CERES Editions 2 & 3 Cloud Microphysical Retrievals

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Edition 2 Cloud Microphysical Properties

- Cloud Retrievals

  - Uses 5 channels: 0.65, 1.6 (2.1), 3.8, 10.8, 12.0 µm

  - particle size from 3.8-µm only

  - tau from VIS or NIR channel daytime

  - reflectance parameterization

  - IWP & LWP computed as f(τ, r_e)

  - Minnis et al. (CERES Edition-2 Cloud Property Retrievals Using TRMM VIRS and Terra and Aqua MODIS data, Part I: Algorithms, Part II: Examples of Average Results and Comparison with other, Submitted to TGRS Dec 2009 & Feb 2010)

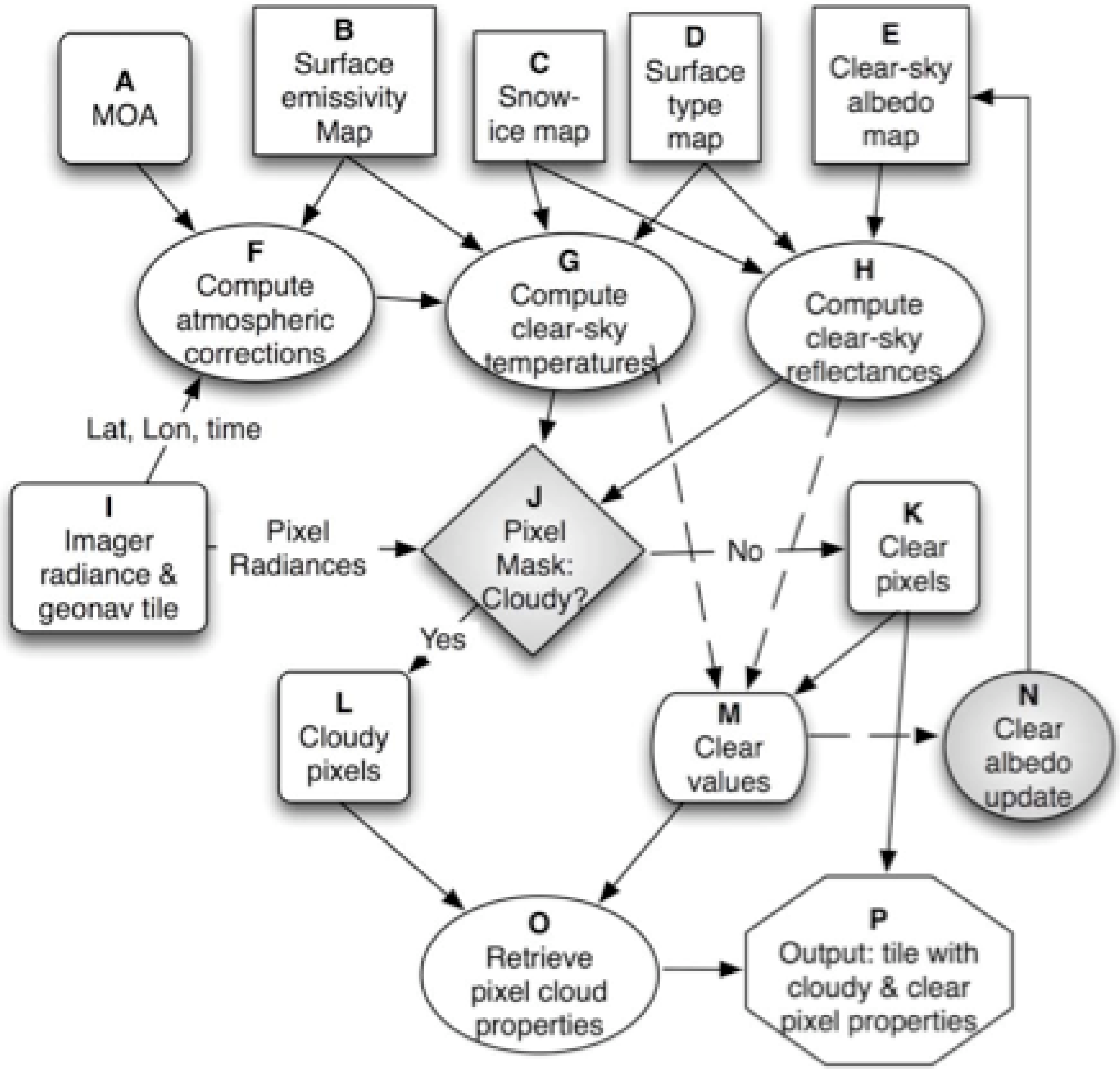
  - Reflectance LUTs & emissivity models

  - water droplet distribution, v_{eff} = 0.10

  - solid hexagonal ice xtal distributions

  - Minnis et al. (JAS, 1998)

CERES Cloud Processing



CERES Analysis

- tile-based (~ 32^2 km^2)
  - *common surface temp, emissivities, clear reflectances, atmos attenuation*
- individual pixel mask & retrievals
- results available in SSF
  - *2-layer avgs of each parameter within a CERES footprint (~20 km)*
- Summary results from individual pixels
  - *QC products*

Ancillary data

Vertical Profiles:

- NASA GMAO Global Earth Observing System (GEOS) 4.03 (1^o grid)

Surface characteristics:

- IGBP surface types (10’ grid)
- Snow & Ice Maps by NESDIS Interactive Multisensor Snow and Ice Mapping System Daily Northern and Southern Hemisphere Snow and Ice Analysis in the vicinity of coastlines. (10’ grid)

Surface emissivity and albedo:

- Seasonal clear-sky surface emissivity and albedo maps created using CERES products in 10’ grid. (*Minnis et al., TGRS, Vol. 46, 3857-3884, 2008)*

Standard Satellite-Derived Parameters

Baseline Daytime Methodology: VISST *(Minnis et al., 1995, 2009)*

Visible Infrared Solar-infrared Split-window Technique; 0.65, 3.8, 10.8, 12.0 µm

- Cloud amount (each pixel cloud or clear)
- *Cloud phase*, optical depth, *effective particle size (r_e)*, ice or *liquid water path*
- Cloud effective temperature (Tc) & height, *top/base height* & pressure

Daytime Snow/Ice Methodology: SINT (*Platnick, JGR, 2001; Minnis et al., TGRS, 2009)*

Solar-Infrared Infrared Near-Infrared Technique; 1.6 (2.1), 3.8, 10.8, 12.0 µm

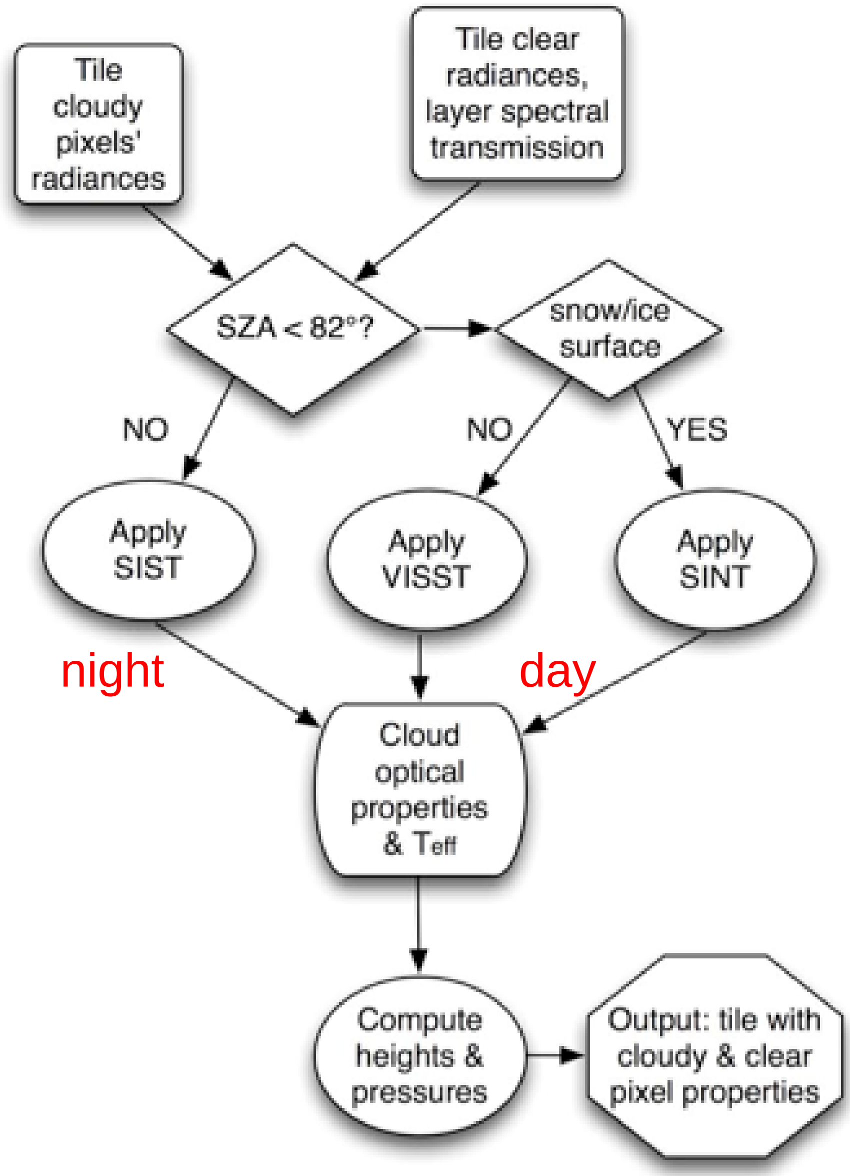
- Same as VISST, except 1.6 or 2.1 µm replaces 0.65 µm

Baseline Nighttime Methodology, SIST *(Minnis et al., 1995, 2009)*

Solar-infrared Infrared Split-window technique; 3.8, 10.8, 12.0 µm

- Same cloud parameters as daytime except optical depth (OD) limited to thin clouds only, no albedos, very sensitive to calibration

Daytime Retrievals



Make initial guess, then process iteratively as

A: water droplet
&
B: ice crystal

Determine phase based on model results & comparison with 12.0 µm model results

- ice, if both Tc < 233 K
- water, if both Tc > 273 K
- A if no B solution
- B if no A solution
- other logic tests using 12-µm / NIR data & likely sizes

SIST: Nighttime Retrievals

- Process as

A: water droplet

&

B: ice crystal

seeking best solution by minimizing error function

Size: $BTD_{3.8\text{-}11}$, Tc: 10.8 µm, Tau: $BTD_{11\text{-}12}$

=> yields solutions for thin clouds

thick clouds given default values, not to be trusted

Determine phase based on model results

- ice, if both Tc < 233 K
- water, if both Tc > 273 K
- A if no B solution
- B if no A solution
- ice, if Tc < 253K
- water, if Tc $\geq$ 255K

Examples of CERES Edition2 Microphysical Cloud Retrievals (Daytime Only)

