CERES Cloud Properties: MODIS, VIIRS, GEOsats

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Joint CERES GERB ScaRaB Science Mtg., ***Toulouse, France, 7-10 October 2014***

Topics

- **Publications**
- **Terra/Aqua** Ed4, comparisons with NPP Ed1, Feb 2012
- **Validations**
- **GEO clouds**

Update of CERES Cloud-related Papers since May 2014

Edition-2 related

Stanfield, R. E., X. Dong, B. Xi, A. Kennedy, A. D. Del Genio, P. Minnis, and J. Jiang, 2014: Assessment of NASA GISS CMIP5 and post-CMIP5 simulated clouds and TOA radiation budgets using satellite observations. Part I: Cloud fraction and properties. *J. Climate*, **27**, 4189-4208, doi: 10.1175/JCLI-D-13-00558.1.

Hamann, U., A. Walther, L. Bugliaro, M. Derrien, P. Francis, A. Heidinger, H. Le Gleau, M. Lockoff, H. J. Lutz, P. Minnis, R. Palikonda, R. Preusker, J. Sauli, M. Stengel, S. Platnick, P. Watts, G. Wind, B. Baum, R. Bennartz, R. Roebeling, A. Thoss, and J. F. Meirink, 2014: Remote sensing of cloud top height from SEVIRI: Analysis of eleven current retrieval algorithms. *Atmos. Meas. Tech.*, **7**, 2839-2867, doi:10.5194/amt-7-2839-2014.

Yan, H., J. Huang, P. Minnis, Y. Yi, S. Sun-Mack, T. Wang, and T. Nakajima, 2014: Comparison of CERES-MODIS cloud microphysical properties with surface observations over the Loess Plateau. *J. Quant. Spectros Rad. Trans.*, in press.

Stanfield, R. E., X. Dong, B. Xi, A. D. Del Genio, P. Minnis, and J. Jiang, 2014: Assessment of NASA GISS CMIP5 and post-CMIP5 simulated clouds and TOA radiation budgets using satellite observations. Part II: TOA radiation budget and CREs. *J. Climate*, submitted.

Edition-4+ related

Xi, B., X. Dong, P. Minnis, and S. Sun-Mack, 2014: Validation of CERES-MODIS Edition 4 marine boundary layer cloud properties using DOE ARM AMF measurements at the Azores. *J. Geophys. Res.*, **119**, doi:10.1002/2014JD021813.

Painemal, D., S. Kato, and P. Minnis, 2014: Biomass burning and the dual microphysical behavior of boundary layer clouds in the southeast Atlantic. *J. Geophys. Res.*, **119**, doi:10.1002/2014JD022182, in press.

Liu, C., P. Yang, P. Minnis, N. Loeb, A. Heymsfield, C. Schmitt, 2014: A two-habit model for the microphysical and optical properties of ice clouds. *Atmos. Chem. Phys.*, submitted.

CERES Cloud Products*

Standard, Single-Layer VISST/SIST

	Cloud
0.65, 1.2, 1.6, 2.1 µm Reflectances	
3.7, 6.7, 10.8 µm Temp	**Mask, Phase**
12 or 13.3 µm Temp	**Optical Depth**, **IR emissivity**
Broadband Albedo	**Droplet/Xtal effective radius**
Broadband OLR	Liquid/Ice Water Path
Clear-sky Skin Temperature	**Effective Temp**, height, pressure
Icing Potential	Top/ Bottom Pressure
Pixel Lat, Lon	Top/ Bottom Height
Pixel SZA, VZA, RAZ	**Overshooting top (OT)**

Multi-Layer, CIRT, CO_2 channel only (BTD11-12 for VIIRS)

Upper & lower cloud

Multilayer ID (single or 2-layer)	
effective temperature	optical depth, thickness
effective particle size	ice or liquid water path
height, top/base height	pressure

Minnis et al., SPIE 2008; TGRS 2011)

* Available parameters depend on sensor complement

CERES or CERES-like Cloud Retrievals

Editions and Projected/Actual Periods of Record

- **TRMM VIRS:** Ed2; 1/98 – 8/98, 3/00
- **Terra MODIS:** Ed2, Ed4; 1/00 – present
- **Aqua MODIS:** Ed2, Ed4; 6/02 – present
- **SNPP VIIRS:** Ed1; 11/11 – present
- **GEOSats (4-5):** 1/00 – present
- **AVHRR:** 1978 – present (NOAA-funded CDR)

CERES MODIS Status (Coll 5 Data)

- Ed2 processing
  - *Aqua: through July 2014, will continue until ED4 ADMs completed*
  - *Terra: through July 2014, will continue until Ed4 ADMs completed*

- Ed4 Beta-2 processing
  - *Aqua: through September 2007*
  - *Terra: through September 2007*

CERES VIIRS Status

- Ed1 delivered, processing begins when all operational bugs eliminated
  - *February 2012; January, April, July 2013 run offline*

CERES GEOSat Status

- Ed4: uses 3/4 channel cloud retrievals with appropriate satellites
  - *Final testing complete by November 2014*

MODIS Edition-4 beta 2 Cautions

- Error in model look-up tables discovered
  - *mismatch between 0.65 and 3.8-µm optical depths*
    - *affects particle size and phase selection primarily*
      - *impacts ADM selection => fluxes*

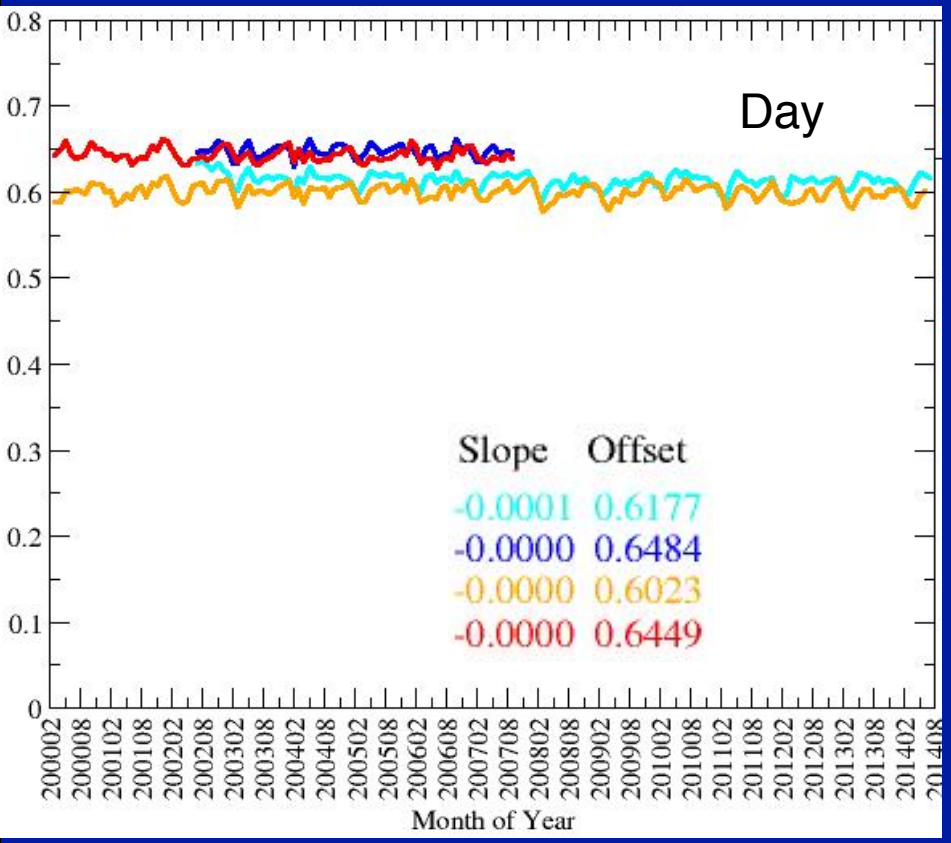
- Thick ice cloud-top height correction not applied
  - *affects cloud base and is inconsistent with VIIRS Ed1*
    - *can be applied externally post facto, simple equation*

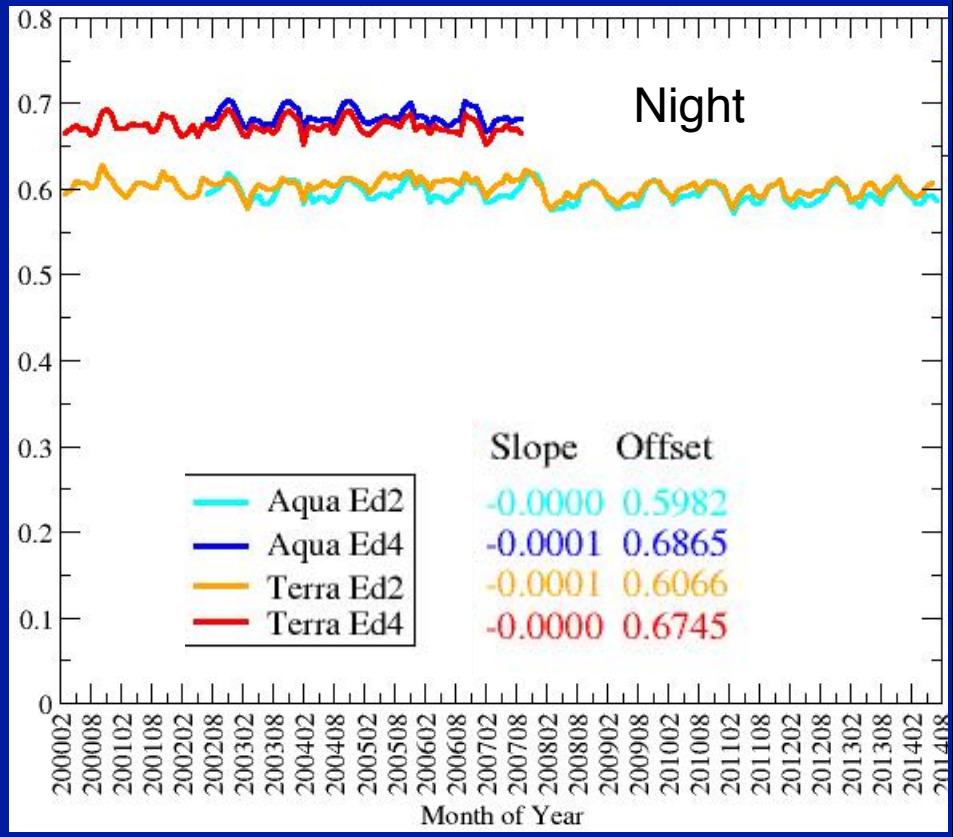
- *CO2 thin ice cloud height correction to Zeff may OE radiative height*
  - *yields more accurate Ztop but underestimate OLR wrt CERES*
  - *Convinced SARB to use Zeff as before => better agreement w/ CERES*
  - *CO2 not used in GEOSat now, 2-channel SIST or VISST only used*

- Error in parameterization of 1.24 and 2.13 µm reflectances
  - *minor affect on Re retrievals and tau over ice/snow*

- *Possible errors in 1.24 and 2.13 µm reflectance models*
  - *possible significant effect on Re retrievals & tau over ice/snow*
  - *differences with VIIRS shown*

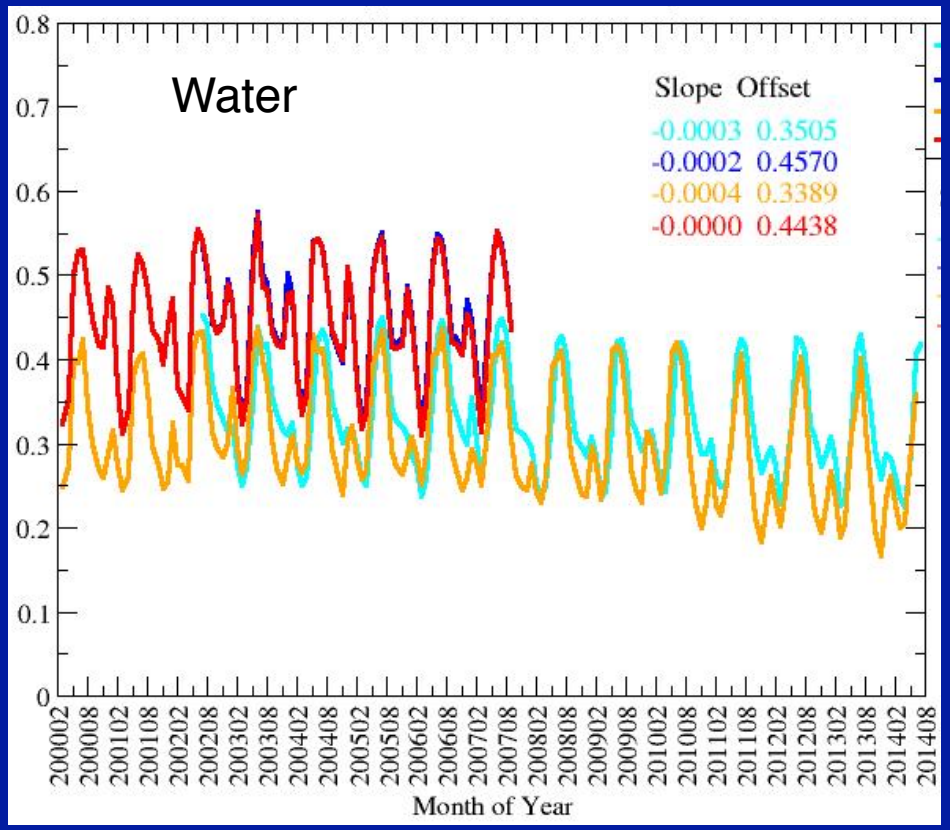
Cloud Fraction, Global From CERES MODIS Retrievals 2000 - 2014

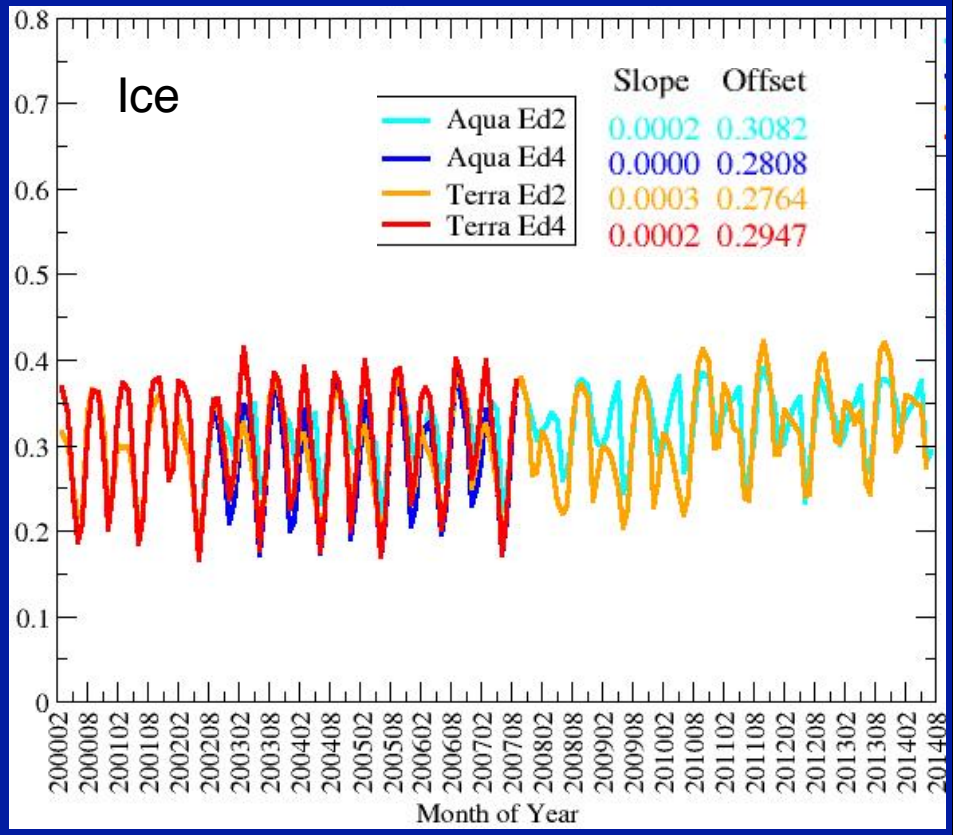




- No trends seen in cloud fraction in either Edition
  - closer agreement between Ed4 Terra & Aqua
- Ed4 night CF = day CF + 0.034
- Additional Ed4 data may change the trend lines

Polar Cloud Fractions From CERES MODIS Retrieval: 2000 - 2014

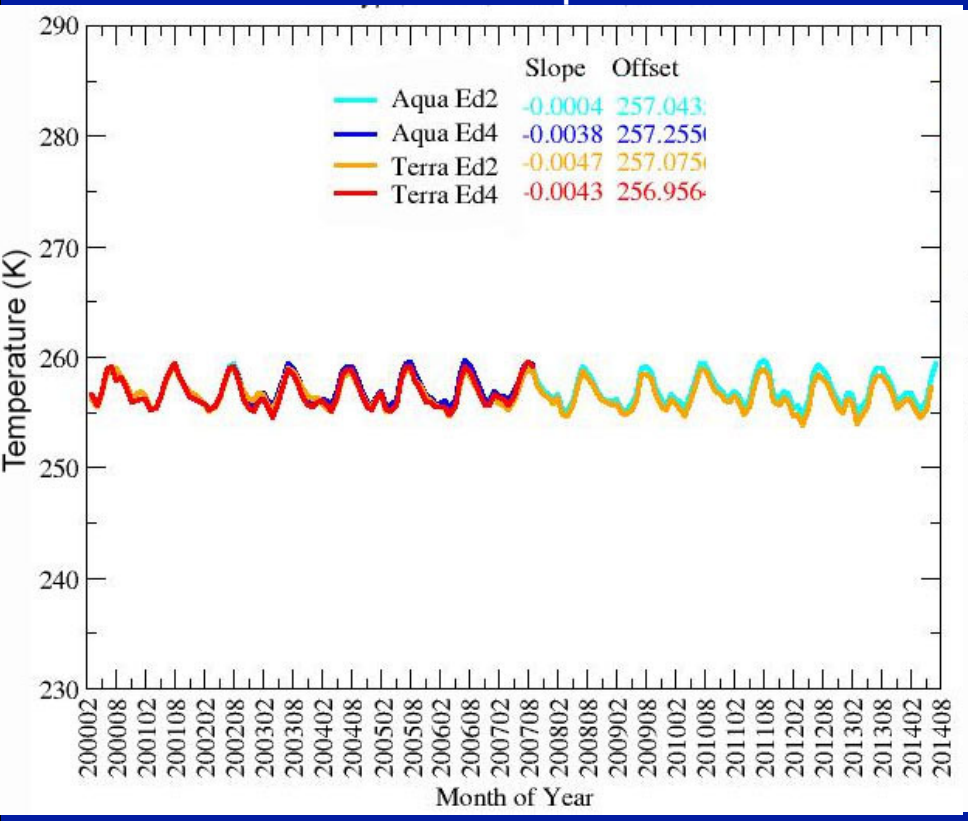




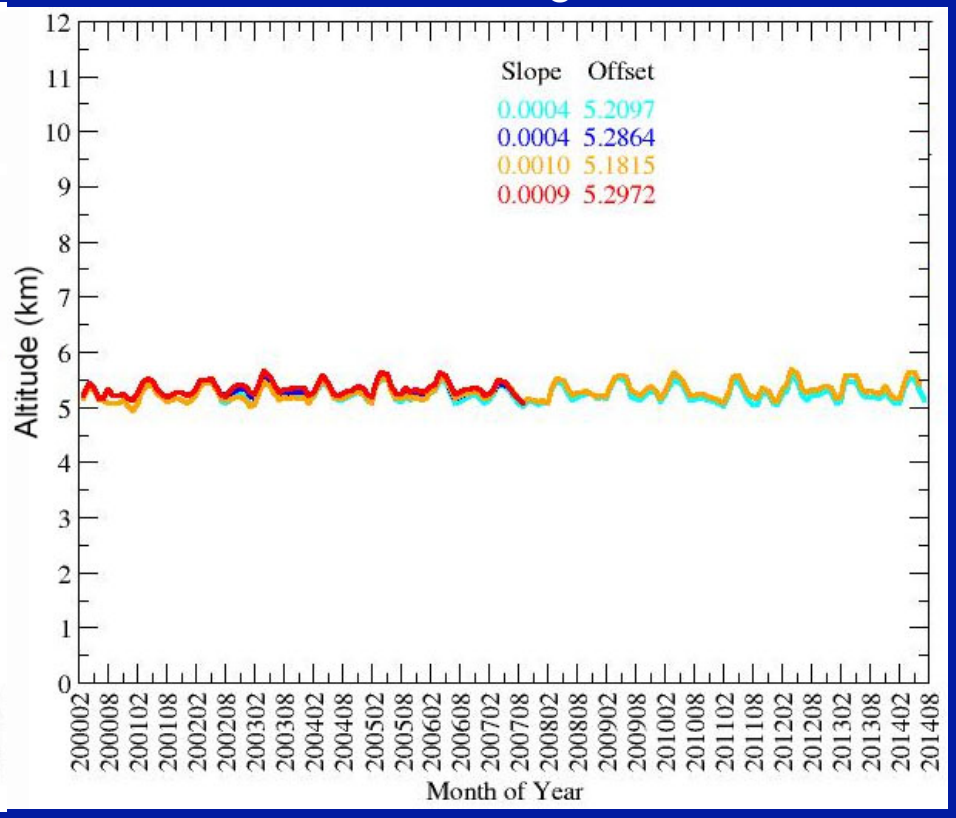
- Ed2 decreases in ice cloud fraction compensated by increases in water cloud fraction
- Terra & Aqua Ed4 very consistent
  - Ed2 Aqua > Terra

Cloud Temperature/Height From CERES MODIS Retrieval: 2000 - 2014
Global all phase, day & night

