CERES Cloud Properties: Ed4, SNPP & GEO

P. Minnis, D. Doelling (calibration)

NASA Langley Research Center, Hampton, VA, USA

S. Sun-Mack (lead), Q. Trepte (mask), F-L. Chang (CO2, ML), T. Chee (web, DM), R. Arduini (RTM), K. Bedka (OT tops, AVHRR), S. Bedka (SIST), R. Brown (QC), Y. Chen (clr props, test runs), S. Gibson (graphics), E. Heckert (web, IG), G. Hong (night tau), M. Khaiyer (val), R. Palikonda (GEO), B. Scarino (cal), R. Smith (web, NPP), D. Spangenberg (polar), C. Yost (phase)

SSAI, Hampton, VA, USA

P. W. Heck (retrieval algo)

CIMSS, U. Wisconsin, Madison, Wi, USA

P. Yang (ice model)

Texas A&M, College Station, TX, USA

CERES Science Team Meeting, Newport News, VA, 7-9 May 2013

Topics

- **Publications**
- **Terra/Aqua** – Ed2, Ed4 in process
- **NPP** – Ed1, June 2013
- **GEOSat** – Ed 1, June 2013

Update of CERES Cloud-related Papers since Oct 2012

Edition-2 related

Stubenrauch, C., W. B. Rossow, S. Kinne, S. Ackerman, G. Cesana, H. Chepfer, B. Getzewich, L. DiGirolamo, A. Guignard, A. Heidinger, B. Maddux, P. Menzel, P. Minnis, C. Pearl, S. Platnick, C. Poulsen, J. Riedi, S. Sun-Mack, A. Walther, D. Winker, S. Zeng, and G. Zhao, 2012: Assessment of global cloud datasets from satellites: Project and database initiated by the GEWEX Radiation Panel. In press, *Bull. Am. Meteorol. Soc.*

Giannechinni, K., X. Dong, B. Xi., A. Kennedy, P. Minnis, and S. Kato, 2012: Comparison of CERES-MODIS Edition-2 cloud properties with CloudSat/CALIPSO and ground-based measurements at the DOE ARM North Slope of Alaska site. Submitted, *J. Geophys. Res.*

Yan, H., J. Huang, P. Minnis, Y. Yi, S. Sun-Mack, T. Wang, and T. Nakajima, 2012: Comparison of CERES-MODIS cloud microphysical properties with surface observations over the Loess Plateau. Submitted to *Remote Sens. Environ.*

Edition-4/5 related

Doelling, D. R., B. R. Scarino, D. Morstad, A. Gopalan, R. Bhatt, C. Lukashin, and P. Minnis, 2013: The calibration of visible imagers using operational hyperspectral SCIAMACHY radiances. *IEEE Trans. Geosci. Remote Sens.*, **51**, 1245-1254, doi:10.1109/TGRS.2012.2227760.

Scarino, B., P. Minnis, R. Palikonda, R. Riechle, D. Morstad, C. Yost, B. Shan, and Q. Liu, 2013: Deriving surface skin temperature for NWP applications using global geostationary satellite data. *Remote Sens.*, **5**, 342-366, doi: 10.3390/rs5010342.

Painemal, D., P. Minnis, and L. O'Neill, 2013: The diurnal cycle of boundary layer height and cloud cover over the Southeast Pacific as observed by GOES-10. *J. Atmos. Sci.*, in press.

Hong, G. and P. Minnis, 2013: Effects of inclusions on scattering properties of small ice cloud particles. *J. Quant. Spectros. Rad. Transfer*, submitted.

Update of CERES Cloud-related Papers, etc.

Edition-4 related

Sun-Mack, S., P. Minnis, Y. Chen, S. Kato, Y. Yi, S. Gibson, P. W. Heck, and D. Winker, 2013: Global cloudy boundary layer apparent lapse rates determined from CALIPSO and MODIS data. Submitted, *J. Appl. Meteorol. Climatol.*

Conferences & Other

Stubenrauch, C., W. B. Rossow, S. Kinne, S. Ackerman, B. Baum, G. Cesana, H. Chepfer, B. Getzewich, L. DiGirolamo, M. Foster, A. Guignard, A. Heidinger, B. Maddux, P. Menzel, A. Menzies, E. Olson, P. Minnis, F. Parol, C. Pearl, R. Pincus, S. Platnick, C. Poulsen, J. Riedi, A. Sayer, S. Sun-Mack, et al., 2013: Assessment of global cloud datasets from satellites. *World Climate Res. Prog. GEWEX Radiation Panel*, WCRP Report No. 23/2012, November, 176 pp.

Painemal, D. and P. Minnis, 2012: Satellite-based investigation of the boundary layer diurnal cycle over the Southeast Pacific. *AGU Fall Mtg 2012*, 3-7 December, San Francisco, CA, A23C-0236.

Palikonda, R., P. Minnis, T. Chee, K. Bedka, L. Nguyen, M. L. Nordeen, and B. Shan, 2012: Development of a near real time global geostationary cloud and radiation product. *AGU Fall Mtg 2012*, 3-7 December, San Francisco, CA, IN41B-1495.

Yost, C. R., P. Minnis, Q. Trepte, R. Palikonda, J. K. Ayers, and D. A. Spangenberg, 2012: Using information from prior satellite scans to improve cloud detection near the day/night terminator. *AGU Fall Mtg 2012*, 3-7 December, San Francisco, CA, A11B-0040.

Loeb, N., D. R. Doelling, S. Kato, D. P. Kratz, P. Minnis, K. J. Priestley, P. W. Stackhouse, W. Su, and T. Wong, 2013: Overview of the Clouds and the Earth's Radiant Energy System (CERES). *9th AMS Ann. Symp. Future Operational Environ. Satellite Systems*, Austin, TX, January 6-10.

Doelling, D., K. Khlopenkov, A. Okuyama, and P. Minnis, 2013: Development of the MTSAT-1 visible footprint point spread function. *GSICS Ann. Mtg.*, Williamsburg, VA, Mar. 4-8.

Minnis, P., K. Bedka, R. Palikonda, Q. Trepte, P. Heck, B. Scarino, S. Bedka, C. Yost, R. Bhatt, A. Gopalan, K. Khlopenkov, G. Hong, and D. Doelling, 2013: A CERES-consistent cloud property and surface temperature climate data rcord using AVHRR data. *NOAA 2013 Satellite Conf. Direct Readout, GOES/POES, and GOES-R/JPSS Users*, College Park, MD, April 8-12.

Scarino, B., P. Minnis, R. Palikonda, C. Yost, B. Shan, R. Reichle, and Q. Liu, 2013: Surface skin temperature from geostationary satellite data. *NOAA 2013 Satellite Conf. Direct Readout, GOES/POES, and GOES-R/JPSS Users*, College Park, MD, April 8-12.

Cloud Parameters in CERES Edition 2

Cloud Mask, Phase
Optical Depth, IR emissivity
Effective Radius/Diameter
Liquid/Ice Water Path
Cloud Effective Temperature
Cloud Top/ Bottom Pressure
Cloud Effective Pressure
Cloud Effective Height
Clear-sky Temperature

All data only available in SSF or 1° averages

New Cloud Parameters in CERES Edition 4

New Size Retrievals
Water droplet eff radius (1.24 μm)
Ice effective radius (1.24 μm)
Water droplet eff radius (2.1 μm)
Ice effective radius (2.1 μm)

CO2 Slicing
Cloud Top Pressure
Cloud Top Temperature
Cloud Top Height
IR Emissivity

Multilayer Cloud Retrieval (Ice Over Water)

Multilayer Identification

Upper Layer (Ice Clouds)	Lower Layer (Water Clouds)
Cloud Top Pressure	Cloud Top Pressure
Cloud Top Temperature	Cloud Top Temperature
Cloud Top Height	Cloud Top Height
Cloud Visible Optical Depth	Cloud Visible Optical Depth
Ice Effective Radius (3.7 μm)	Water Droplet Radius (3.7 μm)
Ice Effective Radius (2.1 μm)	Water Droplet Radius (2.1 μm)

All data available in SSF, 1° averages, & at pixel level

MODIS Processing Status

- Ed2 processing
  - *Aqua: through February 2013, will continue until ED4 ADMs completed*
  - *Terra: through February 2013, will continue until Ed4 ADMs completed*

- Ed4 re-delivered in February: known as Ed4 Beta-2, based on Coll. 5 data
  - *Revised boundary layer lapse rates*
  - *CO2-slicing bug fixed*

MODIS Edition-4 beta 2

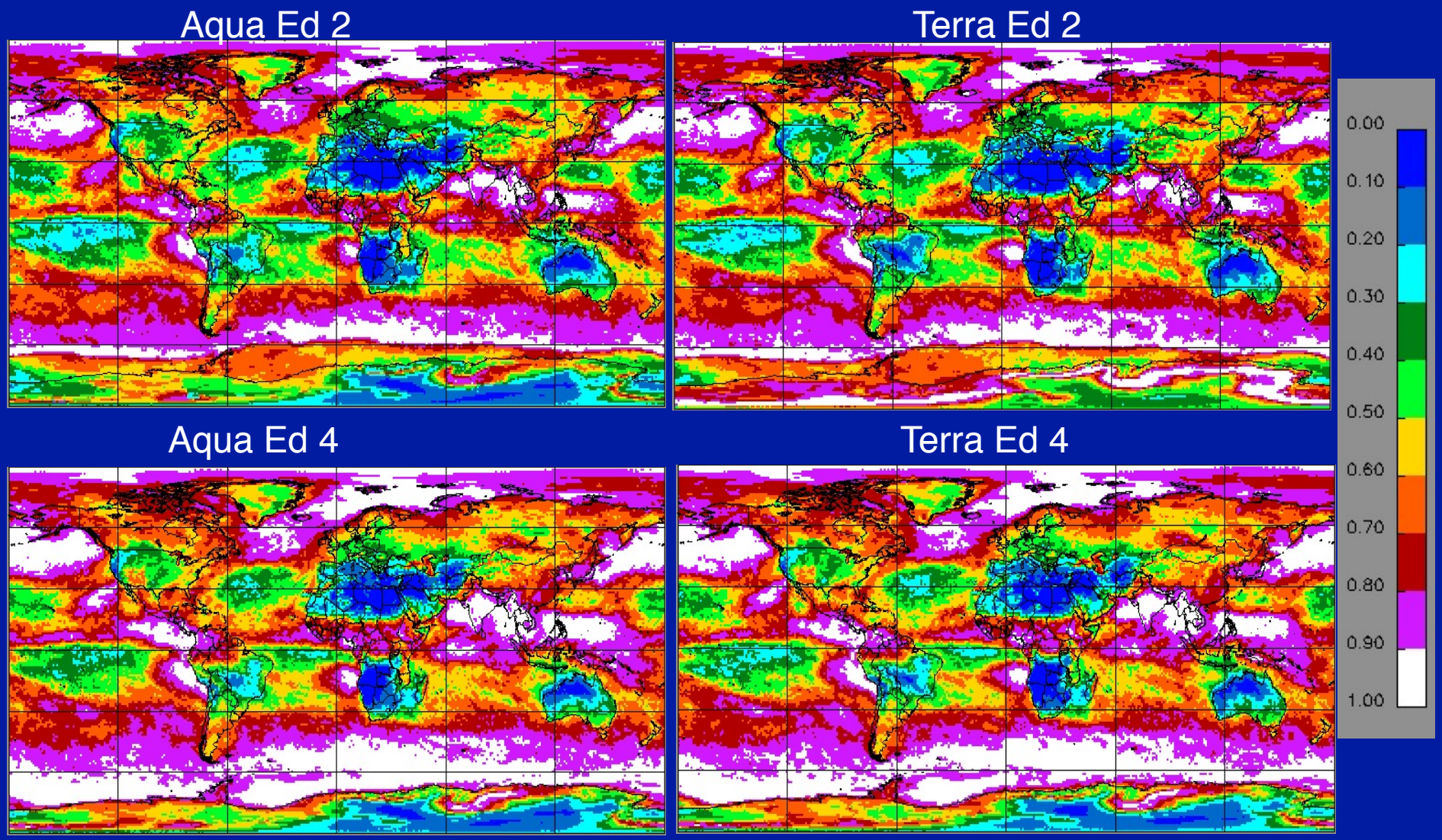
- Mistake in use of MODIS cloud top temperatures in derivation of lapse rates

  - lapse rates rerun
  - reran independent dataset and performed comparisons with other methods
  - CERES regional approach most accurate to date

- CO_2 code bug discovered and corrected

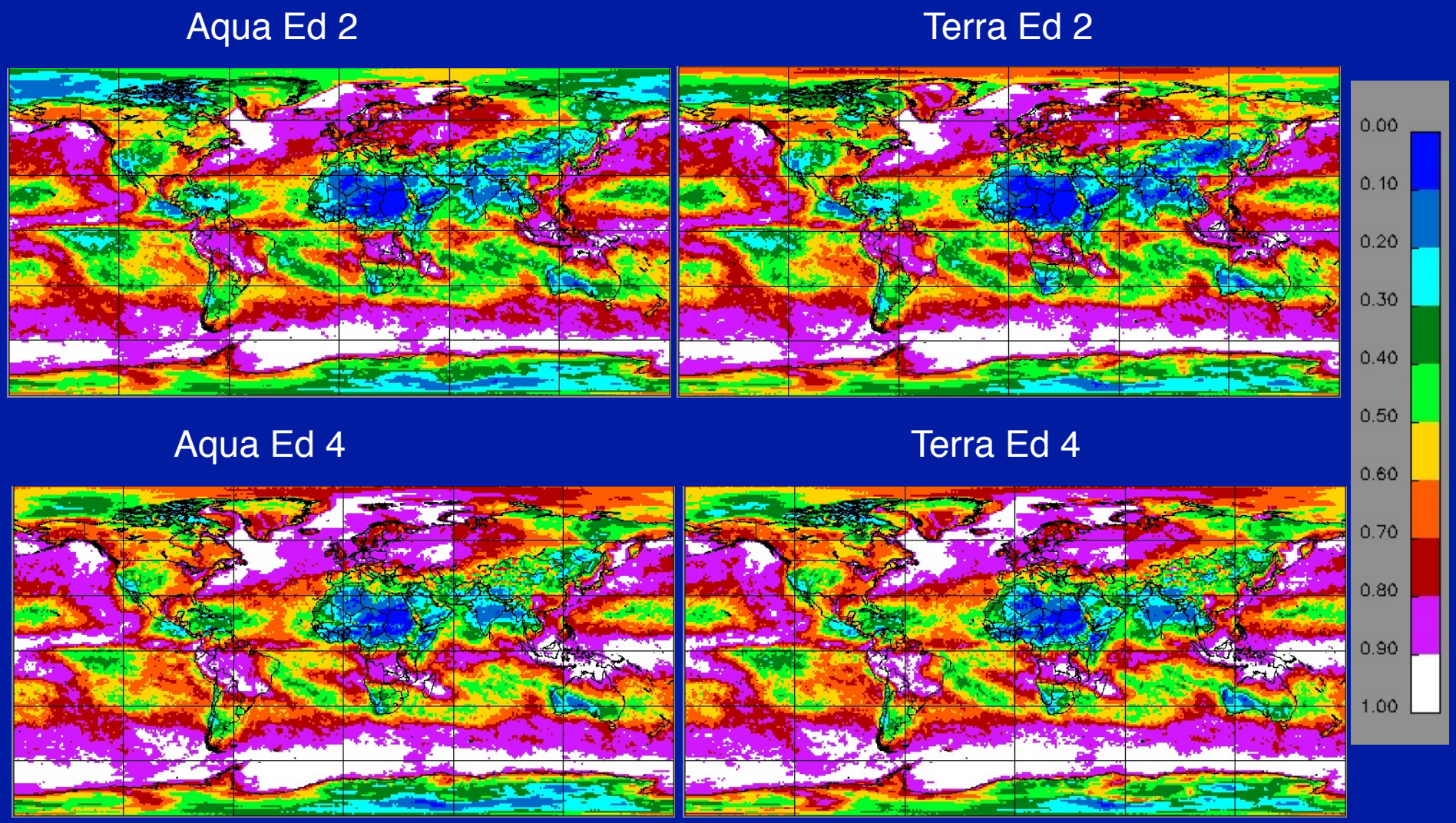
  - much improved, multilayer fraction

MODIS Total Cloud Amounts, June 2006



- Alteration of Terra 3.7-μm Collection-5 calibration seems to have worked well for polar night, Aqua and Terra now very similar in Antarctica

MODIS Total Cloud Amounts, January 2007



- Alteration of Terra 3.7-μm Collection-5 calibration seems to have worked well for polar night, Aqua and Terra now very similar in Arctic

Low Cloud Heights

- Ed2 used 7.1 K/km lapse rate anchored to surface to assign cloud height below 700 hPa

  - Minnis et al. (2011)

- Ed3 would have used zonal mean lapse rate based on MODIS-CALIPSO data

  - Minnis et al. (2010)

