Cloud and Radiation Parameter Retrievals from Satellites Using Updated NASA Langley Algorithms

Patrick Minnis[1], Rabindra Palikonda[2], Qing Z. Trepte[2], Douglas Spangenberg[2], Benjamin Scarino[2], Christopher R. Yost[2], Fu-Lung Chang[2], Gang Hong[2], Robert F. Arduini[2], Sarah T. Bedka[2], Kristopher M. Bedka[1], Michele Nordeen[2], Mandana M. Khaiyer[2], Szedung Sun-Mack[2], Yan Chen[2], Patrick W. Heck[3], David R. Doelling[1], William L. Smith Jr.[1], and Ping Yang[4]

[1]NASA Langley Research Center, Hampton, VA, USA

[2]SSAI, Hampton, VA, USA

[3]CIMSS, U. Wisconsin, Madison, Wi, USA

[4]Texas A&M, College Station, TX, USA

4th Cloud Retrieval Evaluation Workshop, CREW-IV, Grainau, Germany
4-7 March 2014

Introduction

- Cloud retrievals have been ongoing at LaRC for > 3 decades
  - **- bio-optical (1978) - CF**
  - **- VIS-IR(1981) – + CTH, REF**
  - **- VIS-IR(1988) – + COD**
  - **- VIS-IR-MW (1992) – +WER**
  - **- VIS-IR-SIR (1994) + IER, IWP, LWP**
  - **- VISST (1996) - + better phase**
  - **- SIST (1996) – night COD, IER, WER, CTH: COD < 6**
  - **- MCO2AT (2006) – multilayered clouds CO2-VISST**
  - **- CERES Ed3 (2009) – multispectral IER, CER**
  - **- CERES VIIRS Ed1 (2014) – multilayered clouds, BTD-VISST**
- Current retrievals being applied in near-real time and historically to
  - **Global GEOSats** (GOES, Meteosat, MTSAT, COMS) 1994 ->
  - AVHRR (1979 – onward)
  - MODIS (2000 - ?)
  - VIIRS(2012 - ?)

OBJECTIVES & APPLICATIONS

- Produce well-characterized consistent regional & global cloud and surface property datasets covering all time & space scales
  - used intercalibrated data
  - use consistent algorithm as much as possible
  - analyze data in real time and more carefully with lag times
  - validate data as much as possible using independent measures
  - improve as state of the art advances

- Climate research
  - radiation budget studies (CERE, ERBE, etc.)
  - cloud trends and interactions (GEWEX,
  - climate model validation *(e.g., Zhang et al. 2005; Stanfield et al. 2014)*
  - mitigation activities: *e.g., contrails*

- Weather research & applications
  - nowcasting: *aircraft icing, convective initiation, severe storms*
    - *- Mecicalski et al. (2007, 2012), Bedka et al (2010), Smith et al. (2013)*
  - solar energy
  - NWP model assimilation: *global, continental, and regional*
    - *- Jones et al. (MWR, 2013/14), Norton & DaSilva (2014)*

Standard Cloud/Radiation Parameters

Cloud Mask, Phase
Optical Depth, IR emissivity
Effective Radius/Diameter
Liquid/Ice Water Path
Cloud Effective Temperature
Cloud Top/ Bottom Pressure
Cloud Effective Pressure
Cloud Top/Effective/Base Height
Clear-sky & Skin Temperature
SW Albedo/OLR

- Primary channels: 0.65, 3.7, 10.8, 12.0 *μ*m (VISST & SIST), Ed2
  - *Minnis et al., TGRS, 2011*
  - lapse rates from *Sun-Mack et al (2014)*
- Secondary channels for mask & snow retrievals (SINT), Ed4
  - 1.38, 1.2, 1.6, 2.1 *μ*m (*not on AVHRR or most GEOs*)
  - 6.7, 13.3 *μ*m (*not on AVHRR, VIIRS*)
  - *Minnis et al. AMS, 2010*

Apparent BL lapse rates

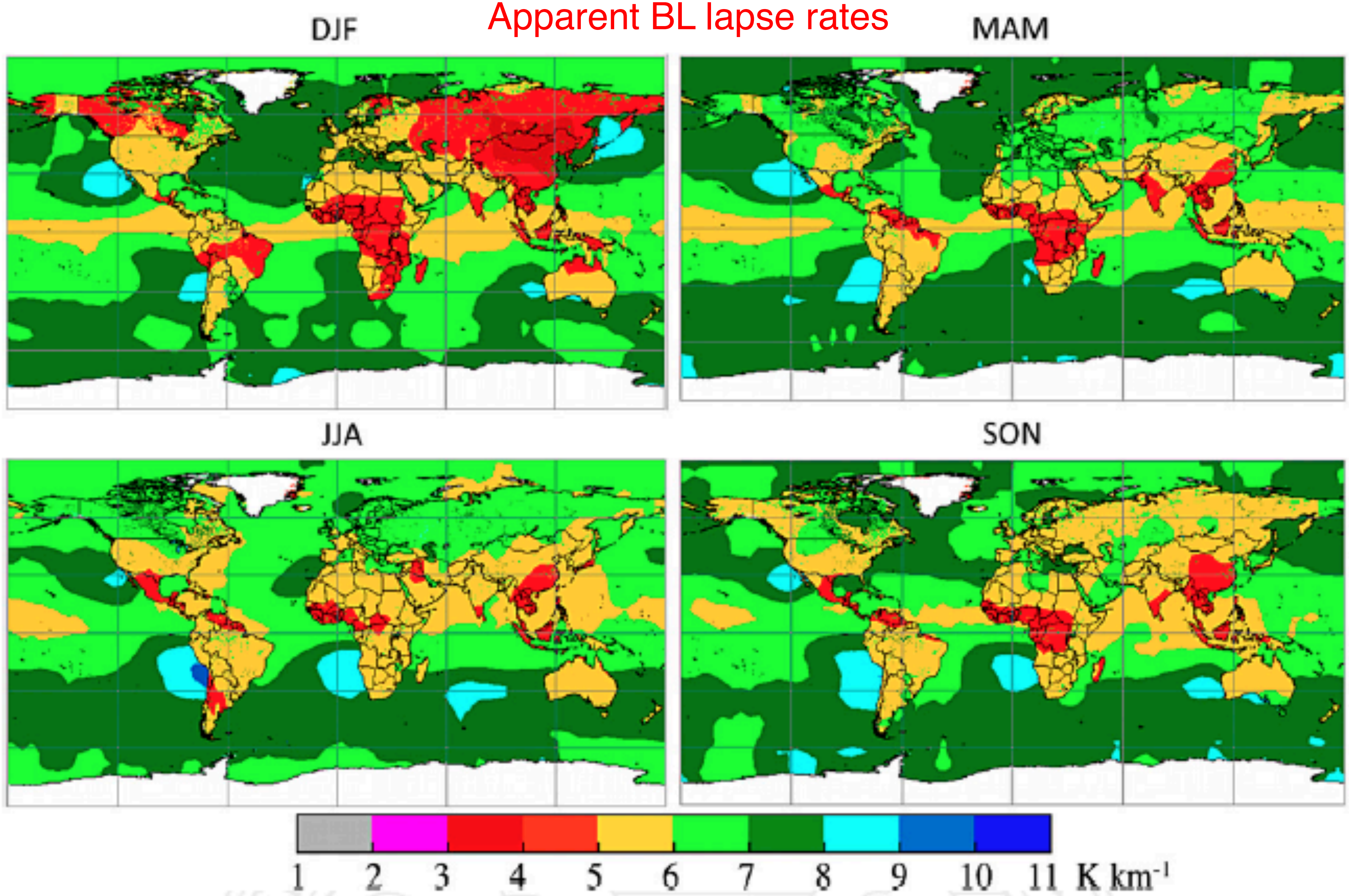


FIG. 6. Daytime boundary layer lapse rates (K km^{-1}) over snow–ice-free scenes for DJF, MAM, JJA, and SON: July 2006–June 2007 and June 2009–May 2010 (2 yr).

Cloud Parameters: CERES Ed 4, VIIRS Ed1

New Size Retrievals
Water droplet eff radius (1.24 μm)
Ice effective radius (1.24 μm)
Water droplet CER(2.1, 1.6 μm)
Ice CER (2.1, 1.6 μm)

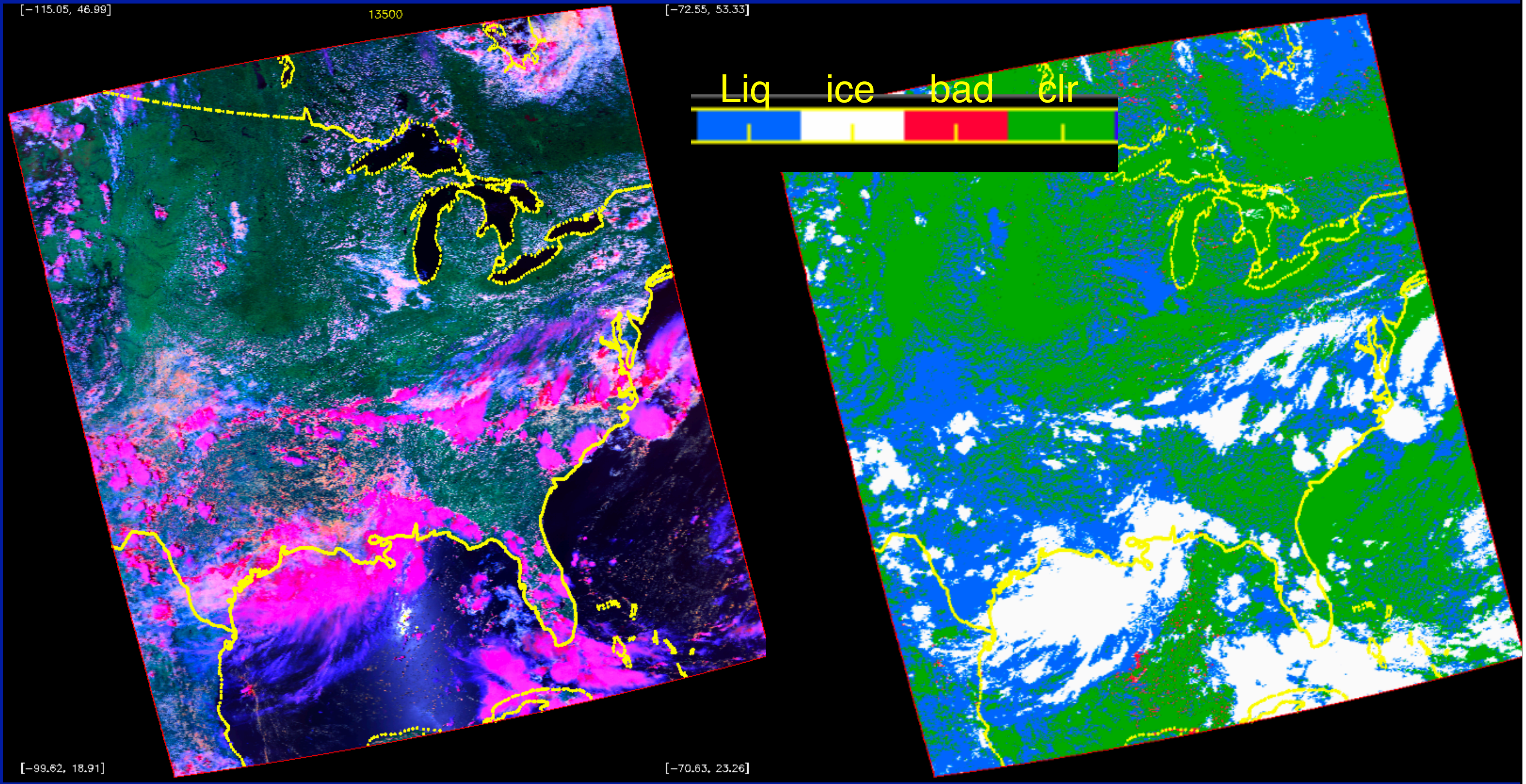
CO_2 Slicing
Cloud Top Pressure
Cloud Top Temperature
Cloud Top Height
IR Emissivity

