CERES Cloud Working Group Report

CERES Science Team Mtg., Virtual#2, 15-17 September 2020

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 lead),

S. Bedka (retrievals, val), C. Yost (val), G. Hong (models), Y. Chen (clr props, test runs),

M. Nordeen (GEO), D. Painemal (val) , B. Scarino (cal, Tskin, GEO), R. Brown (QC), F-L. Chang (CO2, corrk),

E. Heckert (web), B. Shan (GEO), R. Smith (web, NPP), D. Spangenberg (everything), Churngwei Chu (web), Zhujun Li (val)
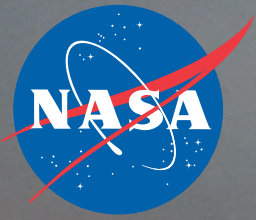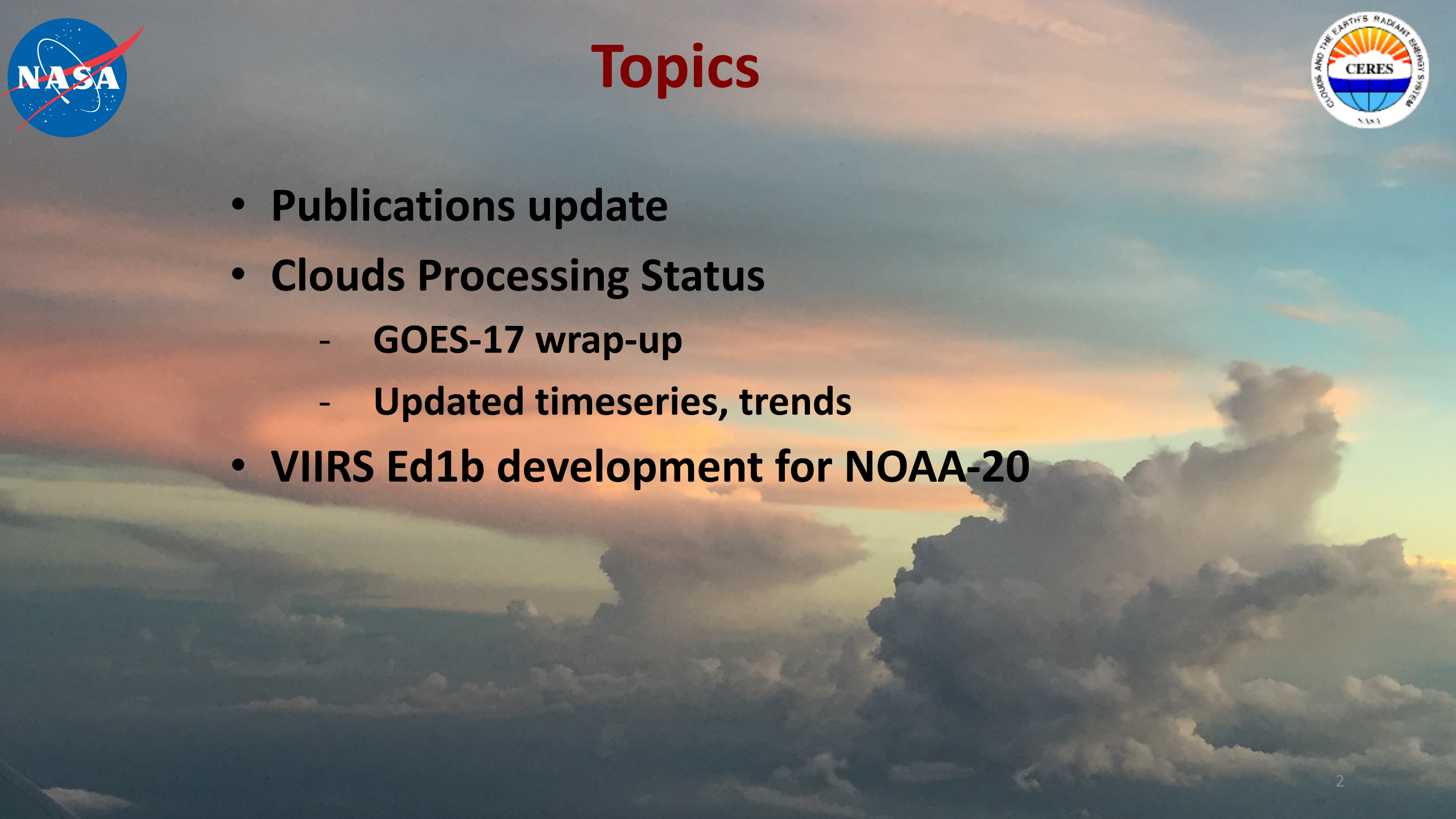
SSAI, Hampton, VA

L. Nguyen (IT lead, GEO), *NASA Langley Research Center*

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

P. Yang (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**

- **Clouds Processing Status**
  - **GOES-17 wrap-up**
  - **Updated timeseries, trends**

- **VIIRS Ed1b development for NOAA-20**

CERES Cloud-related Papers

## Edition-4 References (https://ceres.larc.nasa.gov/science/publications/)

ED4 CALIBRATION   Sun-Mack et al. (2018), IEEE Trans. Geosci. Remote Sens., 56, 6016-6032, doi:10.1109/TGRS.2018.2829902

ED4 CLOUD MASK   Trepte et al. (2019) IEEE Trans. Geosci. Remote Sens., doi: 10.1109/TGRS.2019.2926620.

ED4 RETRIEVALS   Minnis et al. (2020) IEEE Trans. Geosci. Remote Sens., doi: 10.1109/TGRS.2020.3008866

ED4 VALIDATION   Yost et al. (2020), IEEE Trans. Geosci. Remote Sens., doi: 10.1109/TGRS.2020.3015155.

Other Recent Edition-4 Related Papers (2020)

Painemal, D., F.-L. Chang, R. Ferrare, S. Burton, Z. Li., W. L. Smith Jr., P. Minnis., Y.Feng, M. Clayton, 2020, Reducing uncertainties in satellite estimates of **aerosol-cloud interactions** over the subtropical ocean by integrating vertically resolved aerosol observations, Atmos. Chem. Phys. Discuss., Atmos. Chem. Phys., 20, 7167–7177, https://doi.org/10.5194/acp-20-7167-2020

Wall, C. J., J. R. Norris, B. Gasparini, W. L. Smith, M. M. Thieman, and O. Sourdeval, Observational Evidence that Radiative Heating Modifies the **Life Cycle of Tropical Anvil Clouds**. J. Climate, doi: https://doi.org/10.1175/JCLI-D-20-0204.1.

Jones, T.A., P. Skinner, N. Yussouf, K. Knopfmeier, A. Reinhart, X. Wang, K. Bedka, W. Smith, and R. Palikonda, 2020: **Assimilation** of GOES-16 Radiances and Retrievals into the Warn-on-Forecast System. Mon. Wea. Rev., 148, 1829–1859, https://doi.org/10.1175/MWR-D-19-0379.1

Chen, H., Schmidt, S., King, M. D., Wind, G., Bucholtz, A., Reid, E. A., Segal-Rozenhaimer, M., Smith, W. L., Taylor, P. C., Kato, S., and Pilewskie, P.: Shortwave **Radiative Effect of Arctic Low-Level Clouds**: Evaluation of Imagery-Derived Irradiance with Aircraft Observations, Atmos. Meas. Tech. Discuss., https://doi.org/10.5194/amt-2019-344, accepted, 2020.

In Preparation or Review

Painemal, D., Spangenberg, D., Smith Jr., W. L., Cairns, B., Moore, R., Minnis, P.: **Evaluation of satellite retrievals of liquid clouds** from GOES-13 Imager and MODIS over the midlatitude **North Atlantic** during NAAMES campaign , JGR, submitted, 2020.

Kang, L., R. Marchand, W. L. Smith: **Evaluation of MODIS and Himawari-8 Low Clouds Retrievals over the Southern Ocean** with In Situ Measurements from the SOCRATES Campaign, submitted to Earth and Space Science.

Rybka, H., et al.: The behavior of high-CAPE summer convection in large-domain large-eddy simulations with ICON, Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2020-635, in review, 2020. **Model Evaluation**

Smith, W. L., D. Doelling, P.Minnis, D. Painemal, B. Scarino, S. Sun-Mack, K. Bedka: Assessment of CERES and SatCORPS **Cloud Climate Data Records** and Factors that Influence Temporal Continuity and Cross-Platform Consistency, in preparation for MDPI Remote Sensing special issue.

Minnis, P., S. Sun-Mack, W. L. Smith, Jr., Q. Z. Trepte, C. R. Yost, G. Hong, Y. Chen, F.-L. Chang, R. A. Smith, P. W. Heck, C. Liu, and P. Yang, 2020: Edition 1 **SNPP VIIRS cloud property retrievals** for CERES, in preparation for *J. Geophys. Res.*.
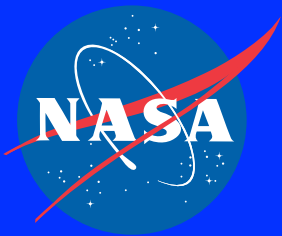
GOES-17 Wrap-up

- GOES-17 Imager (ABI) has a cooling problem at night causing degraded nighttime IR imagery for most channels between 10:30-16:30 GMT ⟶ cloud properties heavily degraded.

- Two bands are not degraded (3.8μm and 10.7μm)

- Two mitigation options
  1. Zero out bad image times and fill with temporal interpolation
  2. Somehow exploit the two good channels to retain hourly cloud properties

- The CWG developed a data fusion approach to reconstruct the radiances for the bad channels using the two good bands

- Nighttime cloud properties derived from the reconstructed radiances have similar accuracies as the standard cloud properties (demonstrated using GOES-16).

- Method delivered in July and has been applied in CERES processing beginning in March 2020 when G17 replaced G15.

- D. Doelling to summarize benefits to TISA subsystem this afternoon.

Cloud Phase from Corrupted Radiances
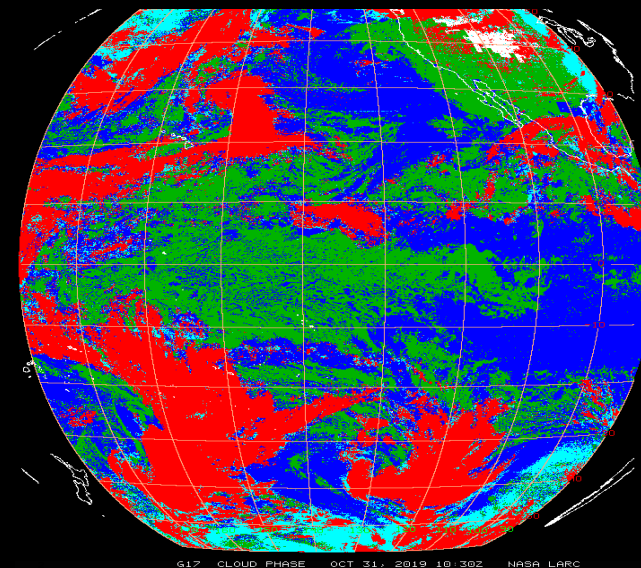
Cloud Phase from Reconstructed Radiances
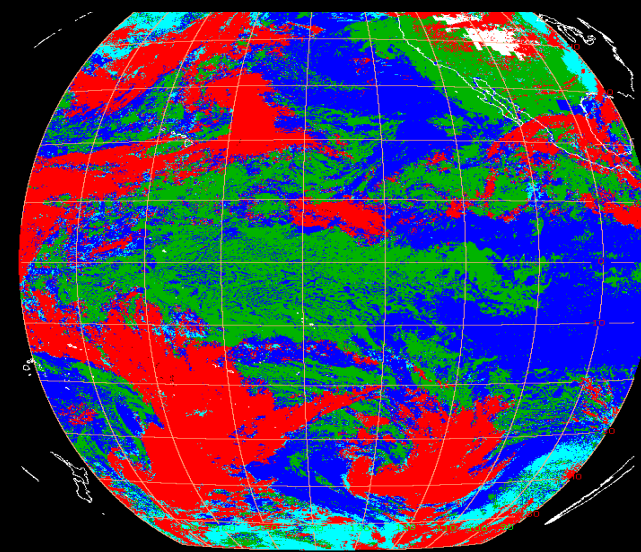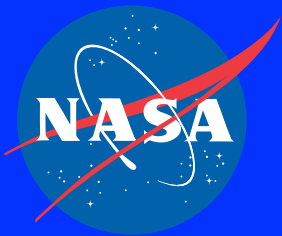
Clouds - Processing Status (LEO)

CERES-MODIS Edition 4 Status

Aqua: Jul 2002 – Jul 2020 (~18 y)

Terra: Feb 2000 – Jul 2020 (~20.5 y)

MODIS Calibration Strategy:
- **MODIS Collection 5 thru Feb 2016,**
- **MODIS Collection 6.1 March 2016 - present**
- **C6.1 radiances are scaled to C5 for consistency over entire record**
- **Terra-MODIS normalized to Aqua-MODIS (Sun-Mack, et al. 2018)**

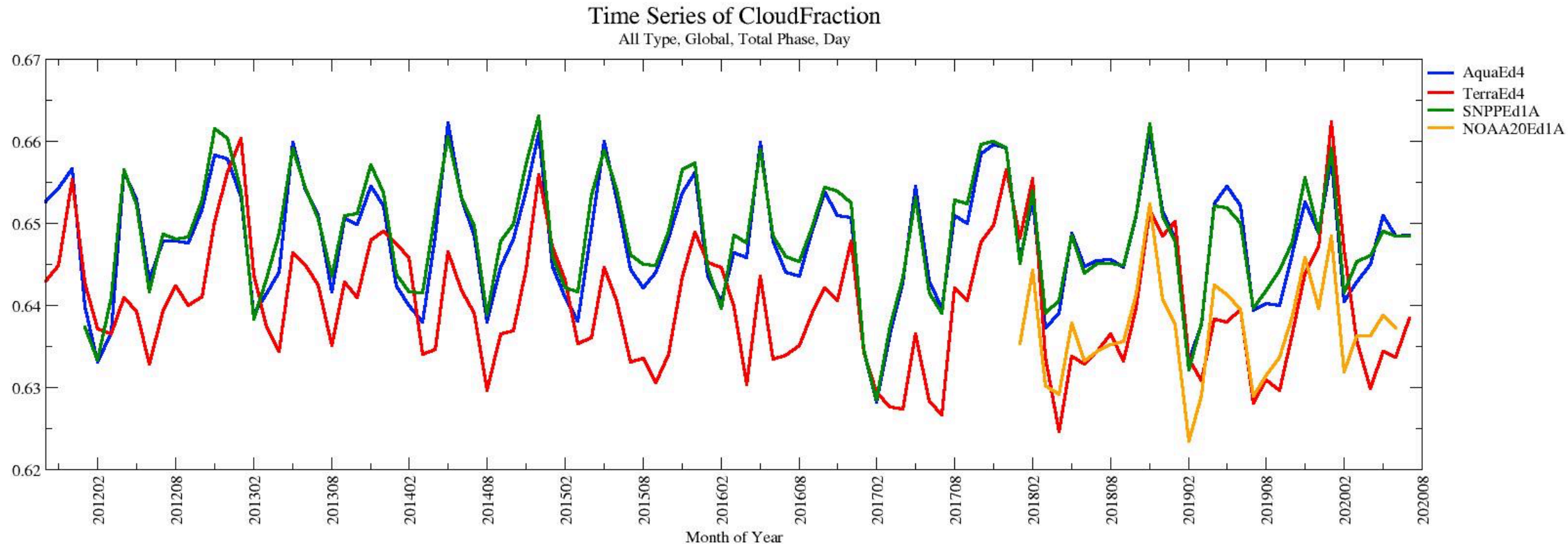## CERES-VIIRS Ed 1A Status

SNPP: Jan 2012 – Jul 2020 (~8.5 y)

VIIRS Calibration Strategy:
- **Use forward processing calibrations, not scaled to MODIS**
- **Inconsistencies/discontinuity in this record**

NOAA-20: Jan 2018 – Jul 2020 (~2.5 y)

VIIRS Calibration Strategy: **Scaled to Aqua-C5 using Jul 2019 data**
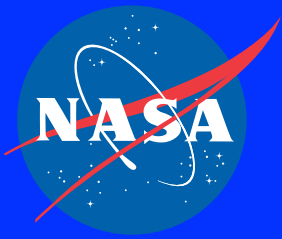
Time Series of CloudFraction
All Type, Global, Total Phase, Day

- Global mean cloud fraction ~0.65, no apparent trends in Aqua MODIS record since 2002.
- All SNPP, and NOAA-20 VIIRS cloud properties track those from AQUA-MODIS very well.
- Some cloud fraction differences due to calibration and algorithm differences

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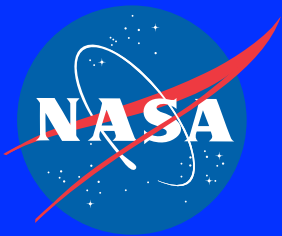
Global Mean Cloud Fraction (Night)

Time Series of CloudFraction
All Type, Global, Total Phase, Night
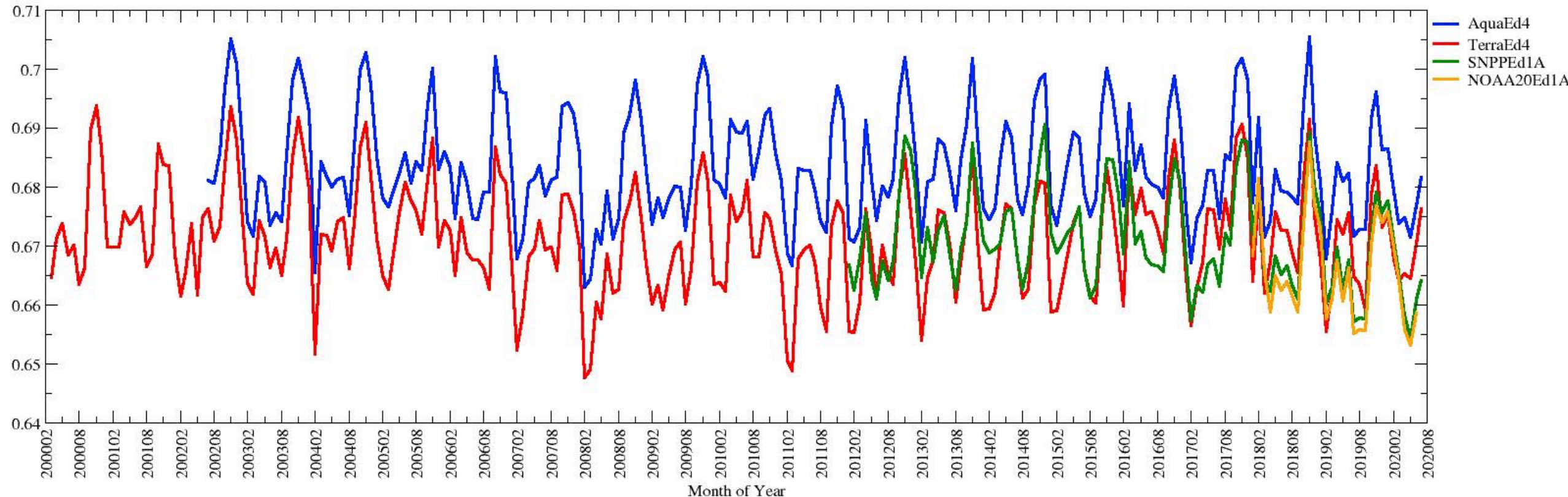
- Global mean cloud fraction ~0.685 (Aqua-MODIS).
- VIIRS and MODIS track well.
- SNPP and N20 VIIRS about 1.5% lower than Aqua-MODIS
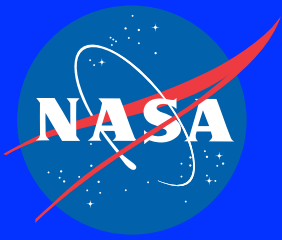
Regional Trends (Aqua MODIS Ed4)
July 2002 – July 2020