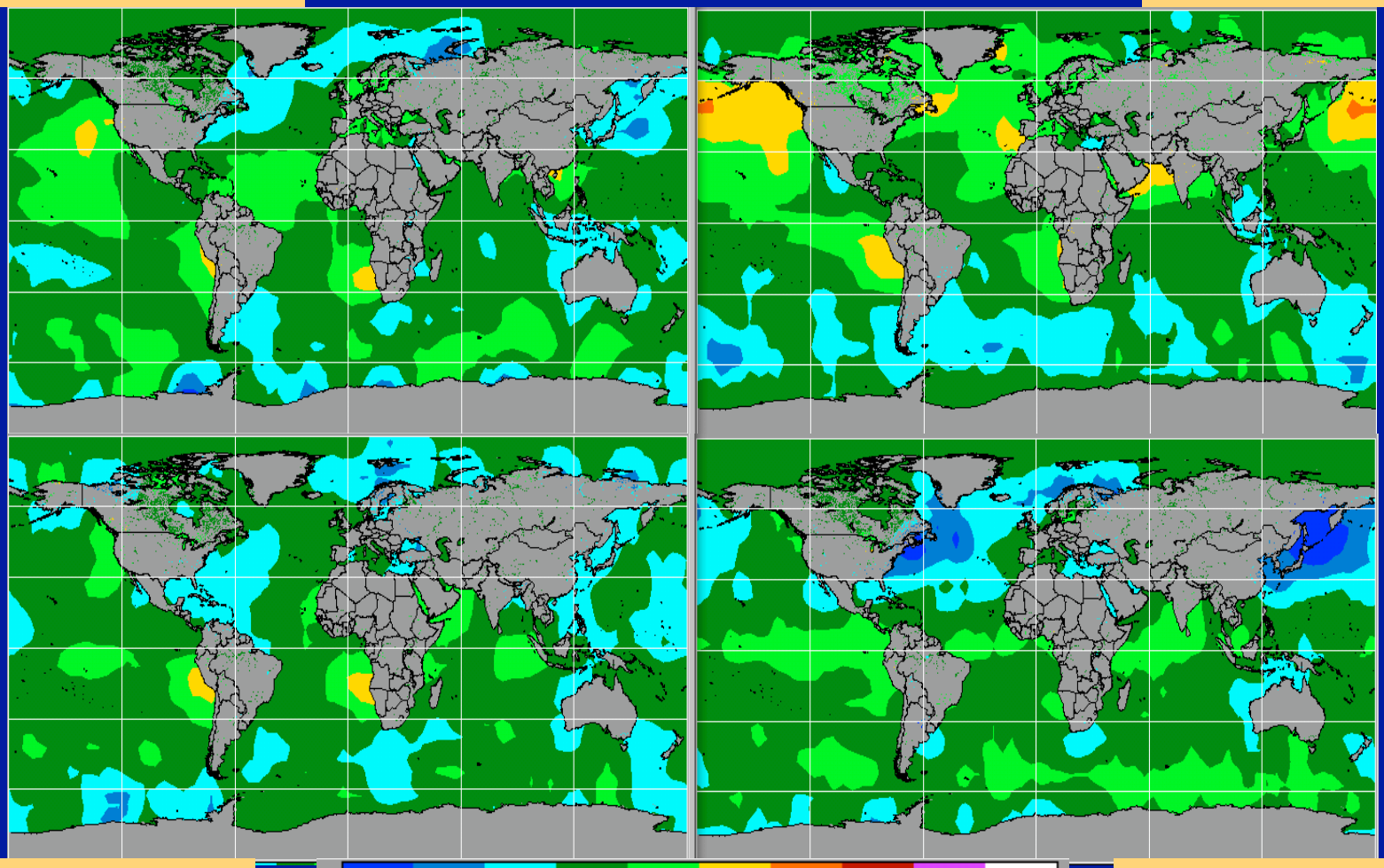
- Ed4 uses regional lapse rates based on MODIS-CALIPSO data

  - Sun-Mack et al. (2013)

Daytime boundary layer lapse rates (K km^{-1}) over snow/ice-free scenes
Ed-4 Beta1, July 2006 - June 2007

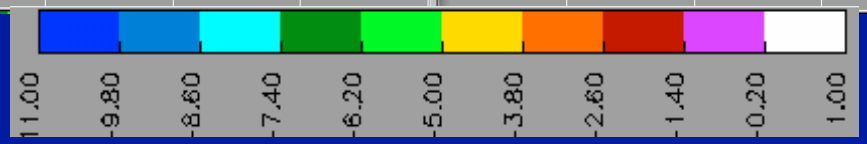
Spring (Mar,Apr,May)

Summer (Jun,Jul,Aug)

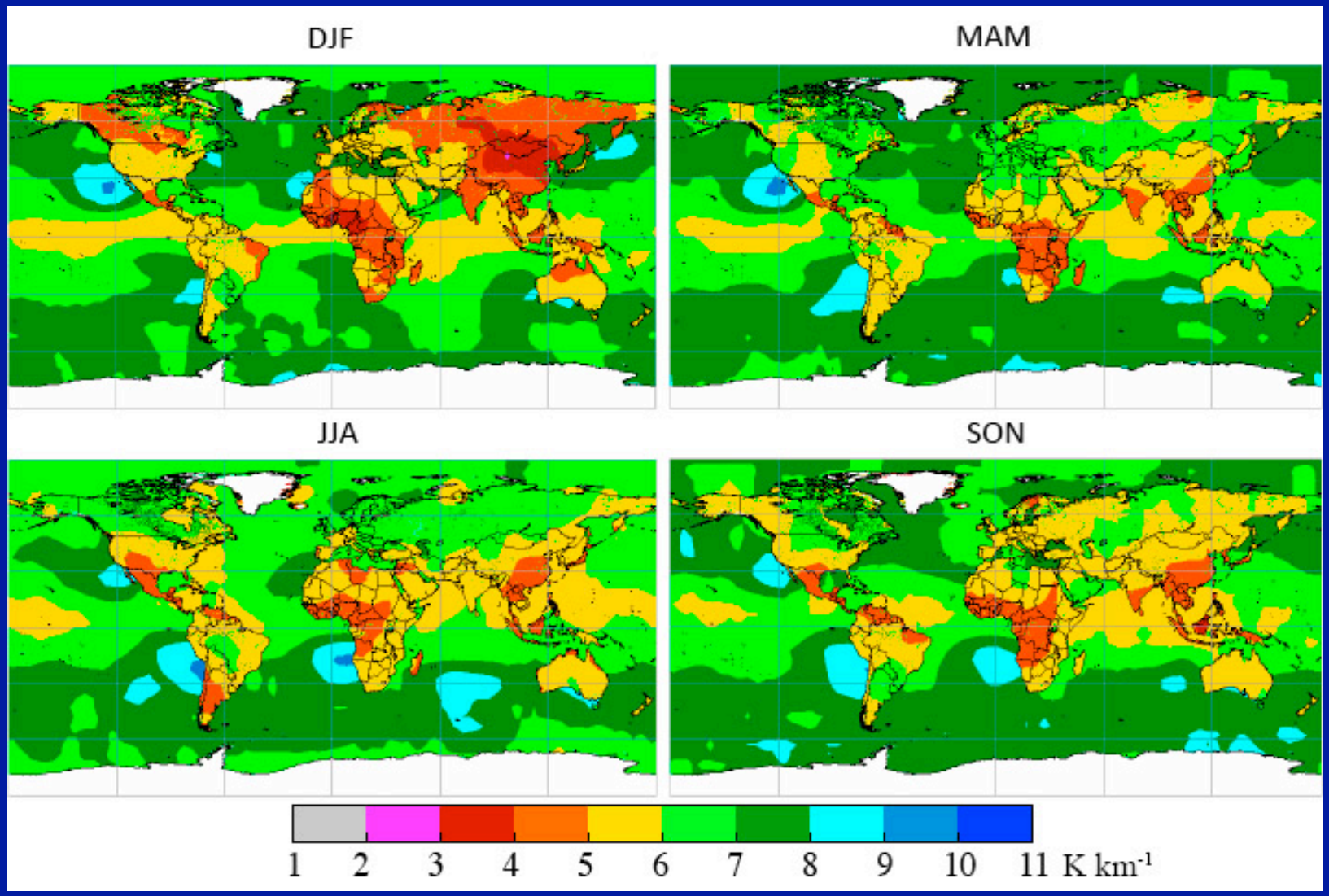


Fall (Sep,Oct,Nov)

Winter (Dec,Jan,Feb)

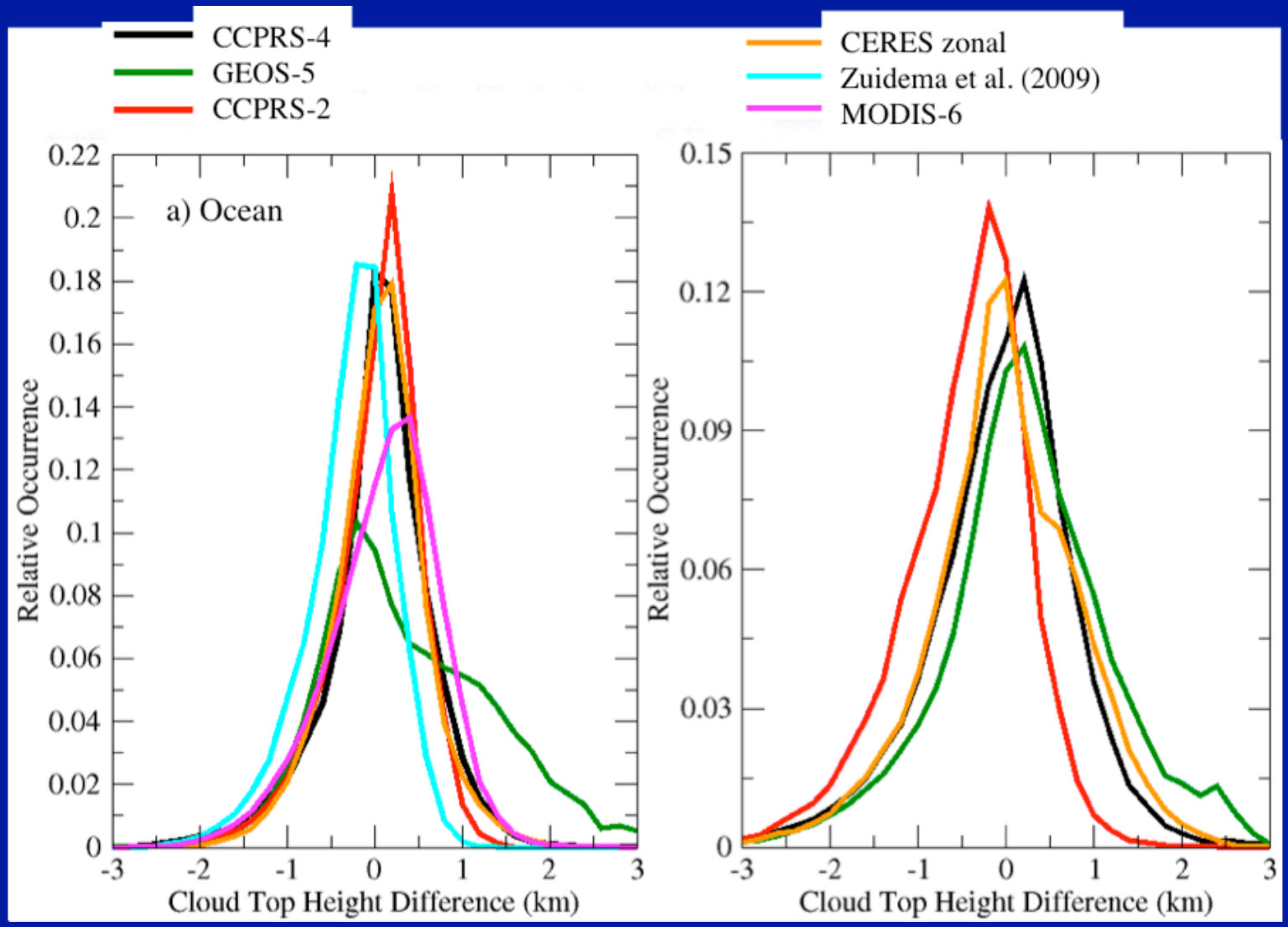


Daytime boundary layer lapse rates (K km^{-1}) over snow/ice-free scenes
Ed-4 Beta2, July 2006 - June 2007



- Gradients different from Beta1 in most cases

Daytime low-cloud top height differences, MODIS – CALIPSO, for MODIS retrievals over snow-free scenes using six methods, October 2007