Multilayer Cloud Retrieval	(Ice Over Water)
Multilayer Identification (also for GOES and Meteosat)	
Upper Layer (Ice Clouds)	Lower Layer (Water Clouds)
Cloud Top Pressure	Cloud Top Pressure
Cloud Top Temperature	Cloud Top Temperature
Cloud Top Height	Cloud Top Height
Cloud Visible Optical Depth	Cloud Visible Optical Depth
Ice Effective Radius (3.7 μm)	Water Droplet Radius (3.7 μm)
Ice Effective Radius (2.1 μm)	Water Droplet Radius (2.1 μm)

See Chang et al. poster

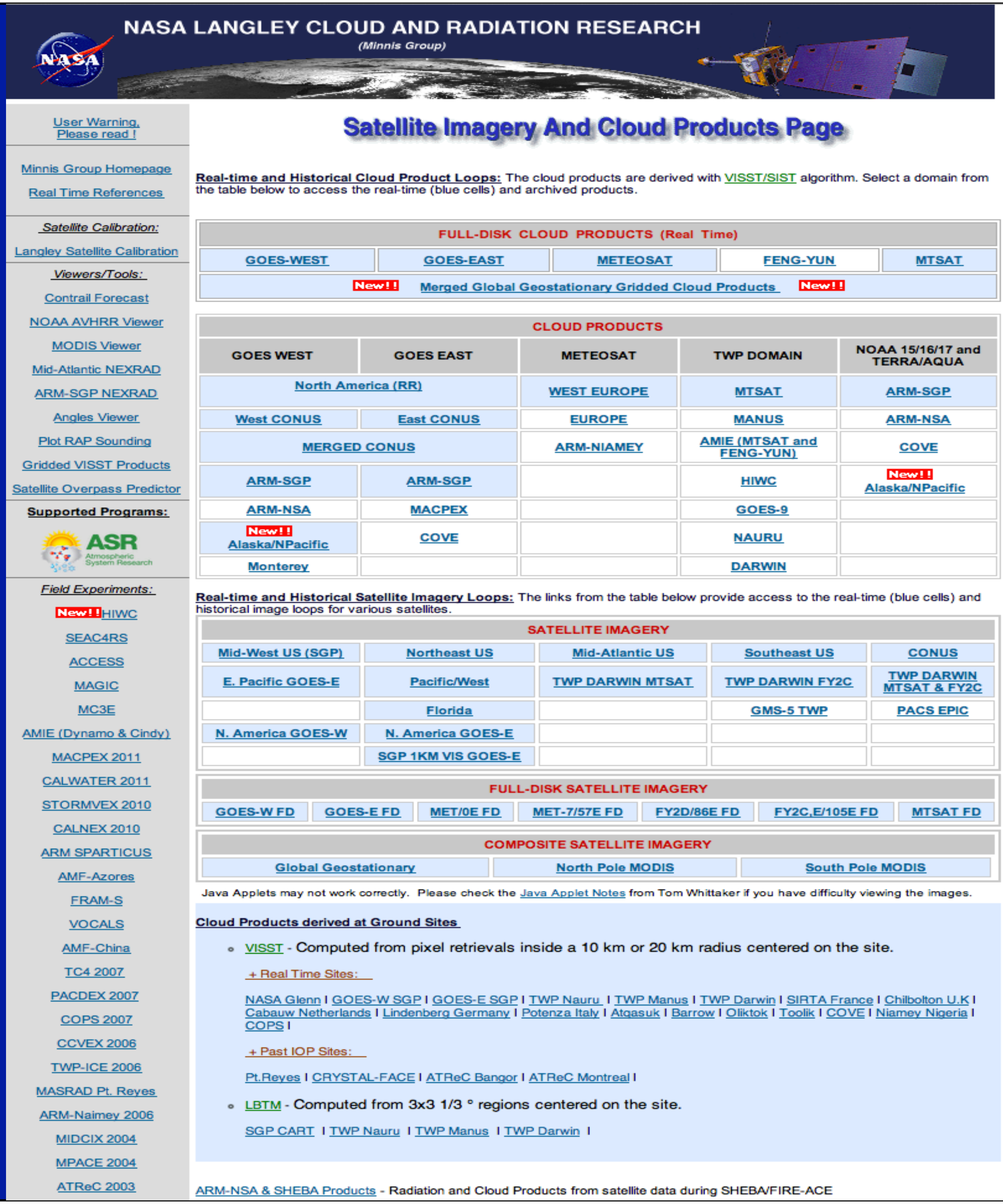
VIIRS Retrievals for CREW Intercomparisons, 5 days

29 March 2013, Phase



Data Can Be Accessed At

cloudsgate2.larc.nasa.gov



NASA LANGLEY CLOUD AND RADIATION RESEARCH
(Minnis Group)

User Warning, Please read !

Minnis Group Homepage

Real Time References

Satellite Calibration:

Langley Satellite Calibration

Viewers/Tools:

Contrail Forecast

NOAA AVHRR Viewer

MODIS Viewer

Mid-Atlantic NEXRAD

ARM-SGP NEXRAD

Angles Viewer

Plot RAP Sounding

Gridded VISST Products

Satellite Overpass Predictor

Supported Programs:

ASR Atmospheric System Research

Field Experiments:

New!! HIWC

SEAC4RS

ACCESS

MAGIC

MC3E

AMIE (Dynamo & Cindy)

MACPEX 2011

CALWATER 2011

STORMVEX 2010

CALNEX 2010

ARM SPARTICUS

AMF-Azores

FRAM-S

VOCALS

AMF-China

TC4 2007

PACDEX 2007

COPS 2007

CCVEX 2006

TWP-ICE 2006

MASRAD Pt. Reyes

ARM-Naimey 2006

MIDCIX 2004

MPACE 2004

ATReC 2003

Satellite Imagery And Cloud Products Page

Real-time and Historical Cloud Product Loops: The cloud products are derived with VISST/SIST algorithm. Select a domain from the table below to access the real-time (blue cells) and archived products.

FULL-DISK CLOUD PRODUCTS (Real Time)				
GOES-WEST	GOES-EAST	METEOSAT	FENG-YUN	MTSAT
New!! Merged Global Geostationary Gridded Cloud Products New!!				

CLOUD PRODUCTS					
GOES WEST	GOES EAST		METEOSAT	TWP DOMAIN	NOAA 15/16/17 and TERRA/AQUA
North America (RR)			WEST EUROPE	MTSAT	ARM-SGP
West CONUS	East CONUS		EUROPE	MANUS	ARM-NSA
MERGED CONUS			ARM-NIAMEY	AMIE (MTSAT and FENG-YUN)	COVE
ARM-SGP	ARM-SGP			HIWC	New!! Alaska/NPacific
ARM-NSA	MACPEX			GOES-9	
New!! Alaska/NPacific	COVE			NAURU	
Monterey				DARWIN	

Real-time and Historical Satellite Imagery Loops: The links from the table below provide access to the real-time (blue cells) and historical image loops for various satellites.

SATELLITE IMAGERY				
Mid-West US (SGP)	Northeast US	Mid-Atlantic US	Southeast US	CONUS
E. Pacific GOES-E	Pacific/West	TWP DARWIN MTSAT	TWP DARWIN FY2C	TWP DARWIN MTSAT & FY2C
	Florida		GMS-5 TWP	PACS EPIC
N. America GOES-W	N. America GOES-E			
	SGP 1KM VIS GOES-E			

FULL-DISK SATELLITE IMAGERY						
GOES-W FD	GOES-E FD	MET/0E FD	MET-7/57E FD	FY2D/86E FD	FY2C,E/105E FD	MTSAT FD

COMPOSITE SATELLITE IMAGERY		
Global Geostationary	North Pole MODIS	South Pole MODIS

Java Applets may not work correctly. Please check the Java Applet Notes from Tom Whittaker if you have difficulty viewing the images.

Cloud Products derived at Ground Sites

- VISST - Computed from pixel retrievals inside a 10 km or 20 km radius centered on the site.

  + Real Time Sites:

  NASA Glenn I GOES-W SGP I GOES-E SGP I TWP Nauru I TWP Manus I TWP Darwin I SIRTA France I Chilbolton U.K I Cabauw Netherlands I Lindenberg Germany I Potenza Italy I Atqasuk I Barrow I Oliktok I Toolik I COVE I Niamey Nigeria I COPS I

  + Past IOP Sites:

  Pt.Reyes I CRYSTAL-FACE I ATReC Bangor I ATReC Montreal I

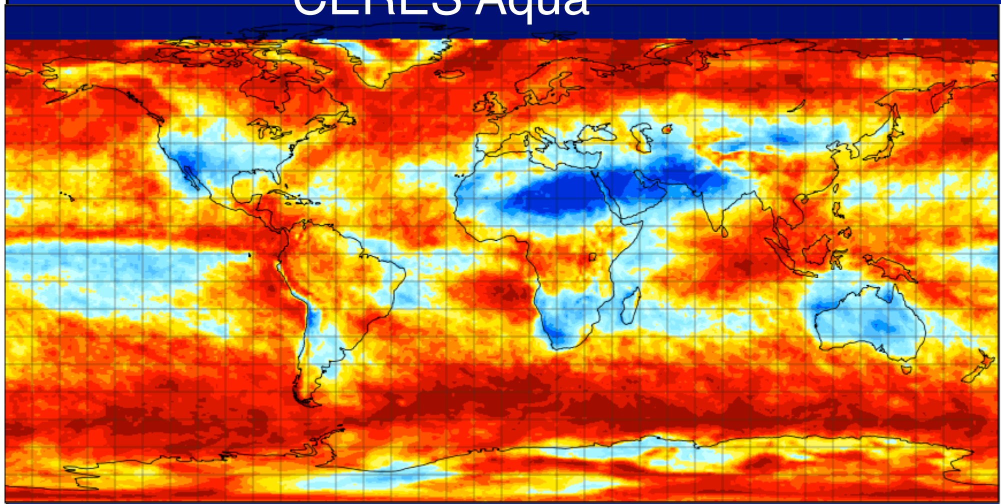
- LBTM - Computed from 3x3 1/3 ° regions centered on the site.