- No trends are found in the global Aqua MODIS total cloud fraction since 2002 (not shown)
- Regional trends still large in 18-year record due to ENSO's and other natural variations
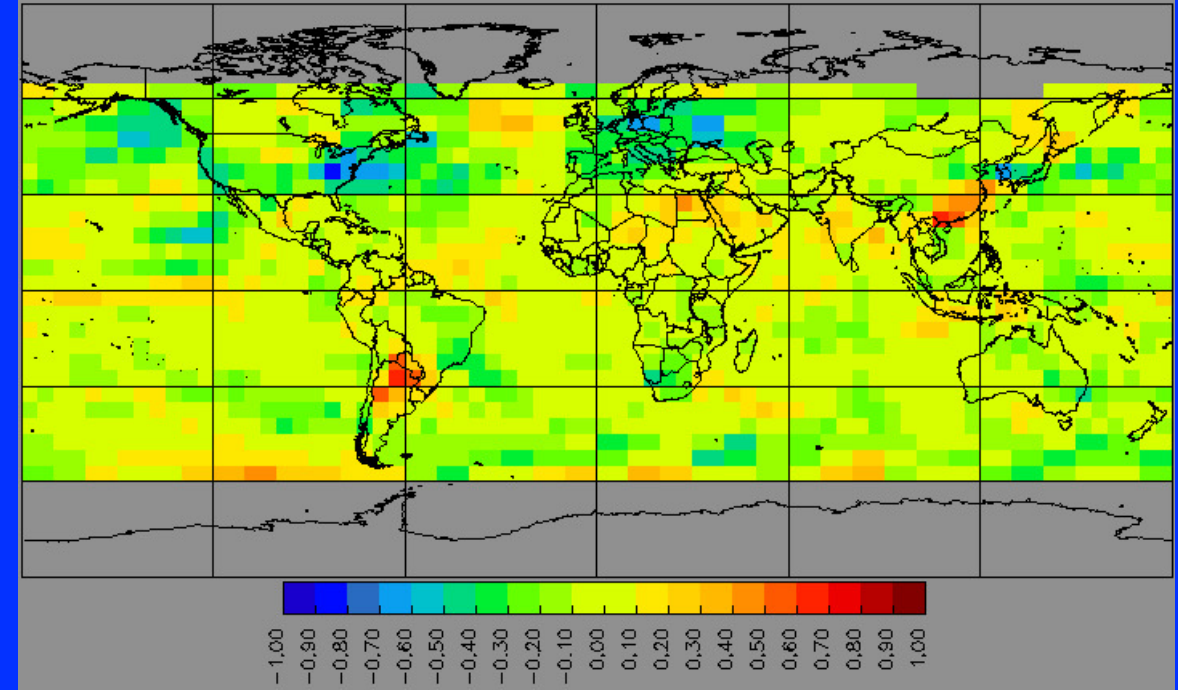
- Generally small or no trends in COD over much of the oceans
- Some interesting trends over/near land areas could be anthropogenic

Regional Trends over Eastern U.S.

CERES Aqua MODIS Ed4   (July 2002 – July 2020)

ΔCOD/decade
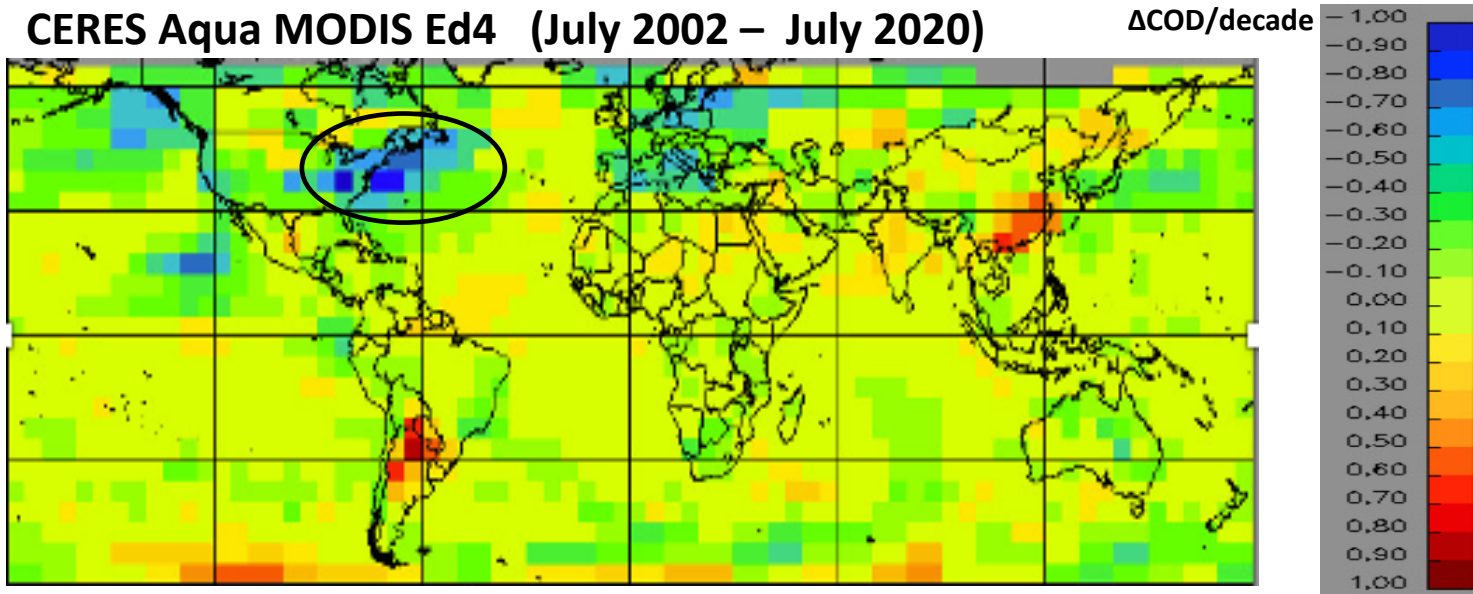
MERRA-2 Sulfate AOD Trends

(1/decade)
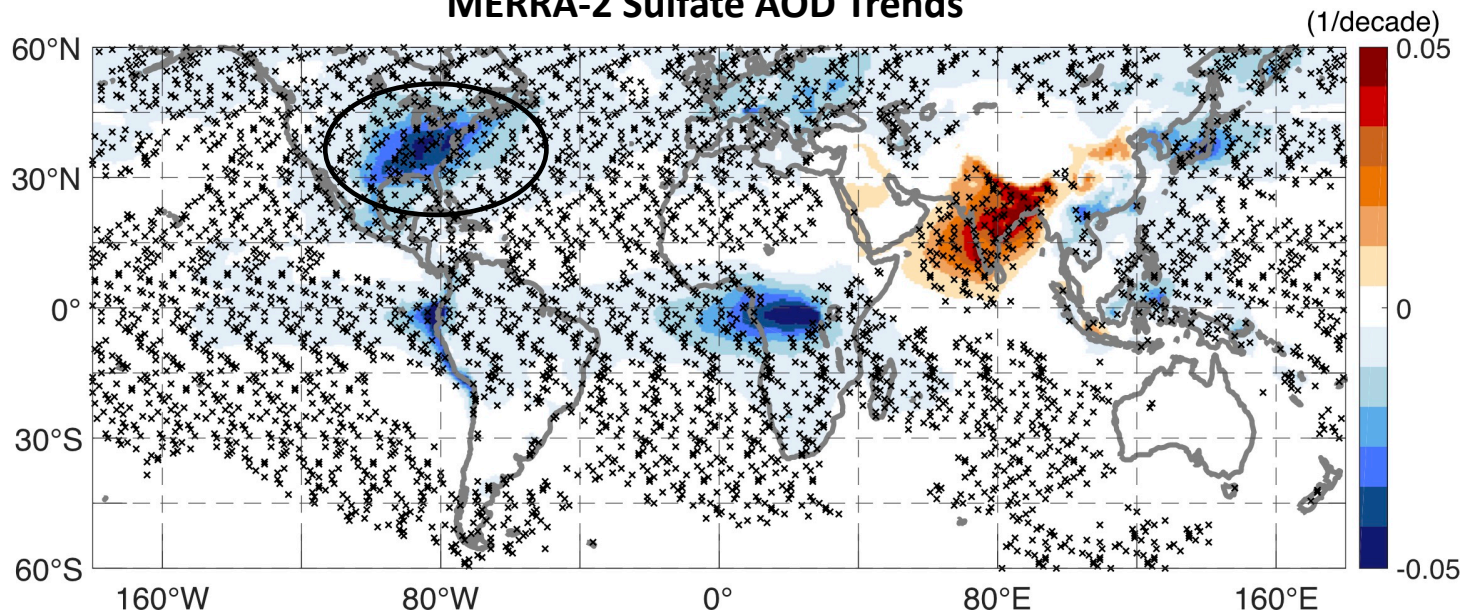
- Significant negative trends are found in the 18-year record of low-level cloud optical thickness over the eastern U.S. and downwind over the adjacent Atlantic.

- Corresponding increases in cloud effective radius, decreases in droplet number concentration also found

- These changes appear to be best associated with changes in pollution and sulfate aerosols as observed from satellites and characterized in MERRA-2 reanalyses rather than with changes in cloud fraction or meteorology (EIS).

- In contrast, changes in cloud properties found over the NE pacific are more correlated with changes in cloud fraction and lower tropospheric stability.

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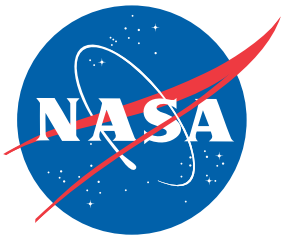
Corresponding Radiative Effects

Preliminary analysis using new CERES Flux-by-cloud-type product (see paper #A11B-07)
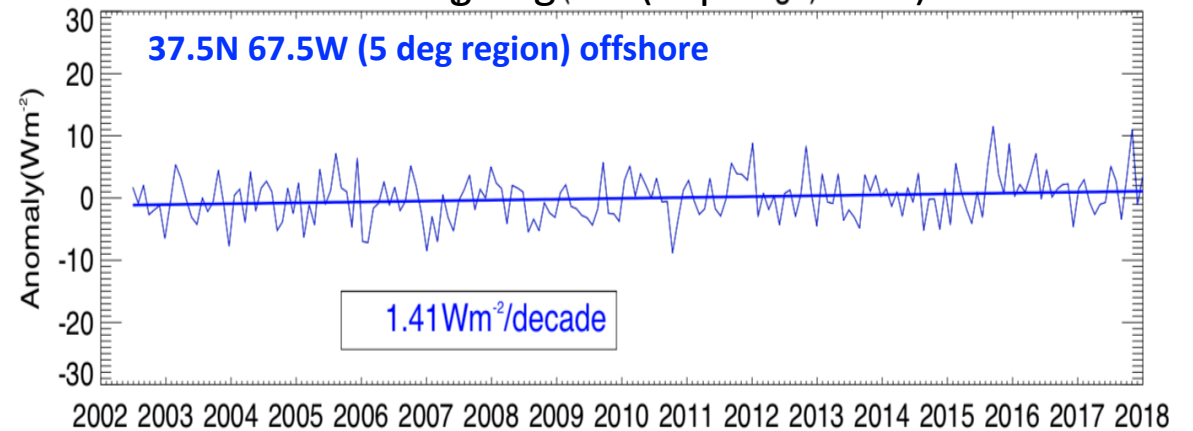

TOA Reflected SW (Liquid Clouds)
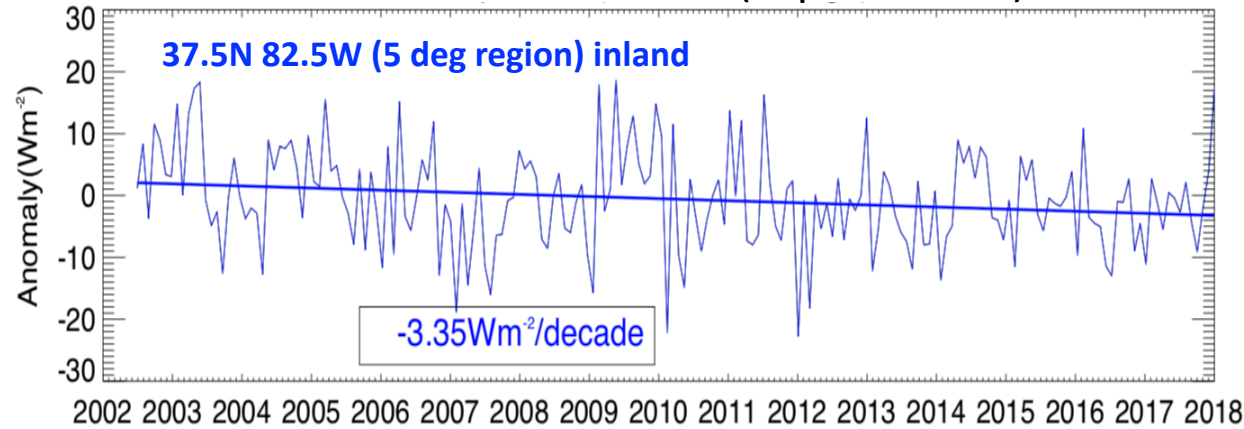
37.5N 82.5W (5 deg region) inland

-3.35Wm⁻²/decade

TOA Reflected SW (Liquid Clouds)

37.5N 67.5W (5 deg region) offshore

-3.84Wm⁻²/decade

Outgoing LW (Liquid Clouds)

37.5N 82.5W (5 deg region) inland

0.25Wm⁻²/decade

Outgoing LW (Liquid Clouds)

37.5N 67.5W (5 deg region) offshore

1.41Wm⁻²/decade
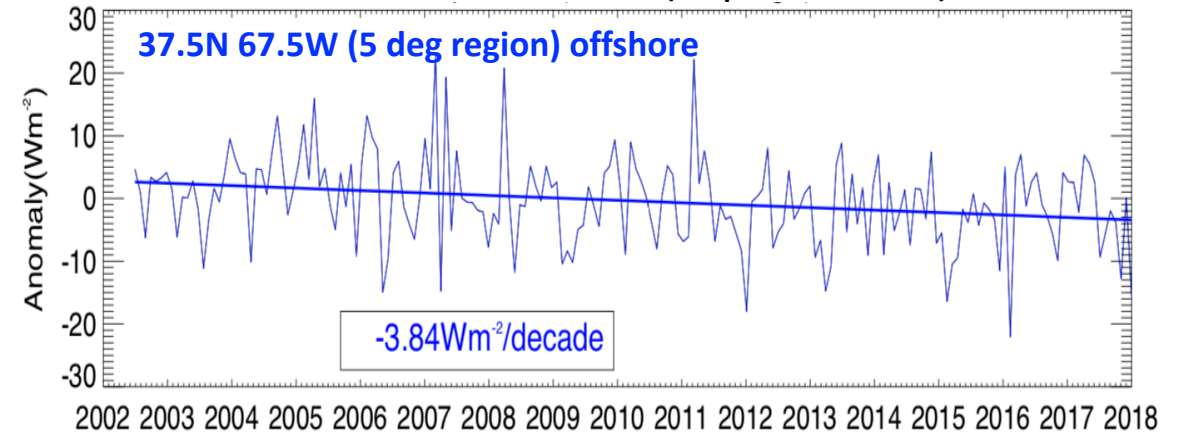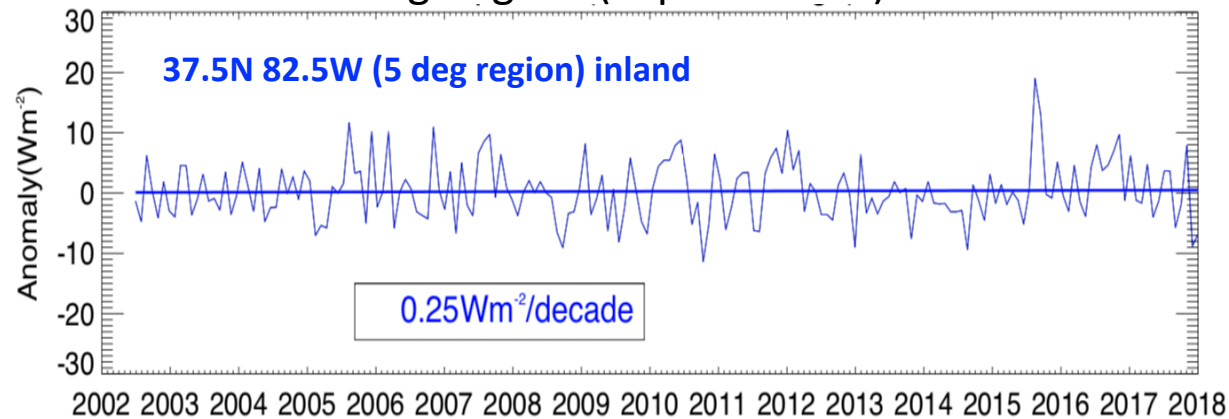
Decreasing reflected SW associated with MODIS low cloud changes (e.g. decreasing N_d) over Eastern U.S.
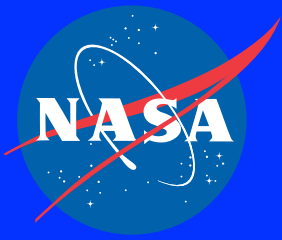
Extending the MODIS Cloud CDR with VIIRS

- Since Terra and Aqua are nearing end of life and begin drifting in 2021 and 2022, the CERES CDR will transition from Aqua to NOAA-20.

- CERES next edition (Ed5) is being developed specifically for this purpose and the Ed5 cloud algorithms are in development with the goal to provide consistent cloud properties across satellite platforms (MODIS to VIIRS, but also improved GEO), using common algorithms and spectral bands.

- Given the recent AQUA anomaly (need to gap fill), potential for another failure and possibility that Ed5 deliveries/processing may not be ready/current at the time CERES transitions, we will need to extend the Ed4 cloud record with NOAA-20 cloud products as seamlessly as possible without discontinuities.

