CERES Clouds Working Group Report

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Thanks to Dave Doelling and his TISA/calibration teams!

Topics

- Data processing status
- Ed5 cloud algorithm development and evaluation
  - Consistency of cloud properties across satellites
  - Neural Net for cloud top heights
  - Two-habit ice model in GEO
  - 2-channel satellite update
- New SatCORPS capabilities

Clouds Processing Status (MODIS & VIIRS)

CERES-MODIS Edition 4 (*CDR)	*Aqua: Jul 2002 – Feb 2023 (~ 20.5 y)* *Terra: Feb 2000 – Feb 2023 (~ 23 y)*	• *Uses frozen Ed4 cloud codes delivered in 2013* • *MODIS Collection 5 radiances thru Feb 2016,* • *MODIS Collection 6.1 March 2016 – present and scaled to C5 for consistency over entire record* • *Terra-MODIS normalized to Aqua-MODIS (Sun-Mack, et al. 2018)*
CERES-VIIRS Edition 1A	*SNPP: Jan 2012 – Jun 2021 (~ 9.5 y)* *NOAA-20: Jan 2018 – Jun 2021 (~ 3.5 y)*	• *Uses VIIRS Ed1A cloud code* • *SNPP uses forward processing calibrations (C1 radiances), not scaled to MODIS; has discontinuity ~2016 due to a calibration update by SIPS* • *N20 uses C2 radiances and scaled to MODIS C5*
CERES-VIIRS Edition 2A	*SNPP: Jan 2012 – Feb 2023 (~ 10 y)*	• *Uses VIIRS Ed1A cloud code* • *Uses C2 radiances and scaled to MODIS C5*
CERES-VIIRS Edition 1B (*CDR)	*NOAA-20: Jan 2018 – Feb 2023 (~ 5 y)*	• *Uses new version of VIIRS cloud code (temporary continuity version until Ed5 is released)* • *Fills Aqua-MODIS gap in Aug 2020*

Ed5 Cloud Algorithms

- MODIS and VIIRS algorithms will be as similar as possible and use 11 common channels while retaining many of the advances made for Ed4.
- For GEO (20+ satellites), a 3-channel approach is developed and being evaluated for daytime (0.63, 3.9, 11 µm) and nighttime (3.9, 11, 6.7 µm).
    - except for Met-5, Met-7, and GMS-5 (0.63, 11 µm) which comprise 20% of GEO data
- To improve accuracies and consistency, Ed5 LEO and GEO algorithms have bug fixes, refined cloud masks, updated cloud models & atmospheric corrections, use of new ancillary datasets (e.g. snow/ice maps, clear sky radiances), and incorporation of machine learning algorithms.
- Ed5 cloud algorithms will employ information from the GEOS-IT to keep pace with latest GMAO reanalysis systems
    - GEOS-IT datasets must be in place to finalize algorithms

MODIS Central Wavelength (µm)	VIIRS Central Wavelength (µm)
0.65	0.64
1.61	1.61
2.13	2.26
3.78	3.74
11.0	10.8
12.0	12.0
8.55	8.55
1.24	1.24
0.47	0.49
1.38	1.38
0.86	0.86
~~6.71~~	N/A
~~13.3~~	N/A

Ed5 Cloud Algorithm Evaluation
(Initial versions)

Ed5 challenge: To what extent can we develop and apply common algorithms to disparate LEO and GEO data?

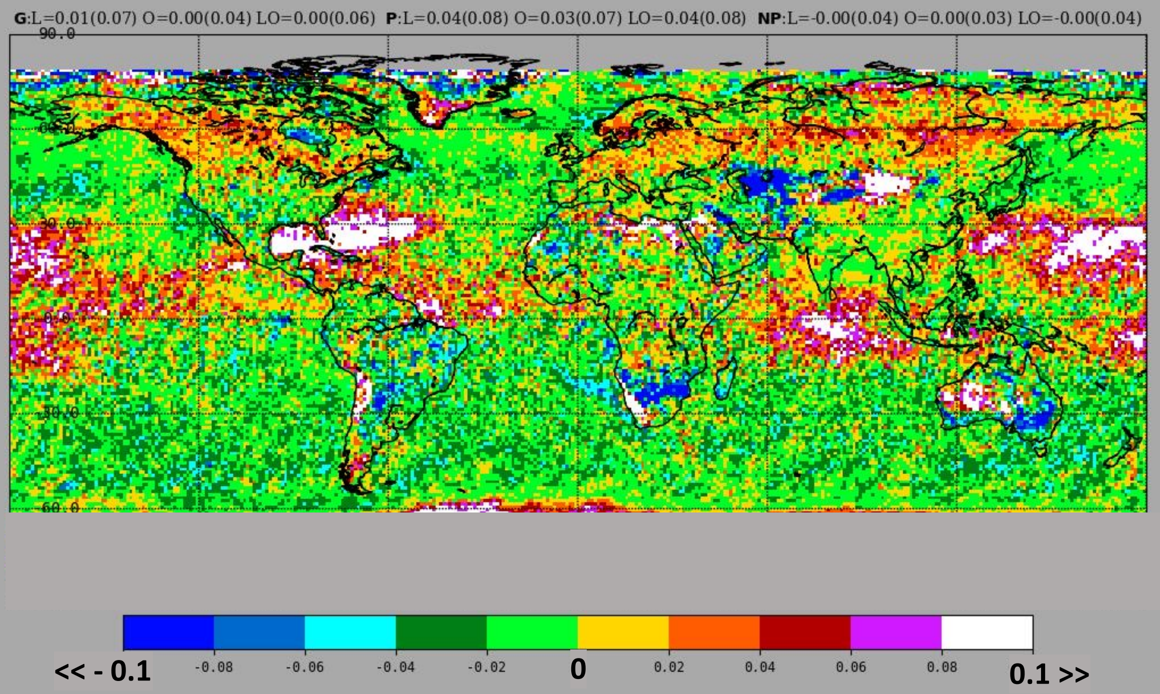
- Cross-platform consistency is a difficult given all of the satellite imagers in the record and their different characteristics.
- Our current focus is on MODIS/VIIRS consistency and the consistency across GEO sensors, particulary with respect to cloud detection (first order problem).
- Goal is to apply a similar cloud mask (10-channels) to MODIS/VIIRS and likewise a common 3-channel mask to the GEO's (want to avoid having to tune 23 GEO satellites).

Evaluations

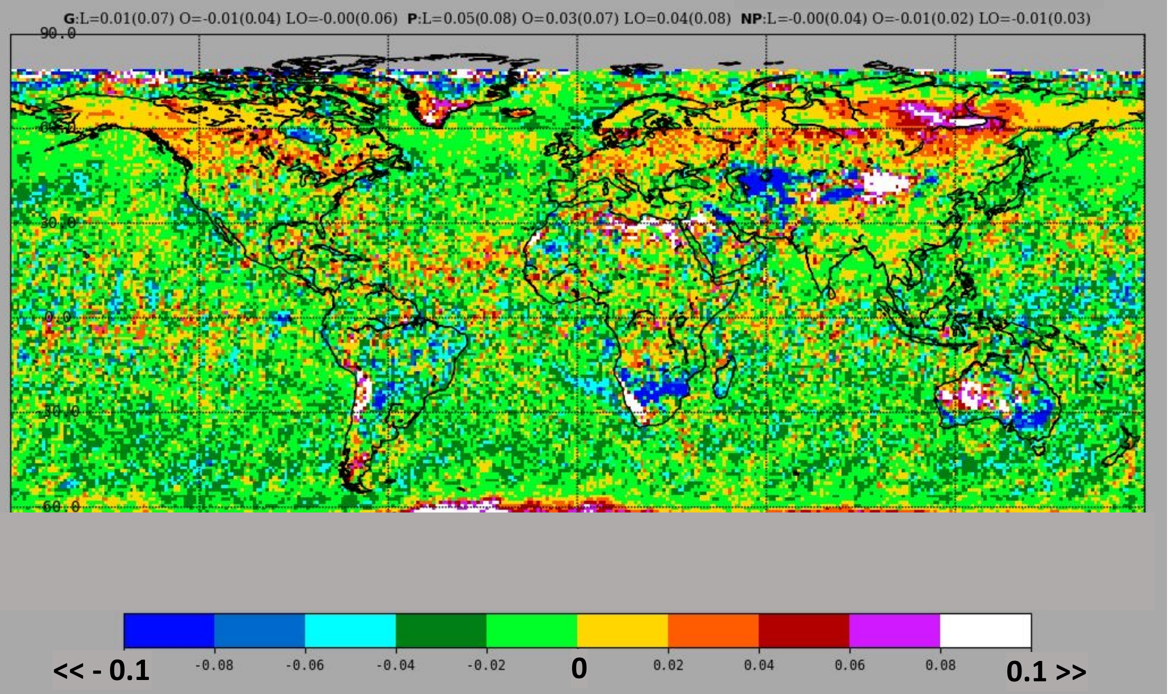
- Cloud property comparisons between Aqua-MODIS and NOAA-20 VIIRS in Ed5 vs. Ed4/Ed1B which comprise the current cloud CDR.
- Cloud property comparisons between GOES-16 and GOES-13 to evaluate Ed5 consistency relative to Ed4.

Total Cloud Fraction Difference: VIIRS Ed5 minus AQUA Ed5 (July 2019, Night)

V1, same cloud mask



V2, tuned masks



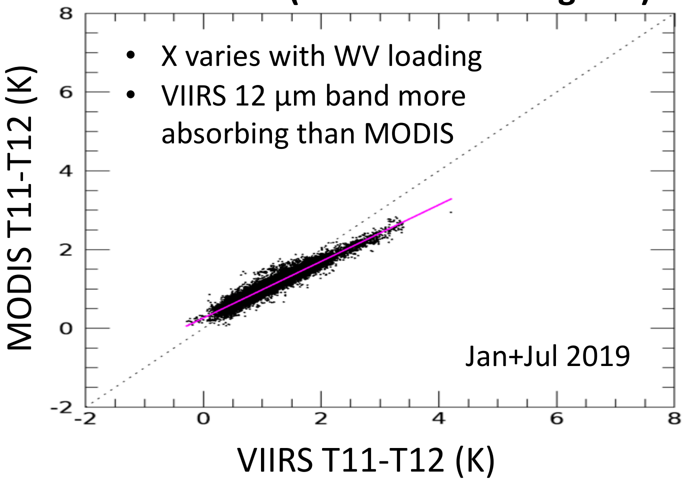
- Focus on non-polar ocean (land mask, polar night awaiting new inputs)
- Untuned (left) is the same cloud mask (v1) applied to MODIS and VIIRS
- Good agreement in many oceanic areas except at low latitudes where many more high clouds are being detected from MODIS
- Tuned version (right) applies different cloud masks, e.g.

  Thin cirrus test: If T11-T12 > X, then test passes (cloud)

  X = 1.5 K (MODIS) & X = 2.2 (VIIRS), X is expected clear sky BTD
- Problems: Tuning is subjective, must tune all 25+ satellites (?), X is constant everywhere (can lead to whack amole)

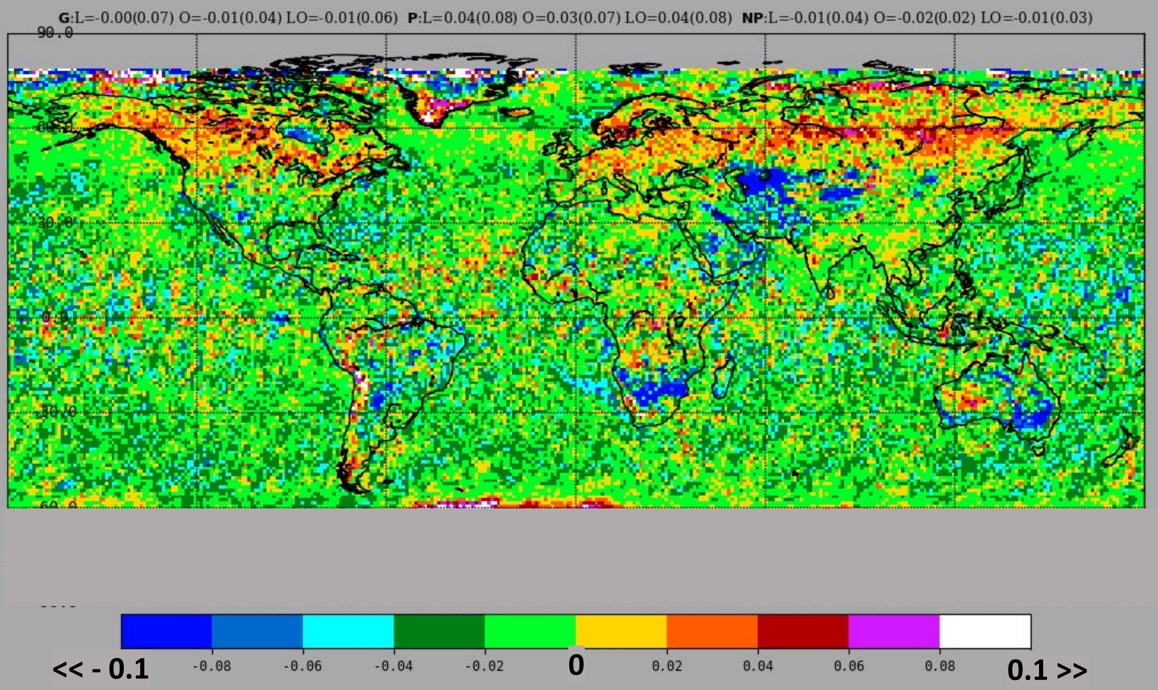
Why tune (why does X vary) ?

Observed X (CALIPSO Clear regions)

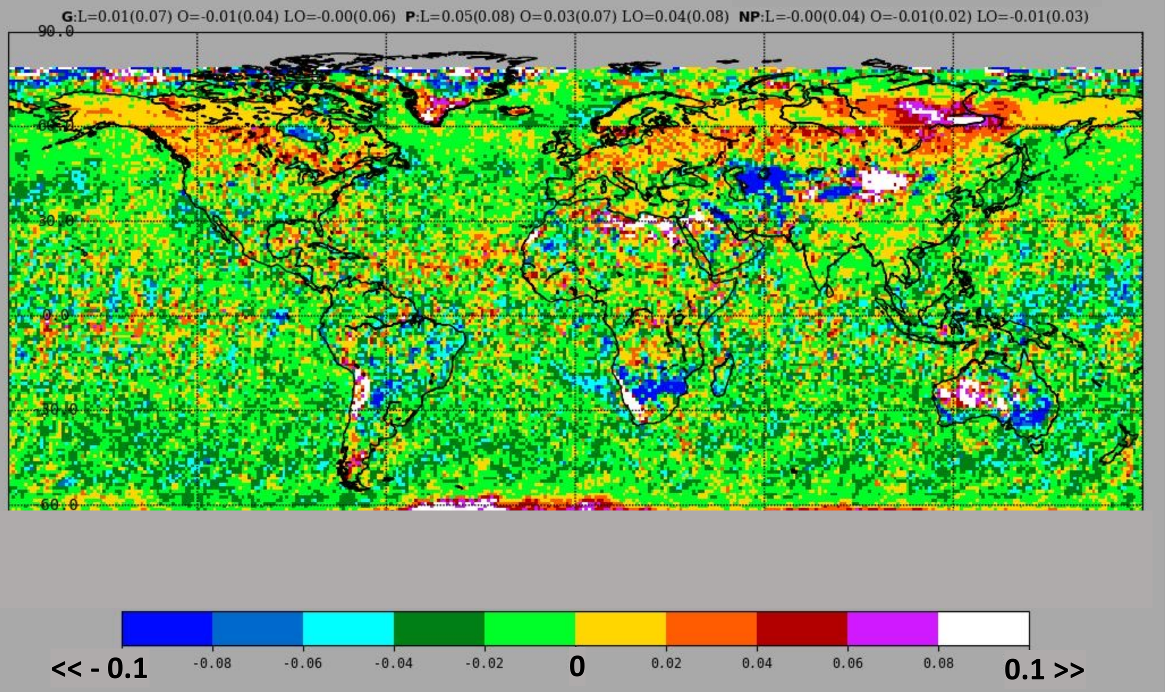


Total Cloud Fraction Difference: VIIRS Ed5 minus AQUA Ed5 (July 2019, Night)

Ed5 (v3), same mask



V2, tuned masks



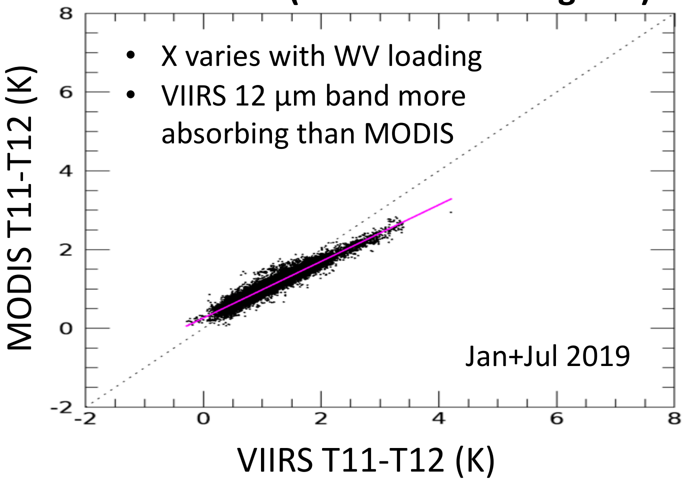
- In the latest version (v3), this thin cirrus test is modified so that the clear sky simulations are included in the threshold to better account for regional variations in water vapor absorption on T11 and T12.

  T11-T12 > X + (csT11-csT12) , X is same for MODIS and VIIRS

- This produces monthly mean differences that are consistent with the tuning approach but allows us to apply an identical cloud mask to both sensors.

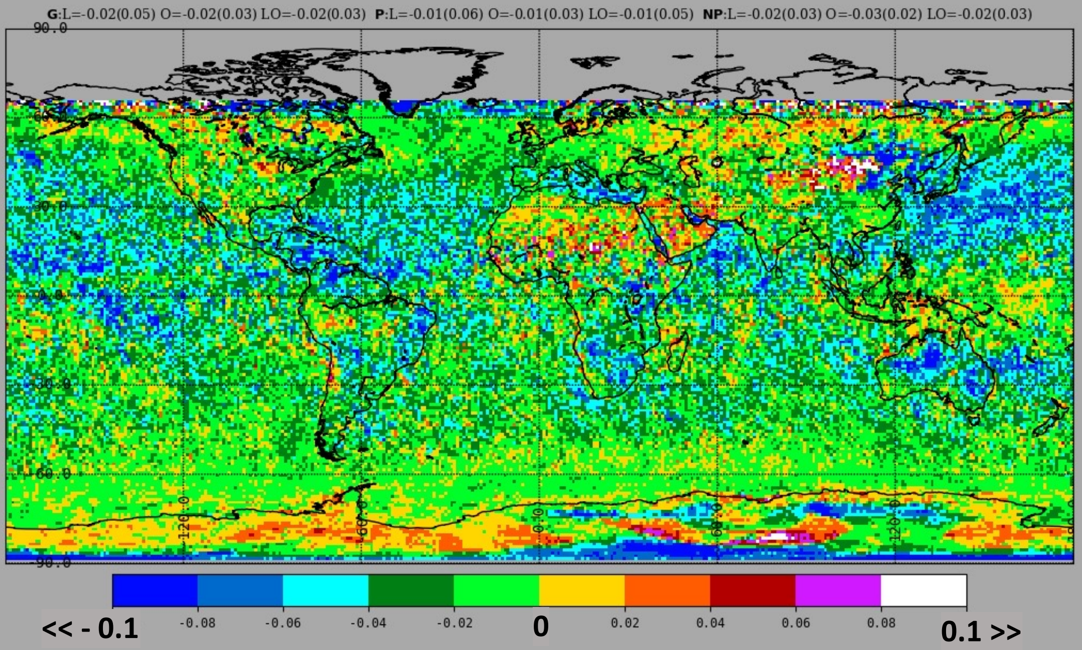
Why tune (why does X vary) ?