  SGP CART I TWP Nauru I TWP Manus I TWP Darwin I

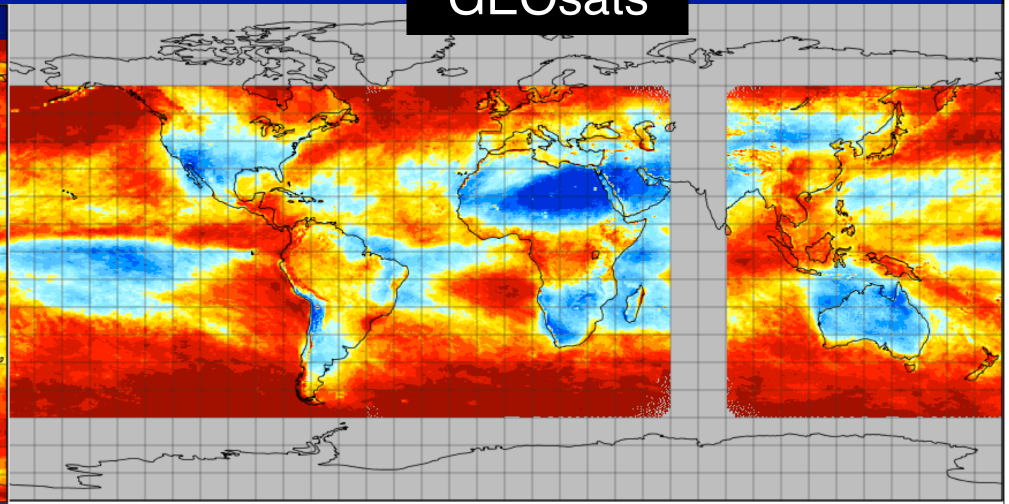
ARM-NSA & SHEBA Products - Radiation and Cloud Products from satellite data during SHEBA/FIRE-ACE

Daytime Cloud Fraction October 2008

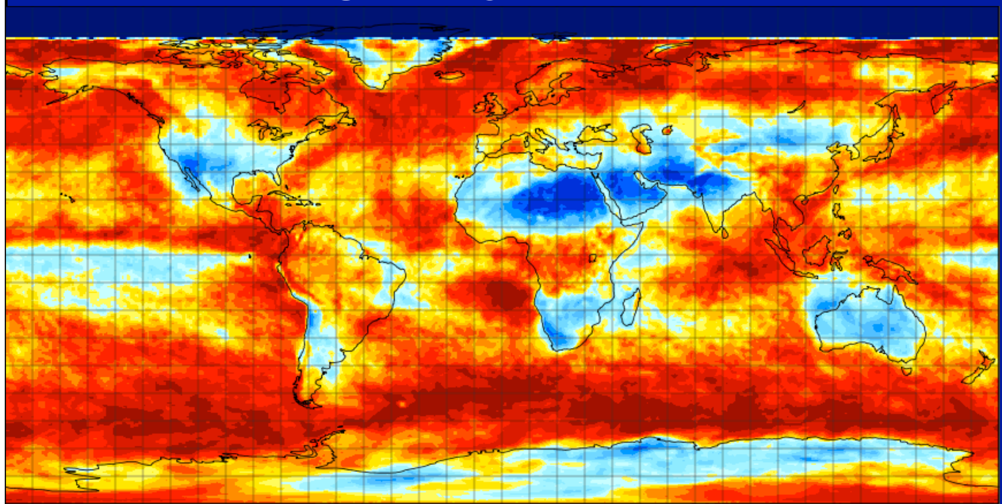
CERES Aqua



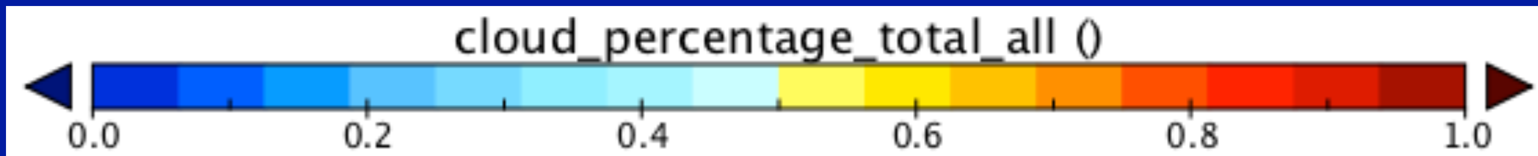
GEOsats



NOAA-18 AVHRR

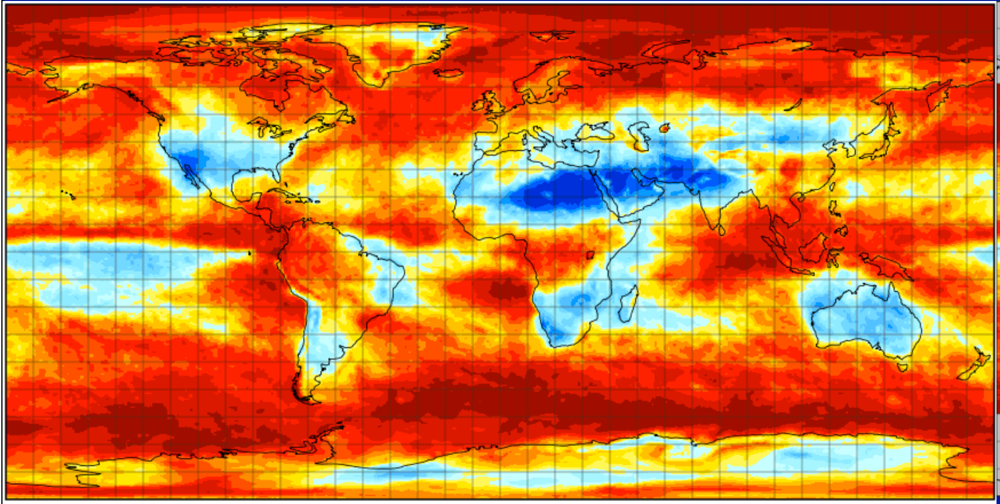


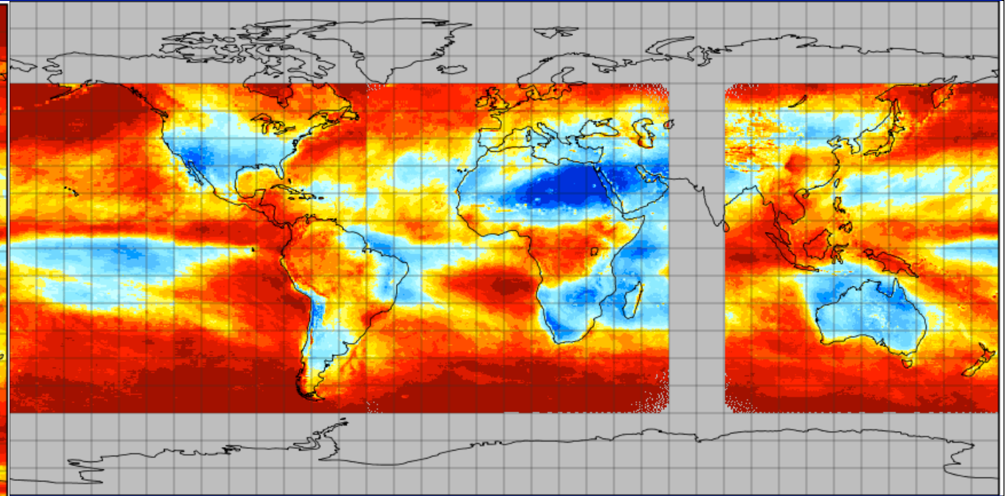
- CERES & AVHRR very similar
- GEOsat CF larger in extreme latitudes and smaller in trade Cu areas



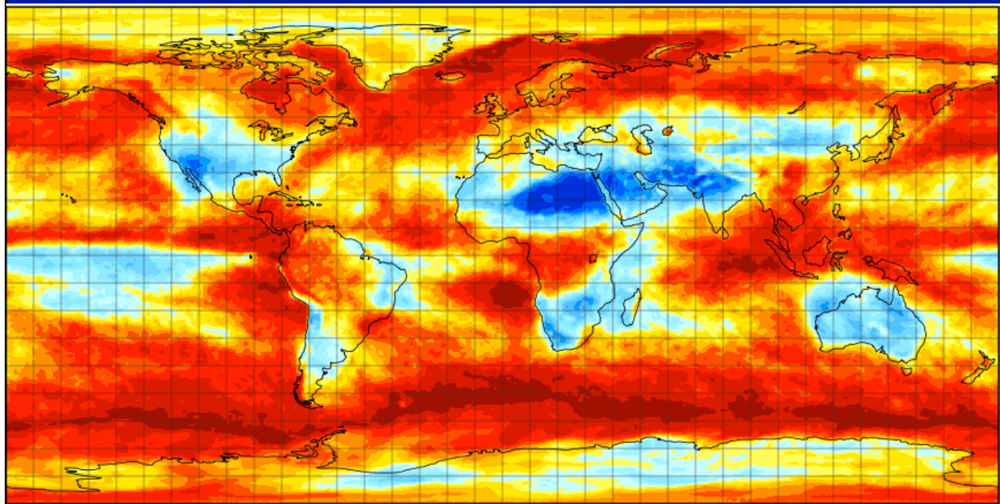
Total (day + night) Cloud Fraction

CERES Aqua **October 2008** GEOsats

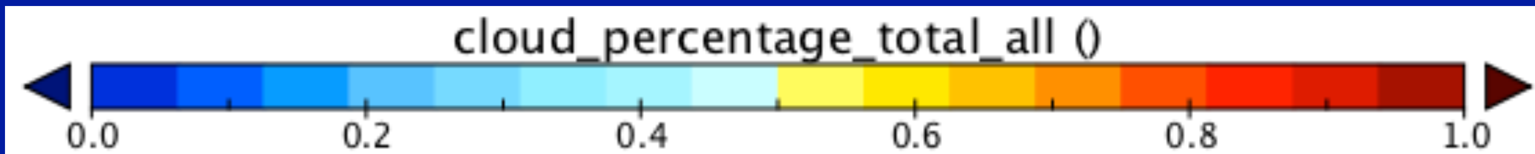




NOAA-18 AVHRR

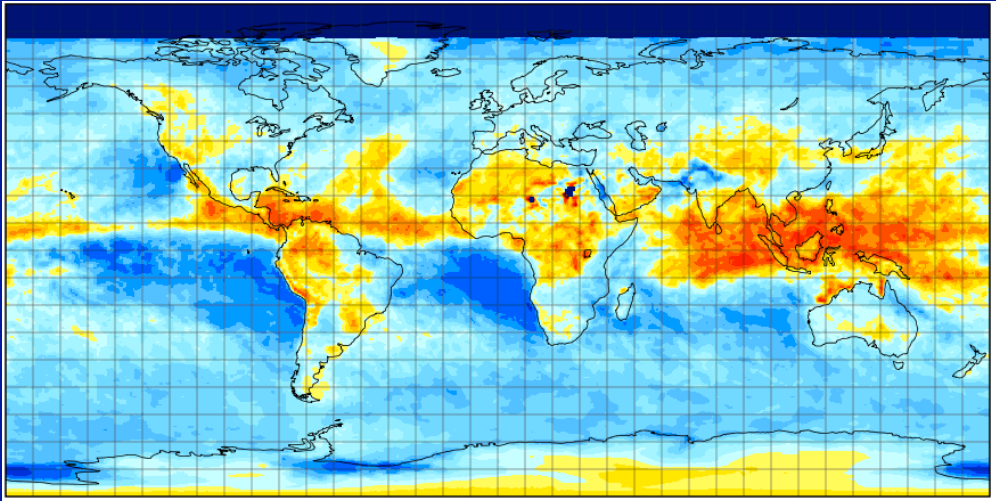


- CERES & AVHRR very similar, except Arctic night
- GEOsat CF larger in extreme latitudes and smaller in trade Cu areas