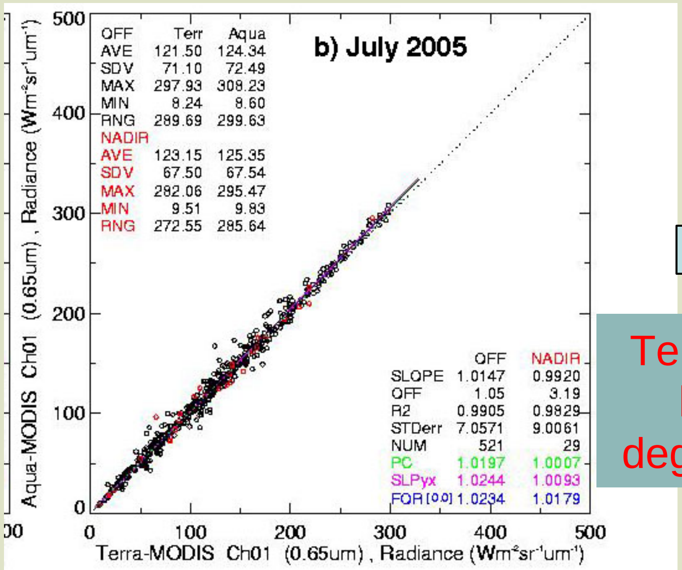
Known problems for Edition2 products:

- Used 1.62 µm atmospheric absorption values in place of 2.13 µm over snow/ice area for Aqua => tau too small
- Calibration differences between Terra and Aqua for 0.65 µm and 3.8 µm channels
- Significant number of cloudy pixels not retrieved over snow because of logic bug in using the snow/ice map
- Nighttime results are not very reliable due to limited information

Examples of Aqua/Terra Intercalibrations

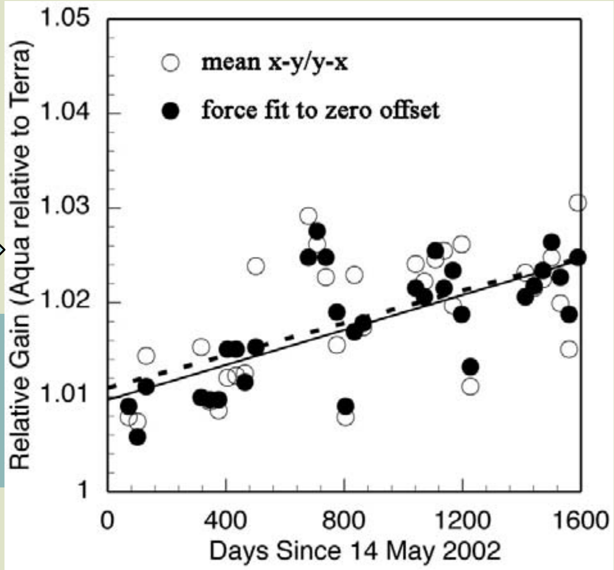
0.65 µm channel

Aqua



Gain

Terra too low, degrading

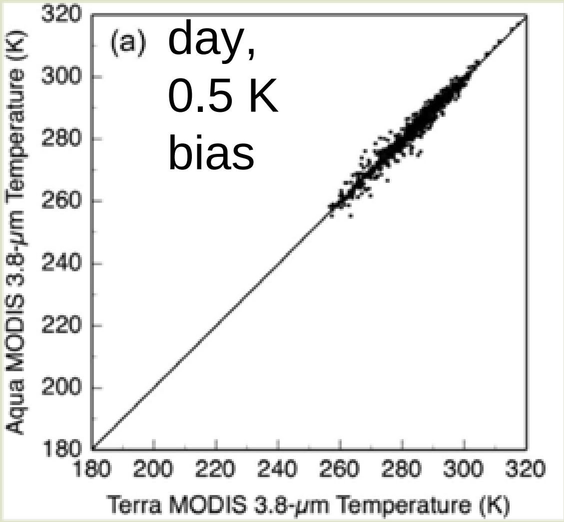


Terra

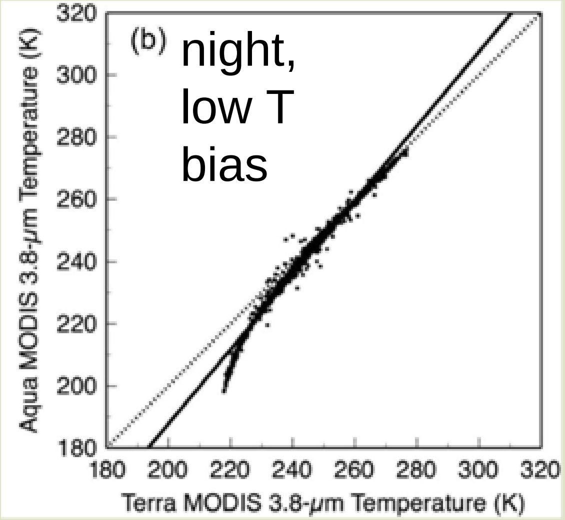
Timeline

3.8 µm channel

Aqua



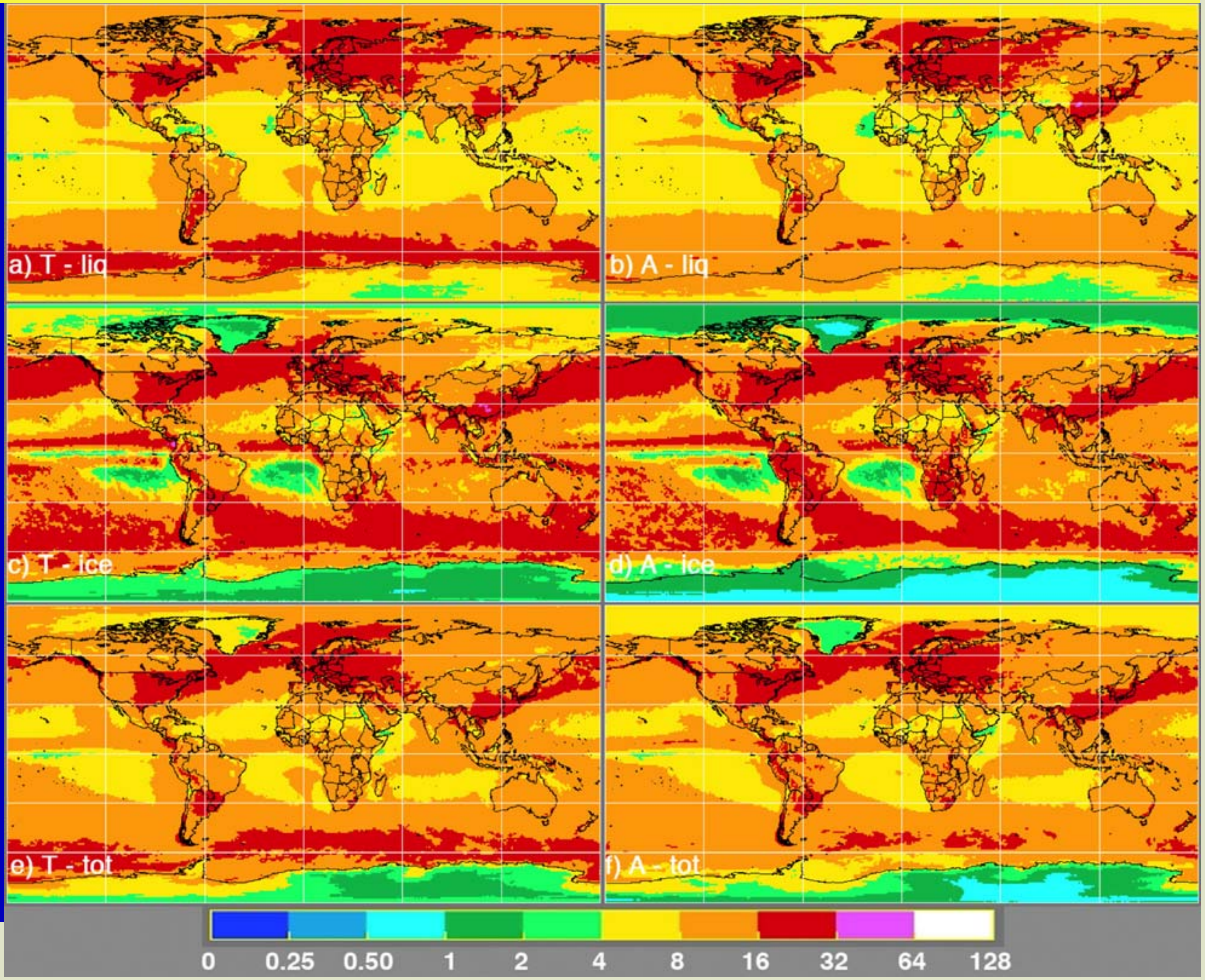
Terra too warm



Terra

Mean Daytime Cloud Optical Depth from Terra (2000-2007) and Aqua (2002-2007) MODIS from CERES Ed2 algorithms

- Aqua & Terra τ have similar global patterns
- Liquid τ has the greatest on mid-latitude Land from Aqua, over marine stratus areas from Terra, reflecting the diurnal cycle
- Terra liquid and ice clouds between 45S and 70S greater than Aqua, due to cloud thinning out during daytime
- •Aqua are much less than Terra over polar region due to the coding error in SINT