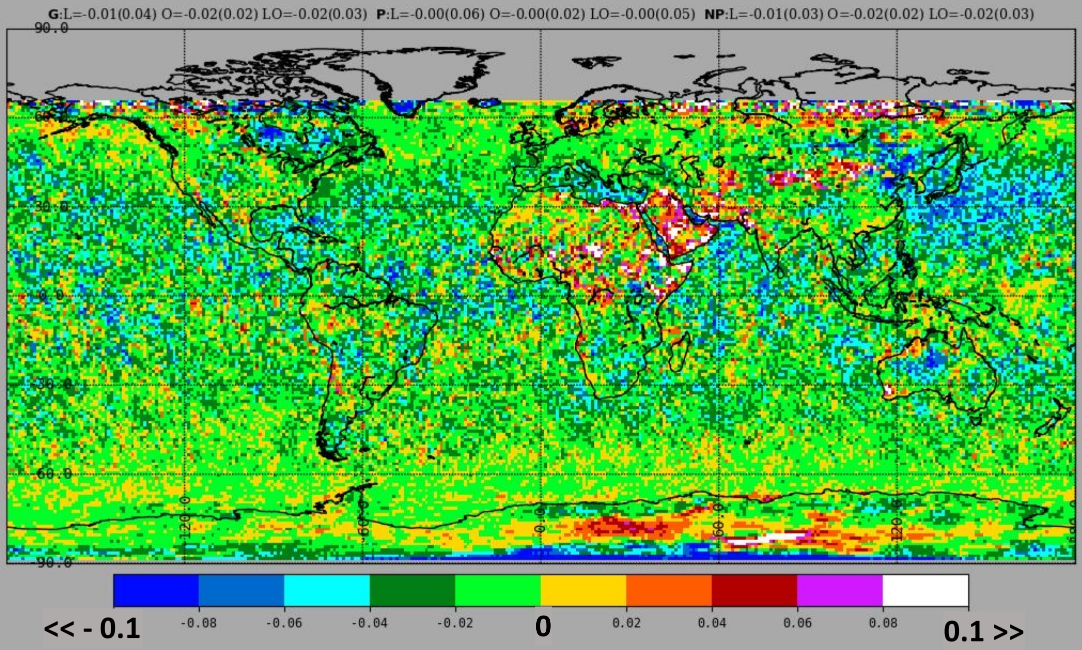
Observed X (CALIPSO Clear regions)



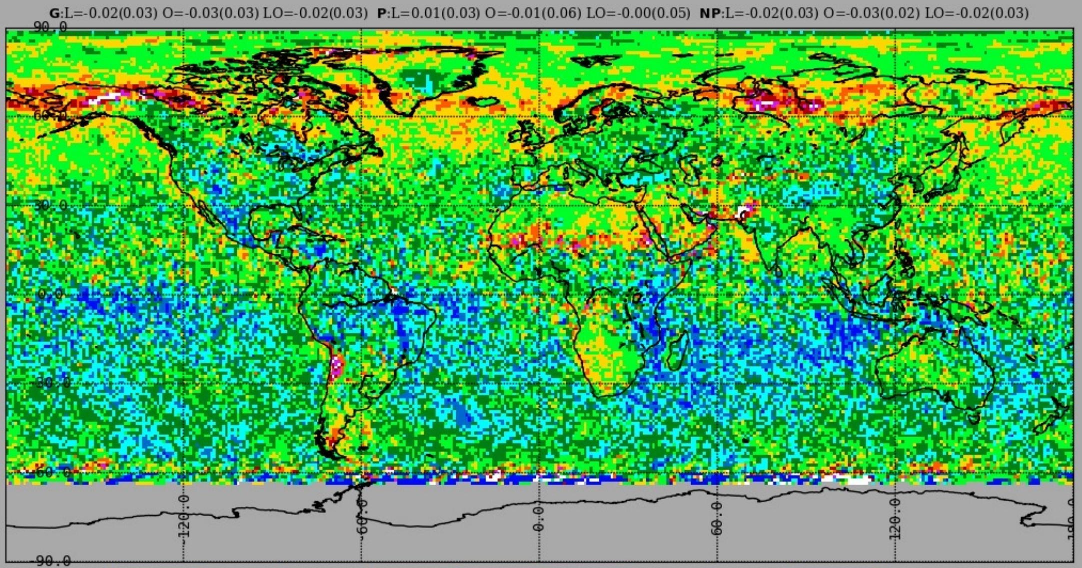
Daytime Total Cloud Fraction Difference: VIIRS minus AQUA

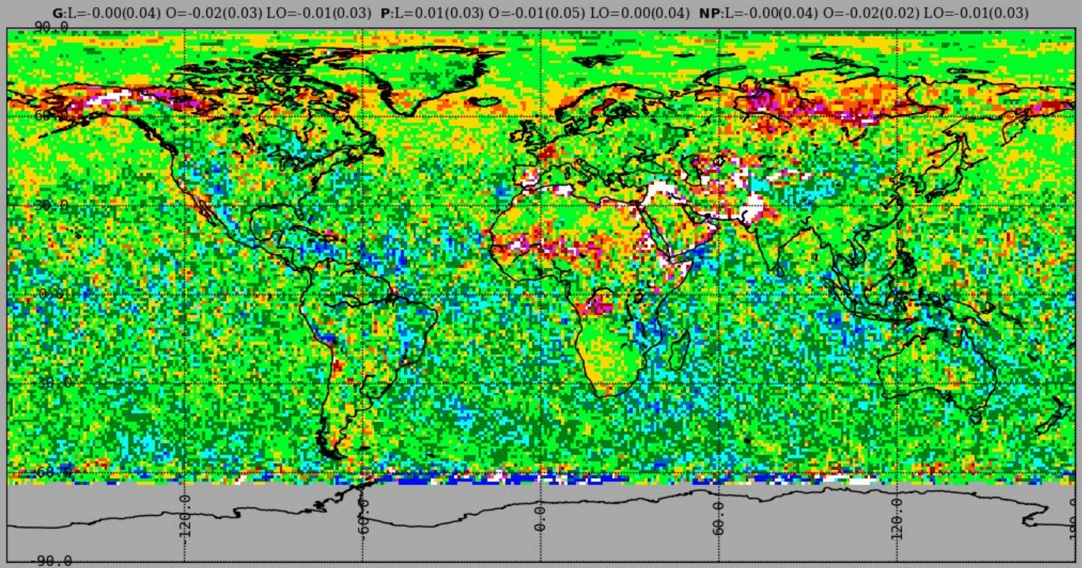
Ed1B – Ed4 | **Ed5 v3**





Jan 2019





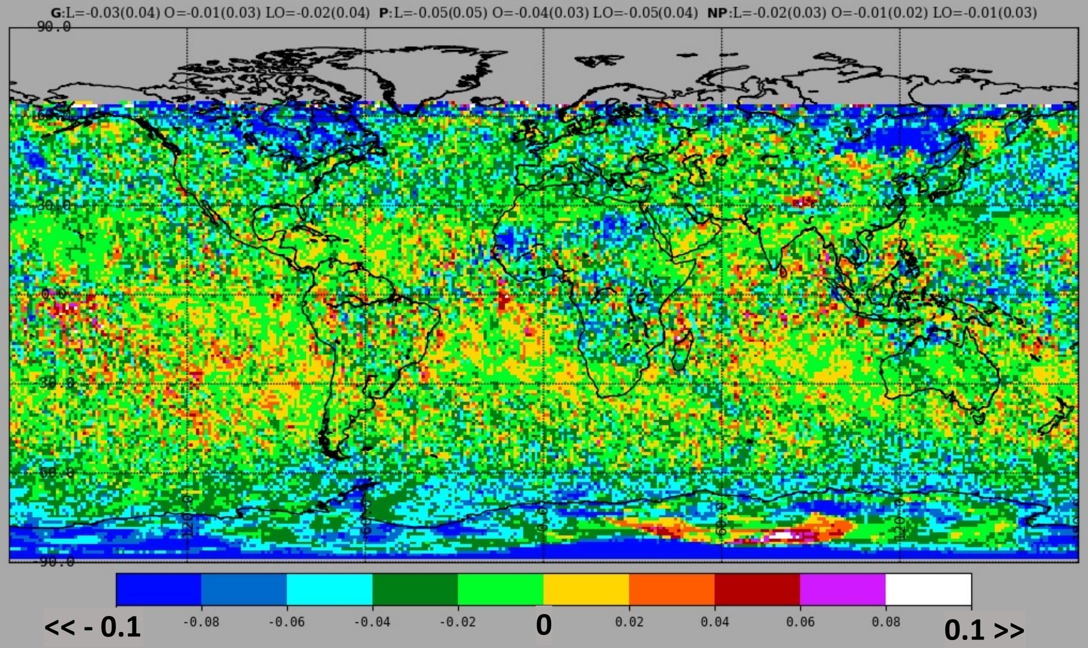
July 2019

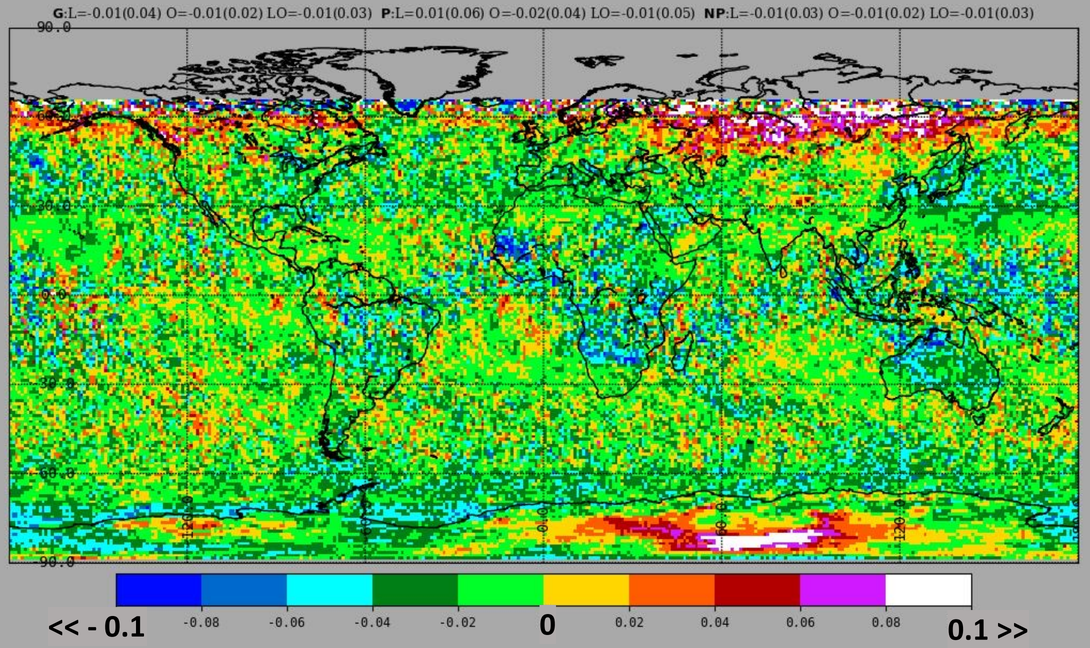
- VIIRS Ed1B tuning to MODIS Ed4 results mixed
- Fewer oceanic clouds detected from VIIRS

- Ocean and polar land consistency better with Ed5 approach
- Non-polar land mask needs work, awaiting new inputs

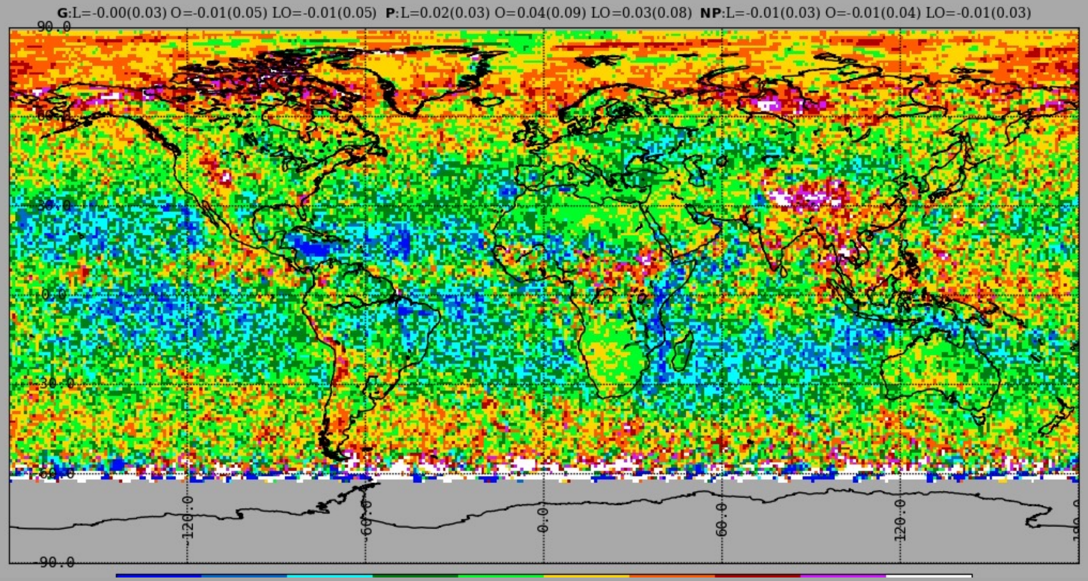
July Daytime Cloud Fraction Difference by Phase: VIIRS minus AQUA

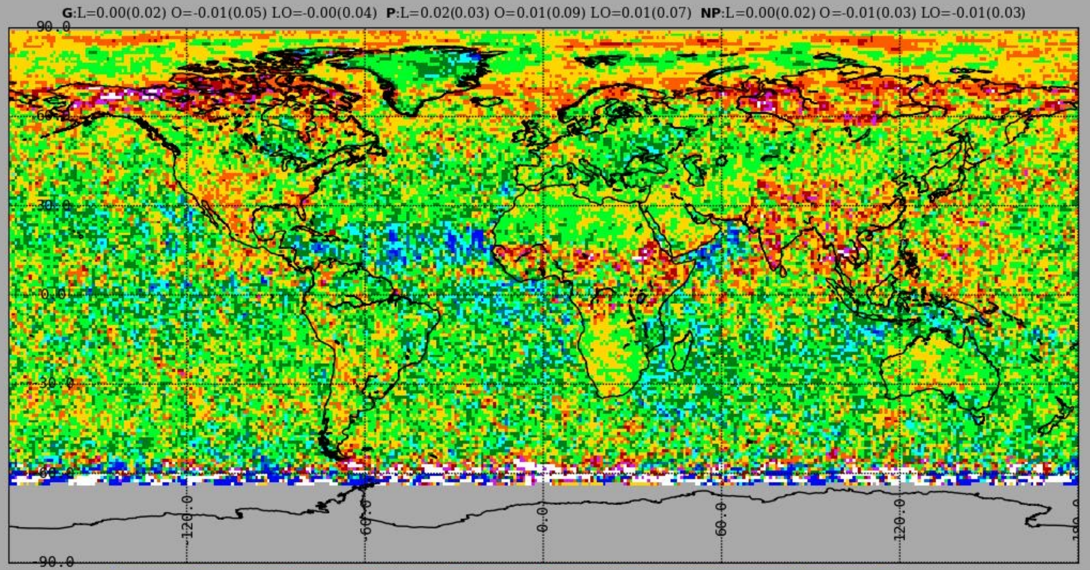
Ed1B – Ed4 | **Ed5 v3**





Ice Cloud Fraction





Water Cloud Fraction

- Fewer oceanic clouds detected from VIIRS are water clouds

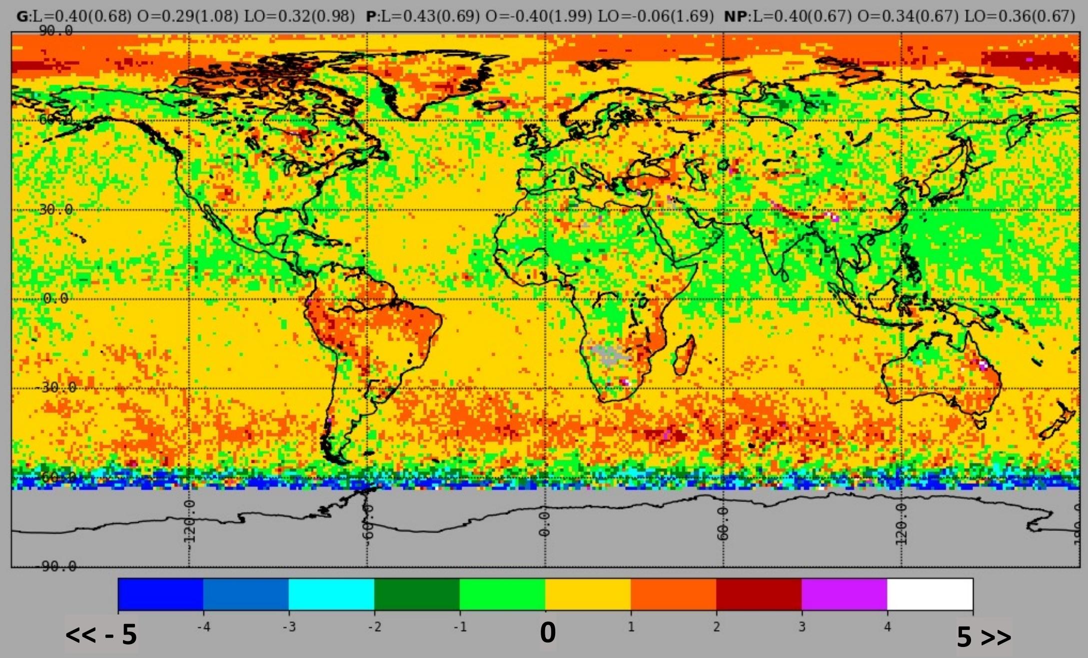
- Ocean and polar land consistency better with Ed5 approach
- Non-polar land mask needs work, awaiting new inputs

