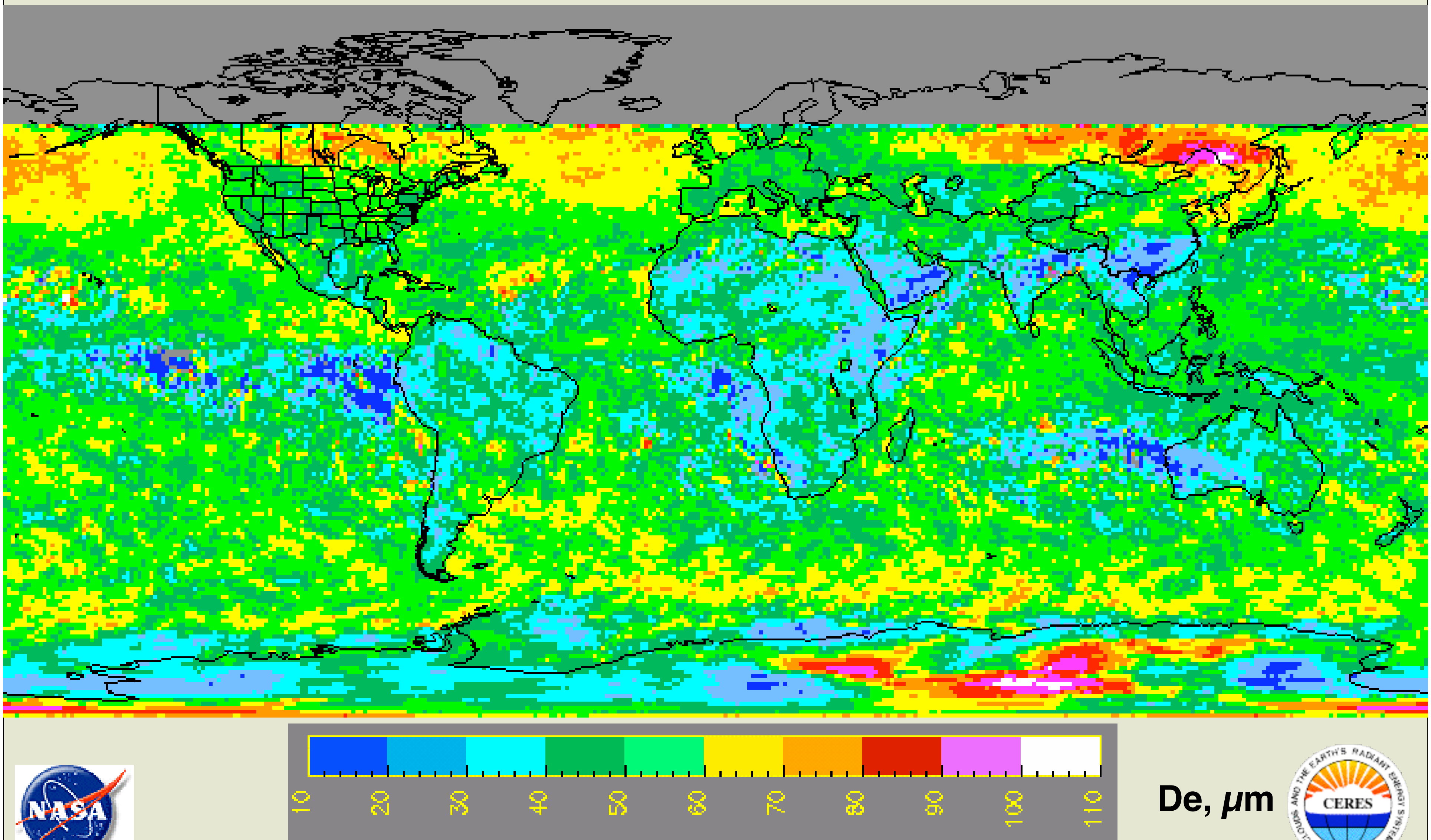
MEAN EFFECTIVE CLOUD HEIGHT, MODIS, DEC 2000

NIGHT



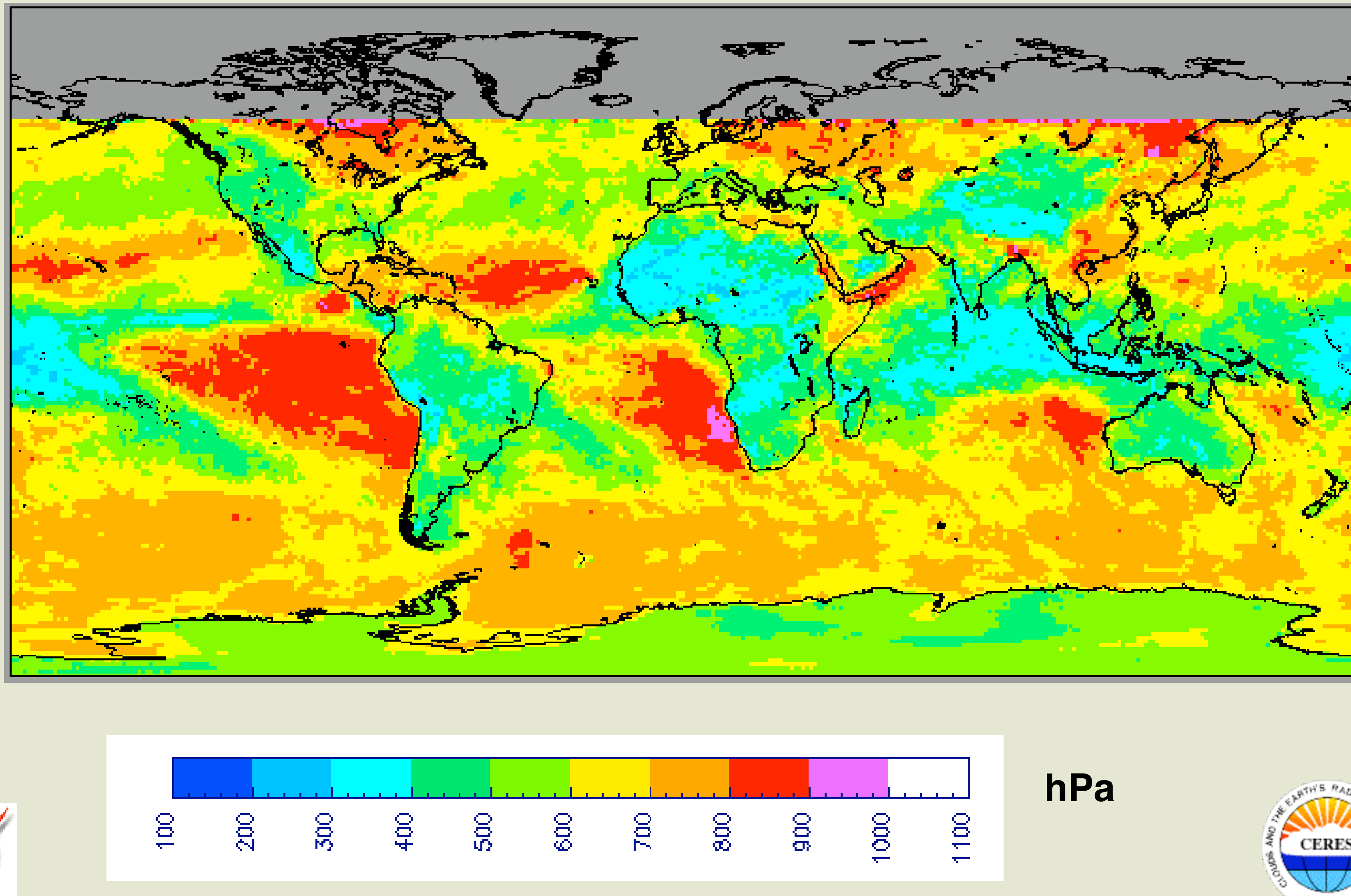
MEAN EFFECTIVE ICE CRYSTAL DIAMETER , MODIS, DEC 2000