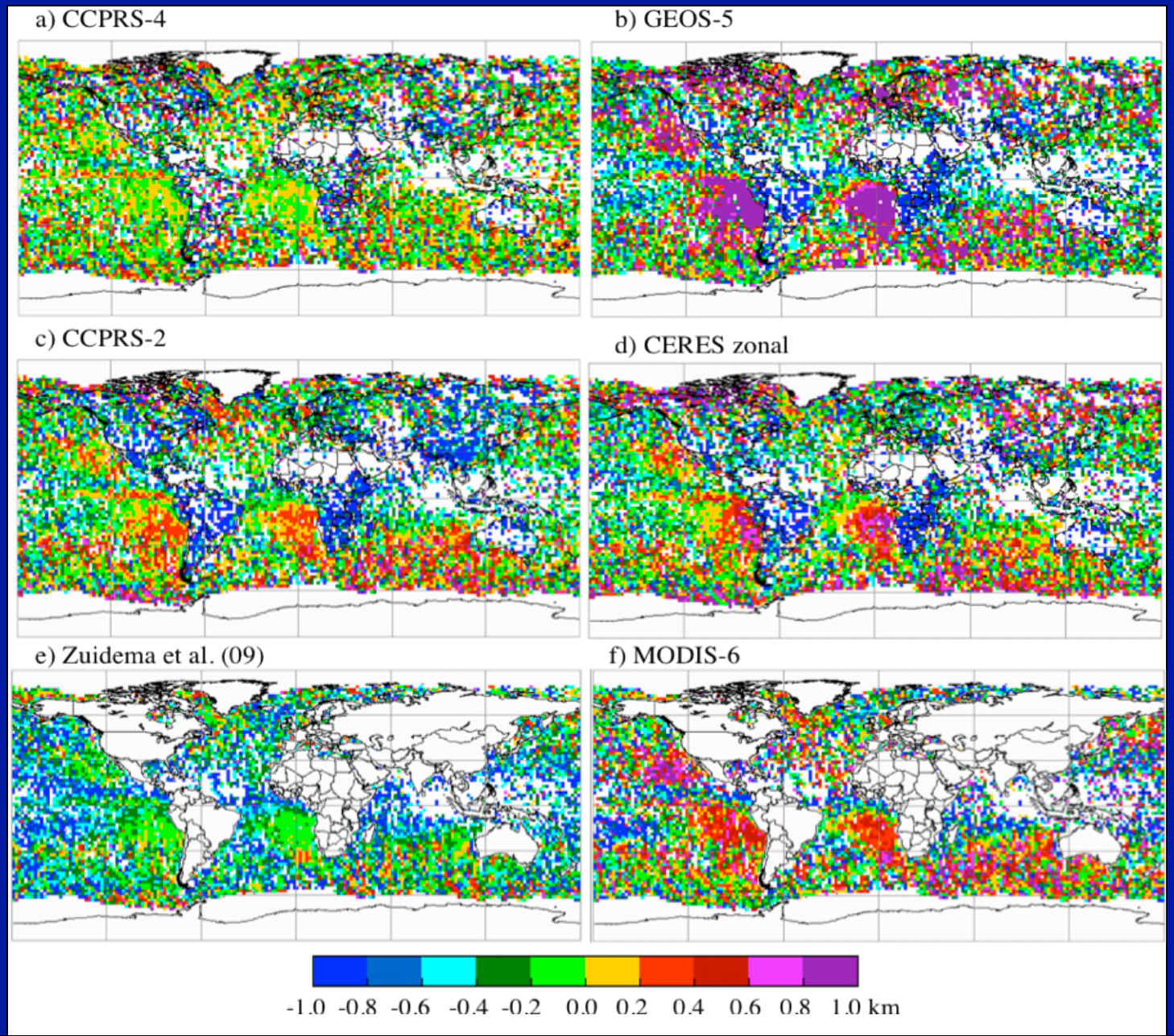


Instantaneous Low Cloud Height Difference Statistics (km)
MODIS - CALIPSO

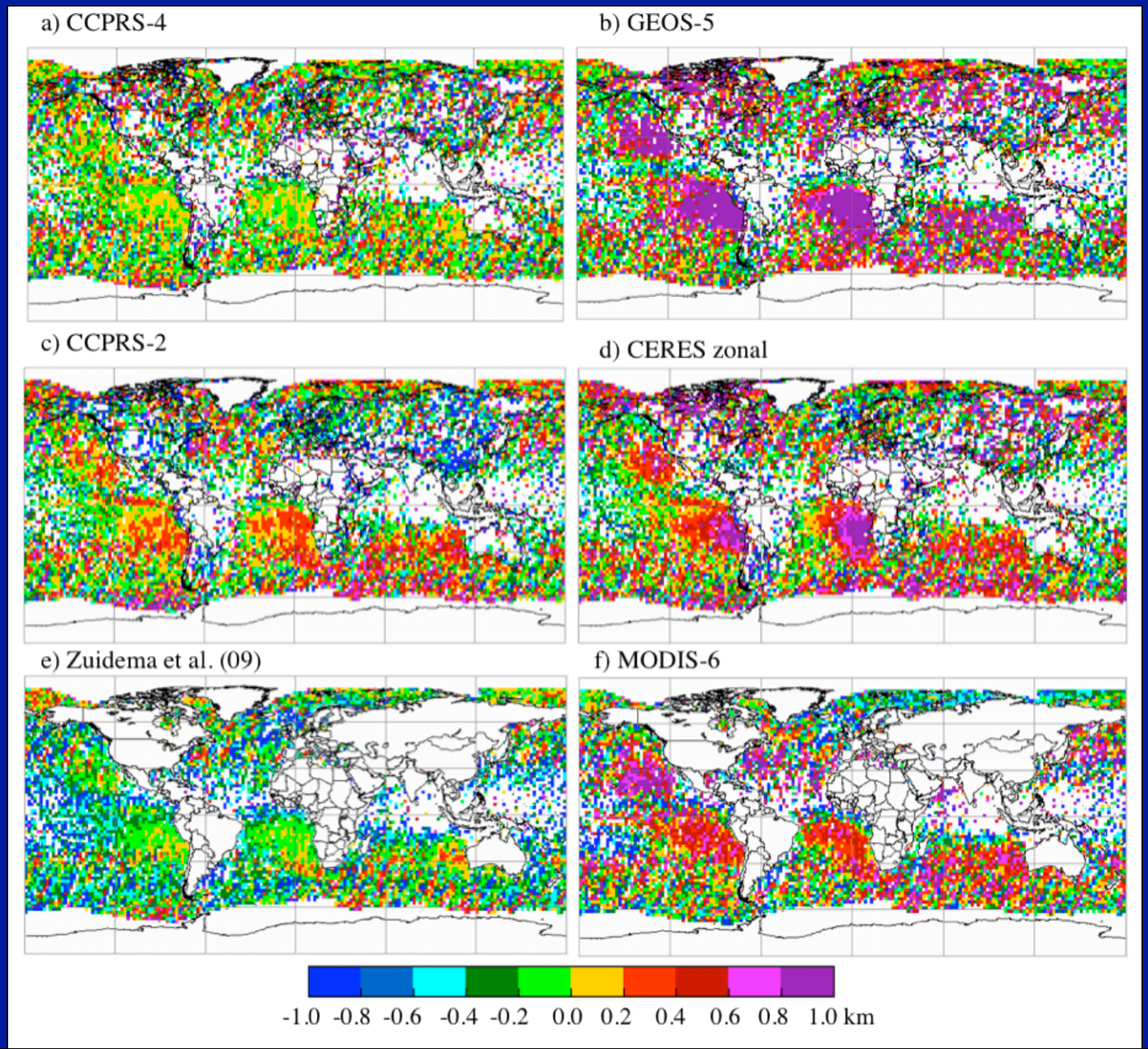
Method	Time	October 2007			January 2009		
		Snow Free		Snow Cover	Snow Free		Snow Cover
		Ocean	Land	Global	Ocean	Land	Global
CCPRS-4	Day	0.05 (0.62)	-0.06 (0.86)	0.38 (0.95)	0.03 (0.67)	-0.09 (0.95)	-0.17 (0.91)
	Night	0.10 (0.63)	-0.02 (0.82)	0.03 (0.92)	0.11 (0.69)	-0.01 (0.88)	-0.17 (0.95)
GEOS-5	Day	0.42 (0.98)	0.24 (1.03)	0.84 (1.14)	0.26 (0.89)	0.21 (1.17)	0.39 (0.93)
	Night	0.64 (0.96)	0.44 (0.98)	0.73 (1.13)	0.51 (0.89)	0.39 (1.17)	0.36 (1.13)
CCPRS-2	Day	0.12 (0.64)	-0.46 (0.82)	-0.04 (0.89)	0.02 (0.69)	-0.64 (0.92)	-0.30 (0.92)
	Night	0.23 (0.66)	-0.29 (0.79)	-0.27 (0.93)	0.17 (0.73)	-0.47 (0.86)	-0.37 (0.93)
CERES zonal	Day	0.12 (0.72)	-0.02 (0.98)	0.75 (1.15)	-0.24 (0.67)	-0.01 (1.17)	-0.21 (0.88)
	Night	0.34 (0.73)	0.29 (0.97)	0.46 (1.11)	0.03 (0.72)	-0.38 (0.88)	-0.41 (0.92)
Zuidema et al. (2009)	Day	-0.20 (0.64)			-0.27 (0.69)		
	Night	-0.07 (0.66)			-0.11 (0.73)		
MODIS-6	Day	0.16 (0.74)			0.06 (0.88)		
	Night	0.25 (0.74)			0.18 (0.88)		

- CERES Ed4 clearly most accurate overall

Regional Mean Daytime Low Cloud Height Differences (km)
Ed-4 Beta2, October 2007

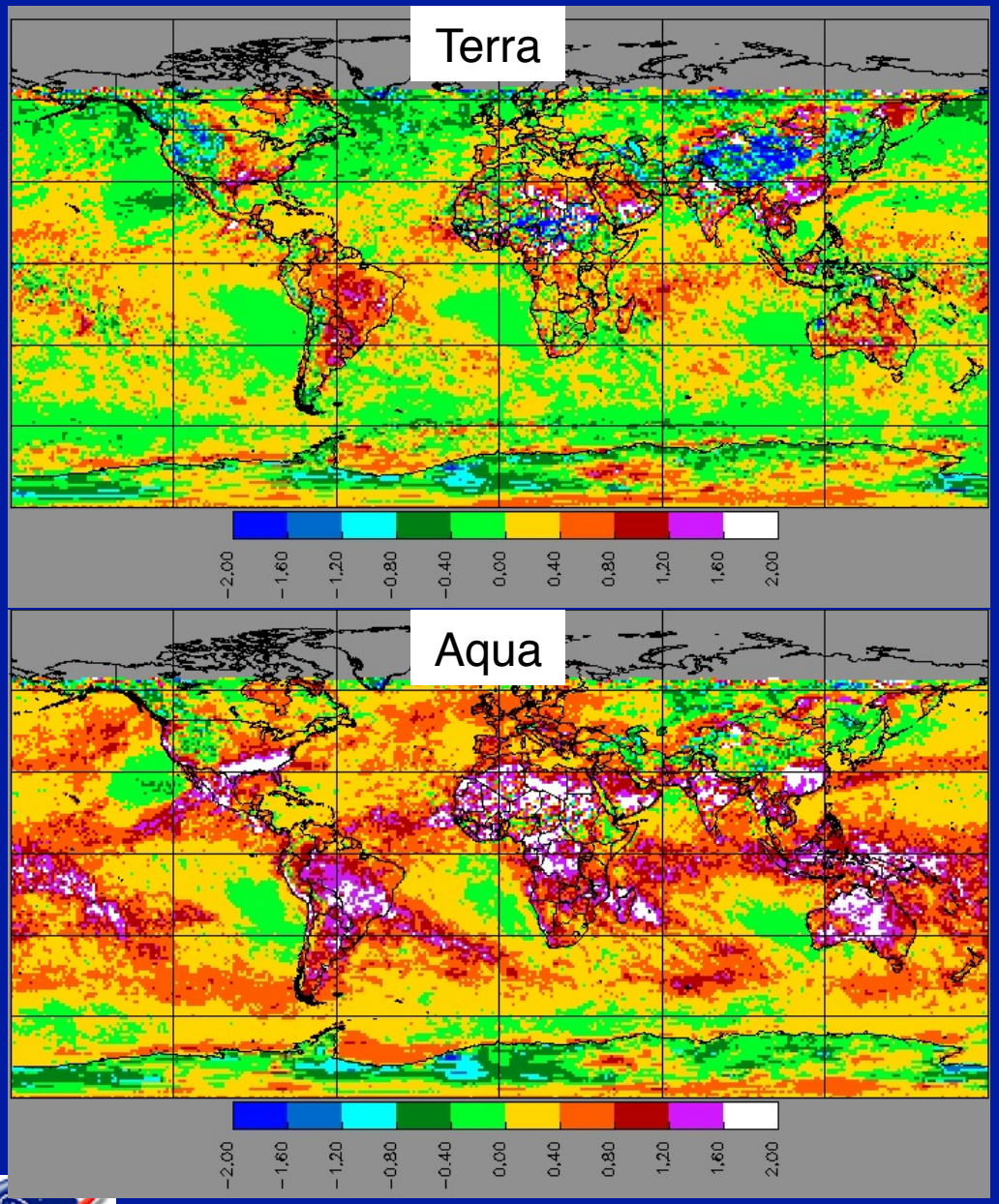


Regional Mean Nighttime Low Cloud Height Differences (km)
Ed-4 Beta2, October 2007



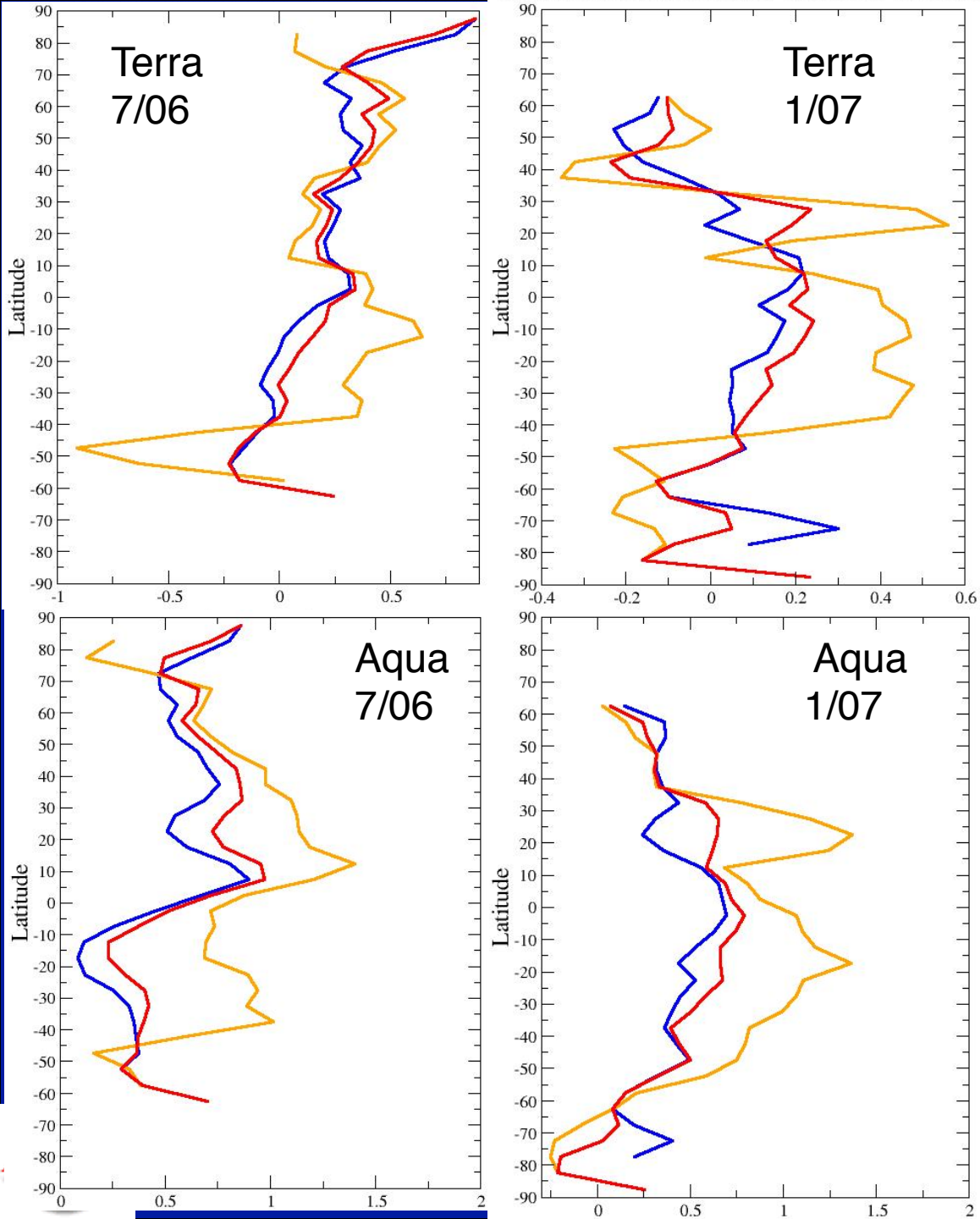
Regional Mean Low Cloud Height Difference Statistics (km)
MODIS - CALIPSO

Method	Time	October 2007			January 2009		
		Snow Free		Snow Cover	Snow Free		Snow Cover
		Ocean	Land	Global	Ocean	Land	Global
CCPRS-4	Day	-0.05 (0.44)	-0.25 (0.74)	-0.20 (0.81)	-0.05 (0.40)	-0.19 (0.82)	-0.32 (0.78)
	Night	-0.04 (0.46)	0.08 (0.77)	-0.07 (0.72)	-0.02 (0.46)	0.04 (0.85)	-0.21 (0.77)
GEOS-5	Day	0.01 (0.69)	-0.51 (0.96)	-0.25 (1.08)	-0.09 (0.62)	-0.35 (1.03)	-0.06 (0.80)
	Night	0.24 (0.68)	0.06 (0.88)	0.23 (0.81)	0.15 (0.65)	0.08 (0.97)	0.21 (0.91)
CCPRS-2	Day	-0.09 (0.48)	-0.75 (0.76)	-0.60 (0.82)	-0.12 (0.42)	-0.73 (0.78)	-0.80 (0.83)
	Night	0.00 (0.49)	-0.21 (0.79)	-0.30 (0.74)	-0.03 (0.47)	-0.29 (0.83)	-0.57 (0.83)
CERES zonal	Day	-0.06 (0.54)	-0.54 (0.92)	0.17 (0.97)	-0.33 (0.44)	-0.12 (0.96)	-0.49 (0.80)
	Night	0.09 (0.56)	0.11 (0.87)	0.26 (0.88)	-0.16 (0.47)	-0.22 (0.83)	-0.55 (0.81)
Zuidema et al. (2009)	Day	-0.41 (0.47)			-0.43 (0.44)		
	Night	-0.32 (0.48)			-0.33 (0.49)		
MODIS-6	Day	-0.10 (0.64)			-0.07 (0.71)		
	Night	0.05 (0.63)			0.10 (0.73)		



