Evaluation of CERES-MODIS Cloud Properties Using CALIPSO and CloudSat Data

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Objectives

- **Use CALIPSO and CloudSat data products to**

  - assess errors in CERES-MODIS cloud properties

  -- *cloud fraction, top/base heights, thickness*

  - develop improved algorithms for CERES Edition 3 clouds

CERES-MODIS Cloud Retrieval Methodology.

(Apply CERES algorithms to MODIS imager data)

1) Apply cloud mask *see Minnis et al. (2007a), Trepte et al. (2007)*

2) Compute ice & water phase solution, select most likely phase based on temperature, model fits, LBTM classification, 2.1-μm reflectance

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

0.65, 3.8, 10.8, & 12.0 μm *see Minnis et al. (1995, 1998, 2007b)*

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

3.8, 10.8, & 12.0 μm *see Minnis et al. (1995, 1998, 2007b)*

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

2.1, 3.8, 10.8, & 12.0 μm *see Platnick (JGR, 2001), Minnis et al. (2007b)*

CERES Cloud-top Height Estimation

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

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

For high clouds: $Z_{eff} = Z(T_{eff})$

Z(T) - sounding from 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 = -7.1K/km

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

(Minnis et al., JAM, 1992; TGARS, 2007)

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)

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., JAM 1992, TGARS, 2007; Chakrapani, ARM 2002)

DATA

Aqua - MODIS:

Data Products Used: L1: MAC02 (radiance), L1:MAC03 (geolocation) and L2; MAC04 (aerosol).

Full resolution (1 km) with 22 bands subset: 201 km MODIS swath centered at the CloudSat nadir track.

CALIPSO:

Data Product Used: Vertical Feature Mask (VFM).

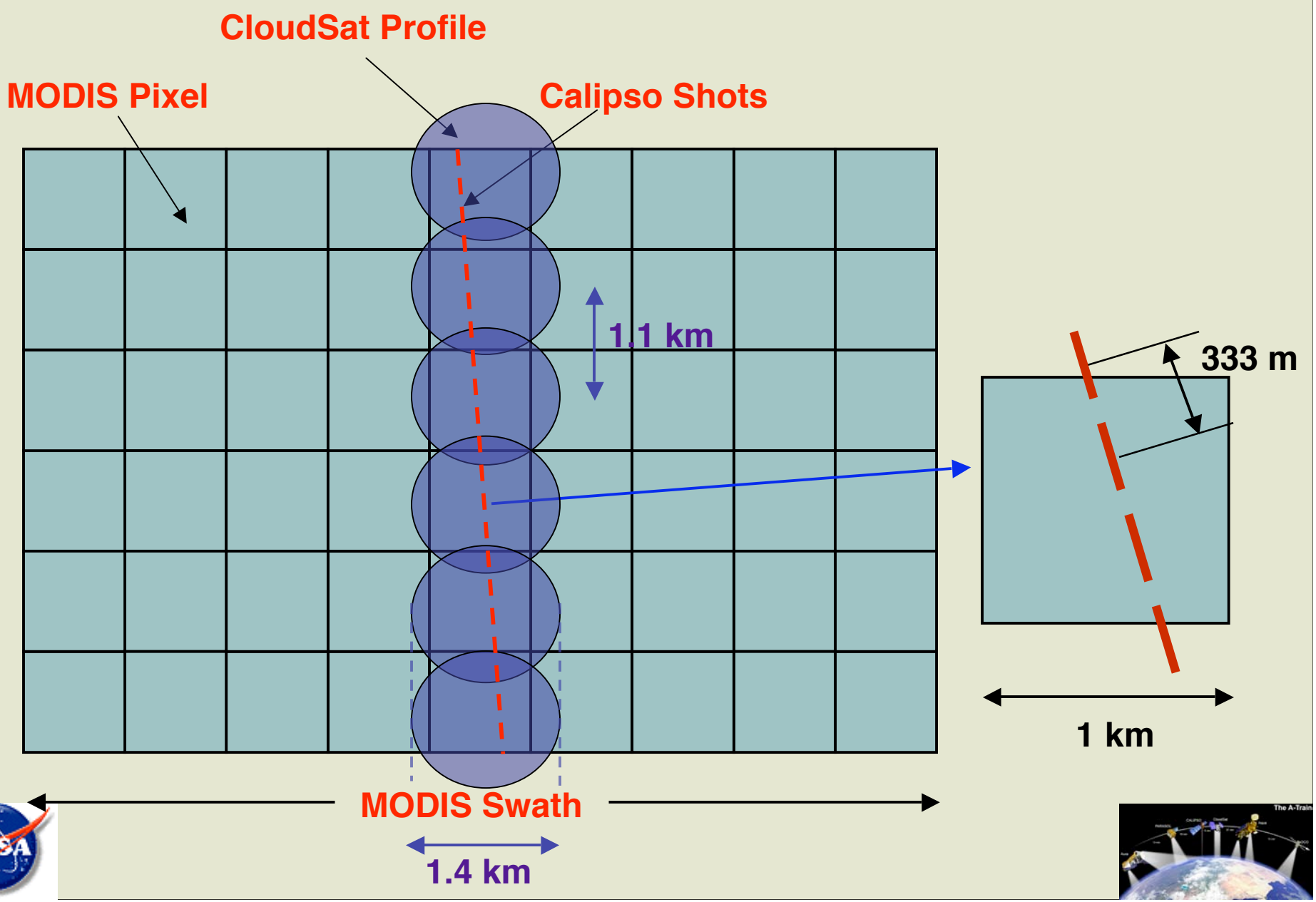
Altitude Region(km)	Vertical Res (m)	Horizontal Res (m)
-0.5 - 8.2	30	333
8.2 - 20.2	60	1000
20.2 - 30.1	180	1667

CloudSat:

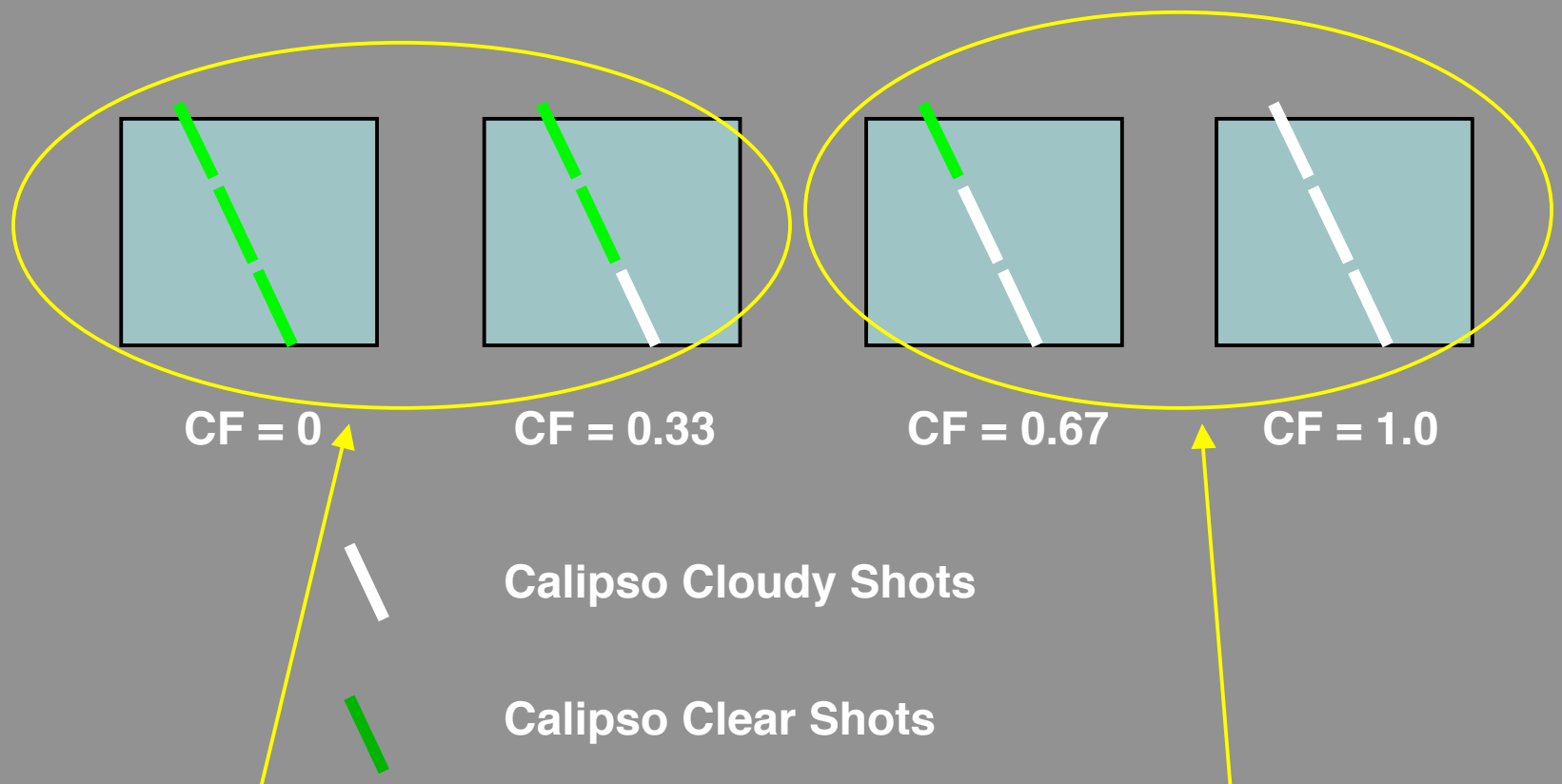
Data Product Used: Cloud Scenario Classification (CLDCLASS):

Altitude Region(km)	Vertical Res (m)	Horizontal Res (km)
0 - 25	240	1.1 x 1.4

MODIS, Calipso and CloudSat Collocation Match Up.



CALIPSO Cloud Fraction for each 1-km MODIS Pixel



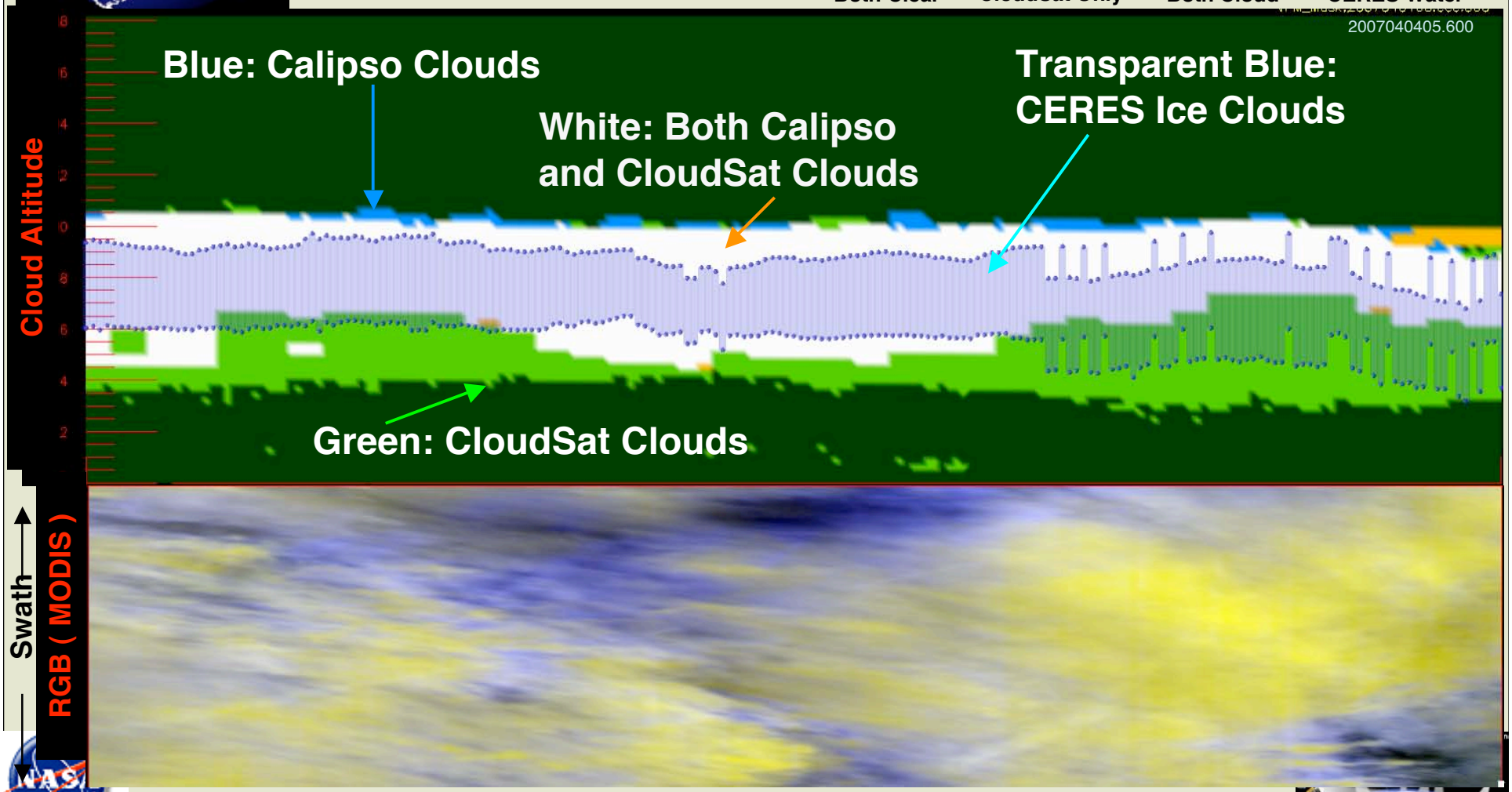
CF < 0.5 -----> CALIPSO Clear

CF > 0.5 ----> CALIPSO Cloudy

A month of data were successfully merged and an integrated product was produced

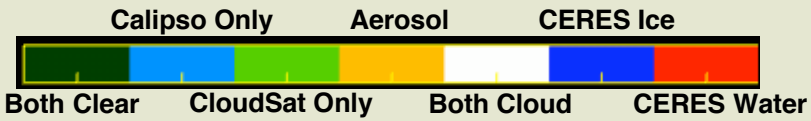
CALIPSO, CloudSat & CERES-MODIS Merged Example 1