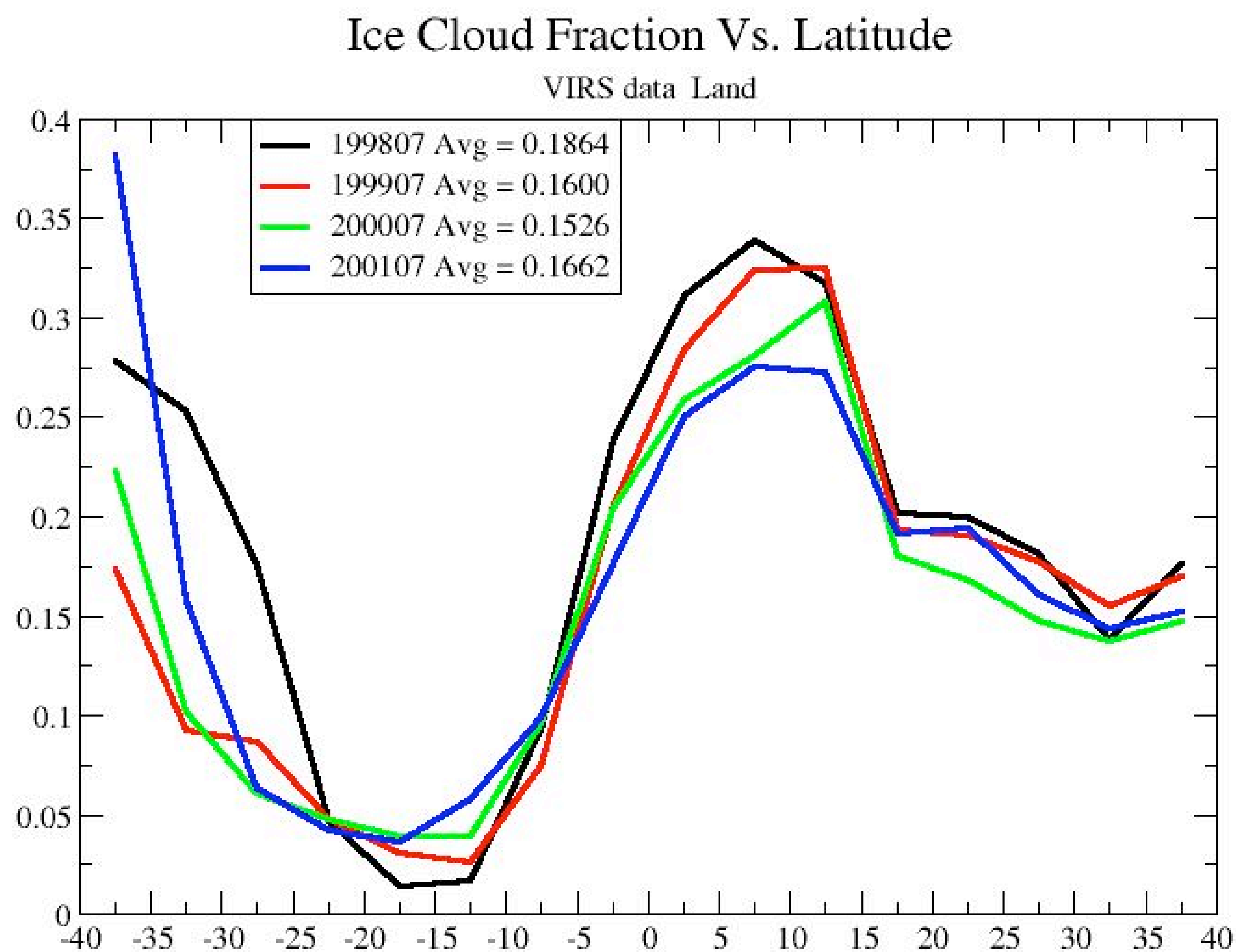
DAYTIME



MEAN CLOUD PRESSURE, AQUA MODIS DEC 2002

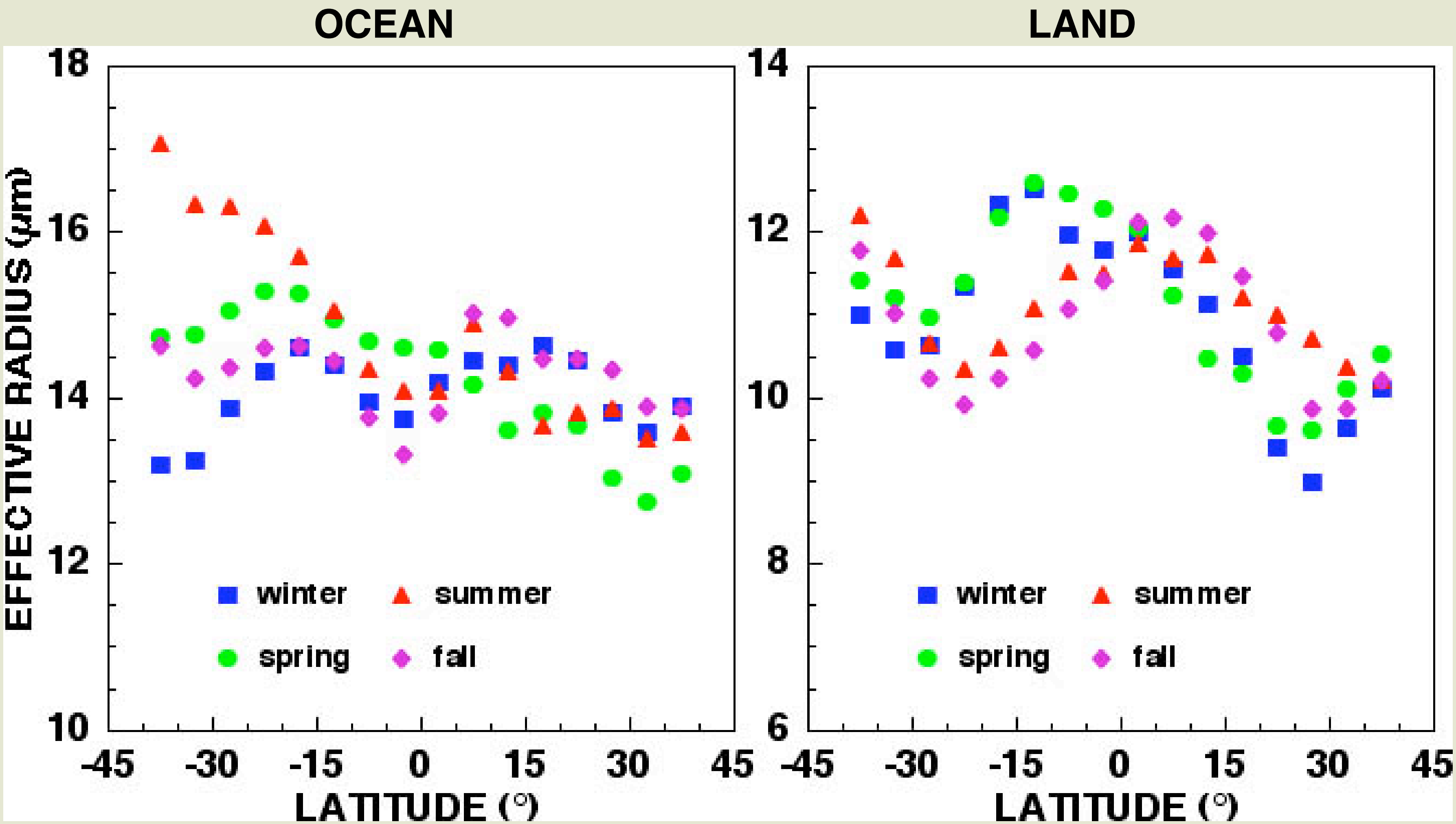
Daytime




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

SEASONAL VARIATION OF EFFECTIVE DROPLET RADIUS

VIRS, 1998 - 2001

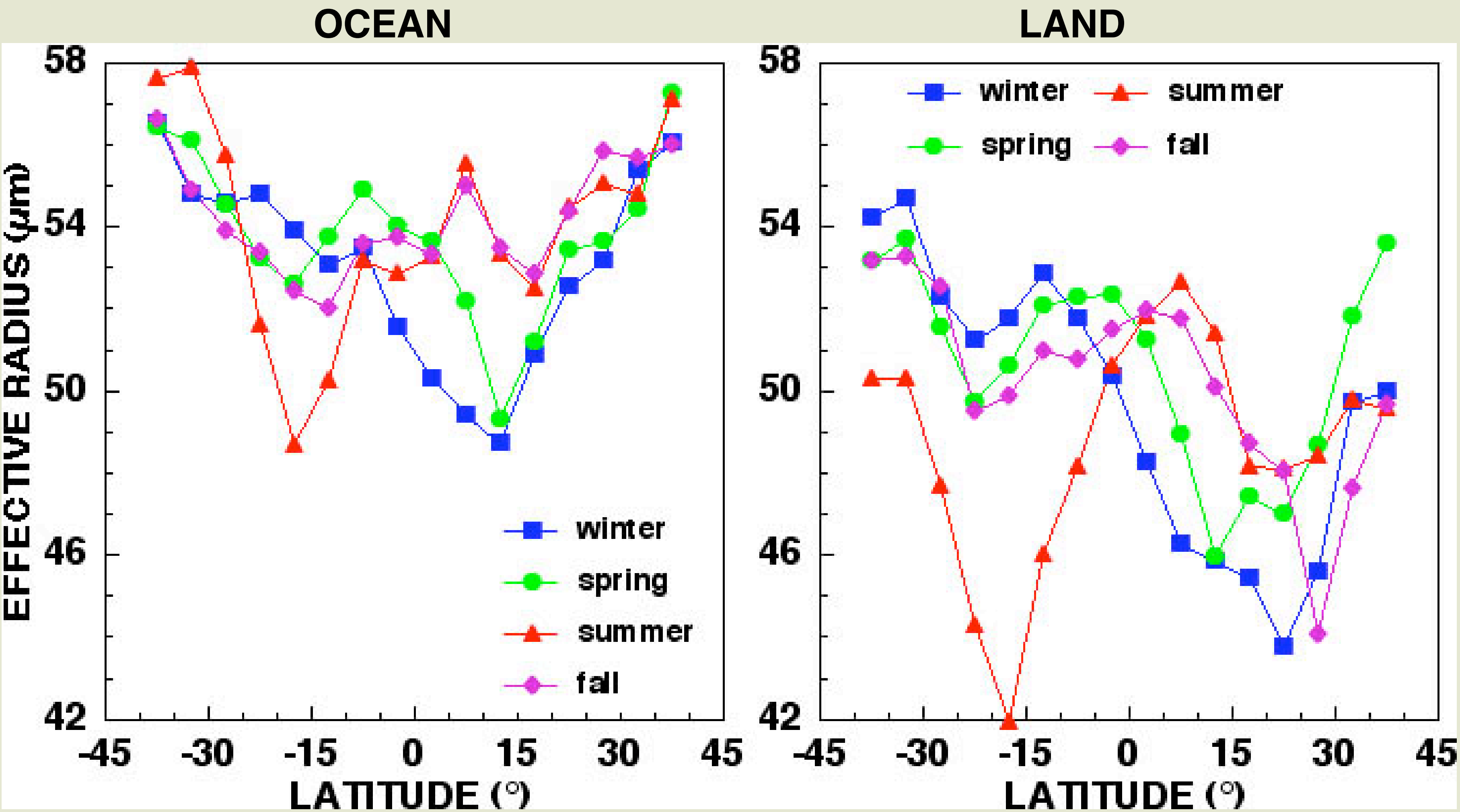


Range in southern ocean is 2 - 4 μm
1 - 2 μm elsewhere

Range over tropical land 1 - 2 μm

SEASONAL VARIATION OF EFFECTIVE ICE CRYSTAL DIAMETER

VIRS, 1998 - 2001



VALIDATION (COMPARISONS)

- with climatological datasets (surface, ISCCP)
  - cloud amount, optical depth

- with surface-based retrievals
  - LWP, r_e, Z_c, T_c, τ from radiometers, radar, lidar

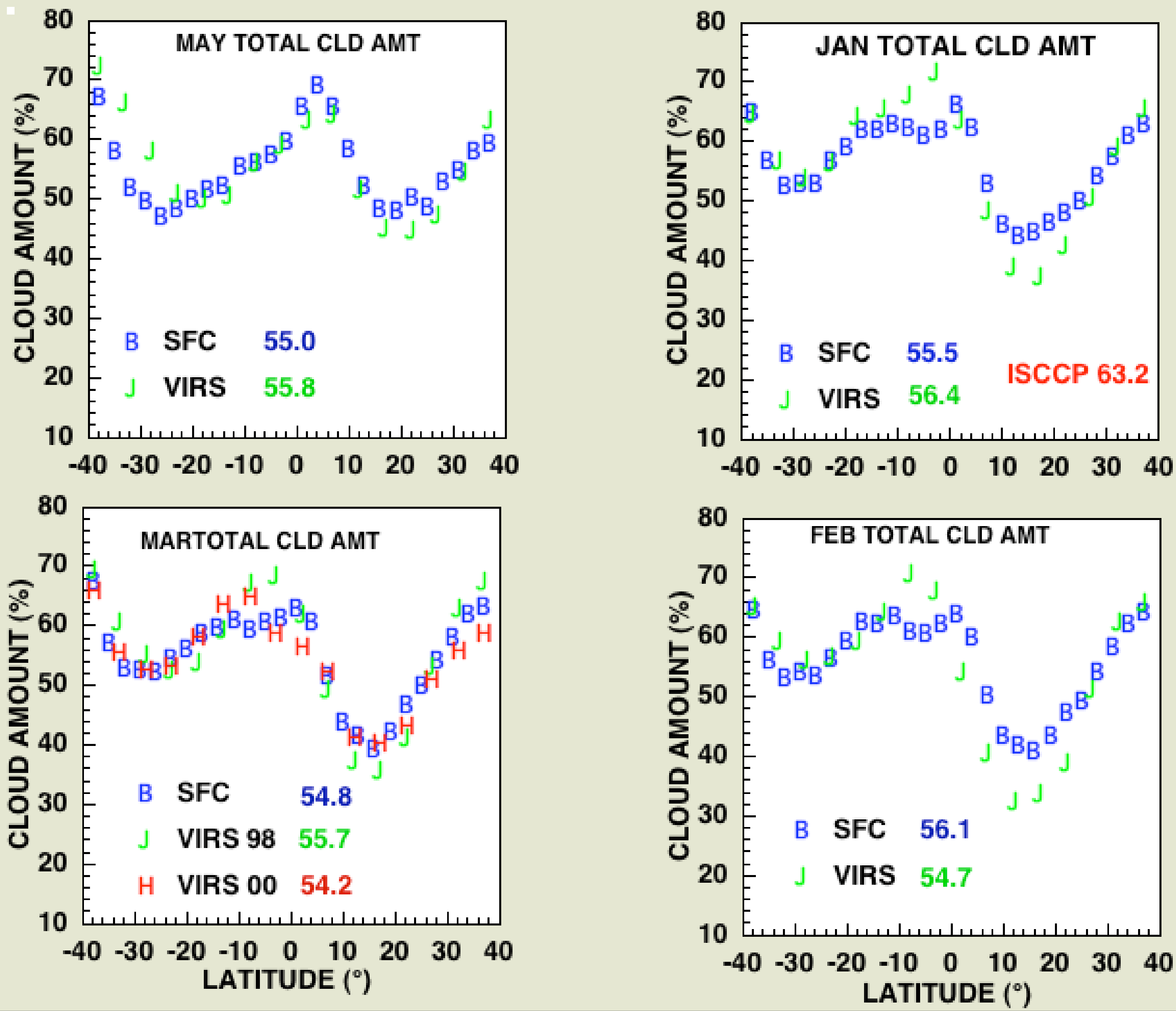
- with aircraft measurements
  - in situ microphysics
  - remotely sensed macrophysics, radiation