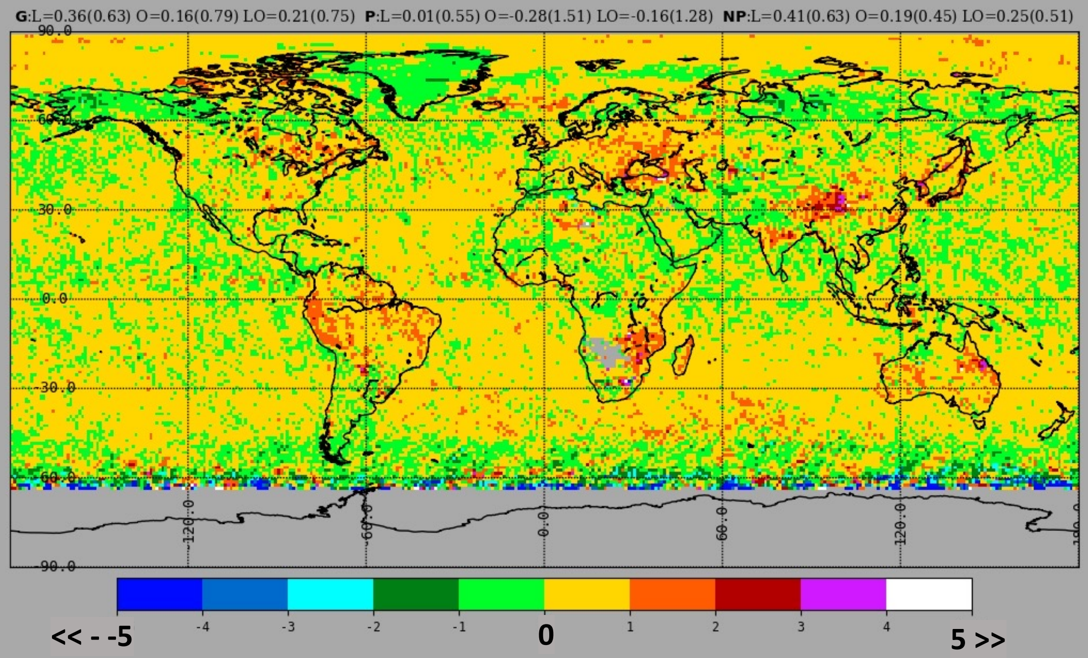
Ed1B – Ed4

July 2019 Daytime COD and CER Differences: VIIRS minus AQUA

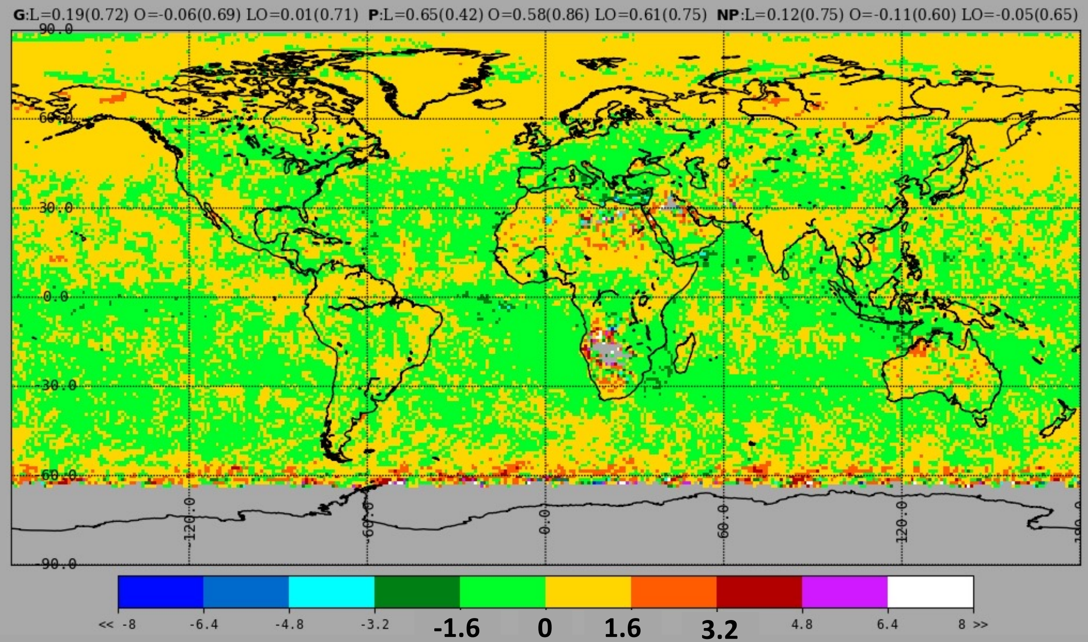
Ed5 v3

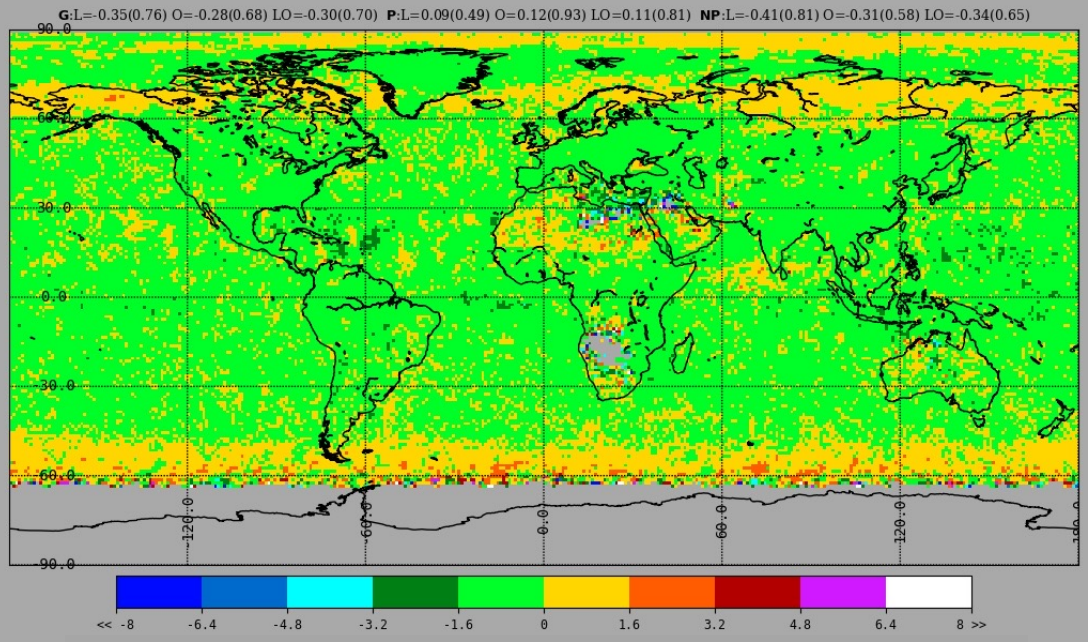
Total COD





Water CER

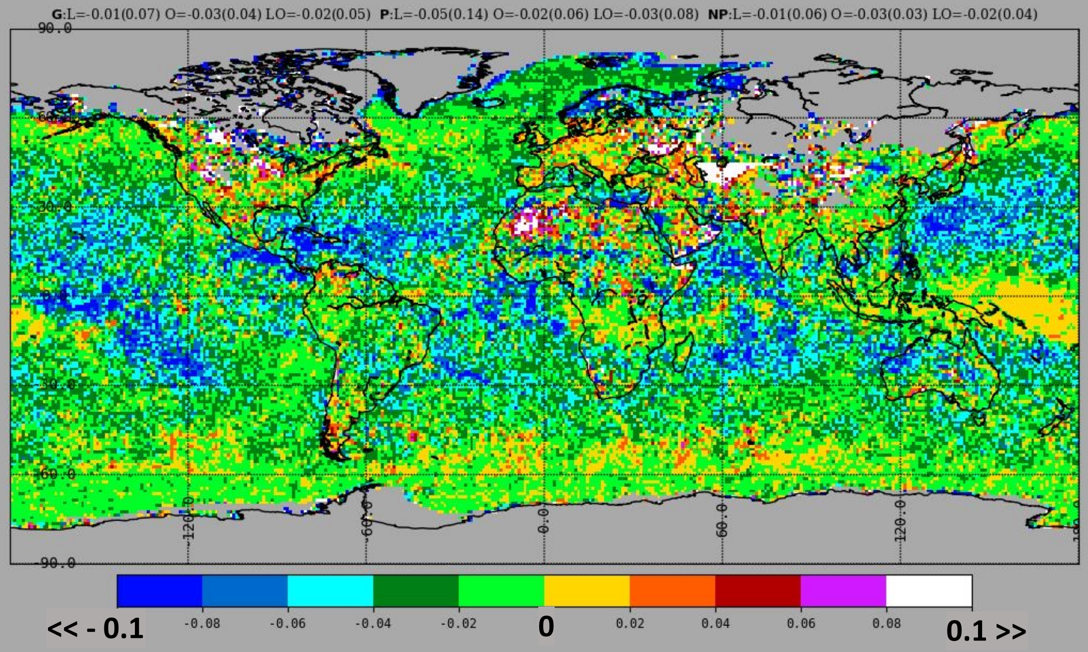


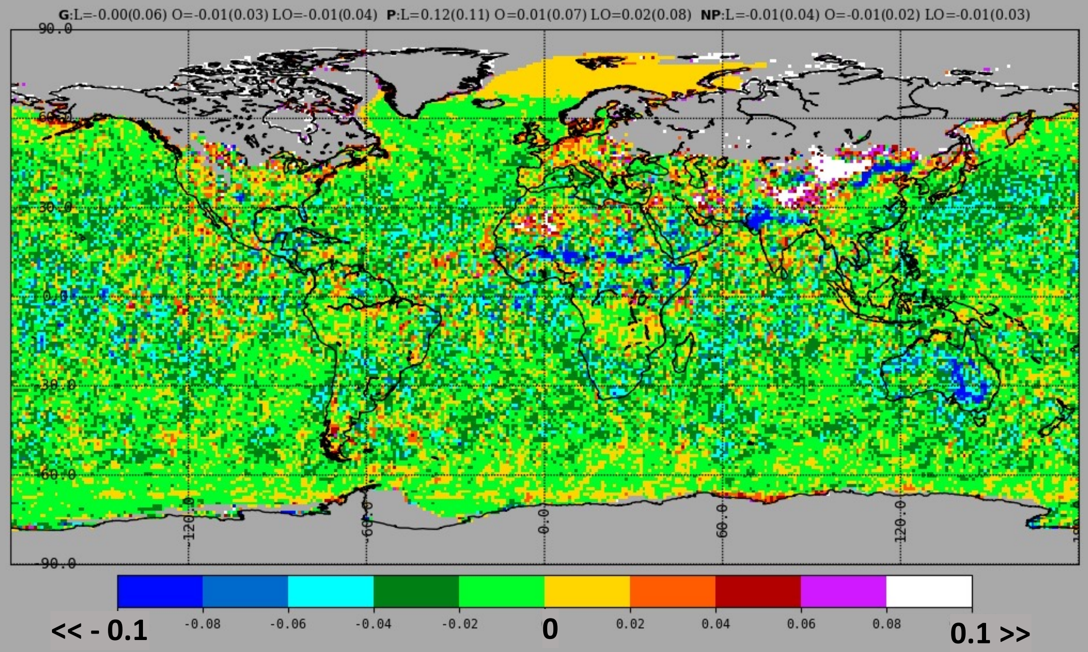


- VIIRS Ed1B tuning to MODIS Ed4 worked pretty well for COD and CER
- Ed5 consistency is better (worse) for COD (CER)

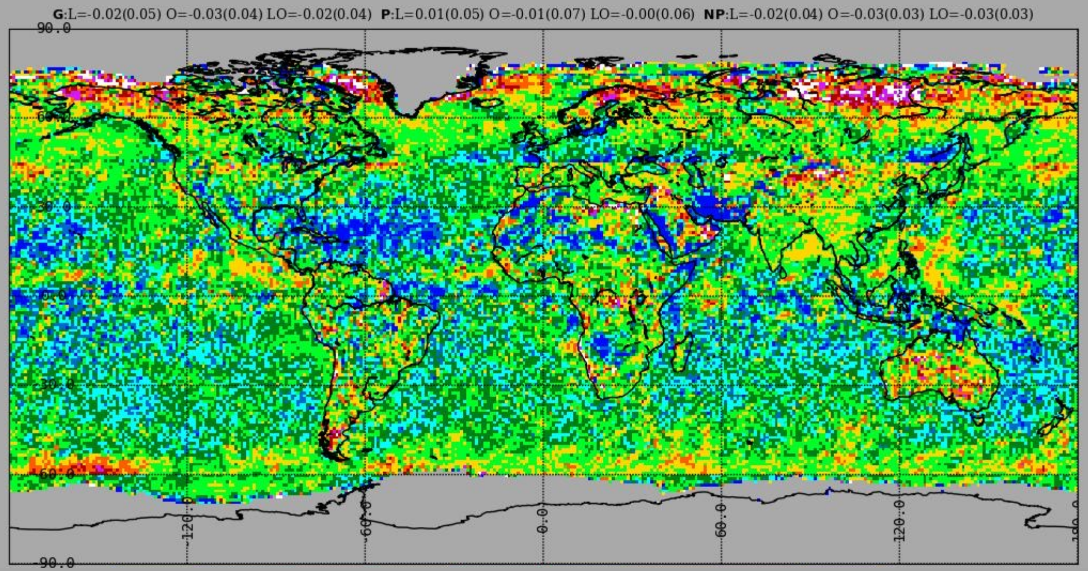
Nighttime Total Cloud Fraction Difference: VIIRS minus AQUA

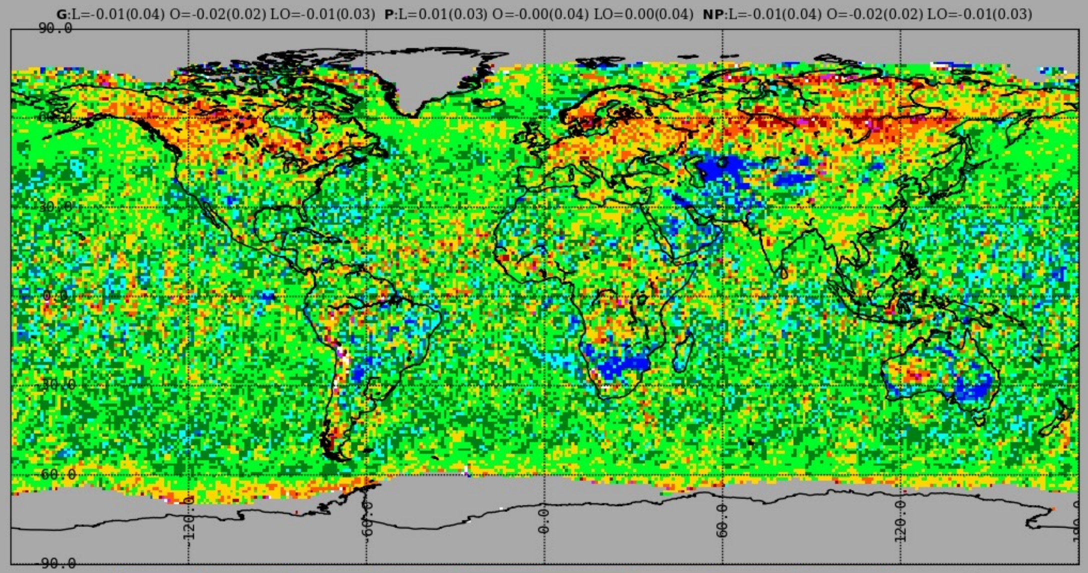
Ed1B – Ed4 | **Ed5 v3**





Jan 2019





July 2019

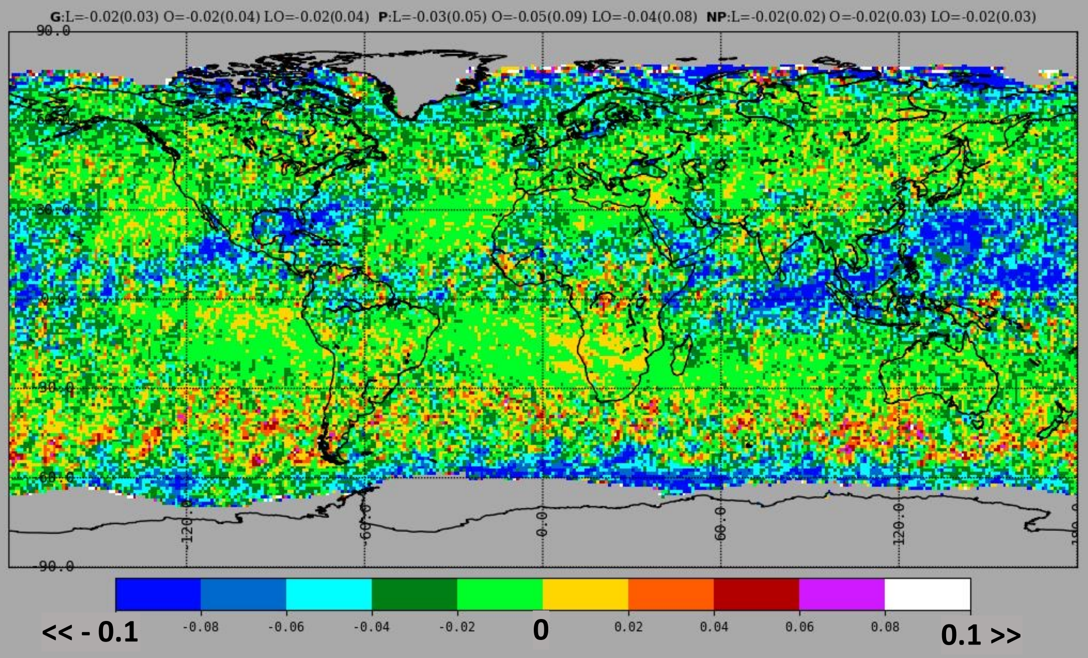
- VIIRS Ed1B tuning to MODIS Ed4 results mixed
- Fewer oceanic clouds detected from VIIRS

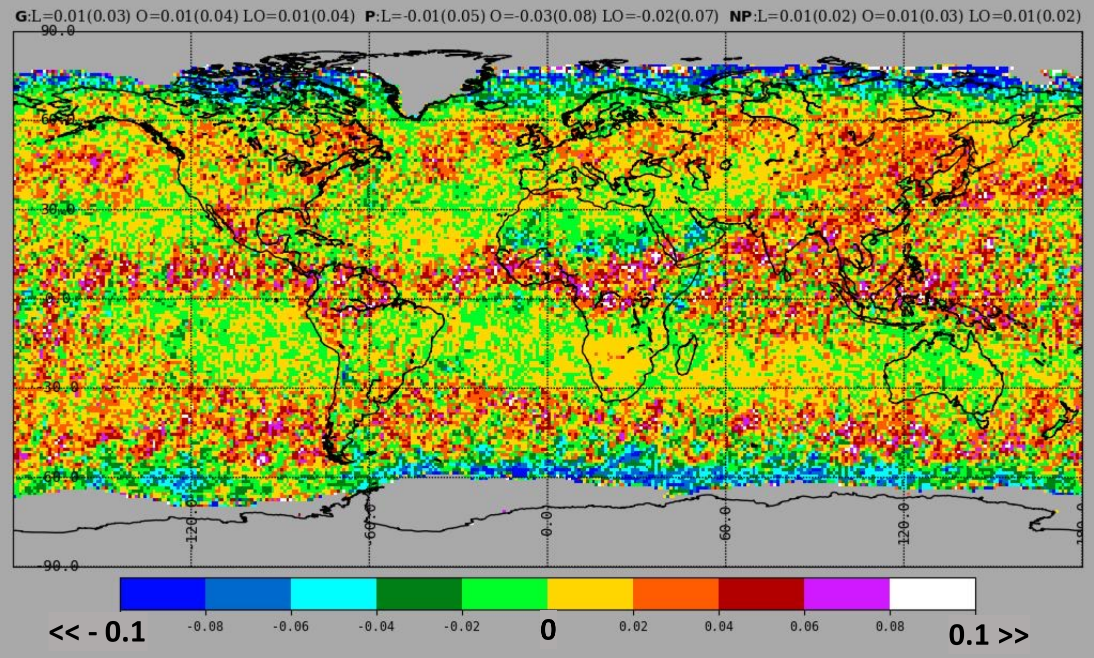
- Ed5 ocean consistency much better (VIIRS still a little low)
- New land mask and Nnet for polar night coming soon

Ed1B – Ed4

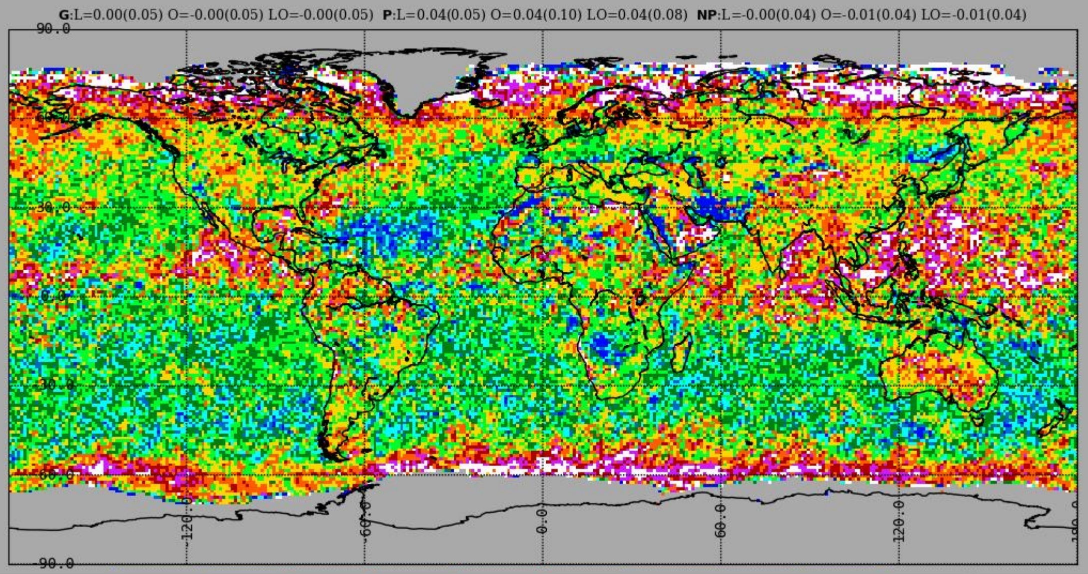
July Nighttime Cloud Fraction Difference by Phase: VIIRS minus AQUA

