CERES Edition 2 & Edition 3 Cloud Cover, Cloud Altitude and Temperature

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GEWEX Cloud Assessment Meeting, Berlin, Germany

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Cloud Cover & Cloud Altitude (Temperature)

- Cloud Mask
  - *Uses mainly 5 channels (0.65, 2.1, 3.8, 10.8, 12.0 μm)*
    - *some assistance from 1.38, 13.3 μm for Aqua*
  - *algorithms*
    - *Minnis et al., TGRS, 2008*

- Cloud temperature (Tc) & altitude (Zc, Pc)
  - *Tc requires estimate of optical depth (τ) and emissivity*
    - *Minnis et al., TGRS, 2009 (submitted)*
    - *yields effective values (radiating temp)*
  - *Zc & Pc found using sounding with T(Z) = Tc*
    - *Lapse rate is used for boundary layer clouds*

DATA

(1) CALIPSO_ATR_0130 AM PM: 2007-2008 **(2yrs)** (GEWEX)

(2) ISCCP_D1_AM PM: 1984-2007 **(24 yrs)** (GEWEX)

(3) MODIS-CE_AQU_0130 AM: 2002-2007 **(6 yrs)** (GEWEX)
MODIS-CE_AQU_0130 PM: 2002-2007 **(6 yrs)** (GEWEX)
MODIS-CE_TER_1030 AM: 2000-2007 **(8 yrs)** (GEWEX)
MODIS-CE_TER_1030 PM: 2000-2007 **(8 yrs)** (GEWEX)

(4) MODIS-ST_AQU_0130 AM: 2003-2009 **(7 yrs)** (GEWEX)
MODIS-ST_AQU_0130 PM: 2003-2009 **(7 yrs)** (GEWEX)
MODIS-ST_TER_1030 AM: 2001-2009 **(9 yrs)** (GEWEX)
MODIS-ST_TER_1030 PM: 2001-2009 **(9 yrs)** (GEWEX)

(5) MODIS-CE_AQU_Ed3 (C3M) 0130 AM PM July 2006-June 2007 **(1 yr)** (Langley, NASA)

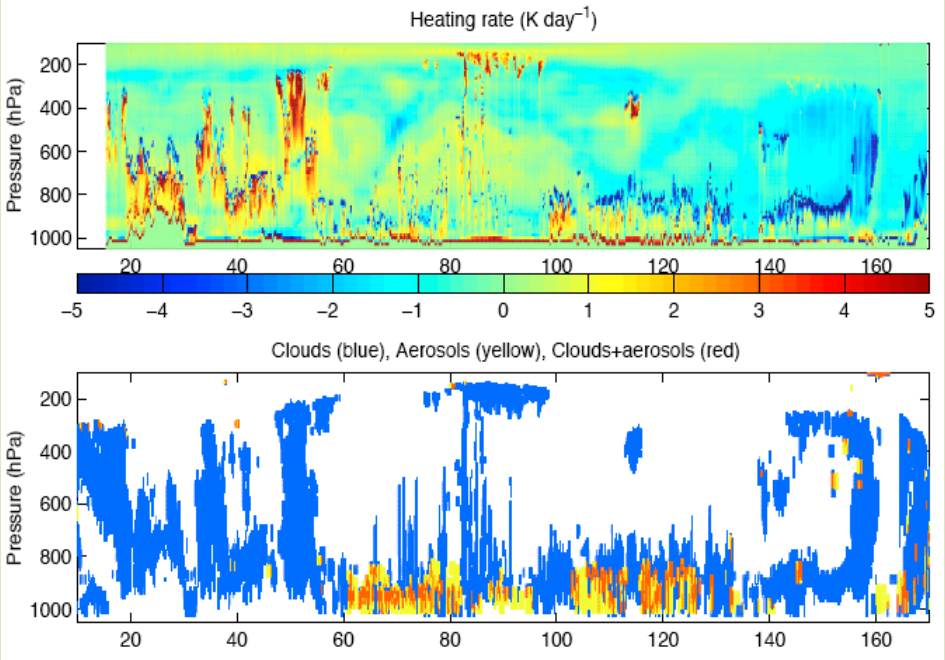
C3M product

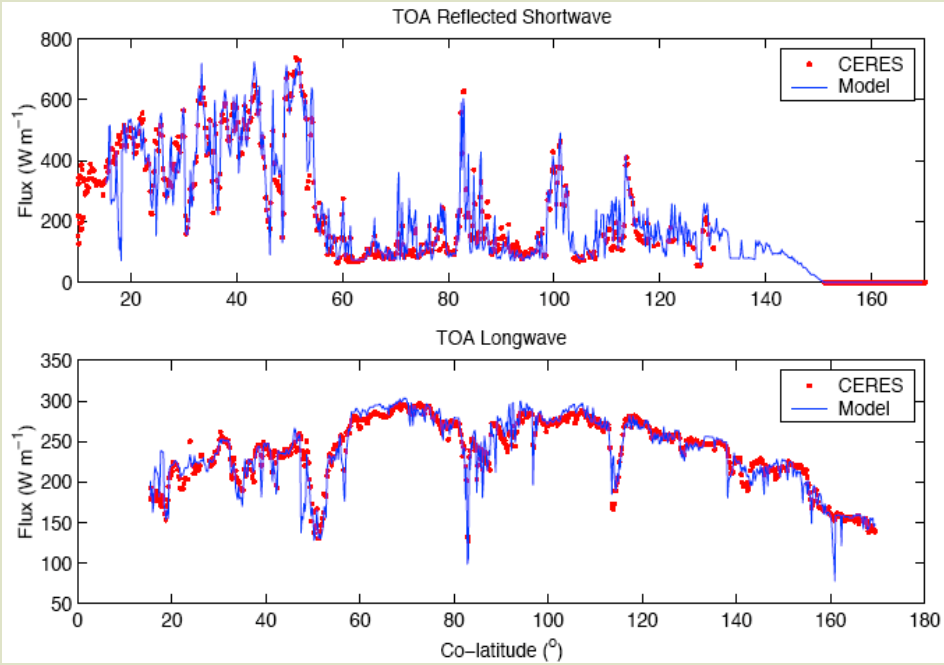
Seiji Kato, Sunny Sun-Mack, Yan Chen, Fred Rose, Walt Miller

- Funded by the NASA Energy Water Cycle Study (NEWS).
- Contains:

1. Merged CALIPSO, CloudSat derived clouds, CERES TOA radiative flux (SW, LW, and WN), MODIS-CE (CERES_ST) derived cloud properties both along CALIPSO-CloudSat ground-track and over the whole CERES footprint,
2. MODIS-CE derived cloud properties by an enhanced cloud algorithm,
3. Vertical radiative flux profiles computed with CALIPSO, CloudSat, and MODIS-CE derived cloud properties.

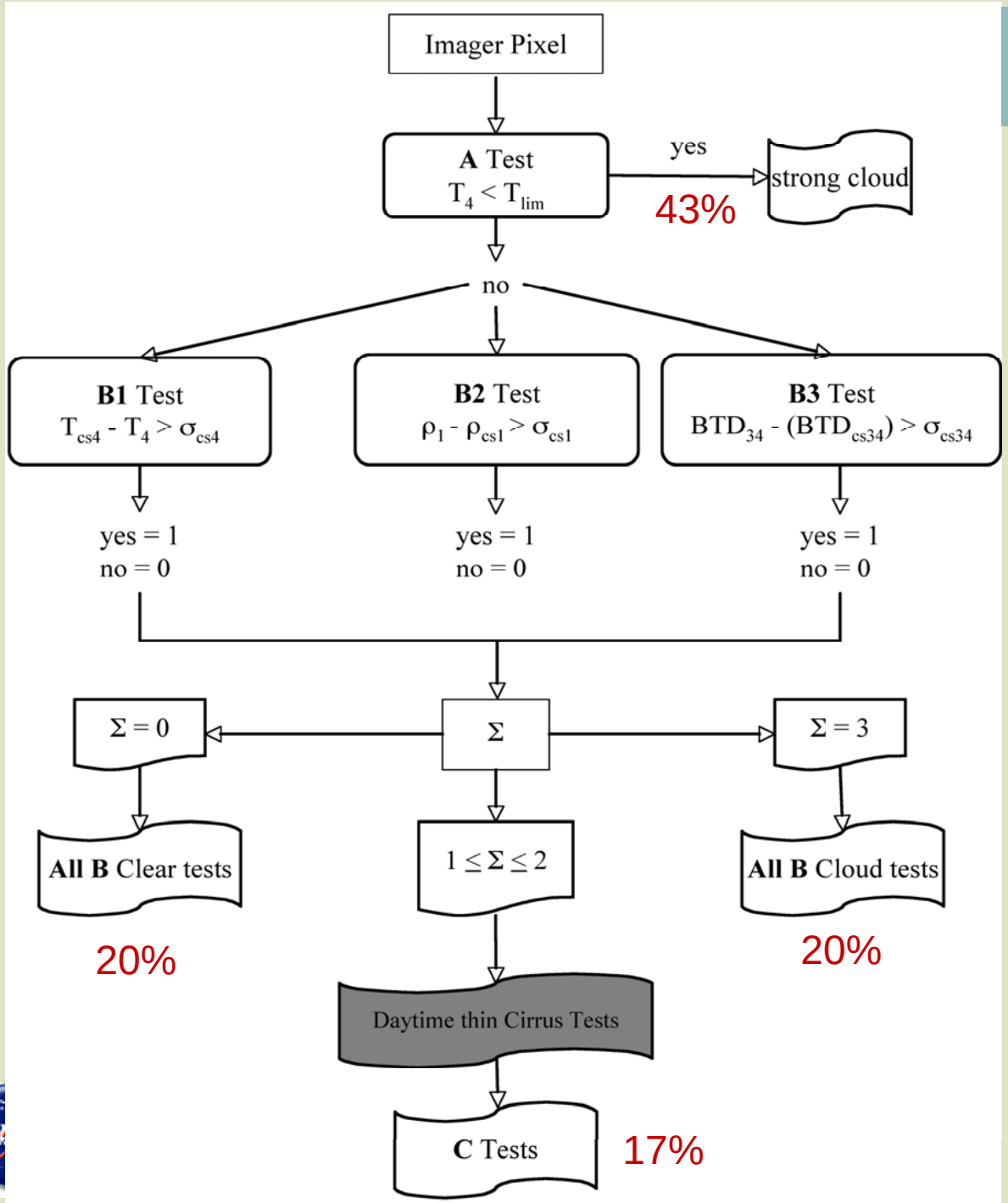
- Data are available from http://eosweb.larc.nasa.gov/PRODOCS/ceres-news/table_ceres-news.html





Cloud Mask

Daytime Cloud Mask
(Minnis et al., TGRS, 2008)

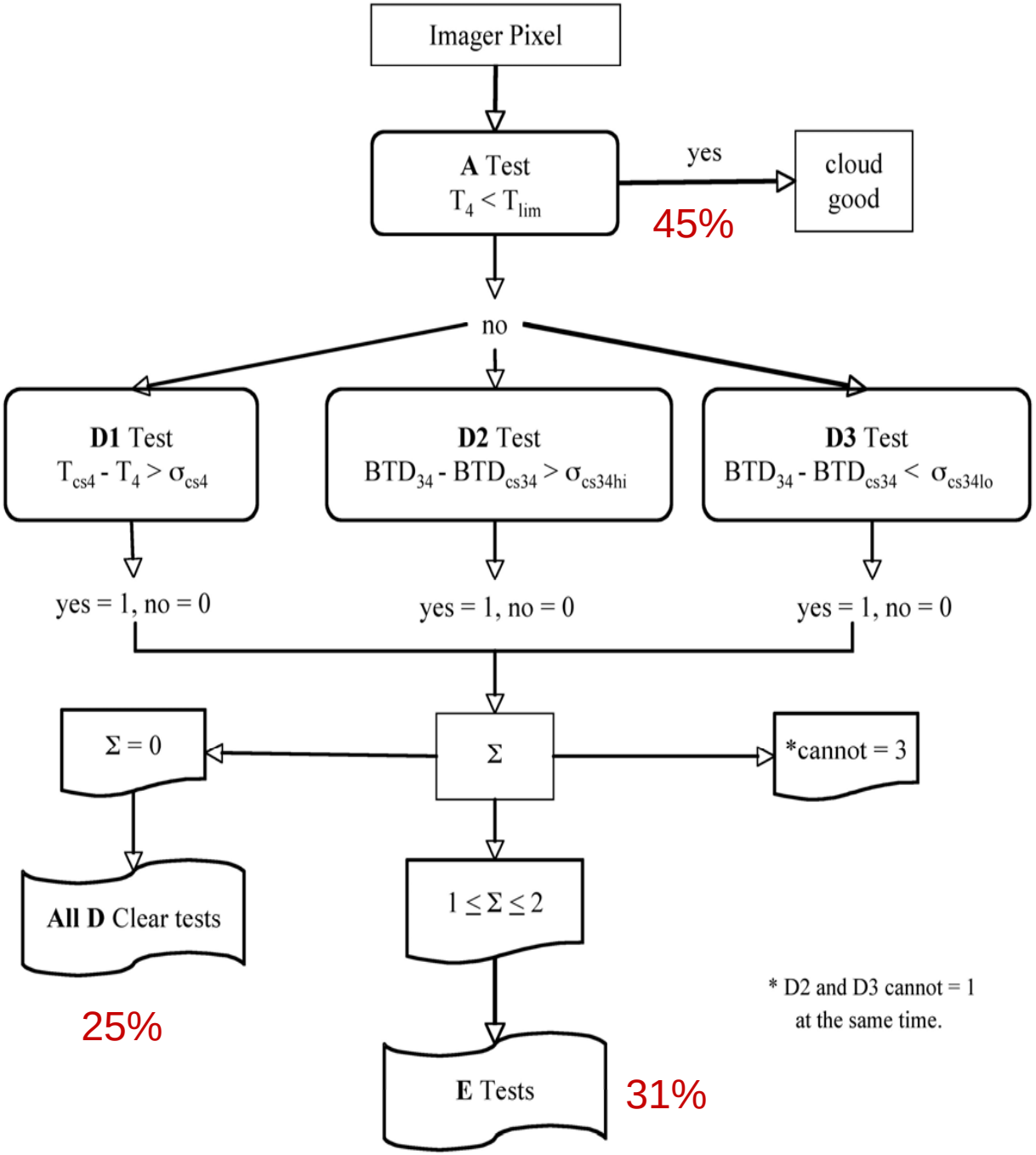


A Test:
- T_{lim} = very unlikely brightness temp for scene

B Tests:
- thresholds above expected clear-sky radiances at 0.65, 3.8, 10.8 μm

Thin Ci Tests:
- thresholds based on 1.38-μm reflectance & 12-μm temp

C Tests:
- refined thresholds for 0.65, 3.8, 10.8 μm radiances



Night time Cloud Mask

(*Minnis et al., TGRS, 2008)*

A Test:

- T_{lim} = very unlikely brightness temp for scene

D Tests:

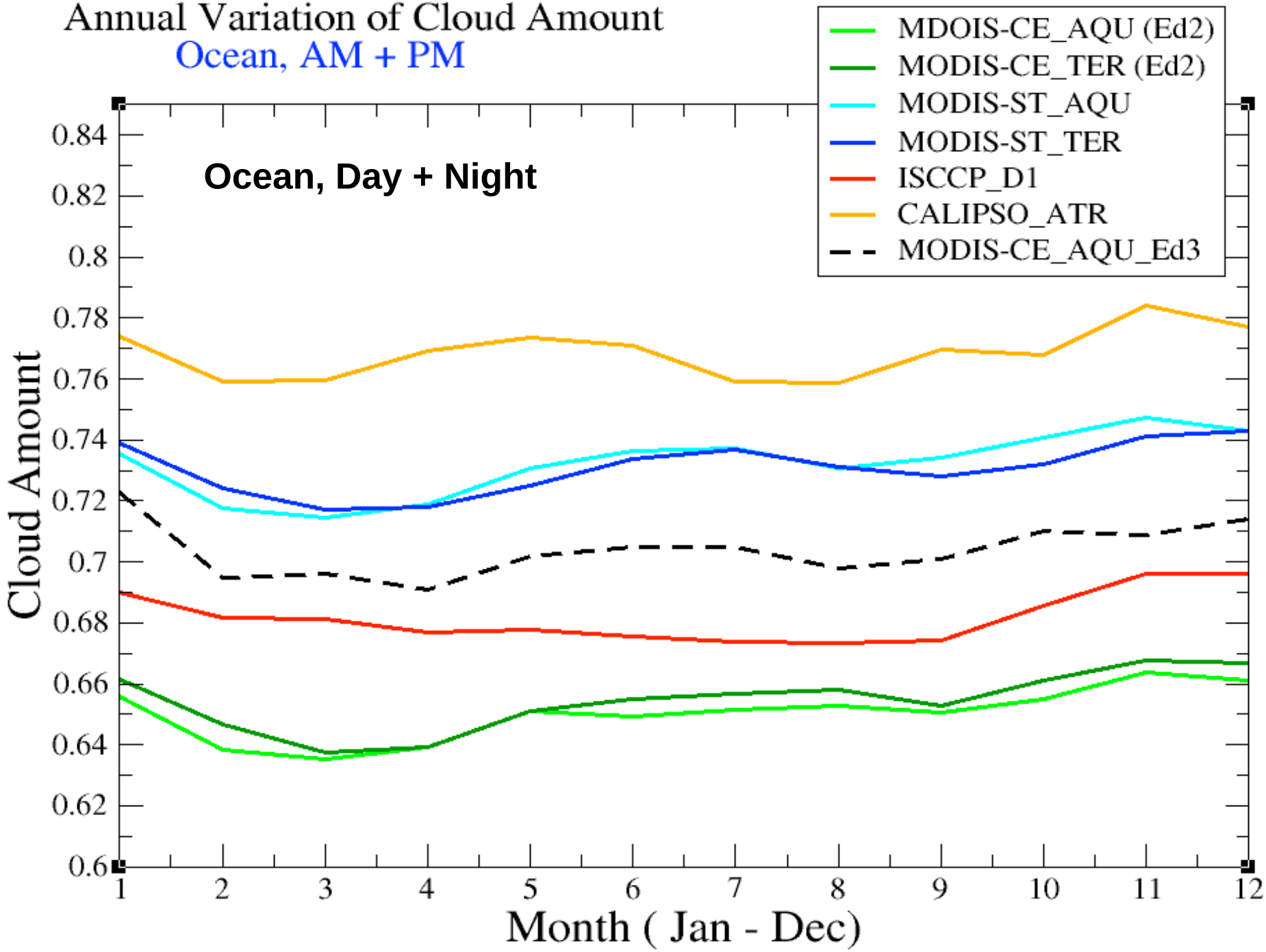
- thresholds above or below expected clear - sky radiances at 3.8 & 10.8 μm

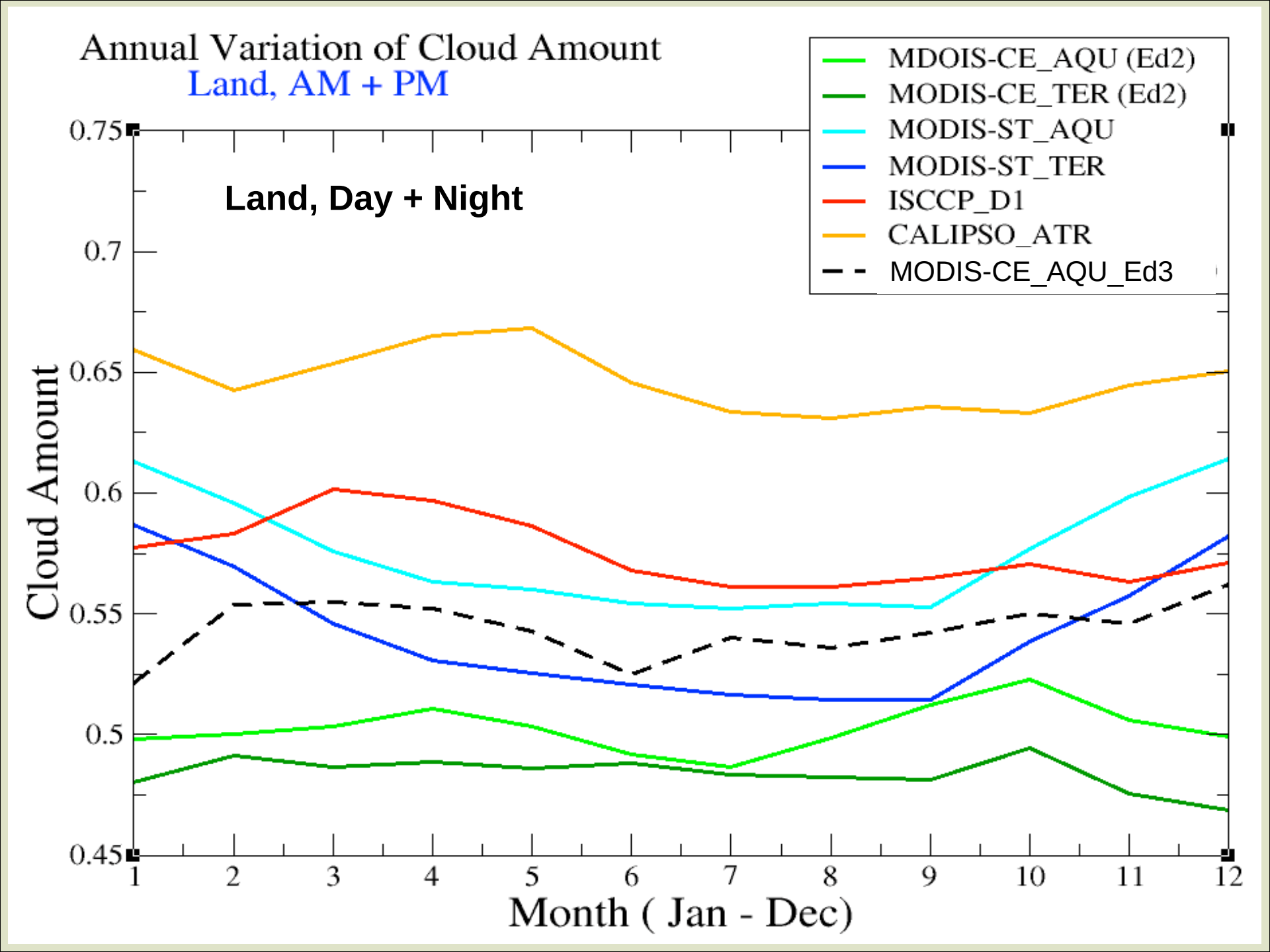
E Tests:

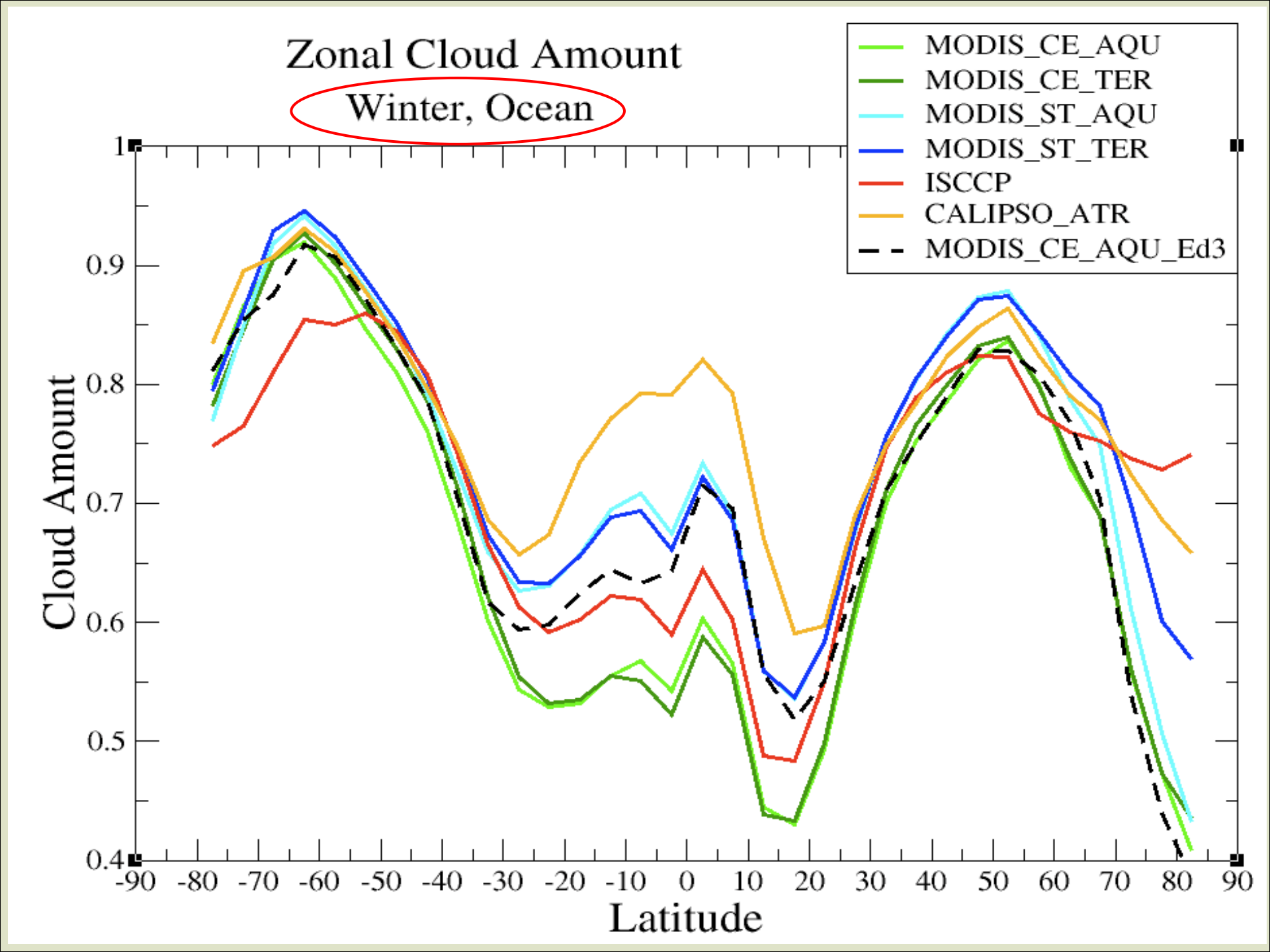
- refined thresholds for 3.8, 10.8, 12-μm radiances

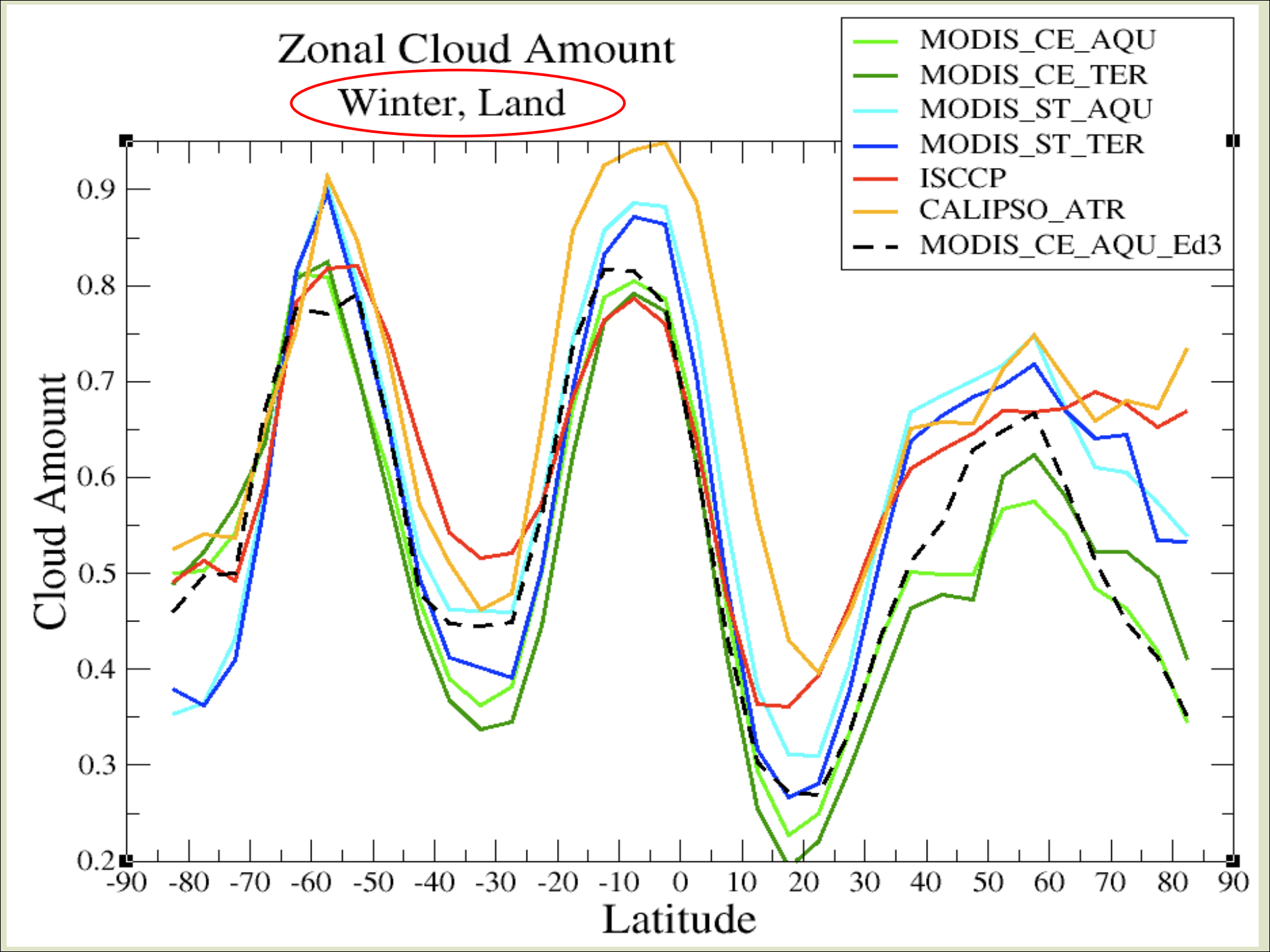
Comparison Results

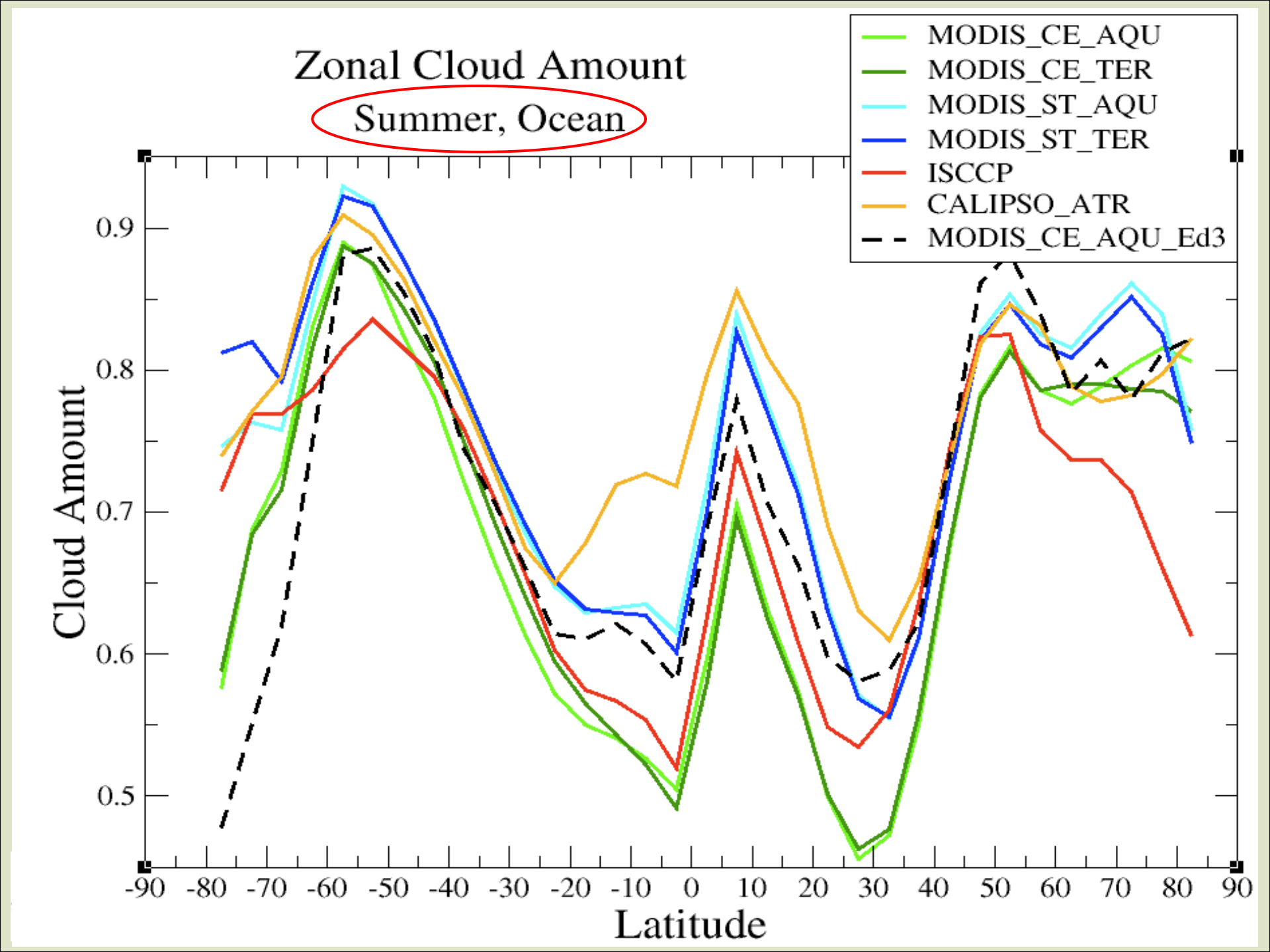
(CALIPSO-ATR, ISCCP-D1, MODIS-CE, MODIS-ST, MODIS-CE-AQU-Ed3)

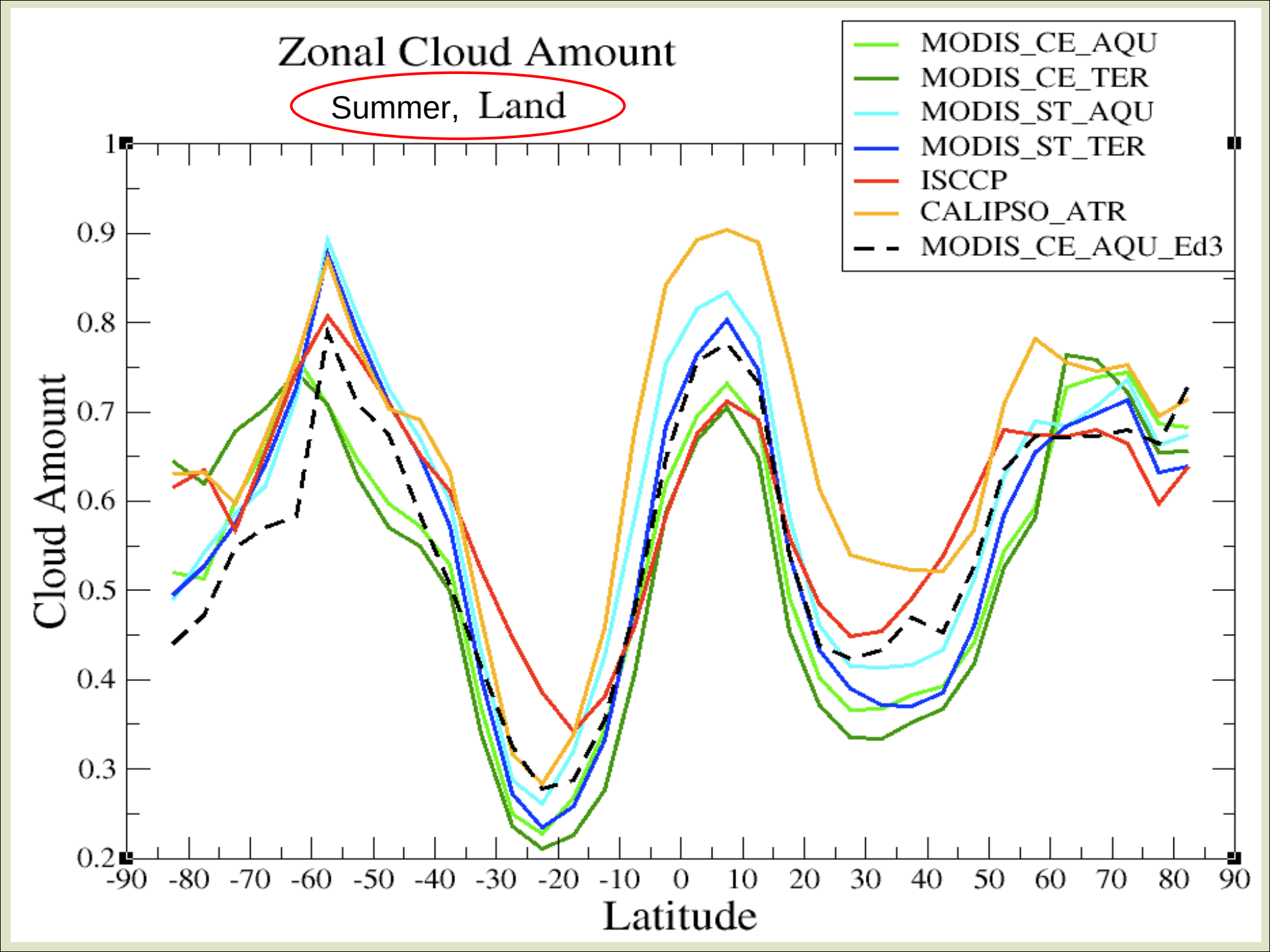

Annual Variation of Cloud Amount
Ocean, AM + PM
Ocean, Day + Night
MDOIS-CE_AQU (Ed2)
MODIS-CE_TER (Ed2)
MODIS-ST_AQU
MODIS-ST_TER
ISCCP_D1
CALIPSO_ATR
MODIS-CE_AQU_Ed3
Cloud Amount
0.84
0.82
0.8
0.78
0.76
0.74
0.72
0.7
0.68
0.66
0.64
0.62
0.6
1
2
3
4
5
6
7
8
9
10
11
12
Month (Jan - Dec)


Annual Variation of Cloud Amount
Land, AM + PM
Land, Day + Night
MDOIS-CE_AQU (Ed2)
MODIS-CE_TER (Ed2)
MODIS-ST_AQU
MODIS-ST_TER
ISCCP_D1
CALIPSO_ATR
MODIS-CE_AQU_Ed3
Cloud Amount
0.75
0.7
0.65
0.6
0.55
0.5
0.45
1
2
3
4
5
6
7
8
9
10
11
12
Month (Jan - Dec)


Zonal Cloud Amount
Winter, Ocean
MODIS_CE_AQU
MODIS_CE_TER
MODIS_ST_AQU
MODIS_ST_TER
ISCCP
CALIPSO_ATR
MODIS_CE_AQU_Ed3
Cloud Amount
1
0.9
0.8
0.7
0.6
0.5
0.4
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90
Latitude


Zonal Cloud Amount
Winter, Land
MODIS_CE_AQU
MODIS_CE_TER
MODIS_ST_AQU
MODIS_ST_TER
ISCCP
CALIPSO_ATR
MODIS_CE_AQU_Ed3
Cloud Amount
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90
Latitude


Zonal Cloud Amount
Summer, Ocean
MODIS_CE_AQU
MODIS_CE_TER
MODIS_ST_AQU
MODIS_ST_TER
ISCCP
CALIPSO_ATR
MODIS_CE_AQU_Ed3
Cloud Amount
0.9
0.8
0.7
0.6
0.5
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90
Latitude


Zonal Cloud Amount
Summer, Land
MODIS_CE_AQU
MODIS_CE_TER
MODIS_ST_AQU
MODIS_ST_TER
ISCCP
CALIPSO_ATR
MODIS_CE_AQU_Ed3
Cloud Amount
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90
Latitude

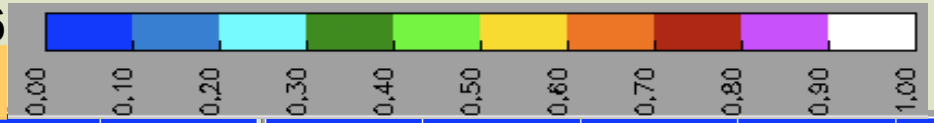
Comparison Results

(CALIPSO and MODIS-CE_Ed3 (C3M))