- with other satellite measurements
  - different type of retrievals (e.g., LWP from μ-wave)
  - dual angle retrievals (phase function, phase, τ)
  - intersatellite consistency

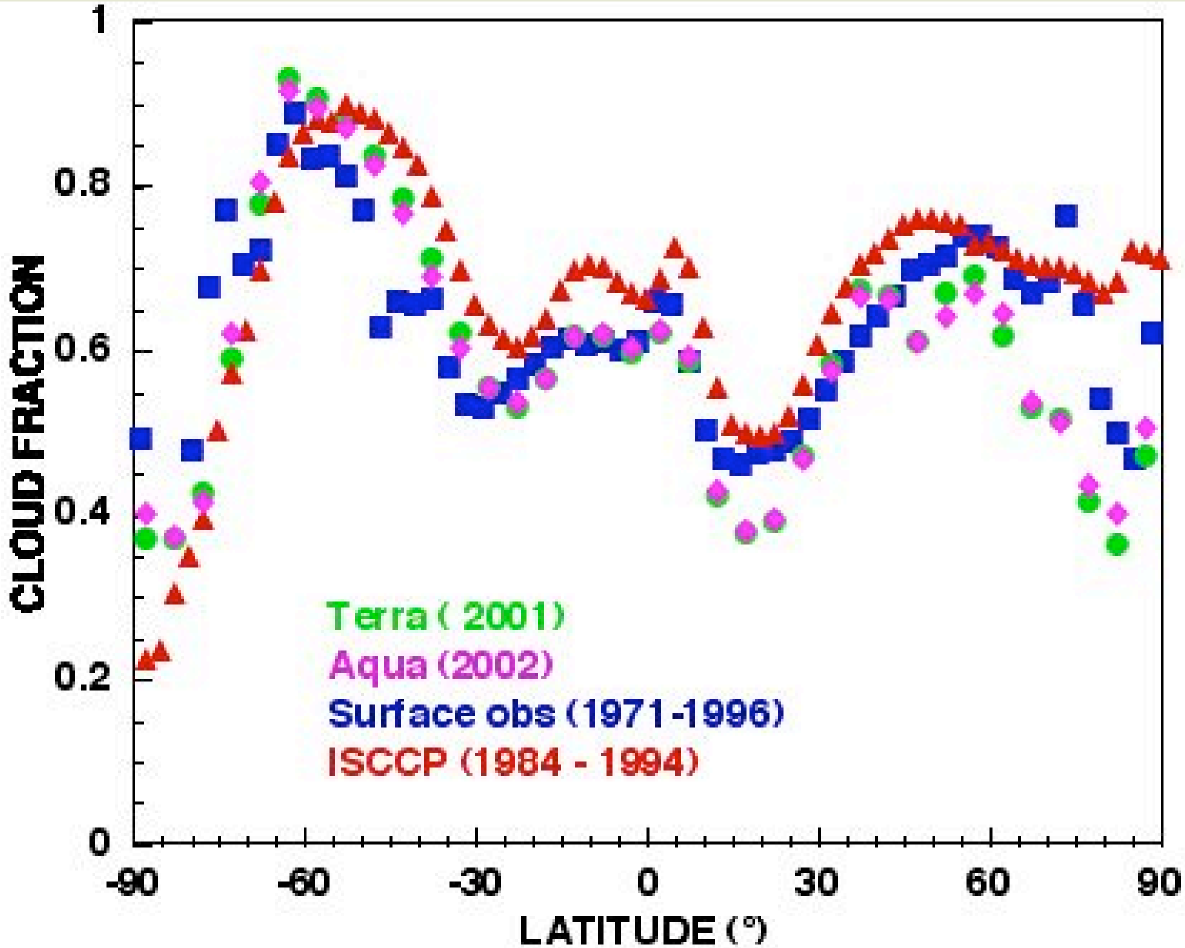
- with theoretical calculations (consistency)
  - TOA fluxes (e.g., SARB results from Charlock)
  - angular variations (e.g., ADMs from Loeb)