Effective Temperature



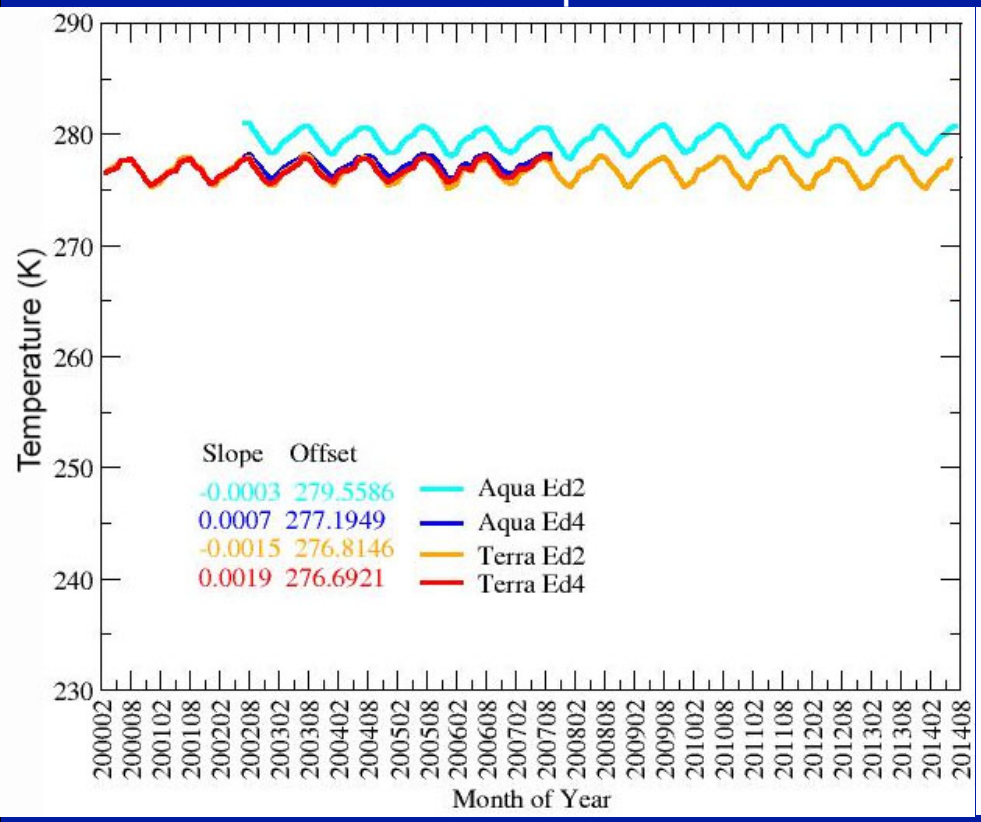
Effective Height



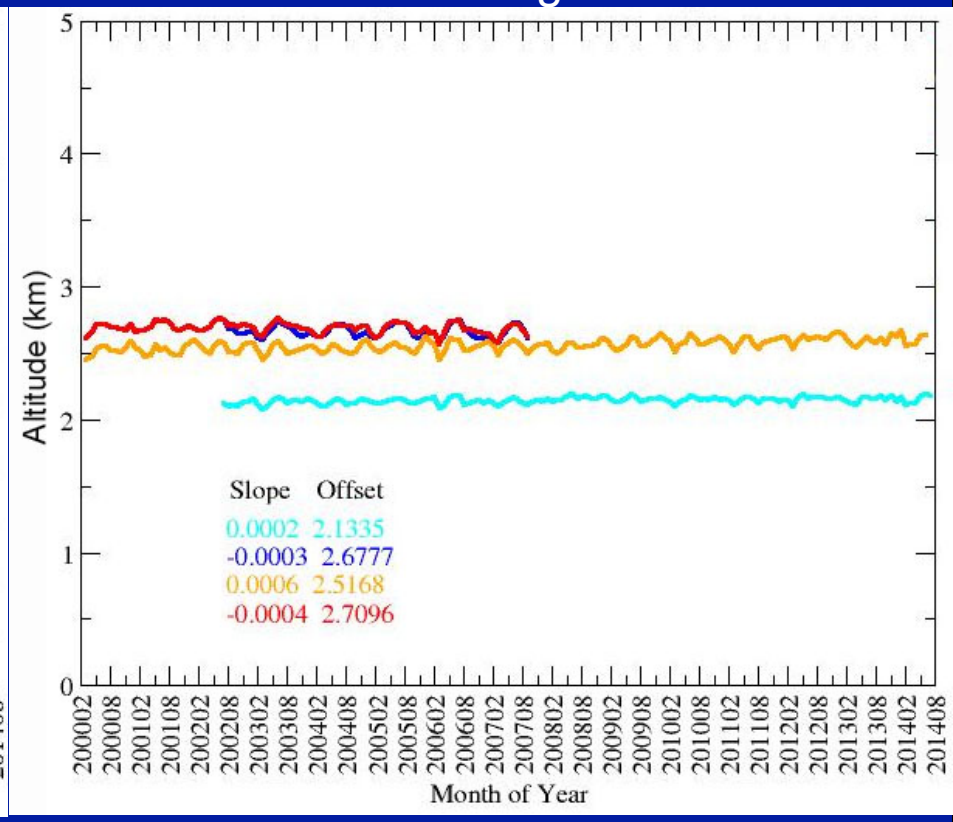
- Overall, Teff appears to be decreasing at ~0.5 K / decade
- Zeff follows: increasing at ~0.09 km / decade
- Preliminary results! Need to verify calibrations, Collection 6 temps?
  - Are they statistically significant?

Cloud Temperature/Height From CERES MODIS: 2000 – 2014
Non-polar liquid phase only, day & night

Effective Temperature



Effective Height



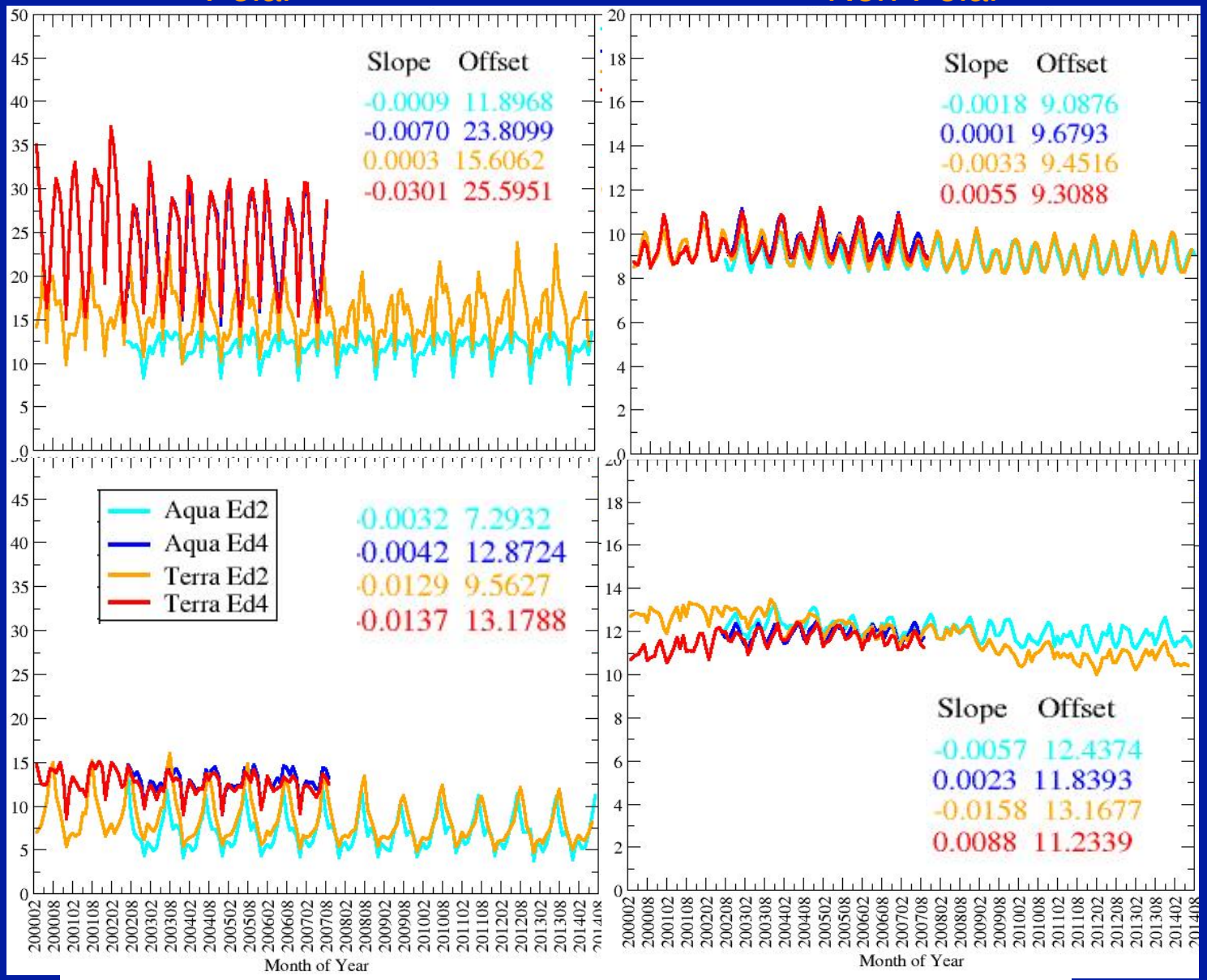
- Teff trends: Ed2, -0.10 K / decade; Ed4, +0.15 K/ decade
- Zeff trends: Ed2: +0.04 km / decade; Ed4, -0.05 km / decade
- Ed4 Terra & Aqua very consistent
  - using same phase logic now

Cloud Optical Depth, Global From CERES MODIS Retrievals: 2000 - 2014

Polar | Non-Polar

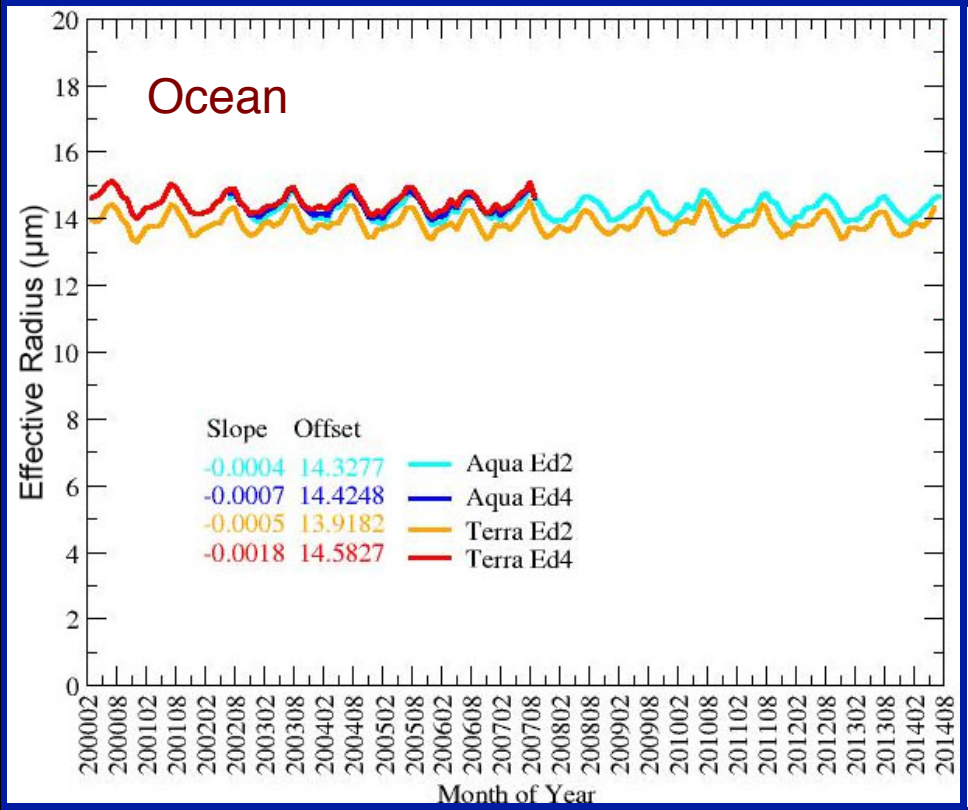
Water

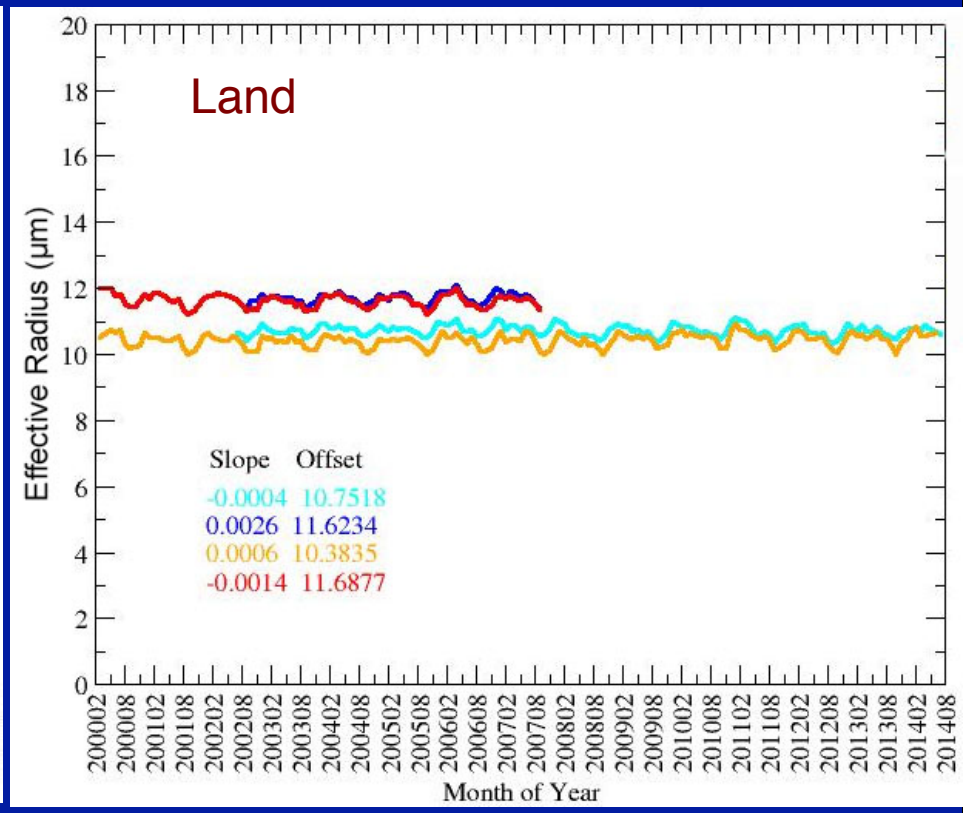
Ice



- Terra Ed2 COD decrease due to calibration, Aqua?

Cloud Droplet Effective Radius From CERES MODIS: 2000 – 2014
Non-polar, day, liquid





- Ed4 Terra & Aqua very consistent, Ed4 0.1 – 1.2 > Ed2
  - 3.8-μm channel normalized to Aqua
- **Ocean trends:** Ed2, -0.05 μm / decade; Ed4, -0.15 μm/ decade
- **Land trends:** Ed2: +0.04 km / decade; Ed4, -0.05 km / decade

Trend Comments

- Aqua & Terra Ed4 products very consistent compared to Ed2

- Possible interesting trends
  - Are they significant?
  - Are they driven by calibrations?
    - Do we need Collection 6 data to make trend conclusions
  - Ed4 needs more years

- Details could provide more insight
  - e.g., phase, surface, and regional breakdowns

VIIRS Edition-1

- Differences from Aqua Ed4

  - no WV or CO_2 channels

  - affects polar mask, ice cloud height & ML detection/retrieval

  - 11-12 μm BTD used in place of CO_2 channel (F-L Chang)

  - not a bad replacement

- Thick ice cloud-top height correction applied

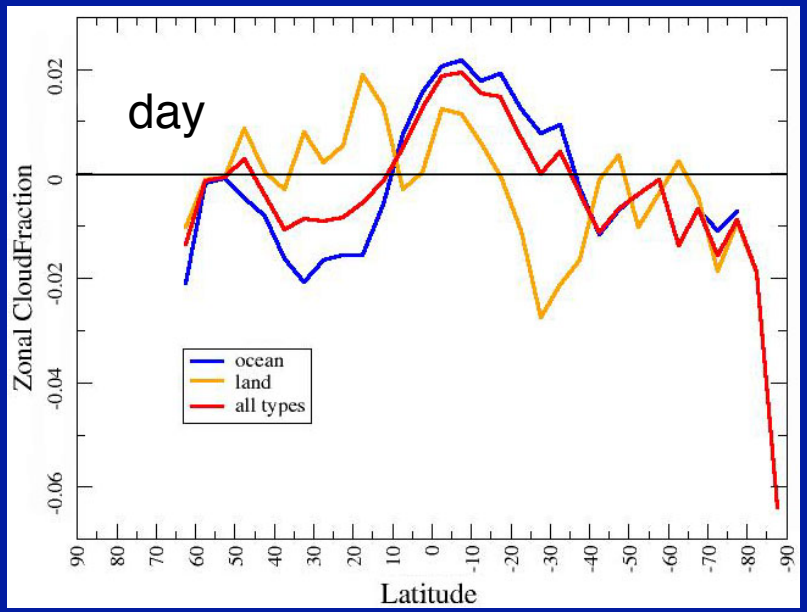
  - no need for external post facto correction

  - affects cloud base and is inconsistent with VIIRS Ed1

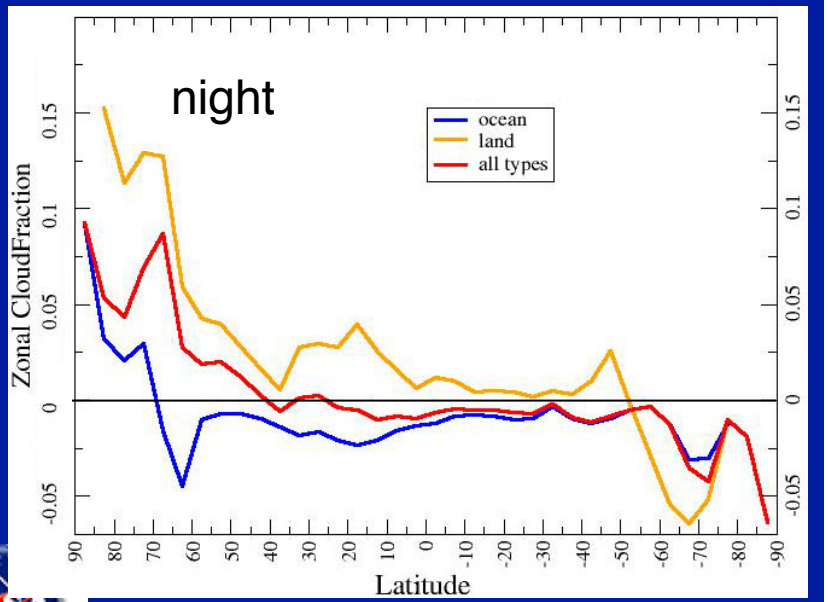
- Uses revised water droplet model

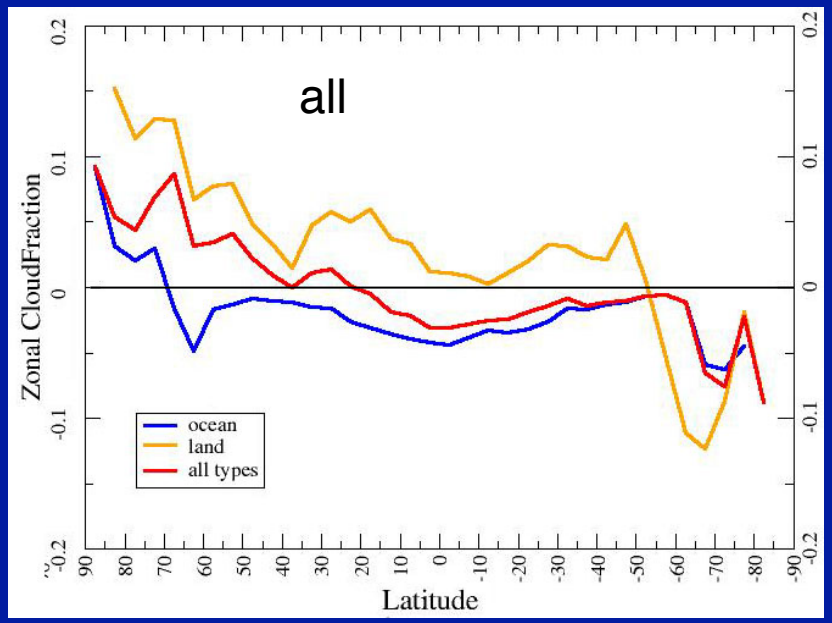
  - 3.7-μm channel has better wavelength & solcon weighting (G Hong)