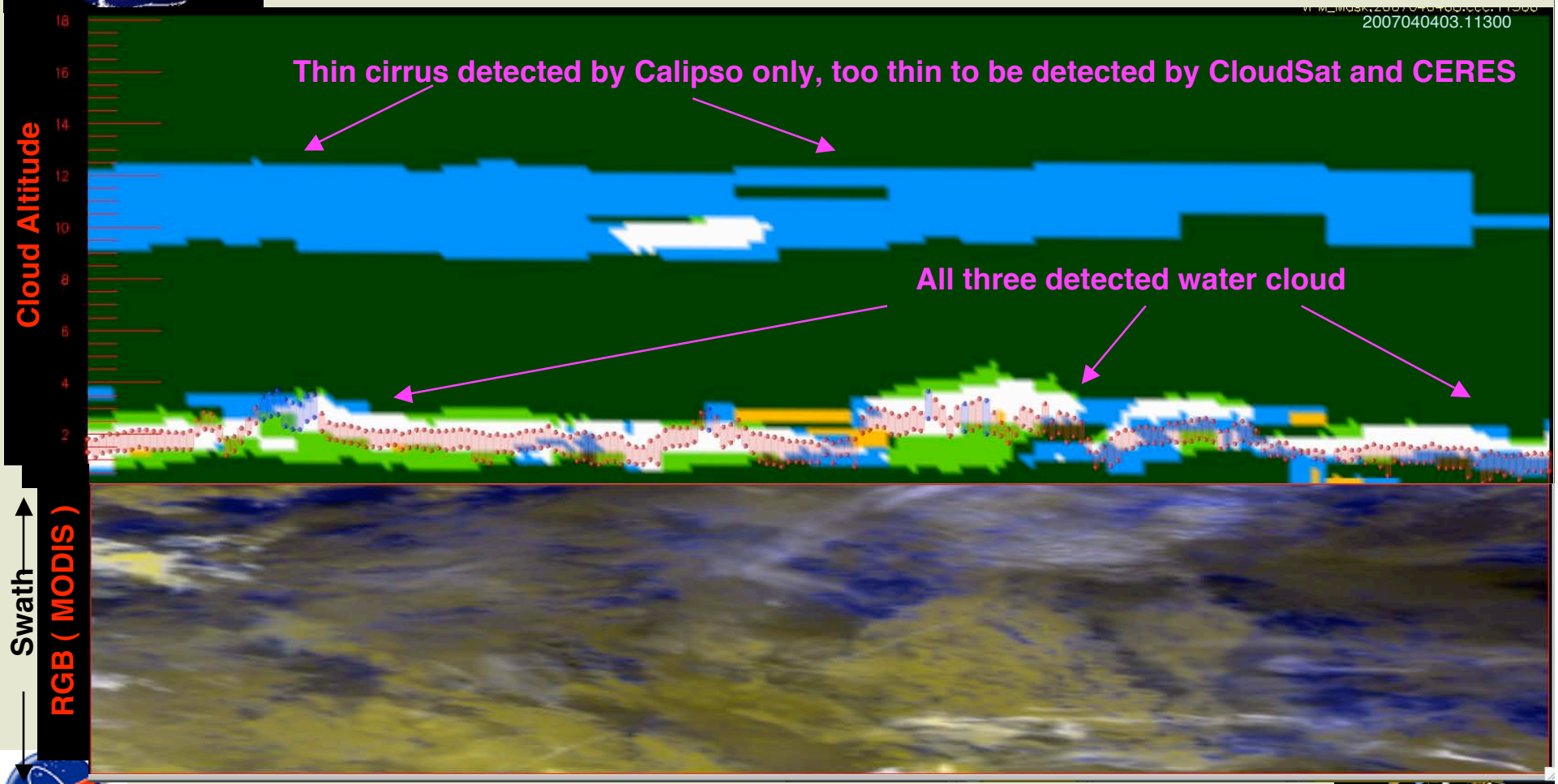
4 April 2007, 0500 UTC (200 km Coverage, night)



CALIPSO, CloudSat and CERES-MODIS Merged Example 2

4 April 2007, 0300 UTC (200 km Coverage, night)

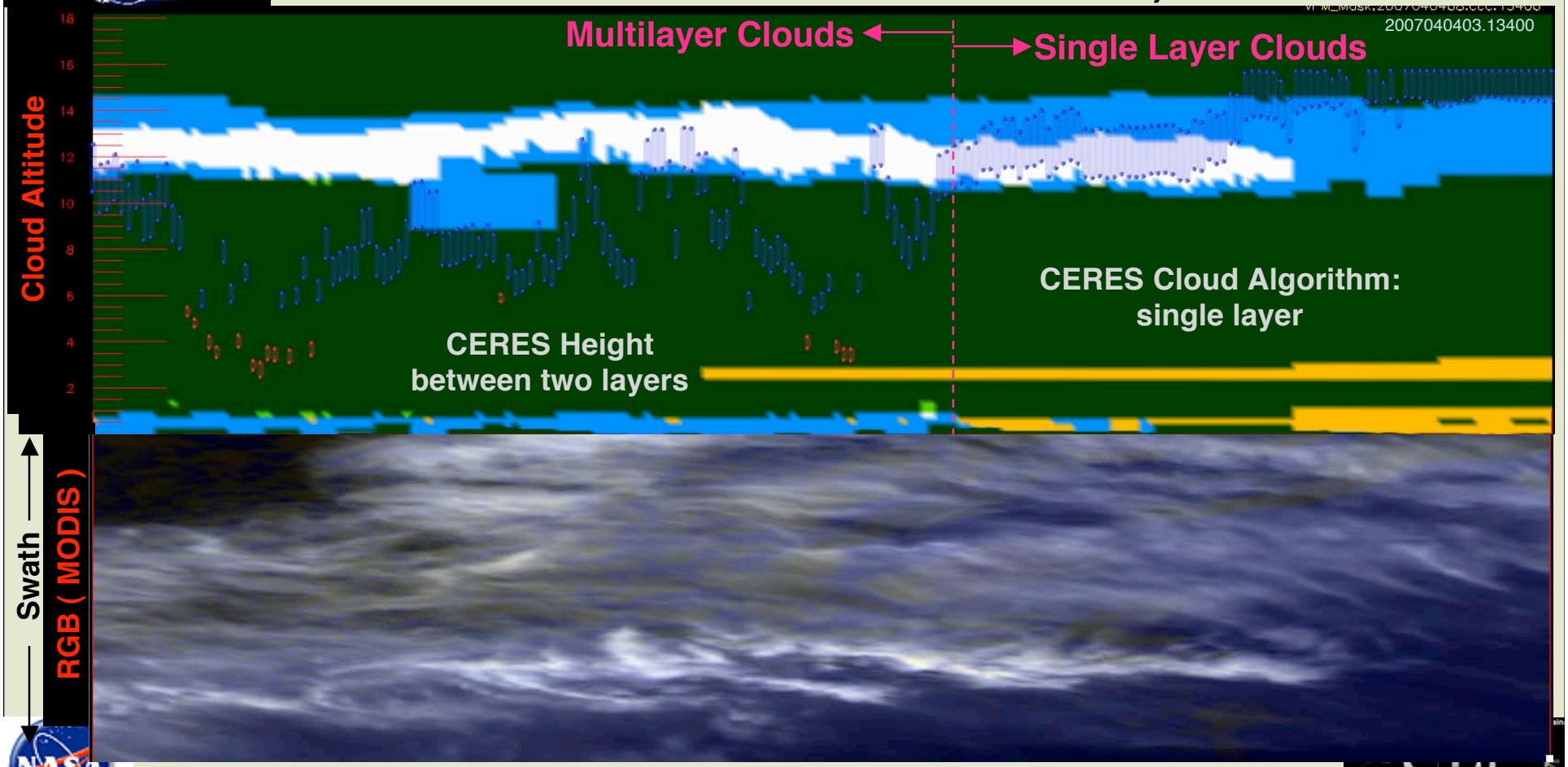




Track →

CALIPSO, CloudSat & CERES-MODIS Merged Example 3

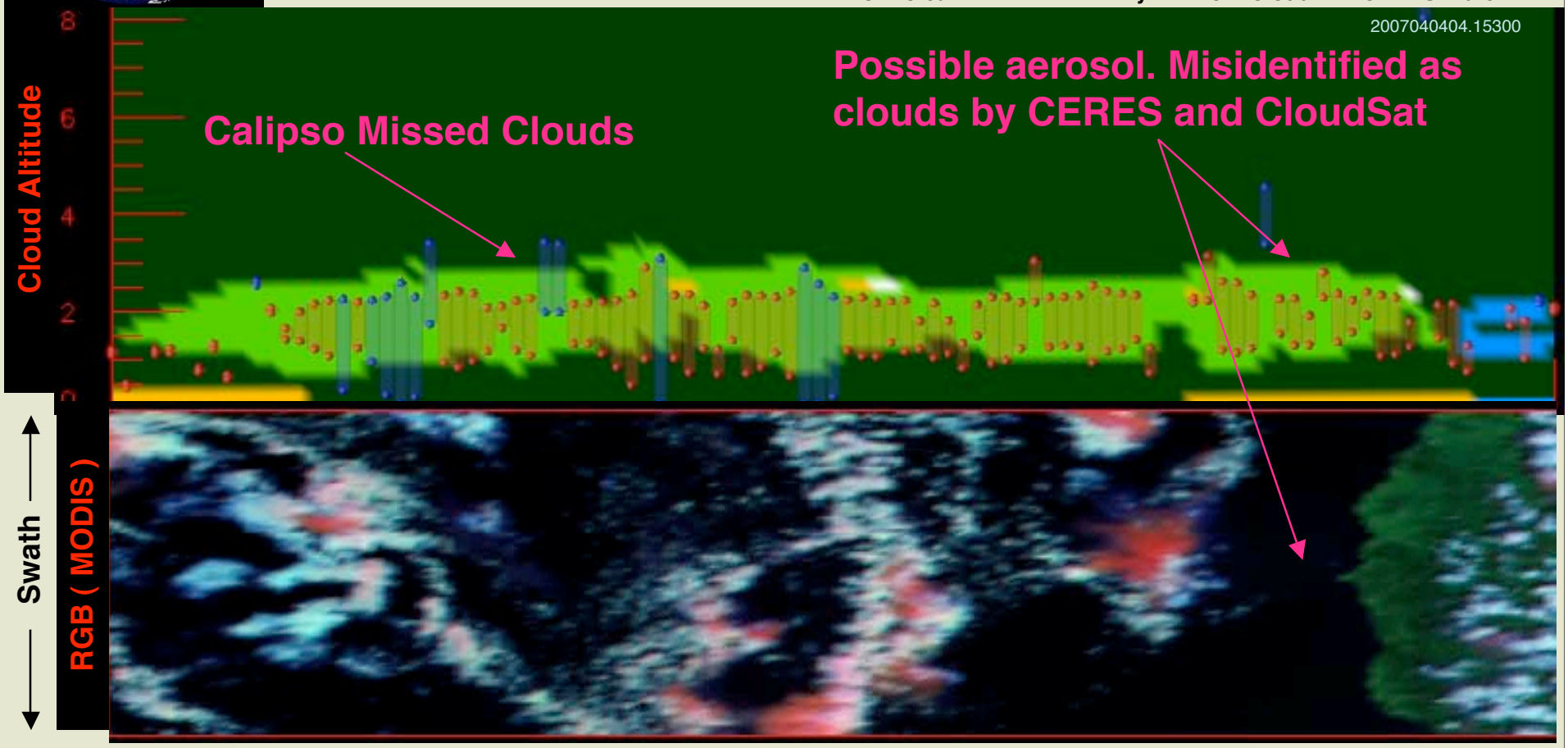
4 April 2007, 0300 UTC (200 km Coverage, night)