COMPARISON OF TOTAL CLOUD AMOUNTS

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

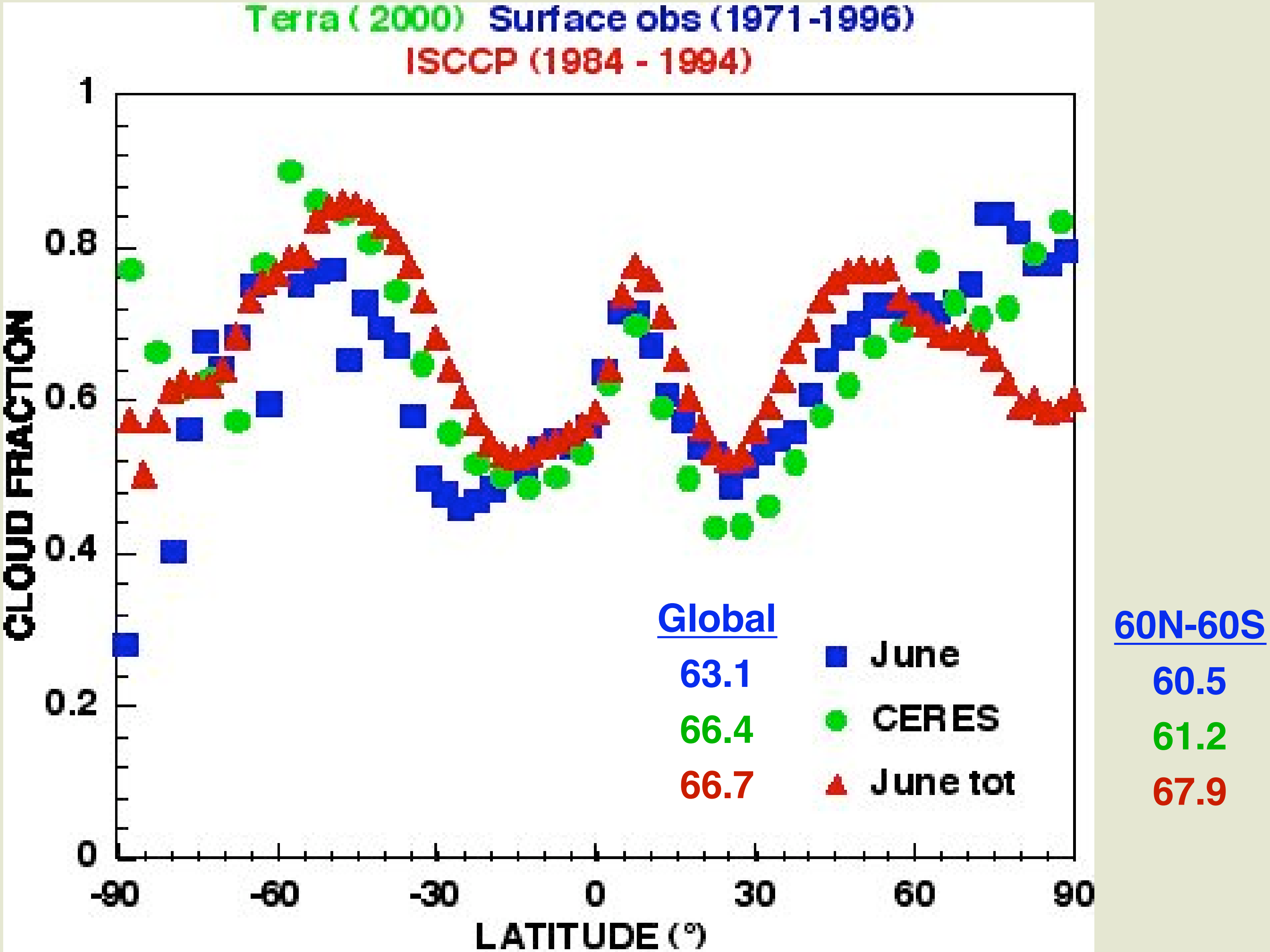


MEAN CLOUD FRACTION, DEC



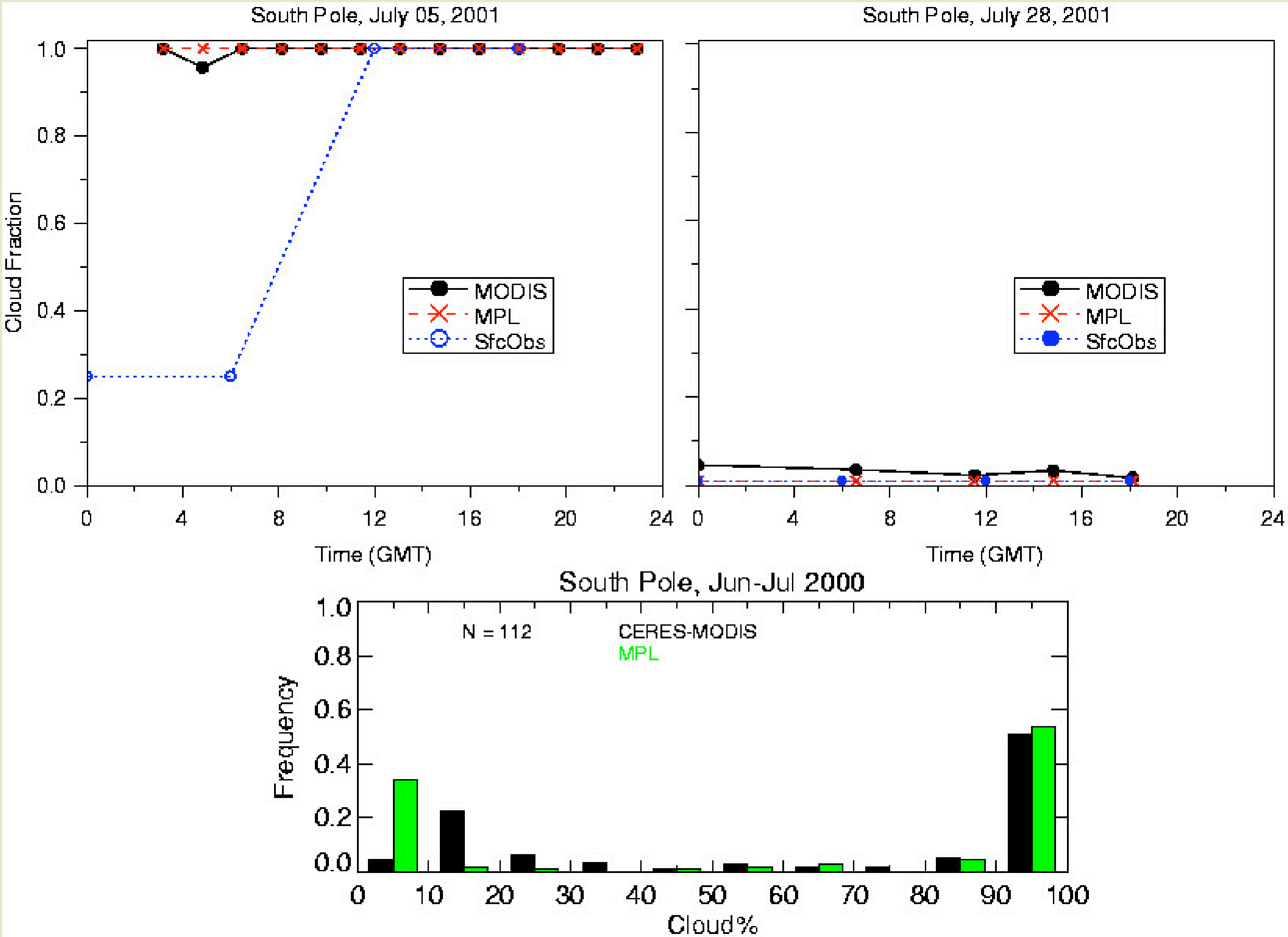
	SURFACE	Terra	Aqua	ISCCP
ALL	0.632	0.611	0.612	0.669
60N - 60S	0.606	0.623	0.619	0.696

COMPARISON OF JUNE CLOUD AMOUNTS

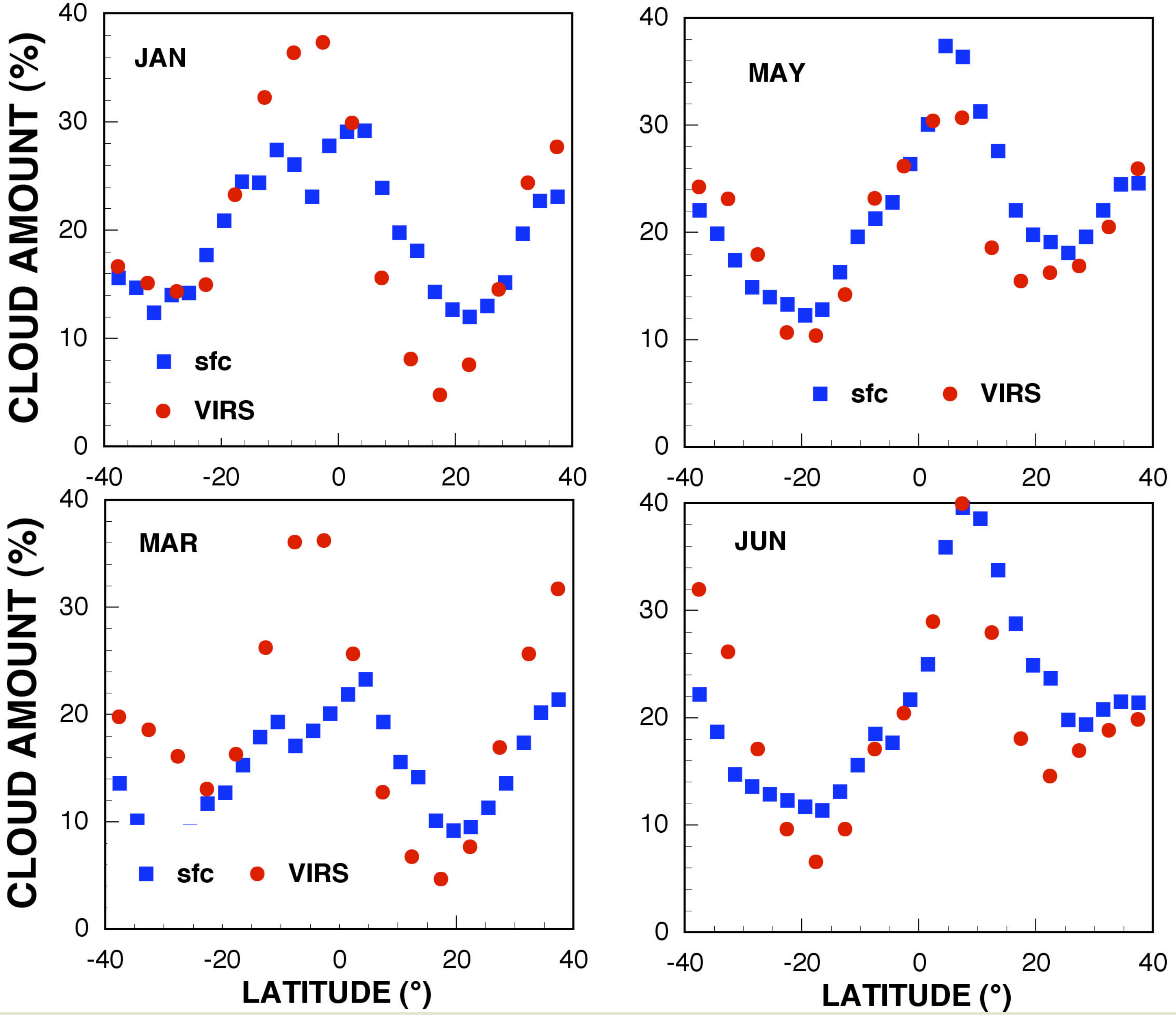


ISCCP: lower resolution => more cloud cover?