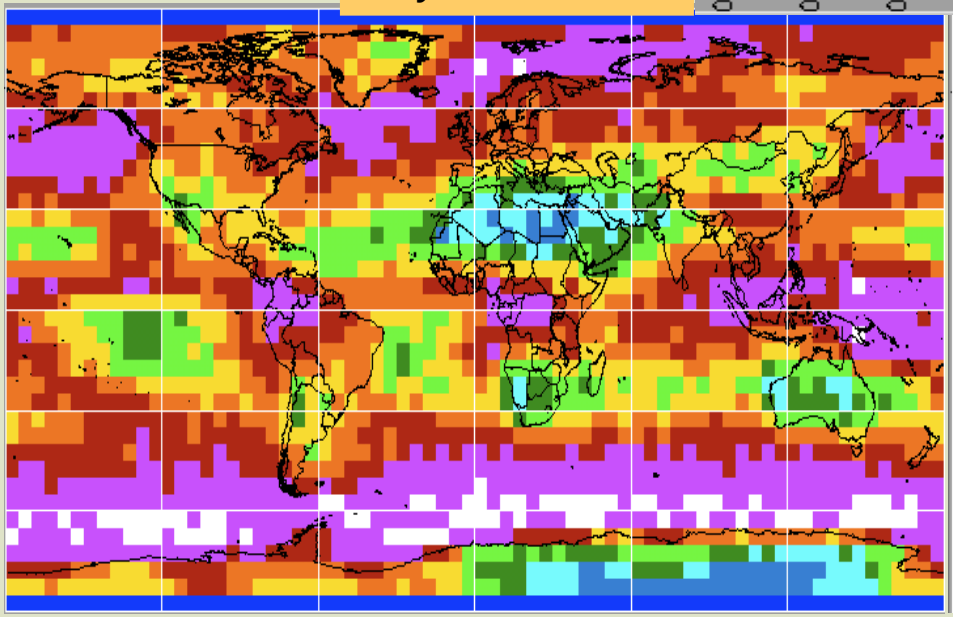
Cloud Amount, 200607-200706

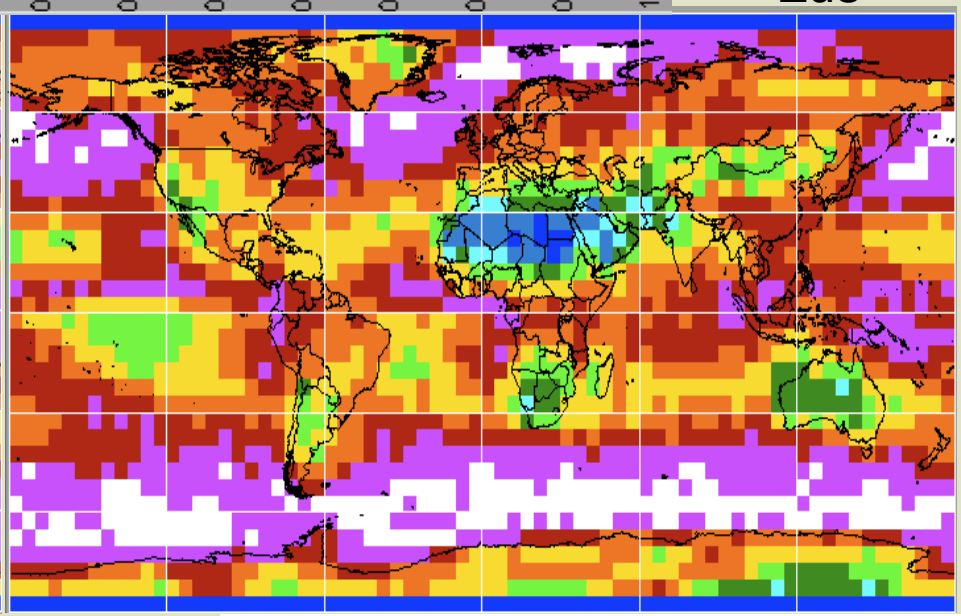
CALIPSO

Day Time, C3M

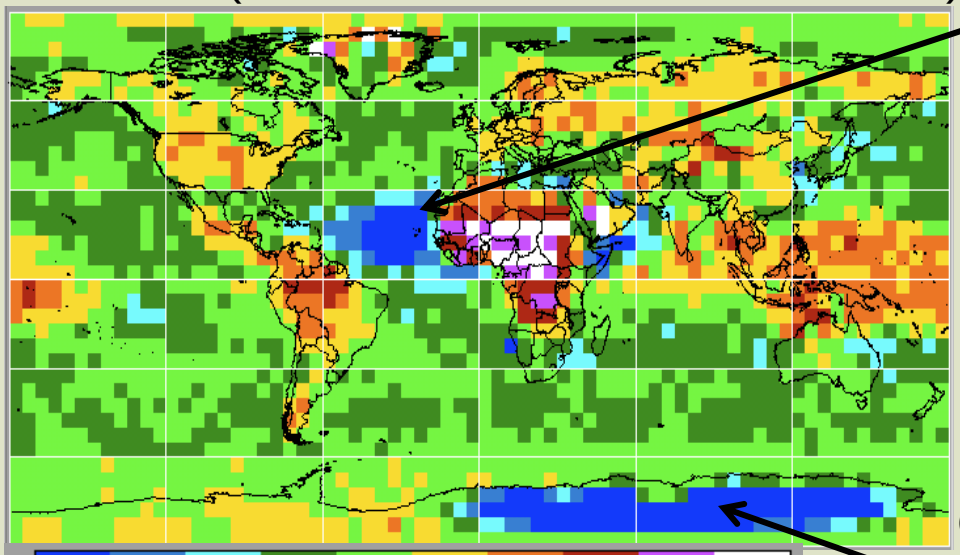


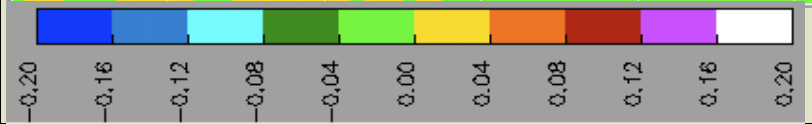
MODIS-CE Ed3





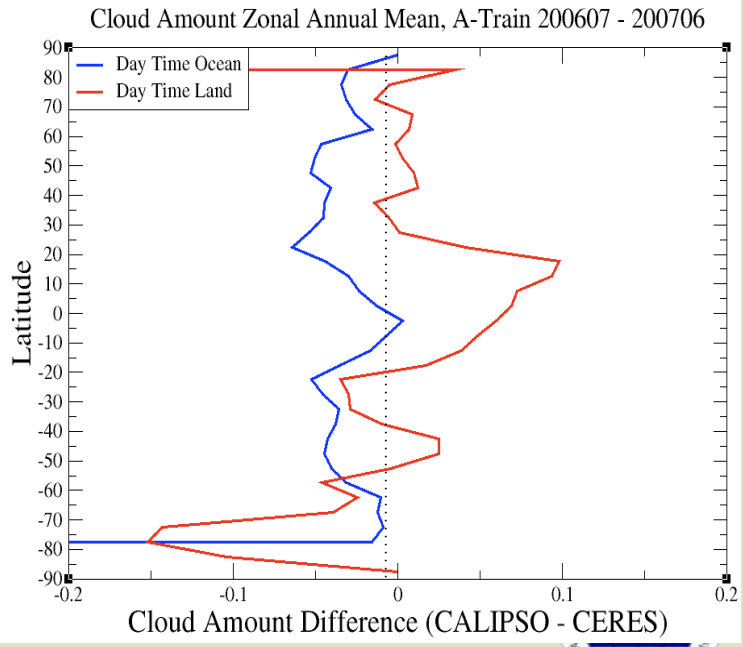
Diff of CA (CALIPSO minus MODIS-CE-Ed3)





CERES calls dust clouds?

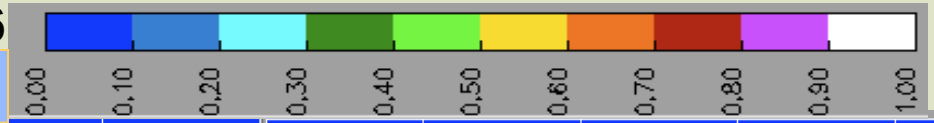
CERES over-detect clouds



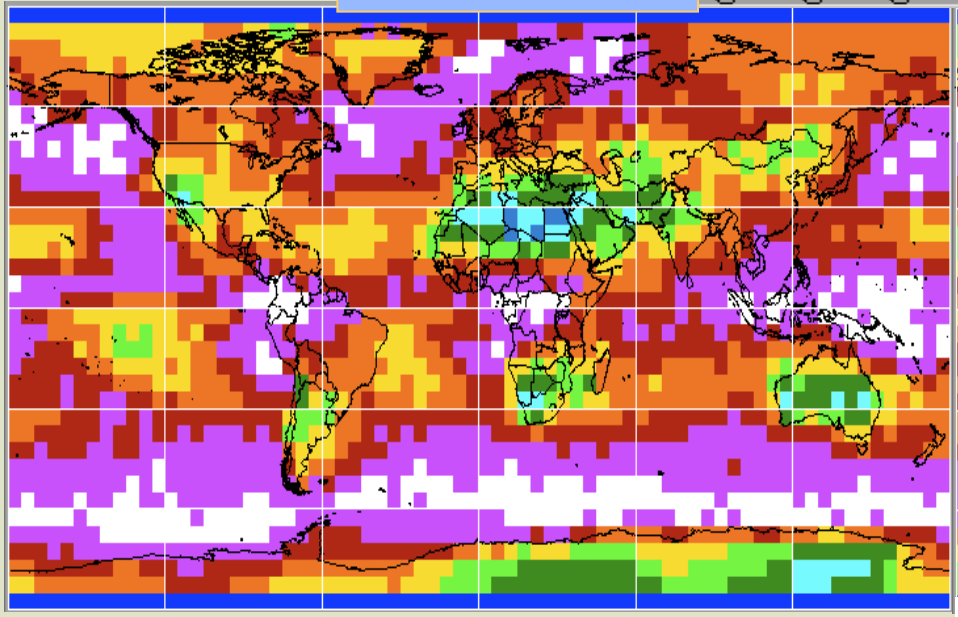
Cloud Amount, 200607-200706

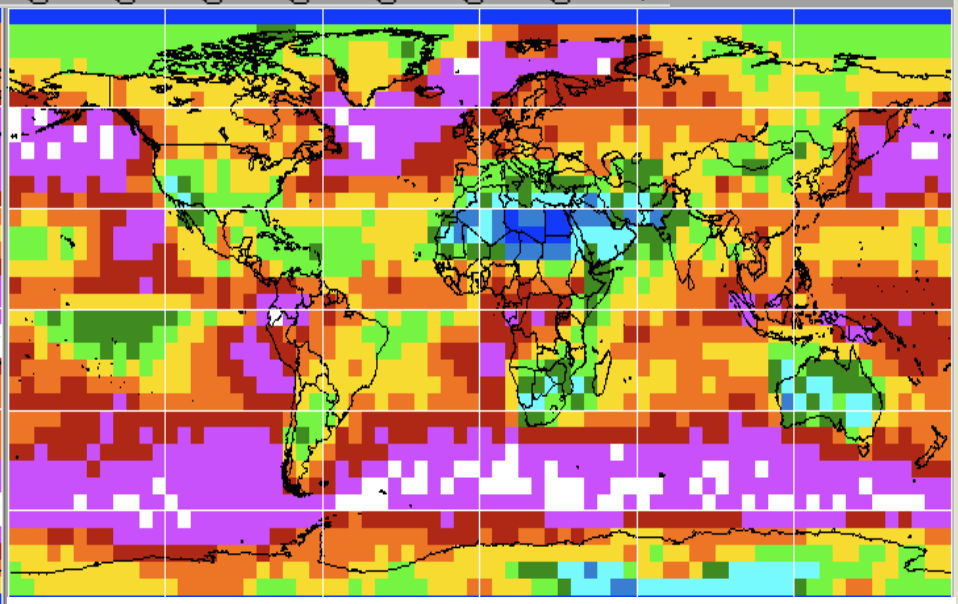
CALIPSO

Night Time, C3M

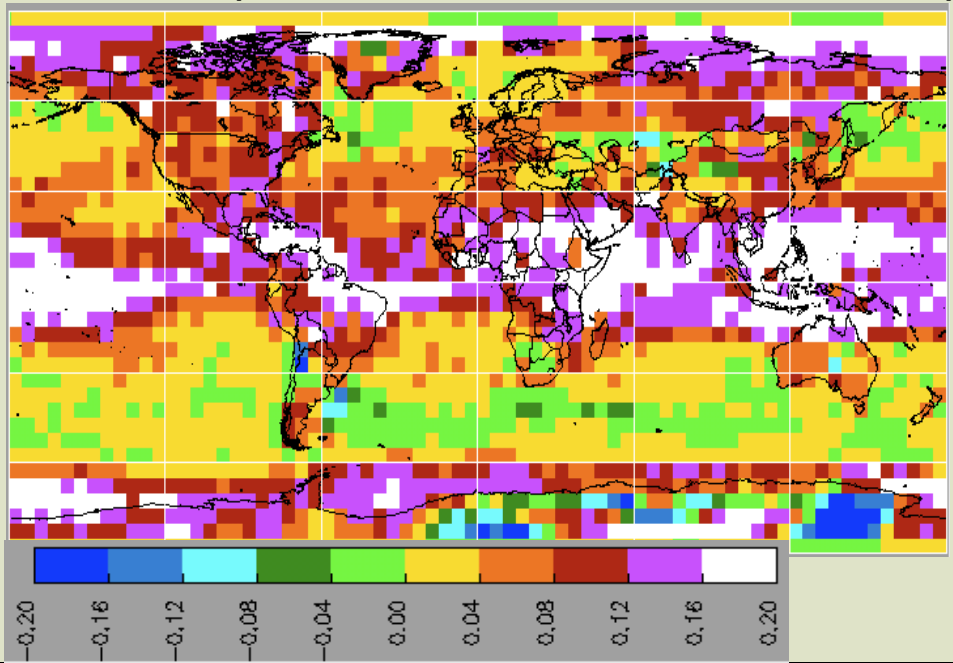


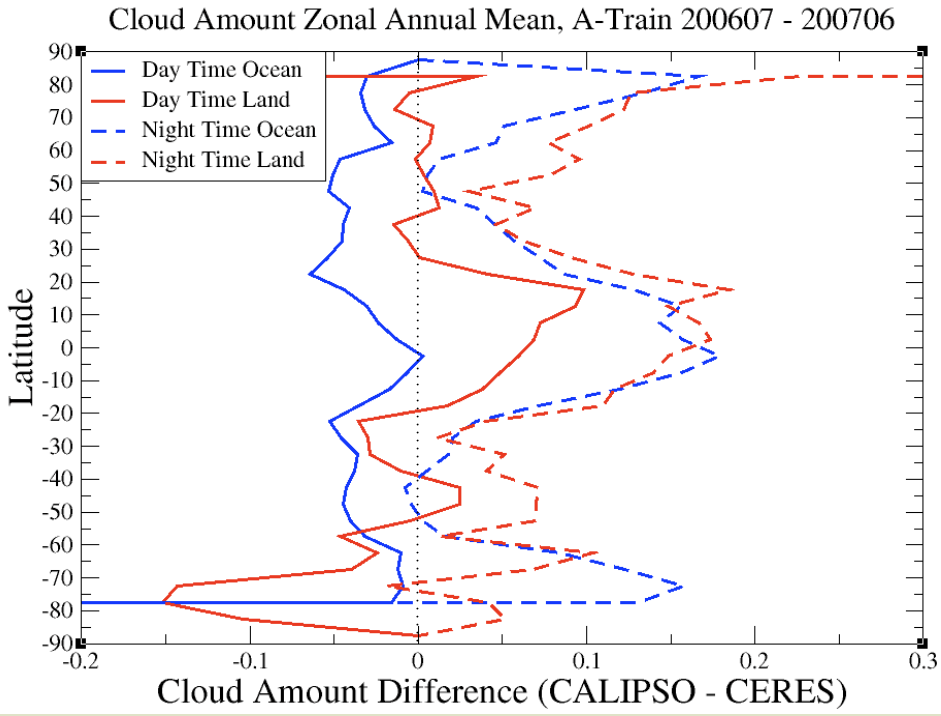
MODIS-CE Ed3





Diff of CA (CALIPSO minus MODIS-CE-Ed3)

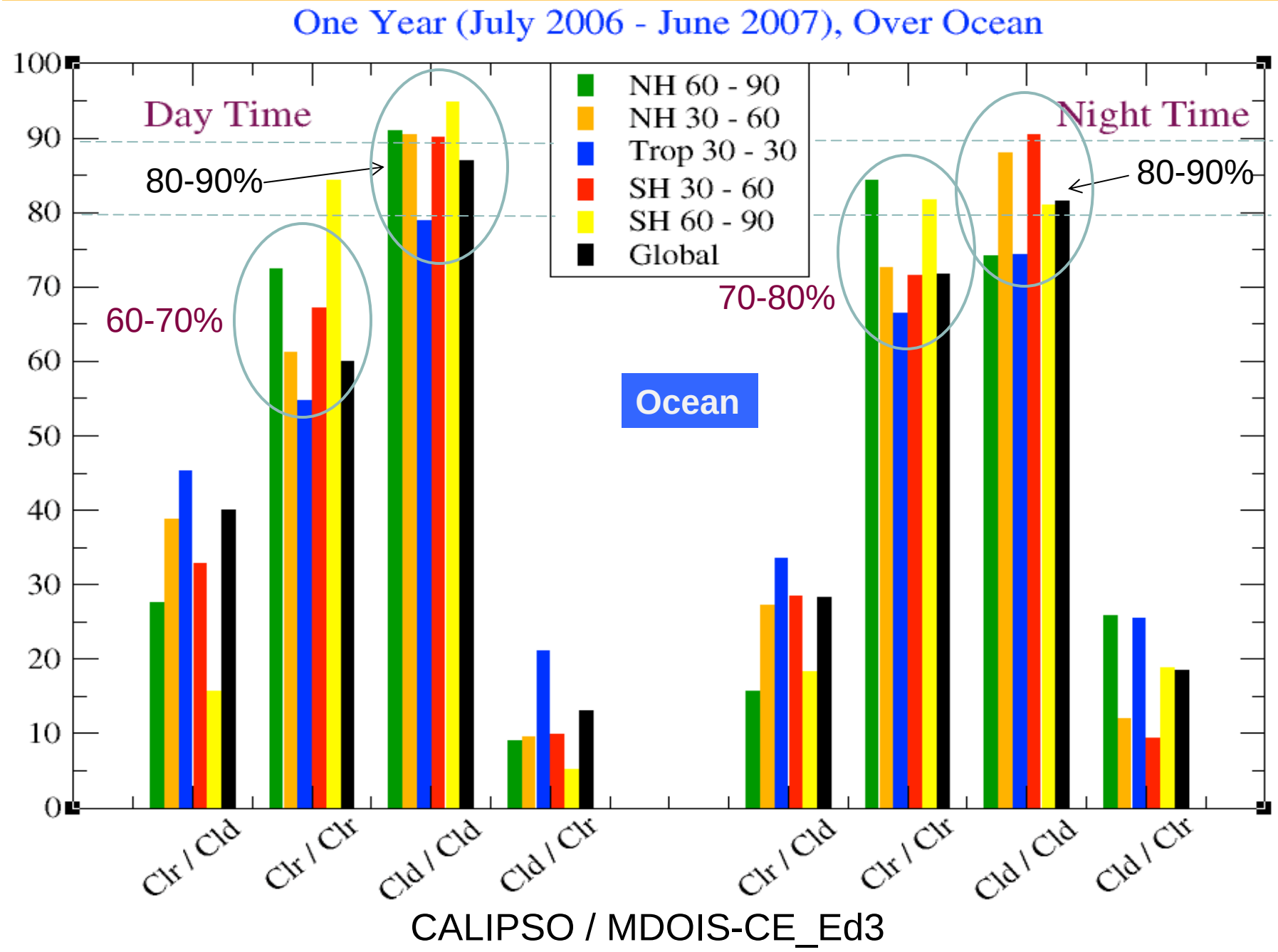




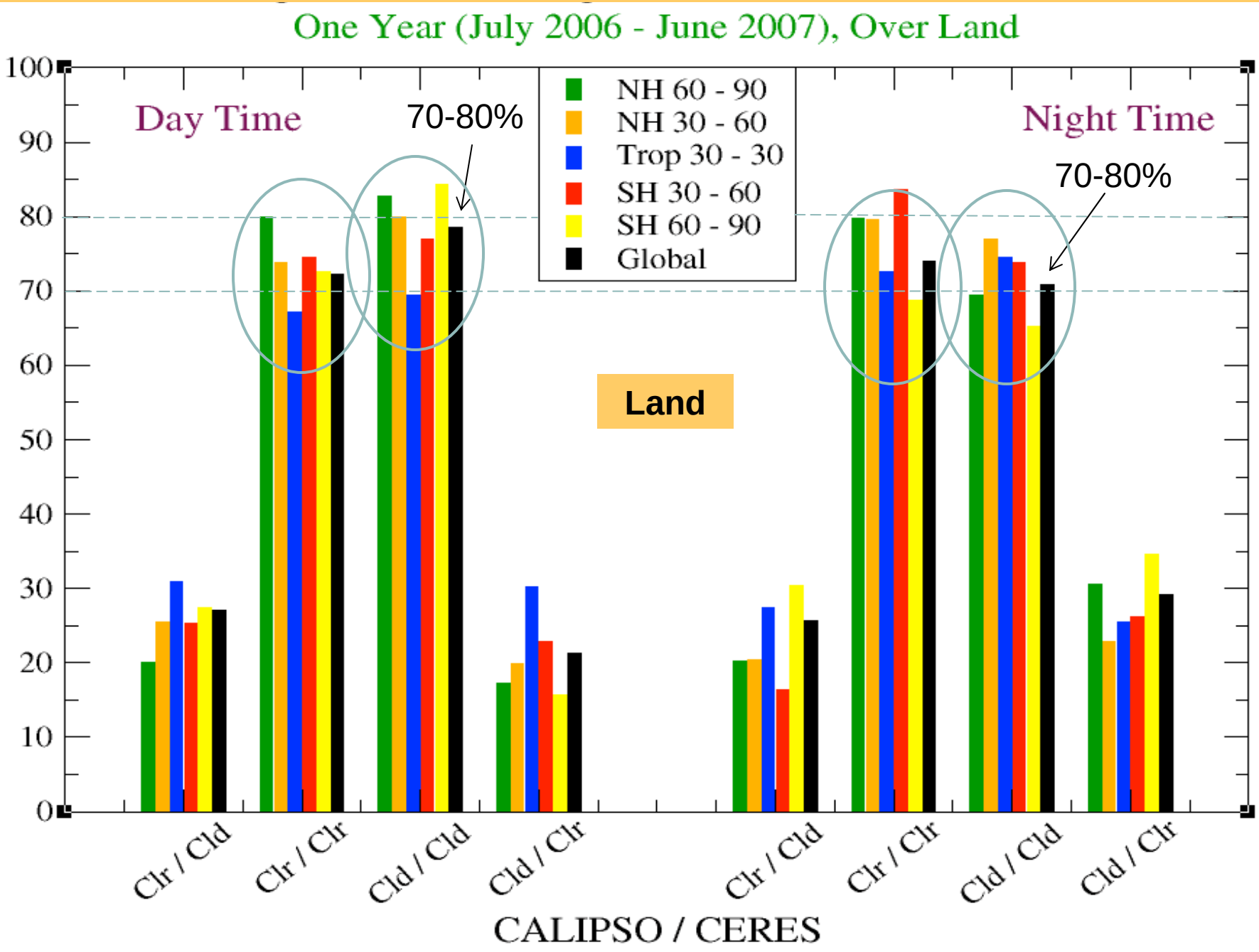
Cloud / Clear Detection Agreement between CALIPSO & MODIS-CE_Ed3

(CALIPSO and MODIS-CE_Ed3 (C3M))

Cloud / Clear Agreement and Disagreement (%) Between CALIPSO and MODIS-CE Ed3



Cloud / Clear Agreement and Disagreement (%) Between CALIPSO and MODIS-CE Ed3



Percent of Correct Classification including Clear / Clear and Cloud / Cloud (CALIPSO/MODIS-CE-Ed3)

July 2006 - June 2007, Ed3

MODIS-CE-Ed3 Correct Classification (%) =
CALIPSO CA x cld / cld frac + CALIPSO (1-CA) x clr / clr frac

