CERES Clouds Working Group Report

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S. Sun-Mack (LEO sys), Q. Trepte (mask), C. Yost (mask, val)

P. Minnis (multi-layer), Y. Chen (clrsky, QC plots), R. Palikonda (GEO sys), S. Bedka (retrievals, val),

F-L. Chang (corrk), C. Wang (machine learning), B. Shan (geo), A. DiNorscia (satellite sounding)

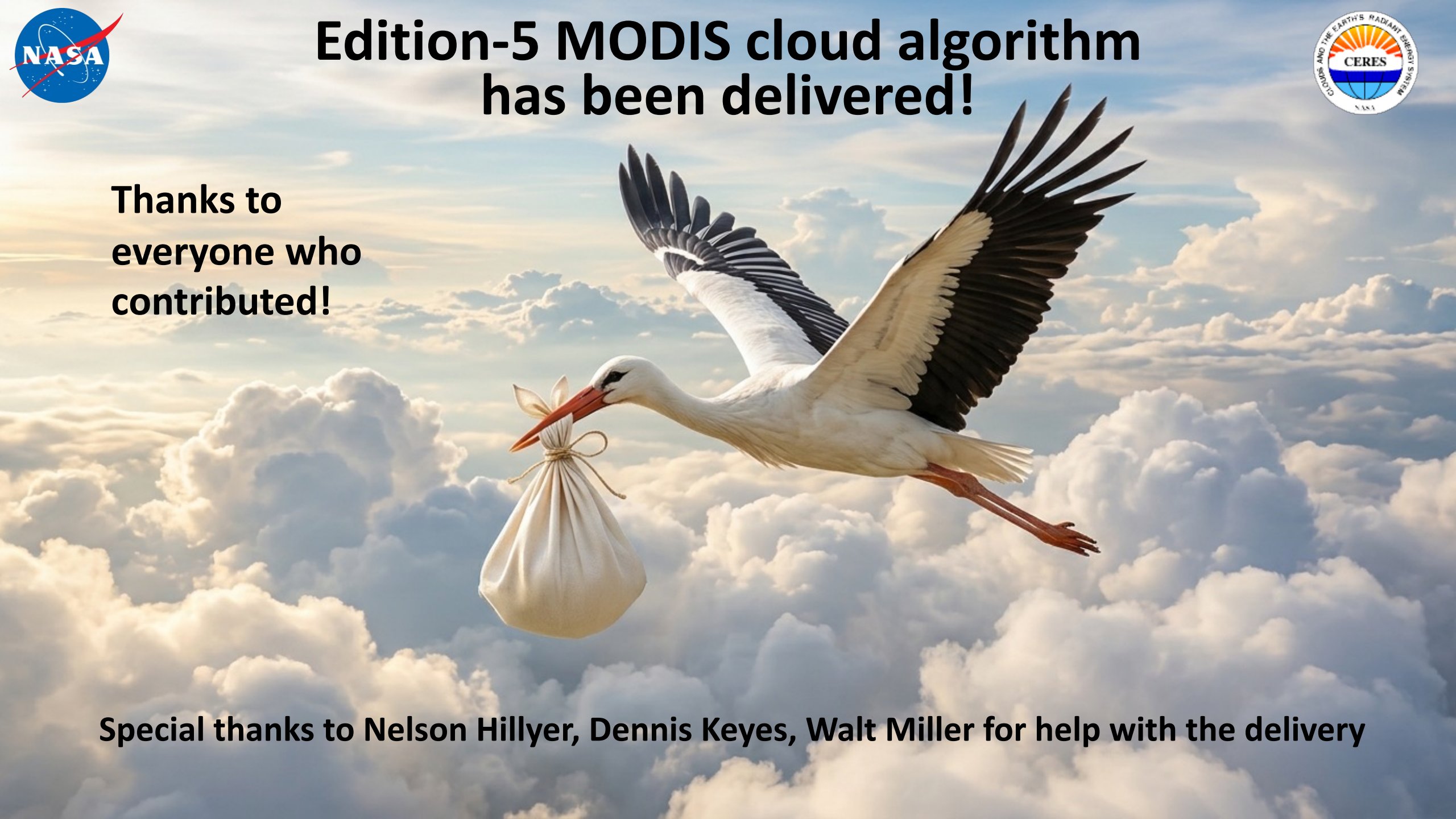
AMA, Hampton, VA

R. Smith (LEO proc.), ***ADNET, Hampton, VA***

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

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

Edition-5 MODIS cloud algorithm has been delivered!

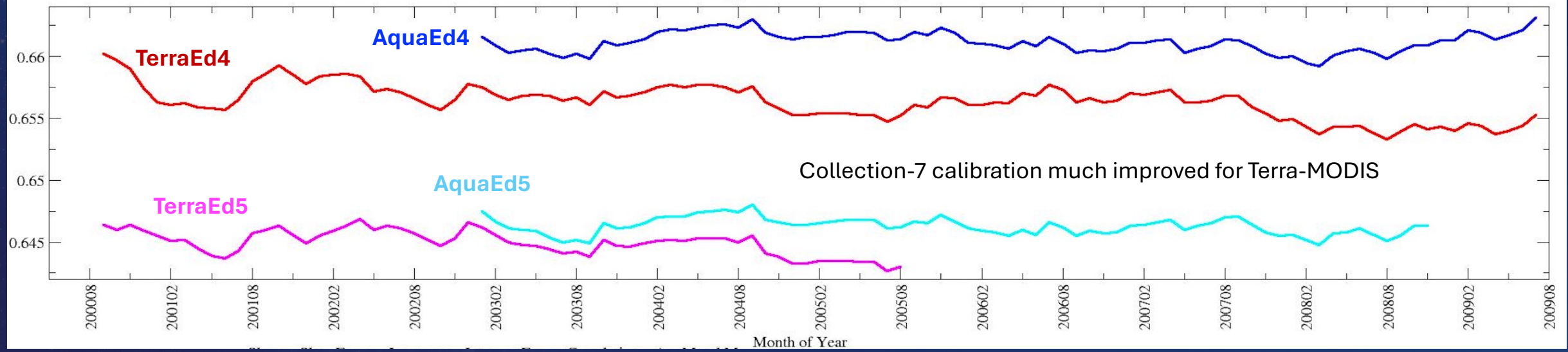


Thanks to everyone who contributed!

