CERES Cloud Algorithm Status & Validation

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CERES Science Team Meeting, New York, NY

27-29 October 2008

CERES Cloud Activities & Plans

- Prepared & submitted papers on algorithms, validation, calibration, science
- Continued validations & development of Ed3 improvements
- Completed Terra Ed2C and Aqua Ed2 through July 2007
  - *Ignored Collection 4 and 5 differences*
  - *GEOS-4 ended December 2007*
  - *Ed2 to continue through 2008 with GEOS-5*
- Edition 3
  - *Delivered Beta 1, evaluate*
  - *Refine Beta 1, add new changes, deliver Beta 2*

CERES cloud-related papers published since last STM

- Dong, X., B. A. Wielicki, B. Xi, Y. Hu, G. G. Mace, S. Benson, F. Rose, S. Kato, T. Charlock, and P. Minnis, 2008: Using observations of deep convective systems to constrain atmospheric column absorption of solar radiation in the optically thick limit. *J. Geophys. Res.,* **113**, D10206, doi:10.1029/2007JD009769.
- Su, J., J. Huang, Quang Fu, P. Minnis, J. Ge, and J. Bi, 2008: Estimation of Asian dust aerosol effect on radiation forcing using Fu-Liou radiative model and CERES measurements. *Atmos. Chem. and Phys.,* **8**, 2763-2771.
- Smith, W. L., P. Minnis, H. Finney, R. Palikonda, and M. M. Khaiyer, 2008: An evaluation of operational GOES-derived single-layer cloud top heights with ARSCL over the ARM Southern Great Plains site. *Geophys. Res. Lett.*, **35**, L13820, doi:10.1029/2008GL034275.
- Lin, B., P. Stackhouse, P. Minnis, B. A. Wielicki, Y. Hu, W. Sun, T.-F. Fan, and L. Hinkelman, 2008: Assessment of global annual energy balance from satellite observations. *J. Geophys. Res.,* **113**, D16114, doi:10.1029/2008JD009869.
- Yang, P., G. W. Kattawar, G. Hong, P. Minnis, and Y. X. Hu, 2008: Uncertainties associated with the surface texture of ice particles in satellite-based retrieval of cirrus clouds: Part I. Single-scattering properties of ice crystals with surface roughness. *IEEE Trans. Geosci. Remote Sens.*, **46**, 1940-1947, doi:10.1109/TGRS.2008.916471.
- Yang, P., G. W. Kattawar, G. Hong, P. Minnis, and Y. X. Hu, 2008: Uncertainties associated with the surface texture of ice particles in satellite-based retrieval of cirrus clouds: Part II. Effect of particle surface roughness on retrieved cloud optical thickness and effective particle size. *IEEE Trans. Geosci. Remote Sens.*, **46**, 1948-1957, doi:10.1109/TGRS.2008.916472.
- Minnis, P., C. R. Yost, S. Sun-Mack, and Y. Chen, 2008: Estimating the physical top altitude of optically thick ice clouds from thermal infrared satellite observations using CALIPSO data. Accepted, *Geophys. Res. Lett.*, doi:10.1029/2008GL033947, **35**, L12801, *doi:*2008GL033947.

CERES cloud-related papers accepted/submitted/ in prep since last STM

- Minnis, P., Q. Z. Trepte, S. Sun-Mack, Y. Chen, D. R. Doelling, D. F. Young, D. A. Spangenberg, W. F. Miller, B. A. Wielicki, R. R. Brown, S. C. Gibson, and E. B. Geier, 2008: Cloud detection in non-polar regions for CERES using TRMM VIRS and Terra and Aqua MODIS data. *IEEE Trans. Geosci. Remote Sens*., in press.
- Waliser, D., F. Li, C. Woods, J. Bacmeister, J. Chern, A. DelGenio, J. Jiang, M. Kharitondov, Z. Kuang, H. Meng, P. Minnis, S. Platnick, W. B. Rossow, G. Stephens, S. Sun-Mack, W. K. Tao, A. Tompkins, D. Vane, C. Walker, and D. Wu, 2008: Cloud ice: A climate model challenge with signs and expectations of progress. *J. Geophys. Res.*, in press.
- Minnis, P., S. Sun-Mack, Y. Chen, and Y. Yi, 2008: Comparison of CERES-MODIS and ICESat GLAS cloud amounts. In revision, J. *Geophys. Res.*
- Lin, B., P. Stackhouse, P. Minnis, B. A. Wielicki, Y. Hu, W. Sun, T.-F. Fan, and L. Hinkelman, 2008: Assessment of global annual energy balance from satellite observations. Submitted to *J. Geophys. Res.*
- Xie, Y., P. Yang, G. W. Kattawar, P. Minnis, and Y. Hu, 2008: Effect of inhomogeneity of ice crystals on retrieving ice cloud optical thickness and particle size. Submitted to *J. Geophys. Res.*
- Xi, B., X. Dong, P. Minnis, and M. M. Khaiyer, 2008: A 10-year climatology of cloud cover and vertical distribution derived from both surface and GOES observations over the DOE ARM SGP site. Submitted to *Geophys. Res. Lett.*
- Minnis, P., S. Sun-Mack, D. F. Young, P. W. Heck, D. P. Garber, Y. Chen, D. A. Spangenberg, R. F. Arduini, W. L. Smith, Jr., M. M. Khaiyer, R. Palikonda, M. L. Nordeen, J. K. Ayers, S. C. Gibson, R. R. Brown, E. B. Geier, Y. Takano, and K.-N. Liou, 2008: Cloud property retrievals for CERES using TRMM VIRS and Terra and Aqua MODIS data, *IEEE Trans. Geosci. Remote Sens.*, in preparation.
- Sun-Mack, P. Minnis, Y. Chen, R. F. Arduini, and D. F. Young, 2008, Visible clear-sky and near-infrared surface albedos derived from VIRS and MODIS data for CERES. *IEEE Trans. Geosci. Remote Sens*., in preparation.
- Trepte, Q. Z, P. Minnis, D. A. Spangenberg, R. F. Arduini, S. Sun-Mack, and Y. Chen, 2008: Polar cloud and snow discrimination for CERES using MODIS data. *IEEE Trans. Geosci. Remote Sens.*, in preparation.

Impact of SANDisk Crash

- Ed3 beta delivery of Feb 2008 is all that we currently have
    - code for all upgrades thereafter have been lost
    - new IGBP map derived MODIS scene ID product gone

- Ed2 conversion to MAC & IBM cluster computers for DAAC
    - Aqua code & QC codes require 2 months to get back where we were (almost running)

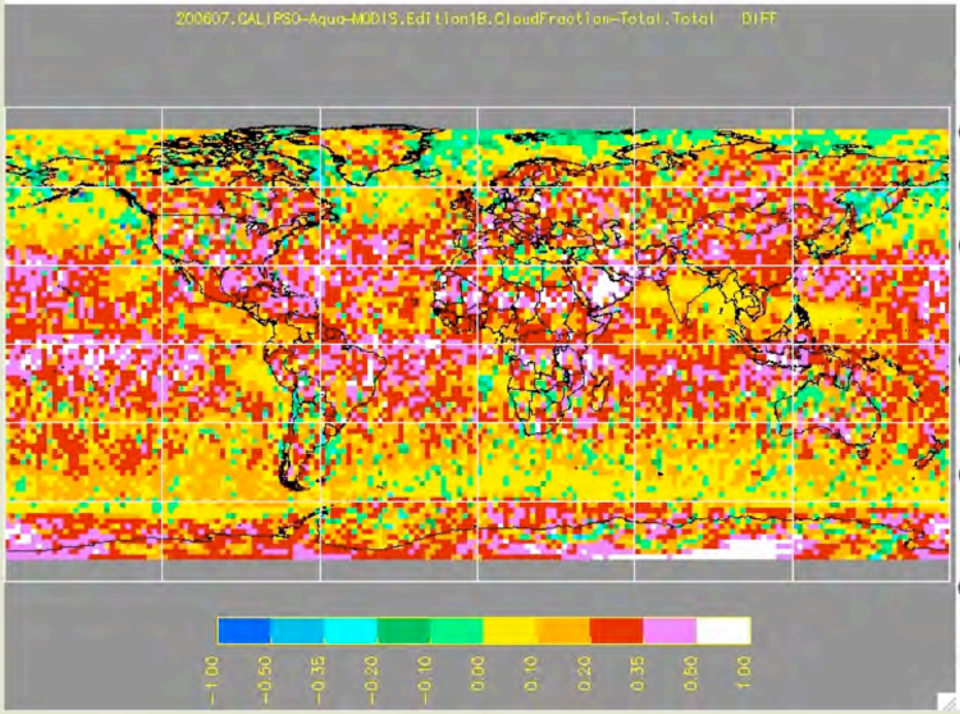
- A-Train matched dataset used for algorithm testing/validation
    - 80% of code is gone
    - Only 1 day of data survived
    - need to develop 4 month reduced swath matched dataset to test & refine Ed3 codes

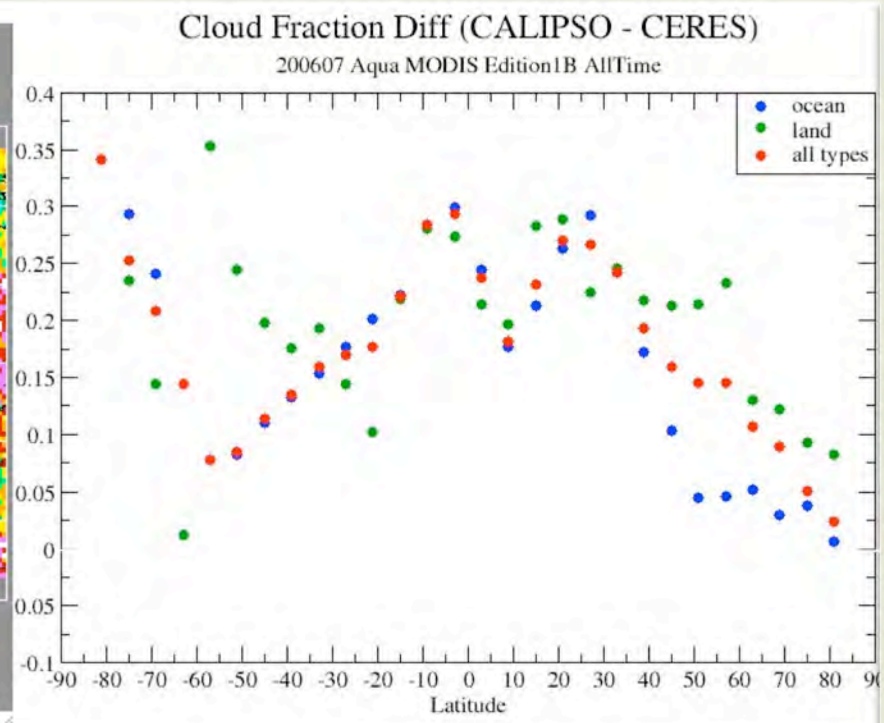
GEOS-5 & Forward Processing

- GEOS-5 now coming in
- Back in time for reprocessing
    - Dec 97 – Dec 07, first month is at DAAC
- New processing
    - Oct 07 – Dec 2011, no files received yet
    - Much of 2007 had mismatch between data & nav files
        - *new files will be ordered to replace current in-house files*

BACKGROUND

Cloud Fraction Difference, July 2006: CALIPSO - CERES





In general, CERES appears to need more clouds -

Mostly polar night & tropics (high & low)

Ed3 Beta1 Cloud Code Changes

- **Cloud Mask Changes**

Non-polar Day

- *improved dust detection using IR BTDs, ref ratios*
- additional low cloud check for SZA > 70°
- better snow tests for high elevation/melting snow
- refined cloud shadow tests
- reduced misclassifications along coasts
- sunglint definition changed from prob > 2% to prob > 10%
- new warm cloud tests in sunglint

Non-polar Night

- attempted reduction in polar-nonpolar discontinuity
- added low/inversion cloud detection test based on sfc emis thresholds
- reduced T3.7-T11 STD (threshold) by 0.5 K
- refined snow & thin cirrus detection tests

- **Cloud Mask Changes**

Polar Day

- Theoretical 2.1-μm snow models used for both Terra & Aqua
- improved classification of TBD pixels
- refined cloud & snow tests over super-cold plateau

Polar Night

- improved cloud detection over super-cold plateau
- enhanced mini-mask for TBD pixels

Twilight

- added visible channel tests to smooth day-night transition
- added new thin cirrus and low-cloud tests

Thin cirrus

- CO2 retrievals complement standard CERES mask

- **Cloud Retrieval Changes**

Single-layer

- CO_2 algorithms: Standard 4-channel; Chang 2-channel (C2C: 11 & 13.3 μm)
  - if VISST/SIST no retrieval, force VISST values to C2C Tcld
- 2.1-μm used for SINT & VINT retrievals for both Aqua & Terra
  - error discovered in Aqua Ed2: 1.6 corr-k's used for 2.1 μm

    Aqua polar optical depths ~ ½ of Terra values
- zonally averaged ocean/land lapse rates from CALIPSO used for low clouds
  - examining use of combined MOA & lapse rates for low clouds
- improved thick ice-cloud top heights
  - developing new thickness parameterizations
- implemented IGBP-dependent snow albedo models
  - testing revealed some problems
- extended optical depth range to 512
  - still questionable
- initial 2.1-μm particle size retrieval algorithm (VINT)
- phase tweaked
  - examining use of mixed CO2/VISST to eliminate cloud edges that are called ice
- partially cloudy pixel algorithm nearing maturation

- **Cloud Retrieval Changes**

Auxiliary data

- *updated IGBP map to be delivered?*
- updated elevation map to be delivered

Multi-layer

- C2C (11 & 13.3 μm) ML detection
  - *Chang has reworked this starting from first principles, no empirical corrections*
- BTD (T11 – T12) algorithm delivered
- Initial C2C ML retrieval algorithm: no iteration on Deff

Edition 3 CERES mask changes since Aqua Edition 1

Framework Level

- Decided not do adjustments from MODIS V004 to V005, for both Terra and Aqua, after studies performed over polar night where largest impact presents.

- In Terra Ed3 cloud detection algorithms, 1.6 um is replaced by 2.1 um. Terra and Aqua cloud masks are consistent using the same algorithms.

- Replaced theoretically 2.1 snow reflectance models with IGBP-dependent snow model - only impacts daytime polar regions.

- New 3.7 μm calibration for Terra MODIS data - Terra Ed3 needs retune.

- CO2 clouds overwrite CERES clear pixels except for polar regions.

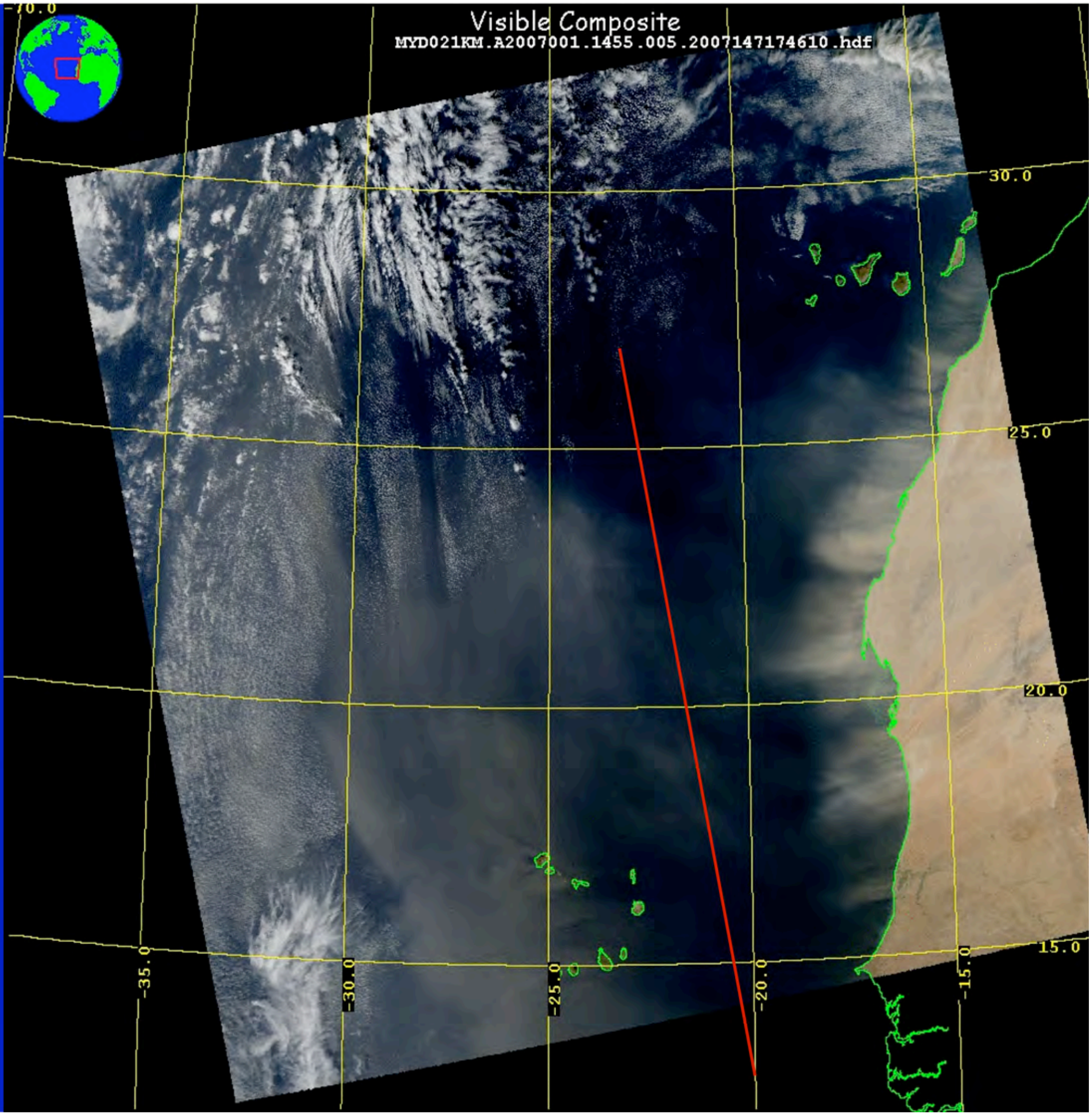
- Restrict clear sky 11 um STD to max value 6 K for land.

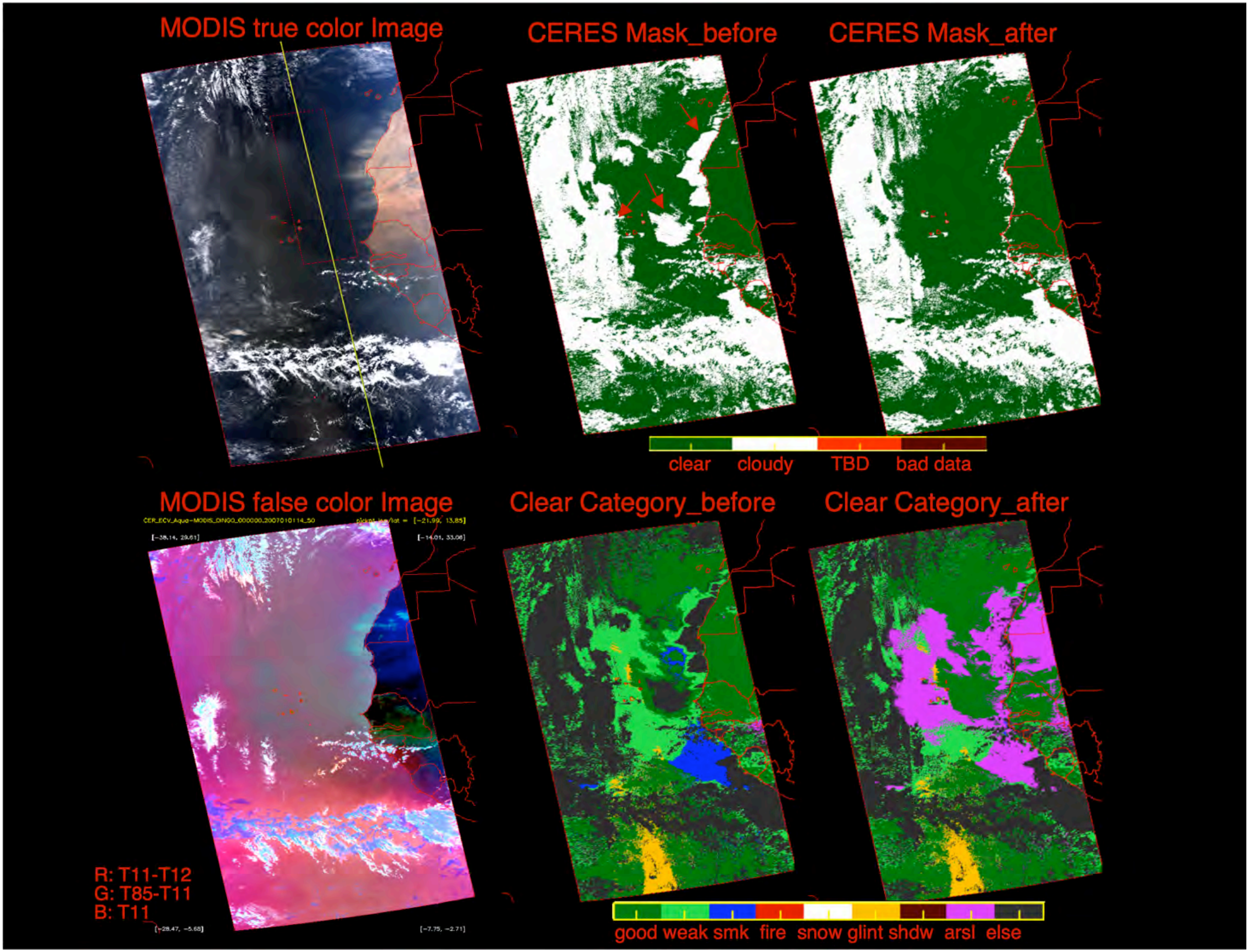
- New elevation map - impacts super-cold plateau.