Track

CALIPSO, CloudSat & CERES-MODIS Merged Example 4

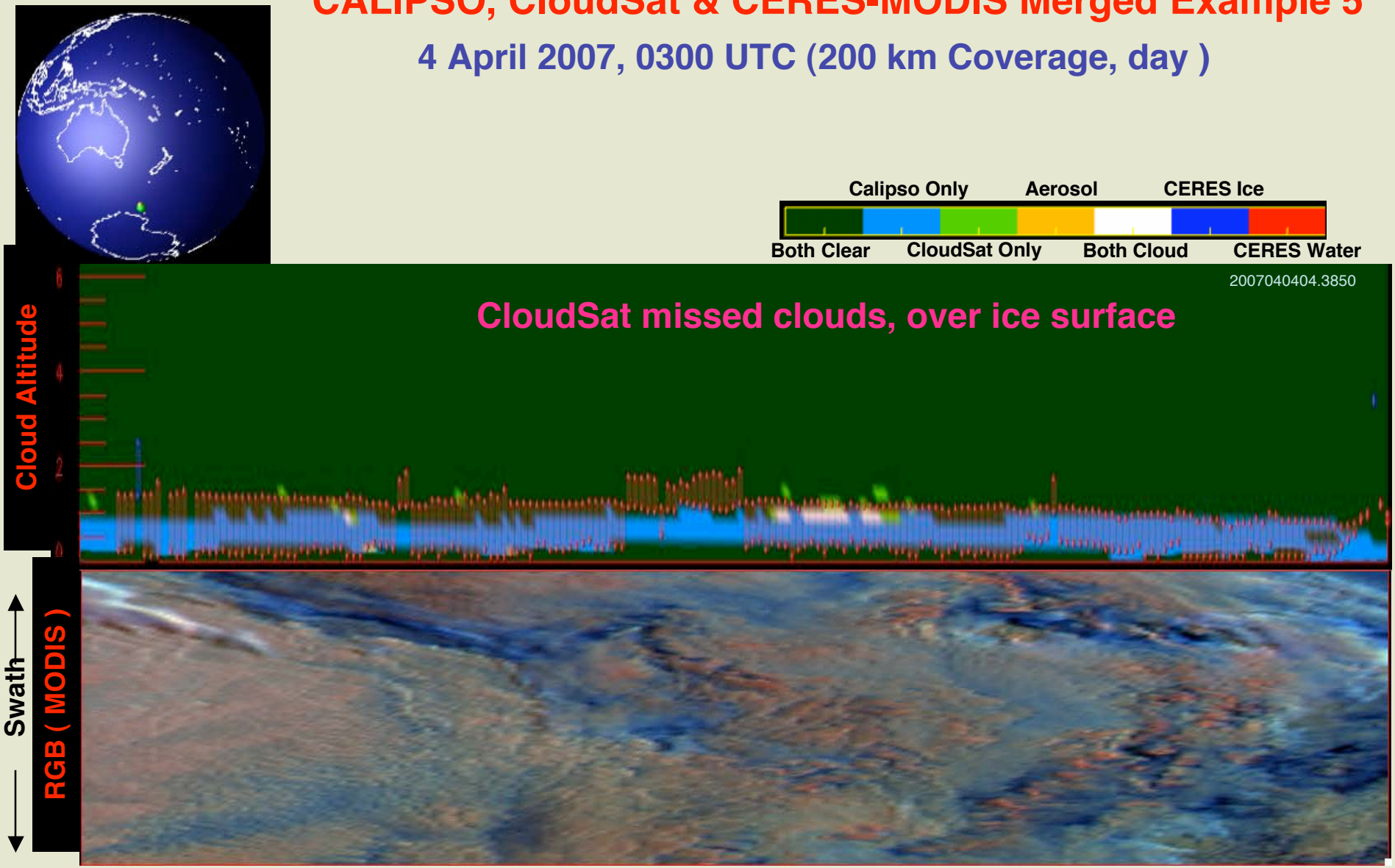
4 April 2007, 0400 UTC (100 km Coverage, day)



Track

CALIPSO, CloudSat & CERES-MODIS Merged Example 5

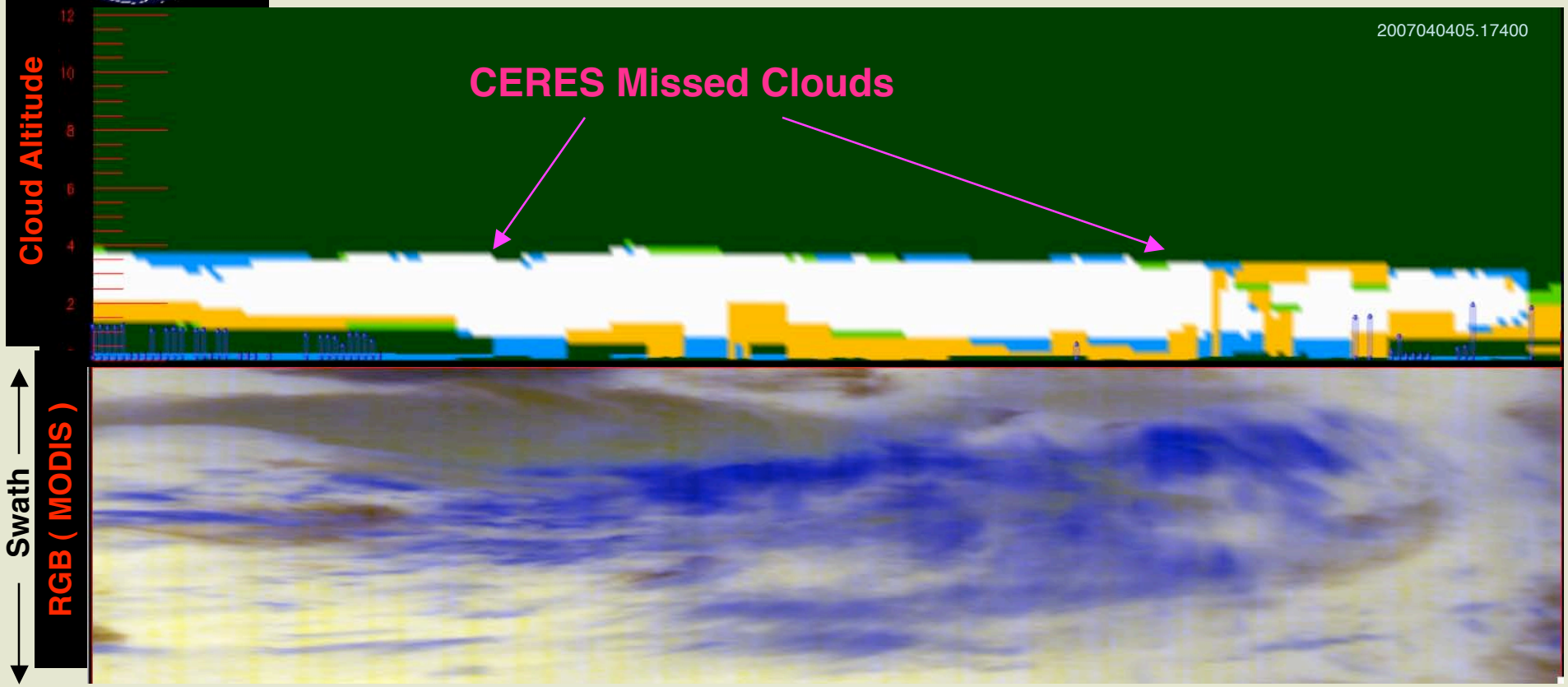
4 April 2007, 0300 UTC (200 km Coverage, day)



Track →

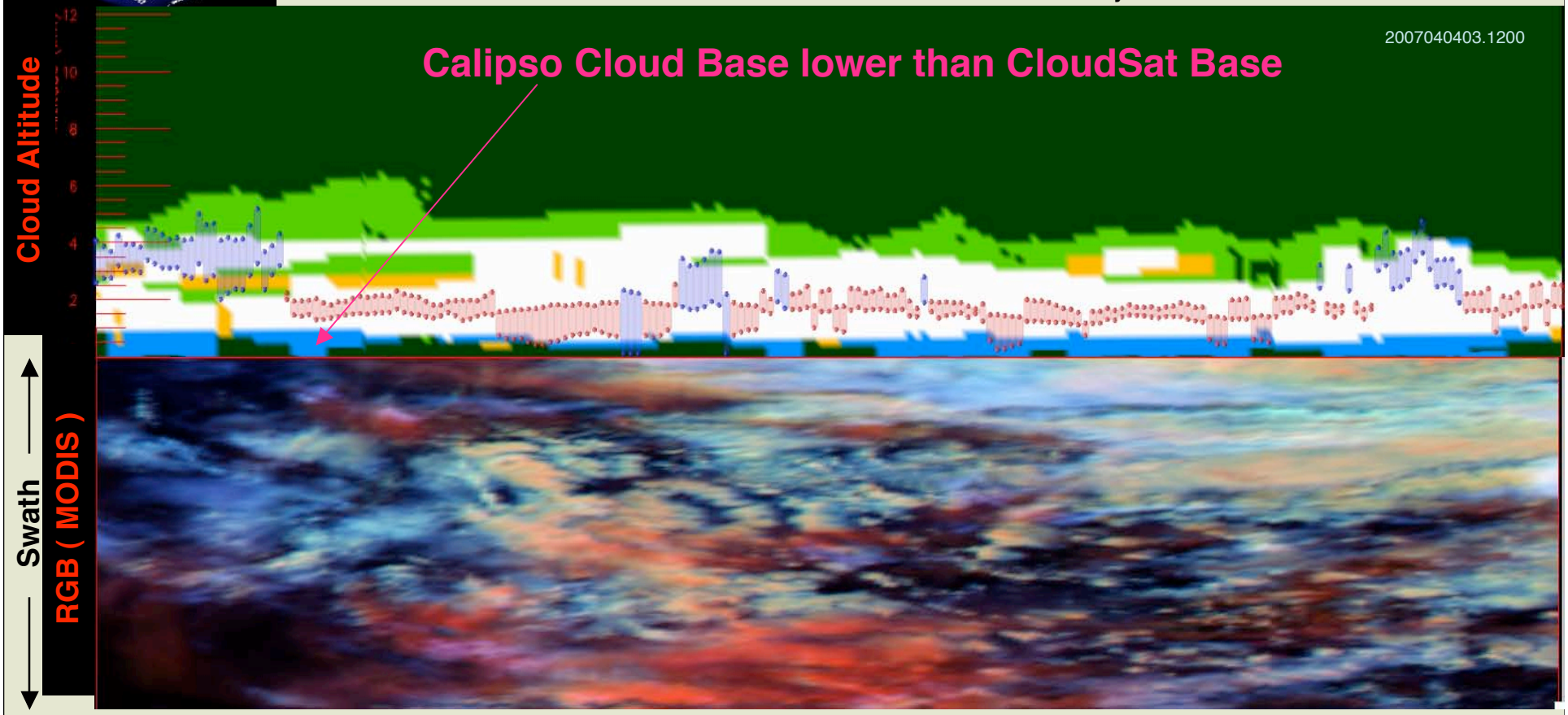
Calipso, CloudSat and CERES-MODIS Merged Example 5

4 April 2007, 0500 UTC, twilight



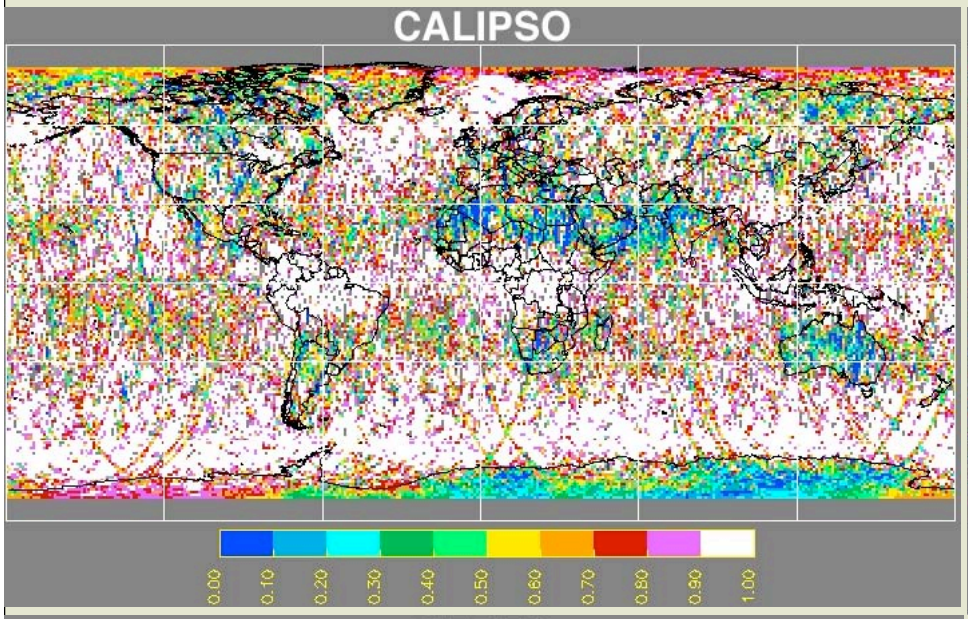
CALIPSO, CloudSat & CERES-MODIS Merged Example 7