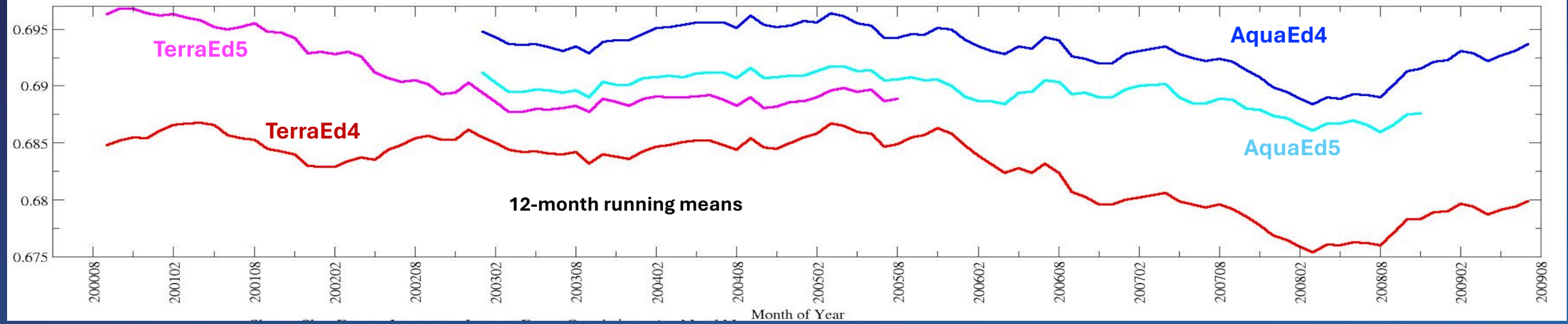
Special thanks to Nelson Hillyer, Dennis Keyes, Walt Miller for help with the delivery

Edition-5 Clouds is Processing!

Time Series of **Daytime** Global Total Cloud Fraction



Time Series of **Nighttime** Global Total Cloud Fraction



Cloud Algorithm Changes for Ed5 LEO

Emphasize cross-platform consistency with common algorithms

Atmos.Corr. / Clear Sky BT's

- Employ IASI spectral emissivity atlas over land (improve derived Tskin)
- IR absorption tuned to account for RTM and WV input errors (improve TOA CS closure)
- Nnet employed to estimate apriori land skin temperature (corrects reanalysis errors)

Cloud mask

- Common cloud mask for MODIS/VIIRS
  - Apply appropriate radiometric scalings to solar channels
  - Removed satellite dependent thresholds; all IR tests include comparisons w/simulated CS BT
  - Nnet nighttime cloud mask over southern hemisphere sea-ice and Antarctica
  - Re-tuned the cloud mask to improve agreement with CALIPSO clouds (used CALIPSO in C-Train to tune off-nadir)

Cloud retrievals

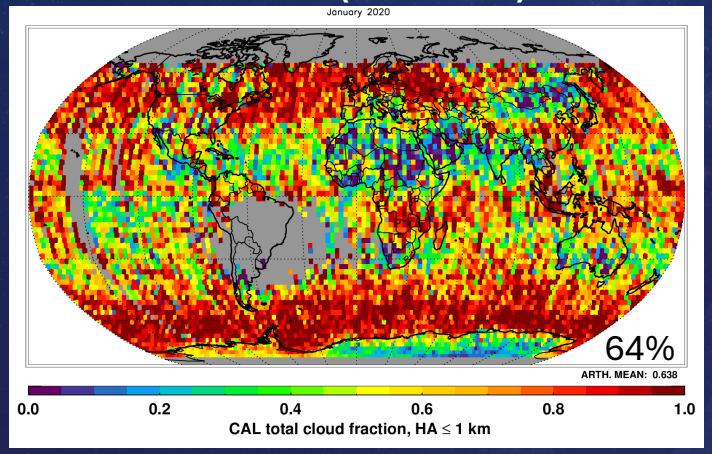
- Ice clouds: replaced roughened hexagonals with two-habit ice cloud model (P. Yang et al.)
- Water Clouds: replaced LUT's
  - Based on spectrally resolved mie parameters, optical properties, reflectances for each instrument (SRF)
- Resurrected use of 1.6 μm band, developed daytime hybrid (1.6/1.24 um) COD over snow/ice surfaces
- Nnet employed for Nighttime optically thick cloud optical depths
- Nnet employed for ice cloud heights (tops and bases)
- Nnet employed to ID multi-layer ice over water clouds, 2-layer top and base heights

experimental parameters

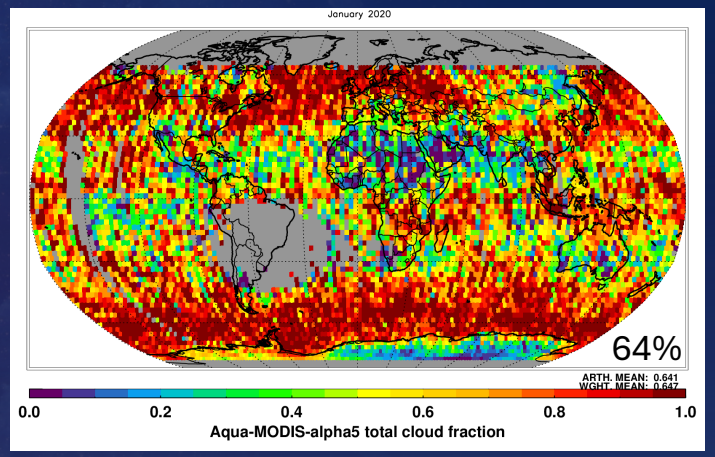
A-MODIS Edition 5 and CALIPSO Cloud Fraction

Daytime (Jan 2020)

CALIOP (HA ≤ 1 km)

