CERES Cloud Working Group Report: Update Fall 2017

W. L. Smith, Jr.

NASA Langley Research Center, Hampton, VA

S. Sun-Mack (modis/viirs lead), P. Minnis (supreme advisor), Q. Trepte (mask),

R. Palikonda (GEO), S. Bedka (retrievals, val), C. Yost (val),

R. Brown (QC), F-L. Chang (CO2, ML), Y. Chen (clr props, test runs),

E. Heckert (web), G. Hong (models, night tau), M. Nordeen (GEO), B. Scarino (cal, Tskin),

B. Shan (GEO avg), R. Smith (web, NPP), D. Spangenberg (everything),

SSAI, Hampton, VA

K. Bedka (convective clouds), L. Nguyen (IT lead), *NASA Langley Research Center*

P. Heck (retrieval code), *CIMSS, UW-Madison*

P. Yang, S. Hioki (ice models), Texas A& M University

X. Dong, B. Xi, J. Tian (validation), University of Arizona

Thanks to Dave Doelling and his TISA/calibration teams!

CERES Science Team Mtg., Greenbelt, MD, 26-28 September 2017

Topics

- Processing status
- Initial MODIS Collection 6.1 testing
- VIIRS cloud properties – consistency with MODIS
- MODIS cloud fraction – comparisons with CALIPSO
- GEO update
- Publications and highlights

Clouds - Processing Status

CERES MODIS Ed 4 Status

Aqua: Jul 2002 – Jul 2017 (~15 y)

Terra: Feb 2000 – Jul 2017 (~17 y)

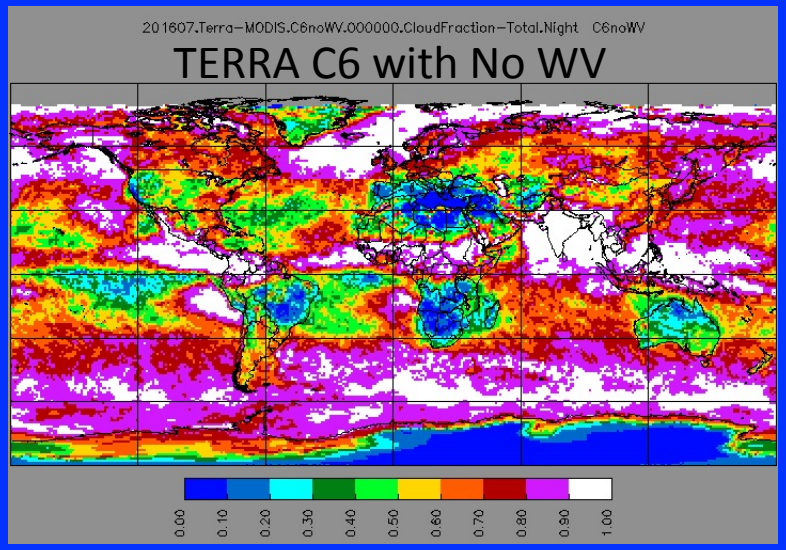
- MODIS C5 thru Feb 2017, C6 Mar-Jul 2017
- TERRA WV Channel not used after Feb 2016

CERES VIIRS Ed 1 Status

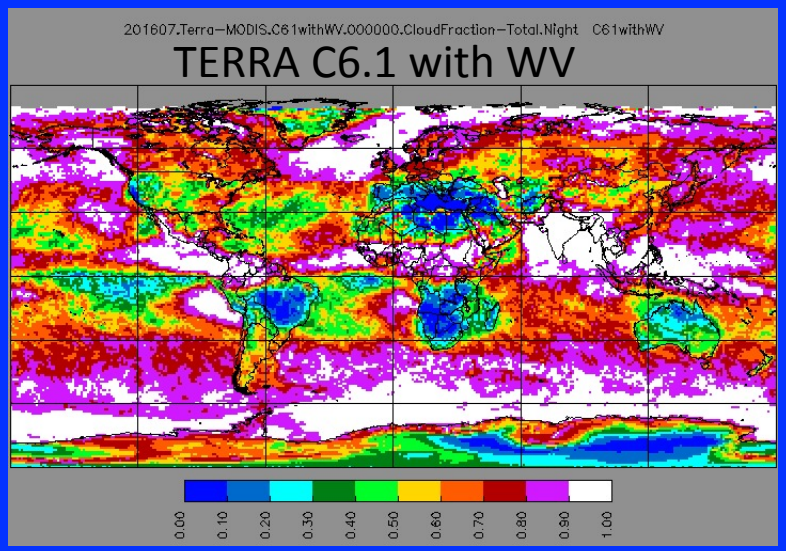
SNPP: Jan 2012 – Mar 2017 (~5 y)

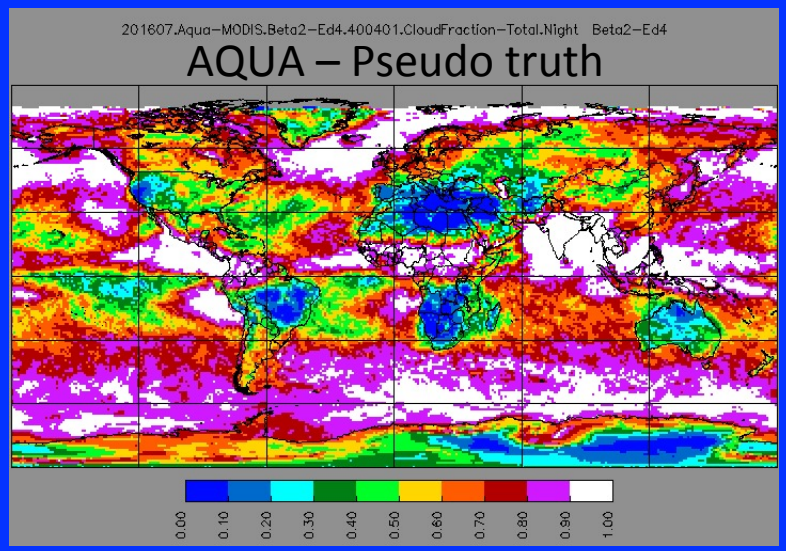
July 2017 Test with C6.1

Total Cloud Fraction



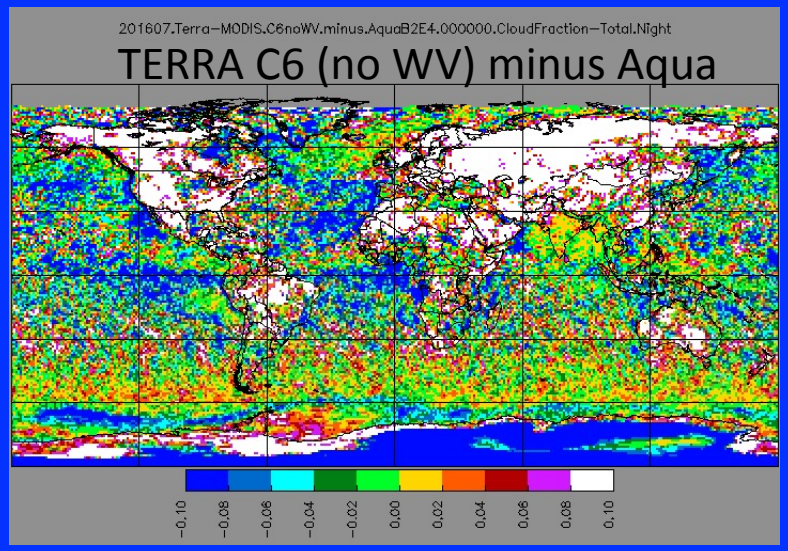
- Major anomaly in TERRA WV channel occurred in Feb 2016
  - most critical for cloud mask (nighttime cryosphere)
- WV channel removed from cloud mask beginning with March 2016 data creates discontinuity
- Re-processing planned using C6.1 which corrects the WV problem
- Initial test with July 2016 C6.1 looks good



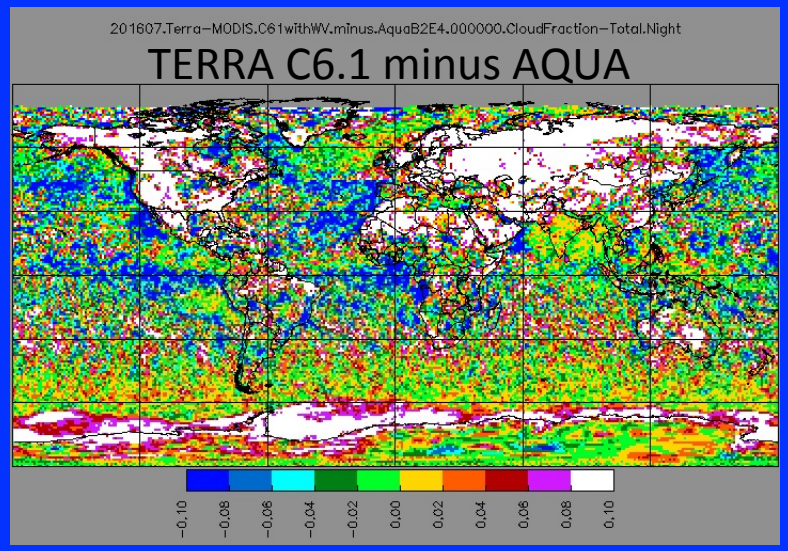


July 2017 Test with C6.1

Total Cloud Fraction



Mostly lost clouds in Polar night with no WV channel

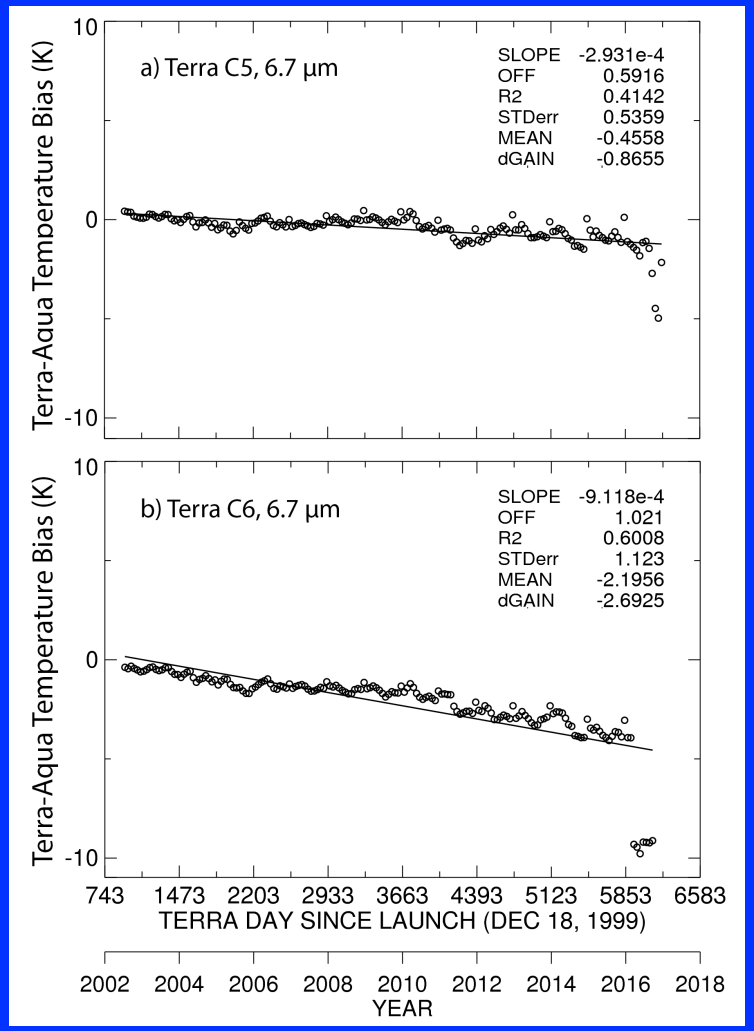


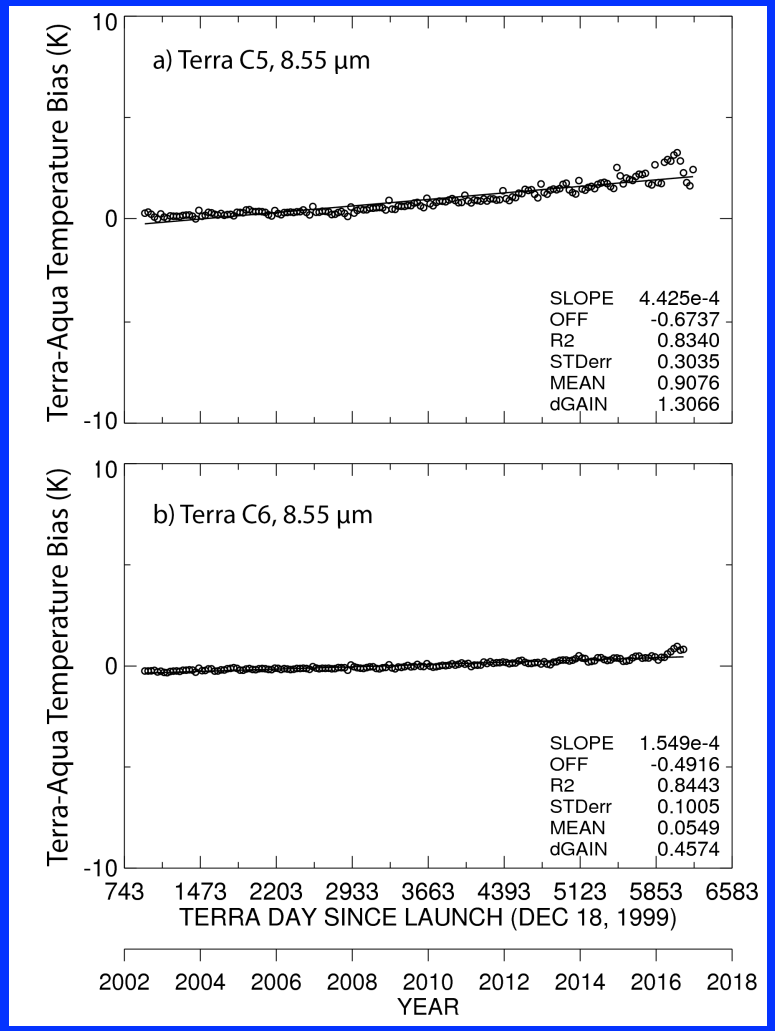
TERRA C.61 (with WV) in reasonably good agreement with AQUA

Large non-polar land differences due to diurnal cycle

Terra-Aqua Brightness Temperature Difference Trends, Collections 5 and 6

- 6.7-µm channel used in nocturnal cloud detection over polar regions
- 8.55-µm channel used in phase selection, especially important at night over poles
- Impacts seen in cloud phase and fraction trends





Terra Collection 6.1 Bands 27, 29, 30

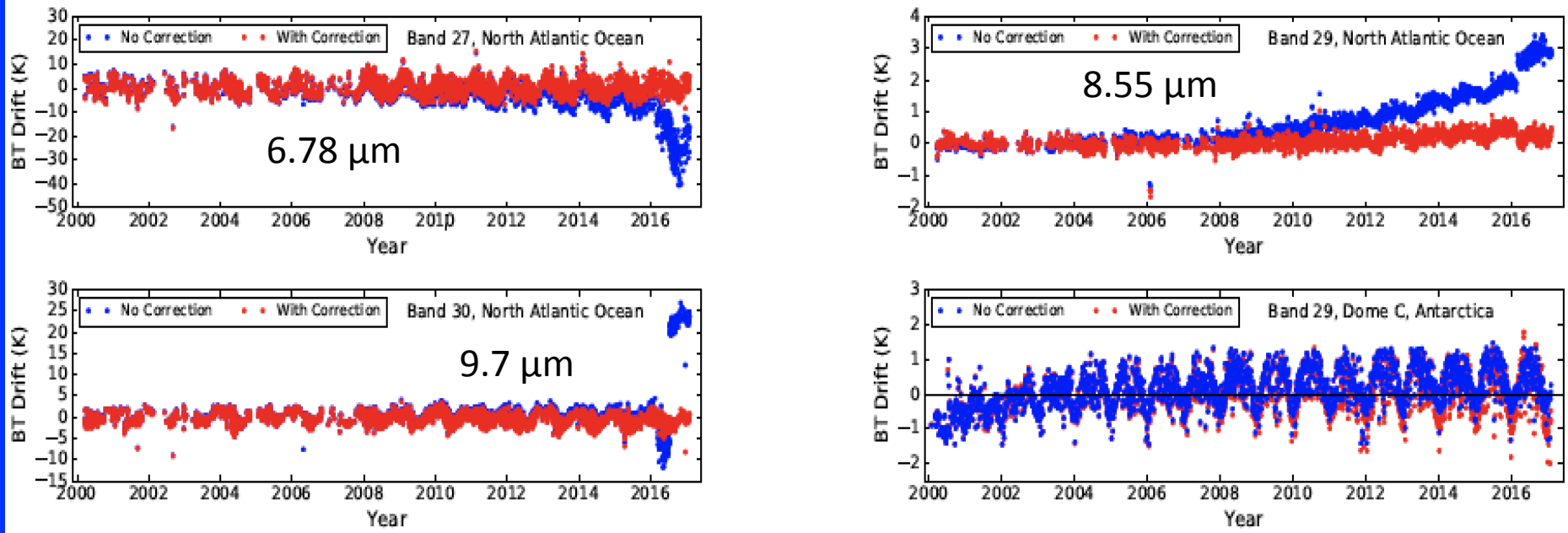


Figure 11. Examples of the brightness temperature drift relative to band 31 for selected bands and scenes. For each set of data, the drift is normalized to the averaged brightness temperature offset in 2003 for the uncorrected data. For the Dome C data for band 29, a black line is shown as a reference for the center of the oscillations in the brightness temperature drift.

Wilson et al. RS, 2017

Collection 6.1 should alleviate the nocturnal phase and cloud detection issues between Terra and Aqua

Consistency between MODIS Ed4 and VIIRS Ed1 Cloud Properties

Algorithm differences

Cloud mask

- VIIRS uses 1.6 μm instead of 2.1 μm (minor difference)
- Lacks 6.7 μm
- Lacks 13.3 μm

} affects polar cloud detection - nighttime & cirrus

Cloud properties

- New water droplet reflectance model used for VIIRS => smaller Re
- ML algorithm uses 11-12 μm instead of CO2, cirrus heights affected some
- Thick ice cloud top height correction applied, not used for MODIS
- Bug in 1.24-μm reflectance computation fixed for VIIRS: greater tau over snow

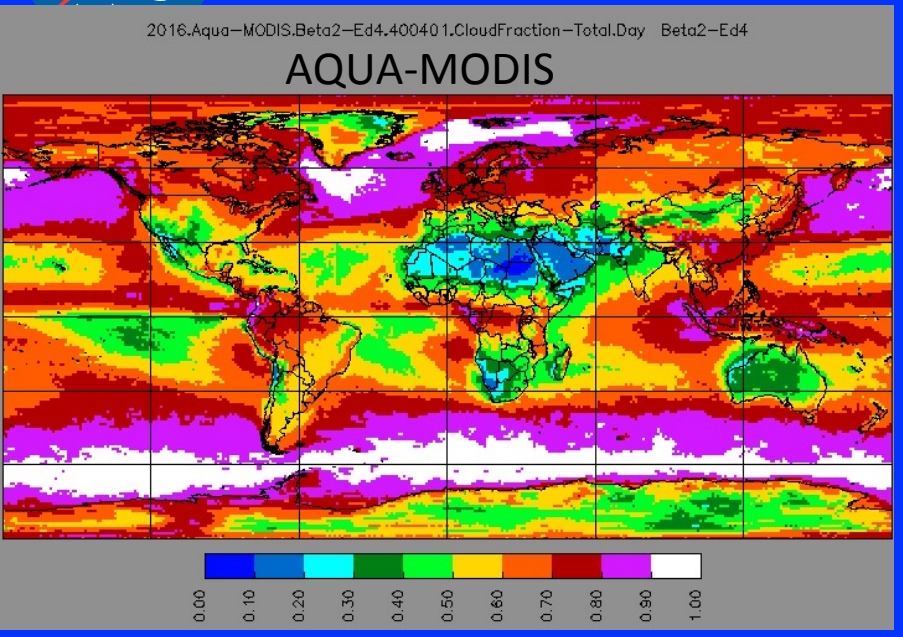
Resolution/calibration differences may also affect cloud properties

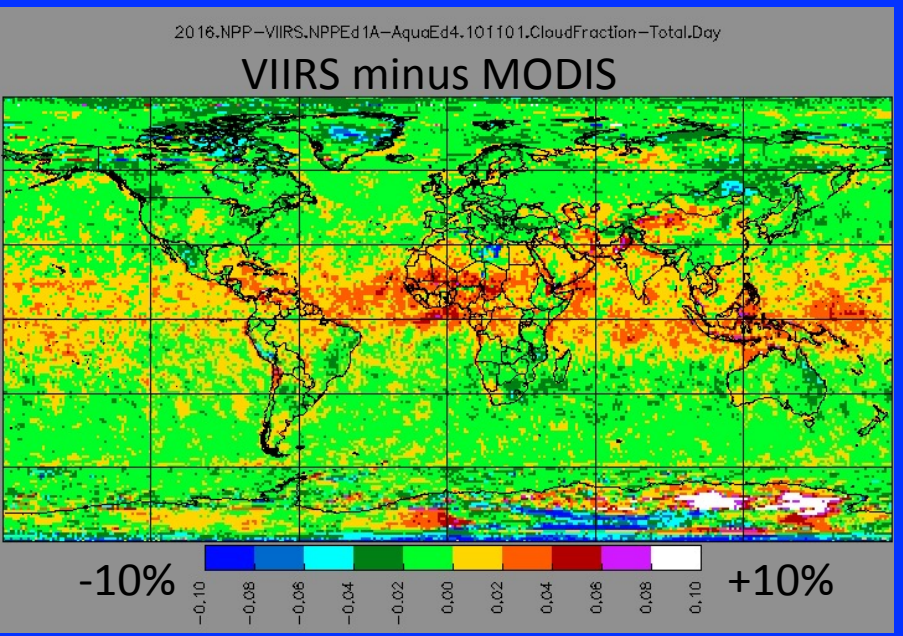
- VIIRS at 750 m (~const w/VZA)

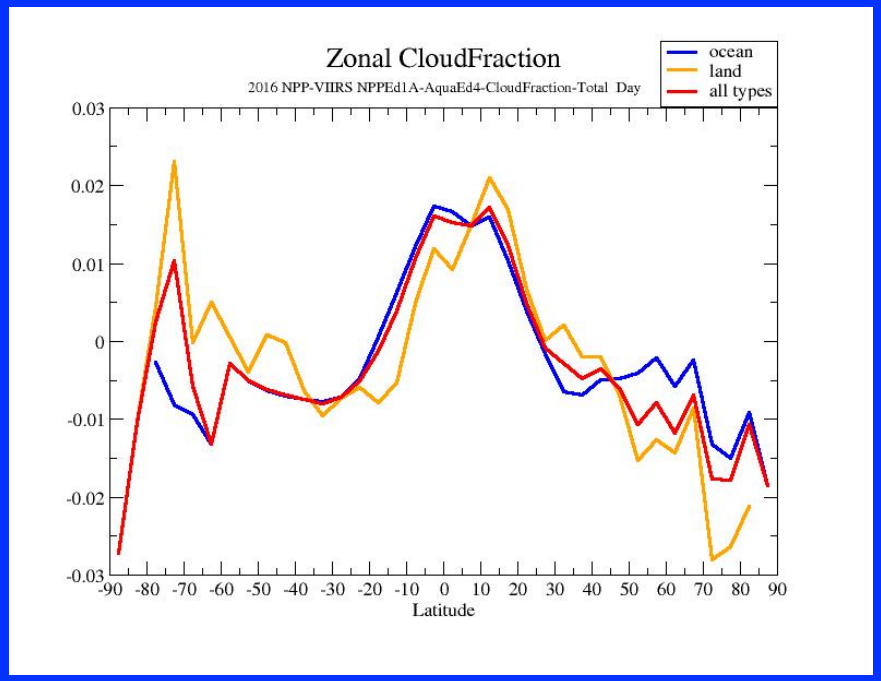
AQUA-MODIS vs VIIRS

Total Cloud Fraction (2016)

Day





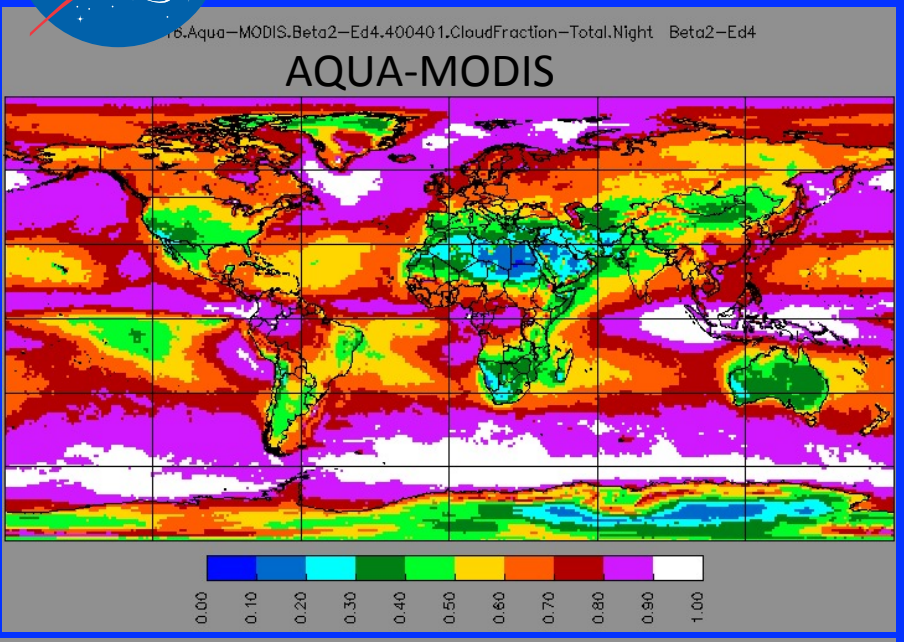


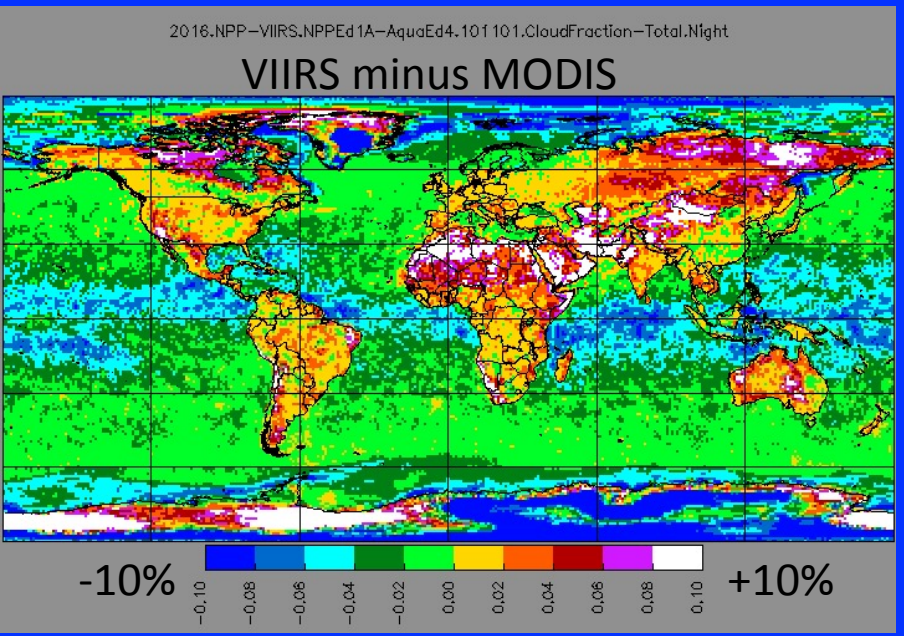
Comparable over much of the world, but

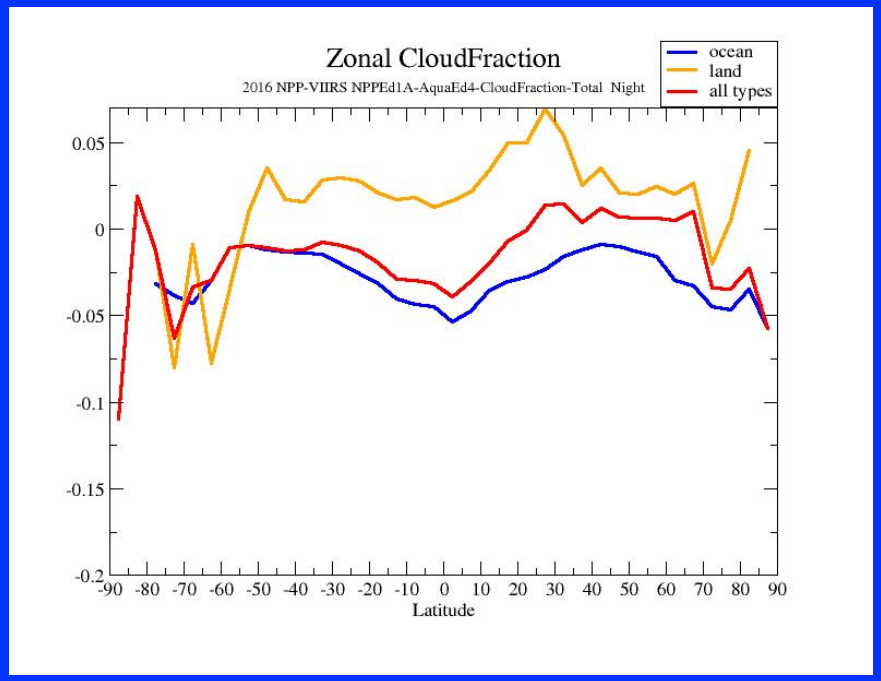
- VIIRS has more tropical clouds, 3-5% in some areas
- Polar Land differences large
- Zonal mean diffs +/- 2%