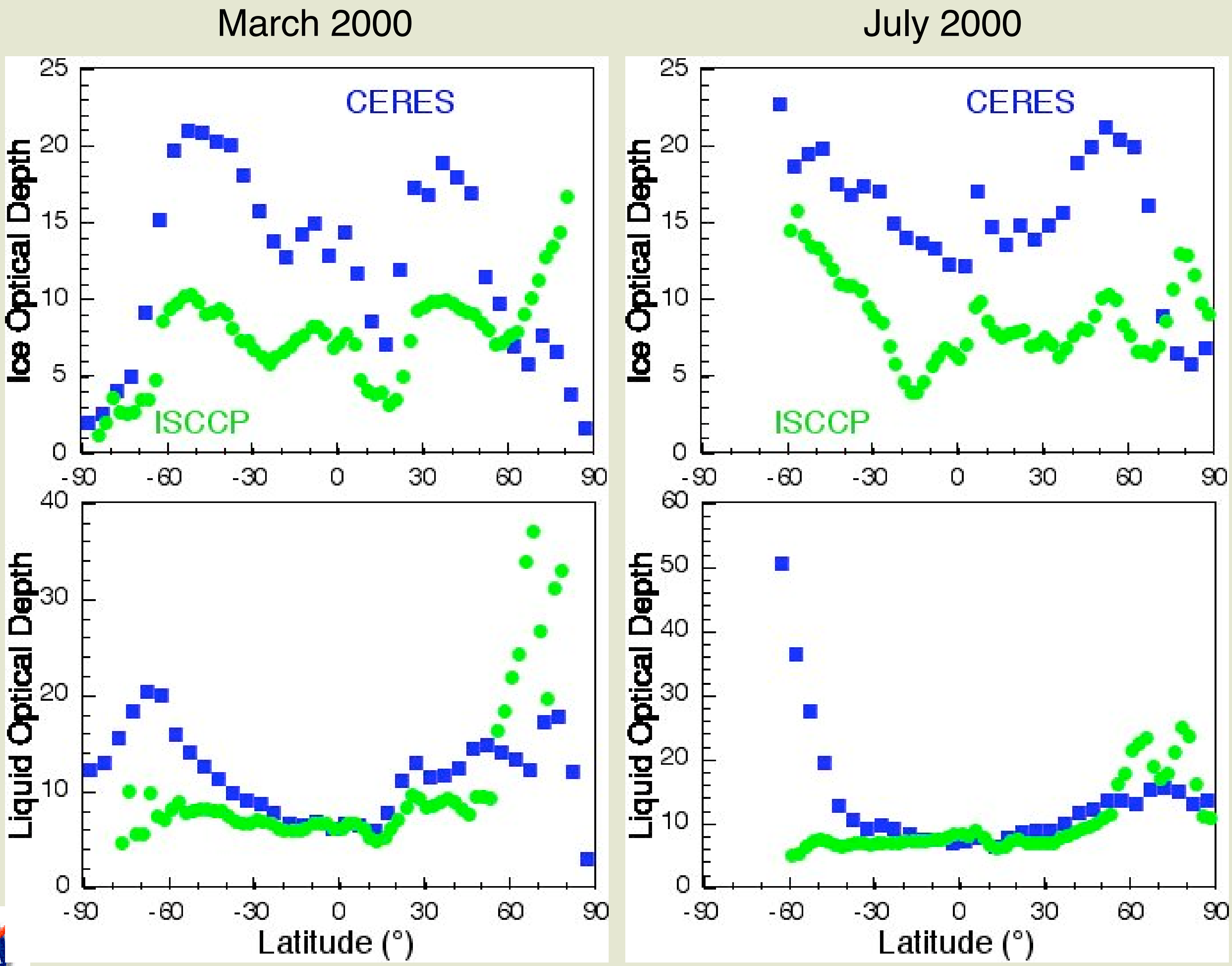
CLOUD AMOUNT AT SOUTH POLE



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

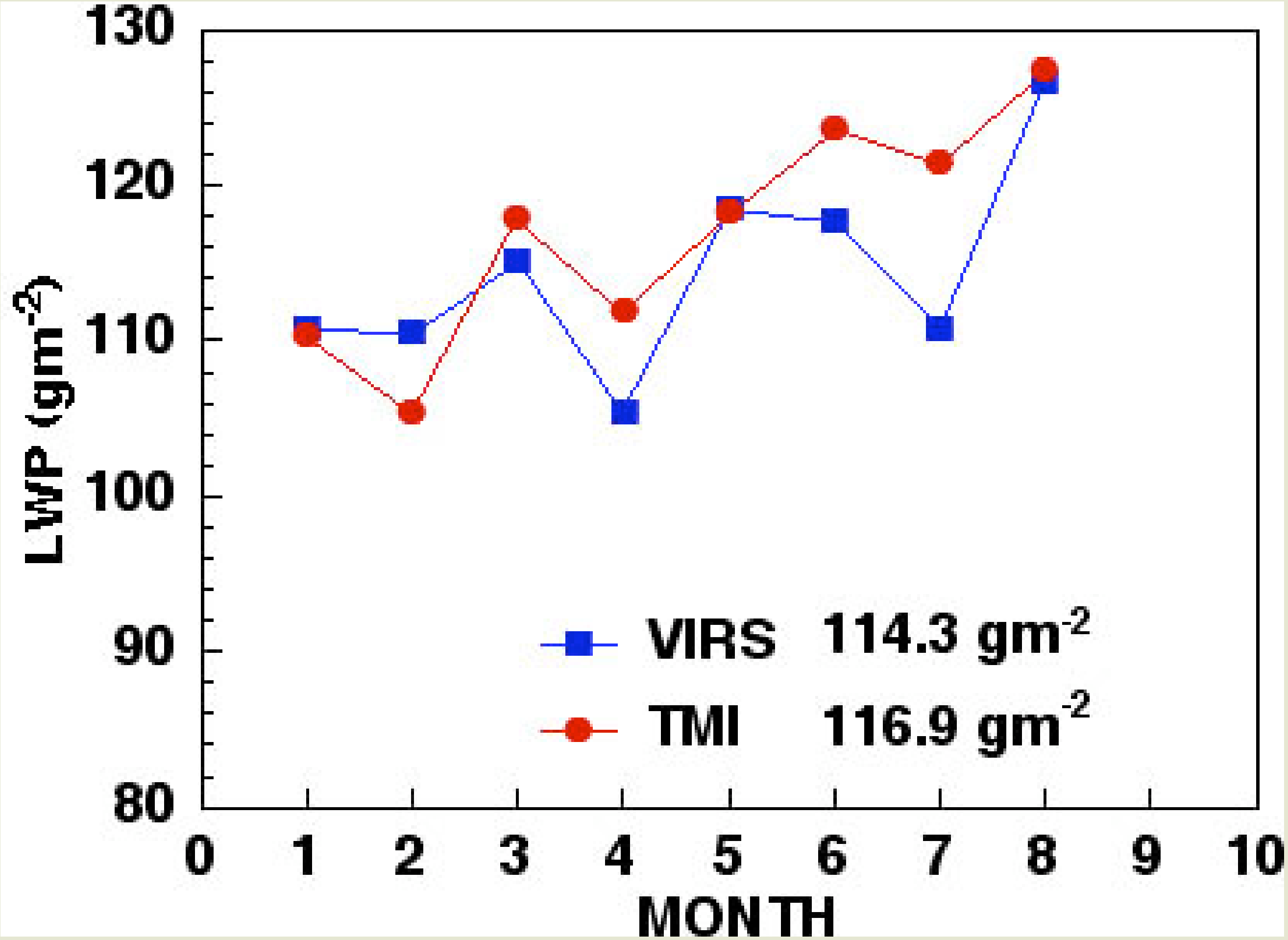


CLOUD OPTICAL DEPTH COMPARISONS



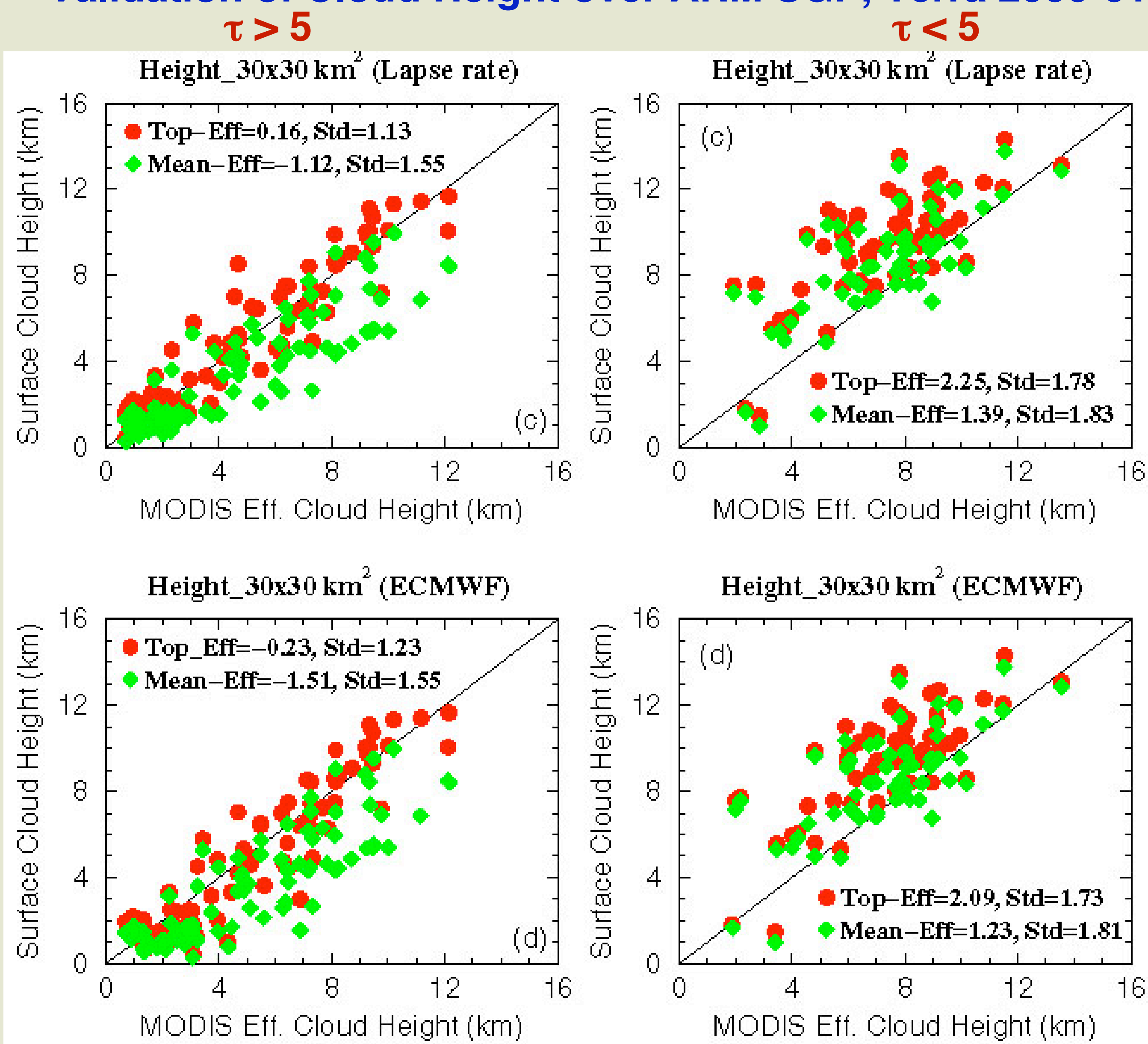
MONTHLY MEAN CLOUD LWP FROM VIRS & TMI OVER OCEANS

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



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

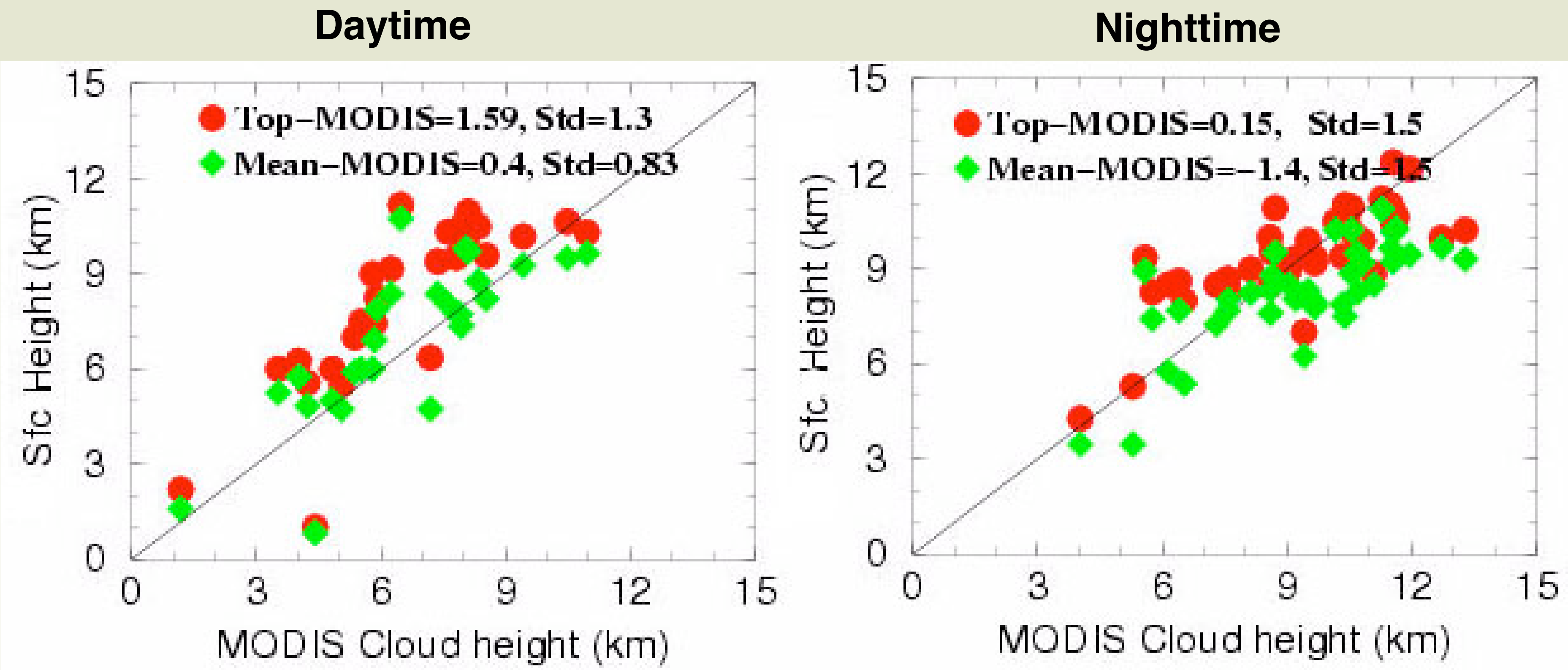
Validation of Cloud Height over ARM SGP, Terra 2000-01



Daytime thin: Ci too low; night best agreement

Dong et al. (submitted JAS 2004)