- VIIRS Ed1A cloud algorithms from S-NPP and NOAA-20 were not designed specifically for continuity with MODIS Ed4. Instead, they were developed (6+ years ago) with a greater focus on accuracy improvements, bug fixes, updated cloud models. Ed1A algorithm also uses different channels.

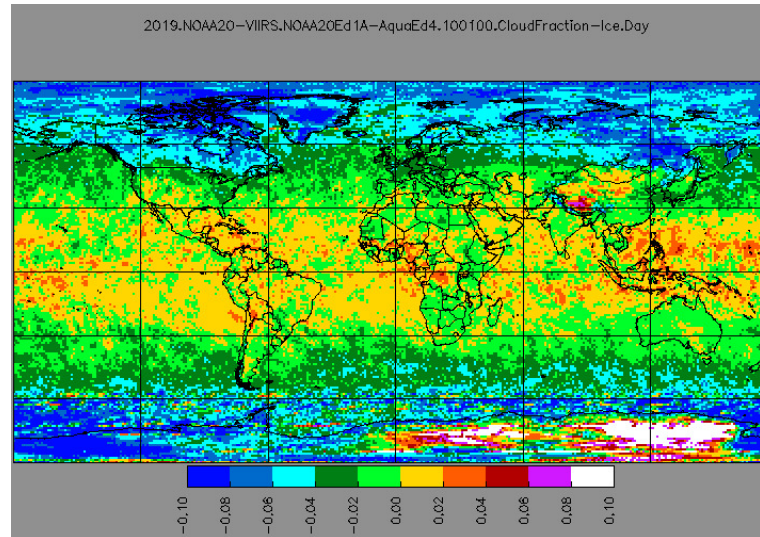- Therefore, we will develop a VIIRS Ed1B to improve consistency with Ed4
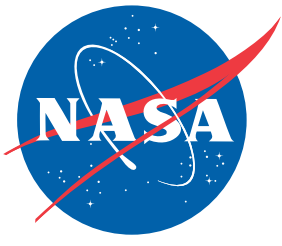
NOAA-20 VIIRS Ed1A vs MODIS Ed4
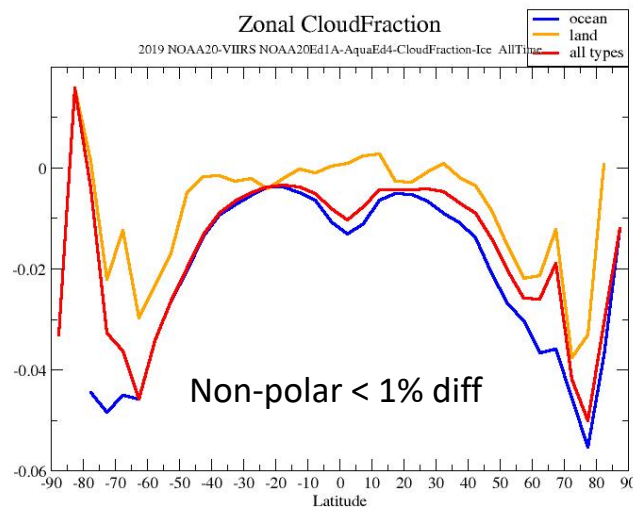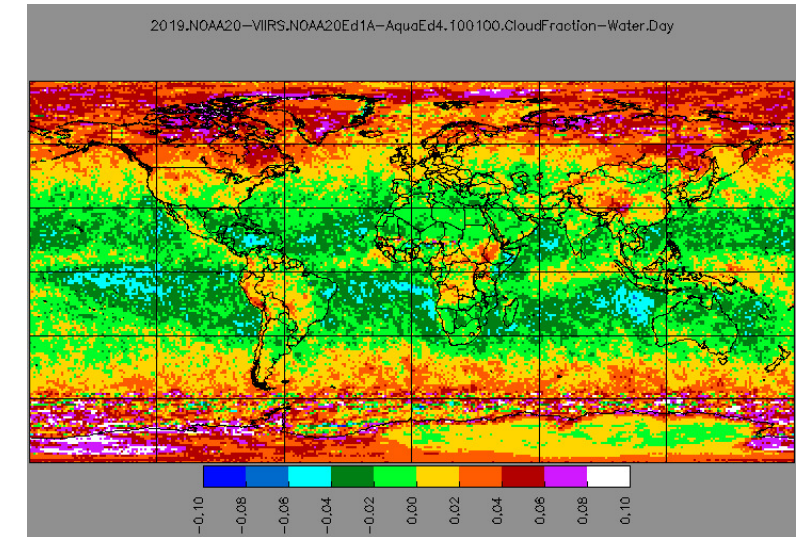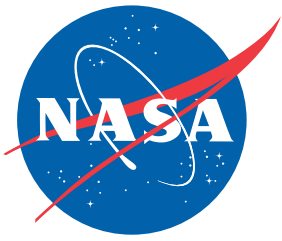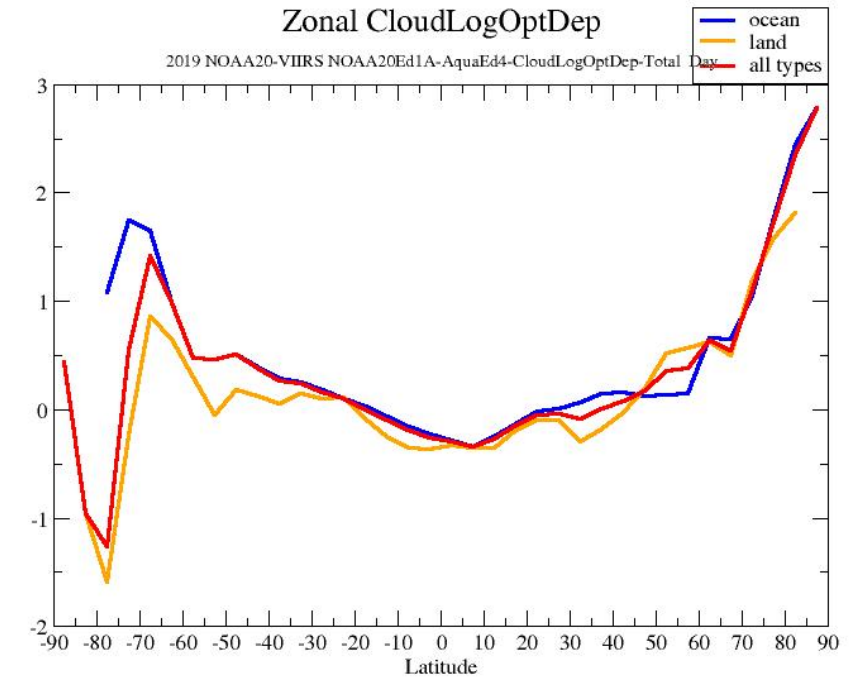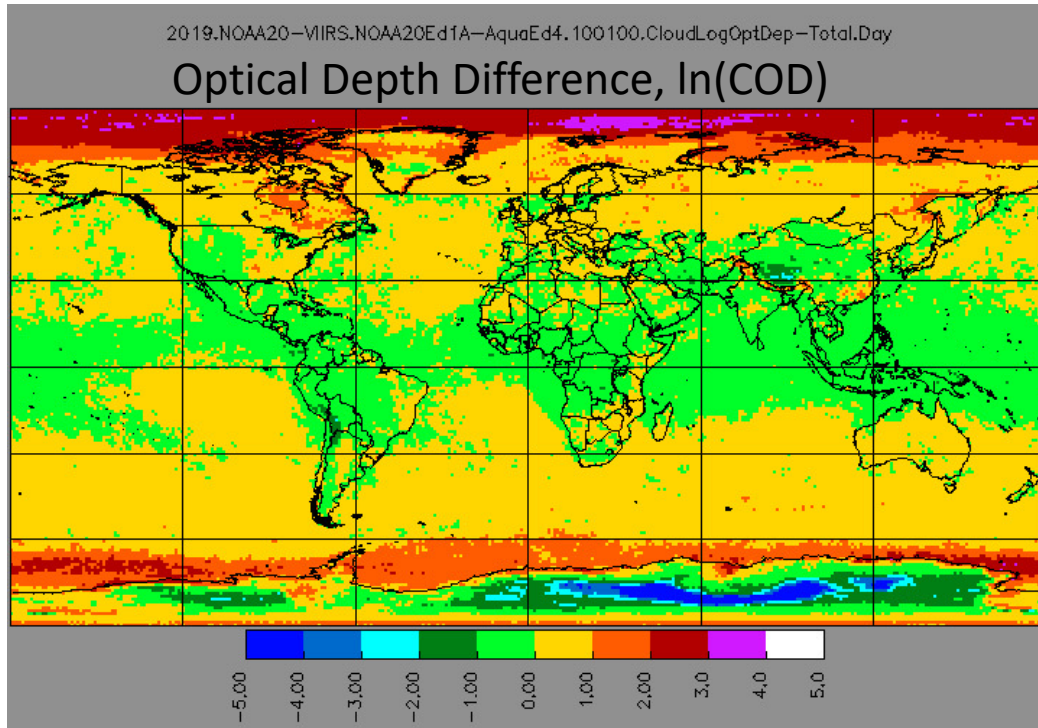## 2019 Cloud Fraction Difference (DAY)

Total
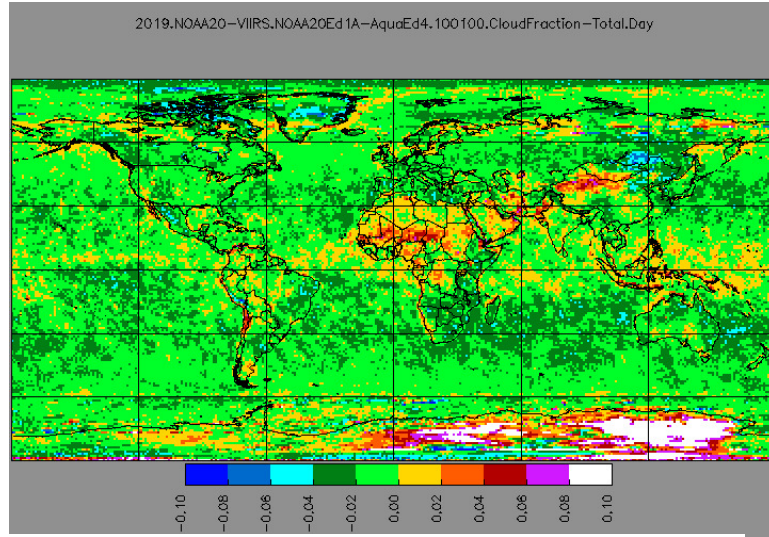
Ice

Water

N20 Ed1A has

- Good agreement with Ed4 for total clouds, most areas in daytime

- Some phase differences: more ice, less water cloud (tropics); less ice, more water clouds (polar regions) except Antarctic plateau

- Phase differences affect other cloud properties (e.g. heights)

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NOAA-20 VIIRS Ed1A vs MODIS Ed4
2019 Cloud Optical Depth Difference (DAY)

- N20 Ed1A has substantially higher COD in most polar regions
- This is due to a bug in the Ed4 1.24 μm reflectance models used for retrievals over snow/ice that was corrected in Ed1A
- Antarctica differences muddled by large cloud fraction differences
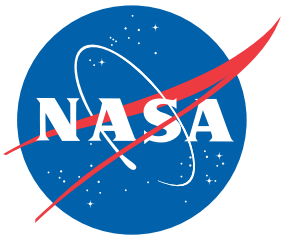
NOAA-20 VIIRS Ed1A vs MODIS Ed4
## 2019 Total Cloud Fraction Difference (NIGHT)

2019.NOAA20-VIIRS.NOAA20Ed1A-AquaEd4.100100.CloudFraction-Total.Night
N20-Ed1A minus Aqua-Ed4
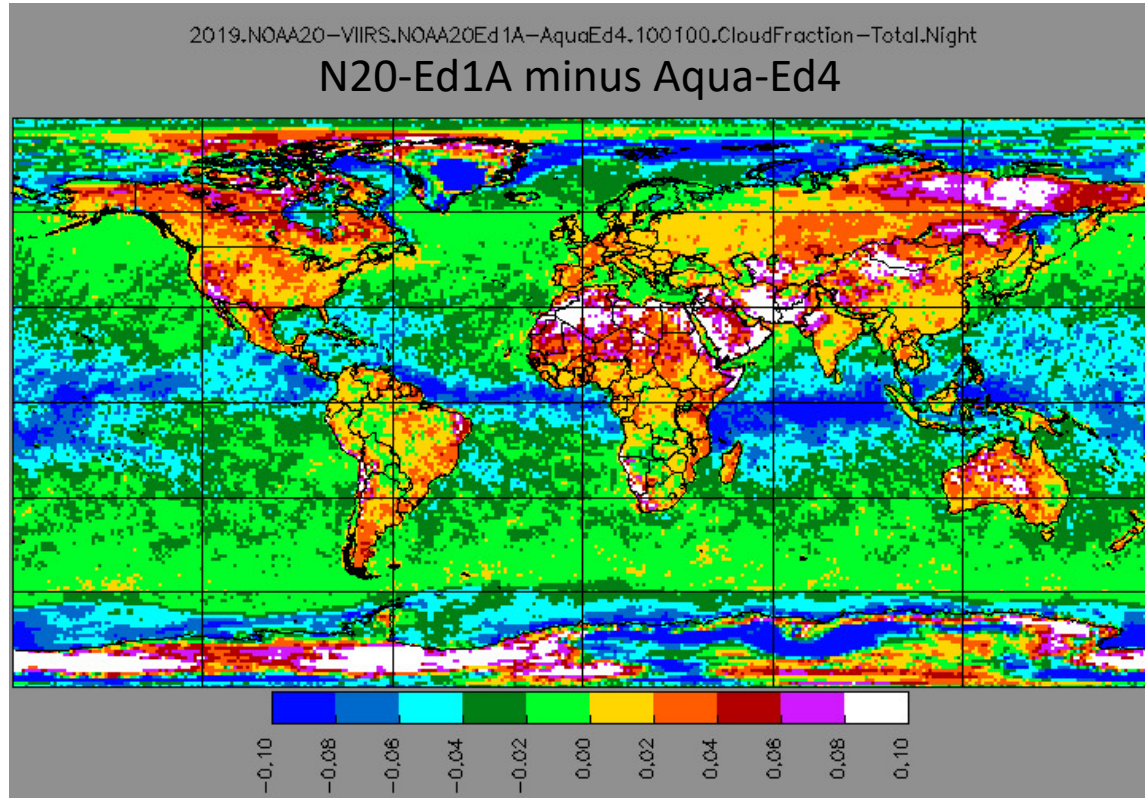
N20 Ed1A has

- Less tropical ocean clouds
- Similar over mid-lat ocean
- More clouds over land
- Substantial polar differences
    - +/- 30% over Antarctica & Greenland

Polar differences are due to the use of different spectral channels in the two cloud masks
- VIIRS does not 6.7, 13 µm channel

Only two ways to deal with this

1. Eliminate 6.7, 13 µm usage in MODIS algorithm (Ed5 plan, no help in short term - can not reprocess Ed4)

2. Reconstruct these bands for VIIRS using CrIS data
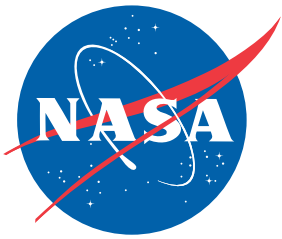
Land SIP

VNP02IMG: Imagery Bands
VNP02MOD: Moderate Bands
VNP02DNB: Day/Night Band
VNP03MOD: Geolocation fields for Moderate Bands
VNP03DNB: Geolocation fields for Day/Night Band

CERES Subsetter

Send to Langley

VNP0203IMD_SS.A

Atmosphere SIP

FSNRAD_L2_VIIRS_CRIS_SNPP.A
Fusion Constructed MODIS Radiances
for VIIRS using CrIS data:
    Band 23: 4.05 μm
    Band 24: 4.47 μm
    Band 25: 4.52 μm
    Band 27: 6.72 μm
    Band 28: 7.33 μm
    Band 30: 9.73 μm
    Band 31: 11.03 μm
    Band 32: 12.02 μm
    Band 33: 13.34 μm
    Band 34: 13.64 μm
    Band 35: 13.94 μm
    Band 36: 14.24 μm

More on this product tomorrow aft. (B. Baum talk)

CERES Clouds Subsystem

One Month
MODIS: 630 GB
VIIRS: 4 T
FSNRAD: 1.5 T

15
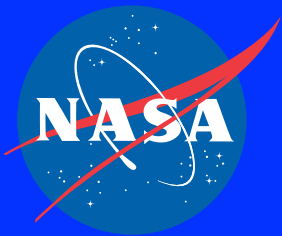
Development plan for VIIRS Ed1B

Low Hanging Fruit – Modifications to Ed1A approaches:

- Re-tune the nighttime cloud mask, i.e. increase clouds over tropical ocean and reduce clouds over non-polar land area

- Replace the 1.24 um and 3.7 um reflectance cloud models/parameterizations with those from Ed4 (Ed4 models have interpolation bug)

- Bring in the fusion data (polar night), evaluate and tune if necessary

- Goal is to improve continuity with Ed not create new problems. May compromise some accuracy

- Deliver in 1-2 month timeframe so the new version can be used to fill the missing two weeks of Aqua data

- If we have time, tweak daytime mask, examine phase logic and better homogenize with Ed4, examine use/impact of fusion data in non-polar regions
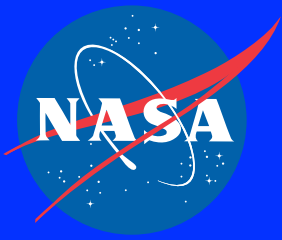
VIIRS Ed1B Initial Results

Cloud Mask

Tune the NOAA 20 Ed1B nighttime non-polar mask (ocean & land)