AQUA-MODIS vs VIIRS

Total Cloud Fraction (2016) Night







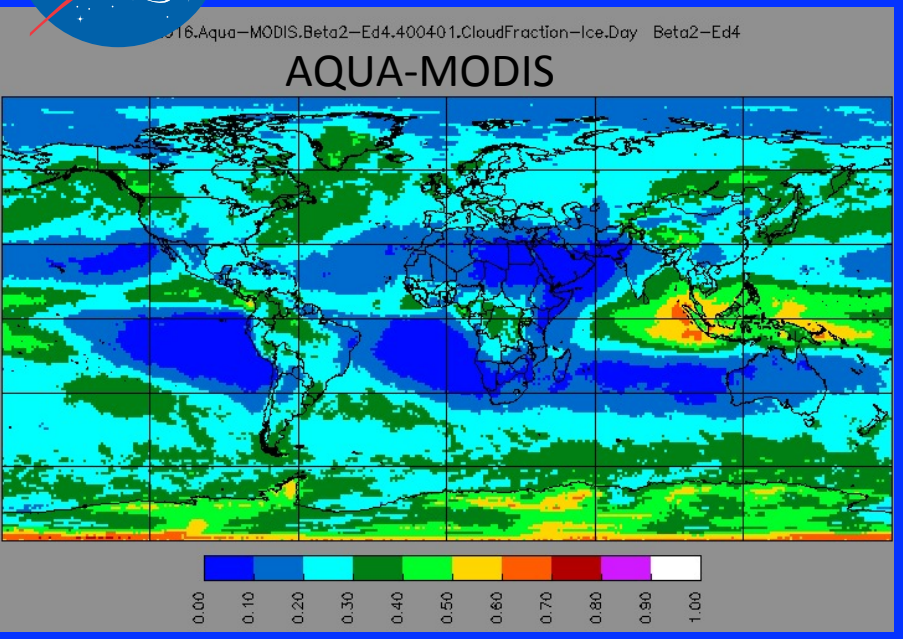
Nighttime differences worse

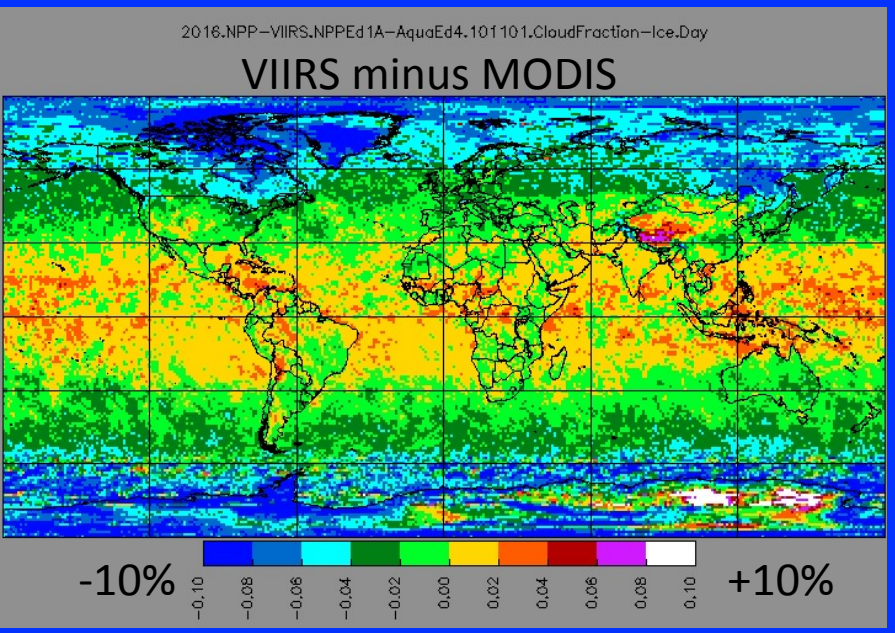
- VIIRS has less tropical clouds over ocean
- More clouds over non-polar land
- Regional polar differences large
- Zonal mean diffs +/- 5%

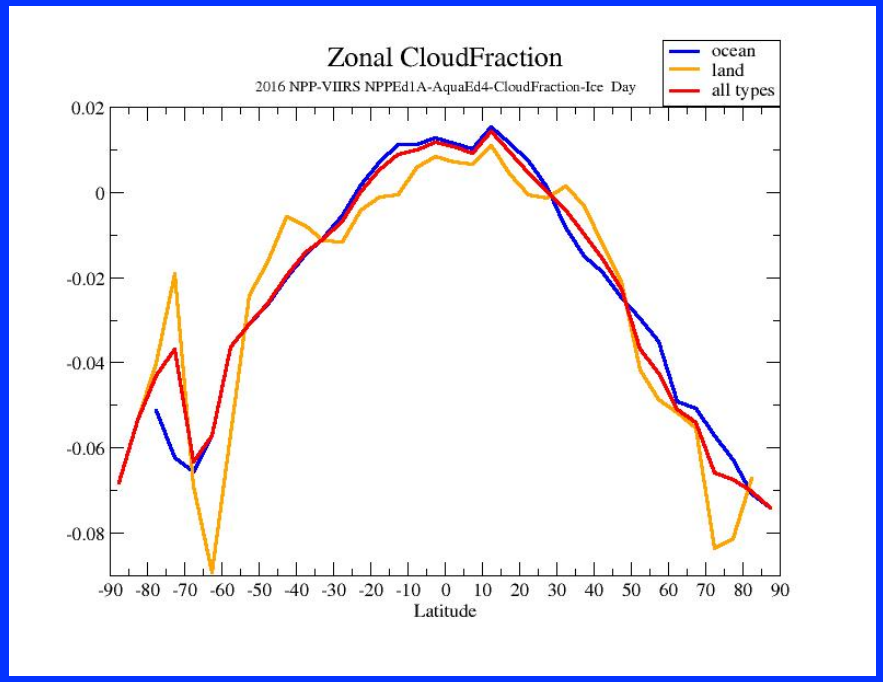
AQUA-MODIS vs VIIRS

Ice Cloud Fraction (2016)

Day





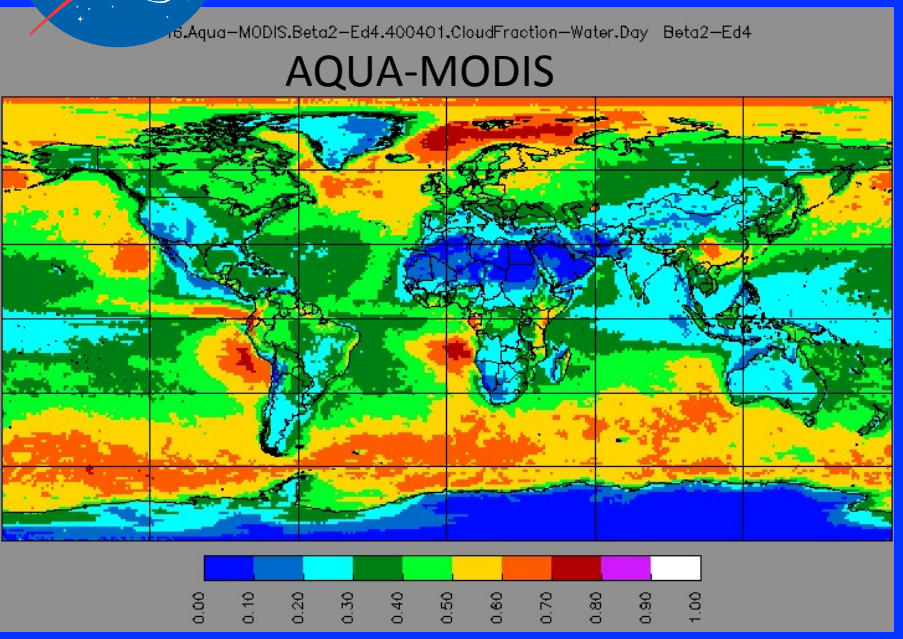


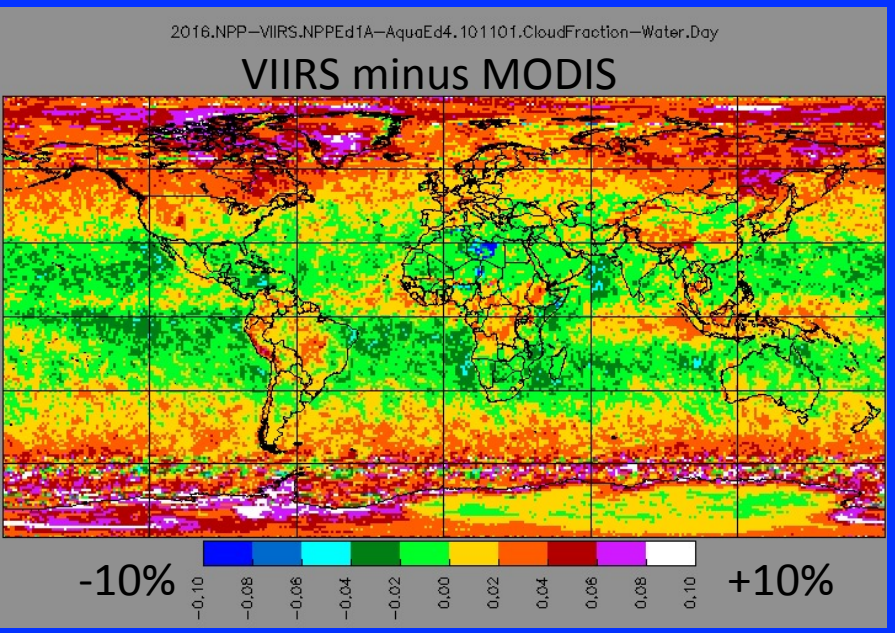
- Daytime tropical diffs mostly ice clouds
- Large ice cloud differences polar regions
  -mostly lower CF's from VIIRS

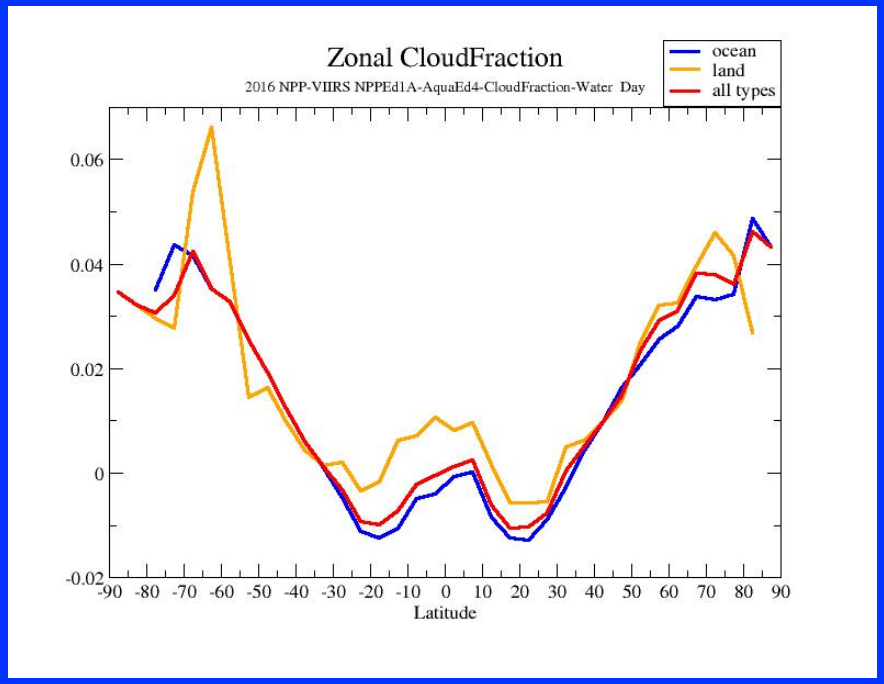
AQUA-MODIS vs VIIRS

Water Cloud Fraction (2016)

Day



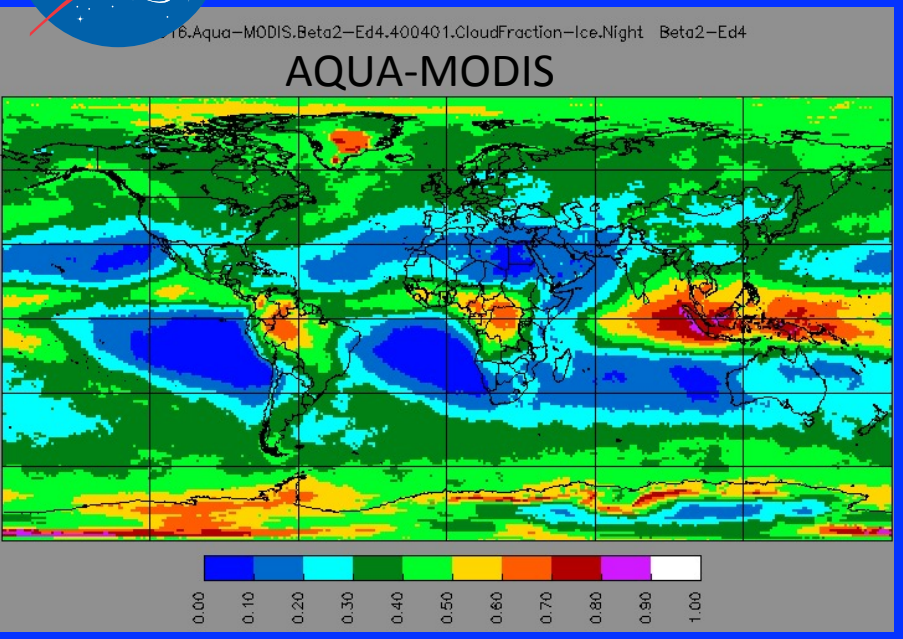


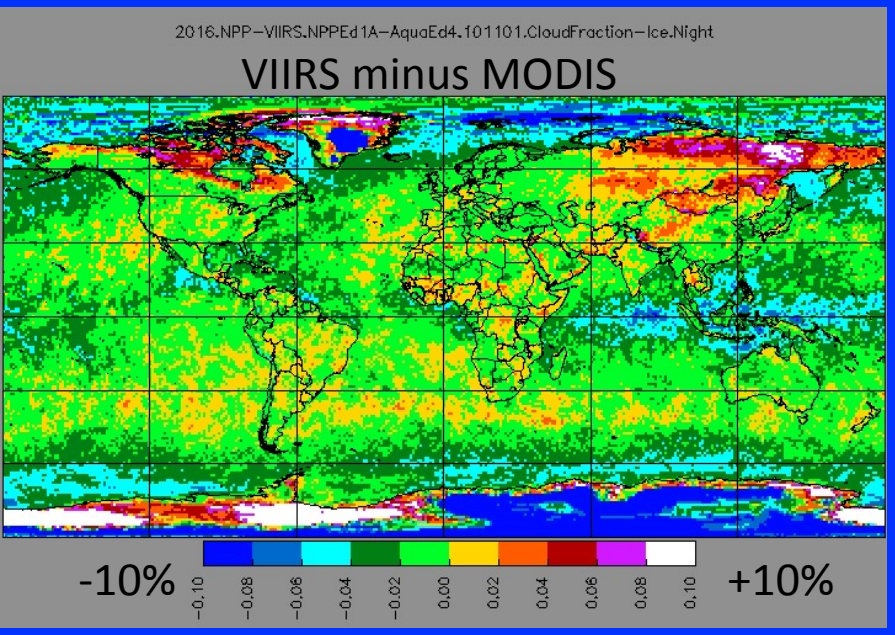


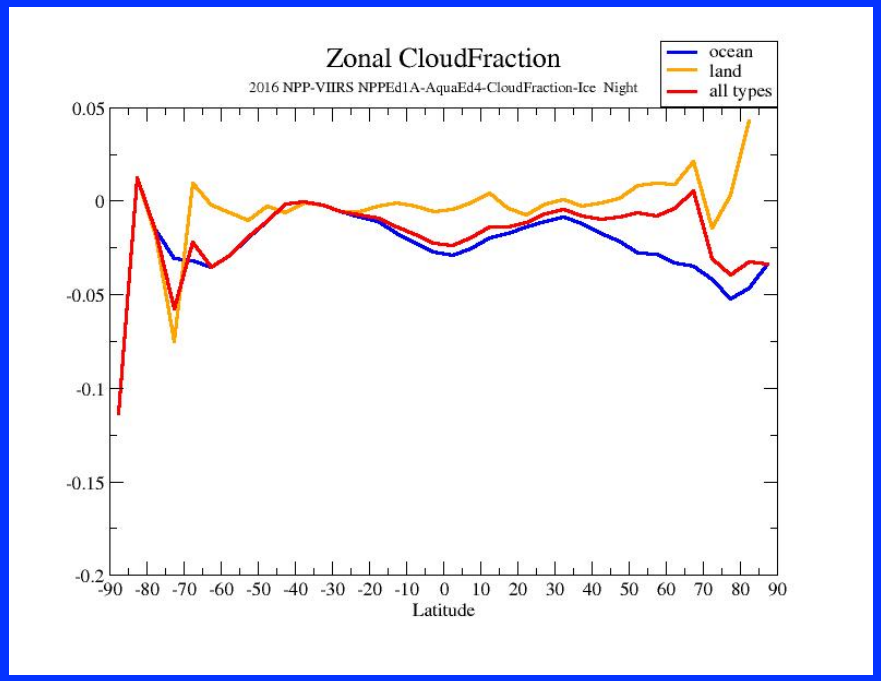
- Polar water cloud fractions mostly higher from VIIRS at higher mid-lats and in polar regions

AQUA-MODIS vs VIIRS

Ice Cloud Fraction (2016) Night



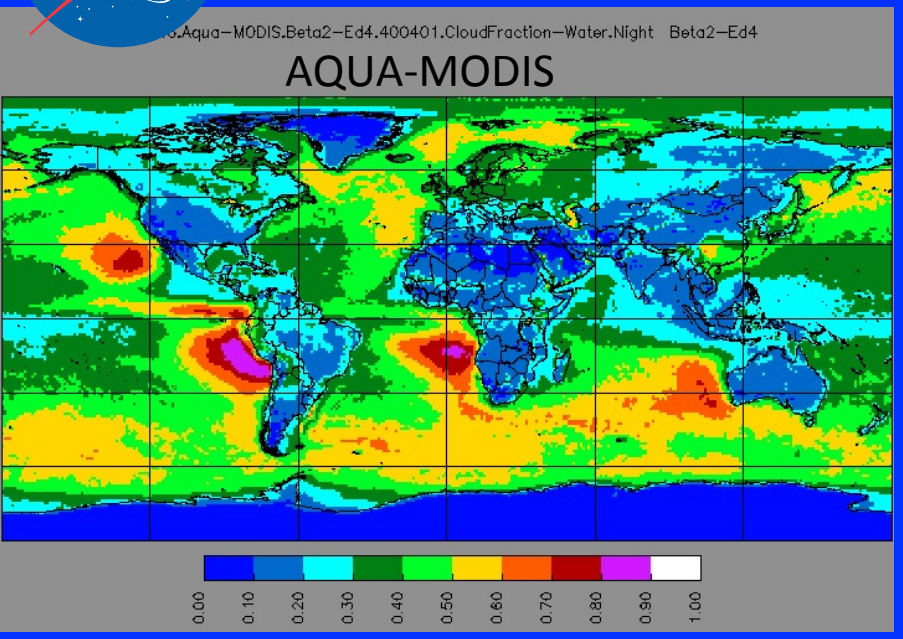


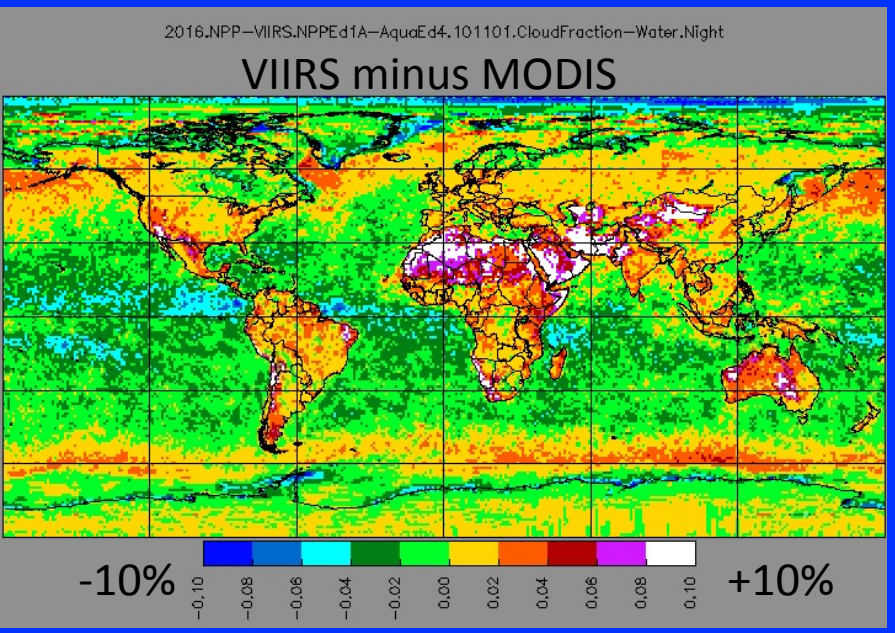


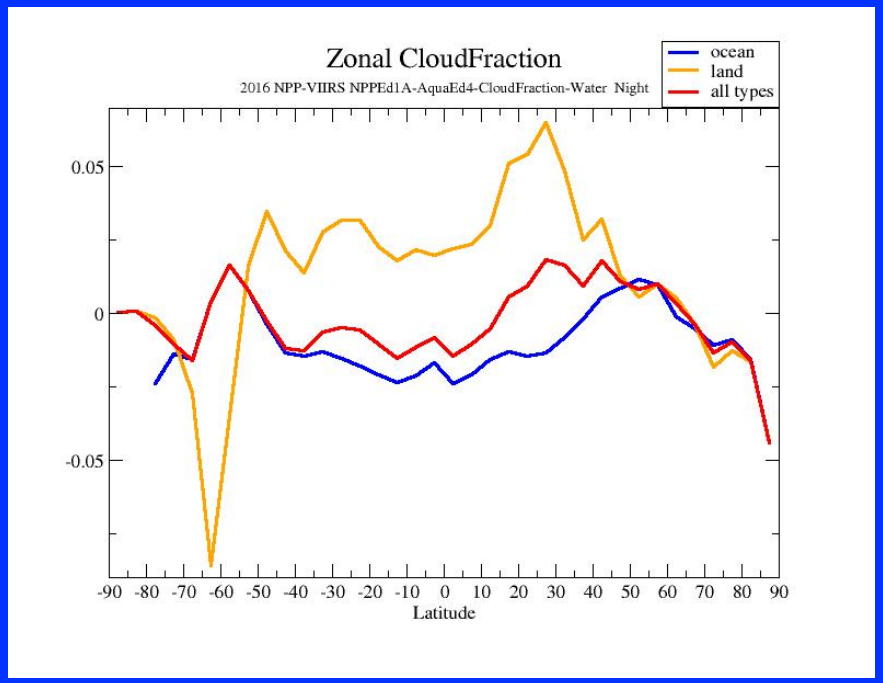
- Largest nighttime ice cloud differences in polar regions and over Russia and Asia

AQUA-MODIS vs VIIRS

Water Cloud Fraction (2016) Night





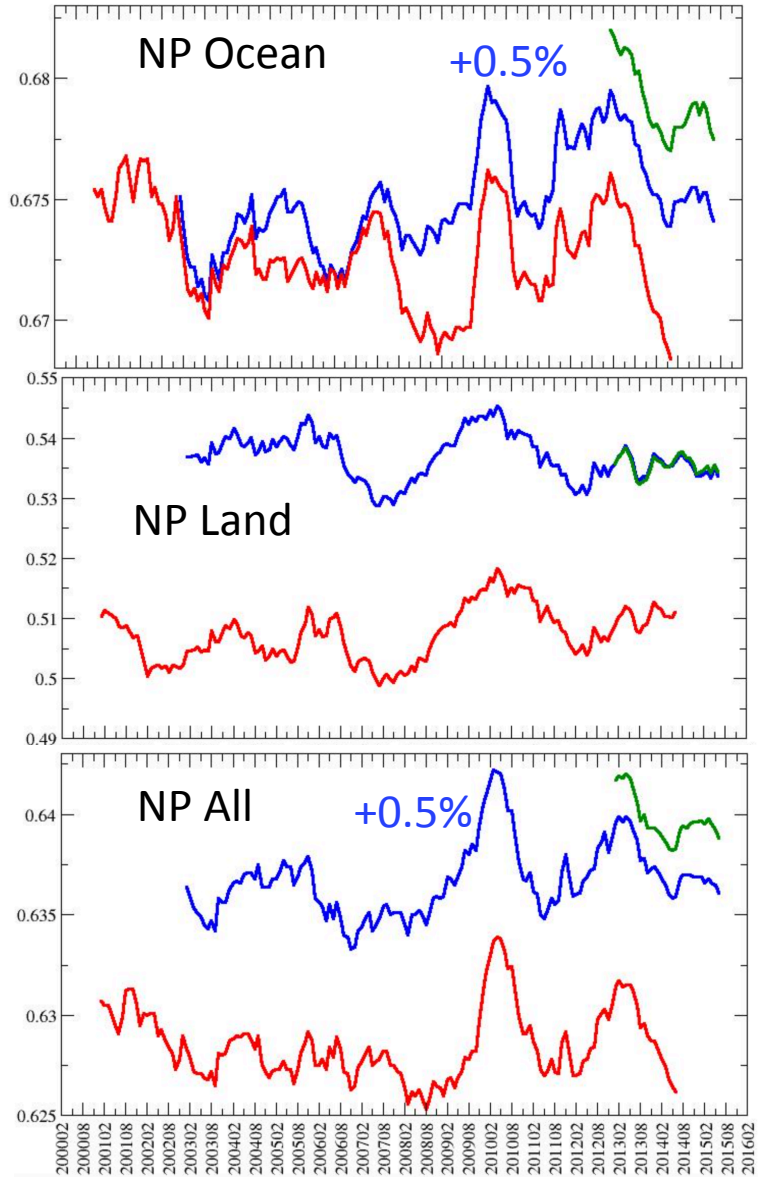


- Water cloud differences most significant over land at night
- MODIS aerosols help reduce false MODIS clouds (e.g. Africa). VIIRS using different aerosol product
- Polar regions fairly consistent

MODIS vs VIIRS Time Series

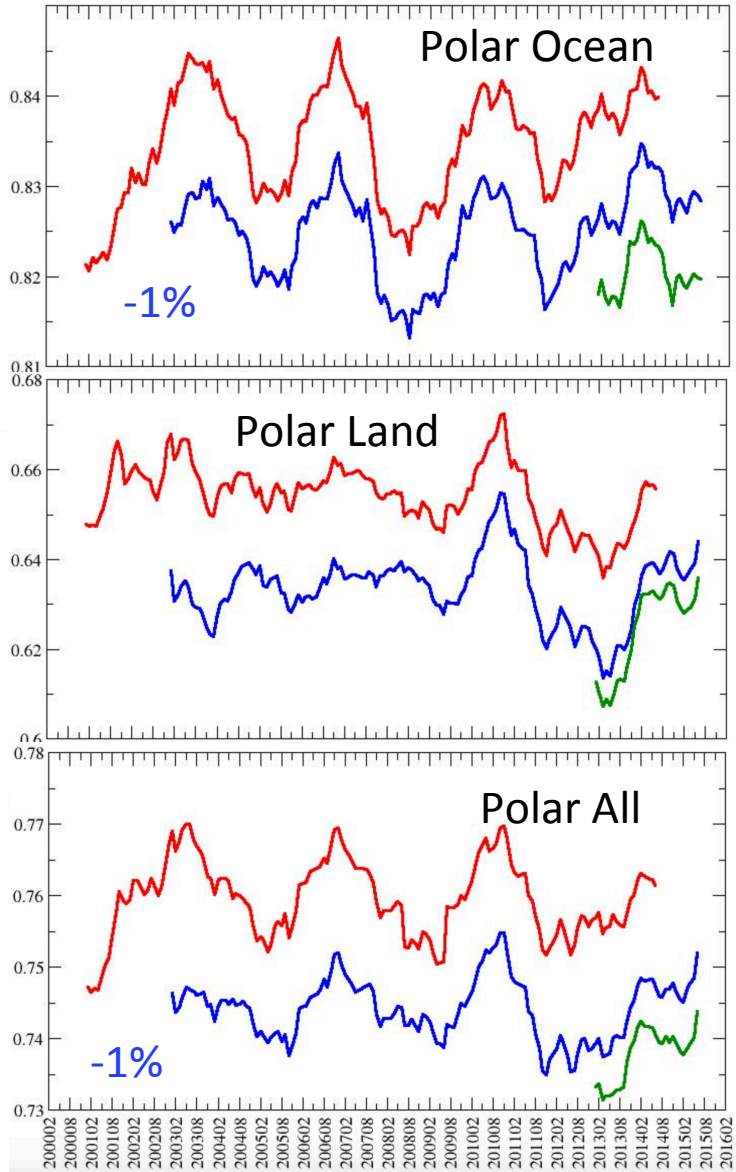
Cloud Fraction (Day)

12-month running means



Cloud fractions track well

Differences less than 1% on average

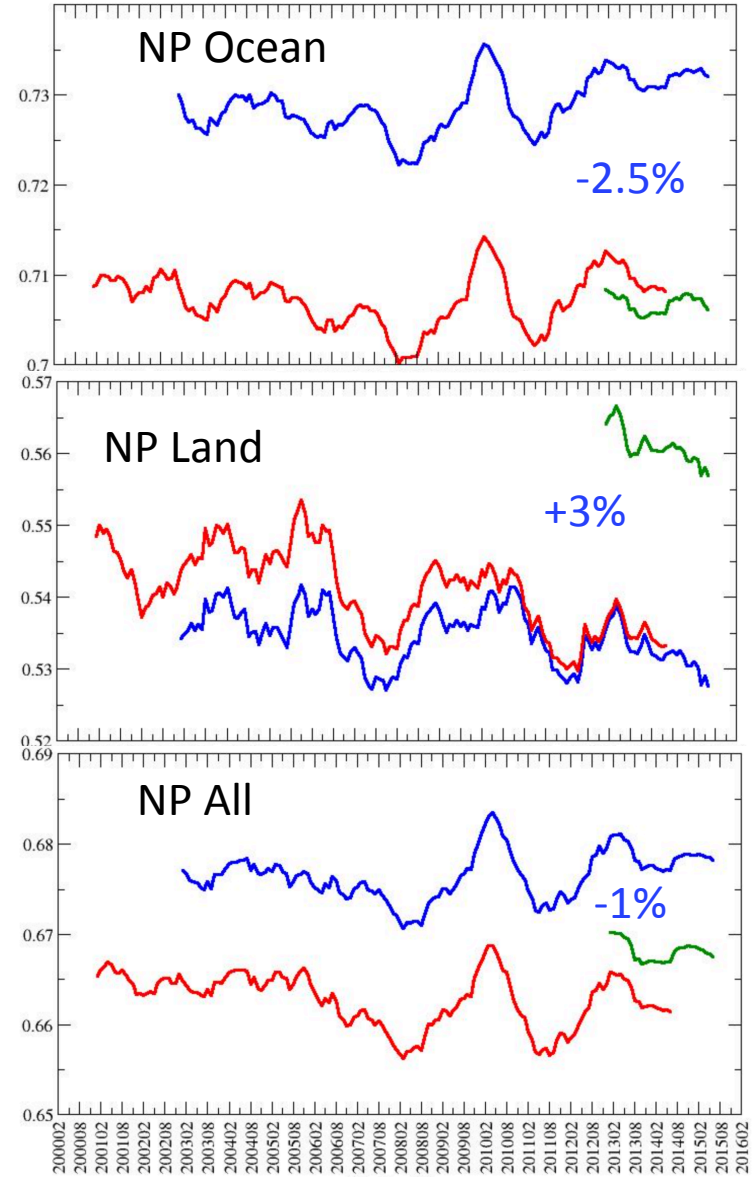


Aqua Ed4
Terra Ed4
SNPP Ed1a

MODIS vs VIIRS Time Series

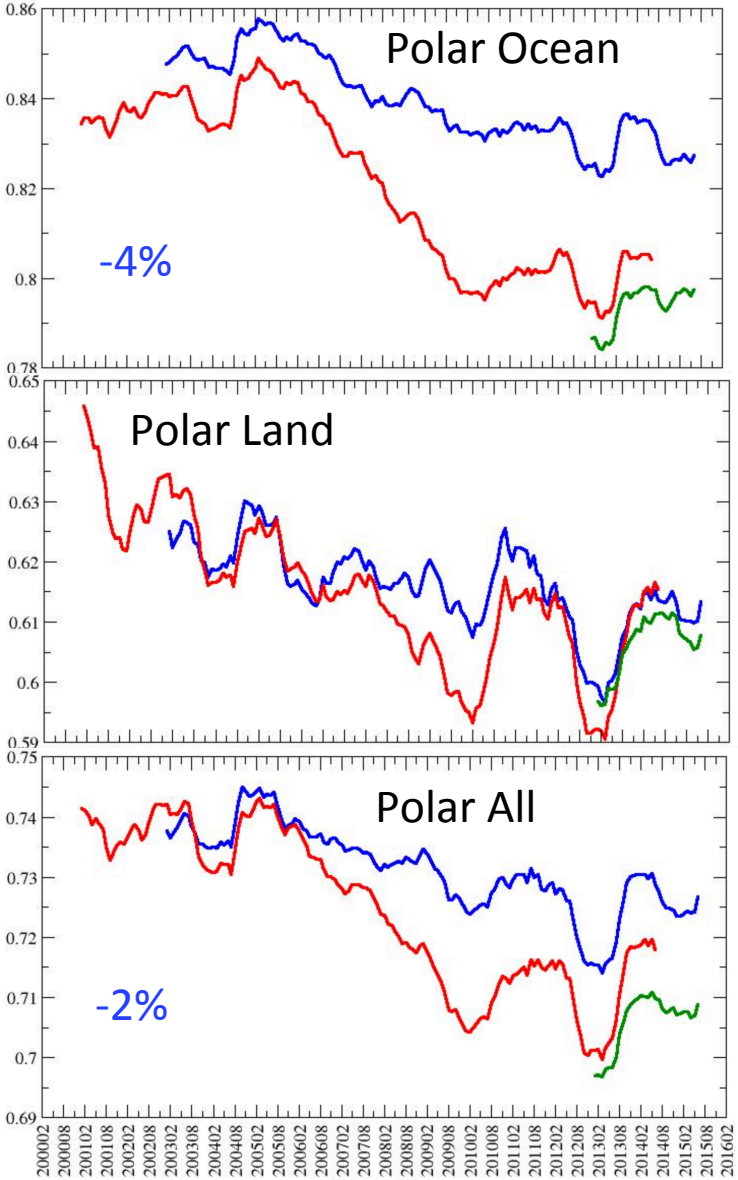
Cloud Fraction (Night)