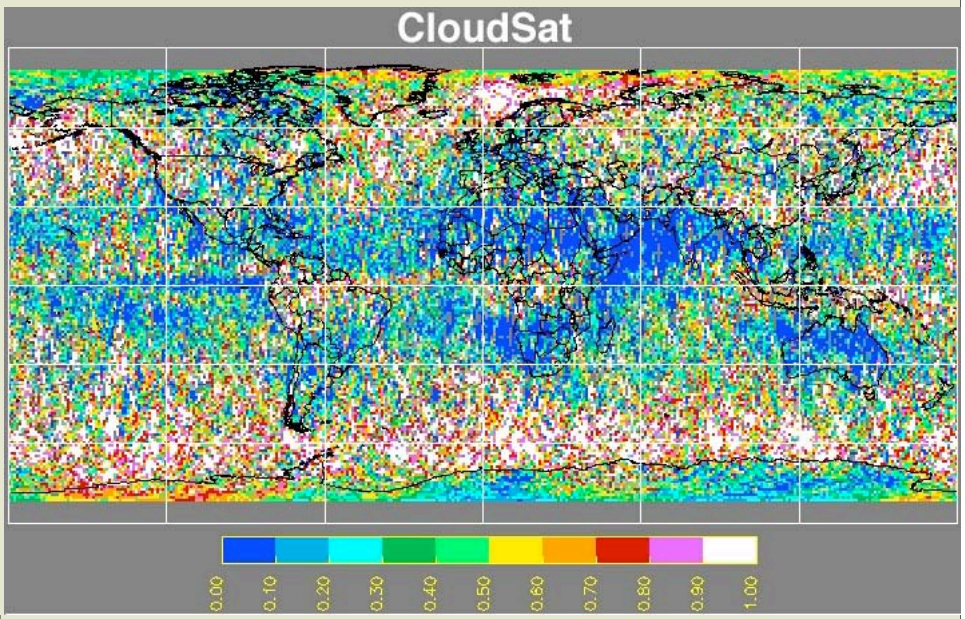
4 April 2007, 0300 UTC, day

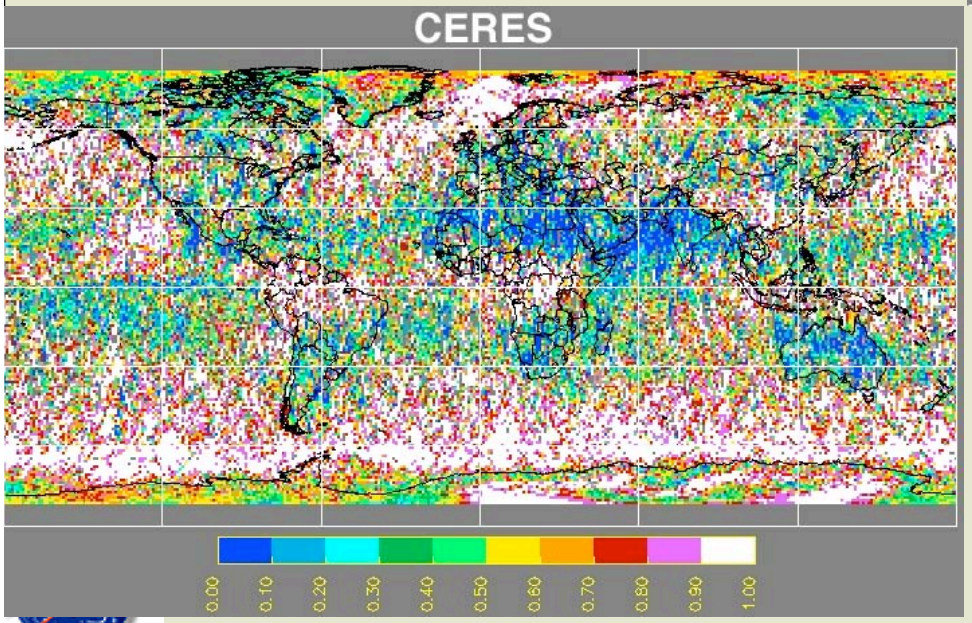


Track →

Mean Cloud Fraction April 2007



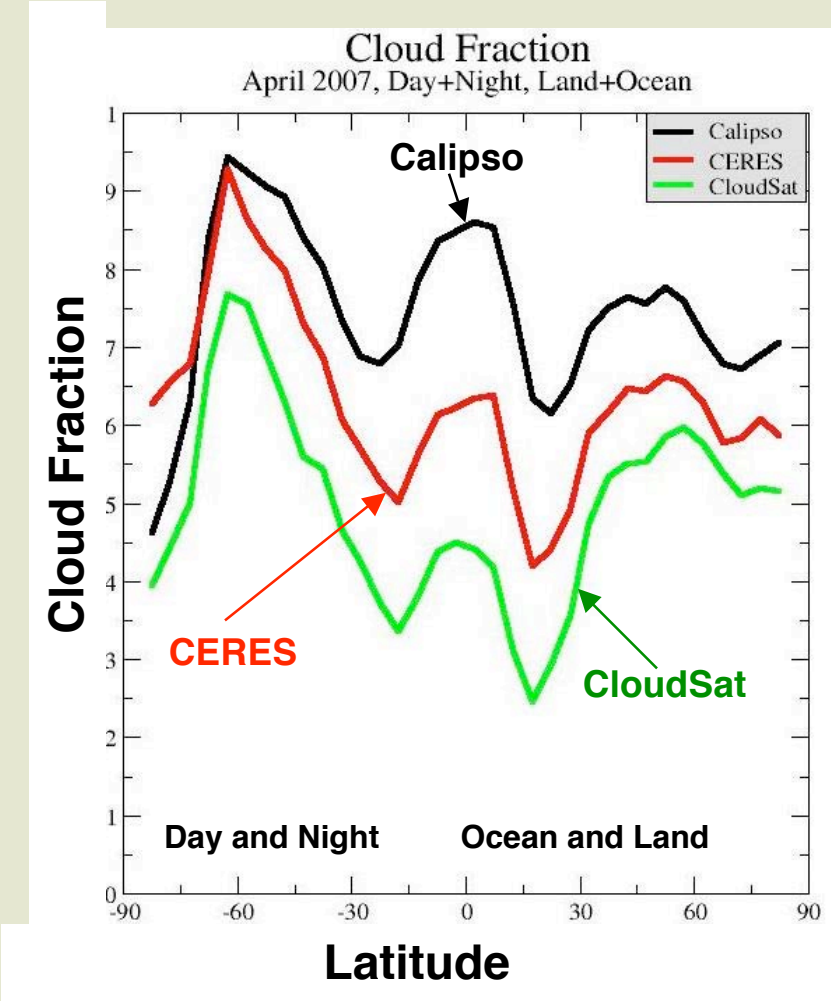




CALIPSO shows most clouds everywhere but Antarctica

CERES Aqua night tuned to bad Terra 3.8-μm calibration - too many super-cold clouds at night

Cloud Fraction Inter-Comparisons (April, 2007)



Day Time

	CALIPSO	CERES	CloudSat	
Ocean	0.77	0.66	0.47	11%, 19%
Land	0.71	0.55	0.43	16%, 12%

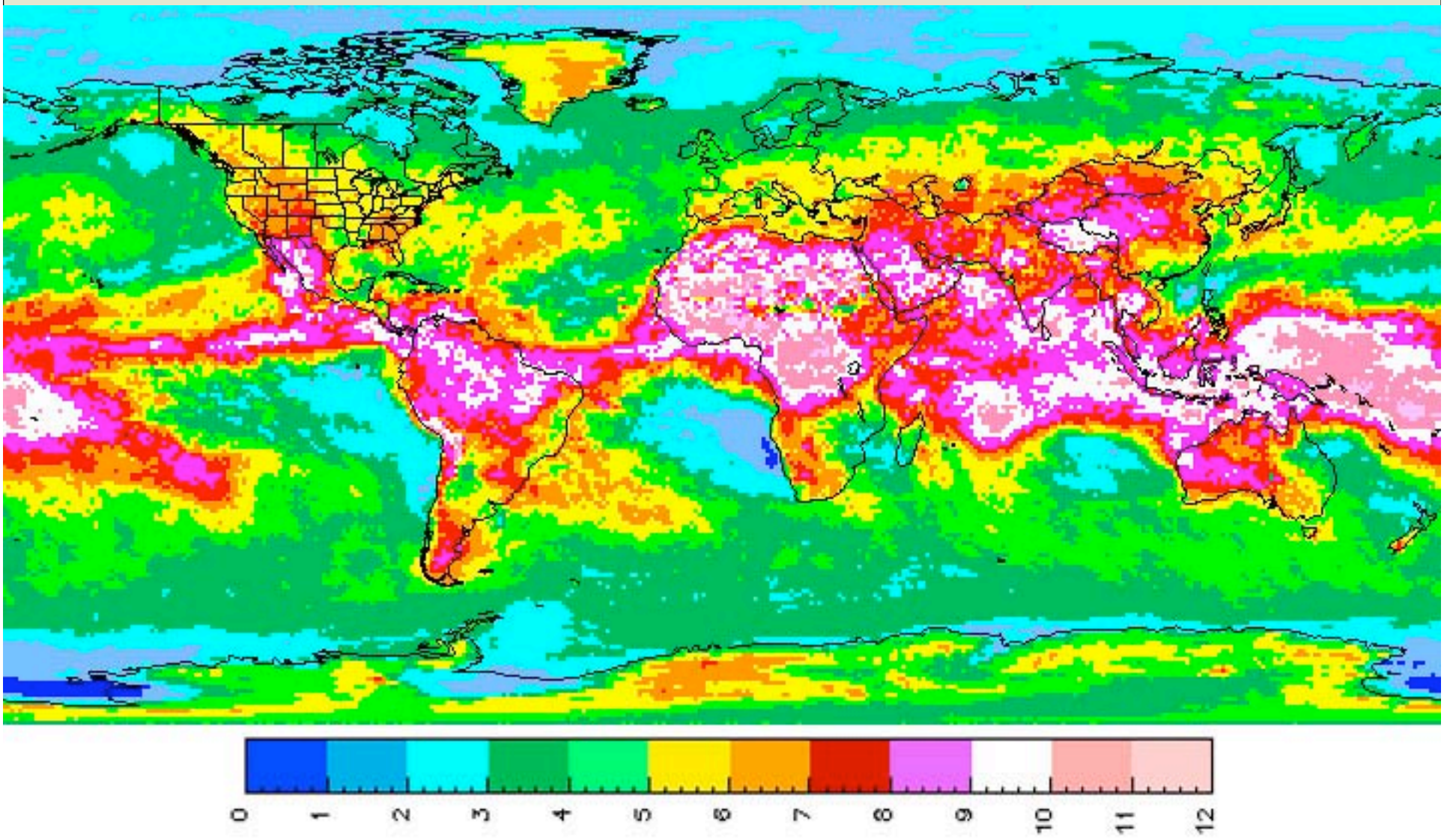
Night Time

	CALIPSO	CERES	CloudSat	
Ocean	0.83	0.65	0.51	18%, 14%
Land	0.69	0.54	0.43	15%, 11%

