CERES Cloud Working Group Report

CERES Science Team Mtg., Hampton, VA, 15-17 May 2018

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), G. Hong (models, night tau), Y. Chen (clr props, test runs),
M. Nordeen (GEO), B. Scarino (cal, Tskin), R. Brown (QC), F-L. Chang (CO2, ML),
E. Heckert (web), 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, (validation), University of Arizona

Thanks to Dave Doelling and his TISA/calibration teams!

Topics

- Publications update
- Processing status
- MODIS Collection 6.1 testing
- GEO update (GOES-16)
- Ed5 Improvements

Update of CERES Cloud-related Papers

Edition-4 related

Tian, J., X. Dong, B. Xi, P. Minnis, W. L. Smith, Jr., S. Sun-Mack, M. Thiemann, and J. Wang, 2018: Comparisons of ice water path in deep convective systems among ground-based, GOES, and CERES-MODIS retrievals. *J. Geophys. Res.*, **123**, doi: 10.1002/2017JD027498.

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, 2018: Ultraclean layers and optically thin clouds in the stratocumulus transition: Part I: Observations. *J. Atmos. Sci.*, **75**, doi:10.1175/JAS-D-17-0213.1.

Sun-Mack, P. Minnis, Y. Chen, D. R. Doelling, B. Scarino, C. O. Haney, and W. L. Smith, Jr., 2018: Calibration changes to Terra MODIS Collection-5 radiances for CERES Edition 4 cloud retrievals. *IEEE Trans. Geosci. Remote Sens.*, 56, doi:10.1109/TGRS.2017.01557.

McHardy, T. M., X. Dong, B. Xi, M. M. Thieman, P. Minnis, and R. Palikonda, 2018: Comparison of daytime low-level cloud properties derived from GOES and ARM SGP measurements. J. Geophys. Res., revision submitted.

Wall, C. J., D. L. Hartmann, M. M. Khaiyer, W. L. Smith, Jr., and P. Minnis, 2018: The lifecycle of convective clouds and the top-of-atmosphere radiation balance over the tropical west Pacific. *J. Climate*, submitted .

Trepte, Q. Z., P. Minnis, C. R. Yost, S. Sun-Mack, Y. Chen, Z. Jin, F.-L. Chang, and W.,L. Smith, Jr., 2018: Global cloud detection for CERES Edition 4 using Terra and Aqua MODIS data. *IEEE Trans. Geosci. Remote Sens.*, **draft completed,** submission soon.

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, 2018: Changes to CERES MODIS cloud product retrieval algorithms for Edition 4. *IEEE Trans. Geosci. Remote Sens.*, **in preparation**.

Edition-5 related

Sun-Mack, S., P. Minnis, W. L. Smith, G. Hong, and Y. Chen, 2017: Detection of single and multilayer clouds in an artificial neural network approach. *Proc. SPIE Conf. Remote Sens. Clouds and the Atmos. XXII*, Warsaw, Poland, 11-14, 10424-7, 12 pp., doi: 10.1117/12.2277397.

Loeb, N., P. Yang, F. G. Rose, G. Hong, S. Sun-Mack, P. Minnis, S. Kato, S.-Ham, and W. L. Smith, Jr., 2018: Impact of ice cloud microphysics on satellite retrievals and broadband flux radiative transfer calculations. *J. Climate*, **31**, doi:10.1175/JCLI-D-7-0426.1.

Saito, M., P. Yang, Y. Hu, X. Liu, N. Loeb, W. L. Smith, Jr., and P. Minnis, 2018: An efficient method for microphysical property retrievals in vertically inhomogeneous marine water clouds using MODIS-CloudSat measurements. *J. Appl. Meteor. Climatol.*, submitted

Clouds - Processing Status

CERES MODIS Ed 4 Status

Aqua: Jul 2002 – Mar 2018 (~16 y)

Terra: Feb 2000 – Mar 2018 (~18 y)

- *MODIS C5 thru Feb 2017, then C6 after that*
- *TERRA WV Channel not used after Feb 2016*
- *Switch to C6.1 coming soon. Will then reprocess beginning with March 2016*

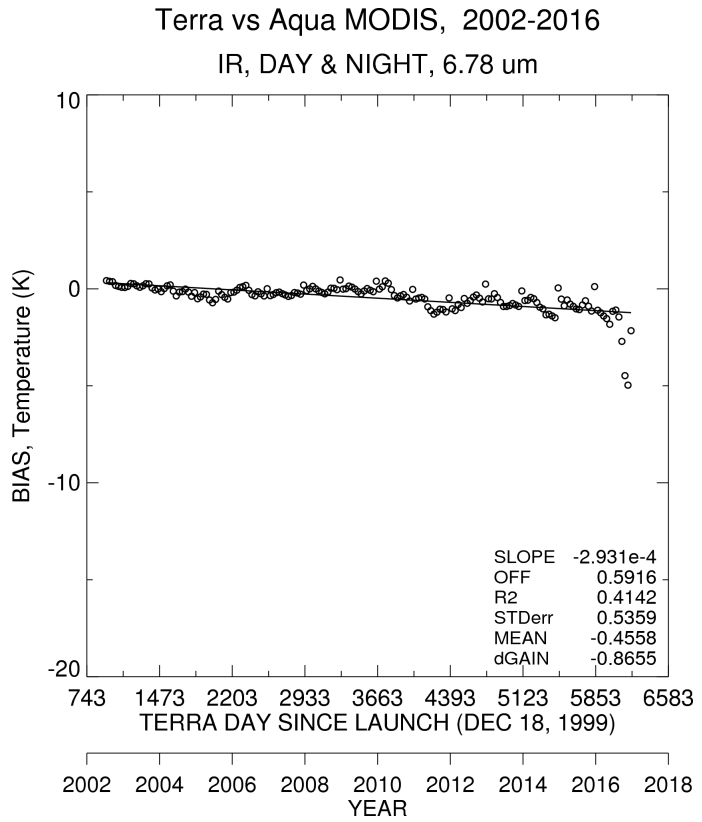
CERES VIIRS Ed 1 Status

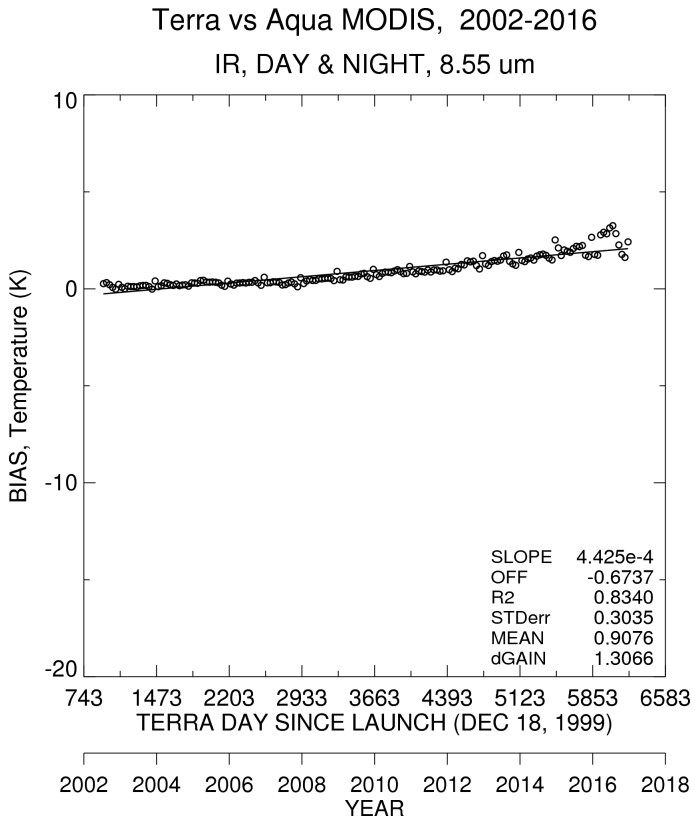
SNPP: Jan 2012 – Dec 2017 (~6 y)

Progress with MODIS Collection 6.1

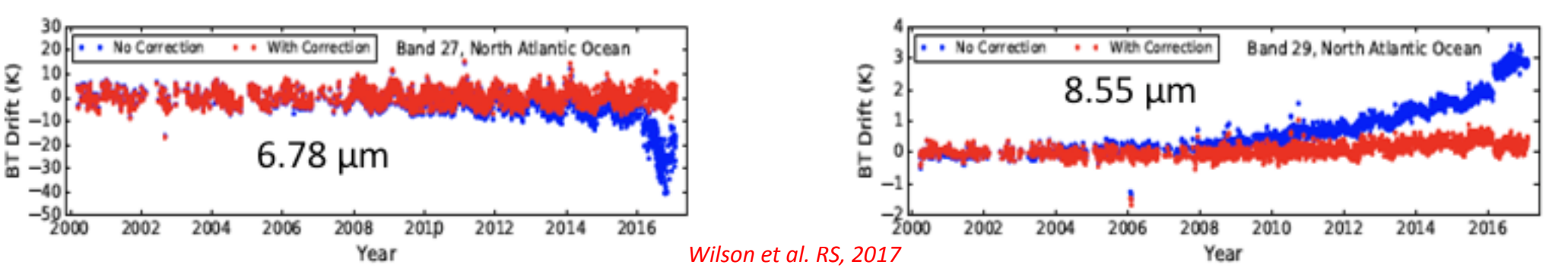
- 6.7 μm WV and 8.6 μm window channels began degrading on TERRA in 2008.
- Used in cloud mask and for cloud phase selection with most significant impacts at night over snow/ice; Artificial trends in some nocturnal cloud properties evident after 2008.
- Major anomaly in TERRA WV channel occurred in Feb 2016

6.7, 8.6 μm Trends (Terra vs Aqua)





Progress with MODIS Collection 6.1



Wilson et al. RS, 2017

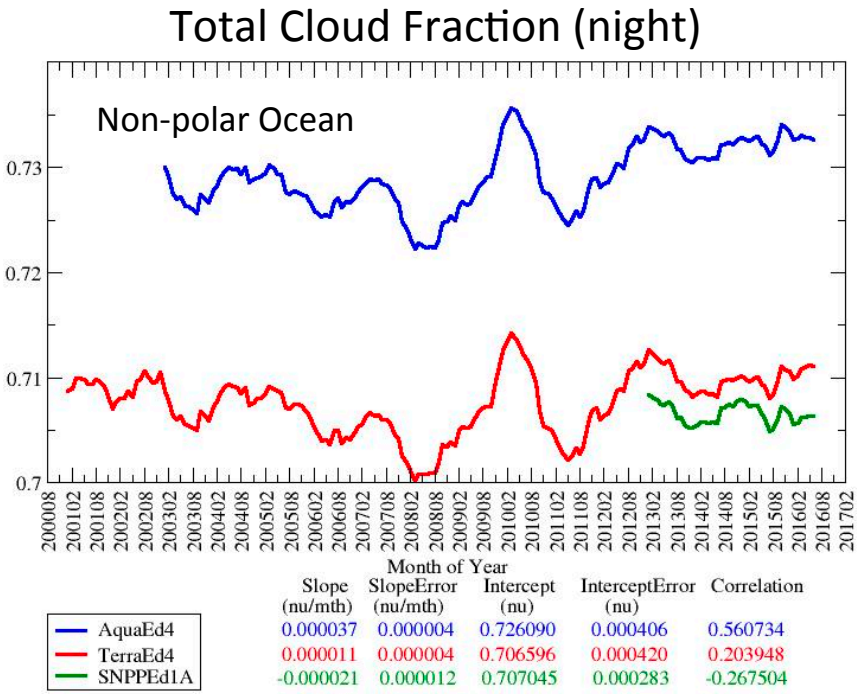
- MODIS C6.1 corrected to achieve stable 6.7 and 8.6 µm radiances across the record
- Should alleviate the nocturnal phase and cloud detection issues between Terra and Aqua
- CERES reprocessing is planned beginning with March 2016 data and using C6.1 scaled to C5

Given the C5 degradation in these channels on Terra and impact on cloud properties (induces some artificial trends), do we know what procedure for scaling C6.1 to C5 makes the most sense?

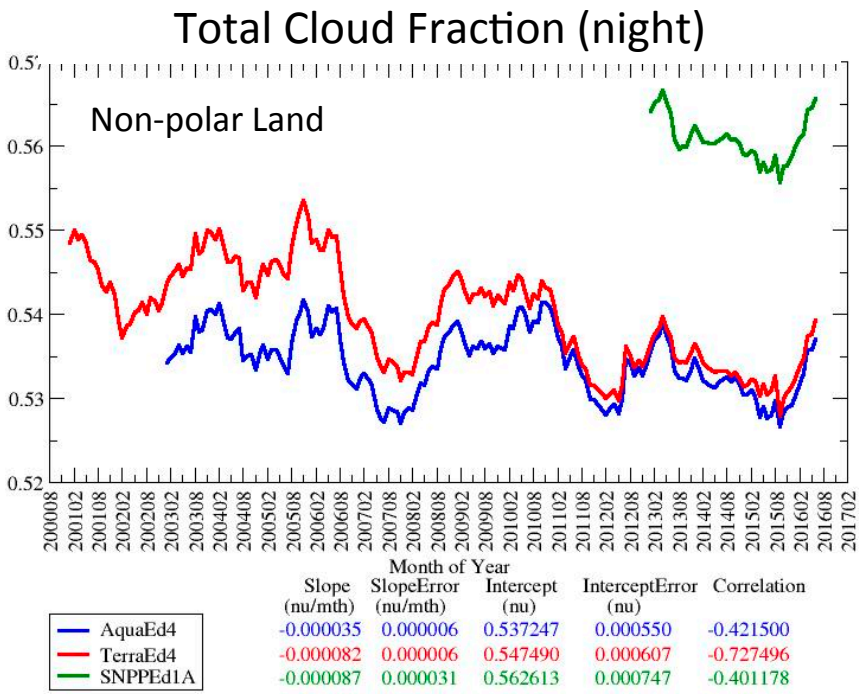
Current approach uses scaling factors for Feb 2016

Option 1: Scale to recent time period (halts artificial trends by stabilizing cloud properties at their current level)
Option 2: Scale to time period before degradation started ~2008 (stabilizes cloud properties moving forward and restores to more accurate pre-degradation levels moving forward (?) but may induce an abrupt discontinuity)

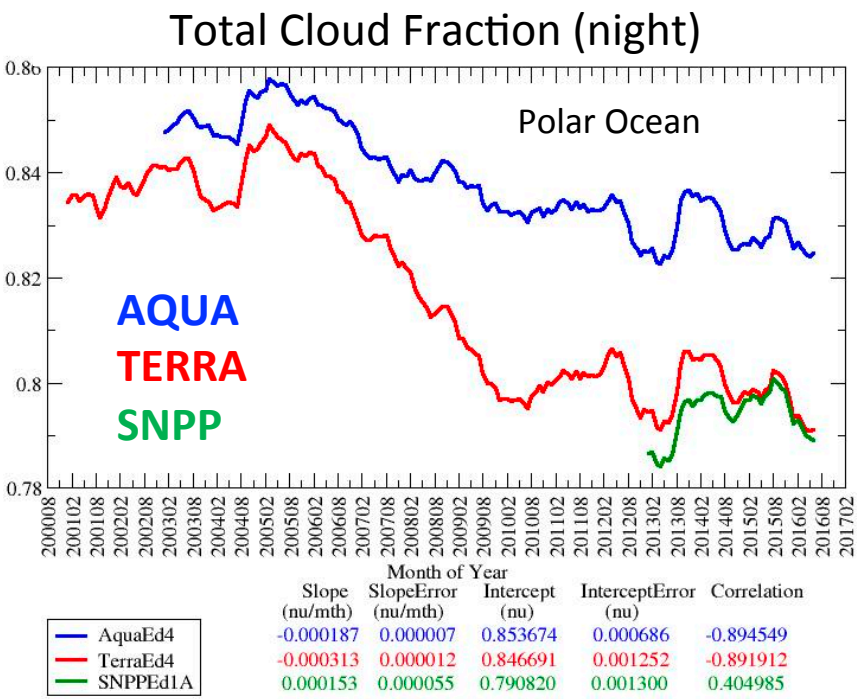
Cloud Fraction Nighttime



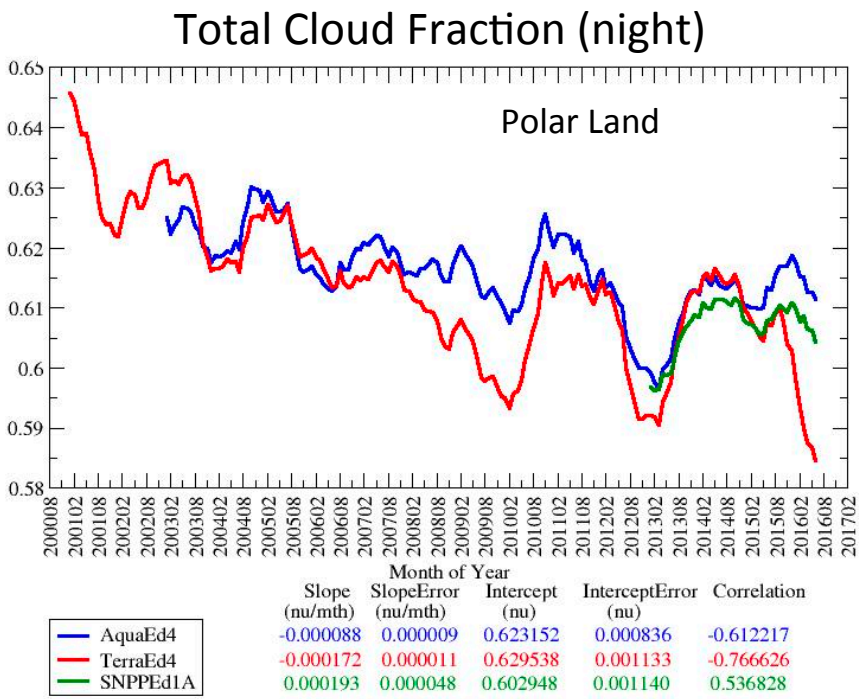
	Slope (nu/mth)	SlopeError (nu/mth)	Intercept (nu)	InterceptError (nu)	Correlation
AquaEd4	0.000037	0.000004	0.726090	0.000406	0.560734
TerraEd4	0.000011	0.000004	0.706596	0.000420	0.203948
SNPPEd1A	-0.000021	0.000012	0.707045	0.000283	-0.267504



	Slope (nu/mth)	SlopeError (nu/mth)	Intercept (nu)	InterceptError (nu)	Correlation
AquaEd4	-0.000035	0.000006	0.537247	0.000550	-0.421500
TerraEd4	-0.000082	0.000006	0.547490	0.000607	-0.727496
SNPPEd1A	-0.000087	0.000031	0.562613	0.000747	-0.401178