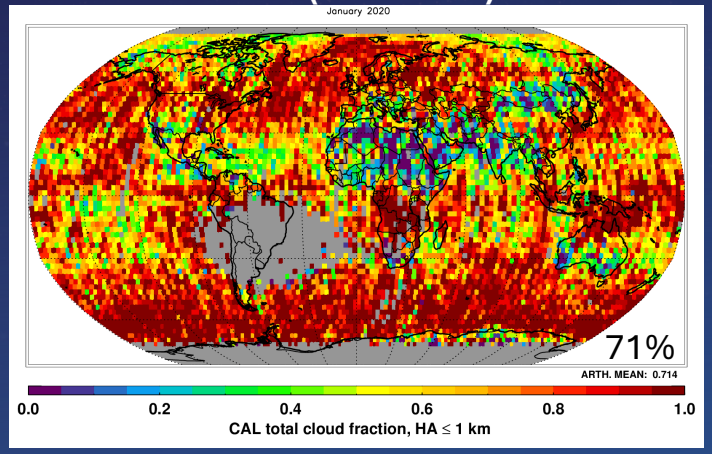


Aqua MODIS Ed5

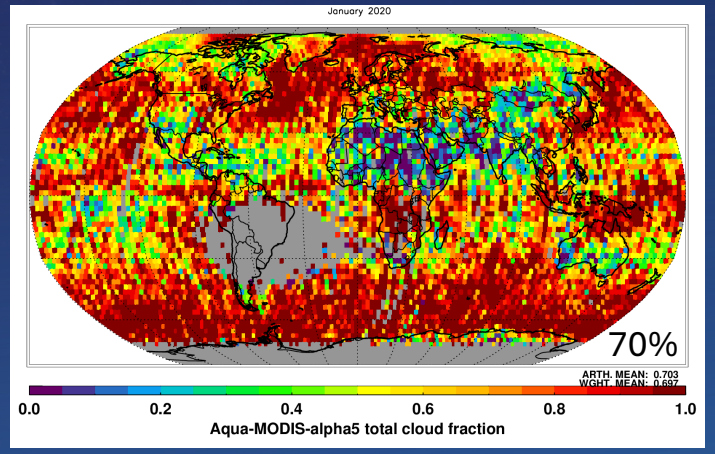


Nighttime Jan 2020

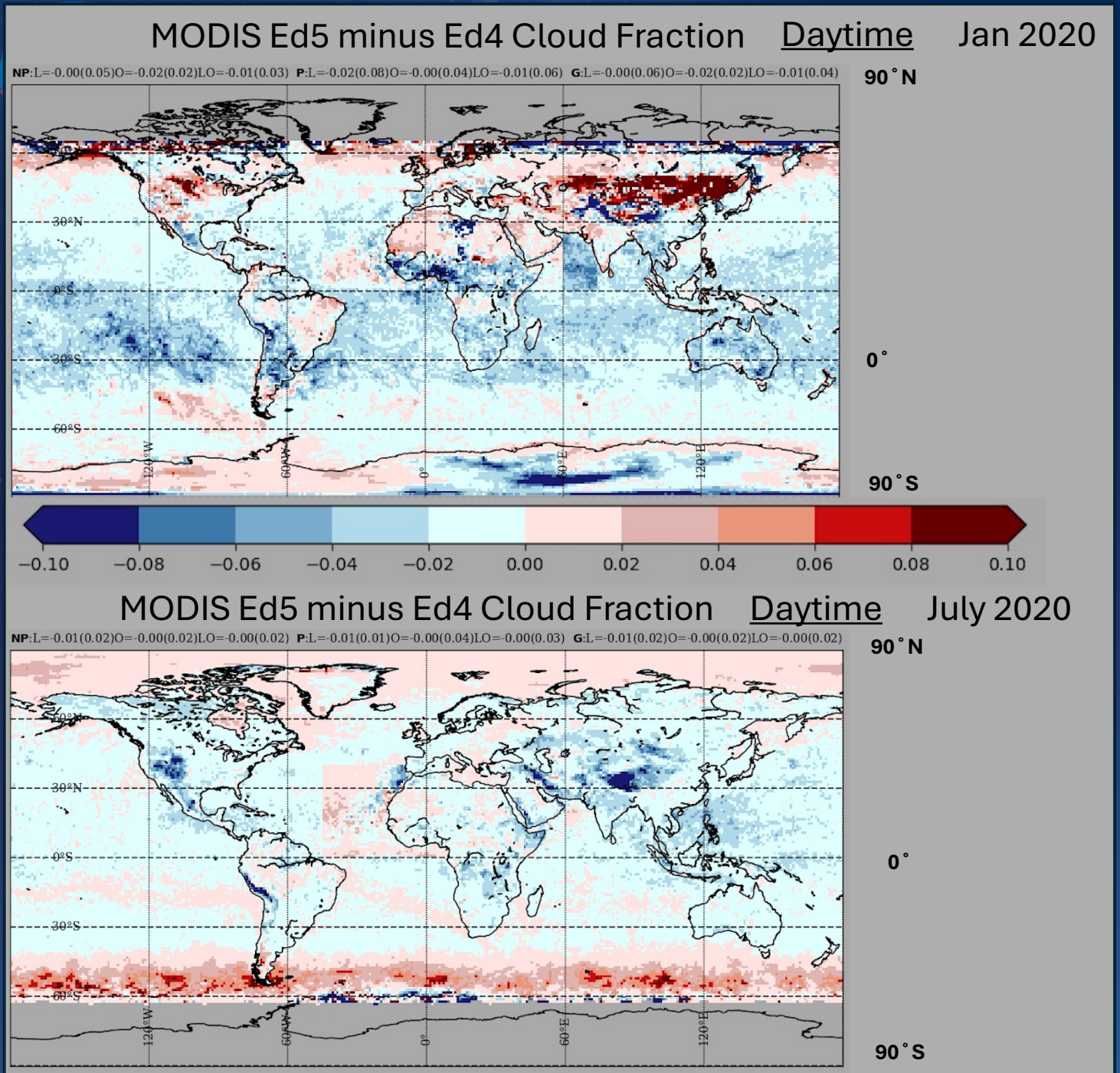
CALIOP (HA ≤ 1 km)



Aqua MODIS Ed5



- Qualitatively, the agreement between the new MODIS Ed5 and CALIOP is excellent.
- Let's look at the changes from Edition 4 to Edition 5

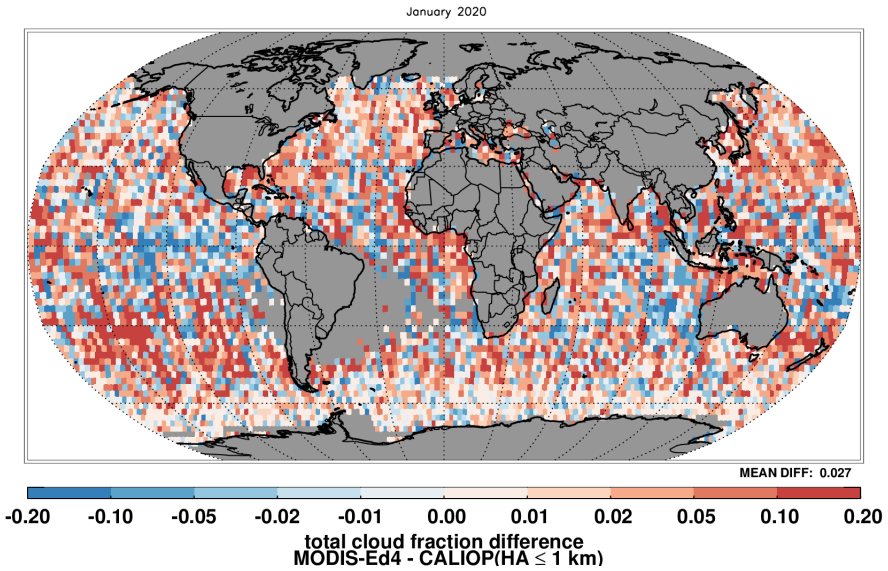


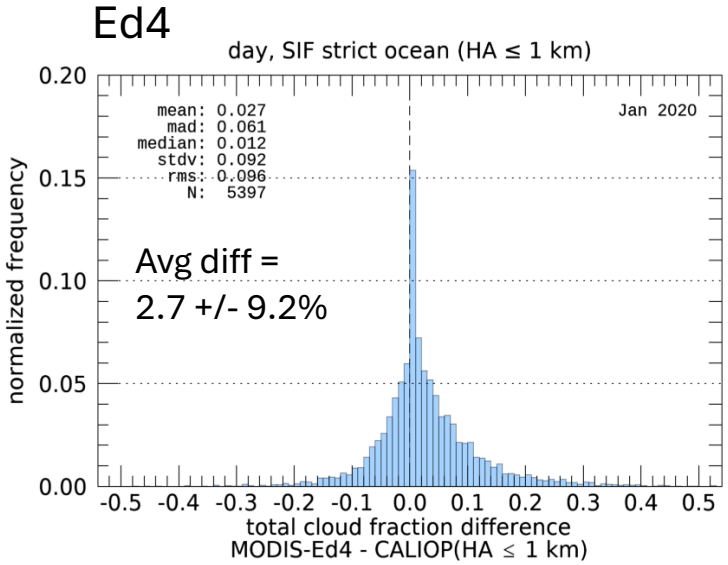
Daytime Cloud Fraction Comparison (Ed5 vs Ed4)

- Daytime CF differences generally small (within +/- 2% most areas) for Jan and July 2020.
- CF reduction over ocean intentional, based on validation with CALIPSO.
- Reduction of false thin cirrus detection over desert and high-elevated arid surfaces also intentional (see July).
- Unexpected increases over snow covered land (NH in Jan) - due to poor ERA5 Tskin.