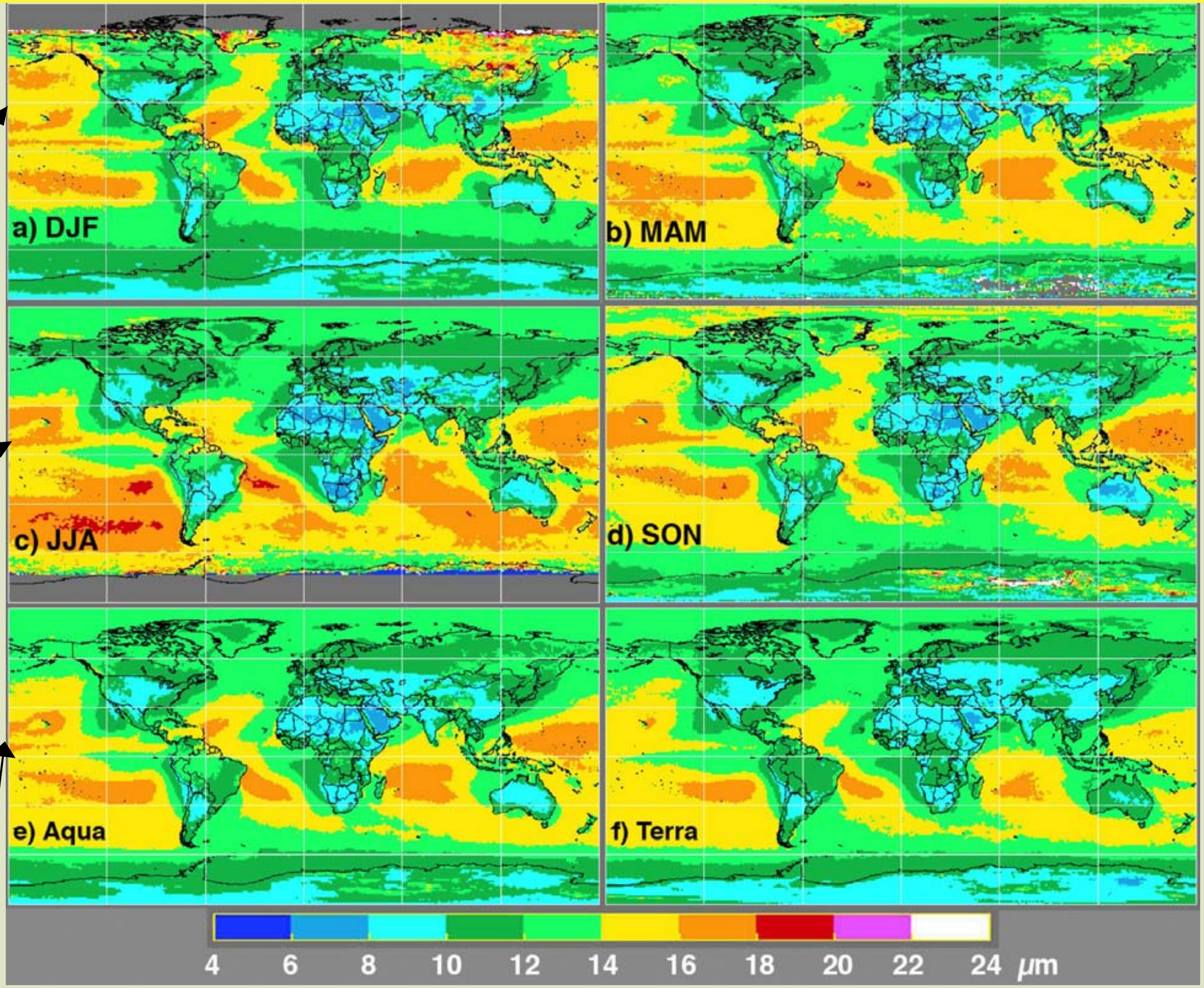


	Global		Non Polar		Polar	
τ	Terra	Aqua	Terra	Aqua	Terra	Aqua
Liquid	10.2	9.6	9.6	9.4	13.8	11.3
Ice	12.9	12.6	13.6	13.6	8.6	6.5

Mean Daytime Cloud Droplet Effective Radius from Terra (2000-2007) and Aqua (2002-2007) MODIS from CERES Ed2

Aqua only

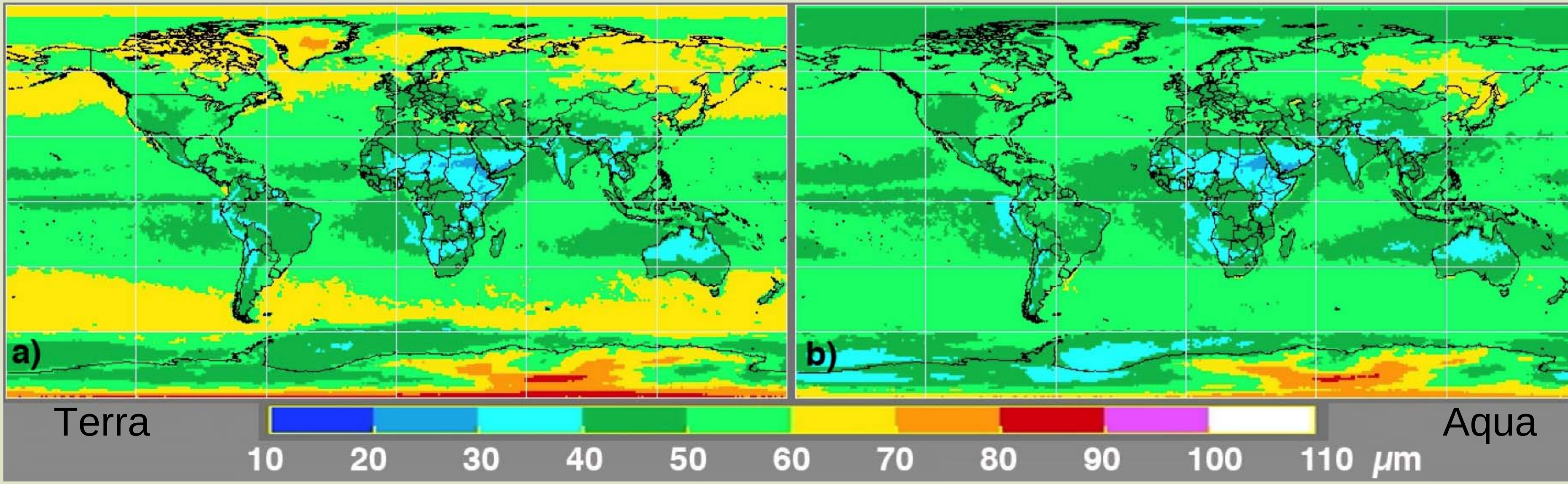
- Seasonal global r_e from Aqua show the variation except little change over Sahara and Saudi Arabia.
- r_e over land are much smaller than over ocean.
- Mean annual r_e from Terra and Aqua are very similar except the Terra values are 0.4 μm smaller that Aqua due to the 0.55K difference of 3.8 μm calibration



Annual Mean

	Global		Non Polar		Polar	
	Terra	Aqua	Terra	Aqua	Terra	Aqua
r_e (μm)	12.7	13.1	12.9	13.3	11.4	11.8

Mean Daytime Cloud Ice Crystal Effective Diameter from Terra (2000-2007)and Aqua (2002-2007) MODIS from CERES Ed2



- Significant ocean-land difference and discrepancies between Terra & Aqua

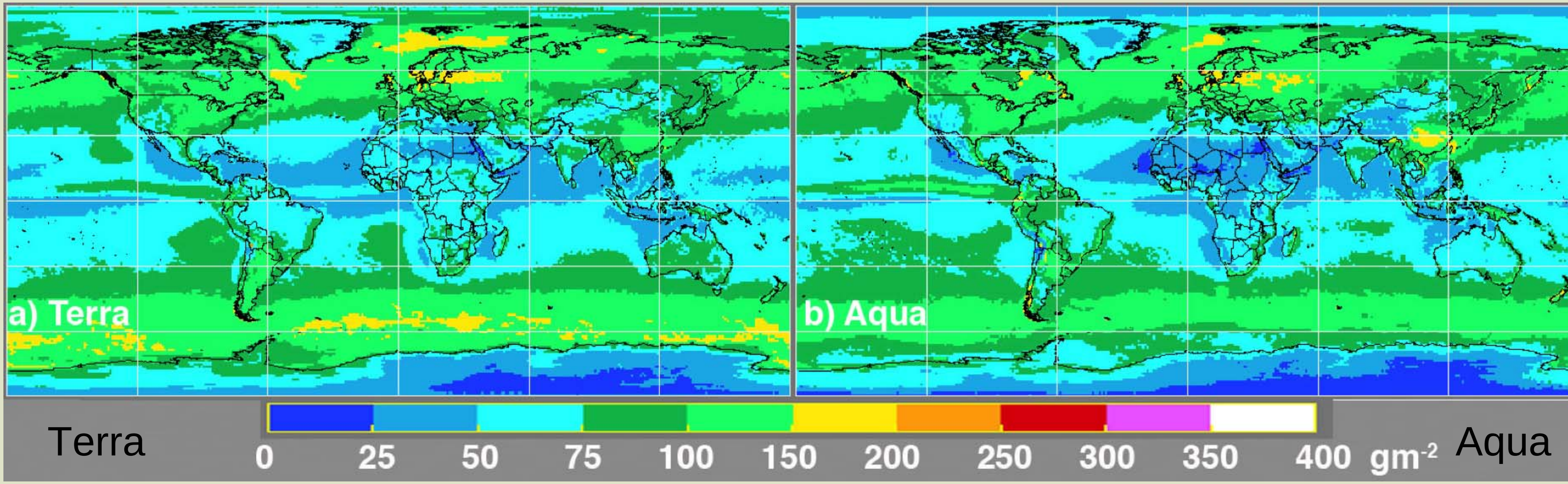
  -Non-polar ocean-land D_e difference is 10.2 μm for Terra and 6.2 μm for Aqua.

  -Aqua D_e is 2.4 μm < Terra in non-polar region; 0.6 μm greater over land

- Differences due to diurnal changes, calibration differences (3.8μm) and different spectral channel use for optical depth retrieval (Terra-1.6μm, Aqua-2.1μm).

	Global		Non Polar		Polar	
	Terra	Aqua	Terra	Aqua	Terra	Aqua
D_e (μm)	53.5	50.5	52.9	50.5	56.3	50.7

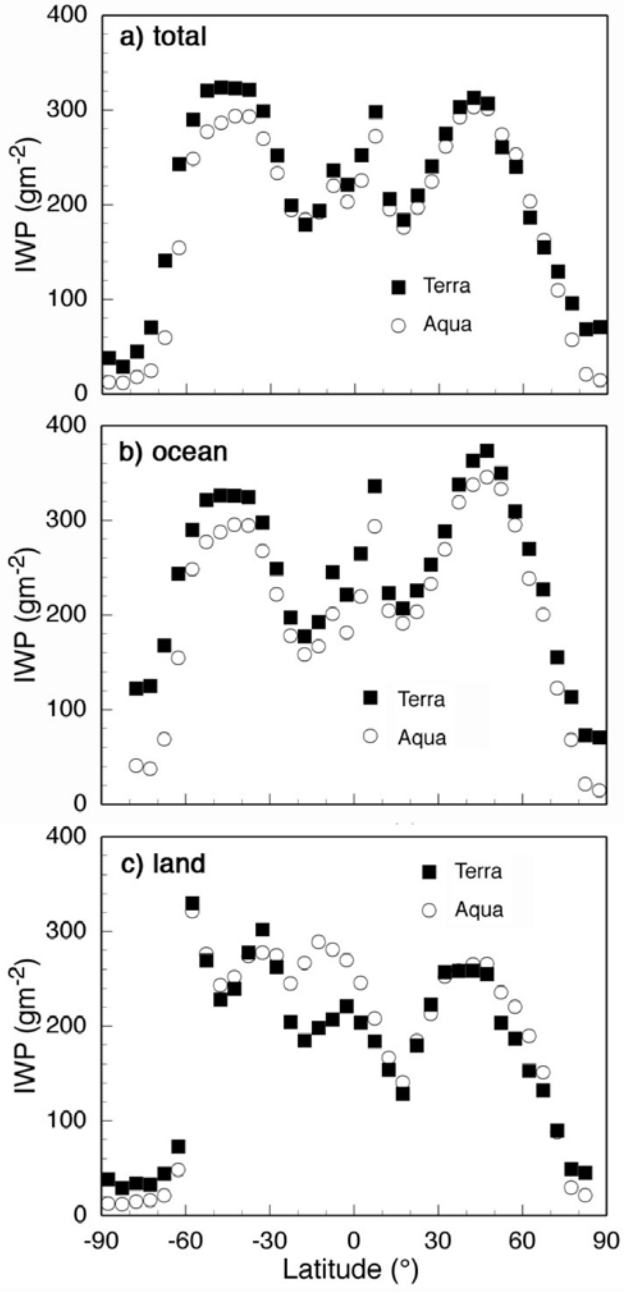
Mean Daytime Cloud Liquid Water Path from Terra (2000-2007) and Aqua (2002-2007) MODIS from CERES Ed2 algorithms



- Aqua has smaller mean *LWP* than Terra over marine stratus regions off the subtropical west coasts of Australia, Africa, and the Americas but larger than Terra near the Equator and over mid-ocean area. In southern hemisphere, Aqua has smaller values than Terra may due to Aqua classifying more thick clouds as ice or to actual thinning of the water clouds during the day.