Cloud Fraction, Ed1A – Ed4
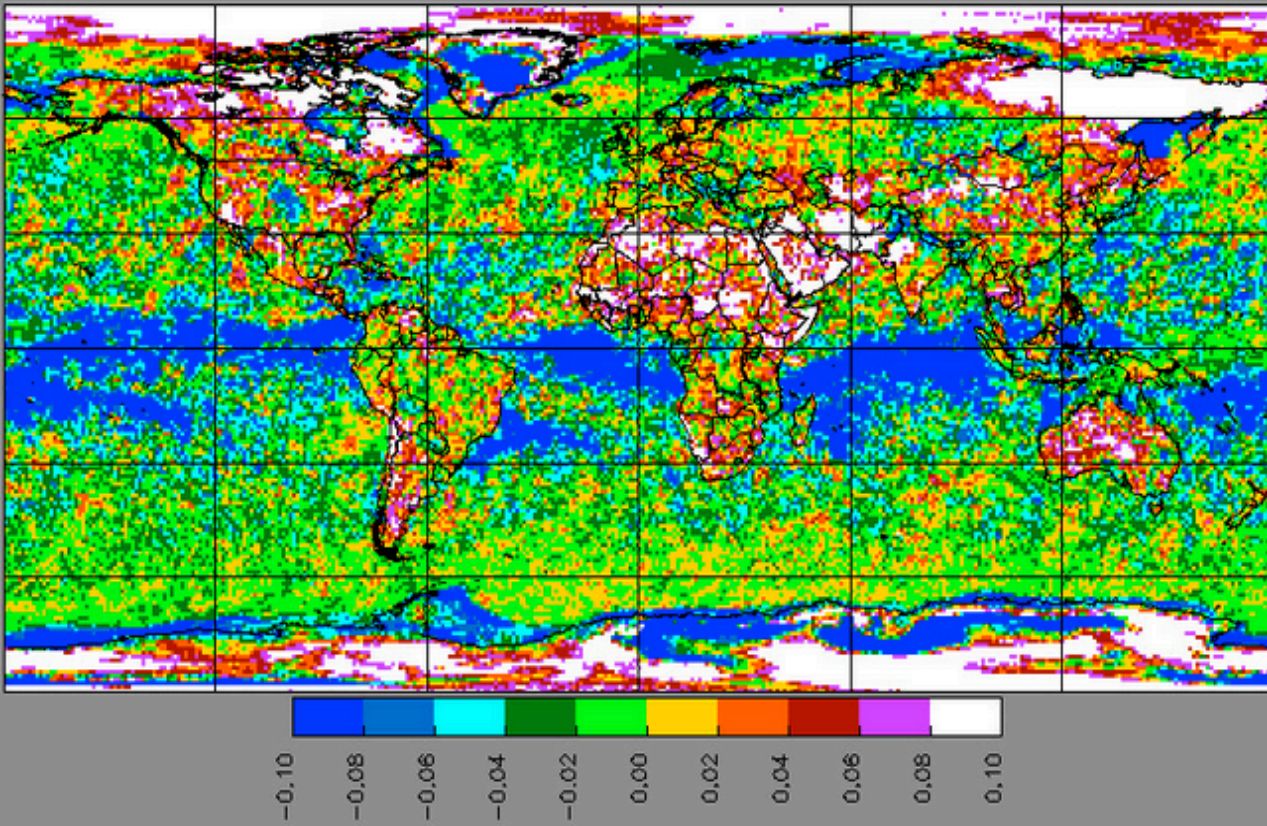
Cloud Fraction, Ed1B – Ed4
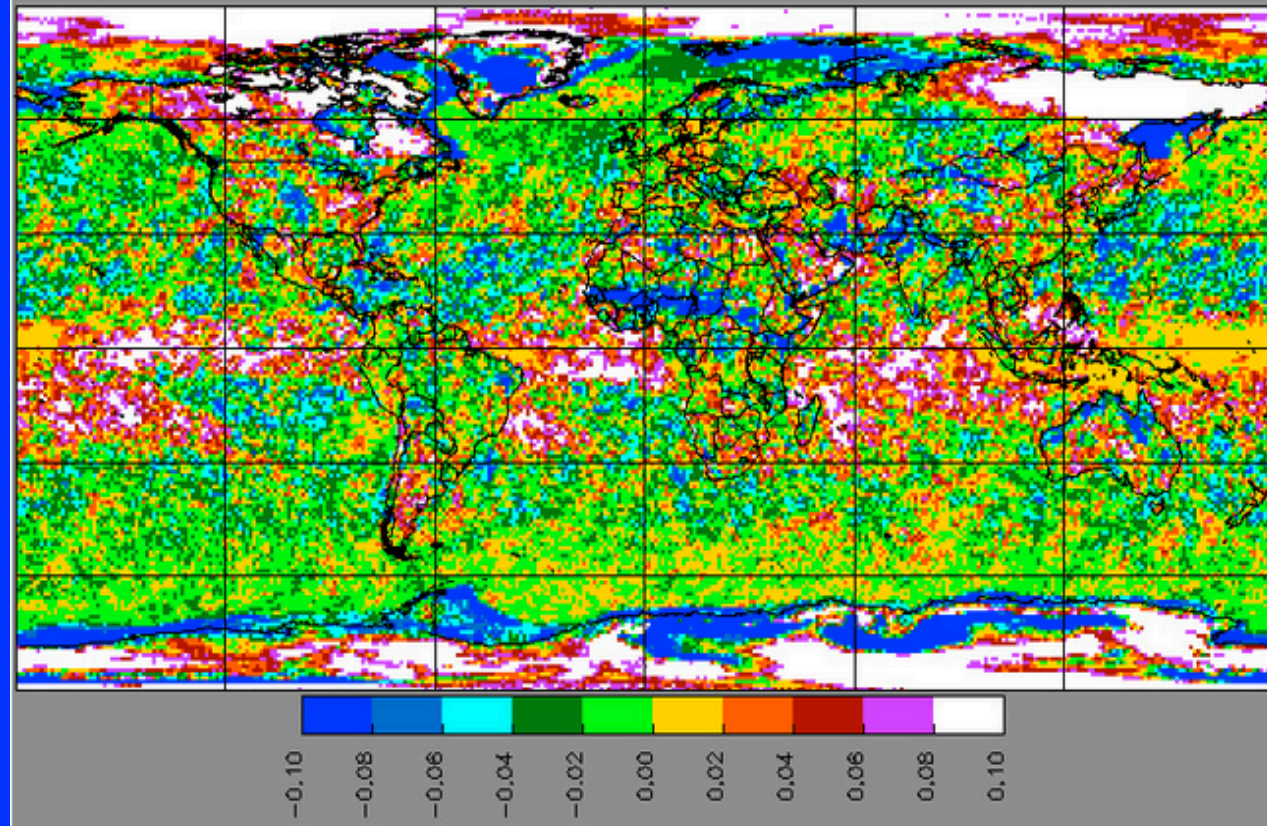
Some land and ocean areas are a little better, but mostly the initial tuning exercise over corrected
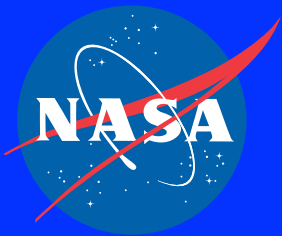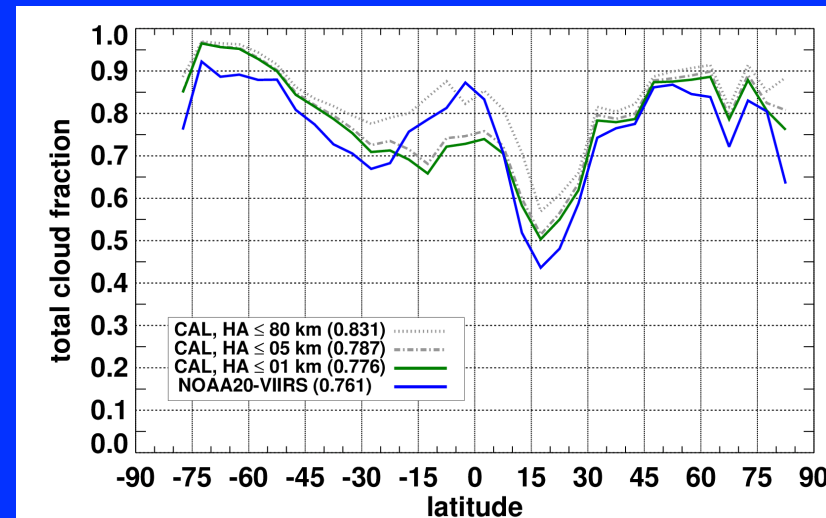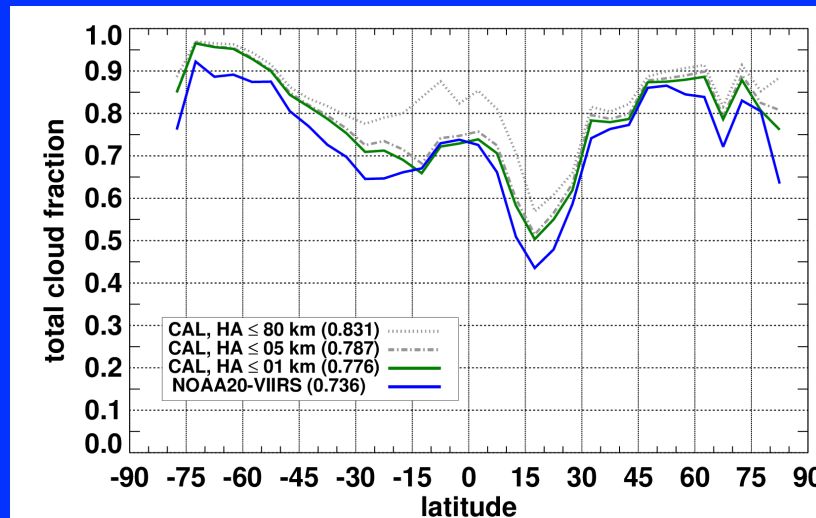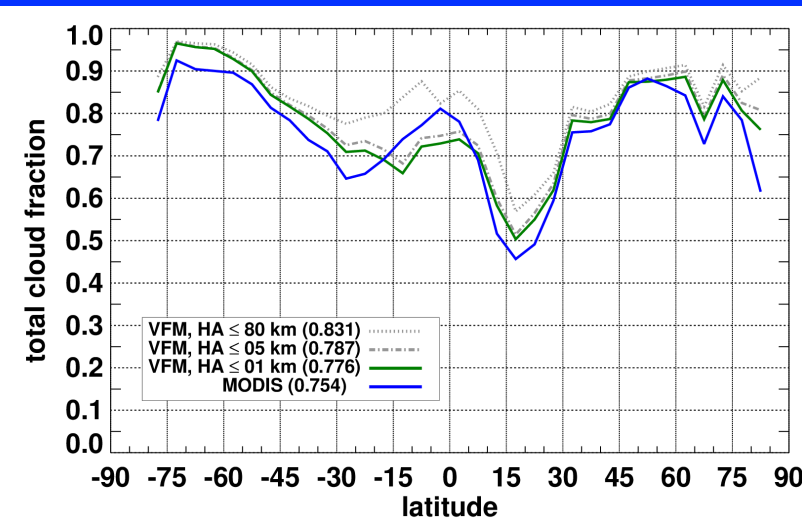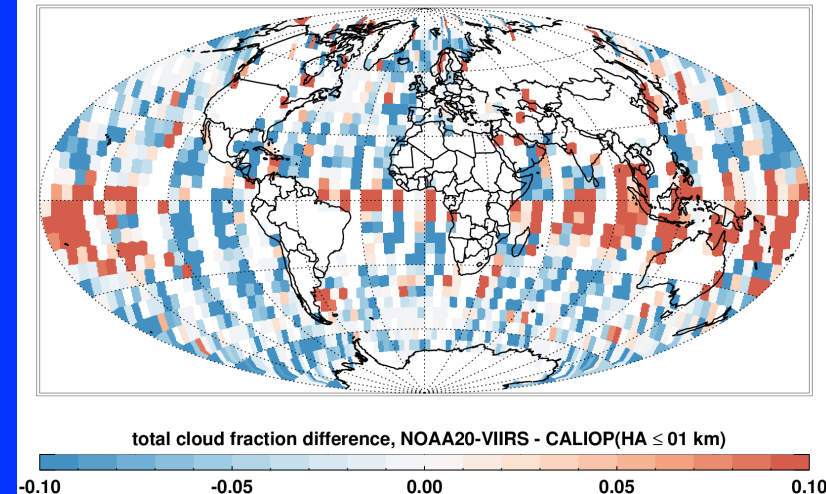
Comparisons with CALIPSO
March 2019, nighttime snow/ice-free ocean
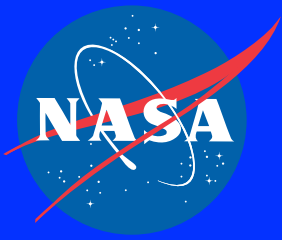## Coincident VIIRS and MODIS: time diffs < 20 mins; any VZA

Aqua MODIS Ed4

N20 VIIRS Ed1A

N20 Ed1B
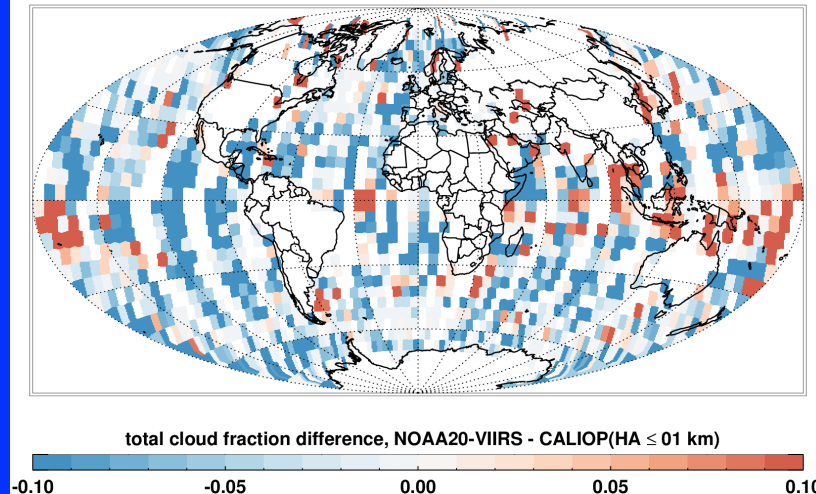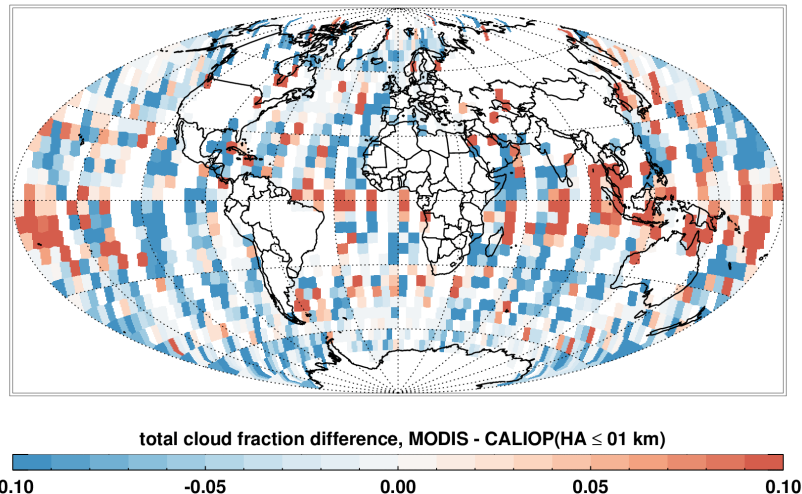
VIIRS Ed1B Initial Results

Cloud Retrieval

Apply in NOAA 20 Ed1B code

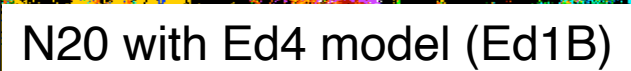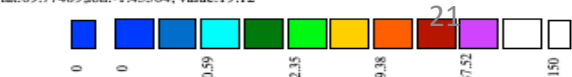- Ed4 MODIS clouds models and parameterizations for retrievals over snow/ice

N20 Ed1A

MODIS Ed4

N20 with Ed4 model (Ed1B)

VIIRS_RGB

VIIRS_RGB

Eff_Cld_Optical_Depth

Eff_Cld_Optical_Depth

Eff_Cld_Optical_Depth

Eff_Cld_Optical_Depth

Eff_Cld_Optical_Depth
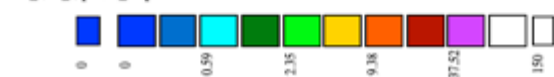
lat:73.09534,lon:-35.62375, value:17.18

lat:69.77489,lon:-1.43564, value:19.12

0   0   0.59   2.35   9.38   37.52   150

0   0   0.59   2.35   9.38   37.52   150

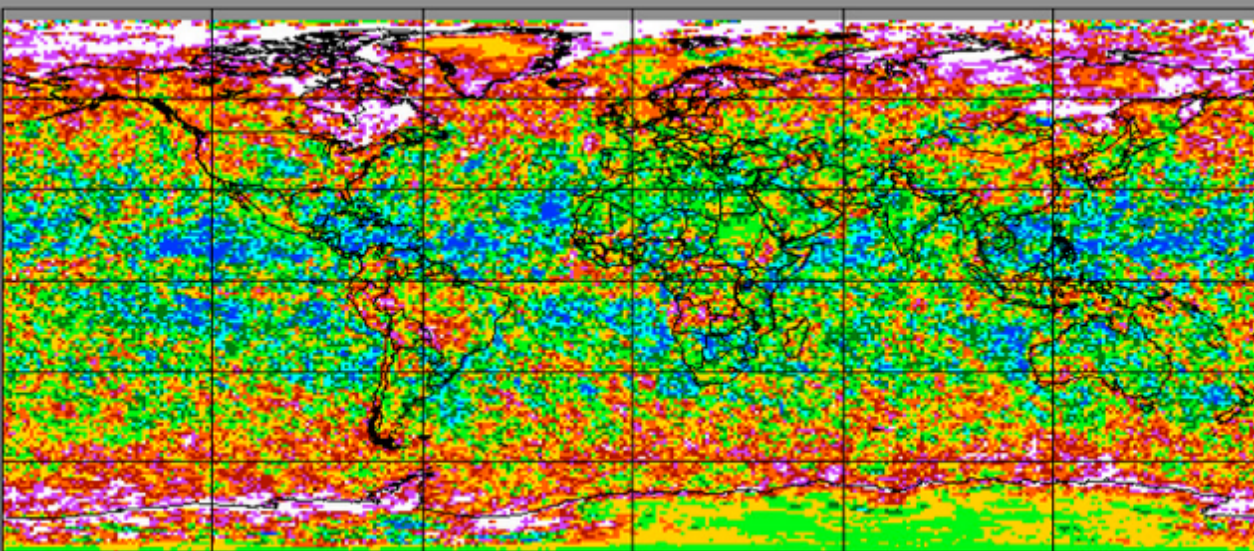0   0   0.59   2.35   9.38   37.52   150
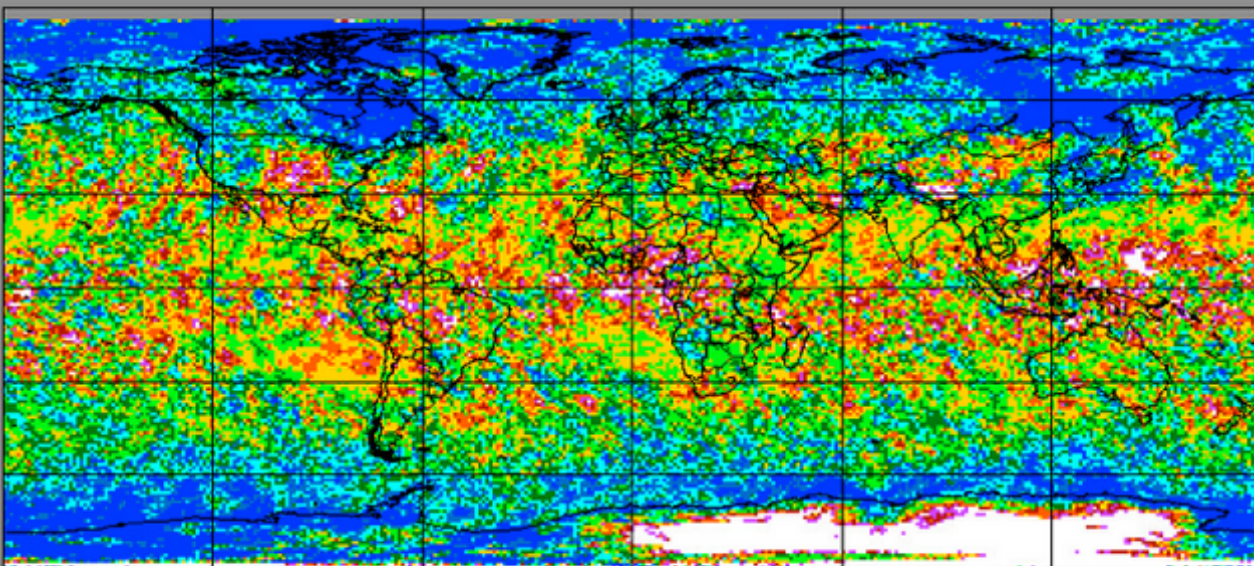
201903.NOAA20-VIIRS.1538.minus.AquaBeta2-Ed4.100100.CloudFraction-Ice.Day