Saharan dust plume on January 1, 2007 1455 UTC

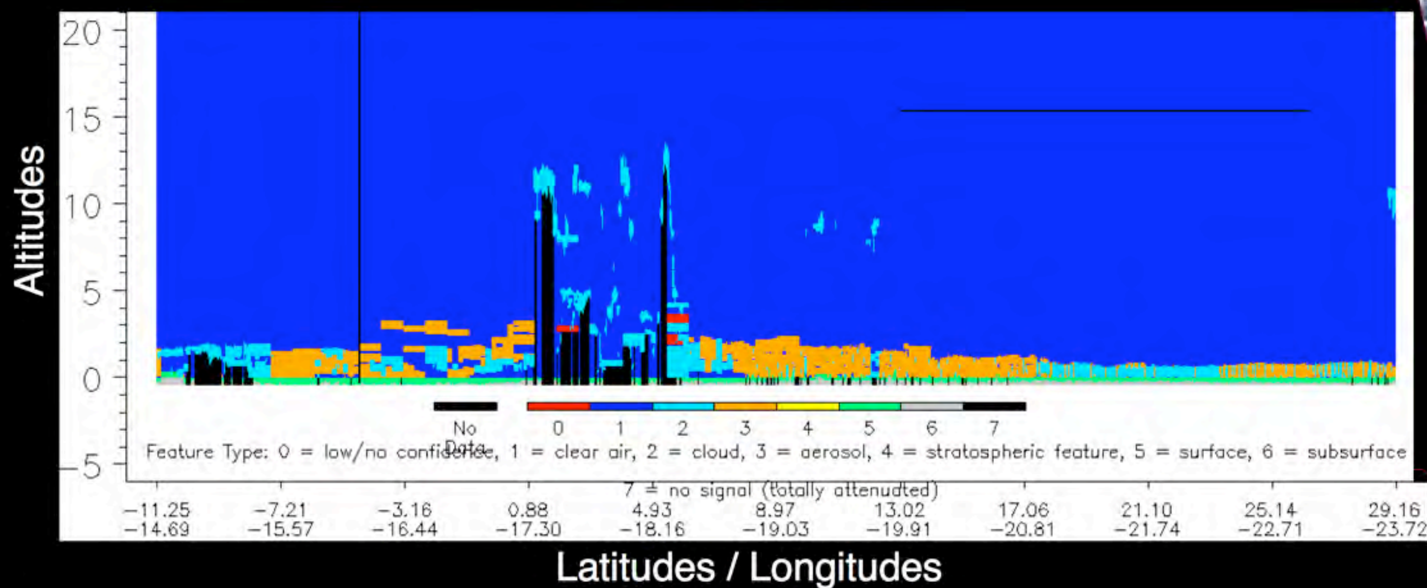
Aqua MODIS

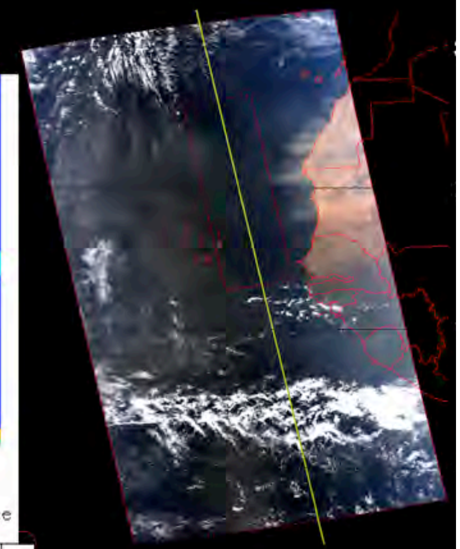
True color Image (Band 1-4-3)




MODIS true color Image
CERES Mask_before
CERES Mask_after
clear
cloudy
TBD
bad data
MODIS false color Image
[-38.14, 29.61]
[-14.01, 33.06]
R: T11-T12
G: T85-T11
B: T11
[-28.47, -5.68]
[-7.75, -2.71]
Clear Category_before
Clear Category_after
good weak smk fire snow glint shdw arsl else

CALIPSO V2 VFM

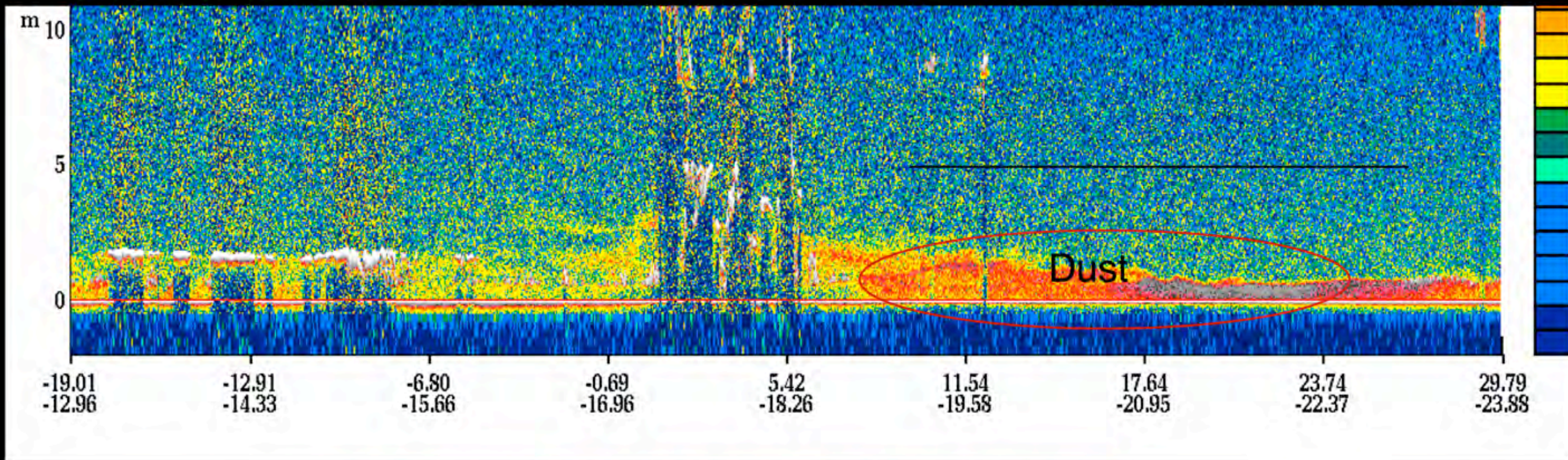




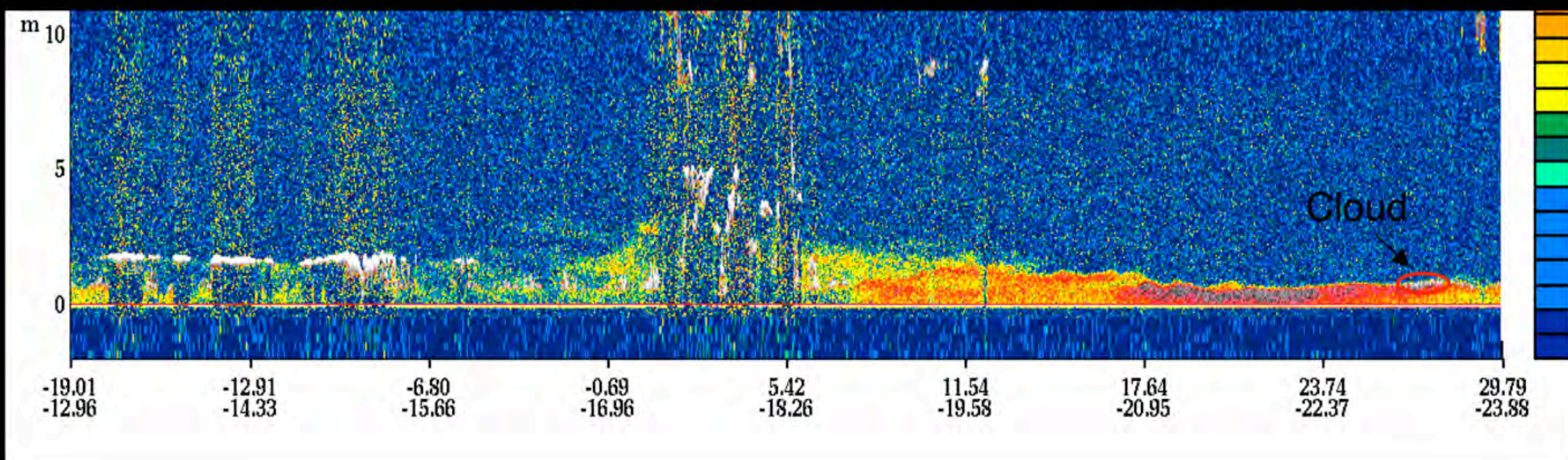
Cloud Fraction Comparison between CERES_MODIS and CALIPSO VFM

Total Aqua Pixel (4061) (1459)	CERES-Cloudy	CERES-Clear	
CALIPSO-Cloudy	23.44% (0%)	41.15% (56%)	64.59%
CALIPSO-Clear	0.394% (0%)	34.99% (44%)	
	23.8%		

532 nm Total Attenuated Backscatter



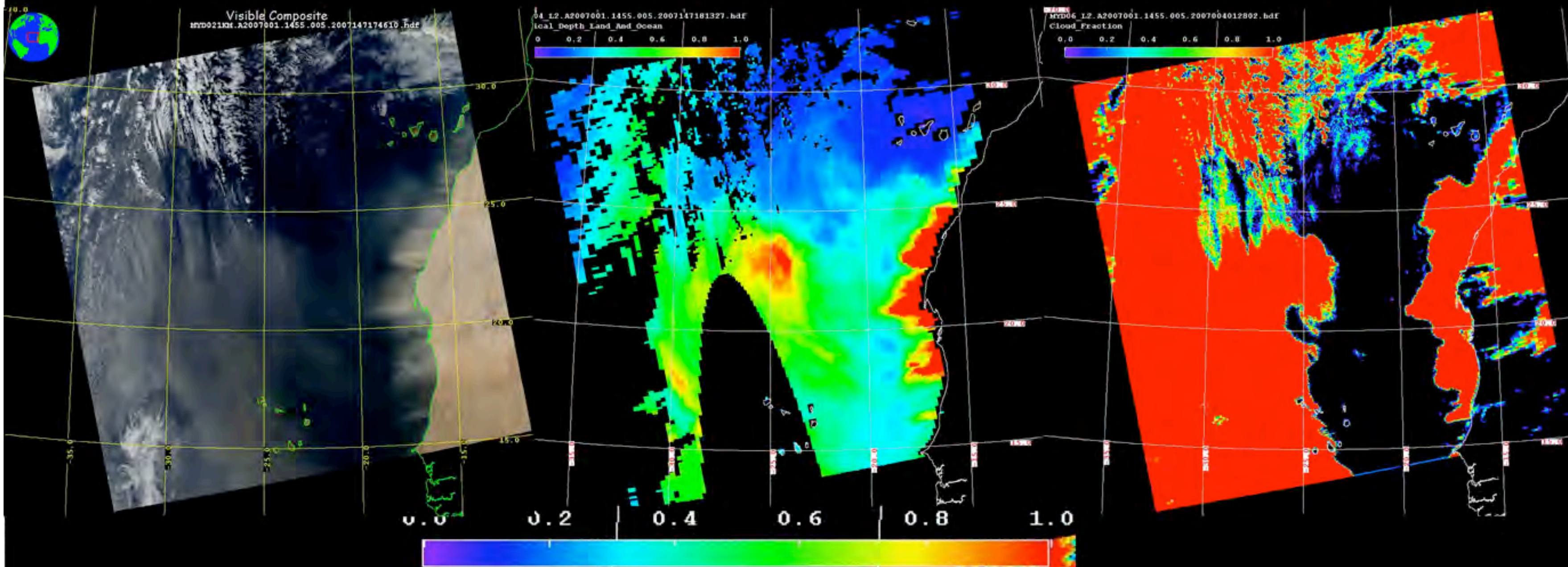
1064 nm Total Attenuated Backscatter



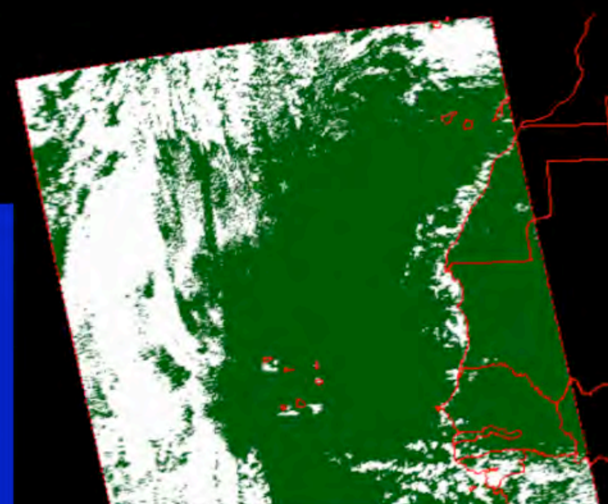
Aqua MODIS Image (Band 1-4-3)

MODIS Aerosol Optical Depth (MYD04)

MODIS Cloud Fraction (MYD06)



MODIS cloud mask can be safely used when AOT < 0.6. (*J. Brennan et. al. IEEE, 2005*)



- New method uses MODIS T_{11}-T_{12}, T_{85}-T_{11}, 0.65, ratios of 2.1 to 0.65, and 0.47 to 2.1 in land and ocean dust tests
- Some false cloud remains along coast
- New cloud mask should minimize false clouds in heavy dust
- More testing needed
- CALIPSO appears to over-diagnose low clouds

Which clouds are being missed?

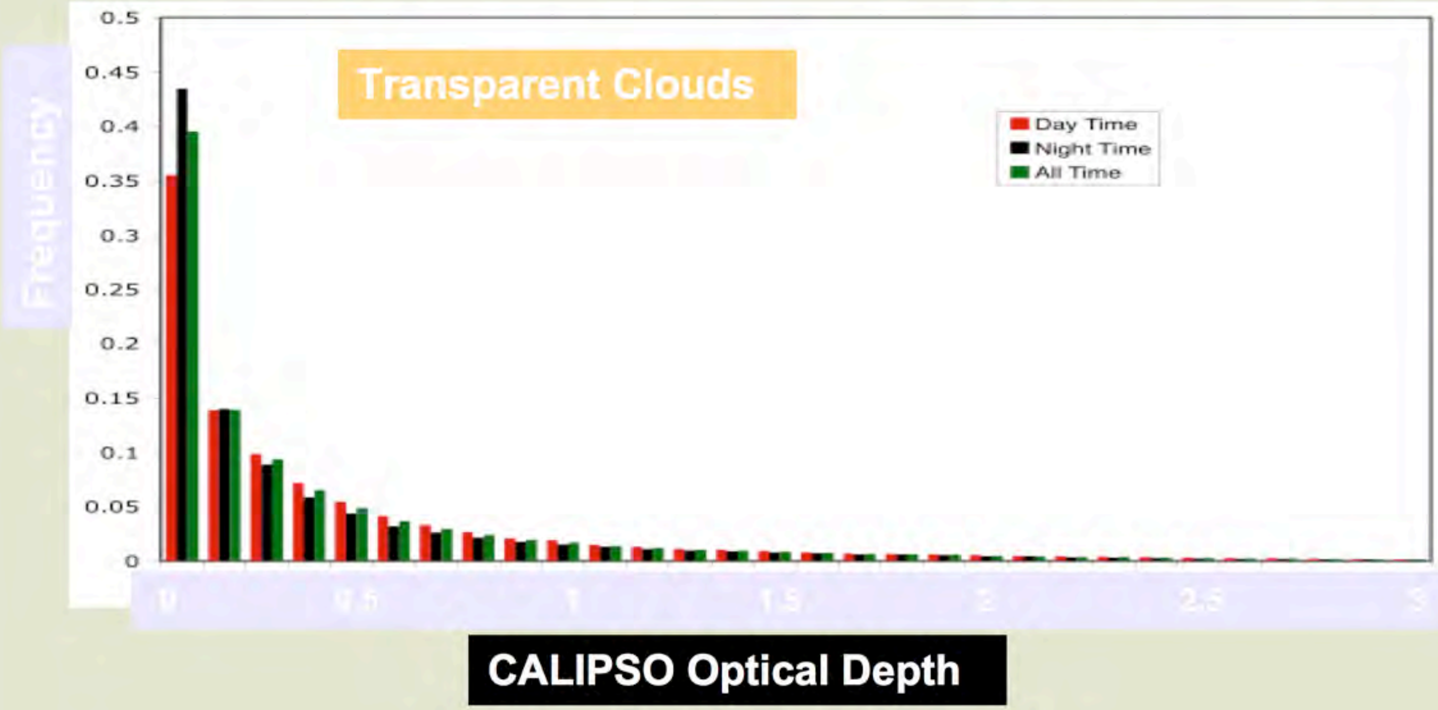
- Previous comparisons with surface and a/c lidar suggest thin cirrus clouds ($\tau < 0.3$)

- Other studies indicate scattered cumulus (trade cu) because of partially filled pixels

First step:

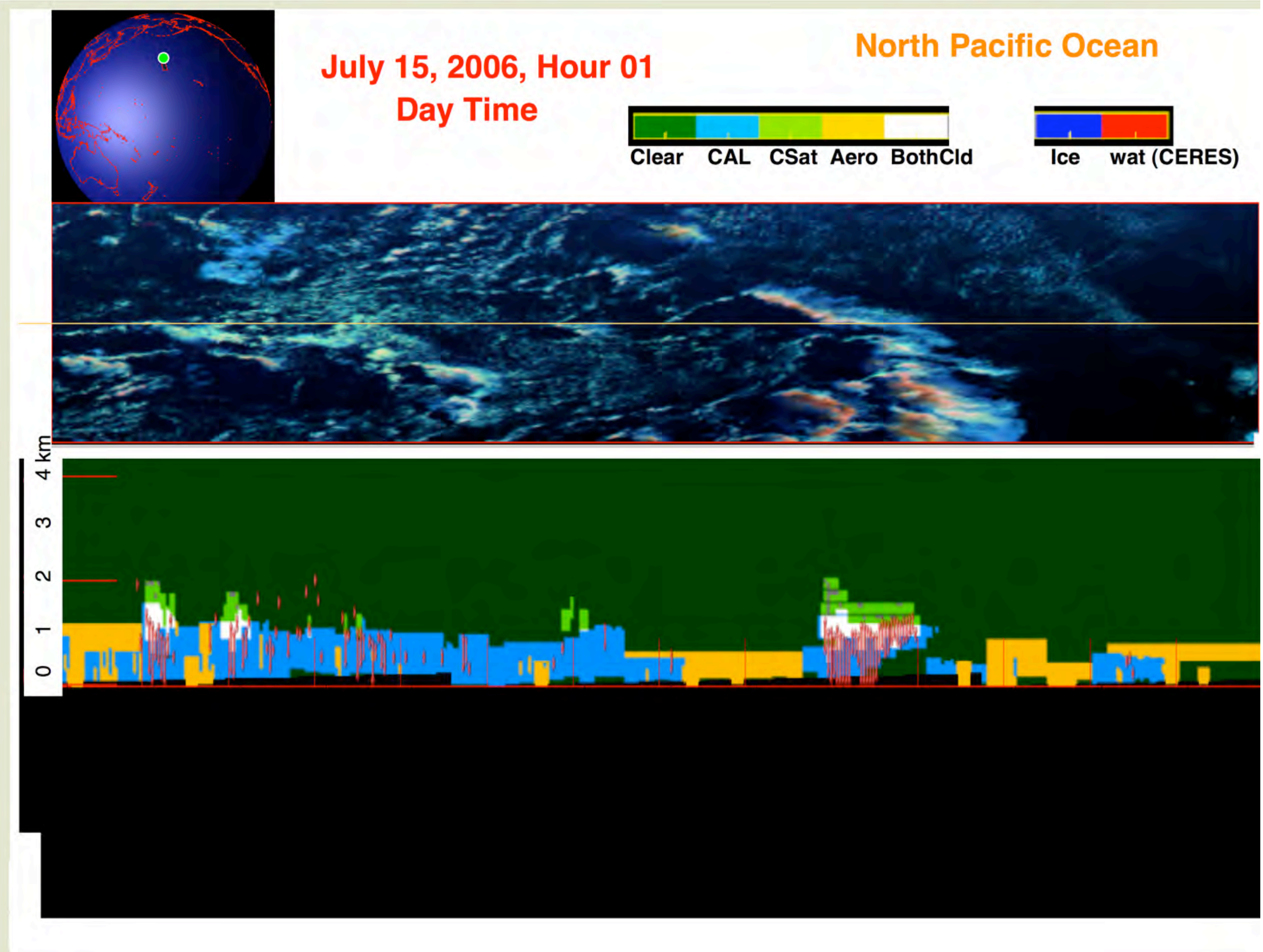
- Examine comparisons for scenes with τ(CALIPSO) < 4
    - semitransparent
    - we suspect where most problems are
    - optical depth product relatively new