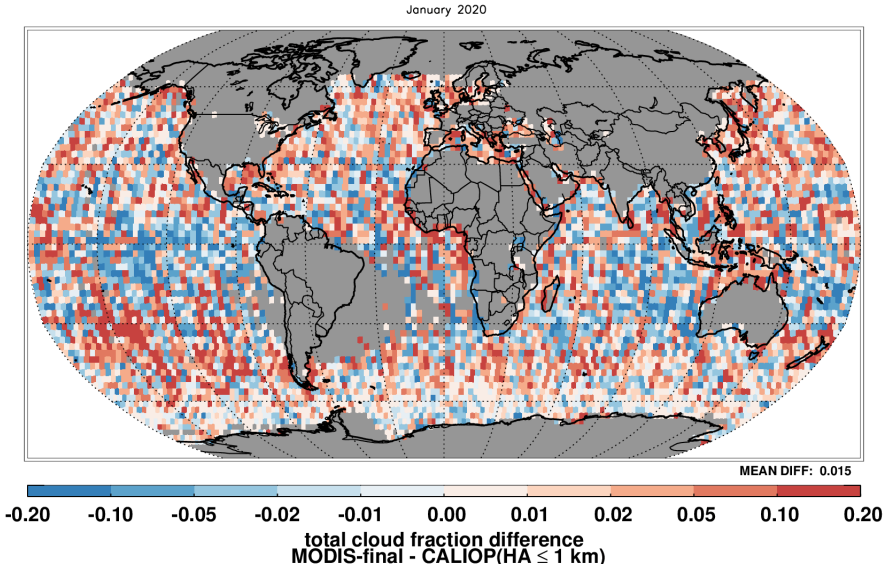
MODIS minus CALIOP Cloud Fraction Daytime Jan 2020

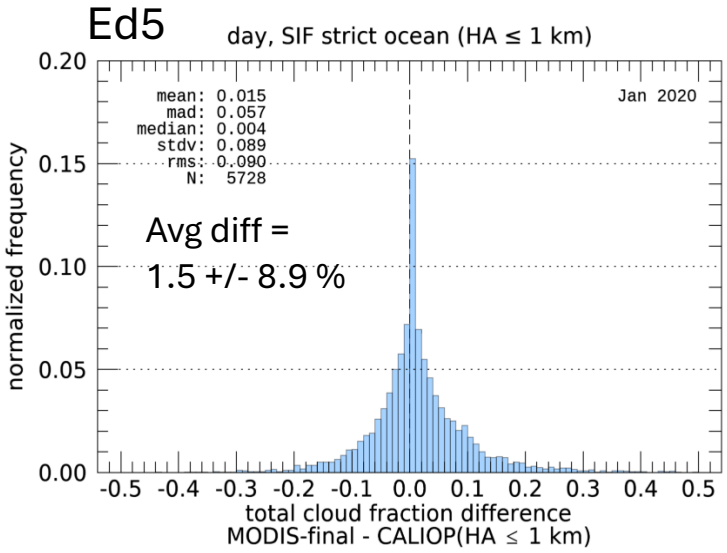
Ed4





Ed5





Ocean CF Comparison with CALIPSO (Daytime)

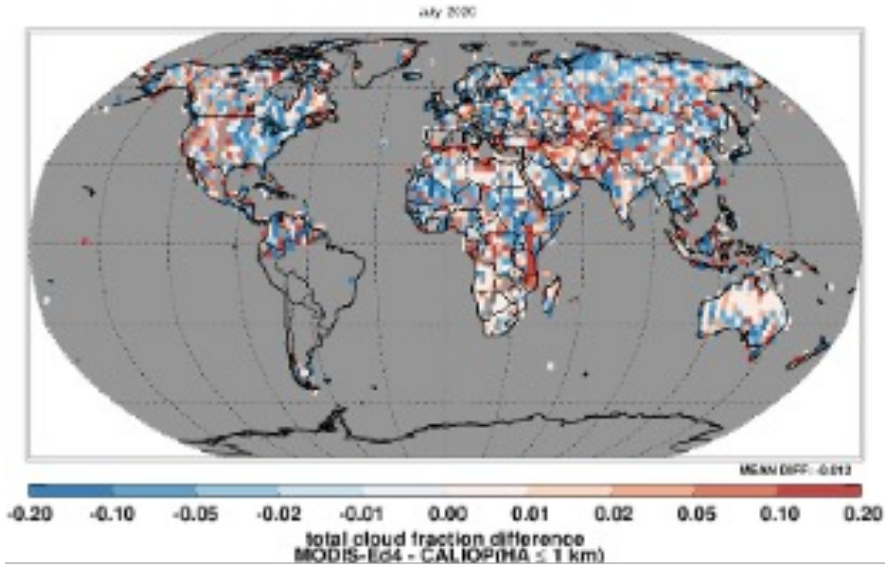
- Globally, Ed4 and Ed5 in very good agreement with CALIOP.
- Over SIF ocean, Ed4 overestimates CF relative to CALIOP by 2.7 +/- 9.2%; PDF skewed to the right.
- Ed5 LOA is 1.5 +/- 8.9%; Median difference less than 0.5%.
- Overall, a modest improvement is found for daytime clouds in Ed5.

Note: CALIPSO in C-train enabled more robust cloud mask tuning for Ed5 (off-nadir MODIS view angles) than A-Train used to tune Ed4.