Total Cloud Amount Differences, January 2012

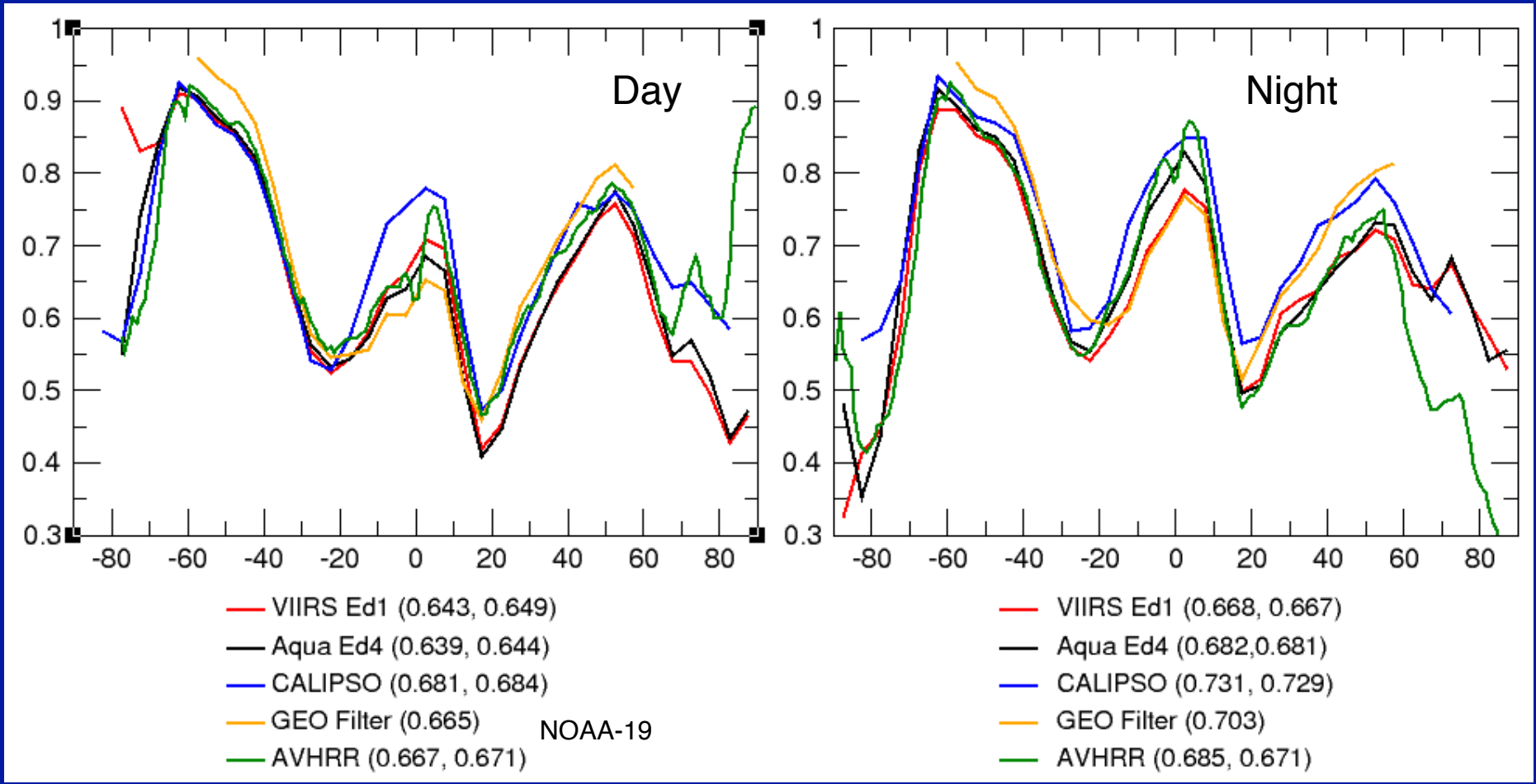


- Daytime differences mostly ±0.02
- Night differences slightly larger
  - polar regions up to 0.15
- January probably the greatest difference





Comparison of Several Cloud Fractions, April 2013



- General range < 0.10, VIIRS & Aqua close, GEO diverges in midlats
- Large difference w/ CALIOP over daytime tropics
- CERES polar day low wrt CALIOP
- NOAA-19 night low in Arctic

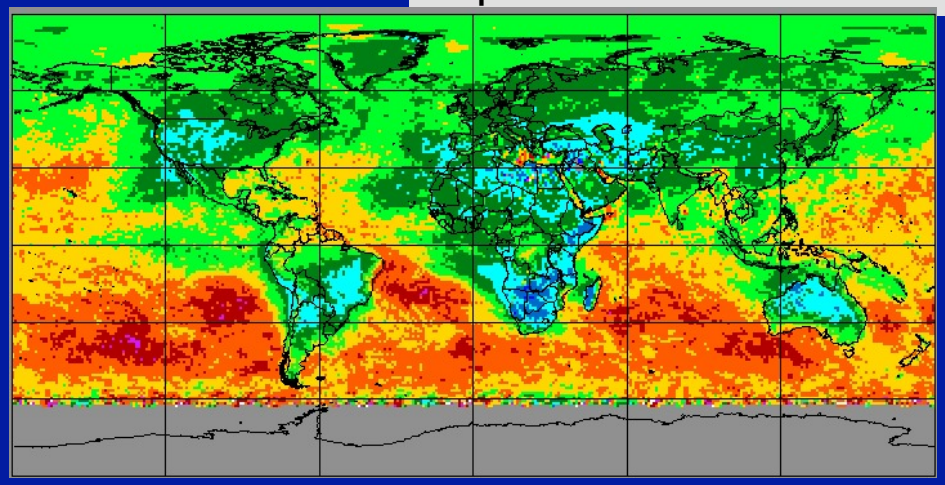
Summary of Mean Cloud Parameter Differences, July 2013
VIIRS - MODIS

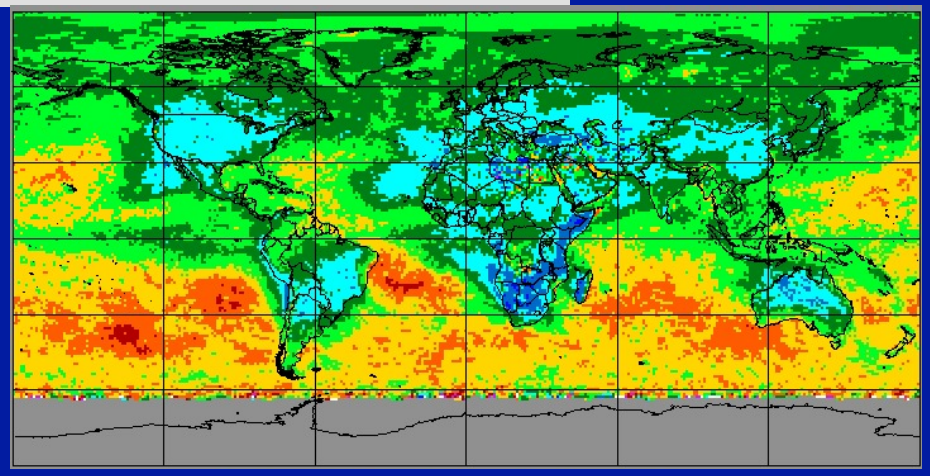
Parameter		Day			Night		
		Global	NonPolar	Polar	Global	NonPolar	Polar
CF	Water	0.000	-0.002	0.025	-0.002	-0.001	-0.008
	Ice	-0.002	-0.001	-0.008	-0.014	-0.011	-0.029
	Total	-0.001	-0.001	-0.004	-0.025	-0.012	-0.034
Zeff (km),	Water	0.15	0.15	0.19	0.08	0.07	0.10
	Ice	0.21	0.22	0.16	0.03	-0.03	0.43
	Total	0.17	0.19	0.02	-0.04	-0.10	0.36
COD,	Water	1.36	1.01	5.15			
	Ice	-0.52	-0.42	-1.64			
	Total	0.72	0.47	3.4			
Re (μm),	Water	-1.1	-1.1	-0.6			
	Ice	0.3	0.3	0.1			

- VIIRS Ed1 very consistent with MODIS Ed4 except
  - higher clouds (IR calibrations?)
  - polar night cloud fraction & day optical depths
  - smaller Re for water clouds, likely more accurate

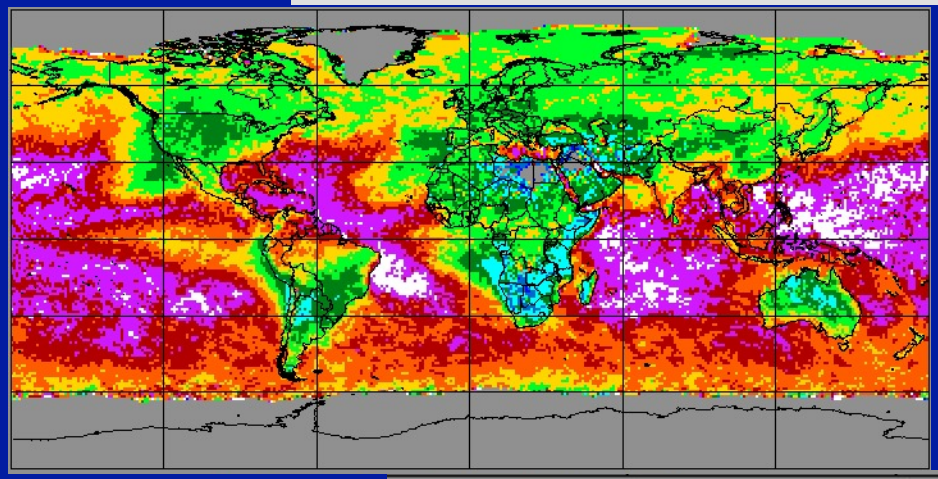
Cloud Effective Droplet Radius (μm), Day, July 2013

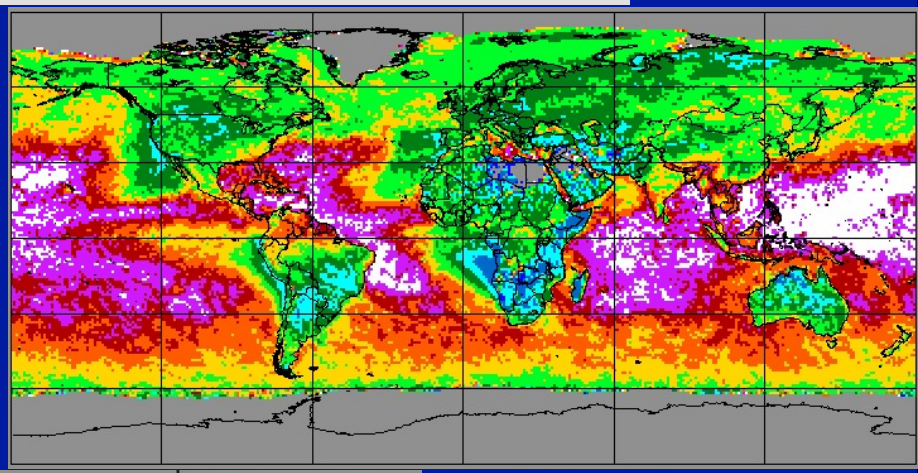
Aqua 3.8 μm VIIRS

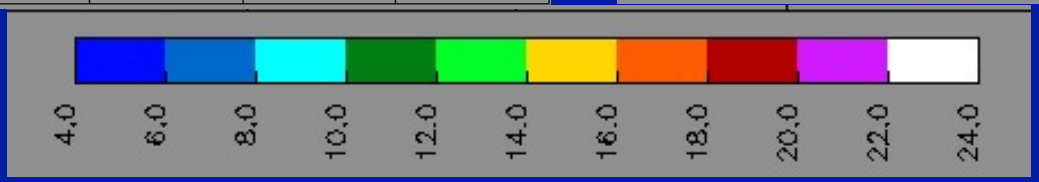




Aqua (2.1 μm) VIIRS (1.6 μm)

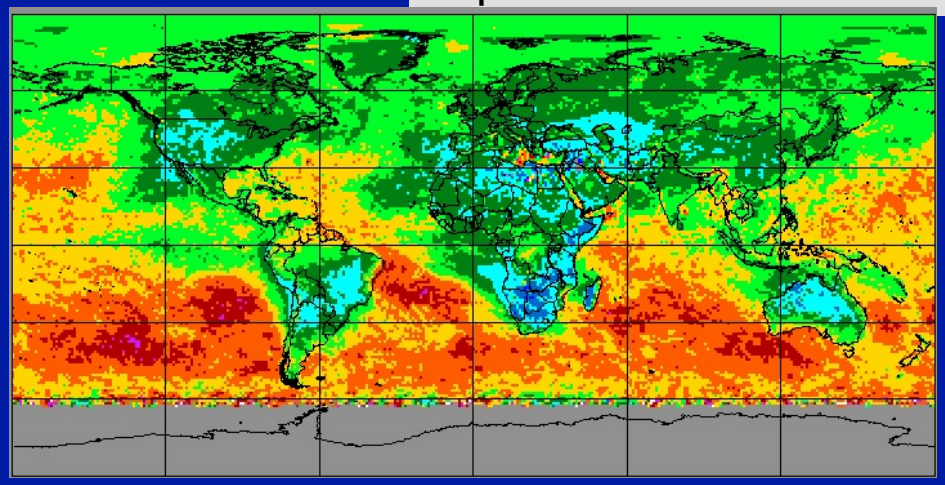


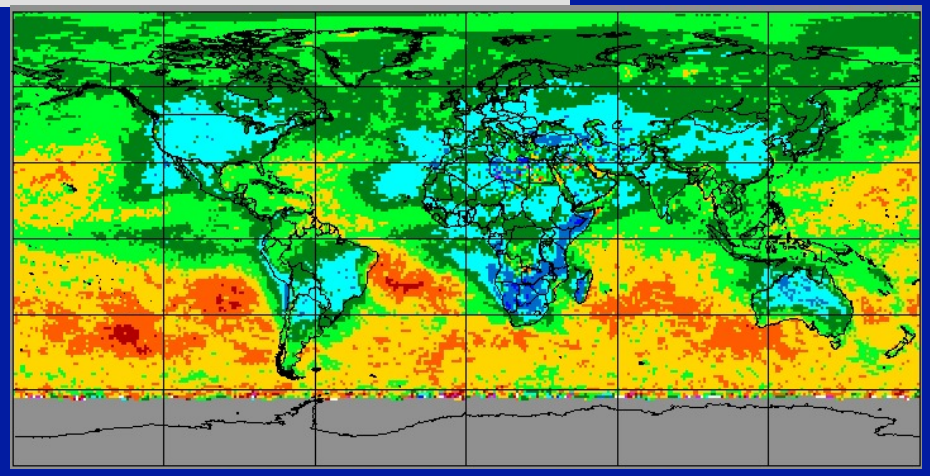




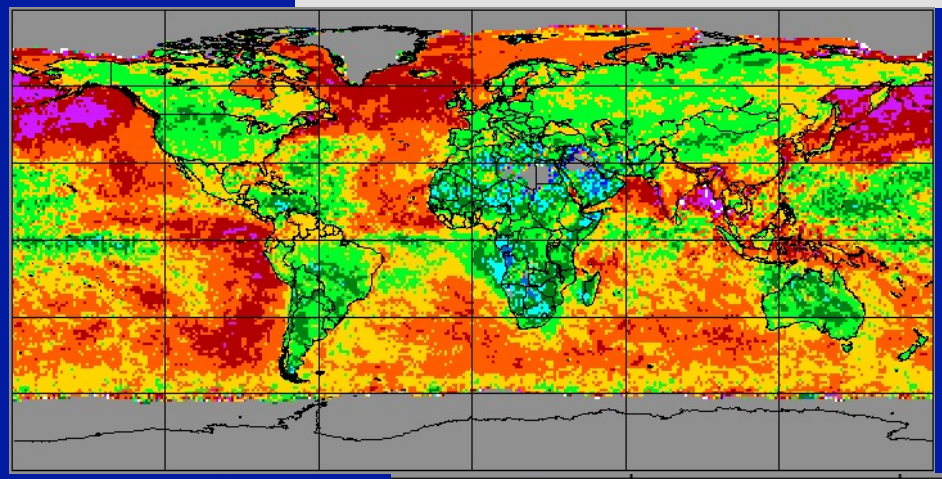
Cloud Effective Droplet Radius (μm), Day, July 2013

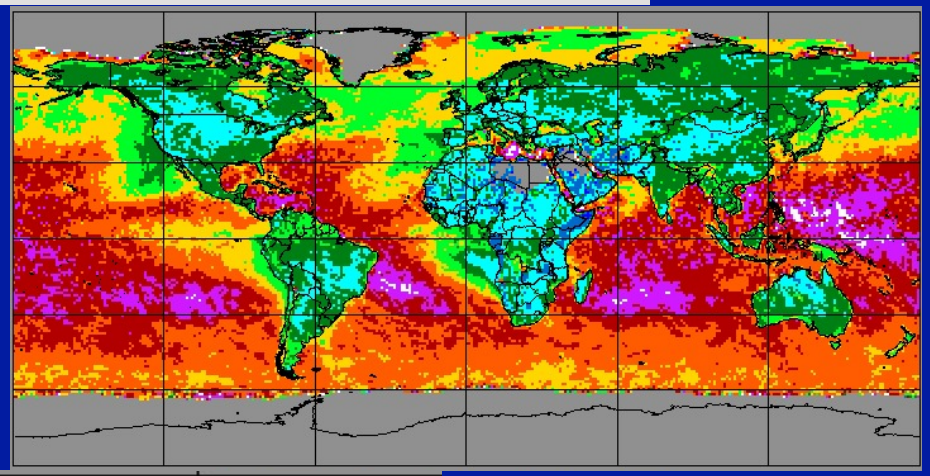
Aqua 3.8 μm VIIRS

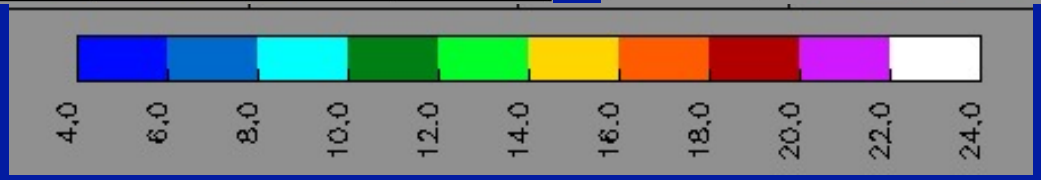




Aqua (1.2 μm) VIIRS (1.2 μm)



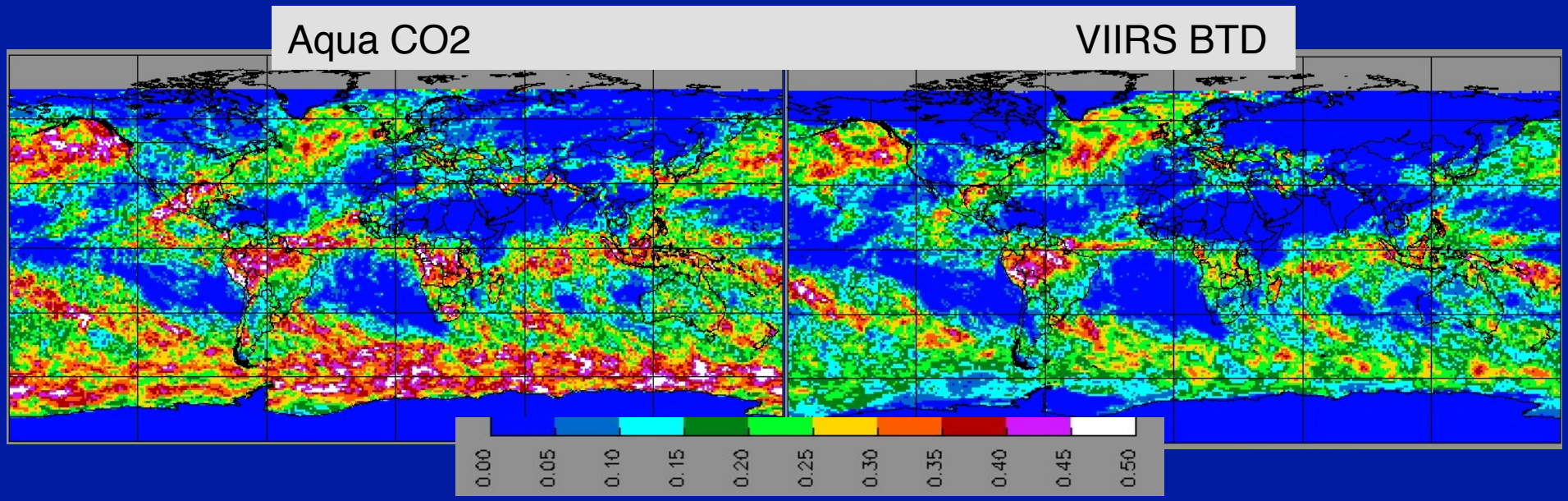


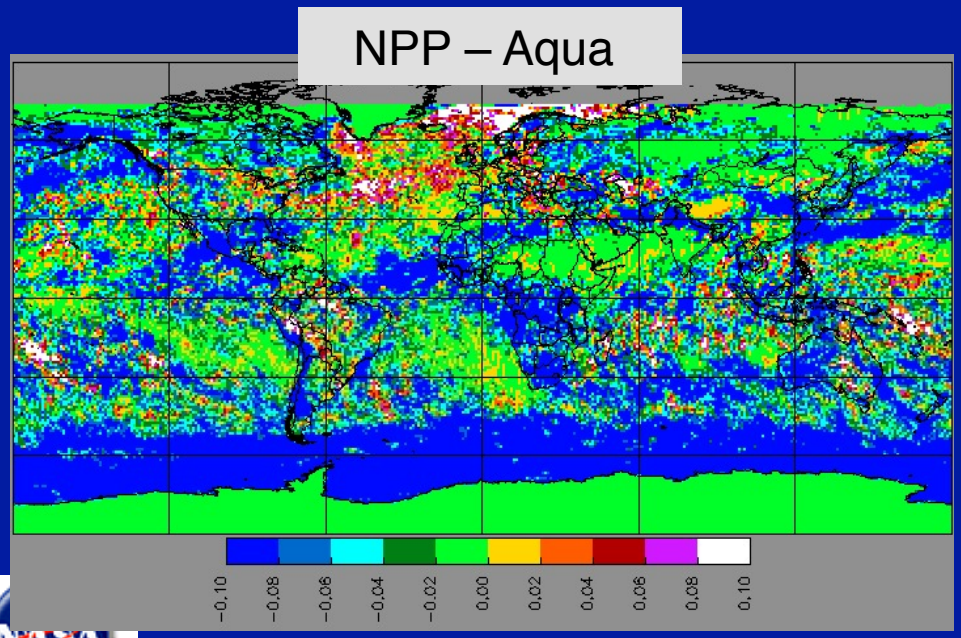


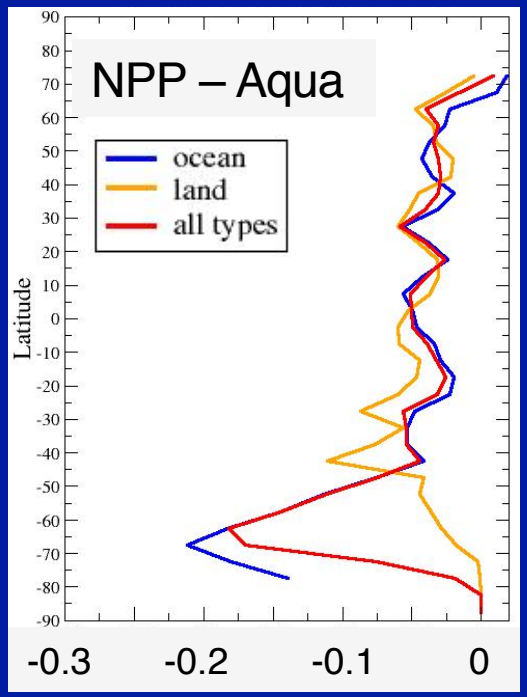
Cloud Particle Sizes

- VIIRS: standard (3.7 μm), and extra (1.2 & 1.6 μm) are fine
- MODIS: standard (3.7 μm) and water fine
- MODIS: extra (1.2 μm) not usable and 2.1 μm ice doubtful