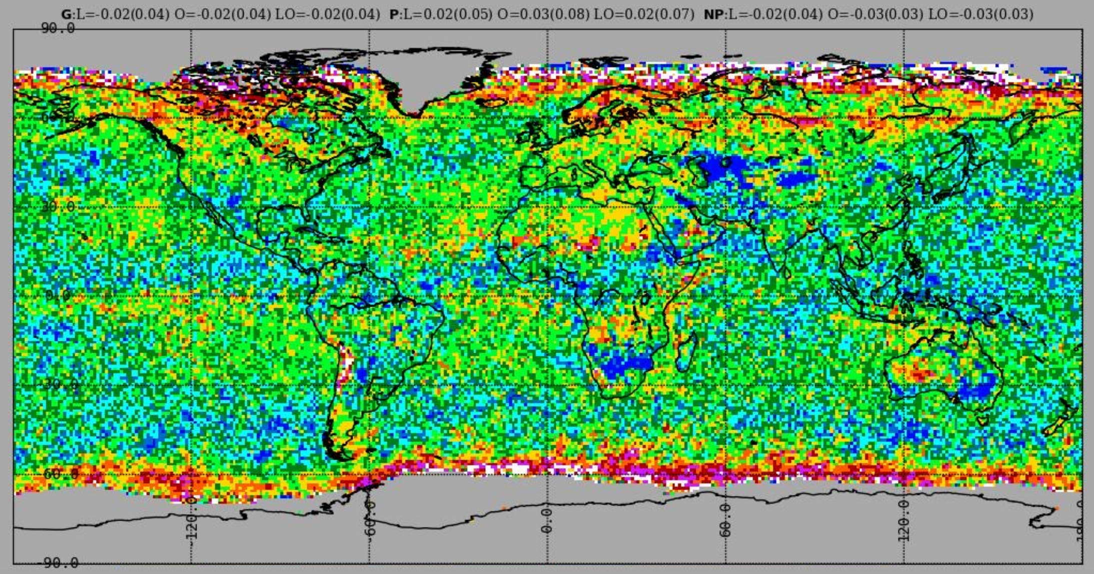
Ed5 v3





Ice Cloud Fraction





Water Cloud Fraction

- Poor agreement at low latitudes and southern ocean

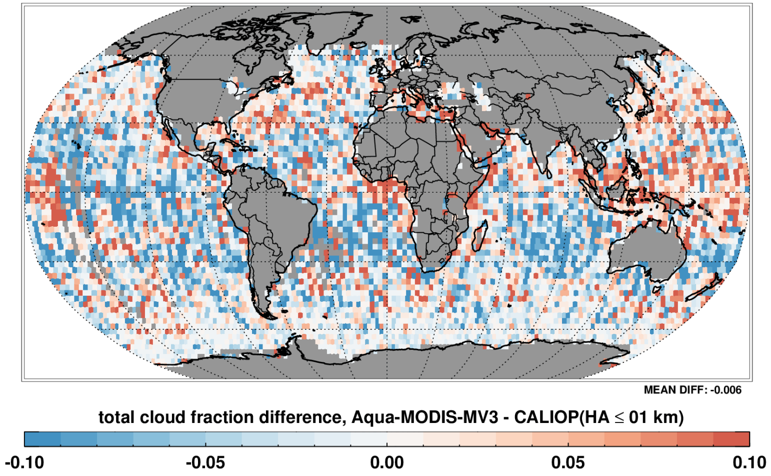
- Ed5 not much better
- Cloud phase logic needs revisit

Ed5 Cloud Fraction Comparisons with CALIPSO

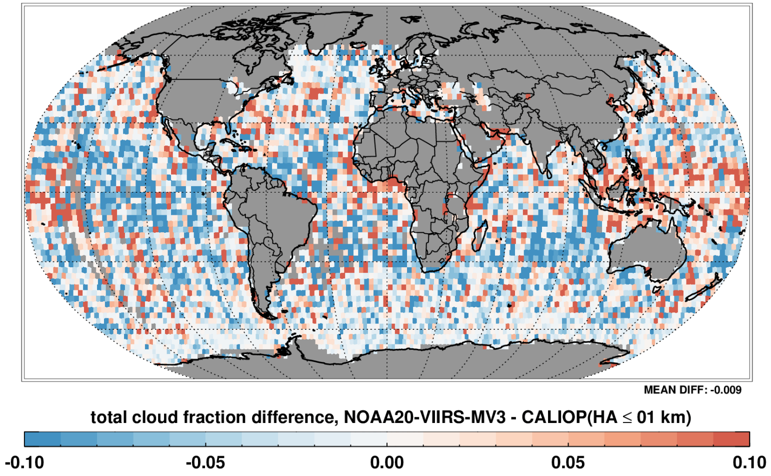
Jan/July 2019

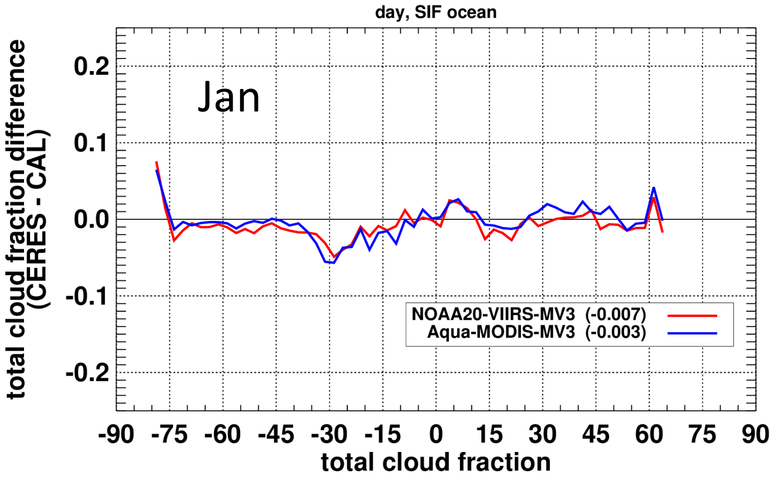
Jan

Ed5 MODIS minus CALIPSO



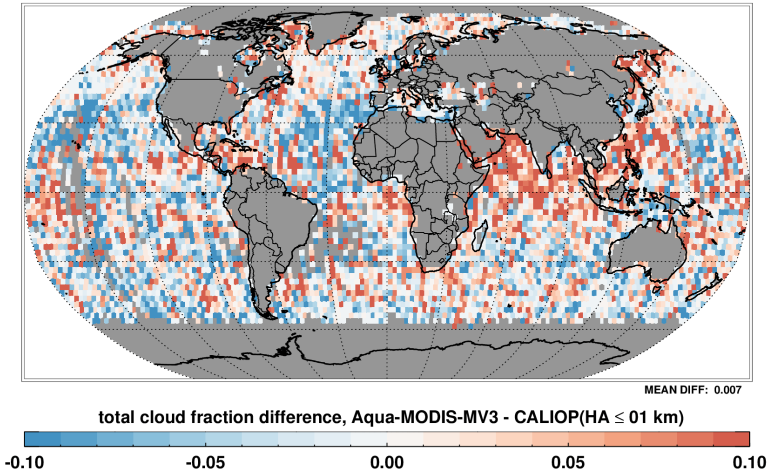
Ed5 VIIRS minus CALIPSO



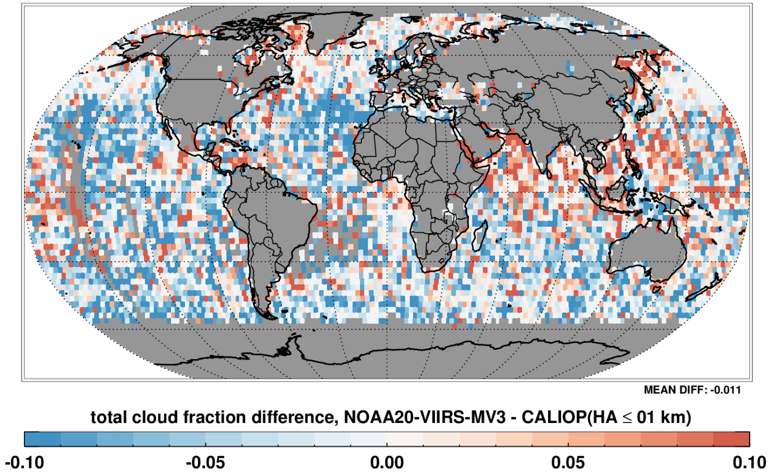


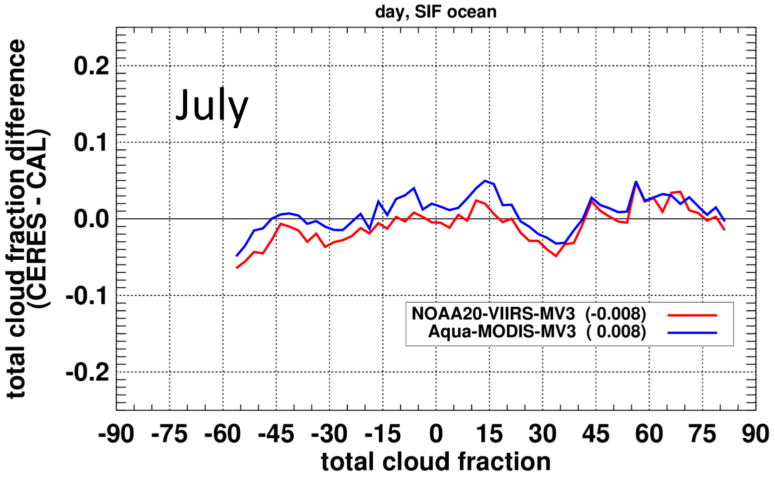
July

Ed5 MODIS minus CALIPSO



Ed5 VIIRS minus CALIPSO





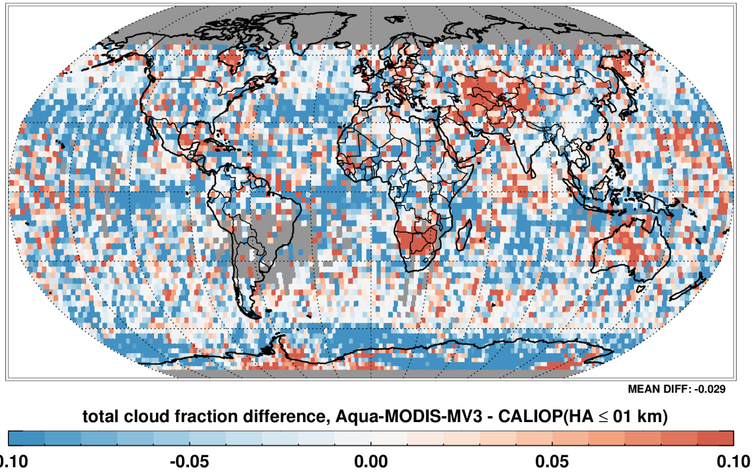
Daytime zonal means compare well with CALIPSO. Some seasonal dependencies for MODIS/VIIRS level of agreement (??)

Ed5 Cloud Fraction Comparisons with CALIPSO

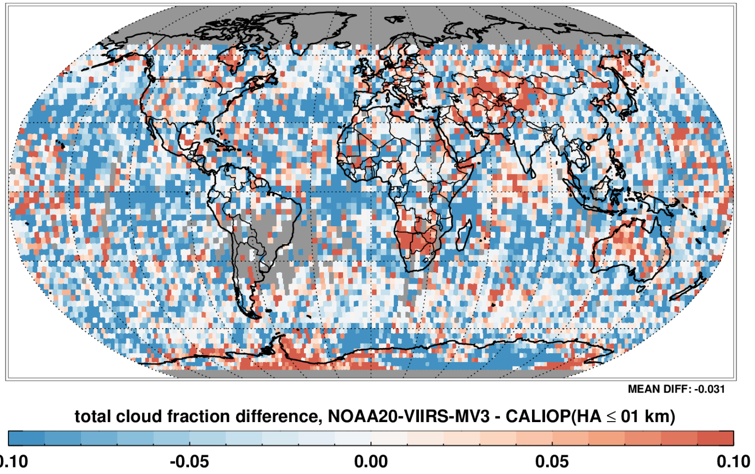
Jan/July 2019

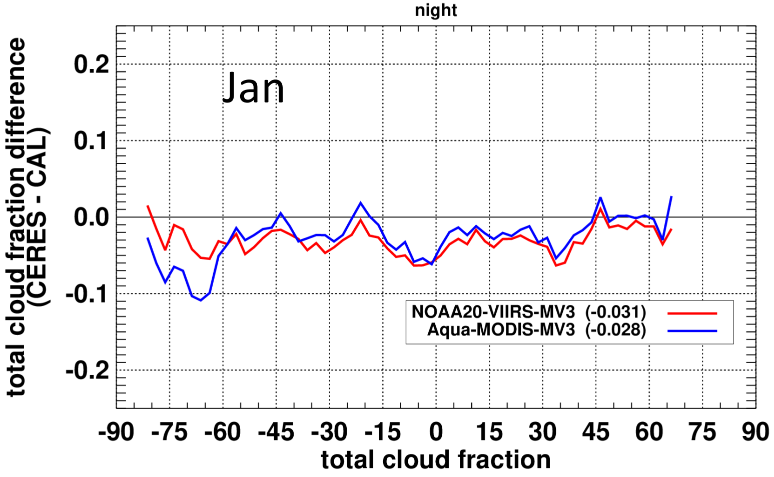
Jan

Ed5 MODIS minus CALIPSO



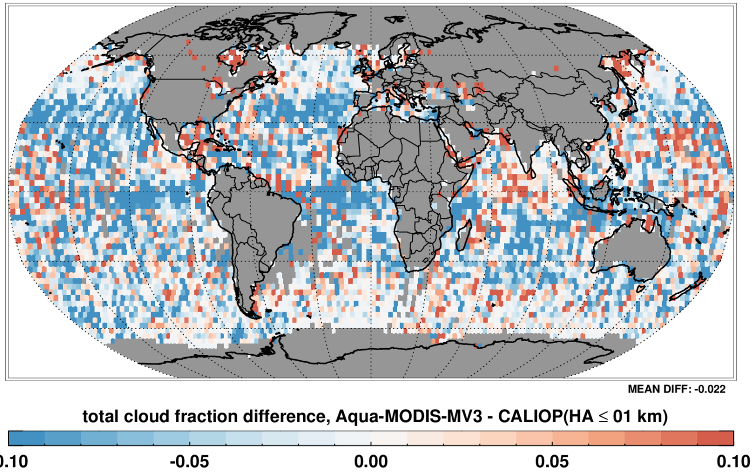
Ed5 VIIRS minus CALIPSO



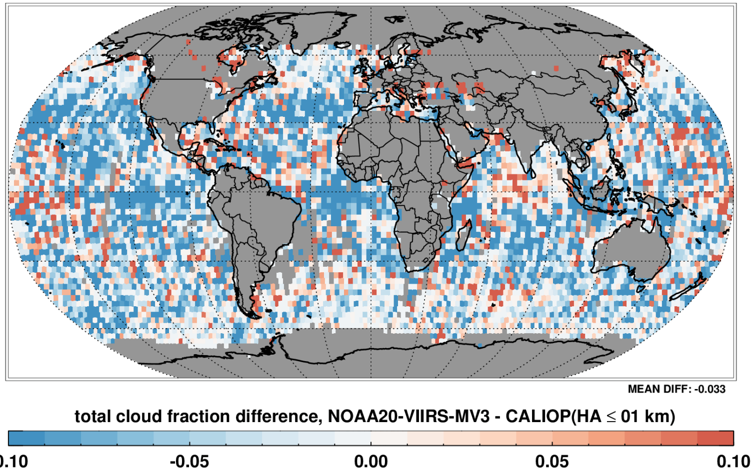


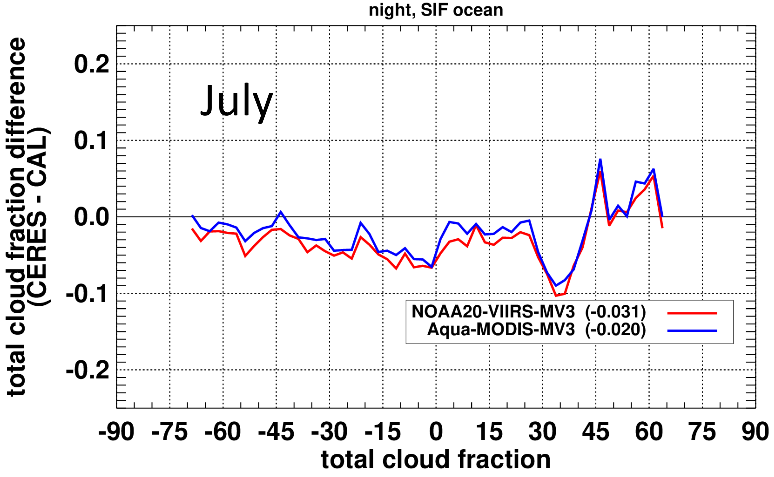
July

Ed5 MODIS minus CALIPSO



Ed5 VIIRS minus CALIPSO

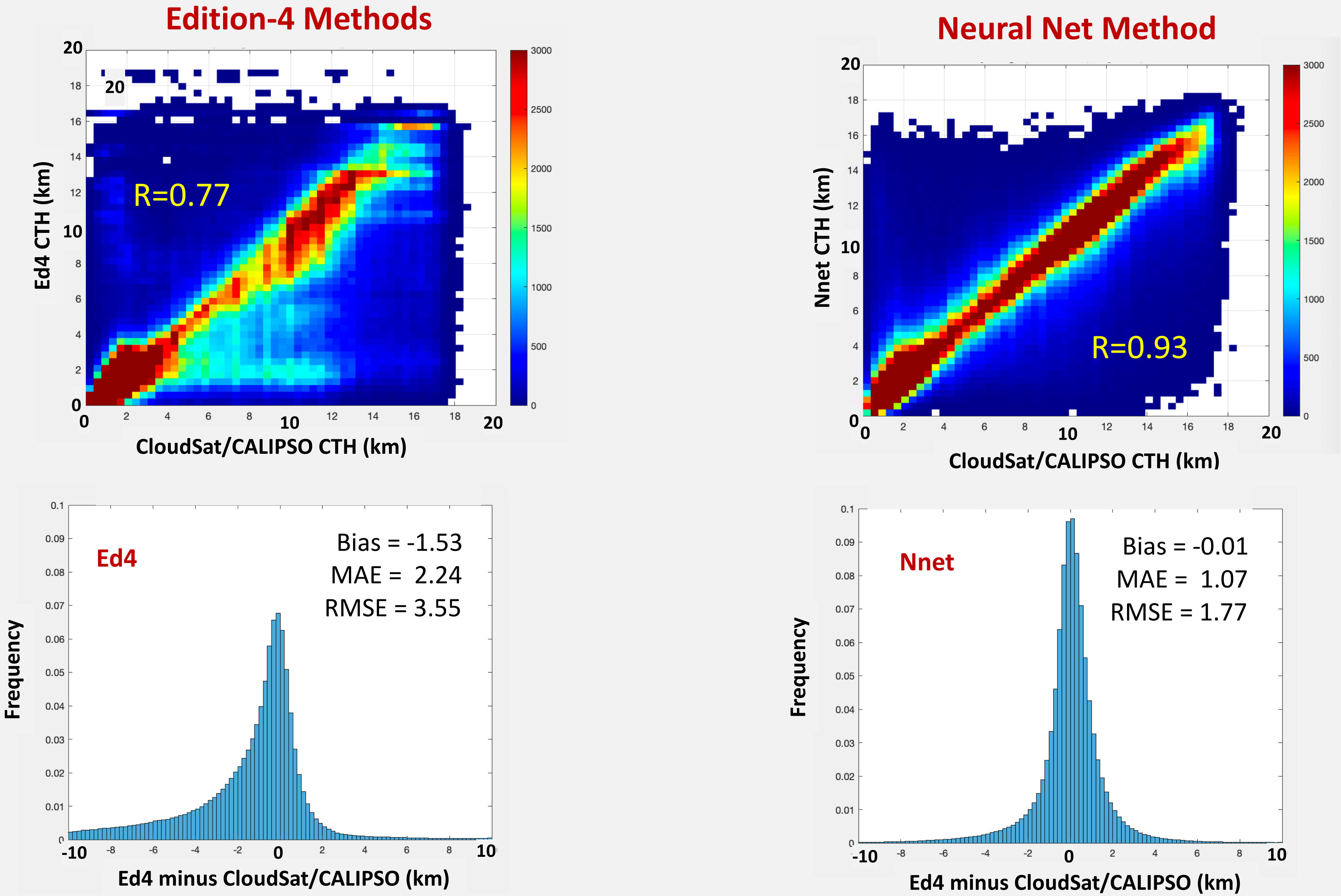




MODIS/VIIRS generally consistent at night in zonal means but under-detecting some low clouds compared to CALIPSO