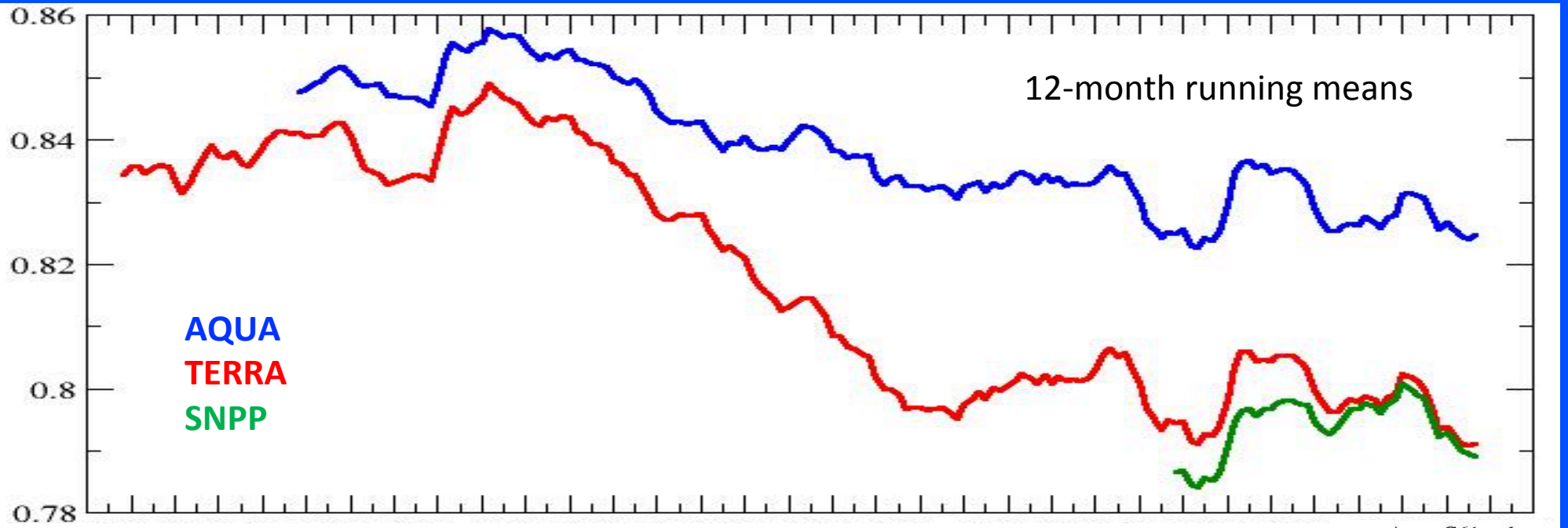
	Slope (nu/mth)	SlopeError (nu/mth)	Intercept (nu)	InterceptError (nu)	Correlation
AquaEd4	-0.000187	0.000007	0.853674	0.000686	-0.894549
TerraEd4	-0.000313	0.000012	0.846691	0.001252	-0.891912
SNPPEd1A	0.000153	0.000055	0.790820	0.001300	0.404985

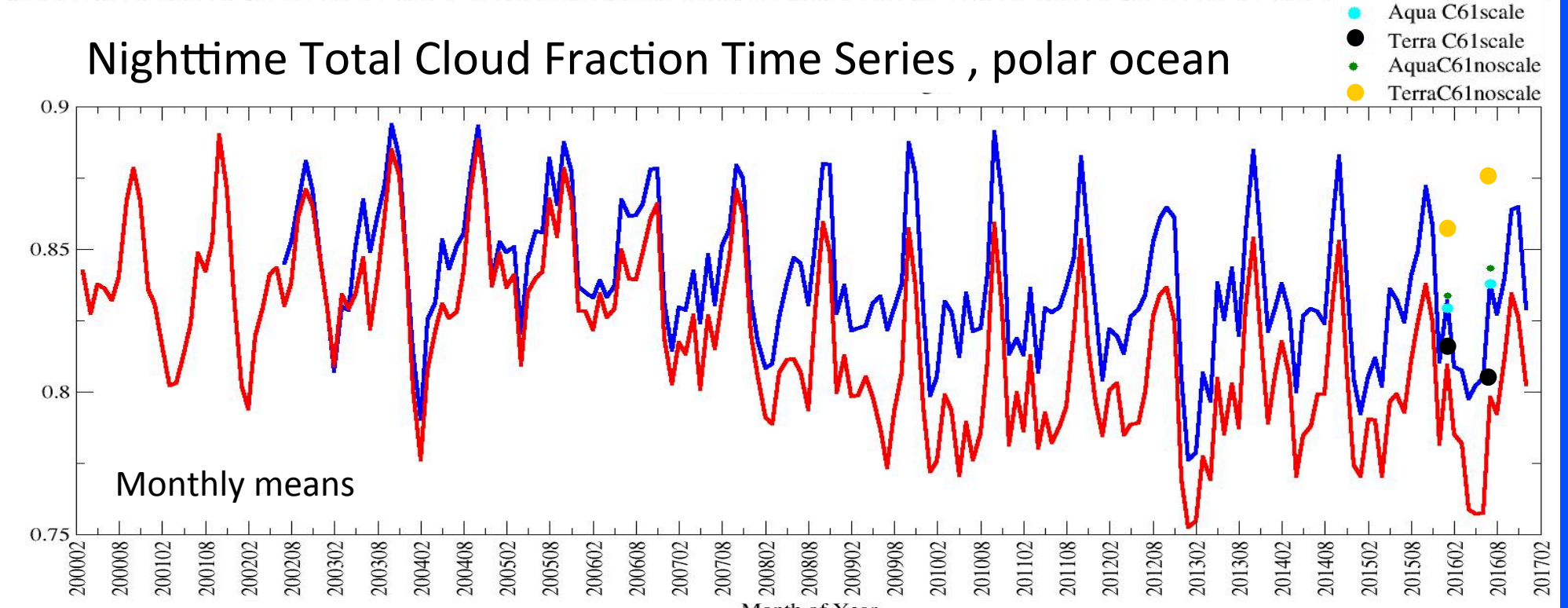


	Slope (nu/mth)	SlopeError (nu/mth)	Intercept (nu)	InterceptError (nu)	Correlation
AquaEd4	-0.000088	0.000009	0.623152	0.000836	-0.612217
TerraEd4	-0.000172	0.000011	0.629538	0.001133	-0.766626
SNPPEd1A	0.000193	0.000048	0.602948	0.001140	0.536828

- Over non-polar ocean, TERRA and AQUA cloud fraction differences are consistent in time
- For non-polar land, polar land and polar ocean, Terra cloud fraction differences change with time after 2008
- For example, differences due to diurnal cycle disappear over non-polar land and grow over polar ocean

Note that for Daytime (not shown), Terra and Aqua cloud fraction differences are found to be much more consistent in time



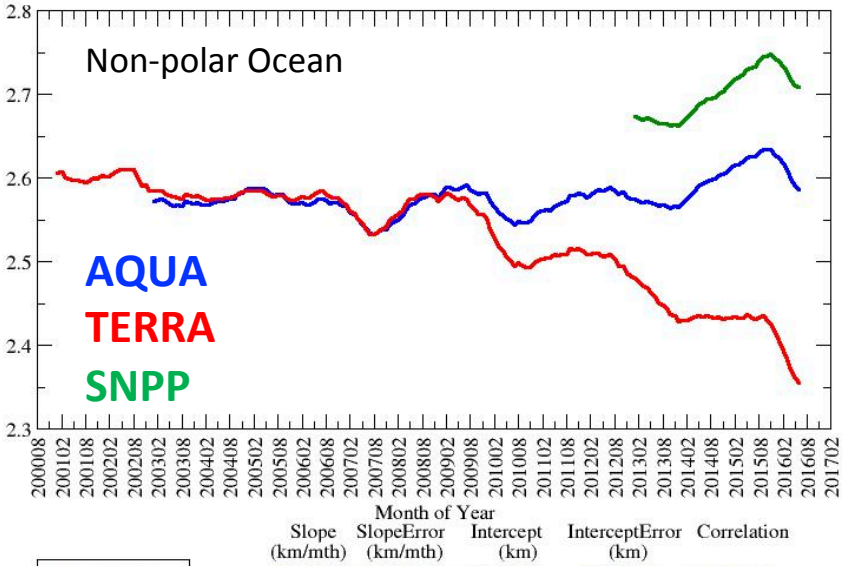


Terra with C6.1 scaling to C5 (black dots) will halt any artificial trend and produce continuity moving forward

Damage already done in earlier record due to degradation

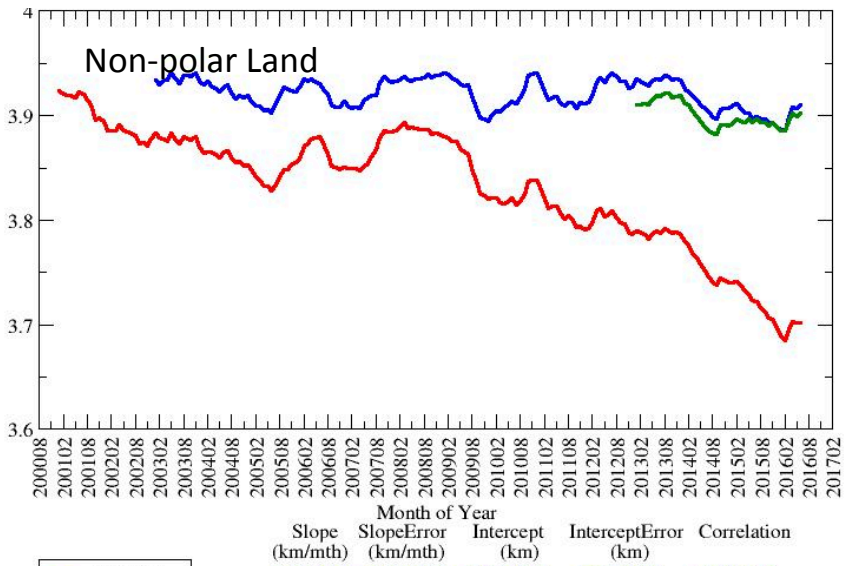
Would it be better to scale to C5 before the degradation occurred (Result would be closer to gold dots)???

Nighttime Water Cloud Height (km)



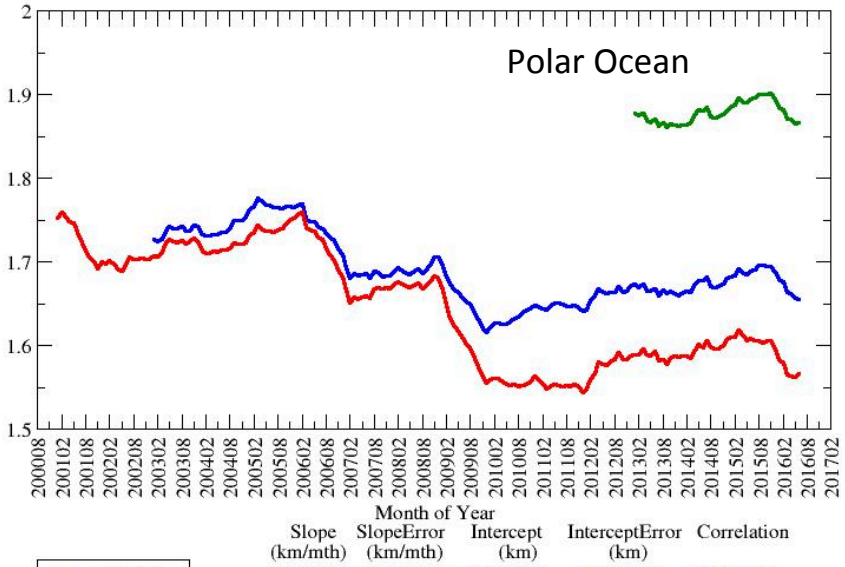
	Slope (km/mth)	SlopeError (km/mth)	Intercept (km)	InterceptError (km)	Correlation
AquaEd4	0.000215	0.000030	2.559964	0.002801	0.491376
TerraEd4	-0.001091	0.000034	2.632195	0.003599	-0.922563
SNPPEd1A	0.002084	0.000171	2.657770	0.004074	0.887536

Nighttime Water Cloud Height (km)



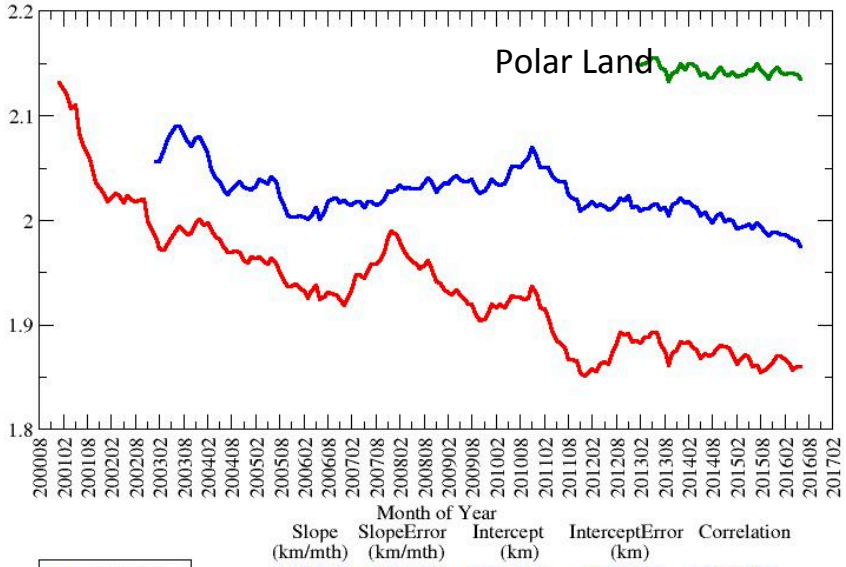
	Slope (km/mth)	SlopeError (km/mth)	Intercept (km)	InterceptError (km)	Correlation
AquaEd4	-0.000117	0.000022	3.930218	0.002052	-0.386245
TerraEd4	-0.000948	0.000035	3.919112	0.003781	-0.892307
SNPPEd1A	-0.000664	0.000112	3.914105	0.002670	-0.683772

Nighttime Water Cloud Height (km)



	Slope (km/mth)	SlopeError (km/mth)	Intercept (km)	InterceptError (km)	Correlation
AquaEd4	-0.000600	0.000051	1.738776	0.004719	-0.683476
TerraEd4	-0.001063	0.000052	1.745820	0.005515	-0.835394
SNPPEd1A	0.000527	0.000139	1.867797	0.003316	0.513788

Nighttime Water Cloud Height (km)

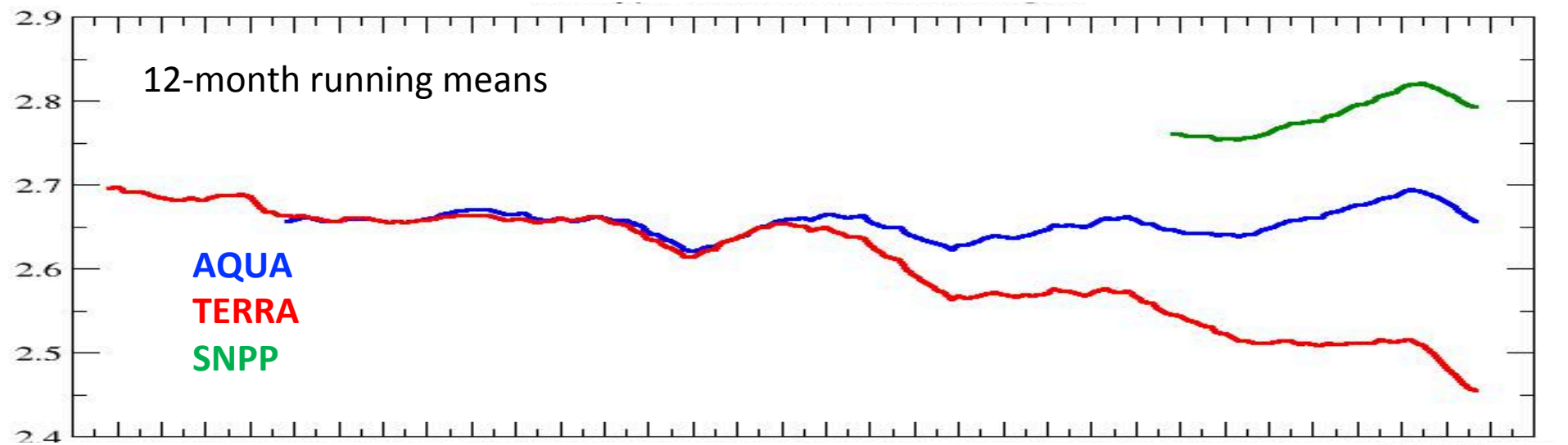


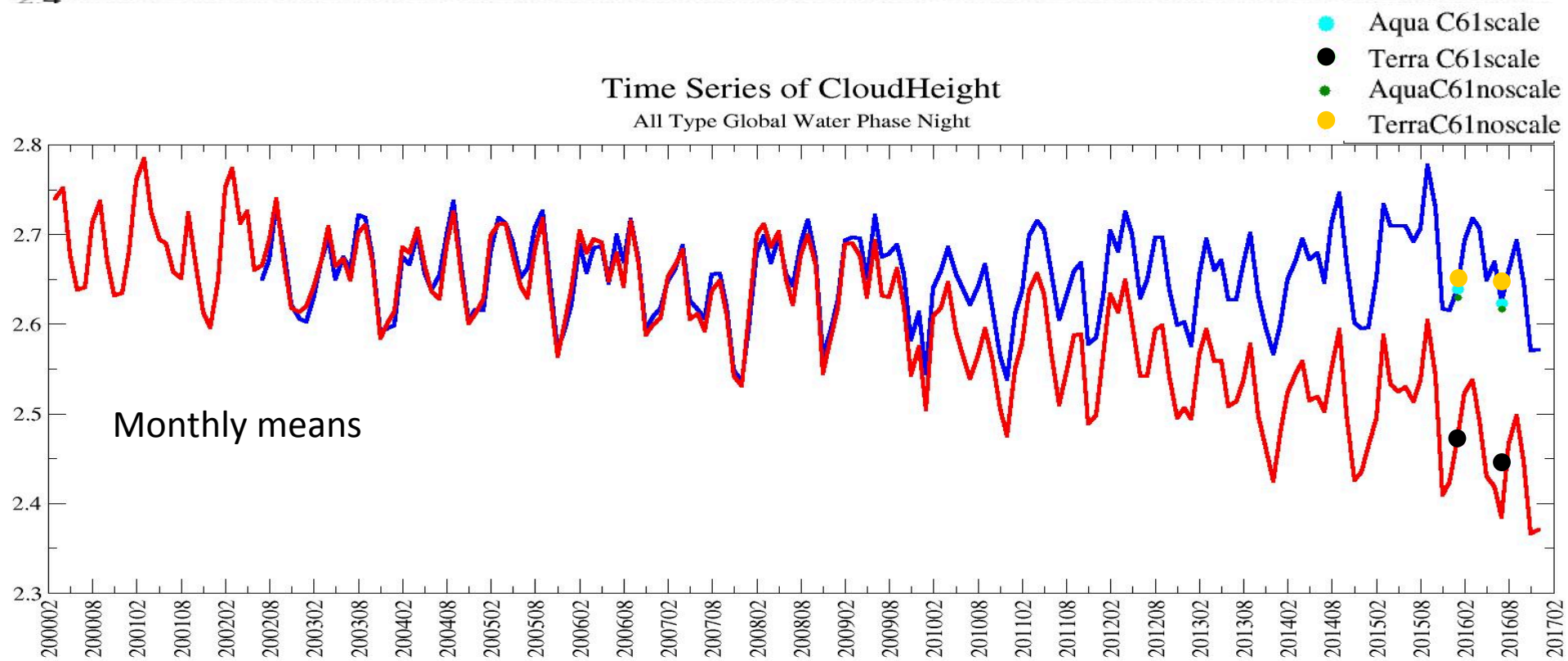
	Slope (km/mth)	SlopeError (km/mth)	Intercept (km)	InterceptError (km)	Correlation
AquaEd4	-0.000325	0.000030	2.051226	0.002805	-0.649122
TerraEd4	-0.001035	0.000034	2.032073	0.003678	-0.911762
SNPPEd1A	-0.000232	0.000060	2.147952	0.001421	-0.523985