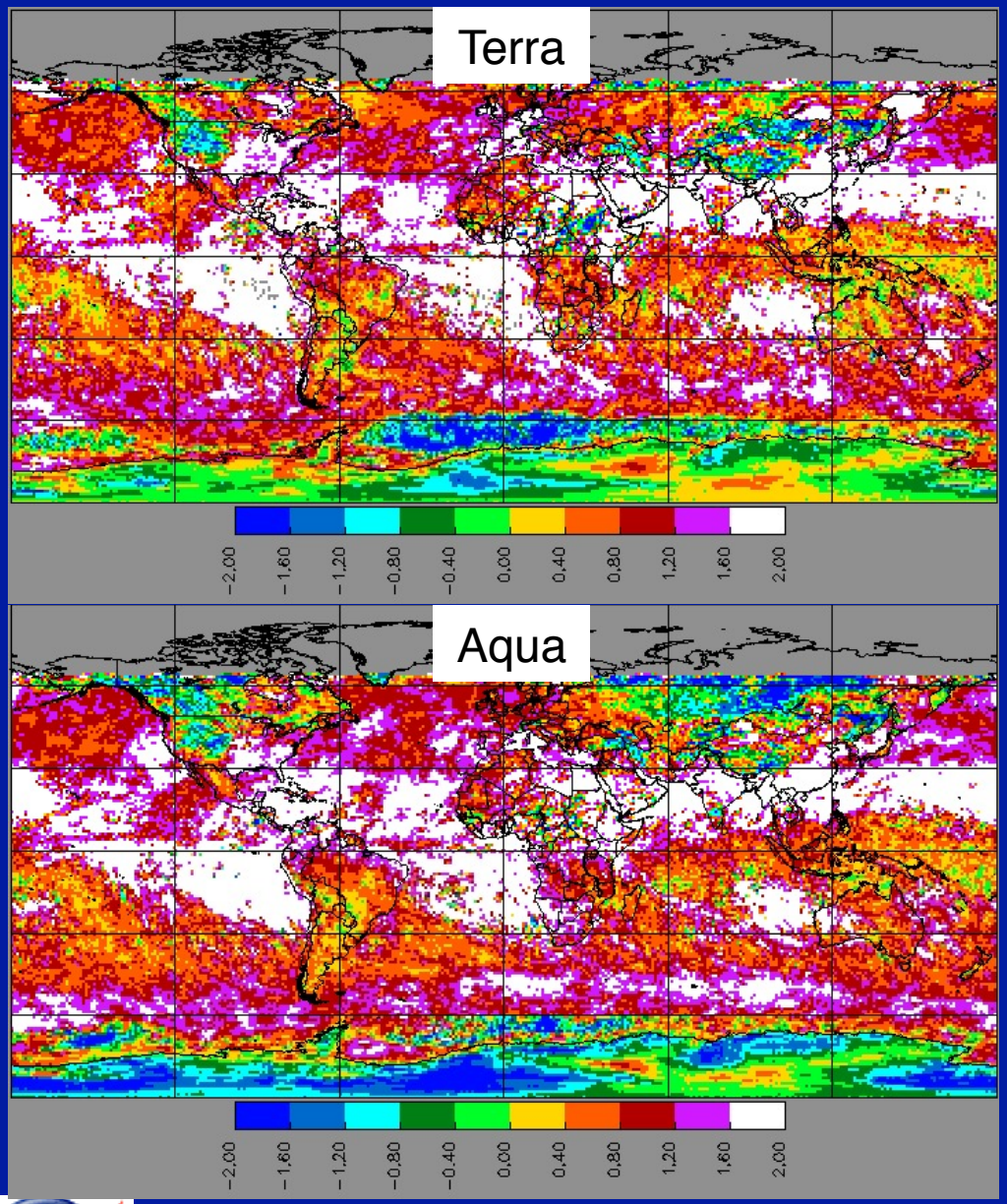
Water Cloud Effective Height Changes Relative to Ed 2
Ed4 – Ed2 (km)
Day, January 2007

- Terra: smaller changes than Aqua
  - *larger lapse rates*
  - *fewer clouds with phase change*
- Aqua: mostly increases
  - *some drops in Sc areas*
  - *more supercooled clouds, so higher clouds*
- Overall: 0.5 km increase
- Cloud-top height: 0.06 km higher to yield 0.56 km increase relative Ed2



Water Cloud Height Changes Relative to Ed 2 Ed4 – Ed2 (km)

- Land: Most heights up by 0.3 – 1.2 km
  - *some drops in SH*
  - *should be closer to CALIPSO now*
- Ocean: heights up by 0.0 – 0.5 km
  - *some drops in SH*
- Changes due to
  - *lapse rates*
  - *phase changes*



Ice Cloud Effective Height Changes Relative to Ed 2
Ed4 – Ed2 (km)
Day, January 2007

- Terra & Aqua: similar changes
  - *impact of CO2, 1.38 µm, phase changes, ice cloud model*

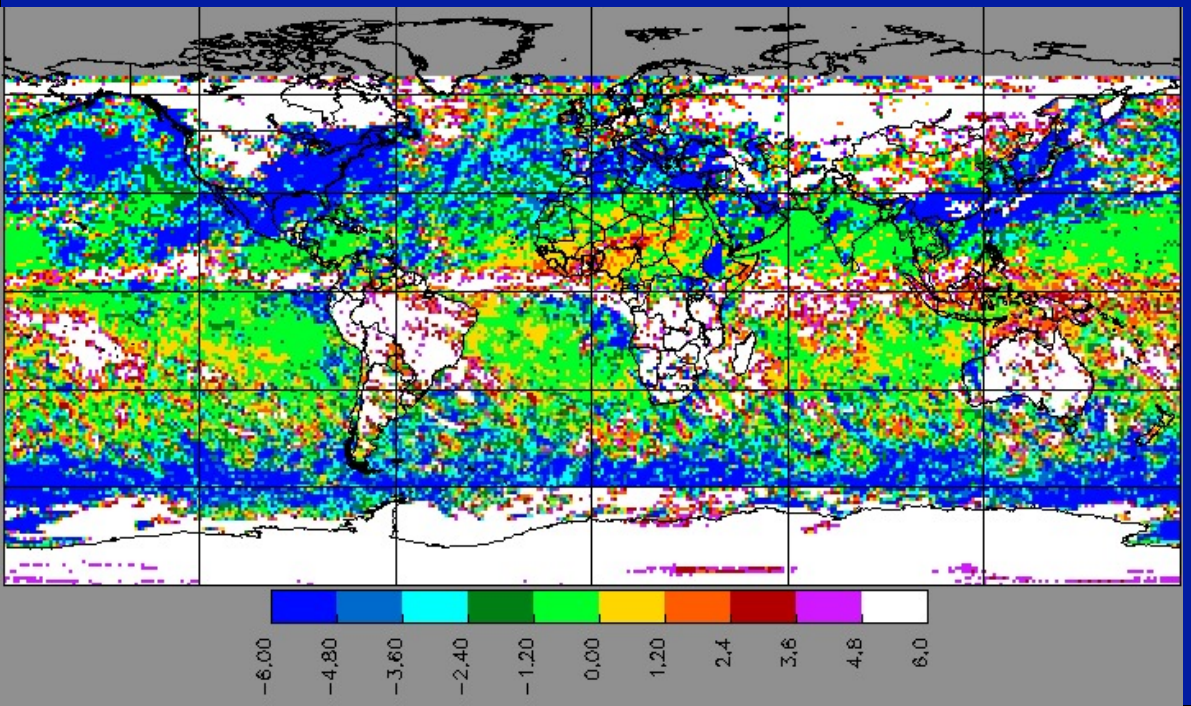
- Overall difference (km)
  - *Polar: -0.05*
  - *Non-Polar: 1.33*
  - *Global: 1.39*

- Cloud-top height: 0.72 km higher than cloud effective height
  - *overall increase of 2.11 km*
  - *should agree better with CALIPSO*

Ed2 to Ed4 Optical Depth Changes

---- A number of changes impact cloud optical depth

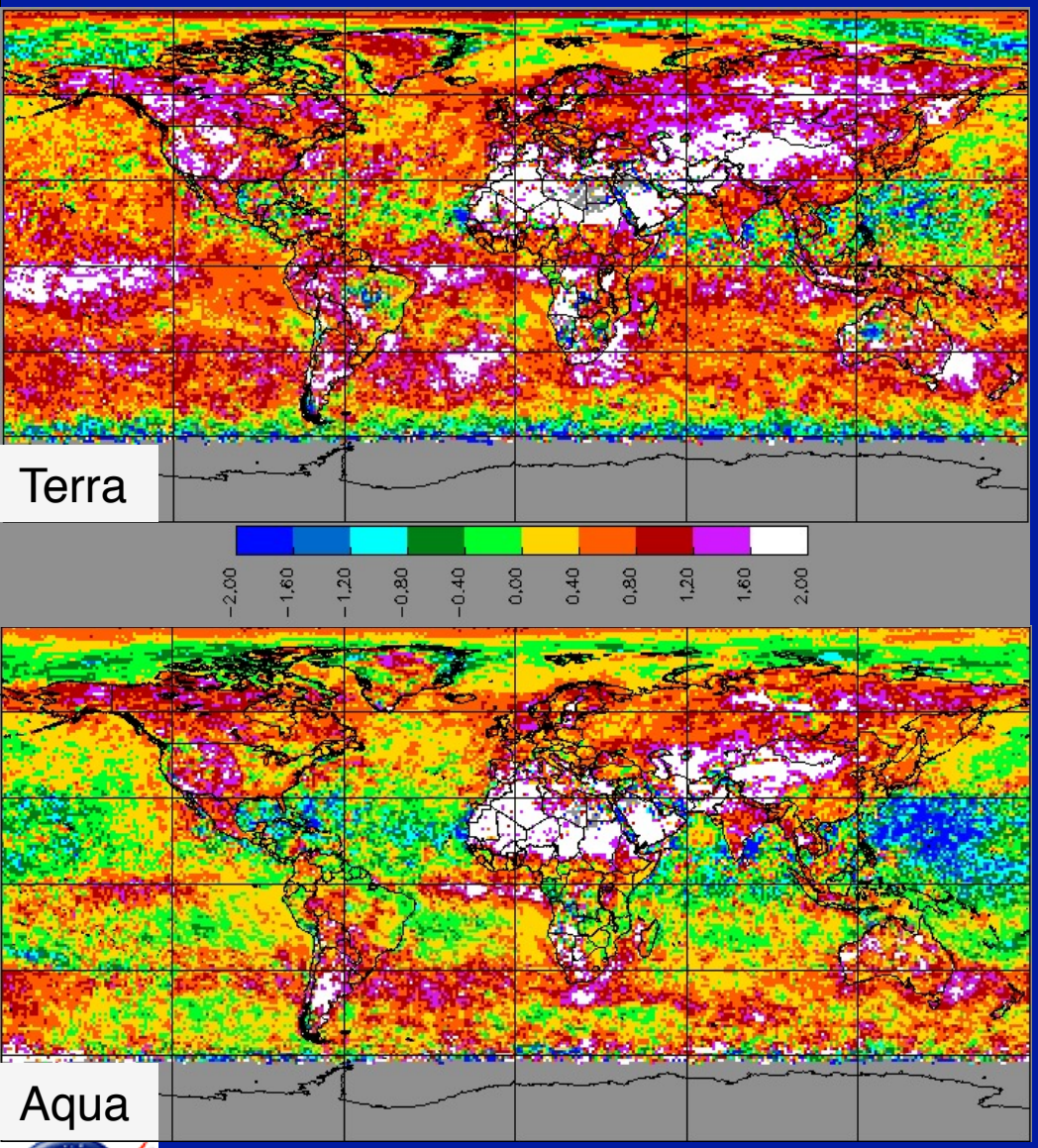
- Correct ozone absorption will decrease COD
- New *cloud retrievals over snow will increase COD*
  - *Aqua Ed2 biased low*
  - *T & A Ed2 threw out many large COD clouds*
- Detection of optically thin cirrus with 1.38 μm will decrease ice COD
  - assume a temperature and Re, perform IR retrieval
- Use of new rough ice crystal models can raise or lower COD
- Max COD =150, was 128



Ed4 - Ed2 COD

- COD rose in snow areas
- COD up in deep convective areas
- decreased in midlatitudes
- decreased slightly in subtropics

Change Water droplet Effective Radius: Ed4 – Ed2
July 2006



- Terra & Aqua: different changes
  - *Terra, new 3.7 calib*
  - *both: more cumulus detected*
    phase changes

- Overall change (μm)

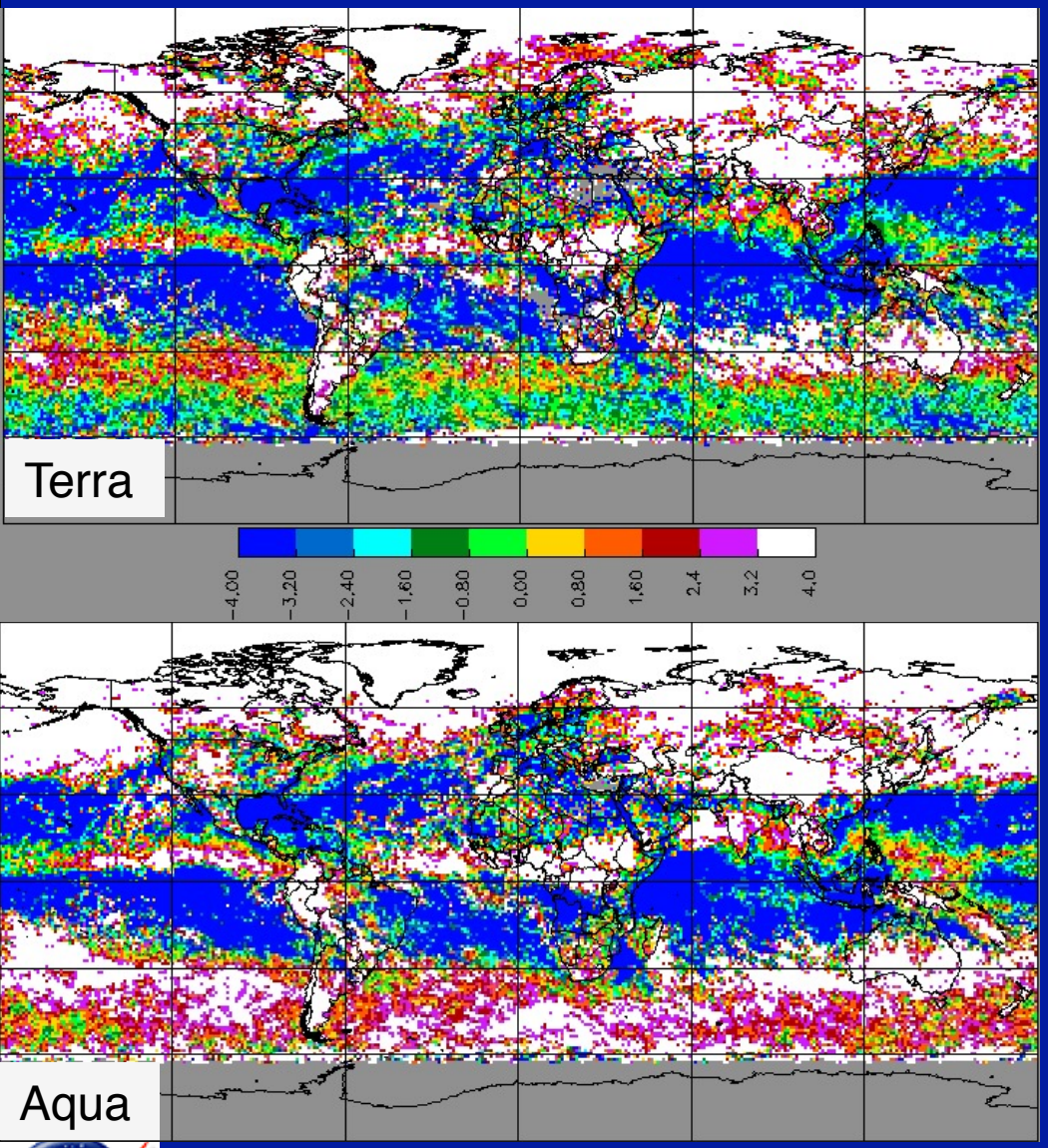
Ocean	Terra	Aqua
- Polar:	*0.11*	*0.37*
- Non-Polar:	*0.57*	*0.12*
- Global:	*0.53*	*0.14*

Land	Terra	Aqua
- Polar:	*0.80*	*0.59*
- Non-Polar:	*1.02*	*0.87*
- Global:	*1.04*	*0.85*

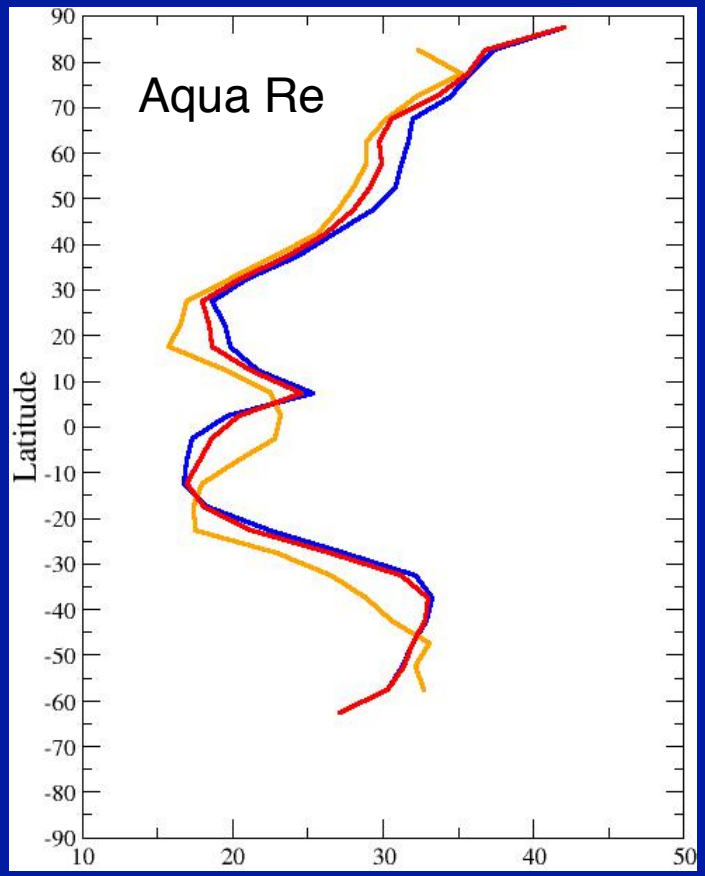
- Land change mainly to 9% increase in water cloud cover
  - *new clouds*
  - *former ice clouds*