Ice Fraction Diff, Ed1A − Ed4

1903.NOAA20-VIIRS.EEd4MOD12437Par.minus.AquaBeta2-Ed4.100100.CloudFraction-Ice.Day

Ice Fraction Diff, Ed1B − Ed4

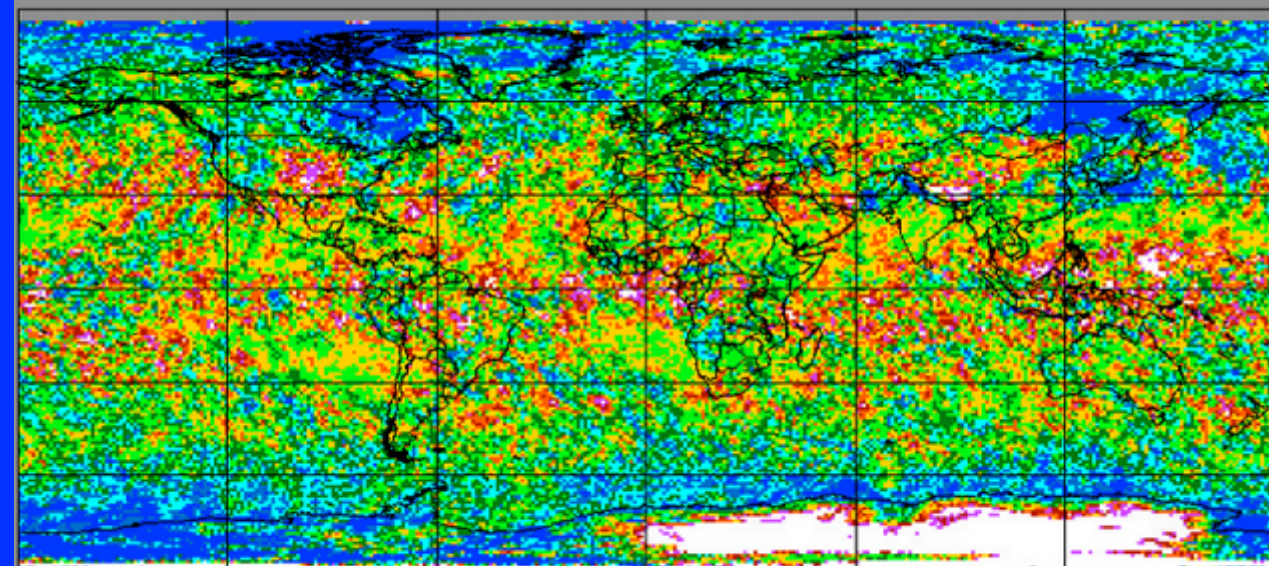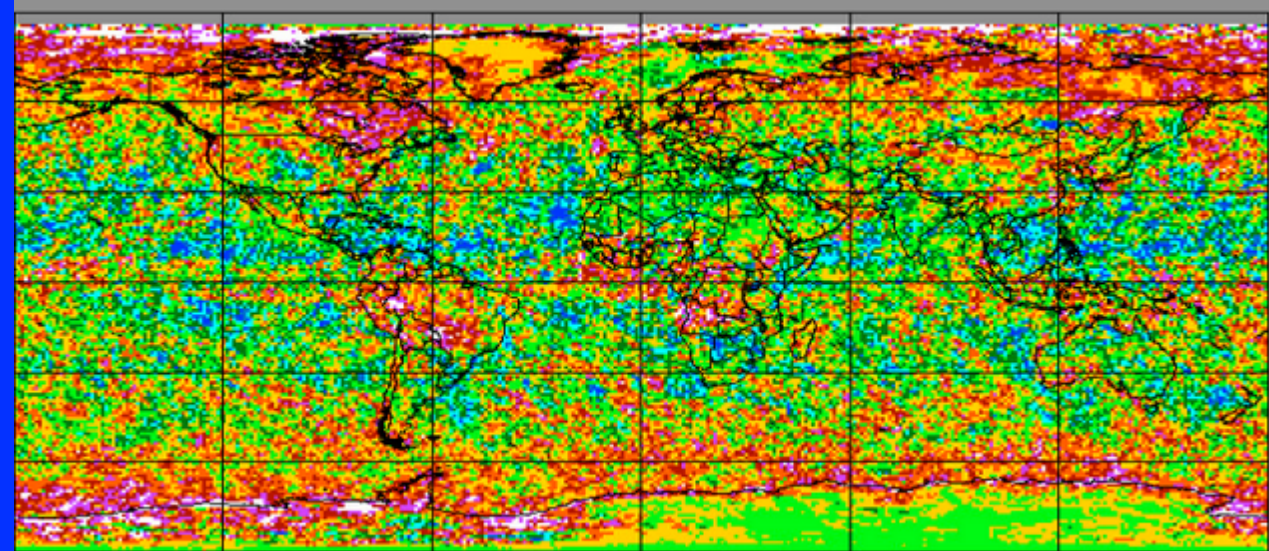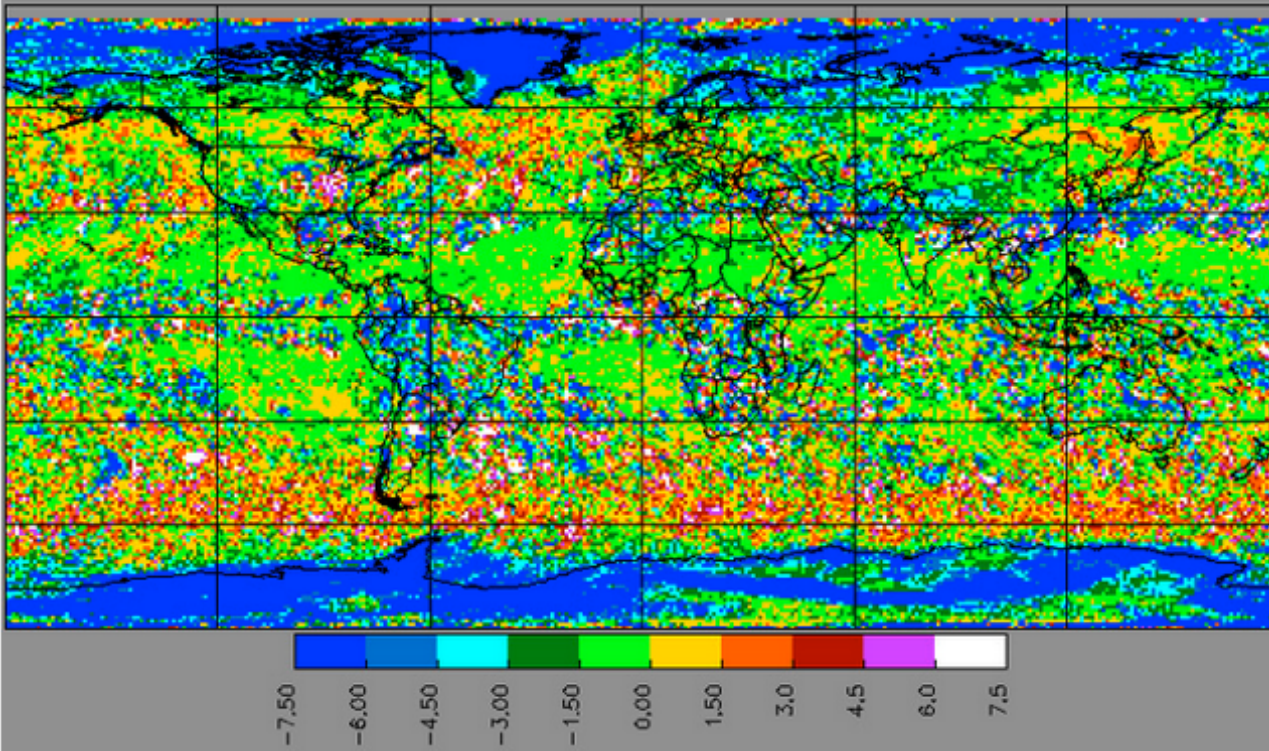201903.NOAA20-VIIRS.1538.minus.AquaBeta2-Ed4.100100.CloudFraction-Water.Day

Water Fraction Diff, Ed1A − Ed4

201903.NOAA20-VIIRS.EEd4MOD12437Par.minus.AquaBeta2-Ed4.100100.CloudFraction-Water.Day
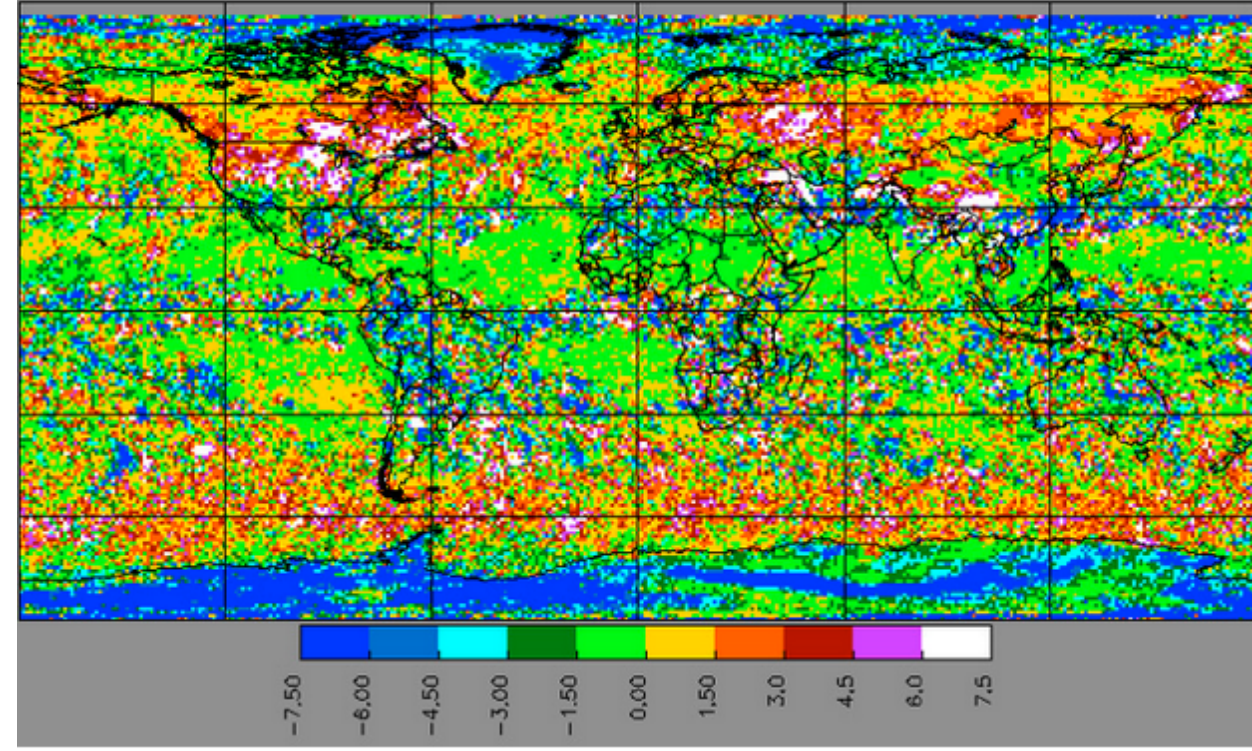
Water Fraction Diff, Ed1B − Ed4

-0.10 -0.08 -0.06 -0.04 -0.02 0.00 0.02 0.04 0.06 0.08 0.10

Ice COD Diff, Ed1A – Ed4

Ice COD Diff, Ed1B – Ed4

```
Global:      -0.8  -2.2  -1.2
Polar:       -3.3  -8.4  -4.9
NonPolar:    -0.5  -1.3  -0.7
```

```
Global:      -0.2  -0.6  -0.3
Polar:       -0.1  -3.3  -1.3
NonPolar:    -0.2  -0.2  -0.2
```

Linear Tau averaging

Water COD Diff, Ed1A – Ed4

Water COD Diff, Ed1B – Ed4

```
Global:      1.5  2.5  1.9
Polar:       6.2  9.2  7.3
NonPolar:    0.8  1.6  1.1
```
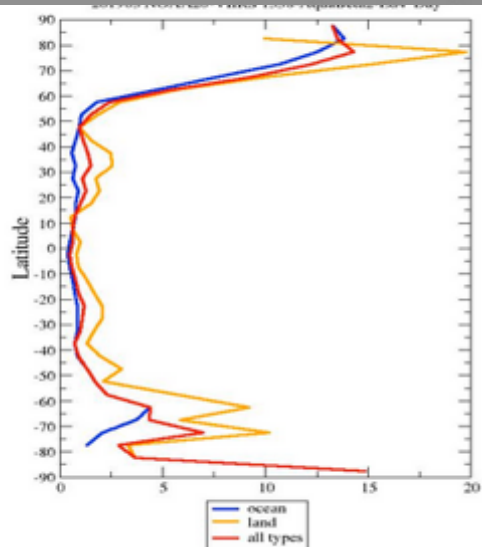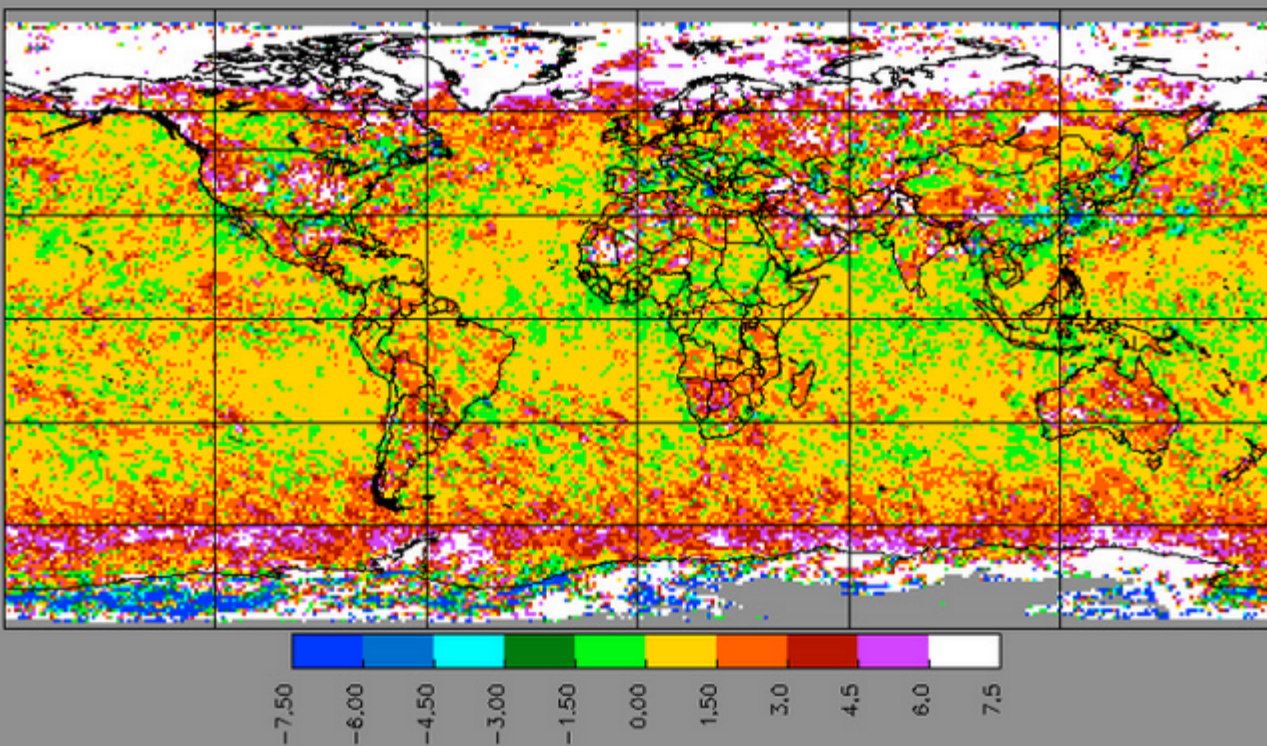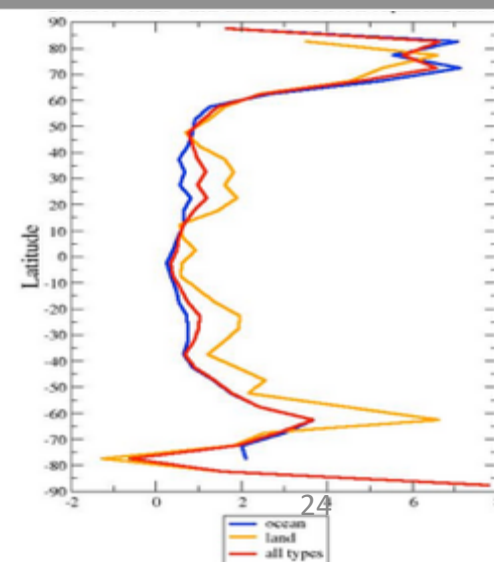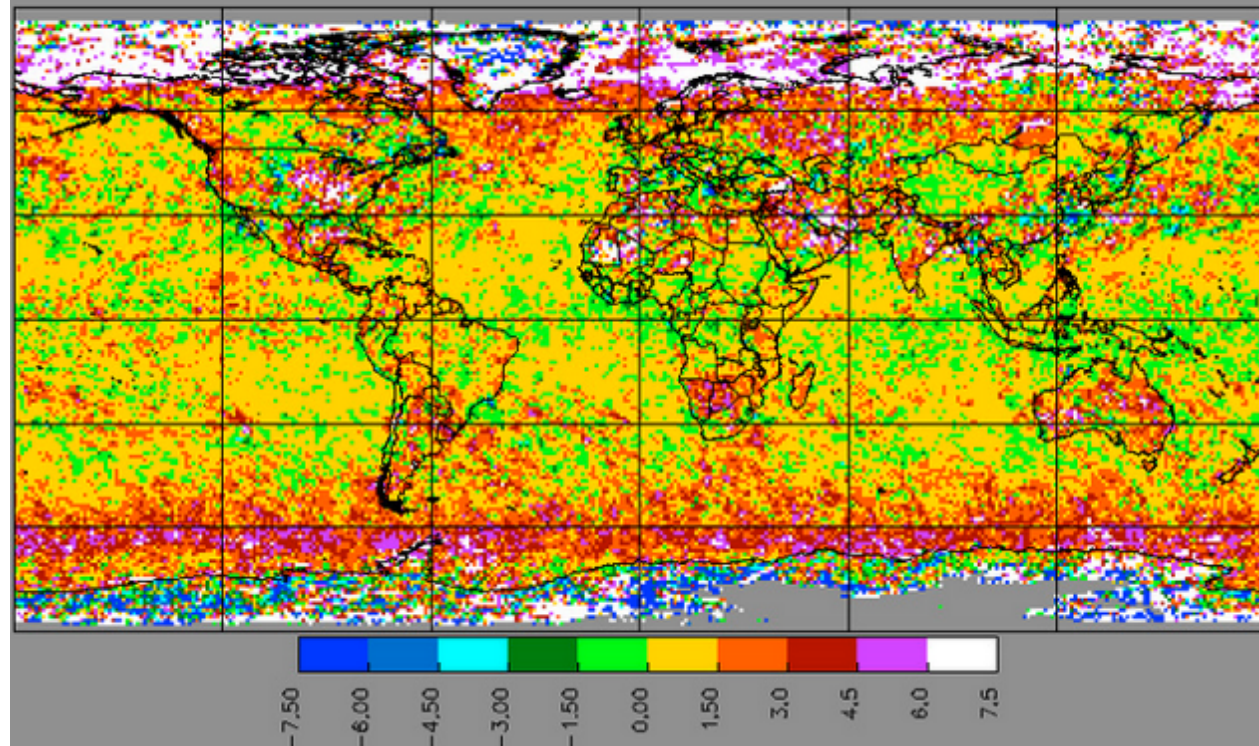
```
Global:      1.1  1.6  1.2
Polar:       4.0  3.3  3.6
NonPolar:    0.7  1.3  0.9
```