Water Cloud Height Nighttime

- Terra heights diverge from Aqua after 2008

Nighttime Water Cloud Height Time Series , global





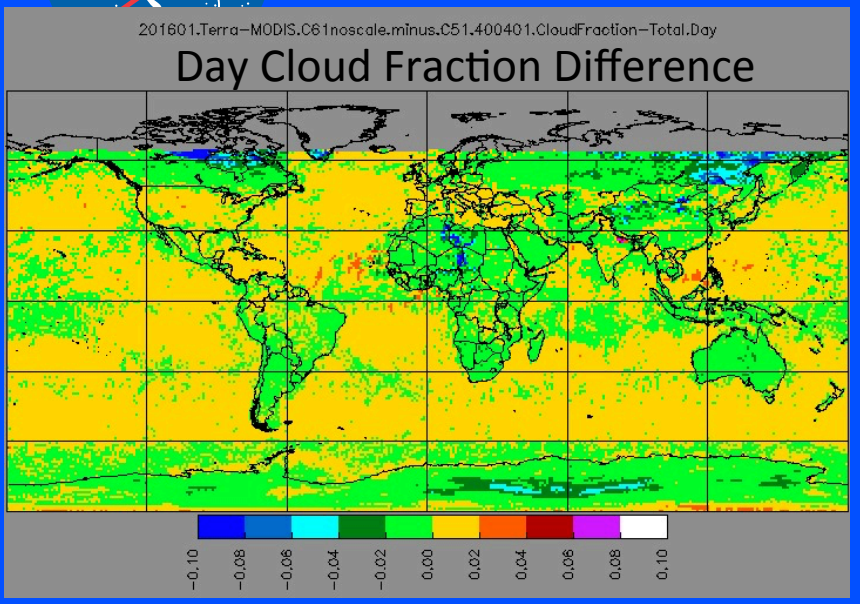
Do we continue producing Terra cloud properties after they've been slowly degrading but halting any further degradation effects using C61 (black dots)

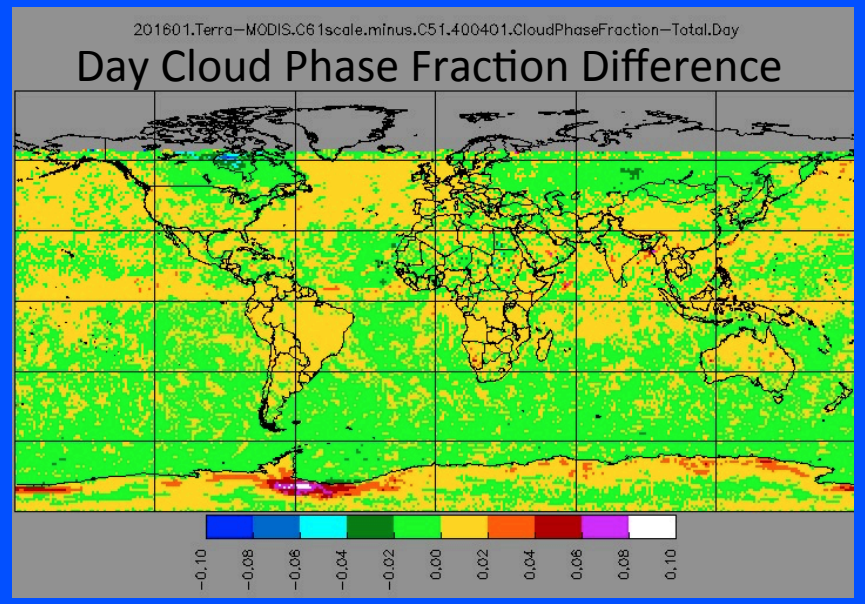
Or do we restore them to pre-degradation levels - scale to C5 before the degradation occurred- (Result would be closer to gold dots)

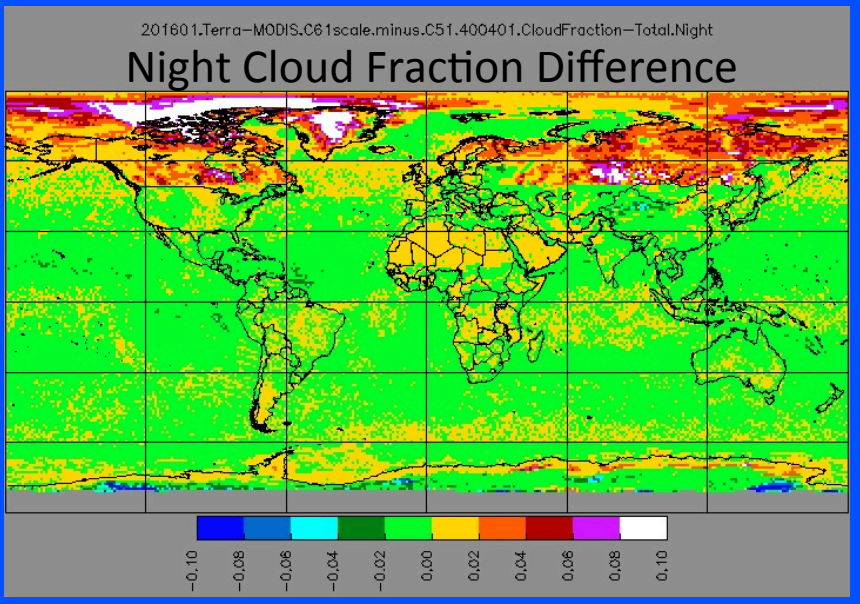
More study and discussion needed

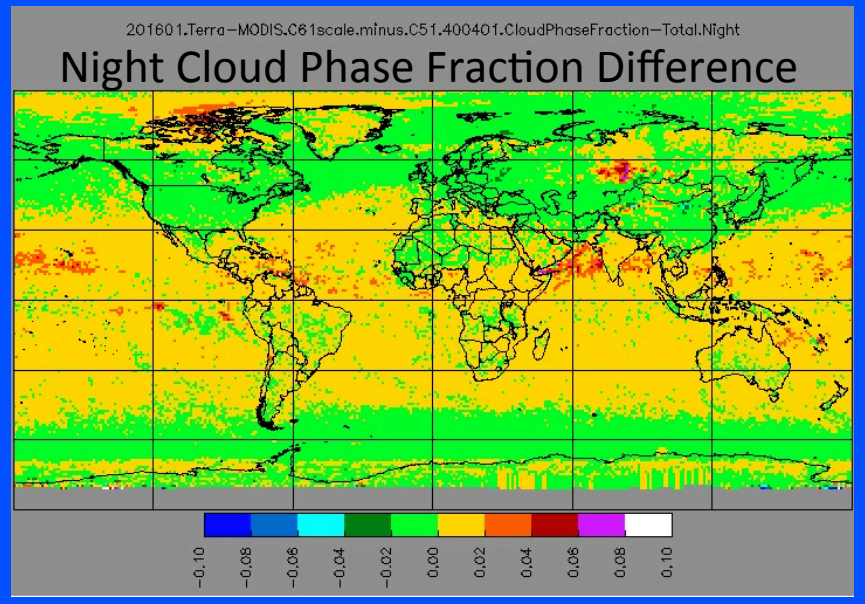
TERRA C6.1 scaled minus TERRA C5 (Jan 2016)

Scale factors derived w/Feb 2016 data









Daytime looks good (consistent)

Nighttime cloud fraction differences apparent in polar regions.

Possible reasons:

- WV channel has low signal especially at cold temps
- Hard to intercalibrate
- Scaling in radiance since linear (nonlinearities in temperature space)
- Other?

→ Scaling not perfect for Terra, needs more study and testing

AQUA also tested, very consistent C6.1 vs C5

GEO UPDATE (GOES-16)

Became operational 11/2017

CWG objective for new satellites is to achieve best consistency with MODIS as possible

GOES-16 ABI similar to Himawari AHI (ABI has 1.38 um channel, not on AHI)

Adapted our AHI code for use with ABI

Developed Calibrations against Aqua-MODIS (Doelling calibration group)

- GOES-16 0.65µm, VIIRS I1 and MODIS are consistent and well calibrated within 1%

Overall assessment against MODIS favorable compared to GOES-13

Some problems remain: ABI data, calibrations not as well behaved as AHI

- Some striping in G16 ABI (not in AHI) for vis, 1.6 and 11 um bands
- GOES-16 1.6µm is very noisy, Him-8 is not (causing some problems over snow)
- GOES-16 3.7µm does not behave like Him-8, more like GOES-13

Initial tuning and testing completed. Code now frozen, delivery finalized next week

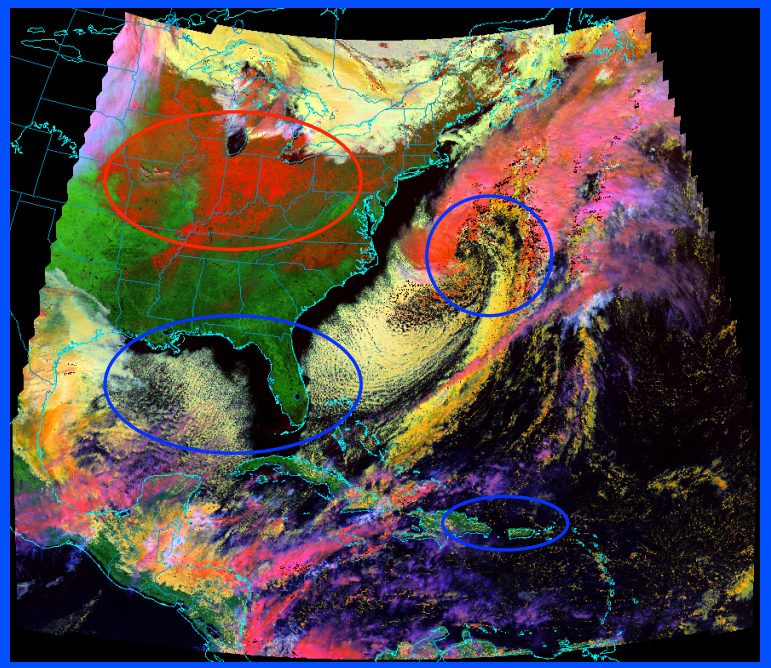
GOES-16 Cloud Mask Development

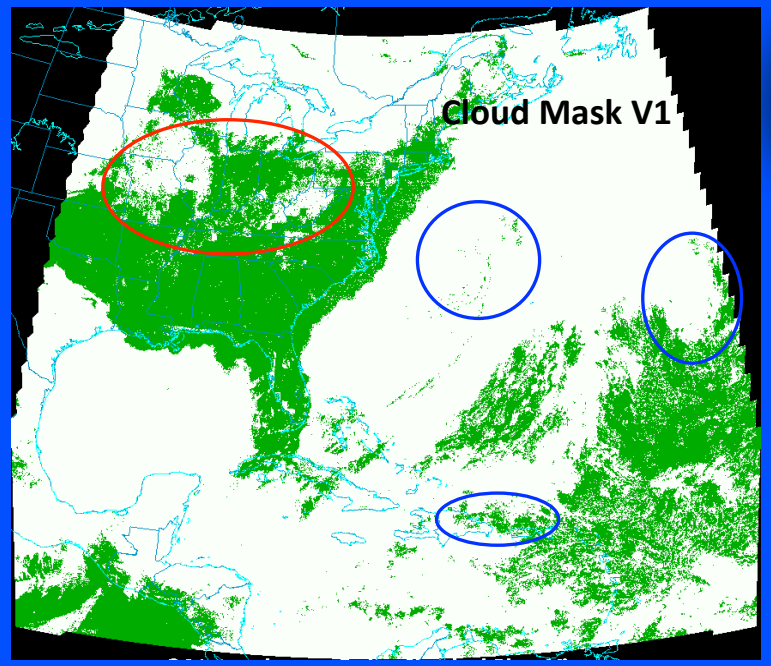
Use GOES-16's 10 channels, (9 Himawari channels + 1.37um)

(0.64, 0.86, 1.37, 1.6, 3.9, 6.9, 8.4, 11.2, 12.3, 13.3)

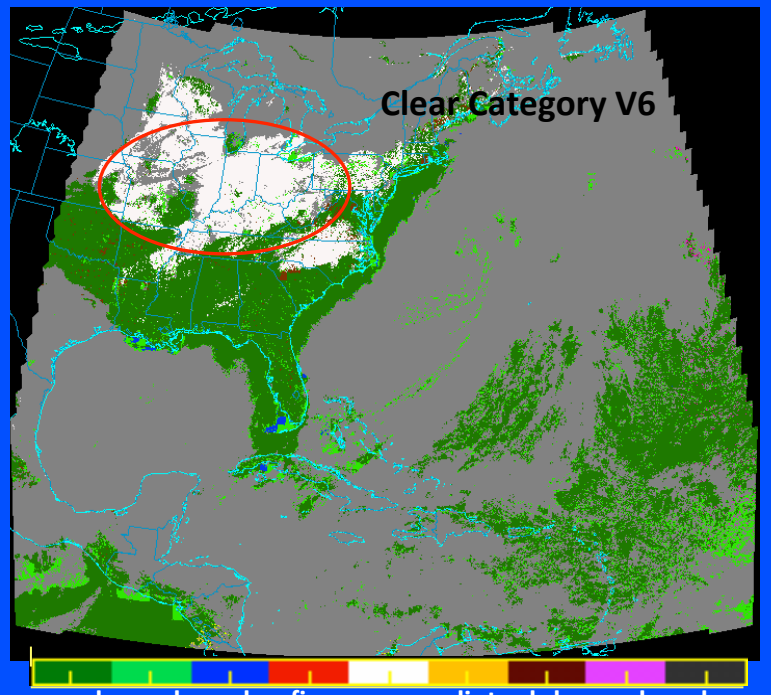
1. Started with Himawari cloud mask, then tuned for GOES-16, lots of initial problems
2. Developed thin Cirrus detection tests for ocean and land using 1.37 μm. Tests are different from MODIS due to different spectral response functions
3. Improved snow detection over CONUS to reduce the occurrence of calling surface snow as clouds. Switched to GEOS54 input, initially used GFS.
4. Reduced cloud chunkiness around Great Lakes due to clear sky maps
5. Increased low cloud detection in strong Sun glint ocean
6. Applied VZA dependent standard deviation for IR test to reduce GEO cloud fraction increasing with VZA.
7. Extended the aerosol detection tests to the west Atlantic Ocean
8. Refined low clouds tests in non Sun glint ocean to reduce over-detection

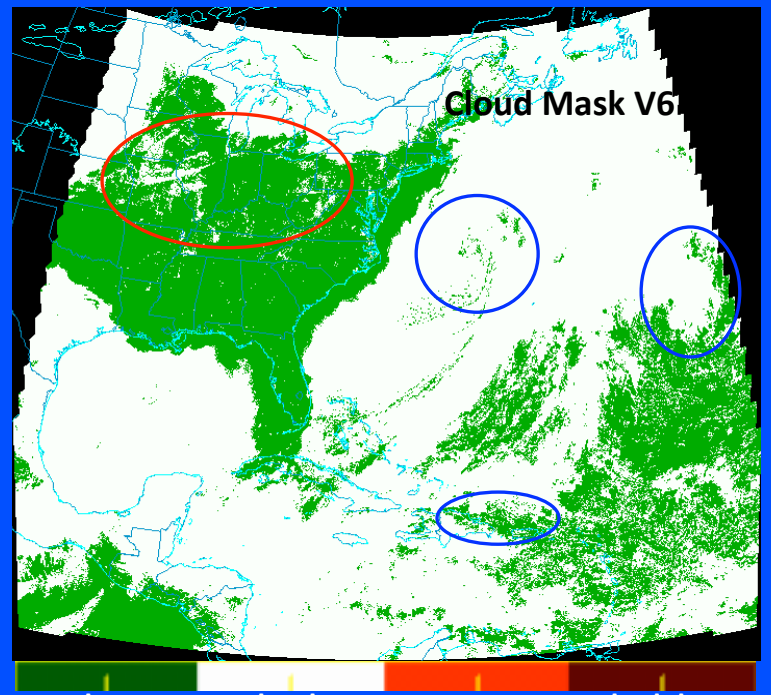
GOES-16
Jan 18
2018
1800Z



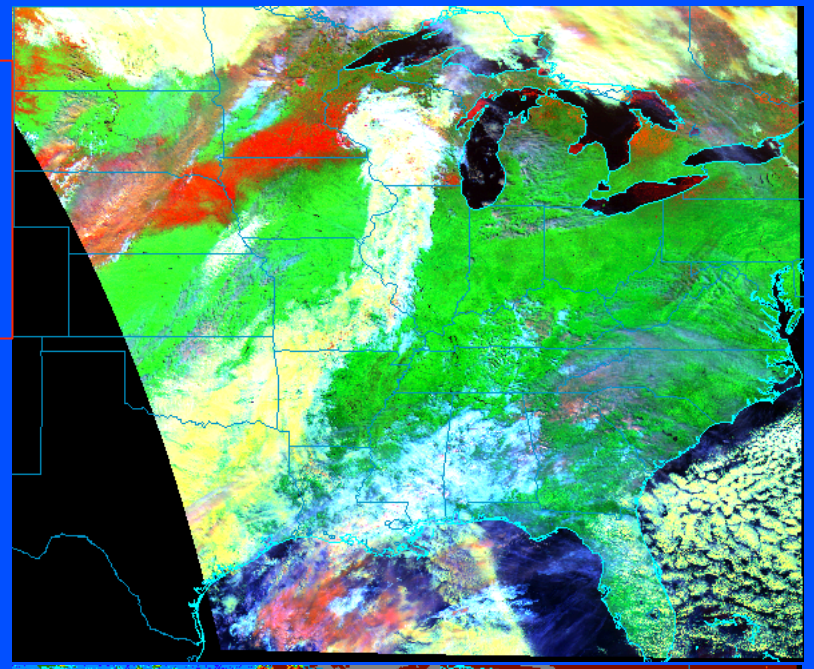


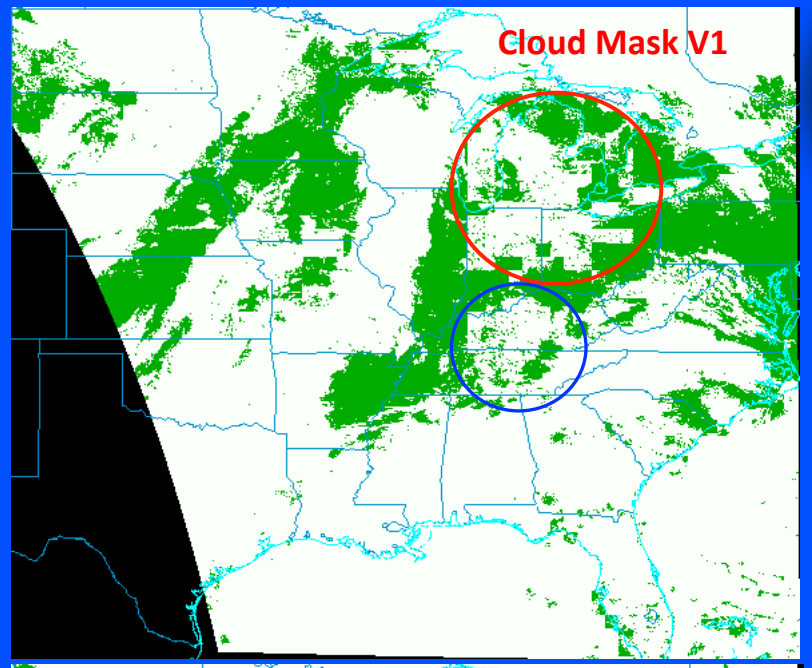
Improved cloud discrimination over snow – reduced false alarms