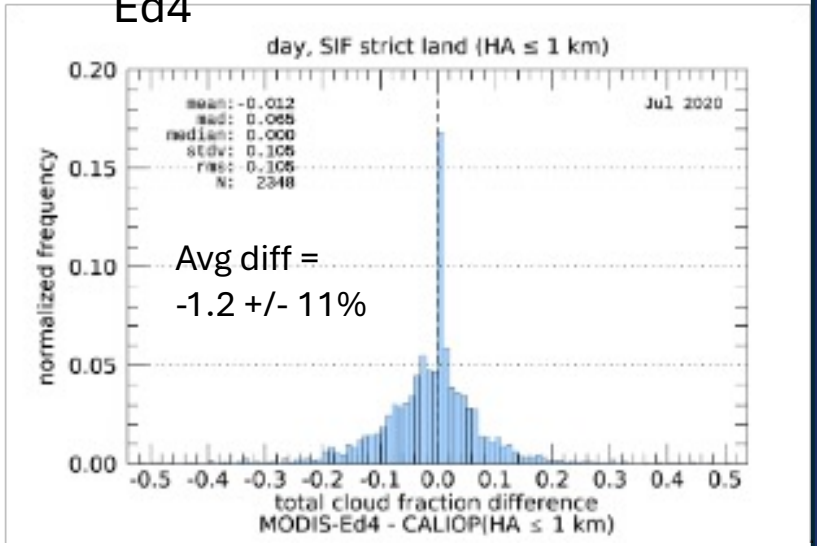
Land CF Comparison with CALIPSO (Daytime)

MODIS minus CALIOP Cloud Fraction Daytime July 2020

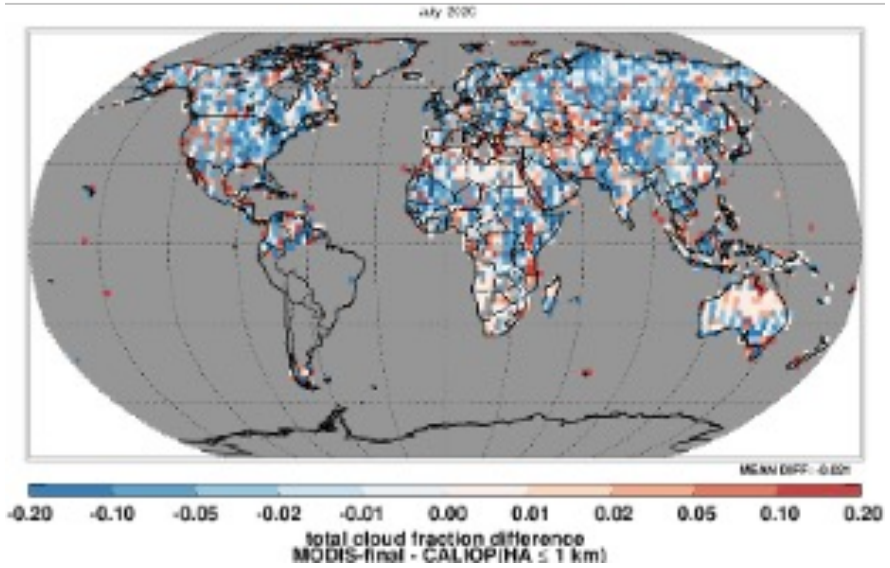
Ed4



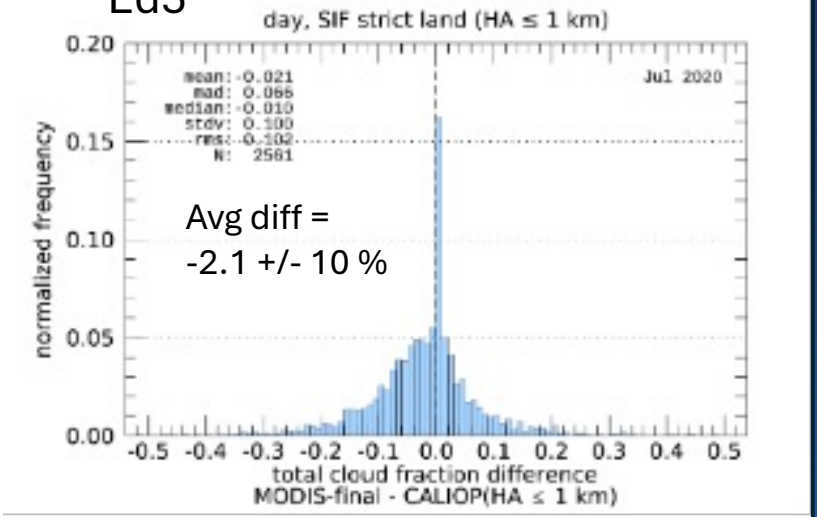
Ed4



Ed5



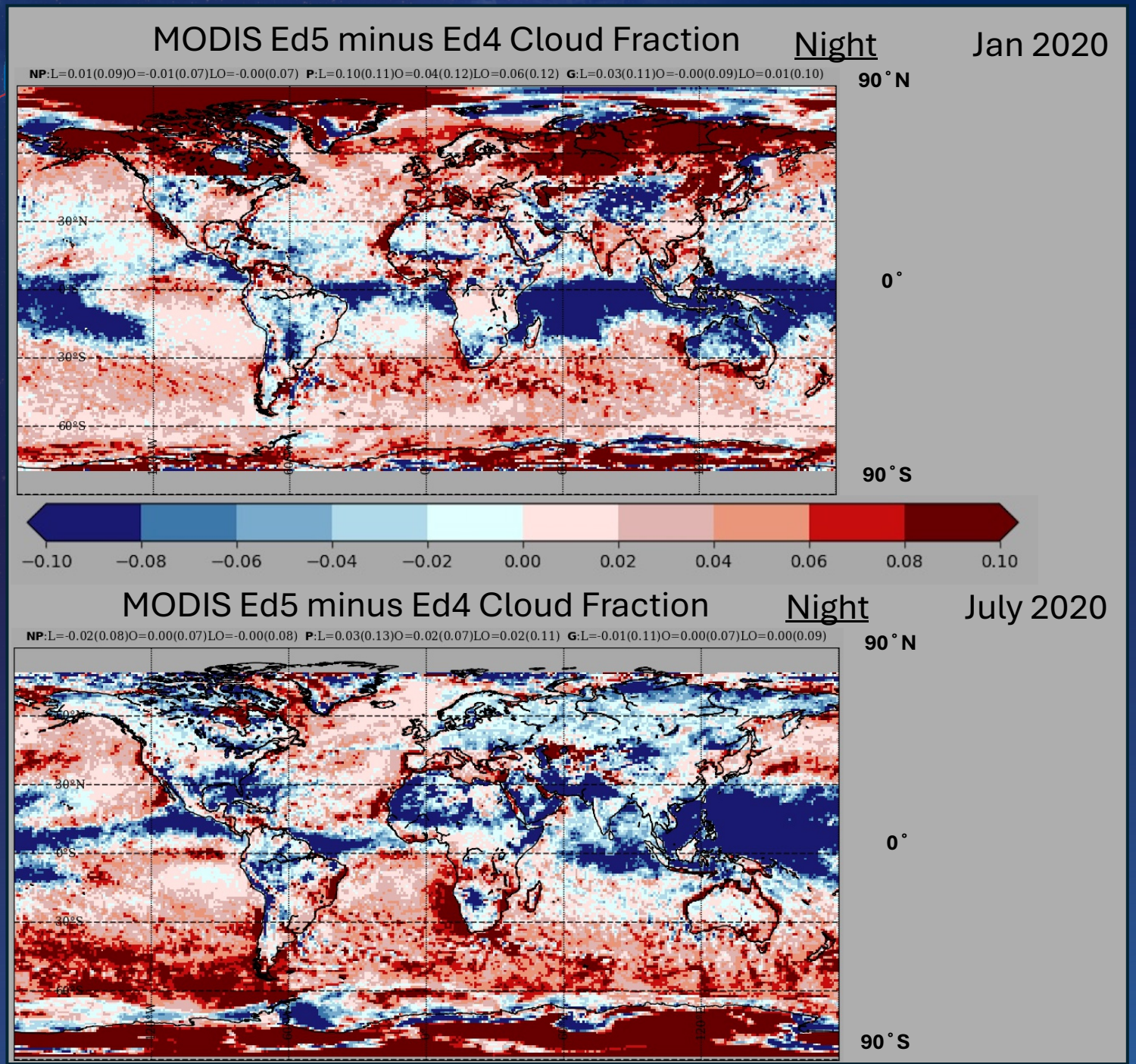
Ed5



- Ed5 agrees better over desert and high-elevated arid areas.
- Difference map less noisy for Ed5 (smaller stddevs).
- Ed5 has larger negative bias