CERES detects 15% < cloud cover than CALIPSO

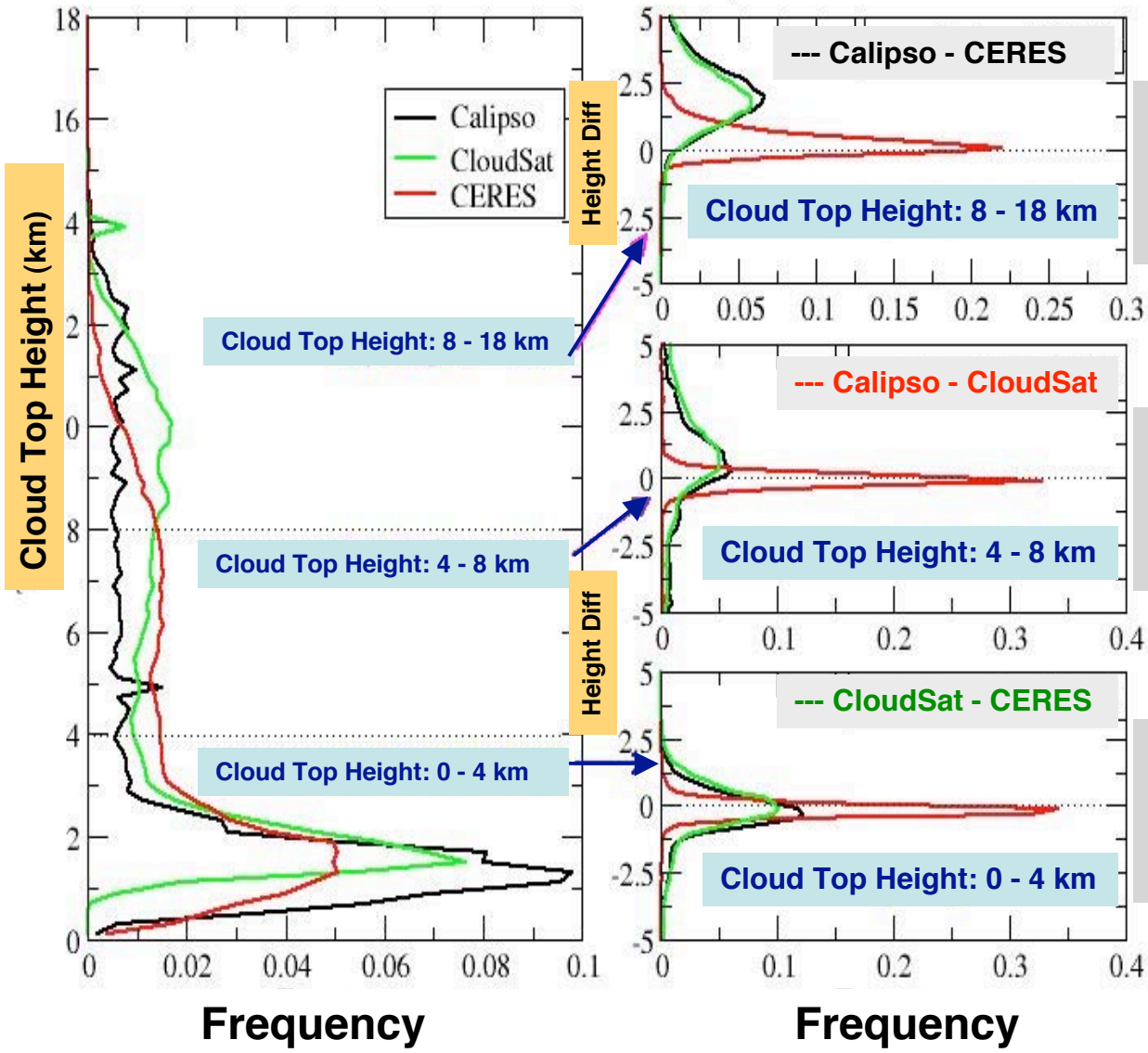
- mainly due to low optical depths?

Mean CERES-MODIS Effective Cloud Top Height (km) April 2007



Cloud Top Height Inter-Comparisons (Single Layer)

April 2007, Ocean, DayTime, Mid-latitude Southern Hemisphere (Lat = -30 --- -60)



Cloud Top Height Difference: Mean (Bias)

Calipso - CloudSat: 0.34 (1.96) km
Calipso - CERES: 2.4 (11.63) km
CloudSat - CERES: 2.2 (11.85) km

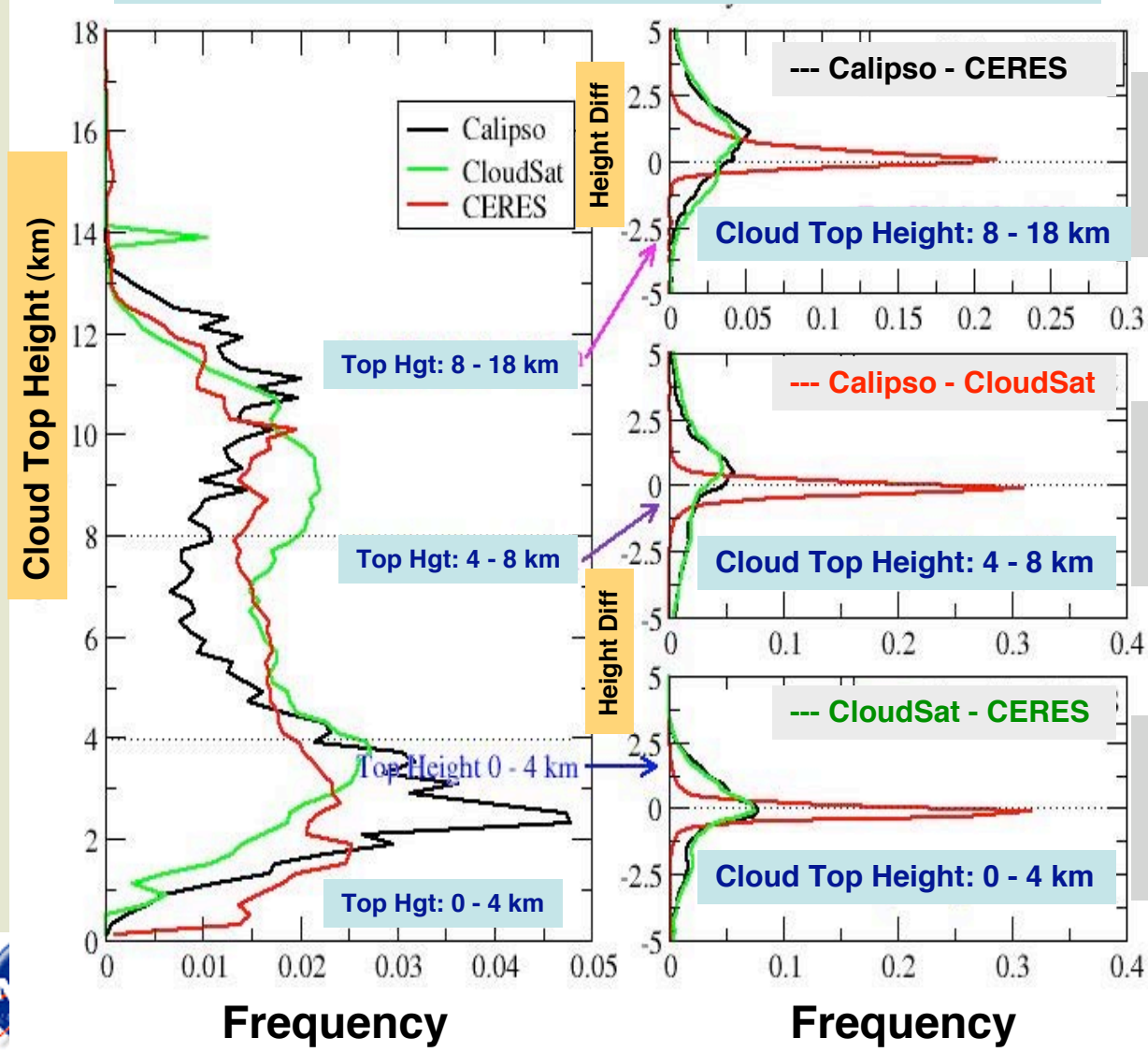
Calipso - CloudSat: -0.25 (2.25) km
Calipso - CERES: 0.15 (3.58) km
CloudSat - CERES: 0.93 (5.02) km

Calipso - CloudSat: -0.32 (2.54) km
Calipso - CERES: -0.51 (4.21) km
CloudSat - CERES: -0.42 (3.94) km

Cloud Top Height Inter-Comparisons (Single Layer)

April 2007, Land, DayTime, Mid-latitude Northern Hemisphere (Lat = 30 --- 60)

Cloud Top Height Difference: Mean (Bias)



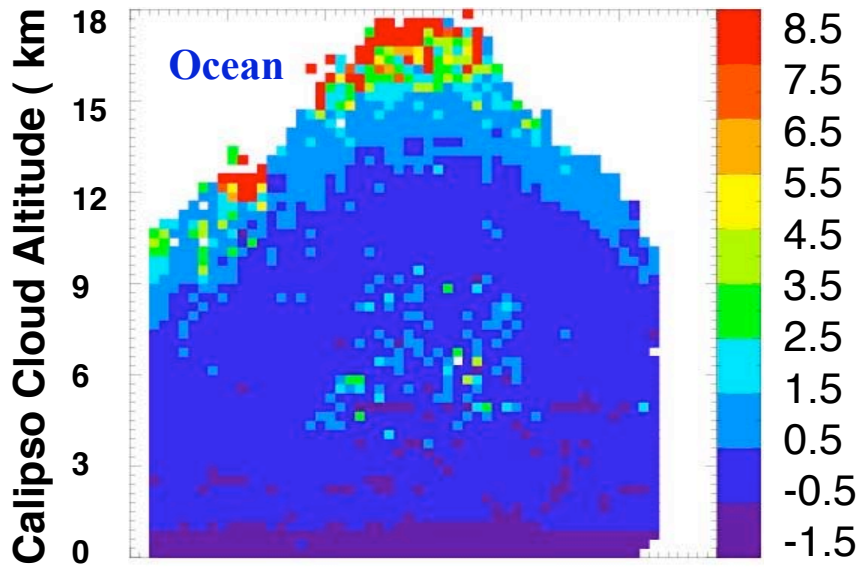
Calipso - CloudSat: 0.50 (1.98) km
Calipso - CERES: 1.62 (5.49) km
CloudSat - CERES: 1.27 (5.04) km

Calipso - CloudSat: -0.14 (1.14) km
Calipso - CERES: -0.17 (4.77) km
CloudSat - CERES: 0.20 (4.13) kmç

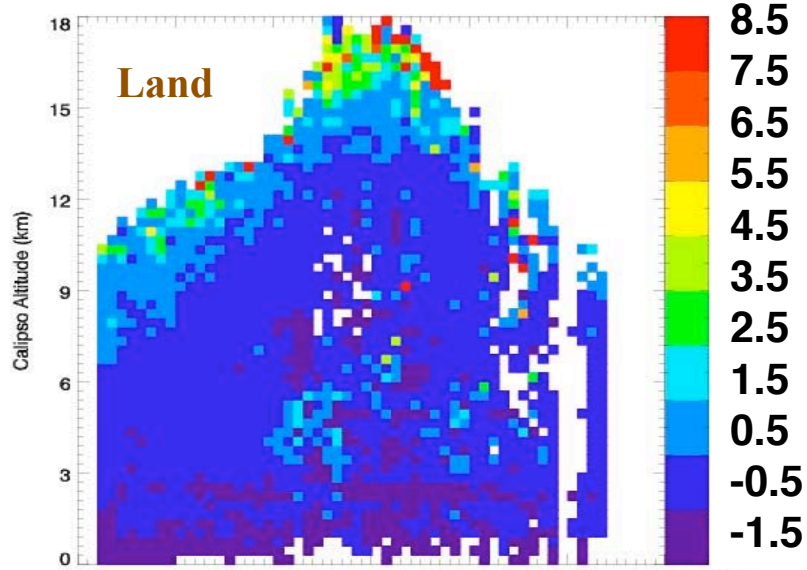
Calipso - CloudSat: -0.42 (3.44) km
Calipso - CERES: -0.55 (5.75) km
CloudSat - CERES: -0.58 (5.70) km

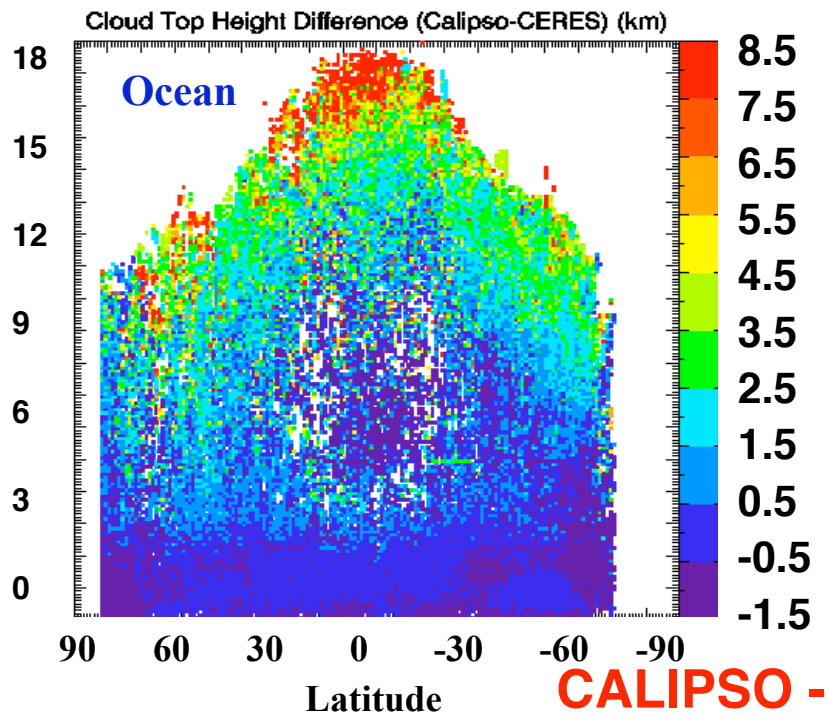
Zonal Cloud Top Height Difference (km) versus Cloud Altitude