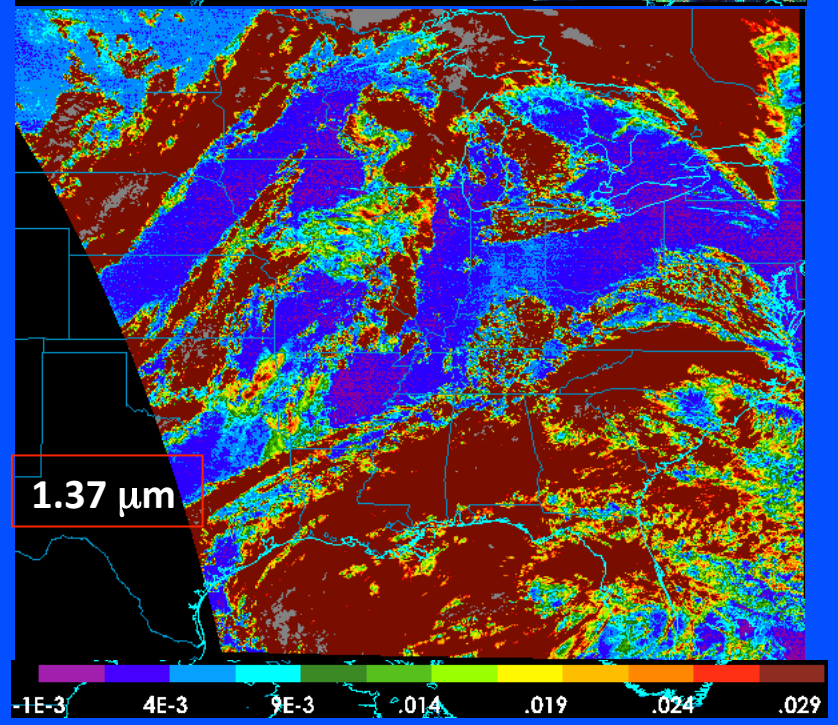


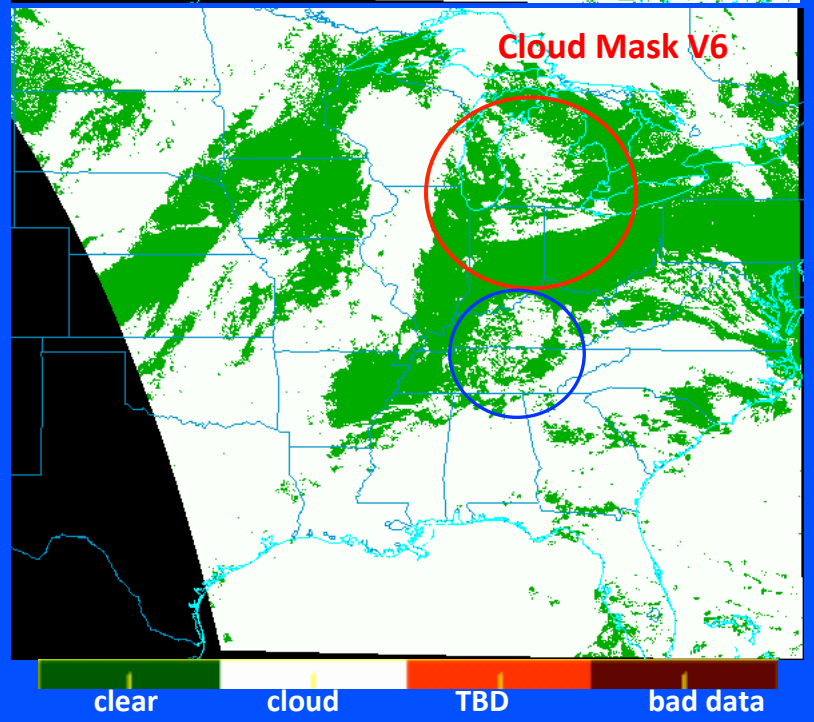
GOES-16
Jan 26
2018
1815Z





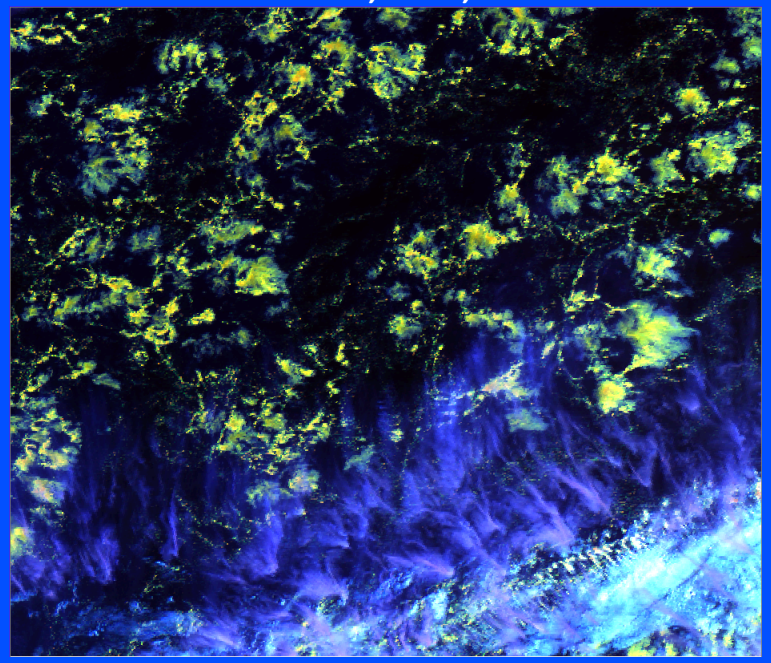
Reduced Chunkiness due to Clear Sky Map & Refined Thin Ci Tests





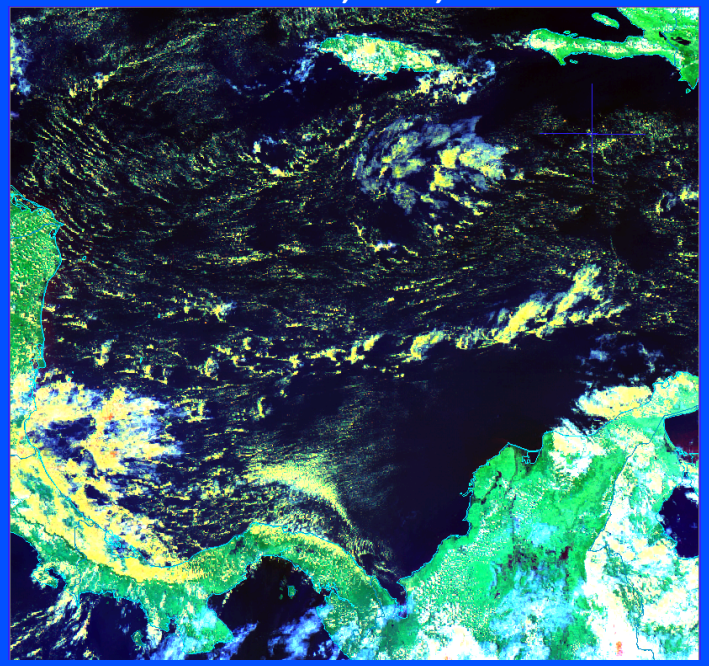
Reduced over-detection in non-glint ocean