  Ed5-Cal: -2.1 +/- 10%

  Ed4-Cal: -1.2 +/- 11%
- *Cloud mask requires accurate clear sky simulations for solar and IR channels – Ed5 has nice improvements over ocean but uncertainties still high over land.*

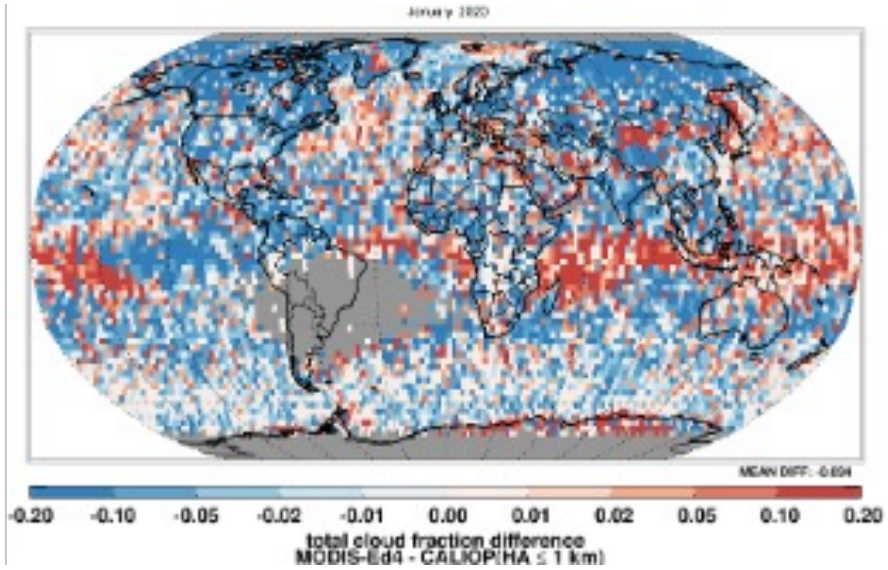


Ed5 vs Ed4 CF Comparison (Nighttime)

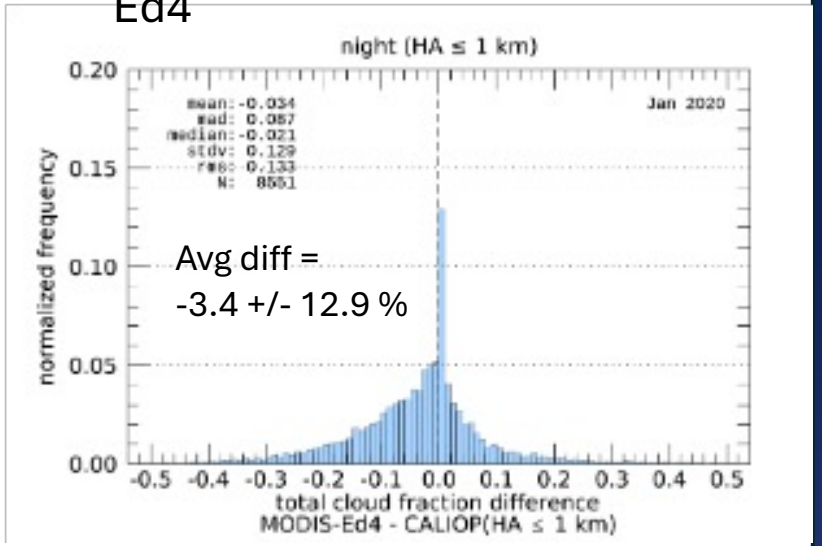
- Nighttime CF differences between Ed5 and Ed4 much larger than daytime.
- Large tropical reduction intentional, based on validation with CALIPSO (too many high clouds in Ed4).
- Unexpected increases over snow covered land (NH in Jan) - due to poor ERA5 Tskin.
- Over the Arctic, Ed5 applies the Ed4 thresholding approach but without the use of 6.7 and 13.1 μm bands. ERA-5 Tskin over snow and ice also problematic.
- Ed5 applied Nnet to help improve cloud detection over Antarctica.