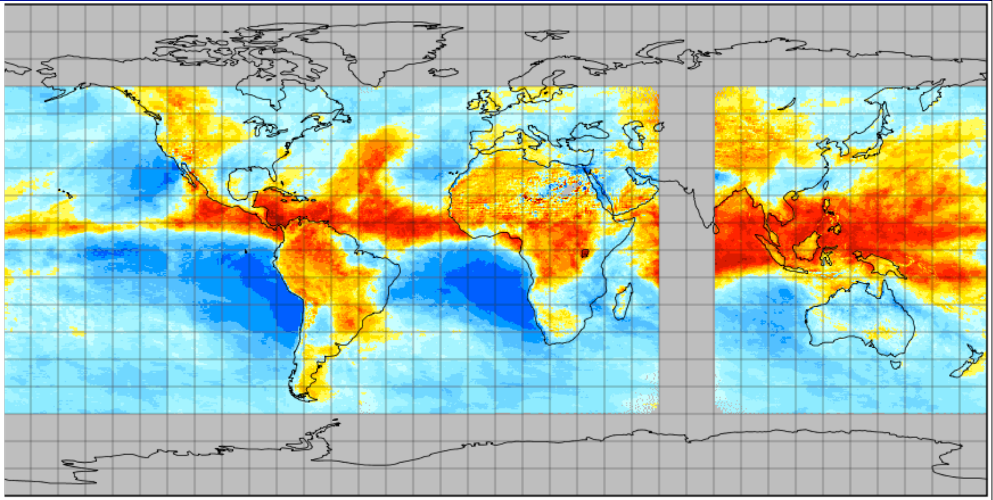


Day Cloud Top Height (km) October 2008

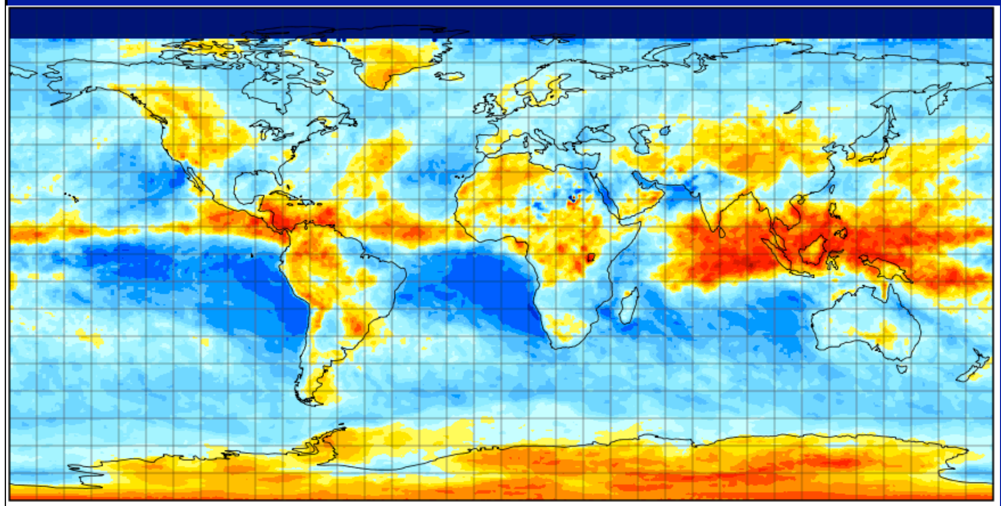
CERES Aqua



GEOsats



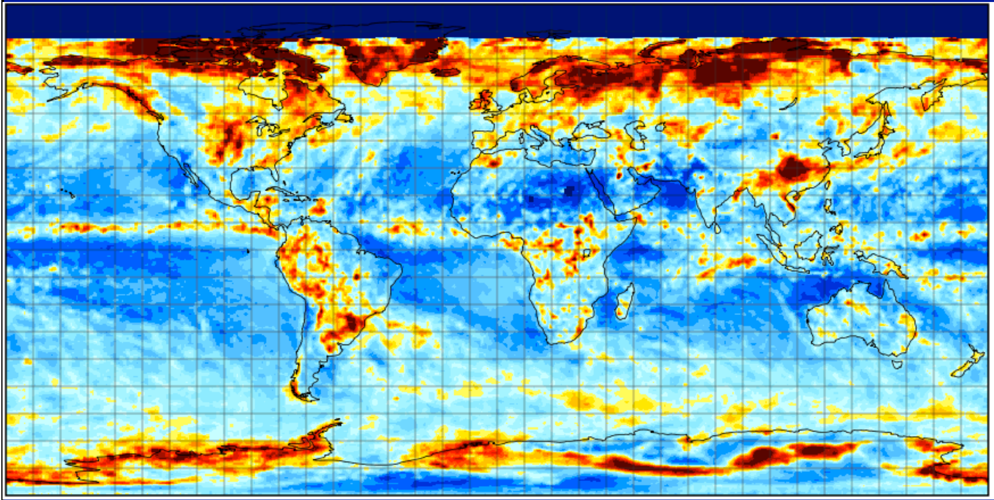
NOAA-18 AVHRR



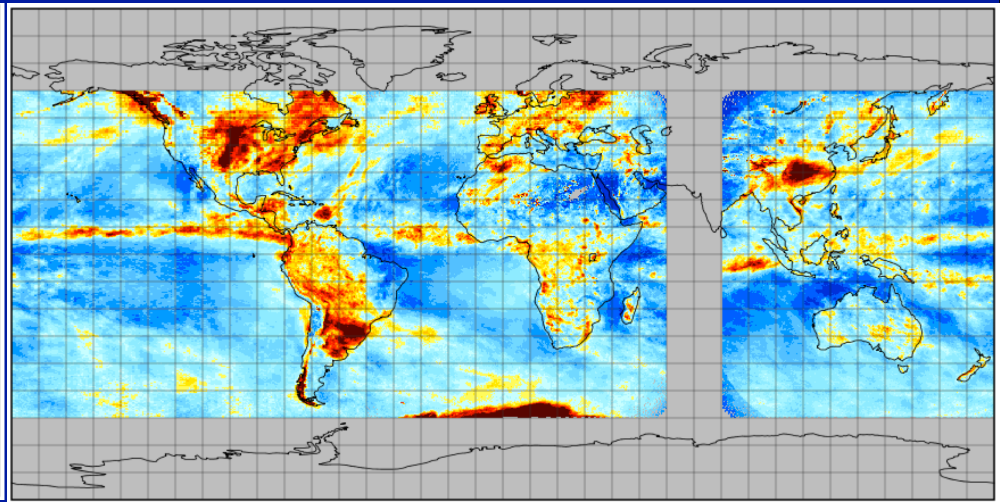
- CERES & AVHRR very similar, except polar, AVHRR little higher ice
- GEOsat ice clouds higher
  - full day sampling?

Day Cloud Optical Depth, October 2008

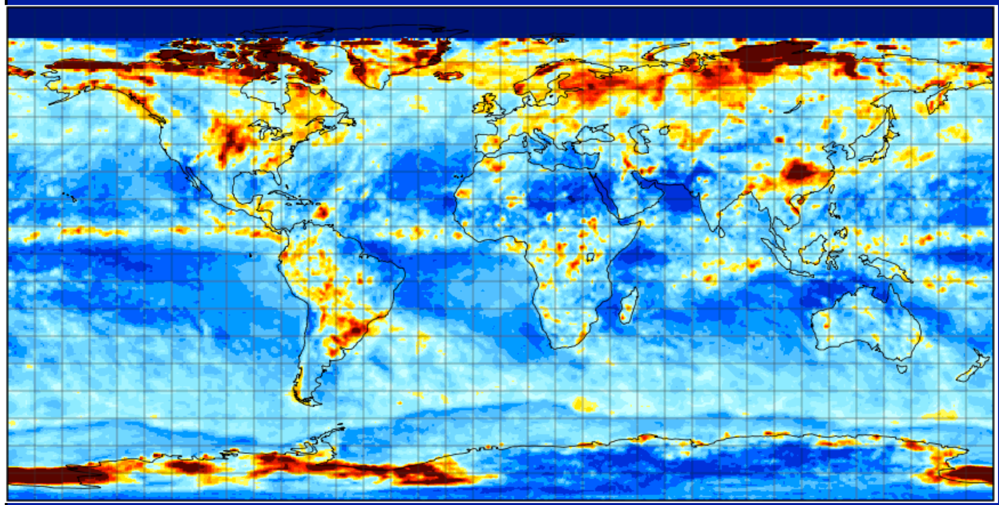
CERES Aqua



GEOsats



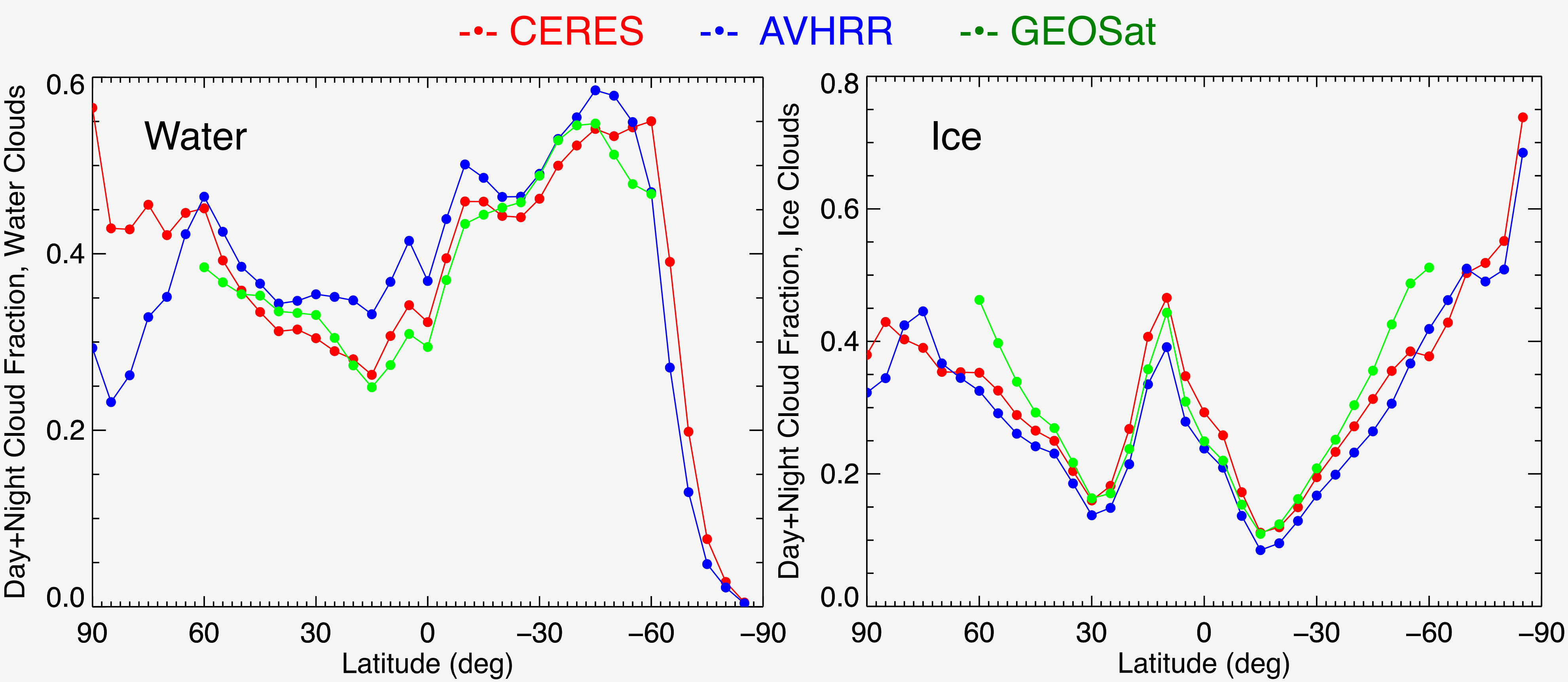
NOAA-18 AVHRR



- AVHRR < CERES, especially polar
    - AVHRR uses SIST + VISST
    - AVHRR: more thin clouds in tropics