Higher Accuracy Cloud Top Heights using Neural Net

All clouds, daytime, snow/ice free



Higher Accuracy Cloud Top Heights using Neural Net

All clouds, daytime, snow/ice free

All Clouds

All	Nnet	Ed4
Bias	-0.01	-1.53
MAE	1.07	2.24
RMSE	1.77	3.55

Low Clouds

Low	Nnet	Ed4
Bias	0.60	0.31
MAE	0.85	0.89
RMSE	1.64	2.01

Mid Clouds

Mid	Nnet	Ed4
Bias	0.51	-0.80
MAE	1.14	1.63
RMSE	1.69	2.20

High Clouds

High	Nnet	Ed4
Bias	-0.48	-2.75
MAE	1.18	3.14
RMSE	1.86	4.38

Ed5 GEO Status

- Two-habit ice scattering model for ice clouds implemented
- Use of GOES-13 and GOES-16 overlap period to evaluate consistency with a common cloud algorithm

  GOES-13: 5-band 2nd generation imager, 4-km IR

  GOES-16 : 16-band 3rd generation imager, 2-km IR

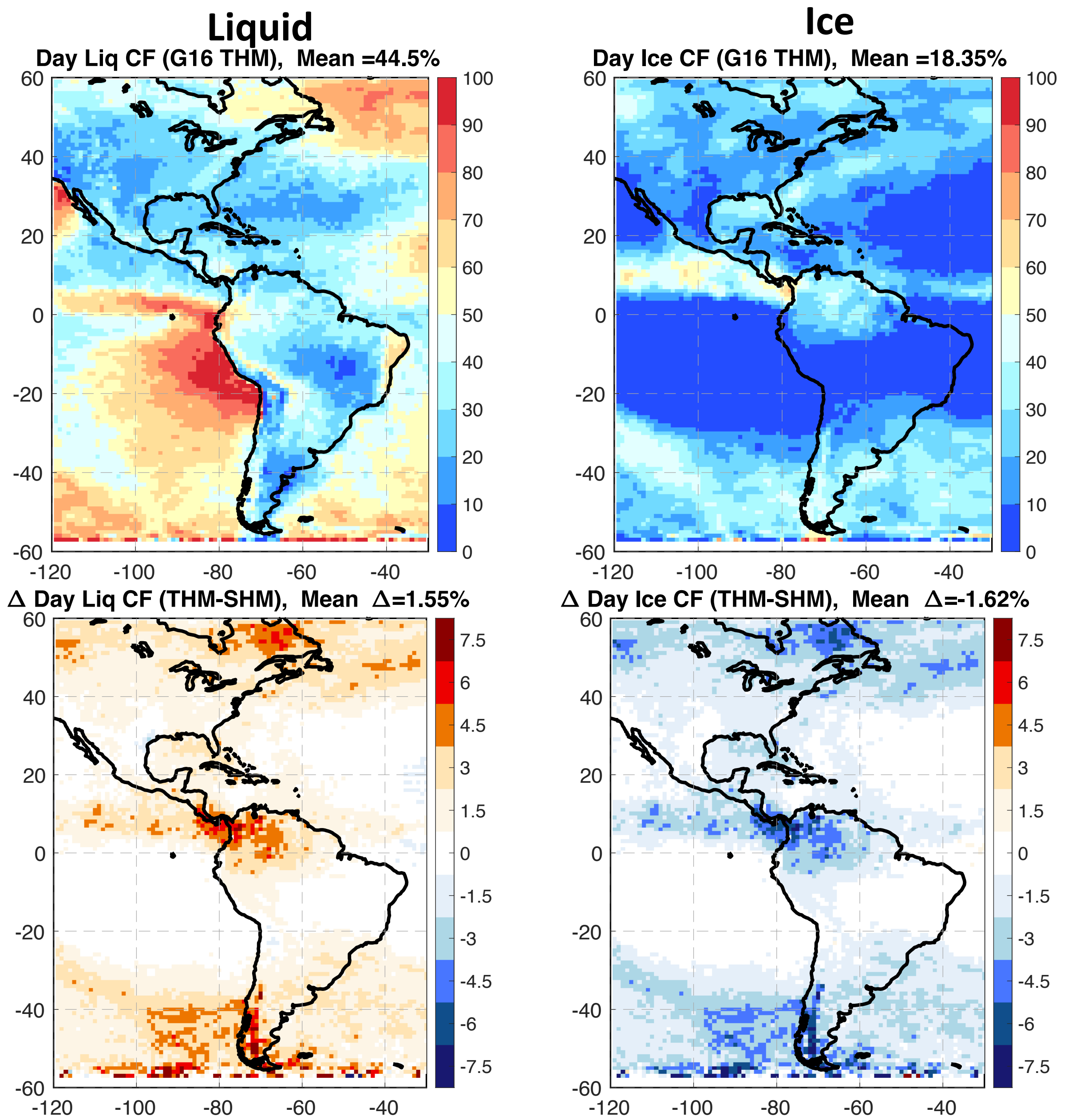
- Clear sky Land/ocean reflectance update for 2-ch satellites

Daytime Cloud Fraction (SZA<75˚)

July 2017

Mean GOES-16 THM

THM – SHM

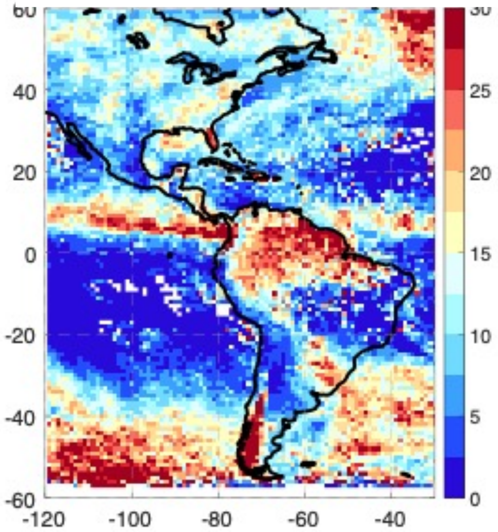


Some notable differences in cloud phase arise due to the change in ice models

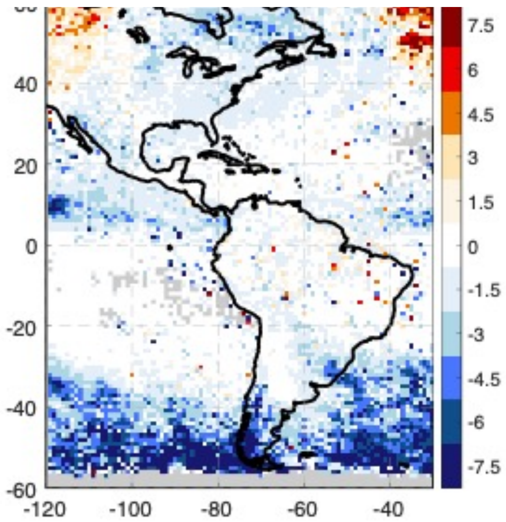
Ice Cloud Optical Depth Comparison (ΔCF<1%)

July 2017, Day

Mean GOES-16 Tau (THM)

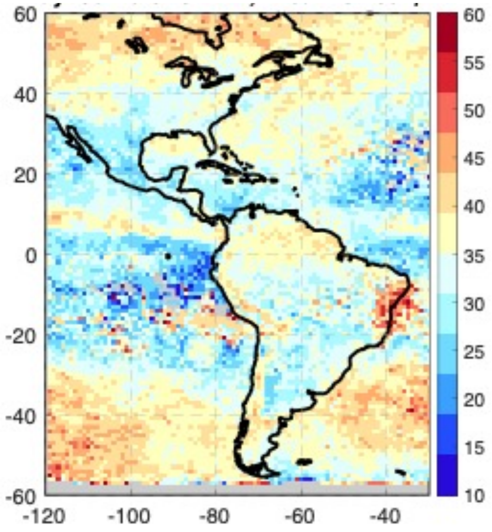


THM – SHM Tau (Δ = -1.52)

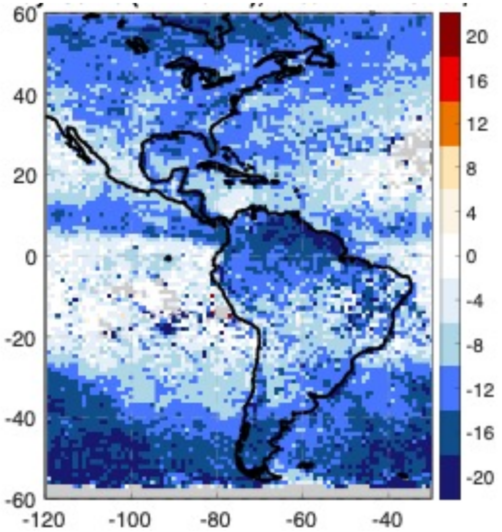


Ice cloud Tau mostly decreases with THM as expected due to the lower asymmetry parameter at 0.65 µm

Mean GOES-16 R_e (THM)



THM – SHM R_e (Δ = -10.8 µm)



Ice cloud R_e decreases substantially for THM due to larger asymmetry parameter for THM at 3.9 µm

GEO results consistent with MODIS

GOES-16 vs GOES-13
3-channel code with THM

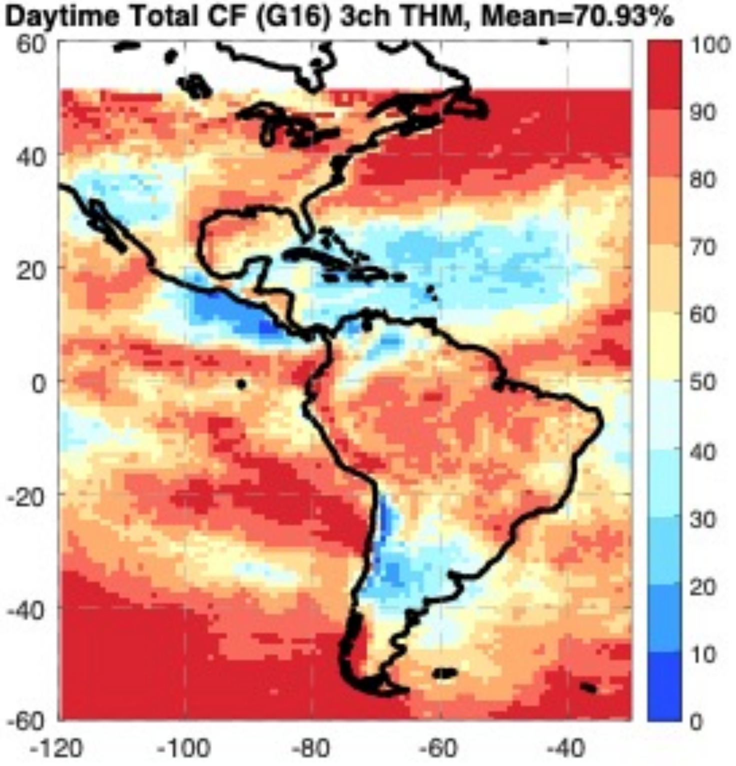
Overlapping period with equivalent subsatellite point (Dec 14-31 20217)

GOES-16 data spatially averaged to match GOES-13 resolution

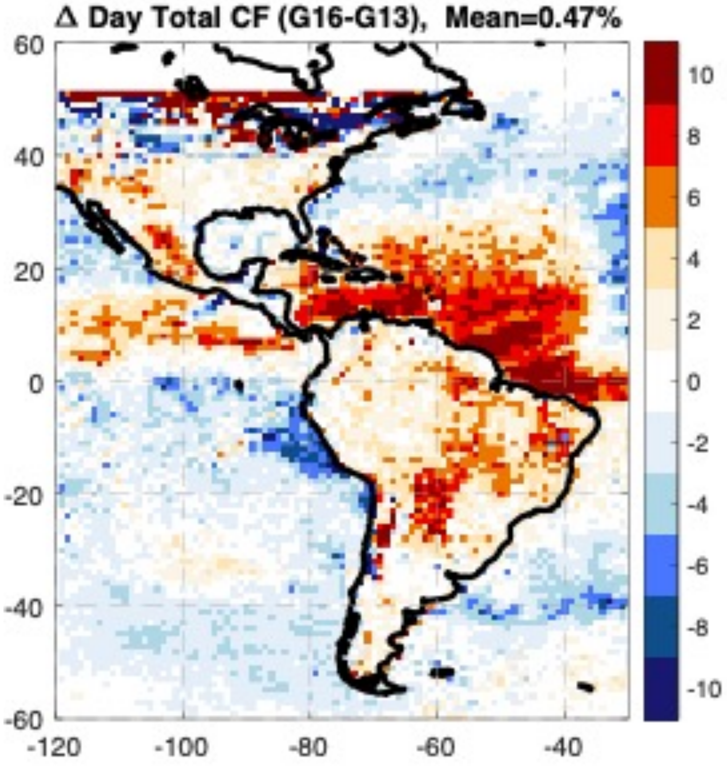
Hourly observations, 15-minutes apart

Daytime Total Cloud Fraction (SZA<75˚)

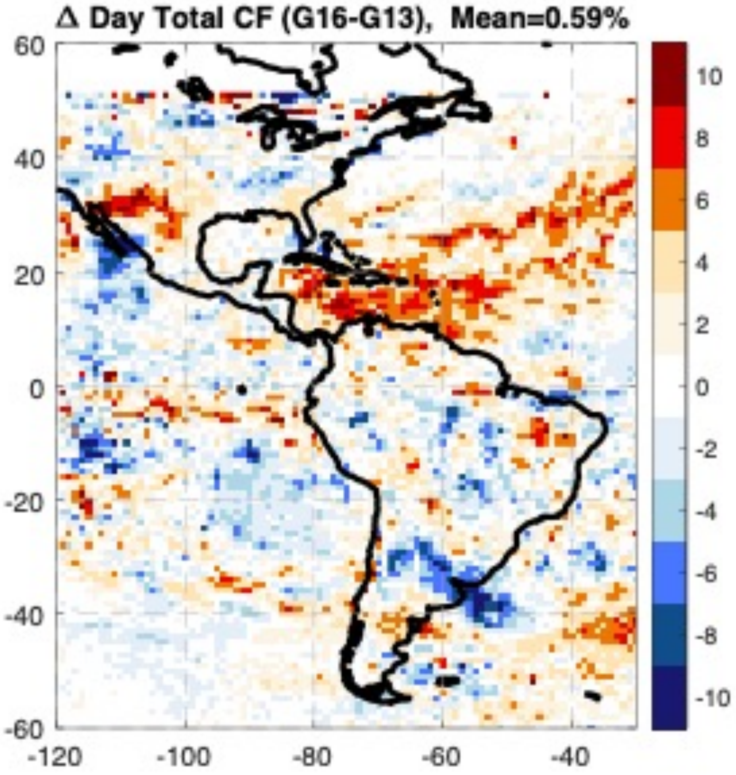
Mean GOES-16 (3ch)



G16 – G13 (Ed4)



G16 – G13 (Ed5)

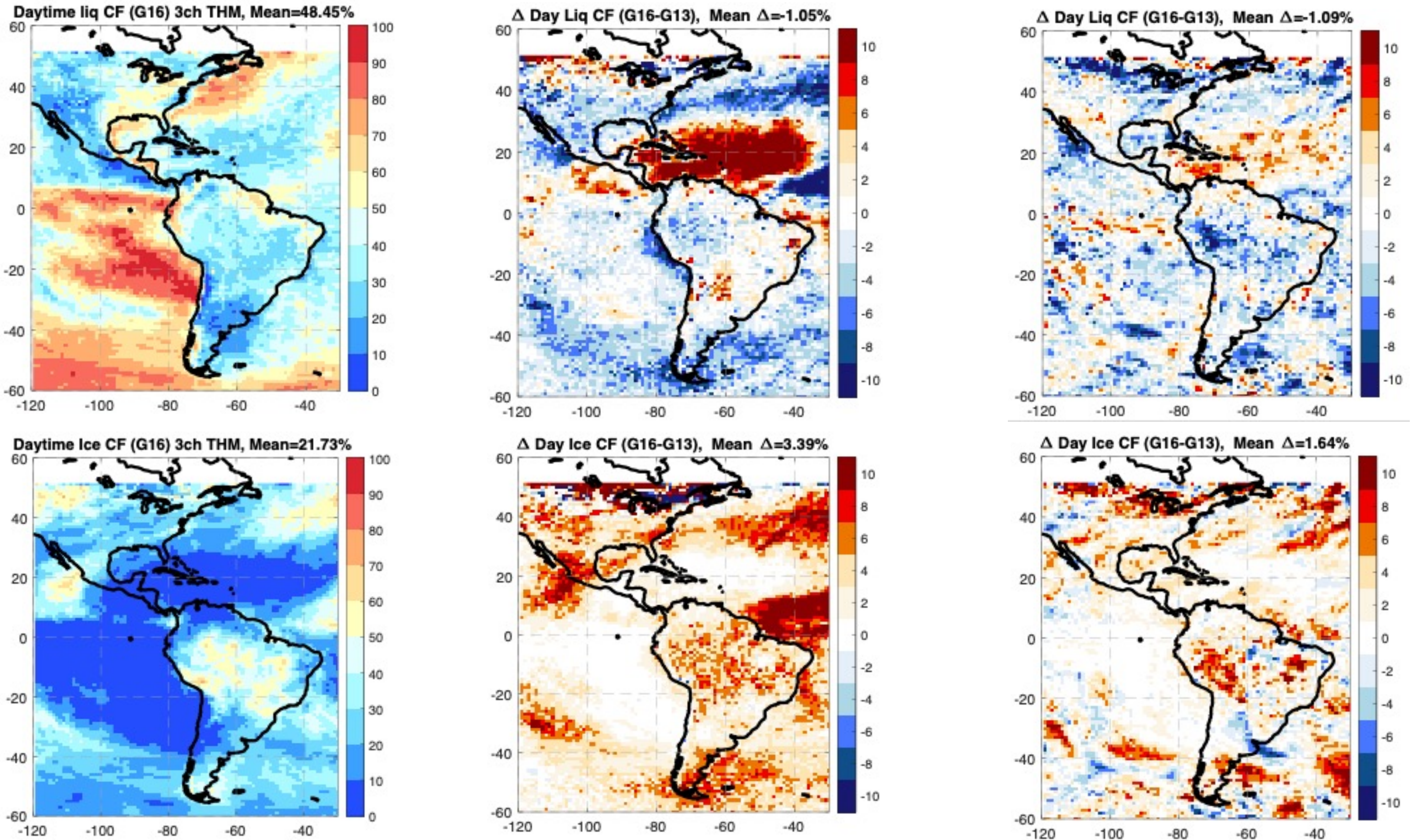


Daytime Cloud Fraction by Phase (SZA<75˚)