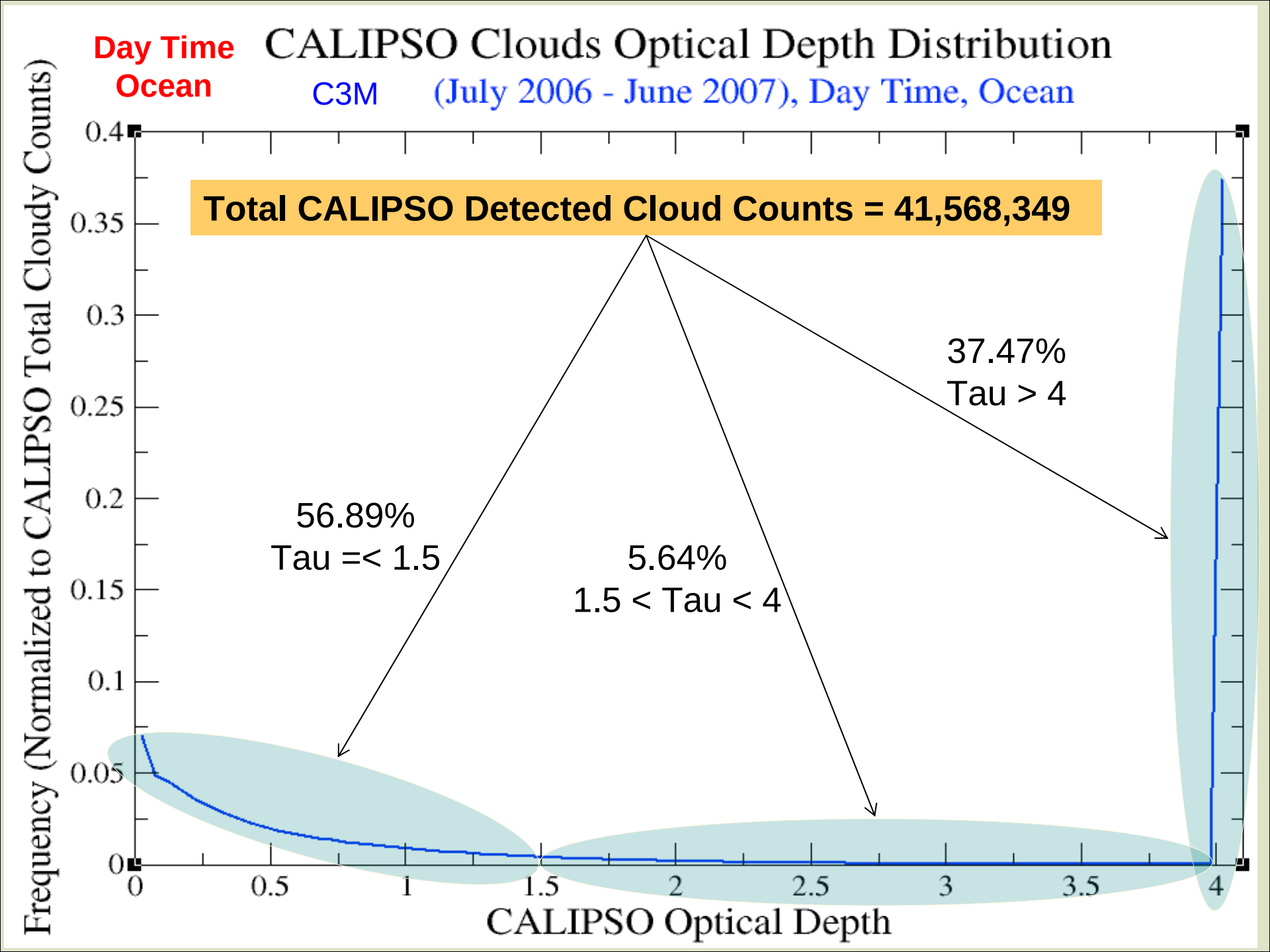
	Day Time		Night Time	
Zone	Ocean	Land	Ocean	Land
60N - 90N	87.09	81.96	76.59	72.41
30N - 60N	83.15	77.73	84.77	78.08
30N - 30S	69.30	68.40	71.78	73.55
30S - 60S	86.52	75.90	88.02	78.84
60S - 90S	93.86	78.81	81.14	66.79
Global	79.70	76.02	79.28	72.20

Cloud Detection as a Function of Optical Depth

Day Time
Ocean

CALIPSO Clouds Optical Depth Distribution

C3M (July 2006 - June 2007), Day Time, Ocean



Optical Depth Distribution for All CALIPSO Detected Cloud Counts
C3M July 2006- June 2007

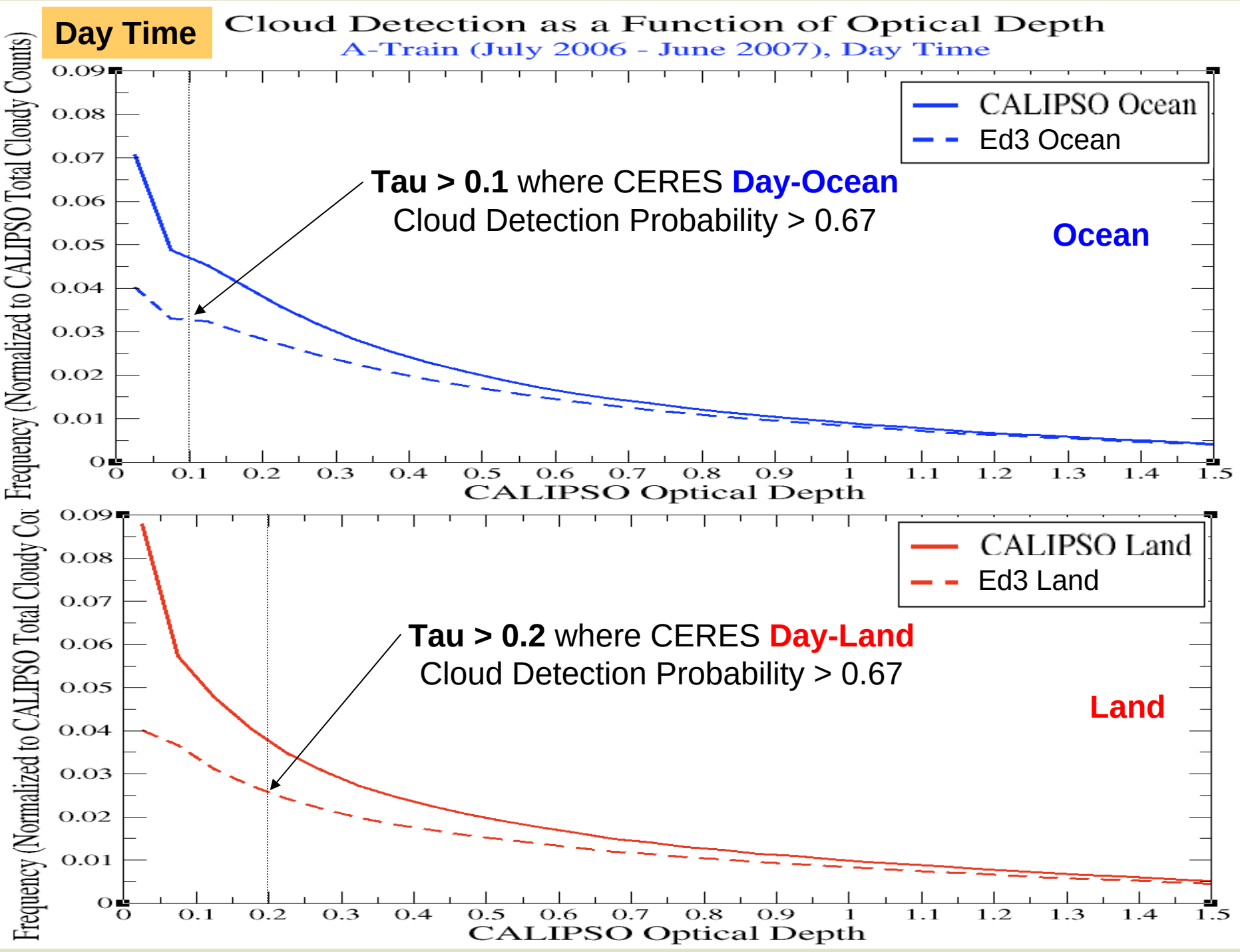
Day Time

	Ocean	Land
Opt. Depth	41,568,349	17,128,153
Tau < 1.5	56.89 %	60.72 %
1.5 < Tau < 4	5.64 %	7.28 %
Tau > 4	37.47 %	32.0 %

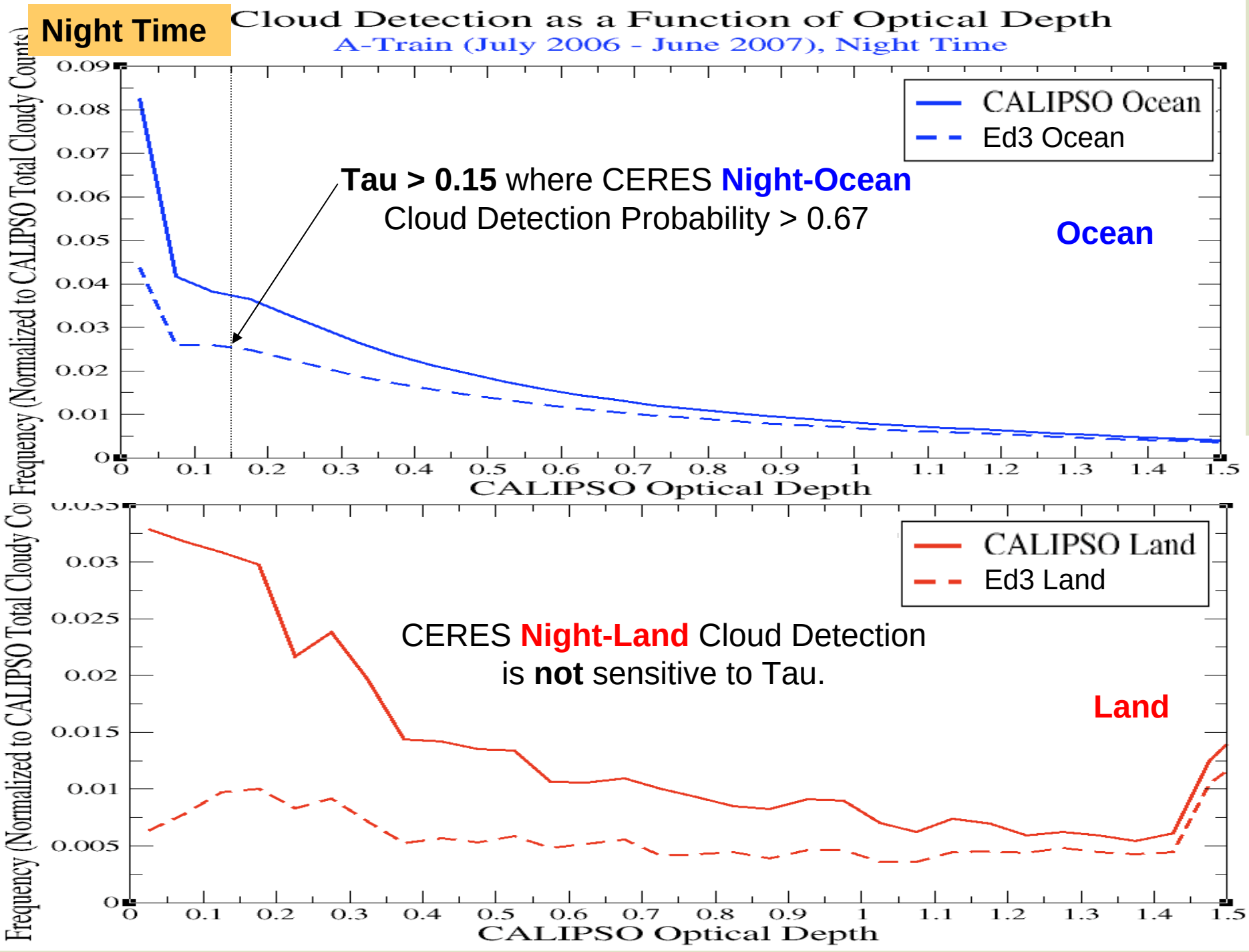
Night Time

	Ocean	Land
Opt. Depth	49,496,153	21,067,483
Tau < 1.5	53.38 %	61.83 %
1.5 < Tau < 4	5.26 %	7.45 %
Tau > 4	41.36 %	30.72 %

Day Time


Cloud Detection as a Function of Optical Depth
A-Train (July 2006 - June 2007), Day Time
Frequency (Normalized to CALIPSO Total Cloudy Counts)
CALIPSO Ocean
Ed3 Ocean
Tau > 0.1 where CERES Day-Ocean
Cloud Detection Probability > 0.67
Ocean
CALIPSO Optical Depth
Frequency (Normalized to CALIPSO Total Cloudy Cou
CALIPSO Land
Ed3 Land
Tau > 0.2 where CERES Day-Land
Cloud Detection Probability > 0.67
Land
CALIPSO Optical Depth

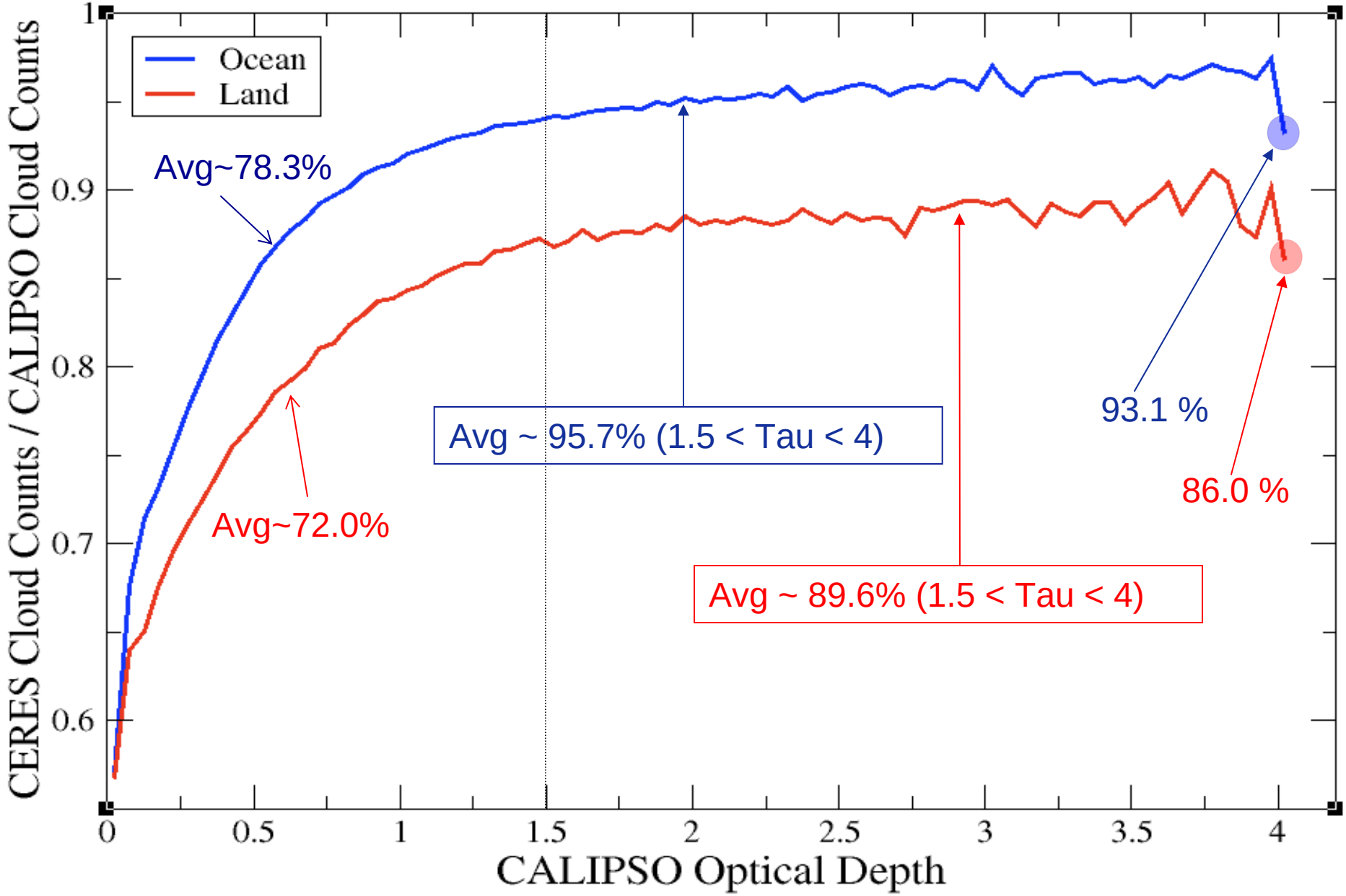
Night Time

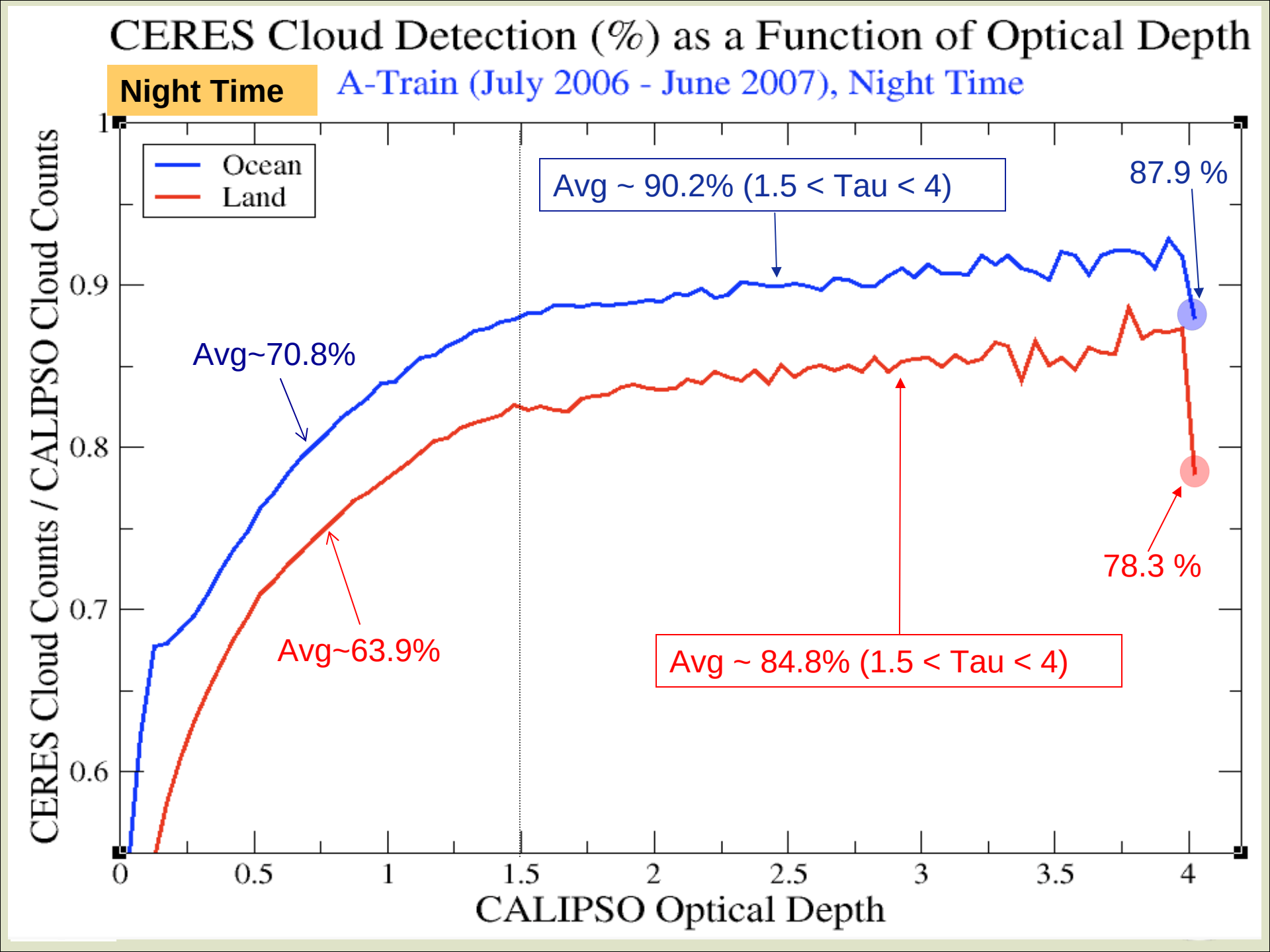

Cloud Detection as a Function of Optical Depth
A-Train (July 2006 - June 2007), Night Time
Frequency (Normalized to CALIPSO Total Cloudy Counts)
CALIPSO Optical Depth
CALIPSO Ocean
Ed3 Ocean
Tau > 0.15 where CERES Night-Ocean
Cloud Detection Probability > 0.67
Ocean
CALIPSO Land
Ed3 Land
CERES Night-Land Cloud Detection
is not sensitive to Tau.
Land