- GEOsat some brighter, some darker
    - full day sampling

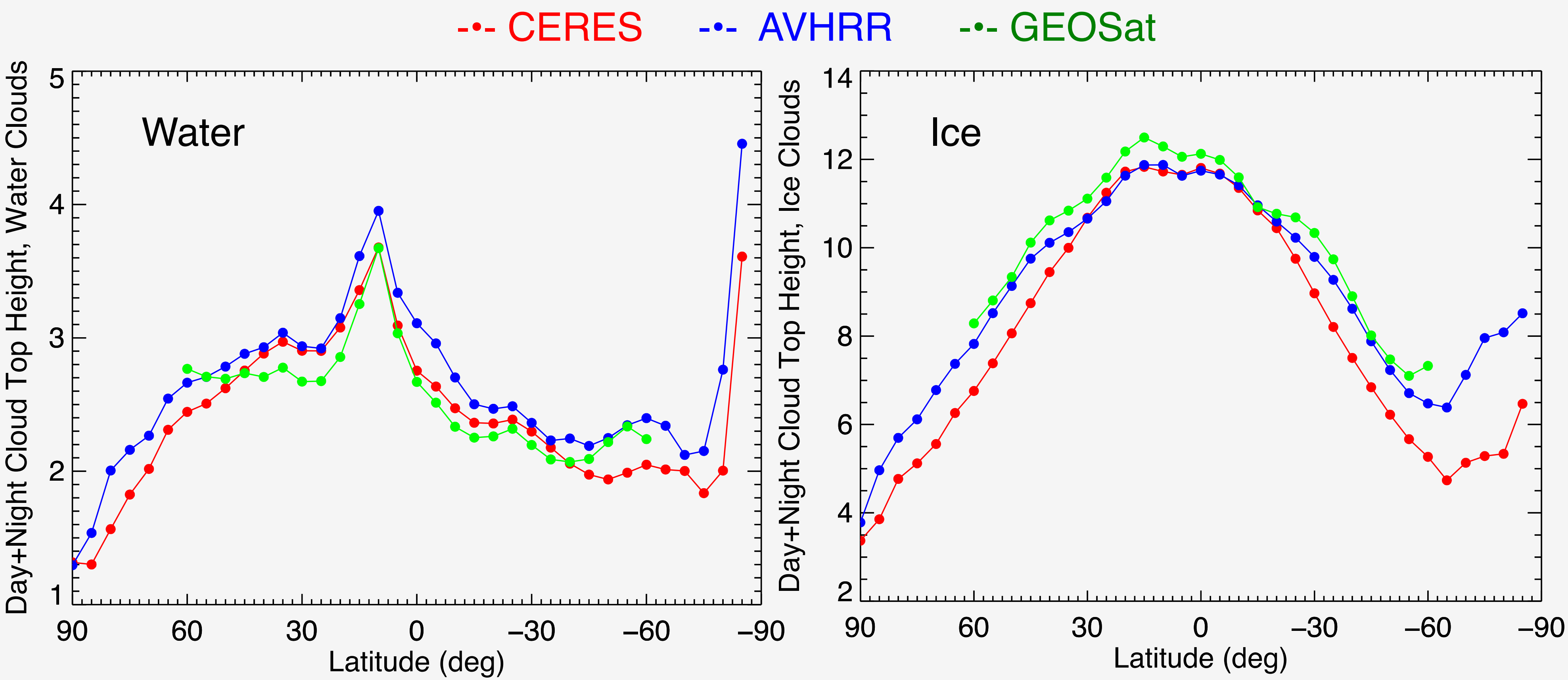
Average Cloud & Phase Fraction, Day + Night, October 2008



"Global Means" (km)

	Water	Ice	Total
CERES	0.387	0.283	0.672
AVHRR	0.413	0.250	0.690
GEoSat	0.356	0.242	0.587

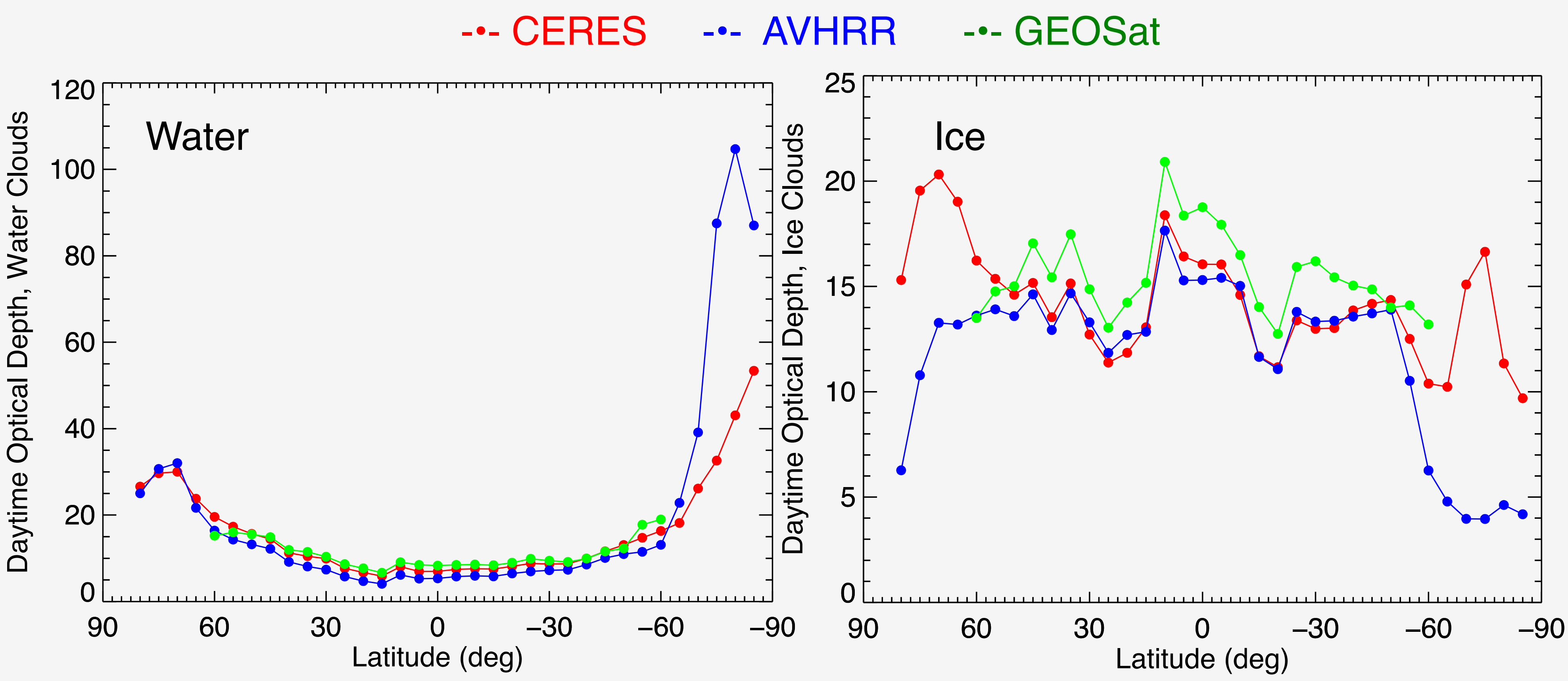
Average Cloud-Top Heights Day + Night, October 2008



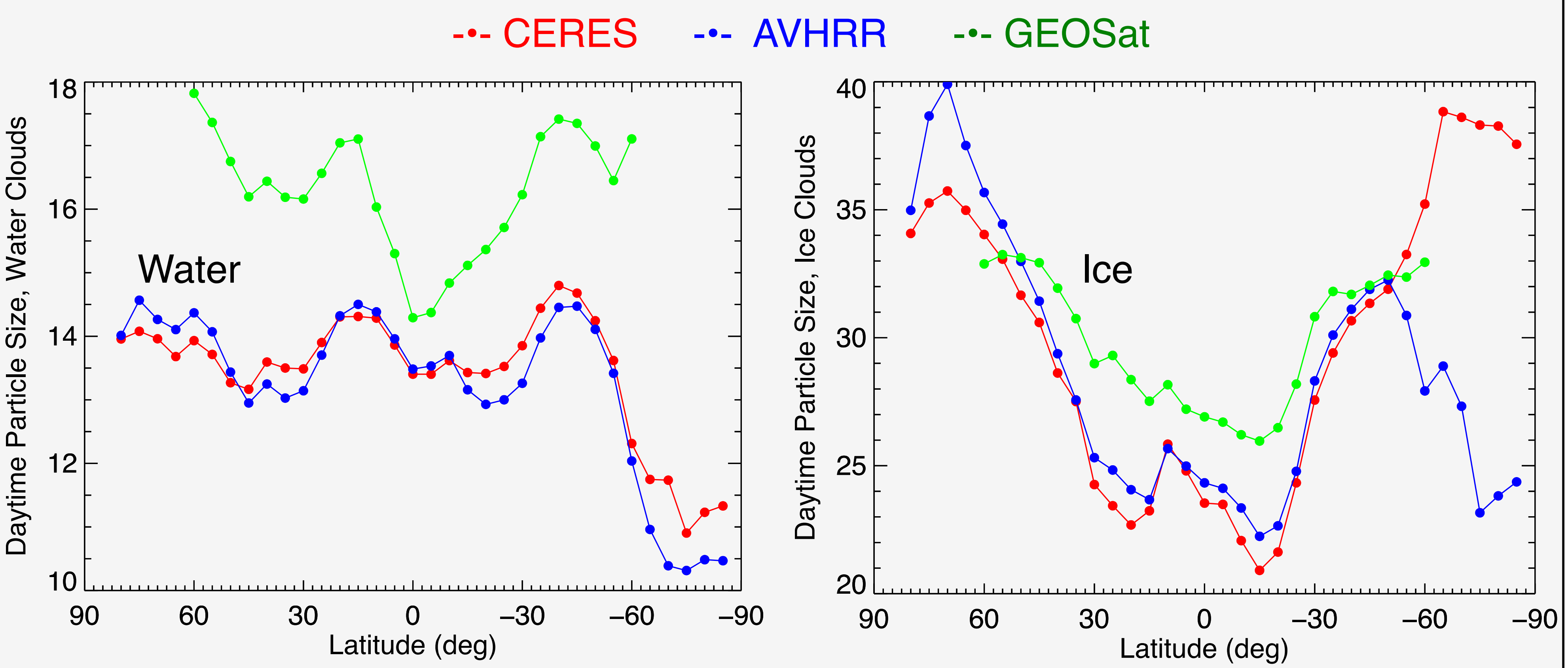
"Global Means" (km)

	Water	Ice	Total
CERES	2.46	9.25	5.28
AVHRR	2.28	9.82	5.28
GEoSat	2.29	9.38	5.13

Average Cloud Optical Depth, Day, October 2008



Average Cloud Particle Effective Radius, Day, October 2008



CALIPSO Validation

- Spatially/temporally matched cloud properties: Aqua 12 d Seasonal mos. 2008
  - VIIRS 3 d Nov 2012
  - AVHRR 6 d Oct 2008

- Selected MODIS cloud properties only – mask, cloud top height, optical depth
  - No cloud base, WP
  - All matches near nadir for Aqua

- CALIPSO data
  - 5-km cloud heights and optical depths, 80-km clouds excluded
  - 333-m cloud detections added for cloud mask comparison
  - VFM for phase, SL/ML identification, and layer opacity
  - Phase uses only pure phase cases from CALIPSO

H - Hit rate, fraction CALIPSO clouds detected

FC – fraction correct**

FAR – false alarm rate

B – bias ratio

CSI – critical success index

HSS – Heidke skill score

Cloud Fraction Comparison

Fraction Correct

Type	Aqua Ocean	Aqua Land	Aqua All	VIIRS Ocean	VIIRS Land	VIIRS All	AVHRR All
Global Day	0.92	0.87	0.89	0.91	0.86	0.88	0.86
Global night	0.91	0.78	0.86	0.85	0.77	0.83	0.83
Global Term			0.89			0.80	0.80

Type	Day	Night
Tropics Day	0.88	0.85
Midlat Day	0.92	0.87
Polar Day	0.90	0.81

- Ed4 mask more accurate than Ed2; Midlat best
- AVHRR & VIRS nearly as accurate Ed4, polar night worst
- Night land is also a source of cloud underestimation
- Including 80-km clouds reduces these numbers by ~0.02 to 0.03