Linear Tau averaging

24

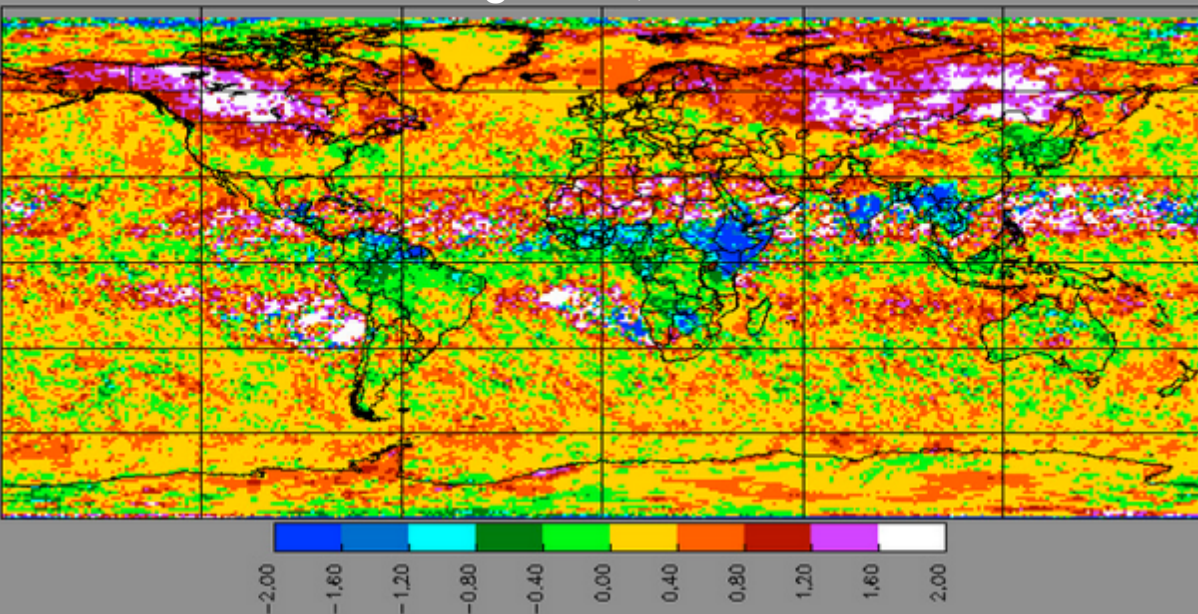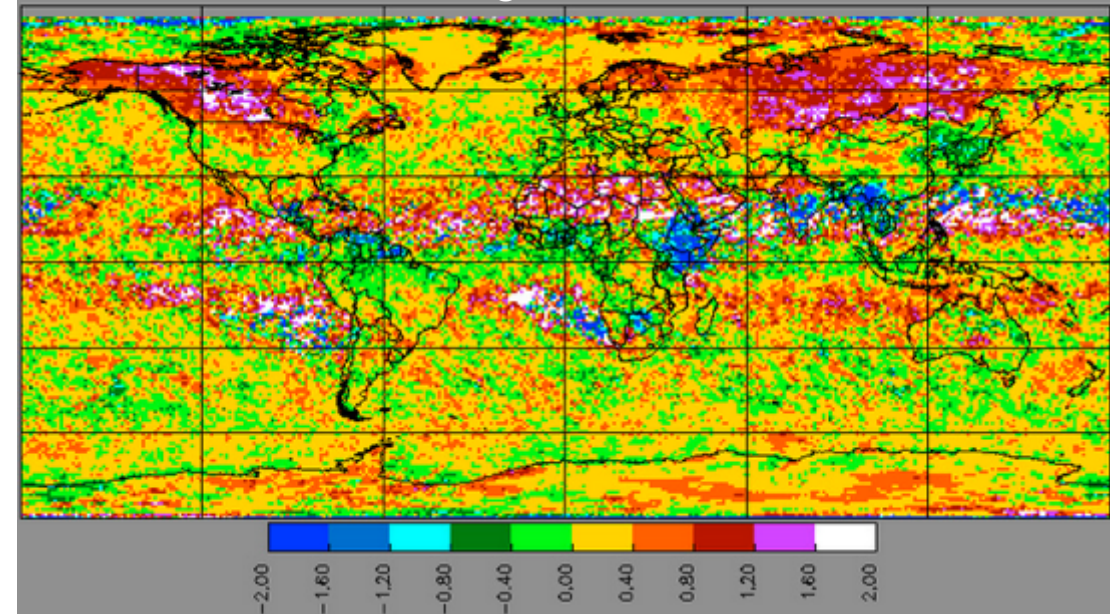201903.NOAA20-VIIRS.1538.minus.AquaBeta2-Ed4.100100.CloudHeight-Ice.Day

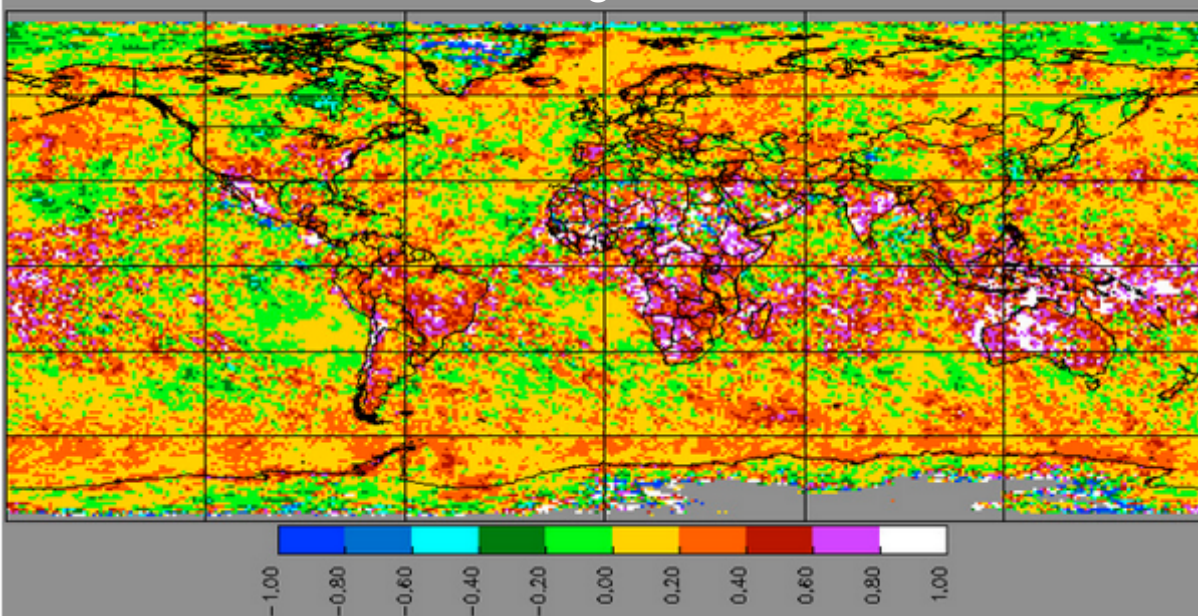Ice Eff Height Diff, Ed1A – Ed4

201903.NOAA20-VIIRS.EEd4MOD12437Par.minus.AquaBeta2-Ed4.100100.CloudHeight-Ice.Day

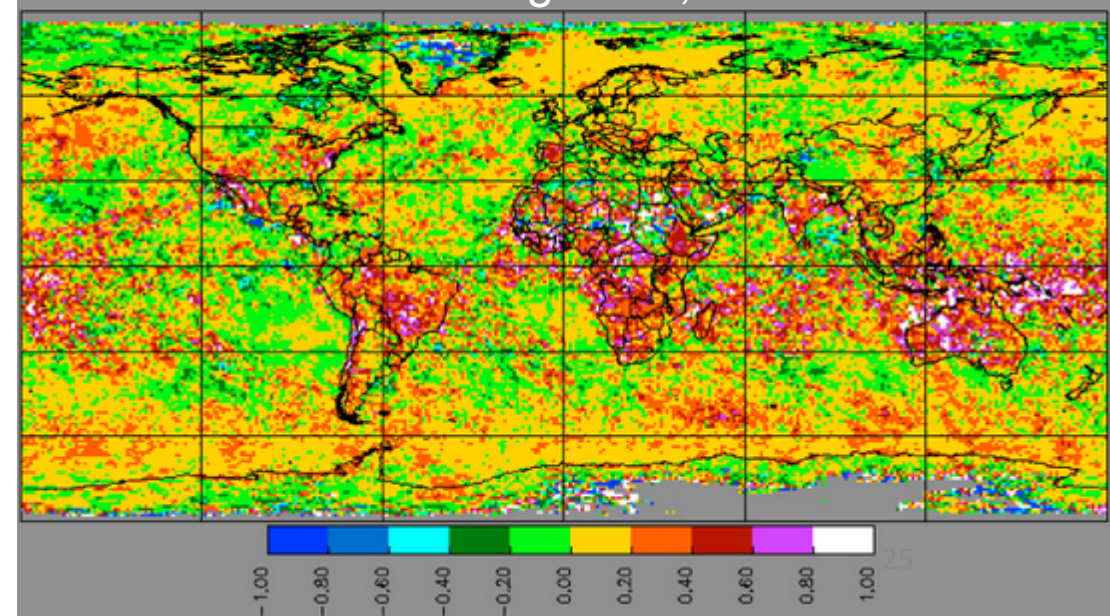Ice Eff Height Diff, Ed1b – Ed4

Eff Height

Ice

201903.NOAA20-VIIRS.1538.minus.AquaBeta2-Ed4.100100.CloudHeight-Water.Day

Water Eff Height Diff, Ed1A – Ed4

201903.NOAA20-VIIRS.EEd4MOD12437Par.minus.AquaBeta2-Ed4.100100.CloudHeight-Water.Day

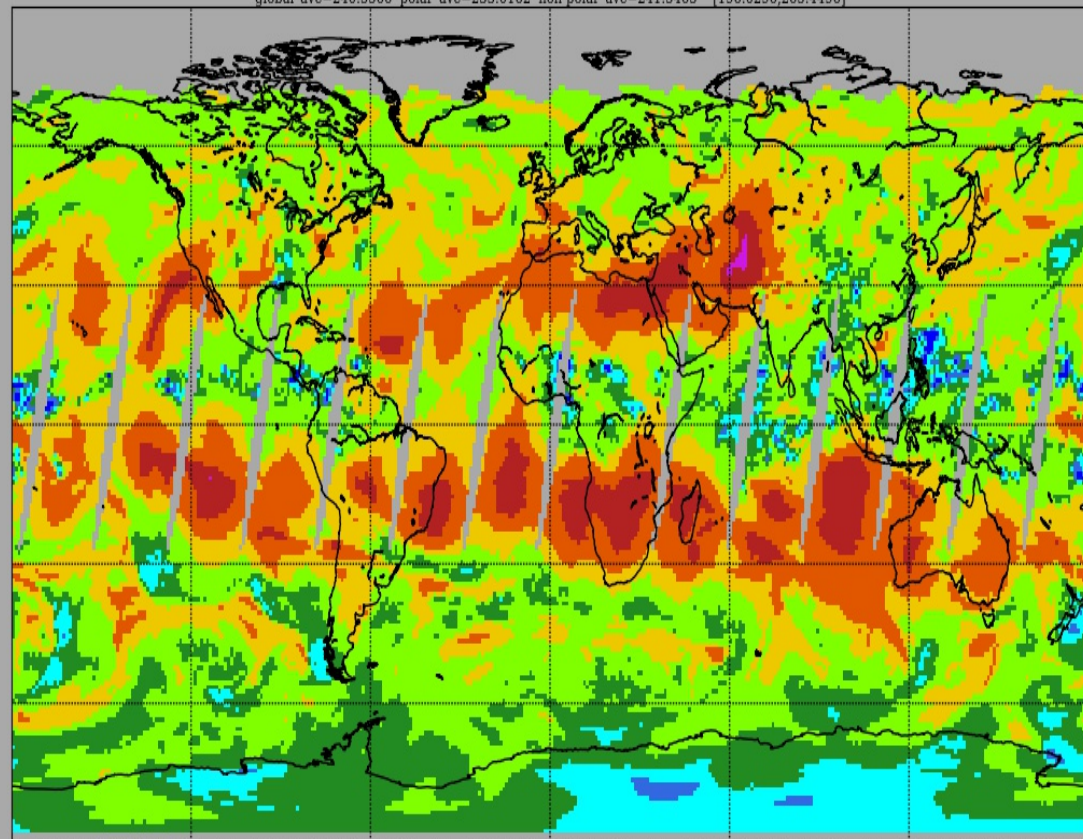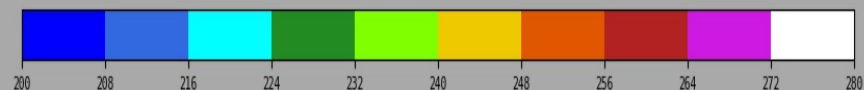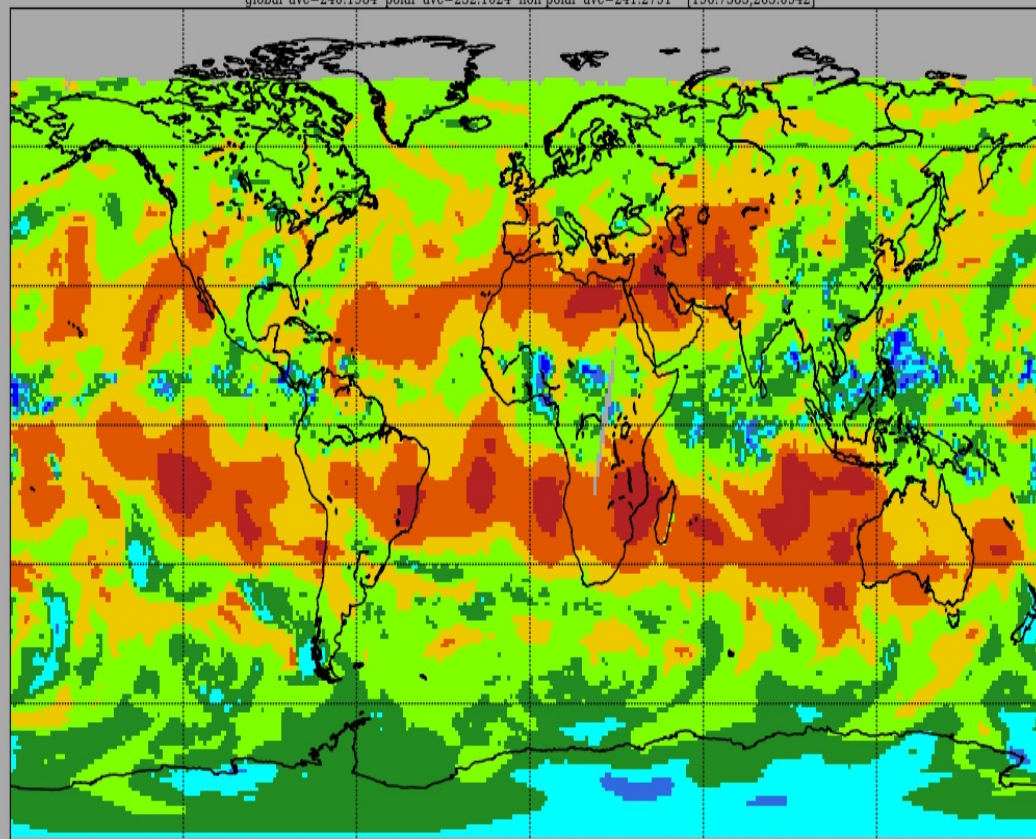Water Eff height Diff, Ed1b – Ed4