Mean GOES-16 (3ch) | **G16 – G13 (Ed4)** | **G16 – G13 (Ed5)**

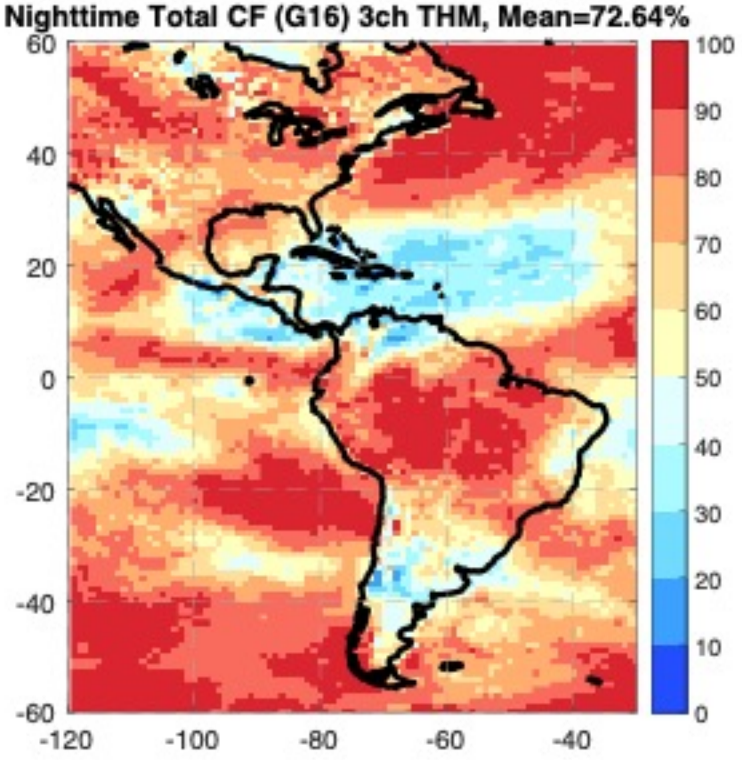
LIQUID

ICE

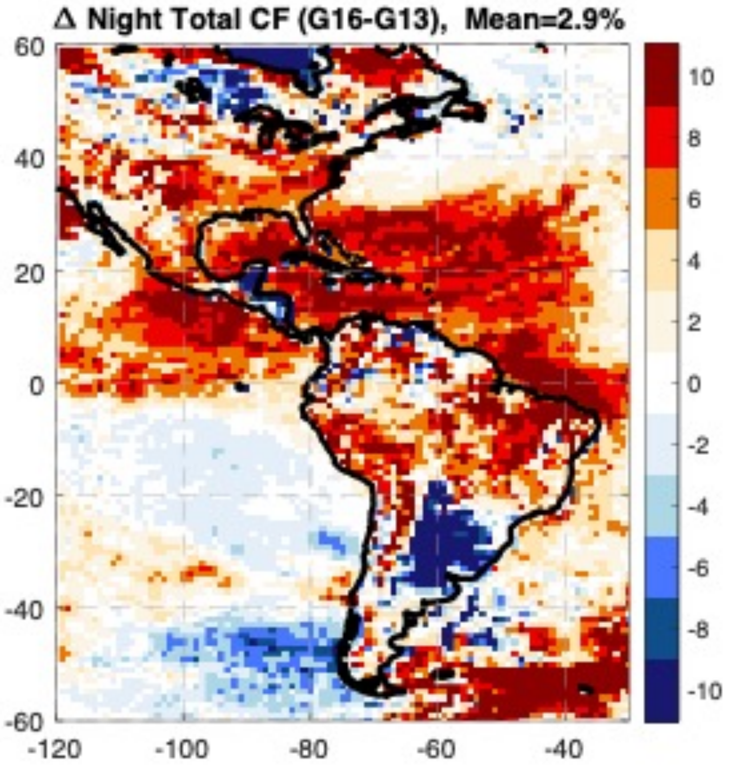


Nighttime Total Cloud Fraction

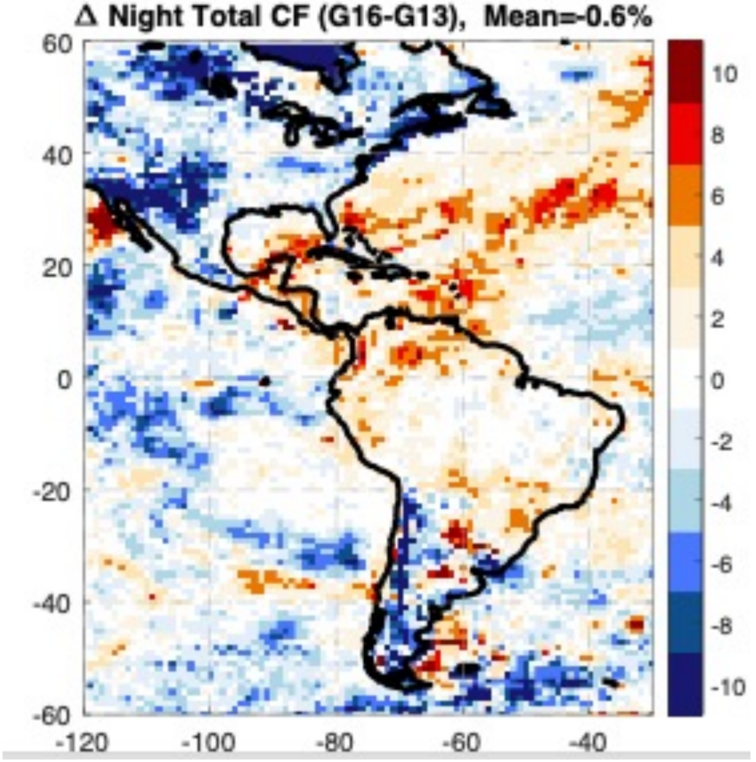
Mean GOES-16 (3ch)



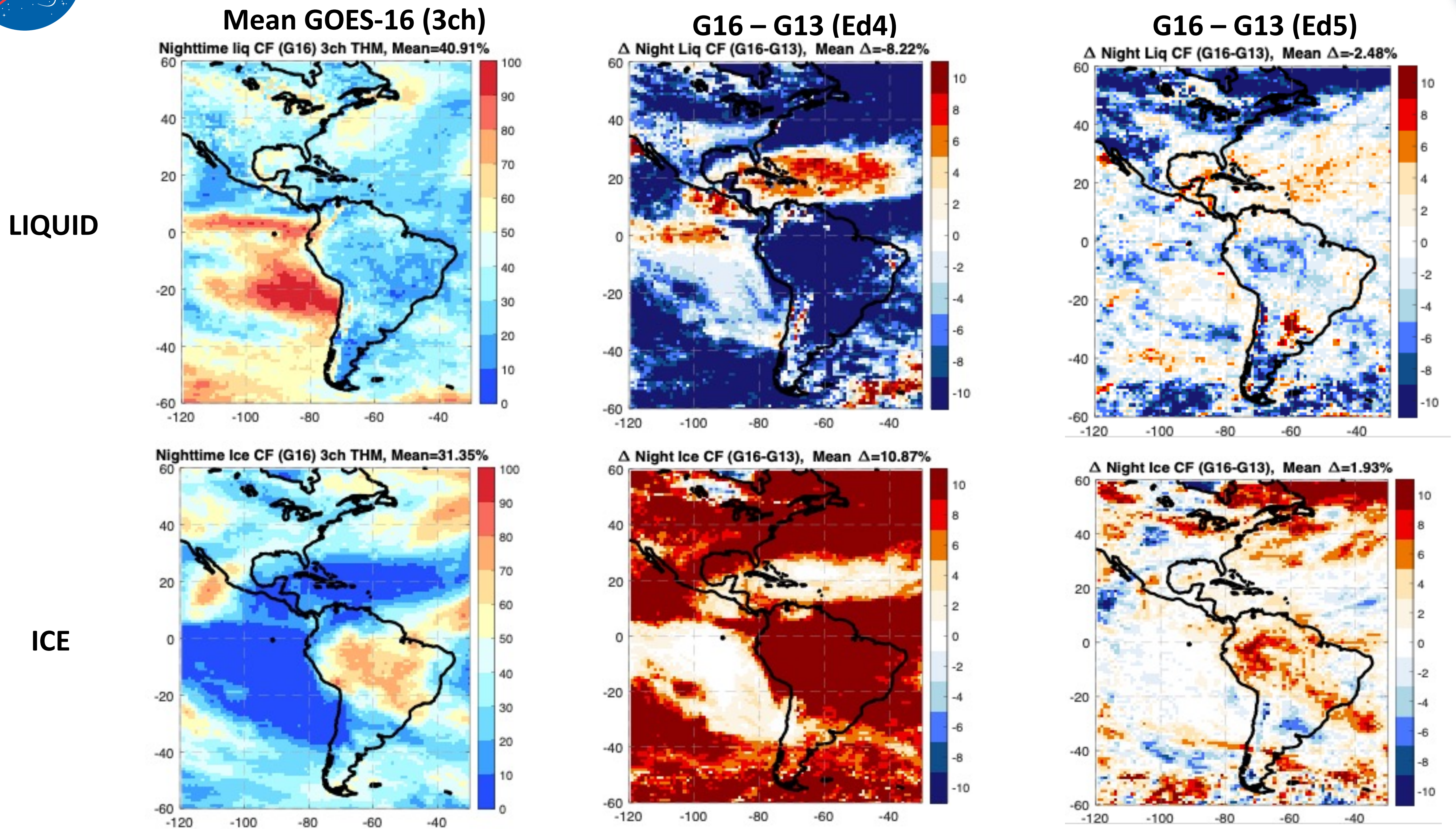
G16 – G13 (Ed4)



G16 – G13 (Ed5)

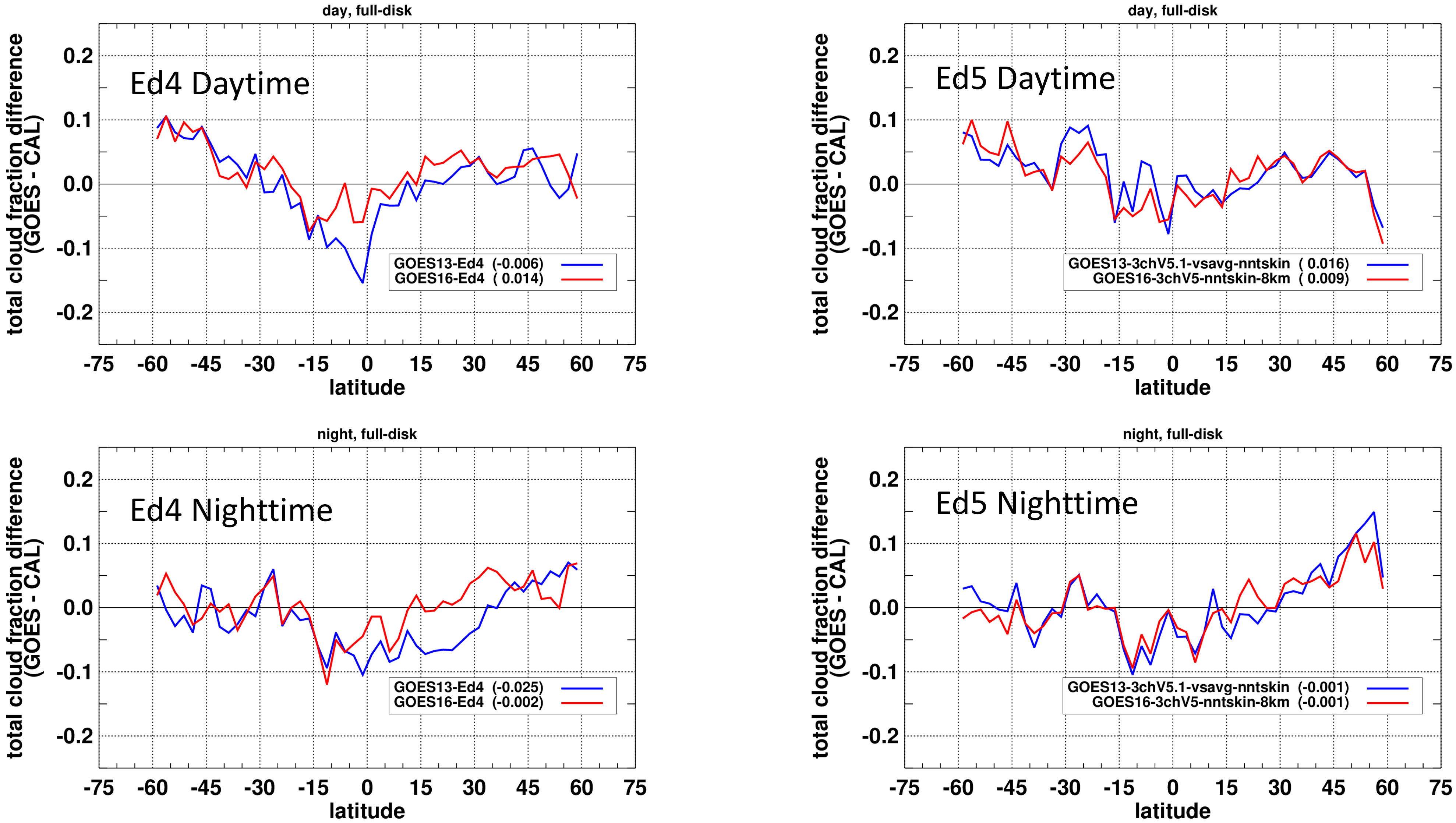


Nighttime Cloud Fraction by Phase



GOES-13/GOES-16 Consistency vs CALIOP

December 2017



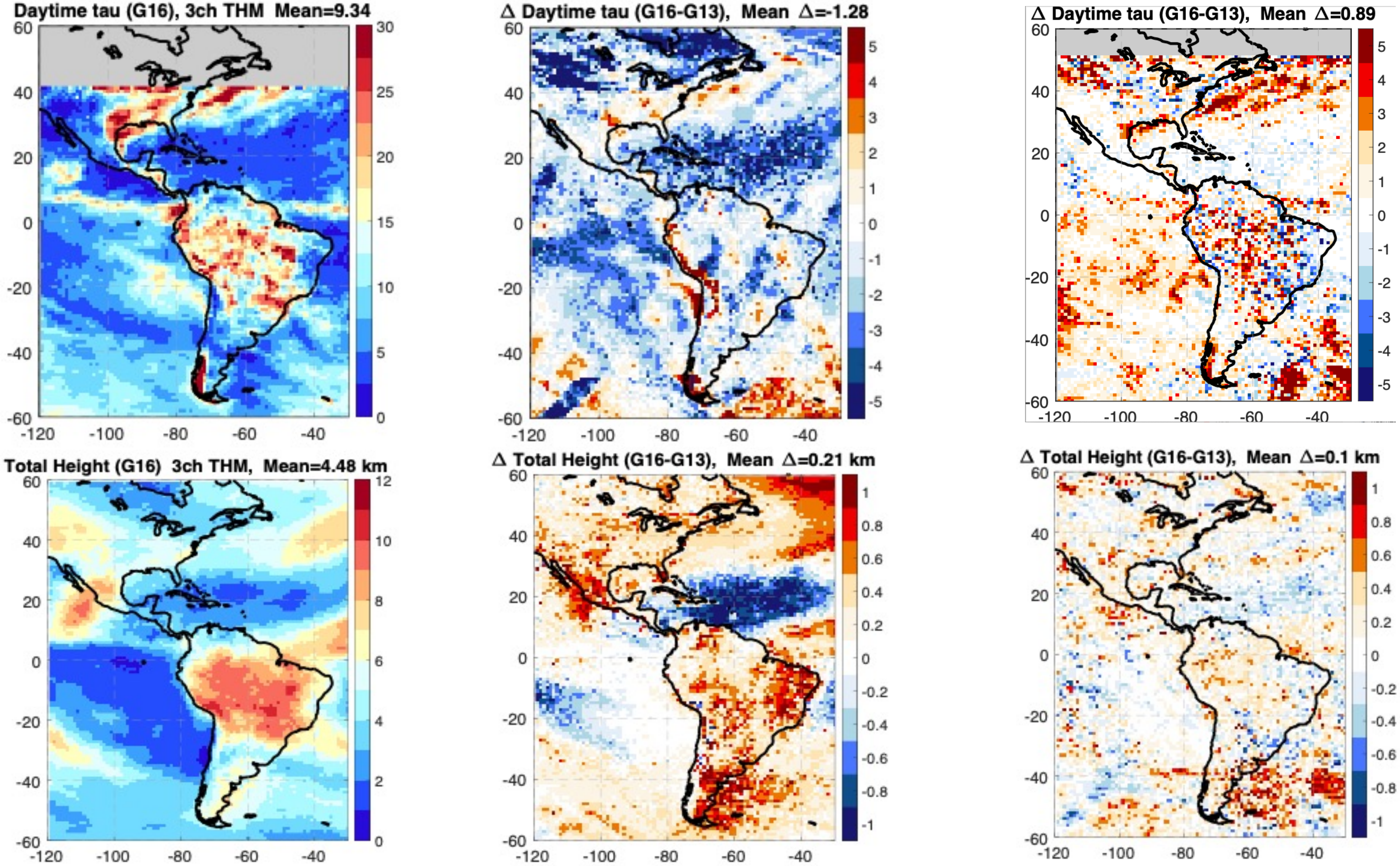
Ed5 more consistent than Ed4; Ed5 cloud mask not yet tuned for accuracy

Optical depth and height for samples with ΔCF<2%

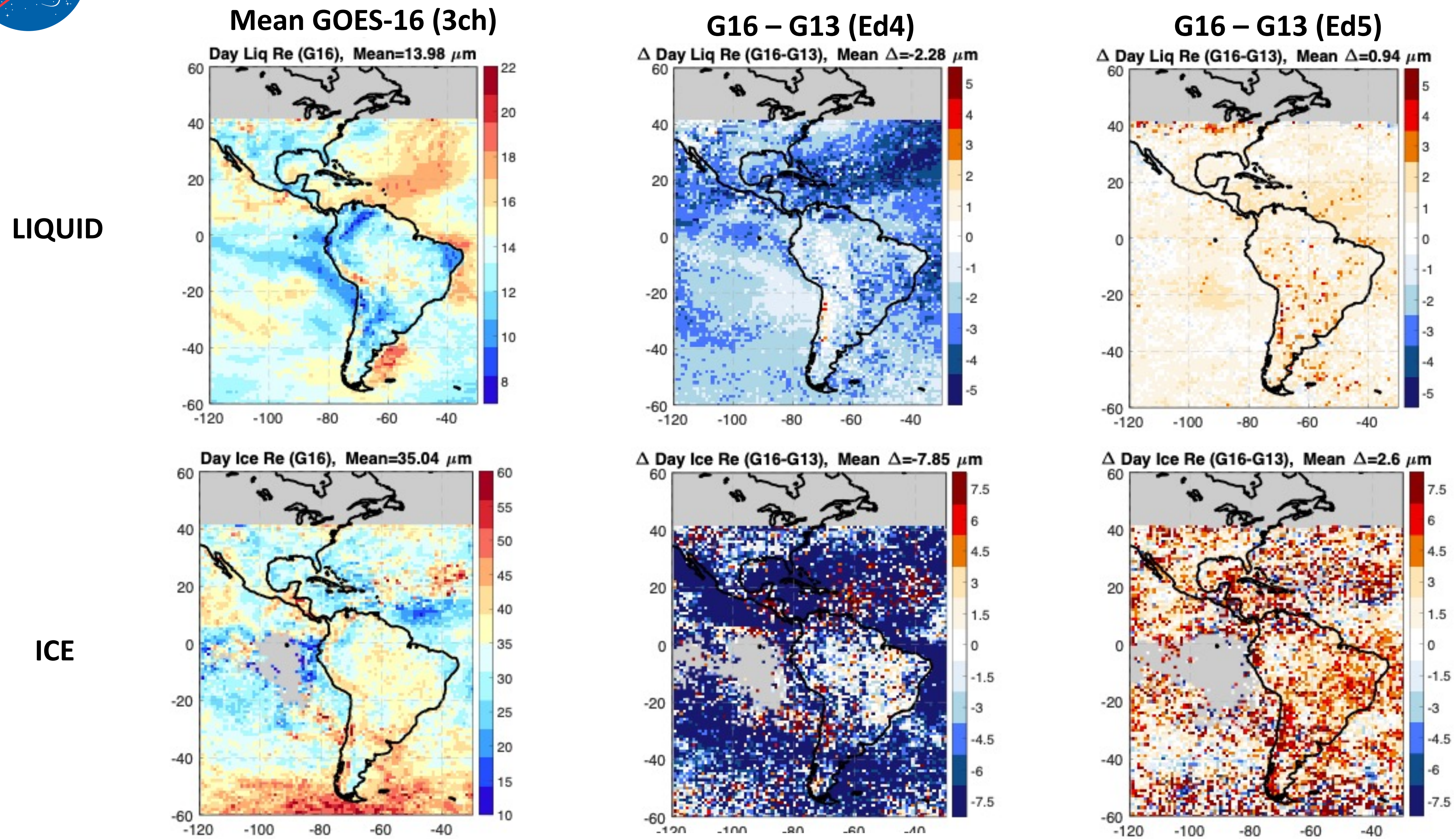
Mean GOES-16 (3ch) | **G16 – G13 (Ed4)** | **G16 – G13 (Ed5)**