- Overall, the mean *LWP* is the same for both Aqua and Terra over non polar regions.

	Global		Non Polar		Polar	
	Terra	Aqua	Terra	Aqua	Terra	Aqua
LWP (gm^{-2})	81.3	78.6	78.5	78.2	99.7	81.1



Zonal Mean Daytime Cloud Ice Water Path from Terra (2000-2007) and Aqua (2002-2007) MODIS from CERES Ed2 algorithms

- Terra has greater total *IWP* than Aqua, especially in the southern mid-latitudes except 15S & 50N - 70N over land.
- Terra mean *IWP* is ~15 gm^{-2} (6%) > Aqua over non-polar regions reflecting possible diurnal (1030LT and 1330LT) changes in ice clouds properties. Impact of calibration differences not yet clear.

IWP (gm^{-2})

Global		Non Polar		Polar	
Terra	Aqua	Terra	Aqua	Terra	Aqua
239.3	221.3	255.2	239.8	136.6	101.8

Comparisons With Surface Data

Liquid Clouds

CERES-MODIS minus surface from 2000 – 2004 for stratus clouds over SCF *(Dong, et al, JGR, 2008)*

Terra: r_e 0.1 $\pm$ 1.9 μm τ -1.3 $\pm$ 9.5 *LWP* 0.6 $\pm$ 49.9 gm^{-2}

Aqua: r_e 0.2 $\pm$ 1.9 μm τ 2.5 $\pm$ 7.8 *LWP* 28.1 $\pm$ 52.7 gm^{-2}

Larger mean LWP difference for Aqua may due to its greater 0.64 gain

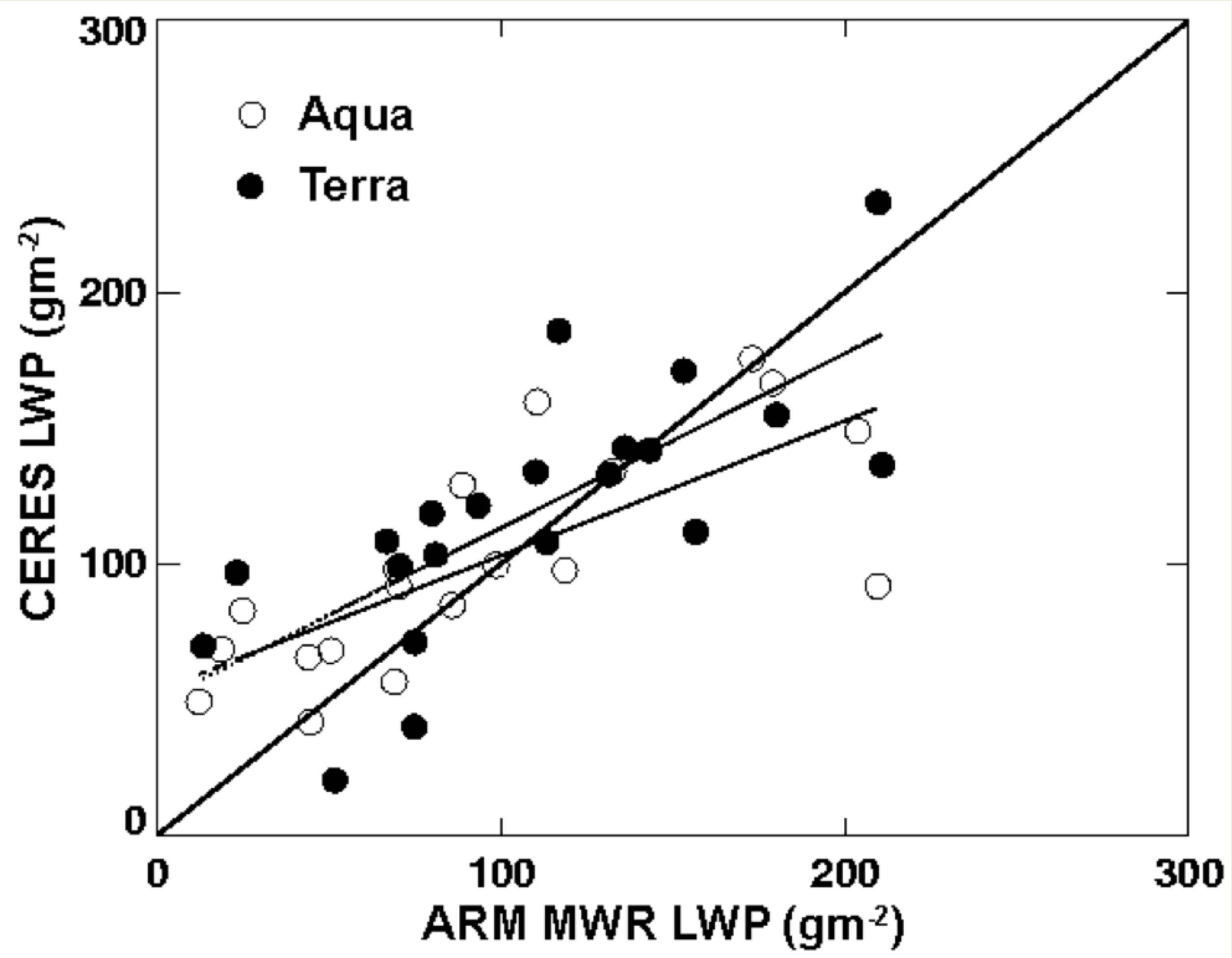
Ice Clouds

CERES-MODIS minus surface from 2000 – 2004 for cirrus clouds over SCF *(Mace, et al, J. Appl. Meteorol., 2005)*

Terra Biases for $\tau < 2$: D_e -18%; τ 15%; *IWP* -16%

Comparison of Cloud LWP using CERES SSF data

over ARM Mobile Facility at Pt. Reyes, CA
Mar 1 – September 14 2005



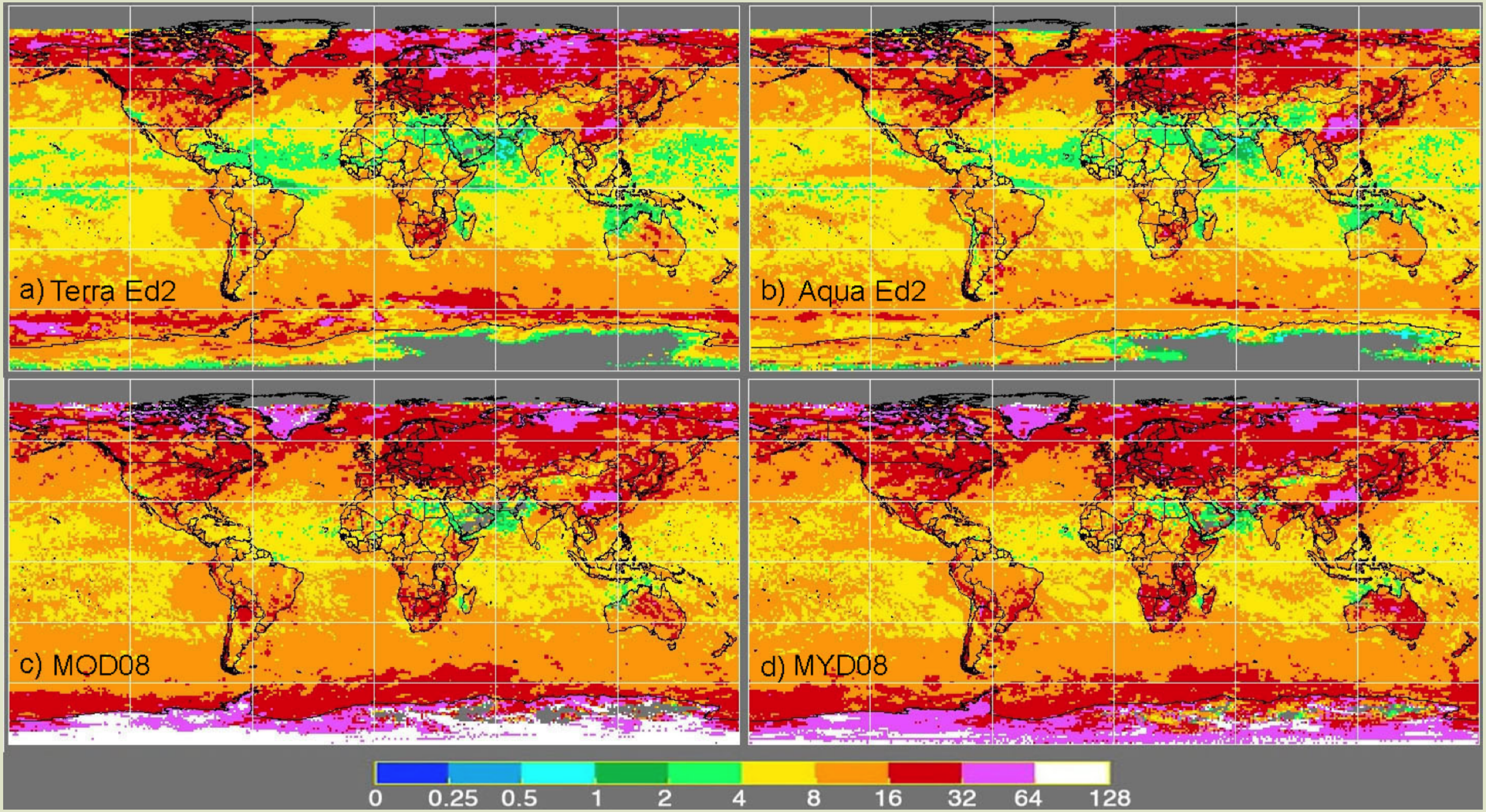
CERES – MWR:	Mean	Std
Terra (gm^{-2})	10.2	38
Aqua (gm^{-2})	5.6	41

Comparisons Between CERES Edition2 and MAST (MODIS Atmospheres Science Team) Collection 5 Retrievals