Multi-Layer Cloud Amounts, Day, February 2012







VALIDATION

- CALIPSO: Tau for thin ice, Ztop, phase, fraction
- Satellite consistency: MODIS, VIIRS, AVHRR, GEOS
- ARM surface obs, Alaska: Ztop, Re, tau, LWP, Zbase

Aqua MODIS Ed-4 & VIIRS Comparison with CALIPSO

- Spatially/temporally matched cloud properties for 1 month, July 2013

- CALIPSO data
  - Vertical Feature Mask (VFM): number of cloud layers, SL/ML identification, cloud phase, and layer opacity
  - 5-km Cloud Layers product: cloud altitudes, optical depths, and IWP
  - 333-m Cloud Layers product: low-cloud altitudes

H - Hit rate, fraction CALIPSO clouds detected

FC – fraction correct

FAR – false alarm rate

B – bias ratio

CSI – critical success index

HSS – Heidke skill score

Cloud Fraction Comparison, Aqua Ed4 vs CALIPSO, July 2013

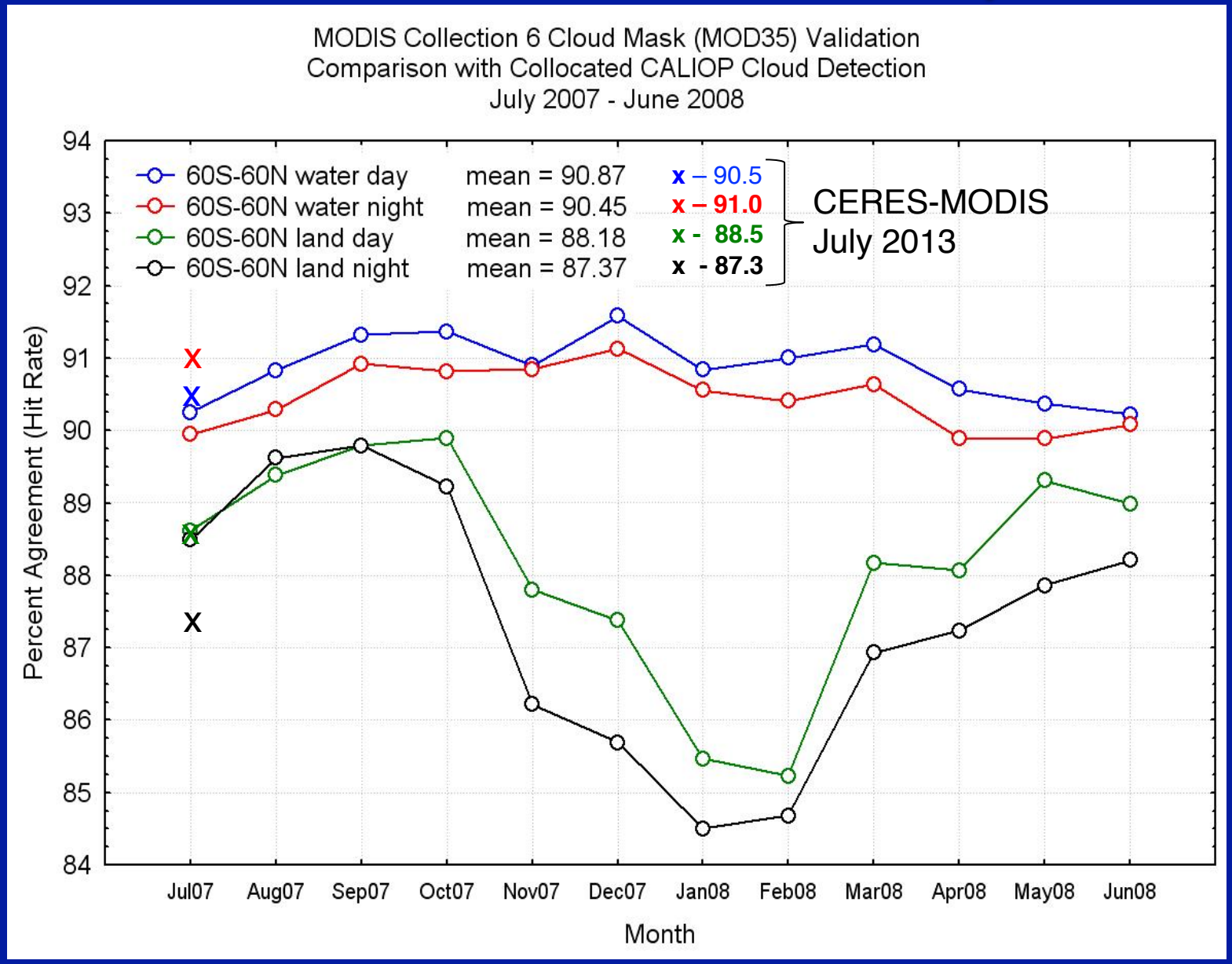
DAYTIME	FRACTION CORRECT	FALSE-ALARM RATE	HEIDKE SKILL SCORE	NUMBER OF MATCHES
Nonpolar, Land, Snow/Ice-free	0.885	0.046	0.76	301696
Polar, Land, Snow/Ice-free	0.887	0.036	0.73	96599
Nonpolar, Ocean, Snow/Ice-free	0.905	0.062	0.76	768435
Polar, Ocean, Snow/Ice-free	0.925	0.061	0.68	104176
Global, Land & Ocean, Snow/Ice-covered	0.887	0.062	0.67	248068
NIGHTTIME				
Nonpolar, Land, Snow/Ice-free	0.873	0.043	0.74	299214
Polar, Land, Snow/Ice-free	0.884	0.060	0.73	64369
Nonpolar, Ocean, Snow/Ice-free	0.910	0.042	0.72	846030
Polar, Ocean, Snow/Ice-free	0.943	0.030	0.63	55305
Global, Land & Ocean, Snow/Ice-covered	0.765	0.104	0.49	534541

Cloud Fraction Comparison, VIIRS Ed1 vs CALIPSO, July 2013

DAYTIME	FRACTION CORRECT	FALSE-ALARM RATE	HEIDKE SKILL SCORE	NUMBER OF MATCHES
Nonpolar, Land, Snow/Ice-free	0.854	0.085	0.70	55063
Polar, Land, Snow/Ice-free	0.869	0.059	0.69	19491
Nonpolar, Ocean, Snow/Ice-free	0.874	0.102	0.70	158880
Polar, Ocean, Snow/Ice-free	0.909	0.070	0.62	22603
Global, Land & Ocean, Snow/ Ice-covered	0.871	0.066	0.65	52463
NIGHTTIME				
Nonpolar, Land, Snow/Ice-free	0.863	0.078	0.72	63191
Polar, Land, Snow/Ice-free	0.821	0.142	0.55	13534
Nonpolar, Ocean, Snow/Ice-free	0.881	0.064	0.67	172941
Polar, Ocean, Snow/Ice-free	0.914	0.037	0.62	11882
Global, Land & Ocean, Snow/ Ice-covered	0.732	0.121	0.43	111896

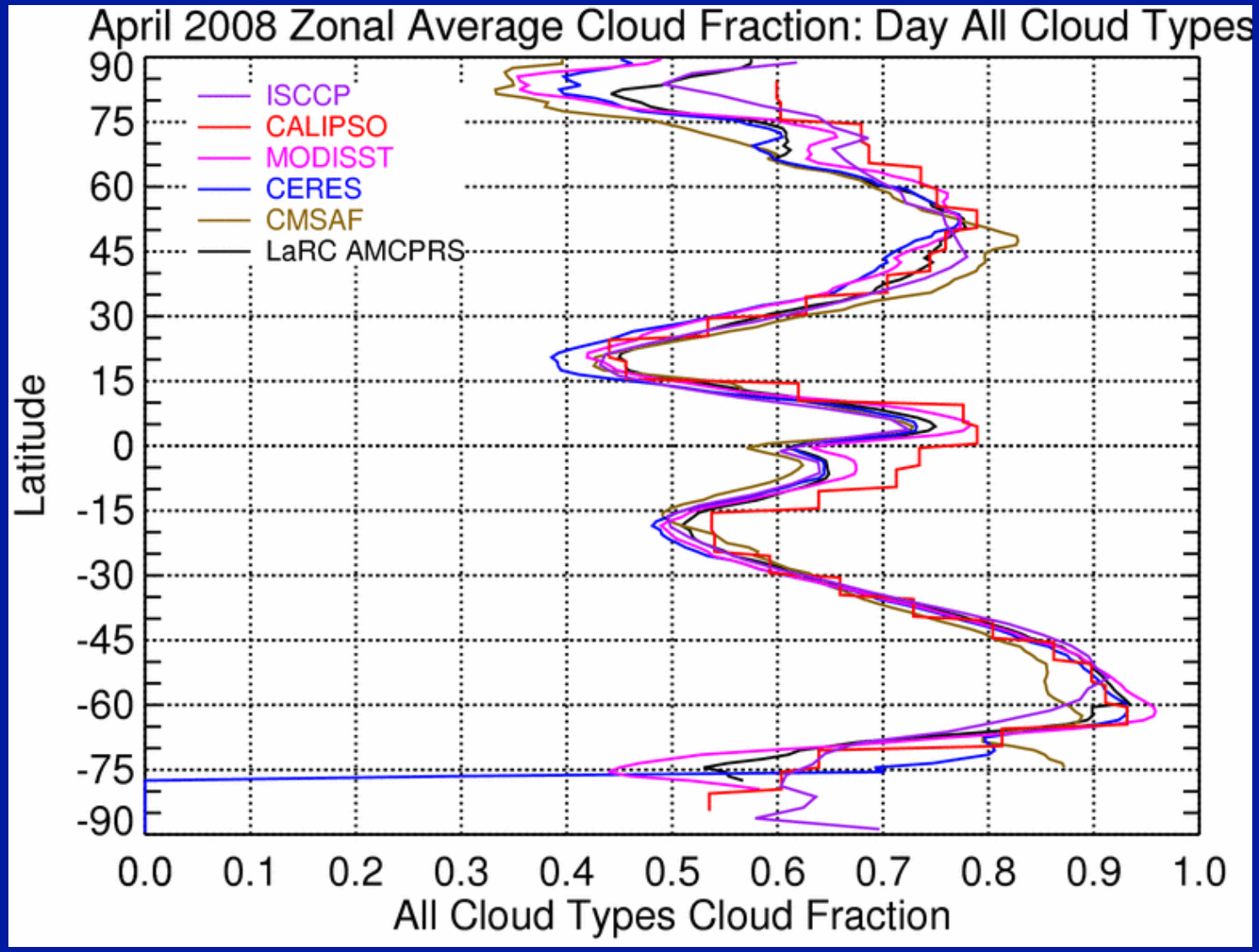
- Collocation of VIIRS and CALIPSO not as good as Aqua

CERES & MAST Collection 6 Detection Accuracy wrt CALIOP

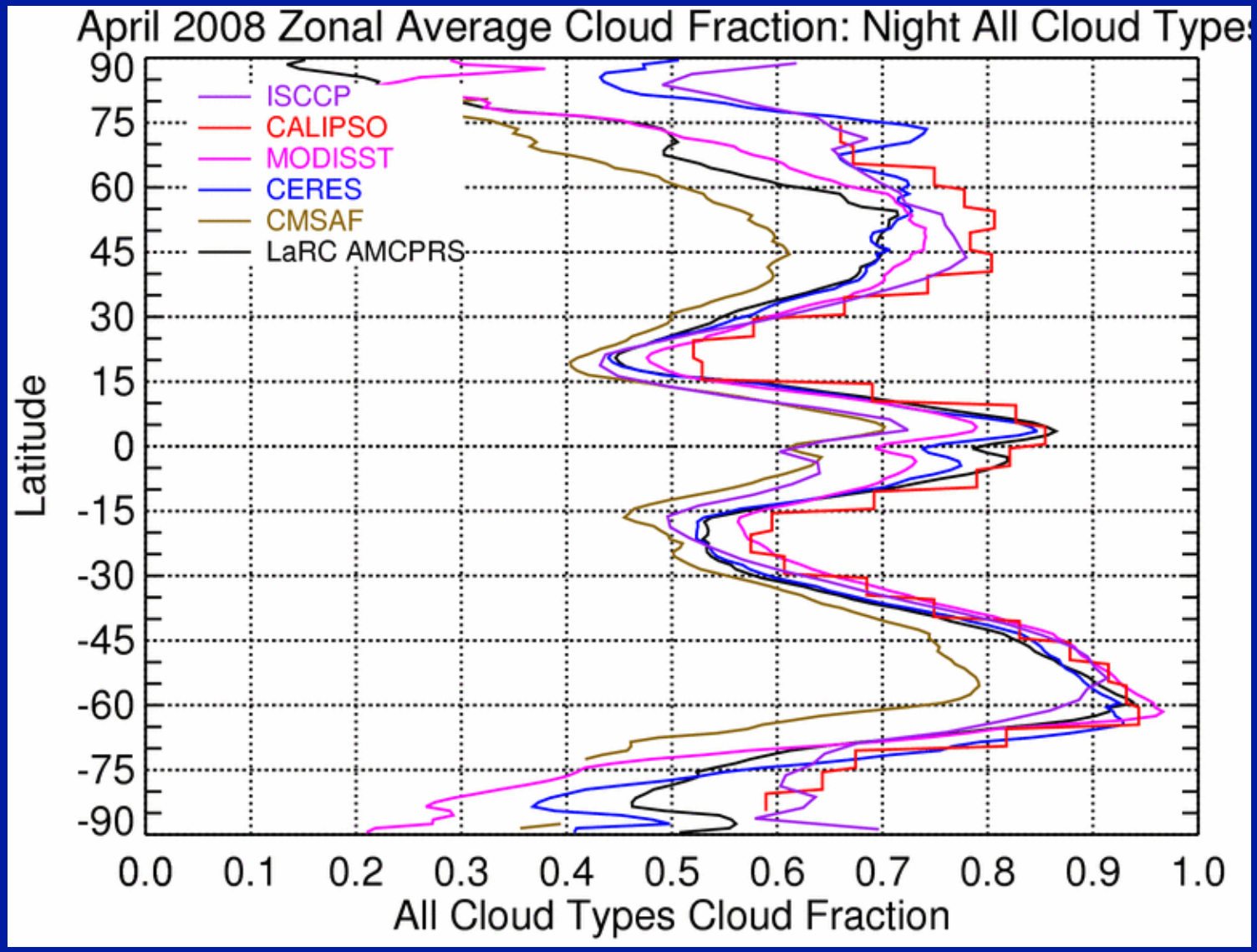


- CERES fraction correct nearly identical to that of MODIS Collection 6

Comparison of Several Cloud Products, April 2008, Day

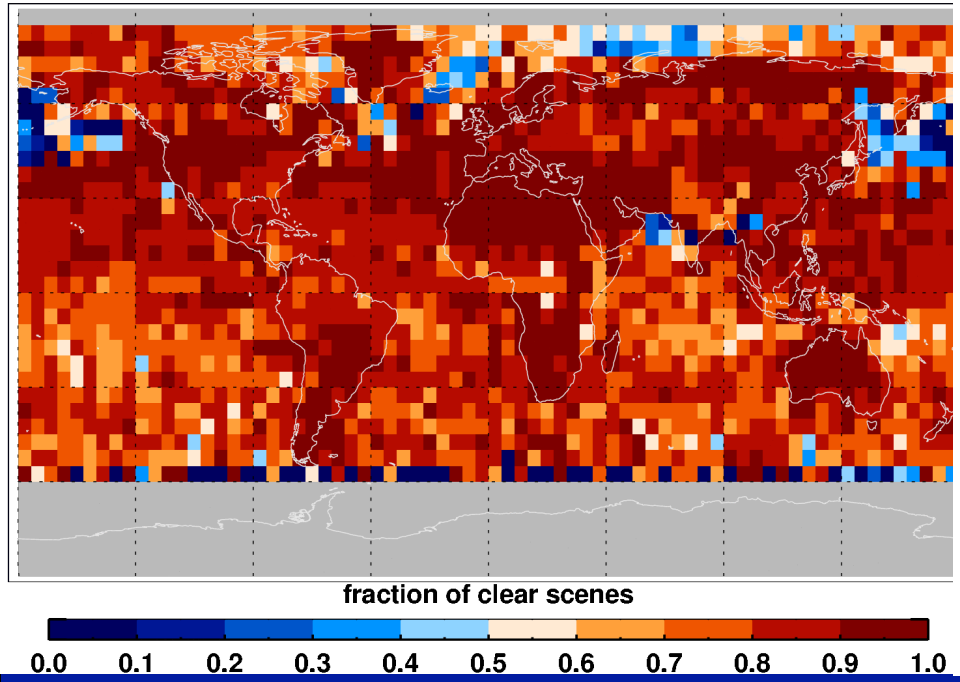


Comparison of Several Cloud Products, April 2008, Night

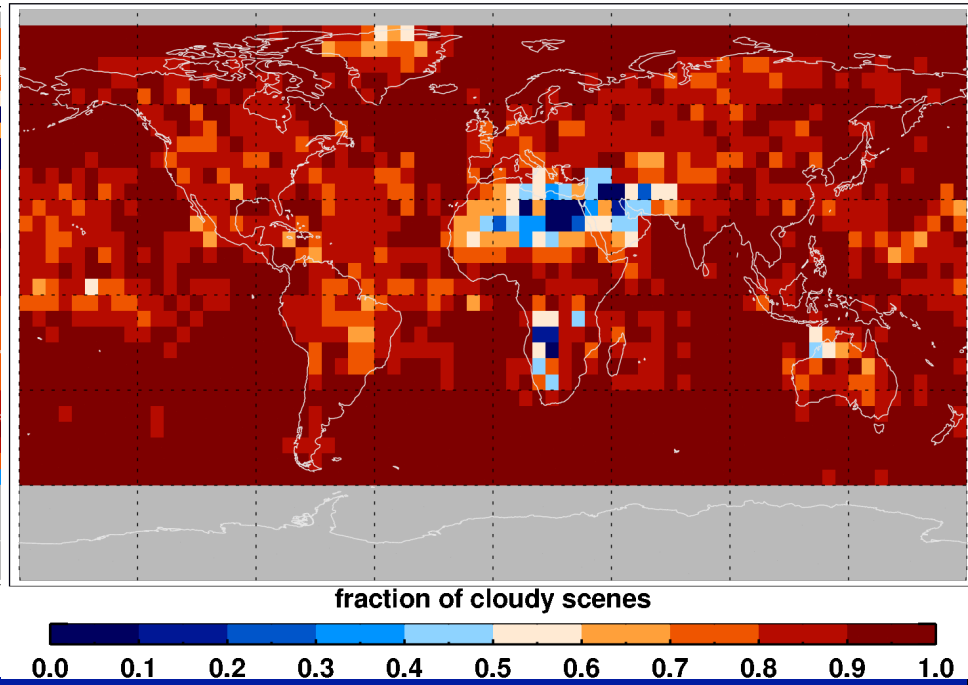


Regional Errors in Cloud Detection, Aqua vs CALIPSO, July 2013

Number of correctly identified clear scenes divided by number of clear scenes



Number of correctly identified cloudy scenes divided by number of cloudy scenes



- Most difficult to detect clear scenes in mostly cloudy areas
- Most dificult to detect clouds over bright surfaces and in sparse cloud regions

Cloud Phase, Aqua MODIS vs CALIPSO, July 2013

DAYTIME	FRACTION CORRECT	Ice FAR	Water FAR	HEIDKE SKILL SCORE	NUMBER OF MATCHES
Nonpolar, Land, Snow/Ice-free	0.952	0.010	0.096	0.902	56830
Polar, Land, Snow/Ice-free	0.939	0.028	0.088	0.878	14655
Nonpolar, Ocean, Snow/Ice-free	0.973	0.023	0.030	0.942	282342
Polar, Ocean, Snow/Ice-free	0.948	0.052	0.052	0.826	29643
Global, Land & Ocean, Snow/Ice-covered	0.914	0.114	0.079	0.763	42475
NIGHTTIME					
Nonpolar, Land, Snow/Ice-free	0.904	0.043	0.216	0.766	55216
Polar, Land, Snow/Ice-free	0.862	0.116	0.165	0.720	11695
Nonpolar, Ocean, Snow/Ice-free	0.950	0.076	0.034	0.894	287706
Polar, Ocean, Snow/Ice-free	0.882	0.201	0.040	0.763	17502
Global, Land & Ocean, Snow/Ice-covered	0.876	0.130	0.064	0.539	127057