Cloud Phase Fraction Comparison

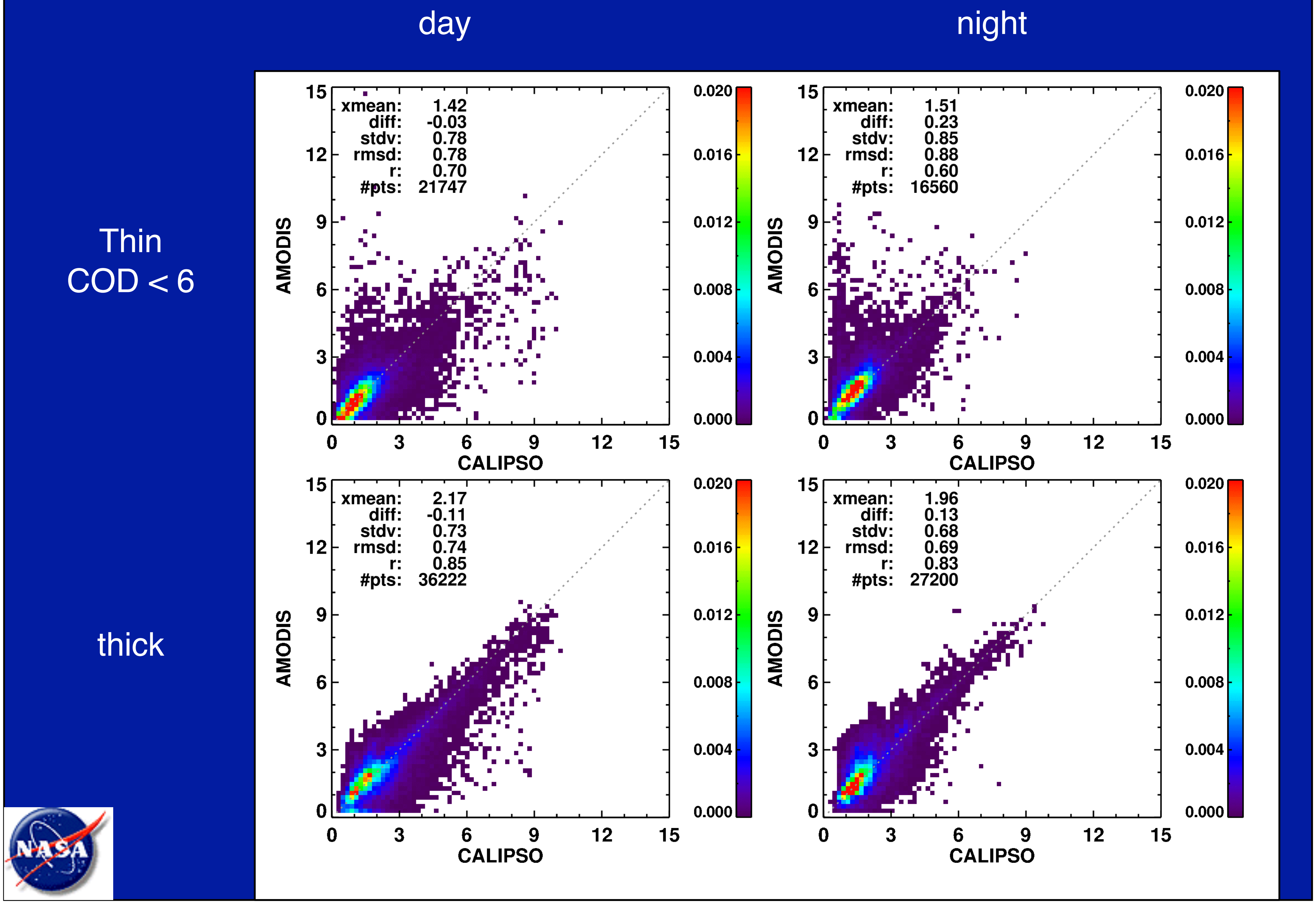
Fraction Correct: Single layer, pure phase only (~1/3 pixels)

	Aqua		VIIRS		AVHRR	
Type	FC	Bal +W	FC	Bal +W	FC	Bal +W
Global Day	0.96	0.012	0.98	0.001	0.92	0.006
Global night	0.93	-0.011	0.96	- 0.005	0.89	0.010
Global Term	0.83	-0.103	0.87	-0.107	0.78	-0.191

	Day	Night
Tropics	0.96	0.90
Midlat	0.97	0.95
Polar	0.94	0.86

- Fairly well balanced phase selection
- terminator (82° < SZA < 89°) area yields too much ice cloud

cloud top height – liquid



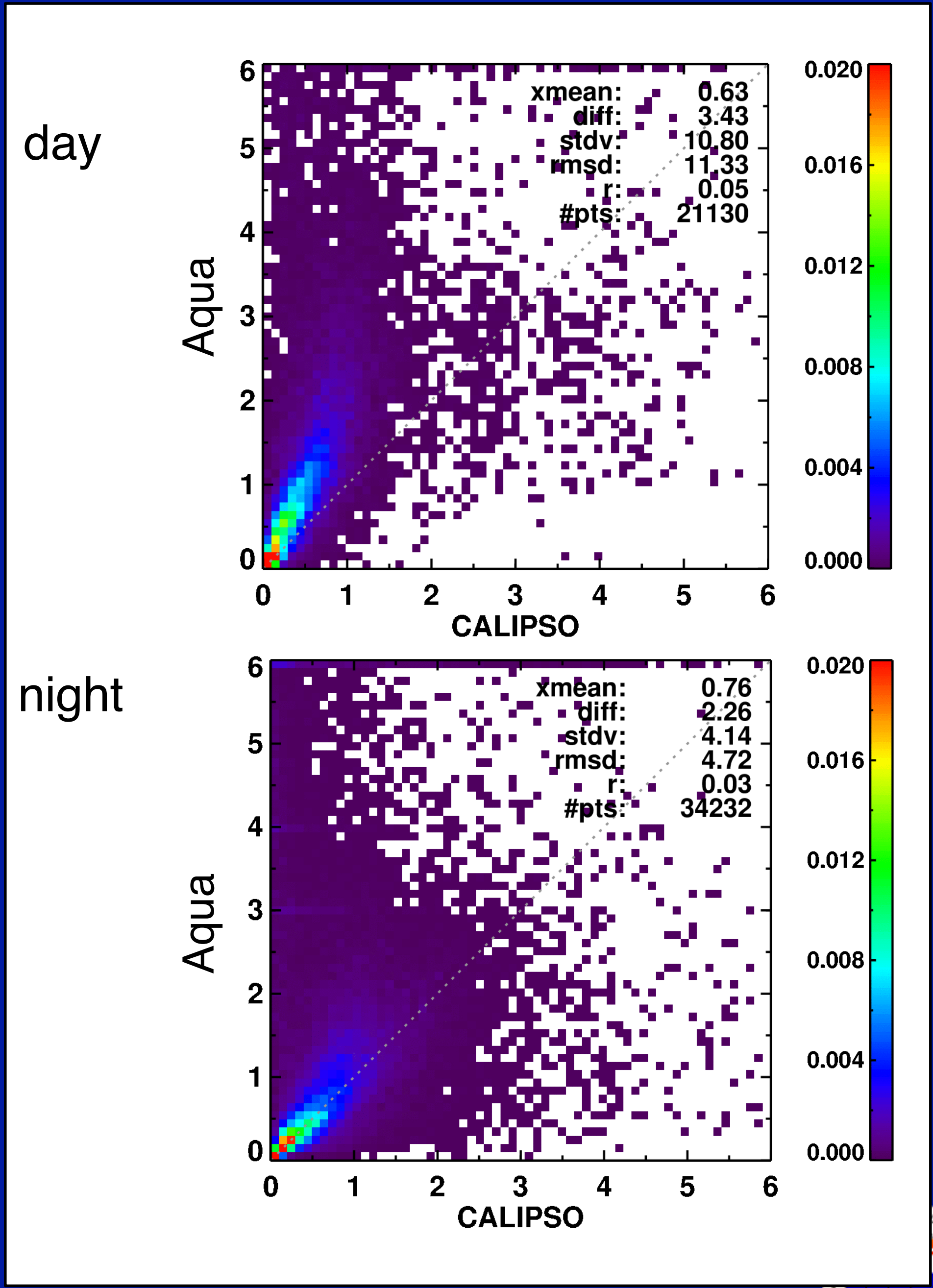
Cloud Height Validation (km)

Type	Aqua (12 d)		VIIRS (3 d)		AVHRR (6d)	
	mean dif	RMSd	mean dif	RMSd	mean dif	RMSd
Ice						
Thin, day	-2.68	3.98	-2.91	4.29	-1.50	3.58
Thin, night	-0.58	2.53	-0.75	2.54	-0.96	3.53
Thick, day	-0.16	1.23	-0.02	1.38	-0.51	1.38
Thick, night	0.01	1.78	0.66	1.78	-0.13	1.09
Water						
Thin, day	-0.03	0.78	0.12	0.78	-0.02	1.03
Thin, night	0.20	0.88	0.10	0.91	0.22	0.87
Thick, day	-0.11	0.74	-0.07	0.79	-0.01	0.75
Thick, night	0.13	0.69	0.10	0.65	0.45	0.96

- All consistent, except AVHRR night thick water

cloud optical depth – ice, thin clouds only

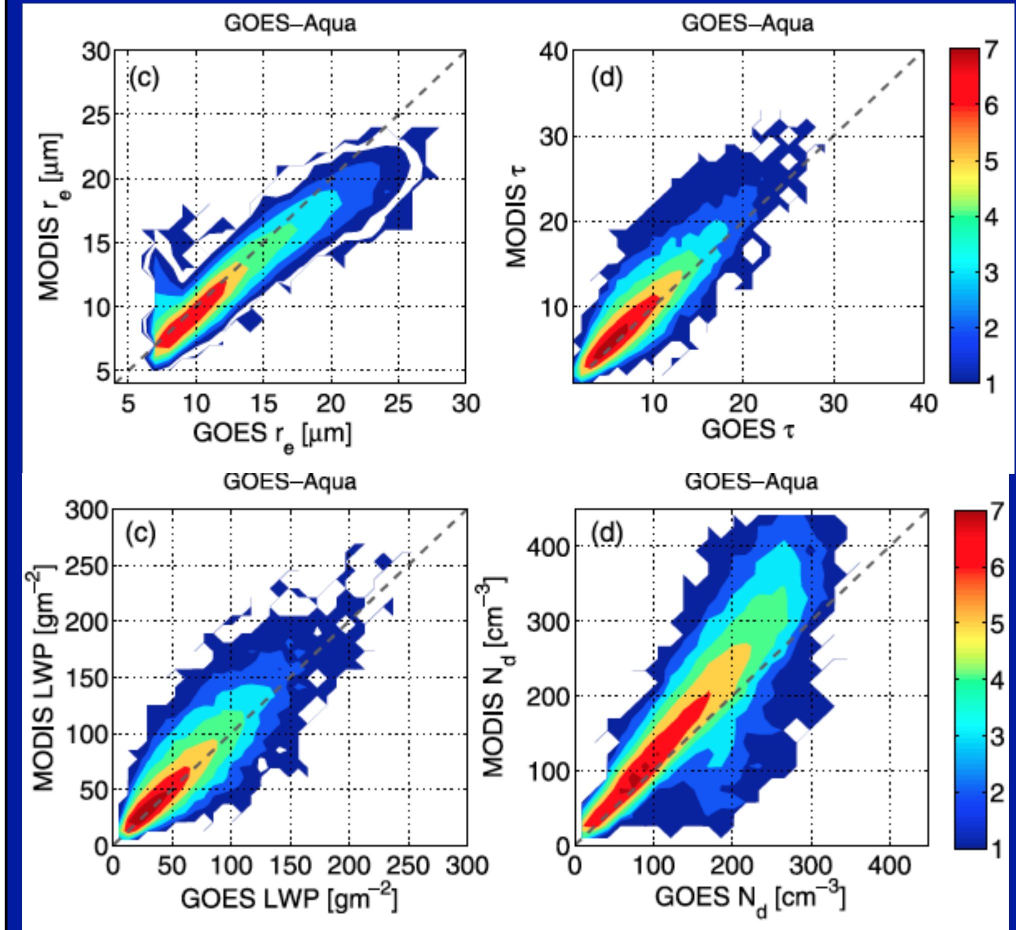
- Daytime cirrus tau ~ 75% > CALIPSO
  - Need scattering phase function for ice with *g* ~ 0.75
    - *next gen from P Yang*
- Nighttime cirrus tau very close to CALIPSO for most points, 0 - 1
  - multilayer clouds in this set