CALIPSO Optical Depth Histogram (Single Ice Layer) for July 2006

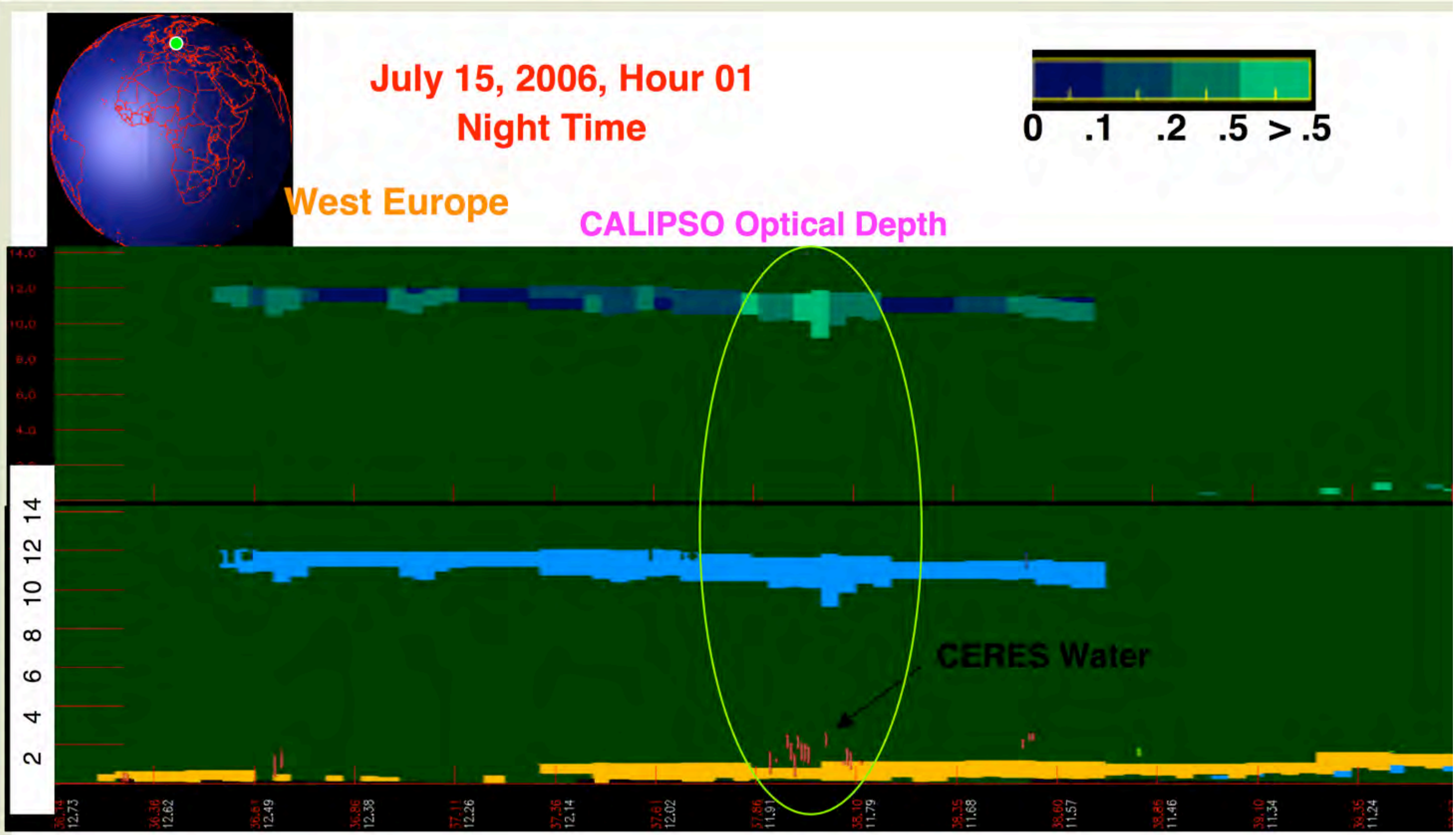


CALIPSO Extinction QC Flag=0 & 1

Majority of CALIPSO thin cirrus have $\tau < 0.3$!



July 15, 2006, Hour 01
Day Time
North Pacific Ocean
Clear
CAL
CSat
Aero
BothCld
Ice
wat (CERES)
4 km
3
2
1
0


July 15, 2006, Hour 01
Night Time
West Europe
CALIPSO Optical Depth
0 .1 .2 .5 > .5
2 4 6 8 10 12 14
CERES Water
12.73
12.62
12.49
12.38
12.26
12.14
12.02
11.91
11.79
11.68
11.57
11.46
11.34
11.24

3 Days of Merged CALIPSO, CloudSat and MODIS
8, 15, 22 July 2006(day & night)

(1) Non-Polar Regions

(2) CALIPSO: Single and Transparent Layer

(3) CALIPSO: Optical Depth < 4

→ 131, 385 pixels

Comparison

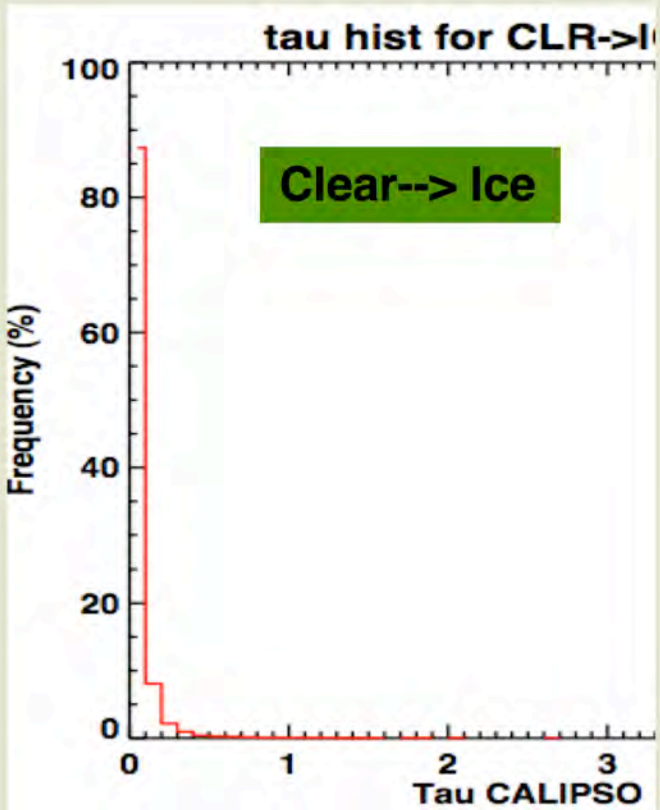
CERES (Before)	Clear	Ice	Water	NoRet	Bad Data
CALIPSO %	71.42 (%)	10.5 (%)	15.59 (%)	2.46	0.03

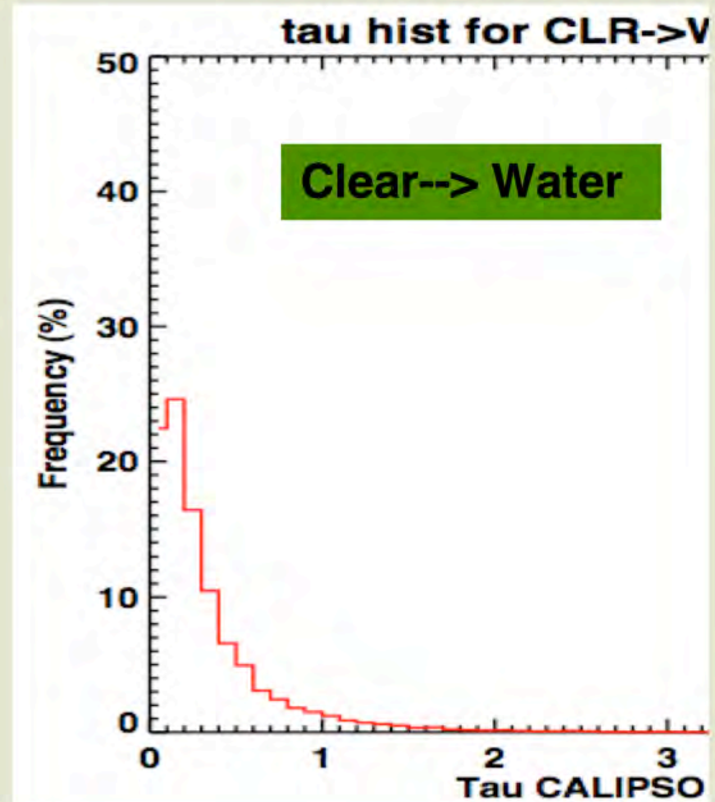
Majority of missing clouds are water

CERES (After)	Ice	Water	Ice	Water	Ice	Water
%	23.97	76.02	85.11	14.89	26.13	73.87

CERES phase successful rate ~ 80%

Summary of Differences for Missed Semitransparent Clouds





0.3

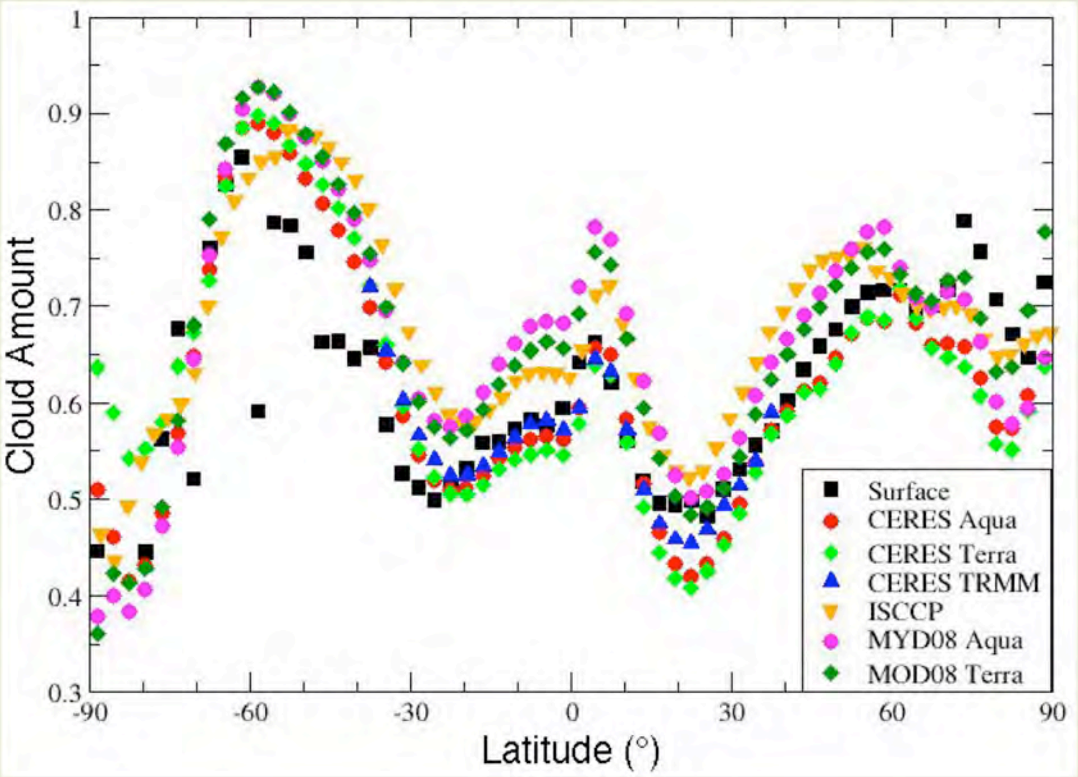
98% of all missed ice clouds have $\tau < 0.3$

87% have $\tau < 0.1$

65% of all missed water clouds have $\tau < 0.3$

84% have $\tau < 0.5$

Why is CERES low compared to other cloud retrieval algorithms?



CERES Ed2 no retrieval percentage is ~4% for nonpolar areas

- retrieved cloud fraction = 0.60
- compare to 0.54 for MODIS products (less for 1.6, 2.1 μm)
- ISCCP forces a retrieval => highest, thinnest cloud category
- surface obs more like CERES

Cloud Fraction Summary

- Total CERES nonpolar underestimate relative to CALIPSO is ~0.18

- Phase determination for SL semitransparent clouds ~80% accurate
  - probably much better during daytime

- 75% of missed cloud cover is semitransparent (0.145)
  - *25% is thin ice clouds mainly with $\tau < 0.3$ (0.035)*
    - not much chance for reliable detection
      - *difficult to make a retrieval*
  - *75% is thin water cloud*
    - *65% has $\tau < 0.3$ (0.07)*
    - *85% has $\tau < 0.5$ (0.093)*

- Remaining missed cloud cover has $\tau > 1$
  - *most likely low clouds at night and large solar zenith angles*
    - small IR contrast
      - multilayered clouds cancel some cloud IR BTD signals
      - IR BTD signals cancelled near terminator (T3.7 – T11)
      - VIS signals ambiguous

How to improve low cloud detection for $\tau > 0.3$?

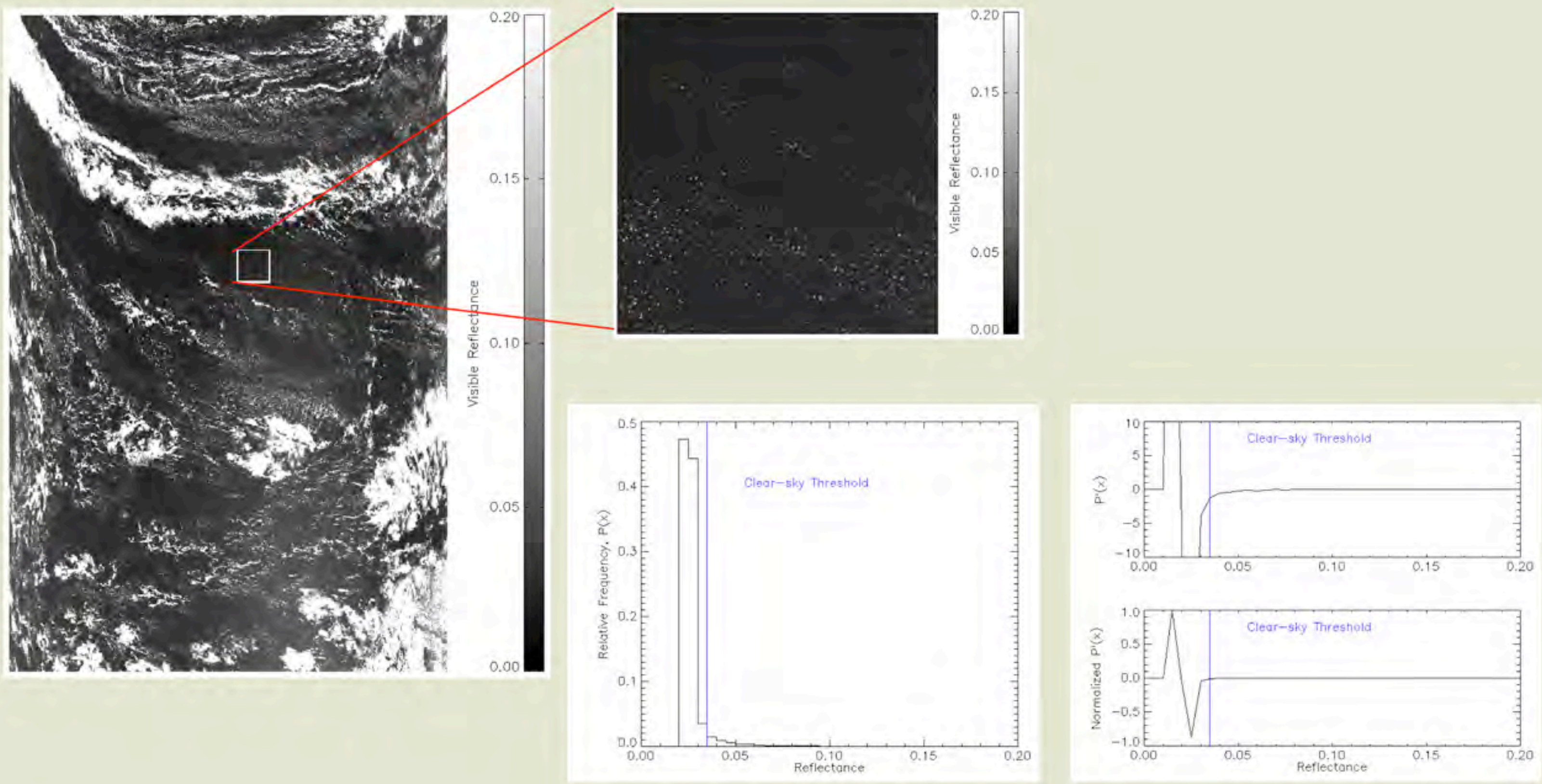
- Tighten thresholds

- Daytime, use high resolution (e.g., 250-m) VIS channels to detect subpixel cloud cover
    - examine reality of these low tau clouds

- Use additional channels (8.5, 13.3 μm)

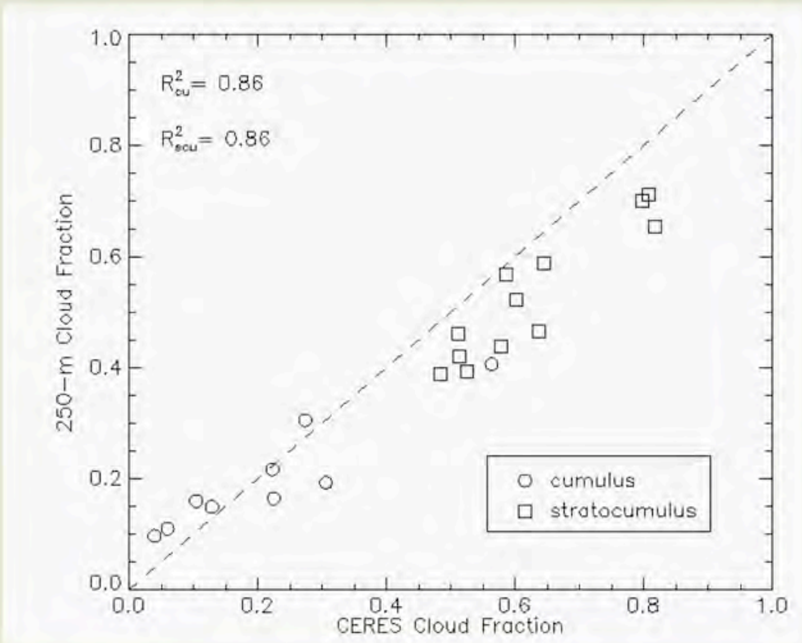
250-m cloud mask

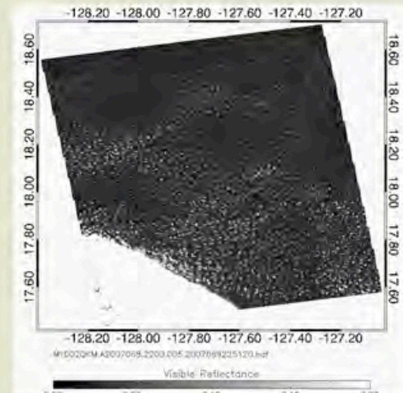
- Use 250-m MODIS visible reflectance to assess Aqua-CERES cloud amounts
  - Based on the derivative of the reflectance frequency distribution
  - Tuned by comparing initial results with MODIS 250-m reflectance images
  - Apply to every 1-km MODIS pixel