Validation of Thin ($\tau < 5$) Cloud Height over ARM SGP, MODIS 2001

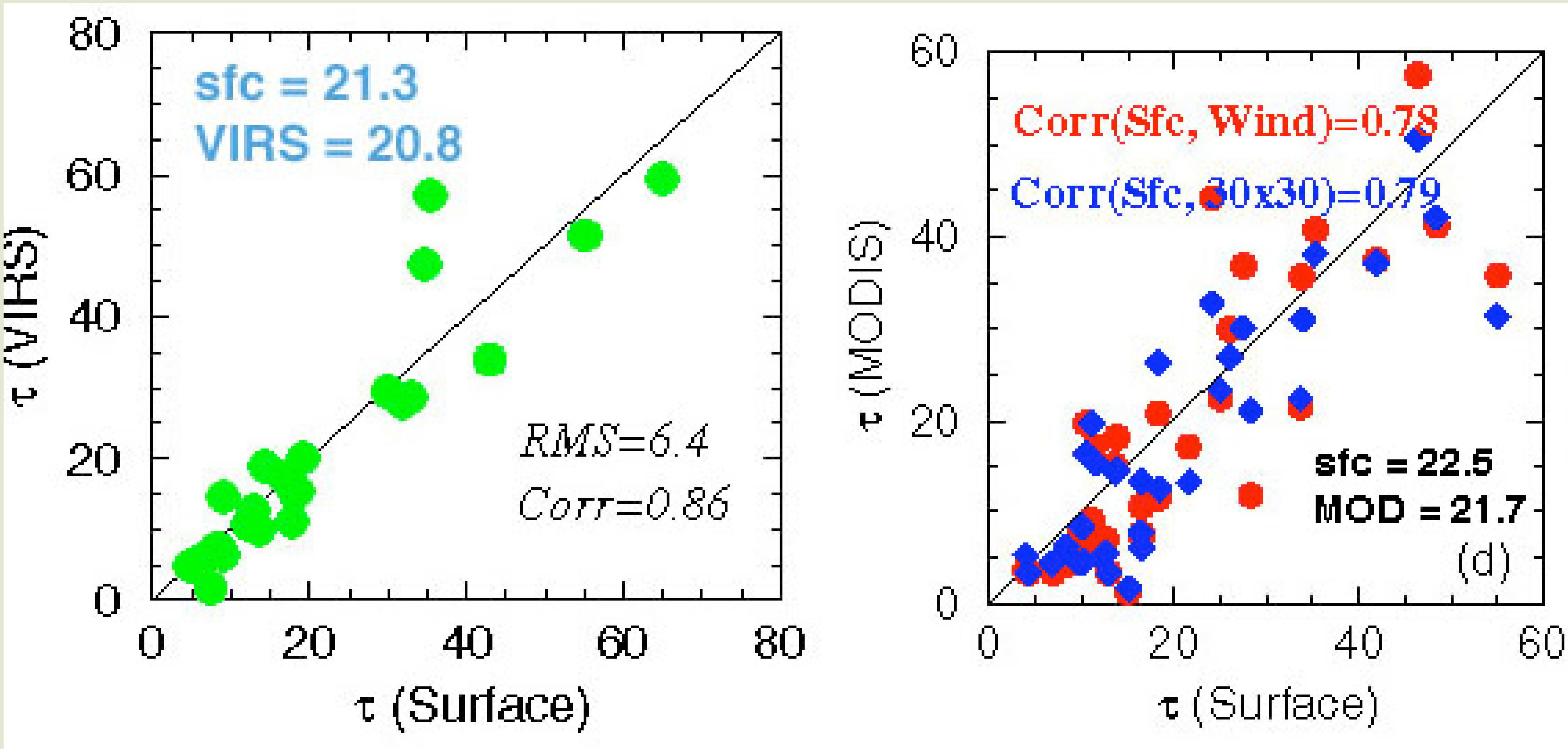


Nearly all thin cloud heights are within boundaries of cloud:

- 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)

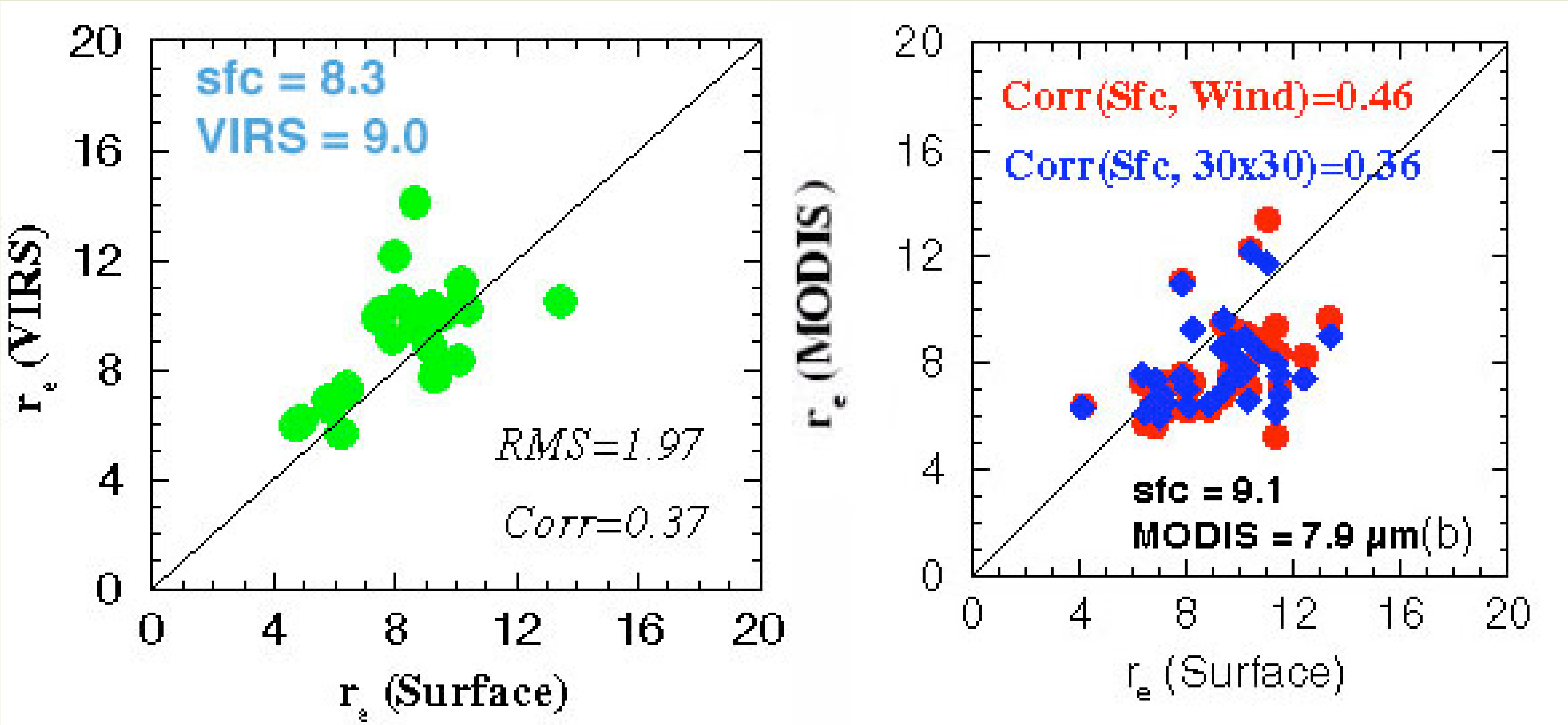
ARM SGP, VIRS 1998; MODIS 2000-2001



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

Validation of CERES Cloud Droplet Size (Stratus)

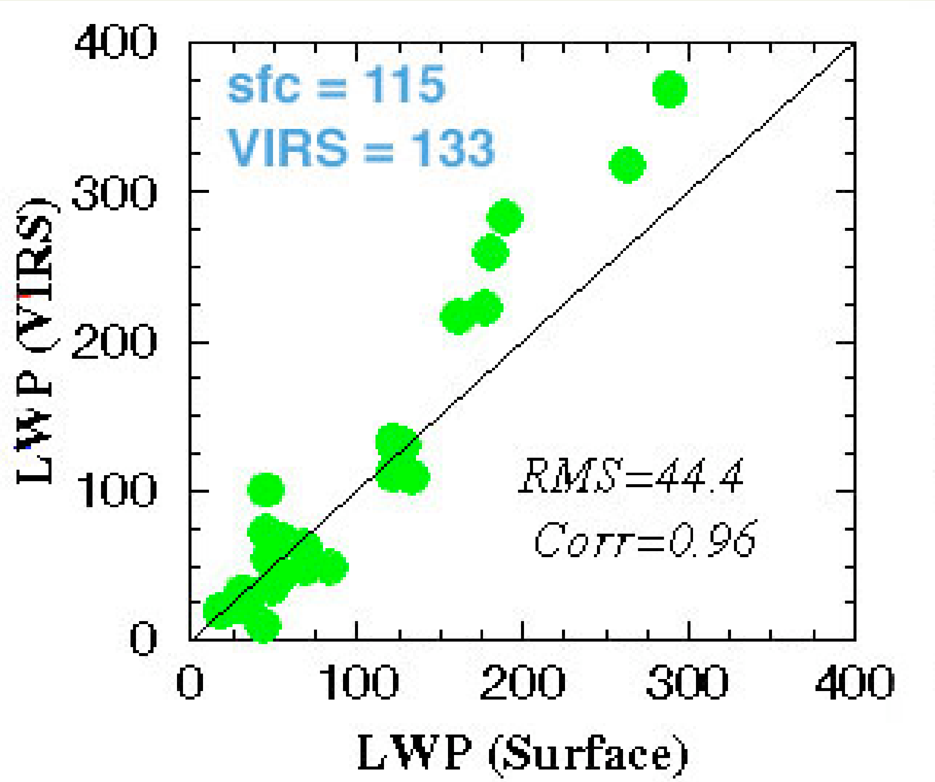
ARM SGP, VIRS 1998; MODIS 2000-2001

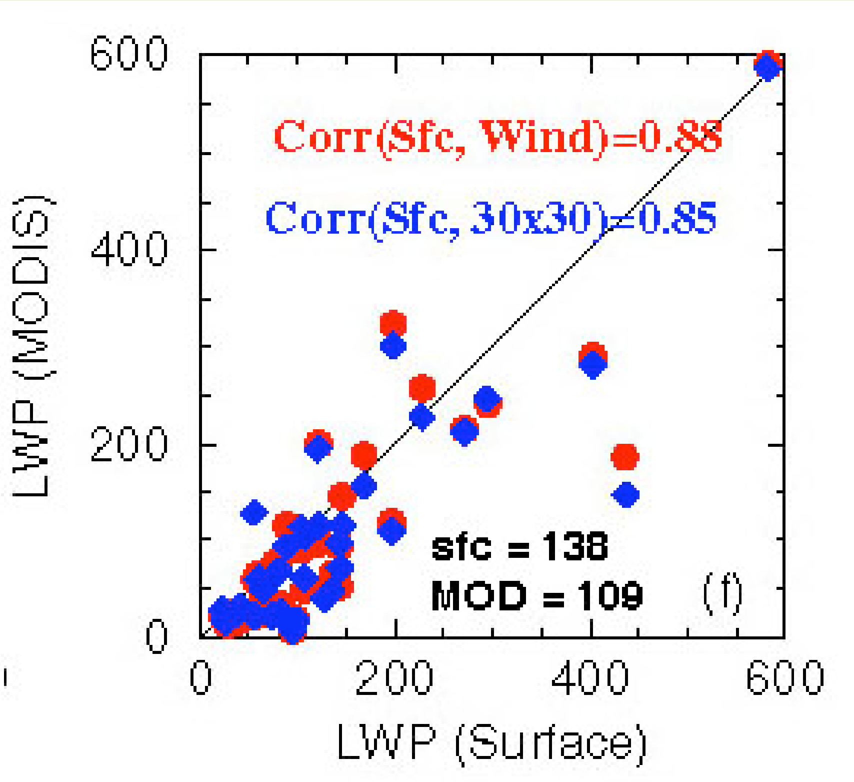


CERES average droplet sizes within $\pm$ 1 µm of surface-based values over ARM SGP site