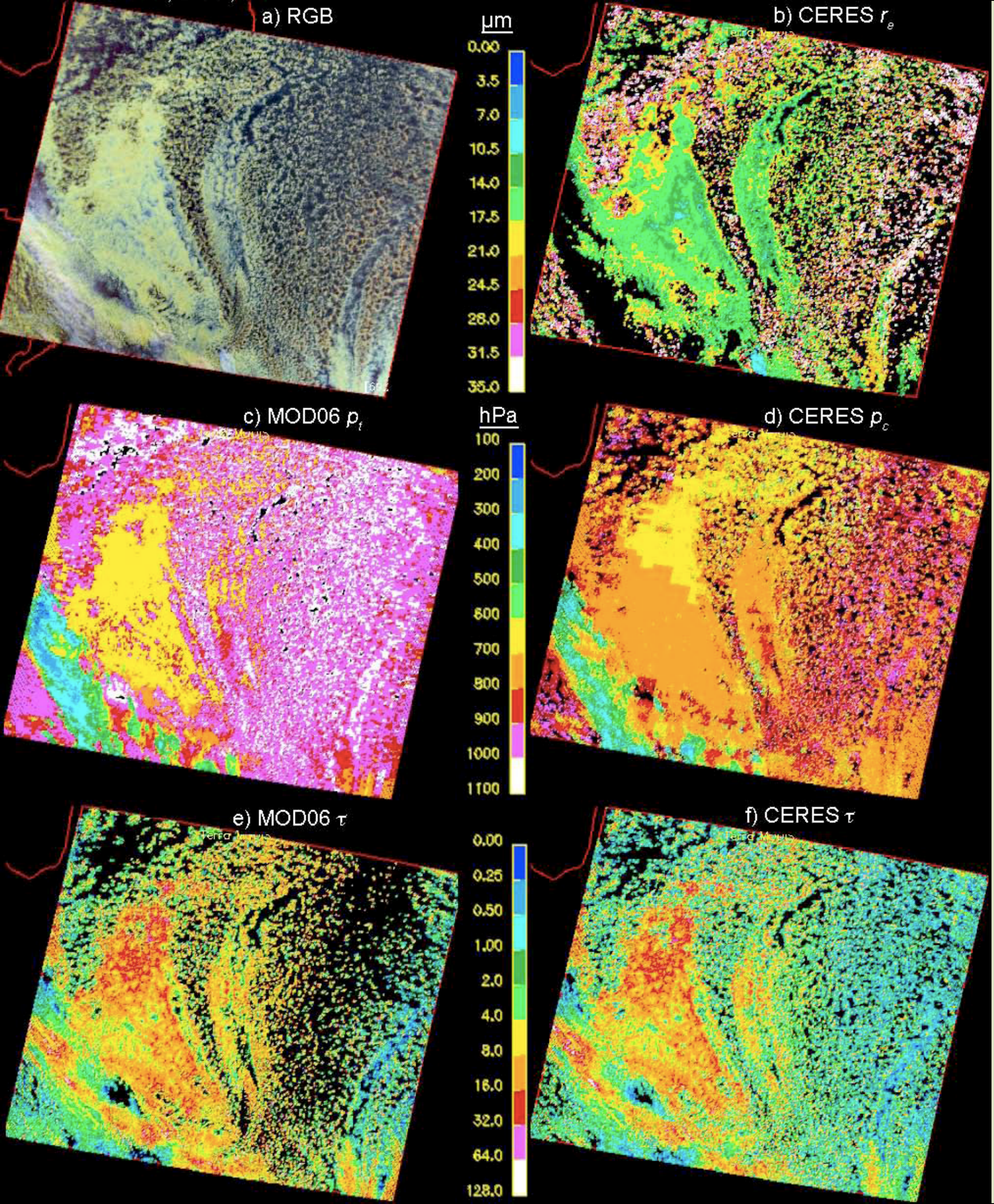
DATA used:

- Terra and Aqua October 2003
- MAST : MOD08, MYD08 (1° gridded data)
- CERES Ed2: QC (1° gridded data)

Mean Daytime Liquid Water Cloud Optical Depth



	Global		Non Polar		Polar	
CERES-MAST	Terra	Aqua	Terra	Aqua	Terra	Aqua
τ, (liquid)	-2.9	-4.1	-1.5	-2.7	-11.4	-13.4



Differences in Average Optical Depths CERES vs MAST

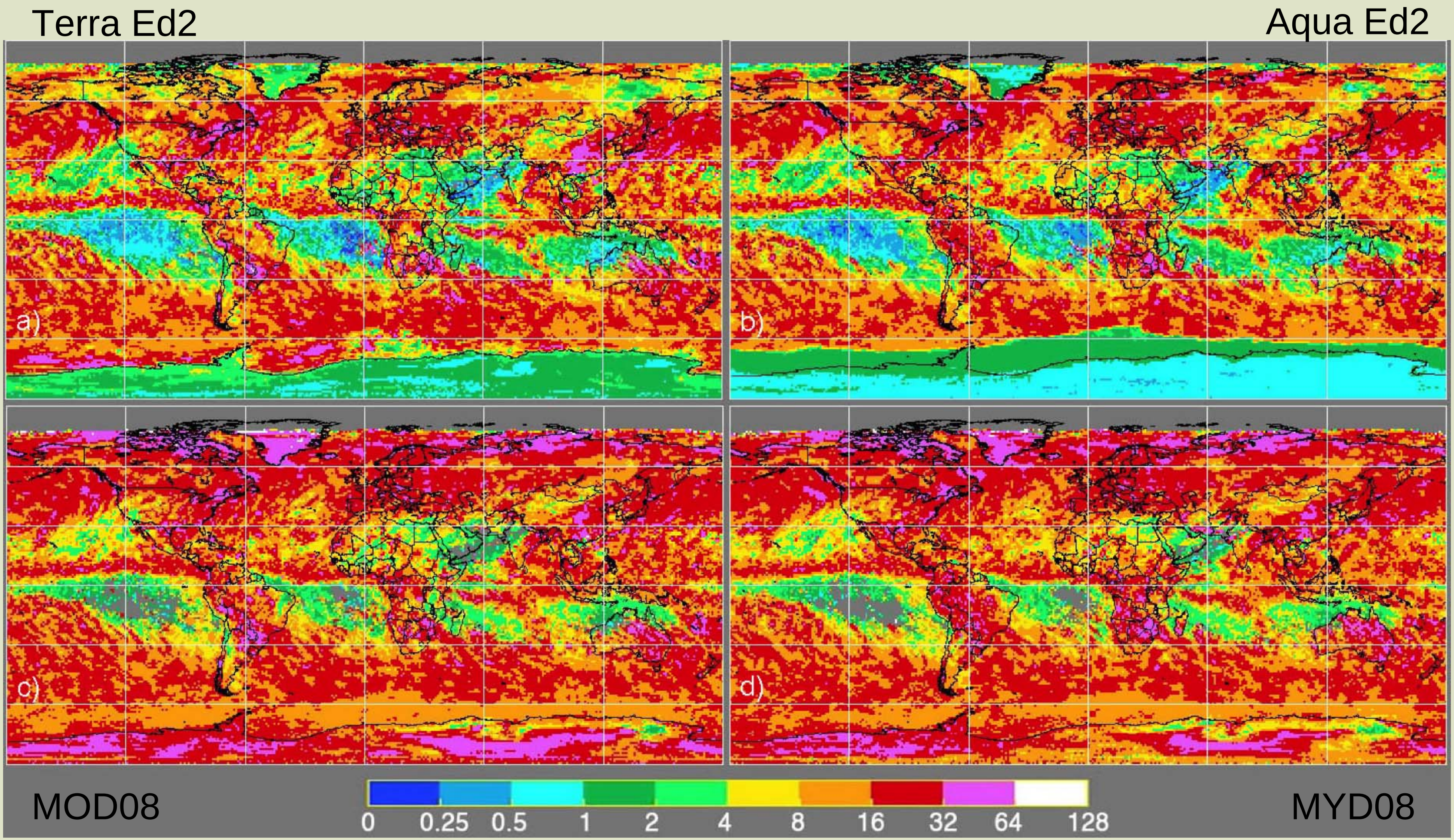
Ex: stratus, Indian Ocean,
Terra, 0615 UTC, 3 July 2005

- MAST retrieves p_c for more clouds than CERES

- MAST retrieves τ for fewer clouds than CERES
  - many small τ clouds eliminated by MAST

=> This example is typical. It suggests that the large biases in the average optical depths compared to the MAST results is likely due to the lack of small τ in the averages for MAST.

Mean Daytime Ice Cloud Optical Depth



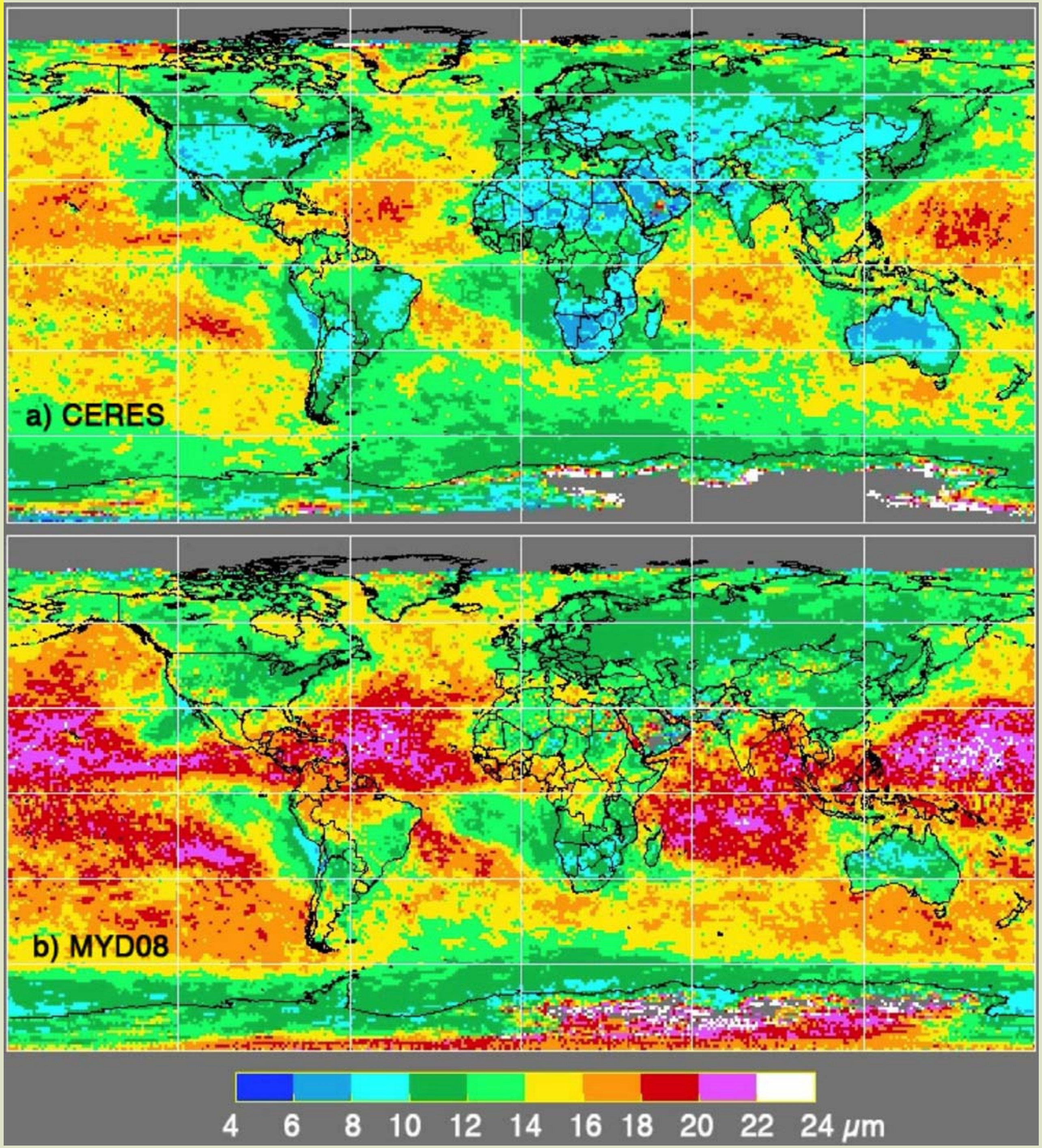
	Global		Non Polar		Polar	
CERES-MAST	Terra	Aqua	Terra	Aqua	Terra	Aqua
τ, (ice)	-4.0	-4.6	-2.7	-3.1	-12.8	-14.3