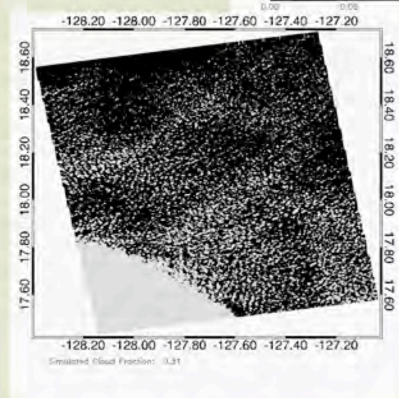


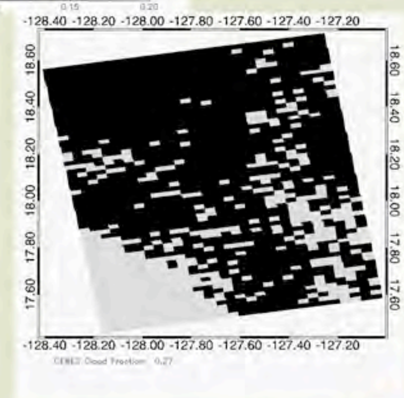
250-m Mask Performance

- Examined 21 cases of Scu and Cu from Jun 2006 - Mar 2007
- Good linear correlation with CERES for both Cu and Scu fields
- CERES generally has higher cloud fraction values, especially for Scu
- Higher CERES cloud fractions expected - CERES has larger FOV
- CERES may underestimate cloud fraction when true fraction is < 0.30









CALIPSO Sensitivity for Broken Cloud Fields

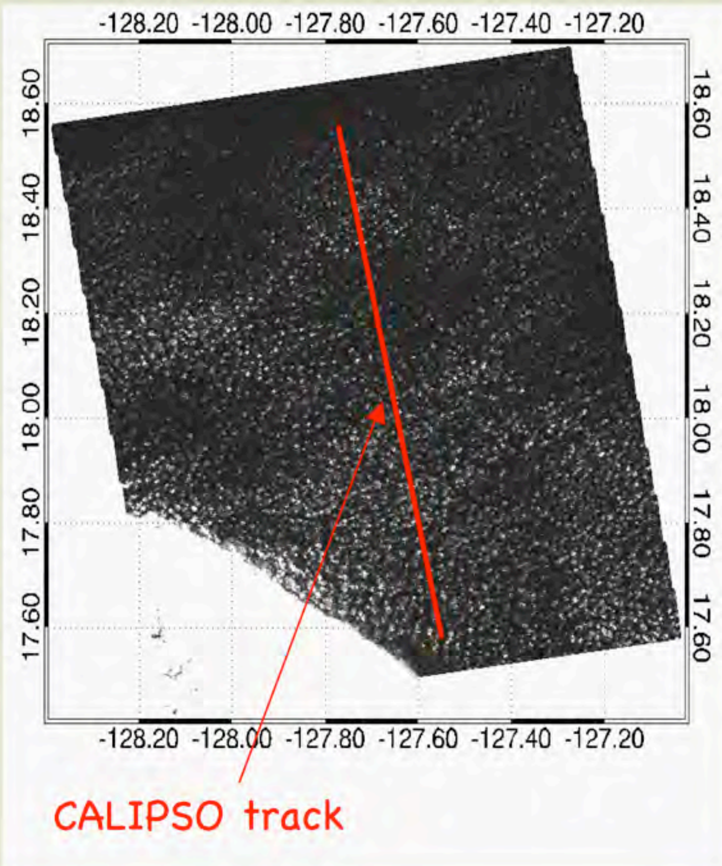
- CALIPSO sensitivity to $\tau < 0.3$ suggests that tiny fraction of cloud in 70-m footprint will cause 100% cloud cover return
  - e.g., for detection limit of 0.05, a cumulus with $\tau = 2$ only 1.5 m of cloud needs to be in the fov

- haziness between clouds in cumulus fields may be classified as clouds
  - e.g., earlier example where cloud field is continuous in CALIPSO retrieval, but imagery shows probable cumulus fields and aerosol nearby when no cumulus are evident in imagery

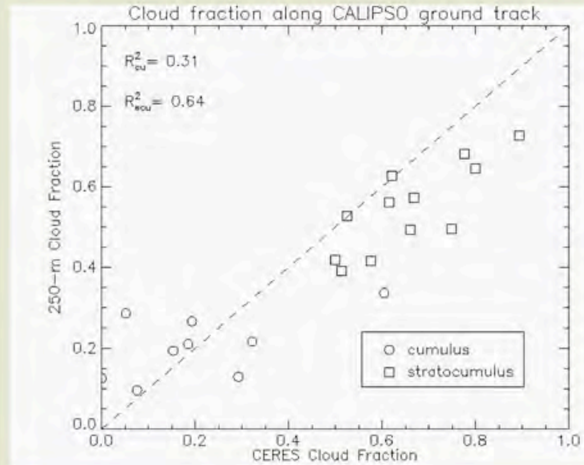
Examine this idea with hi-res imagery!

Cloud Fractions

- Examine cloud fractions along CALIPSO track for same 21 cases
- Matched data from CERES, Aqua-MODIS, and CloudSat to CALIPSO track



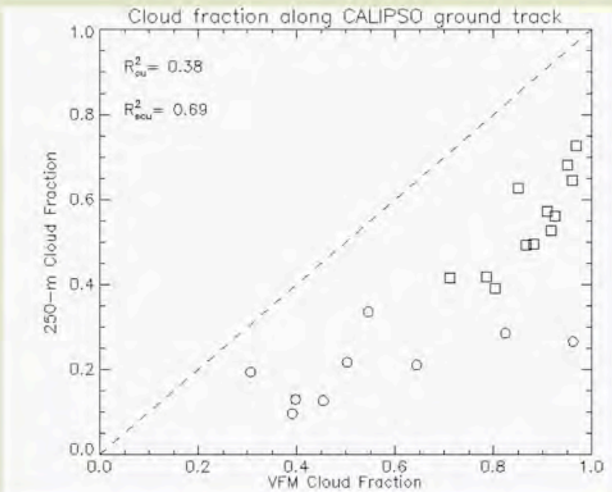
CERES



- CERES
  - Scu - fairly good linear correlation; overestimates
  - Cu - more scatter; tends to underestimate for cloud fractions < 0.30
- CloudSat - very few cloud detections at the highest 2 levels of confidence

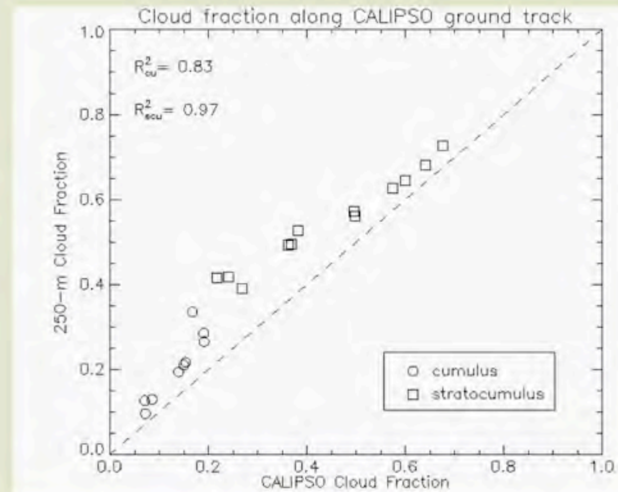
Cloud Fractions

- Examined 2 CALIPSO products
  - Vertical Feature Mask (VFM)
    - Contains cloud/aerosol classifications
    - 30-m vertical resolution from -0.5 - 8.2 km AMSL
  - 333-m Cloud Layer Product
    - Cloud products for up to 5 cloud layers
    - Valid from the surface to 8.2 km



VFM Product

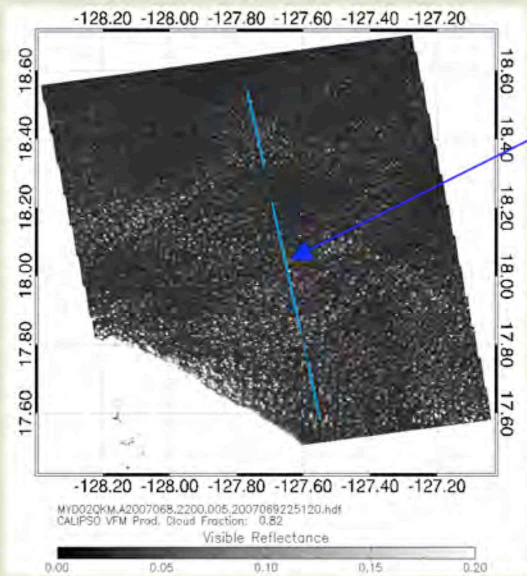
VFM has many more cloud detections, but very good agreement with the CALIPSO cloud products



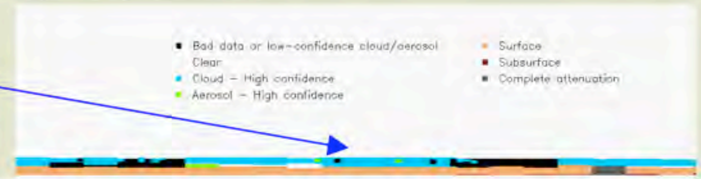
333-m Cloud Product

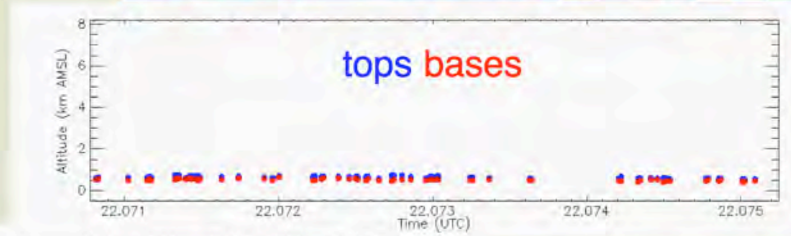
Cloud Fractions

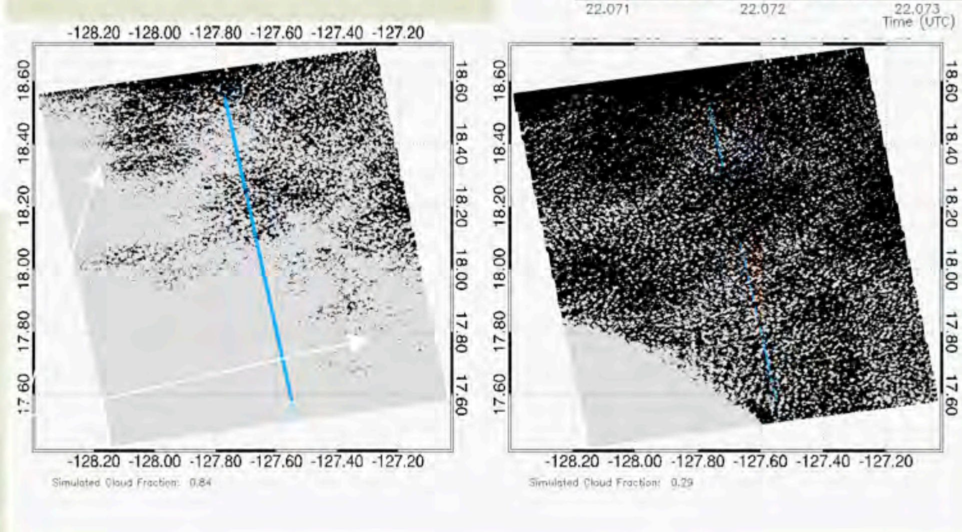
- Relaxed thresholds to match VFM product
- VFM shows solid deck of clouds while satellite images show scattered Cu
- Some cloud detections get averaged out in the Cloud Layers product?



Solid cloud deck in VFM
CF = 0.82



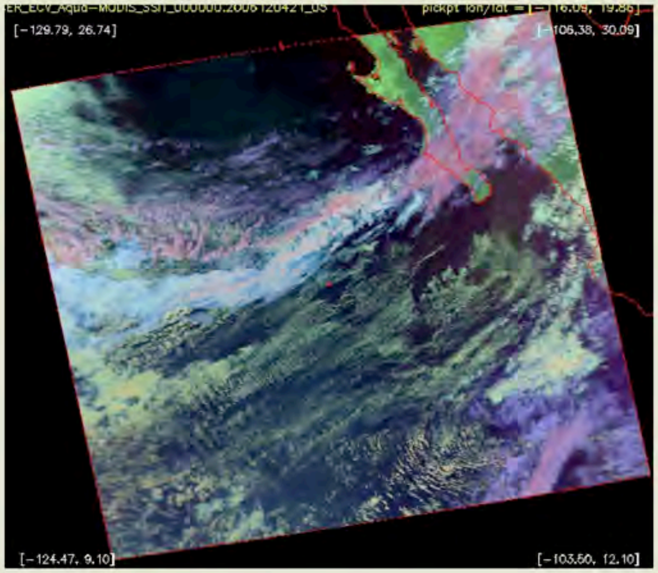




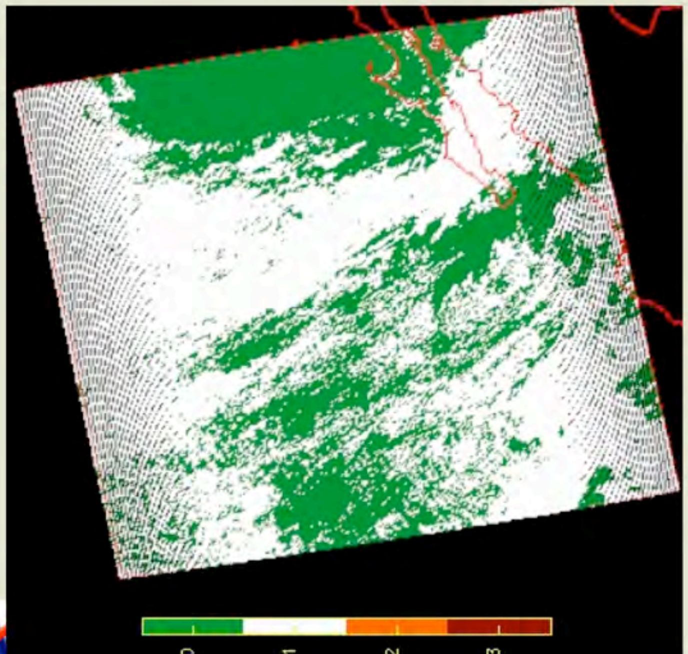
Too much cloudiness is areas of scattered cumulus, CF = 0.84, relaxed threshold too low

Normal threshold seems to match satellite image, CF = 0.29

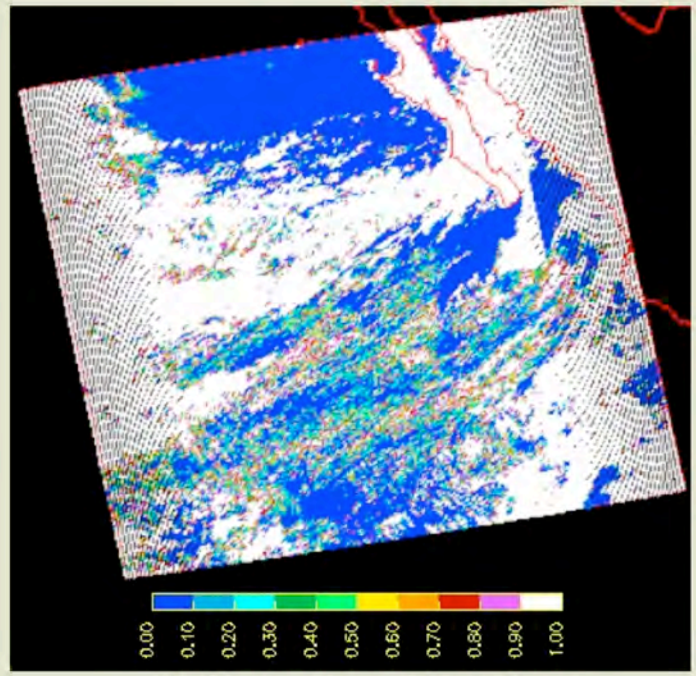
Cloud Amounts Using Ed2 & 250-m Mask
4 Dec 2006, 21 UTC



- 250-m mask picks up many small clouds missed by CERES mask
- Calls land & smoke clouds
  - easily remedied



CERES Scene ID



250-m cloud fraction

Summary

- 250-m Aqua-MODIS data to determine cloud fraction within each 1-km footprint
- Generally good agreement with CERES
  - Highly correlated
  - CERES tends to overestimated cloud amount because its FOV is larger
  - CERES may underestimate cloud fraction for scattered cumulus scenes
  - 250-m MODIS visible reflectance data should help in both cases
    - Many small clouds missed earlier are now detected
- Good agreement with CALIPSO 333-m Cloud Layers product
- CALIPSO VFM finds much more cloudiness than all methods
- Future work – work on adjusting cloud fraction to optimize retrieved cloud properties, especially optical depth and effective size, for cumulus clouds and cloud edges; determine constraints for applying this mask

Ed 3 Mask Summary

- Considerable number of changes made
  - some made things worse, some better
  - increase in nighttime cloudiness may/may not be accurate
    - need more CALISPO matches
    - if realistic, need increase in daytime

- Beta 2 will have additional changes plus refinements
  - Hi-res VIS
  - adjusted thresholds
  - final CO2 detection
  - altered polar for transition

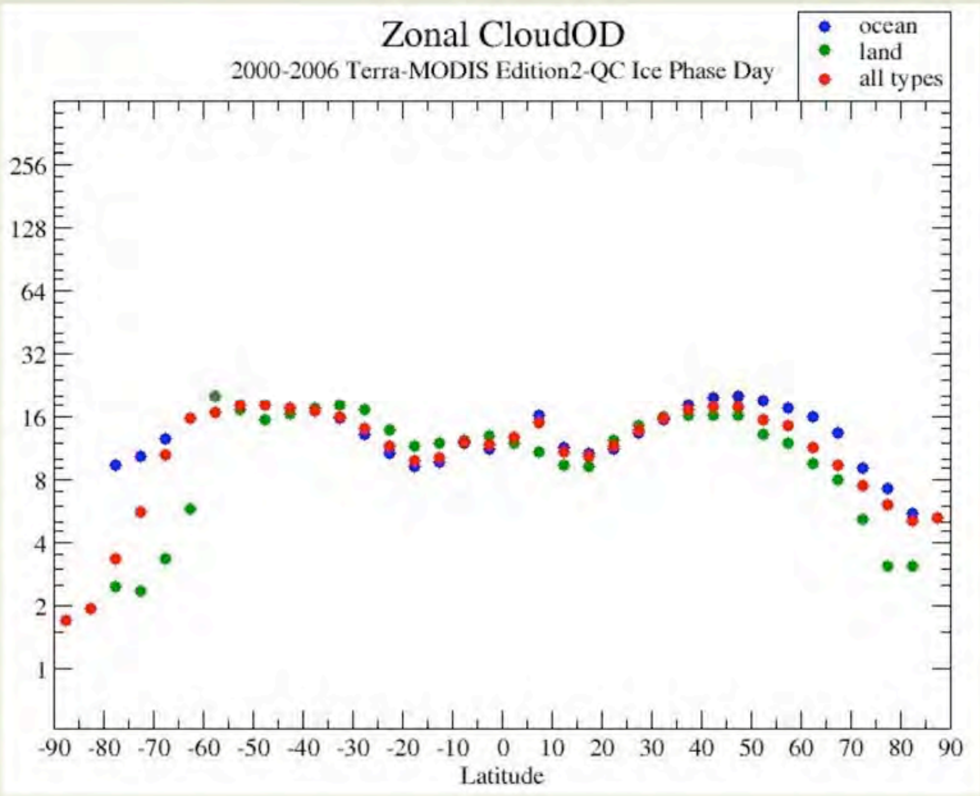
Future Work for Ed3 Beta2

- Still working on polar cloud fraction discontinuity
  - Tuning cloud mask over Super Cold Plateau
  - Tune Terra mask to new 3.7 calibration
- Revise use of IGBP models - theo over perm snow?
- Examine & tune impact of CO2 retrievals
  - take care of no retrieval cirrus
- Define lower tau limit of detection w/CALIPSO data
- Integrate hi-res VIS retrieval results