CERES Cloud Detection (%) as a Function of Optical Depth

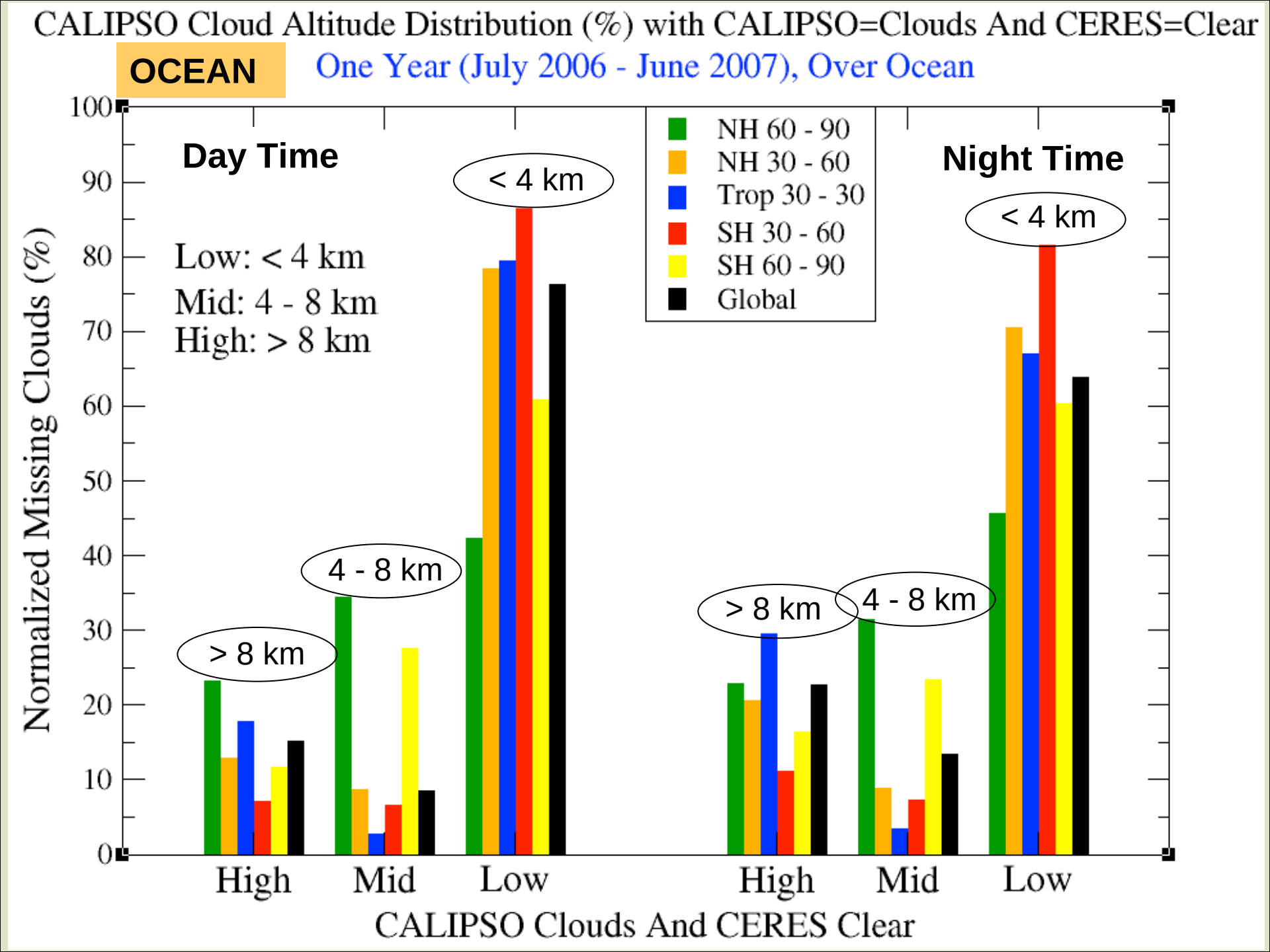
Day Time

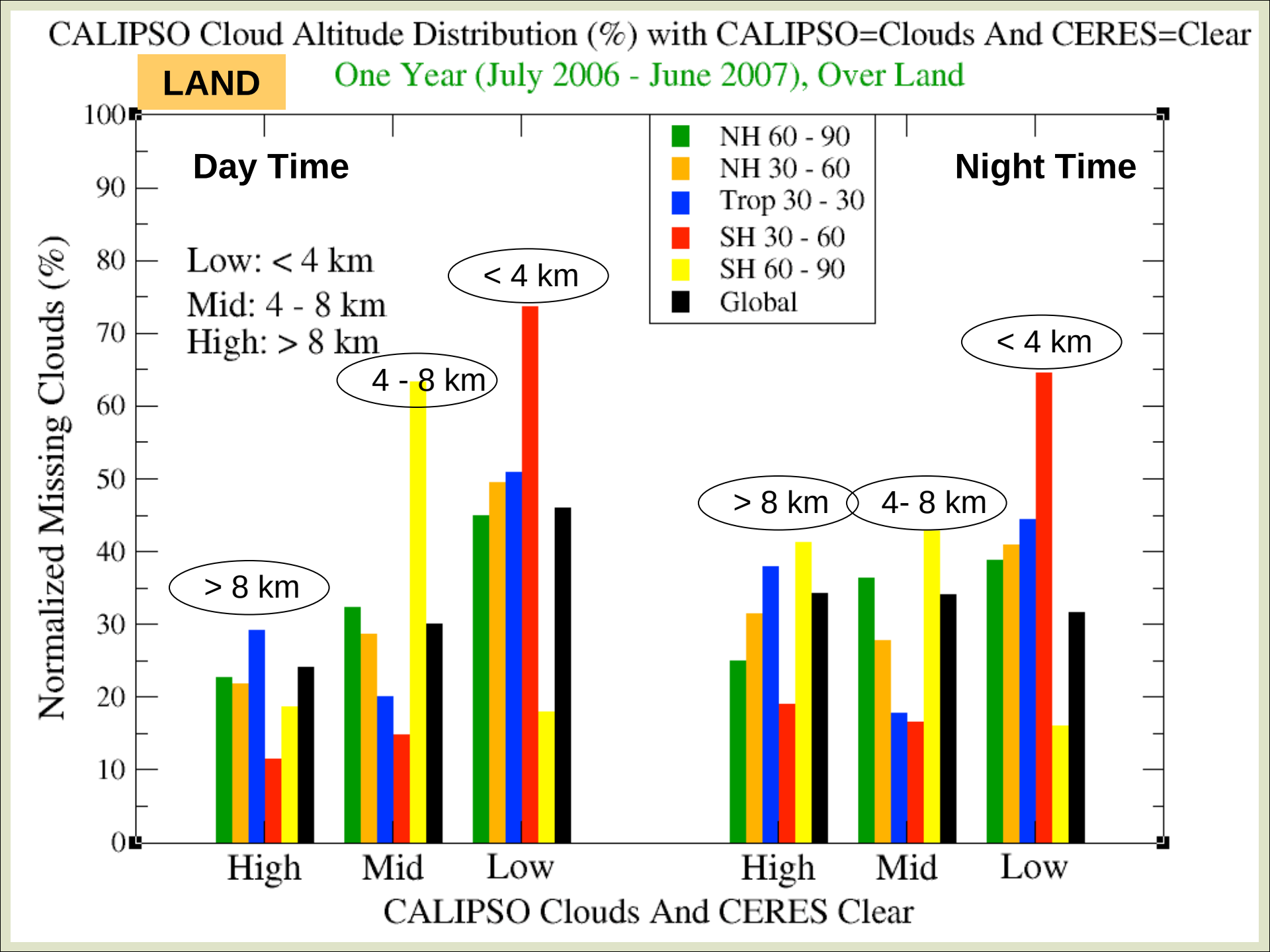
A-Train (July 2006 - June 2007), Day Time




CERES Cloud Detection (%) as a Function of Optical Depth
Night Time
A-Train (July 2006 - June 2007), Night Time
Ocean
Land
Avg ~ 90.2% (1.5 < Tau < 4)
87.9 %
Avg~70.8%
Avg~63.9%
78.3 %
Avg ~ 84.8% (1.5 < Tau < 4)
CERES Cloud Counts / CALIPSO Cloud Counts
CALIPSO Optical Depth
1
0.9
0.8
0.7
0.6
0
0.5
1
1.5
2
2.5
3
3.5
4

Missing Clouds Distribution as a Function of Cloud Height


CALIPSO Cloud Altitude Distribution (%) with CALIPSO=Clouds And CERES=Clear
OCEAN
One Year (July 2006 - June 2007), Over Ocean
Day Time
Night Time
Low: < 4 km
Mid: 4 - 8 km
High: > 8 km
NH 60 - 90
NH 30 - 60
Trop 30 - 30
SH 30 - 60
SH 60 - 90
Global
< 4 km
4 - 8 km
> 8 km
> 8 km
4 - 8 km
< 4 km
Normalized Missing Clouds (%)
100
90
80
70
60
50
40
30
20
10
0
High
Mid
Low
High
Mid
Low
CALIPSO Clouds And CERES Clear


CALIPSO Cloud Altitude Distribution (%) with CALIPSO=Clouds And CERES=Clear
LAND
One Year (July 2006 - June 2007), Over Land
Day Time
Night Time
Low: < 4 km
Mid: 4 - 8 km
High: > 8 km
NH 60 - 90
NH 30 - 60
Trop 30 - 30
SH 30 - 60
SH 60 - 90
Global
< 4 km
4 - 8 km
> 8 km
> 8 km
4- 8 km
< 4 km
Normalized Missing Clouds (%)
100
90
80
70
60
50
40
30
20
10
0
High
Mid
Low
High
Mid
Low
CALIPSO Clouds And CERES Clear

Non Polar (60 S - 60 N)

High Cloud (> 8 km)

CERES \ Calipso	Cloudy	Clear
Cloudy	0.87	0.39
Clear	0.13	0.61

Mid Cloud (4 - 8 km)

	Cloudy	Clear
Cloudy	0.80	0.29
Clear	0.20	0.71

Low Cloud (< 4 km)

	Cloudy	Clear
Cloudy	0.94	0.44
Clear	0.06	0.56

Polar (60S - 90S, 60N - 90N)

CERES \ Calipso	Cloudy	Clear
Cloudy	0.93	0.22
Clear	0.07	0.78

	Cloudy	Clear
Cloudy	0.93	0.29
Clear	0.07	0.71

	Cloudy	Clear
Cloudy	0.93	0.22
Clear	0.07	0.78

Day Time , Ocean, MODIS-CE-AQU-Ed3, July 2006 - June 2007

Cloud Fraction Summary

- When cloud fraction is calculated independently (or alone by itself), compared with CALIPSO, CERES (MODIS-CE_ED3)
  - overestimate ~ 3.4 % for day time ocean
  - overestimate ~ 1.6 % for day time land
  - underestimate ~ 7.5 % for night time ocean
  - underestimate ~ 9.5 % for night time land

- CERES cloud detection optical depth thresholds are:
  - tau: 0.1 for day time ocean
  - tau: 0.2 for day time land
  - tau: 0.15 for night time ocean
  - cloud detection not sensitive to tau until tau > 1.45 for night time land

- Out of all the missing clouds,
  - 82 % having tau < 1.5, day time ocean
  - 84 % having tau < 1.5, night time ocean
  - 76 % having tau < 1.5, for both day and night, land

Cloud Fraction Summary Cont'

- Percent of correct classification including clear/clear and cloud/cloud between CALIPSO and CERES (MODIS-CE_Ed3):
  - 79.70% ocean, day
  - 76.02% land, day
  - 79.28% ocean, night
  - 72.20% land, night
    - main problem is high mis-match for CERES clouds when CALIPSO clear
      - 15.7% ocean, day
      - 27.3% land, day
      - 18.4% ocean, night
      - 30.4% land, night

- Most of the clouds CERES (MODIS-CE_ed3) misses are low clouds.

Cloud Temperature and Height

Cloud Effective Temperature and Height

(Minnis et al., JCAM, 1985, JAM, 1992; TGRS, 2009 (submitted))

Observed 11-μm radiance: $L = (1- \varepsilon) L_s + \varepsilon L_{eff}$

Corresponding effective cloud temperature: $T_{eff} = B^{-1}(L_{eff})$

Effective cloud height for high clouds: $Z_{eff} = Z(T_{eff})$

Z(T) - sounding from GMAO GEOS 4.03

For low clouds: $Z_{eff} = (T_{eff} - T_o) / \Gamma + Z_o$

Z_o = surface height above sea level, T_o = skin temp , Γ = lapse rate (K/km)

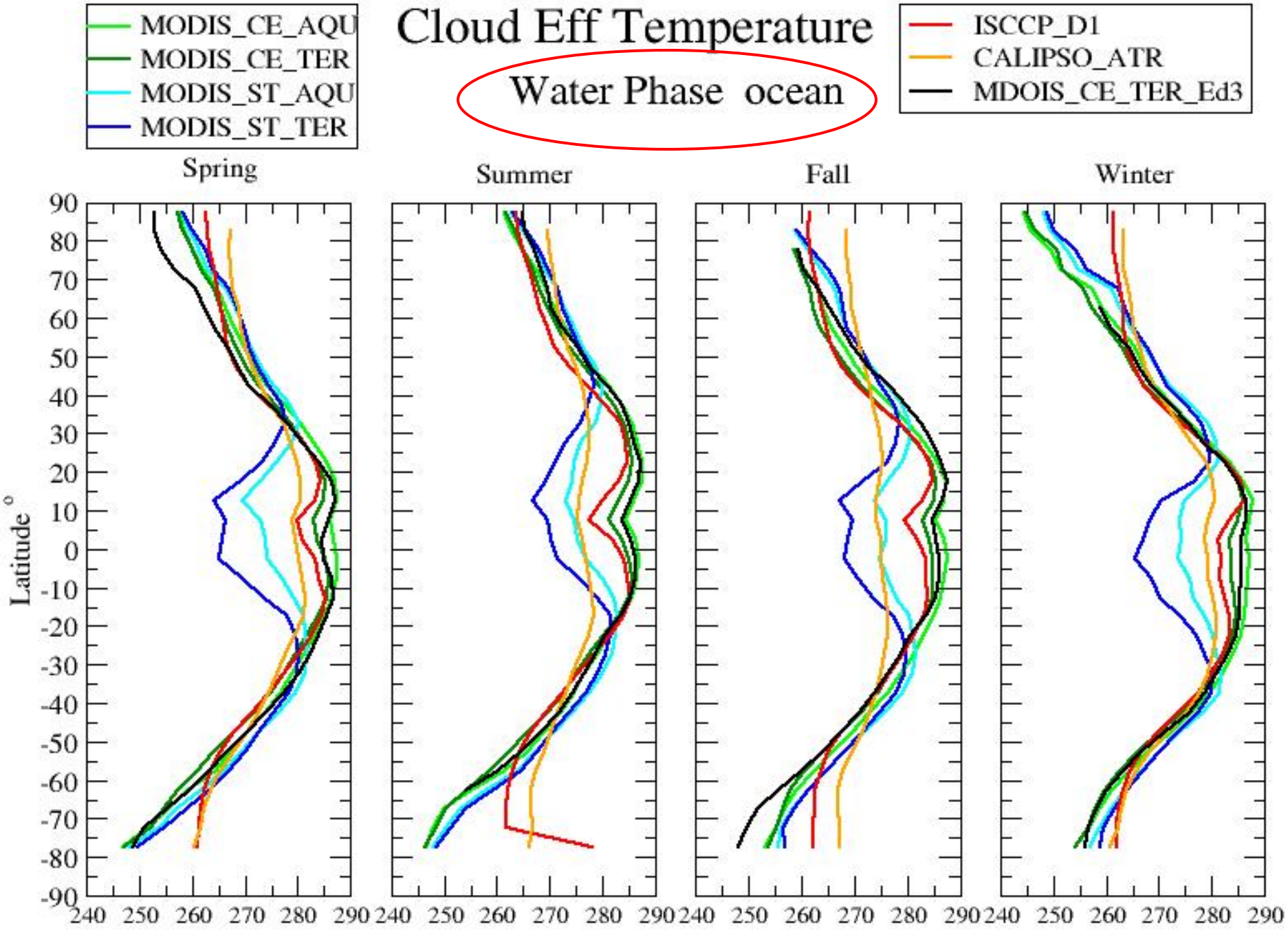
is adjusted between 700 & 500 hPa so that $T_{500} = T_{500}$(GEOS 4)

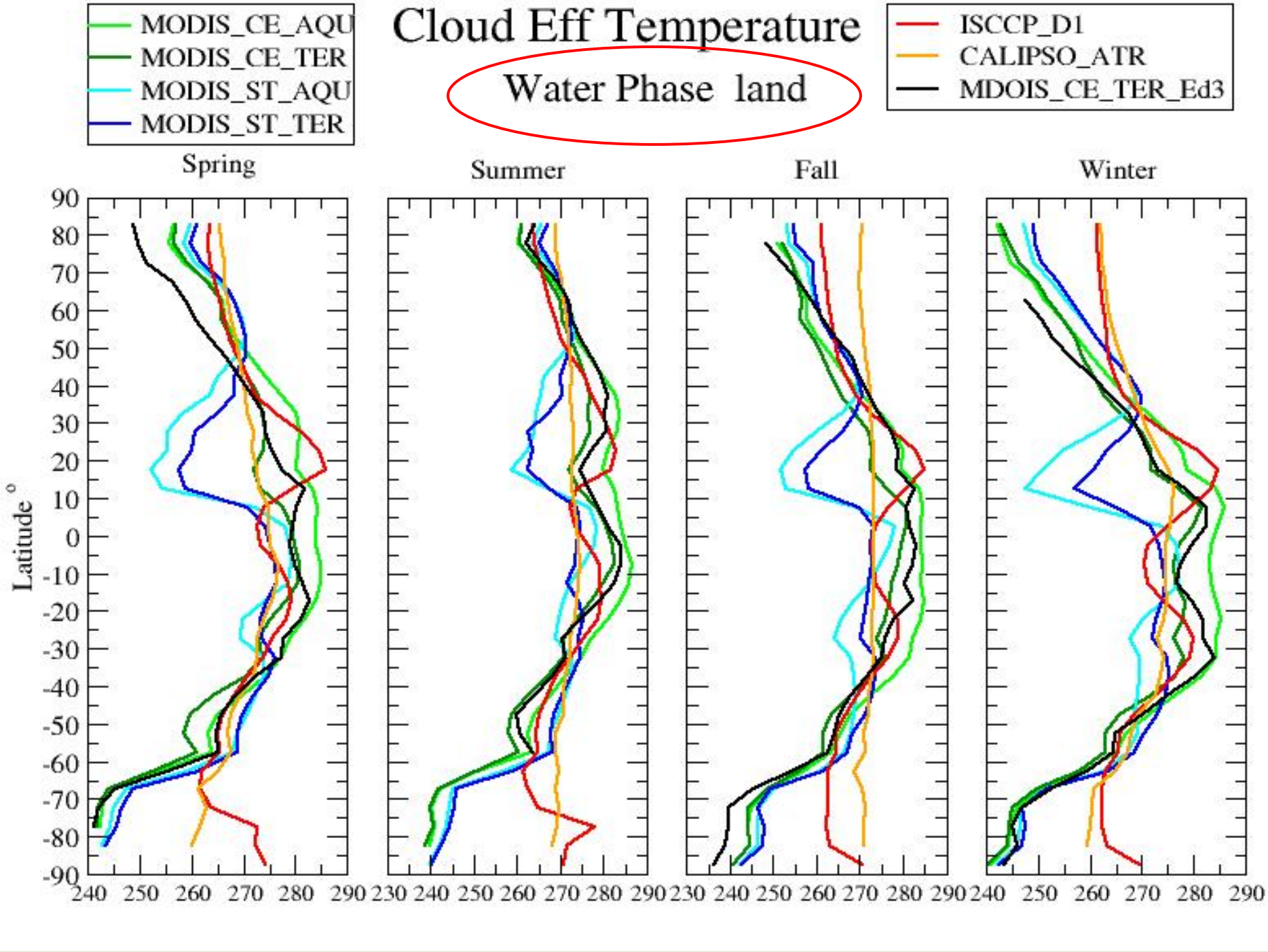
(Minnis et al., JCAM, 1985, JAM, 1992; TGRS, 2009 (submitted))

For optically thick & water clouds, $Z_{top} = Z_{eff}$

For optically thin ice clouds, $Z_{top} = Z(T_{eff}, \tau)$

(Minnis et al., JAS, 1991)


MODIS_CE_AQU
MODIS_CE_TER
MODIS_ST_AQU
MODIS_ST_TER
Cloud Eff Temperature
Water Phase ocean
ISCCP_D1
CALIPSO_ATR
MDOIS_CE_TER_Ed3
Spring
Summer
Fall
Winter
Latitude °
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
240 250 260 270 280 290