Mean Daytime Liquid Water Effective Radius

Aqua MODIS Oct. 2003

CERES-MAST r_e (μm)

	Terra	Aqua
Global	-2.5	-2.0
Non-polar	-2.9	-2.4
Polar	-0.1	0.1



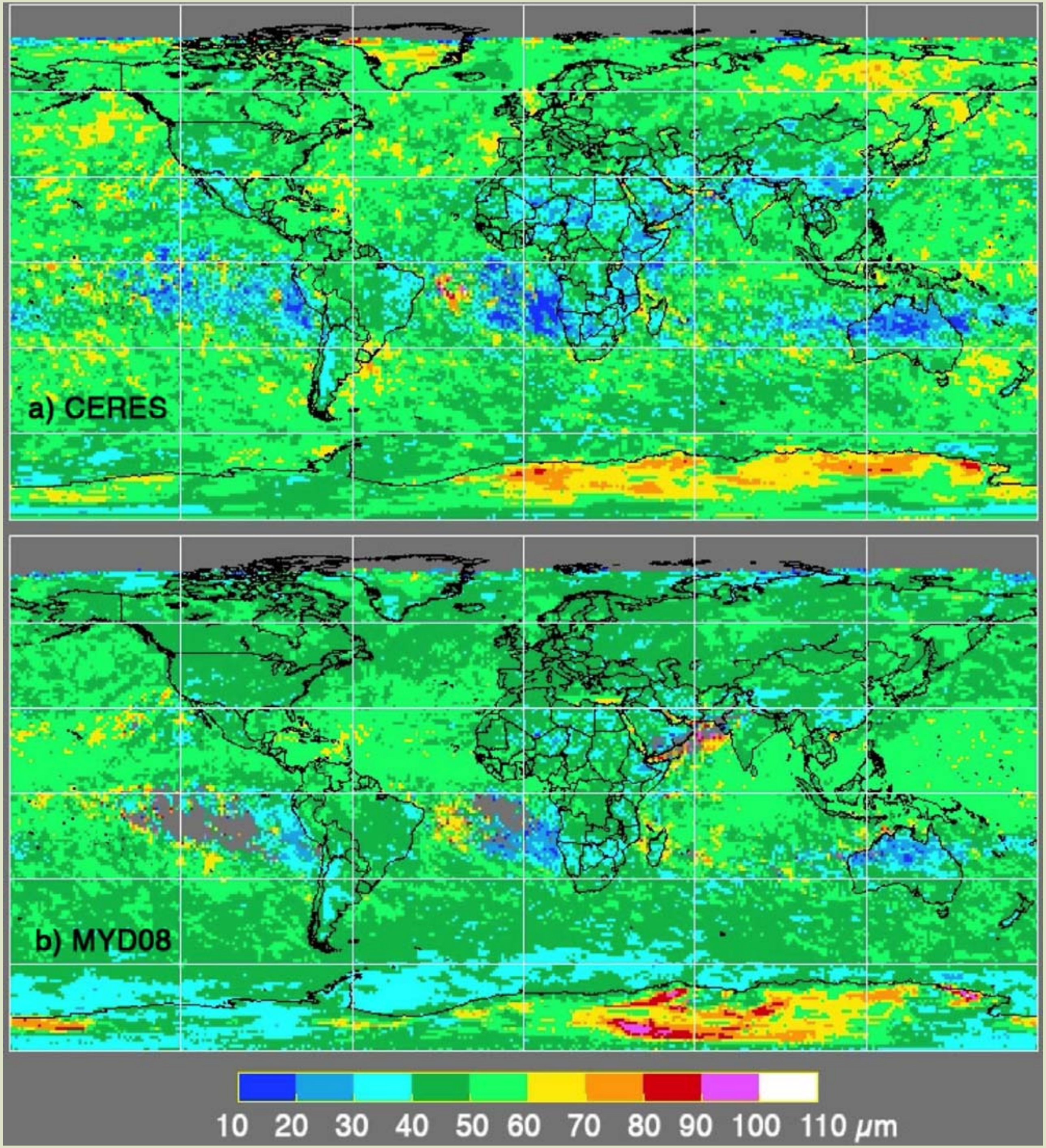
Mean Daytime Ice Crystal Effective Diameter

Aqua MODIS Oct 2003

CERES-MAST D_e (μm)

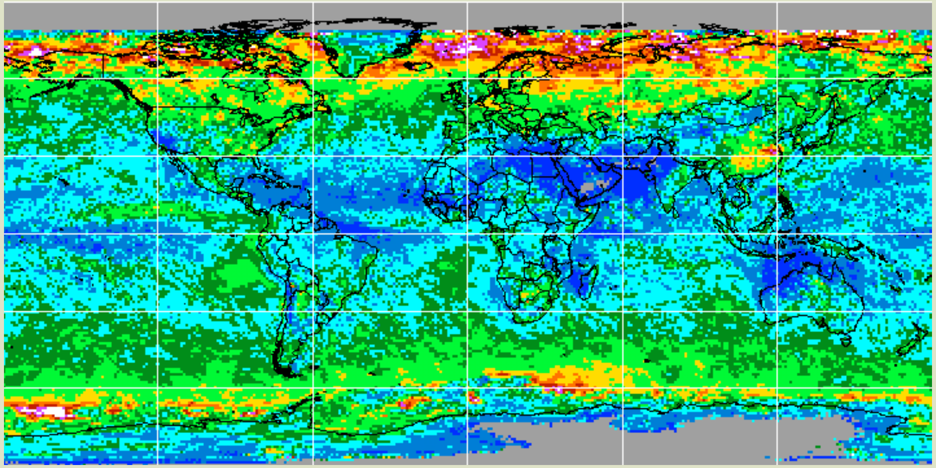
	Terra	Aqua
Global	1.6	0.2
Non-polar	1.0	-0.1
Polar	5.5	2.0