- LWP changed by 20% and 6% in Aqua & Terra results

Change Ice Crystal Effective Radius: Ed4 – Ed2
July 2006



- Terra & Aqua: different changes
  - *Aqua, more phase changes*
  - *both: more zonal dependence*
    - *drop in tropics, increase midlat*



- IWP changed by 5% and 2% in Aqua & Terra results

MODIS Edition 4 Tasks

- Continue validation
  - *see B. Xi & X. Dong talks*
  - *other ground site and satellite comparisons*

- Complete Ed-4 documentation

- Determine differences in Coll 6 vs CERES-altered Coll 5 data
  - *use overlapped months to see if calibration problems disappeared*
  - *adjust codes as needed to smoothly use Coll 6*
  - *perform repeat cross calibration*

- Refine techniques when possible
  - *respond to feedback from downstream*

- Continue processing

VIIRS Edition 1 Tasks

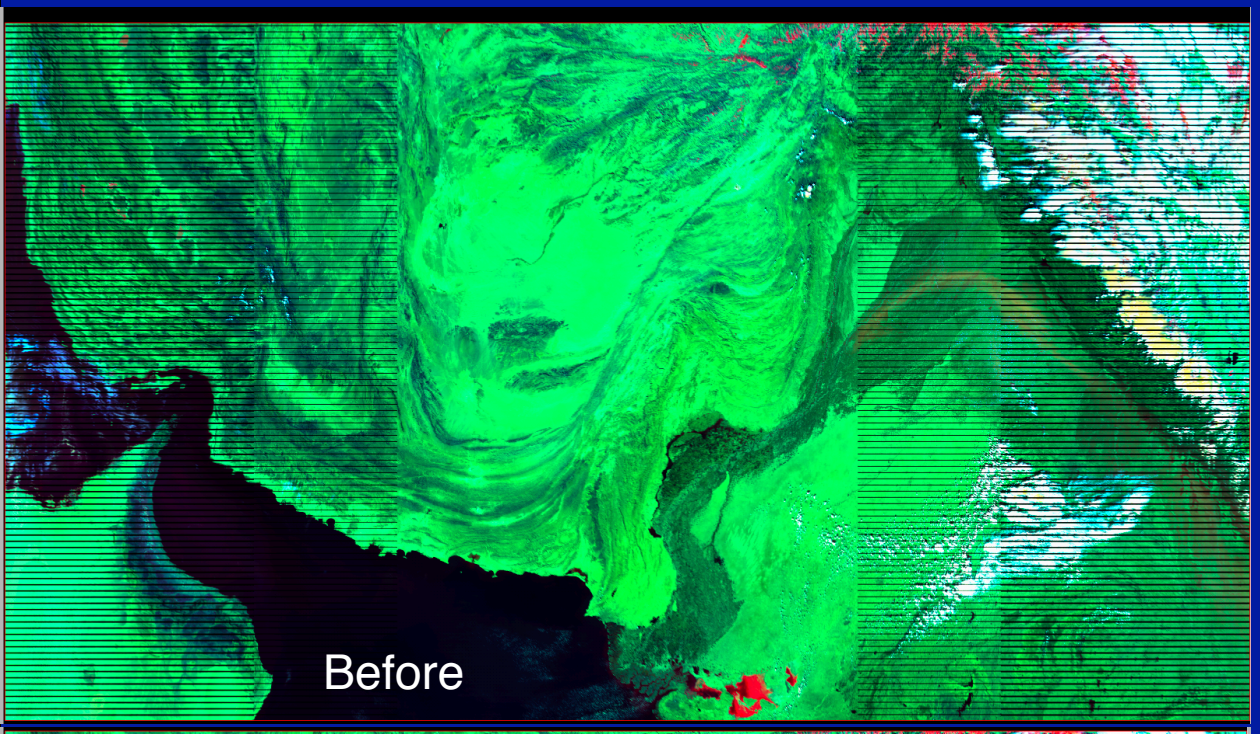
- Develop reader for new format (Sunny)
- Acquire necessary auxiliary information
  - *corr-k coefficients (done)*
  - *solar constant*
  - *reflectance/emittance models*
    - *e.g., 2.25 µm from P. Yang*
  - *test in code*
- Tune cloud masks (Qing)
  - *use matched CALIPSO & Aqua data as guide*
  - *polar need adjustments, new snow model adjustment*
- Cross calibrate Aqua and VIIRS
- Develop QC and graphical software
- Perform independent validations
  - *ARM sites*
  - *other satellite data*
- Work on BTD multilayer code using MODIS (see Chang talk)
  - *move to VIIRS*
- Deliver Ed1, End of June 2013

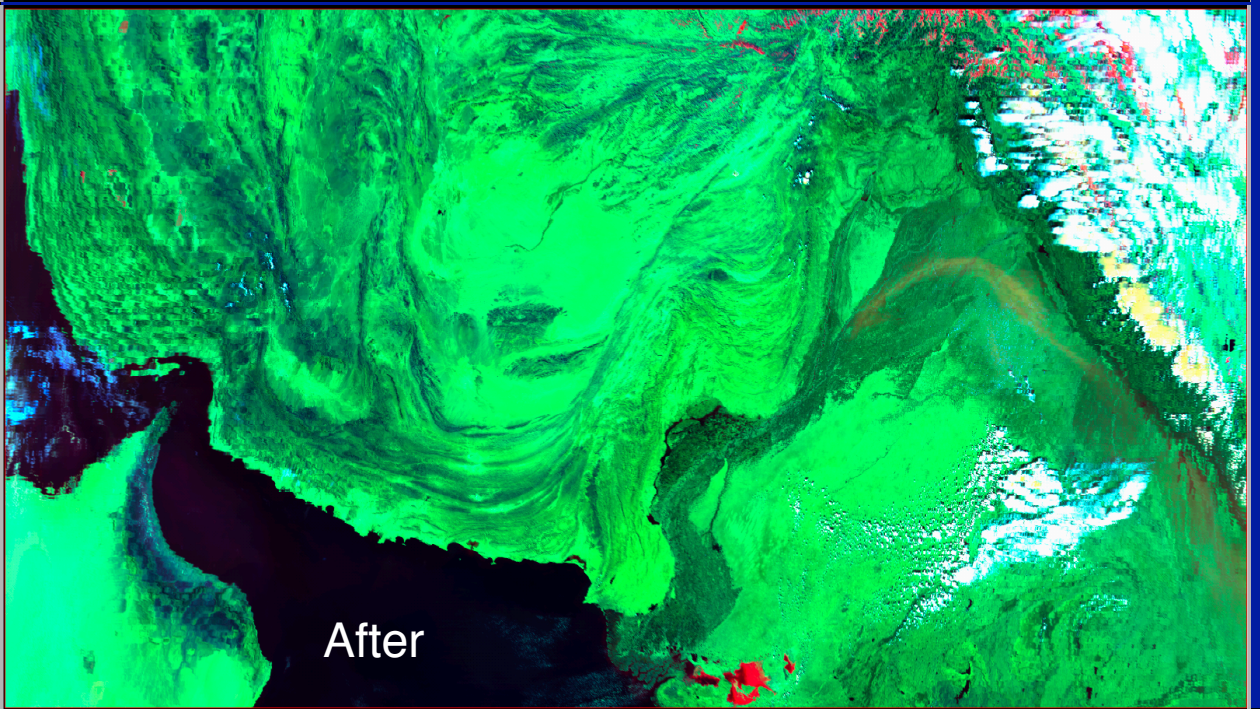
VIIRS Spectral Channels

Channels	Micron	Resolution (km)
I1	0.64	0.375 & **0.750**
I3	1.61	0.375 & **0.750**
I4	3.74	0.375 & **0.750**
I5	11.45	0.375 & **0.750**
M3	0.488	**0.750**
M4	0.555	**0.750**
M5	0.672	**0.750**
M7	0.865	**0.750**
M8	1.24	**0.750**

Channels	Micron	Resolution (km)
M9	1.378	**0.750**
M10	1.61	**0.750**
M11	2.25	**0.750**
M12	3.70	**0.750**
M14	8.55	**0.750**
M15	10.763	**0.750**
M16	12.013	**0.750**
DNB	0.7	0.750

Prettying Up VIIRS Imagery





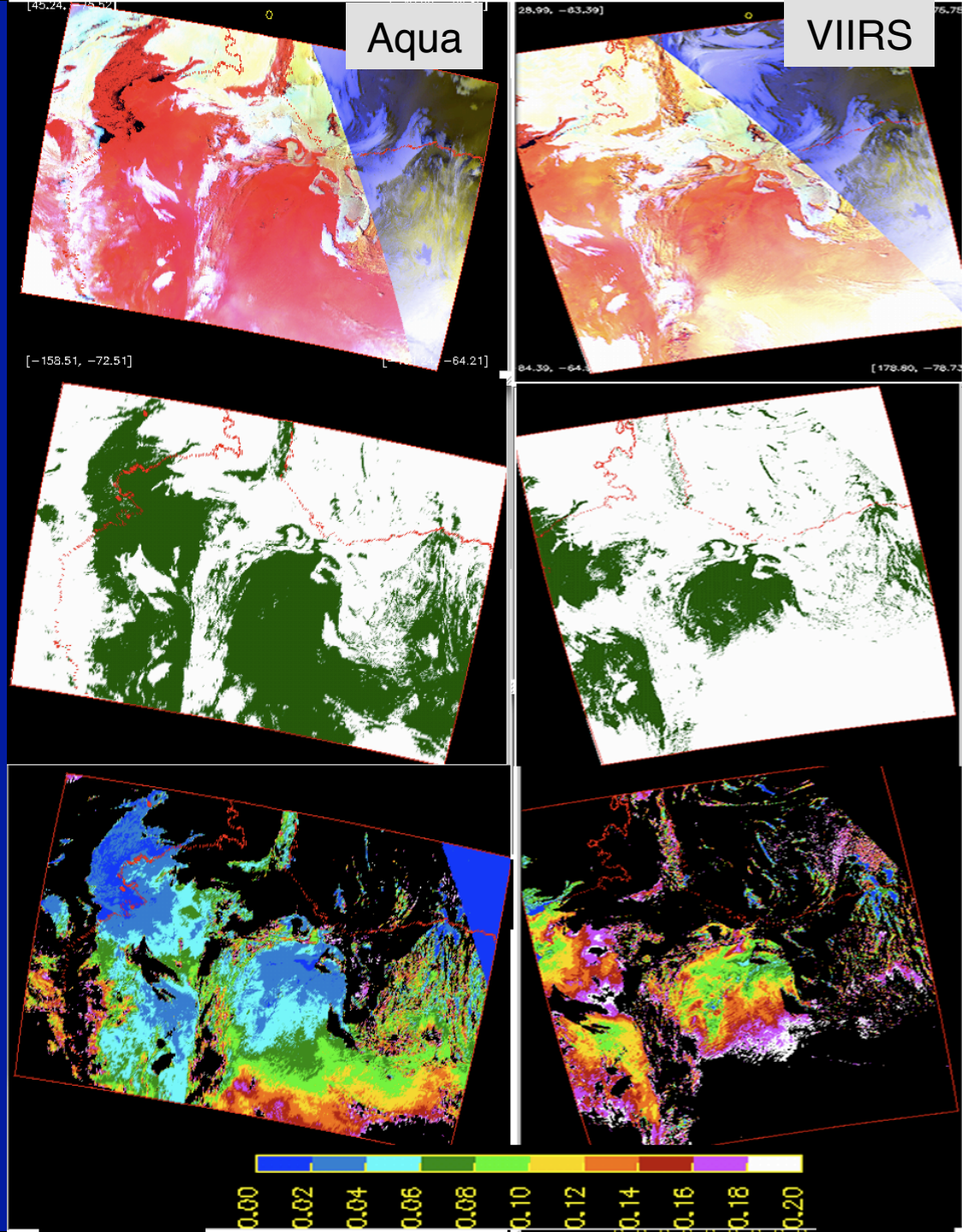
- linear gaps filled by averaging adjacent pixels along the lines

- Acquire necessary auxiliary information
  - *corr-k coefficients*
  - *solar constant*
  - *reflectance/emittance models*
    e.g., 2.25 instead of 2.13 µm

- *imaginary index of refraction*

	water	*ice*
2.13	*4.32×10^{-4}*	*5.5×10^{-4}*
2.25	*3.80×10^{-4}*	*2.1×10^{-4}*

- *ice less absorptive than water at 2.2 µm, affects cloud detection and phase selection, as well as particle sizes*



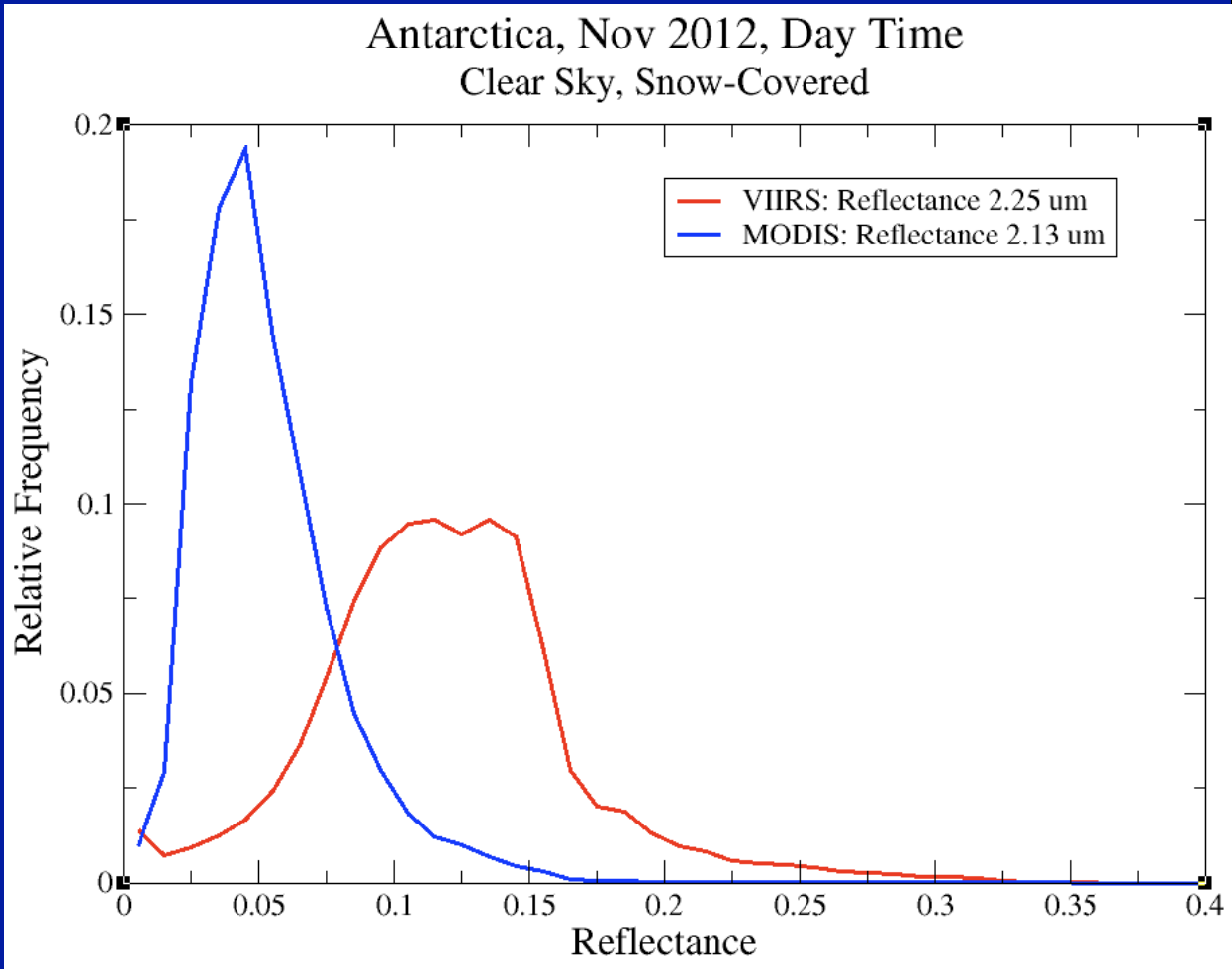
VIIRS Mask Tuning

What a difference 0.1 μm makes!