Validation of CERES LWP (Stratus)

ARM SGP, VIRS 1998; MODIS 2000-2001





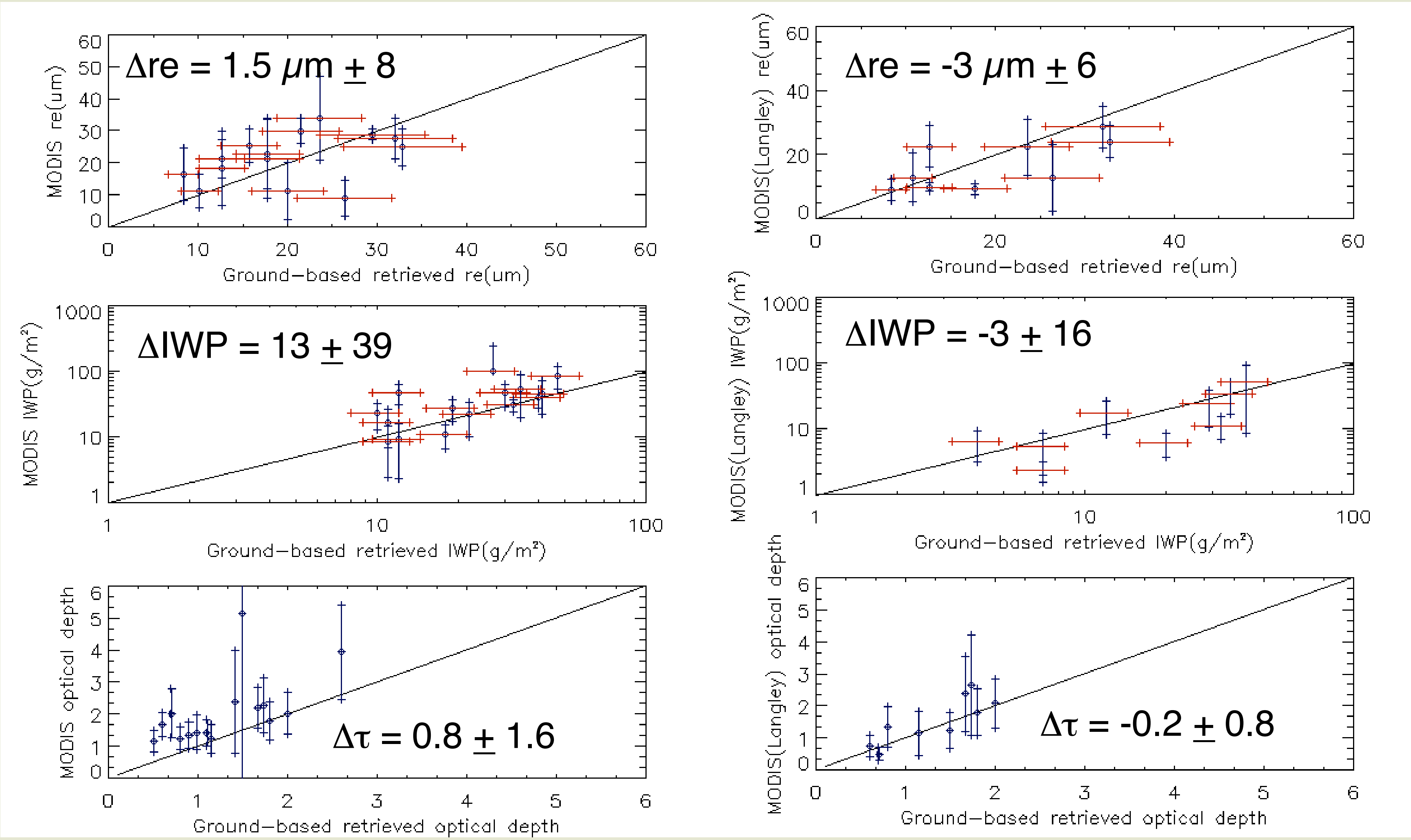
CERES LWP within 20% of surface-based values over ARM SGP site

LWP from μ-wave not very accurate at small LWP

snow cases not identified yet

COMPARISON WITH SURFACE RADAR RETRIEVALS OF THIN CIRRUS

MOD06 **CERES**



Over ARM SGP Central Facility, (see *Mace et al. 2004*)

COMPARISON OF CERES MODIS & SFC-DERIVED CLOUD PROPERTIES

ARM SGP 2000-2001 DAYTIME

Parameter	MODIS-sfc	std dev	SD(%)	N
Thin Tc vs mean	7.0 K	6.4 K -	18	
Thick Tc vs mean	-5.0 K	10.5 K	-	41
Thin Zc vs. mean	-1.4 km	1.8 km	-	18
Thin Zc vs. top	-2.1 km	1.8 km	-	18
Thick Zc vs. mean	0.2 km	1.1 km	-	41
Thick Zc vs. top	-1.1 km	1.5 km	-	41
Stratus τ	-0.8	6.2	21	25
Stratus re (μm)	-1.1	1.8	20	25
LWP (gm^{-2})	-29	41	35	25
Cirrus τ	0.2	0.8	40	9
Cirrus De (μm)	6.0?	17.0	72	9
IWP (gm^{-2})	3.0	16.2	51	9

COMPARISON OF CERES MODIS & SURFACE-DERIVED CLOUD PROPERTIES

ARM SGP 2000-2001 NIGHTTIME

Parameter	MODIS-sfc	std dev	SD(%)	N
Thin Tc vs mean	-1.6 K	9.5 K	-	49
Thick Tc vs mean	-6.9 K	14.5 K	-	31
Thin Zc vs. mean	0.6 km	2.1 km	-	49
Thin Zc vs. top	-0.6 km	2.2 km	-	31
Thick Zc vs. mean	-1.3 km	2.1 km	-	49
Thick Zc vs. top	-0.2 km	1.7 km	-	49

CONSISTENCY WITH RADIATIVE TRANSFER CALCULATIONS

• **MEASURE BROADBAND RADIANCE AT ONE ANGLE & CONVERT TO FLUX**

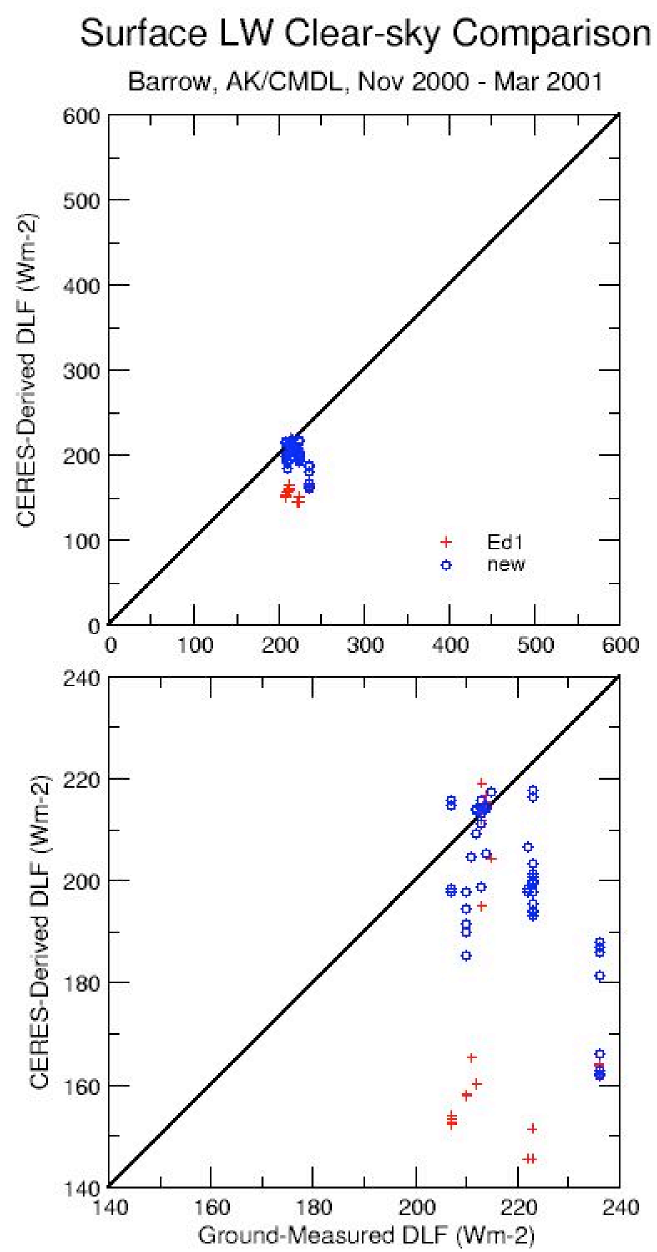
• **DETERMINE CLOUD PROPERTIES FROM ANOTHER ANGLE & COMPUTE FLUX USING CLOUD PROPERTIES AS INPUT TO RADIATIVE TRANSFER MODEL**