GOES-10 Comparisons VOCALS-Rex, 2008

-Painemal et al.JGR, 2012)

Compare w/ MAST Collection 5



Compare w/ A/C in situ profiles

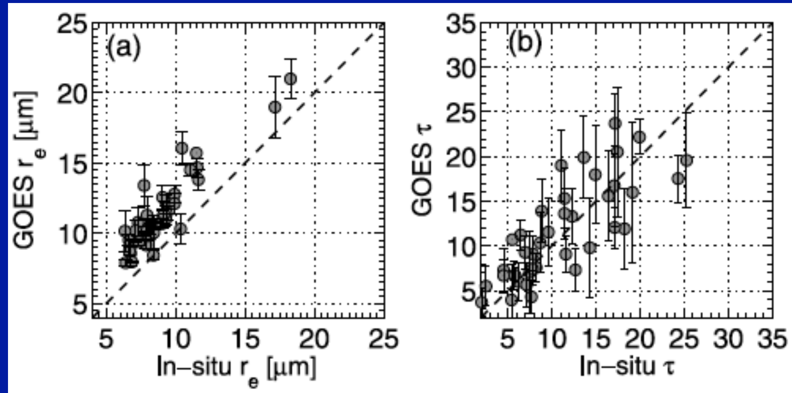
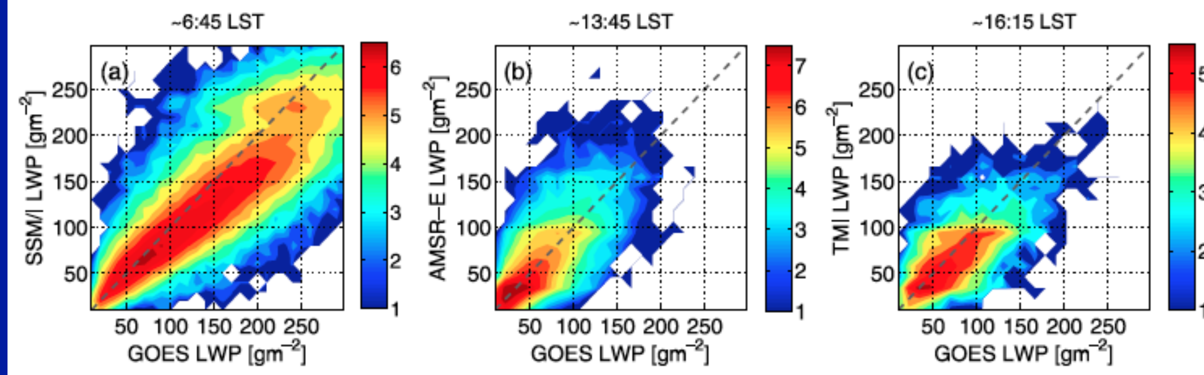


Figure 1. Scatterplot between GOES and in situ observations: (a) cloud optical thickness and (b) cloud effective radius. Vertical error bars denote the 20 km GOES standard deviation.

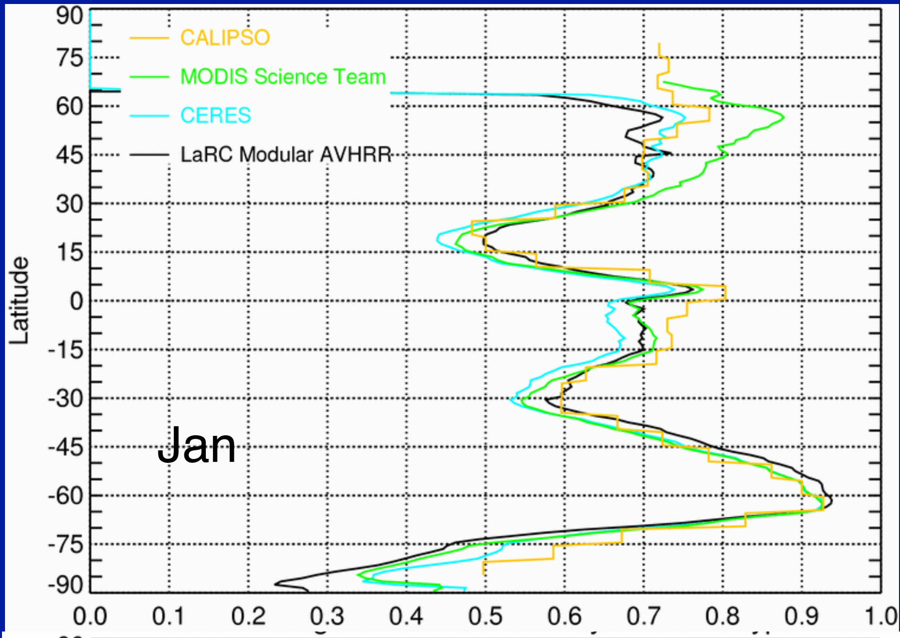
Compare w/ satellite MWR LWP at different local times

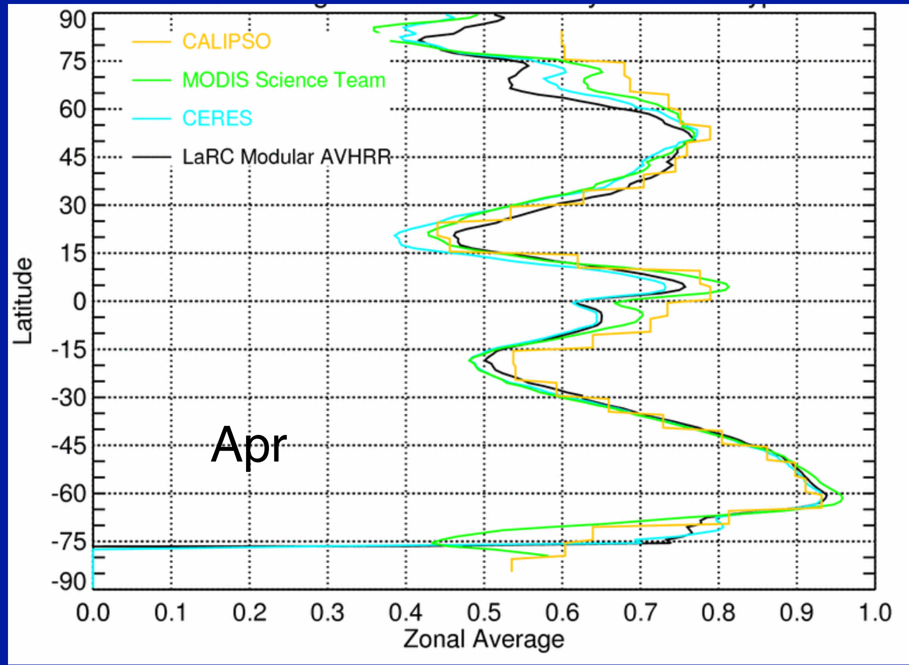
DMSP SSM/I,
Aqua AMSR-E, TRMM TMI

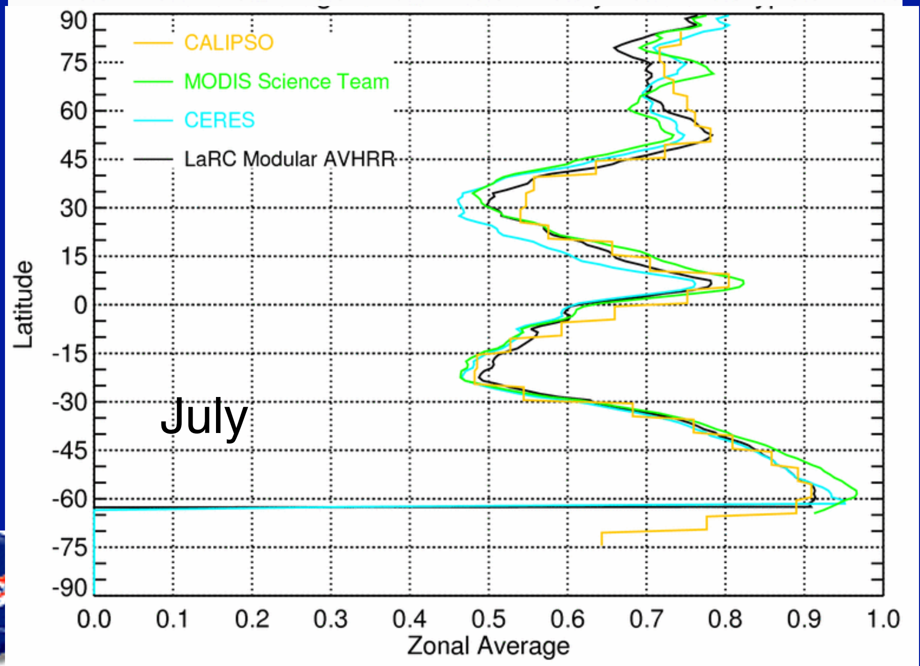
PAINEMAL ET AL.: MARINE CLOUDS MICROPHYSICS FROM GOES-10