MODIS minus CALIOP Cloud Fraction Nighttime Jan 2020

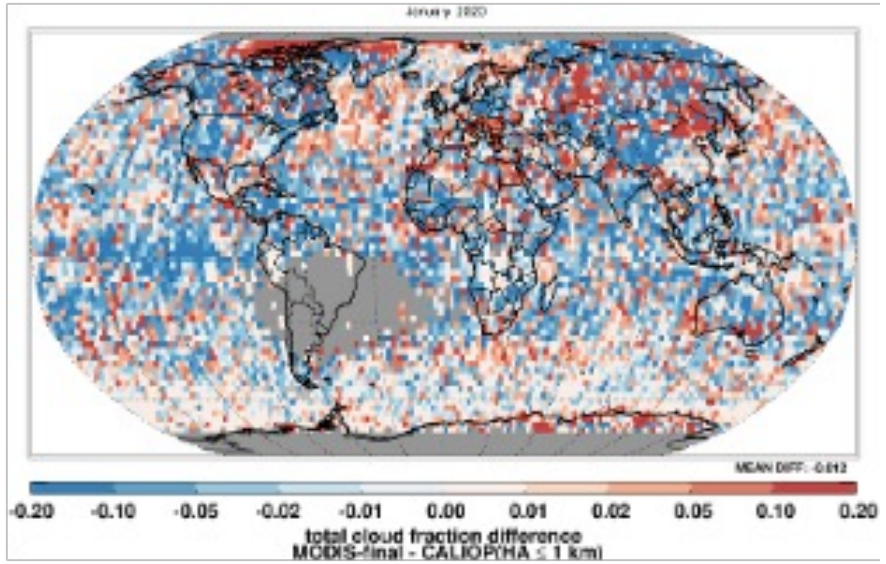
Ed4



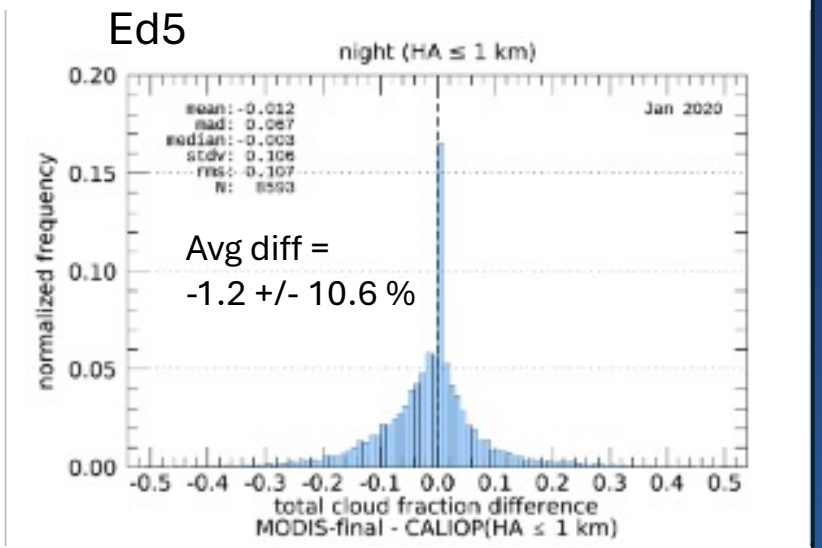
Ed4



Ed5



Ed5



CF Comparison with CALIPSO (Nighttime)

- Tropical thin cirrus detection much improved in Ed5.
- Ed4 uncertainties (-3.4 +/-12.9 %) larger at night than during day.
- Ed5 uncertainties (-1.2 +/-10.6 %) lower than Ed4 and consistent with daytime.
- Regional biases reduced in many areas in Ed5.
- Arctic cloud fractions better on average but positive and negative biases are large (poor skill regionally at night).

Ed5 Aqua MODIS vs NOAA-20 VIIRS Consistency Check

VIIRS cloud algorithm to be delivered Spring 2027

Cloud Fraction Consistency:

- First order problem that affects consistency for all other derived cloud properties
- Ed5 applies a common cloud detection algorithm (one for LEO's, one for GEO's)
- Solar channels need to be appropriately scaled to a common reference (e.g. MODIS C7)

Enabling a common cloud mask for Ed5

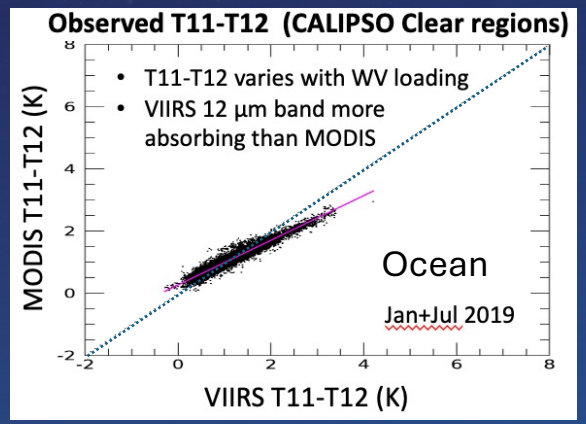
Ed4 cloud mask applied different thresholds to MODIS and VIIRS since they have different SRF's.

Objective for Ed5 is to apply a common cloud mask (want to avoid tuning multiple satellites).

For Ed5, all satellite dependent thresholds were removed and all IR tests updated to include comparisons with clear sky simulations that account for the various sensor SRF's.

Example:
(Thin cirrus test)

If T11-T12 > X,
then test passes
(i.e. cloud)



X is expected clear sky value + uncertainty (σ)

Ed4 (different masks)

X = 1.5 K (MODIS)
X = 2.2 K (VIIRS)

Must tune all satellites
No regional dependence

Test (common mask)

X = 1.5 K (MODIS)
X = 1.5 K (VIIRS)

Poor consistency for tropical high clouds

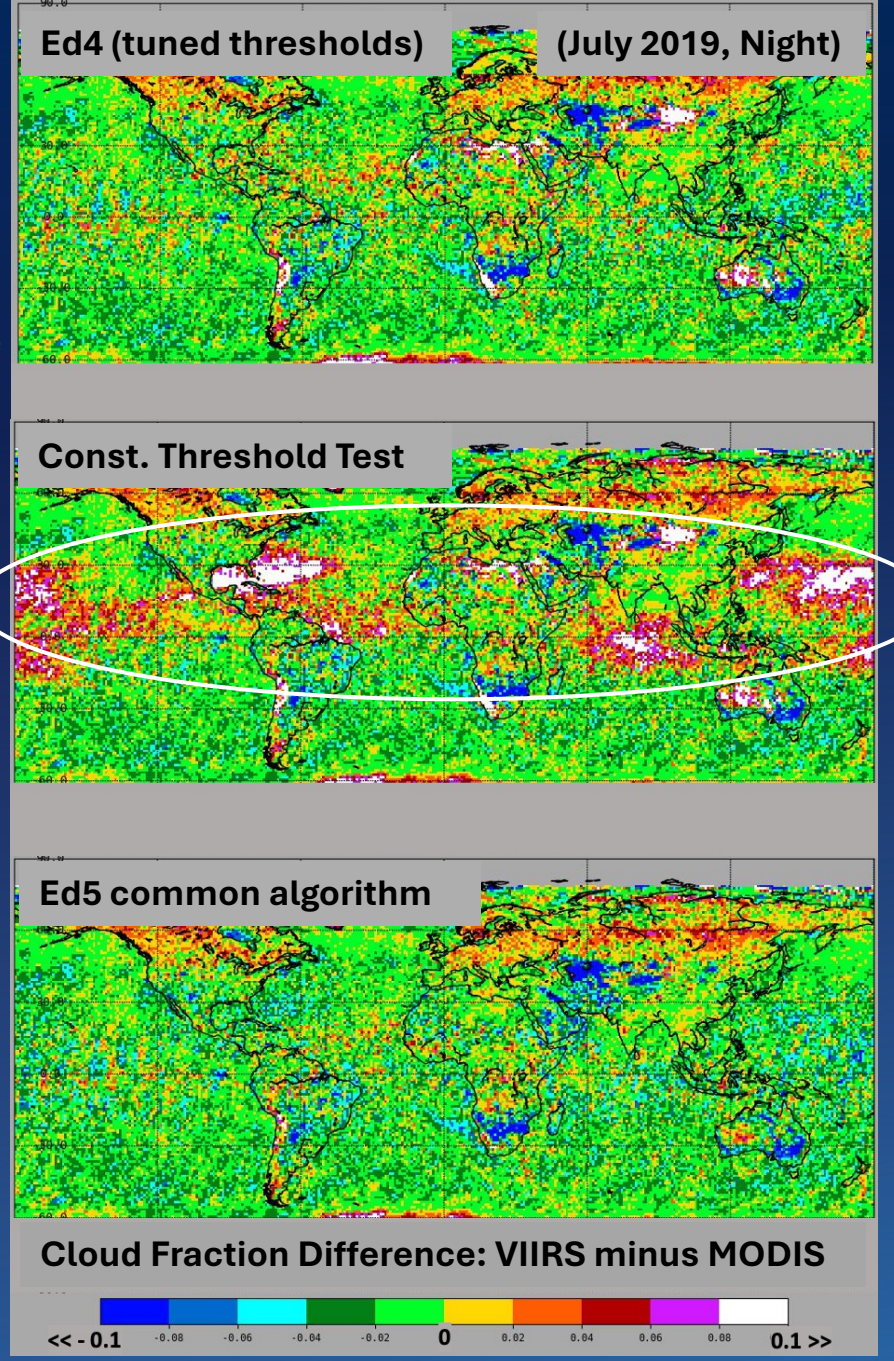
Ed5 (common algo)