GOES-16 Feb 16, 2018, 1645 Z

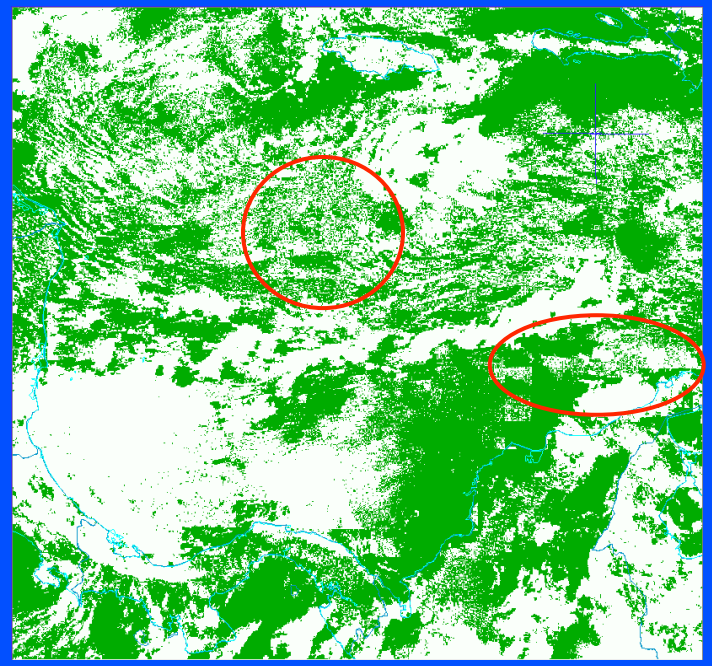


Cloud Mask V1

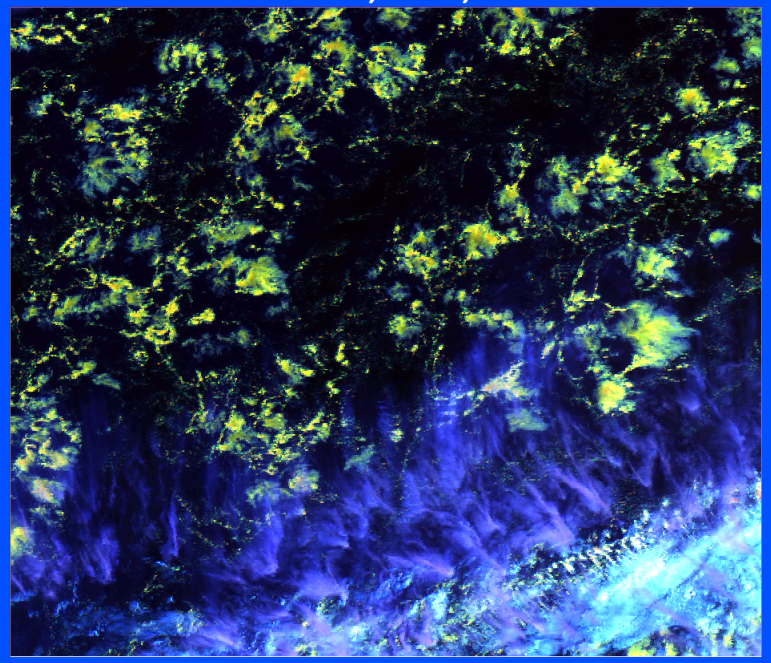
GOES-16 Feb 15, 2018, 1900Z



Cloud Mask V1



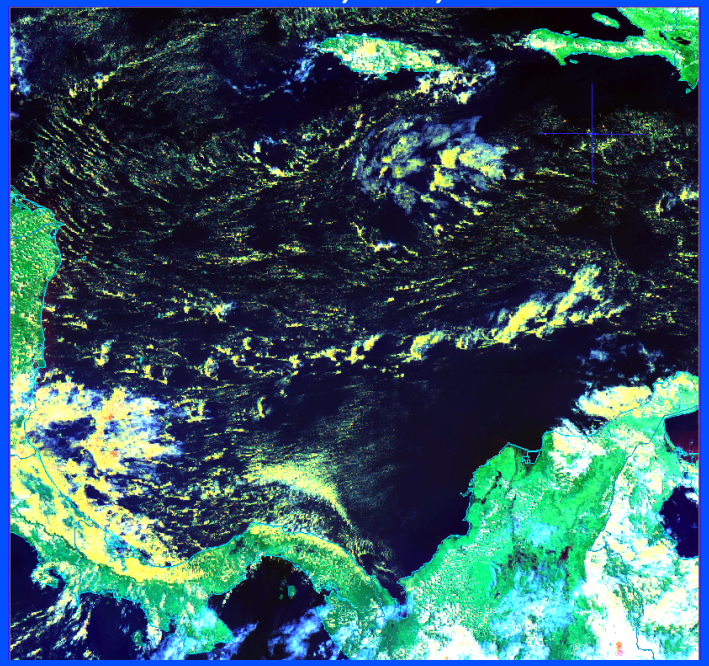
GOES-16 Feb 16, 2018, 1645 Z



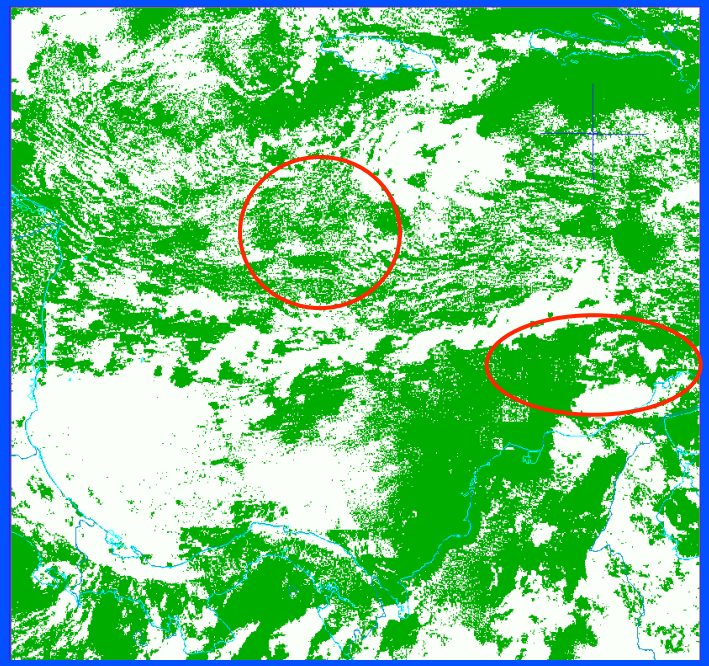
Cloud Mask V6

Reduced over-detection in non-glint ocean

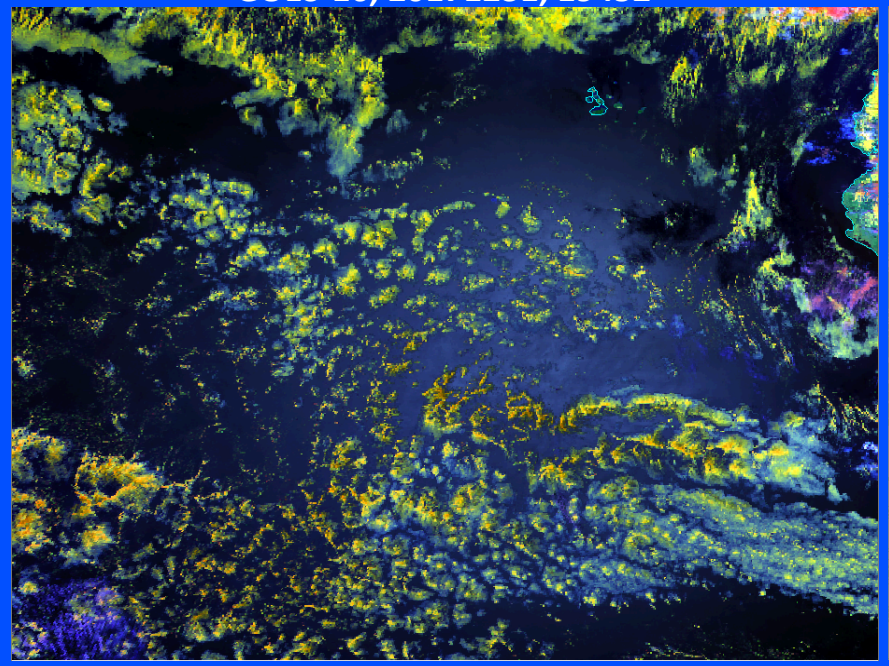
GOES-16 Feb 15, 2018, 1900Z



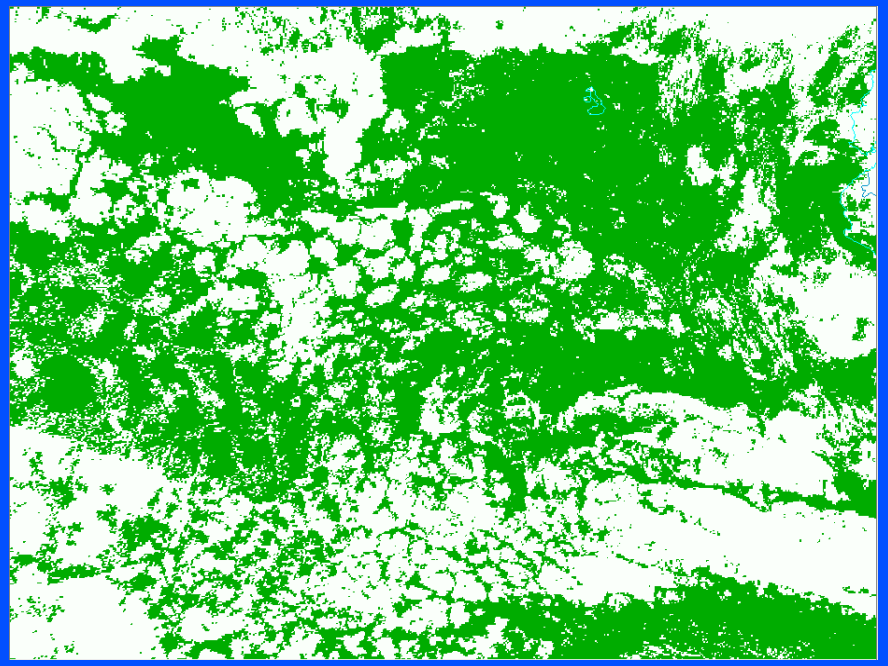
Cloud Mask V6



GOES-16, 20171231, 1945Z

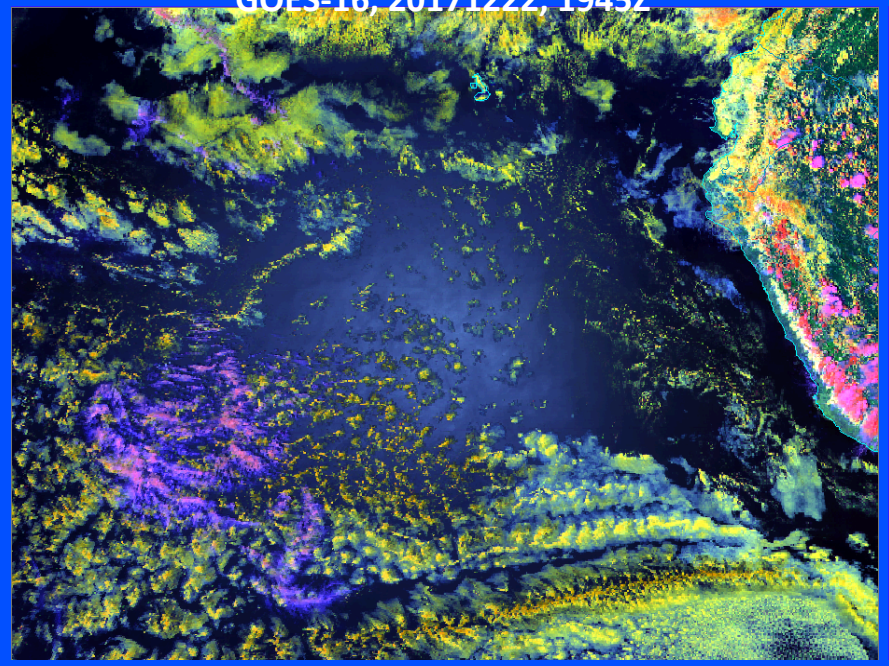


Cloud Mask V1

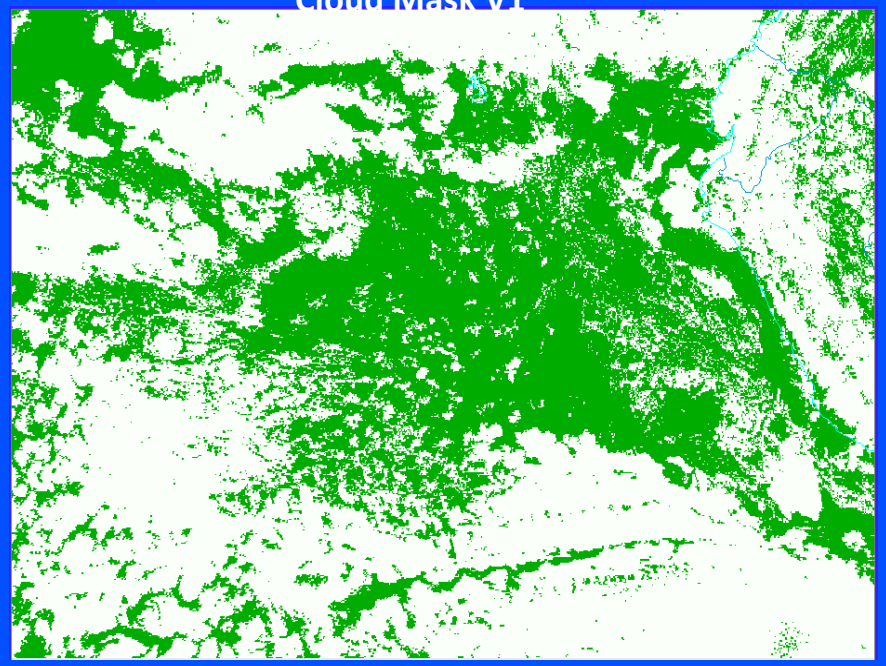


Increased Low Clouds in Strong Sun Glint Ocean

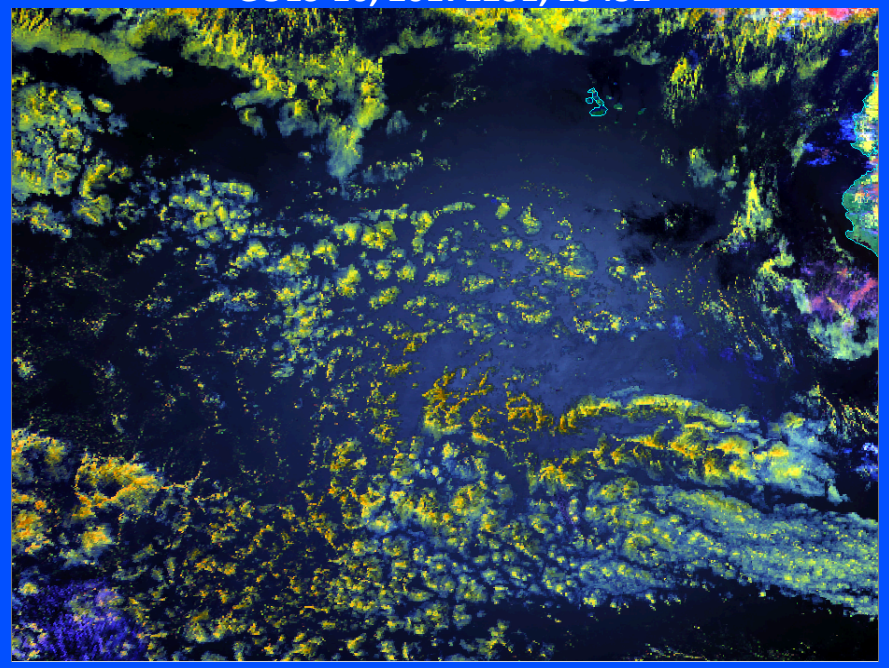
GOES-16, 20171222, 1945Z



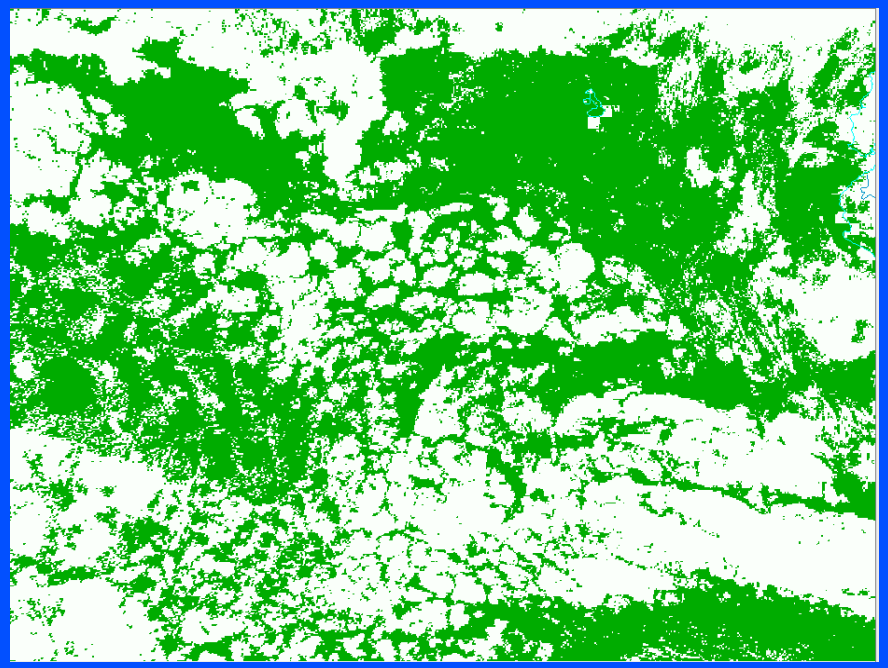
Cloud Mask V1



GOES-16, 20171231, 1945Z

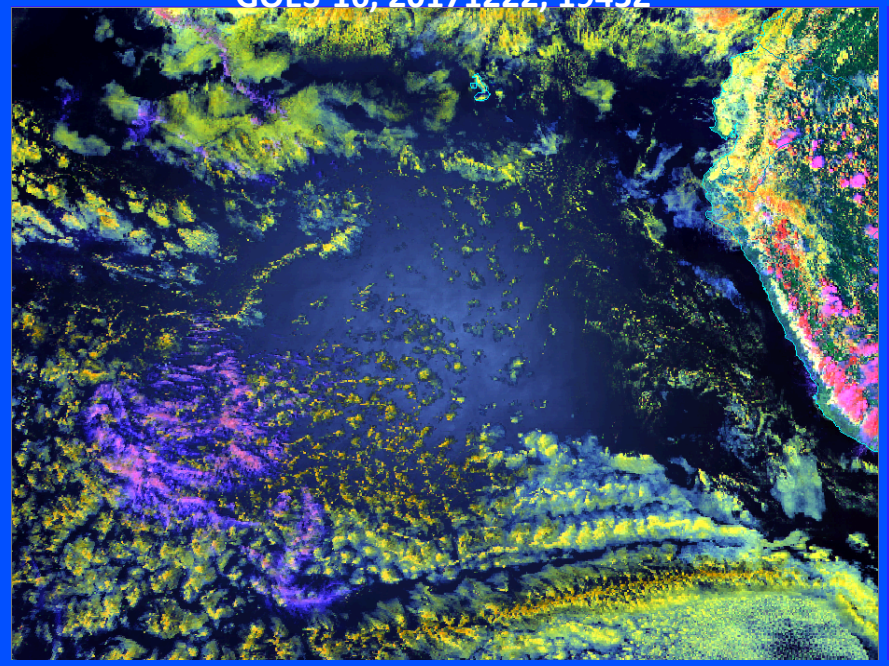


Cloud Mask V6

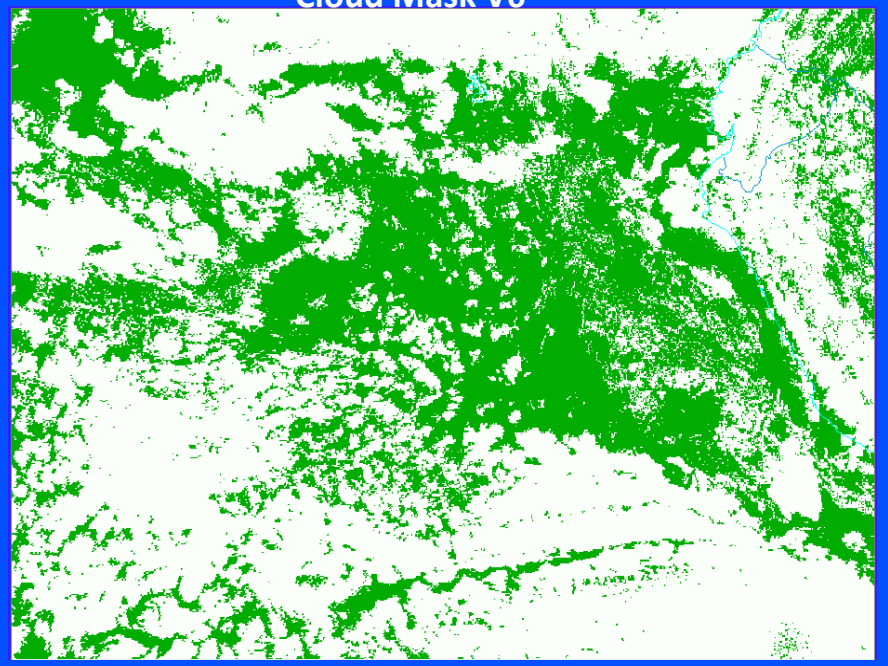


Increased Low Clouds in Strong Sun Glint Ocean

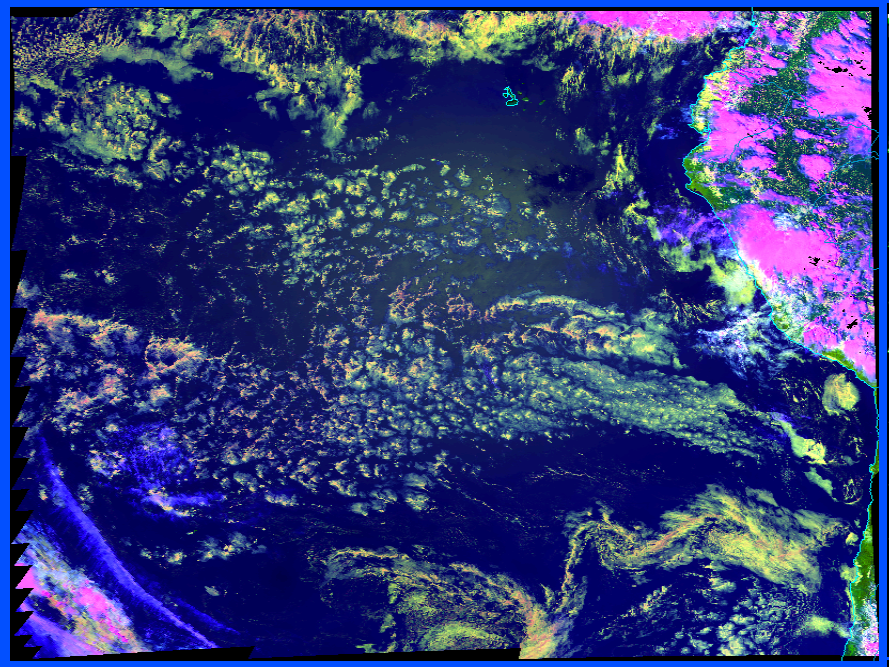
GOES-16, 20171222, 1945Z



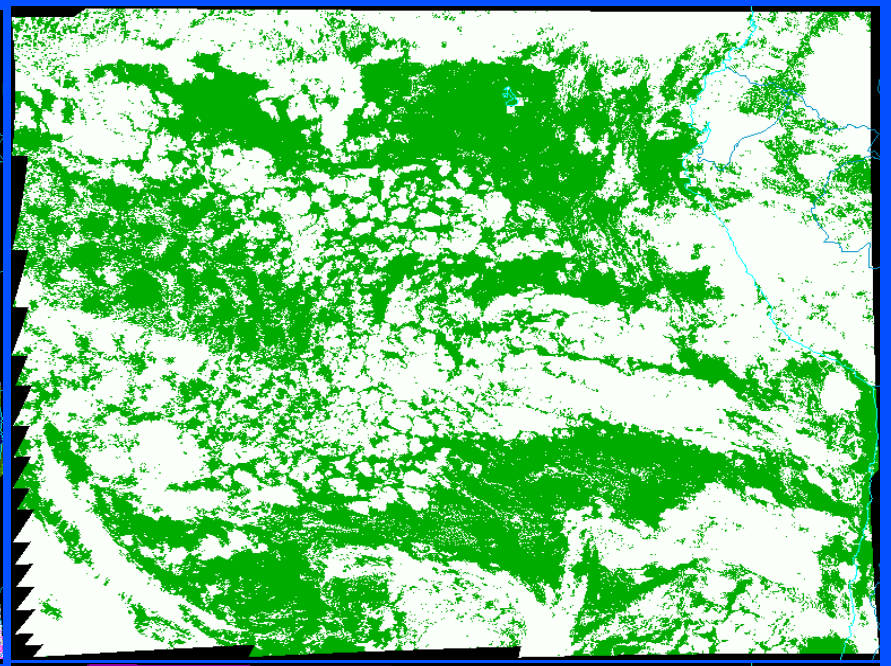
Cloud Mask V6

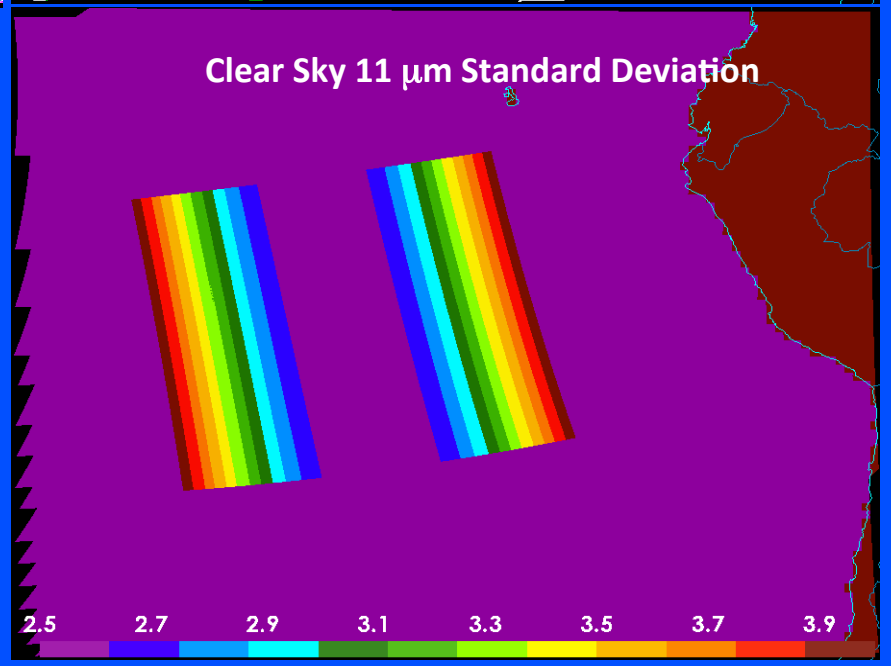


GOES-16, 20171231, 1945Z



GOES-16 Cloud Mask V6

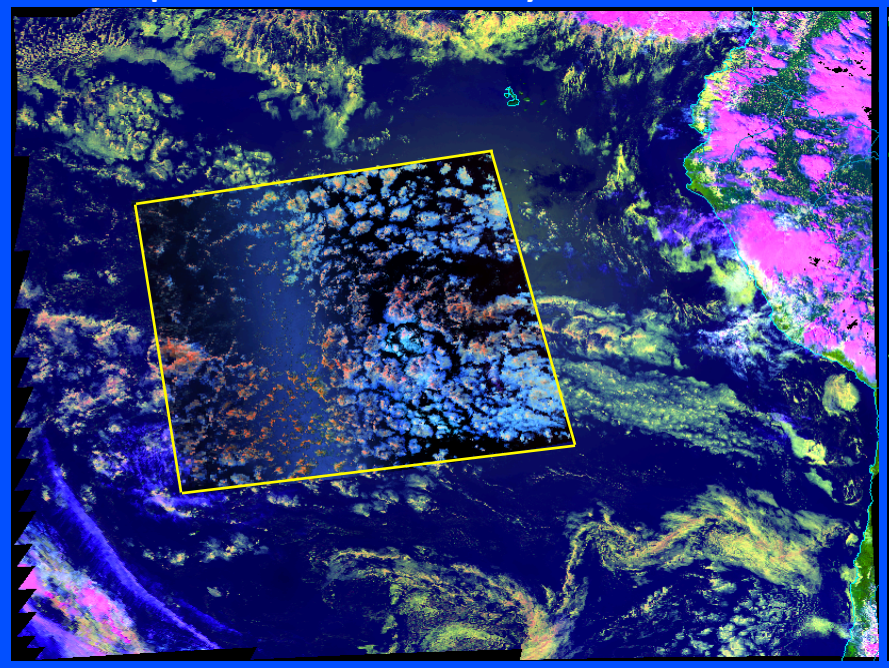




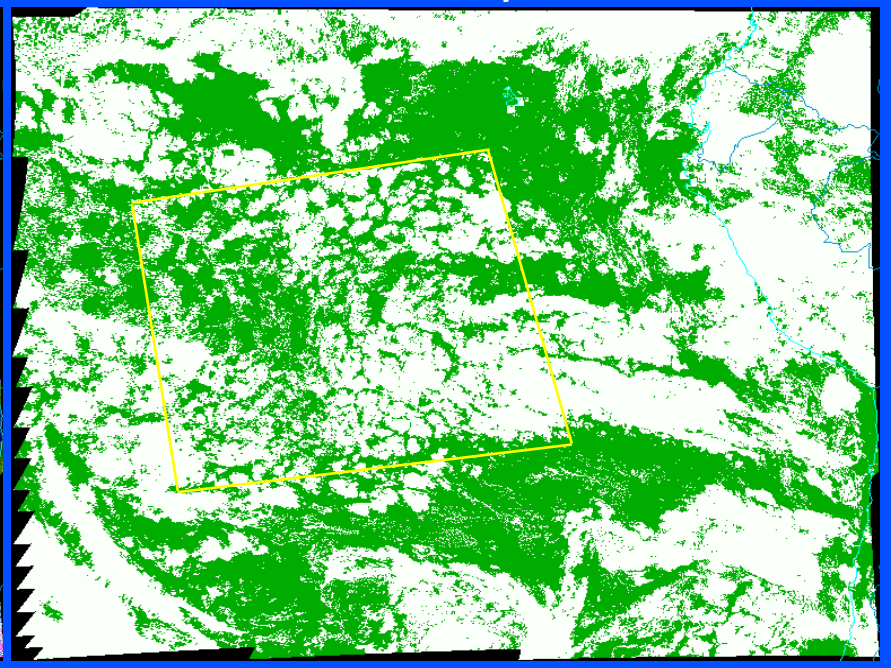
MODIS and GOES-16 Sun Glint Clouds and VZA Dependency