Cloud Eff Temperature
Water Phase land
MODIS_CE_AQU
MODIS_CE_TER
MODIS_ST_AQU
MODIS_ST_TER
ISCCP_D1
CALIPSO_ATR
MDOIS_CE_TER_Ed3
Spring
Summer
Fall
Winter
Latitude °
90
80
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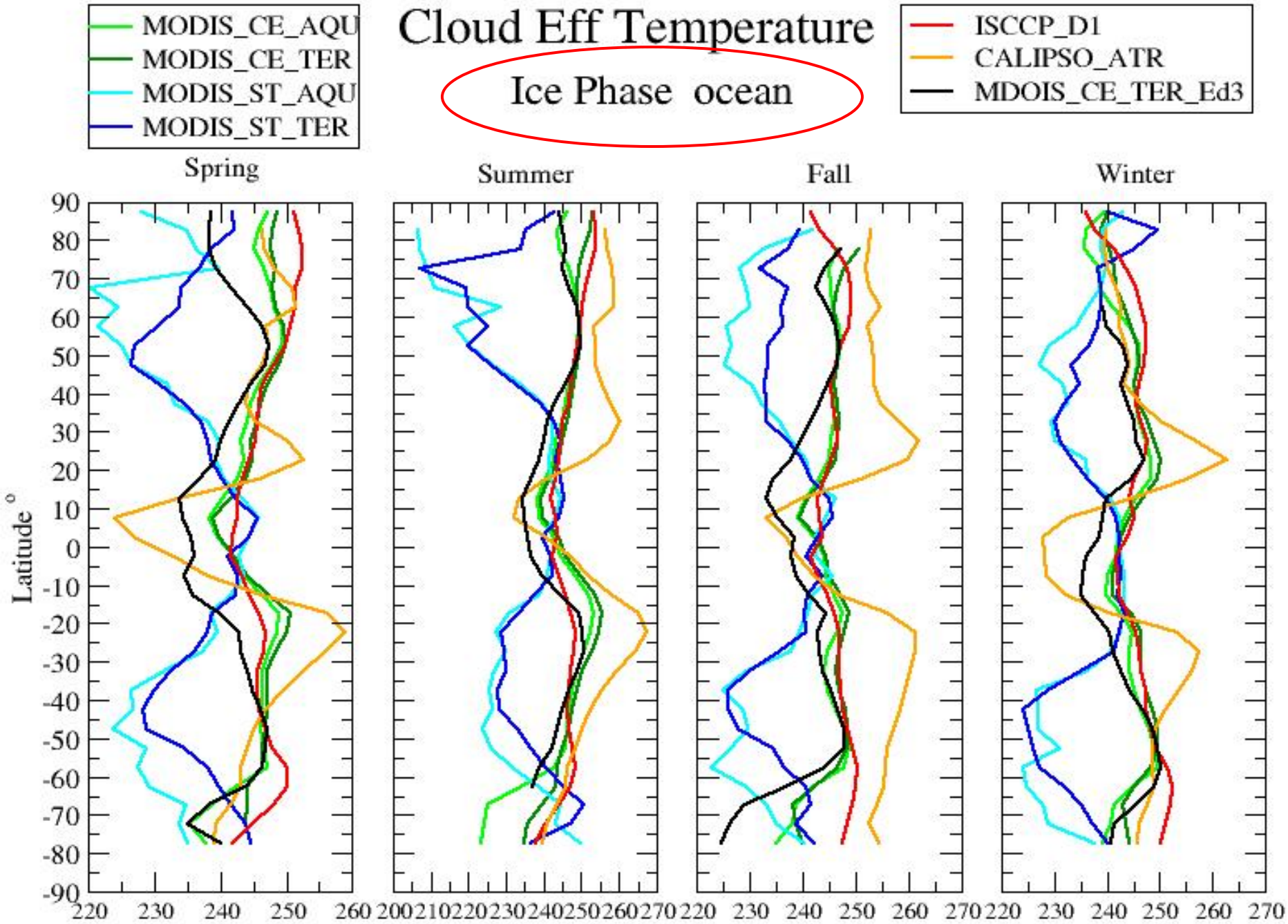
230 240 250 260 270 280 290
240 250 260 270 280 290


Cloud Eff Temperature
Ice Phase ocean
MODIS_CE_AQU
MODIS_CE_TER
MODIS_ST_AQU
MODIS_ST_TER
ISCCP_D1
CALIPSO_ATR
MDOIS_CE_TER_Ed3
Spring
Summer
Fall
Winter
Latitude °
90
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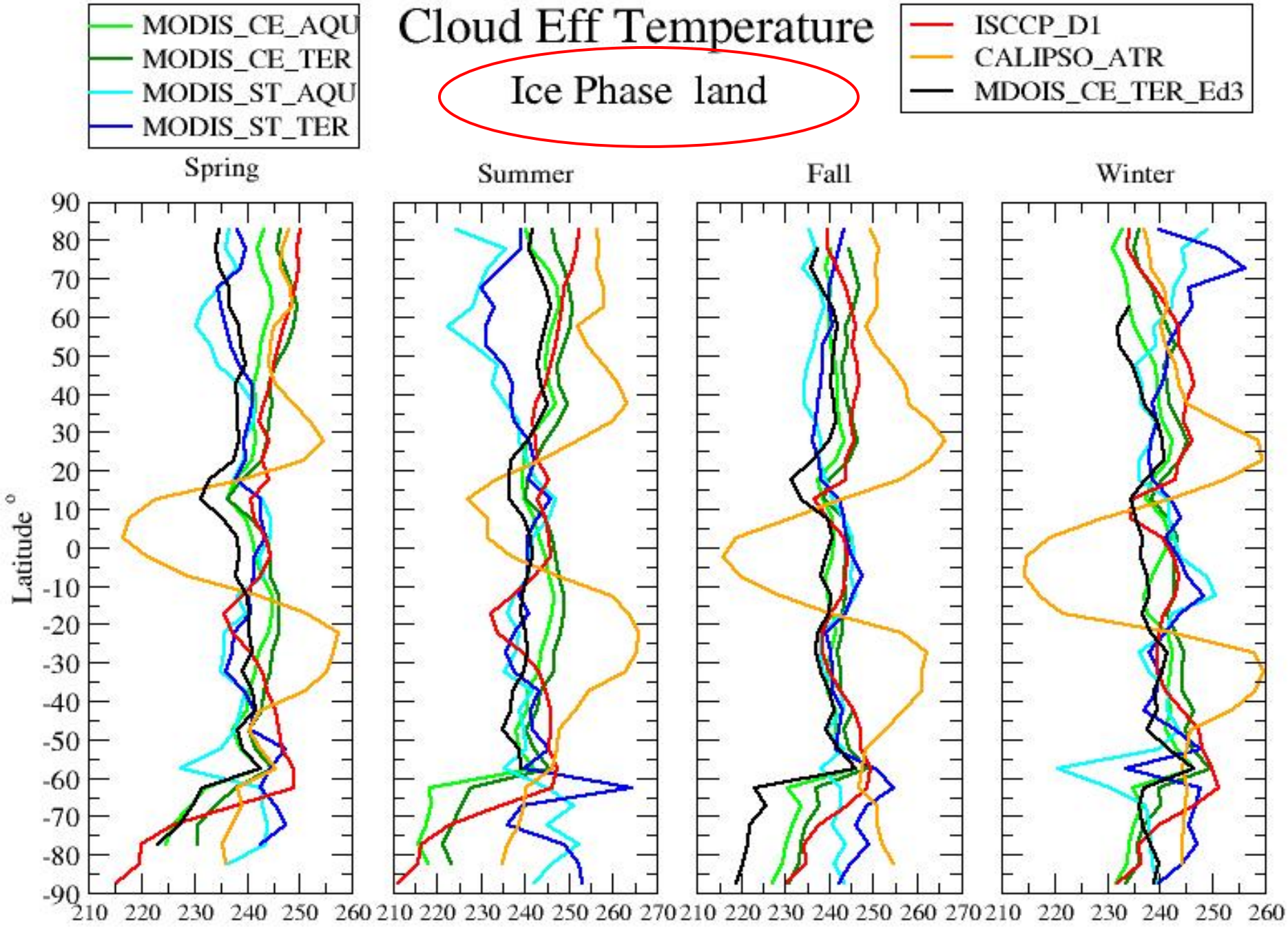
220 230 240 250 260 270


Cloud Eff Temperature
Ice Phase land
MODIS_CE_AQU
MODIS_CE_TER
MODIS_ST_AQU
MODIS_ST_TER
ISCCP_D1
CALIPSO_ATR
MDOIS_CE_TER_Ed3
Spring
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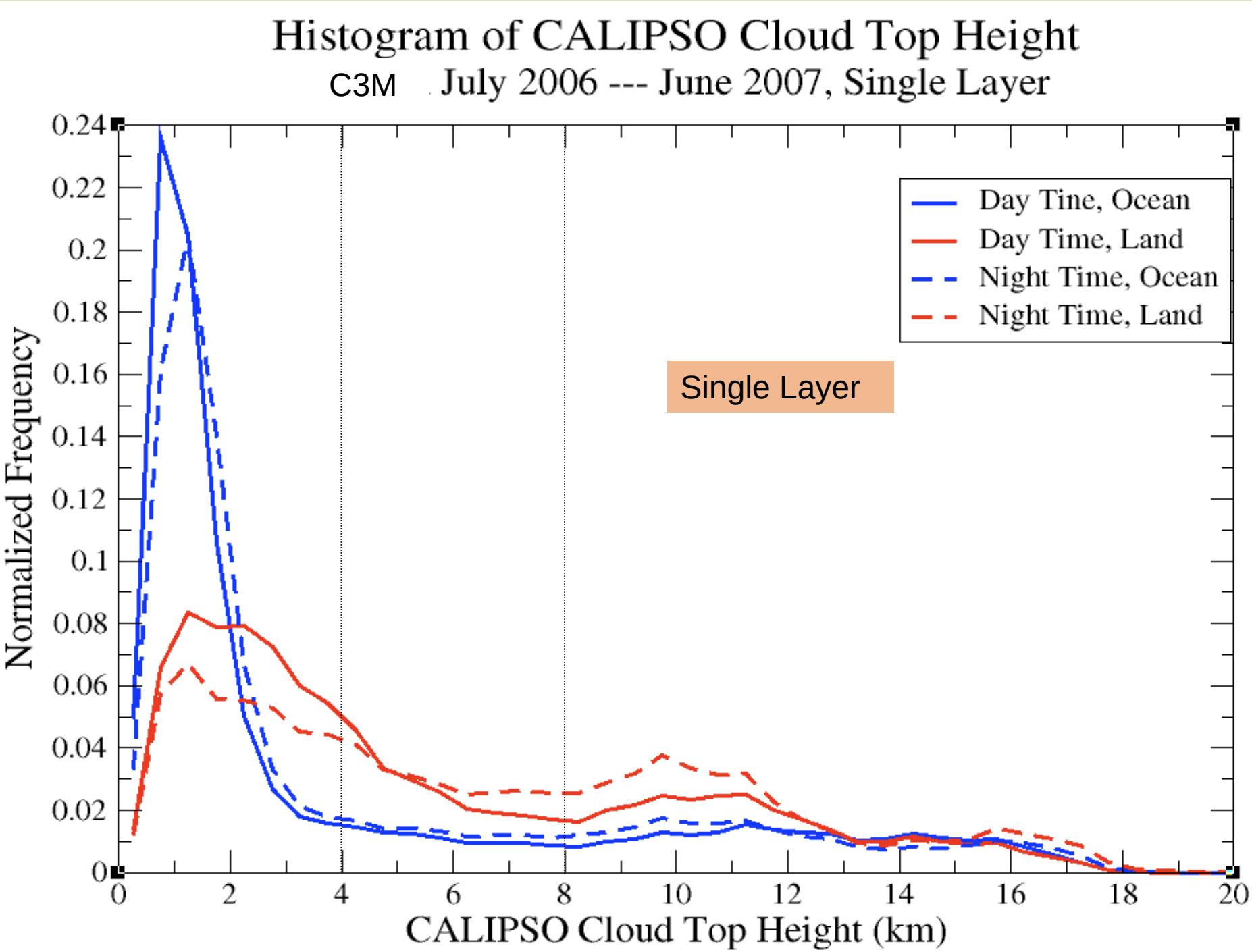
-60
-70
-80
-90
210 220 230 240 250 260
210 220 230 240 250 260 270
210 220 230 240 250 260 270
210 220 230 240 250 260

Single Layer

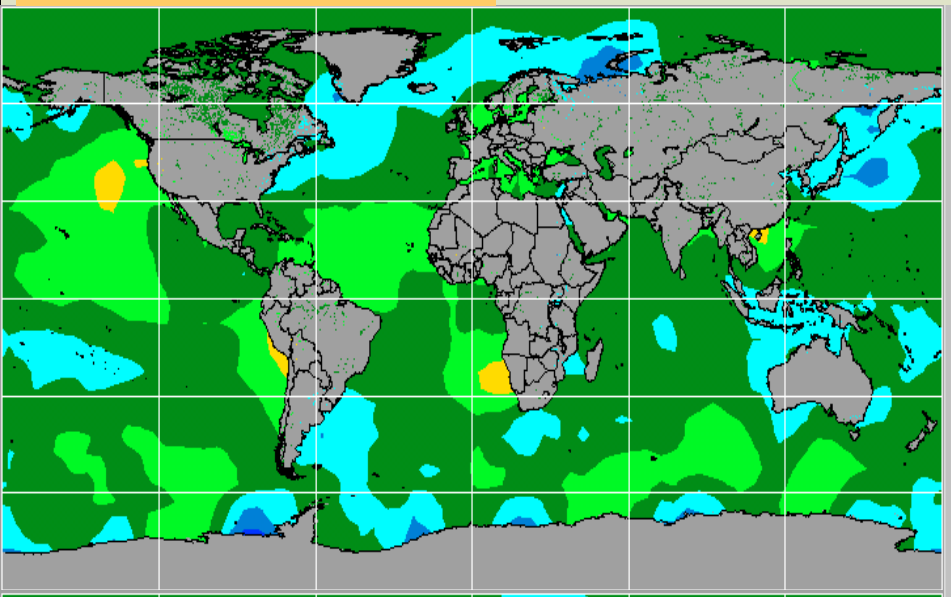
(CALIPSO and MODIS-CE_Ed3 (C3M))

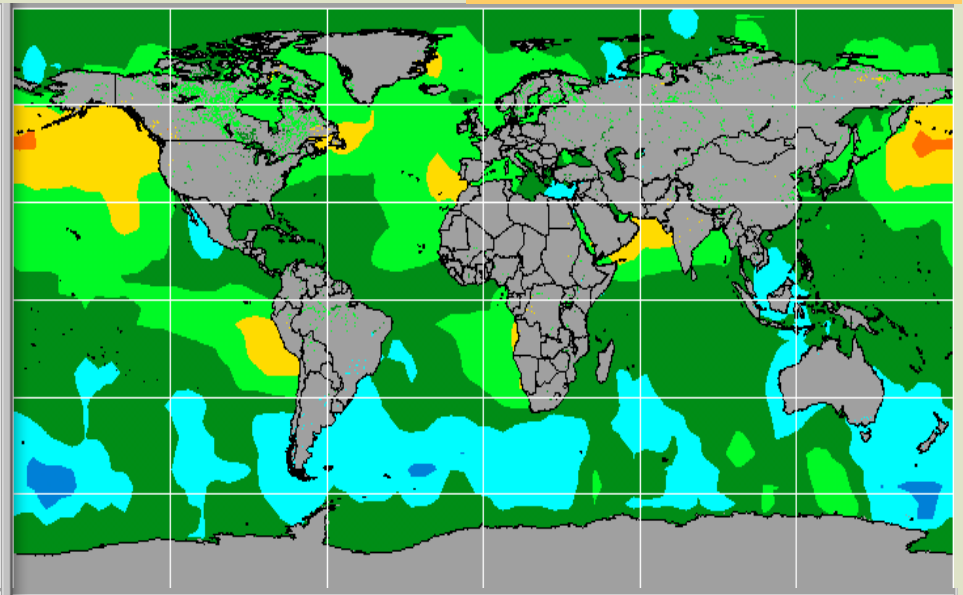

Histogram of CALIPSO Cloud Top Height
C3M July 2006 --- June 2007, Single Layer
Day Tine, Ocean
Day Time, Land
Night Time, Ocean
Night Time, Land
Single Layer
Normalized Frequency
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
2
4
6
8
10
12
14
16
18
20
CALIPSO Cloud Top Height (km)

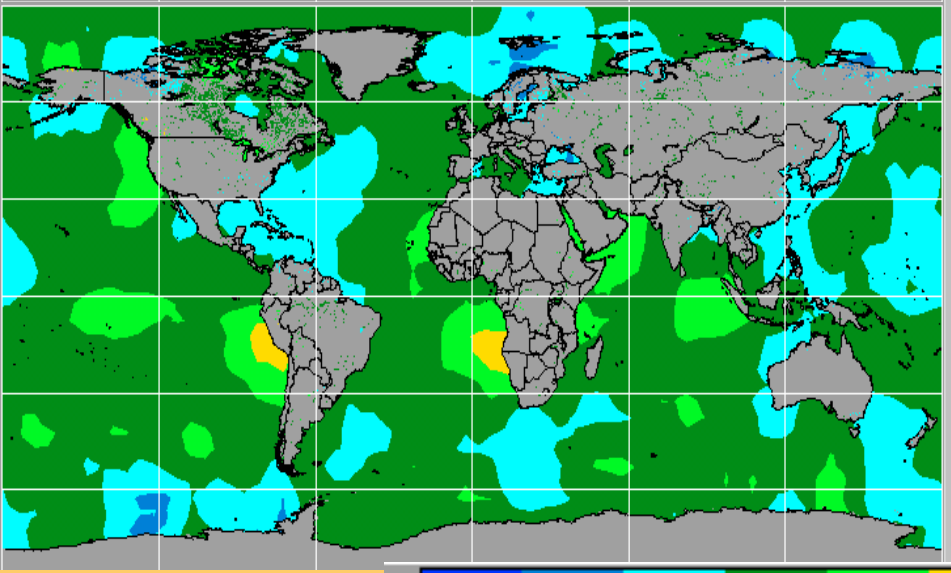
Spring (Mar,Apr,May)

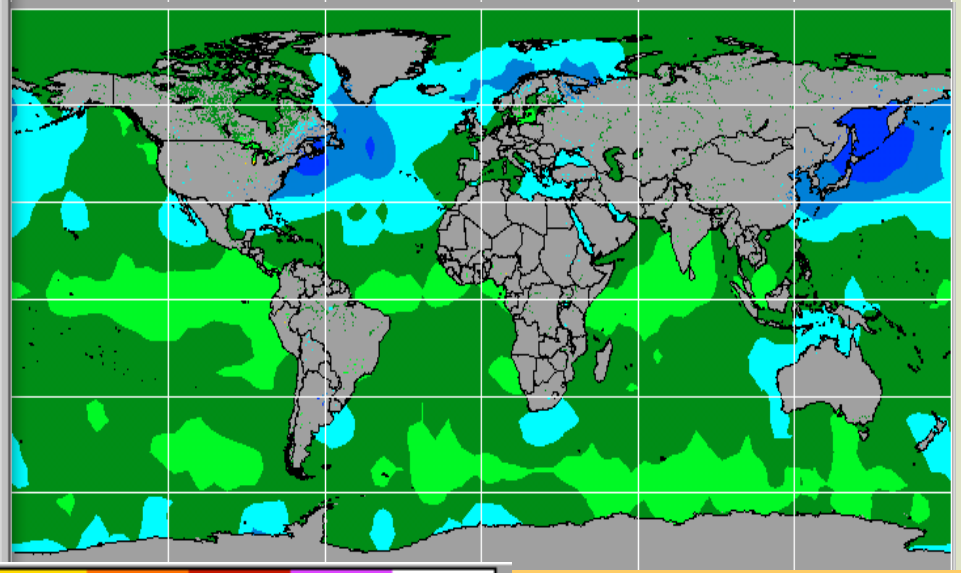
Lapse Rate (k/km), Ocean (Snow Free), Day

Summer (Jun,Jul,Aug)





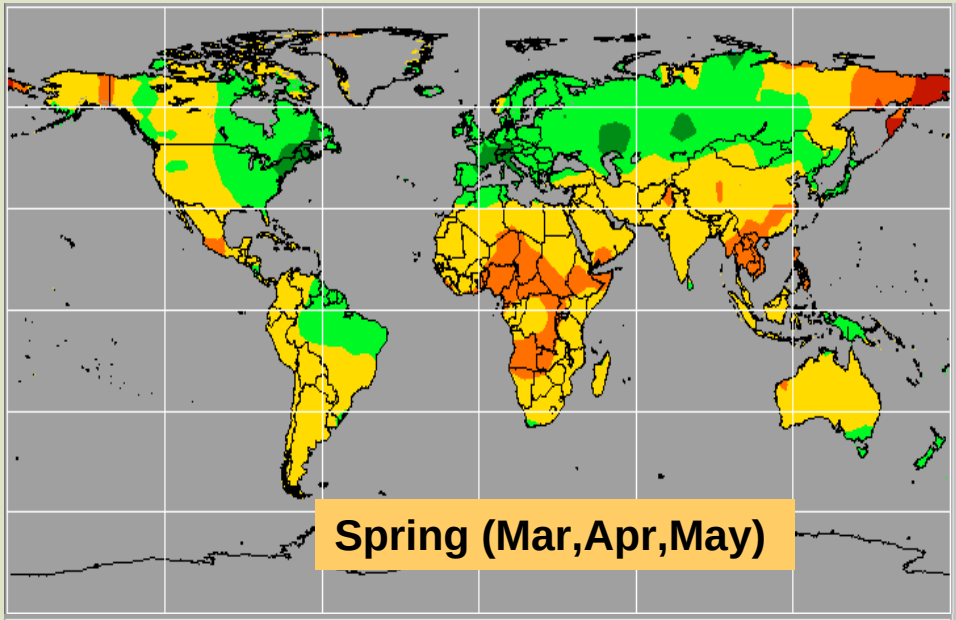


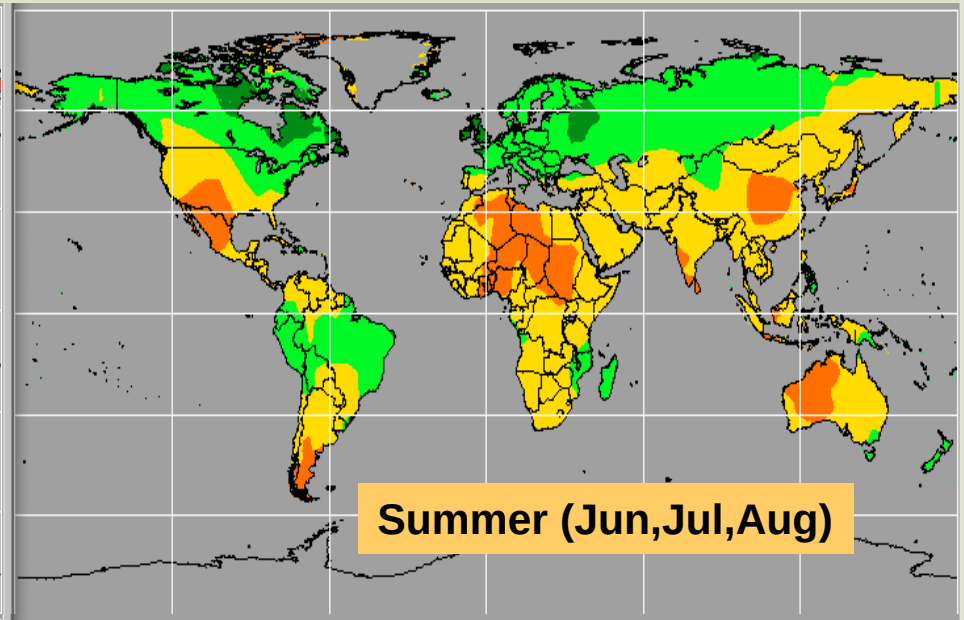


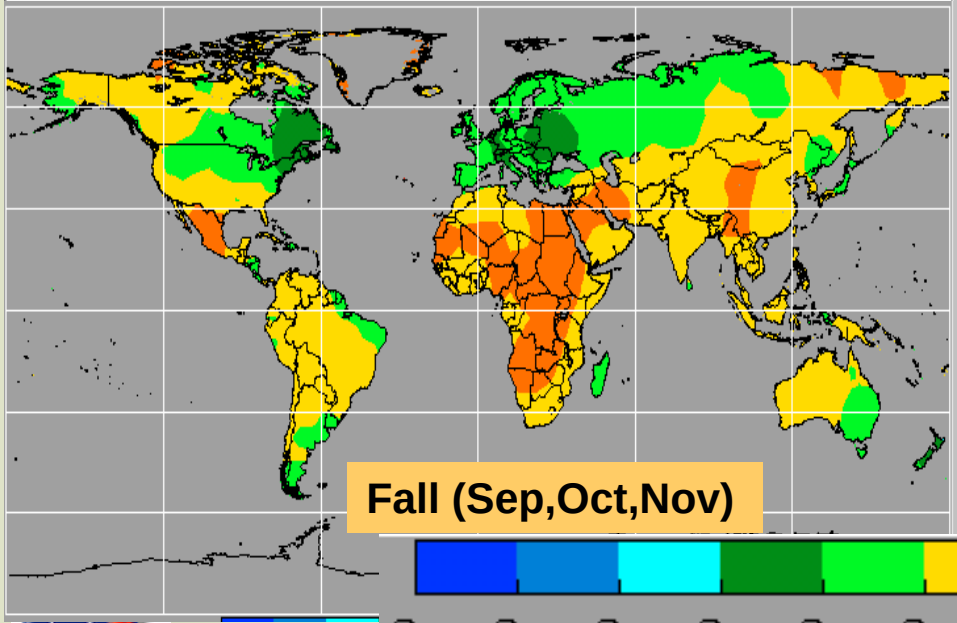
Fall (Sep,Oct,Nov)