Cloud Phase Comparison, VIIRS Ed1 vs CALIPSO
July 2013, only single-layered

DAYTIME	FRACTION CORRECT	Ice FAR	Water FAR	HEIDKE SKILL SCORE	NUMBER OF MATCHES
Nonpolar, Land, Snow/Ice-free	0.924	0.014	0.149	0.845	11145
Polar, Land, Snow/Ice-free	0.911	0.026	0.128	0.819	3095
Nonpolar, Ocean, Snow/Ice-free	0.951	0.027	0.063	0.897	59133
Polar, Ocean, Snow/Ice-free	0.929	0.049	0.075	0.751	5866
Global, Land & Ocean, Snow/ Ice-covered	0.897	0.071	0.110	0.697	8486
NIGHTTIME					
Nonpolar, Land, Snow/Ice-free	0.895	0.047	0.232	0.748	13000
Polar, Land, Snow/Ice-free	0.796	0.128	0.273	0.594	2738
Nonpolar, Ocean, Snow/Ice-free	0.948	0.074	0.040	0.888	58739
Polar, Ocean, Snow/Ice-free	0.923	0.149	0.024	0.840	3853
Global, Land & Ocean, Snow/ Ice-covered	0.911	0.095	0.036	0.646	25258

VIIRS phase accuracy slightly less than Aqua

Cloud Height Difference (Aqua Ed4 – CALIPSO), July 2013, single-layer liquid

Non-opaque DAYTIME	MEAN DIFF [km] (AVHRR-CALIPSO)	RMSD [km]	R	NUMBER OF MATCHES
Global, Ocean, Snow/Ice-free	0.02	0.73	0.64	64412
Global, Land, Snow/Ice-free	-0.32	1.15	0.65	8749
Global, Land & Ocean, Snow/Ice-covered	-0.06	0.85	0.69	9432
NIGHTTIME				
Global, Ocean, Snow/Ice-free	0.18	0.81	0.63	57039
Global, Land, Snow/Ice-free	0.03	0.91	0.75	5138
Global, Land & Ocean, Snow/Ice-covered	0.36	0.93	0.43	3687
opaque **DAYTIME**				
Global, Ocean, Snow/Ice-free	-0.11	0.69	0.83	129972
Global, Land, Snow/Ice-free	-0.15	0.85	0.89	21064
Global, Land & Ocean, Snow/Ice-covered	-0.53	1.09	0.83	21048
NIGHTTIME				
Global, Ocean, Snow/Ice-free	0.03	0.65	0.76	122158
Global, Land, Snow/Ice-free	-0.08	0.82	0.87	12449
Global, Land & Ocean, Snow/Ice-covered	0.28	0.95	0.59	8151

- Largest biases over ice/snow, smallest over ocean
- STD of differences generally < 1.0 km, over ocean < 0.8 km

Cloud Height Difference (VIIRS Ed1 – CALIPSO), July 2013
Non-opaque, single-layer liquid

Non-opaque, Day	MEAN DIFF [km]	RMSD [km]	R	NUMBER OF MATCHES
Global, Ocean, Snow/Ice-free	0.05	0.75	0.66	13194
Global, Land, Snow/Ice-free	0.09	1.17	0.66	2334
Global, Land & Ocean, Snow/Ice-covered	0.00	0.71	0.76	1882
Non-opaque, Night				
Global, Ocean, Snow/Ice-free	0.33	0.94	0.57	12399
Global, Land, Snow/Ice-free	0.07	1.14	0.68	1392
Global, Land & Ocean, Snow/Ice-covered	0.56	1.03	0.33	546

- Largest biases over ice/snow, smallest over ocean
- STD of differences generally < 1.0 km, over ocean < 0.8 km

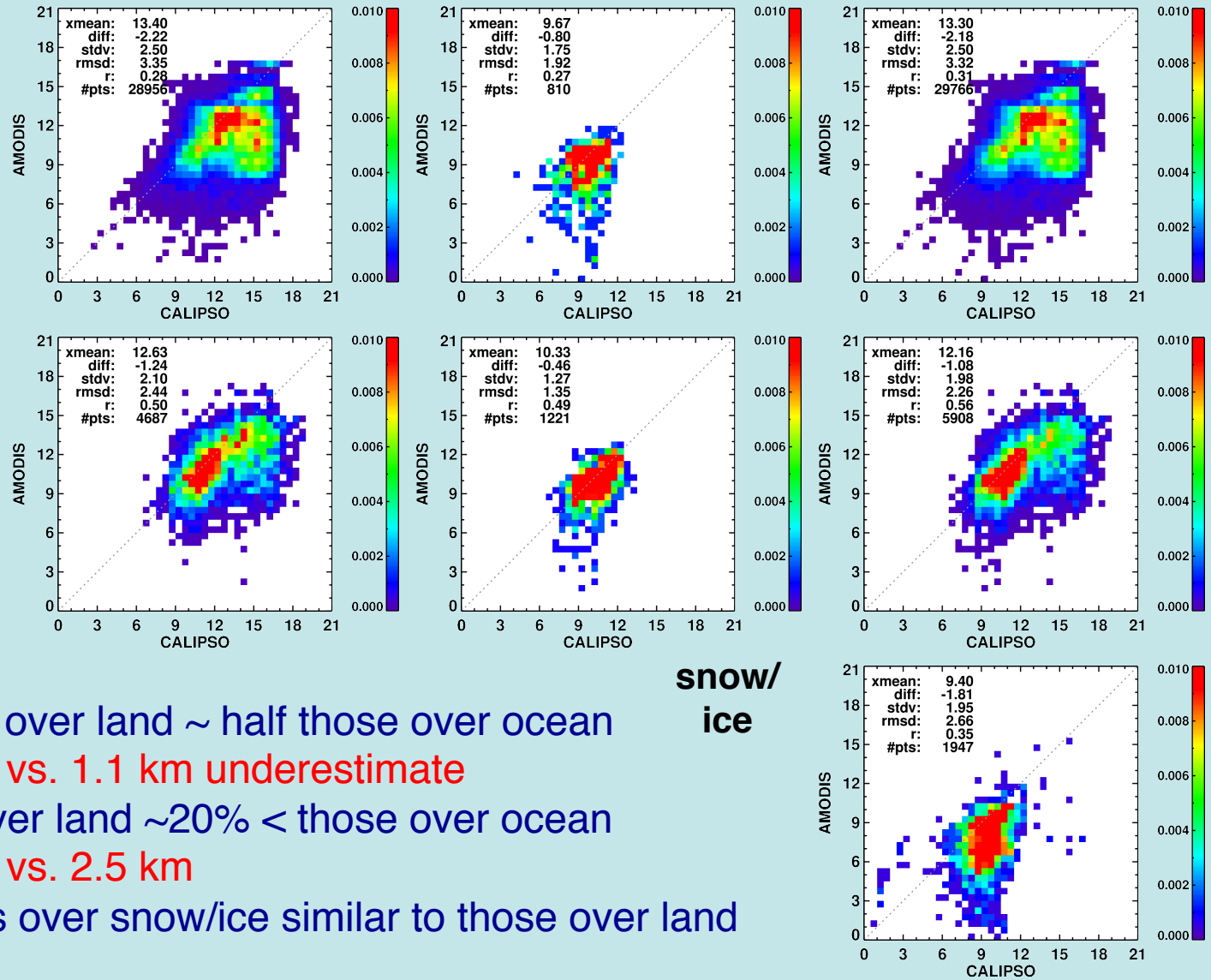
Cloud Height Difference (VIIRS Ed1 – CALIPSO), July 2013
Opaque liquid single-layer

Opaque, Day	MEAN DIFF [km]	RMSD [km]	R	NUMBER OF MATCHES
Global, Ocean, Snow/Ice-free	-0.13	0.78	0.82	25890
Global, Land, Snow/Ice-free	-0.06	0.94	0.88	3697
Global, Land & Ocean, Snow/Ice-covered	-0.43	1.06	0.85	4354
Opaque, NIGHTTIME				
Global, Ocean, Snow/Ice-free	0.09	0.71	0.72	25134
Global, Land, Snow/Ice-free	0.09	0.88	0.86	2790
Global, Land & Ocean, Snow/Ice-covered	0.62	1.11	0.52	2001

- VIIRS liquid cloud height comparisons similar to Aqua
- Slightly larger biases

Cloud Top Altitude, Aqua MODIS vs CALIPSO, July 2013

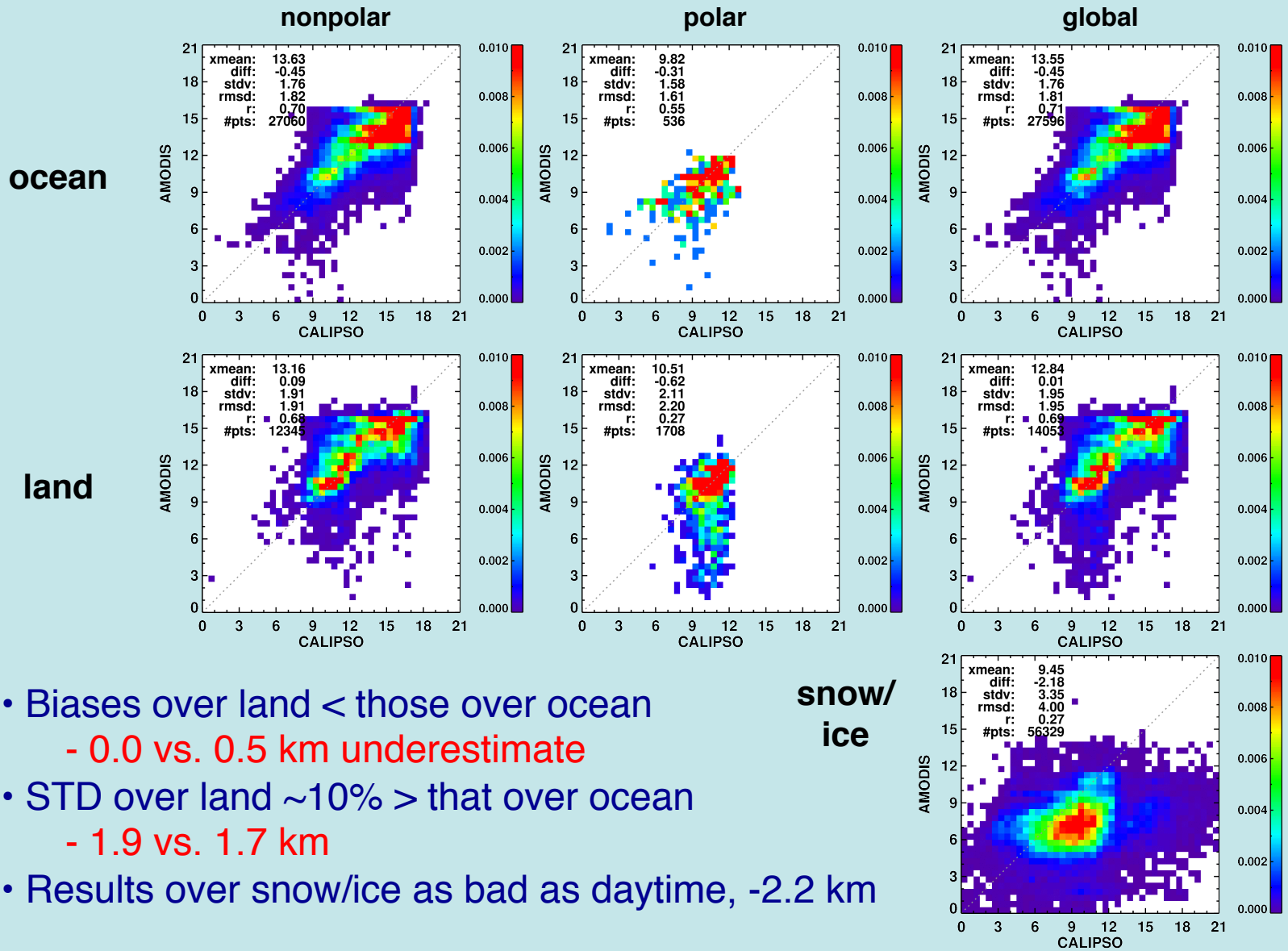
ice phase, daytime, non-opaque



- Biases over land ~ half those over ocean
  - 2.2 vs. 1.1 km underestimate
- STD over land ~20% < those over ocean
  - 2.0 vs. 2.5 km
- Results over snow/ice similar to those over land

Cloud Top Altitude, Aqua MODIS vs CALIPSO, July 2013

ice phase, nighttime, non-opaque



- Biases over land < those over ocean
  - 0.0 vs. 0.5 km underestimate
- STD over land ~10% > that over ocean
  - 1.9 vs. 1.7 km
- Results over snow/ice as bad as daytime, -2.2 km

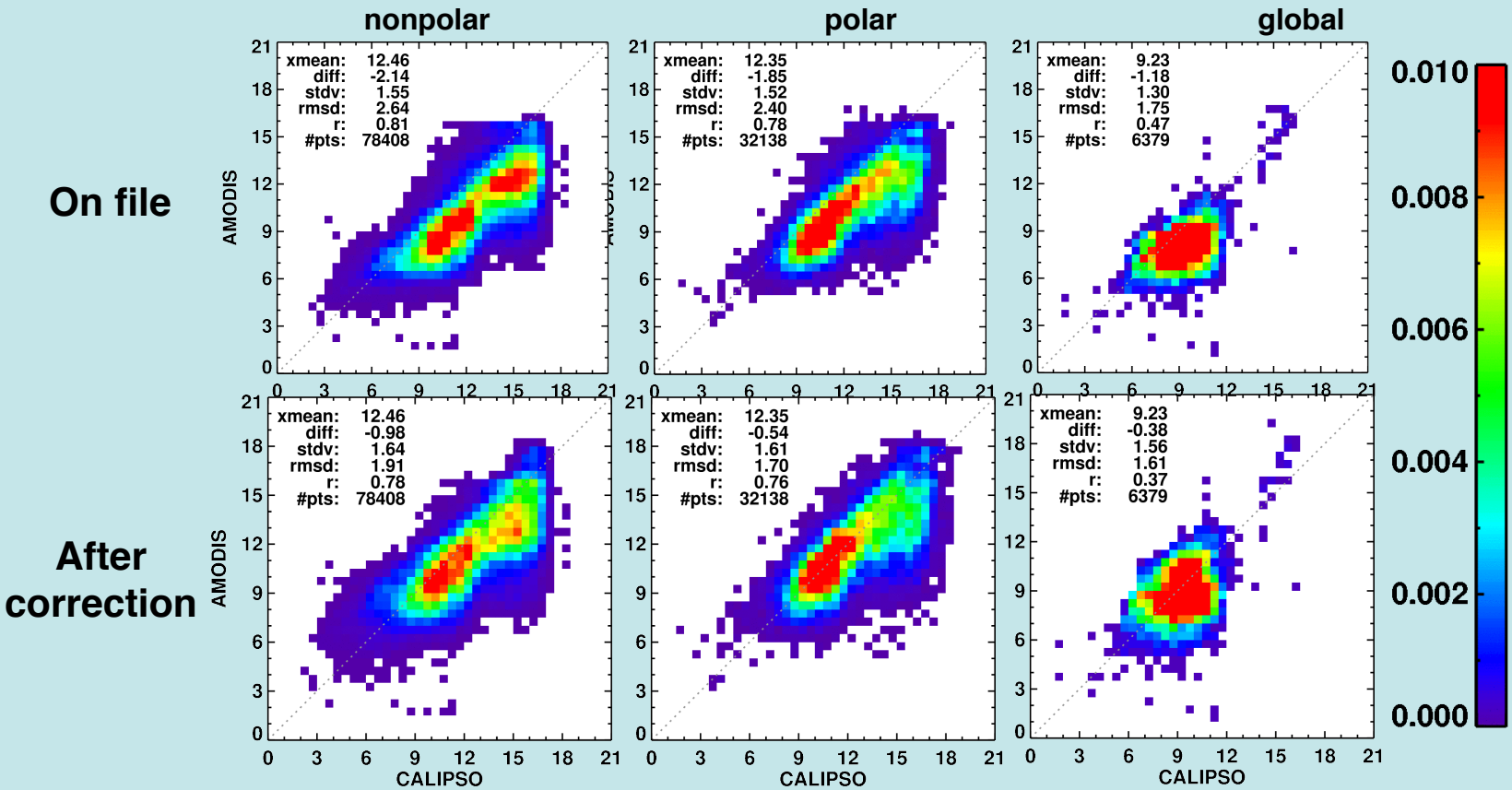
Cloud Height Difference (Aqua Ed4 – CALIPSO), July 2013, single-layer **ice**
Non-opaque

DAYTIME	MEAN DIFF [km]	RMSD [km]	R	NUMBER OF MATCHES
Global, Ocean, Snow/Ice-free	-2.18	3.32	0.31	29766
Global, Land, Snow/Ice-free	-1.08	2.26	0.56	5908
Global, Land & Ocean, Snow/Ice-covered	-1.81	2.66	0.35	1947
NIGHTTIME				
Global, Ocean, Snow/Ice-free	-0.45	1.81	0.71	27596
Global, Land, Snow/Ice-free	0.01	1.95	0.69	14053
Global, Land & Ocean, Snow/Ice-covered	-2.18	4.00	0.27	56329

* Thick ice cloud top correction not applied, applying the correction post facto reduces biases to -0.16 (day) and 0.01 (night)

Cloud Top Altitude, Aqua MODIS vs CALIPSO, July 2013

ice phase, nighttime, opaque with & without height correction



- Biases w/o correction
  - 1.2 – 2.1 km underestimate
- Biases w/ correction
  - 0.4 – 1.0 km underestimate
- Correction increases STD by ~6%

Users!
Apply the correction.
In Ed4 Data Quality Summary.

Cloud Height Difference (Aqua Ed4 – CALIPSO), July 2013, single-layer **ice Opaque**

DAYTIME	MEAN DIFF [km]	RMSD [km]	R	NUMBER OF MATCHES
Global, Ocean, Snow/Ice-free	-2.14	2.64	0.81	78408
Global, Land, Snow/Ice-free	-1.85	2.40	0.78	32138
Global, Land & Ocean, Snow/Ice-covered	-1.18	1.75	0.47	6379
NIGHTTIME				
Global, Ocean, Snow/Ice-free	-1.46	2.09	0.85	81889
Global, Land, Snow/Ice-free	-1.36	2.30	0.75	28307
Global, Land & Ocean, Snow/Ice-covered	-1.84	2.73	0.59	43158

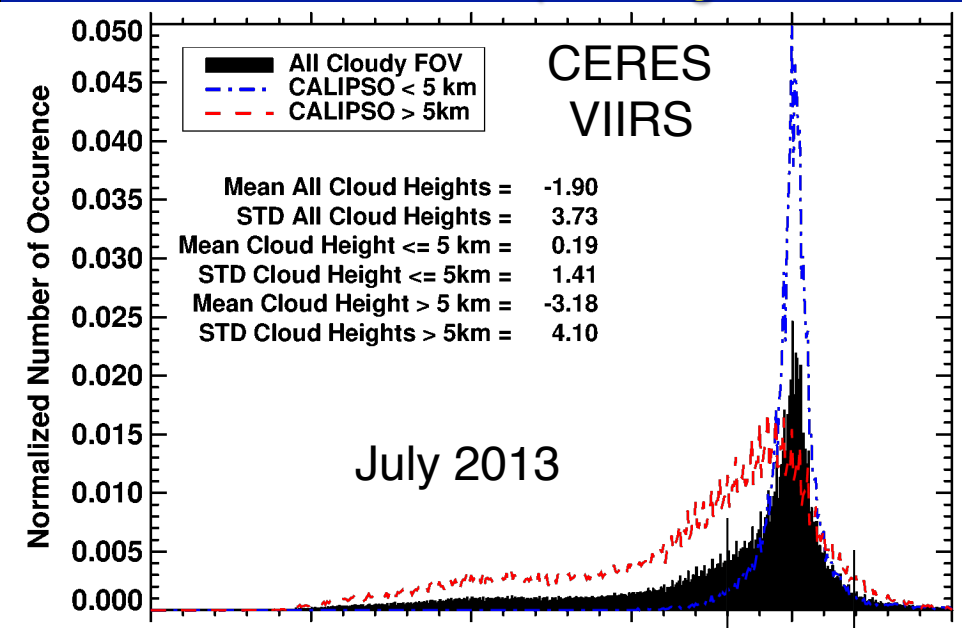
* Thick ice cloud top correction not applied

Cloud Height Difference (Aqua Ed4 – CALIPSO), July 2013, single-layer **ice**
Opaque, Correction applied externally