12-month running means



Cloud fractions track well

Nighttime differences significant



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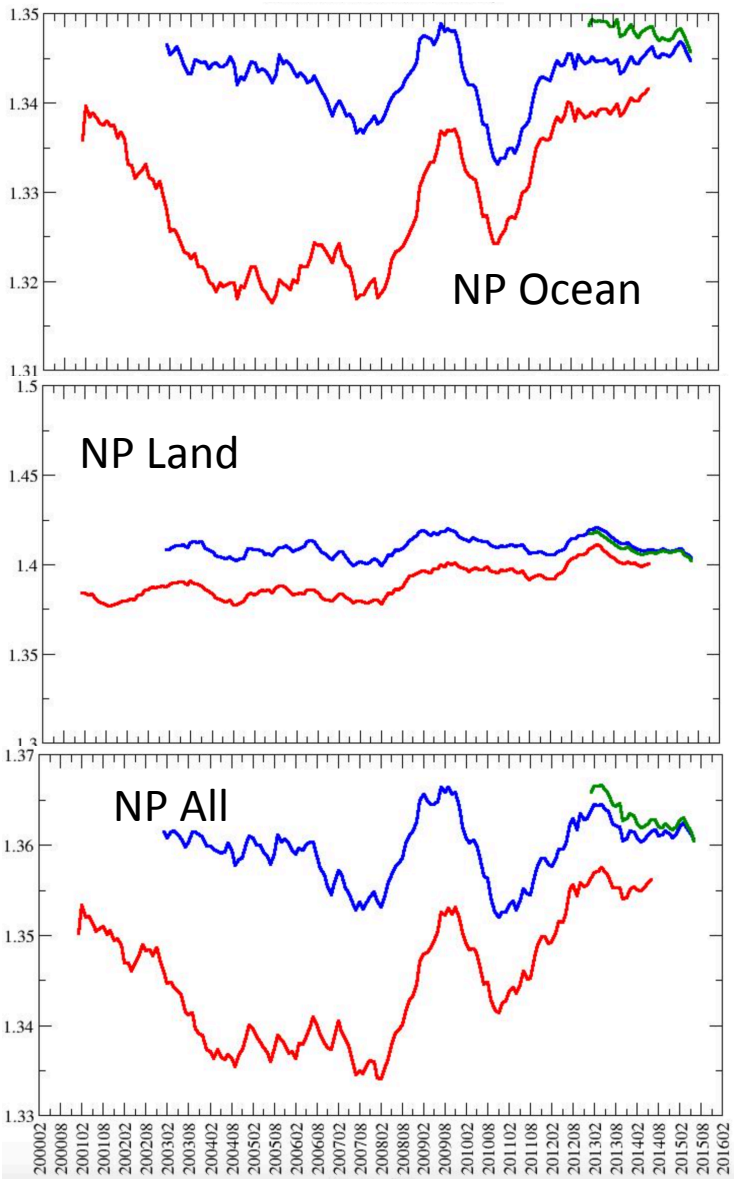
Terra Ed4
SNPP Ed1a

MODIS vs VIIRS Time Series

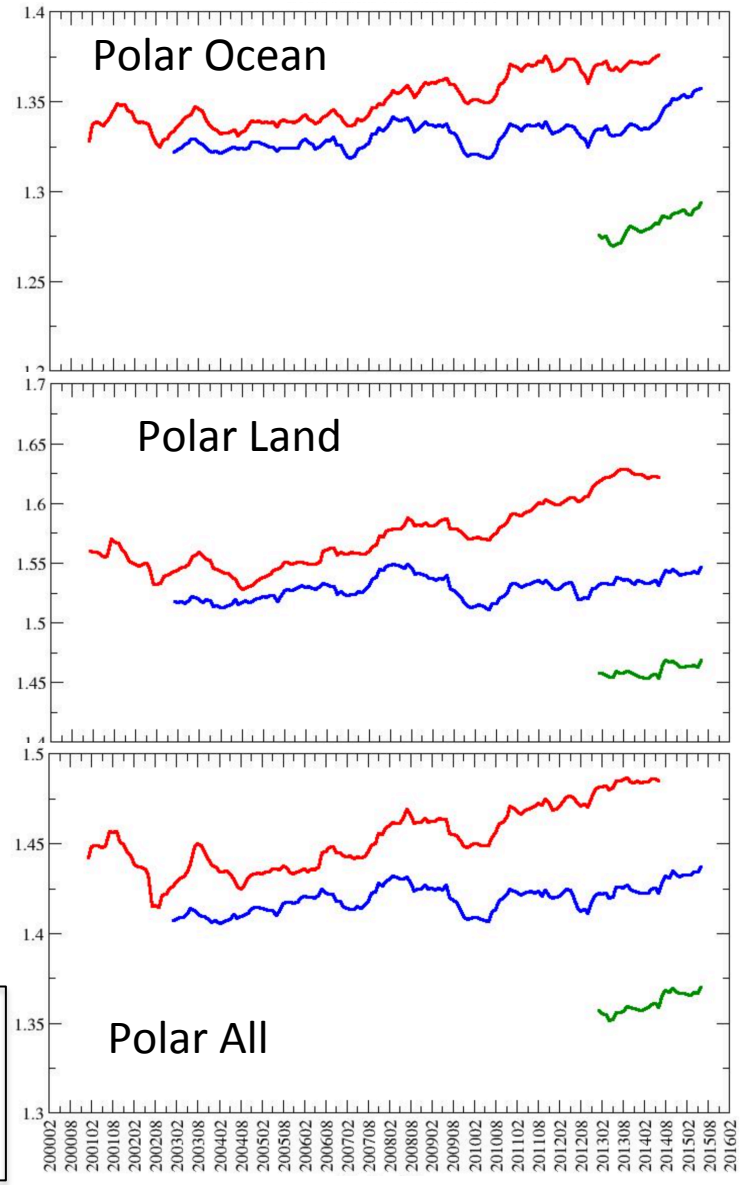
Cloud Phase Fraction (Day)

12-month running means



Daytime, non-polar is consistent

Less ice, more water clouds (5-7%) from VIIRS in polar regions

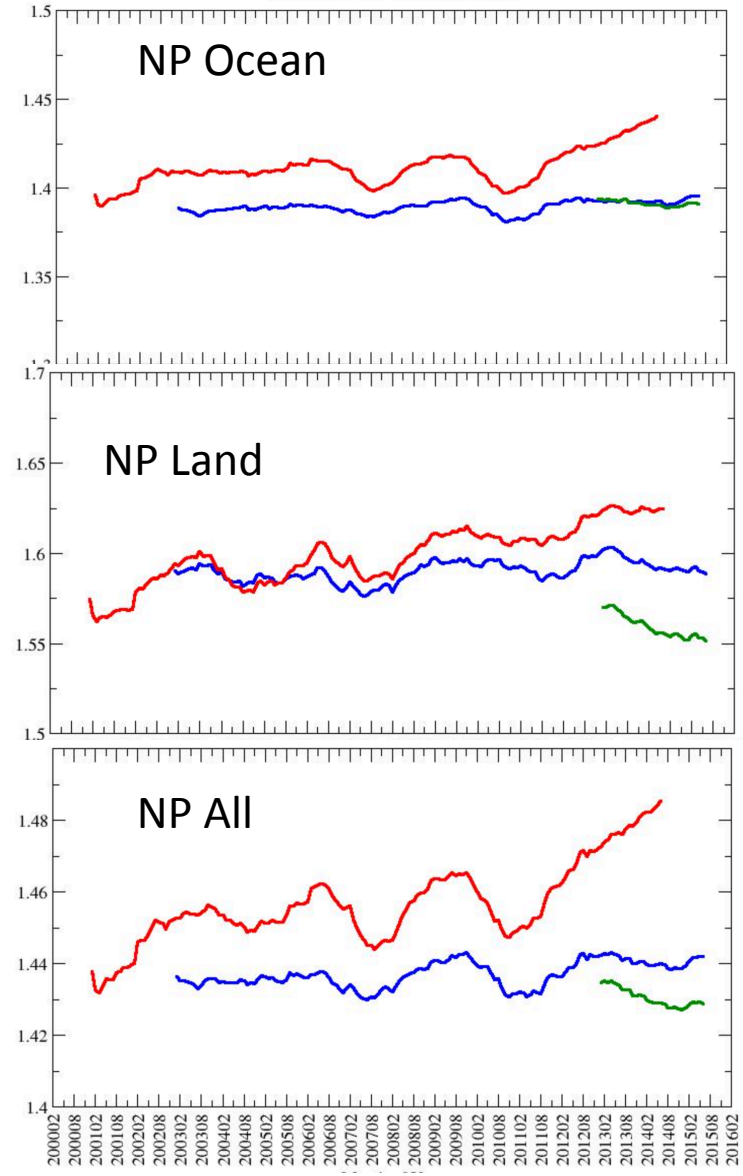


Aqua Ed4
Terra Ed4
SNPP Ed1a

MODIS vs VIIRS Time Series

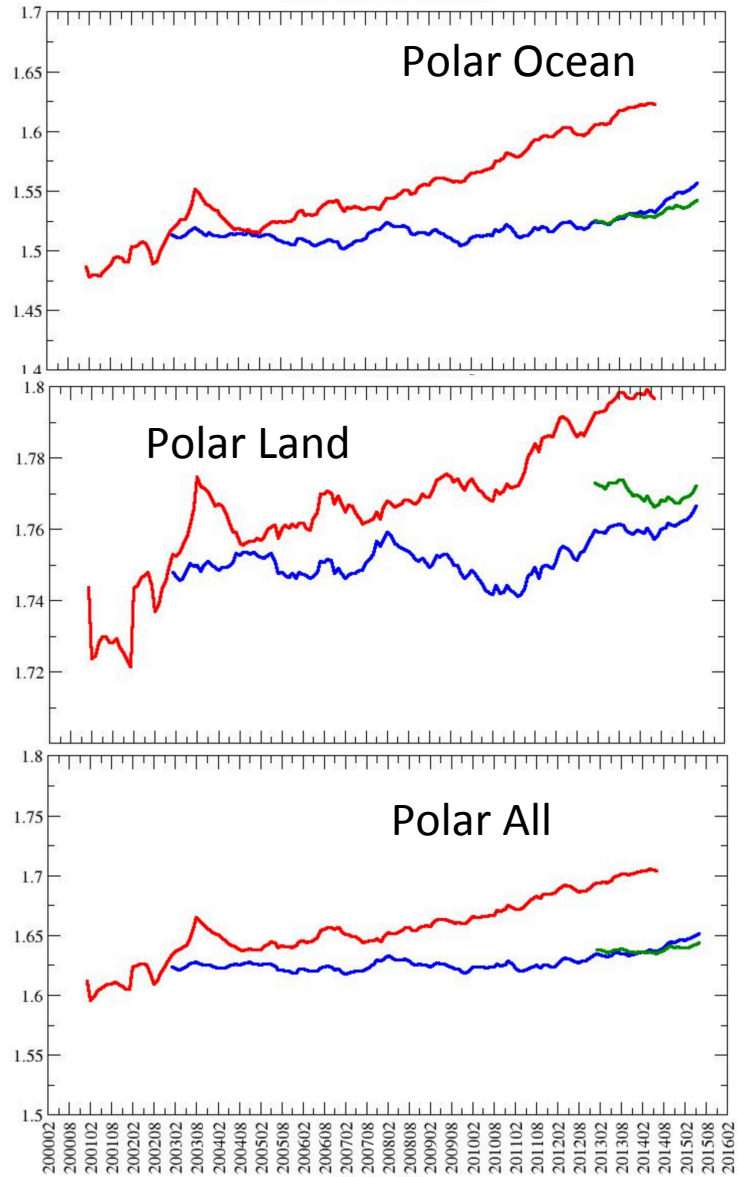
Cloud Phase Fraction (Night)

12-month running means



Better cloud phase consistency over polar regions at night

Trend in Terra phase fraction (8.5 um degradation ?)



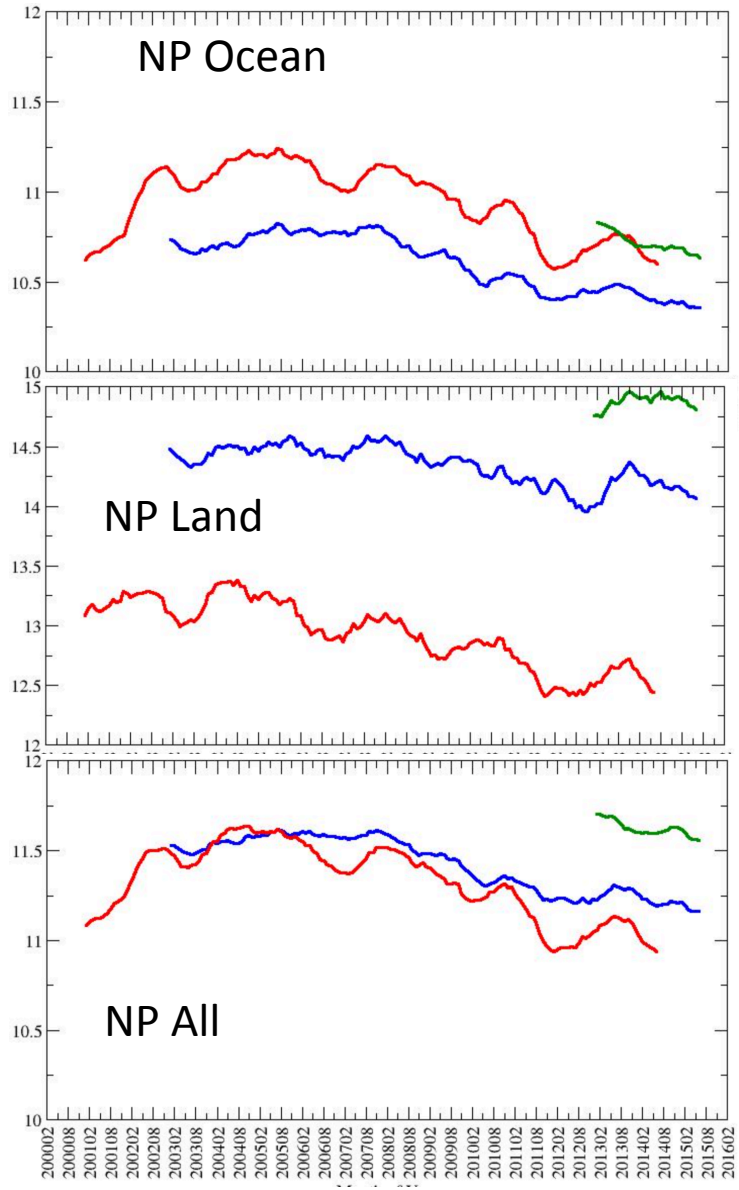
Aqua Ed4
Terra Ed4
SNPP Ed1a

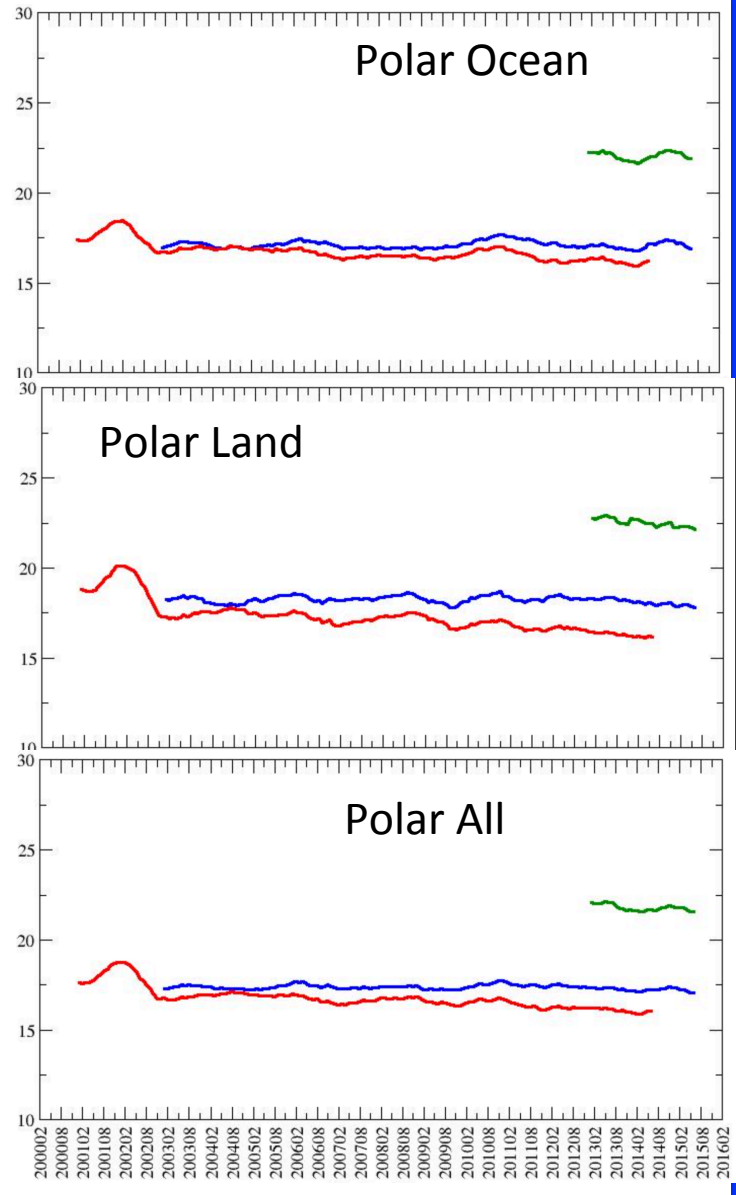
MODIS vs VIIRS Time Series

Cloud Optical Depth (Day)

12-month running means

All clouds





VIIRS optical depths higher

Differences more significant over polar regions

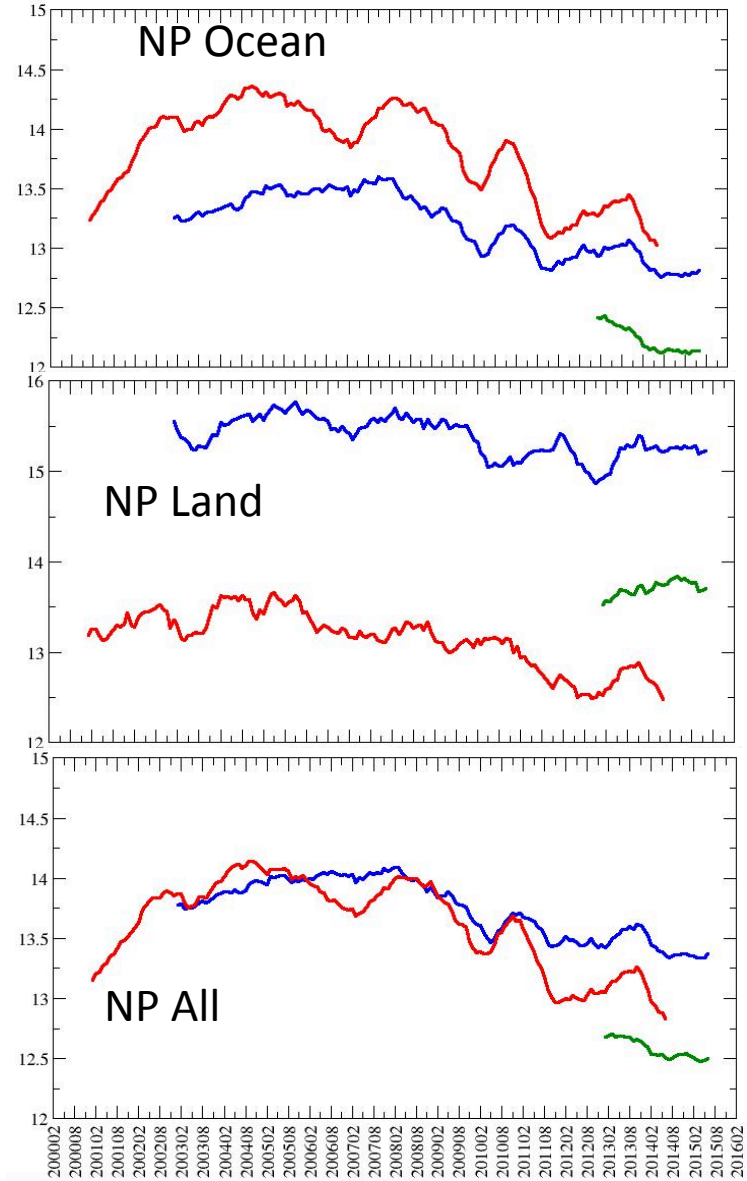
Trends interesting
- No trend NP Land (VIIRS)
- Decreasing elsewhere

Aqua Ed4
Terra Ed4
SNPP Ed1a

MODIS vs VIIRS Time Series

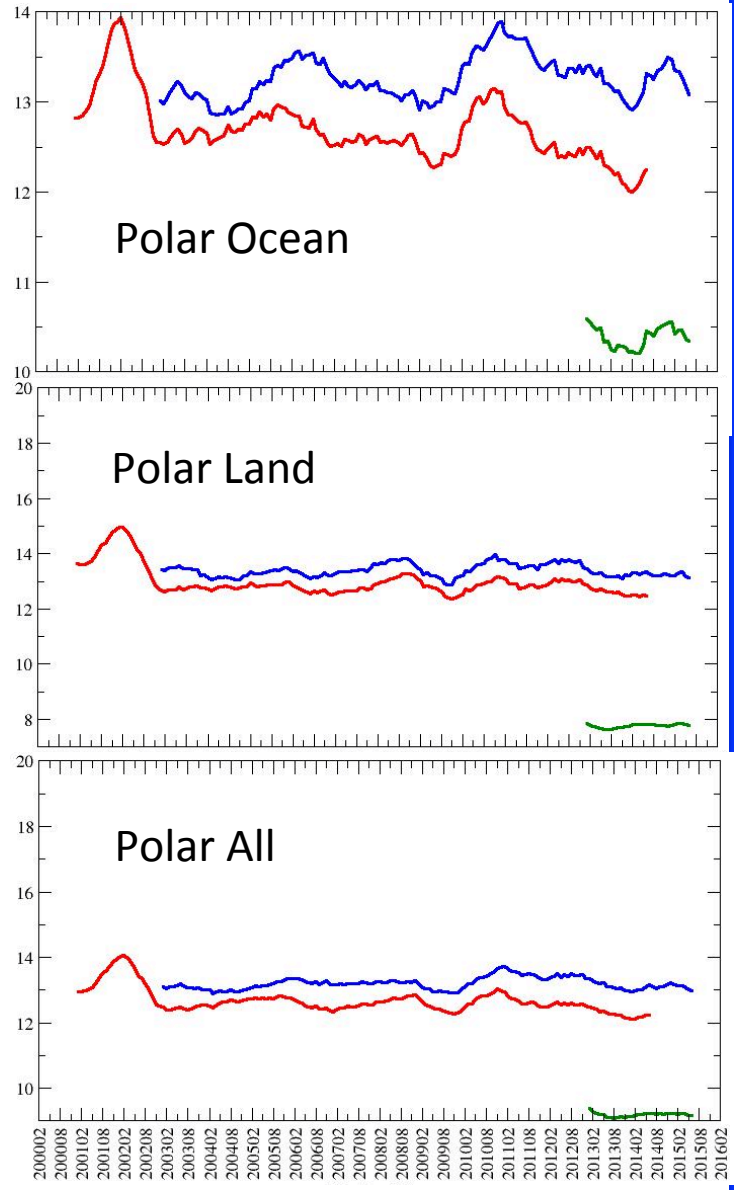
Cloud Optical Depth (Day)

Ice clouds



VIIRS ice cloud optical depths lower

Differences more significant over polar regions

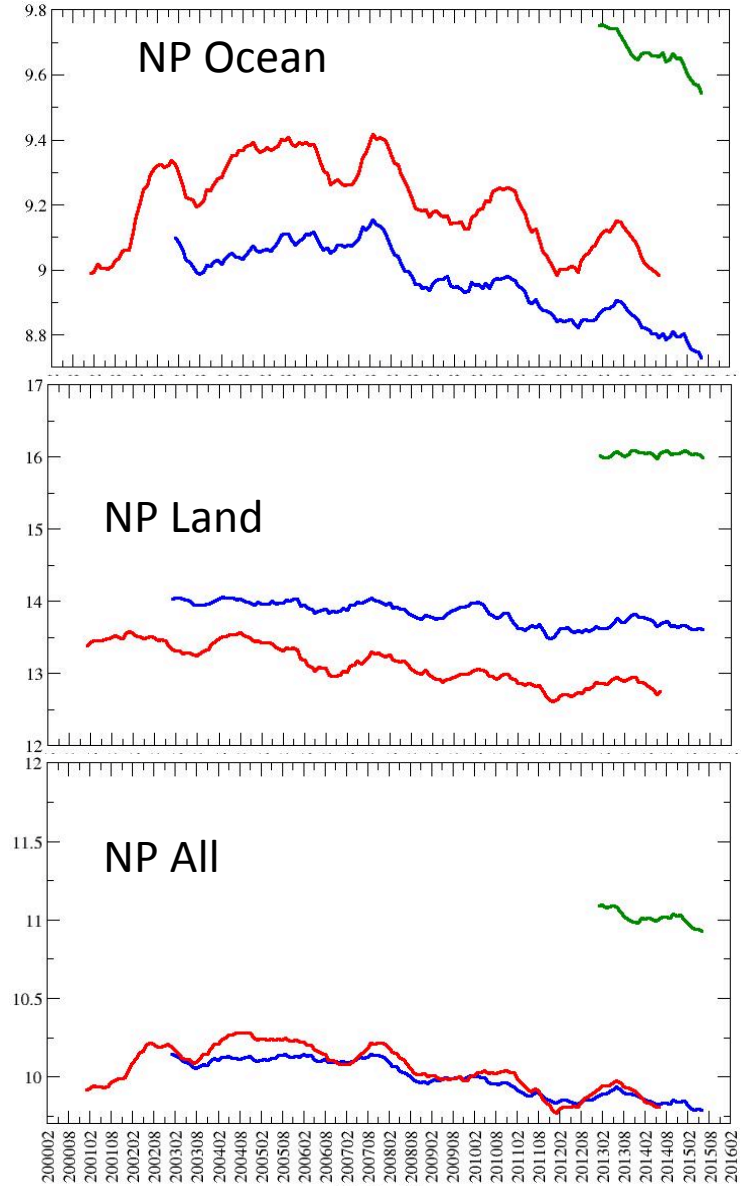


Aqua Ed4
Terra Ed4
SNPP Ed1a

MODIS vs VIIRS Time Series

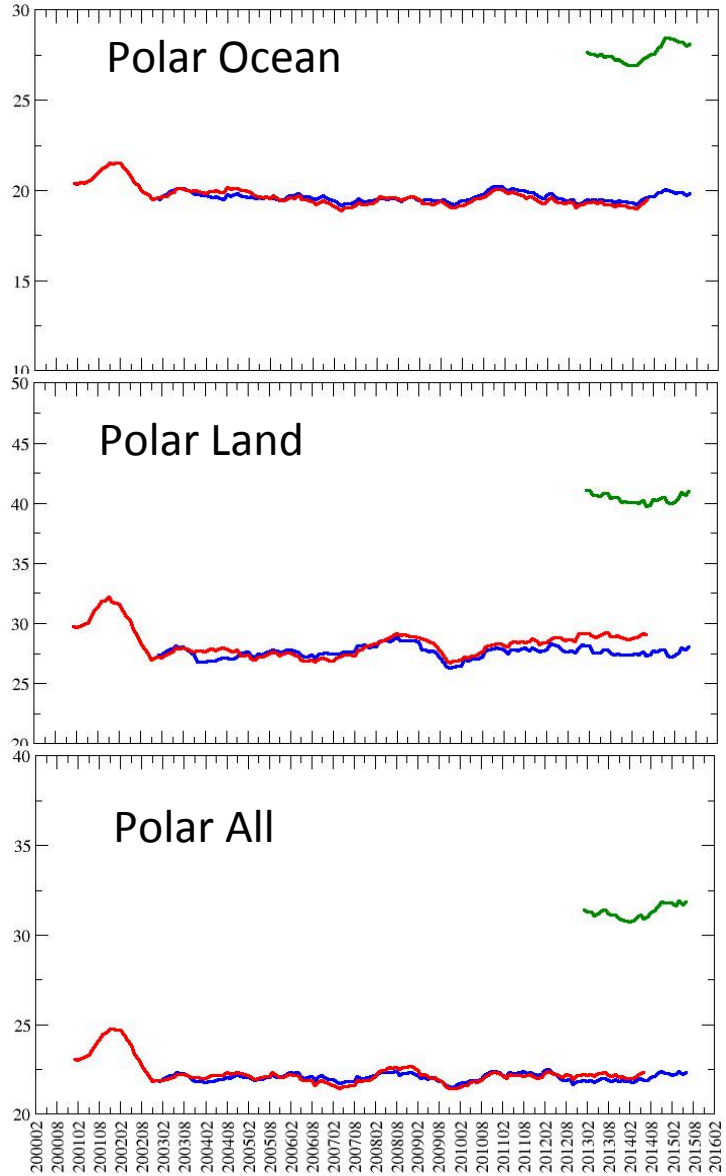
Cloud Optical Depth (Day)