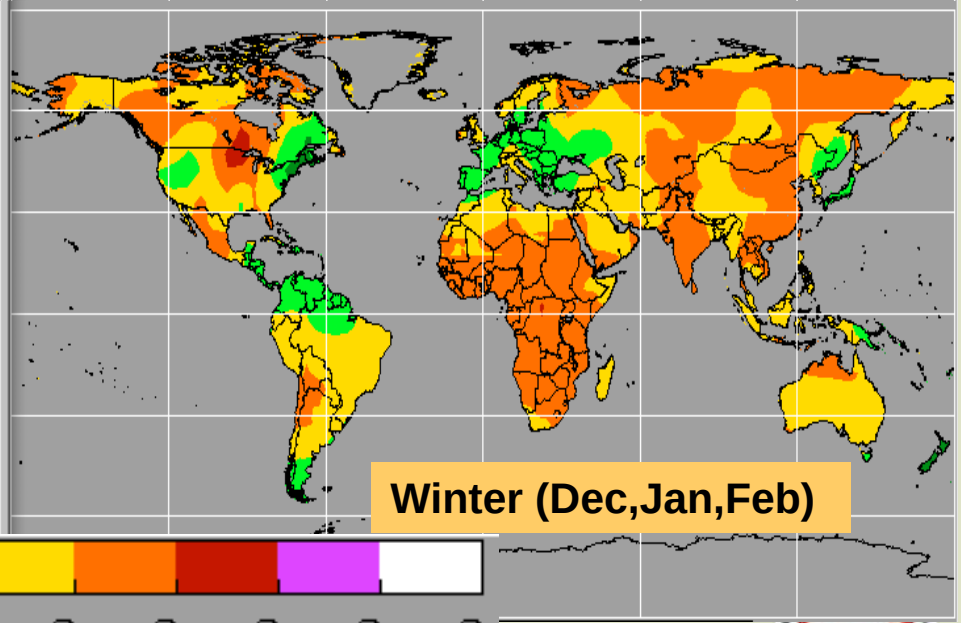
Winter (Dec,Jan,Feb)

Lapse Rate (k/km), Land (Snow Free), Day Time



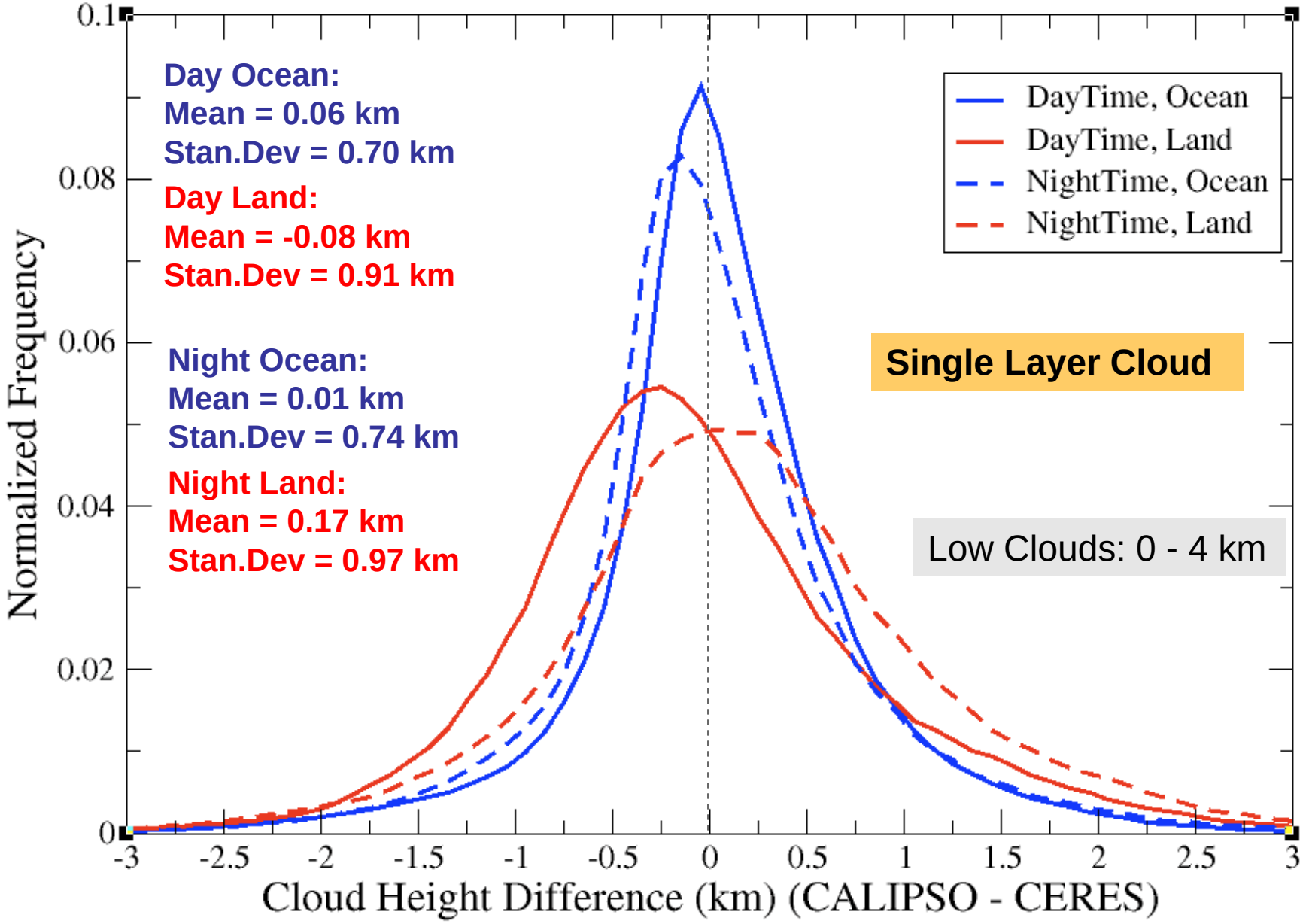






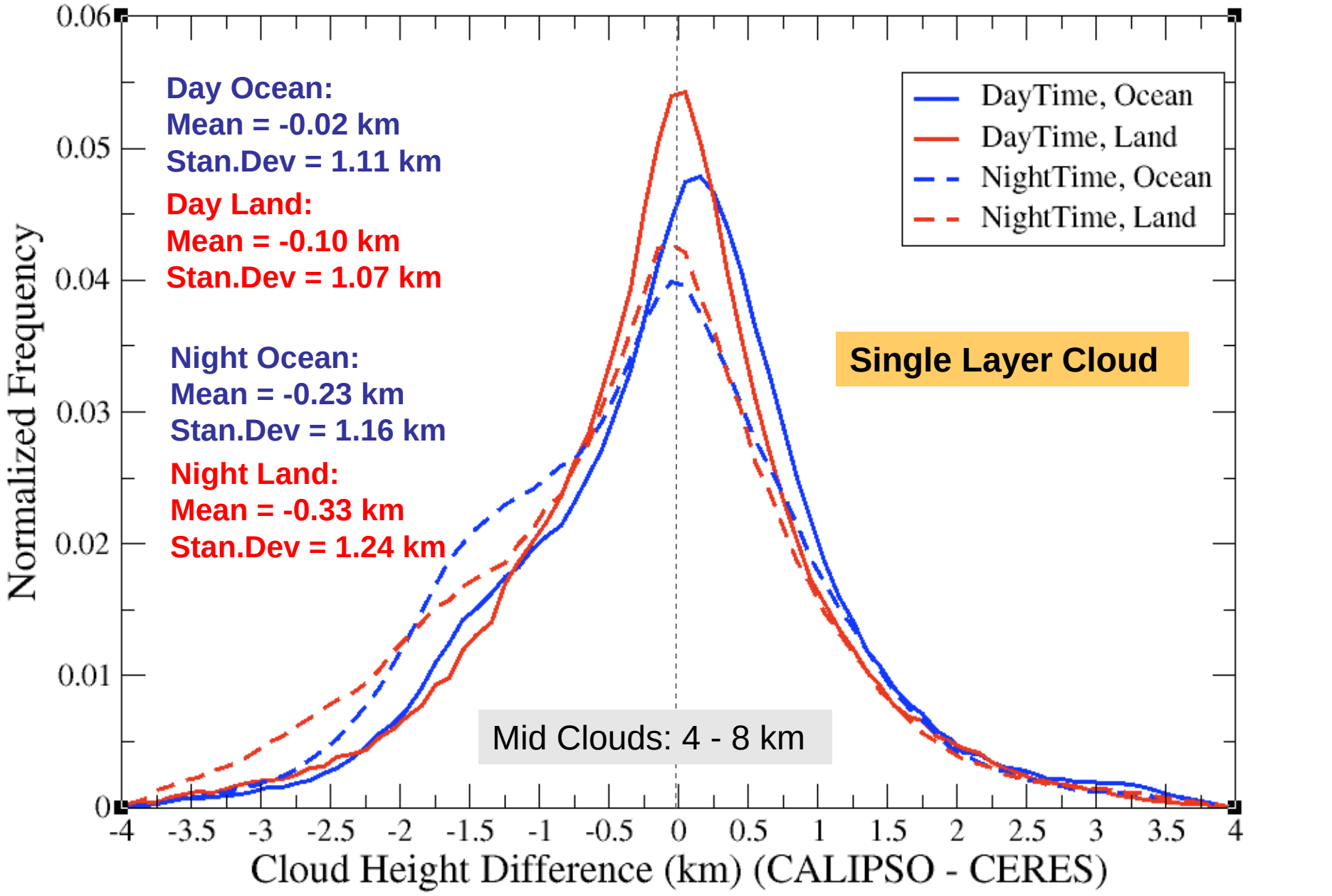
Low Cloud Height (0-4 km) Comparisons between CALIPSO and CERES

C3M July 2006 - June 2007



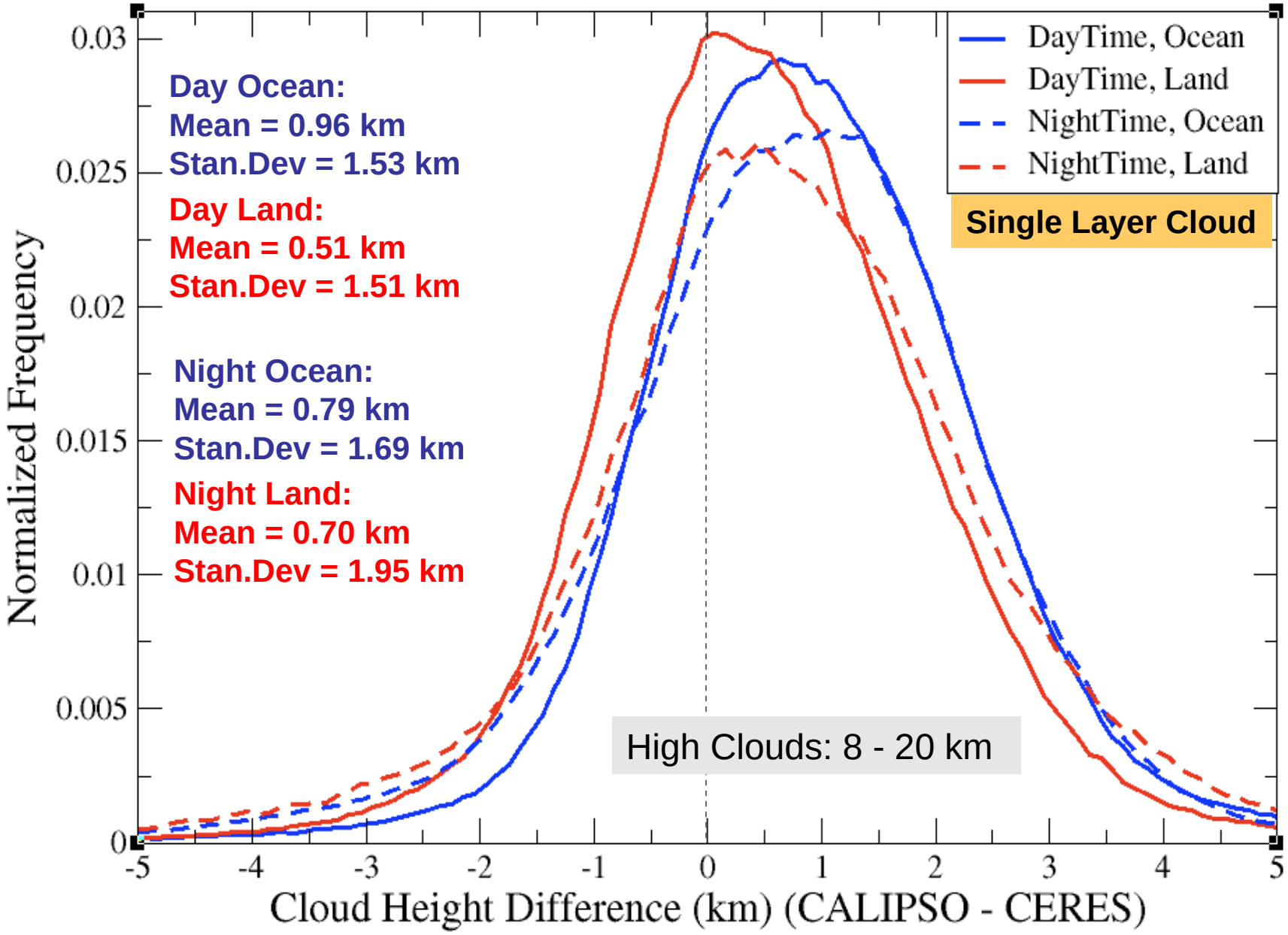
Mid Cloud Height (4-8 km) Comparisons between CALIPSO and CERES

C3M July 2006 - June 2007, Single Layer Clouds



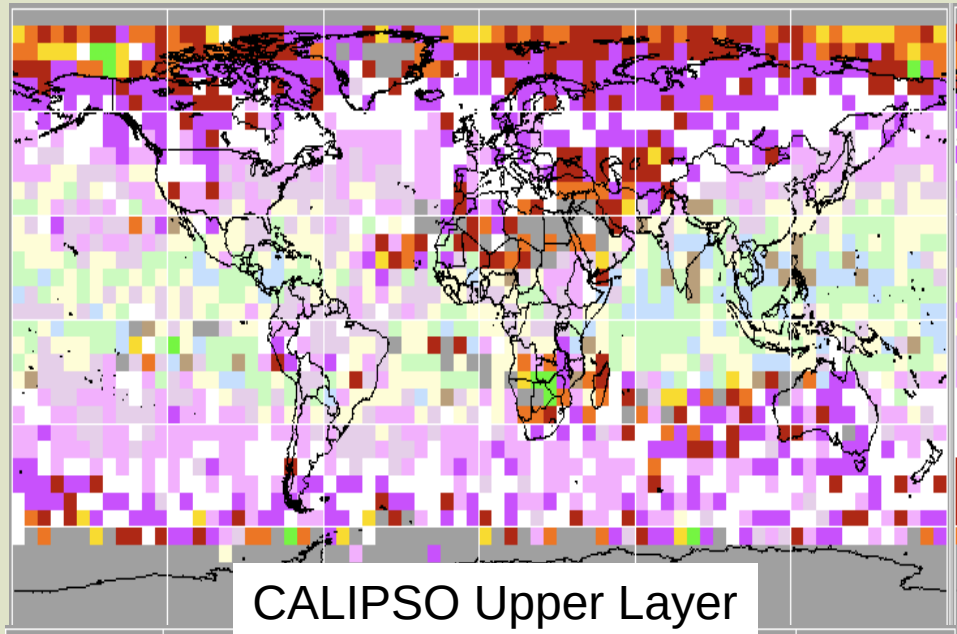
High Cloud Height (8-20 km) Comparisons between CALIPSO and CERES

C3M July 2006 - June 2007, Single Layer Clouds

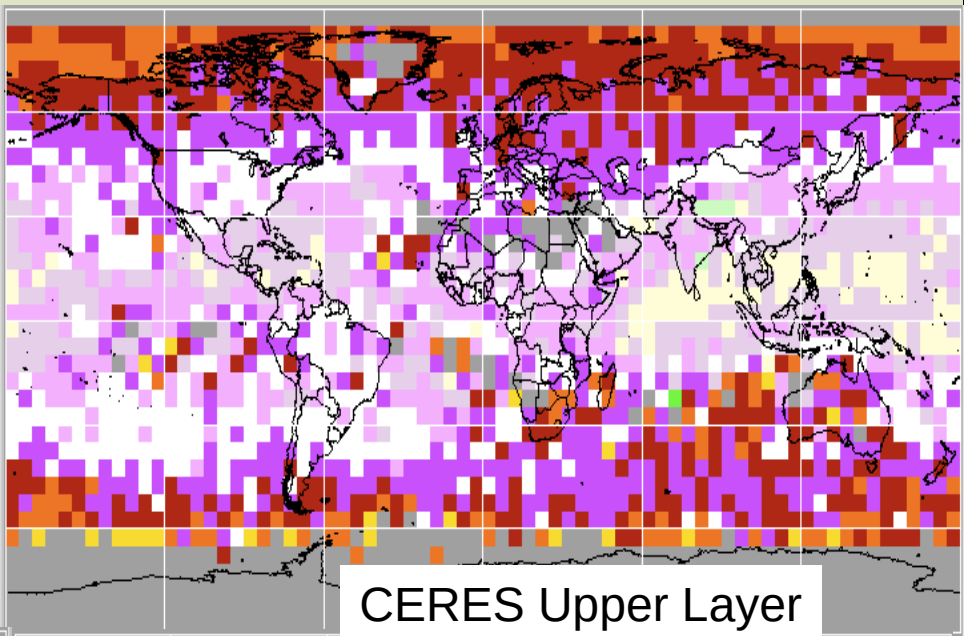


Multilayer (ice over water)

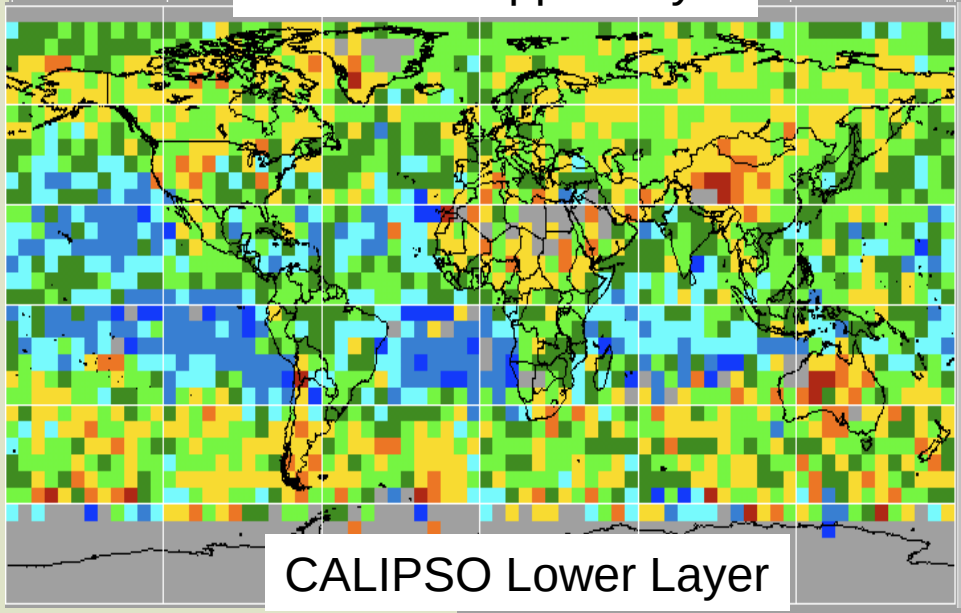
- MODIS-CE Edition 3:
  - only detects multilayer clouds when upper cloud $\tau < 4$
  - Chang et al., JGR 2009 (in press), for retrieval technique