(*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**

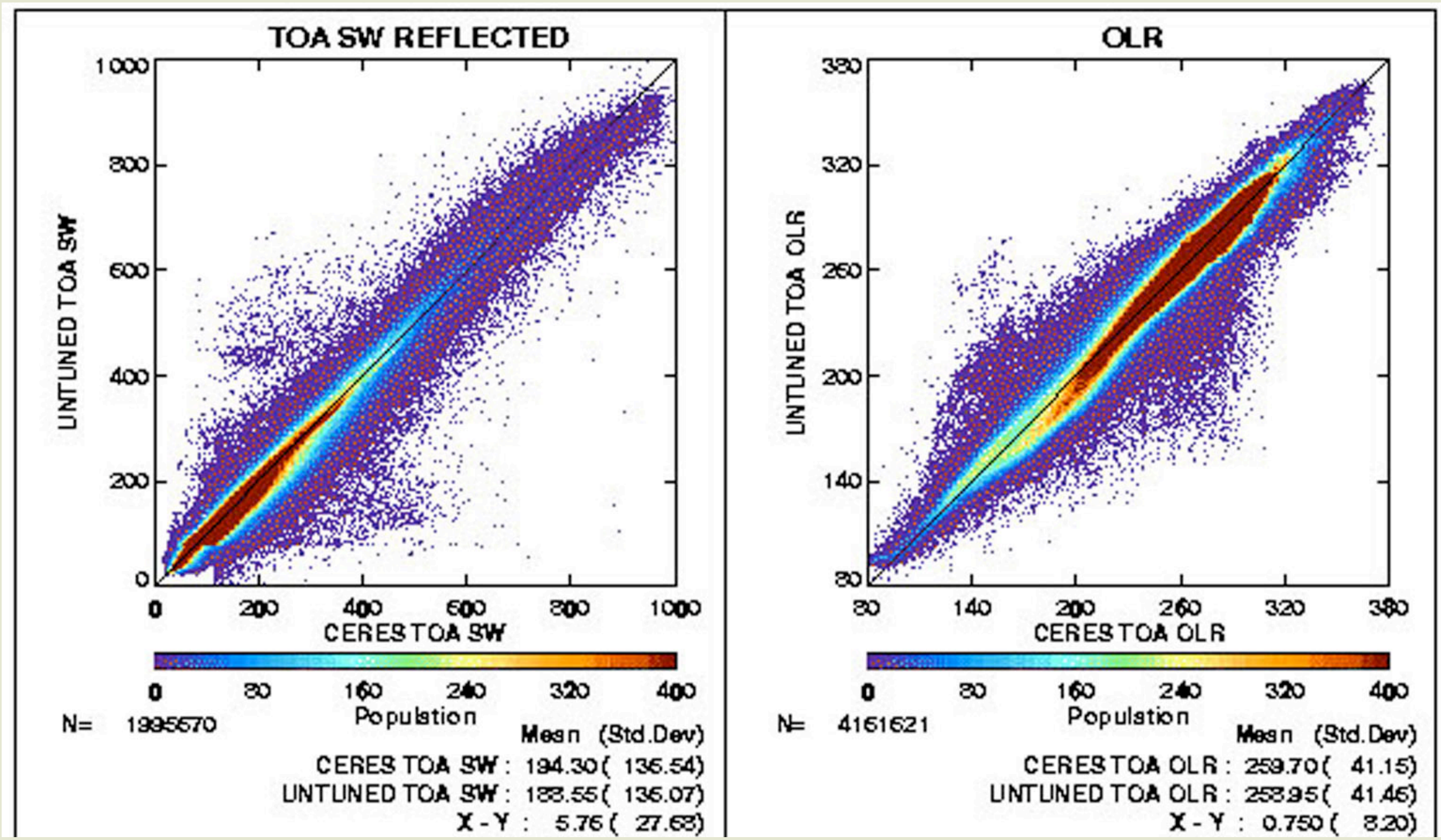
• **UNCERTAINTY TELLS US HOW ACCURATE A CLIMATE OR WEATHER MODEL SHOULD COMPUTE THE INSTANTANEOUS FLUX IF THE CLOUD PROPERTIES ARE PROPERLY COMPUTED IN THE MODEL**

NIGHTTIME FLUXES IN ARCTIC



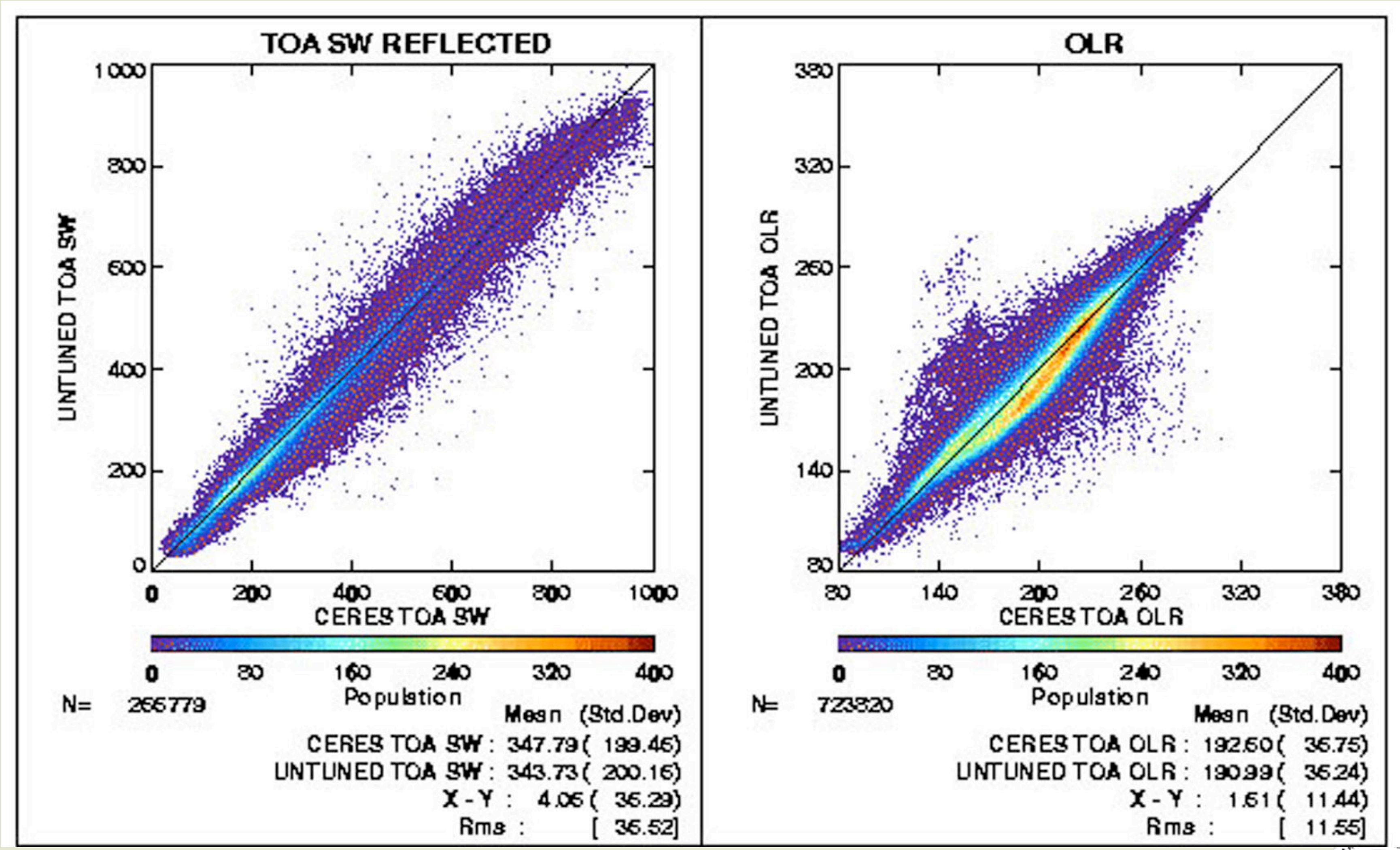
COMPARISON OF OBSERVED & COMPUTED SW & LW FLUXES
ALL SCENE TYPES, TRMM VIRS/CERES, APRIL 18, 1998

$\Delta SW = 5.8 \pm 28\ Wm^{-2}$ (14%) **$\Delta LW = 0.7 \pm 8\ Wm^{-2}$ (3%)**



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

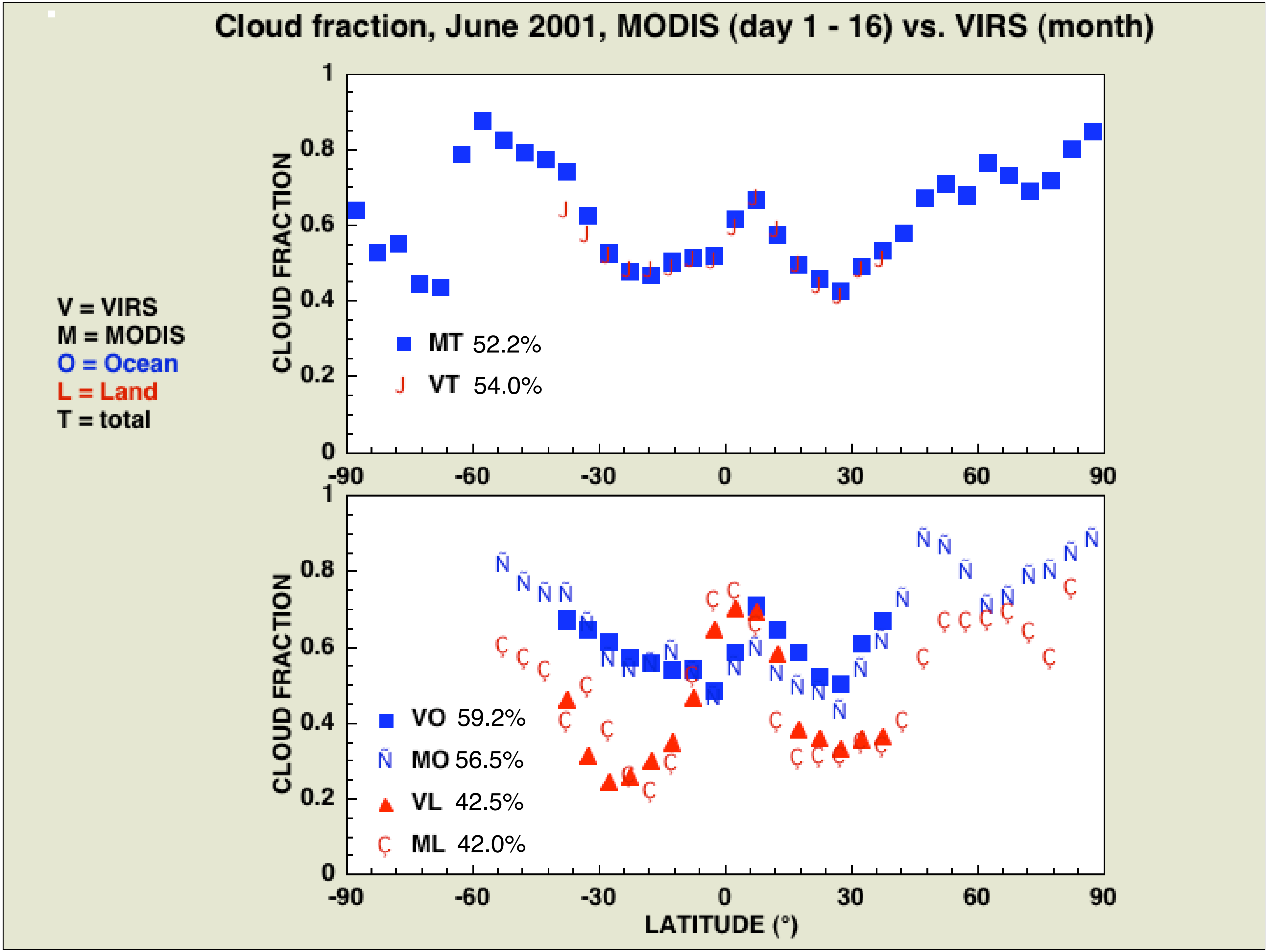
ΔSW = 4.1 ± 36 Wm^{-2} (10%) **ΔLW = 1.6 ± 11 Wm^{-2} (6%)**



CERES-DERIVED CLOUD PROPERTIES

YIELD EXCELLENT AGREEMENT BETWEEN FLUX OBSERVATIONS & RADIATIVE TRANSFER MODELS

CONSISTENCY


Cloud fraction, June 2001, MODIS (day 1 - 16) vs. VIRS (month)
V = VIRS
M = MODIS
O = Ocean
L = Land
T = total
MT 52.2%
VT 54.0%
VO 59.2%
MO 56.5%
VL 42.5%
ML 42.0%
CLOUD FRACTION
LATITUDE (°)

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%*

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 μ-physical properties at night

- Nighttime polar cloud amounts & near-terminator still uncertain

  Look for discontinuities at 60° latitude

- Nighttime ice cloud heights somewhat greater (~ 1.0 km for ice)

- Optical depths, De over snow tres uncertain

- Others, see Data Quality Summary

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)

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/