- Ratios of 2.25/0.65 μm reflectance used in mask

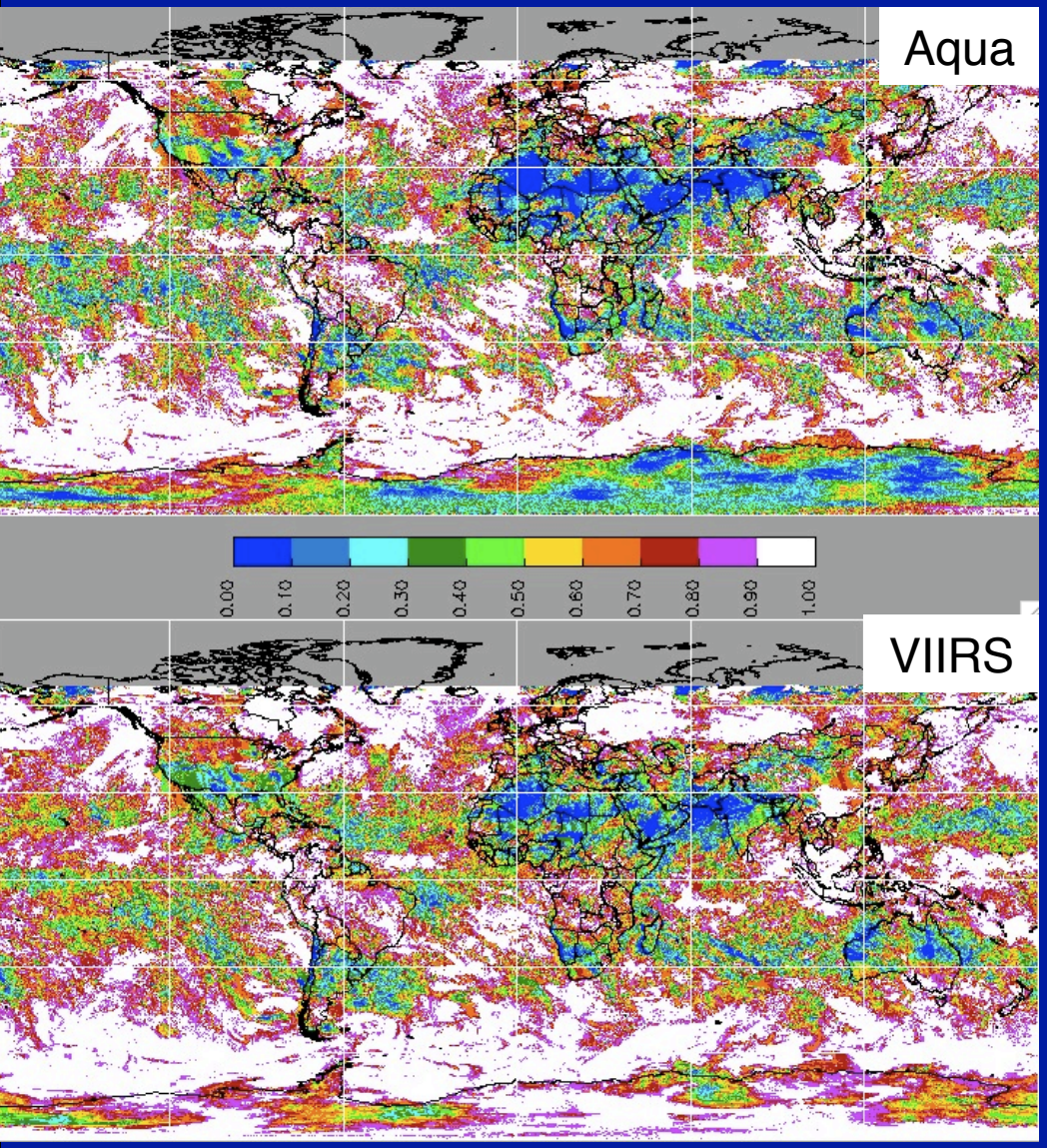
  - need to adjust ratios to account for snow reflectance differences

- Will need changes over other surfaces, particularly deserts



VIIRS Cloud Fraction Comparison w/ Aqua

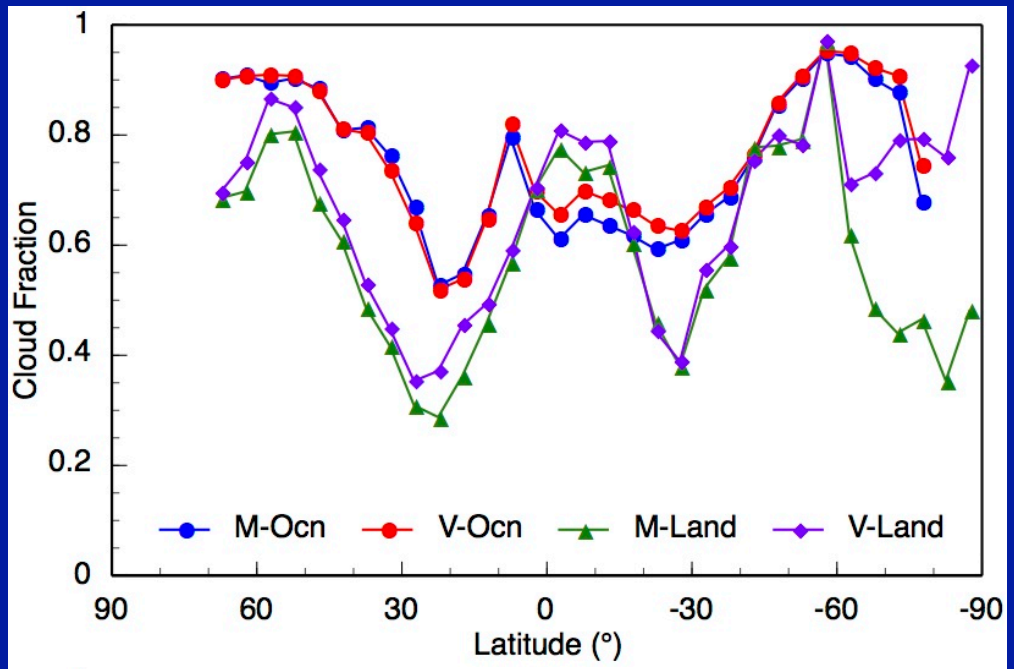
Daytime 3 days, Nov 2012

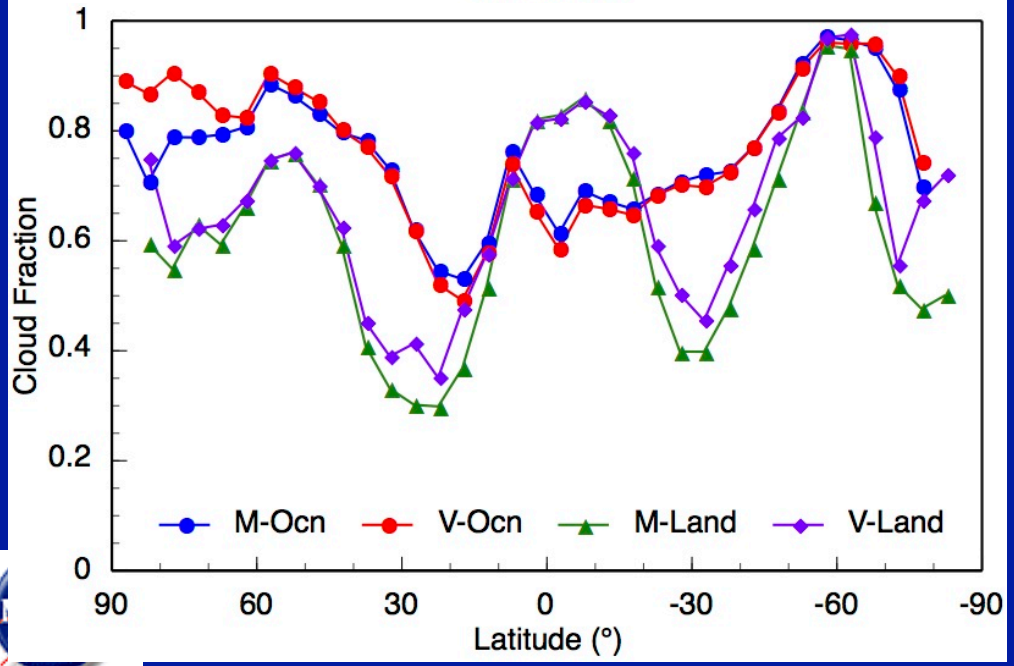


- Reasonably similar, except over snow & desert
  - *corr-k for MODIS*
  - *clear-sky reflectances need improvement*
- daytime difference = 0.031
  - *mainly over poles & deserts*
- night difference = 0.008
  - *mainly over poles & deserts*

VIIRS Cloud Fraction Comparison w/ Aqua

Daytime 3 days, Nov 2012





- Daytime polar difference up to 0.4
- Night polar 0.2 over Antarctica
- Desert bias day and night

VIIRS Cloud Detection

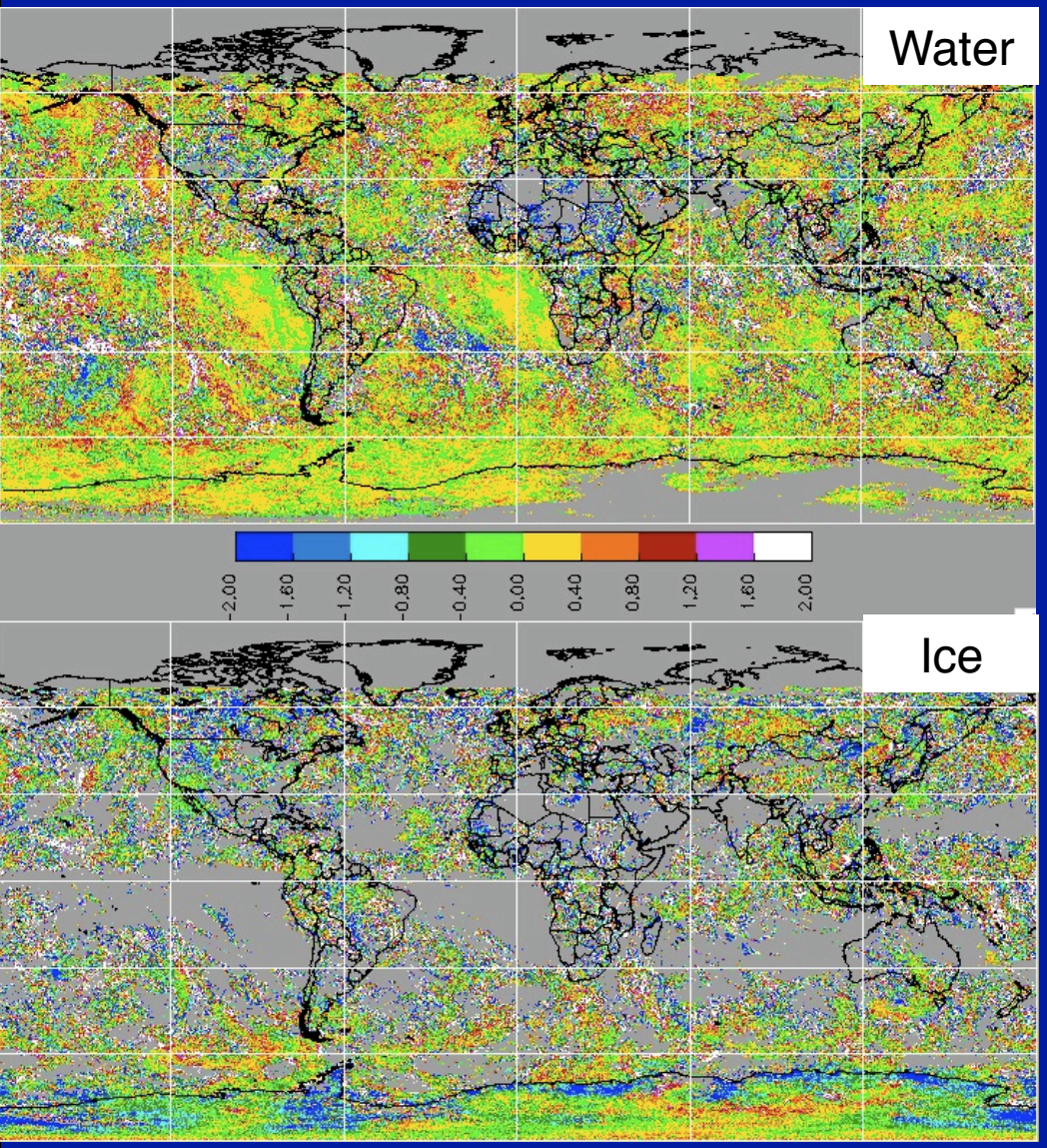
- Tune cloud masks
  - *use matched CALIPSO & Aqua data as guide*
    - *CALIPSO matching with VIIRS*
    - *Aqua matching*

  - *polar day & night adjustments underway*
    - *no WV or CO2 channels*

  - *new background maps from a first year run*
    - *2.25 µm DRMs and surface albmap (Yan)*
    - *new snow albedos by adjusting 2.13 values*
    - *or use 1.6 µm*

VIIRS Cloud Height Difference w/ Aqua

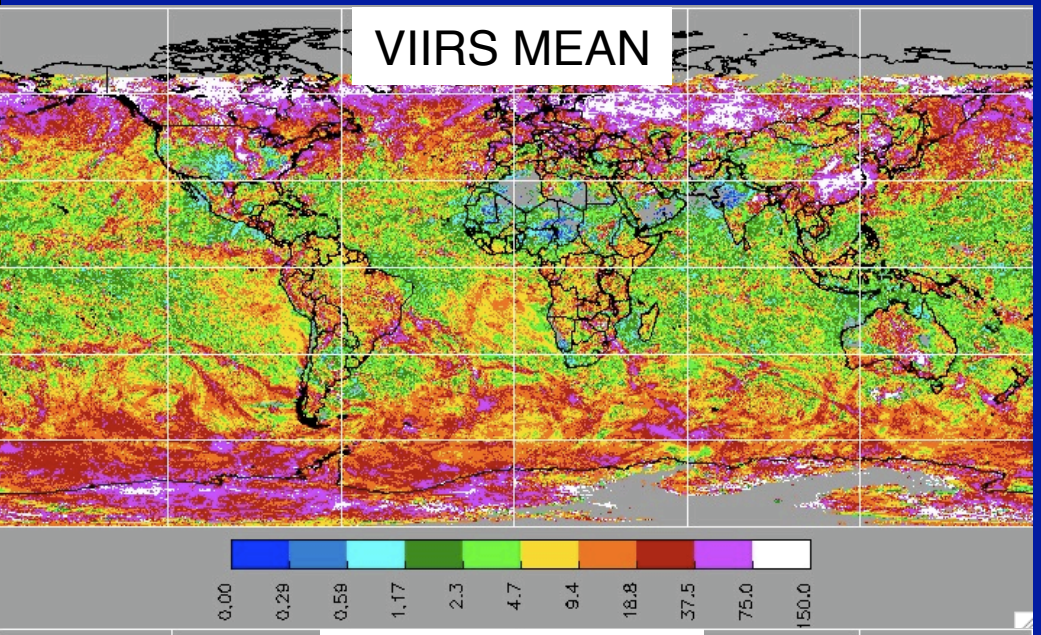
Daytime 3 days, Nov 2012

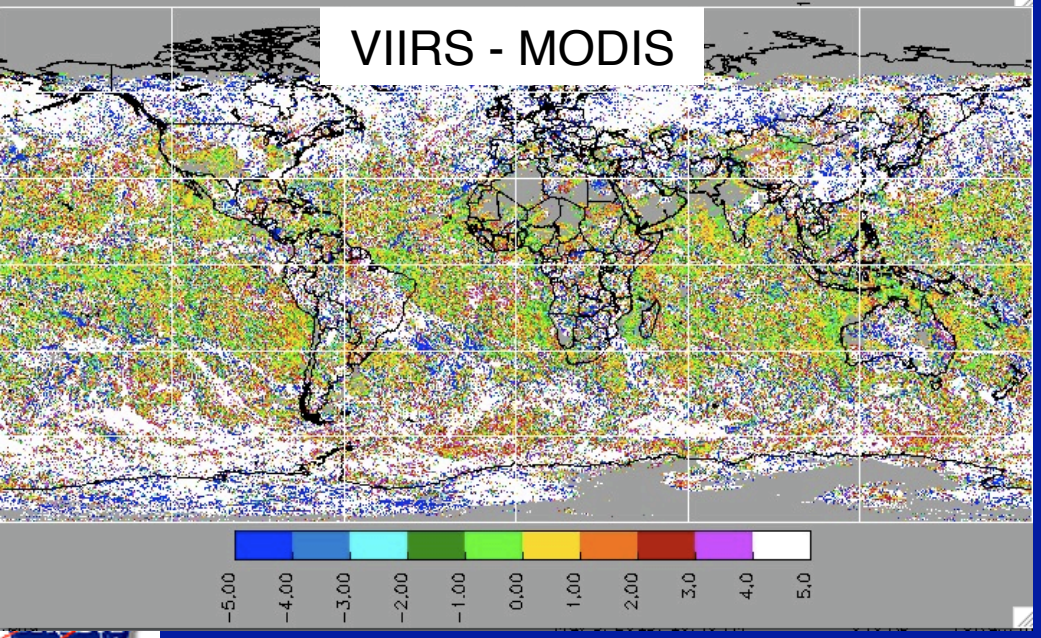


- Very similar, some larger differences may reflect orbit path differences
  - *VIIRS higher by 0.119 km for water by 0.098 km for ice*
  - *absence of CO2 does not hurt too much*
  - *at night, VIIRS higher by 0.070 km*