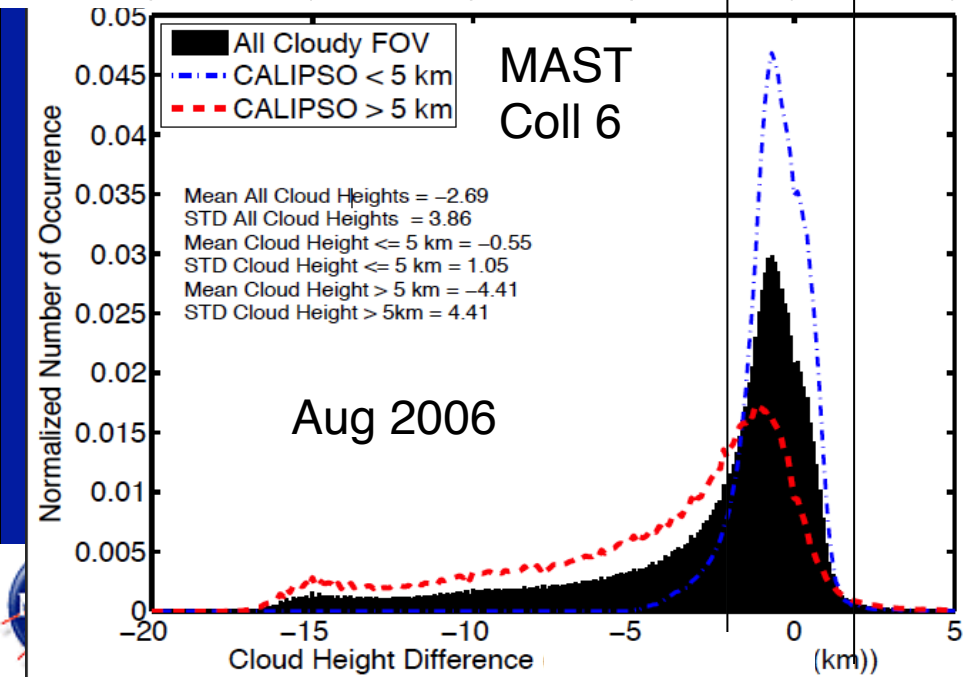
DAYTIME	MEAN DIFF [km]	RMSD [km]	R	NUMBER OF MATCHES
Global, Ocean, Snow/Ice-free	-0.98	1.91	0.78	78408
Global, Land, Snow/Ice-free	-0.54	1.70	0.76	32138
Global, Land & Ocean, Snow/Ice-covered	-0.38	1.61	0.37	6379
NIGHTTIME				
Global, Ocean, Snow/Ice-free	-0.80	1.79	0.84	81889
Global, Land, Snow/Ice-free	-0.69	1.94	0.76	28307
Global, Land & Ocean, Snow/Ice-covered	-1.67	2.68	0.55	43158

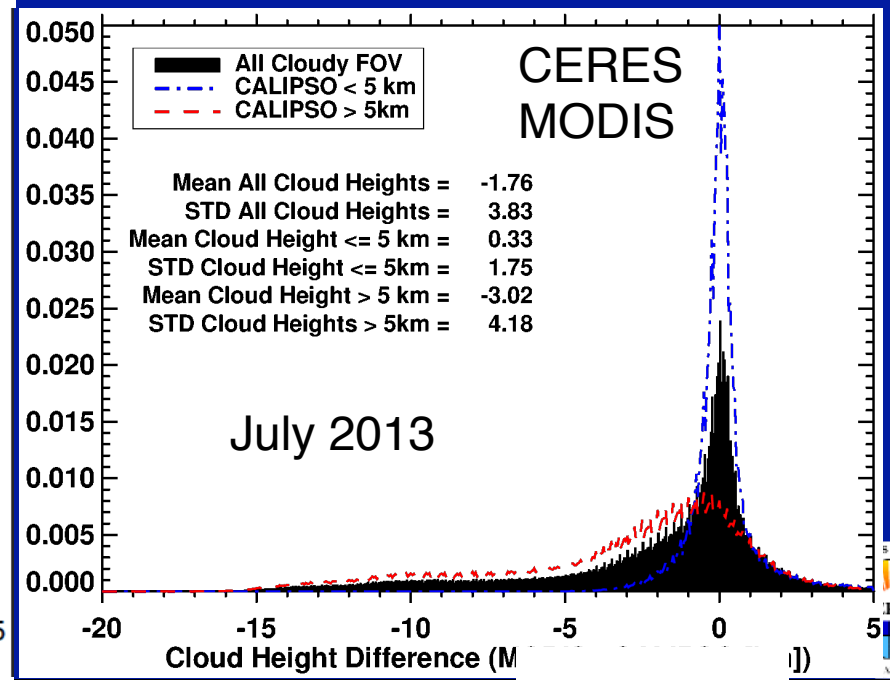
* Thick ice cloud top correction not applied, applying the correction post facto reduces biases to -0.16 (day) and 0.01 (night)

Distribution of Cloud Height Differences (Satellite – CALIPSO)
All clouds (use highest for multilayered pixels), 60° - 60°S

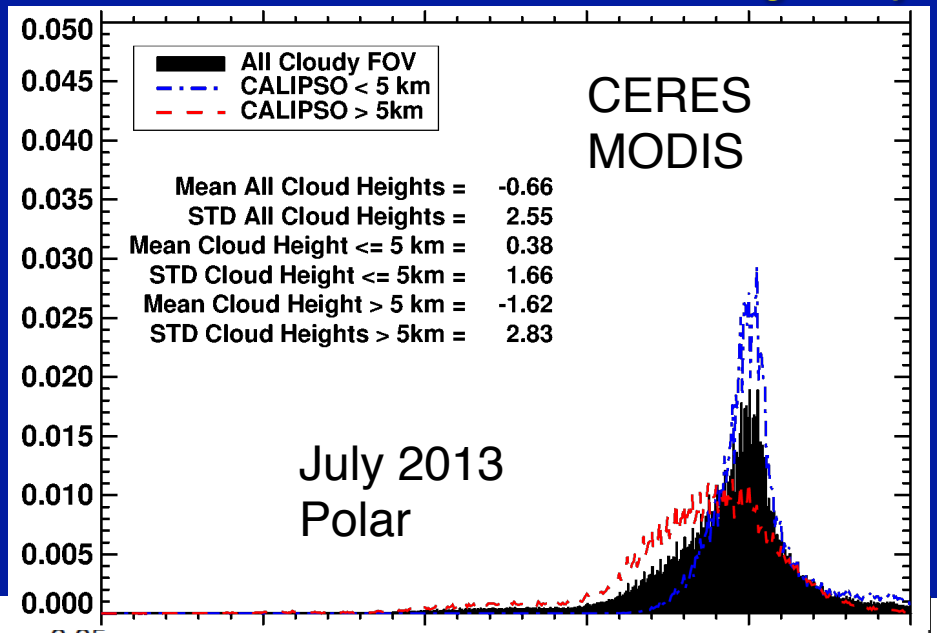


- CERES low cloud differences narrowly distributed
  - STD > Coll 6? ~1.75 vs 1.05
  - bias is smaller, ~0.33 vs -0.55
- CERES hi cloud difference
  - STD = Coll 6 – 0.2 km
  - bias smaller by ~1.3 km

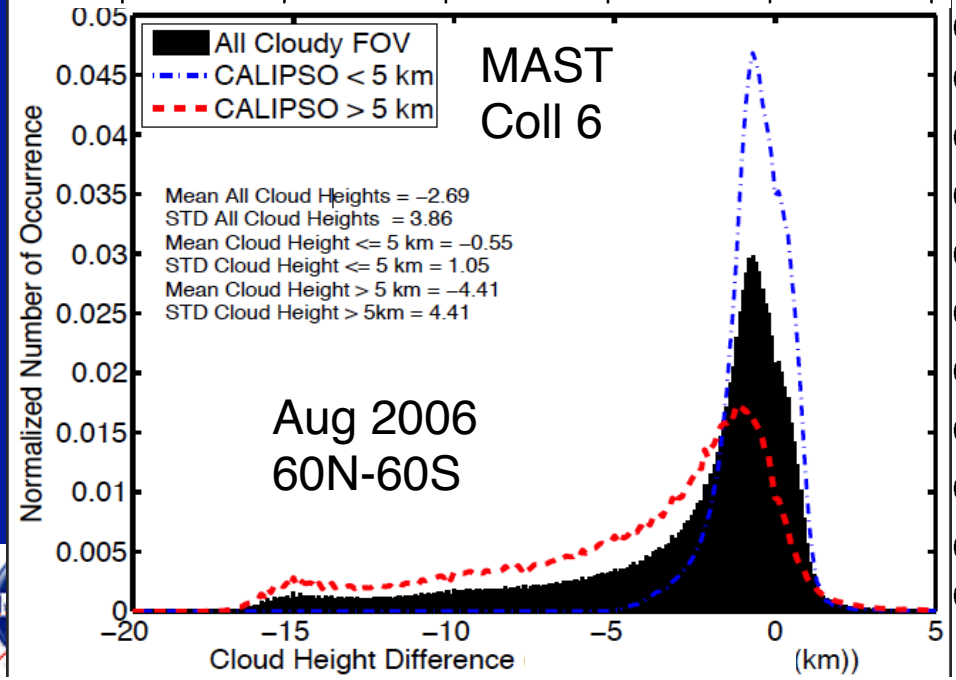


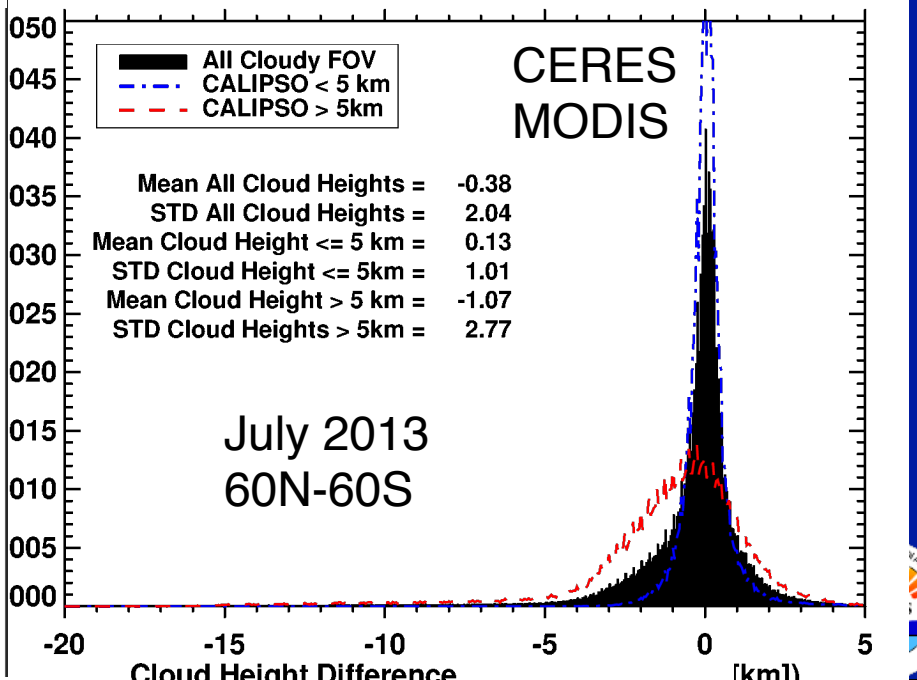


Distribution of Cloud Height Differences (Satellite – CALIPSO)
Single-layered pixels

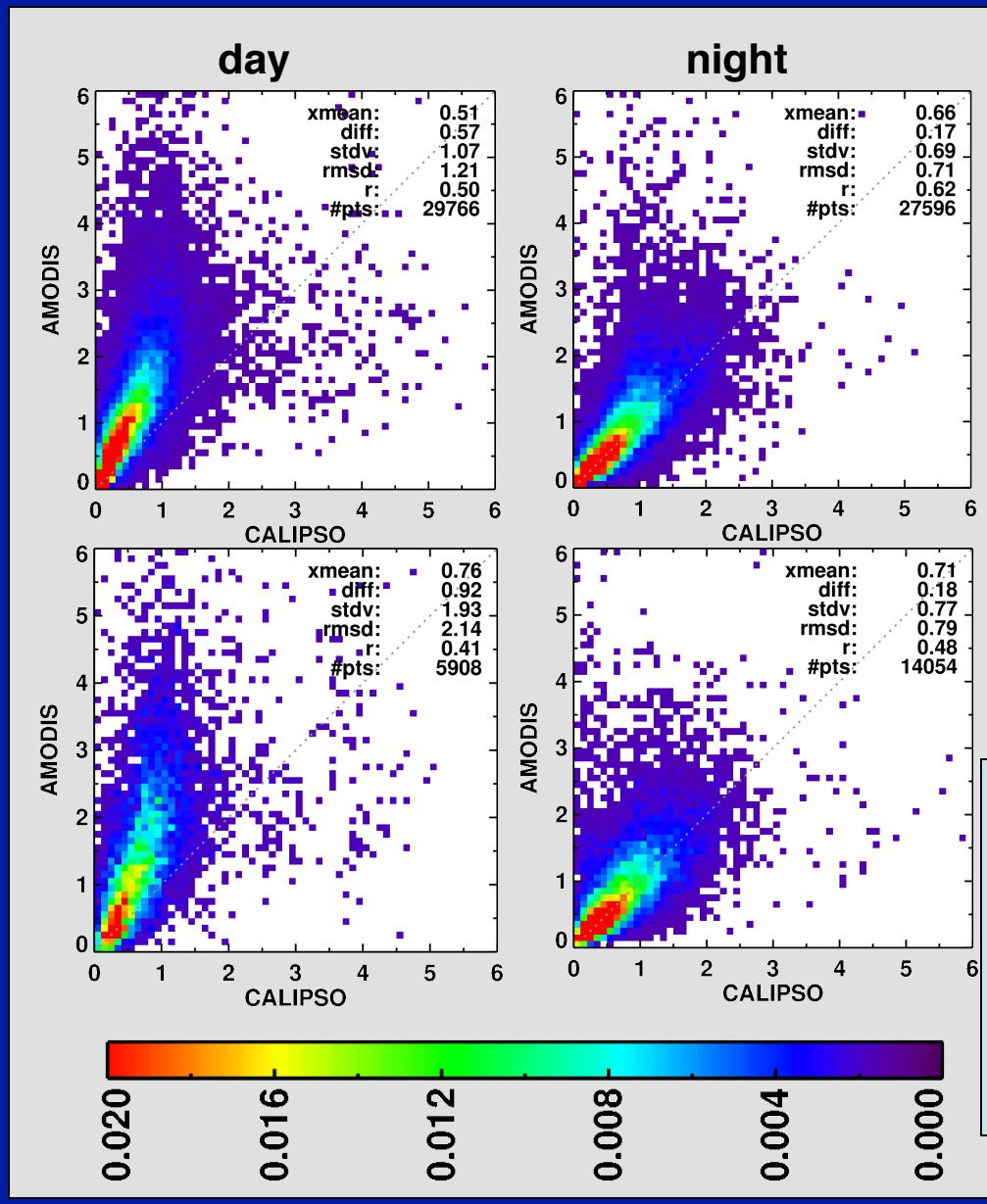


- CERES low cloud differences narrowly distributed
  - STD reduced ~1.75 to 1.01 km
  - bias is smaller, ~0.13 from 0.33 km
- CERES hi cloud difference
  - STD = Coll 6 – 0.2 km
  - bias smaller by ~1.3 km
- Not clear if MAST used 5 or 1 km pixel





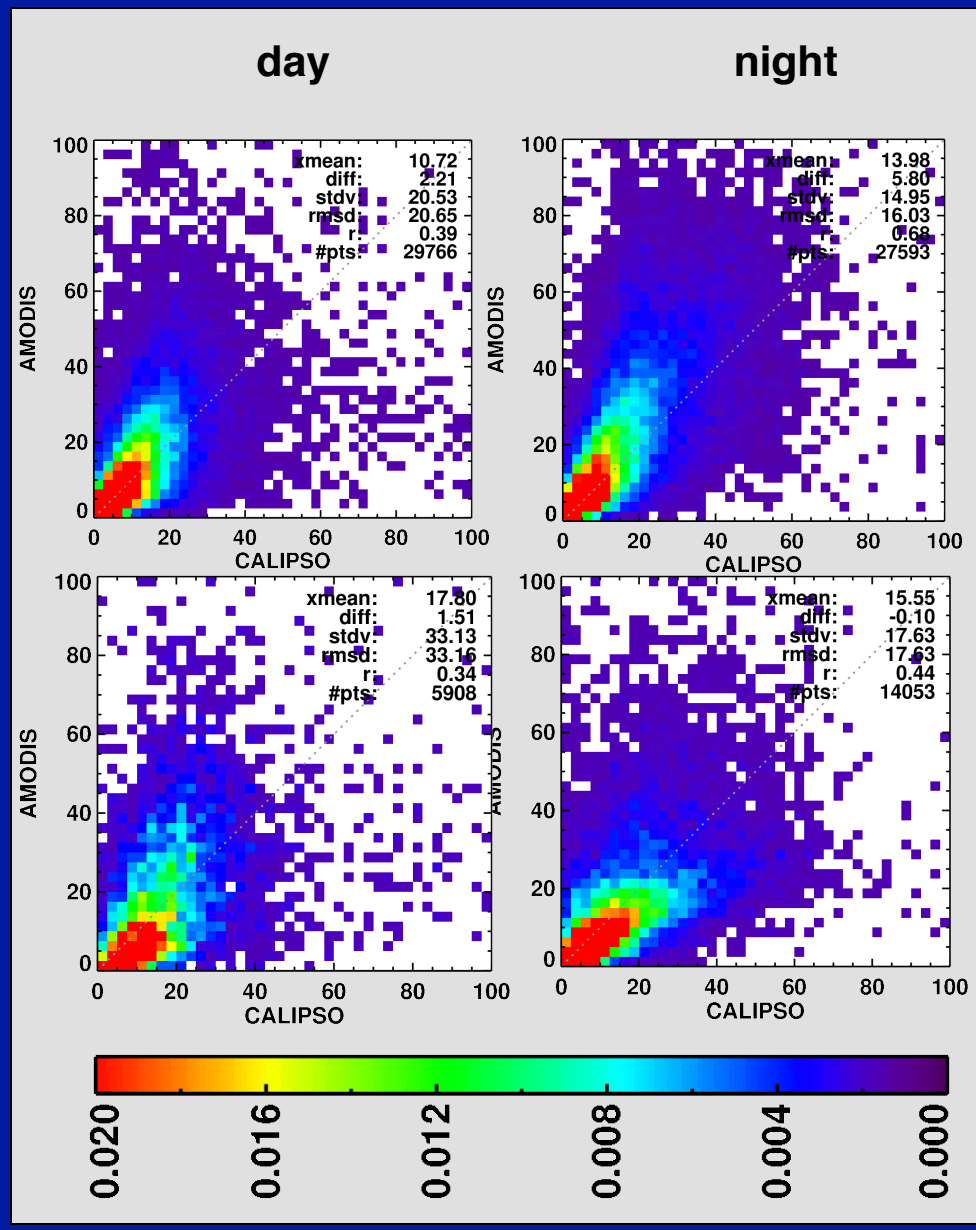
Ice cloud optical depth, non-opaque, no snow/ice
Aqua CM vs CALIPSO, July 2013



- **Day:** $COD_{CM} = 2*COD_{CAL}$
  - new ice xtal model no help
  - yields Zeff underestimate
- **Night:** $COD_{CM} = 1.25*COD_{CAL}$
  - mostly $COD_{CM} = COD_{CAL}$
  - SIST very effective
  - scatter large
- **VIIRS:** Results nearly identical

- Apply SIST during day?
  - testing soon
- Try new scattering model?
  - *Liu et al. (ACP, 2014)*
  - testing soon

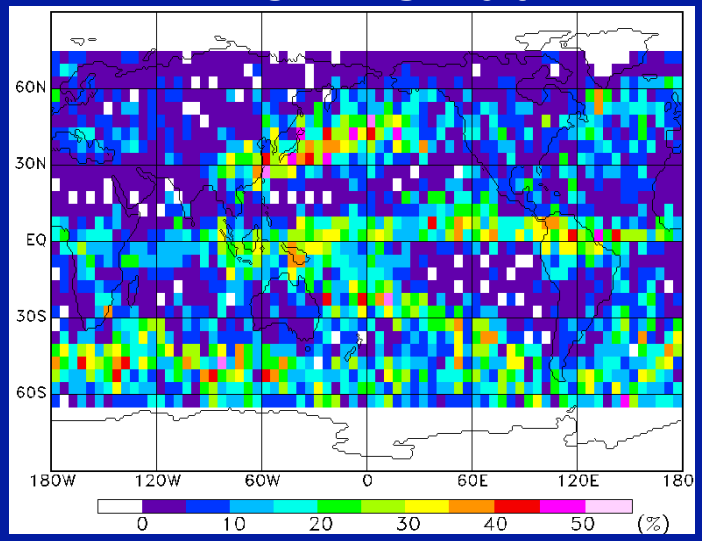
Ice water path, non-opaque, no snow/ice, Aqua CM vs CALIPSO, July 2013



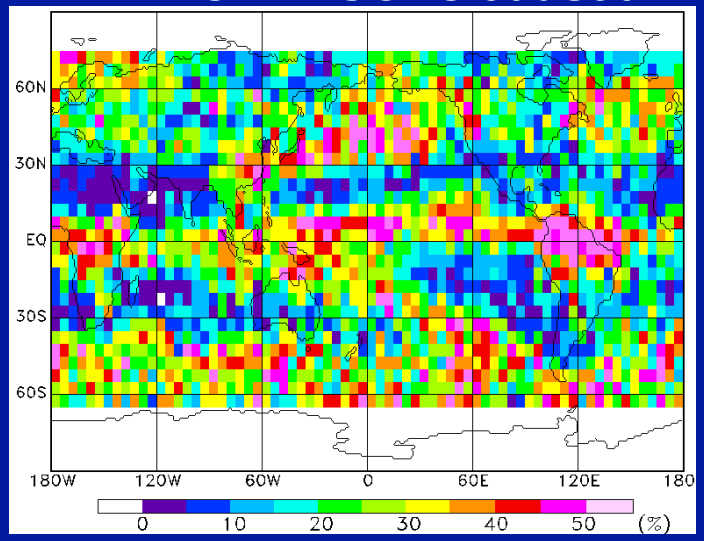
- **Day:** $IWP_{CM} = 1.2*IWP_{CAL}$
  - most points around 1:1 over ocean
  - Re must balance COD bias
- **Night:** $IWP_{CM} = 1.25*IWP_{CAL}$ -
  - most points around 1:1 line over ocean
  - land points below 1:1 line
  - Re probably very good
    - *bias same as COD*
- **VIIRS:** Results nearly identical