Tau Day

Cloud Height Day/Nite



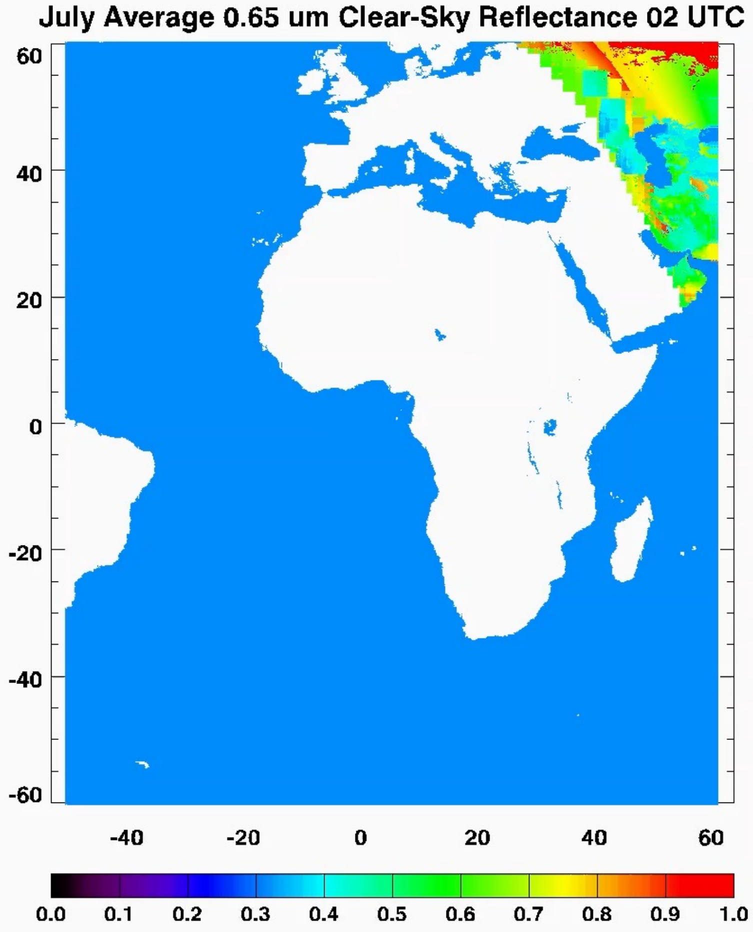
Particle size for samples with ΔCF<2%



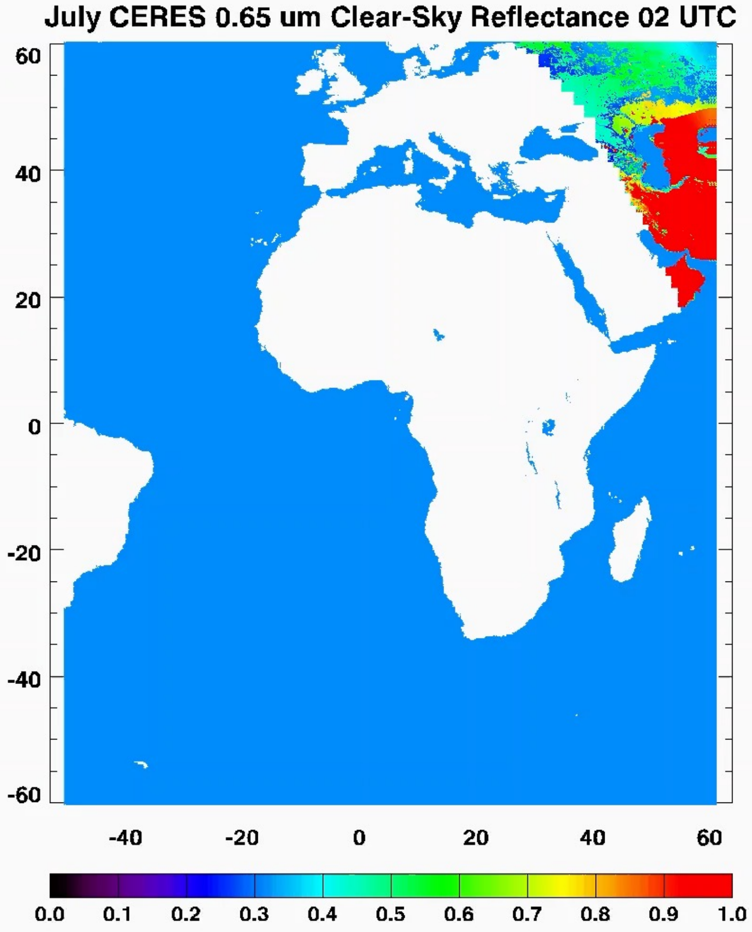
Clear-Sky Reflectance Update for 2-channel Satellites

- Ed4 overhead albedo maps from ISCCP and anisotropic models inadequate for Met-5, Met-7, and GMS-5
- Land: monthly hourly composites created for Ed5 using two years of data
- Marked improvement compared to the Ed4 method

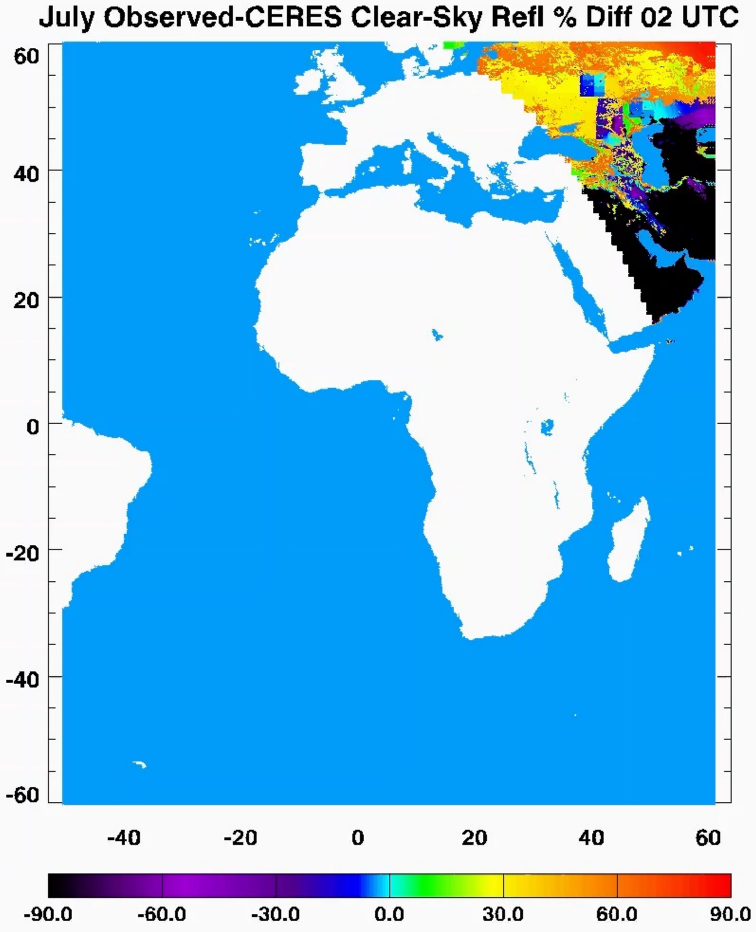
Ed4



Ed5



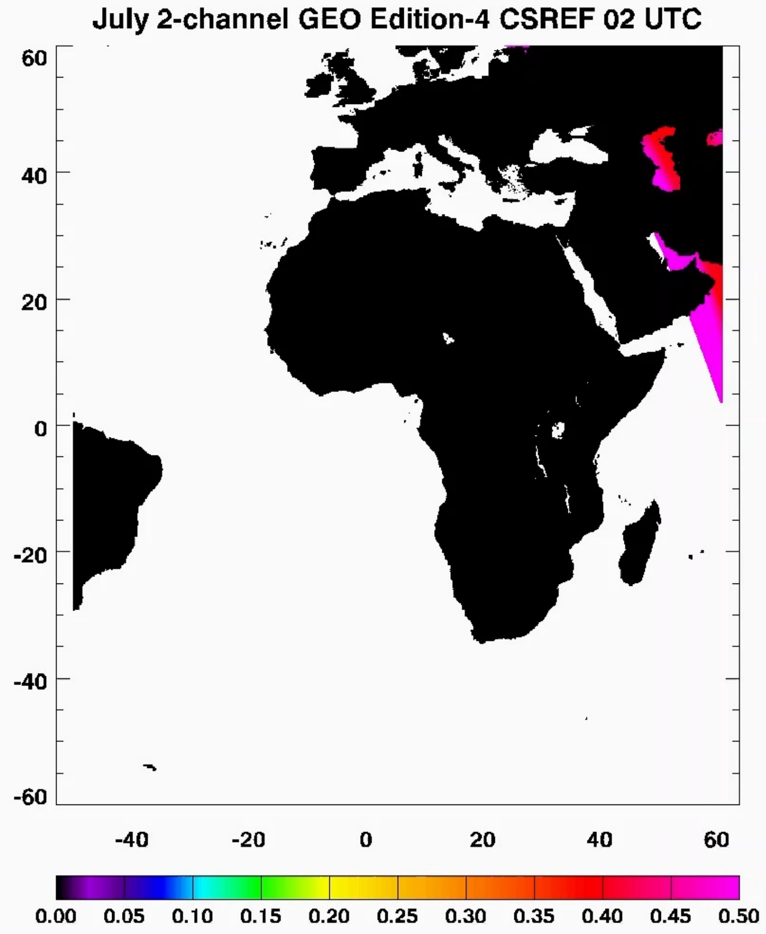
Ed5 minus Ed4



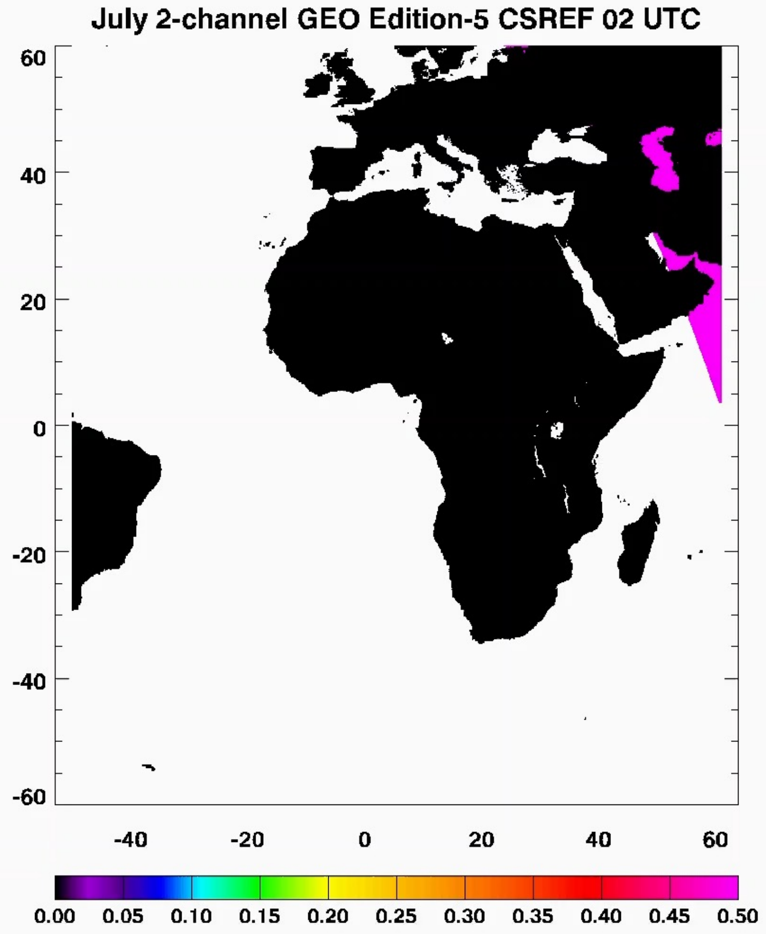
Clear-Sky Reflectance Update for 2-channel Satellites

- Ed4 OA maps w/ fixed ocean value and VIRS bidirectional model inadequate for Met-5, Met-7, and GMS-5
- Ocean: Jin theoretical ocean reflectance model updated for SRF’s for the 2-ch satellies
- Marked improvement compared to the Ed4 method

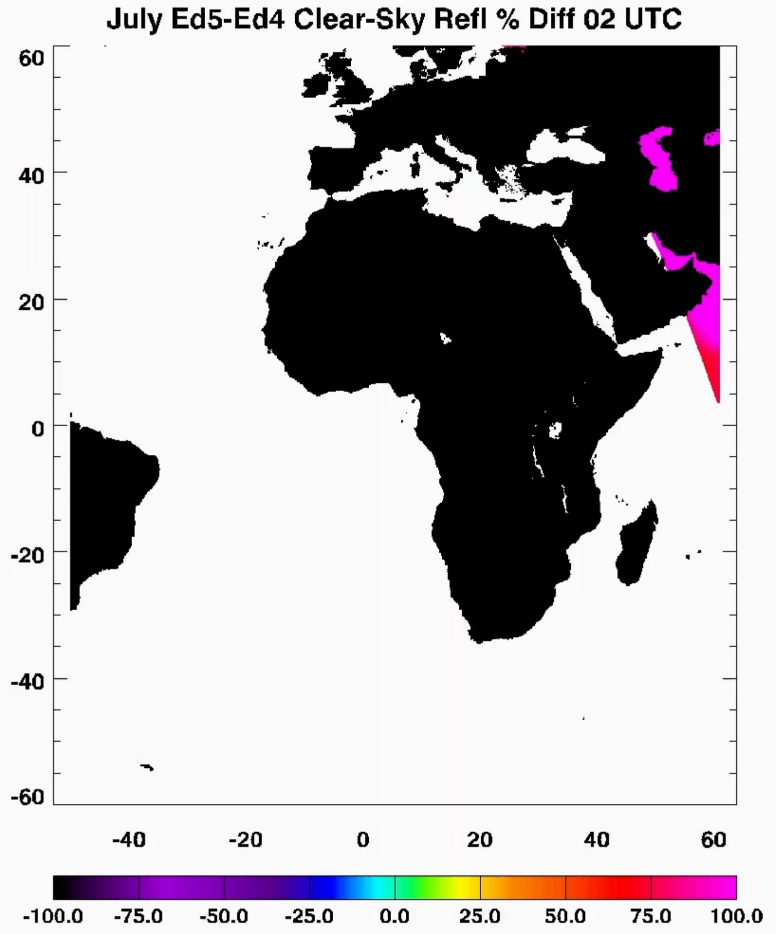
Ed4



Ed5



Ed5 minus Ed4



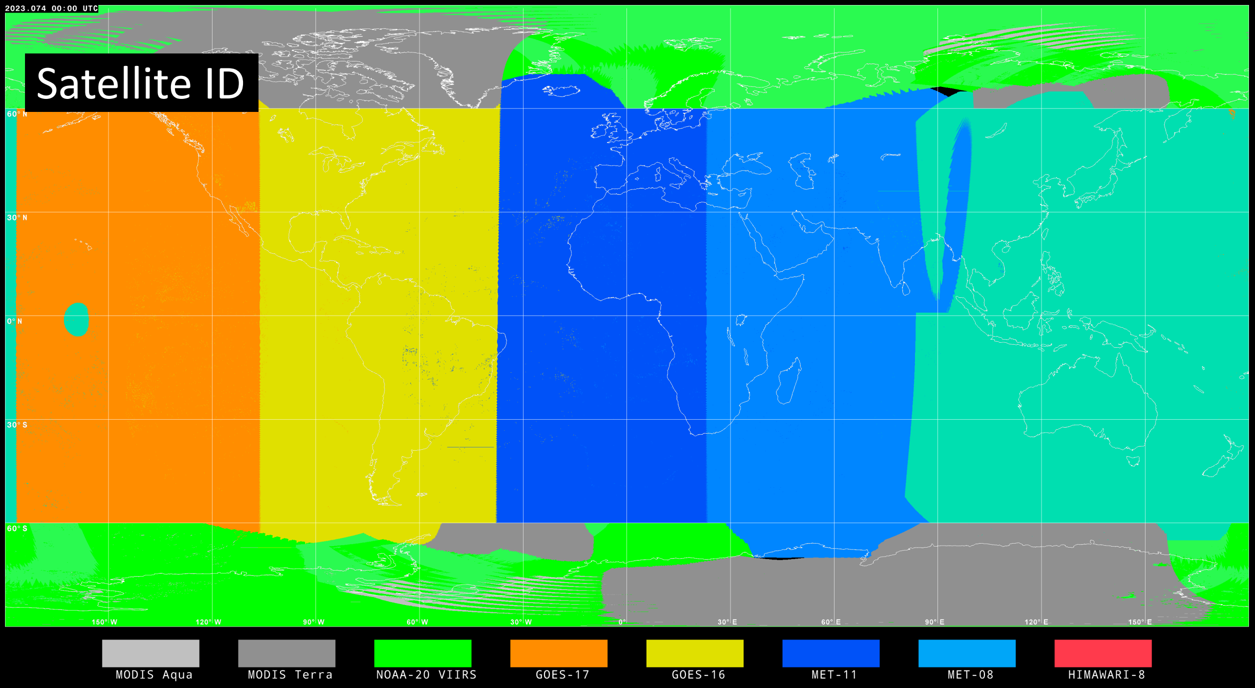
Summary

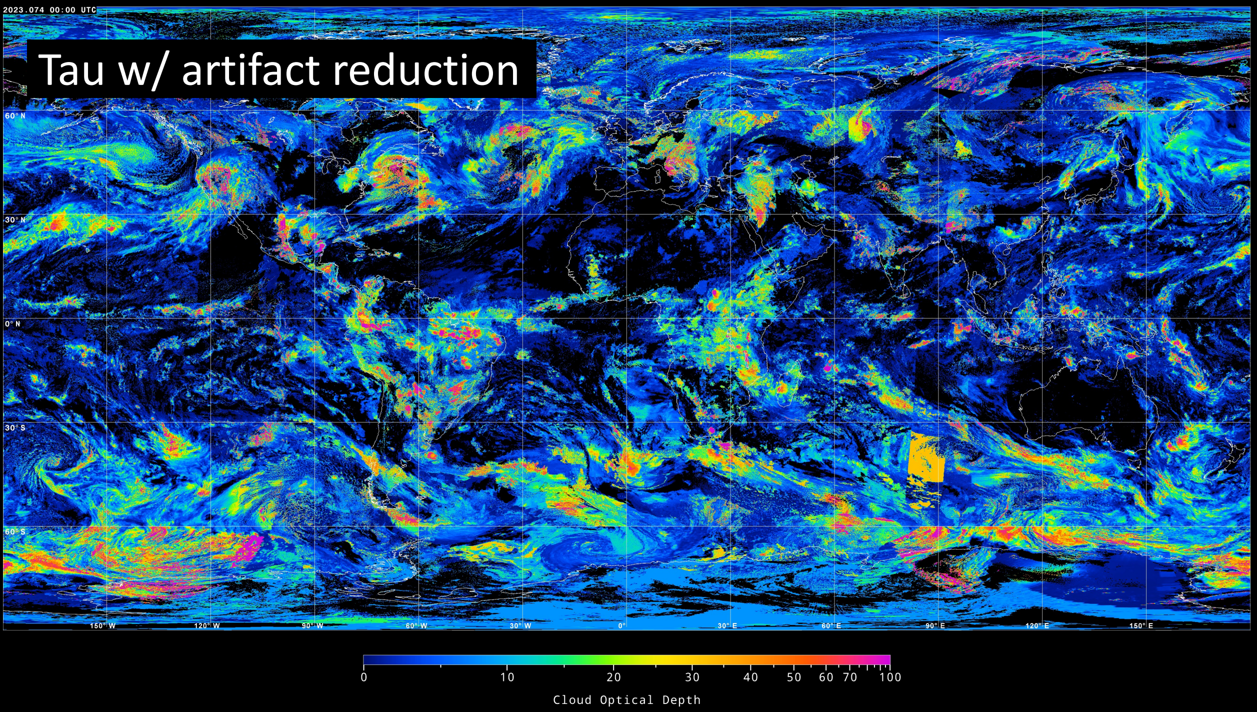
- The continuity algorithms for Ed5 clouds are progressing well.
- Revised satellite specific atmospheric correction procedures, more accurate clear-sky radiance procedures, updated cloud models, improved ancillary datasets, and cloud mask updates that better account for temporal and regional variations in WV absorption are leading to more consistent cloud properties from MODIS and VIIRS and also among GEOsats than previously achieved (demonstrated over ocean).
- Some next steps include
    - Further refinements to the ocean cloud mask
    - Incorporating a neural net applied to GEOS-IT data to better define LST's to support cloud mask refinements over land
    - Incorporating a neural net applied to GEOS-IT data to better detect clouds during polar night.
    - Implementing and testing new cloud top height and phase methods
    - Tuning for accuracy using CALIPSO and other data