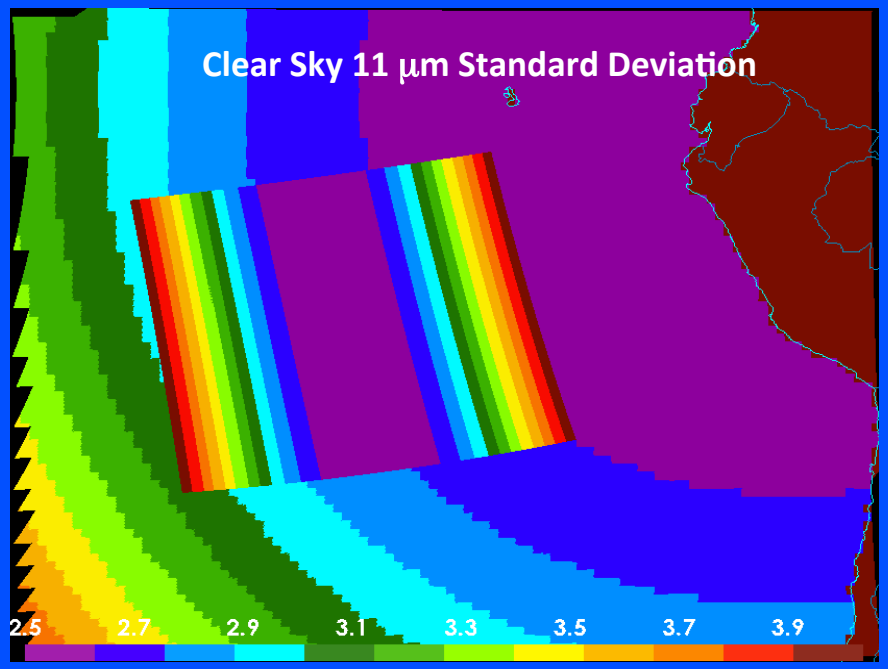
MODIS CST11 STD is VZA dependent. Initially no VZA dependence applied to GOES-16

Aqua MODIS 2025Z overlay GOES 16 1945Z



CM Ed4 overlay GOES-16

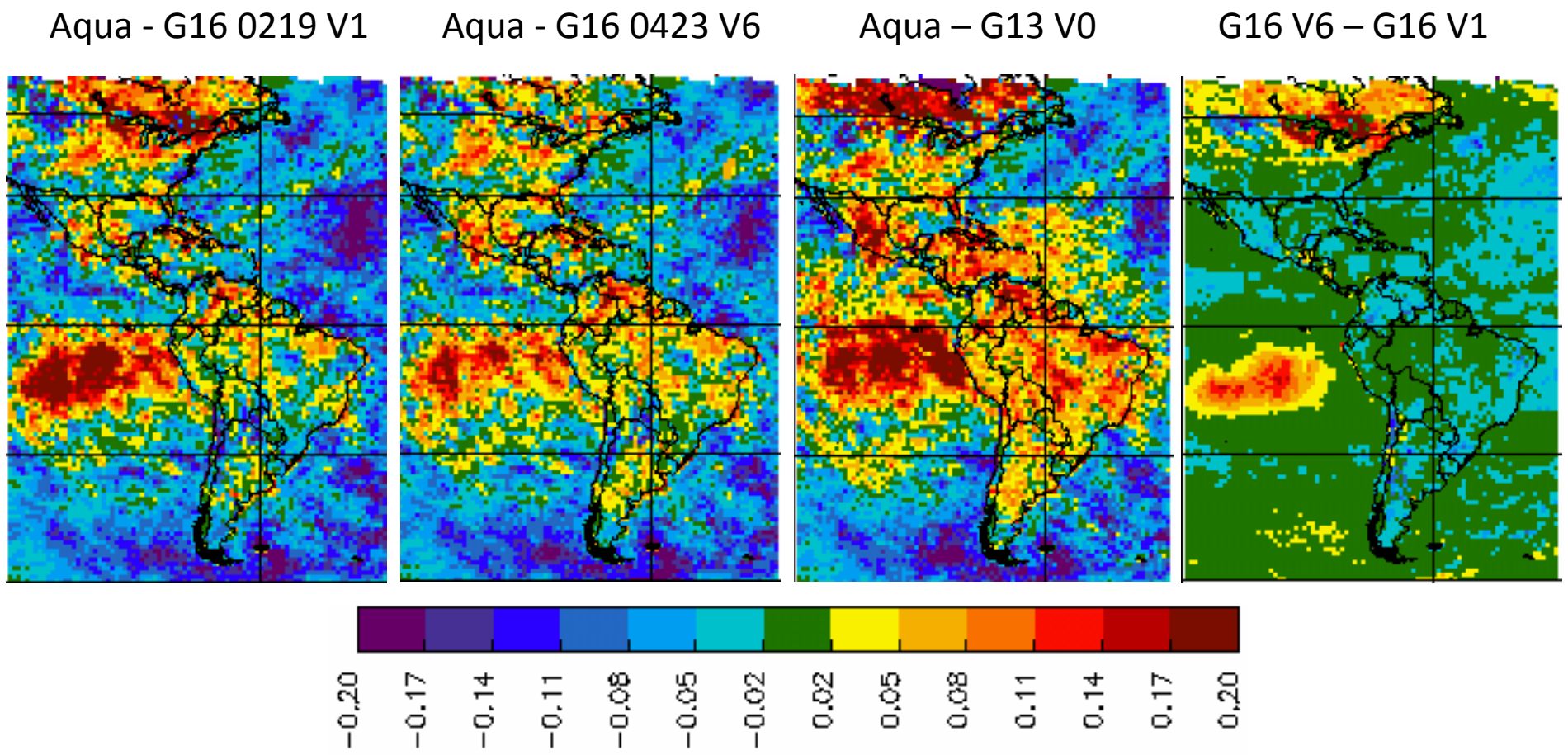




MODIS and GOES-16 Sun Glint Clouds and VZA Dependency

Applied MODIS VZA dependent function to GOES-16 CST11 STD

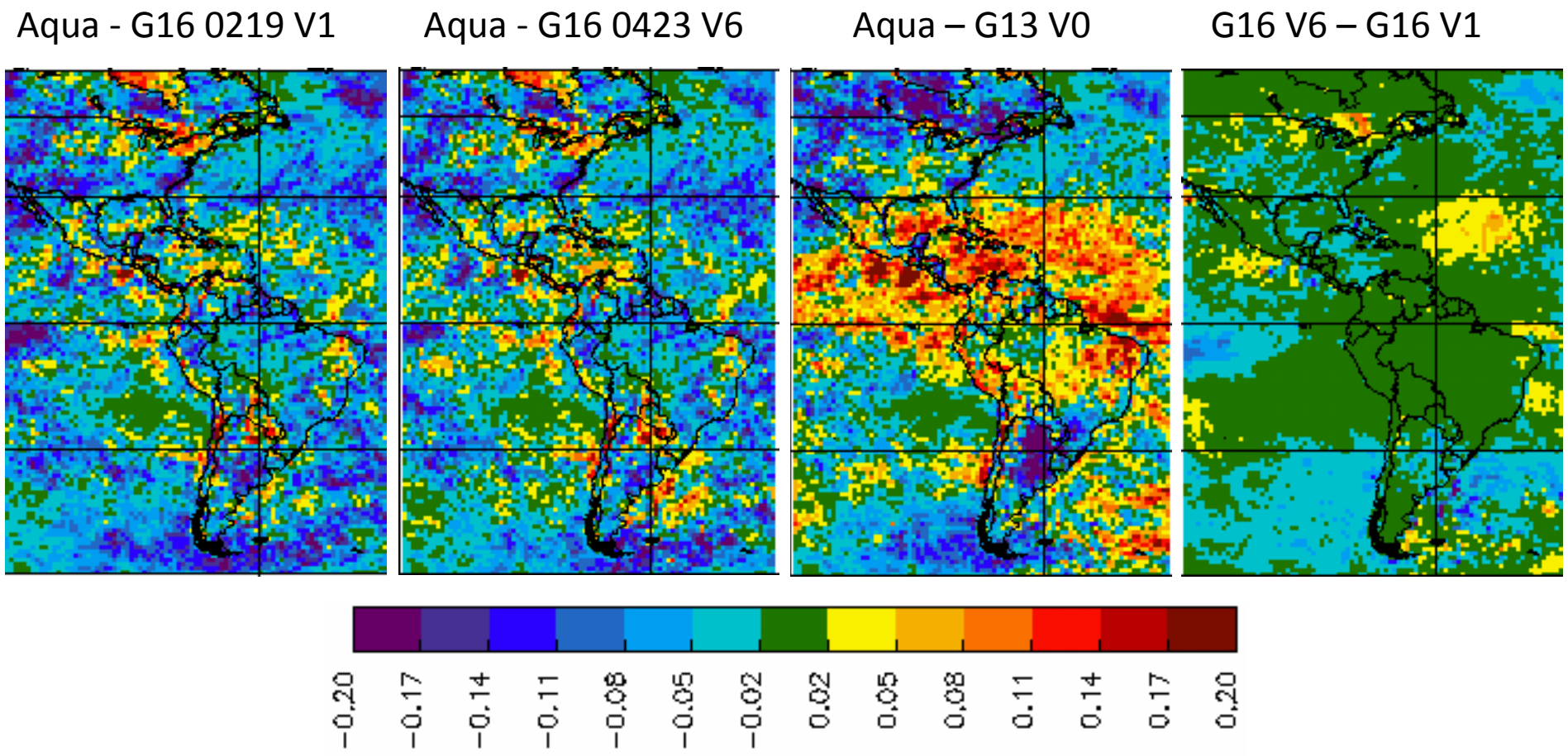
Daytime Cloud Fraction Differences, December 2017, day 15-31



Relative to Aqua MODIS:

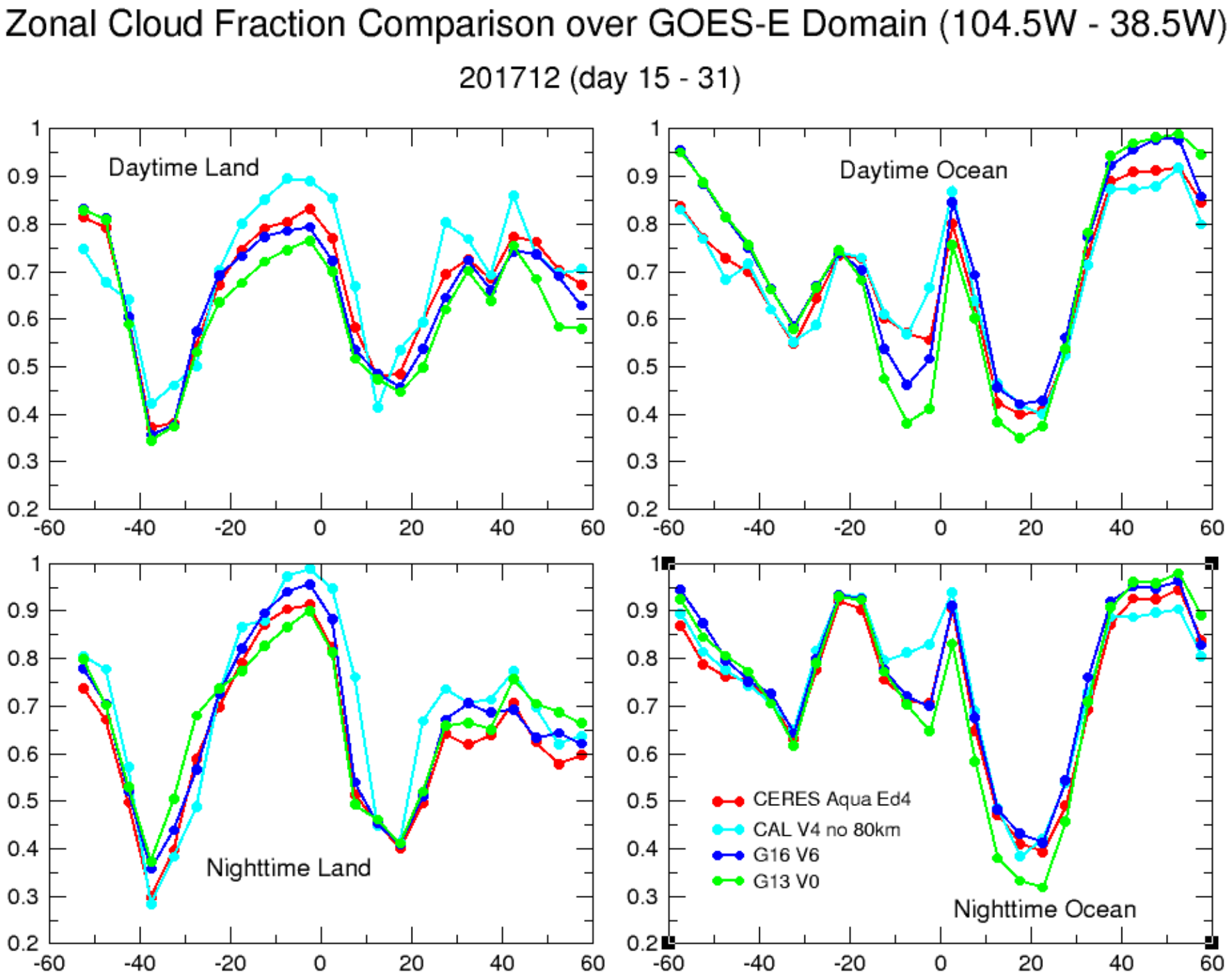
- G16 V6 much improved vs V1 and GOES-13 V0

Nighttime Cloud Fraction Differences, December 2017, day 15-31



Marked nighttime improvements also compared to GOES-13

GOES-16 zonal means generally in better agreement with MODIS and CALIPSO than GOES-13



Toward MODIS Ed5

Improved Calibration
- use MODIS Collection 6.1 (or later version) calibrations
- improved stability for entire record
- improved AQUA/TERRA consistency for most channels (6.7, 8.6 μm ??)

Modifications to improve VIIRS/MODIS consistency (TBD, discussion later)
- No 6.7, 13 μm on VIIRS (construct from CrIS or drop from MODIS or improve current approach)

Employ same water reflectance model as VIIRS Ed1
- Improved accuracy and consistency w/VIIRS

Nighttime ice cloud optical depths from neural network
- Extends tau limit beyond 50 and improves day/night consistency

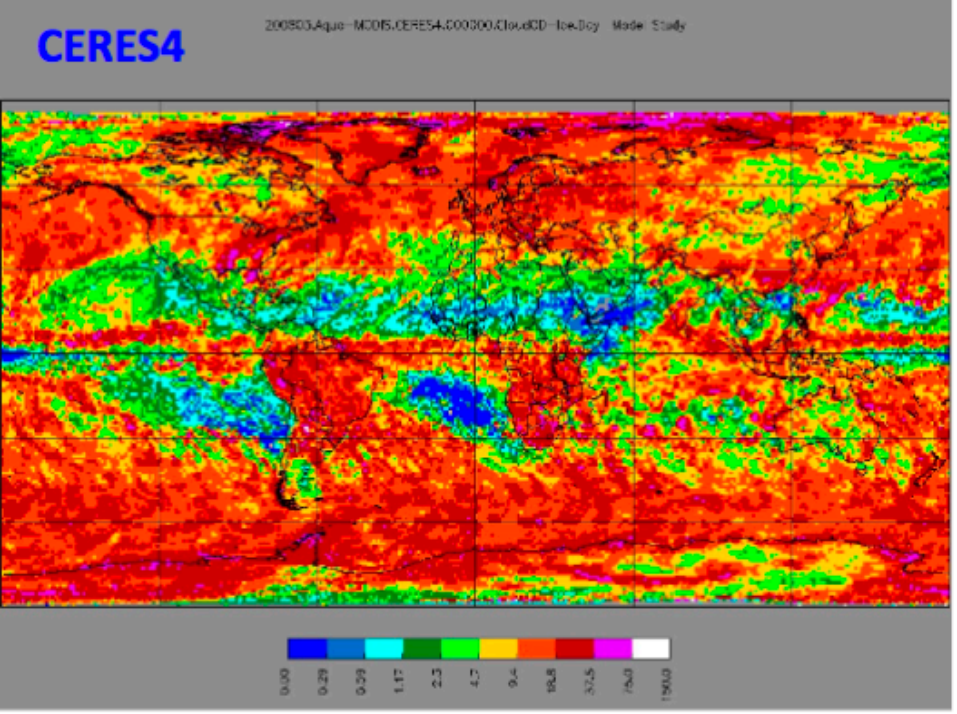
Improved multi-layer algorithms using neural net
- Skill level needed for practical use not met with Ed4 approach (F-L Chang revisits Thursday)

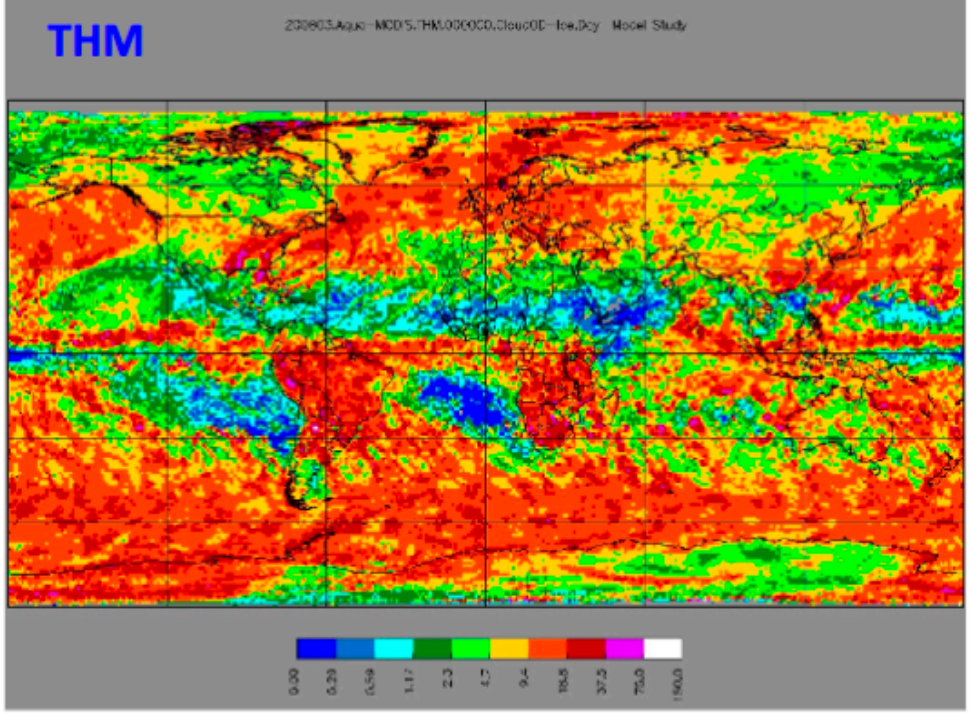
Improved cloud thickness and waterpath parameterizations
- Exploit knowledge gained from Atrain synergy