Water clouds



VIIRS water cloud optical depths higher

Differences more significant over polar regions

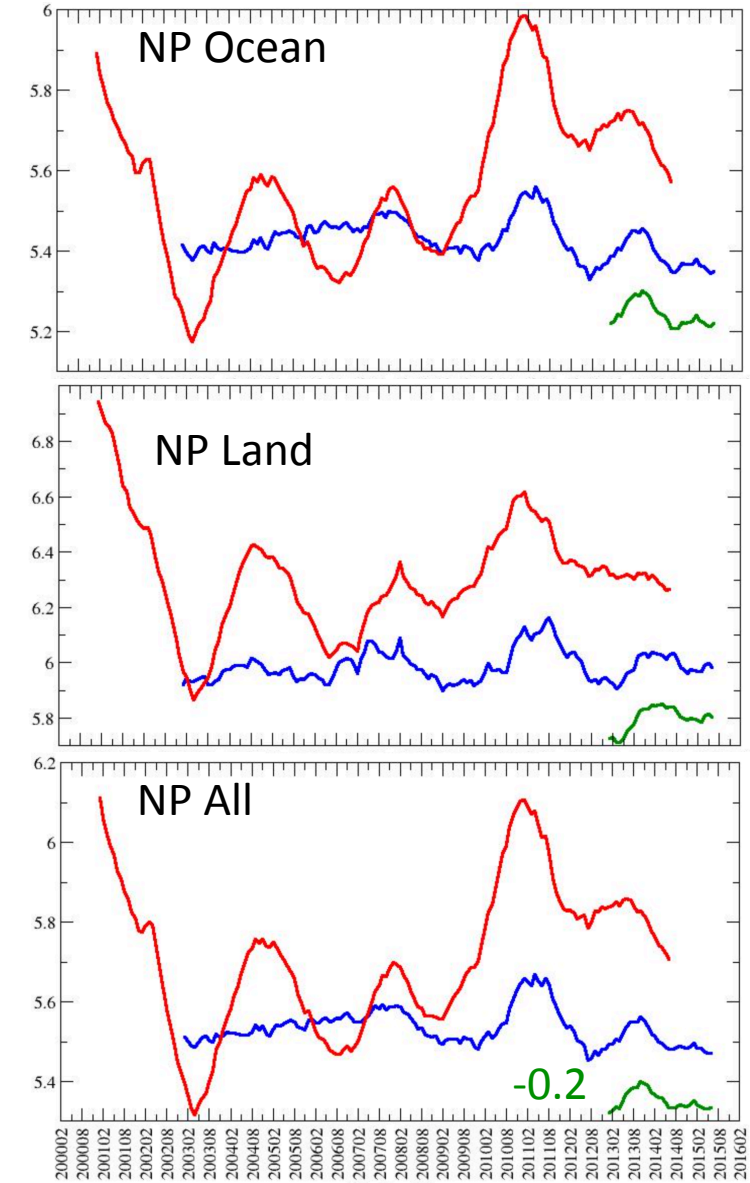


Aqua Ed4
Terra Ed4
SNPP Ed1a

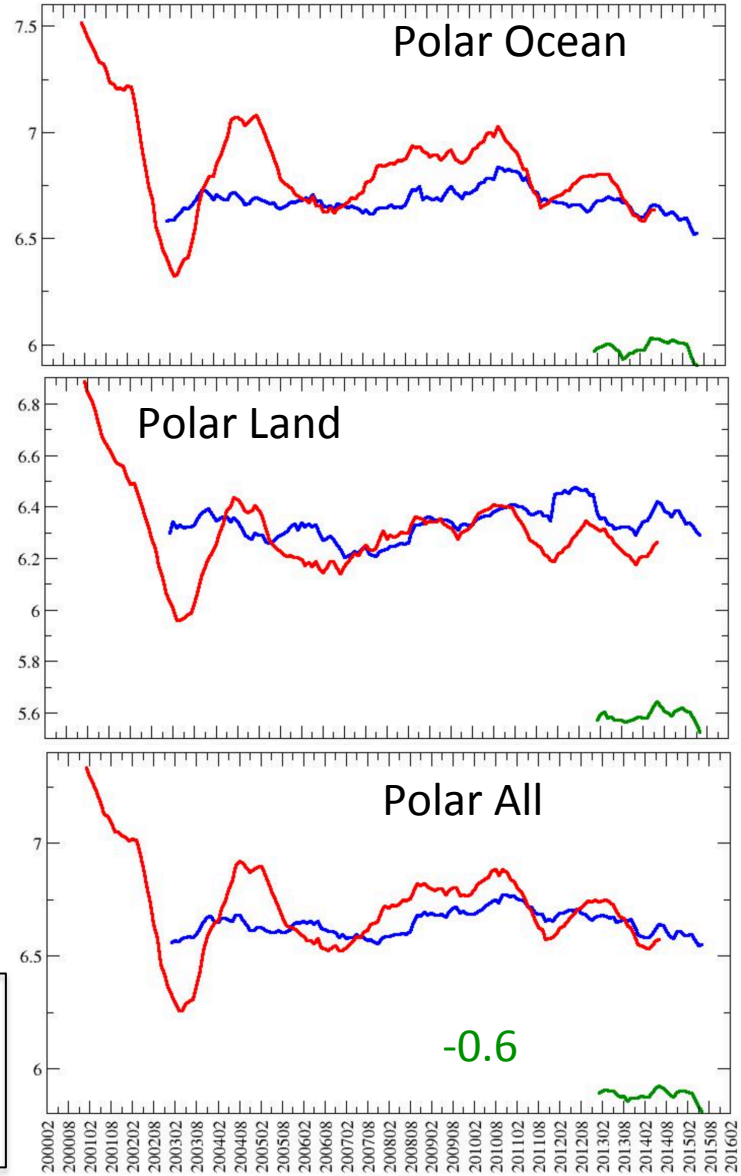
MODIS vs VIIRS Time Series

Cloud Optical Depth (Night)

All clouds



Nighttime diffs much smaller than found for daytime



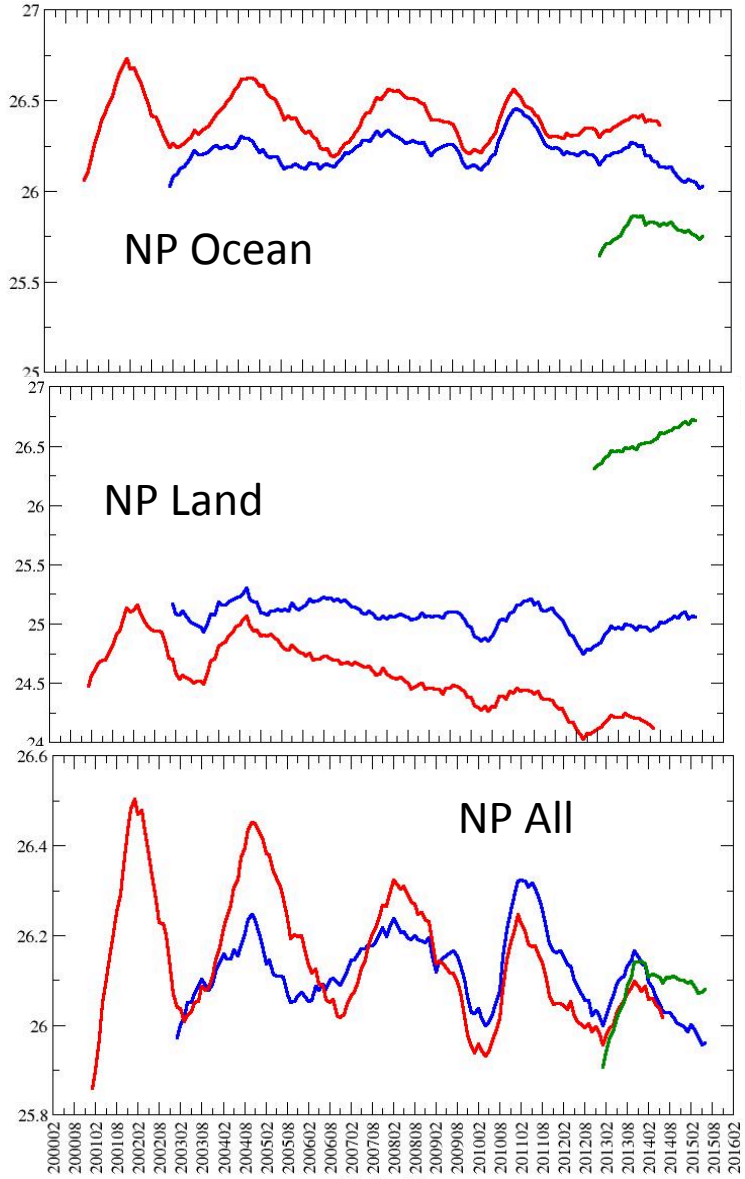
Aqua Ed4
Terra Ed4
SNPP Ed1a

MODIS vs VIIRS Time Series

Cloud Particle Size (Day)

12-month running means

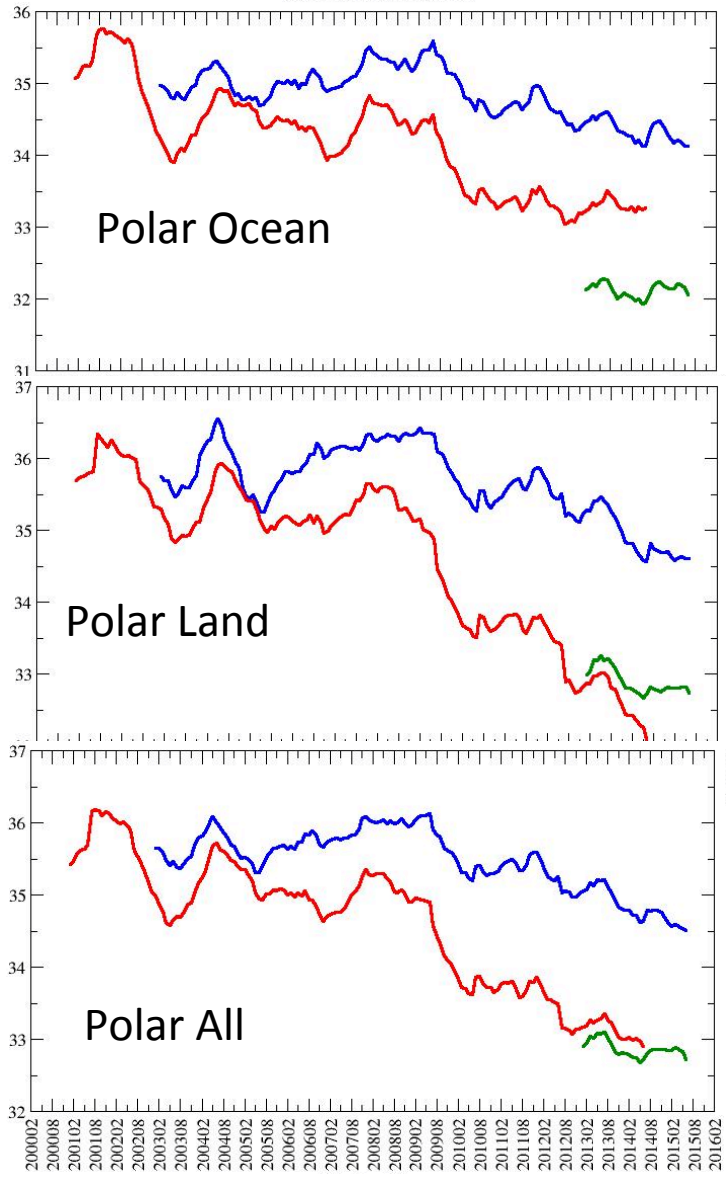
Ice clouds



Ice Particle size tracking well

Small NP diffs

VIIRS 2 um lower polar regions



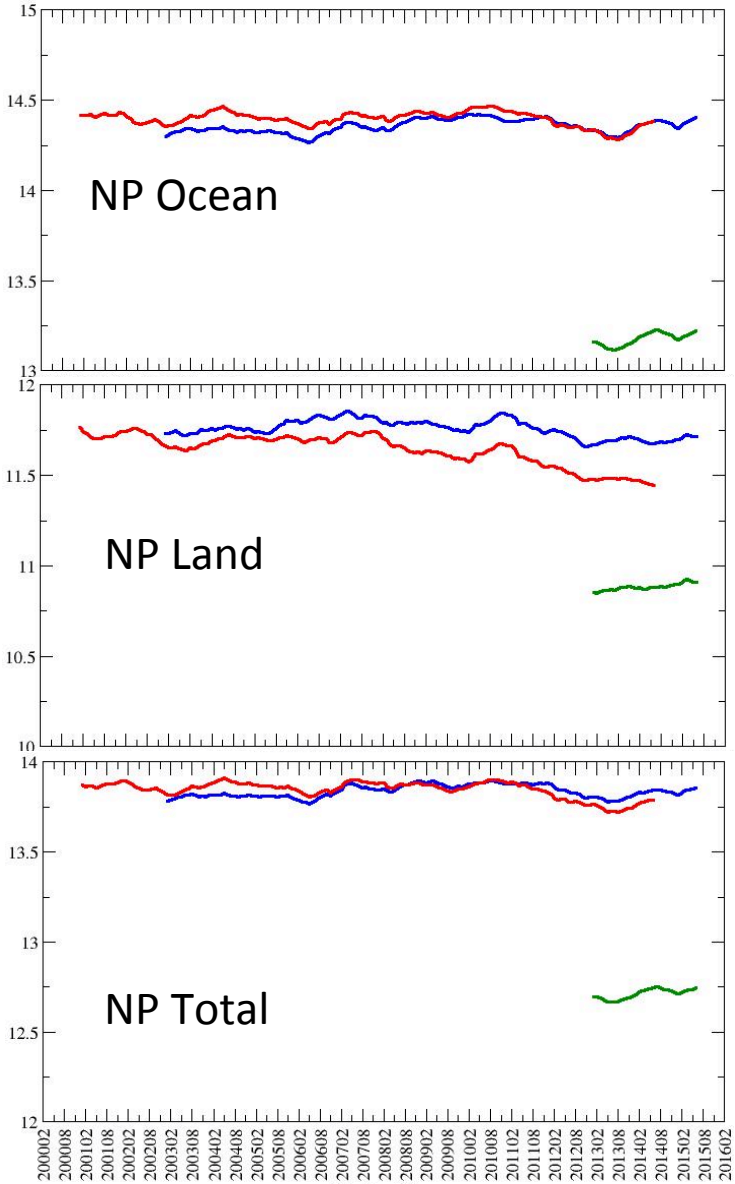
Aqua Ed4
Terra Ed4
SNPP Ed1a

MODIS vs VIIRS Time Series

Cloud Particle Size (Day)

12-month running means

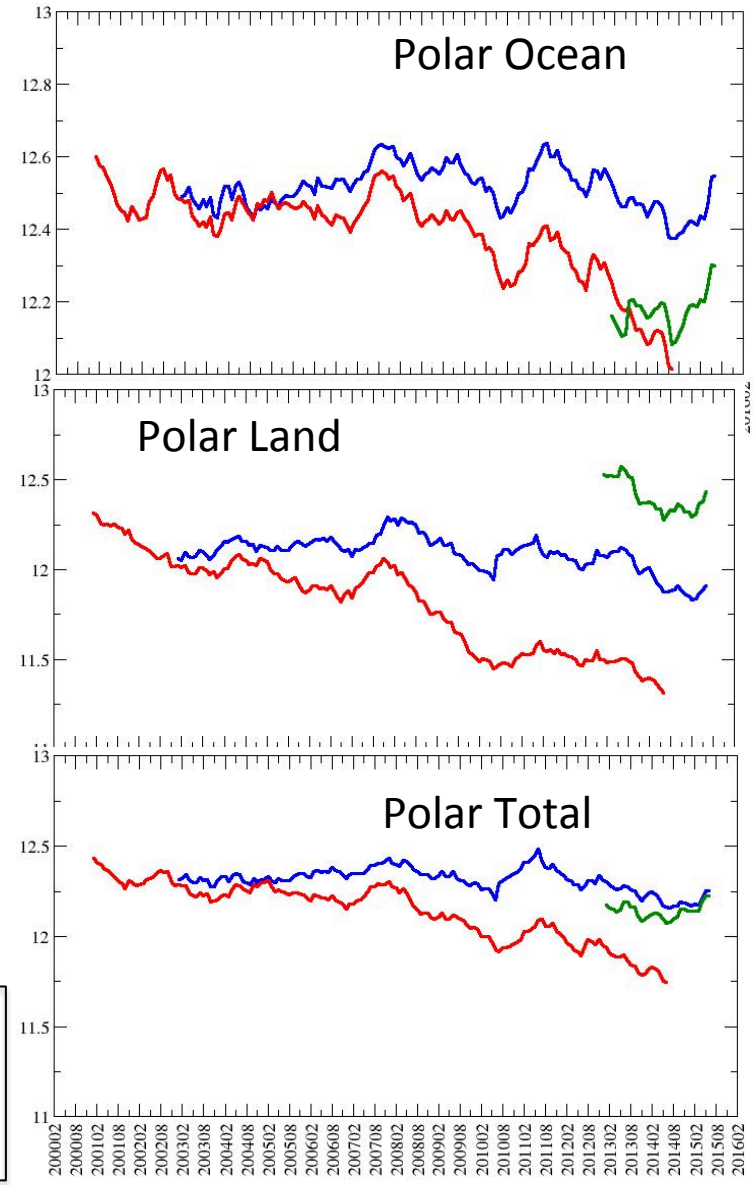
Water clouds



Water drop size tracking well

Small NP diffs

VIIRS 1-2 um lower NP regions



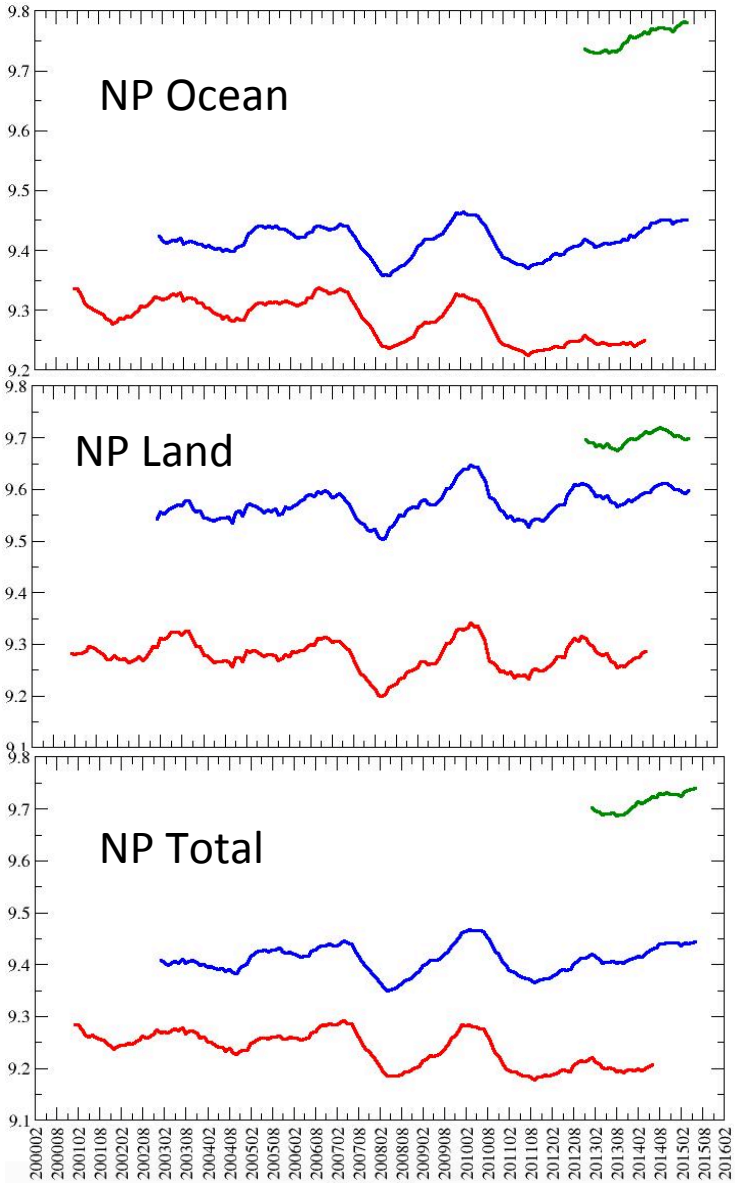
Aqua Ed4
Terra Ed4
SNPP Ed1a

MODIS vs VIIRS Time Series

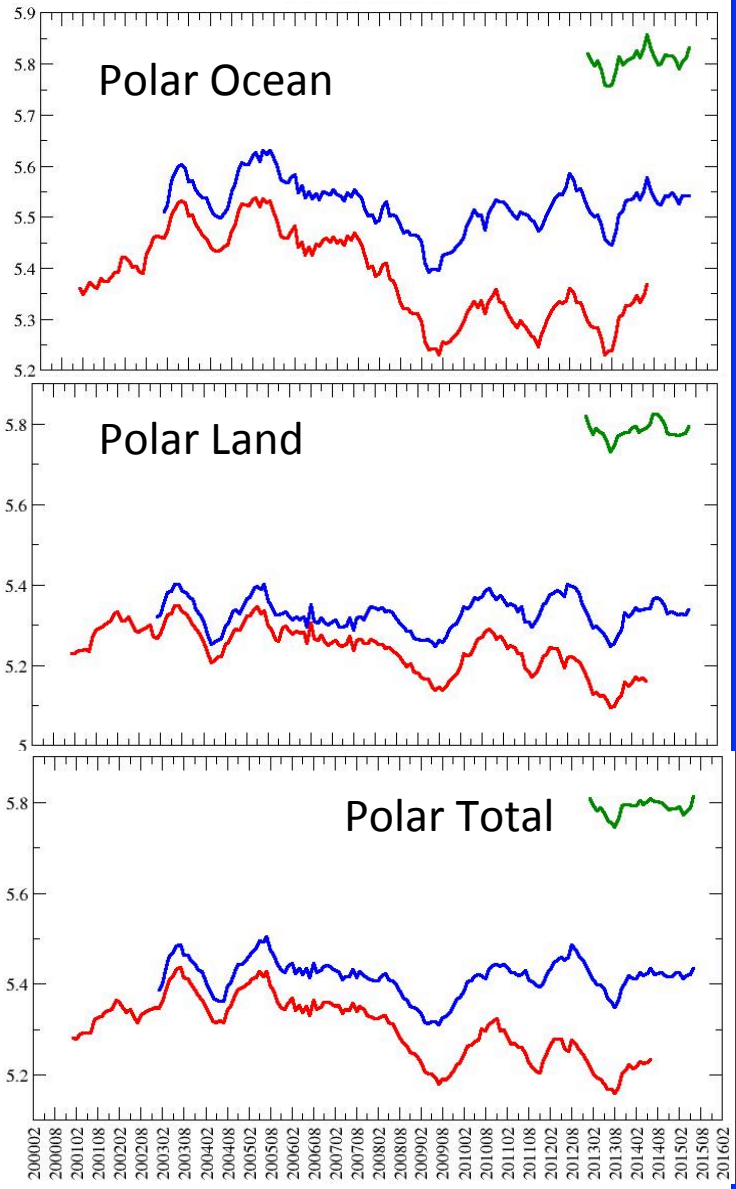
Cloud Height (Day)

12-month running means

Ice clouds



VIIRS daytime ice cloud heights 300m higher



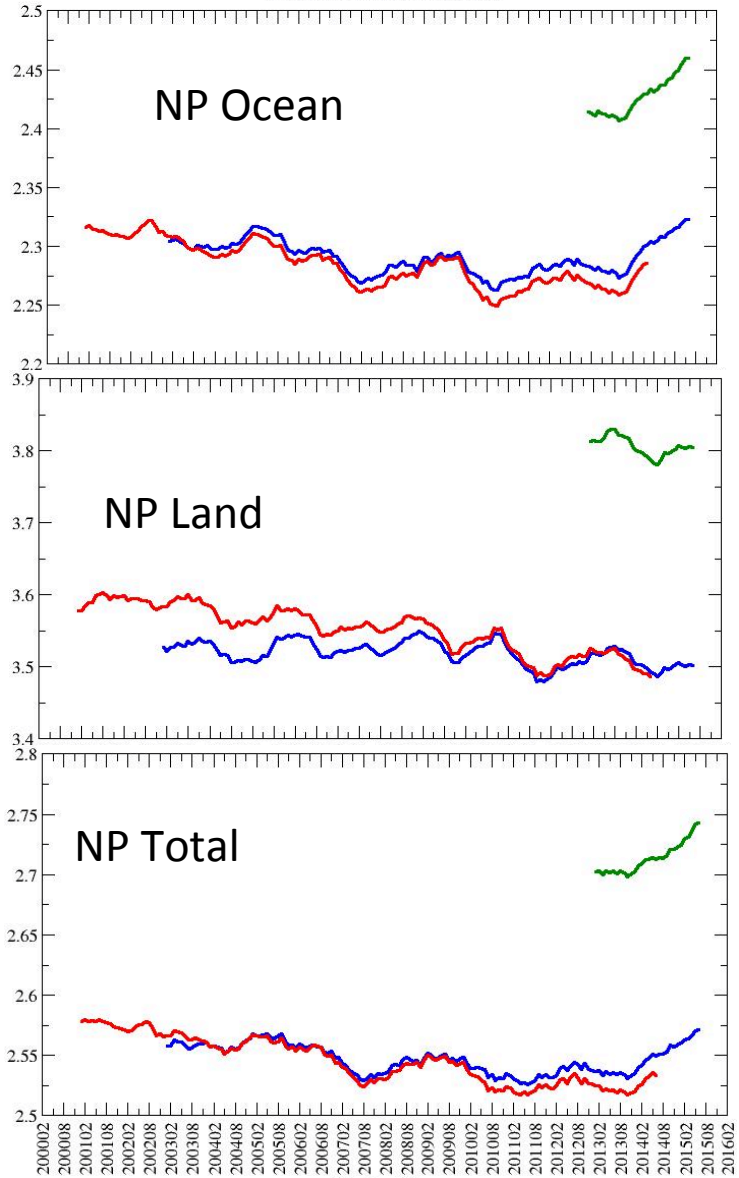
Aqua Ed4
Terra Ed4
SNPP Ed1a

MODIS vs VIIRS Time Series

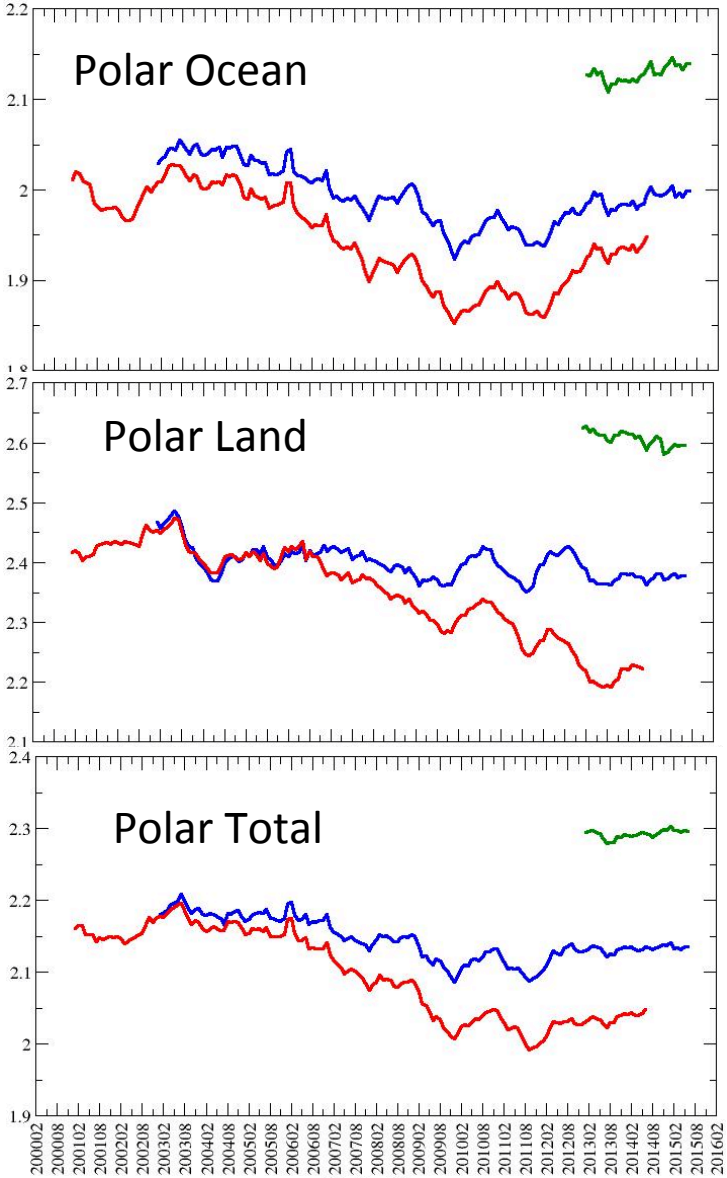
Cloud Height (Day)