Daytime Monthly Mean Cloud Fraction, 2008

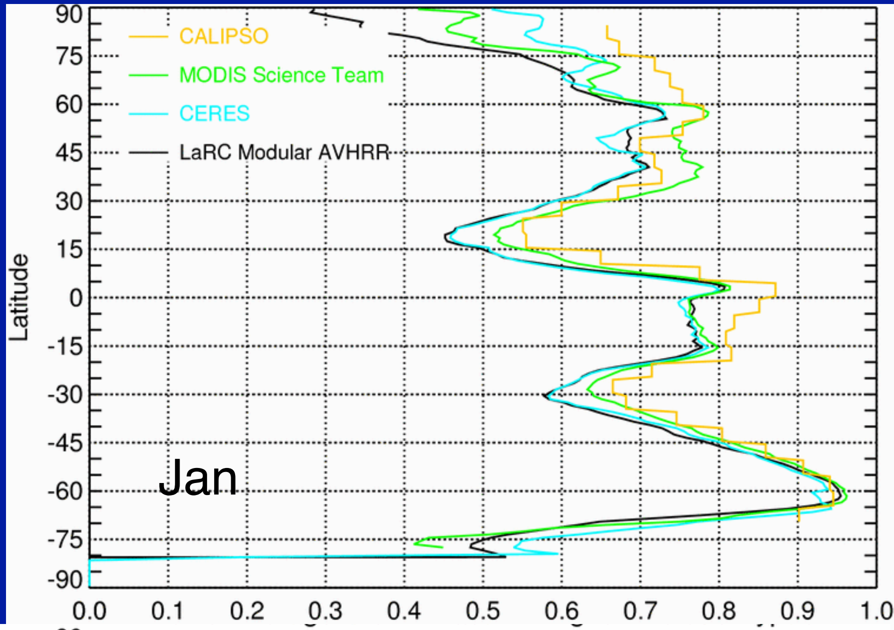


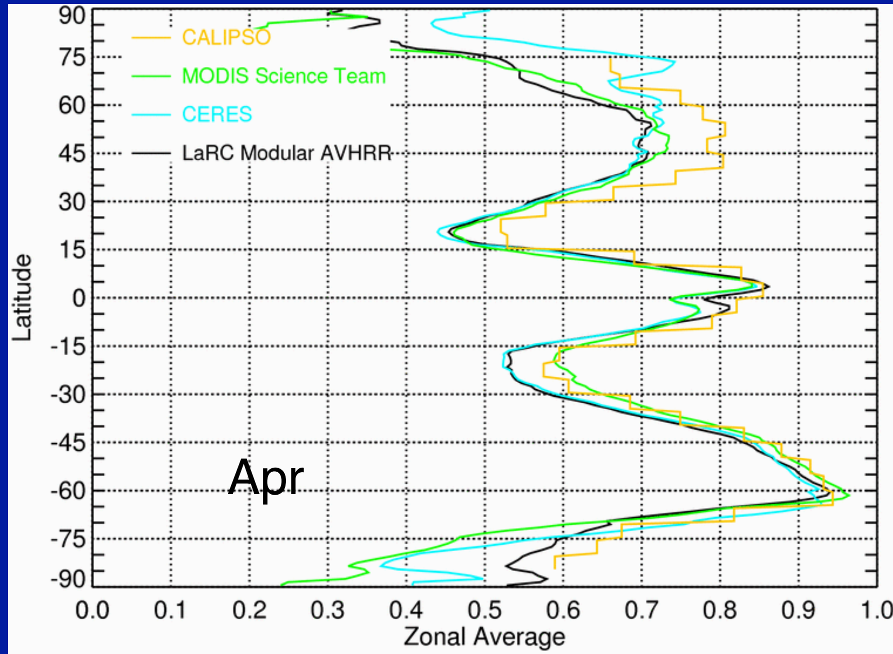


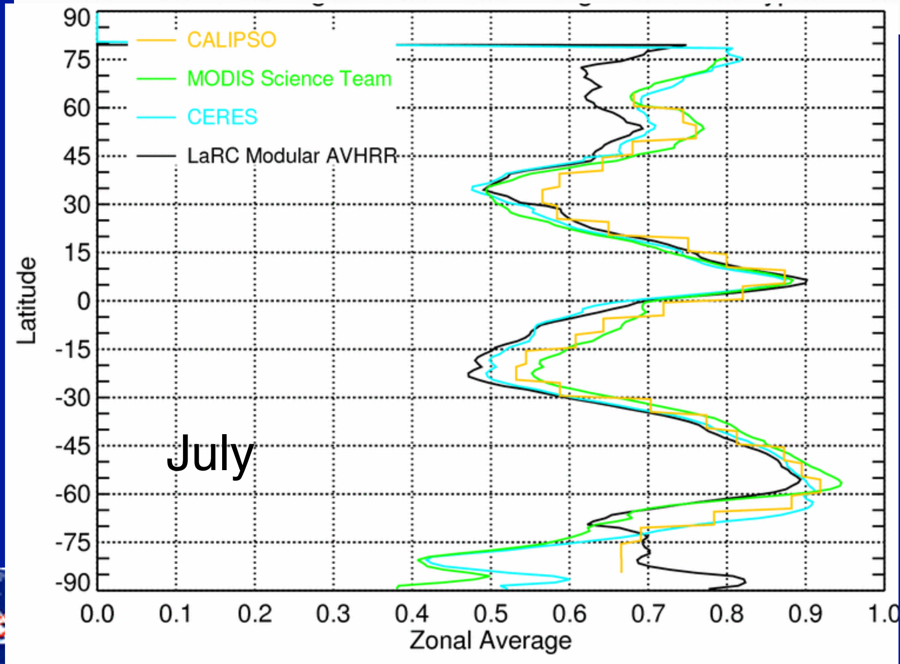


- AVHRR generally very close to CERES, sometimes closer to CALIPSO and MAST Collection 5

Night Monthly Mean Cloud Fraction, 2008







- AVHRR very close to CERES, except polar regions
  - need more channels

Summary

- Cloud fractions very consistent, agreeing 85-92% with CALIPSO
  - polar regions source of biggest discrepancies

- Cloud heights consistent on average within
  - 0.3 km for water, 1 km for ice
  - AVHRR water a little higher at night, confirmed by CALIPSO
  - thin ice clouds ok at night, too thick in daytime
    - need lower *g* values
  - how do we deal with multilayer?

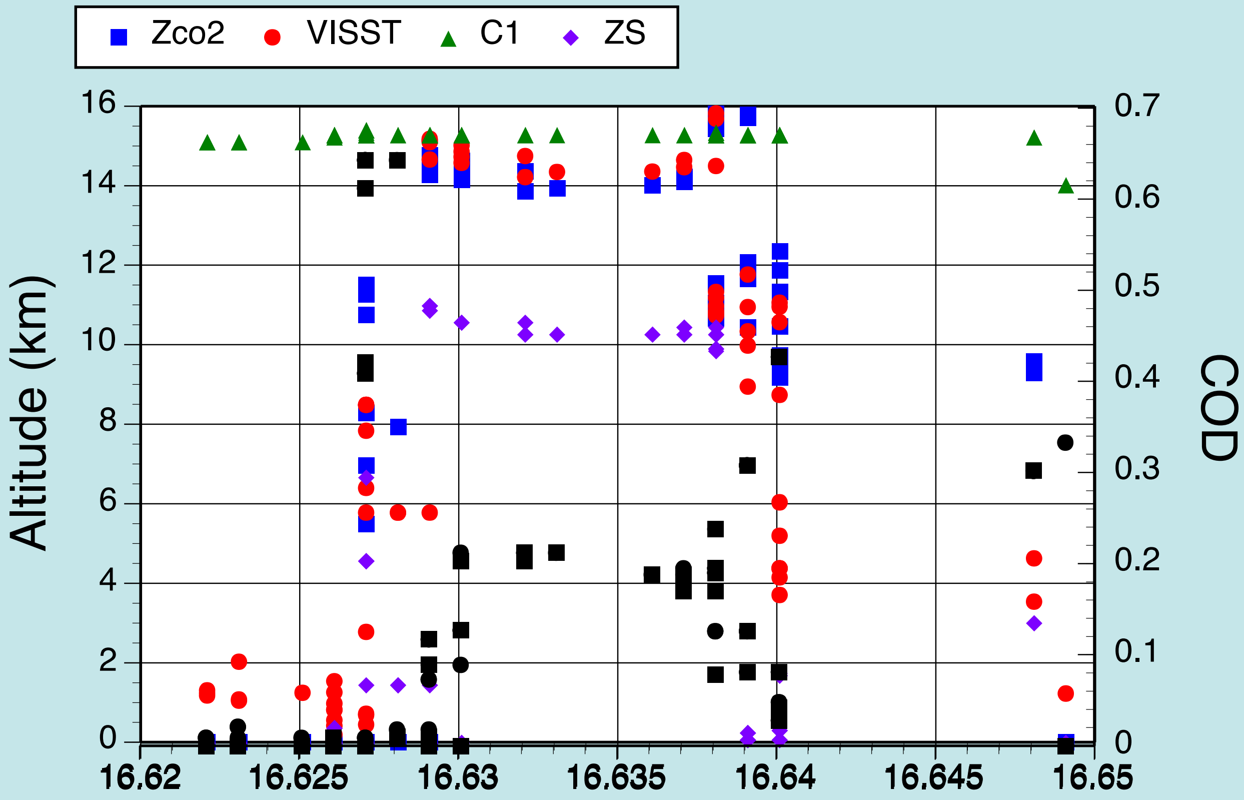
- Phase agreements very close, except poles
  - terminator area biased to ice
  - how do we deal with mixed phase and multilayer?

- AVHRR COD too low for water clouds
  - models? Corrections?

- GEOsat Re too large
  - reflectance models?

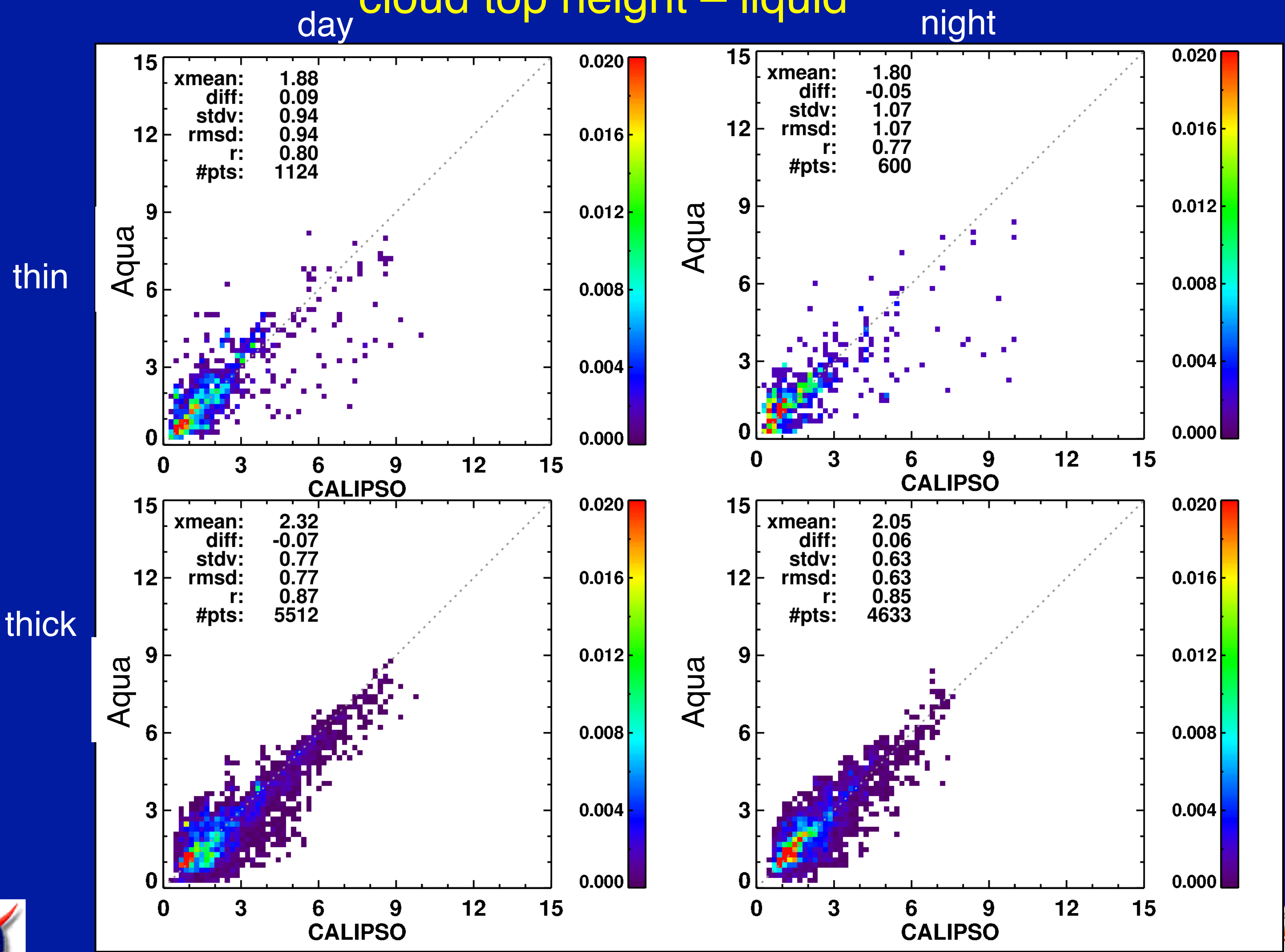
Future

- Revise GEOsat 3.9-μm reflectance models
- Implement profiles to estimate CWC(z)
  - see Smith talk
- Replace ice models with new 2-habit model from Yang
- Test and implement DNB nighttime retrievals
- Test other techniques to improve night COD/CWP estimates
- Examine optimal methods for estimating LWP
  - multispectral CER retrievals
  - meteorology?
- Improve terminator detection and retrieval
- Refine multilayer retrievals
  - see Chang poster



Zco2
VISST
C1
ZS
Altitude (km)
COD
16
14
12
10
8
6
4
2
0
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
16.62
16.625
16.63
16.635
16.64
16.645
16.65

cloud top height – liquid



cloud top height – ice, Zt correction applied