Comparison of CERES Multilayer Cloud Amount with CALIPSO+CloudSat

CERES Multi



CALIPSO+CloudSat

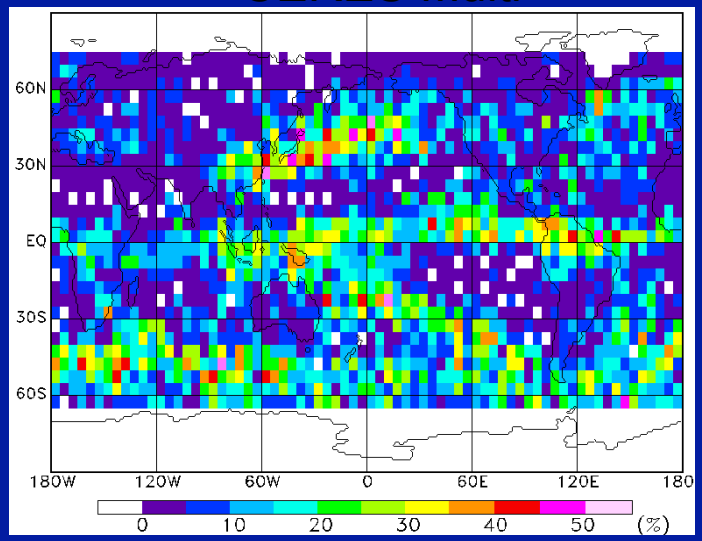


- Collocated data: 2010 April daytime
- 5°-box average:

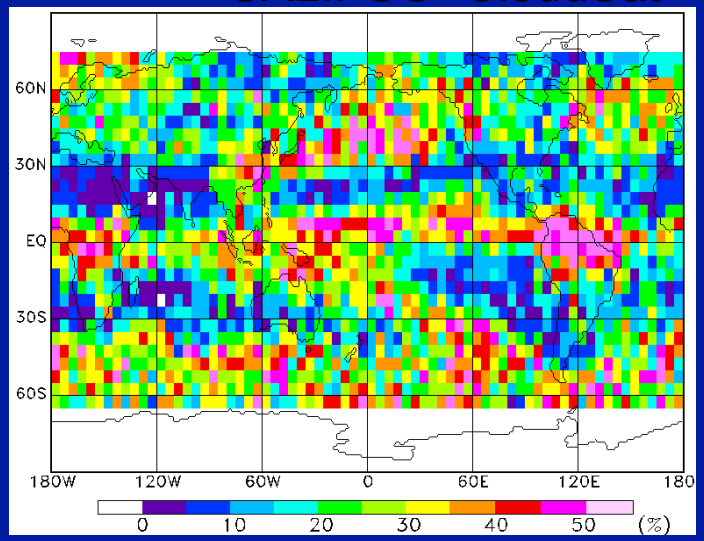
	CERES Multi	CL+CS Multi
Global	10.2%	23.4%
Ocean	12.1%	24.3%
Land	7.0%	21.7%

CERES Multilayer Cloud Amount versus CALIPSO+CloudSat

CERES Multi



CALIPSO+CloudSat



✧ Ocean:

(%)	CL+CS ML YES	CL+CS ML NO
CERES ML YES	7.9	4.2
CERES ML NO	16.4	71.5

✧ Land:

(%)	CL+CS ML YES	CL+CS ML NO
CERES ML YES	4.3	2.7
CERES ML NO	17.4	75.6

Evaluation of CERES Missed Multilayer Clouds, Tropics, April 2014

	Multilayer Categories						
	M0	M1	M2	M3	M4	M5	Total
(%)	8.3	3.5	6.9	3.1	1.8	1.1	
CL+CS ML	YES	YES	YES	YES	X	X	21.8
CERES CO2	X	YES	YES	YES	YES	YES	16.4
CERES ML	X	X	YES	X	YES	YES	9.8

- M0: Optically thin upper cirrus cloud that CERES CO2 missed;
- M1: Optically thin low cloud that CERES ML missed;
- M2: Agreement
- M3: Semi-opaque upper clouds that CERES ML skipped;
- M4: CALIPSO saturated and no CloudSat detection of low cloud;
- M5: Vertically continuous but semi-transparent clouds.

- M0: need to improve the retrieval of optically thin cirrus clouds;
- M1: need to improve the retrieval of optically thin low clouds;
- M3: need to identify low clouds beneath semi-opaque upper clouds;
- M4: need to validate the retrieved low clouds;
- M5: need to identify vertically continuous clouds.

Ed-4 Validation Studies Over North Slope of Alaska

See Talk by Xiquan Dong, Thursday

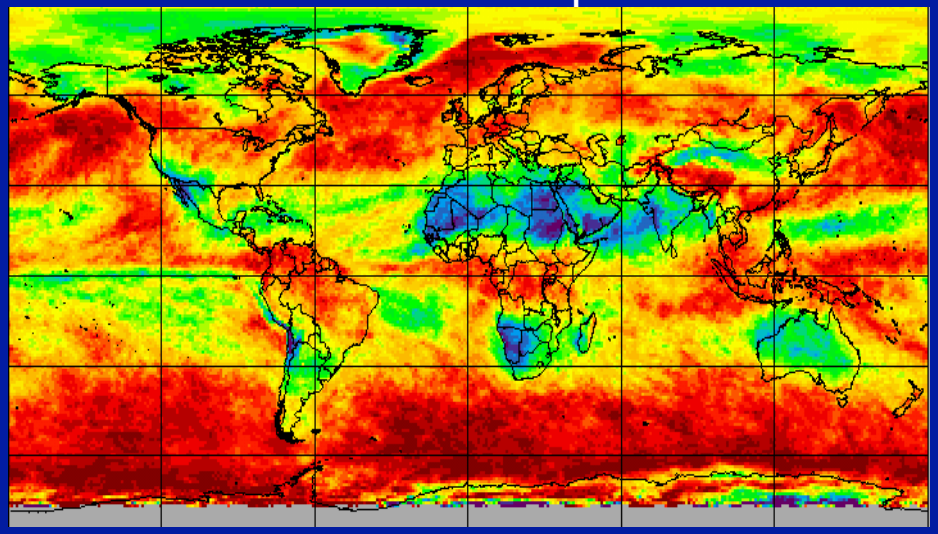
GEOSat Analyses

- Provide hourly cloud properties from geostationary satellites for TISA
  - Ed2 uses 3-h, VIS-IR retrievals (fixed Re/phase selection)
  - Ed4 uses 1-h, VIS-IR and multispectral (retrieve phase & Re)
  - Ed4 retrievals more like MODIS or VIIRS clouds

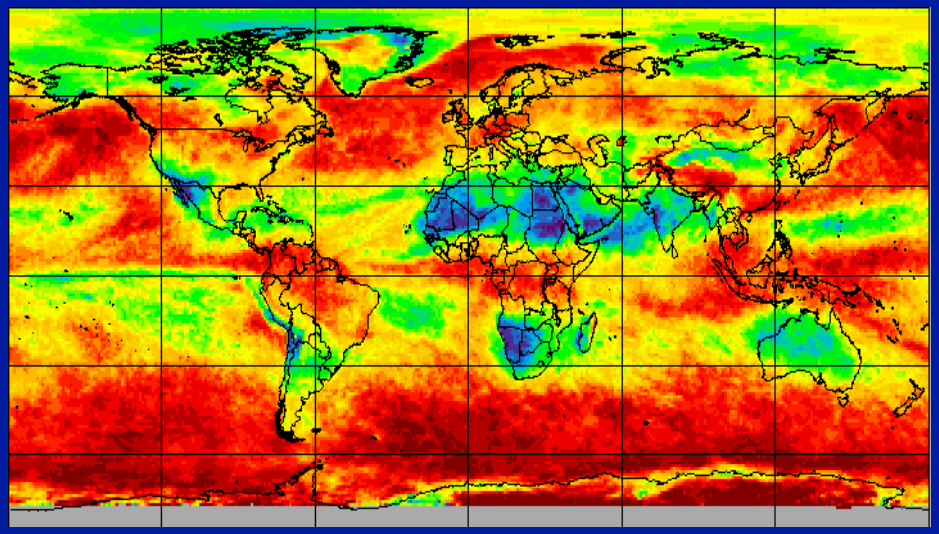
- Attempt to make retrievals consistent across platforms
  - VIS calibrations implemented
  - do not use CO2 channels: not on all GEOSats
  - basic 0.65-3.75-11 μm retrievals

Mean Cloud Fraction, April 2013, day

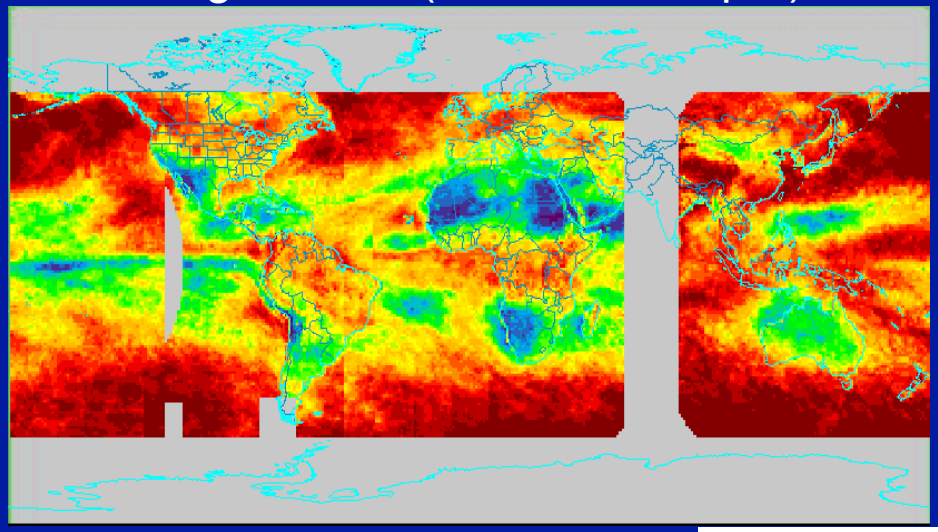
CM Ed4 - Aqua



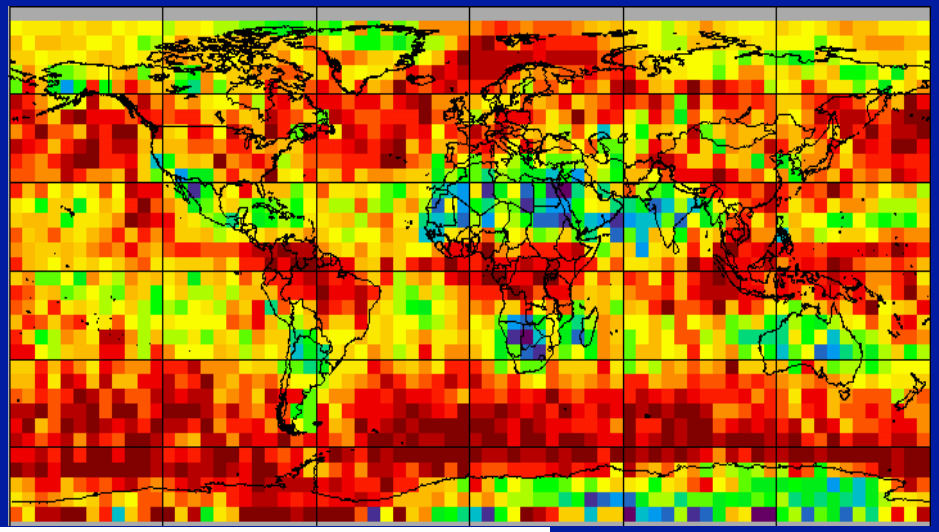
NPP VIIRS Ed1

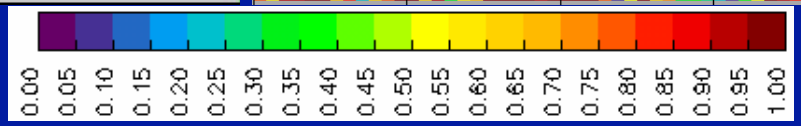


Merged GEO (local time 1-3pm)



CALIPSO VFM – no 80 km

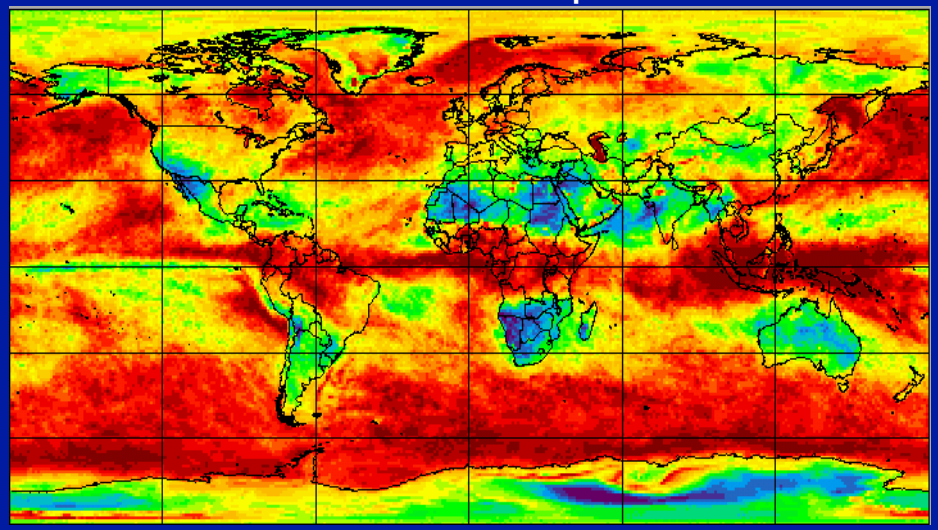




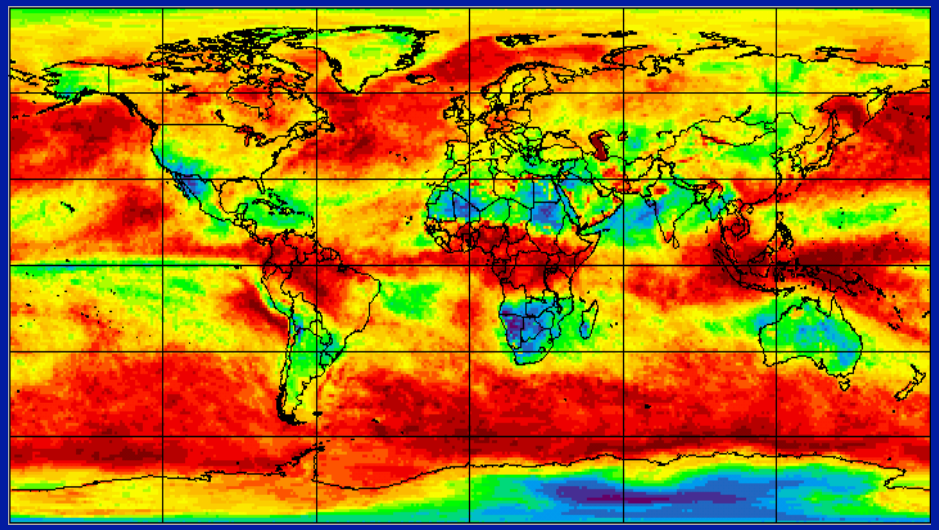
GEO day tropical underdetecting
Mid-lat ocean too large, VZA?

Mean Cloud Fraction, April 2013, night

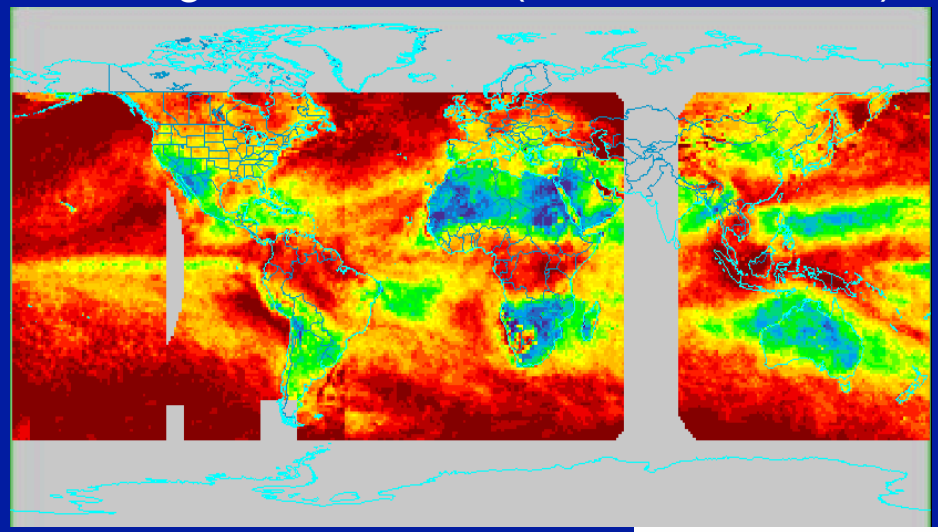
CM Ed4 - Aqua



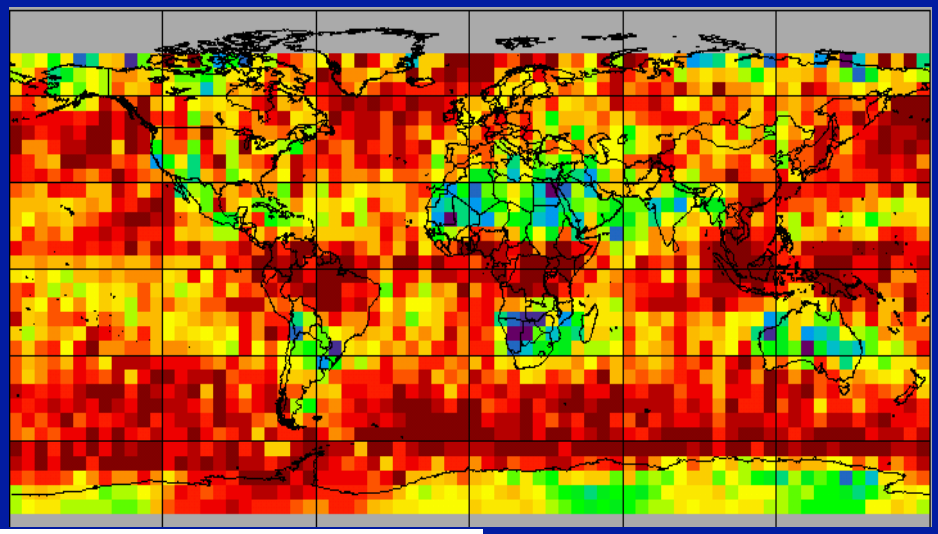
NPP VIIRS Ed1

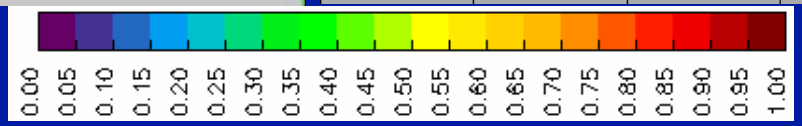


Merged GEO Filter (local time 1-3am)



CALIPSO VFM – no 80 km



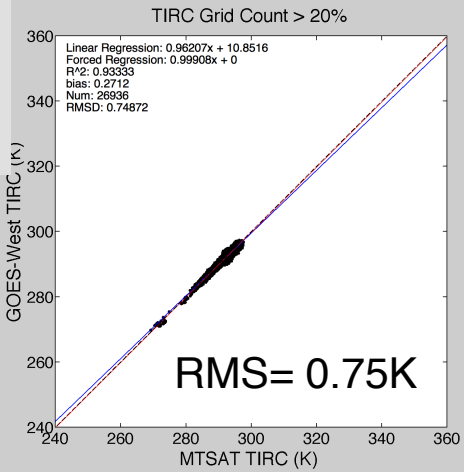


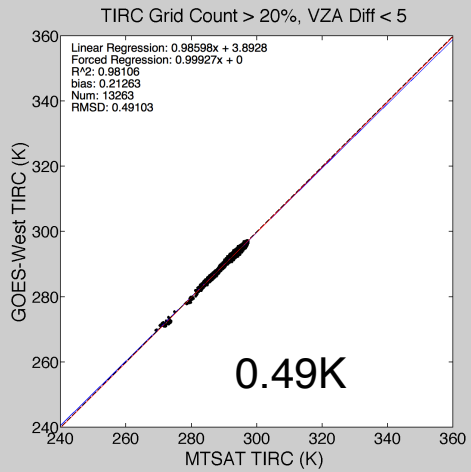
GEO nighttime ocean ~ 3-5% over-detecting

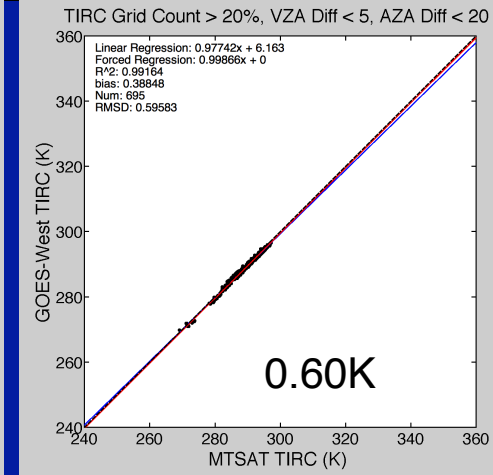
Surface Skin Temperature

- Skin temperature determines clear OLR in SARB products
- Measure of consistency among the satellites
- 1°x1° matching during April 2013
  - 20% of pixels must be clear
  - minimum of 13 samples
- Use overlap regions for
  - GOES-West/MTSAT-2
  - GOES-East/GOES-West
  - MSG/GOES-East
- Angular conditions
  - no constraints
  - matched VZA to ± 5°
  - matched VZA to ± 5° and AZA to ± 20°