VIIRS Water Cloud COD Comparison w/ Aqua

3 days, Nov 2012



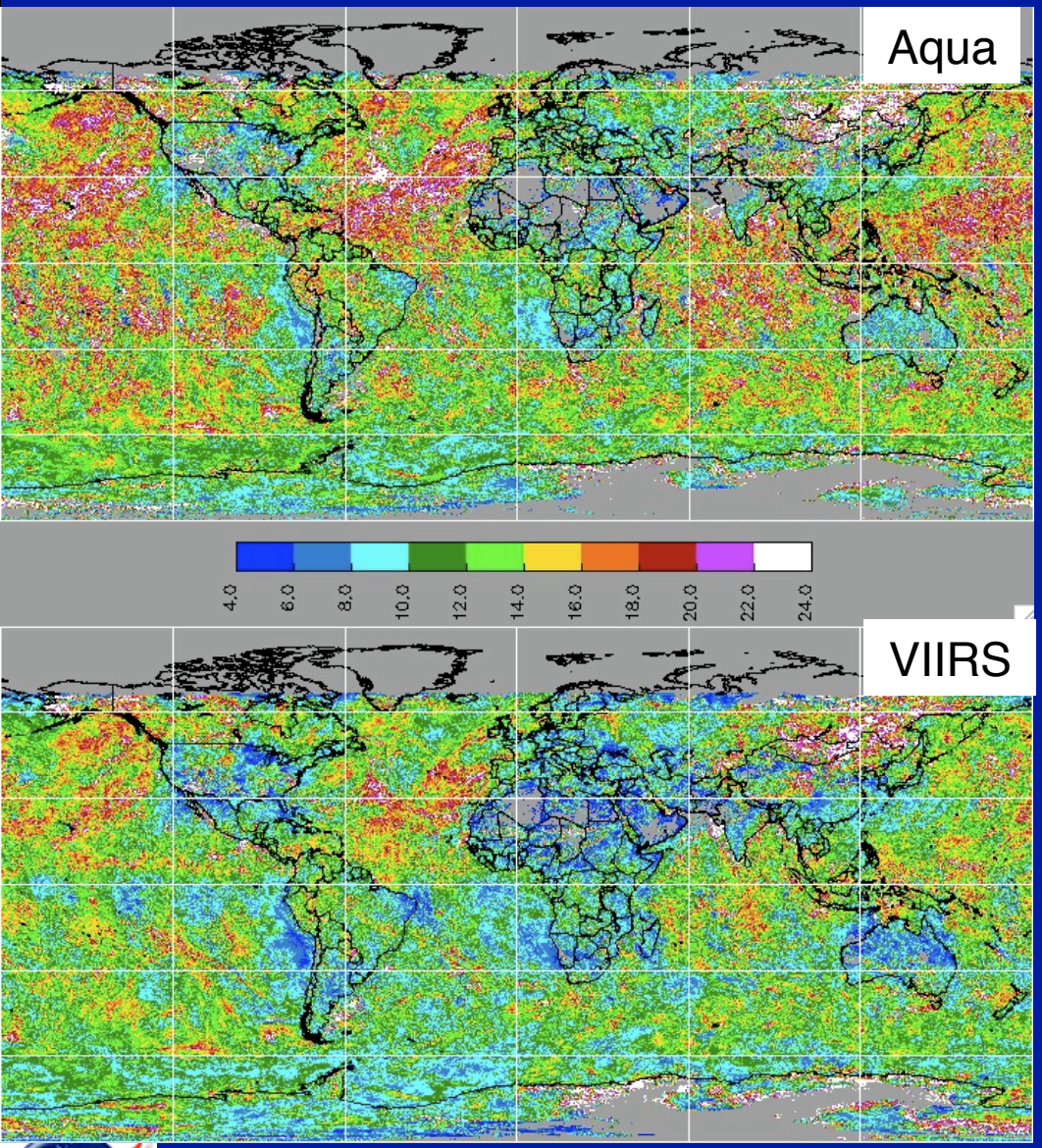


- Small differences, but for thickest clouds
  - ***- corr-k for MODIS***
  - *- phase selection differences*
  - *- solar constant*

  - *- VIIRS COD greater by 3.7*

VIIRS Water Cloud Re Comparison w/ Aqua

Daytime 3 days, Nov 2012



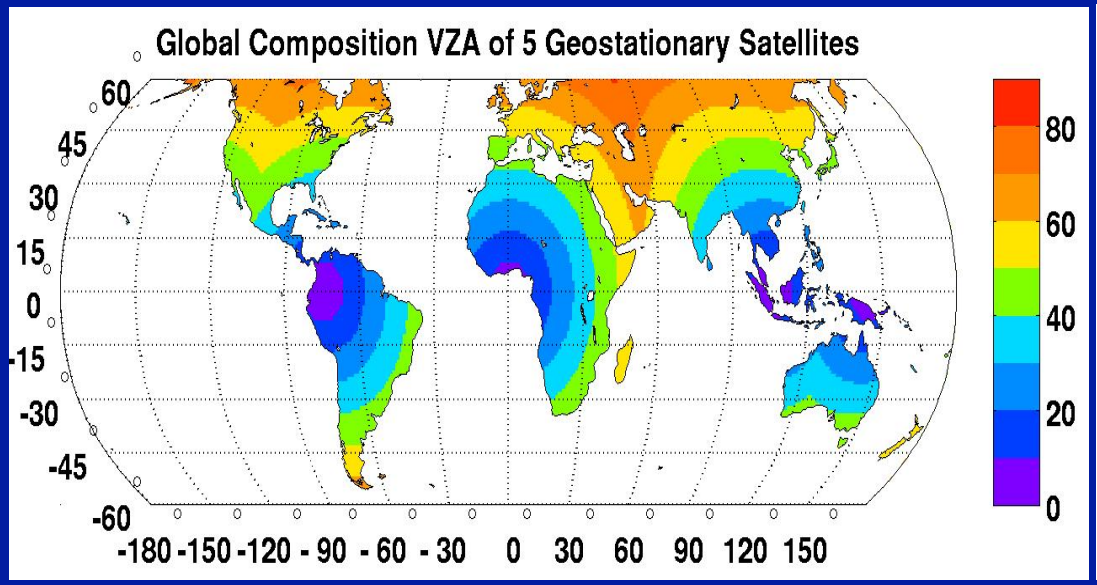
- Patterns similar, VIIRS smaller
  - *corr-k for MODIS*
  - *VIIRS 2 µm smaller over ocean*
    1.2 µm smaller over land
- Smaller VIRS not surprising
  - *3.7-µm brighter than MODIS 3.8 µm*

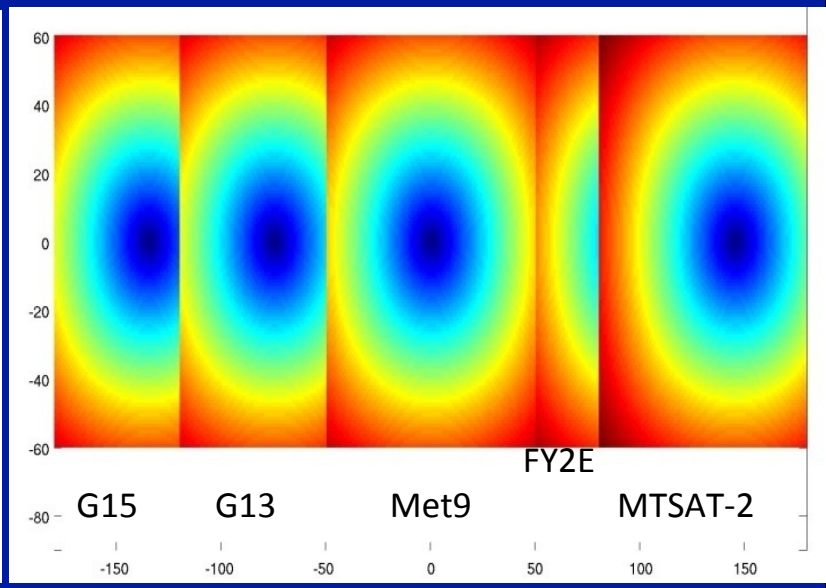
What's Ahead for CERES SNPP VIIRS

- Set up to run VIIRS through system
- corr-k changes, cloud reflectance models, VIIRS solar constants to be incorporated this week
- background maps and snow models will be updated
- Mask will be tuned
- initial validations will be tuned
- Multilayer algorithm will be tested
- Deliver Ed1, End of June 2013

Hourly GEOSat Data for TISA

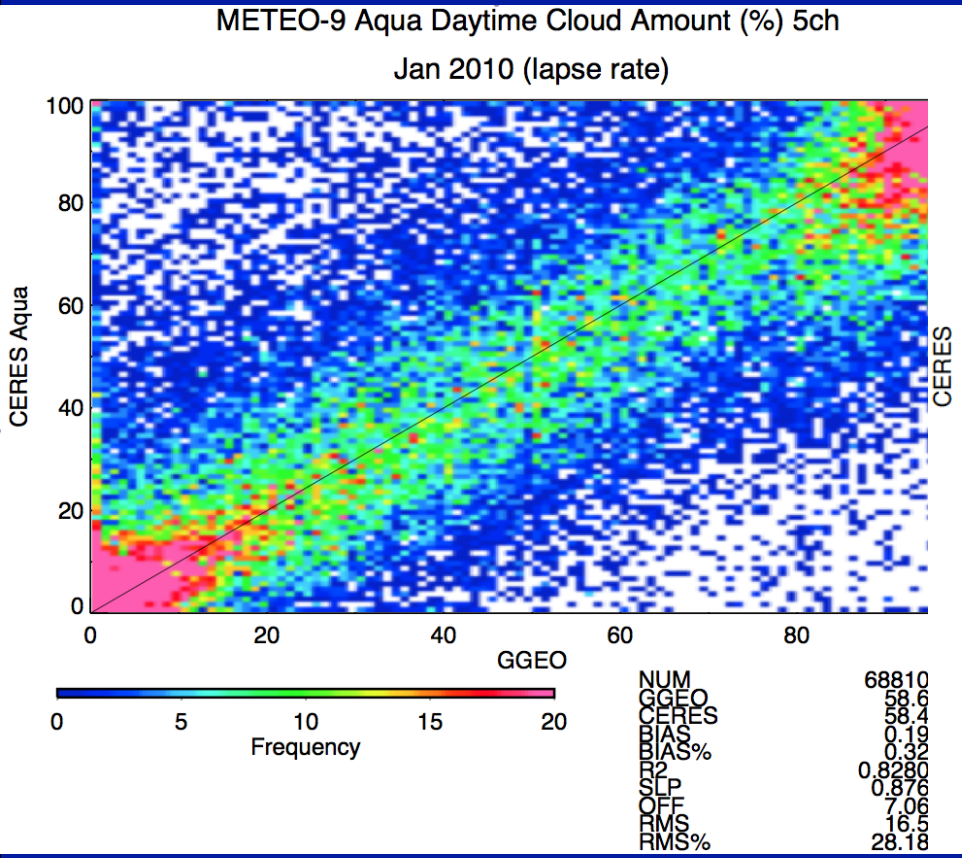
- Available geostationary satellites provide up to 1-hour global monitoring between ~60°S and ~60°N
- CERES Ed2 cloud retrieval algorithm (VISST/SIST) from MODIS adapted for geostationary satellite data processing

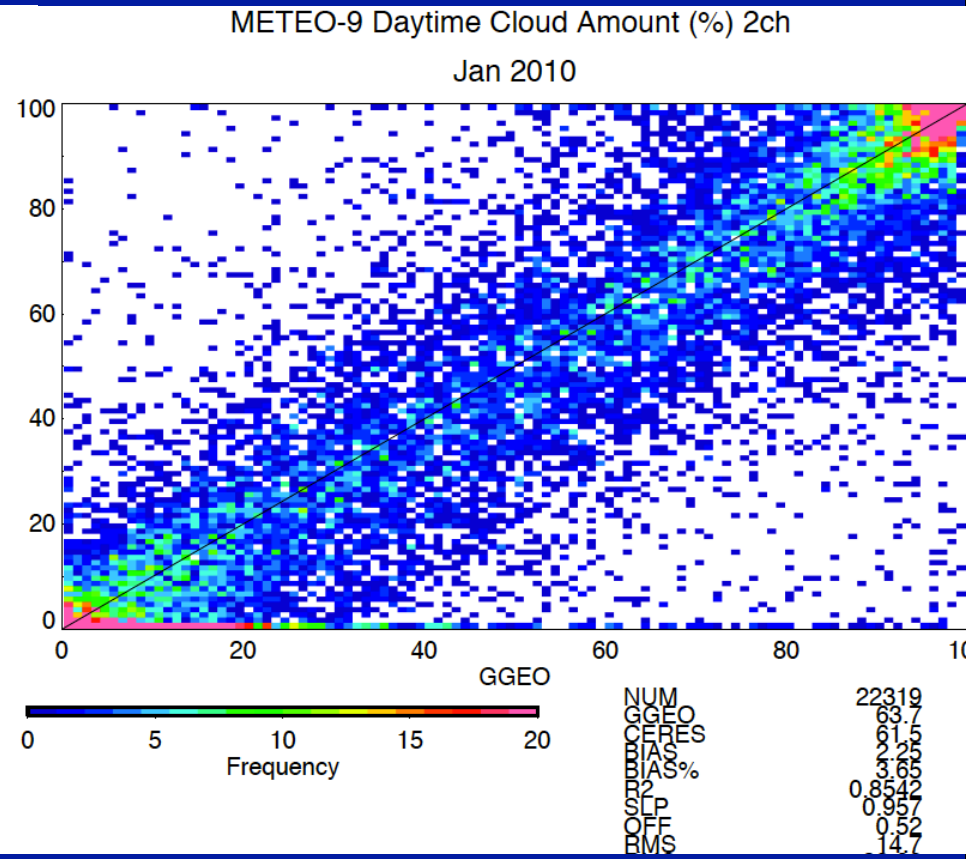




- FY-2 series will not be included in TISA analysis because of unreliability
  Meteosat-7 & 2-channel algorithm will be used for the gap
- Currently running in near-real time, will process backward in time
  - GMAO working on assimilation of these data

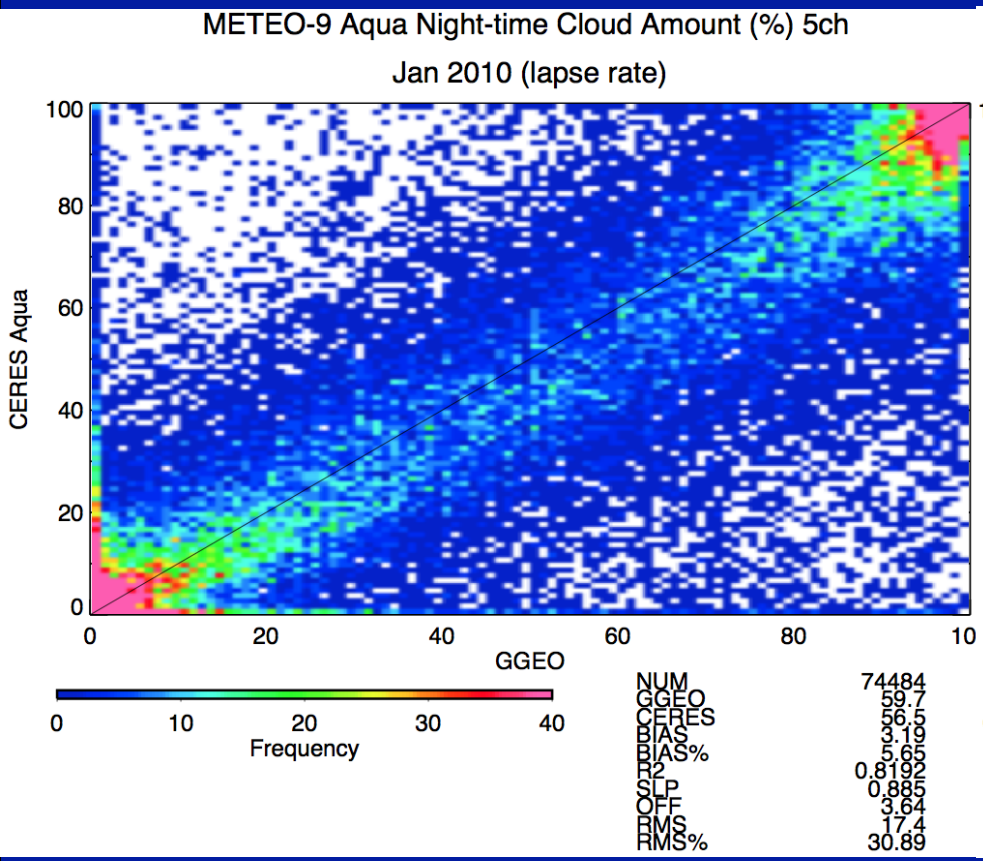
Meteosat-9 vs Aqua Cloud Amounts, Daytime