RETRIEVALS

Error in Aqua Ed2 Polar Retrievals

- No retrieval problem found in Terra Ed2 code eliminated in Aqua Ed2
  - Aqua returns many fewer no-retrieval pixels than Terra
- But, 1.6-μm atmospheric correction was used mistakenly for Aqua 2.1-μm retrieval in SINT



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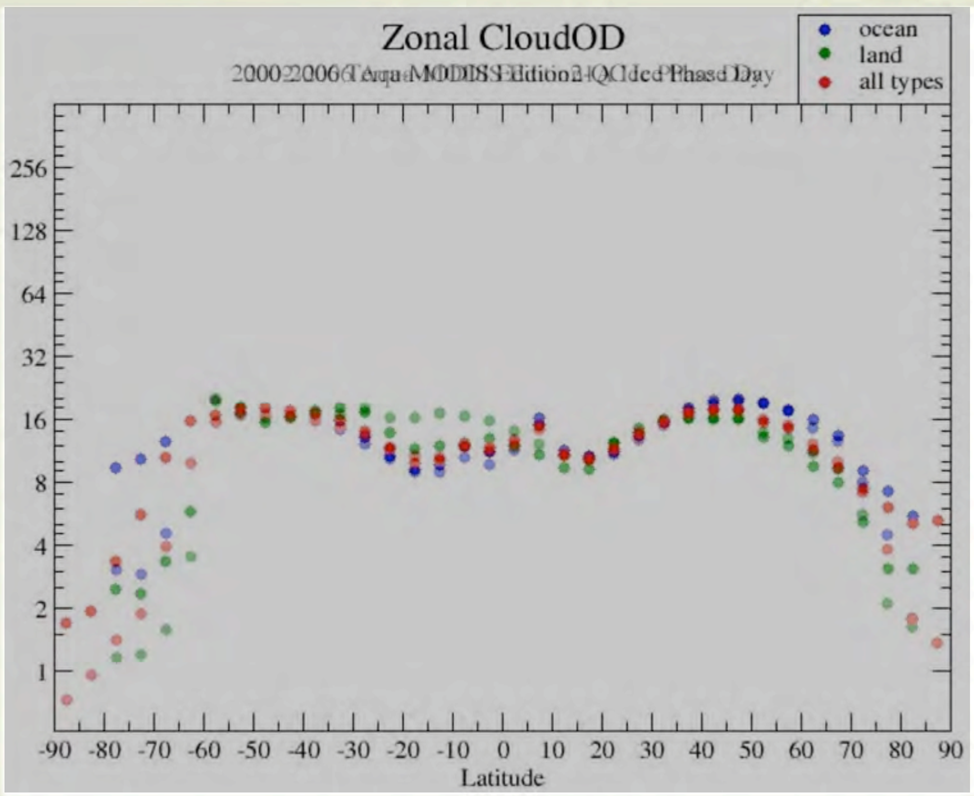

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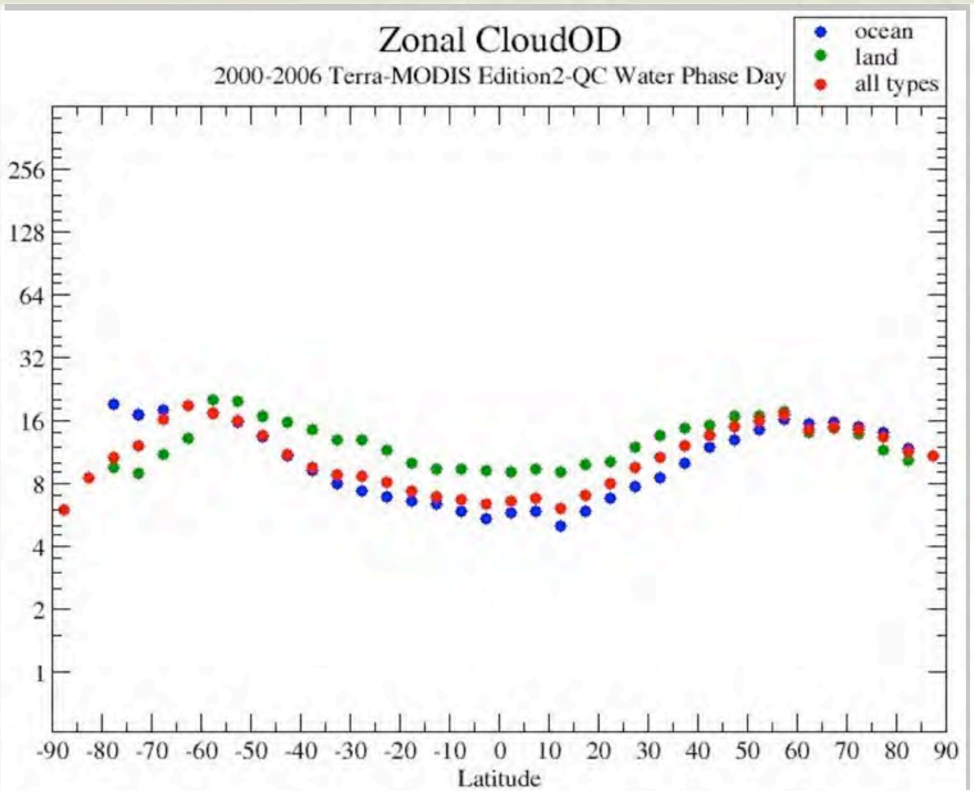

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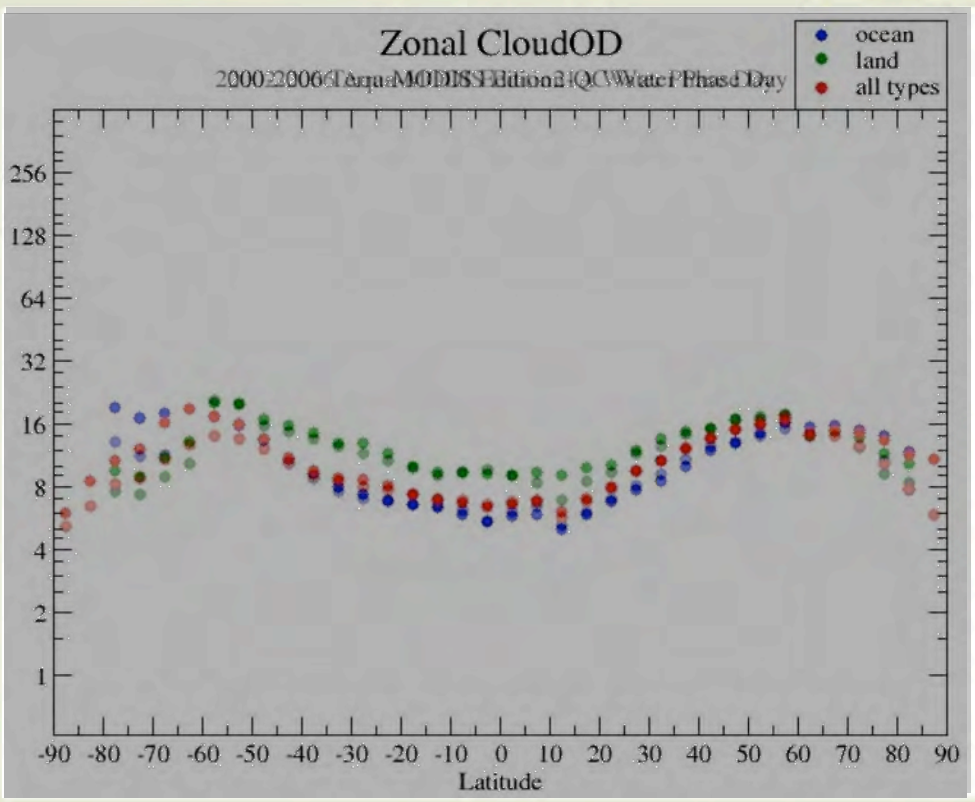

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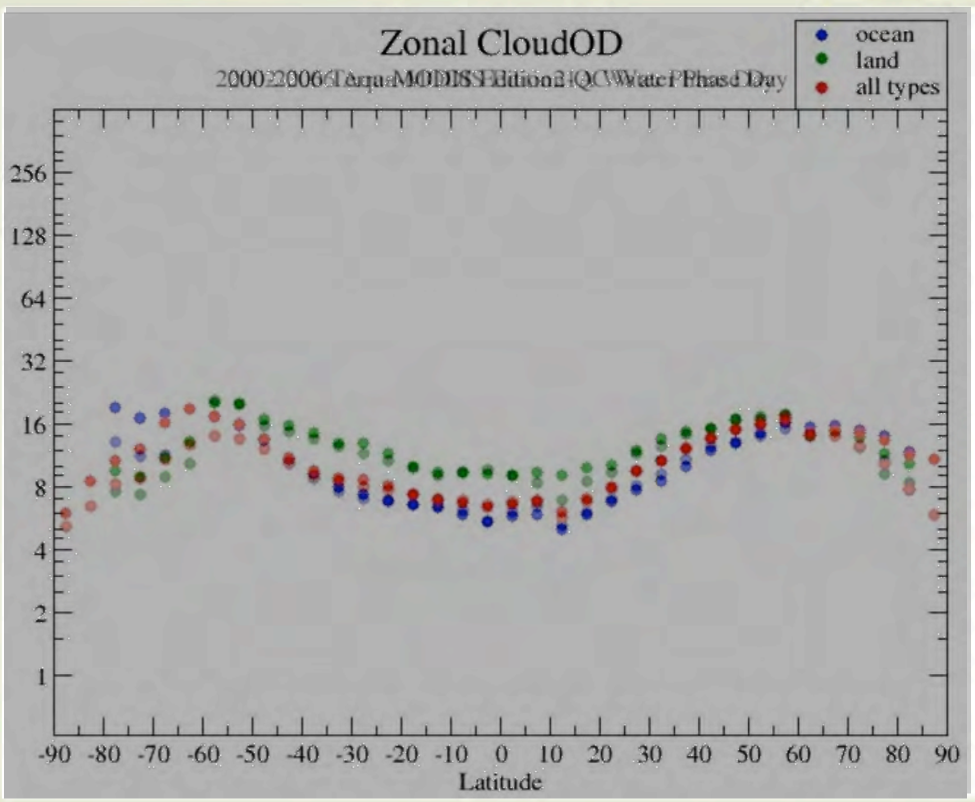


- reduced ice & water cloud taus by 10-50% in snow/ice regions
- Does not affect areas without snow

- *Call to correct corr-k absorption coefficients in place for Ed3*

“Validation” Using CloudSat Products

- Examined phase, LWP, IWP
  - CloudSat IWP not yet validated, do not know the error
  - Assumes CERES TWP is all ice for SL clouds
    - => IWP ~ 42% less in ML clouds
    - => ~85% overall if 35% ML cover

Cloud Ice Water Path (From Waliser et al. 2008)

Annual mean IWP (gm^{-2})

a) ISCCP: 2005

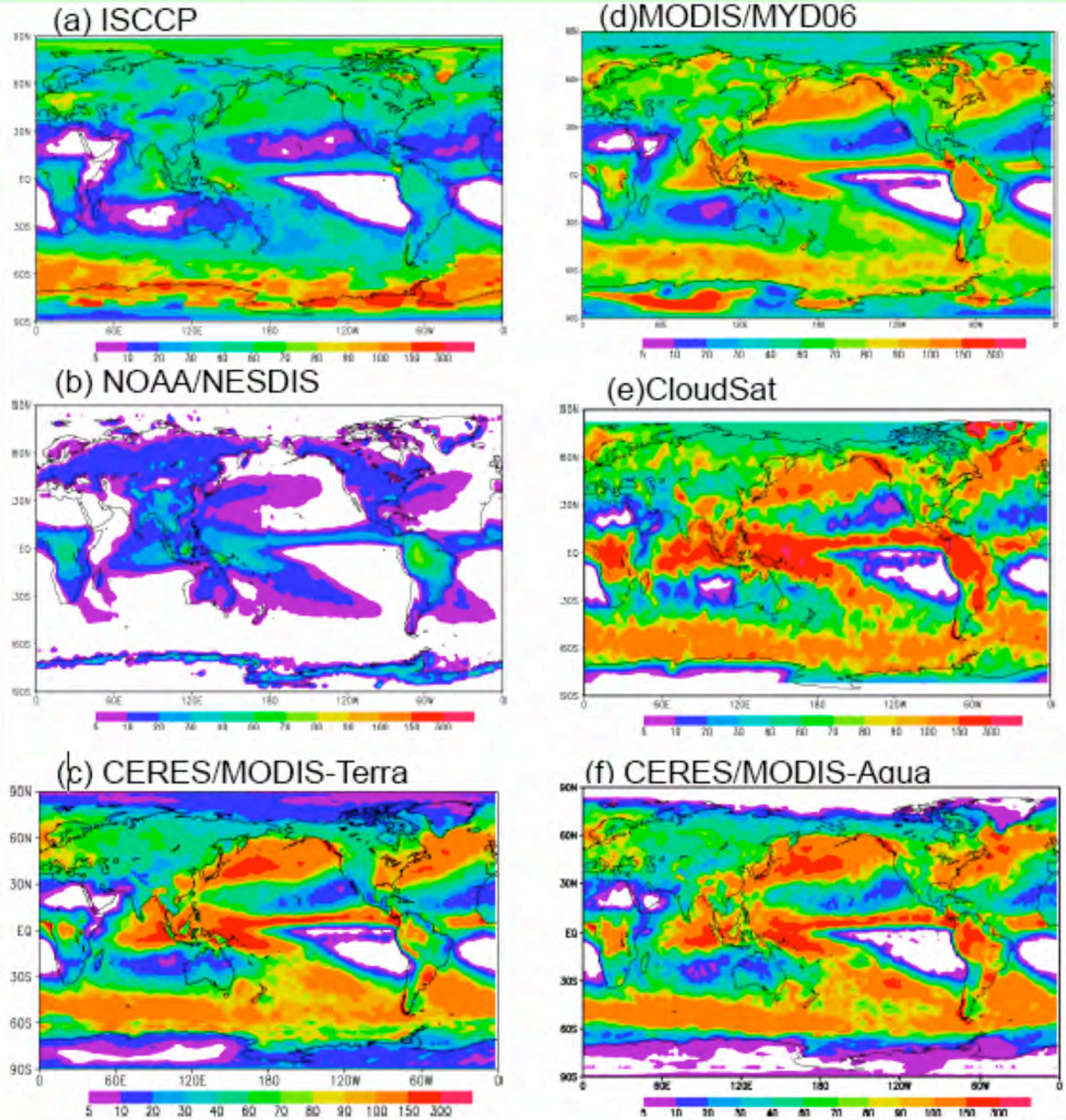
b) NOAA: 2000-2006

c) CERES-Terra: 2001-2005

d) MODIS: 7/2002-6/2007

e) CloudSat: 8/2006-7/2007

f) CERES-Aqua: 2001-2005



Phase Comparison between CloudSat and VISST
15 July 2006, daytime only

VISST \ CloudSat		Water	Ice	Mixed
90N-60N	Water	96.01	65.28	85.37
	Ice	3.92	34.72	14.63
60N-30N	Water	94.85	30.94	59.89
	Ice	5.14	69.06	40.1
30N-0	Water	88.28	12.72	24.4
	Ice	11.72	87.28	75.6
0-30S	Water	94.43	15.49	28.77
	Ice	5.56	84.51	71.23
30S-60S	Water	95.54	29.45	47.32
	Ice	4.46	70.55	52.68

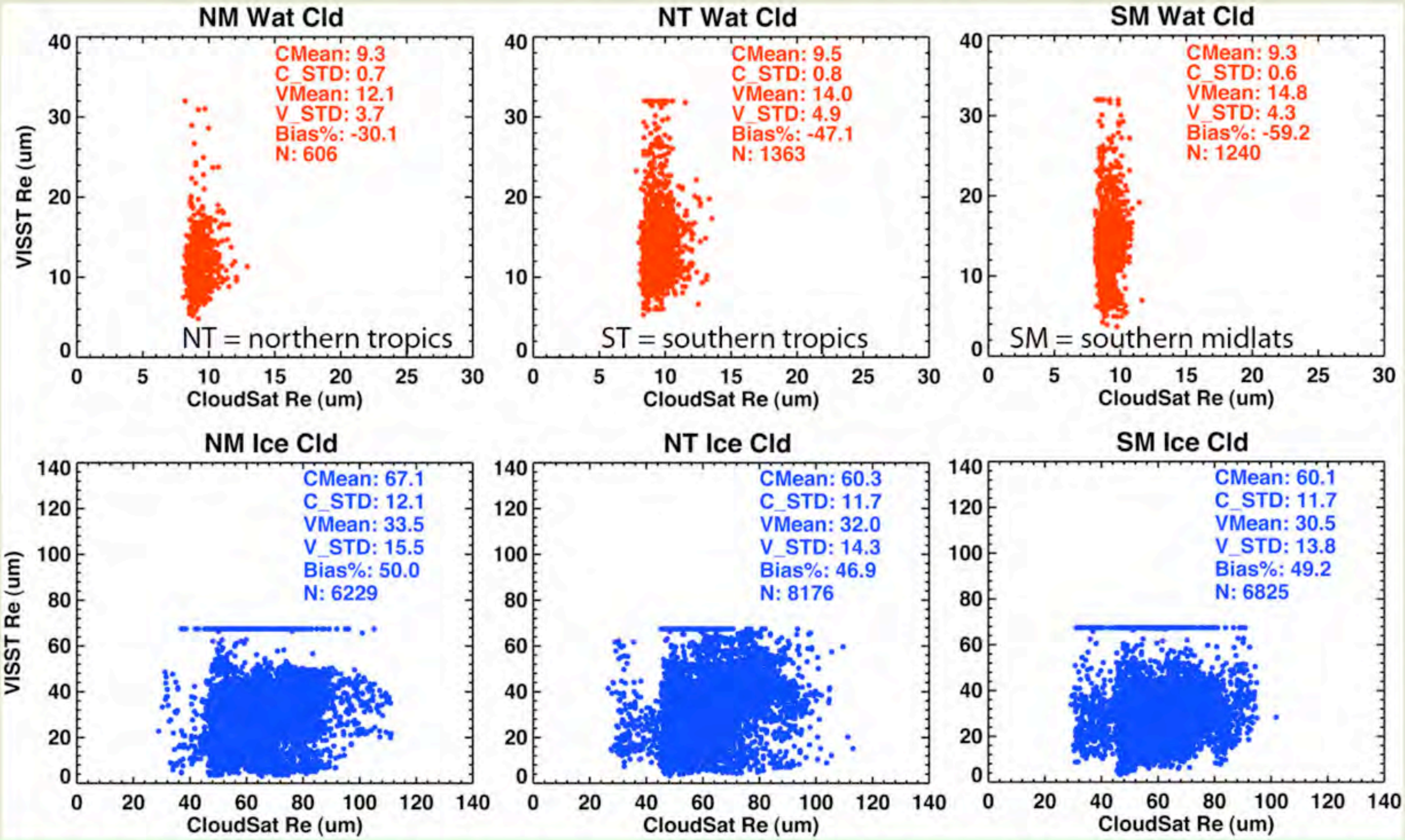
Nonpolar
- 93% agreement for liq
- 79% agreement for ice