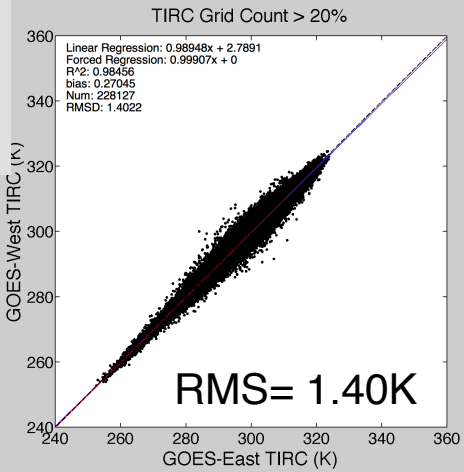
GOES-W Vs MTSAT

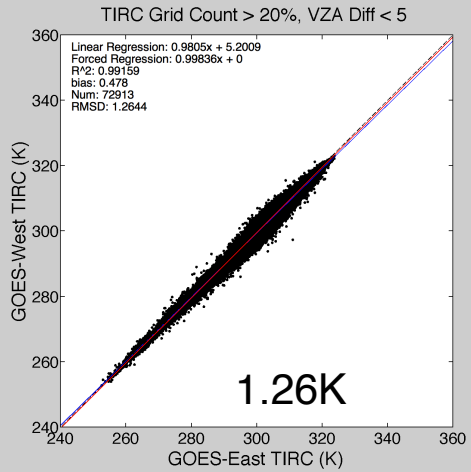


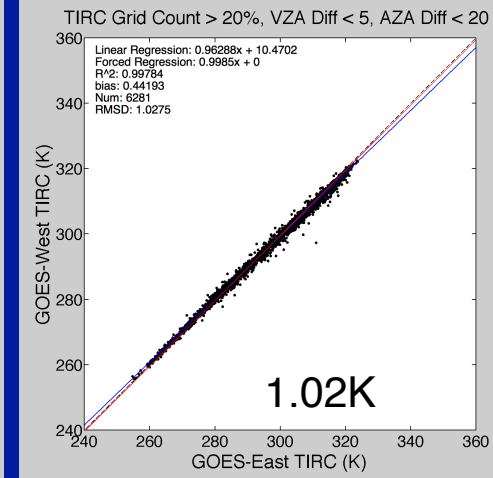




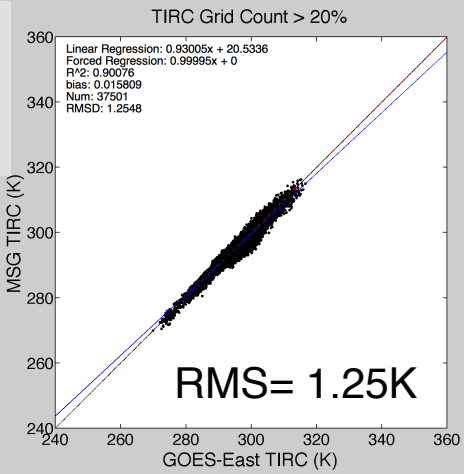
GOES-W Vs GOES-E

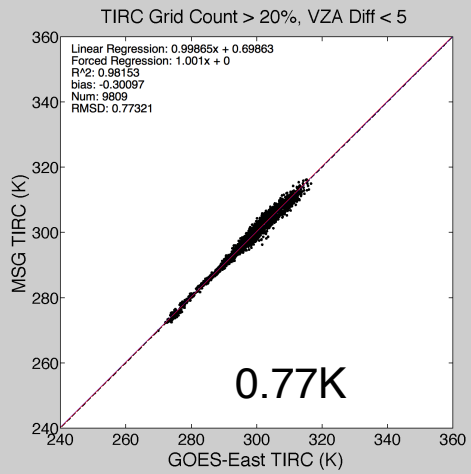


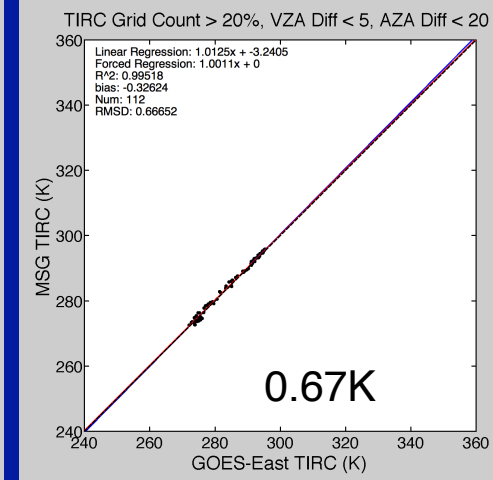




MSG Vs GOES_E





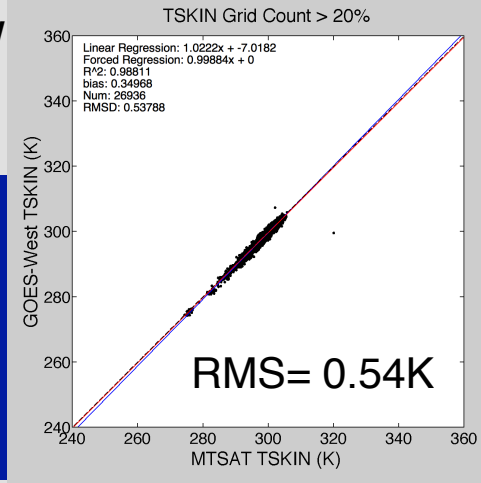


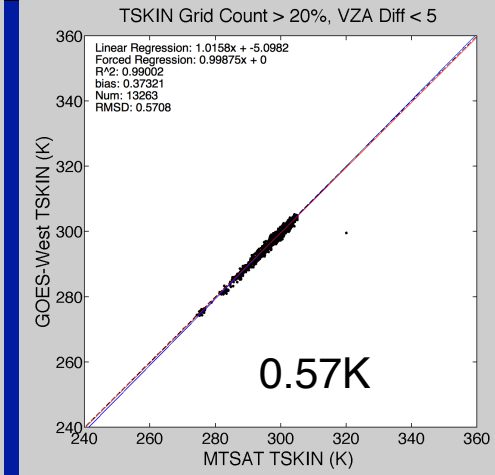
TOA Tclr

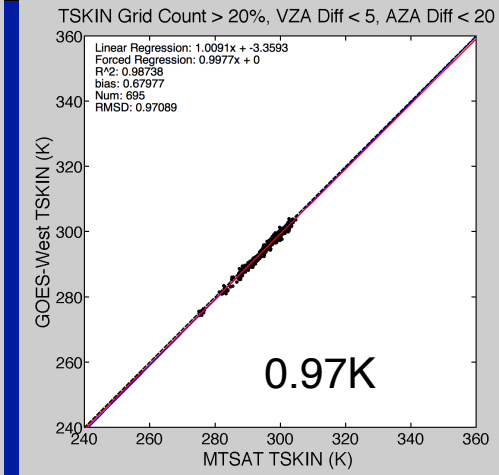
GOES-W Vs MTSAT

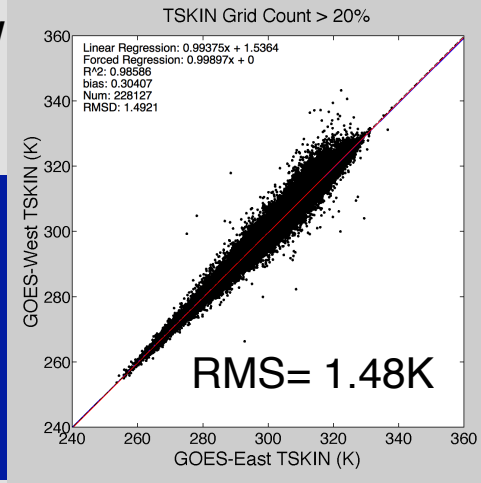
GOES-W Vs GOES-E

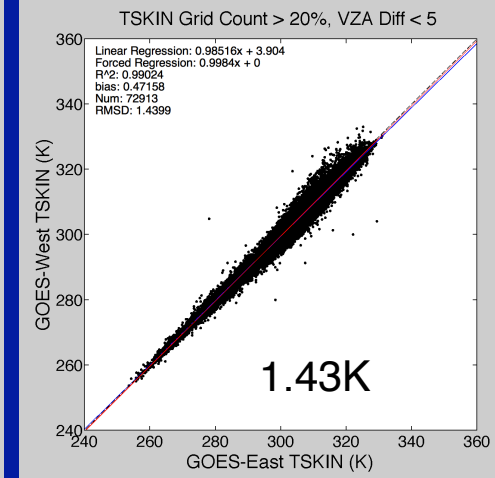
MSG Vs GOES_E

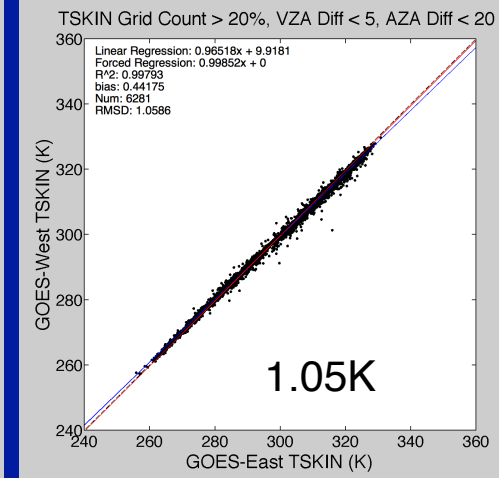


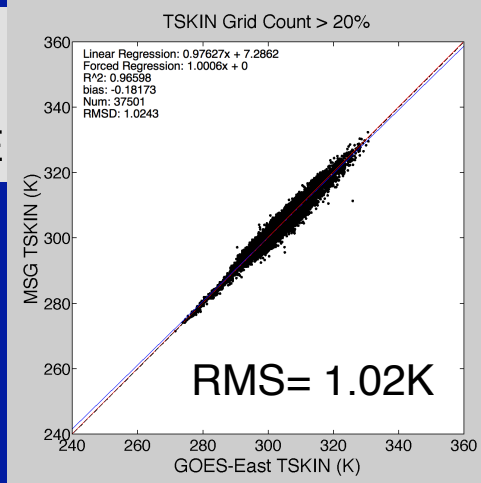


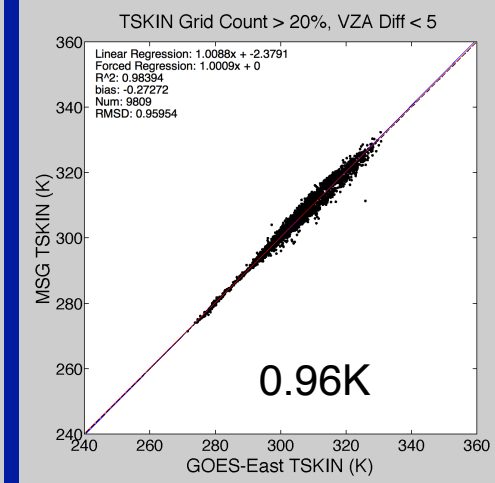


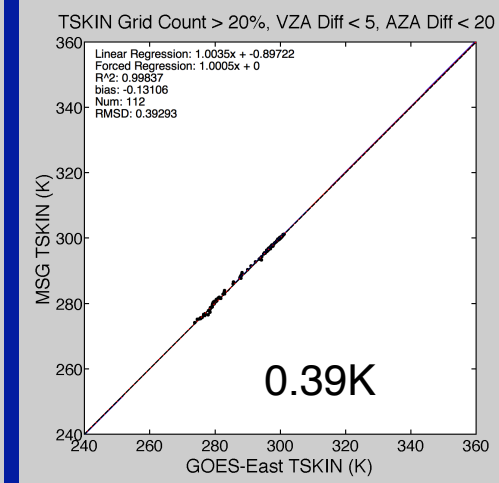






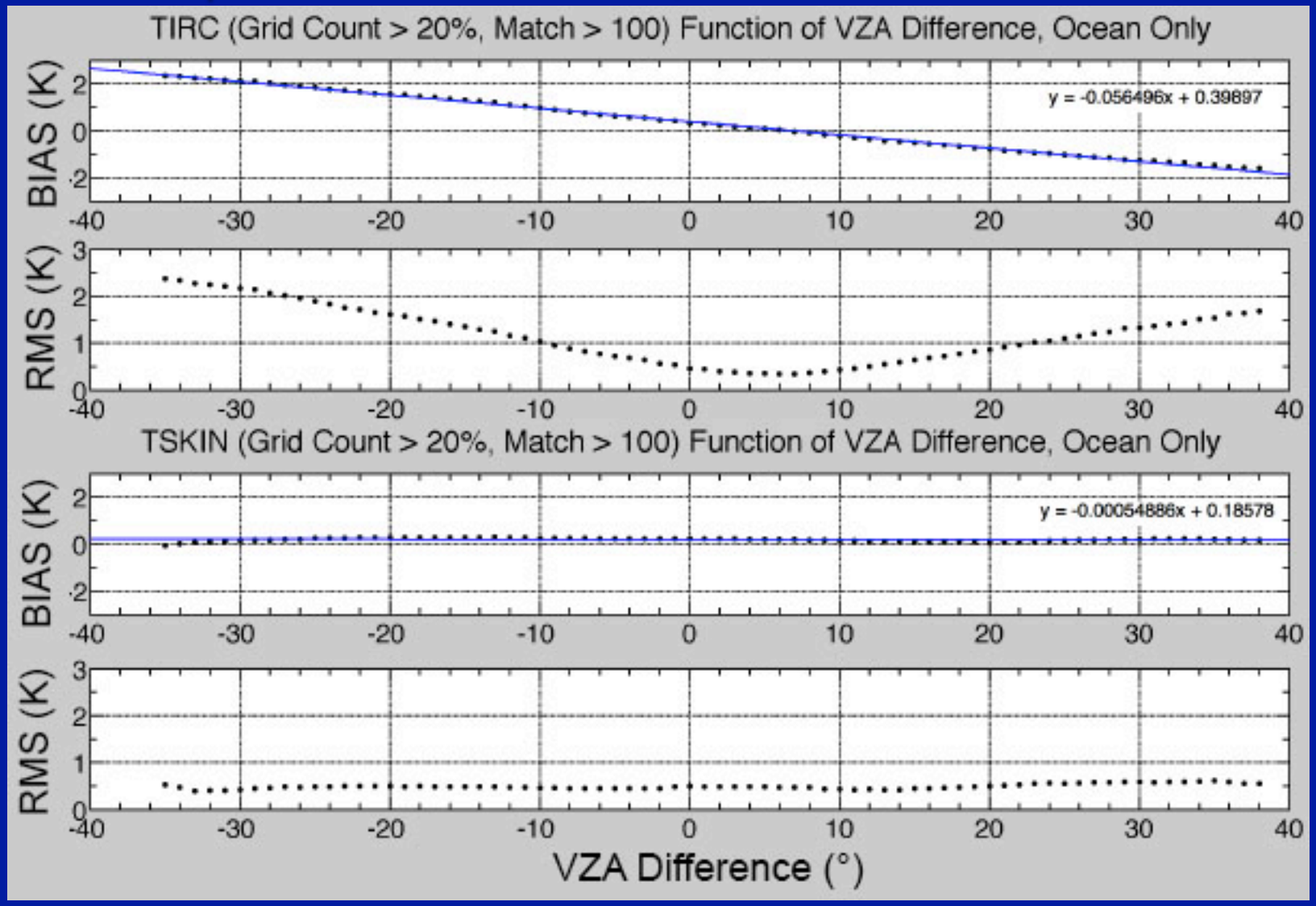






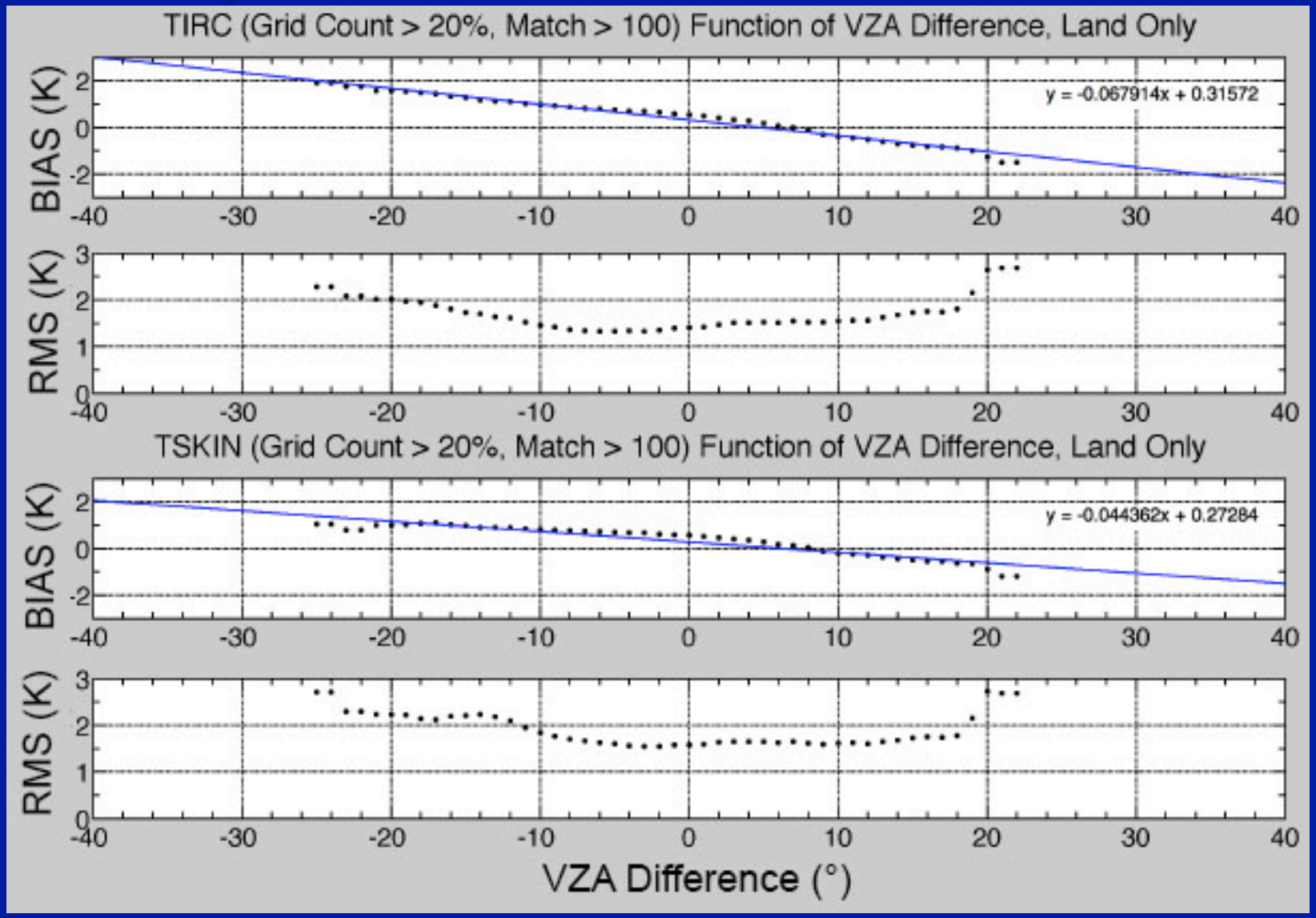
Tskin

Clear Temperature Differences, GOES-E – GOES-W, Ocean



- Atmospheric correction & surface emissivity model minimize bias & RMS
- Intercalibration of IR channels needed: ~0.25 K
- Similar results with MSG/GOE-E & GOES-W/MTSAT

Clear Temperature Differences, GOES-E – GOES-W, Land



- Atmospheric correction slightly reduces bias & RMS
- Surface emissivity VZA model needs to minimize bias & RMS
- Similar results with MSG/GOE-E

Skin Temperature Results

- Initial results indicate likely IR calibration differences in GEOSat IR channels
  - affects cloud detection, especially over ocean
  - intercalibrations TBD
- Ocean VZA-dependent emissivity model removes angular dependence
  - Thanks Zhonghai Jin!
- Land VZA-dependent model needed
  - Initial empirical model developed using Meteosat & MODIS
    - *reduces biases compared to surface Tskin by 15-60%*
    - *reduces RMS in dual-angle comparisons by 15%*

Summary

- Aqua cloud mask gets it right 90% of the time, tradeoffs for misclassified pixels=> only small bias in cloud fraction wrt CALIPSO (ignore 80-km clouds)
  - Aqua & Terra very consistent in Ed4
  - VIIRS Ed1 nearly identical: more clouds in tropics, fewer in Arctic
    - *polar night is the big difference*

- Aqua and VIIRS cloud phase very similar, but VIIRS tends to detect fewer water clouds in polar night *- any remedy for this in next Edition*

- VIIRS cloud heights: 0.15 km (water) > Aqua, 0.4 km (ice) > Aqua
  - *if true Ztop desired, use thick ice correction for MODIS Ed4*
  - *thin ice cloud heights too low in day: need lower tau (same as Aqua)*

- VIIRS optical depths > Aqua, especially in polar regions
  - *thin ice cloud tau ~0.5 of CALIPSO value => need new ice models*

- VIIRS Re(liq) < Aqua, Re(ice) ~ Aqua

- VIIRS ML clouds < Aqua, mainly in storm tracks => *UL Ztop higher, tau lower*

- Validation efforts lend confidence to the results

Future

- Refine VIIRS polar night mask

- Continue work with SARB & TISA to improve TOA flux consistency, esp. GEOsats
  - *what parameters to use from SSF? Peff? Ptop?*
  - *what IWC profiles to use in OLR computations?*

- Quantify uncertainties and try to understand 1.24-µm and 1.6/2.1-µm retrievals
  - *provide new models for Ed5*

- Continue testing new P Yang 2-habit ice crystal model to reduce ice COD error
  - Ed5
- Continue validation & normalization efforts to determine changes for Ed5
  - *Ztop in all clouds*
  - *tau, IWP, LWP in thick clouds*
  - *ML clouds!!*
  - *clouds over snow (ARM, Greenland, ARISE)*
  - *GEOSat calibrations*
  - *edge pixel treatment*

- Document Ed4 & NPP Ed1
  - 1st draft of DQS complete