12-month running means

Water clouds



VIIRS daytime water cloud heights 150-200 m higher than Aqua



Aqua Ed4
Terra Ed4
SNPP Ed1a

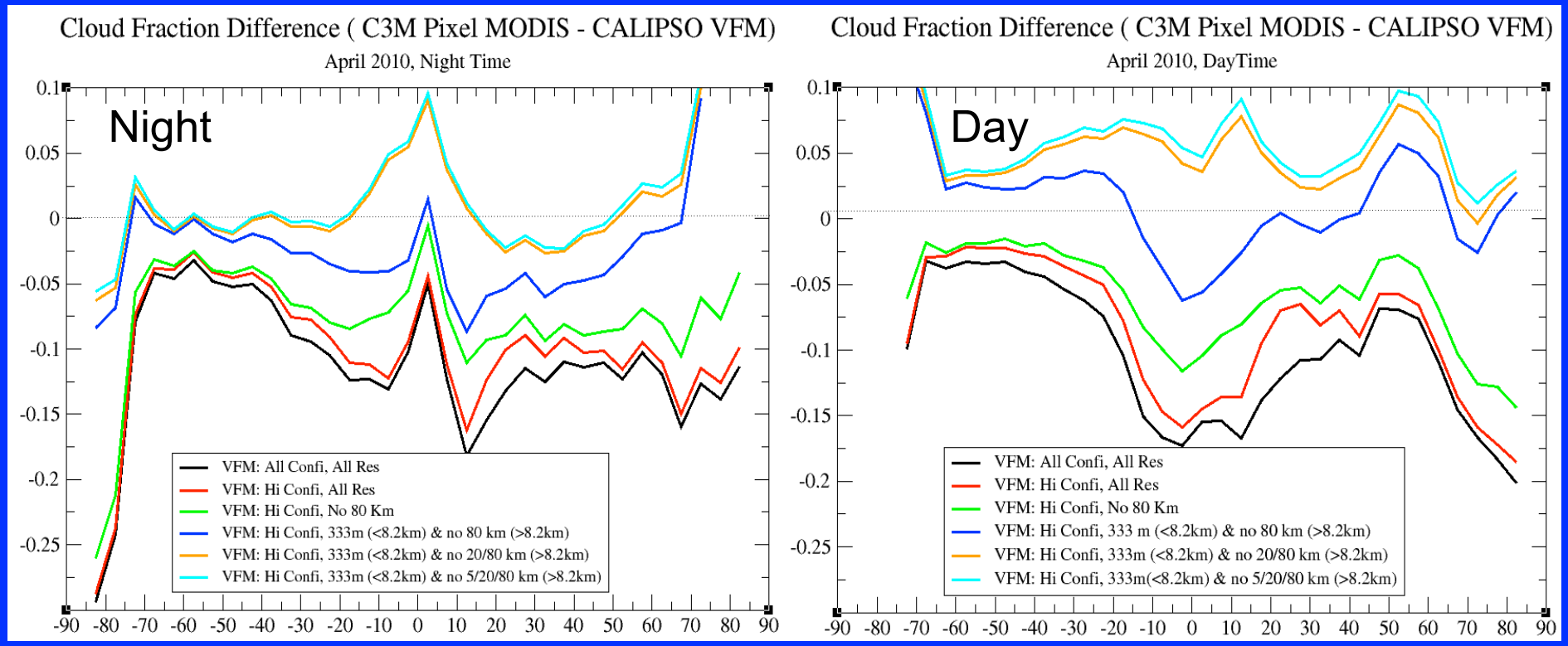
VIIRS/MODIS Consistency Summary

- Lack of 6.7 and CO_2 channels on VIIRS, resolution and possible calibration differences impact the consistency of VIIRS cloud properties relative to MODIS Ed4.
- Largest impacts appear to be on polar night detection, cirrus detection, cloud phase determination
- Inconsistent cloud phase determination leads to inconsistencies in other cloud properties (COD, Re, Z)
- Bug fixes and new models implemented in VIIRS Ed 1 also cause some differences which can be at least partially mitigated in MODIS Ed5/VIIRS Ed3
- Another option for improved consistency is to merge 6.7, CO_2 spectral info from CrIS with VIIRS (Sunny Sun-Mack reporting progress on Thursday)
- Or, drop 6.7, CO_2 from MODIS Ed5 (not preferred by CWG)

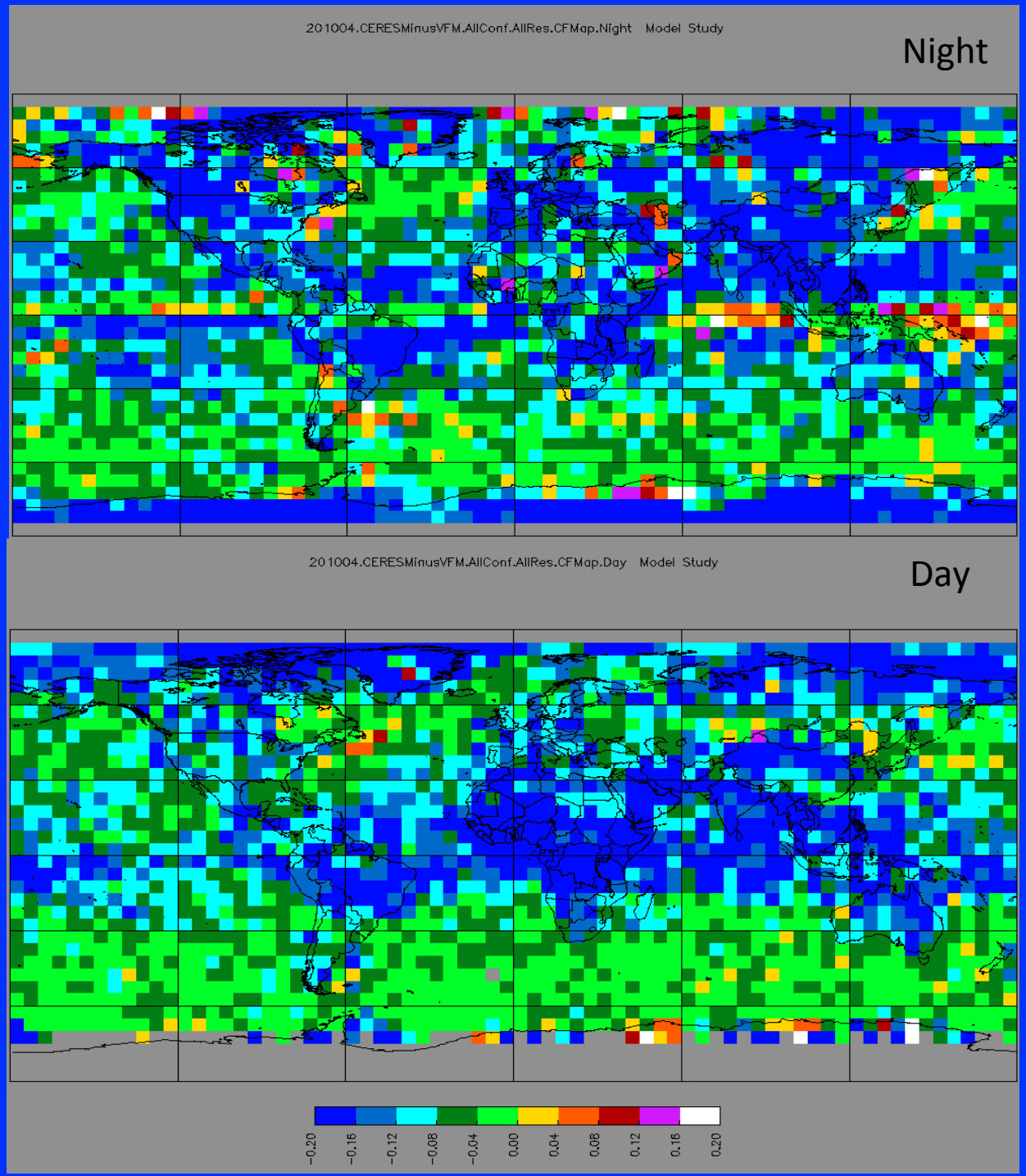
Are MODIS Cloud Fractions too high?

SARB radiative closure problems at TOA (RT calcs too cold and bright compared to CERES)

- Last STM, we looked at GEO (comprises ~85% of data in SYN1)
  - Higher GEO cloud fractions than MODIS relative to CALIOP (VZA and satellite dependencies)
  - Comparisons depend on interpretation of CALIPSO data (moving target, still learning)



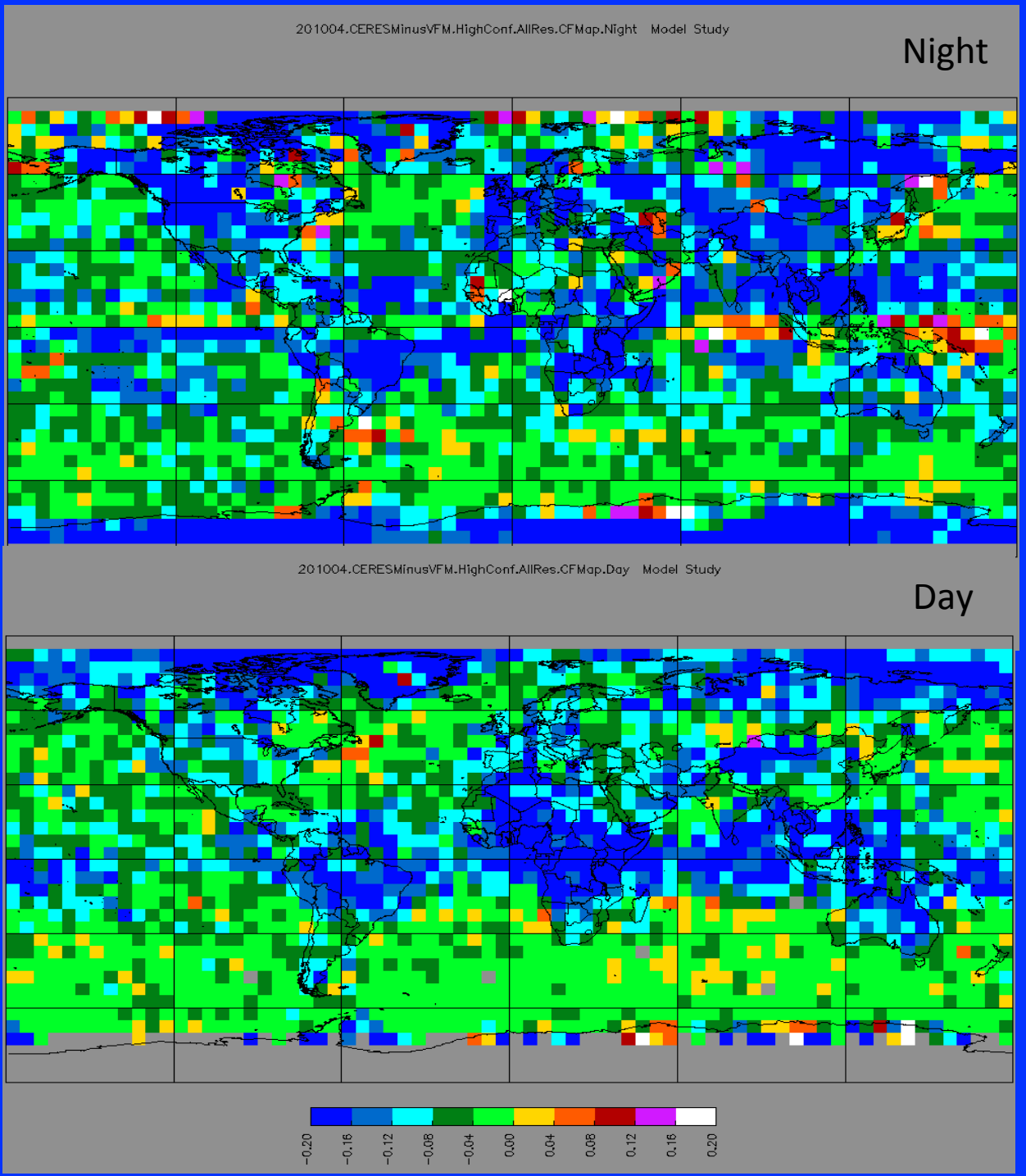
VFM: All Confi, All Res
VFM: Hi Confi, All Res
VFM: Hi Confi, No 80 Km
VFM: Hi Confi, 333 m (<8.2km) & no 80 km (>8.2km)
VFM: Hi Confi, 333m (<8.2km) & no 20/80 km (>8.2km)
VFM: Hi Confi, 333m(<8.2km) & no 5/20/80 km (>8.2km)



Cloud Fraction Diff
2010 04
C3M Pixel MODIS - VFM

VFM
All Conf, All Resolution

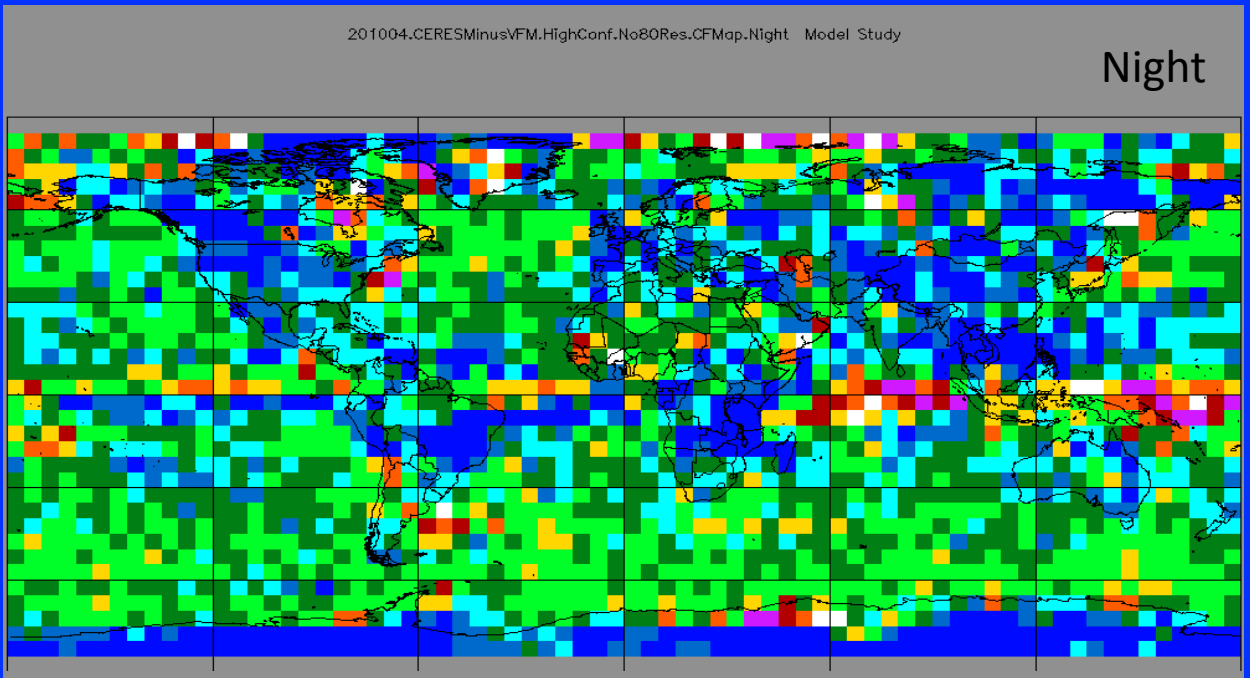
Cloud Fraction Diff
2010 04
C3M Pixel MODIS - VFM

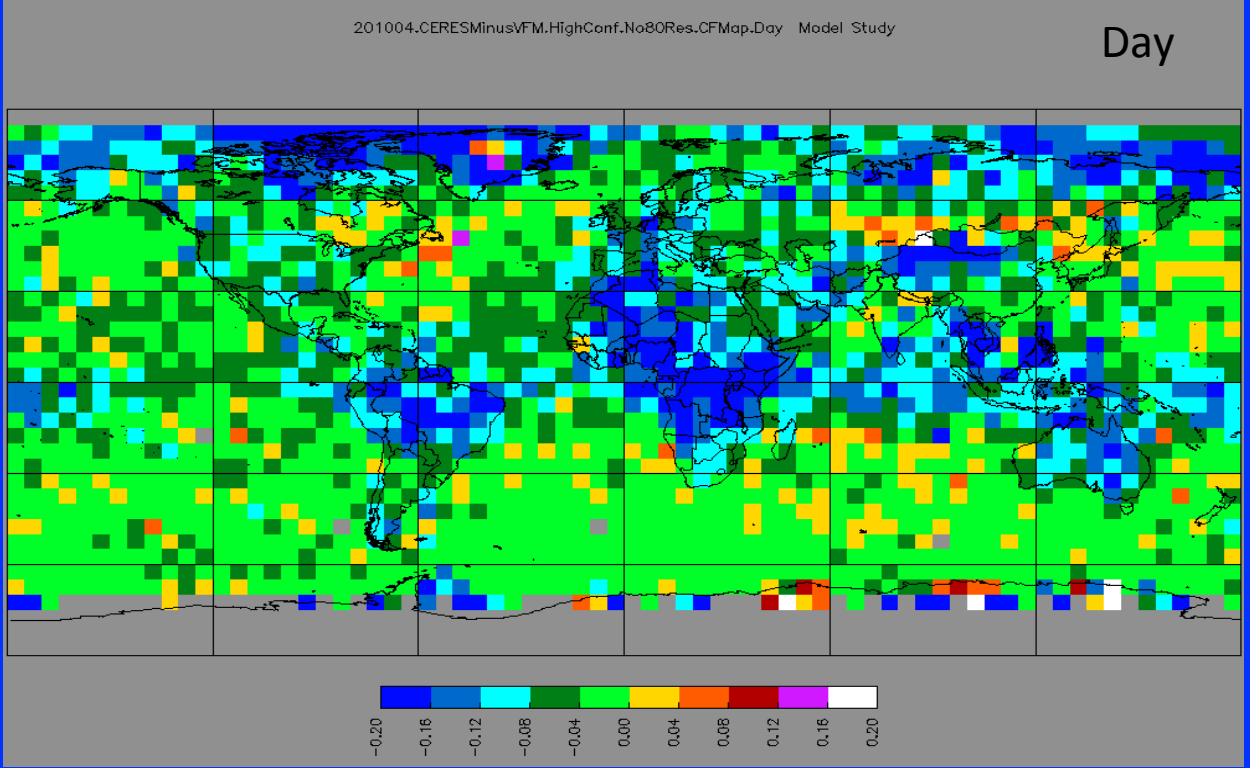


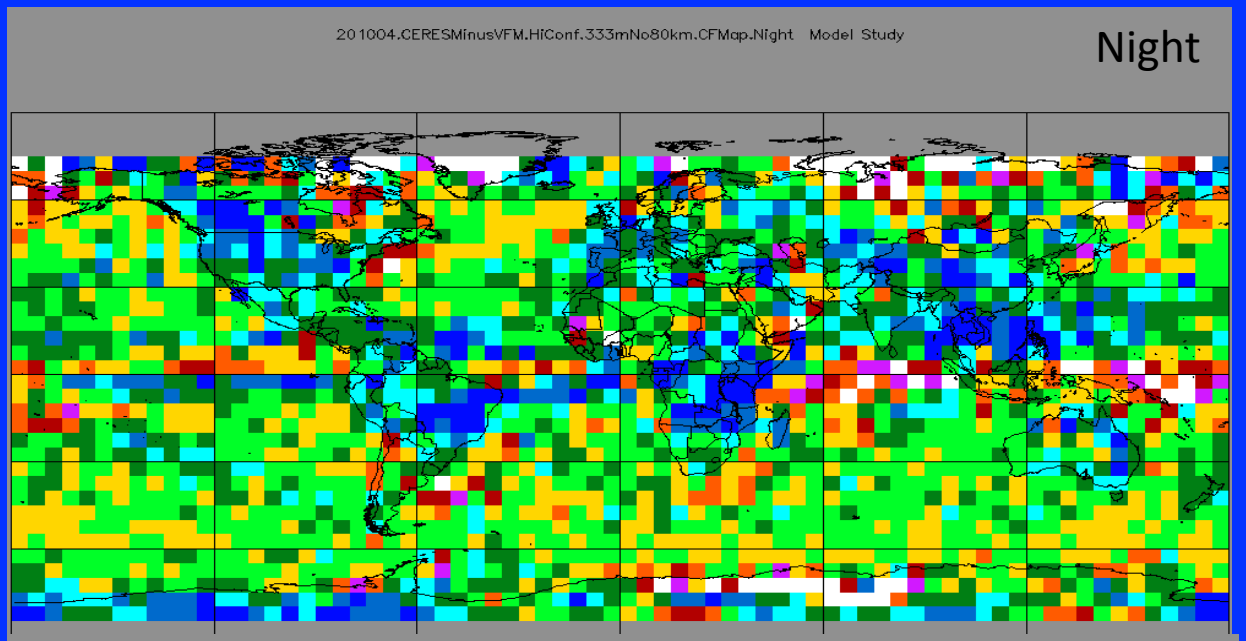
VFM
Hi Conf, All Resolution

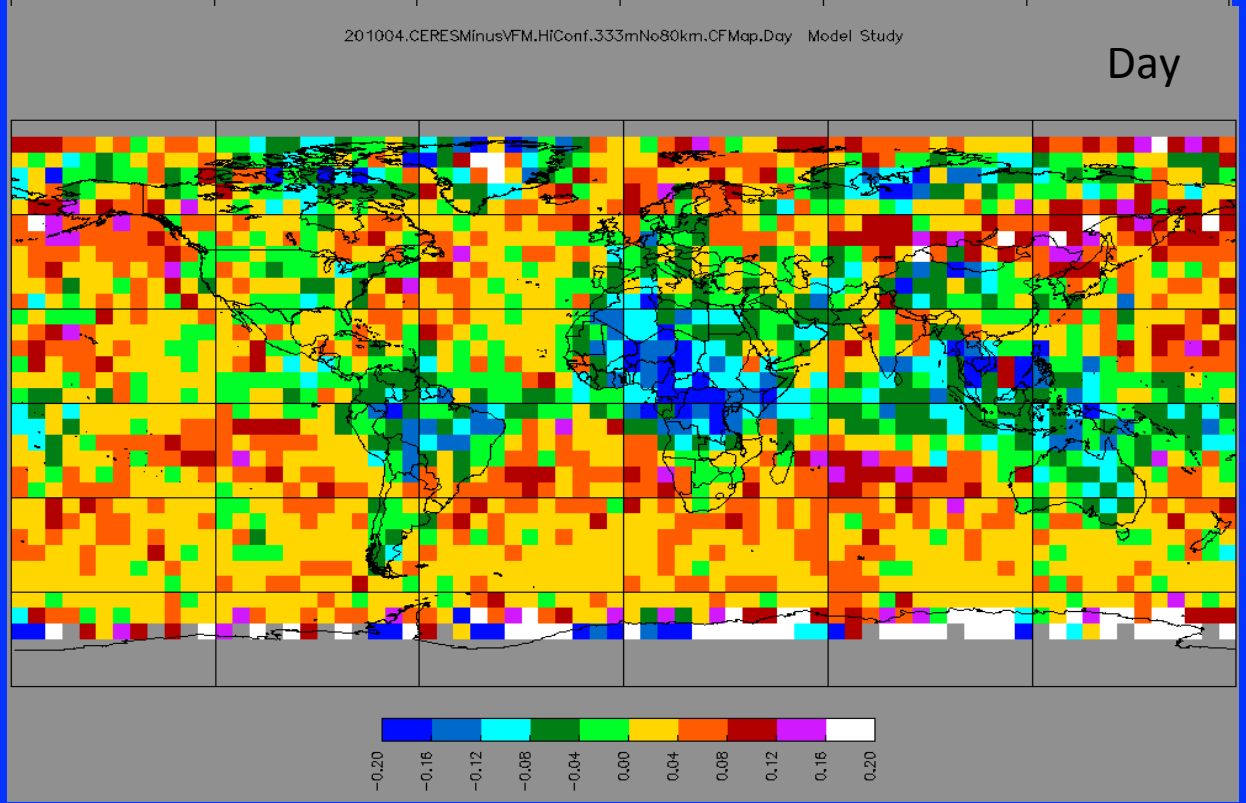
Cloud Fraction Diff
2010 04
C3M Pixel MODIS - VFM

VFM
Hi Conf, No 80 km







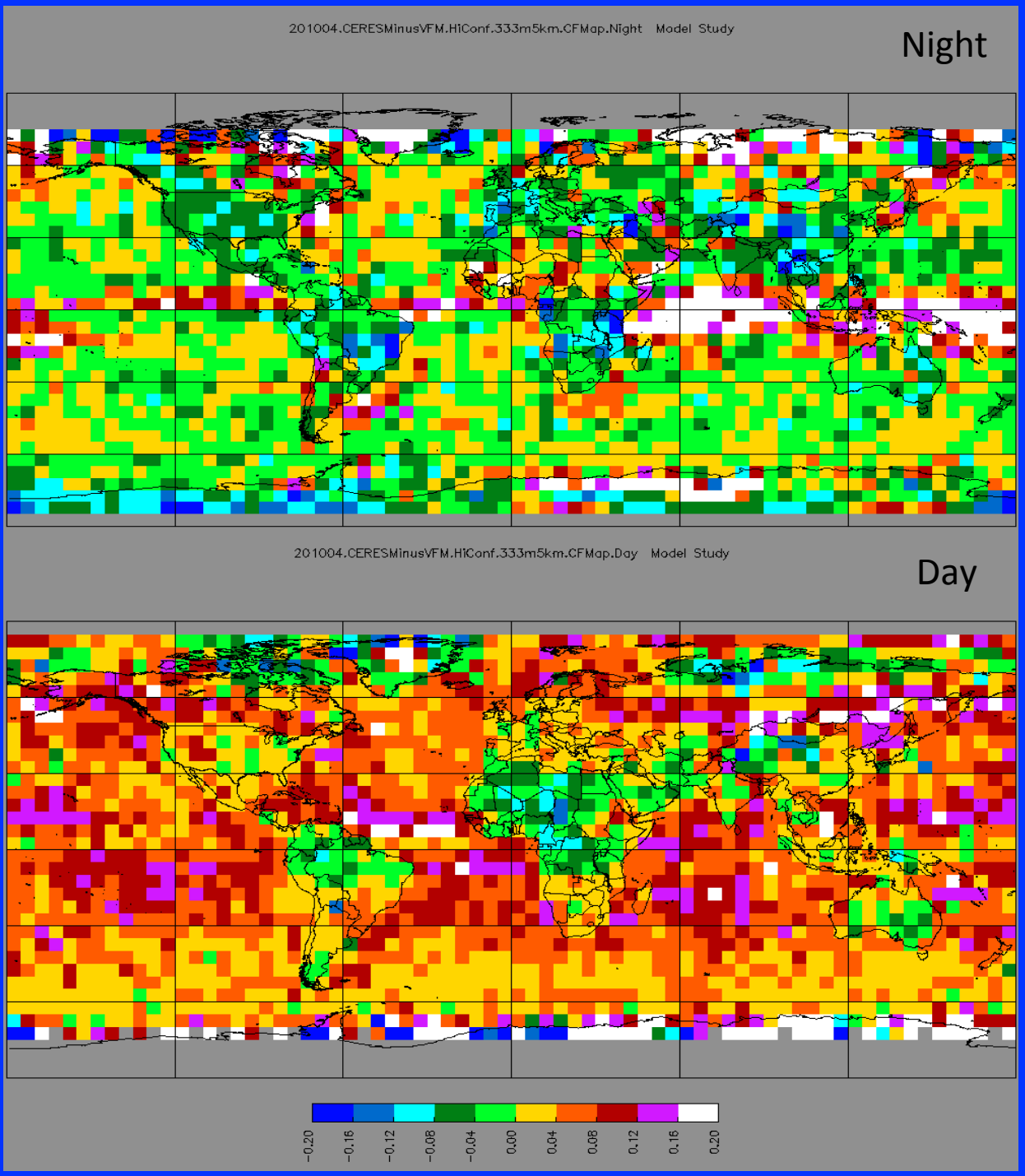


Cloud Fraction Diff
2010 04
C3M Pixel MODIS - VFM

VFM
Hi Conf
Resolution
Only 333 m for <= 8.2 km
No 80 km >8.2 km

Dave Winker said always use 333m for clouds < 8.2km

Cloud Fraction Diff
2010 04
C3M Pixel MODIS - VFM



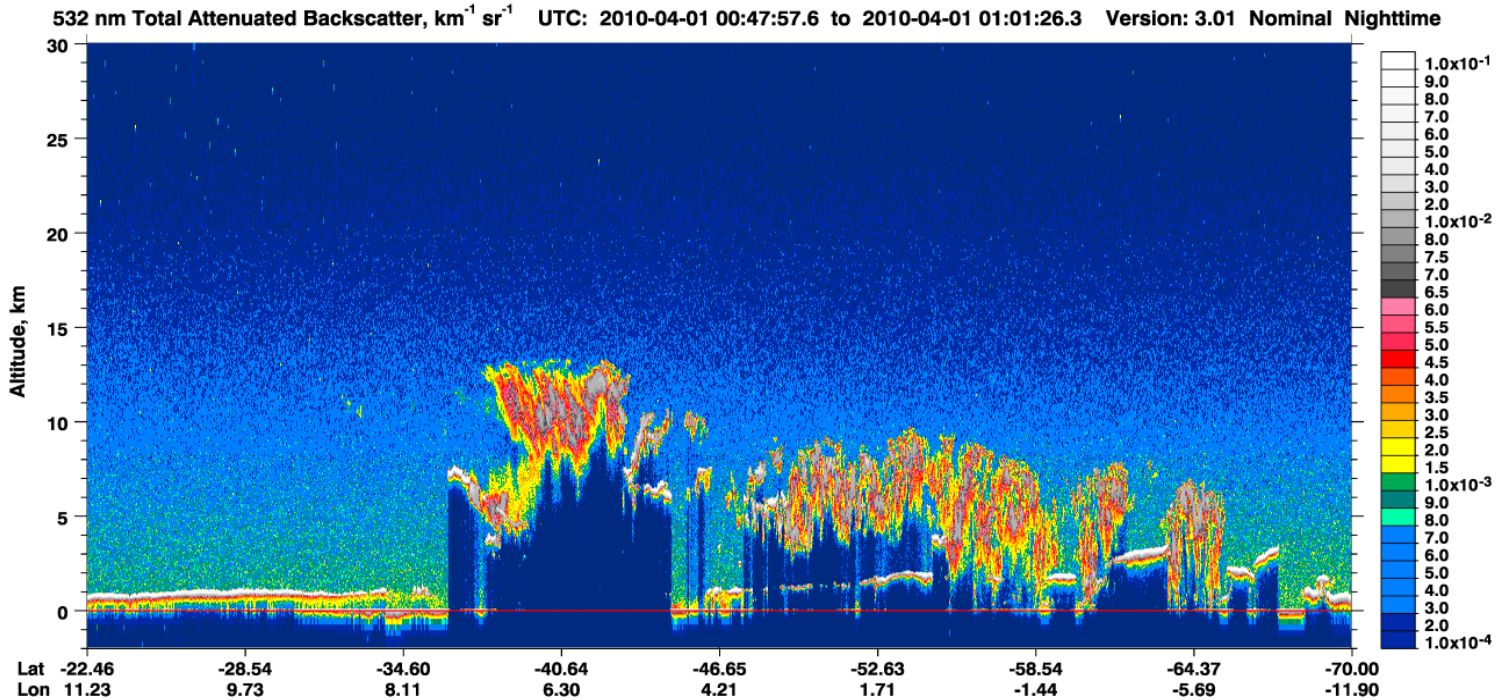
VFM
Hi Conf
Resolution
333 m for <= 8.2 km
No 20 km or 80 Km>8.2 km