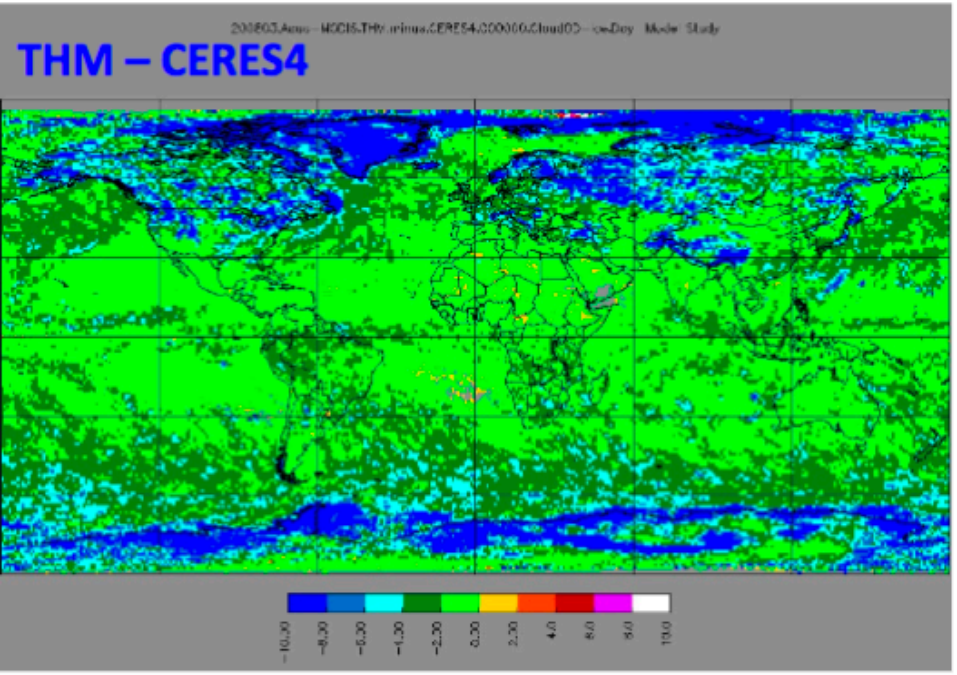
Improved surface skin temperature
- Accounts for VZA dependence over land

Revised Algorithms for 1.24, 1.6 and 1.2 μm retrievals
- Optimal multi-channel algorithm for retrievals over snow/ice

Employ new 2-habit model from P. Yang for ice clouds
- reduces and improves VIS tau, more consistent with IR tau
- increases and improves cloud height
- reduces Re, IWP (maybe ok for thin clouds)







Ice Optical Depth

Aqua MODIS, March 2008
Ice Phase, Day Time

Ed4 1.24 um tau retrievals over snow seem to high

THM producing much lower optical depths over snow than Ed4

Points to a bug in the Ed4 1.24 um reflectance models

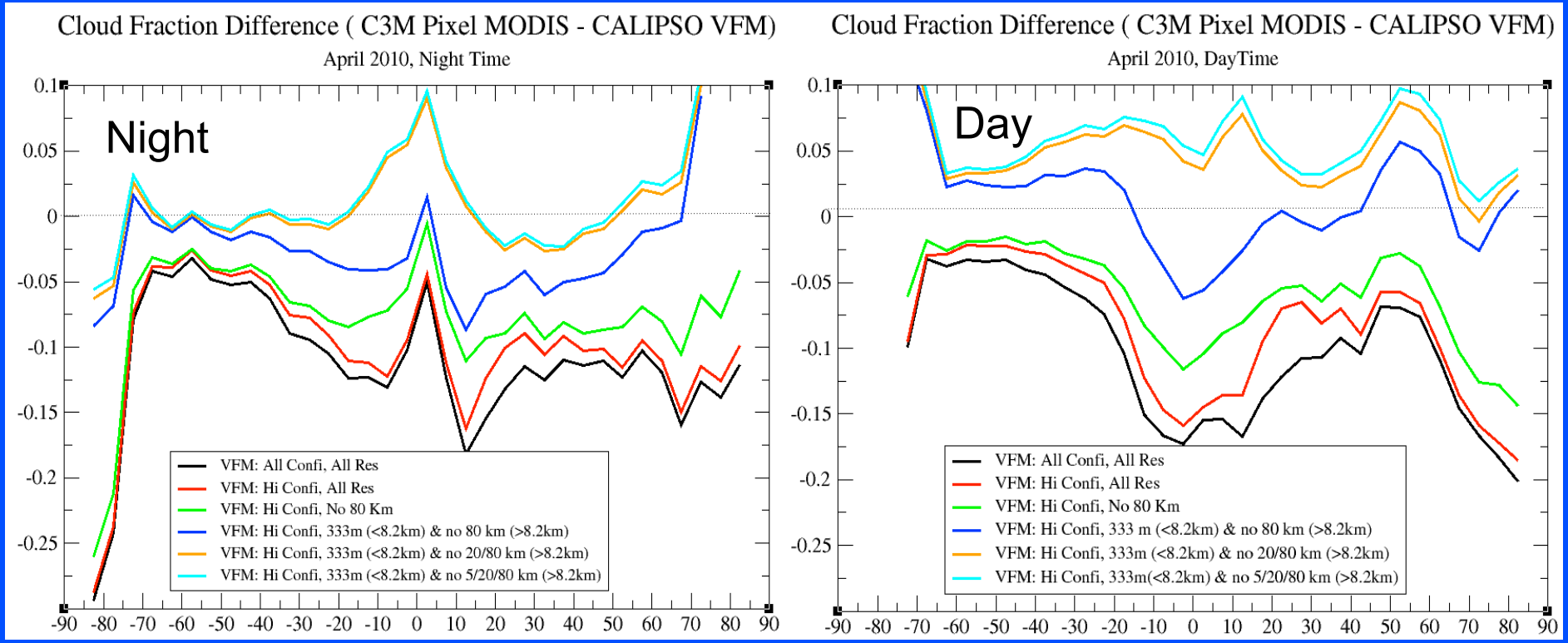
Toward MODIS Ed5

Improved cloud detection

- New Cloud Detection Assessment working group formed at LaRC
- Collaboration between CERES and CALIPSO science team's
- Leading to improved understandings of how the data are being used, product uncertainties, appropriate methods for intercomparison

MODIS Cloud detection assessment with CALIPSO

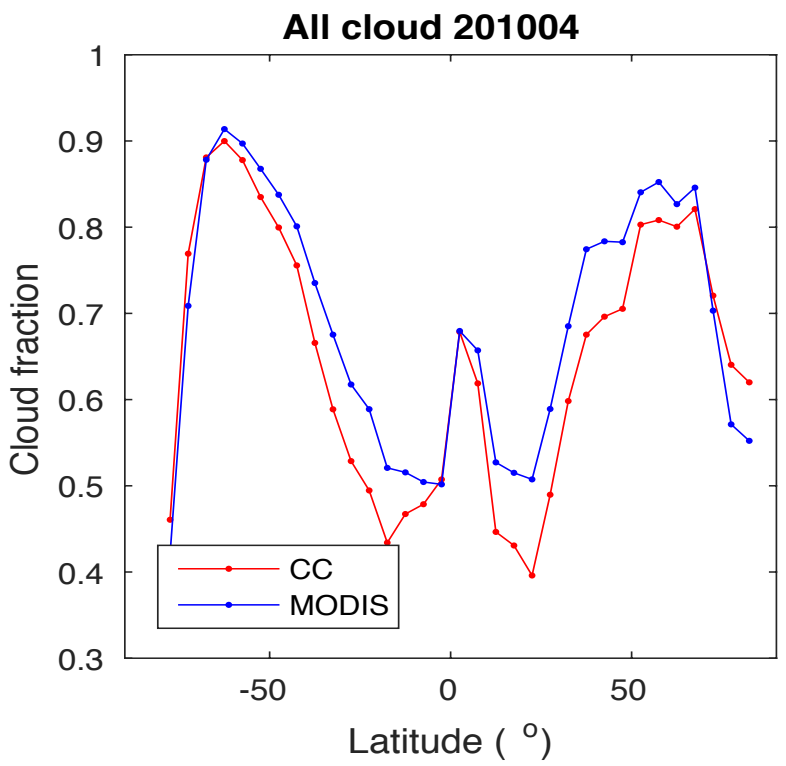
- Initial assessments using C3M data suggested MODIS low cloud fractions may be too high
- CALIPSO team provides confidence level for cloud detections for single shots and over several horizontal averaging distances to improve signal
- Verification statistics depend on which criteria are selected for the comparison (+/- 10% dependency shown below)



MODIS Cloud detection assessment with CALIPSO

Much has been learned already, more to come (more details by C. Yost on Thursday)

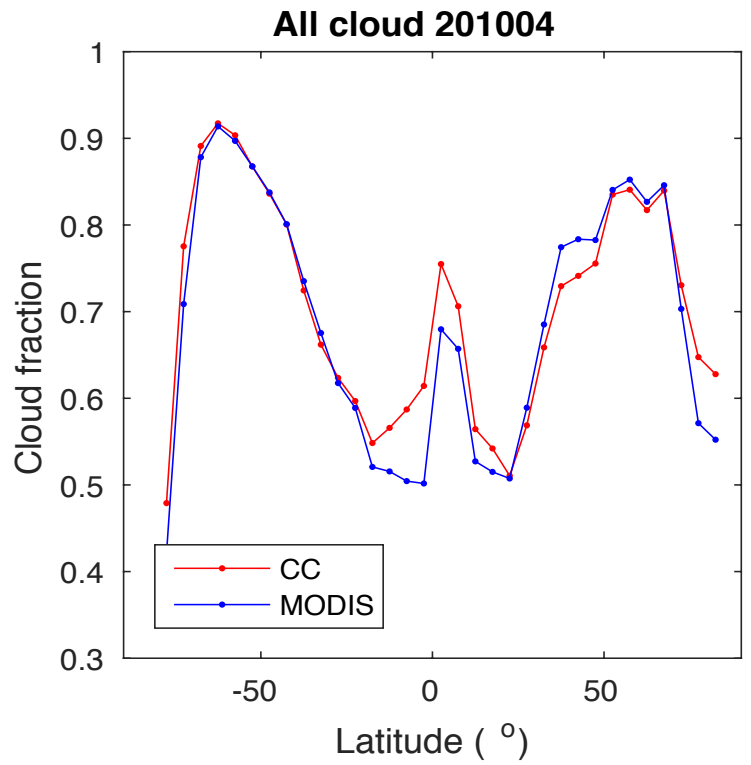
- CERES team improved knowledge on how to interpret CALIPSO products
- CALIPSO team learned how CERES (and others) are using their products and how they might improve them
- Bug found in C3M logic used for MODIS/CALIPSO comparisons, an oversight due to not having enough information on how the CALIPSO data are being reported



Some single-shot low cloud detections not counted

Global mean over ocean
CC: 61.6
MODIS: 66.9

+5.3% difference



single-shot low cloud detections properly counted

Global mean over ocean
C3M: 68.6
MODIS: 66.9

-1.7% difference

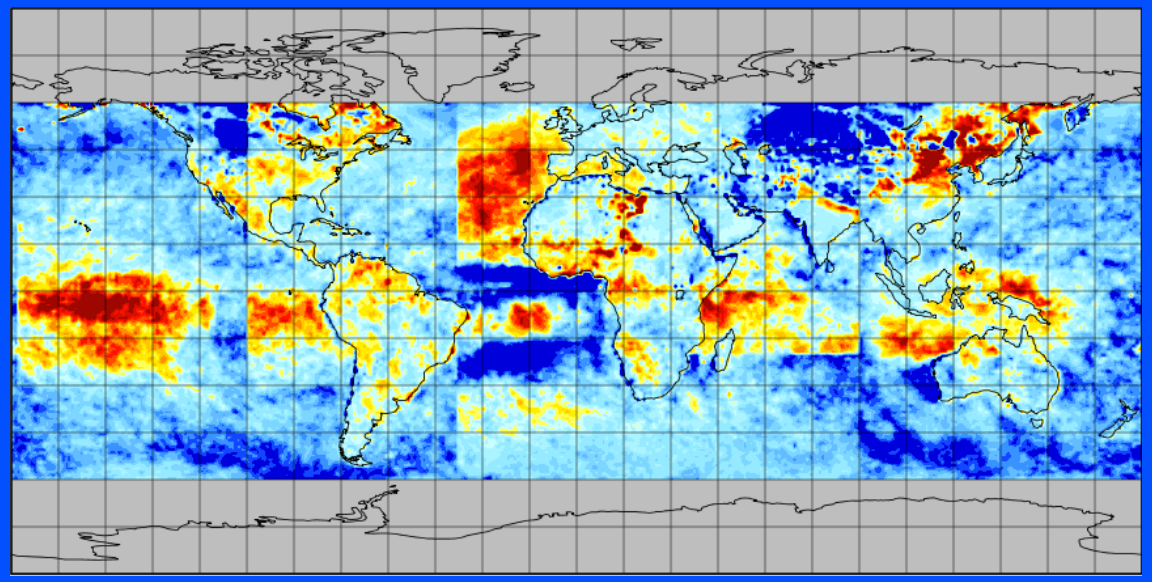
Toward MODIS Ed5

Improved GEO cloud properties

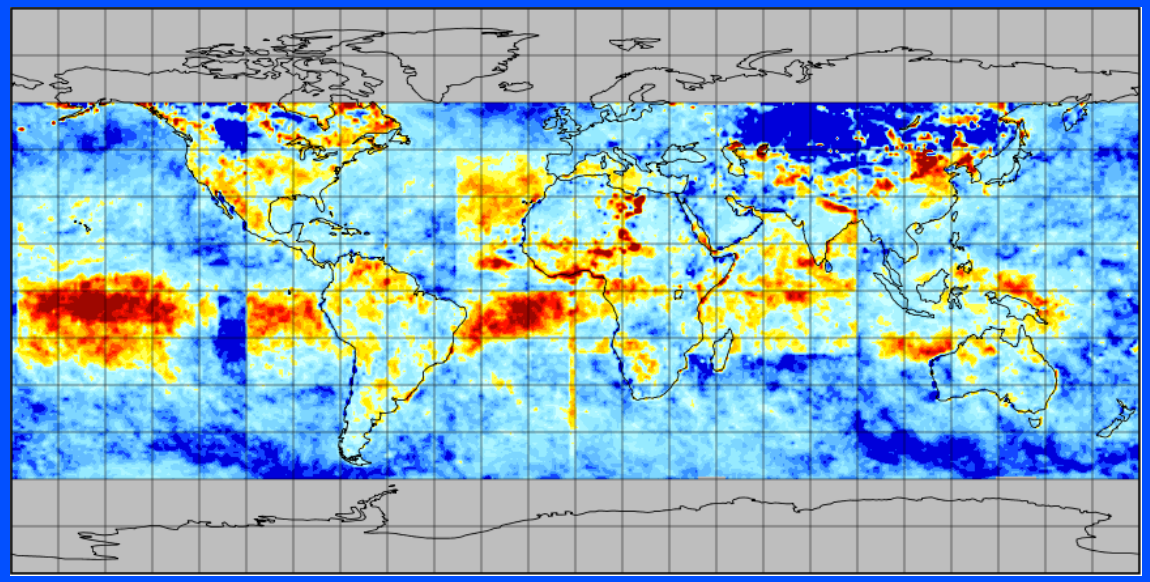
- Satellite specific SRF's applied in LUT's, parameterizations, atmos. correction
- Newer satellites more consistent with MODIS
- Lots of nighttime clod detection improvements and bug fixes
- Significant reductions in no retrievals
- Work needed to improve consistency with older satellites

AQUA_MODIS - GEO CLOUD FRACTION DIFFERENCES

ED4



ED5



Day, Jan 2018

Ed4 is frozen version since delivery
Ed5 is R/T version in SatCORPS

GOES-16 new, same for Ed4 and Ed5

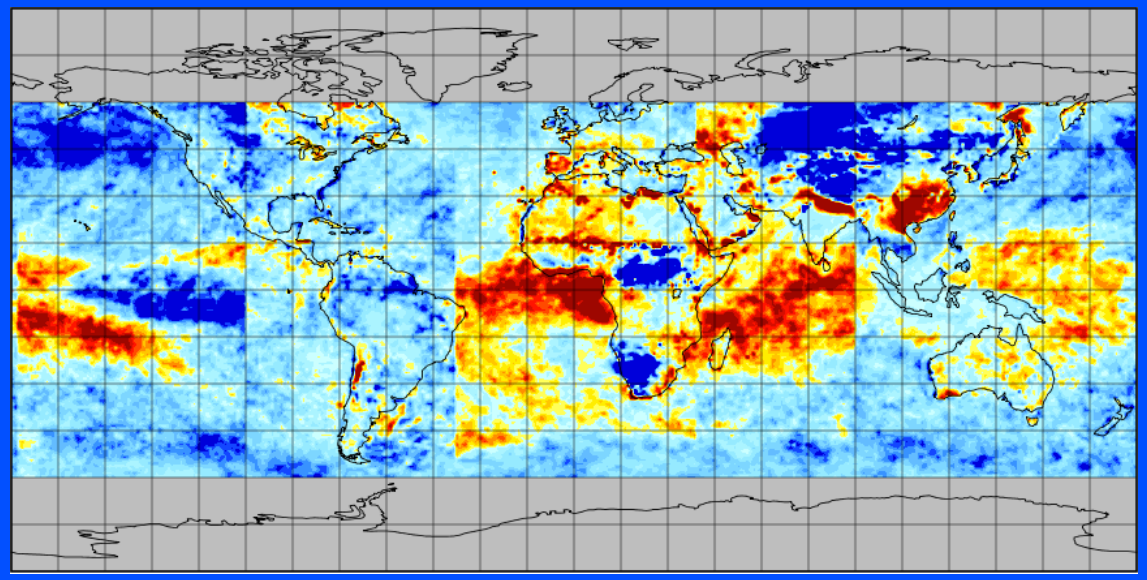
Most significant daytime improvements for Met-8 and Met-10