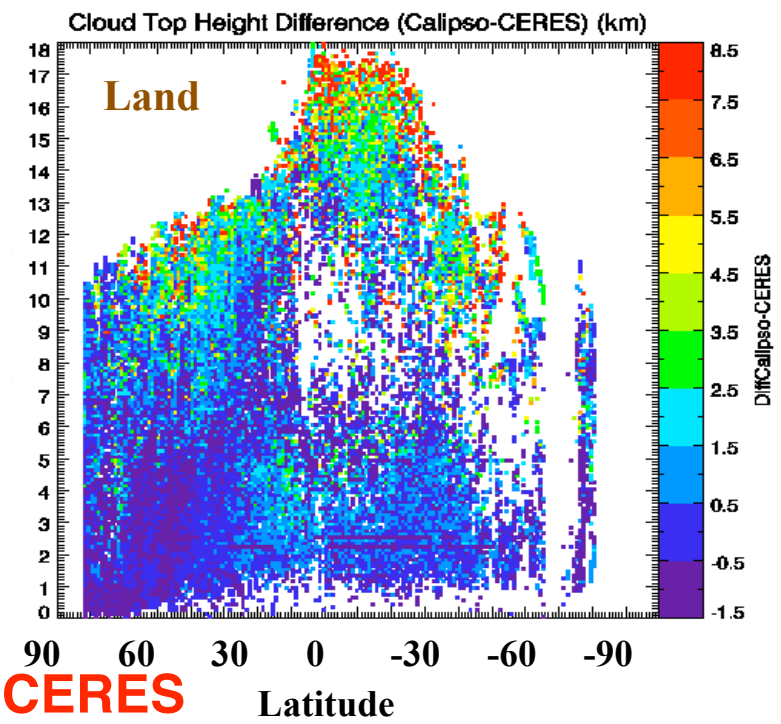
CALIPSO - CloudSat



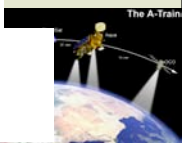
CALIPSO - CloudSat







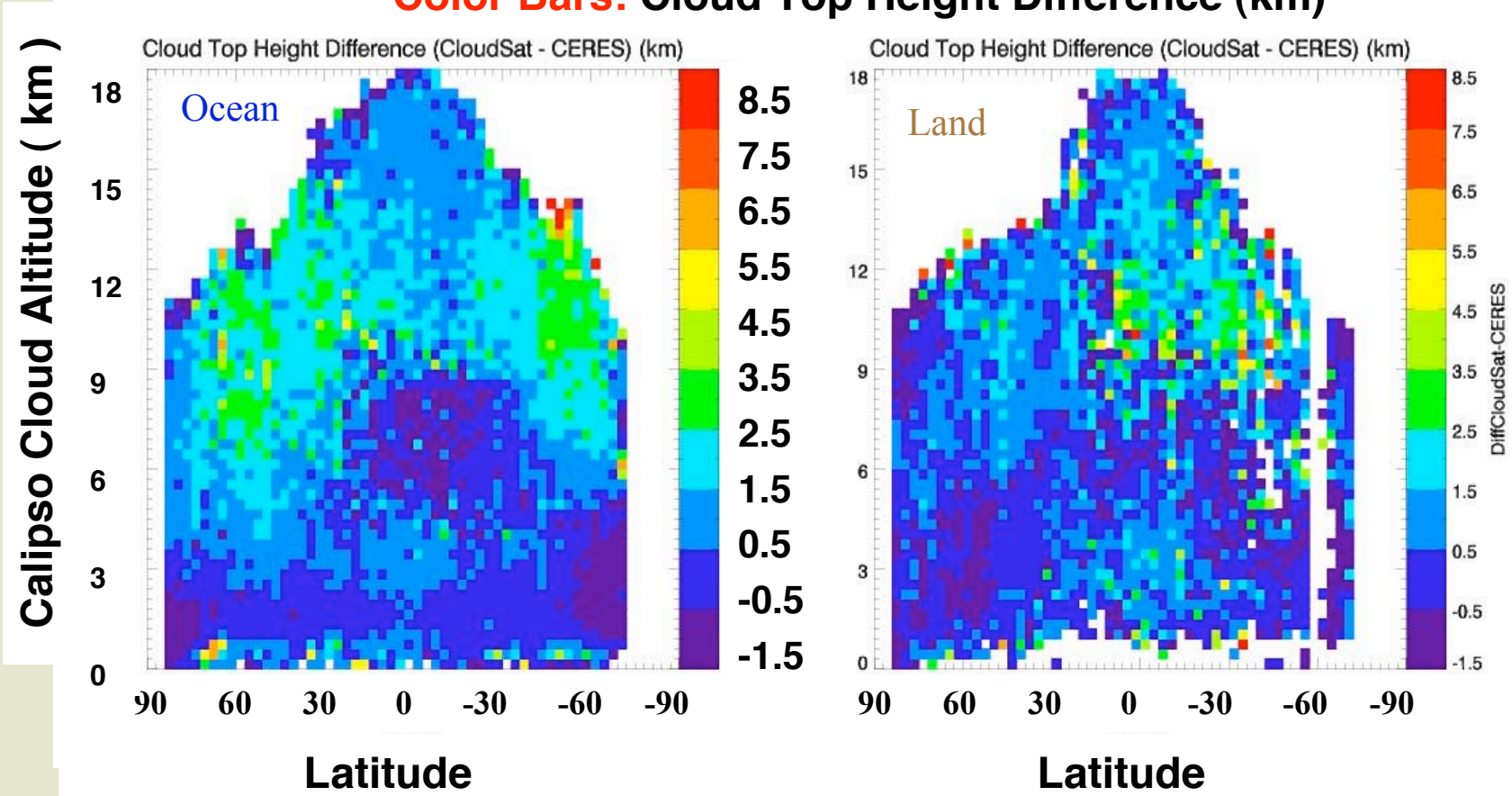
CALIPSO - CERES

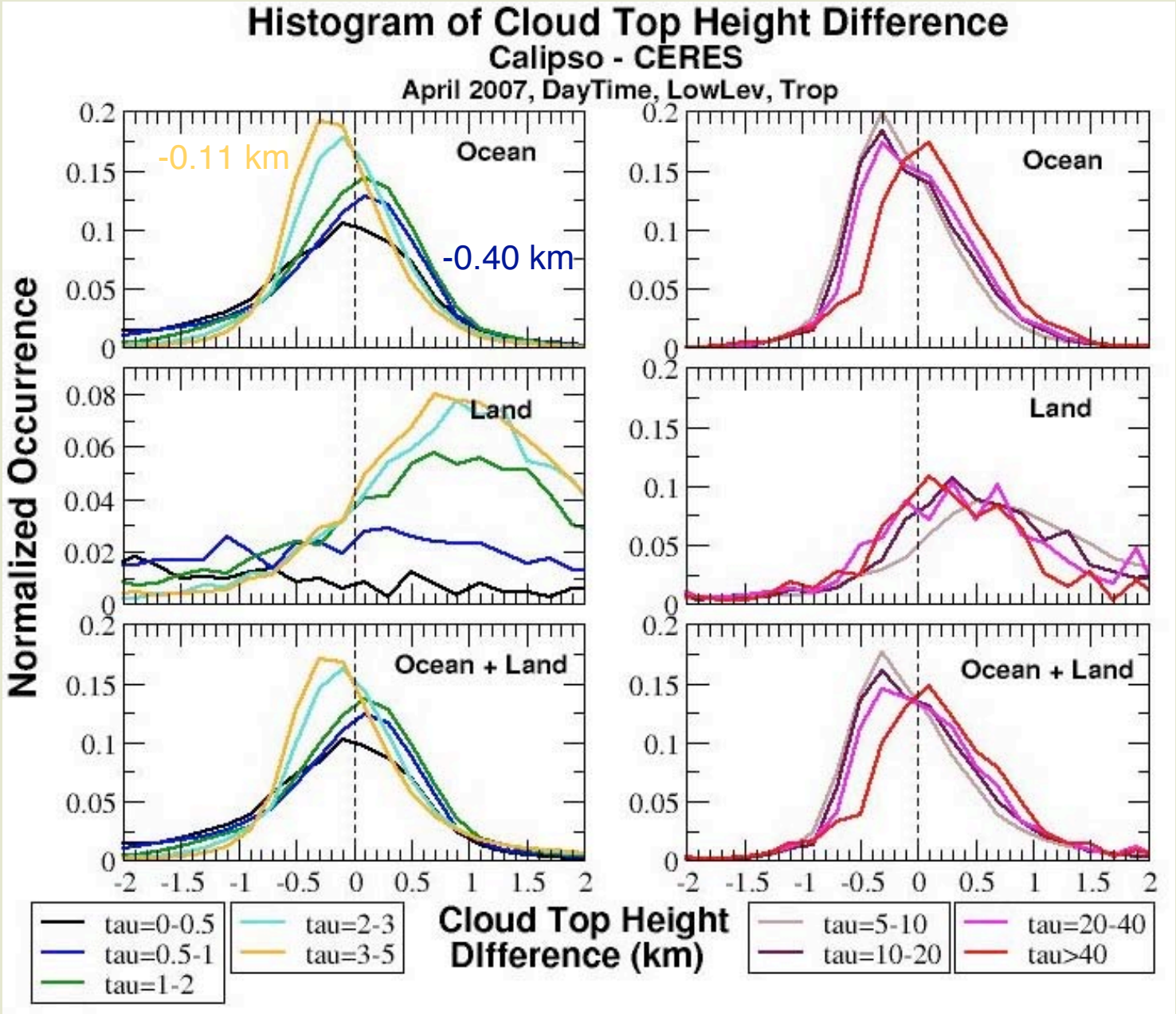


Zonal Cloud Top Height Difference (km) versus Cloud Altitude

CloudSat - CERES

Color Bars: Cloud Top Height Difference (km)