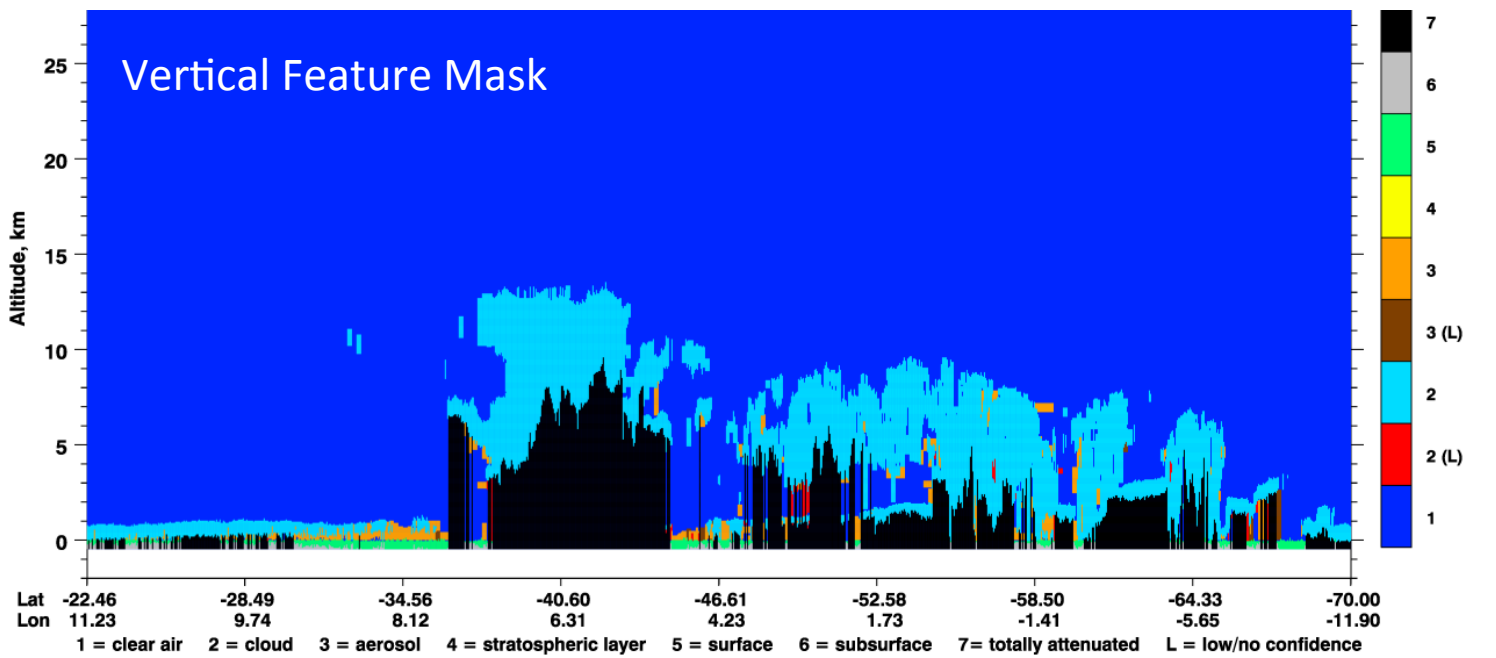
Cloud Fraction Mean Difference (C3M Pixel MODIS – VFM), 2010 04

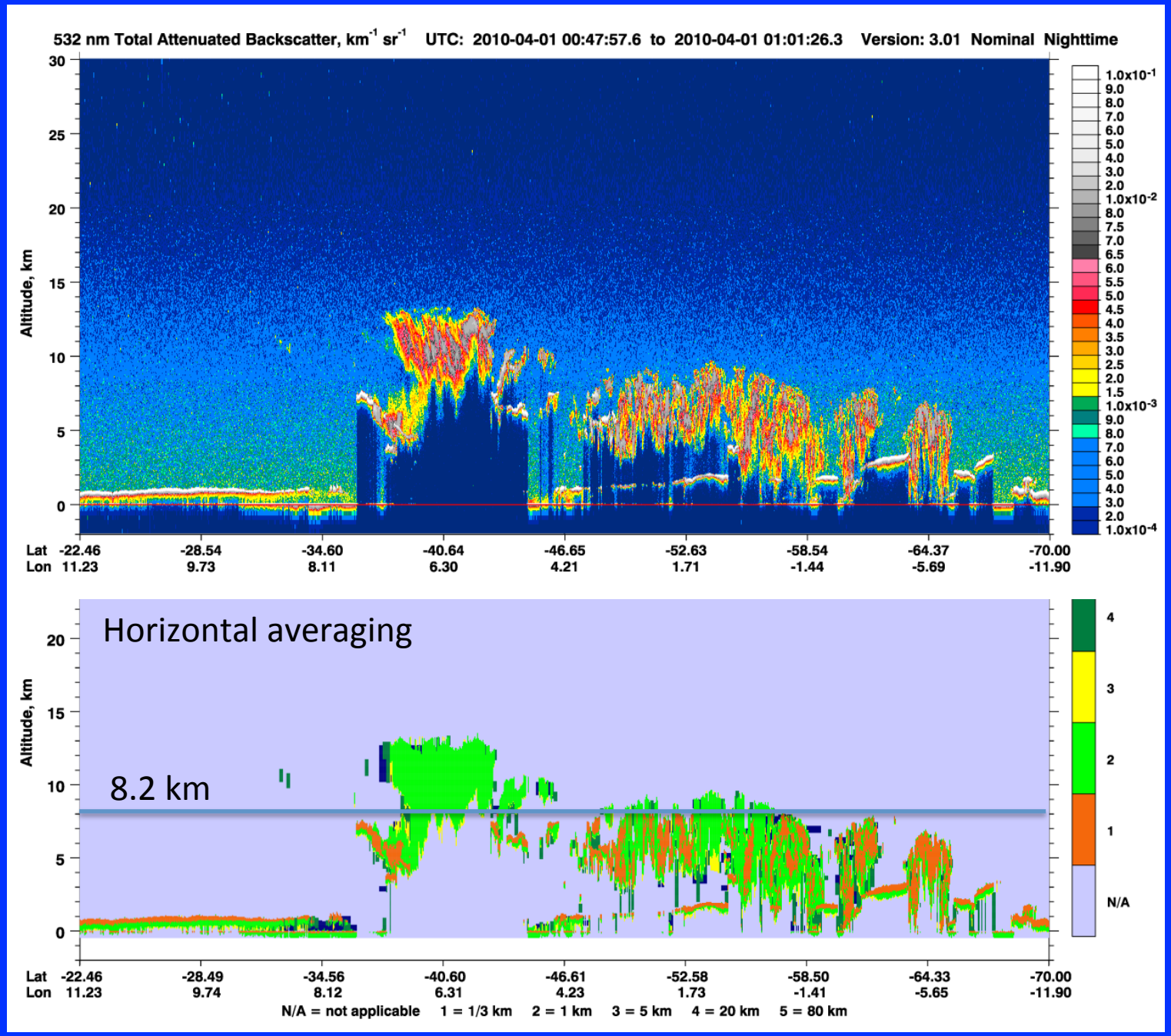
Night	All Confi All Res	Hi Confi All res	Hi Confi No 80	Hi Confi 333 & no80	Hi Confi 333 & no20/80	Hi Conf 333 & no5/20/80
Global	-0.1072	-0.0939	-0.0711	-0.0321	0.0071	0.0110
Polar	-0.1176	-0.1094	-0.0816	-0.0021	0.0123	0.0182
Non-Polar	-0.1056	-0.0916	-0.0695	-0.0361	0.0064	0.0101

Day	All Confi All Res	Hi Confi All res	Hi Confi No 80	Hi Confi 333 & no80	Hi Confi 333 & no20/80	Hi Conf 333 & no5/20/80
Global	-0.1041	-0.0835	-0.0585	0.0052	0.0507	0.0592
Polar	-0.1069	-0.0987	-0.0729	0.0315	0.0491	0.0582
Non-Polar	-0.1037	-0.0815	-0.0566	0.0018	0.0509	0.0593

Much more work needed to understand how to interpret CALIPSO products

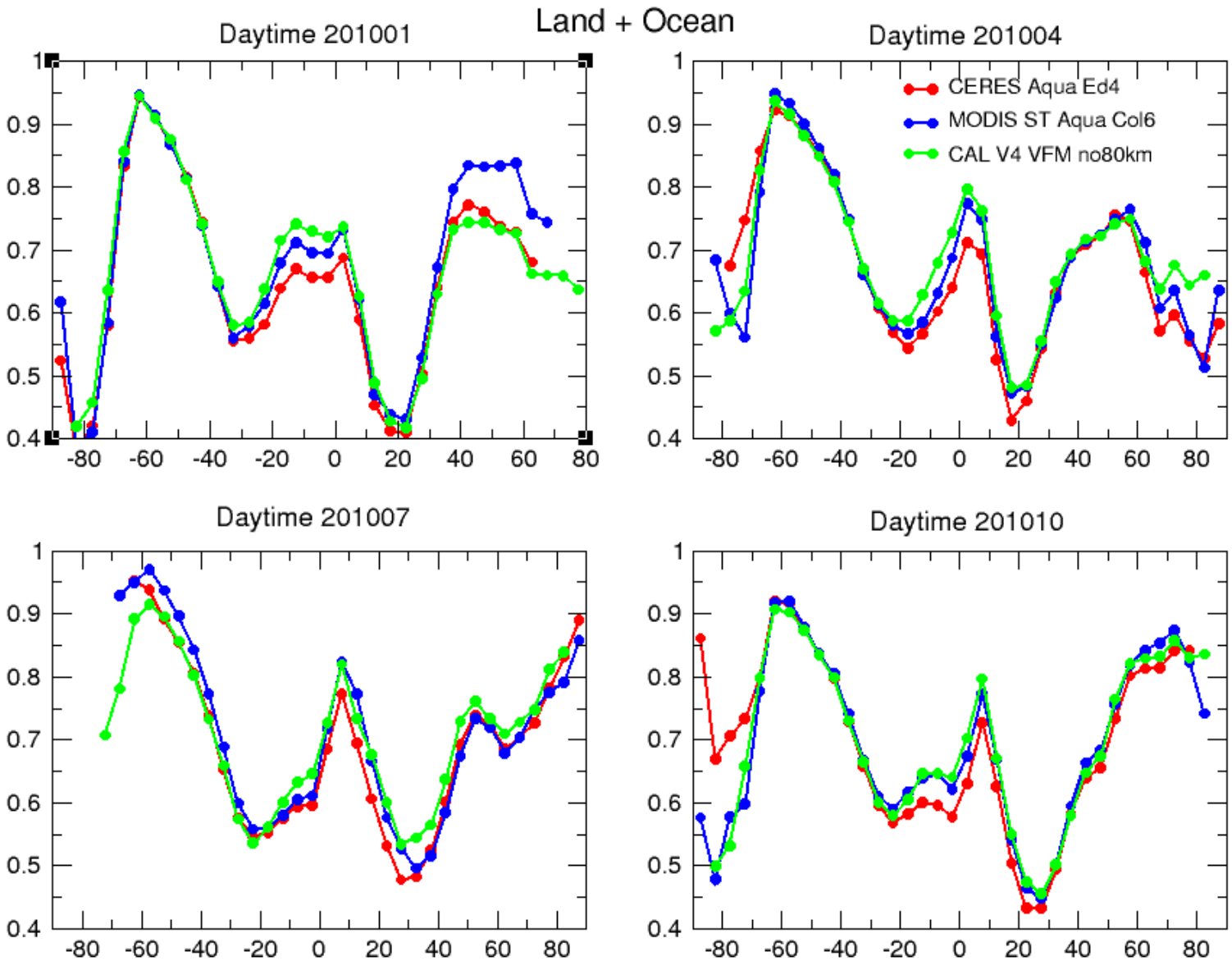

532 nm Total Attenuated Backscatter, km^{-1} sr^{-1} UTC: 2010-04-01 00:47:57.6 to 2010-04-01 01:01:26.3 Version: 3.01 Nominal Nighttime
Altitude, km
30
25
20
15
10
5
0
Lat -22.46 -28.54 -34.60 -40.64 -46.65 -52.63 -58.54 -64.37 -70.00
Lon 11.23 9.73 8.11 6.30 4.21 1.71 -1.44 -5.69 -11.90
1.0x10^{-1}
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0x10^{-2}
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0x10^{-3}
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0x10^{-4}


Vertical Feature Mask
Altitude, km
25
20
15
10
5
0
Lat -22.46 -28.49 -34.56 -40.60 -46.61 -52.58 -58.50 -64.33 -70.00
Lon 11.23 9.74 8.12 6.31 4.23 1.73 -1.41 -5.65 -11.90
1 = clear air 2 = cloud 3 = aerosol 4 = stratospheric layer 5 = surface 6 = subsurface 7= totally attenuated L = low/no confidence
7
6
5
4
3
3 (L)
2
2 (L)
1


532 nm Total Attenuated Backscatter, km-1 sr-1 UTC: 2010-04-01 00:47:57.6 to 2010-04-01 01:01:26.3 Version: 3.01 Nominal Nighttime
Altitude, km
Lat -22.46 -28.54 -34.60 -40.64 -46.65 -52.63 -58.54 -64.37 -70.00
Lon 11.23 9.73 8.11 6.30 4.21 1.71 -1.44 -5.69 -11.90
Horizontal averaging
8.2 km
Altitude, km
Lat -22.46 -28.49 -34.56 -40.60 -46.61 -52.58 -58.50 -64.33 -70.00
Lon 11.23 9.74 8.12 6.31 4.23 1.73 -1.41 -5.65 -11.90
N/A = not applicable 1 = 1/3 km 2 = 1 km 3 = 5 km 4 = 20 km 5 = 80 km

Daytime Zonal Cloud Fraction Comparison for all surfaces between CERES Aqua Ed4, MODIS Science Team (MYD08) Col 6, CALIPSO Version 4 VFM for Four Seasonal Months in 2010

Zonal Cloud Fraction Comparison between CM Ed4, MYD08 and CALIPSO

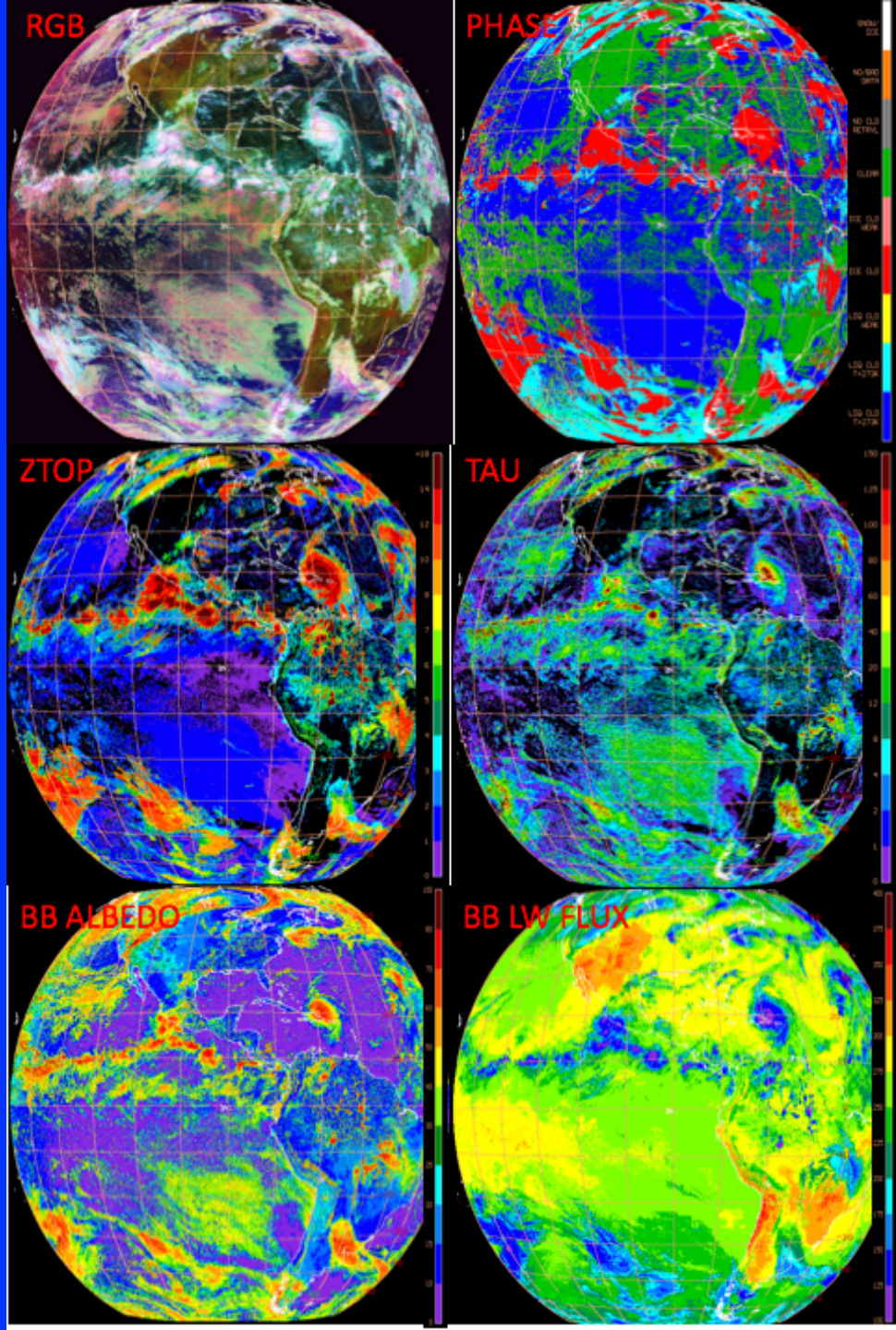


Good agreement in some areas but MYD08 generally higher CF than CERES Ed4

GEO UPDATE

GOES-16
Cloud Properties
Sept 21, 2017
17:00 UTC

- Becomes operational 11/2017
- Not yet ready for quantitative retrievals (calibration, band-to-band co-registration, and other problems still apparent)

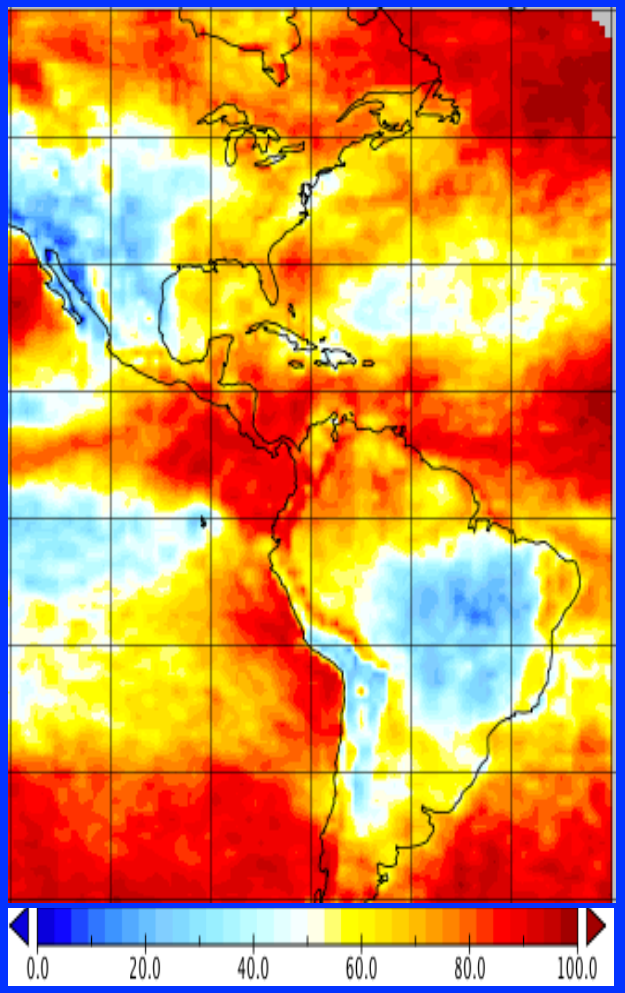


Initial Comparison with GOES-13

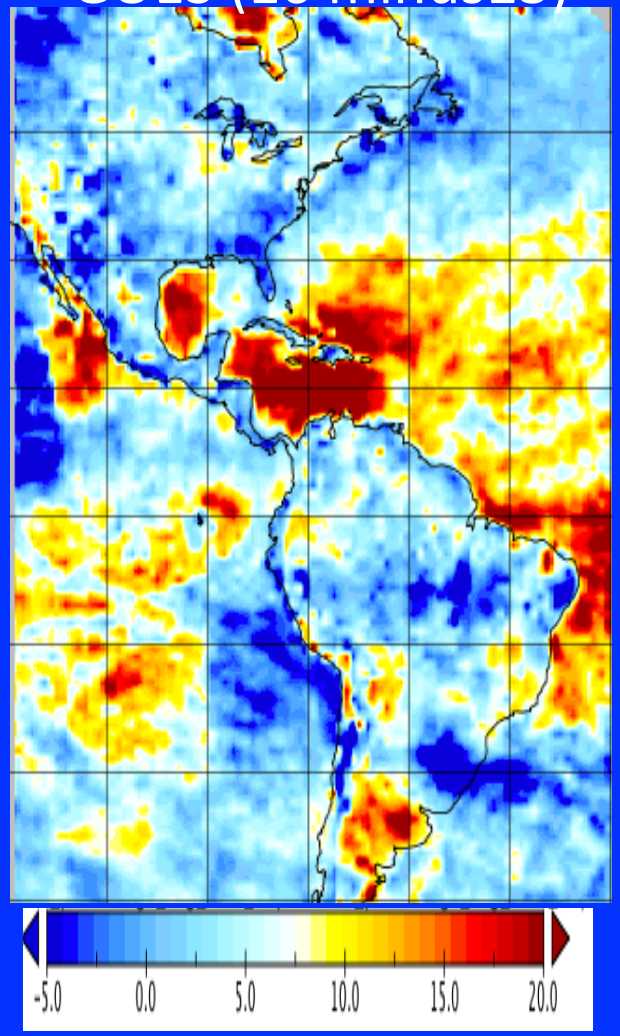
TOTAL CLOUD FRACTION (June 2017)

Expect better assessment after operational data become available

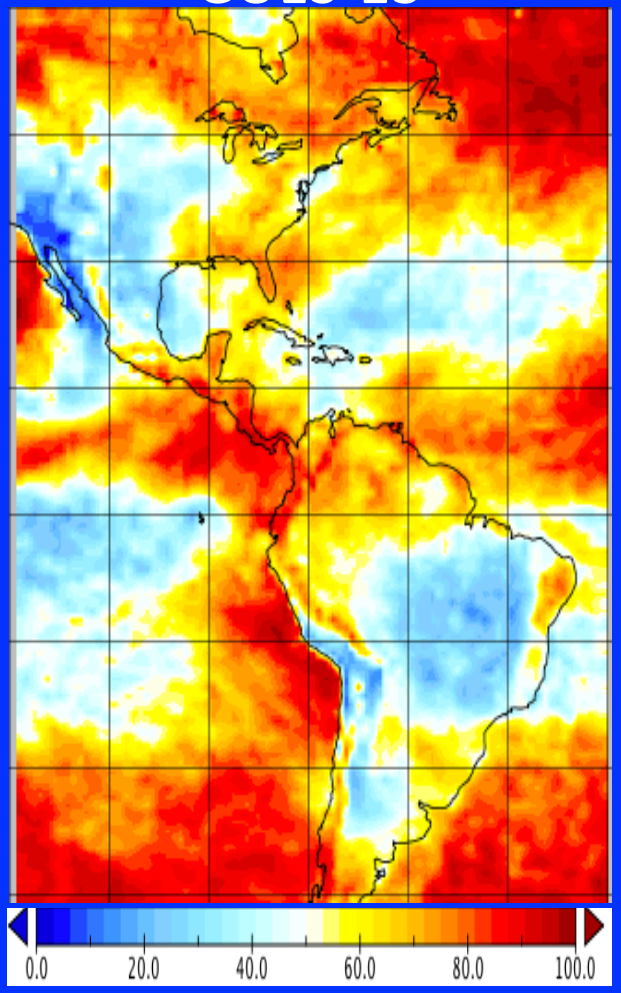
GOES-16



GOES (16 minus13)



GOES-13



Update of CERES Cloud-related Papers

Edition-4 related

Foster, M. J., S. A. Ackerman, R. A. Frey, L. Di Girolamo, A. K. Heidinger, S. Sun-Mack, W. P. Menzel, P. Minnis, G. Zhao, 2017: Cloudiness [in "State of the Climate 2016"]. *Bull. Amer. Meteorol. Soc.*, **98**, S27-S28.

Trends in cloud cover from Ed4 MODIS included for 2000-2016

Tian, J., X. Dong, B. Xi, P. Minnis, W. L. Smith, Jr., S. Sun-Mack, M. Thiemann, and J. Wang, 2016: Comparisons of ice water path in deep convective systems among ground-based, GOES, and CERES-MODIS retrievals. *J. Geophys. Res.*, submitted.

Shows IWP is realistic particularly in non-precip heavy anvils. Needs Smith algorithm to increase TWP and maybe adjust max tau.

McHardy, T. M., X. Dong, B. Xi, M. M. Thieman, P. Minnis, and R. Palikonda, 2017: Comparison of daytime low-level cloud properties derived from GOES and ARM SGP measurements. J. Geophys. Res., submitted.

Validates GEO retrievals of stratus over land. Shows most of 3.9 μm overestimate in Re due to SZA > 65°scat < 90°.
LWP overestimated by 17% on average due to Re. Tau is unbiased on average but has an SZA dependence.

Wood, R., K.-T. O, C. S. Bretherton, J. Mohrmann, B. A. Albrecht, P. Zuidema, V. Ghate, C. Schwartz, E. Eloranta, S. Glienke, R. Shaw, J. Fugal, and P. Minnis, 2017: Ultraclean layers and optically thin clouds in the stratocumulus transition: Part I: Observations. *J. Atmos. Sci.*, submitted.

Demonstrates that large 20-30 μm droplets retrieved by satellite are realistic.

Sun-Mack, P. Minnis, Y. Chen, D. R. Doelling, W. L. Smith, Jr., B. Scarino, and C. O. Haney, 2017: Calibration changes to Terra MODIS Collection-5 radiances for CERES Edition 4 cloud retrievals. *IEEE Trans. Geosci. Remote Sens.*, in prep.

Indicates we did a good or better job than MODIS 6.0 or 6.1 in normalizing solar channels for Terra and Aqua.
Shows that Ed5 will require some thermal channel adjustments and that the Terra Coll 6.1 1.24 μm needs normalization to Aqua.
Paper sets up the Ed4 mask and algorithm papers.

Trepte, Q. Z., P. Minnis, C. R. Yost, S. Sun-Mack, and Y. Chen, 2017: Global cloud detection for CERES Edition 4 using Terra and Aqua MODIS data. *J. Atmos. Oceanic Technol.*, In preparation.

Minnis, P., S. Sun-Mack, C. R. Yost, Y. Chen, W. L. Smith, Jr., F.-L. Chang, P. W. Heck, R. F. Arduini, Q. Z. Trepte, K. Ayers, K. Bedka, S. Bedka, R. R. Brown, D. R. Doelling, A. Gopalan, E. Heckert, G. Hong, Z. Jin, R. Palikonda, R. Smith, B. Scarino, D. A. Spangenberg, P. Yang, Y. Xie, and Y. Yi, 2017: Changes to CERES MODIS cloud product retrieval algorithms for Edition 4. *IEEE Trans. Geosci. Remote Sens.*, in preparation.

Edition-5 related

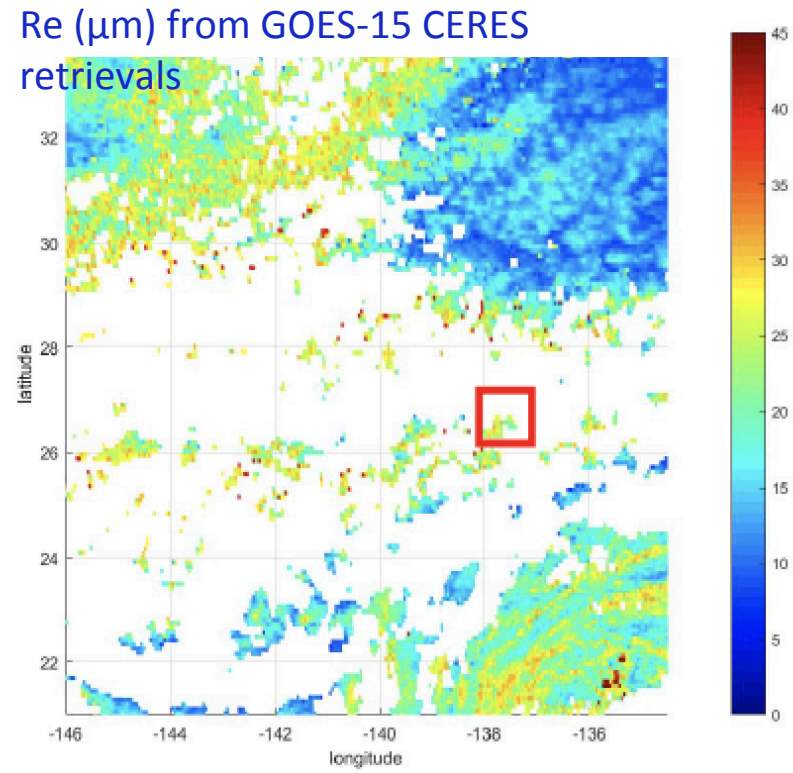
Loeb, N., P. Yang, F. G. Rose, G. Hong, S. Sun-Mack, P. Minnis, S. Kato, S.-Ham, and W. L. Smith, Jr., 2017: Impact of ice cloud microphysics on satellite retrievals and broadband flux radiative transfer calculations. J. Climate, submitted.