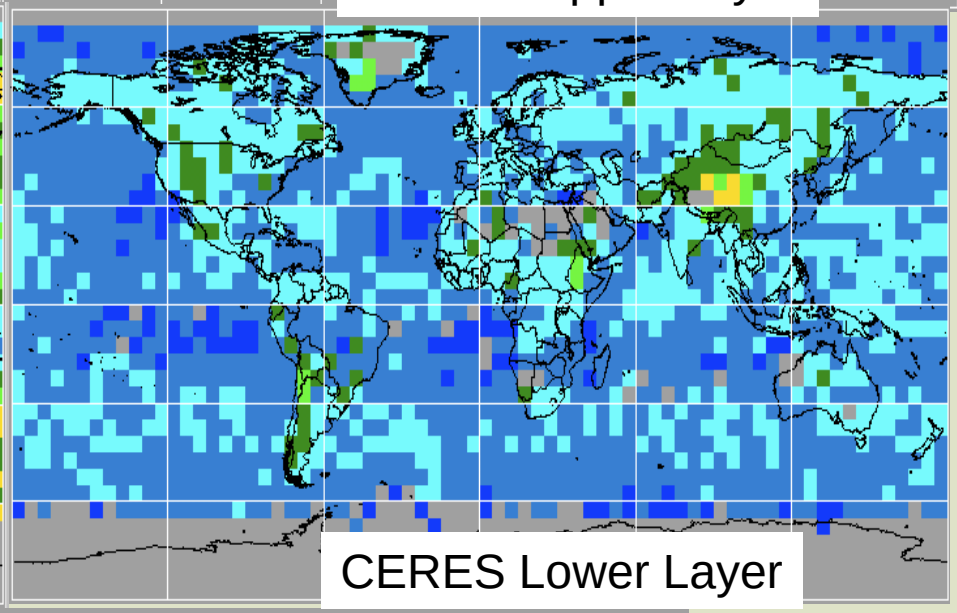
CALIPSO Upper Layer



CERES Upper Layer

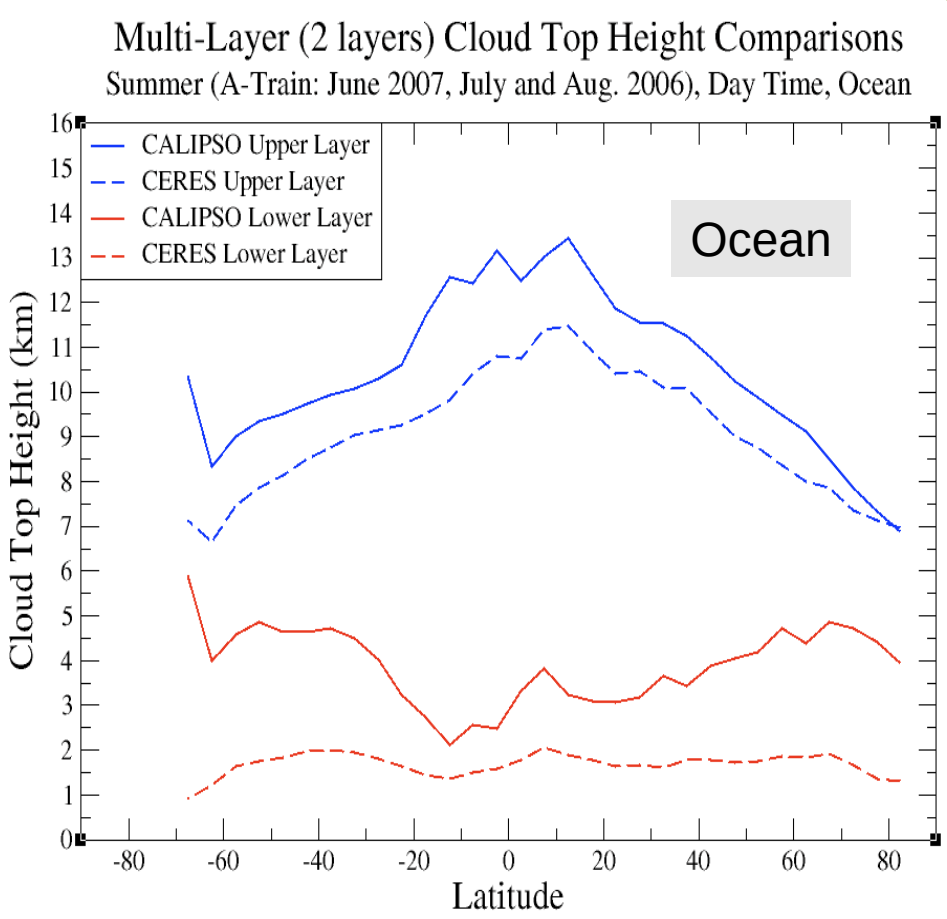


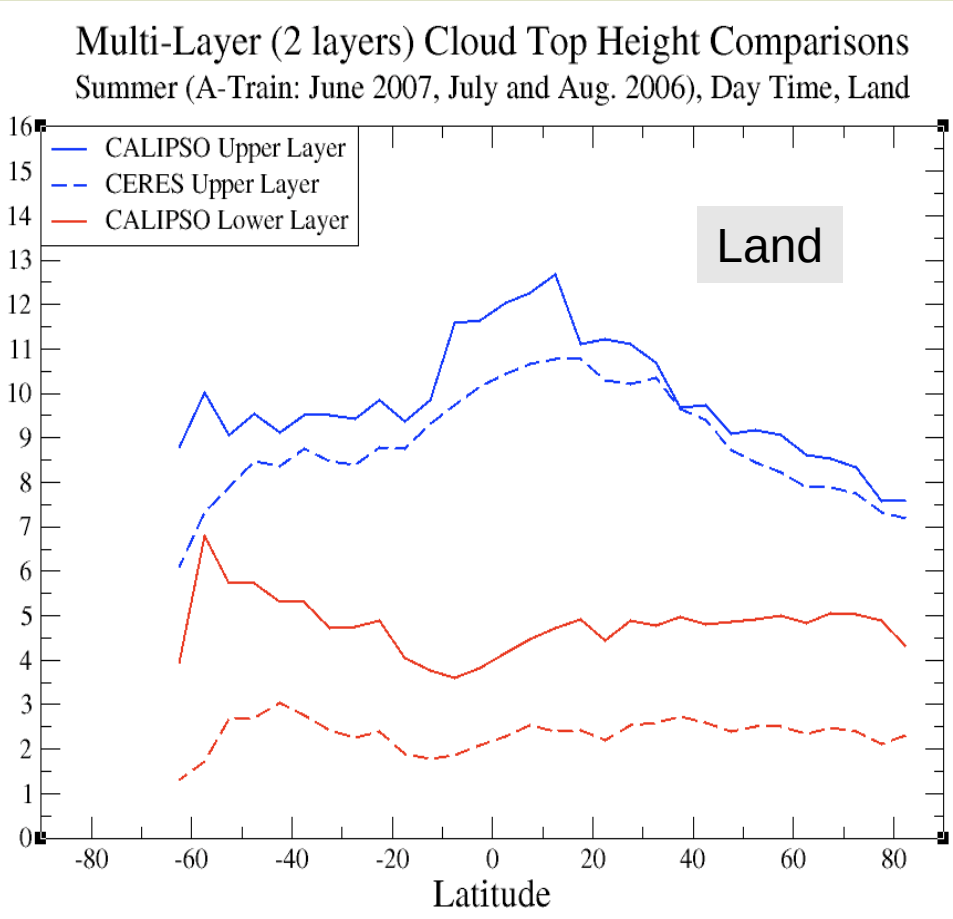
CALIPSO Lower Layer



CERES Lower Layer

Day, Summer





Mean cloud top height difference (CALIPSO -MODIS-CE-Ed3) (km)

Hgt Dif	Upper Layer		Lower Layer	
(km)	Ocean	Land	Ocean	Land
Global	1.41	0.87	1.83	2.09
Polar	0.55	0.42	1.85	1.40
NonPolar	1.53	0.93	.83	2.18

Day Summer

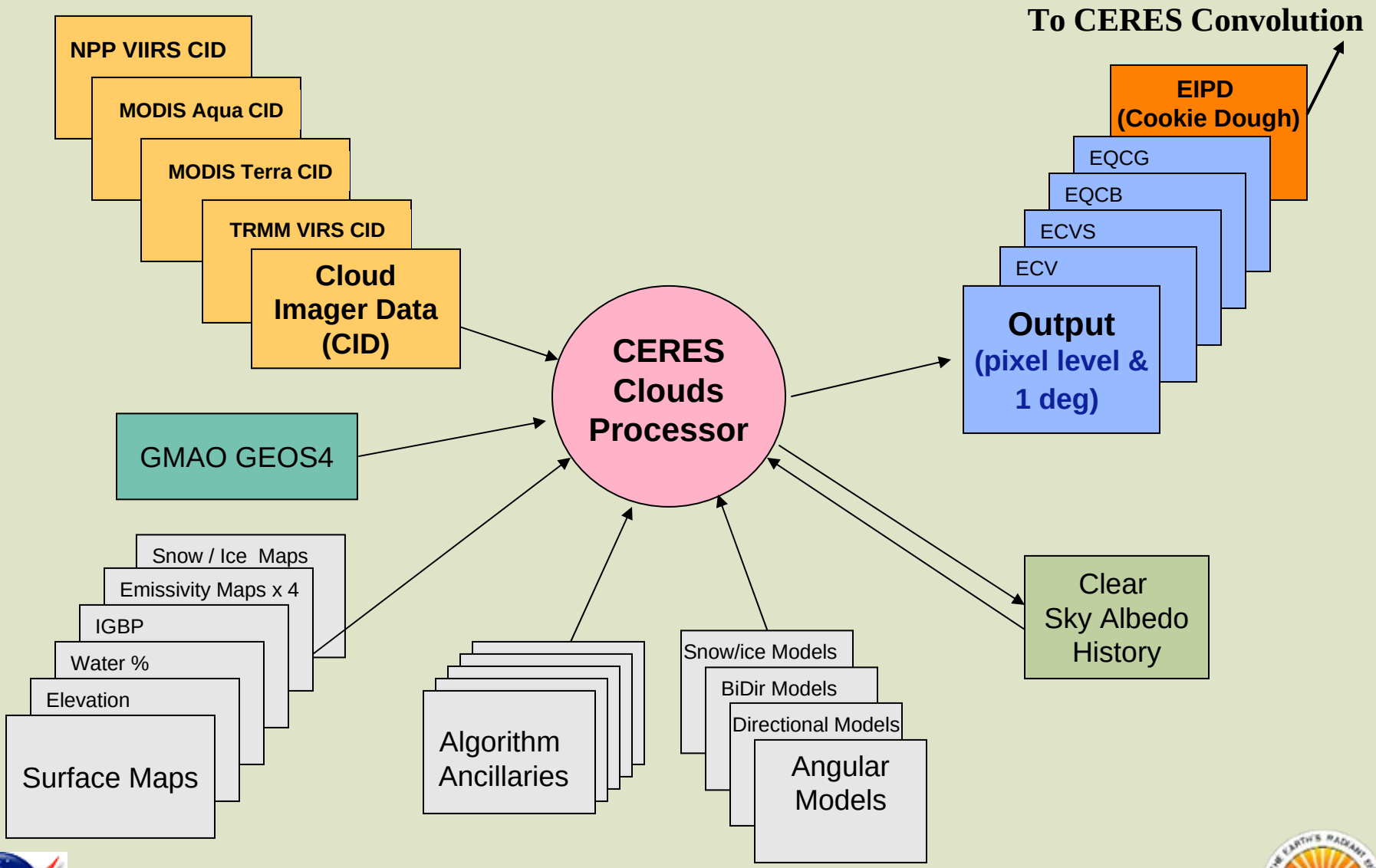
Summary & Future

- Single layer: CERES cloud top heights agree with CALIPSO within
  - ~ 50 meter for low and mid clouds
  - ~ 1 km for high clouds (CERES is lower) cloud top

- Multilayer: CERES clouds top heights agree with CALIPSO within
  - ~ 1 km for upper layer (CERES is lower)
  - ~ 2 km for lower layer (CERES is lower)

Backup Slides

CERES Cloud Processing



Clear-sky albedos:

- early AVHRR/MODIS analyses (Sun-Mack et al., AMS, 2004)

Sfc emissivity:

- early AVHRR/MODIS analyses (Chen et al., AMS, 2004)

Skin temperature:

- GMAO GEOS 4 3-hourly

Atmos profiles:

-GMAO GEOS 4 1 deg, 52 levels, 6 hourly

Snow and Ice surface data:

-NESDIS, 25-km daily maps, interpolated to 10 min grid.

Day Time

Ocean:

Cloud Amount Difference (CALIPSO - CERES) = - 0.034 (global)

= - 0.0188 (polar)

= - 0.036 (non-polar)

Land:

Cloud Amount Difference (CALIPSO - CERES) = 0.016 (global)

= - 0.032 (polar)

= - 0.02 (non-polar)

Night Time

Ocean:

Cloud Amount Difference (CALIPSO - CERES) = 0.075 (global)

= 0.096 (polar)

= 0.072 (non-polar)

Land:

Cloud Amount Difference (CALIPSO - CERES) = 0.095 (global)

= 0.080 (polar)

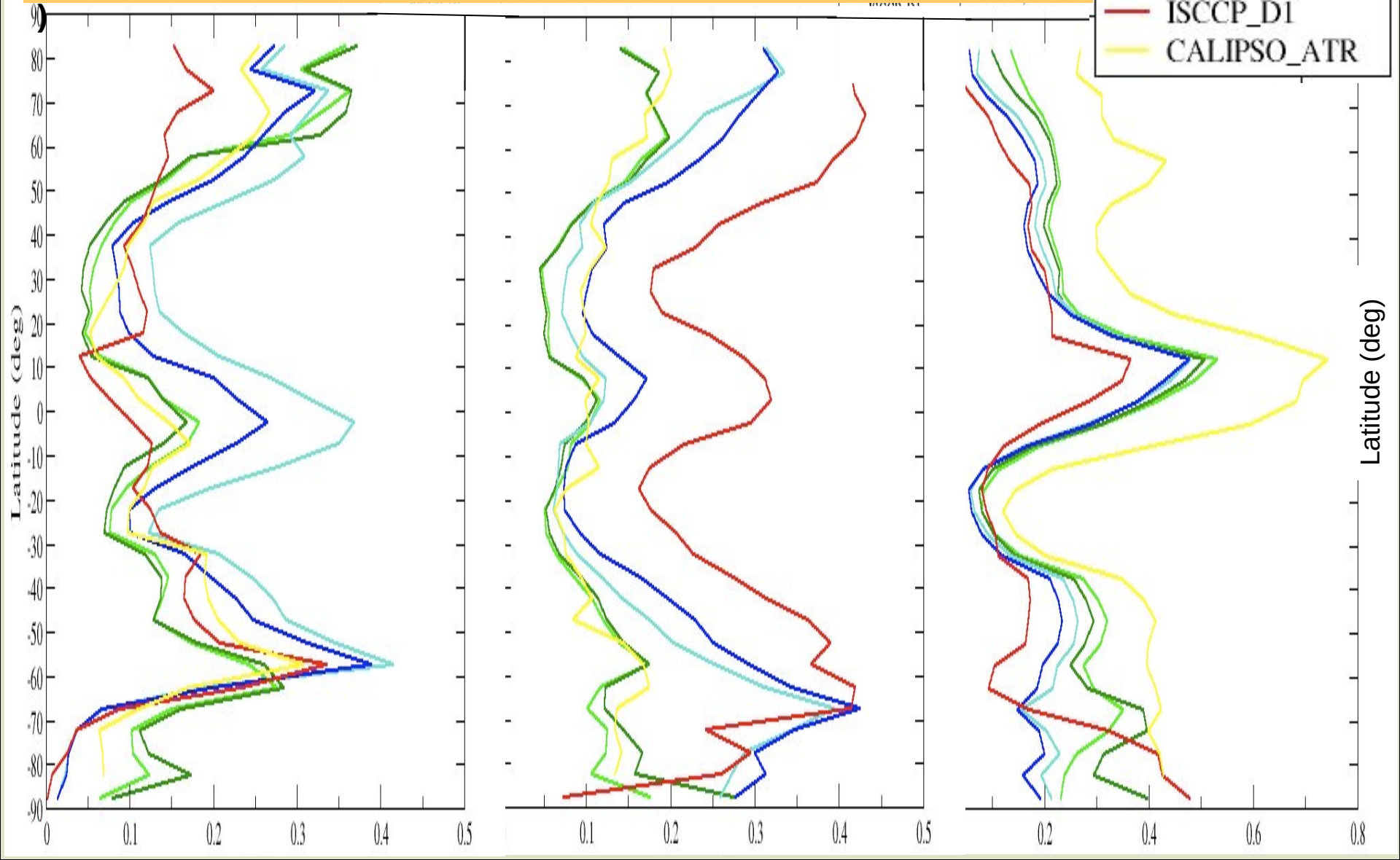
= 0.097 (non-polar)

Land

Cloud Amount

Summer

Low (P > 680 hPa) **Middle (440< P <680 hPa)** **High (P <440hPa**



How to improve low cloud detection for $\tau > 0.2$?

- Tighten thresholds

- Daytime, use high resolution (e.g., 250-m) VIS channels to detect subpixel cloud cover

- Use additional channels (8.5, 13.3 μm)

Non Polar (60 S - 60 N)

High Cloud (> 8 km)

CERES \ Calipso	Cloudy	Clear
Cloudy	0.76	0.28
Clear	0.24	0.72

Mid Cloud (4 - 8 km)

	Cloudy	Clear
Cloudy	0.79	0.31
Clear	0.21	0.69

Low Cloud (< 4 km)

	Cloudy	Clear
Cloudy	0.62	0.21
Clear	0.38	0.79

Polar (60S - 90S, 60N - 90N)

CERES \ Calipso	Cloudy	Clear
Cloudy	0.84	0.24
Clear	0.16	0.76

	Cloudy	Clear
Cloudy	0.81	0.36
Clear	0.19	0.64

	Cloudy	Clear
Cloudy	0.85	0.36
Clear	0.15	0.64

Day Time , Land, MODIS-CE-AQU-Ed3, July 2006 - June 2007

Non Polar (60 S - 60 N)

CERES \ Calipso	Cloudy	Clear
High Cloud (> 8 km)		
Cloudy	0.84	0.30
Clear	0.16	0.70
Mid Cloud (4 - 8 km)		
Cloudy	0.93	0.34
Clear	0.07	0.66
Low Cloud (< 4 km)		
Cloudy	0.78	0.24
Clear	0.22	0.76

Polar (60S - 90S, 60N - 90N)

CERES \ Calipso	Cloudy	Clear
High Cloud (> 8 km)		
Cloudy	0.78	0.19
Clear	0.22	0.81
Mid Cloud (4 - 8 km)		
Cloudy	0.78	0.19
Clear	0.22	0.81
Low Cloud (< 4 km)		
Cloudy	0.72	0.18
Clear	0.28	0.82

Night Time , Ocean, MODIS-CE-AQU-Ed3, July 2006 - June 2007

Non Polar (60 S - 60 N)

High Cloud (> 8 km)

CERES \ Calipso	Cloudy	Clear
Cloudy	0.75	0.21
Clear	0.25	0.79

Mid Cloud (4 - 8 km)

	Cloudy	Clear
Cloudy	0.77	0.19
Clear	0.23	0.81

Low Cloud (< 4 km)

	Cloudy	Clear
Cloudy	0.52	0.12
Clear	0.48	0.88

Polar (60S - 90S, 60N - 90N)

CERES \ Calipso	Cloudy	Clear
Cloudy	0.67	0.26
Clear	0.33	0.74

	Cloudy	Clear
Cloudy	0.61	0.26
Clear	0.39	0.74

	Cloudy	Clear
Cloudy	0.65	0.28
Clear	0.35	0.72

Night Time , Land, MODIS-CE-AQU-Ed3, July 2006 - June 2007

CERES Cloud-base Height Estimation

Cloud thickness: $\Delta Z = f(\text{phase}, T_{eff}, \tau)$

based on surface & aircraft radar/lidar data

Cloud base Height: $Z_{base} = Z_{top} - \Delta Z$

Constraint: $Z_{base} > Z_o$

(Minnis et al., JAS, 1991; JAM 1992, TGRS, 2009; Chakrapani, ARM 2002)

Lapse Rate Calculation

C3M: Merged CALIPSO and CERES Clouds

CALIPSO

(1) Single Layer

(2) Transparent Clouds

(3) Cloud Top Height: Z_{top}

CERES-MODIS

(1) Water Clouds

(2) Cloud Top Temp: T_{top}

(3) T_{skin} , for Ocean

(4) $T_{sfc\text{-}24h\text{-}mean}$ for Land

(5) Z_{sfc}, Surface Height

$Z_{top} - Z_{sfc} < 5$ km

Lapse Rate $= (T_{top} - T_{skin}) / (Z_{top} - Z_{sfc})$ <------ For Ocean

Lapse Rate $= (T_{top} - T_{sfc\text{-}24h\text{-}mean}) / (Z_{top} - Z_{sfc})$ <------ For Land