Some of ice discrepancy may be due to low clouds missed by CloudSat

CERES vs CALIPSO
April 2007

- 90% phase agreement in daytime
- 70% at night for semitransparent clouds only

Particle Size Comparison between CloudSat & CERES
15 July 2006, daytime only

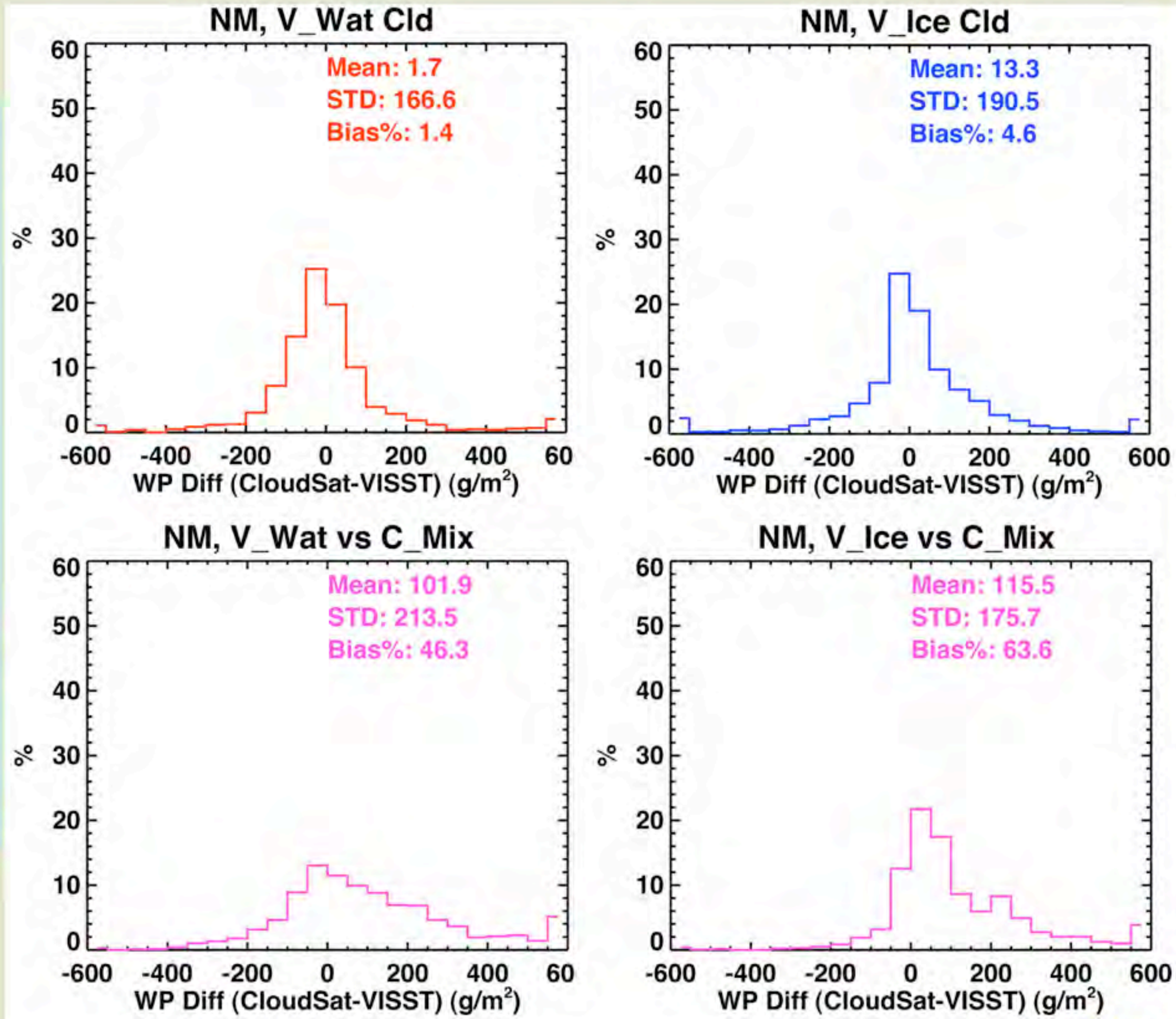


- liquid, little spread in CS Re, Re(CERES) ~ 1.5 CloudSat
- ice, Re(CERES) ~ 0.5 Re(CloudSat)

CloudSat WP – CERES WP, Histograms, N. M-Lat, 15 July 2006, Daytime

- CERES unbiased wrt CloudSat for single-phase scenes
  - some large tails, mismatch or same problem as MIX

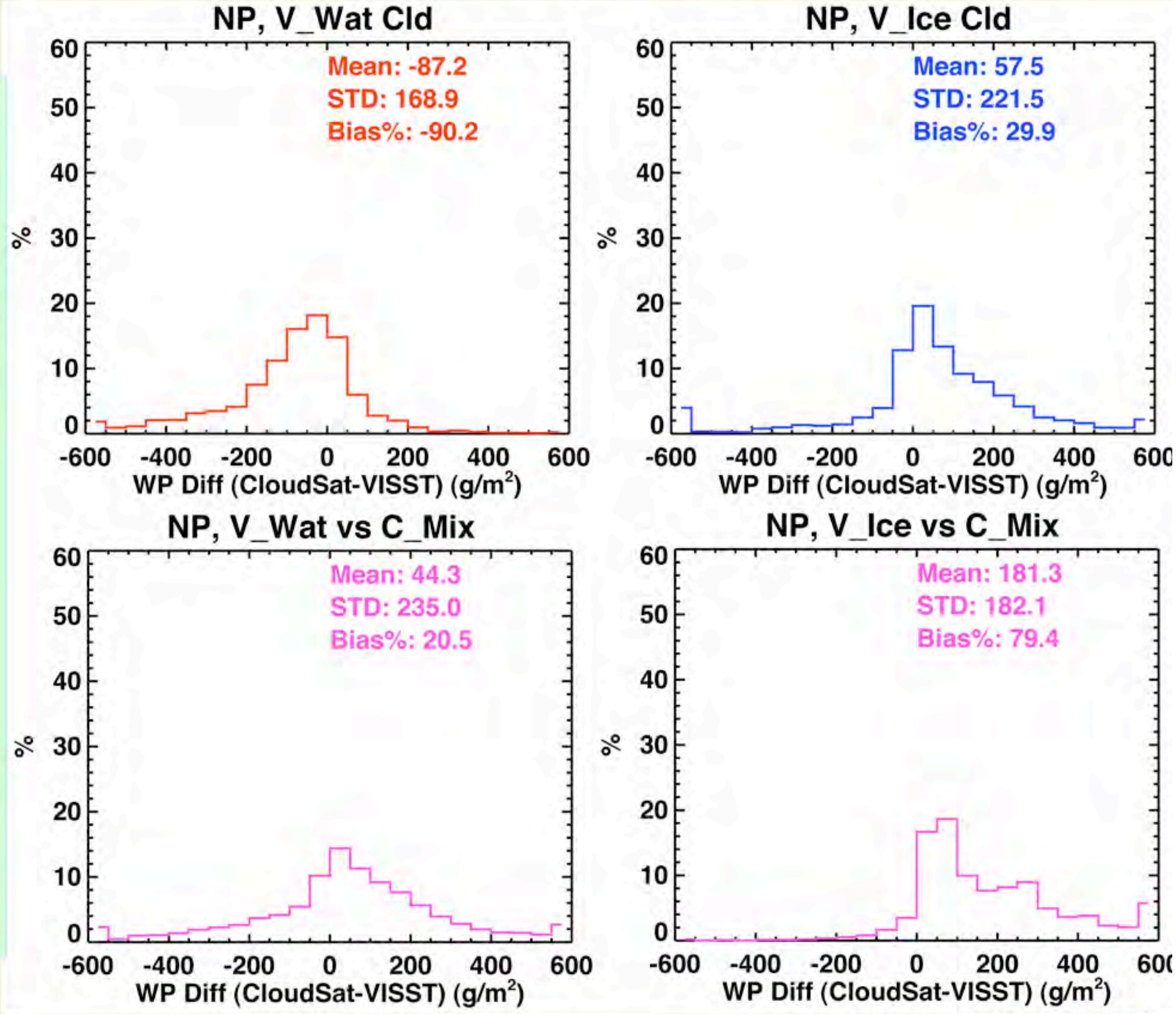
- CERES too low for mixed scenes
  - many scenes with large differences
  - need to examine imagery and detailed data



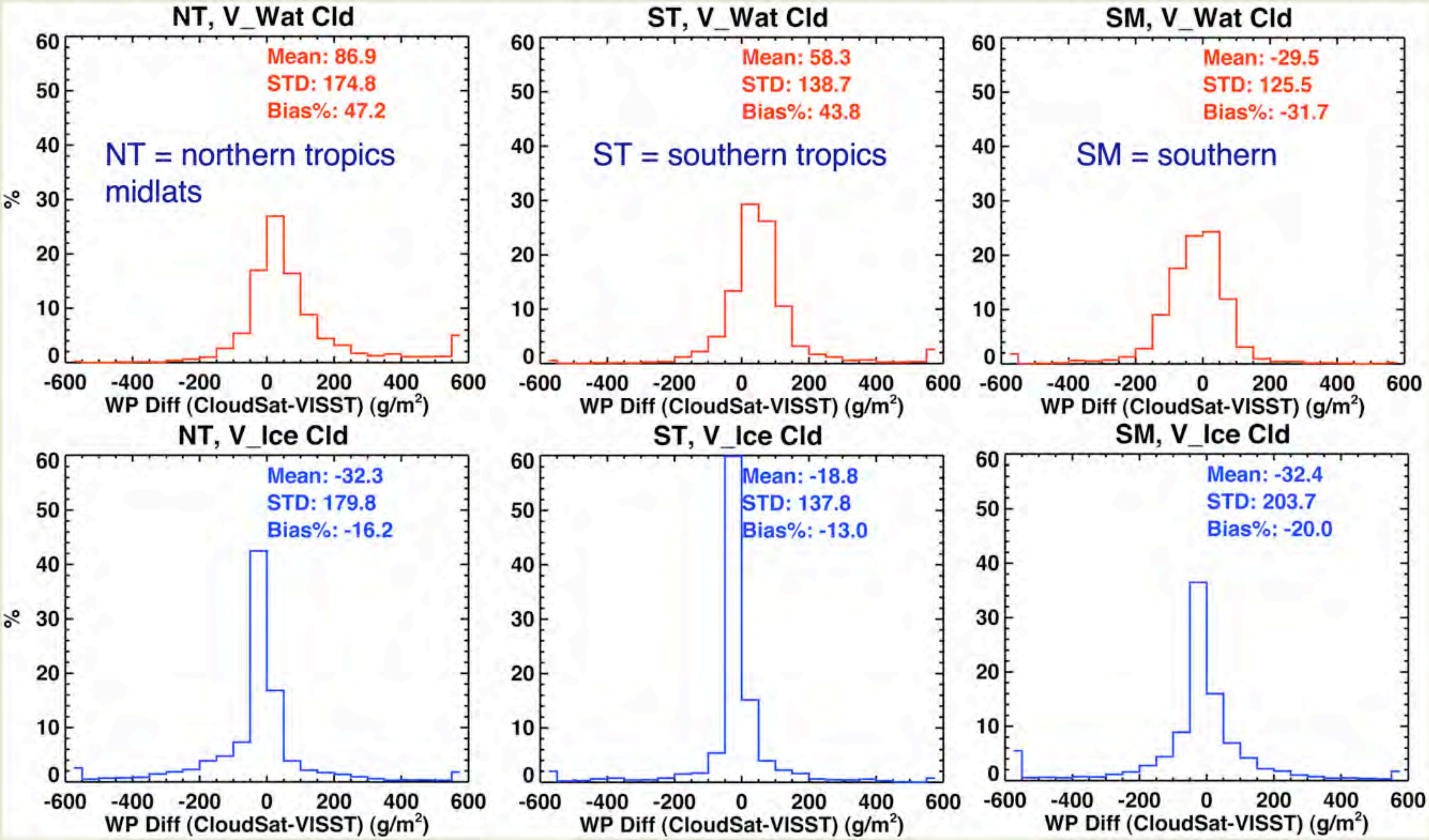
CloudSat WP – CERES WP, Histograms, Arctic, 15 July 2006, Daytime

- CERES LWP much greater than CloudSat for single-phase scenes
  - CloudSat missing lowest clouds over Arctic?
  - CERES should be less because of wrong atmo attenuation in 2.1-μm retrieval, SZA?

- CERES too low for mixed scenes & ICE
  - many scenes with large differences
  - Ice results as expected from 2.1-μm problem



CloudSat WP – CERES WP, Histograms, NT-SM, 15 July 2006, Daytime

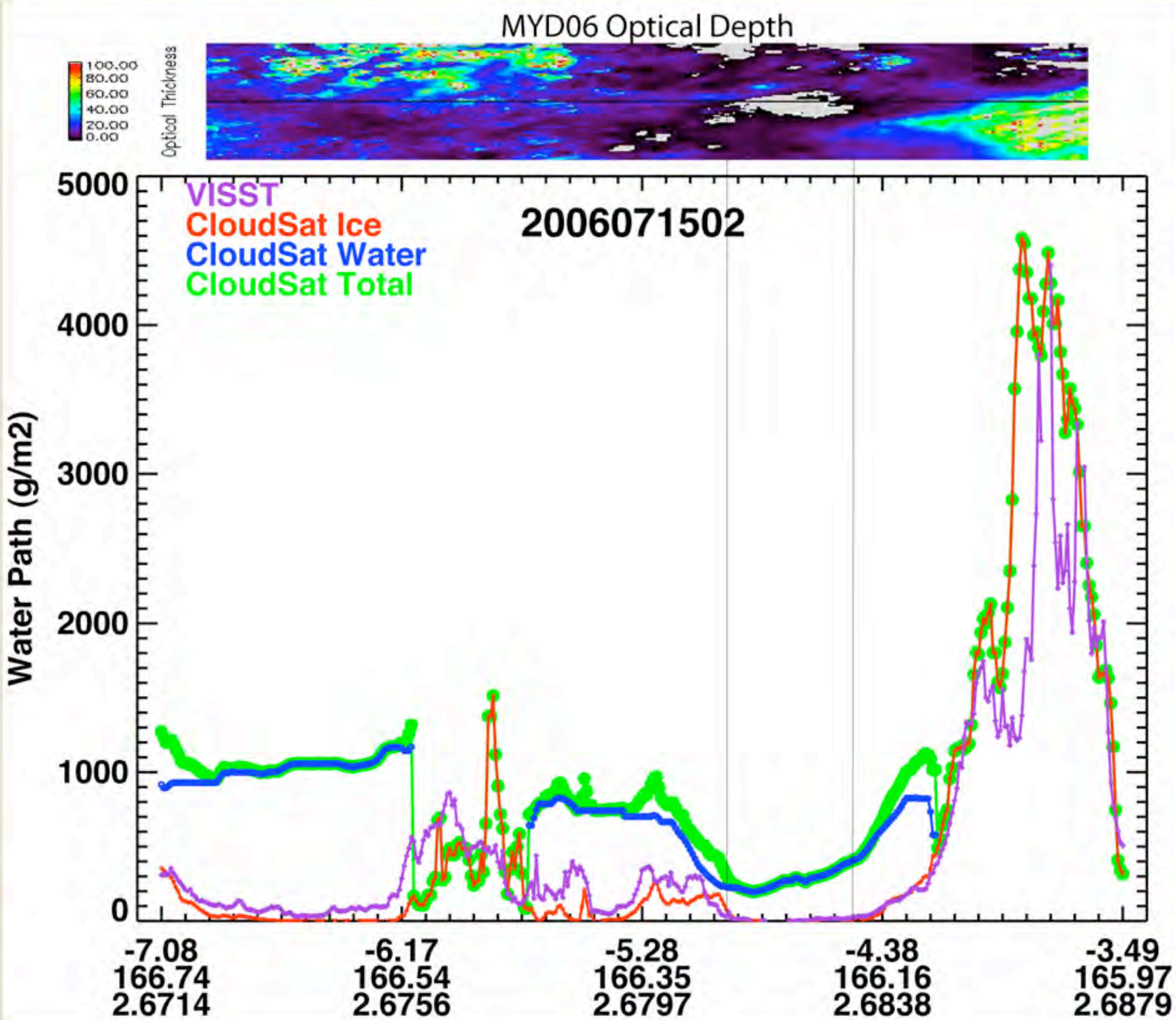


- good agreement for ice only, LWP high in tropics (still have > 500 gm^{-2} diffs)

Case Study to Examine Source of Large Differences in Mixed Cases

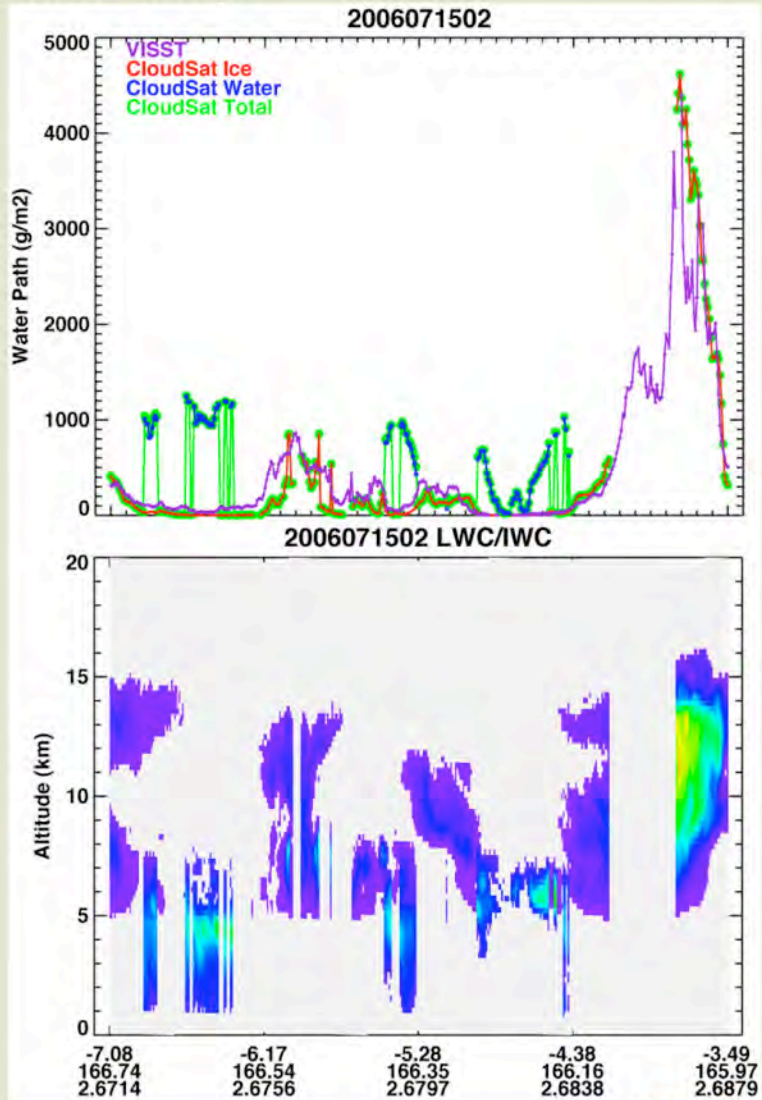
2.68 UTC, 15 July 2006

- CERES tracks pure ice cases reasonably well
- When LWC is also retrieved, the values are extraordinarily large given the MYD06 optical depths, = 0 in some cases
- e.g., 1000 $gm^{-2} \rightarrow \tau =$ 100 for Re = 15 μm
- case is typical



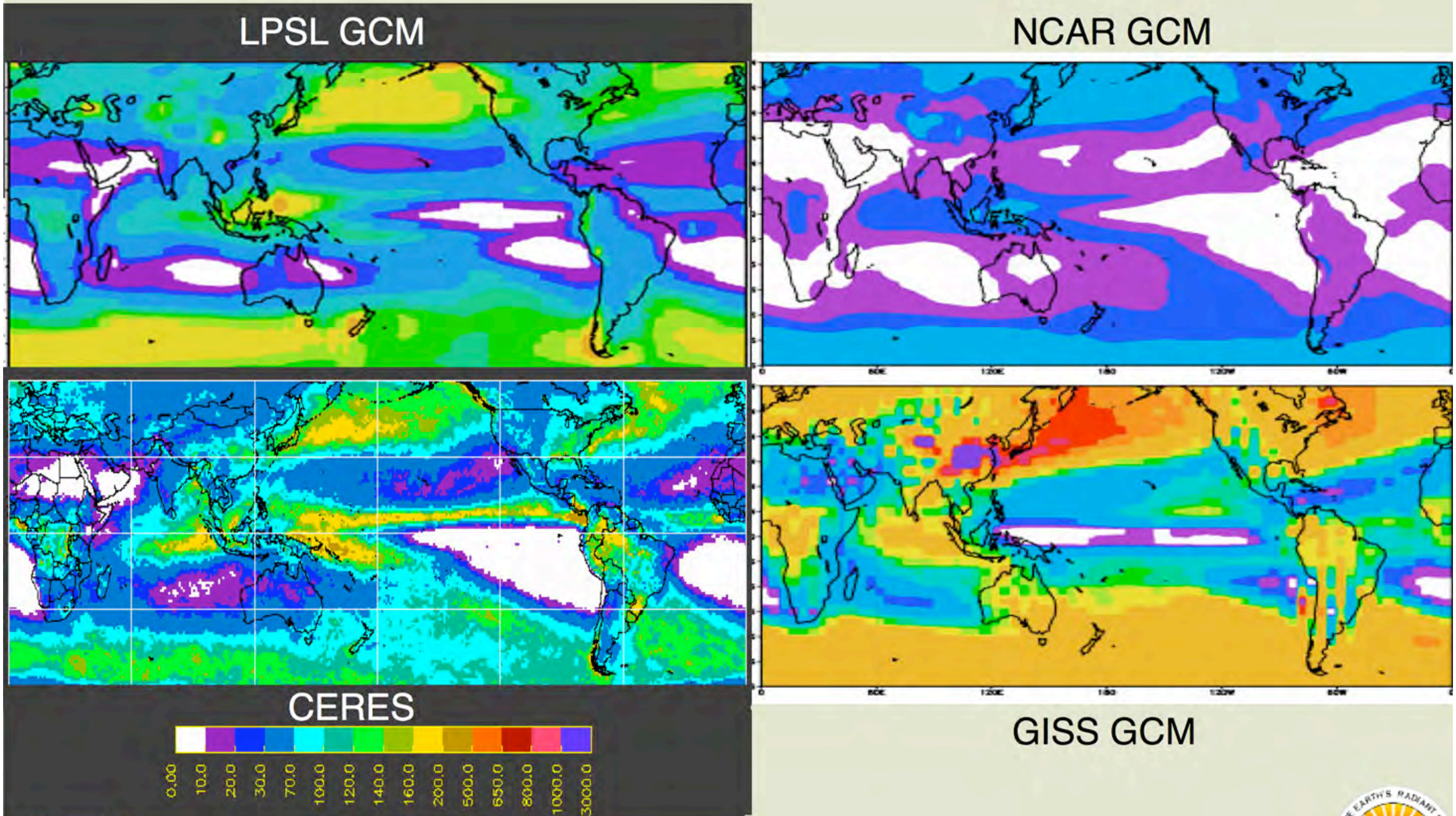
2.68 UTC, 15 July 2006 Case Study

- Curtain file indicates large LWC in areas where small IWC occur
- Are we misinterpreting?
- Is something wrong with the CloudSat LWC retrievals?
  - there cannot be that much water in those locations