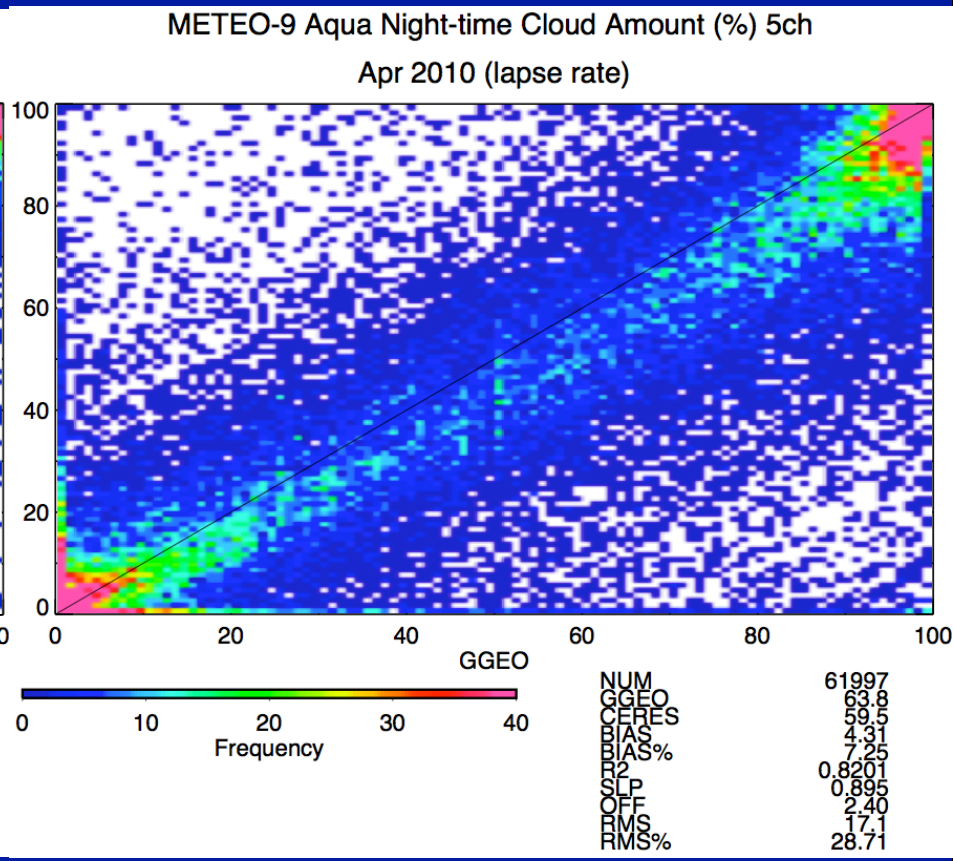




- Better agreement with 5 channel code

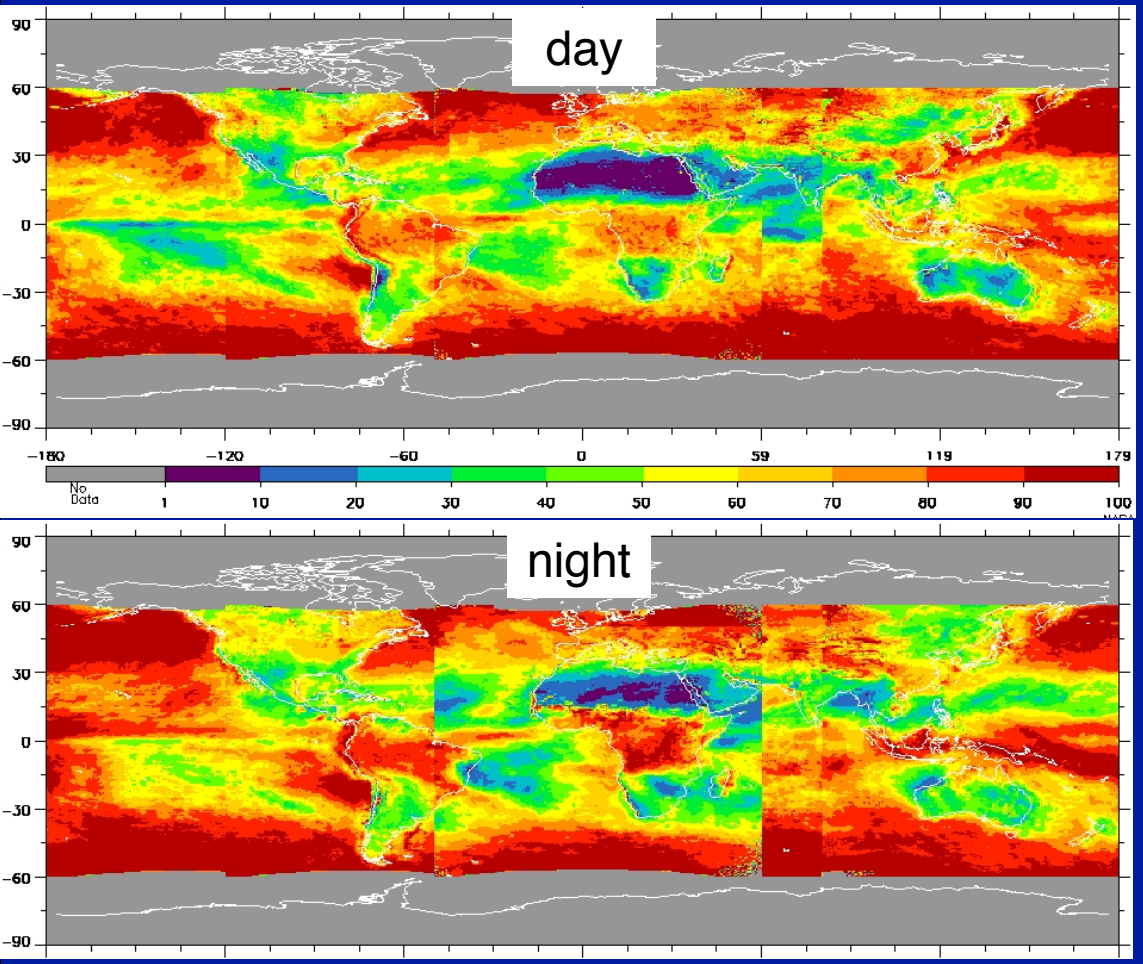
Meteosat-9 vs Aqua Cloud Amounts, Night



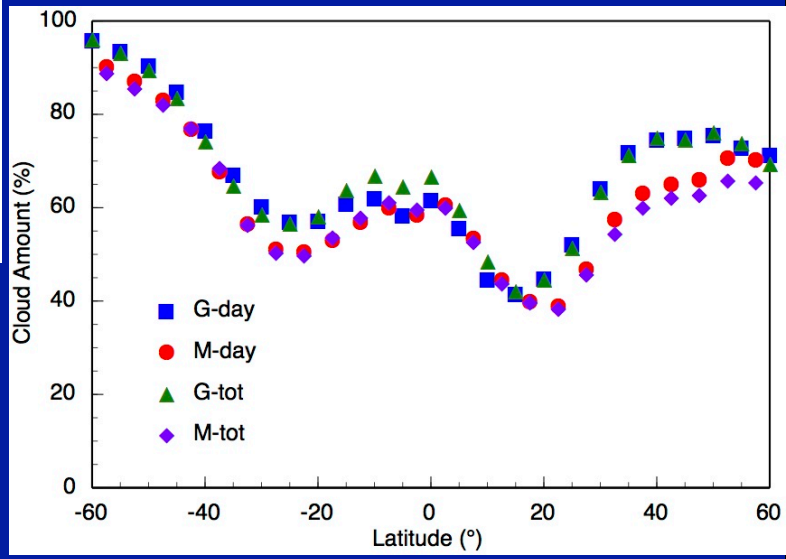


- Meteosat higher by 3% both months
- Correlations with other parameters look quite good also

GEOSat Cloud Fraction, March 2013



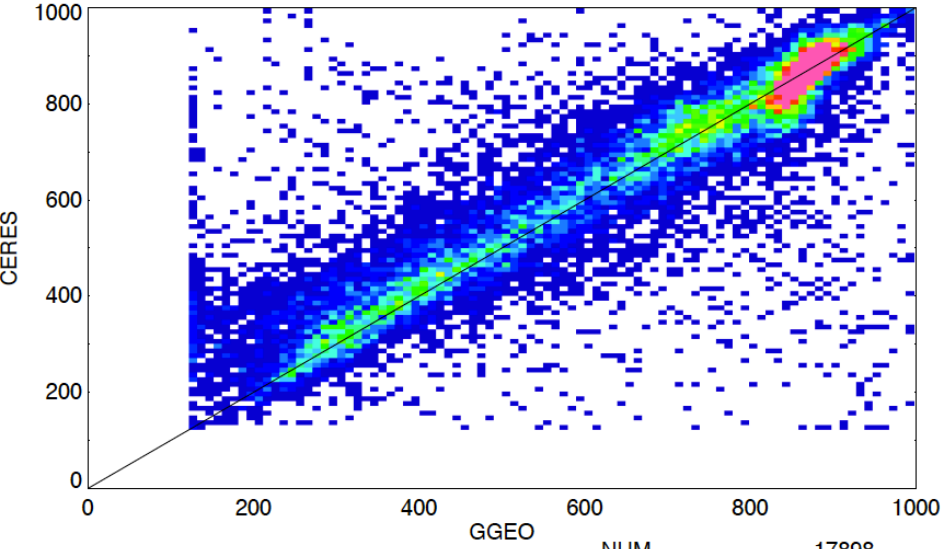
Zonal Means vs. Aqua Ed2, March 2012



- GOES has too much cloud at night, Meteosat too little over ocean
  - mask adjustments needed

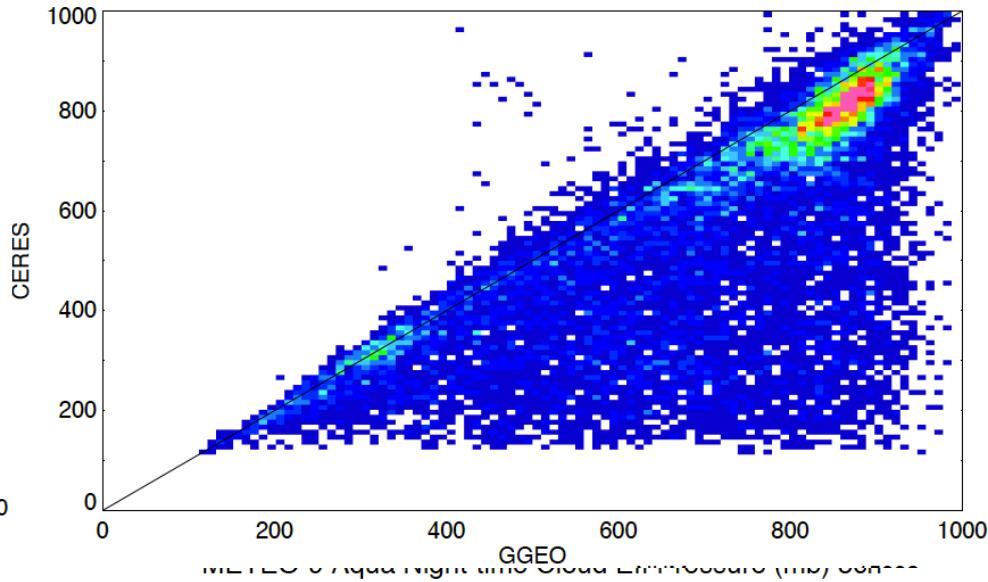
METEO-9 Daytime Cloud Eff Pressure (mb) 2ch

Apr 2010



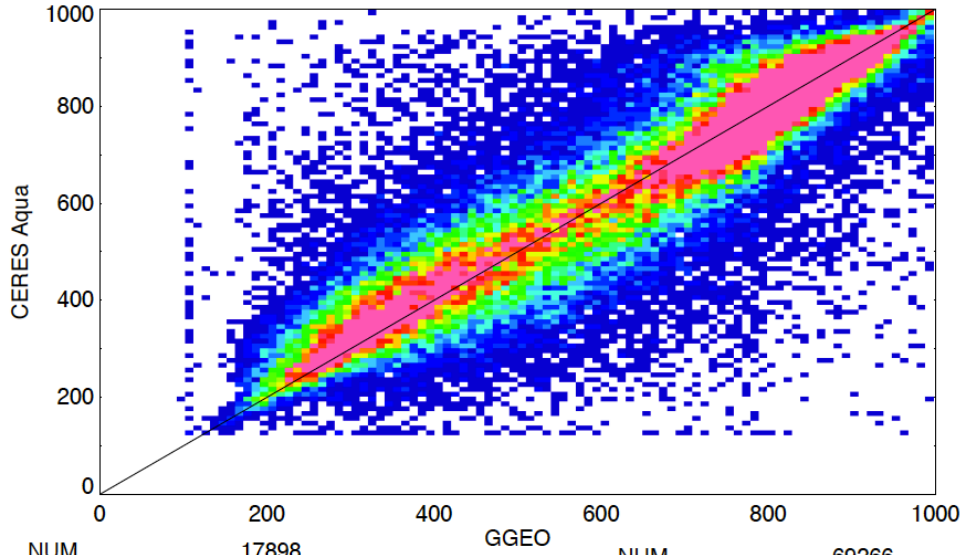
METEO-9 Night-time Cloud Eff Pressure (mb) 2ch

Apr 2010



METEO-9 Aqua Daytime Cloud Eff Pressure (mb) 5ch

Apr 2010 (lapse rate)

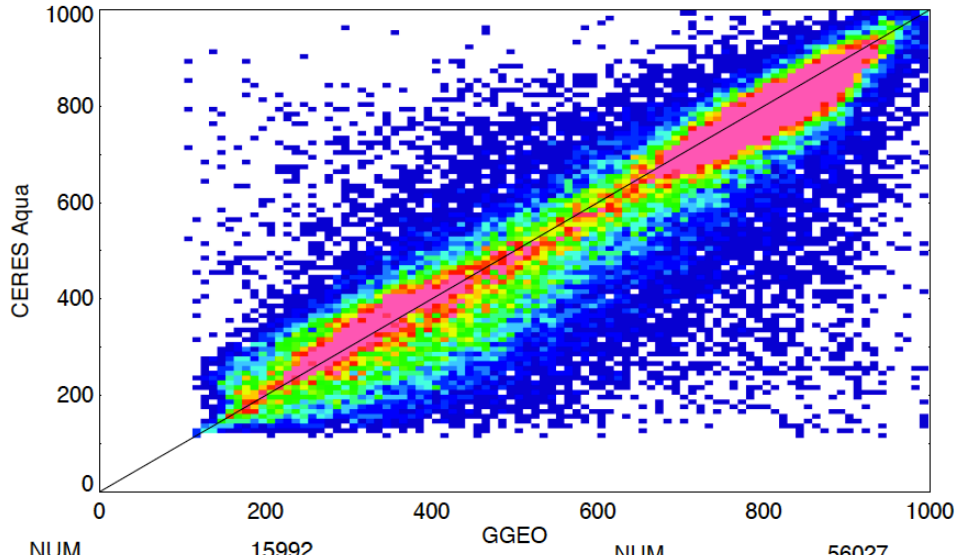


NUM	17898
GGEO	631.6
CERES	646.2
BIAS	-14.60
BIAS%	-2.26
R2	0.7830
SLP	0.816
OFF	130.96
RMS	110.2
RMS%	17.06

30 40

NUM	69266
GGEO	639.1
CERES	643.3
BIAS	-4.20
BIAS%	-0.65
R2	0.7902
SLP	0.872
OFF	85.80
RMS	100.2
RMS%	15.58

Apr 2010 (lapse rate)



NUM	15992
GGEO	695.3
CERES	547.9
BIAS	147.33
BIAS%	26.89
R2	0.4824
SLP	0.830
OFF	-29.45
RMS	225.9
RMS%	41.23

30 40

NUM	56027
GGEO	595.7
CERES	566.7
BIAS	29.00
BIAS%	5.12
R2	0.8083
SLP	0.903
OFF	28.61
RMS	106.6
RMS%	18.82

GEOSat Tasks

- Validate calibrations, determine source of discontinuities
  - *GOES especially,*
  - *perform detailed comparisons with all GEOSats*

- Tune cloud masks, needed

- Test & implement nighttime thick ice cloud algorithm

- Develop fixes for twilight parameters
  - cloud amount not too bad, but other parameters (height)

- Process gobs of data
  - need allocation of resources on AMIE & storage
  - alter code to work on AMIE