Water

Aqua BTemp 6.7 μm

NPP CrIS-constructed BTemp 6.7 μm

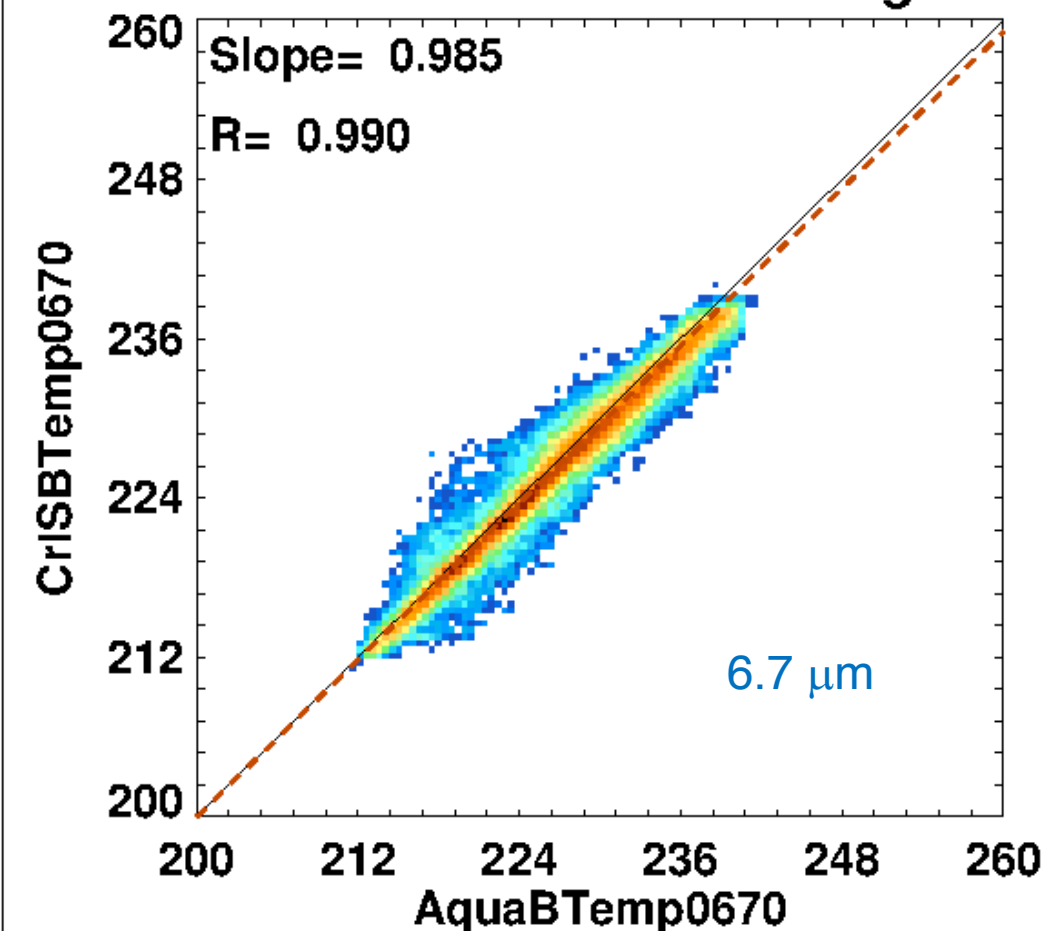global ave=240.5566 polar ave=233.0162 non-polar ave=241.5465   [196.0296,265.4496]

global ave=240.1984 polar ave=232.1024 non-polar ave=241.2791   [196.7385,263.0942]

Zonal Averages

(LATweighted)

		ocean	land	total
90.0 -	85.0:	nan	nan	nan
85.0 -	80.0:	nan	nan	nan
80.0 -	75.0:	nan	nan	nan
75.0 -	70.0:	236.43	237.19	236.71
70.0 -	65.0:	236.55	237.2	237.02
65.0 -	60.0:	236.64	237.04	236.92
60.0 -	55.0:	237.69	237.66	237.67
55.0 -	50.0:	238.5	238.55	238.53
50.0 -	45.0:	239.36	240.03	239.73
45.0 -	40.0:	239.92	242.79	241.26
40.0 -	35.0:	241.81	243.95	242.72
35.0 -	30.0:	243.89	245.27	244.48
30.0 -	25.0:	244.52	246.46	245.3
25.0 -	20.0:	244.09	244.43	244.21
20.0 -	15.0:	240.6	239.77	240.36
15.0 -	10.0:	234.35	231.86	233.79
10.0 -	5.0:	232.53	235.32	233.2
5.0 -	0.0:	237.32	235.69	236.99
0.0 -	-5.0:	241.17	239.52	240.79
-5.0 -	-10.0:	244.42	244.69	244.48
-10.0 -	-15.0:	248.34	252.0	249.06
-15.0 -	-20.0:	250.16	250.92	250.34
-20.0 -	-25.0:	248.97	248.72	248.91
-25.0 -	-30.0:	245.95	246.18	246.0
-30.0 -	-35.0:	242.06	245.67	242.64
-35.0 -	-40.0:	238.65	239.91	238.73
-40.0 -	-45.0:	237.8	234.36	237.68
-45.0 -	-50.0:	237.47	239.61	237.27
-50.0 -	-55.0:	234.1	239.36	234.03
-55.0 -	-60.0:	232.88	nan	232.88
-60.0 -	-65.0:	231.76	227.46	231.75
-65.0 -	-70.0:	229.75	229.29	229.65
-70.0 -	-75.0:	229.08	226.09	227.3
-75.0 -	-80.0:	230.8	224.25	225.07
-80.0 -	-85.0:	nan	225.08	225.08
-85.0 -	-90.0:	nan	223.55	223.55
polar:		232.54	231.66	232.1
non-polar:		240.91	242.32	241.28
global:		240.21	240.16	240.2

200 208 216 224 232 240 248 256 264 272 280

200 208 216 224 232 240 248 256 264 272 280

20190715 Antarctica Ngt

Slope= 0.985

R= 0.990

CrISBTemp0670

AquaBTemp0670

6.7 μm

Log10(Population)
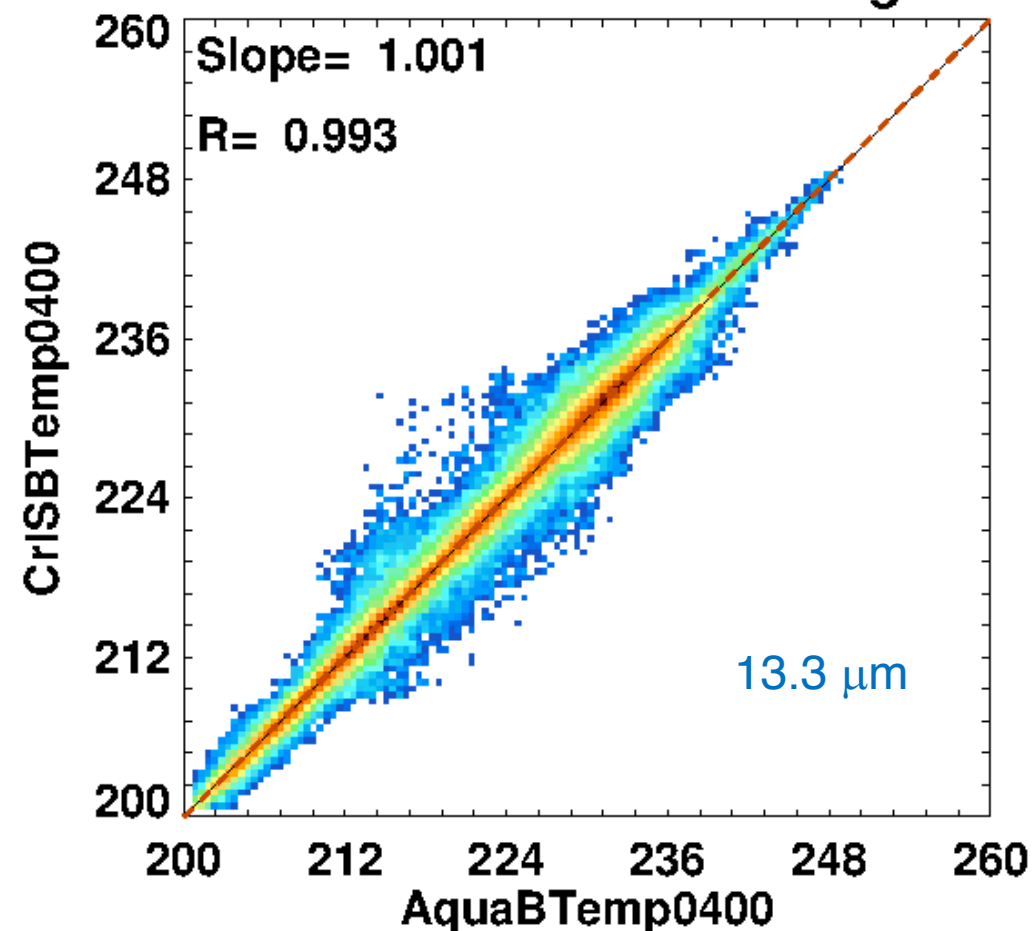0.00 0.71 1.42 2.14 2.85 3.56

N= 242676.   Mean (StdDev)
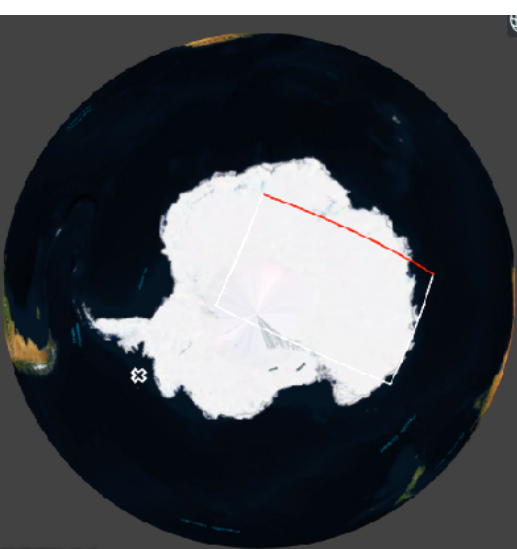AquaBTemp0670   226.3(6.16)
CrISBTemp0670   225.6(6.01)
Y-X   -0.686(0.882)
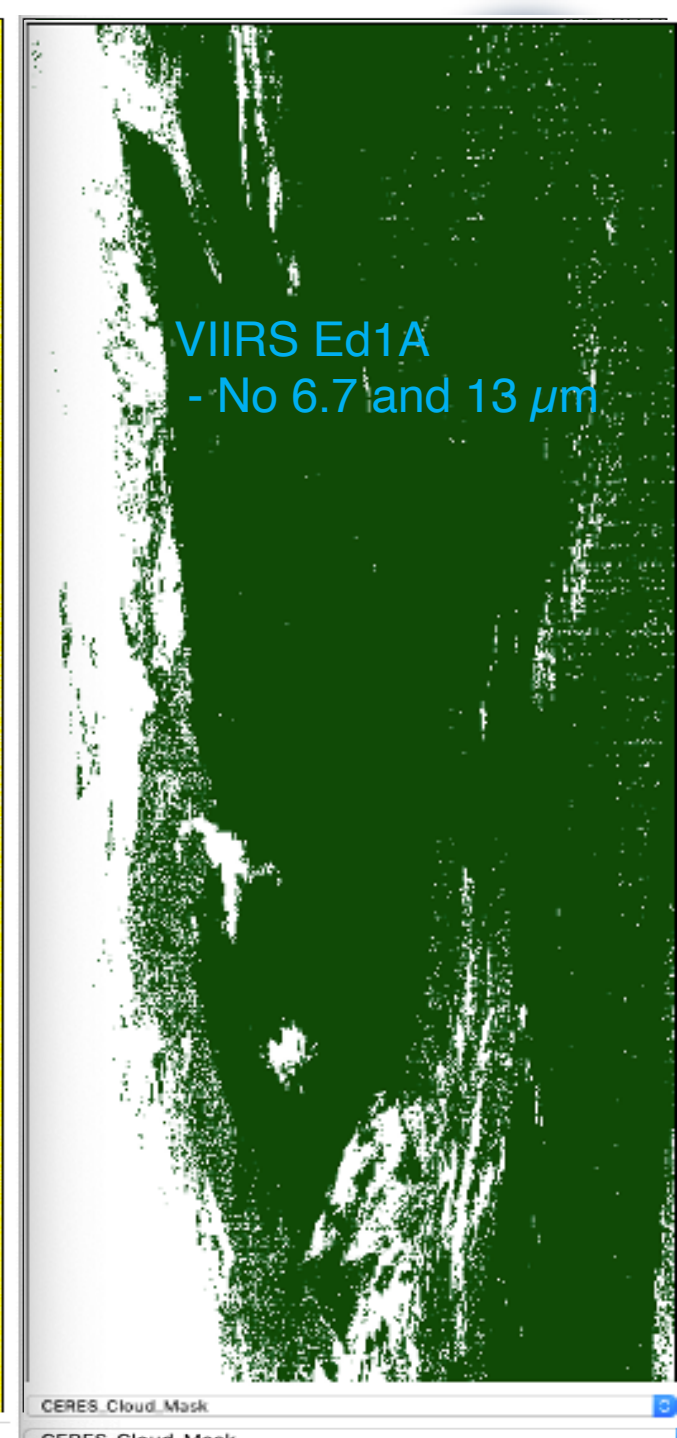RMS(1.12)..............

20190715 Antarctica Ngt

Slope= 1.001

R= 0.993

CrISBTemp0400

AquaBTemp0400

13.3 μm

Log10(Population)
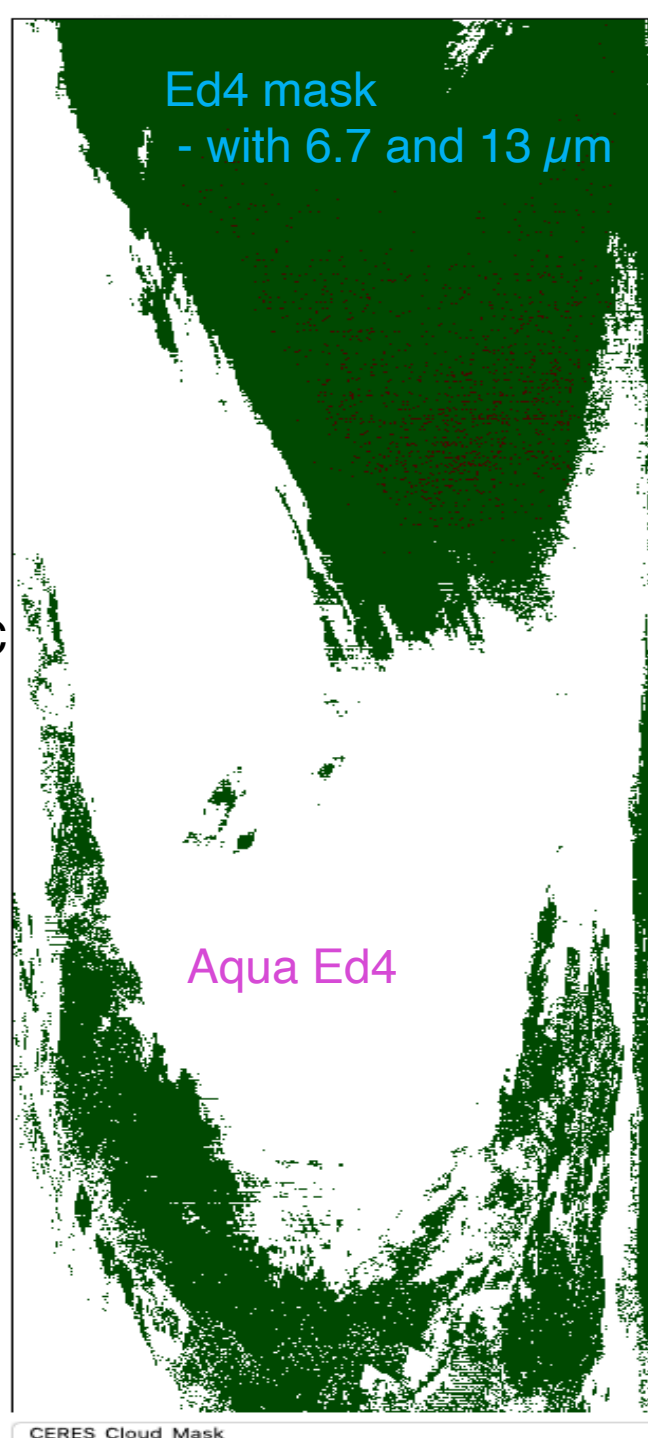0.00 0.68 1.37 2.05 2.74 3.42

N= 242063.   Mean (StdDev)
AquaBTemp0400   221.5(9.72)
CrISBTemp0400   221.5(9.78)
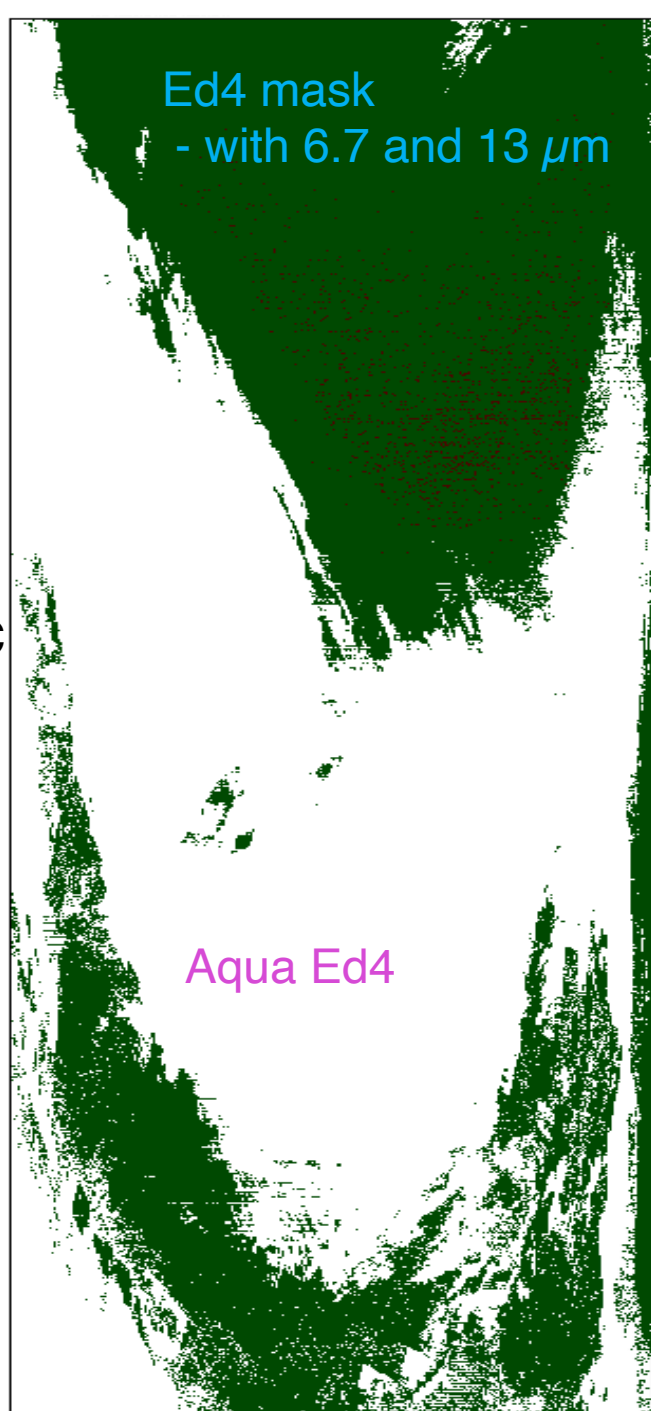Y-X   0.049(1.14)
RMS(1.14)..............