New SatCORPS Capabilities

The **Sat**ellite **ClO**ud and **R**adiative **P**roperty retrieval **S**ystem

- The SatCORPS is an activity that has evolved synergistically with CERES.
- CERES cloud algorithms adapted to operate with low-latency to produce datasets for weather community (e.g. NCEP) and to support NASA field campaigns.
- Produce historical and long-term datasets to support needs from other agencies (e.g. DOE ARM program).
- Useful testbed for validating cloud algorithm features used in CERES.
- Processing framework, website (https://satcorps.larc.nasa.gov/indexV2.html), data dissemination and visualization services are in the process of being significantly upgraded.
- Several new capabilities recently installed.





Global Cloud Composites (GCC) from Satellites

Objective: Optimally combines radiances and derived products (cloud properties and radiative fluxes) from multiple GEO and LEO satellite imagers as seamlessly as possible

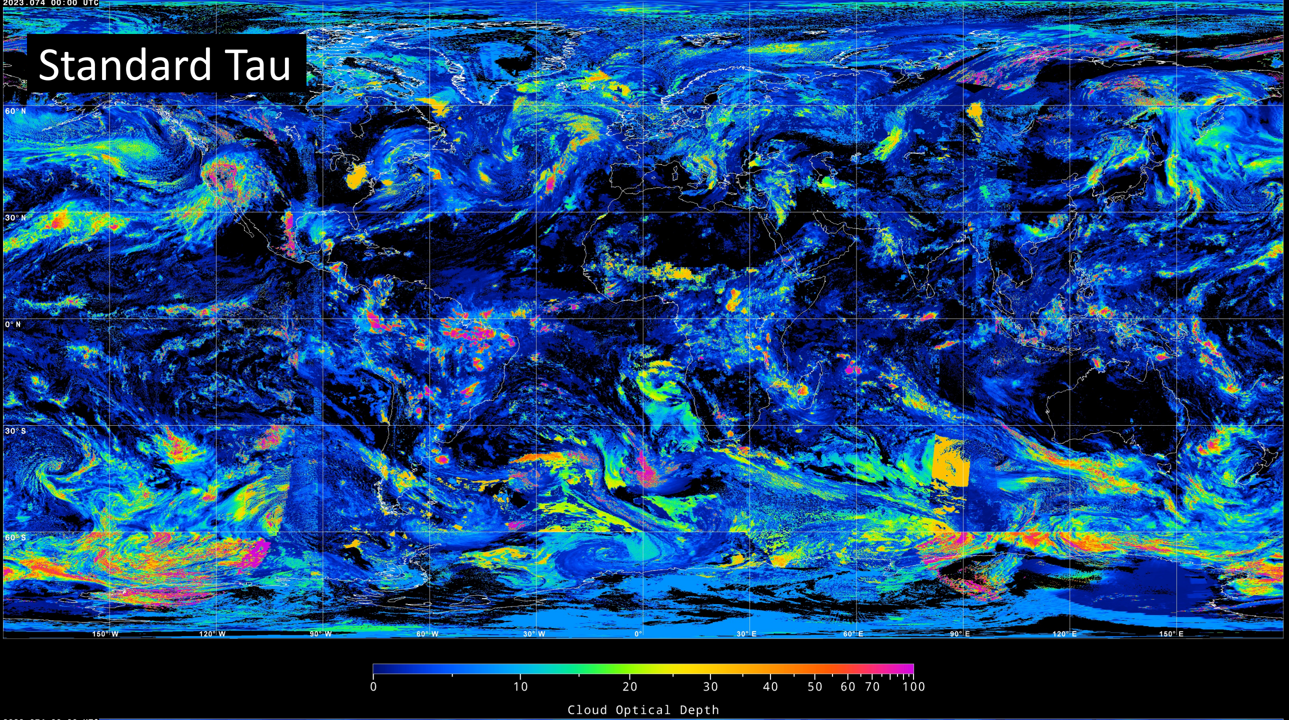
Based on system developed for DSCOVR ERB project (Khlopenkov et al., 2017, SPIE)

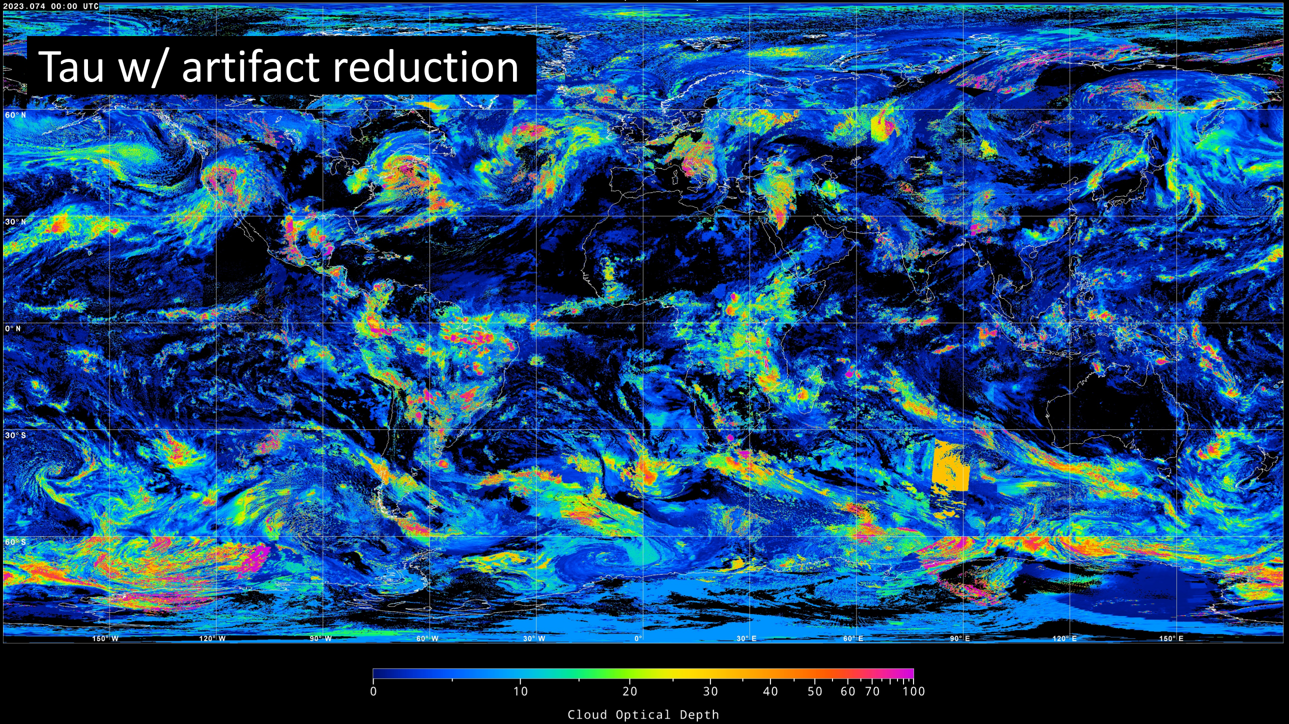
- Daytime only, 5-km grid, 1-2 hourly, limited set of radiances and basic cloud parameters

New system is intended for the broader community

- Partially funded by NASA SNWG to produce a multi-year, hourly dataset to serve modeling needs related to cloud parameterizations
- Day & Night, 3-km grid, 30-60 minutes
- Incorporates many CERES Ed5 cloud algorithm enhancements to improve accuracies, cross-platform consistency, and reduce artifacts (e.g sunglint, terminator)

System runs operationally to support various low latency (e.g. FlashFlux?) and NRT applications





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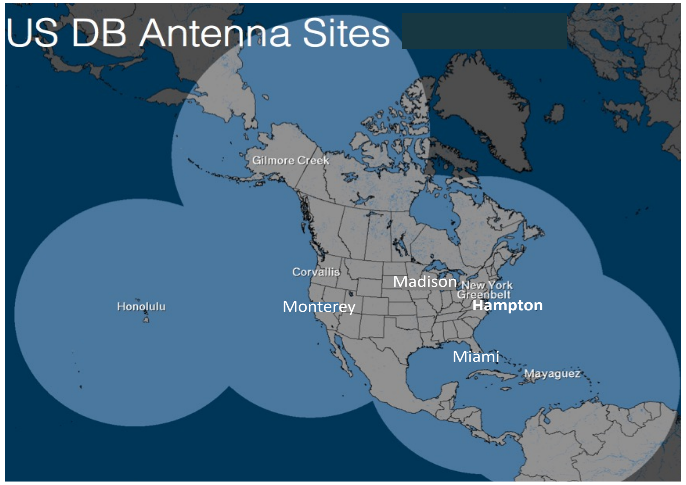
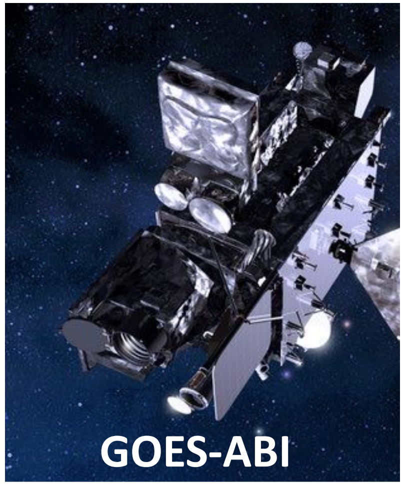
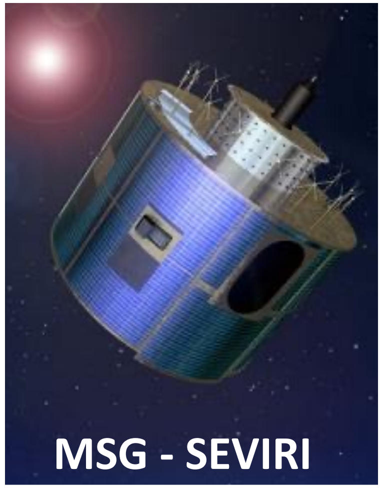
Enhancing the SatCORPS with Satellite Sounding Capabilities

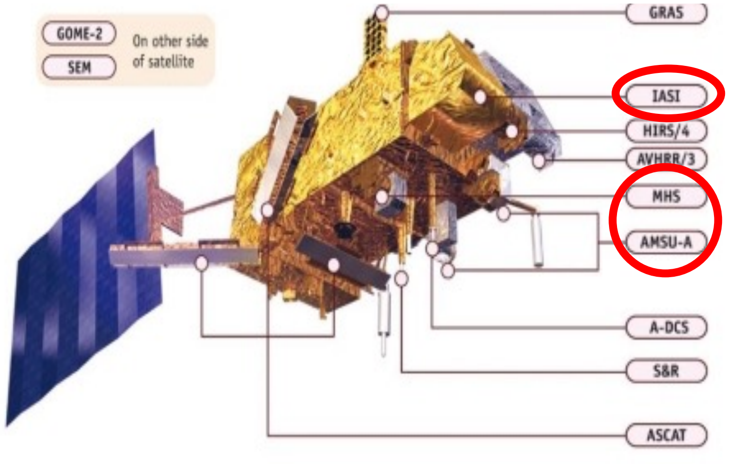
SatCORPS collaboration with William Smith Sr., Qi Zhang (UW) & **Anthony DiNorscia (SSAI)**

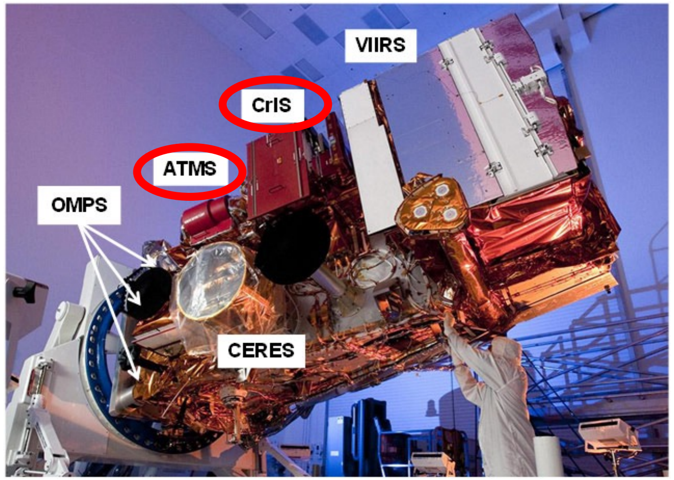
Creating next-gen high-res (2km /30min) GEO/LEO "hyperspectral" sounding proxy data via the fusion of current polar and geostationary satellite measurements





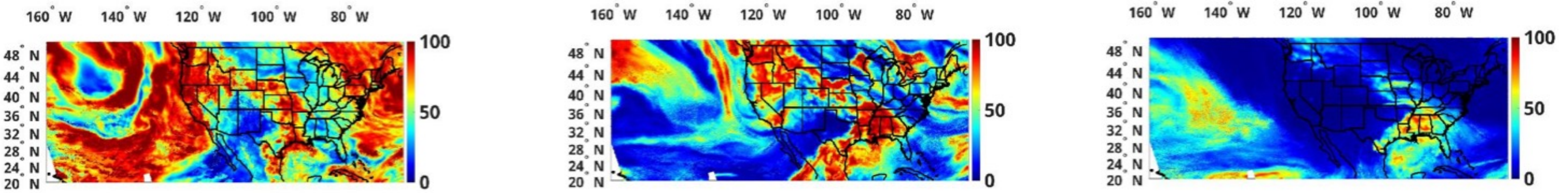




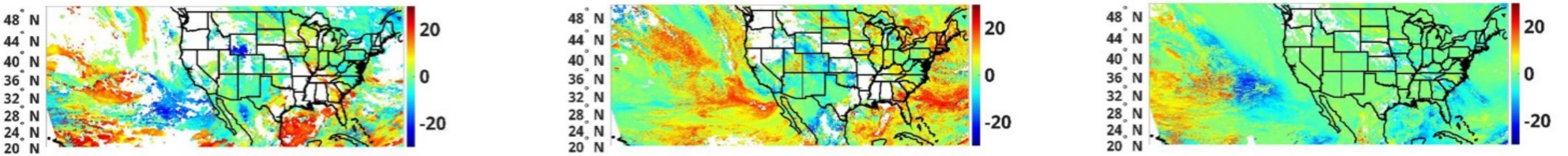


Data System Characteristics

- Full Spectral Resolution Used
- Full Spatial Resolution Used
- Polar Hyperspectral clear soundings above cloud & MW soundings below cloud are retrieved with 2-km spatial and 30-minute temporal resolution
- Soundings assimilated into 3-km Res. NWP (HRRR) Model
- Continuous Humidity data assimilation used to diagnose winds and dynamics
- 0-to-12-hour forecast cycle conducted every hour

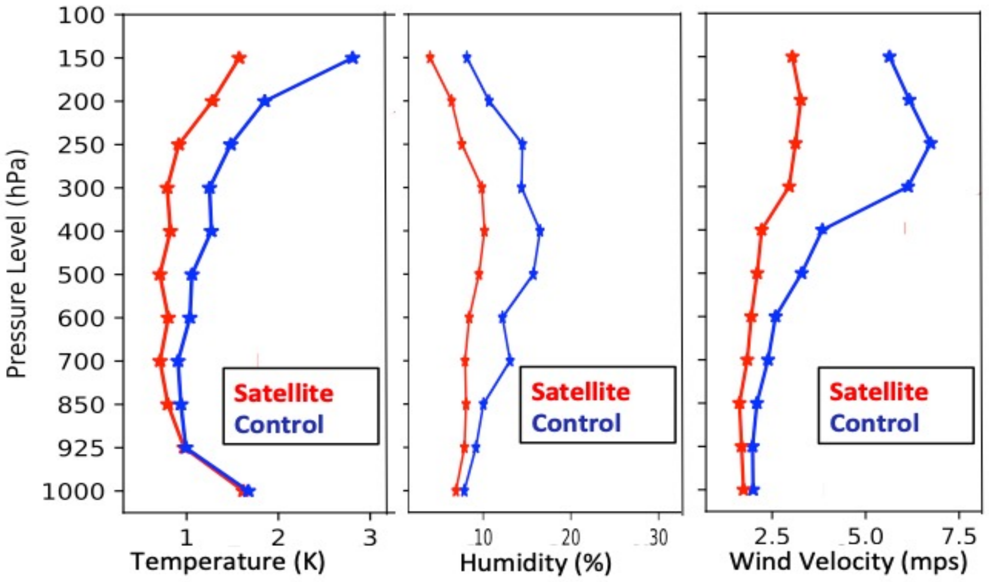


SAT+RAP 850 hPa RH (Percent) SAT+RAP 500 hPa RH (Percent) SAT+RAP 200 hPa RH (Percent)



SAT-RAP 850 hPa RH (Percent) SAT-RAP 500 hPa RH (Percent) SAT-RAP 200 hPa RH (Percent)

Standard Deviations Between Radiosondes and 6-hr Forecasts (Feb/Mar 2021)



- **Satellite sounding fusion data dramatically improve definition/predicton of atmospheric thermodynamics and winds**
- **CERES CWG plans to explore these high-resolution data for understanding/correcting RH biases in reanalyses to improve clear sky radiance simulations for the cloud mask.**

Datasets, visualizations, validation tools:

https://satcorps.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=phs
https://www.ssec.wisc.edu/hufusion/

QUESTIONS ?