Comparison of model & CERES GCM IWP

data from Waliser et al., JGR, 2008



Important to get IWP correct

Cloud Heights

- CERES Ed2 Satellite Retrievals Use $Z_c = z(T_c)$

  - $p > 700$ hPa, $Z_c = (T_c - T_{sfc}) / \Gamma$

    - for ocean, T_{sfc} = SST
    - for land, T_{sfc} = 24-h running mean T_{skin}(model)

  - $p < 500$ hPa, $Z_c = z(T_c)$, where $z(T)$ is NWA (e.g.,GEOS-5)

  - $500 < p < 700$ hPa, Z_c = avg of the above two

    Z_c, T_c = cloud effective height, temperature

    $\Gamma = -7.1$ K/km *(Minnis et al., JAM 1992)*

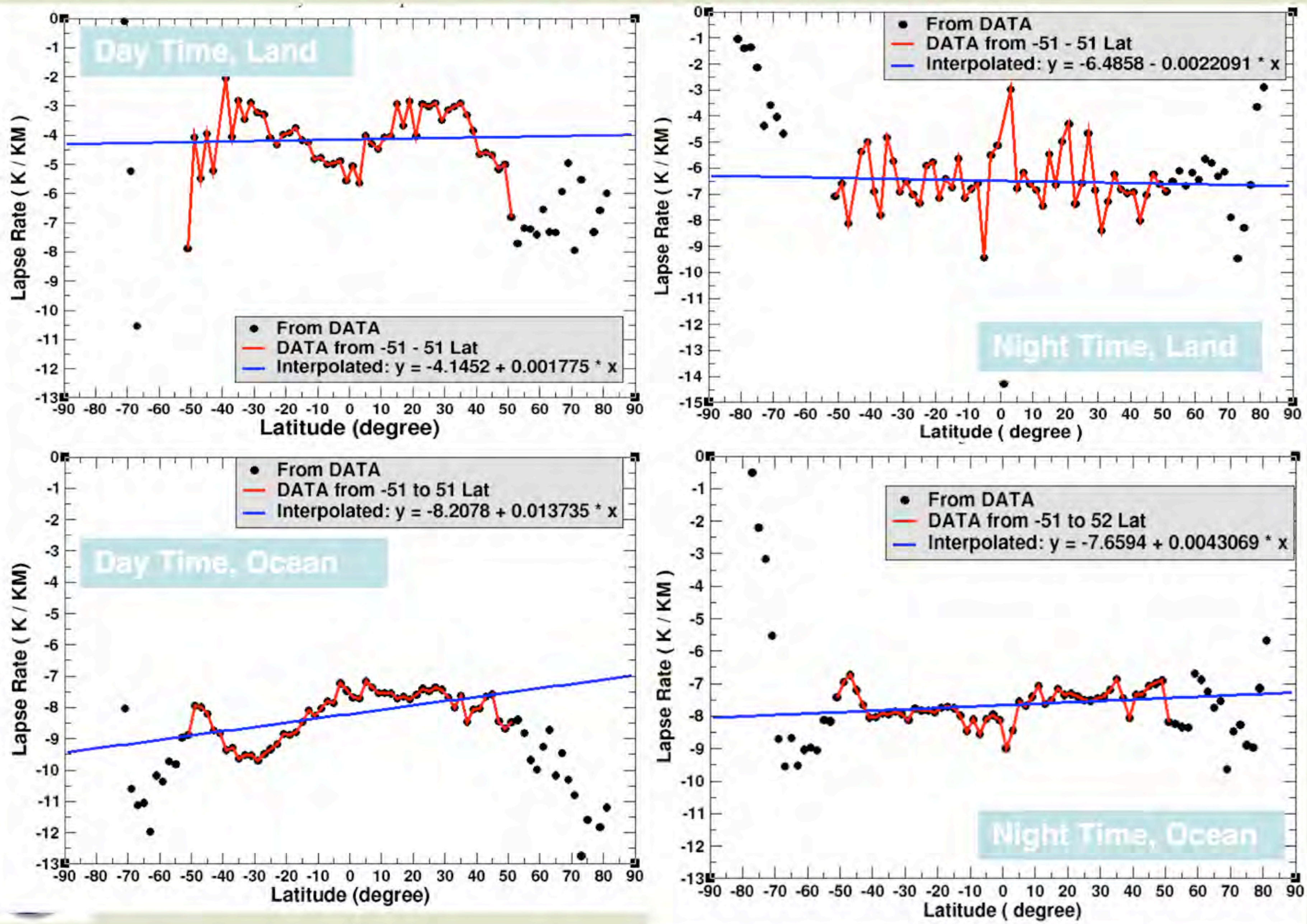
- CERES Ed3 beta 1 uses $\Gamma = \Gamma$(lat, sfc type) based on 1 month of CALIPSO-MODIS comparisons

- New empirical lapse rate developed by Zuidema et al. (2008)

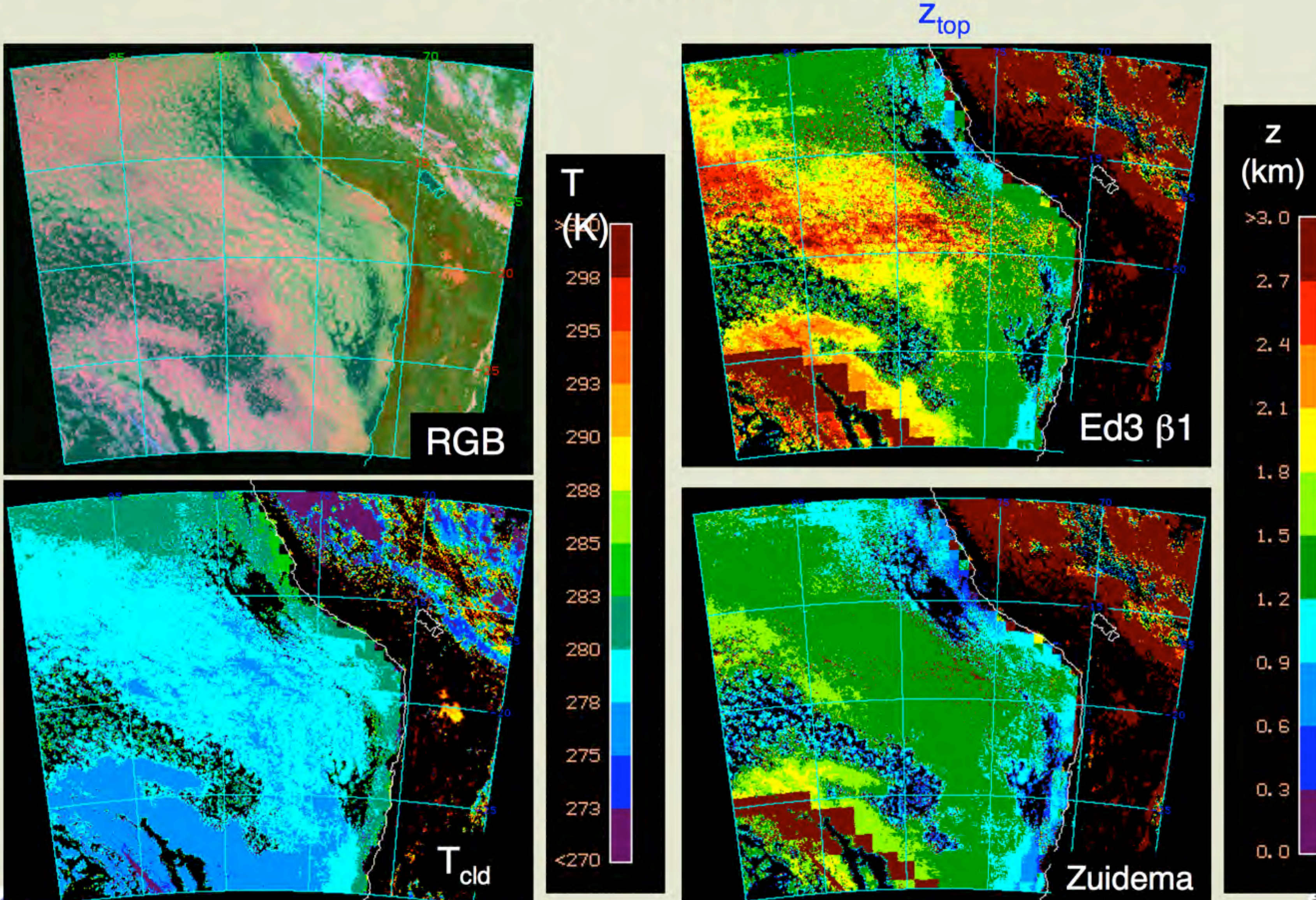
  - $Z_c = [\, T_{sfc} - T_c - 2.35 \text{ K}] / 0.0069$

We plan to examine this type of fit to reduce errors for low clouds.

Zonal Lapse Rate (April 2007)



Lapse Rate Based Cloud Height Comparisons, GOES-10
1545 UTC, 26 Oct 2008



• New fit not as sensitive to SST gradients

Lapse rate summary

- Ed3 beta 1 should minimize biases in low cloud heights, but std still large and regional biases will remain

- Newer approaches could reduce std & regional biases
  - *repeat Zuidema approach using matched MODIS & CALIPSO data for several months; examine regional & sfc type fits*
  - *test results using independent month*
  - *examine use of minimum Z from GEOS-5 or lapse rate*
  - *redo Dong study over SGP*

- examine cloud temperatures and lapse rates over polar regions

- Need to process more months of matched CC & MODIS data

Edition 3 Retrievals of Thin Cirrus Cloud Properties, Daytime

- Perform VISST & CO_2-slicing retrievals

  => T_{eff}, τ_{sm}, p_{eff}, D_{sm} + T_{co2}, p_{co2}, τ_{co2}

- If single-level and $\tau_{sm} < 6$, then

  - if $p_{eff} - p_{co2} > 50$ mb, then attempt to find new ice crystal model

- Perform retrieval with VISST-R, where nominal models replaced with roughened models, $\sigma = 1.0$: => T_{reff} , g_{ro}, τ_{ro}, D_{ro}

- If $T_{co2} \leq T_{reff}$ then use results of VISST-R, otherwise

$$\tau = (\tau_{sm} - \tau_{ro})/(T_{eff}-T_{reff}) + \tau_{ro}$$

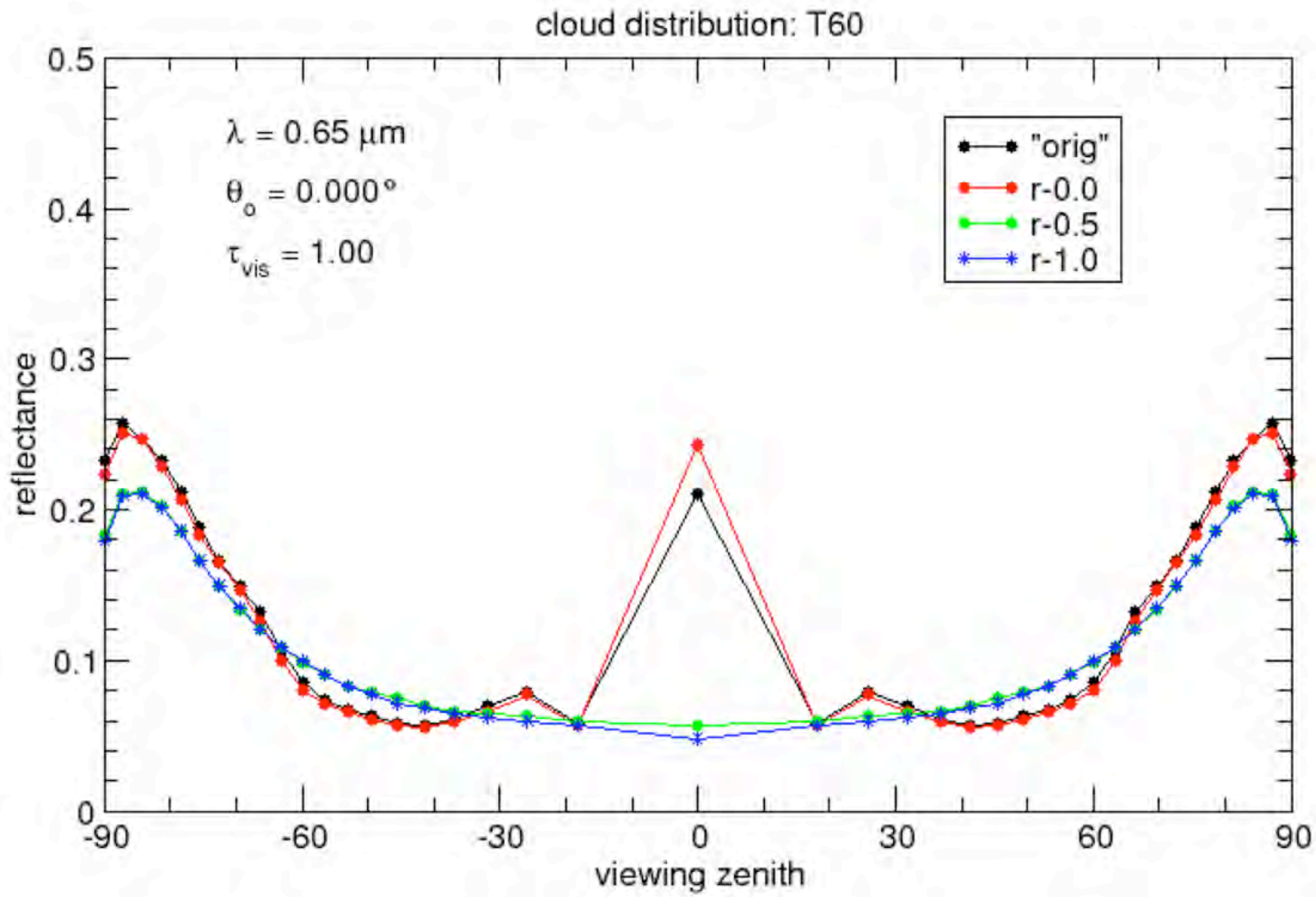
And so forth for g, D_{eff}

- Retrieval structure implemented without the models

  - now force τ to yield τ_{co2}

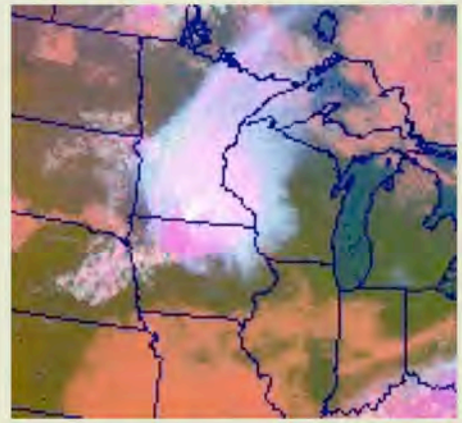
  - code to use models being tested

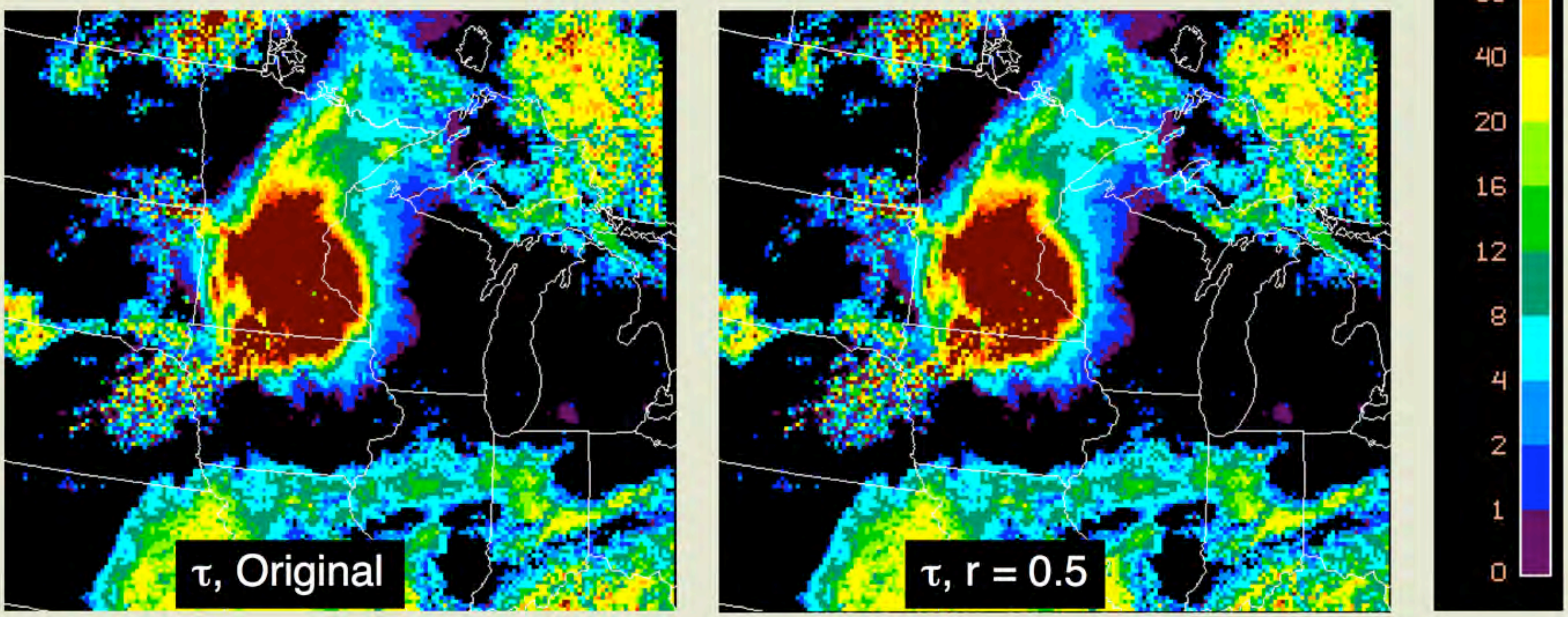
Reflectance fields for smooth & roughened ice hexagonal columns



Impact of Rough Ice Crystal Model on Optical Depth Retrieval, GOES-12, 31 July 08, 1415 UTC

- Applied only to ice clouds
- roughness factor of 0.5 used
- optical depth reduced for all ice clouds
  - Z_c should increase for $\tau < 3$





- r = 1.0 model will be tested with MODIS & CALIPSO data for Ed3

Edition 3 Improvement of SIST Retrievals, Night/Twilight

- Perform SIST & CO_2-slicing retrievals

  => T_{eff}, τ_{sm}, p_{eff}, D_{sm} + T_{co2}, p_{co2}, τ_{co2}

- If single-level and $\tau_{sm} < 6$, then

  if $p_{eff} - p_{co2} > 50$ mb, then attempt to find new ice crystal model

- Perform retrieval with SIST-C, where $T_{reff} = T_{co2}$, solve for τ, D_{eff}

- Retrieval structure has been developed and is in Ed3 Beta 1

  - results to be statistically analyzed when CC-matched dataset available

Cloud Thickness

- Used to estimate physical tops and bottoms of clouds for radiation calculations
  - fills volume of atmosphere with cloud