Antarctica
Night Time
Matched Pixels
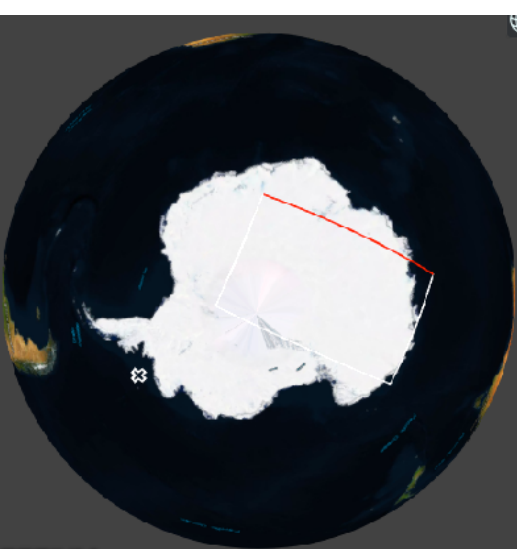
Aqua 2019 07 15 09UTC

Ed4 mask
- with 6.7 and 13 μm

Aqua Ed4

VIIRS Ed1A
- No 6.7 and 13 μm

CERES_Cloud_Mask

Modis_RGB

CERES_Cloud_Mask

CERES_Cloud_Mask

Aqua 2019 07 15 09UTC

Ed4 mask
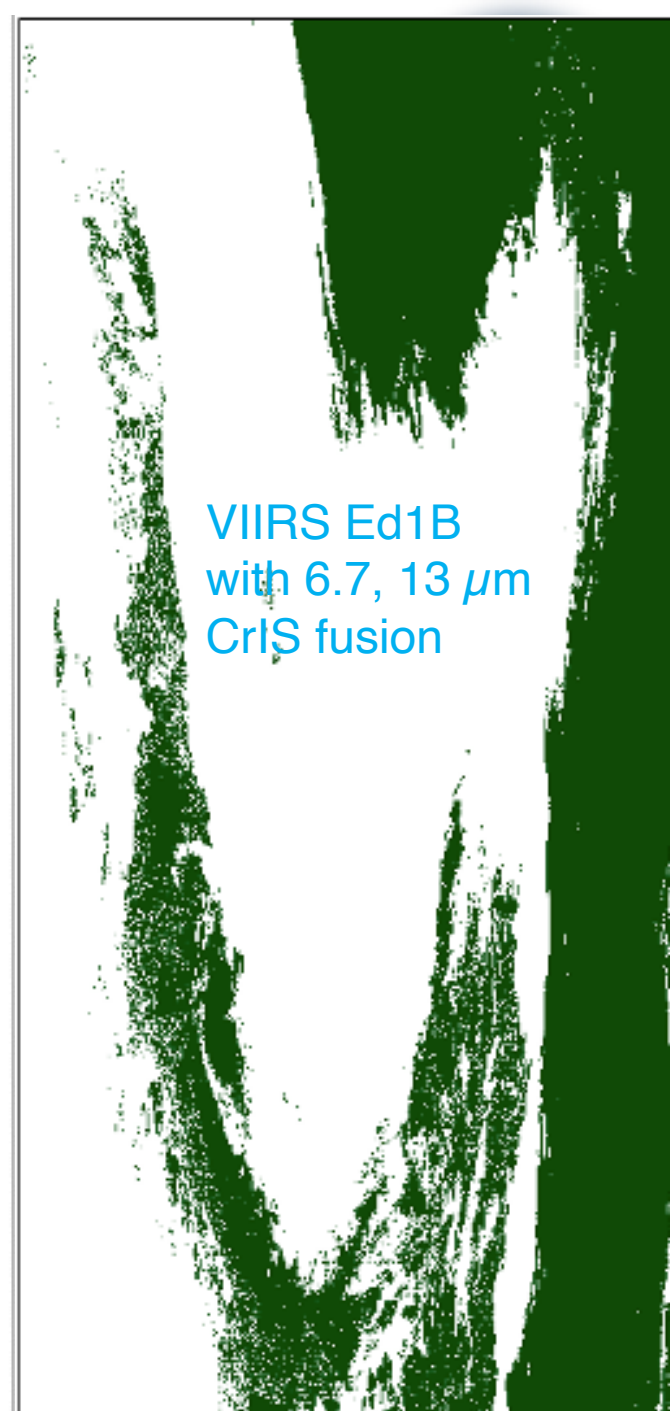- with 6.7 and 13 μm
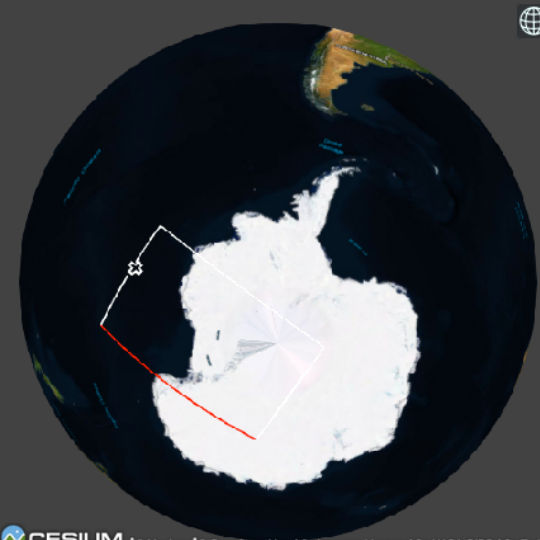
Aqua Ed4

VIIRS Ed1B
with 6.7, 13 μm
CrIS fusion

CERES_Cloud_Mask

Modis_RGB

CERES_Cloud_Mask

Aqua 2019 07 15 04UTC

Clear Restore
With 6.7 & 13.3 μm

Ed4 mask
- with 6.7 and 13 μm

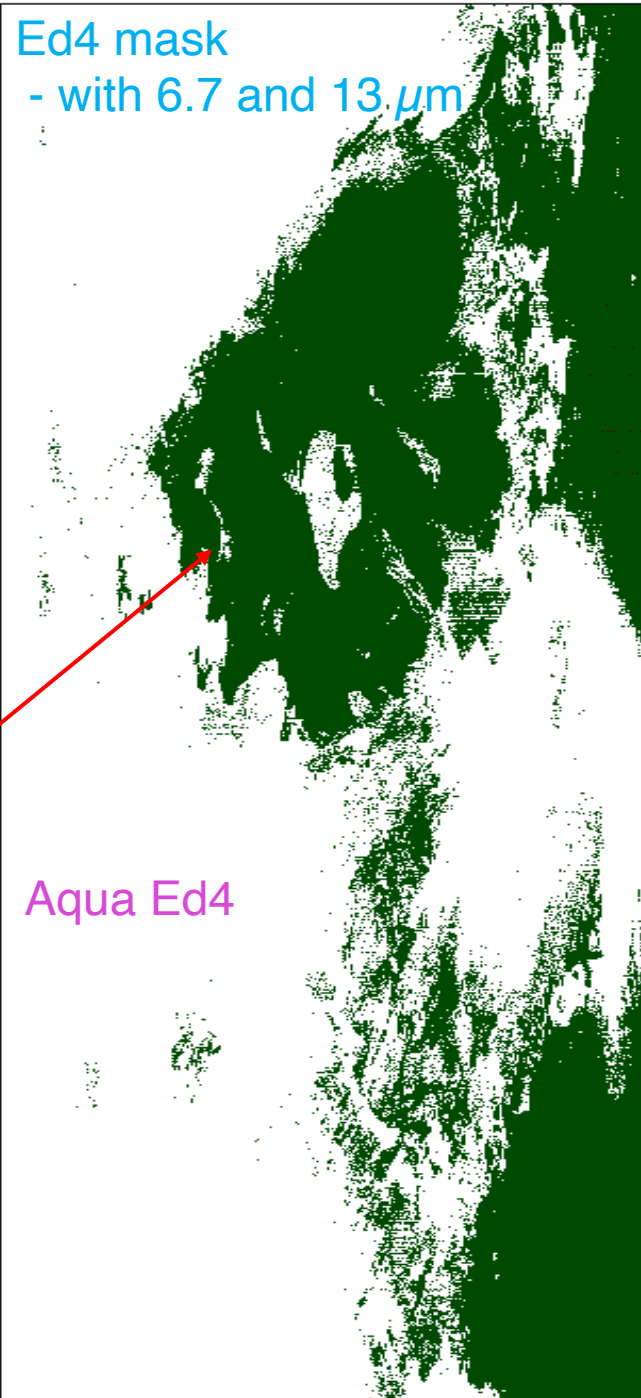Aqua Ed4

VIIRS Ed1A
- No 6.7
and 13 μm

CERES_Cloud_Mask

Modis_RGB

CERES_Cloud_Mask
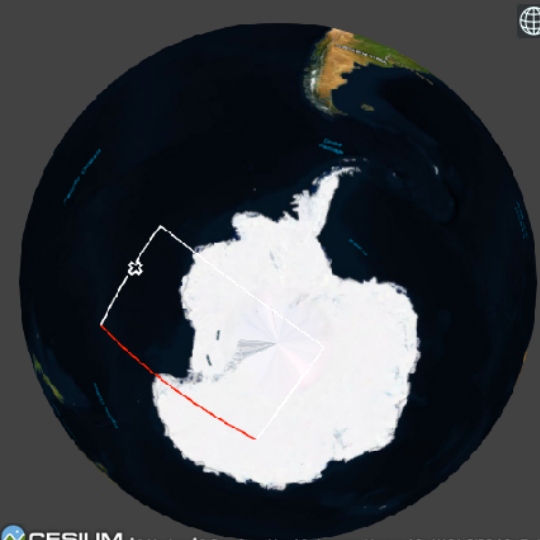
Aqua 2019 07 15 04UTC

Clear Restore
With 6.7 & 13.3 μm

Ed4 mask
- with 6.7 and 13 μm

Aqua Ed4
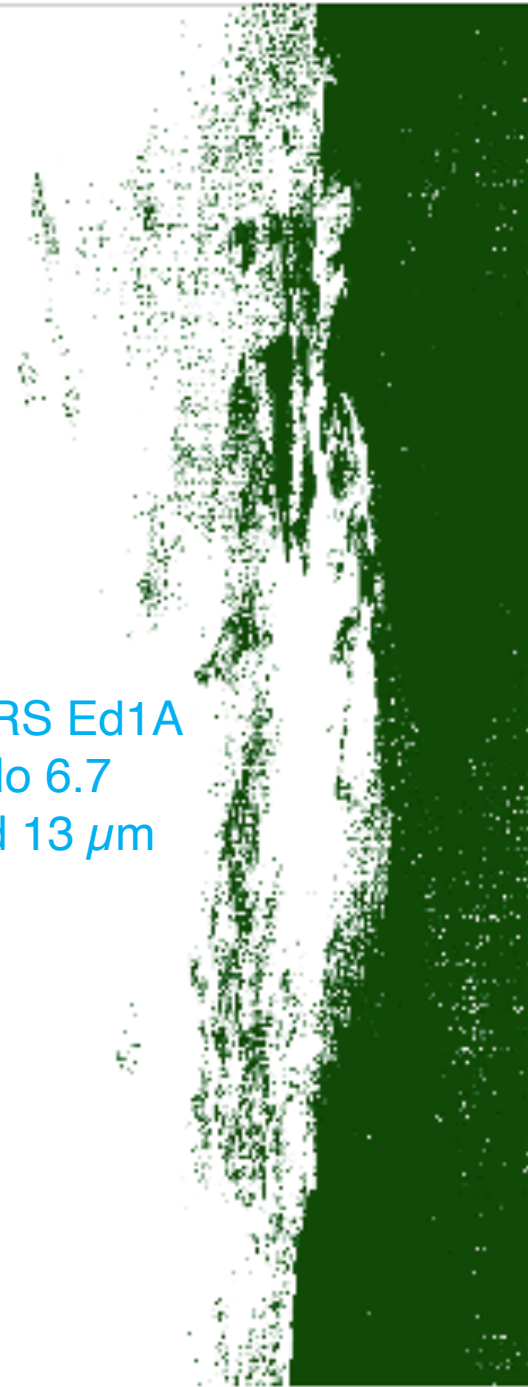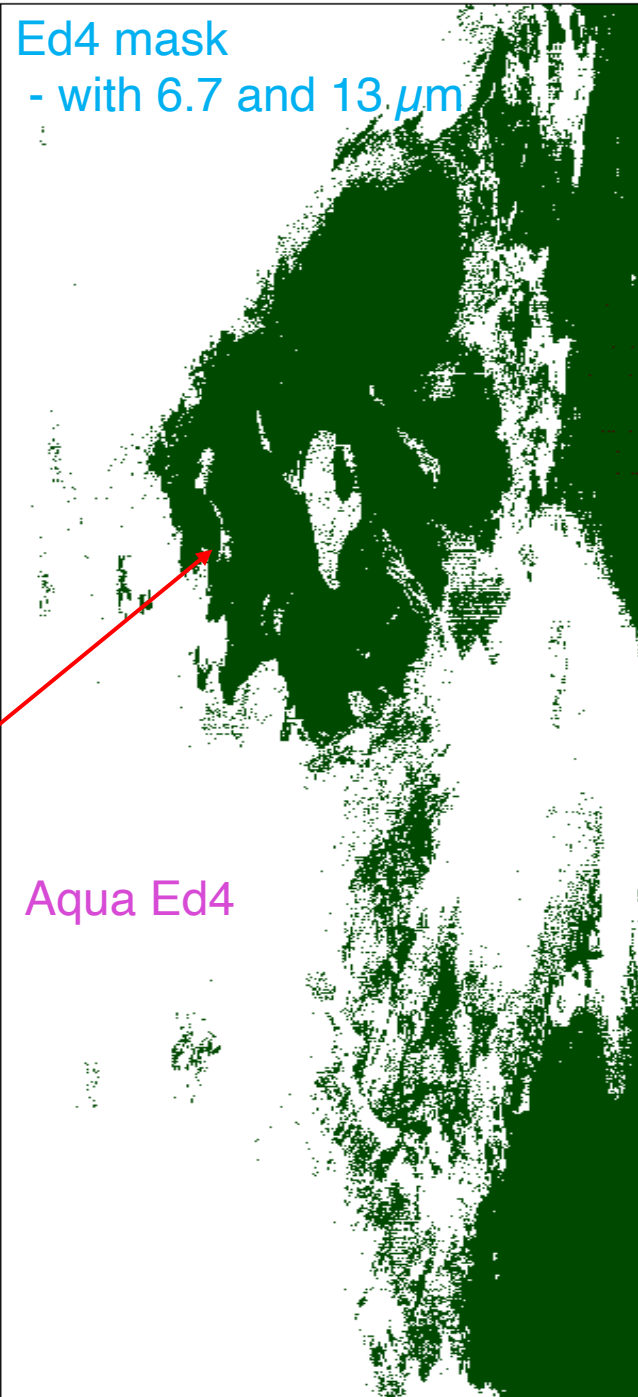
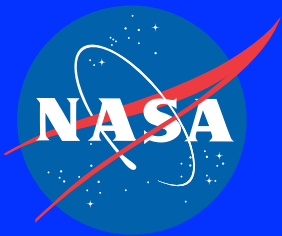VIIRS Ed1B
with 6.7, 13 μm
CrIS fusion
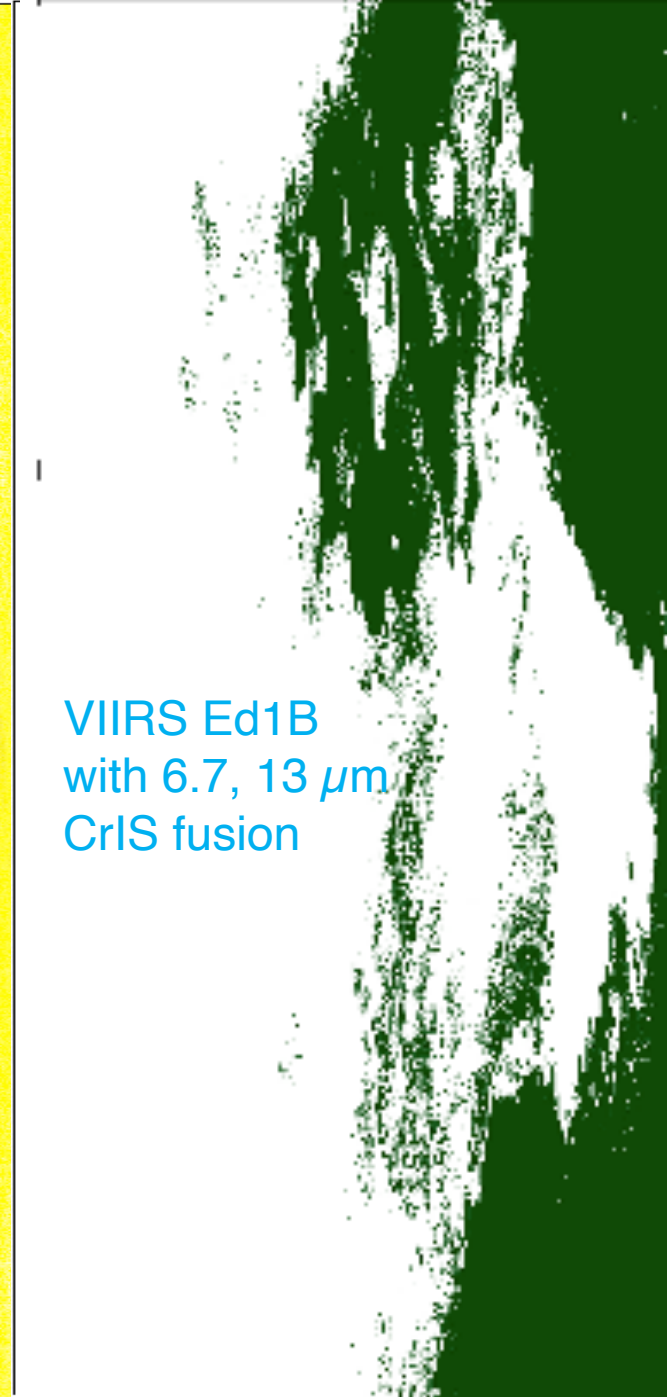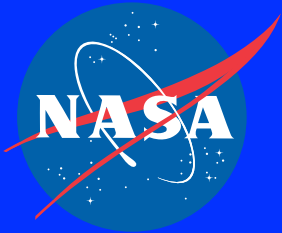
CERES_Cloud_Mask   Modis_RGB   CERES_Cloud_Mask

Summary

- GOES-17 is delivered and processing using an approach that mitigates the loss of nighttime imagery in some bands due to a detector cooling problem. Appears to be working great.

- We've started developing an intermediate VIIRS edition (Ed1B) for NOAA 20 to improve consistency with Ed4 that could be used to exetnd the Aqua CDR prior to Ed5 (or fill gaps).

- Initital results are encouraging and should improve further once we put everything together (mask + retrieval + fusion) .

- Ed1B should significantly improve consistency with Ed4 relative to Ed1A and we will learn a lot moving forward with Ed5 development.

QUESTIONS ?