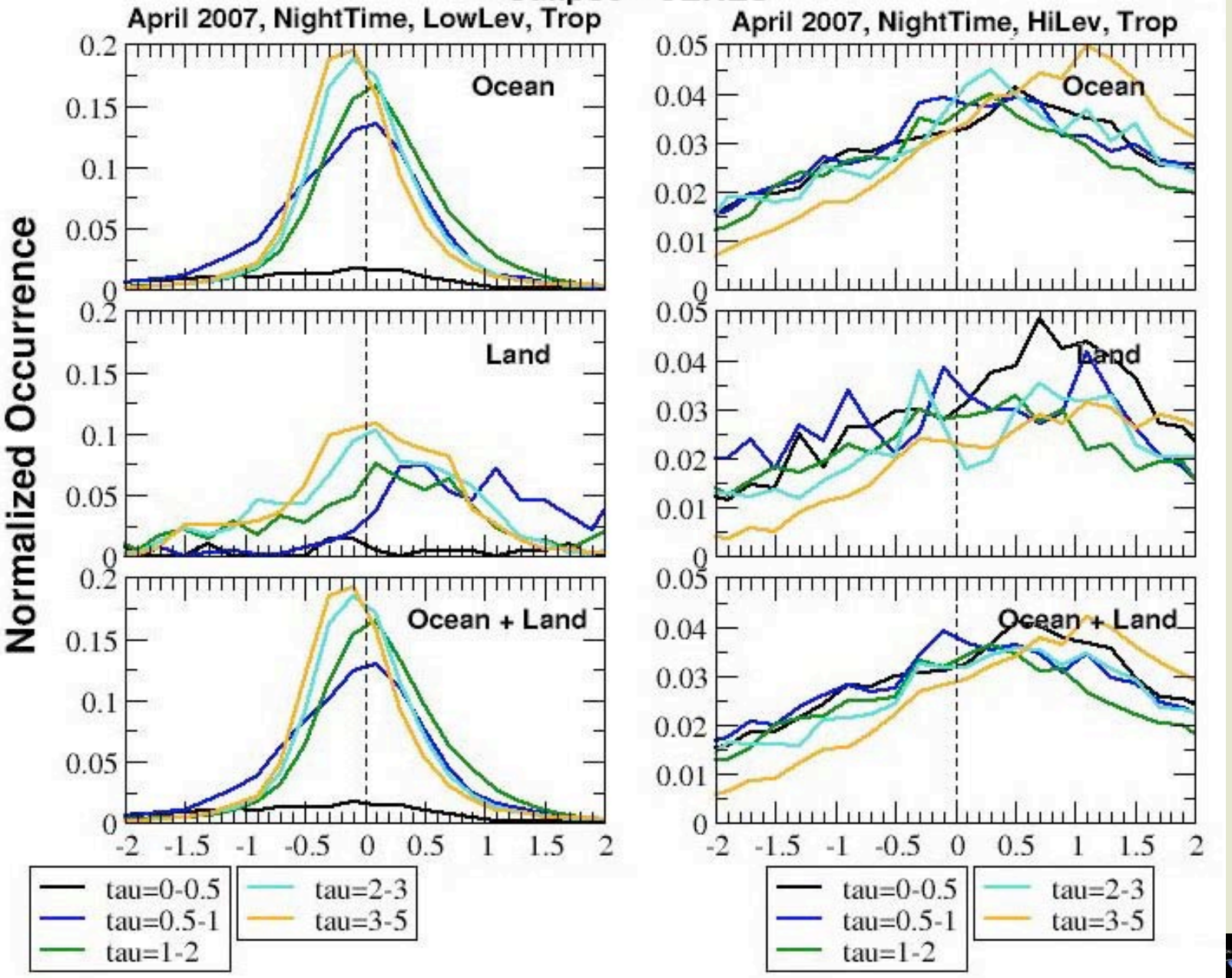




Different lapse rates needed over land and water

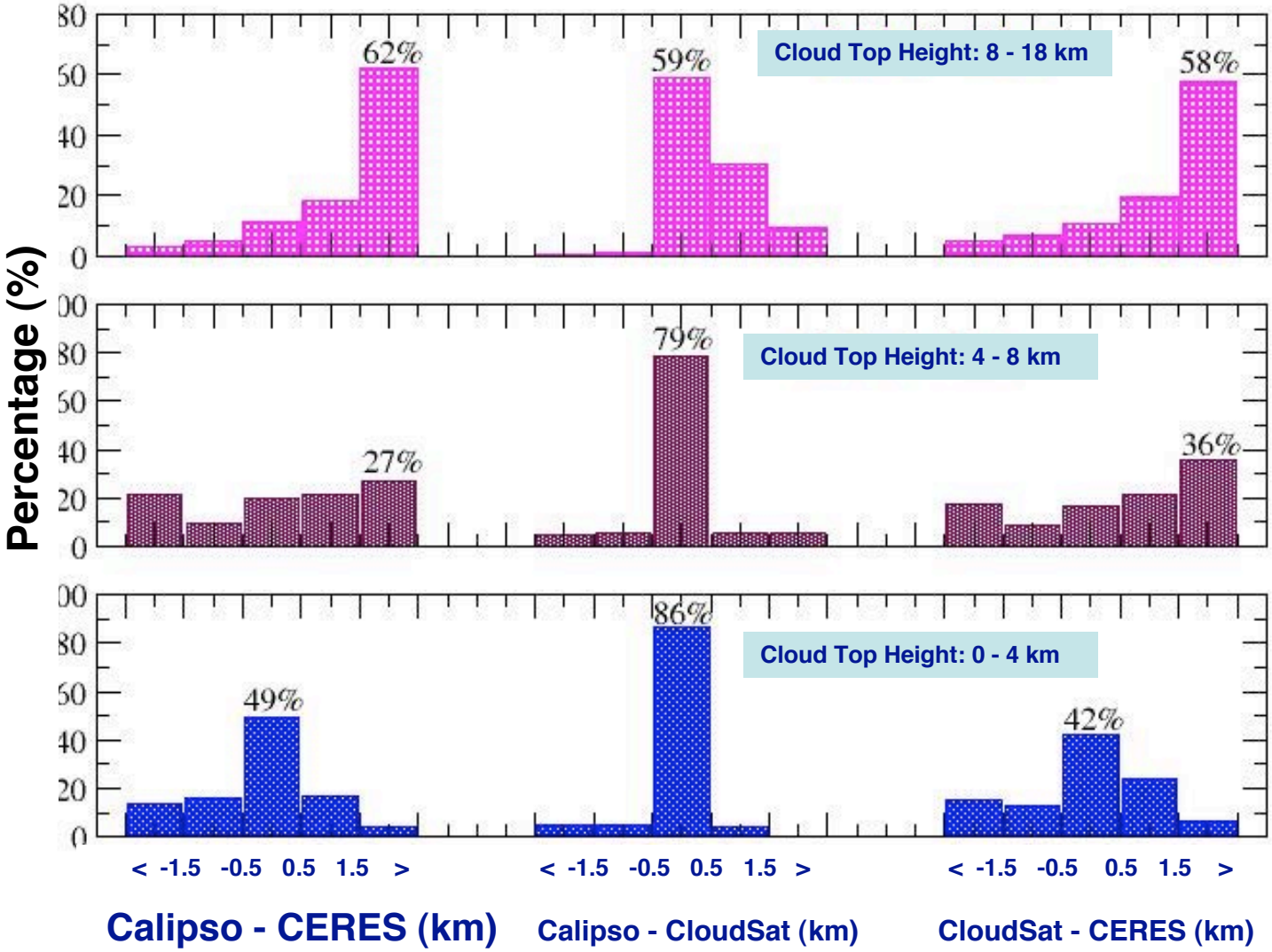
Histogram of Cloud Top Height Difference

Calipso - CERES



Global Cloud Top Height Difference Percentage (%)

April 2007, Day Time, Land and Ocean

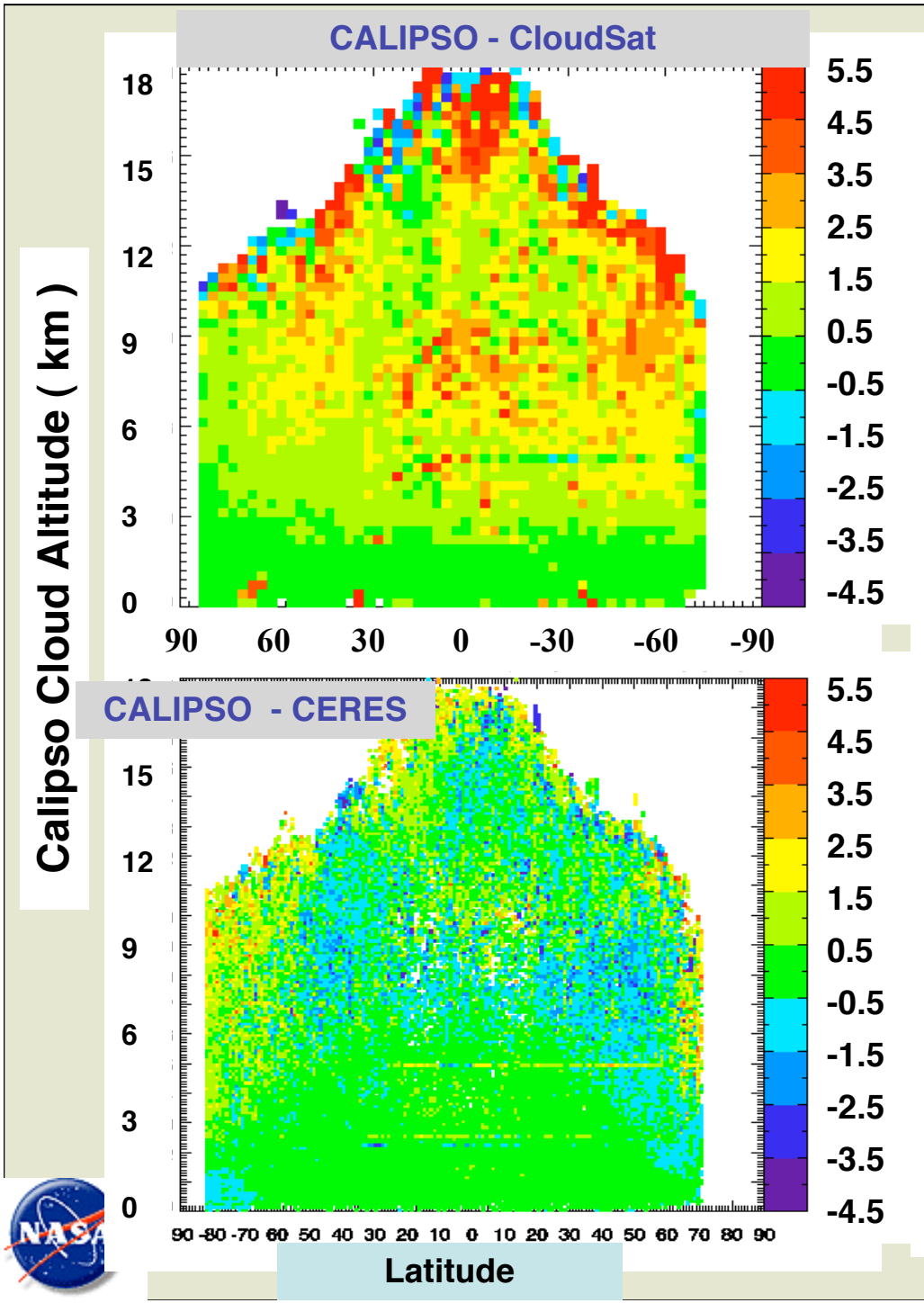


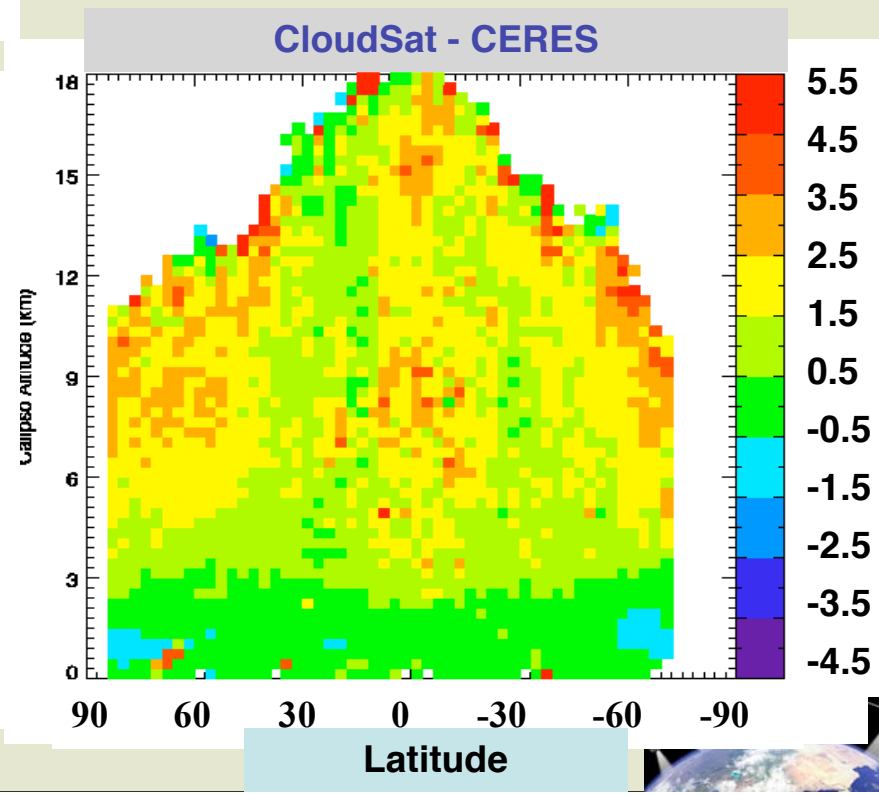
Cloud Top Height Difference

Zonal Cloud Thickness Difference (km) versus CALIPSO Cloud Altitude

Single Layer

Color Bars:
Cloud Thickness Difference (km)





IMPROVING THE ALGORITHMS FOR CERES EDITION 3

- Enhanced cloud detection (more channels, adjusted thresholds)

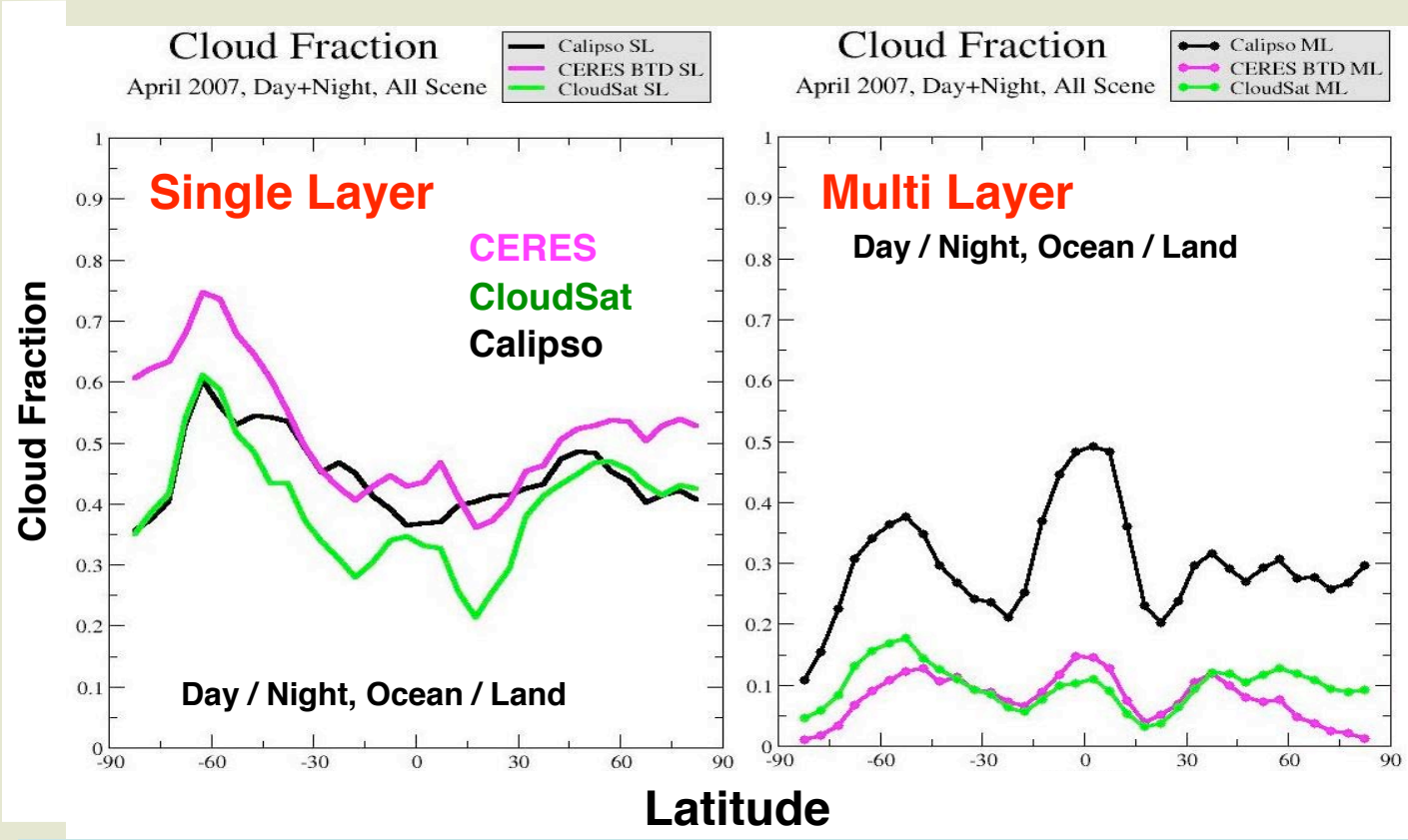
- New formulas for cloud thickness

-

- New corrections for thick cloud tops

- Multilayer cloud detection / retrieval

Single and Multi Layer Cloud Fractions Proto-Ed3 (April, 2007)