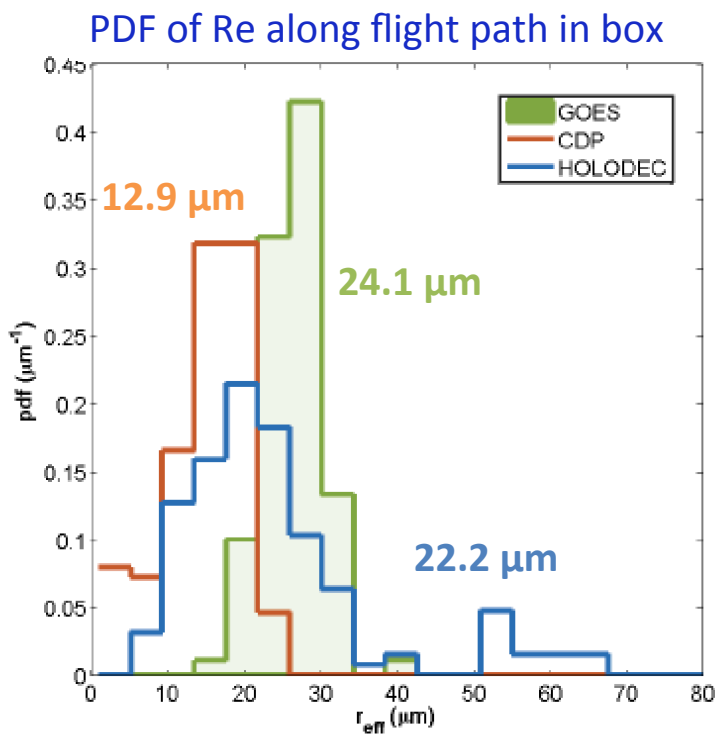
Impact of new two-habit model

Large Effective Radii from MODIS/GOES Realistic

20:50 UTC, 19 July 2015 Northeast Pacific Ocean

Area of in situ measurements





- Large values of droplet effective radius (Re > 20 µm) often considered suspect: a satellite retrieval artifact due to 3D effects

- In-situ HOLODEC measures a wider spectrum of droplets than CDP and yields larger Re than CDP because of drizzlets (beginning of coalescence, 40-80 µm)

- HOLODEC confirms large Re values from satellite over E. Pacific

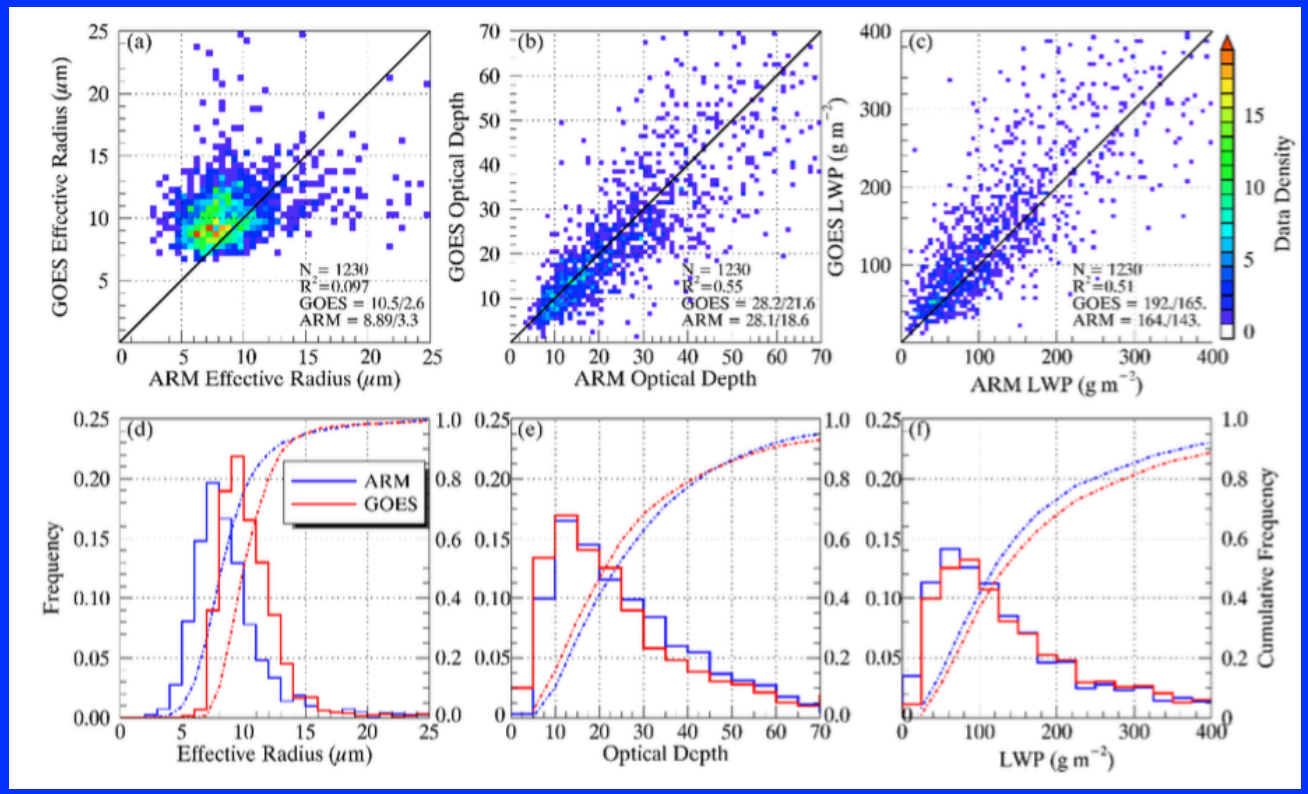
From *Glienke et al.*, 2017,GRL

Low Cloud Validation with ARM Data

GOES/MODIS vs Radar/Radiometer Method

1998-2006 (N=1286)

From *McHardy et al.*, submitted, JGR



Cloud microphysical properties from GOES in good overall agreement with ARM estimates

- Tau agreement good
- Re 1.5 um higher
- LWP also higher (~15%)

Biases found at high SZA and low SCA (not shown) well quantified

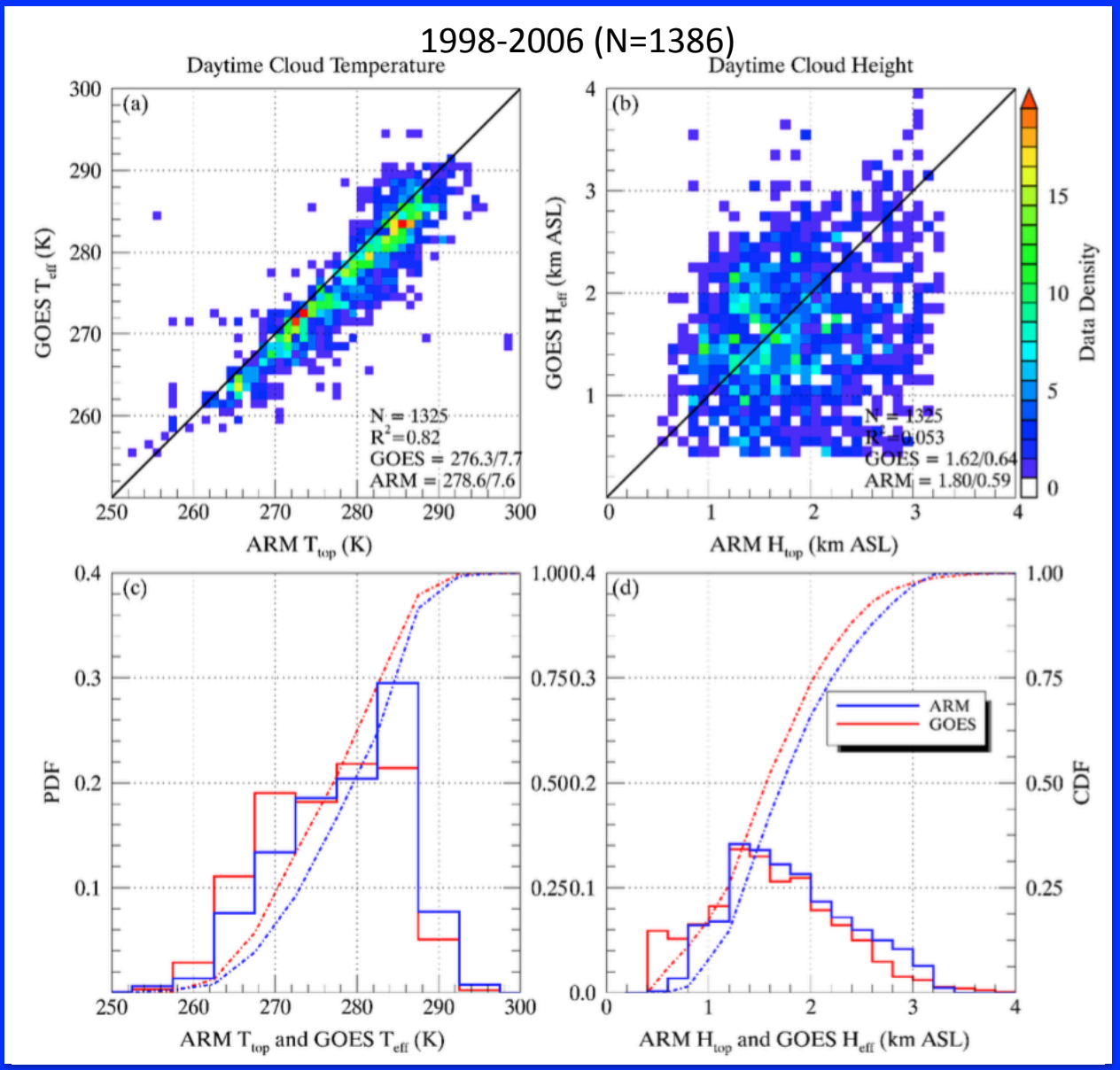
Boundary layer cloud validation, Thursday, X. Dong Talk

Arctic mixed phase cloud validation, Thursday, Baike Xi Talk

Thank You

Low Cloud Validation, ARM SGP

GOES vs Radar/Radiometer Method



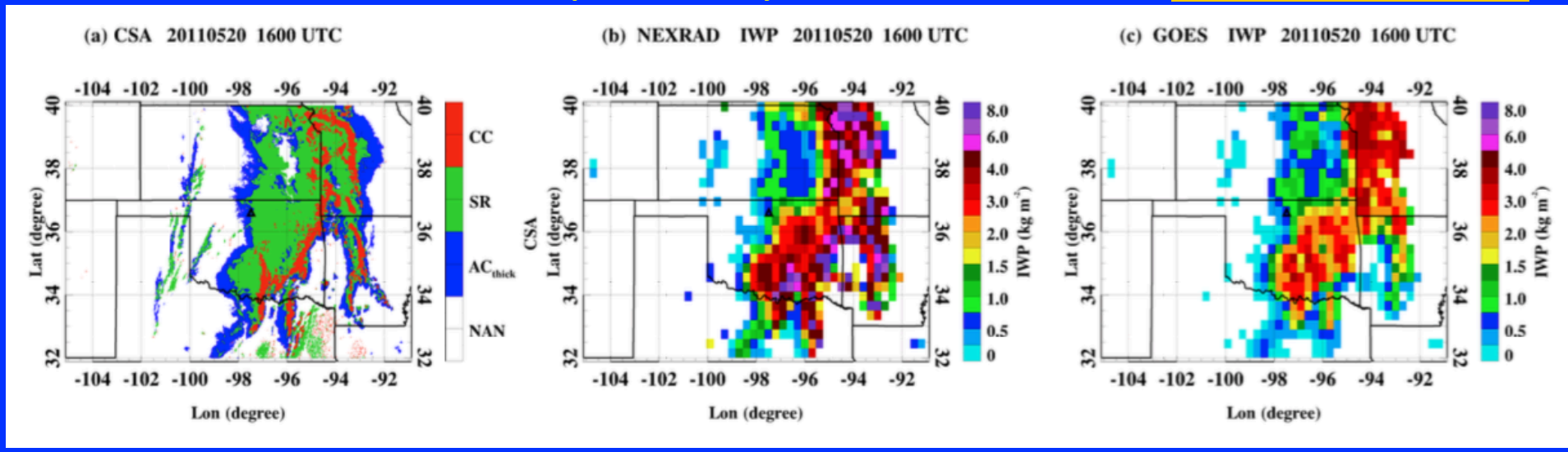
From *McHardy et al.*, submitted, JGR

X. Dong talk on thursday

- Cloud top air temperature and emission temperature differ by 2.5 degrees
- Lapse rate method for CTH works well on average but poor instantaneous skill. False diurnal cycle also found due to hourly T_{sfc} anchor (ARM-GOES problem not in CERES)

NEXRAD IWP retrievals confirm satellite underestimates in deep cloud systems

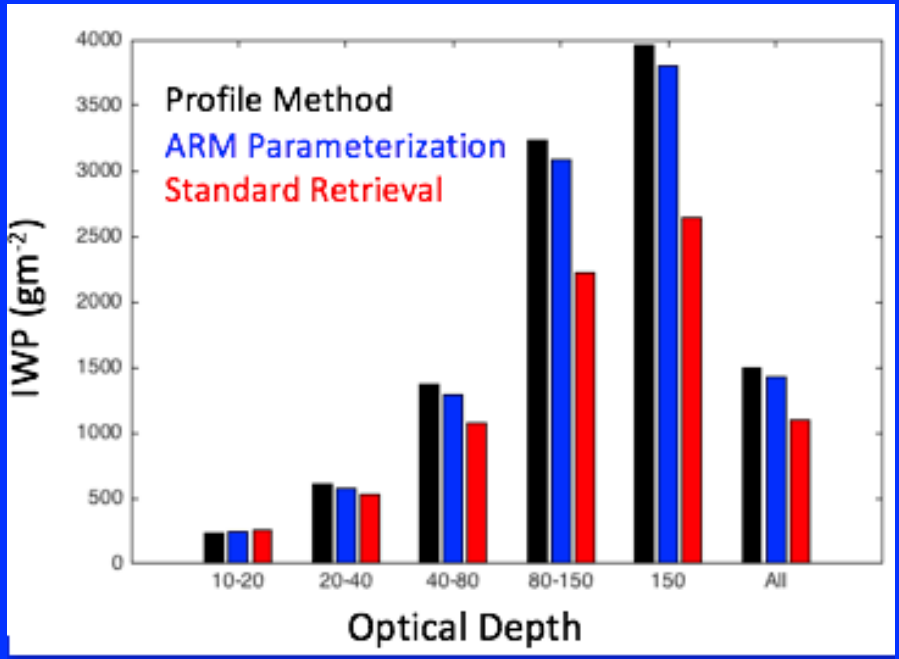
From *Tian et al.*, submitted, JGR



Similar to differences found using Smith (2014) parameterizations and profiling method that better account for cloud vertical structure.

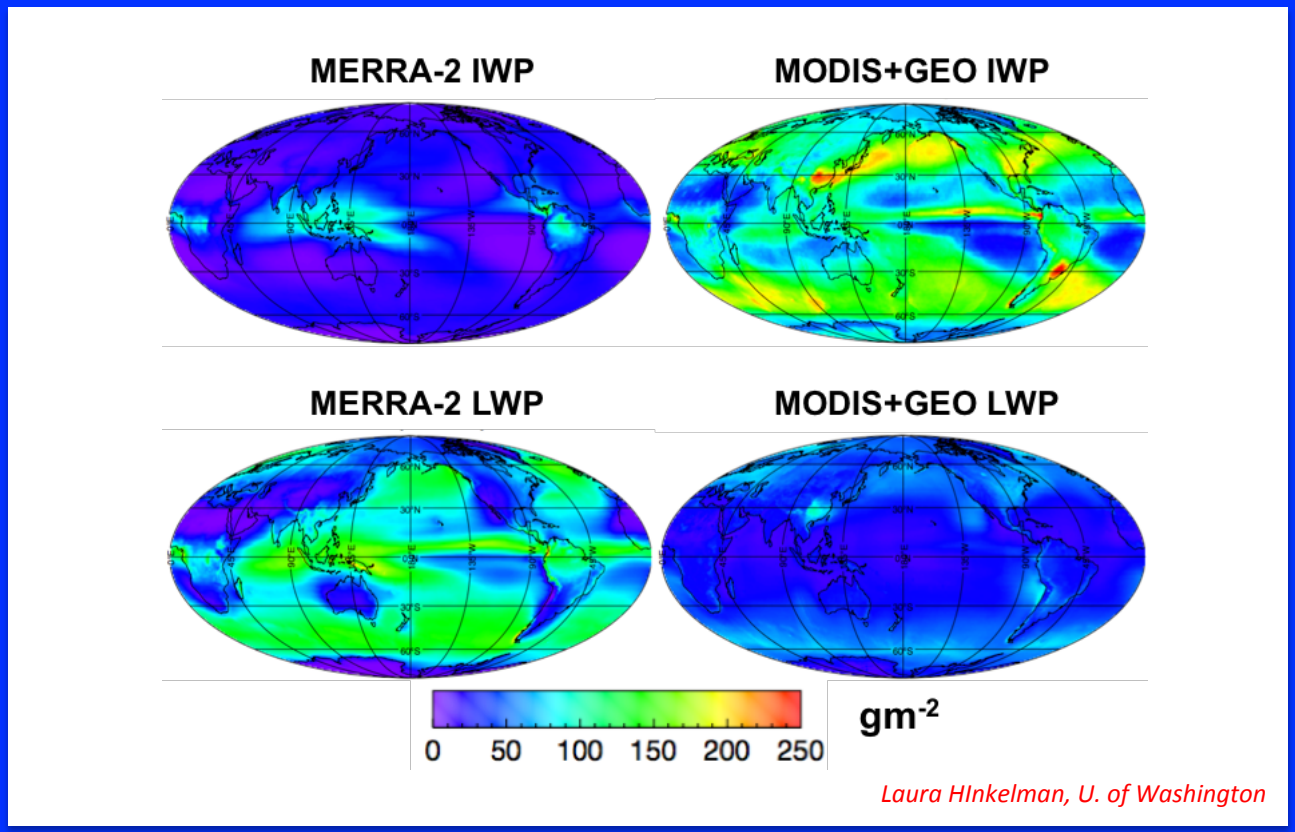
NEXRAD data provide additional information for DCC's

Ongoing work to improve IWP/ LWP estimates for CERES Ed5



Satellite Observations vs Models

2001-2015 average IWP and LWP (Day+Night)



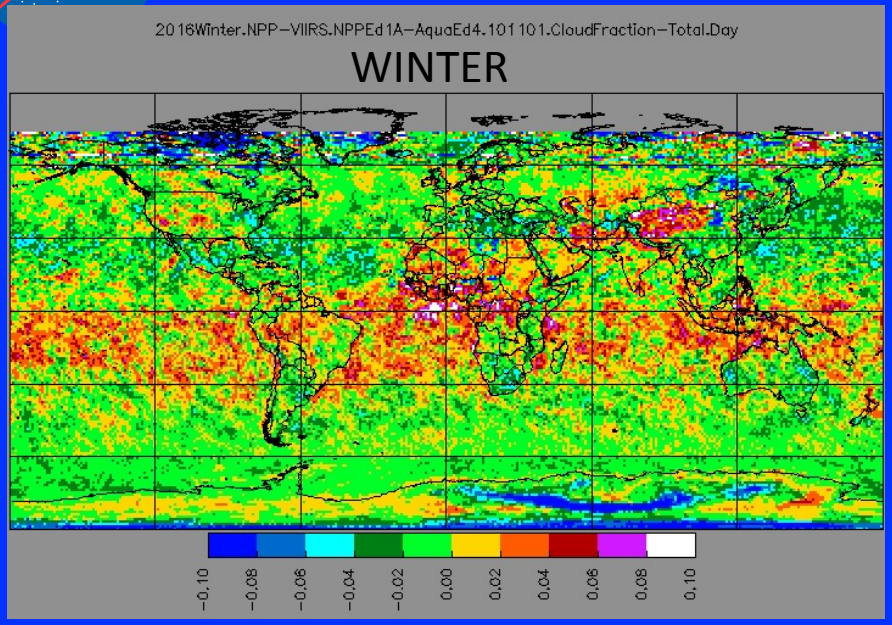
Same planet but different representations and error sources

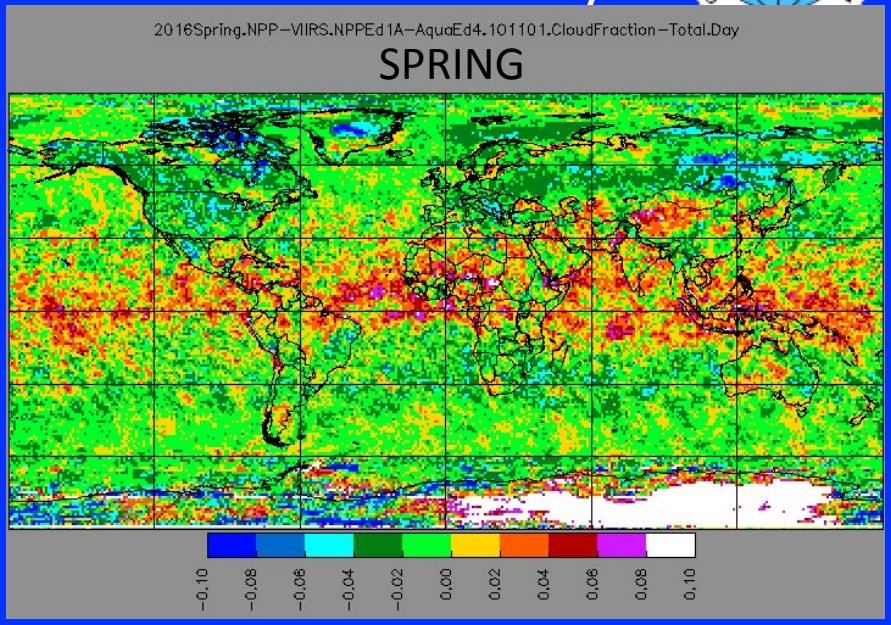
- Model deficiencies
- Satellite data lack vertical structure info (VH, single phase assumptions)
- Satellite not sensitive to optically thick clouds at night (standard methods)

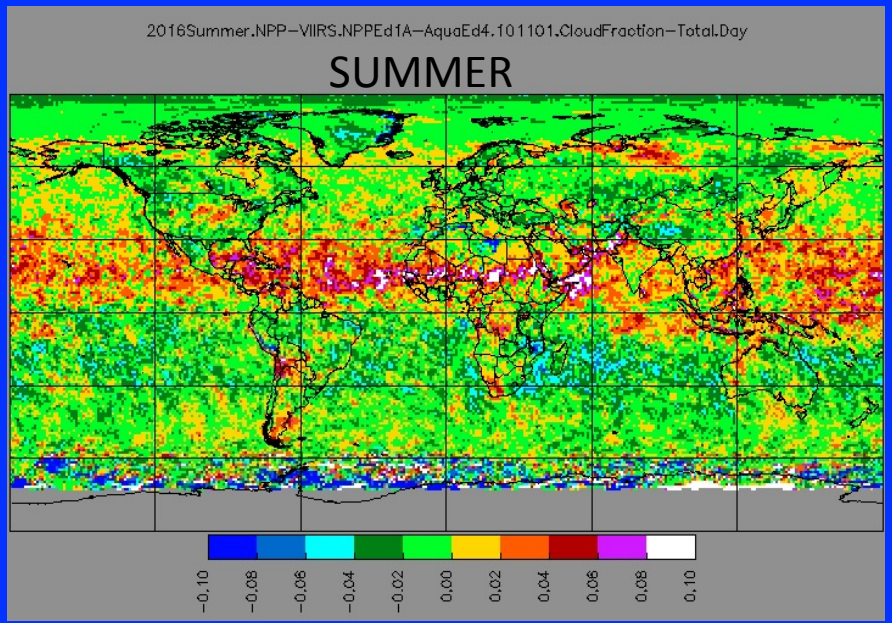
→ Model output and satellite estimates not comparable in many conditions