Note:
MAST R_e x 2 ~ D_e

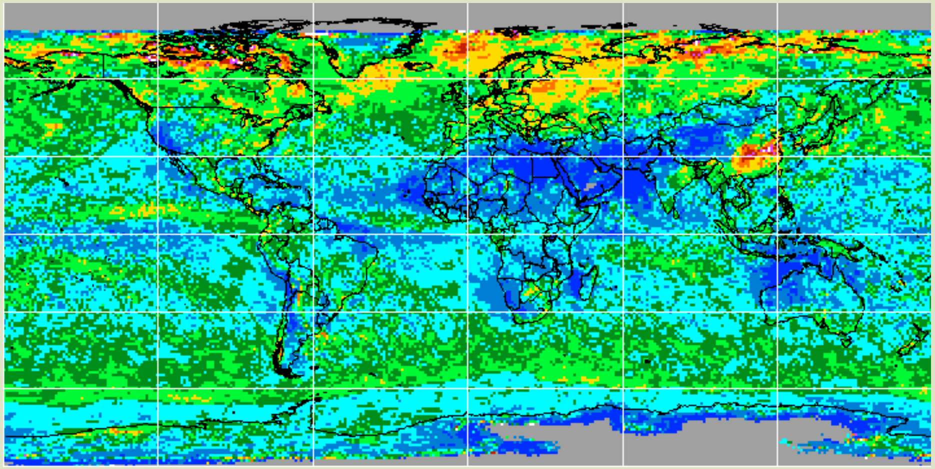


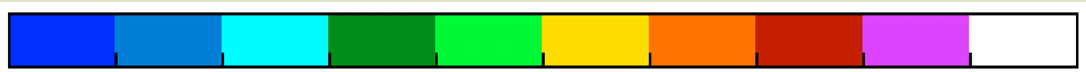
Mean Daytime Liquid Water Path

Terra Ed2

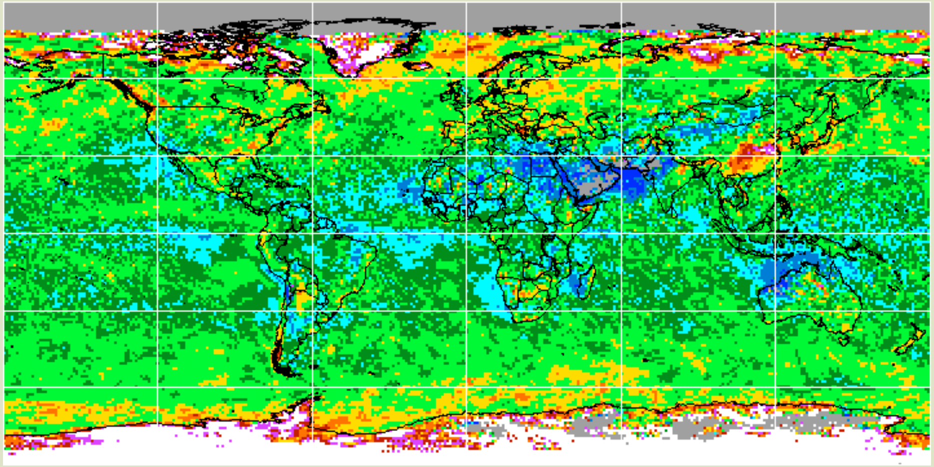


Aqua Ed2

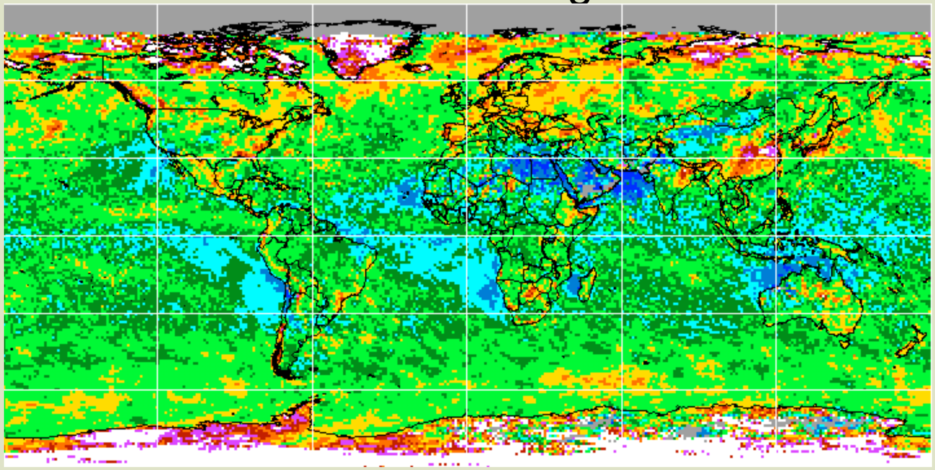




MOD08

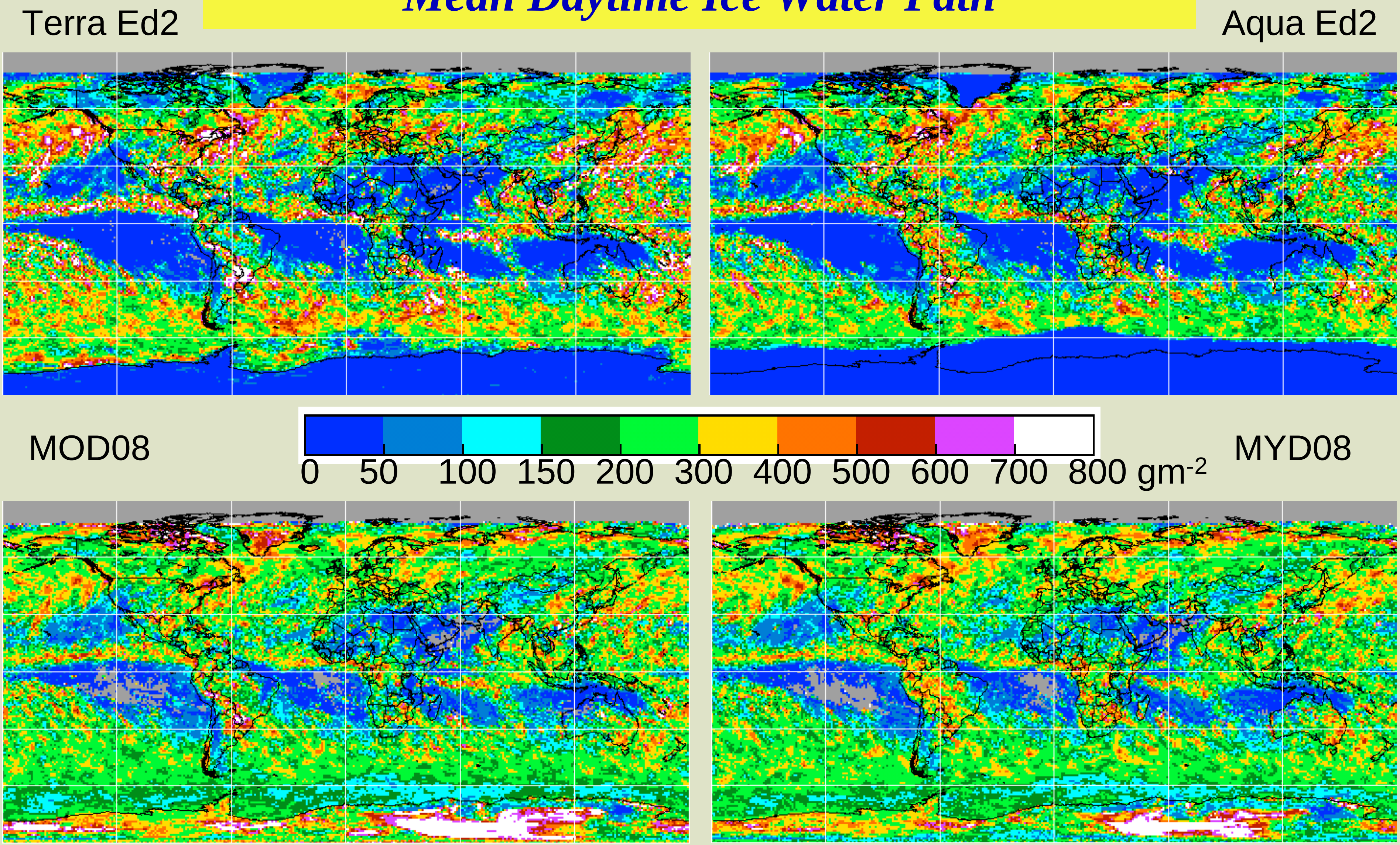


MYD08



gm^{-2} CERES-MAST LWP, (liquid)	Global Terra	Global Aqua	Non Polar Terra	Non Polar Aqua	Polar Terra	Polar Aqua
	-31.7	-44.3	-24.4	-34.9	-79.0	-104.8

Mean Daytime Ice Water Path



gm^{-2}	Global		Non Polar		Polar	
CERES-MAST IWP, (Ice)	Terra	Aqua	Terra	Aqua	Terra	Aqua
	-3.3	-26.3	18.2	-2.9	-142.1	-177.3

CERES Ed2 and MAST Retrieval Summary

• CERES Ed2 and MAST τ have similar patterns, except CERES < MAST due to different approach, ancillary data and some missing thin clouds in MODIS MAST retrievals. (E.g., max τ value for CERES Ed2 is 128; MAST is 150.)

• CERES Ed2 and MAST r_e have similar patterns, except CERES < MAST because CERES uses 3.8 µm and MAST uses 2.1 µm retrieval. Some phase identification differences affects bias. Difference in D_e between both products mainly due to different ice crystal models & channel differences.

• LWP and IWP based on products of optical depth and particle size so differences in τ, r_e and D_e transfer into LWP and IWP.

• 0.65 µm and 3.8 µm calibration differences between Aqua & Terra introduce the smaller biases between Aqua & Terra results.

• Use of 1.62 µm atmospheric absorption values for Aqua 2.13 µm over snow/ice creates additional discrepancies in polar regions between Terra & Aqua results.

Comparison Using GEWEX datasets

MODIS_CE-AQU: 0130PM 2002-2007

MODIS_CE-TER: 1030AM 2000-2007

MODIS_ST-AQU: 0130PM 2003-2009

MODIS_ST-TER: 1030AM 2001-2009

ISCCP_D1: AMPM 1984-2007

MODIS_CEEd3-TER: 1030AM 200401, 200404, 200407, 200410

Converted De to Re for MODIS_CE:

$$Re = (7.918*1.0e-9*De^2 + 1.0013*1.0e-3*De + 0.4441)*De$$

CERES Ed3-Beta2 improvement

• Terra 3.8 μm calibration changed. More cumulus clouds & thin cirrus detected

- mean tau decreases, r_e increases.

• ozone optical depth was overestimated by 13.3% in Ed2

- tau decreases, most for high SZA, Re increase

• set maximum tau to 150.(Ed2 -128)