For improved multilayer algorithm, see F. Chang poster

Multilayer Cloud Fraction

Day Time

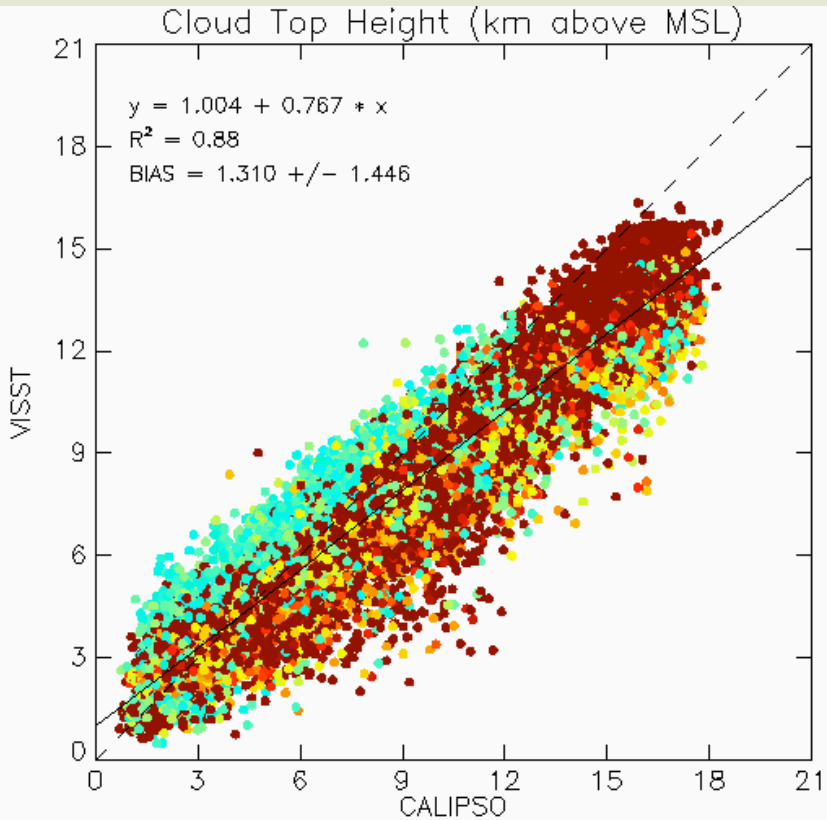
	Calipso	CERES	CloudSat
Ocean	0.32	0.11	0.10
Land	0.32	0.13	0.09

Night Time

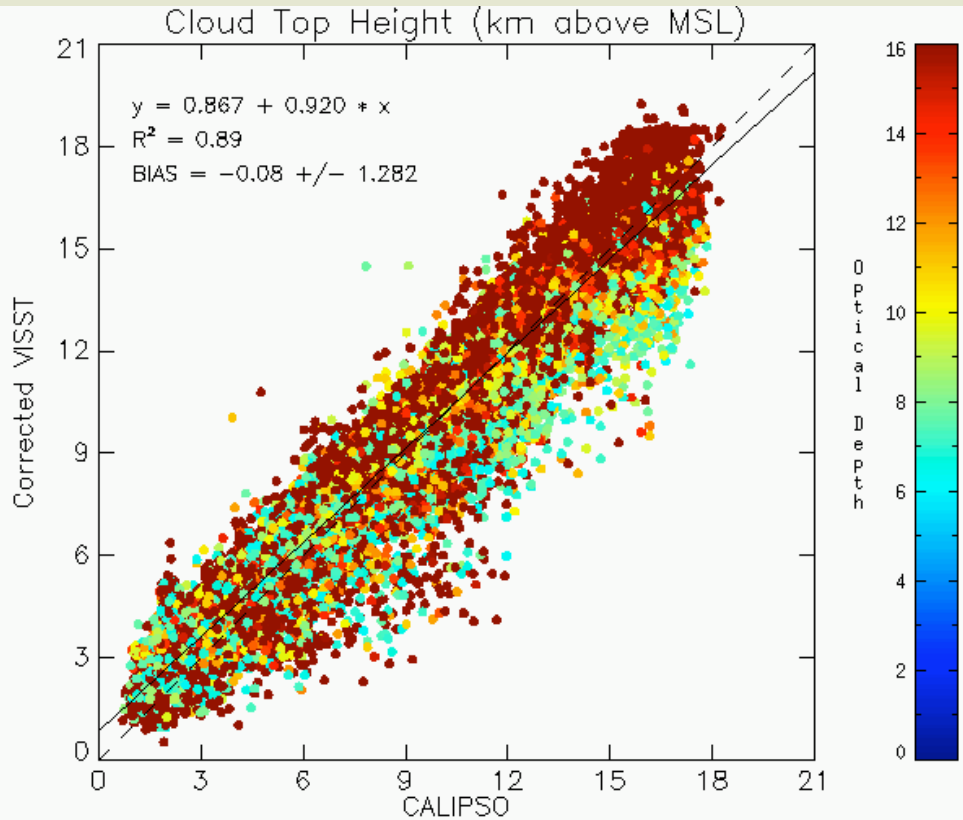
	Calipso	CERES	CloudSat
Ocean	0.34	0.07	0.11
Land	0.31	0.08	0.08

Correcting Cloud-Top Heights for Optically Thick High Clouds

Data for 27 April to make fit

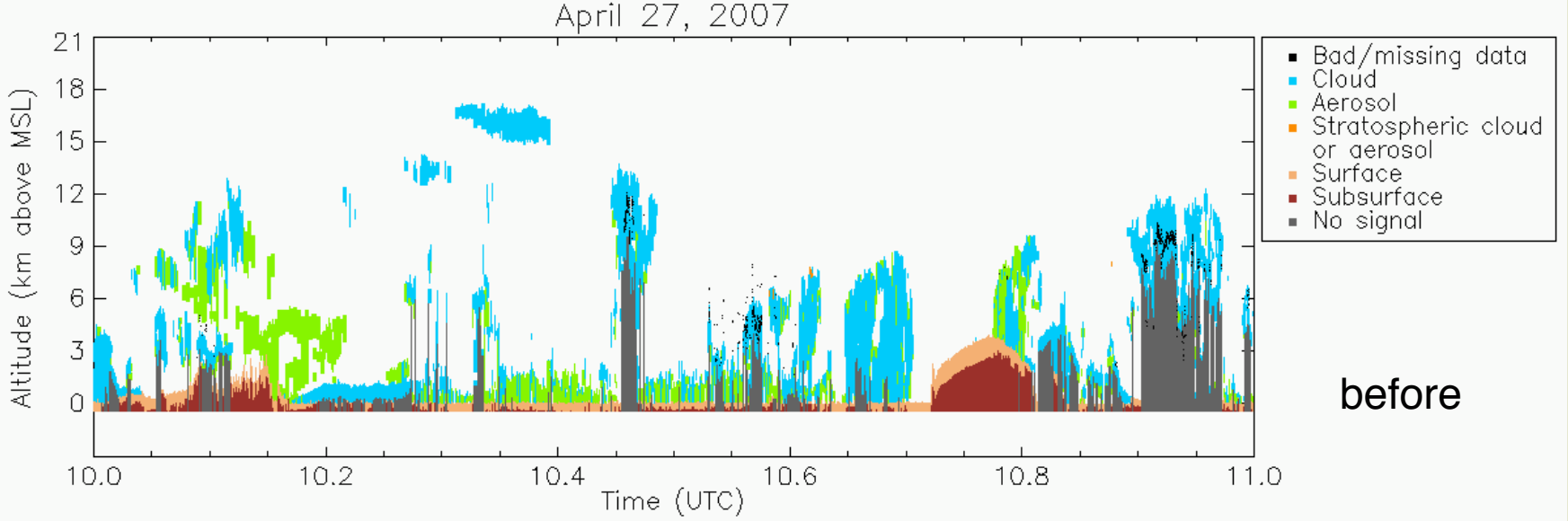


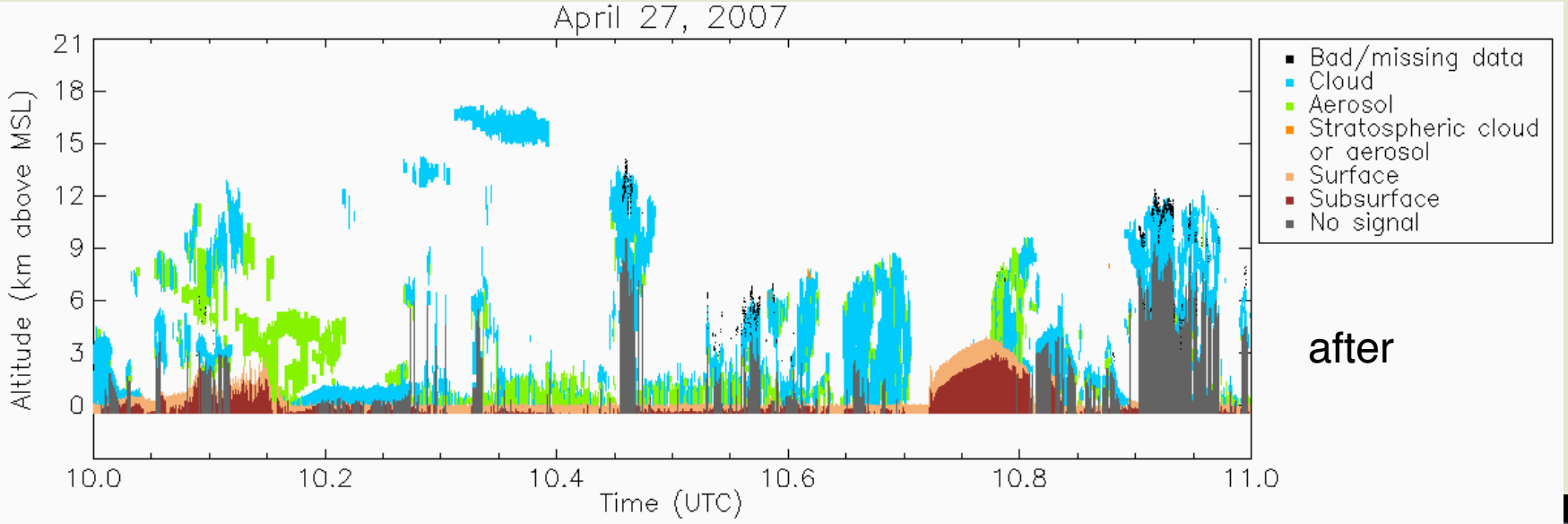
Data for all April using fit



Empirical corrections can be refined with theory and more data slicing to improve accuracies!

Example of improved cloud-top heights





Conclusion

- **CALIPSO, CloudSat & CERES-MODIS merged at NASA Langley**

- **CALIPSO, CloudSat & CERES cloud fractions: 0.76, 0.47, & 0.62**
  - **CALIPSO detects many more optically thin clouds**

- **Cloud-top height (single layer clouds)**
  - Low clouds: CERES within ±0.8 km of CALIPSO
    CloudSat > CALIPSO when top < 1 km
  - Mid clouds: CERES higher by 0.1 km, CloudSat very close
  - High clouds: CERES too low by 2.5 km, CloudSat by 0.5 km

- **Cloud thickness: CloudSat best for optically thick clouds**
  - **CERES & CALIPSO agree for clouds up to 8 km**
  - **CloudSat much thicker CALIPSO & CERES by 1.5 km**

- **CALIPSO & CloudSat will improve CERES retrievals**

- **More validation & improvements expected when other CC parameters are available (e.g., opt depth, LWP, IWP, etc.)**