Still some problems in polluted, dust areas

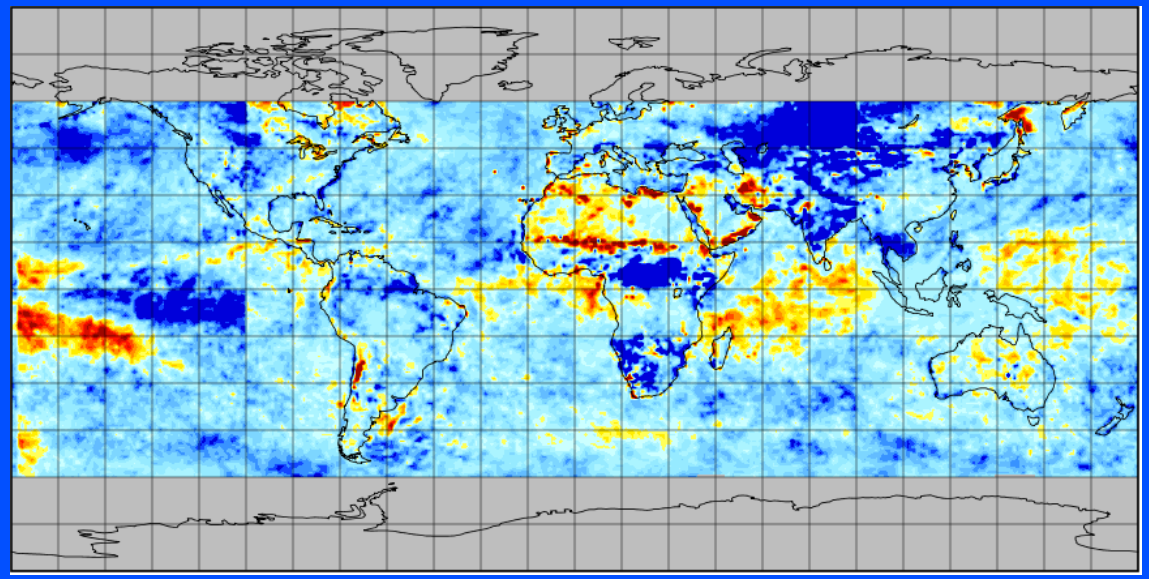
AQUA_MODIS - GEO CLOUD FRACTION DIFFERENCES

Night, Jan 2018

ED4



ED5



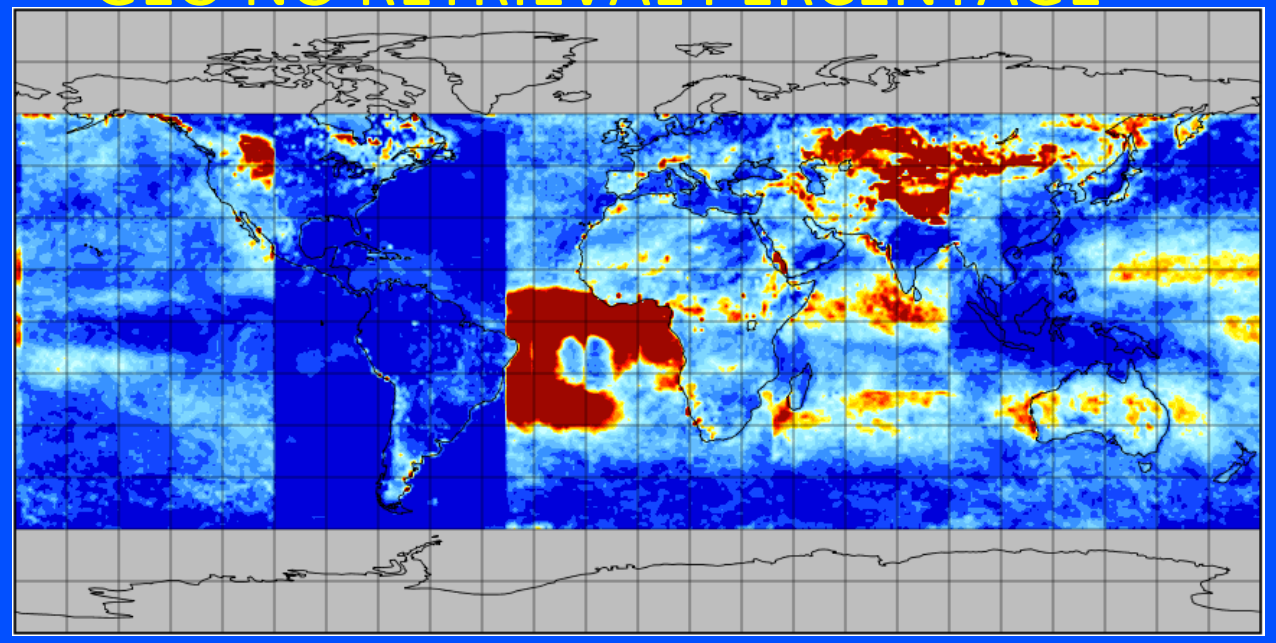
Ed4 is frozen version since delivery
Ed5 is R/T version in SatCORPS

GOES-16 new, same for Ed4 and Ed5

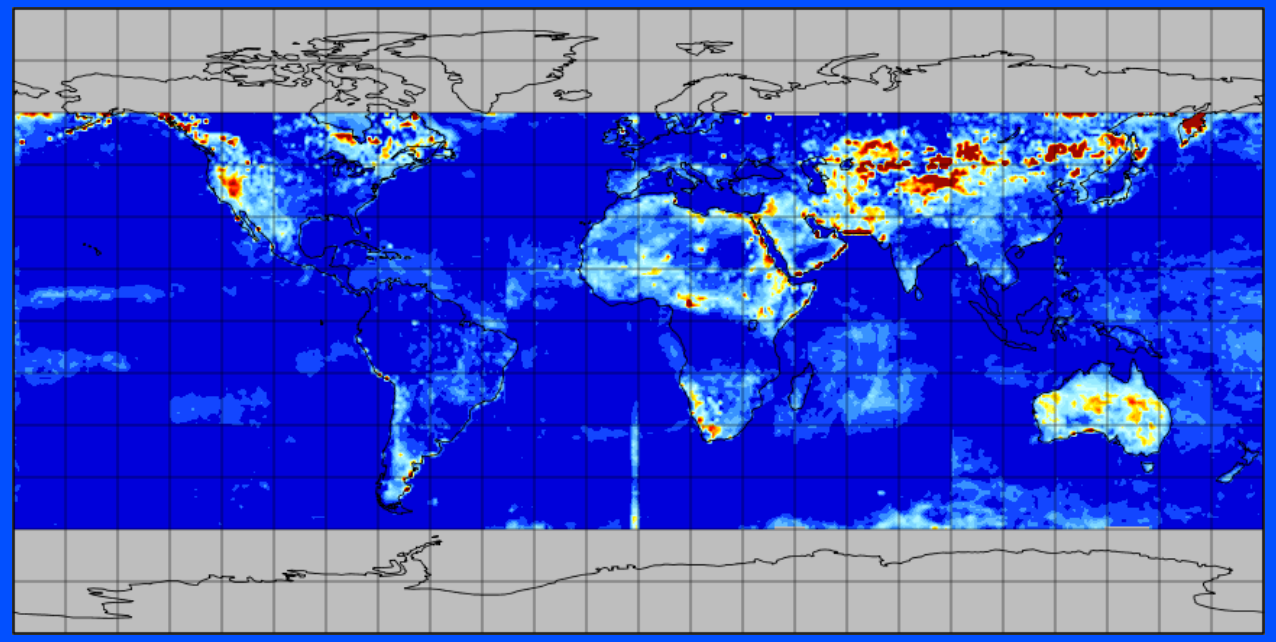
Significant nighttime improvements for all satellites

GEO NO RETRIEVAL PERCENTAGE

ED4



ED5



Day, Jan 2018

Ed5 is R/T version in SatCORPS
Ed4 is frozen version since delivery

GOES-16 new, same for Ed4 and Ed5

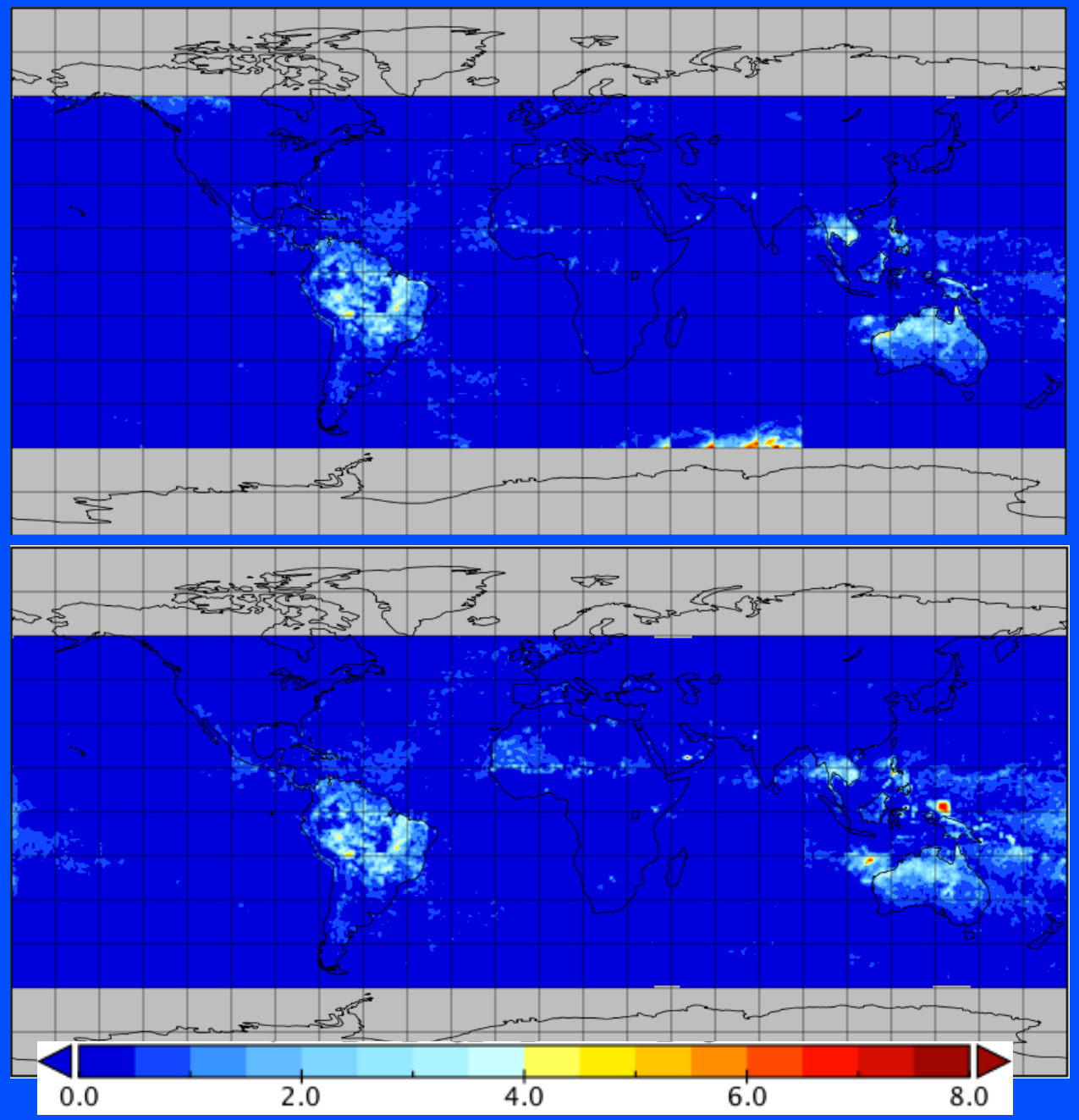
Significant reductions in daytime no retrievals most areas

Increase over western U.S needs study

GEO NO RETRIEVAL PERCENTAGE

ED4

ED5



Night, Jan 2018

Ed5 is R/T version in SatCORPS
Ed4 is frozen version since delivery

GOES-16 new, same for Ed4 and Ed5

Some problems over S. Hem. Land

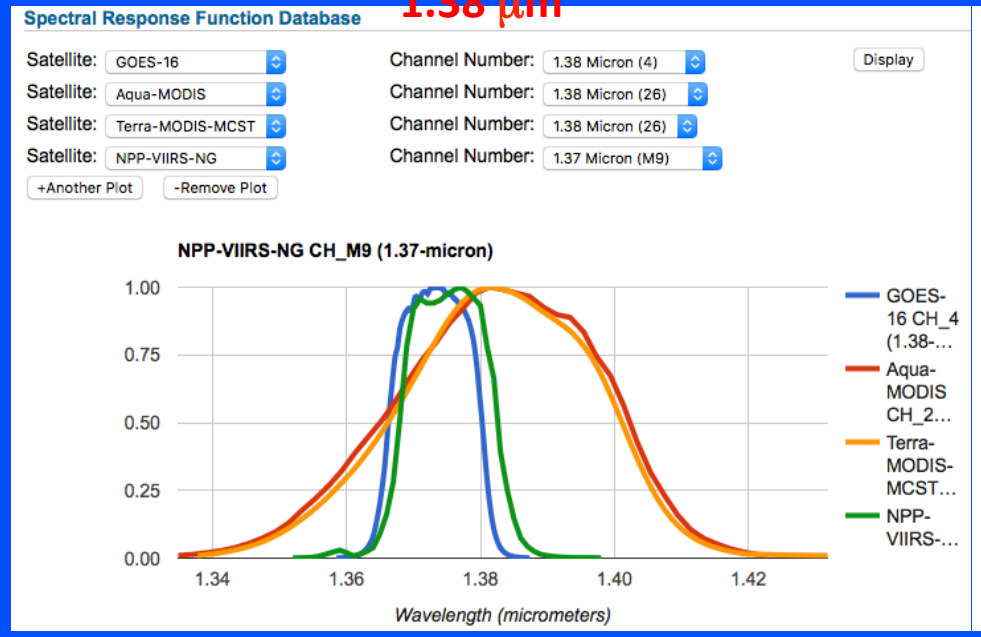
Increase over TWP (HIM-8)

MET-8 better near 60S

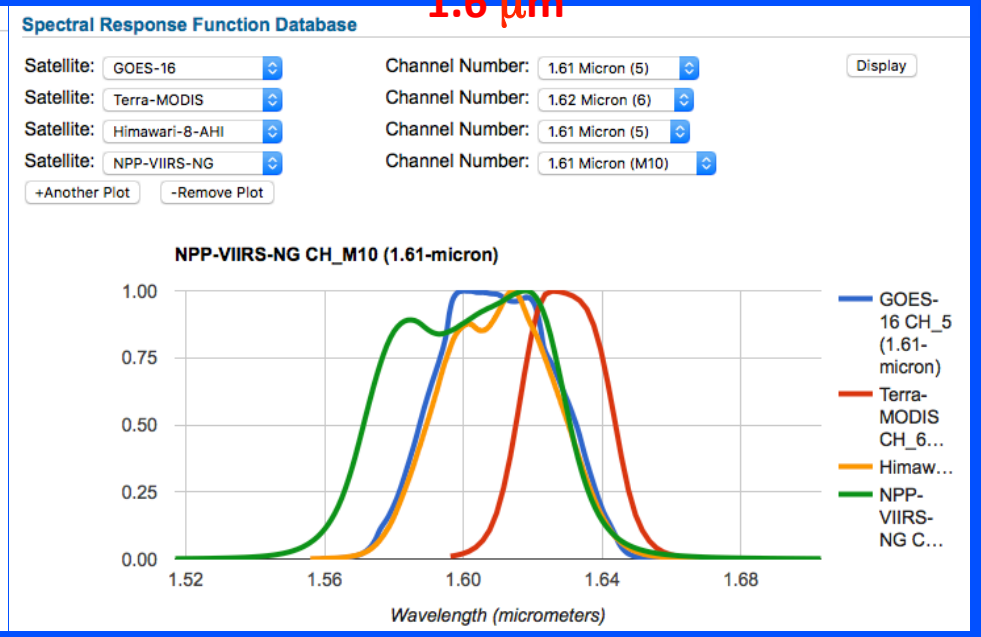
QUESTIONS ?

Spectral Response Functions

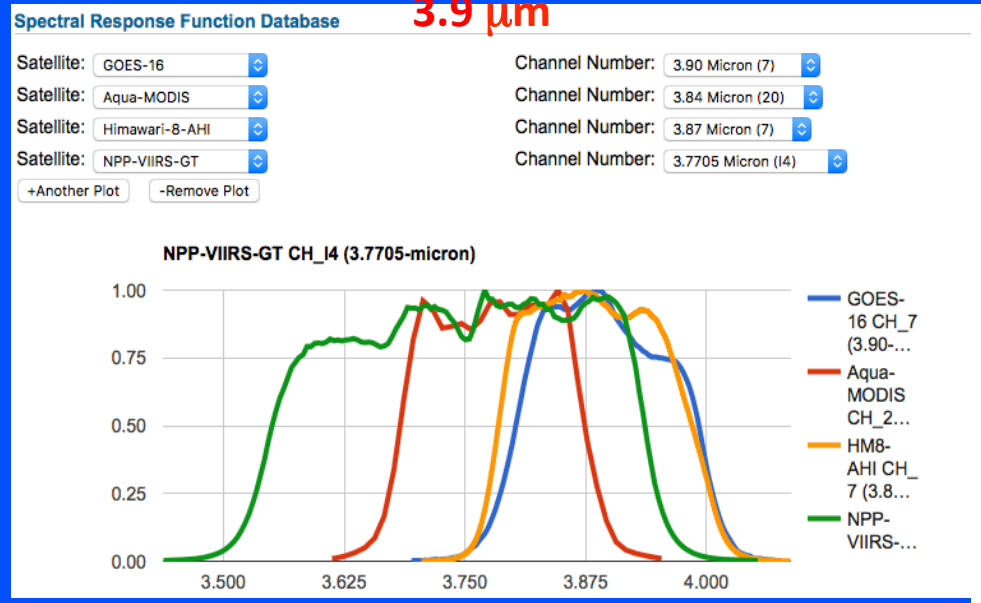
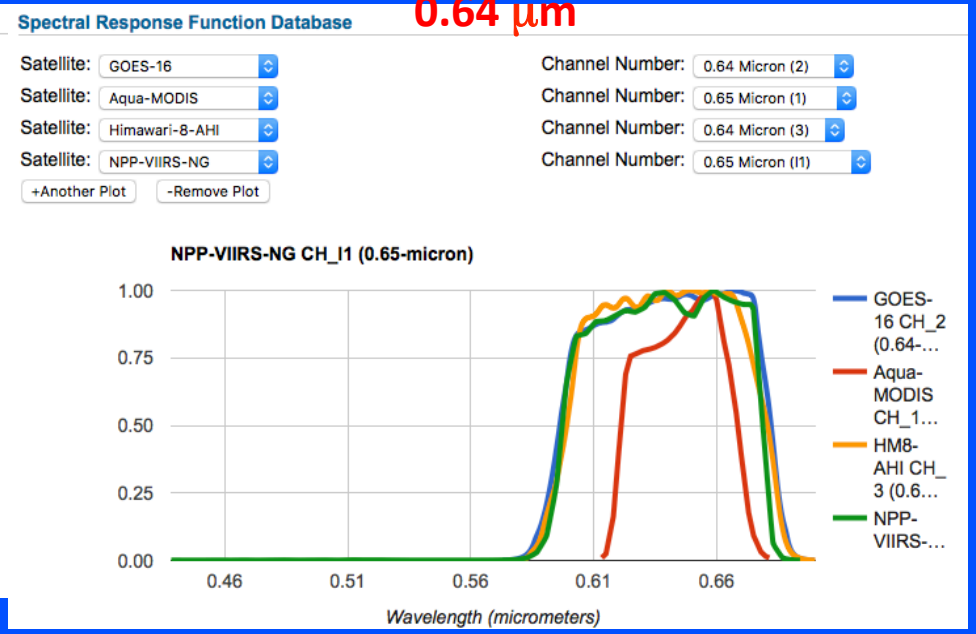
1.38 µm



1.6 µm



3.9 µm



0.64 µm