- avg tau increases

• surface reflectance decreased over ocean

- tau increases for thin clouds, r_e decreases

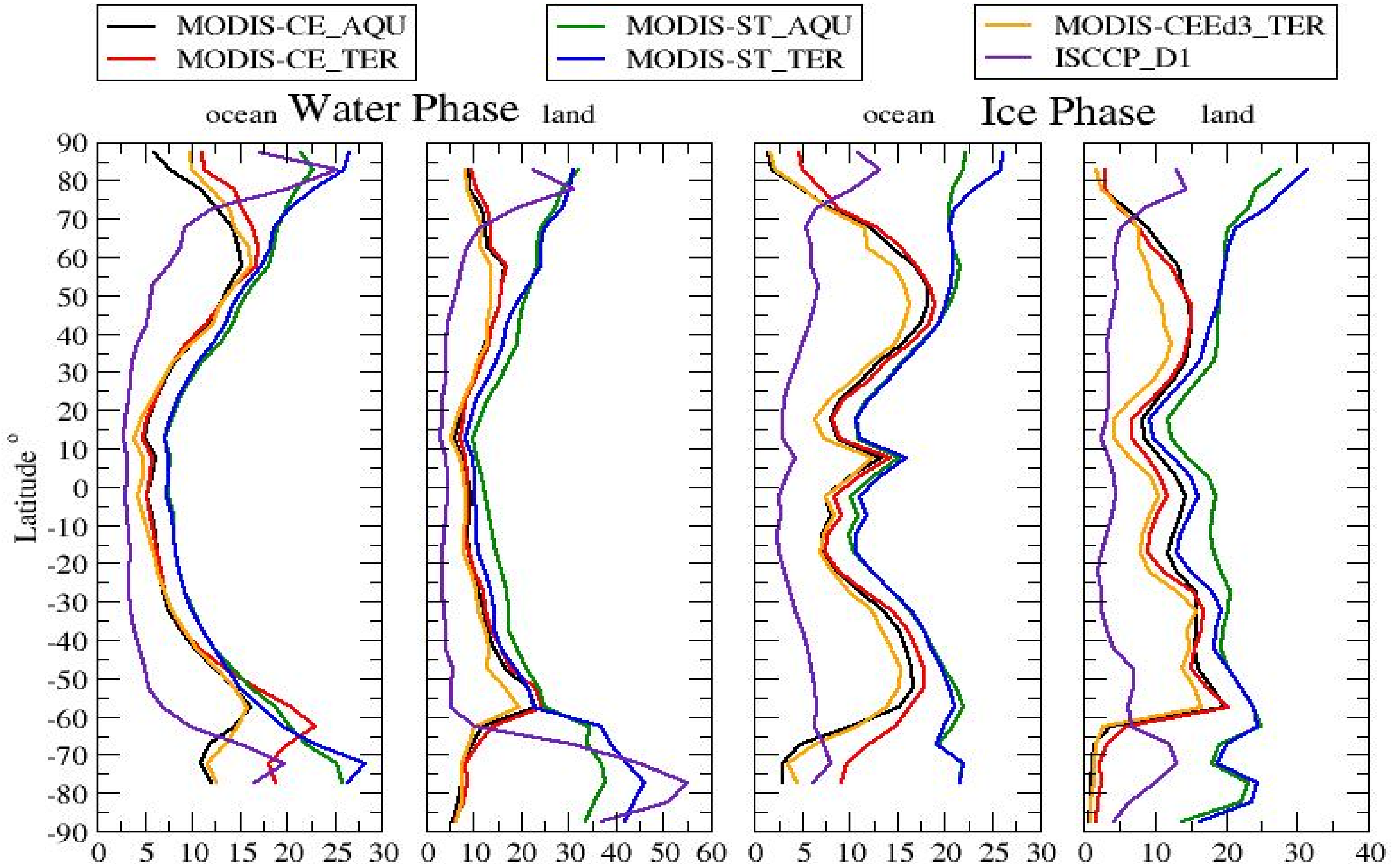
• 2.13 μm used over snow surfaces

- Saturates at $\tau < 16$ often, less for ice clouds, Re increases

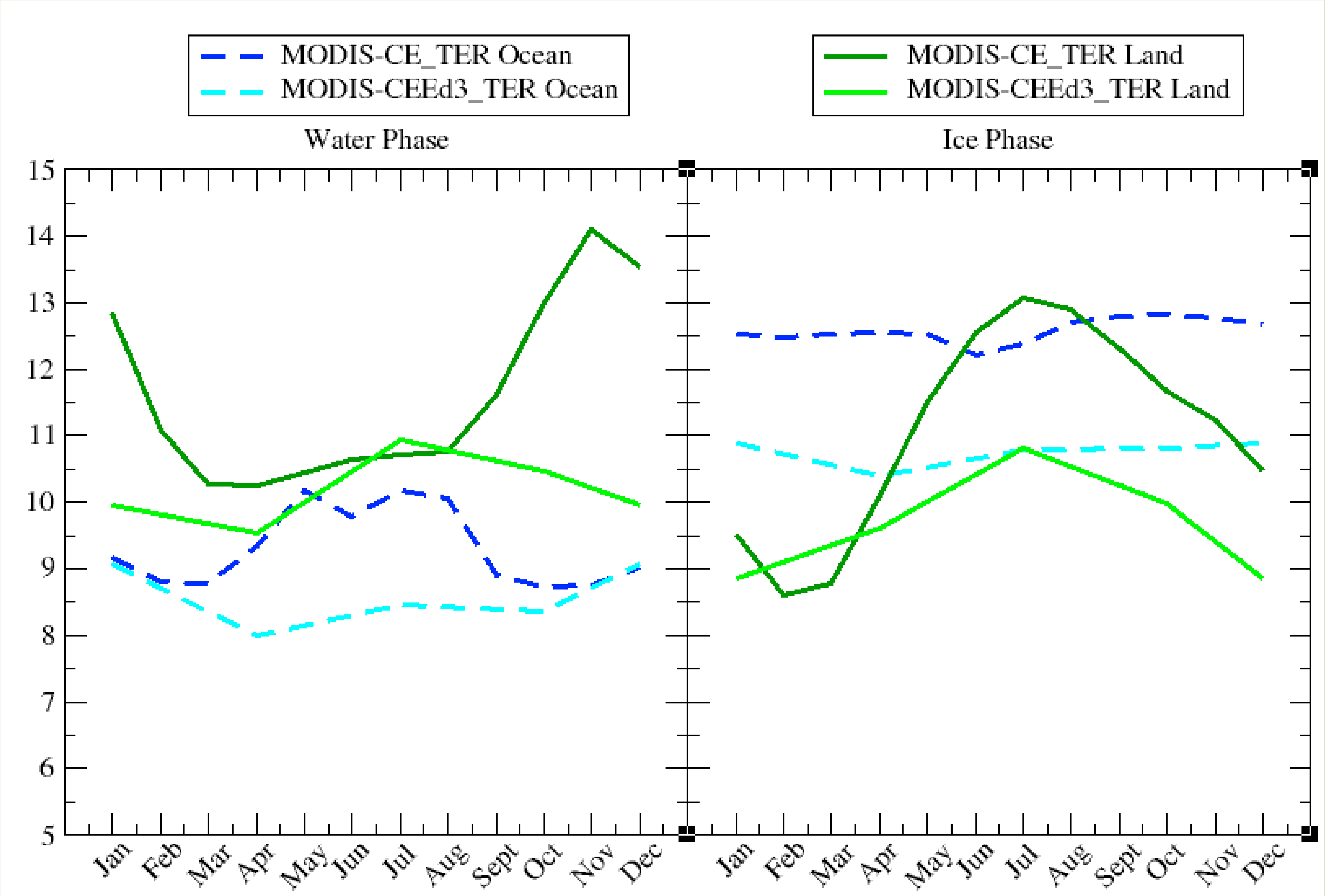
• false thin clouds thrown out in polar transition

- avg tau increases

Zonal Mean Daytime Optical Depth

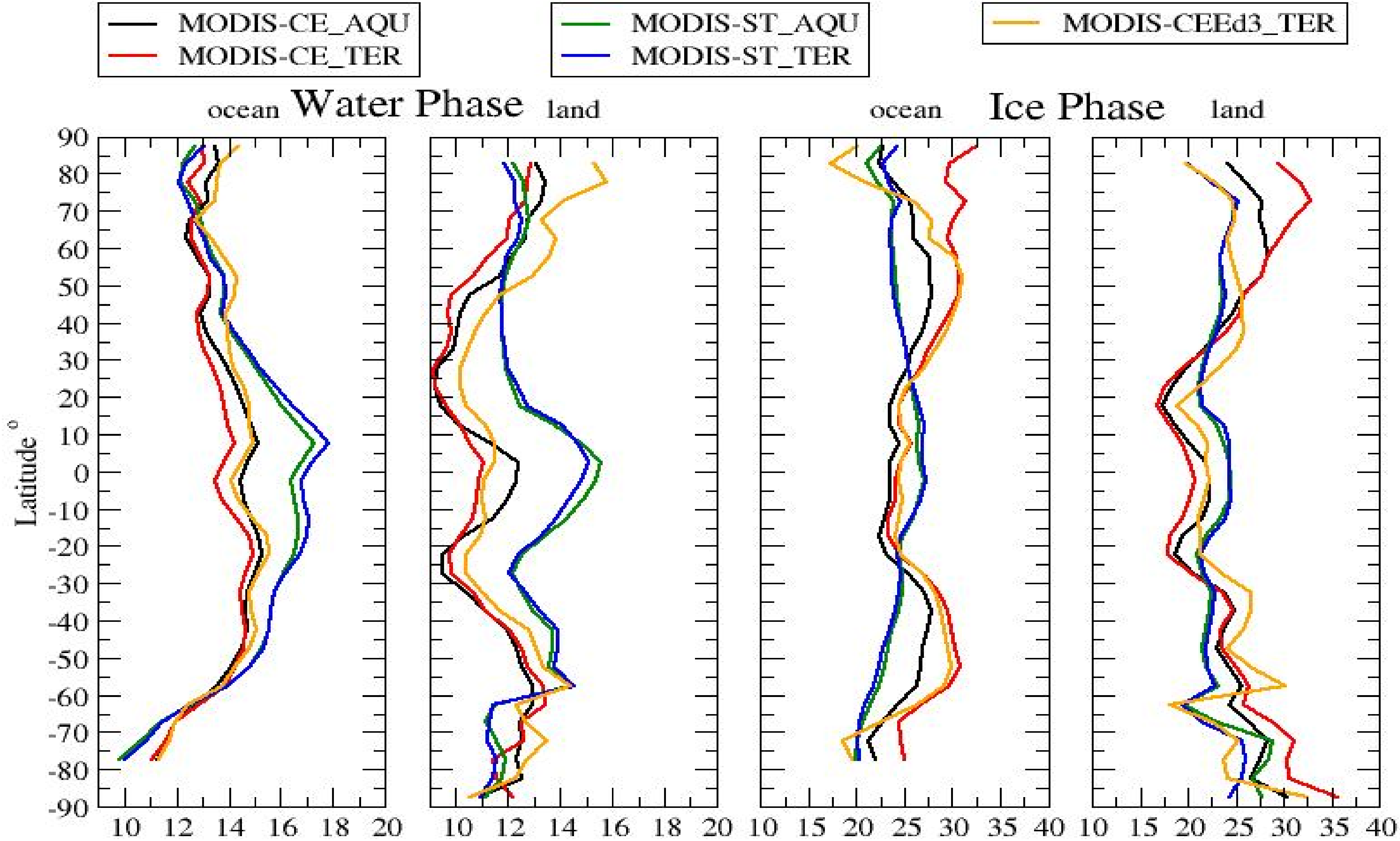


Daytime Cloud Optical Depth Annual Variation

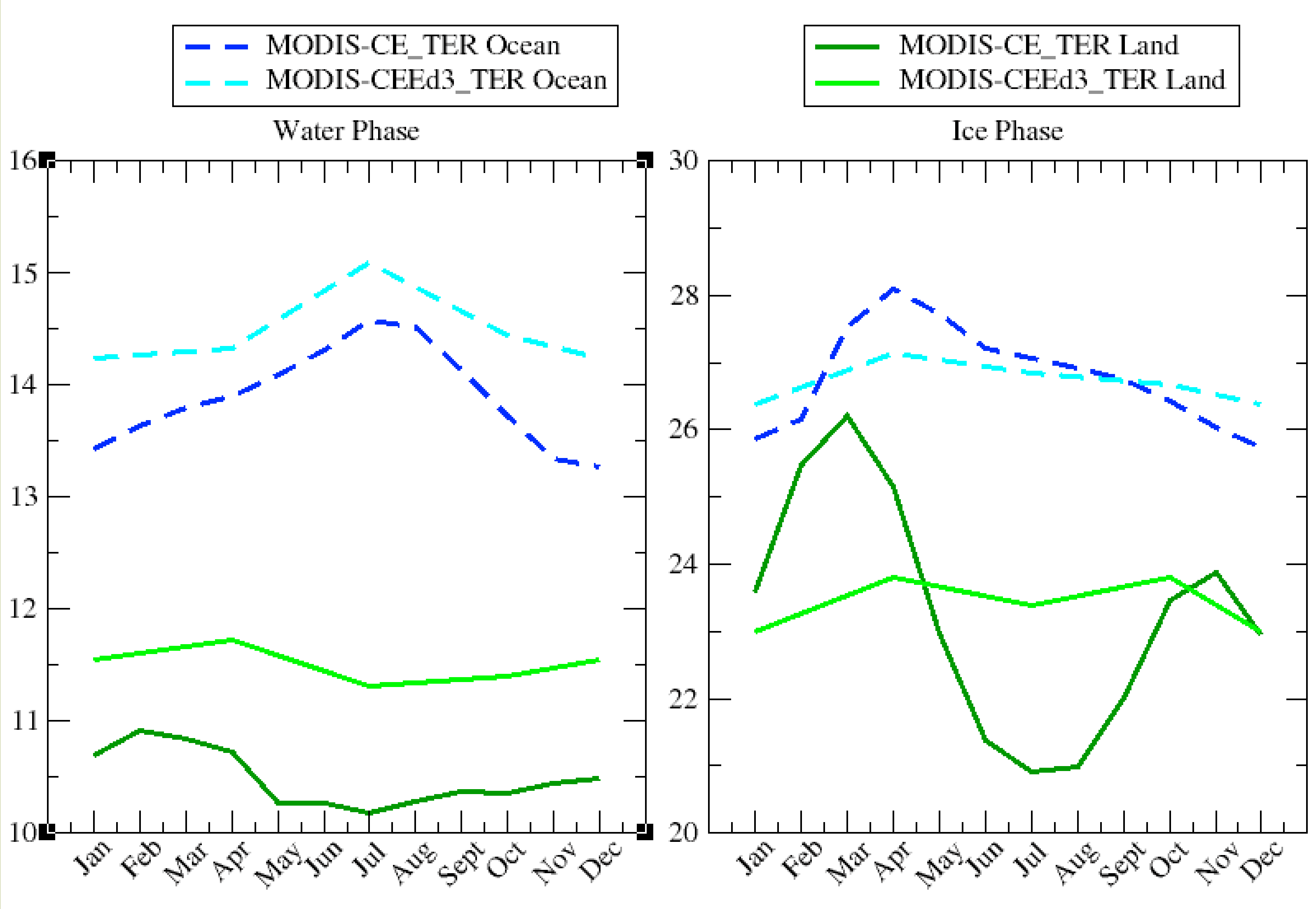


tau values decrease from Ed2 to Ed3

Zonal Mean Daytime Particle Size (μm)



Daytime Cloud Particle Size (μm) Annual Variation



r_e values increase from Ed2 to Ed3

Summary & Future Work

- CERES τ , r_e, and WP generally in good agreement with surface
  - slight overestimate from Aqua stratus (calibration effects)
  - slight tau overestimate during day for thin cirrus (impacts height)
  - IWP overestimated in ML clouds
  - Aqua tau retrievals over snow underestimated
- CERES Edition 3
  - variable ice xtal model (rough, bubble, smooth)
  - retrieval of r_e for 1.6, 2.1 µm plus 3.8 µm
  - fix 2.1-µm atmos corrections; use 1.24 µm cloud model over snow
  - ML retrievals for thin ice over water clouds
    - Chang & Li technique (CO2 + VISST)
  - other changes

References

CERES Edition-2 cloud property retrievals using TRMM VIRS and Terra and Aqua MODIS data, Part I: Algorithms

Submitted to IEEE Transactions on Geoscience and Remote Sensing, Dec. 2009

http://www-pm.larc.nasa.gov/ceres/pub/journals/CERES.Retrieval.TGARS.09.1o.pdf

CERES Edition-2 cloud property retrievals using TRMM VIRS and Terra and Aqua MODIS data, Part II: Examples of average results and comparisons with other data

Submitted to IEEE Transactions on Geoscience and Remote Sensing, Feb. 2010

http://www-pm.larc.nasa.gov/ceres/pub/journals/CERES.Retrieval.TGARS.10.2.pdf