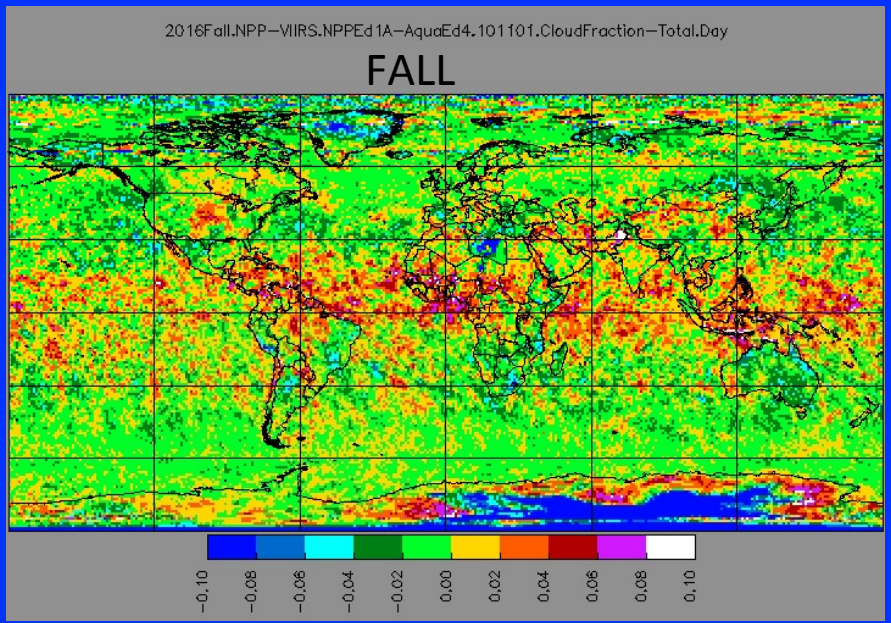
AQUA-MODIS vs VIIRS

VIIRS minus MODIS Cloud Fraction (2016) Day



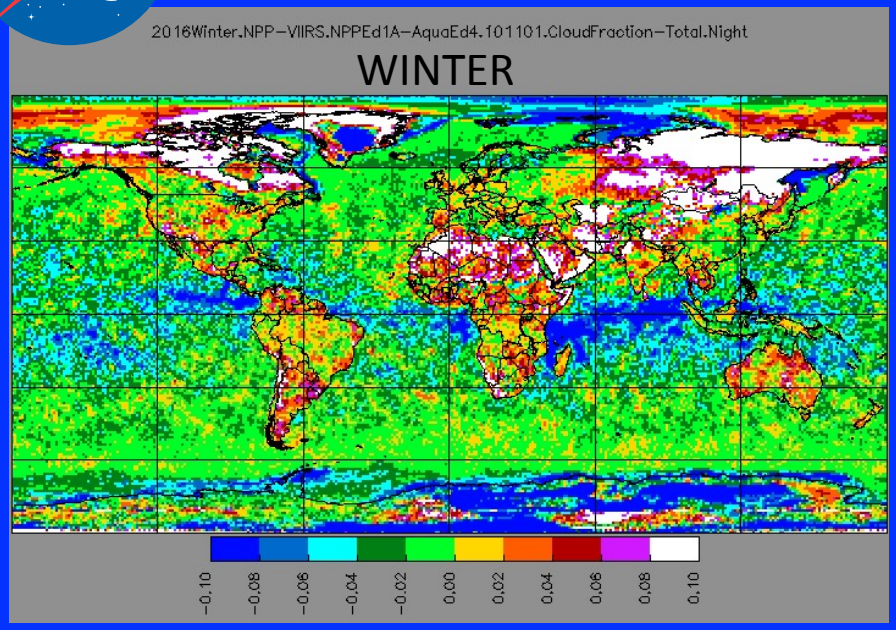


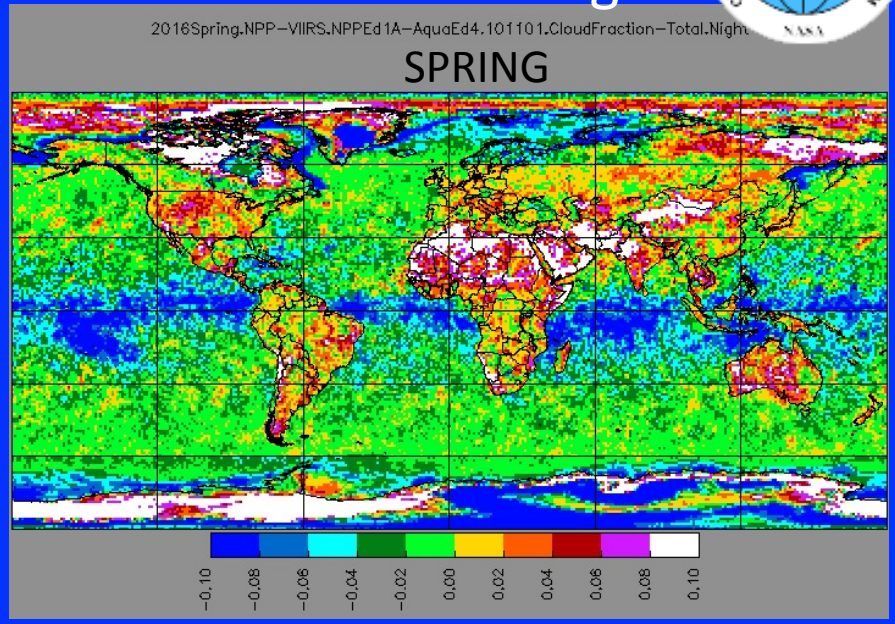


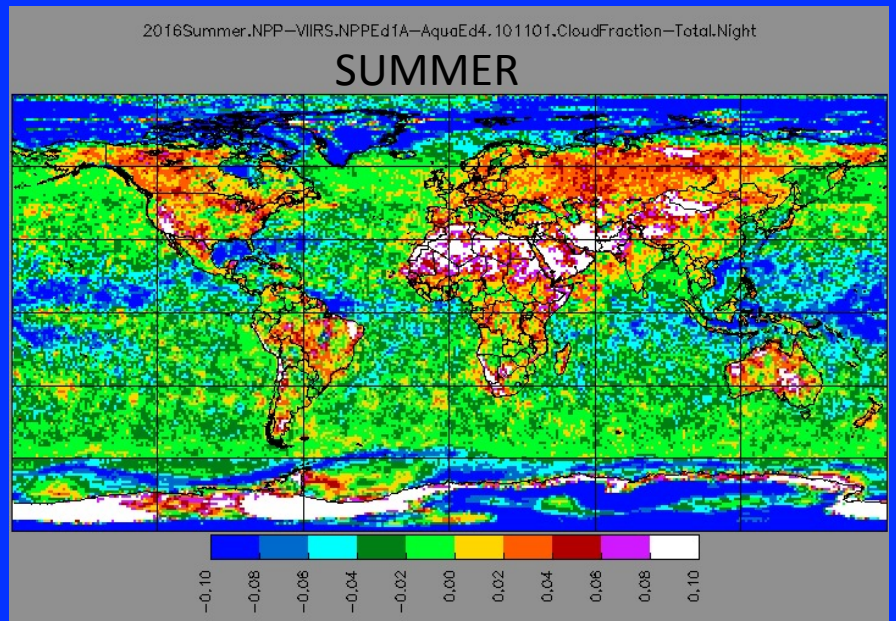


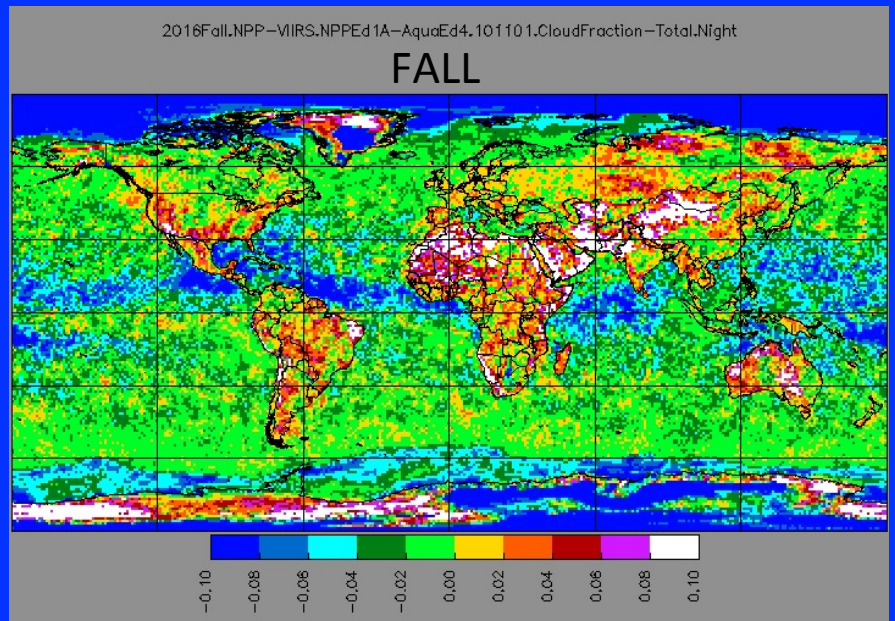
AQUA-MODIS vs VIIRS

VIIRS minus MODIS Cloud Fraction (2016) Night



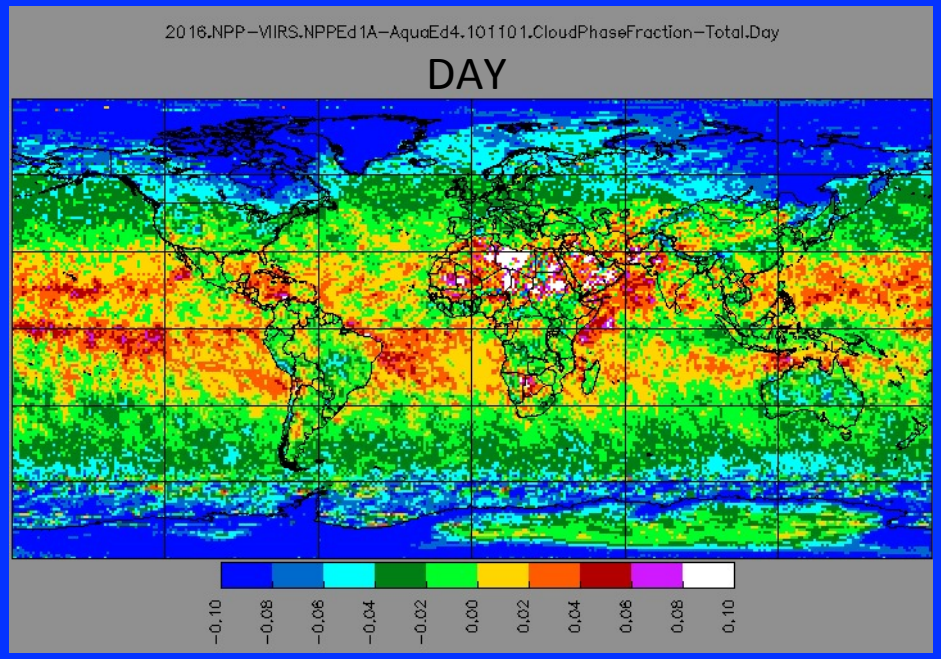


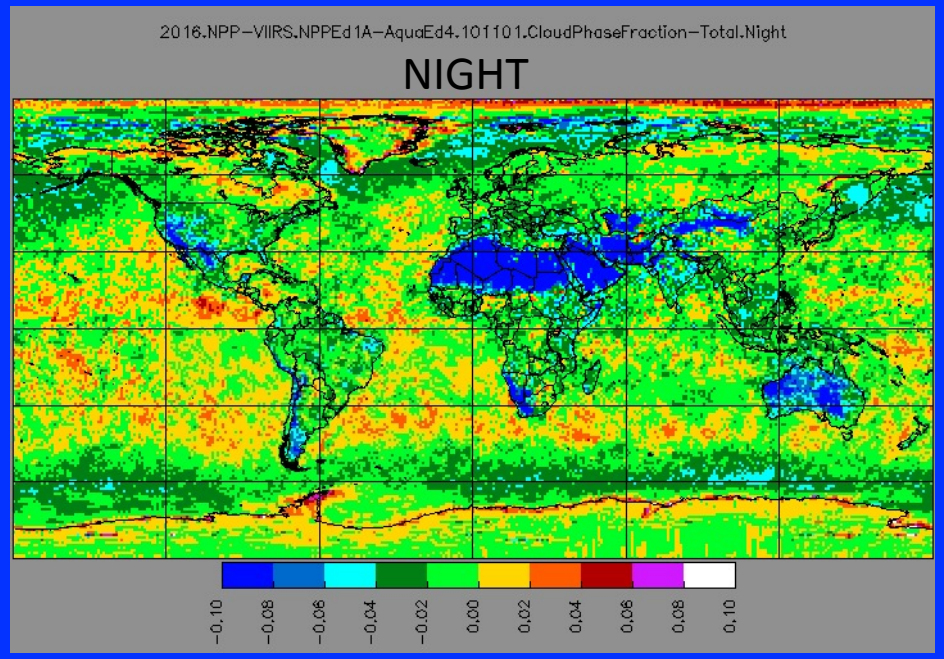




AQUA-MODIS vs VIIRS

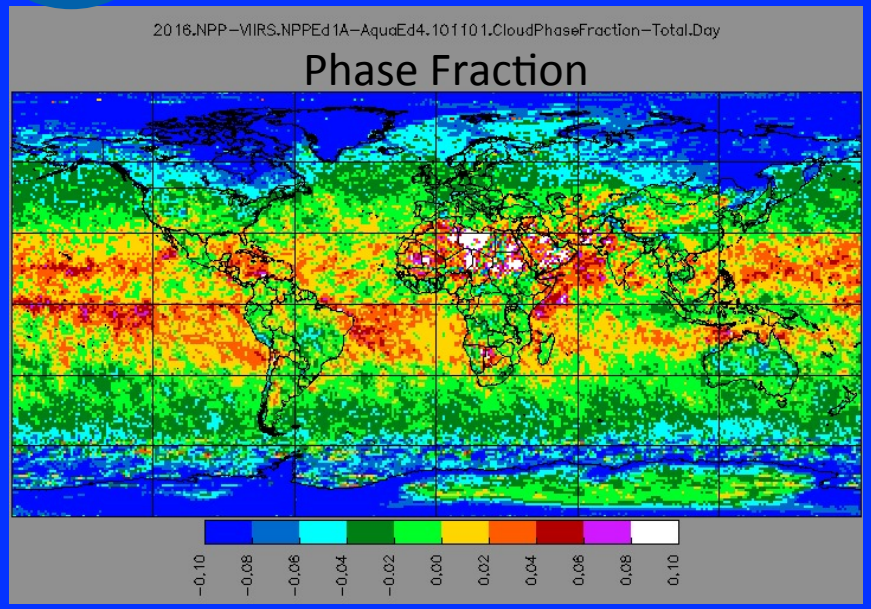
VIIRS minus MODIS Cloud Properties (2016)

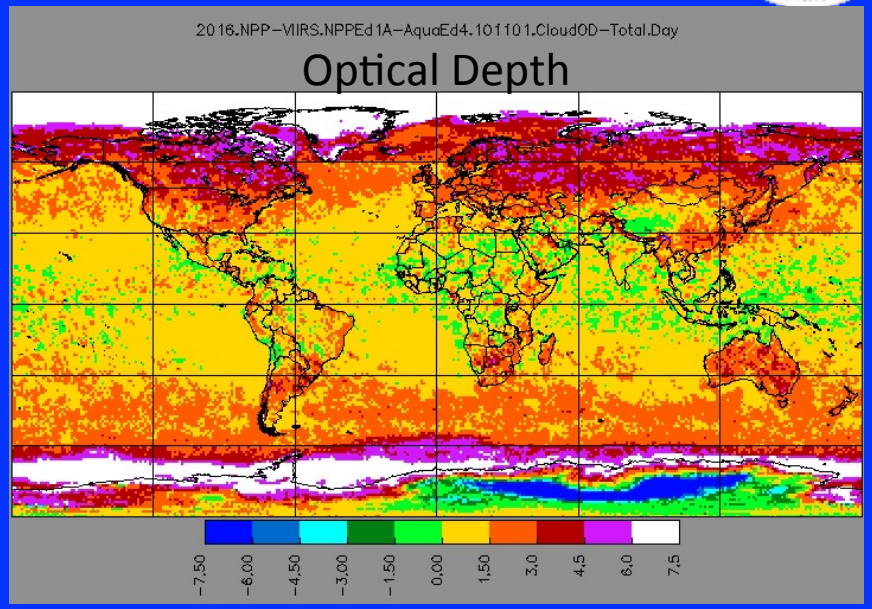


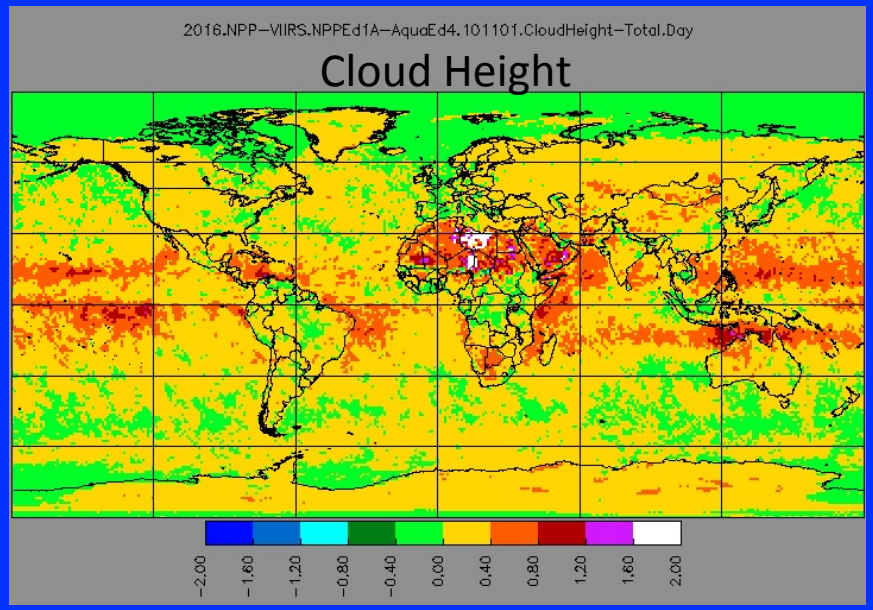


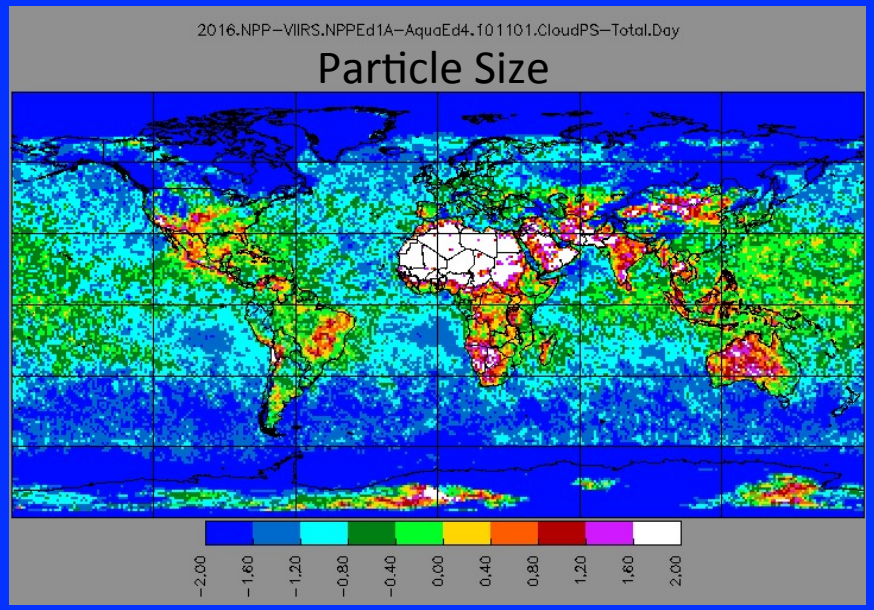
AQUA-MODIS vs VIIRS DAY

VIIRS minus MODIS Cloud Properties (2016)



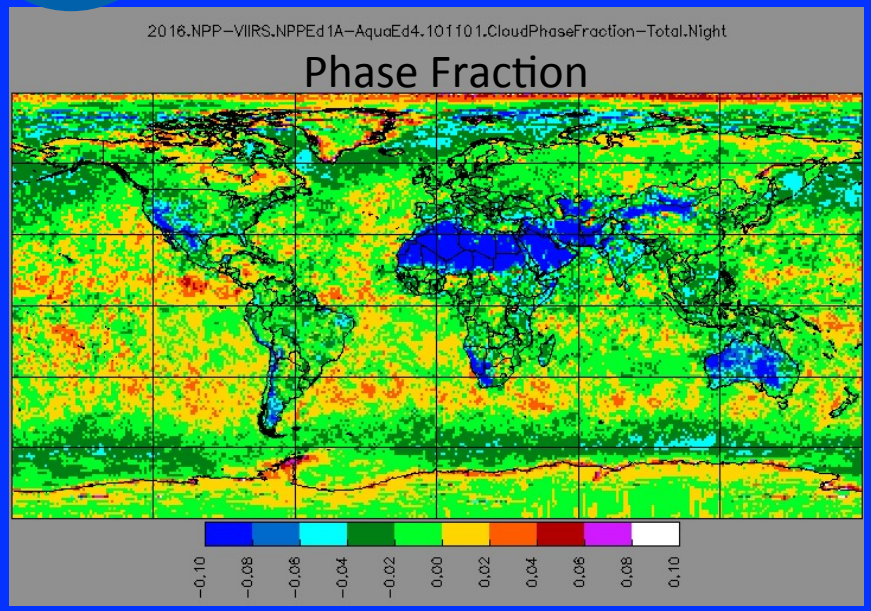


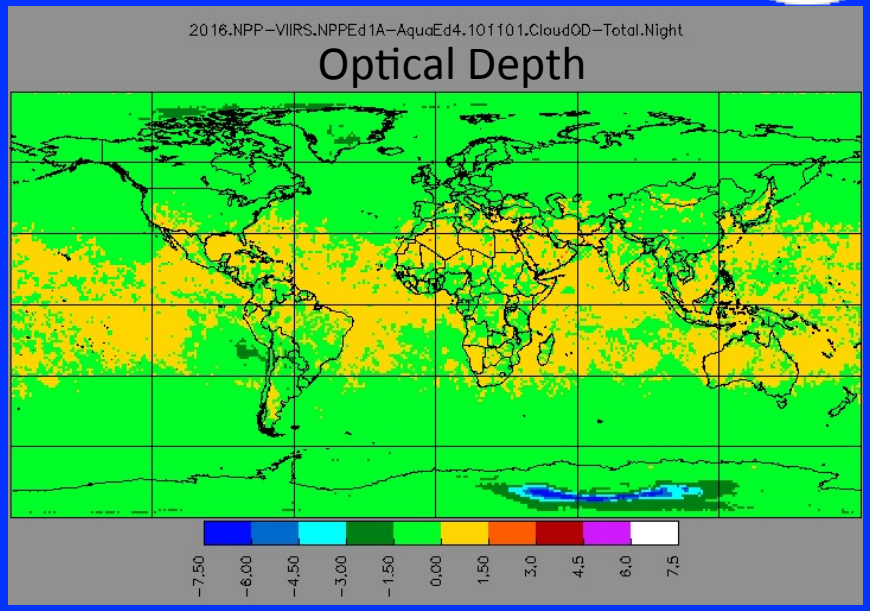


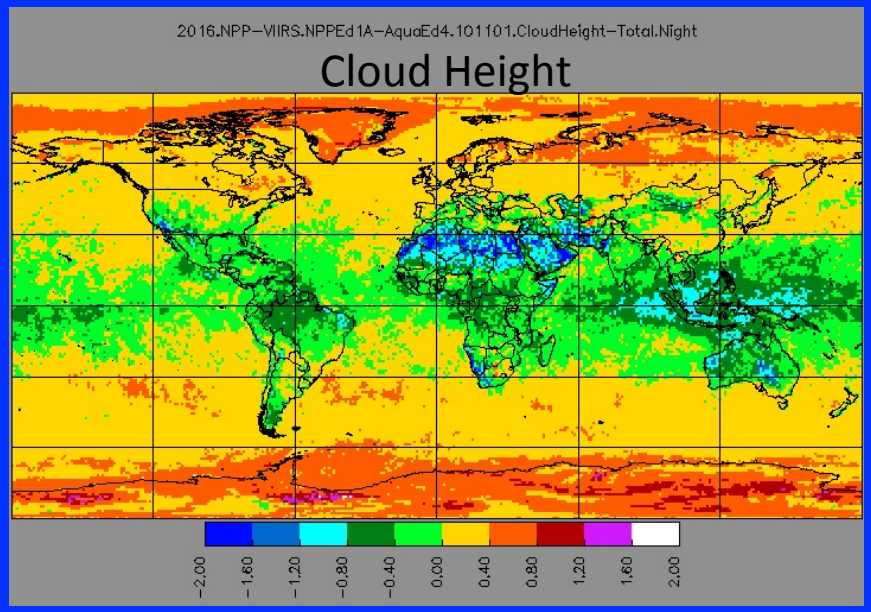


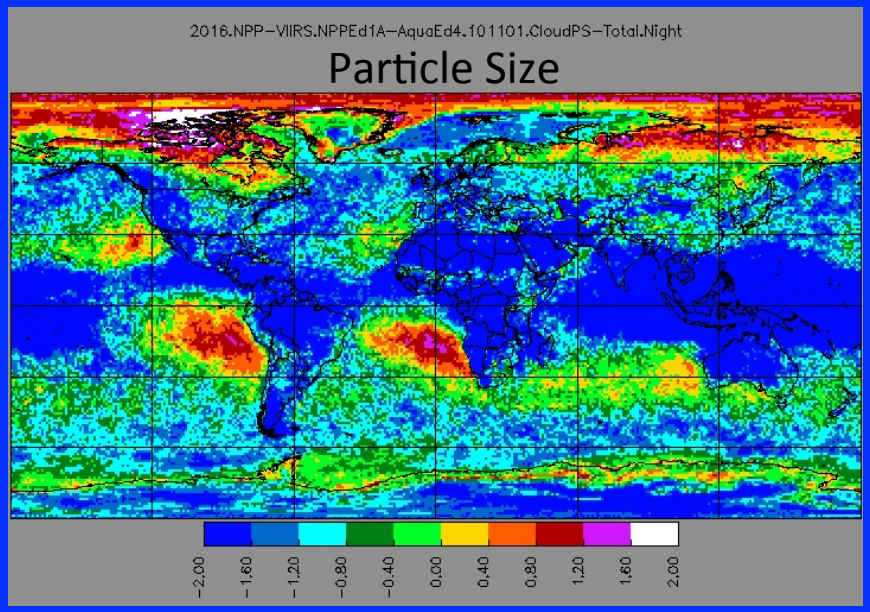
AQUA-MODIS vs VIIRS Night

VIIRS minus MODIS Cloud Properties (2016)







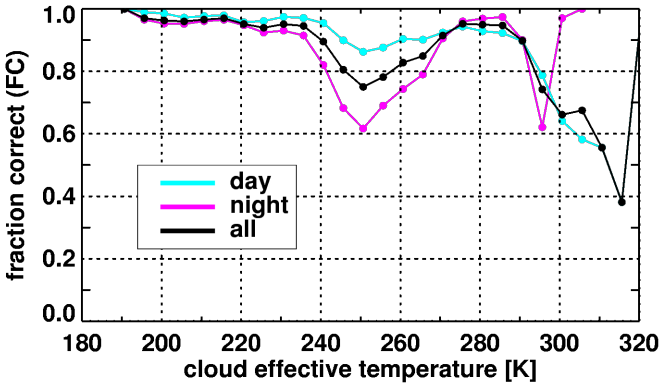


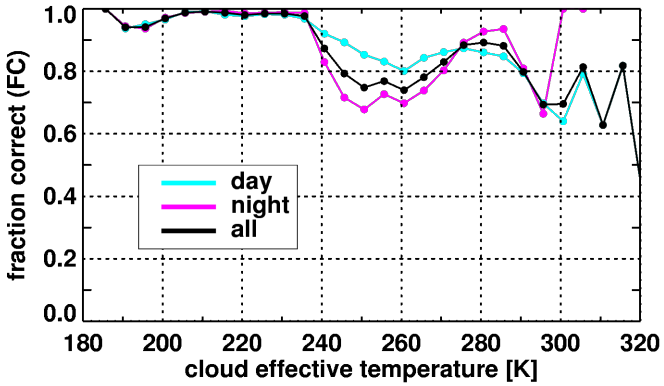
cloud phase

fraction correct as function of cloud effective temperature

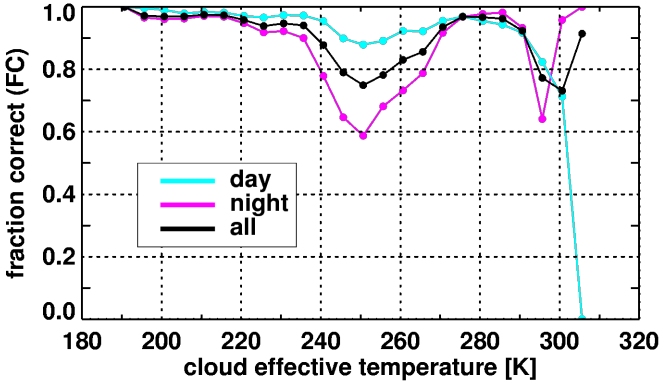
MODIS | **Him-8**

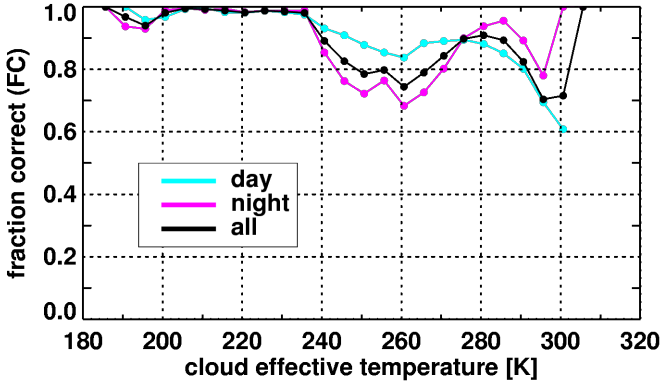
Full-disk, snow/ice free



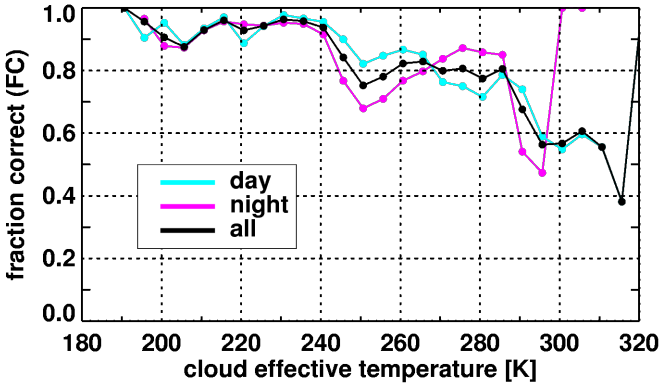


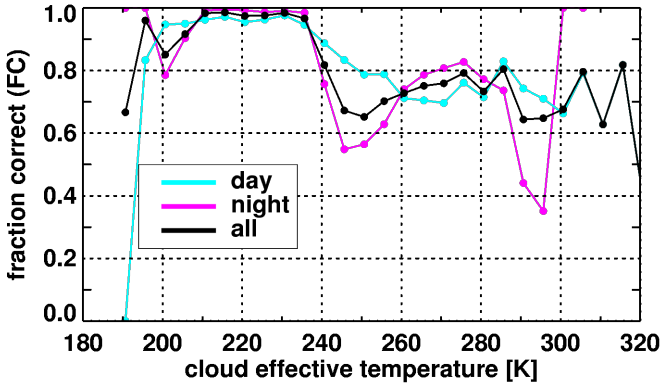
Full-disk, snow/ice free, ocean



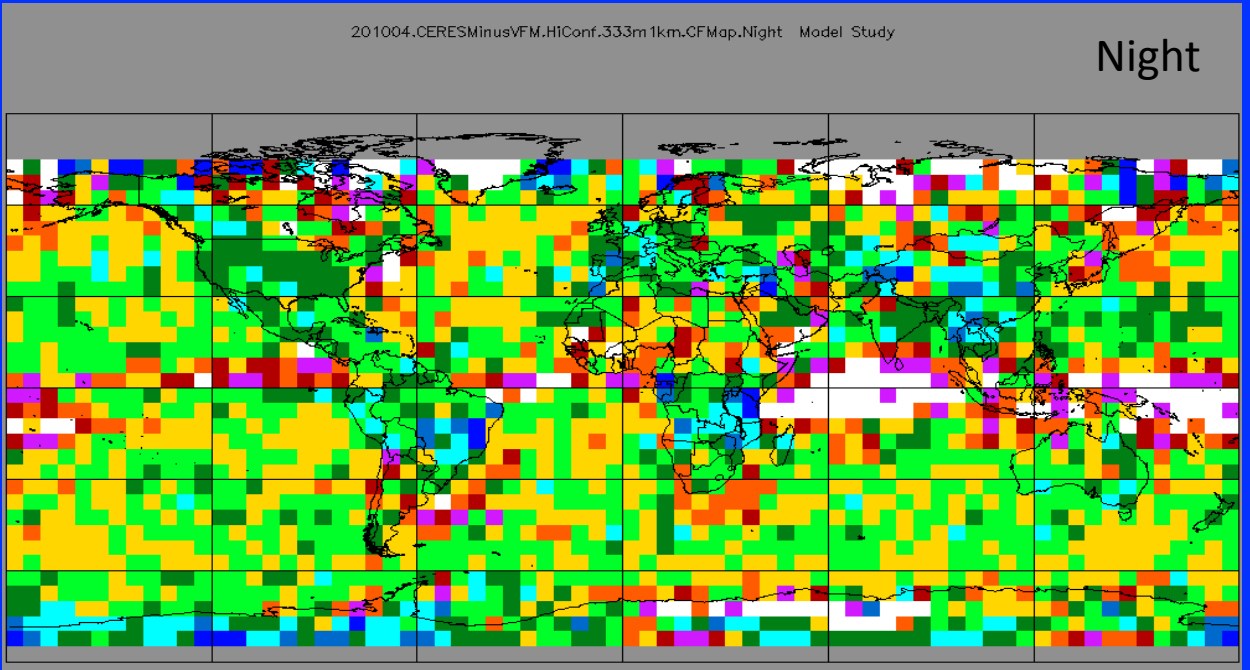


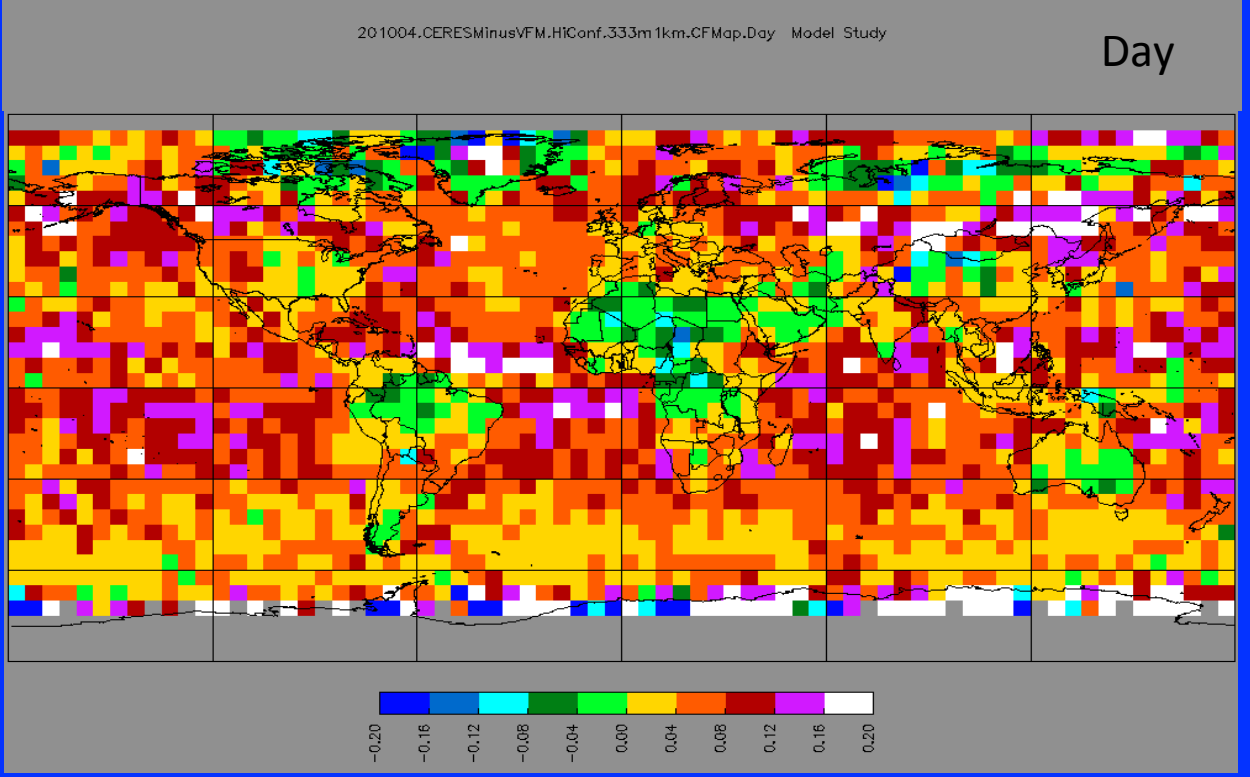
Full-disk, snow/ice free, land





Cloud Fraction Diff
2010 04
C3M Pixel MODIS - VFM



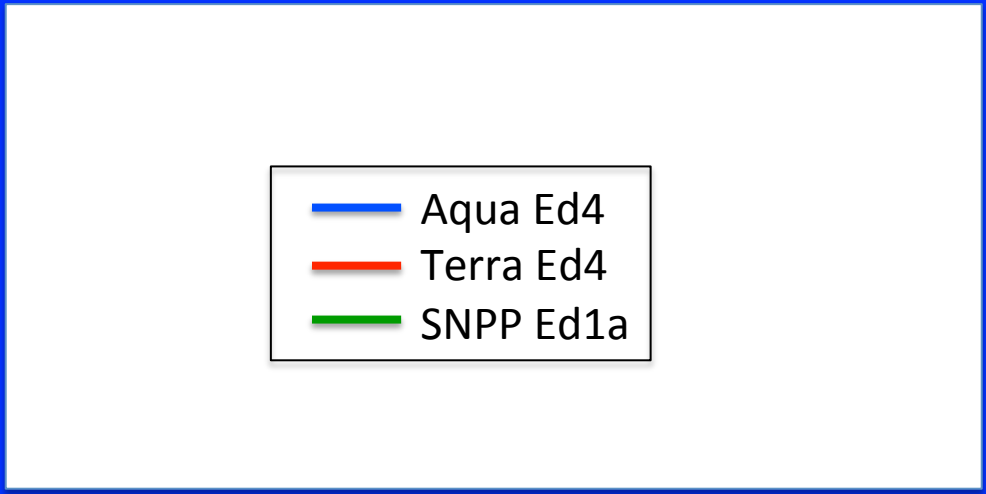


VFM
Hi Conf
Resolution
Only 333 m for <= 8.2 km
Only 1 km for > 8.2 km

CERES CWG OBJECTIVES

Produce consistent pixel-level cloud properties from imager & GEO radiances (SSF, Level 2).

- Cloud properties are used in downstream CERES processing: Inversion WG to convert measured radiances to radiative fluxes; SARB WG to compute surface fluxes; TISA WG for improved time-interpolation of TOA radiative fluxes.
- Because cloud properties are such an integral part of CERES processing, a dedicated Clouds WG is essential. As a radiation budget project, CERES requires cloud retrievals even for the most challenging cases (e.g., near cloud edges).
- CERES cloud algorithm changes must be coordinated with those of higher-level data products in order to minimize discontinuities in the CERES CDR.
- Cloud algorithm must be consistent across multiple platforms (Aqua MODIS-> S-NPP VIIRS; 16 geostationary instruments)
- Need consistent forward models between retrieval system and other subsystems
- MODIS "Collection" reprocessing events are independent of and more frequent than CERES "Edition" changes (MODIS is on Collection 6.1 while CERES is on Edition 4.0).
- MODIS Collection changes can introduce discontinuities in CERES climate data record. CERES team attempts to mitigate MODIS calibration changes to some extent.


Aqua Ed4
Terra Ed4
SNPP Ed1a