- Empirical fits used to estimate cloud thickness separately for low water clouds and ice clouds, and interpolated between
  - Ed2 fits based on relationships developed over ARM SGP

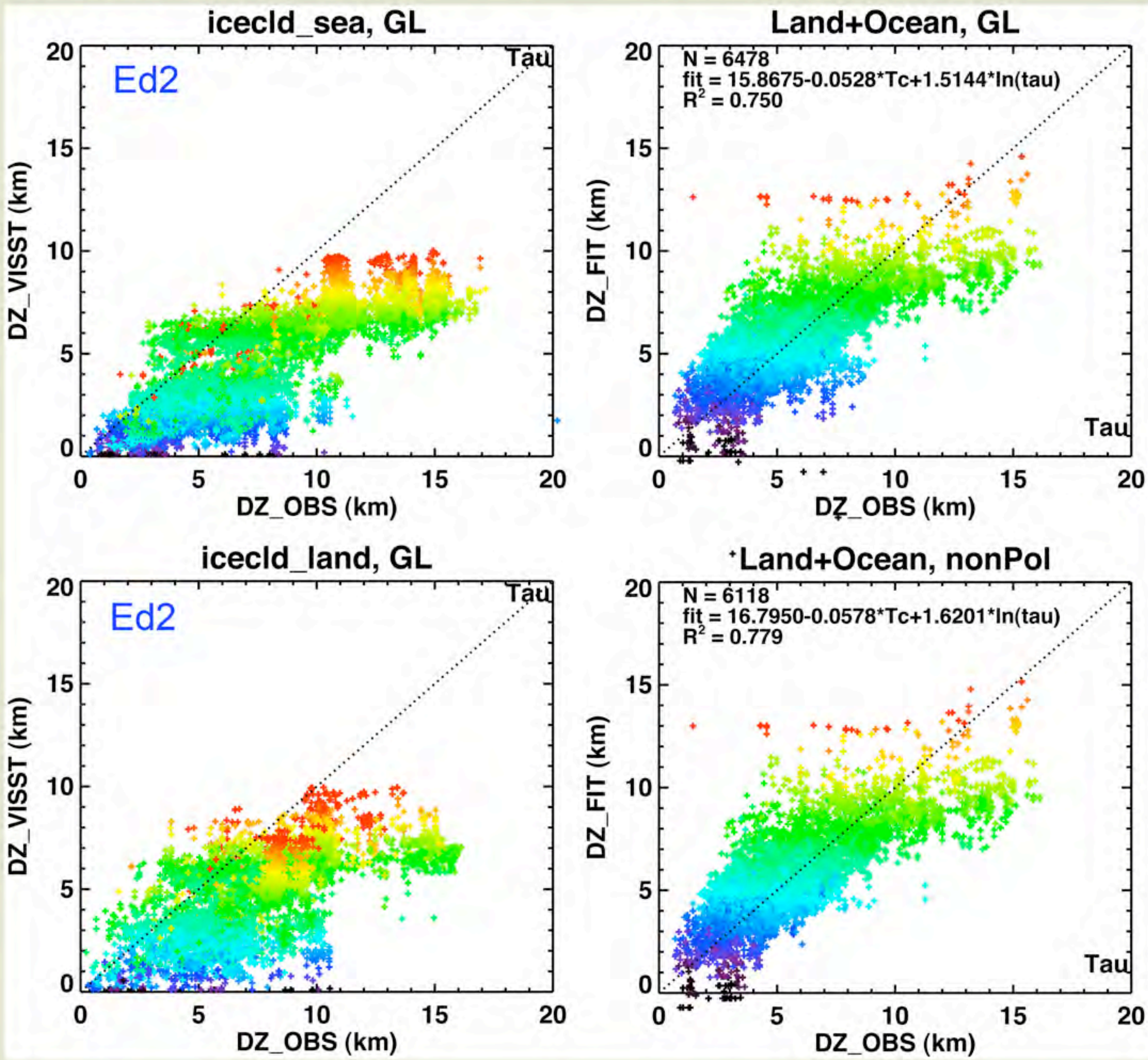
    limited data, limited cloud types

- CloudSat/CALIPSO data
  - new opportunity to verify/improve the fits
  - only 1 day of data used: 15 July 2006
  - single-layer clouds only

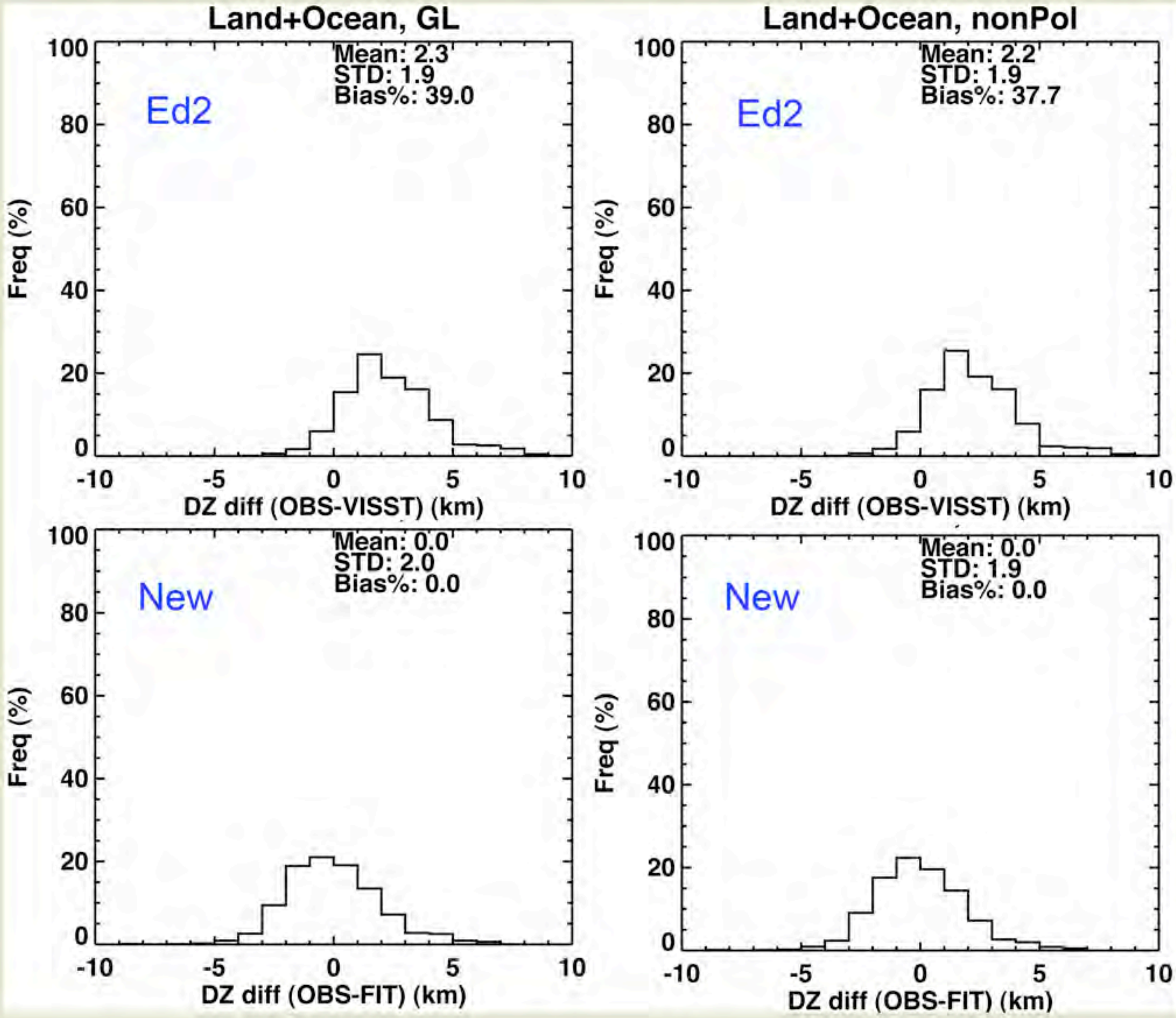
Single Layer Ice Cloud, Tc < 245 K, over land +sea

	Sample #	a_0	a_1*Tc	a_2 *alog(Tau)	r^2
Global	6478	15.868	-0.05278	1.51437	0.75
Non Polar (60N-60S)	6118	16.795	-0.05785	1.6201	0.778
Tropical (15N-15S)	1828	13.123	-0.04049	1.84542	0.823
North Polar (>60N)	360	8.193	-0.01173	0.20079	0.136
N Mid-Lat (60N-30N)	1262	21.009	-0.07534	1.66156	0.809
N Tropical (30N-0)	1857	8.693	-0.02219	1.86053	0.823
S Tropical (0-30S)	960	21.682	-0.07954	1.97038	0.833
S Mid-Lat (30S-60S)	2039	19.533	-0.06896	1.27236	0.714

Ice Clouds, T_c < 245 K, Ed2 and new fits vs. CALIPSO/CloudSat Thicknesses



Observed - Fit Differences, Ice Clouds, Global and Non-polar



- Bias eliminated, RMS still high, further digging warranted

Single Layer Water Cloud, Tc > 275 K, over land +sea

	Sample #	a_0	a_1*Tc	a_2 *alog(LWP)	a_3*alog(tau)	r^2
Global	8243	0.9470	-0.00323	0.4214	-0.4307	0.2589
Non Polar	7646	2.7957	-0.00964	0.4246	-0.4303	0.2703
Tropical	2124	18.6036	-0.06705	0.9072	-0.9083	0.5112
North Polar	597	14.0475	-0.0498	0.2258	-0.3287	0.2062
N Mid-Lat	1592	-2.1465	0.00942	0.0209	0.0112	0.1447
N Tropical	1976	14.7109	-0.05334	0.7756	-0.7339	0.3836
S Tropical	2752	7.6887	-0.0272	0.5445	-0.5286	0.4127
S Mid-Lat	1326	1.7738	-0.00298	0.03999	-0.03982	0.0385

Additional regression analyses needed using more data

- CloudSat has problems defining cloud base for low clouds

No Retrieval Minimization

- CERES Ed2 no retrieval fraction
  - Aqua = 0.036
  - Terra = 0.048
    - difference mainly in polar regions, *error logic in Terra Ed2*
- To reduce no retrievals in Ed3
  - fix error logic in Terra Ed2 as done in Aqua
  - use LBTM (VIS & IR only, assume particle size)
  - use IR (CO2) techniques for thin clouds
  - use high-res data for partially cloudy pixels
- Test runs indicate LBTM reduces no retrievals to < 1%
  - IR techniques (SIST/CO2) needed for remainder
    - recalculate clear sky reflectances/sfc temps?

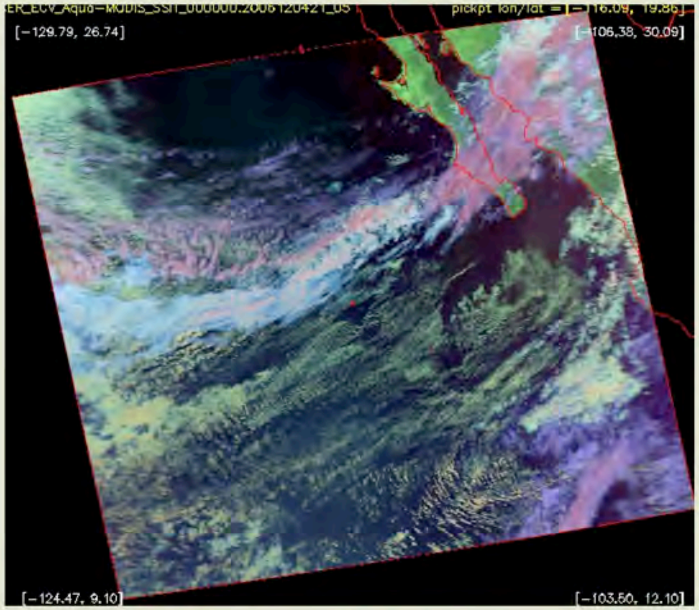
CO_2 & Multilayer Methods

- Applicable to SL & ML clouds both day and night
- Faster than 5-channel method
- Applicable to many satellites (any imager with 11 and 13.3 μm)
- Chang developed new code for 2 and 5-channel methods for comparison
- BTD & CO2 techniques - ~85% accurate in detecting SL clouds

  - minimal skill at detecting ML clouds (~ 50%)

  - both will be retained in Ed3

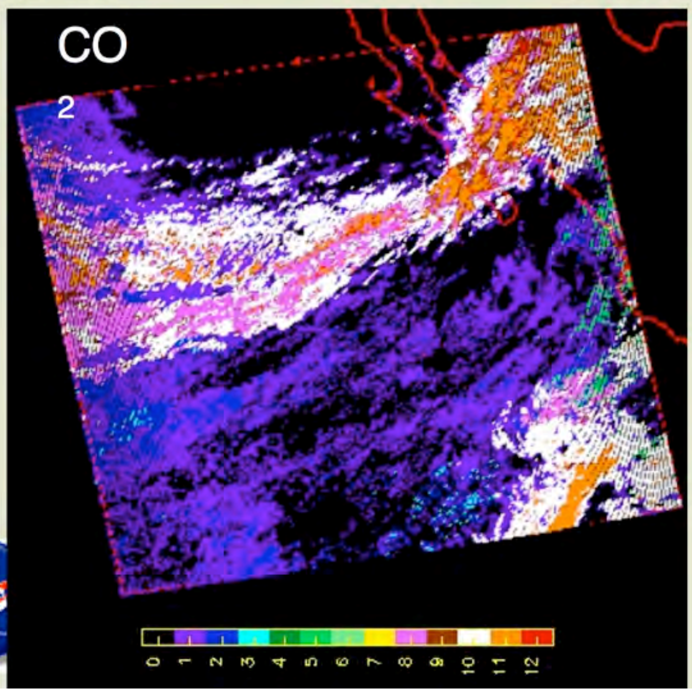
Multilayer cloud detection example

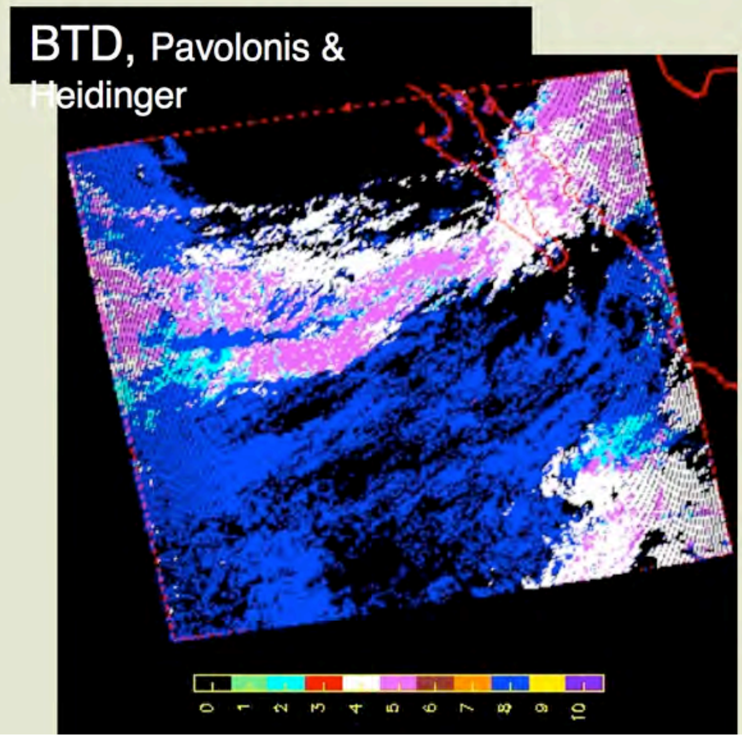


- Similar ML detection results but distinct differences between CO2 & BTD

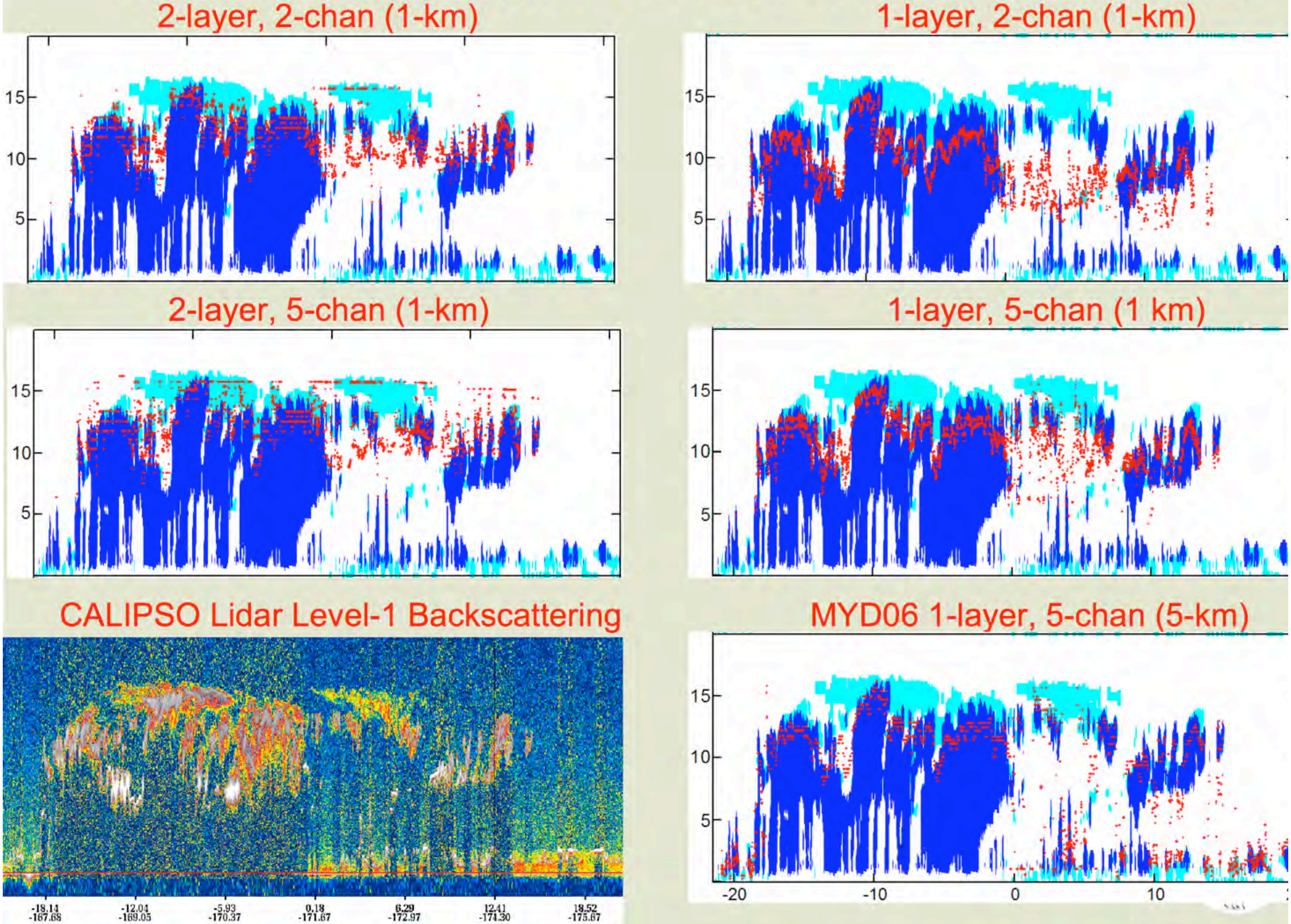
- Can only validate using CALIPSO/CloudSat
  - determine what ML means for each system

- Need the matched CC & MODIS reduced-swath dataset & CERES Ed3 code to systematically test & refine results





Comparison of Multilayer IR-CO2 Cloud Retrievals (Pacific Ocean)



Edition 3 Betas

- **Cloud mask improvements**
  - C2C method working;
  - clear-sky model, threshold, polar transition improvements
    - *- more work needed, need more eval of CALIPSO CFs*
- **Cloud retrieval improvements**
  - multipsectral retrievals *look good*, fewer no retrievals
  - improved lapse rates w/ blended C2C heights => *better heights*
  - new ice cloud phase functions: *rough xtals in Beta 2*
  - expanded tau range: *cut back to a smaller max?*
  - polar retrievals: *turn on SINT for Terra*
- **Multilayer cloud detection & retrieval**
  - New code working: *Beta 2 update*
  - CALIPSO opt depth now available for assessment
- **Hi-res cloud detection/retrieval of low clouds (250 m - 1 km):** *Beta 2*
- **New thickness parameterization**: *Beta 2*
- **Continue work on BTD ML method**: *NPP (no CO2 on VIIRS)*