X= csBTD + σ

csBTD = simulated BTD
σ = const for all sats

Accounts for WV variability & SRF's

Consistent results across satellites



Radiometric Scaling Noaa-20 VIIRS to Aqua-MODIS (solar channels)

The cloud algorithm requires two sets of scalings

1. Applies SBAF to remove SRF differences (pure calibration normalization)
   - *Needed for cloud optical properties (sensor SRF's included in forward models)*
2. Does not apply SBAF (Make the VIIRS imager band look like MODIS)
   - *Needed for the cloud mask (sensor SRF differences not accounted for)*
   - *e.g. the ocean reflectance model is not satellite dependent*
   - *Emphasis should be on the clear sky or dark end of the dynamic range*

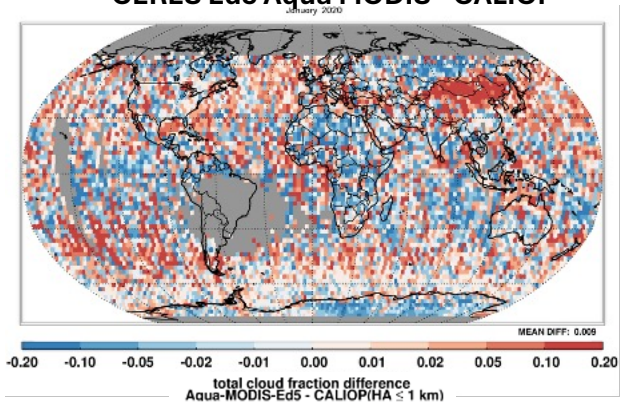
N20-VIIRS/Aqua-MODIS visible channel scaling factors for solar channels used in the cloud algorithm

Bands (μm)	Non-Polar	
	No SBAF	SBAF
0.86	1.0018	1.0152
1.24	0.9886	0.9866
1.38	-	-
0.65	1.0292	1.0321
1.6	1.0567	1.0006

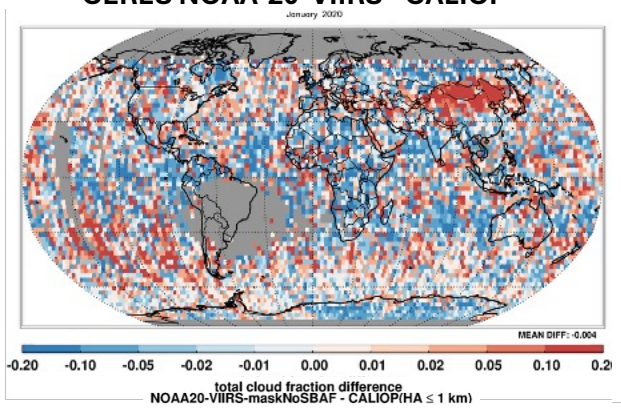
MODIS and VIIRS Cloud Fraction Consistency Assessment
Jan 2020 Day & Night (Ed5)

DAY

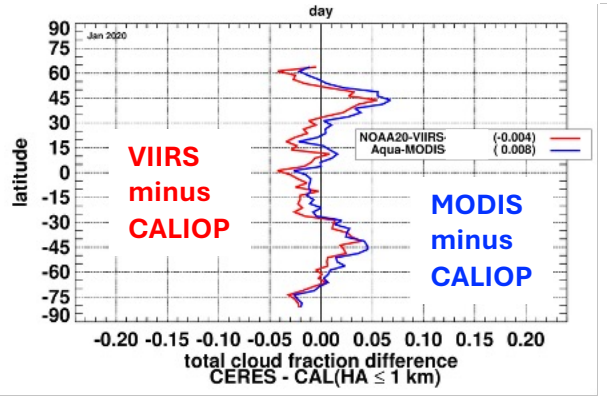
CERES Ed5 Aqua MODIS - CALIOP



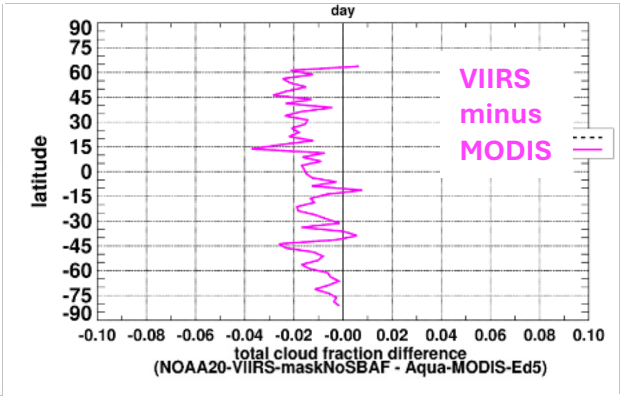
CERES NOAA-20 VIIRS - CALIOP



CERES Ed5 Zonal Means vs CALIOP

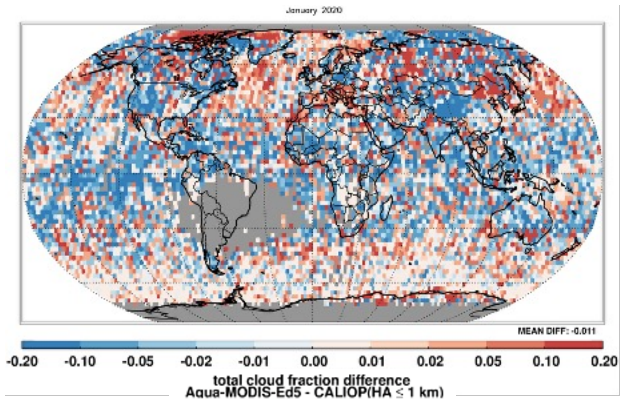


CERES Ed5 Zonal Mean Differences

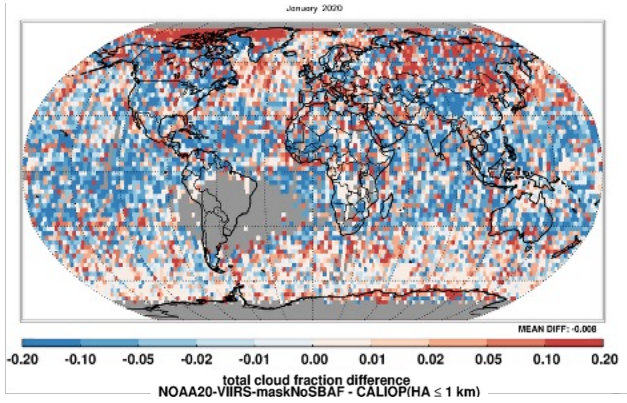


Night

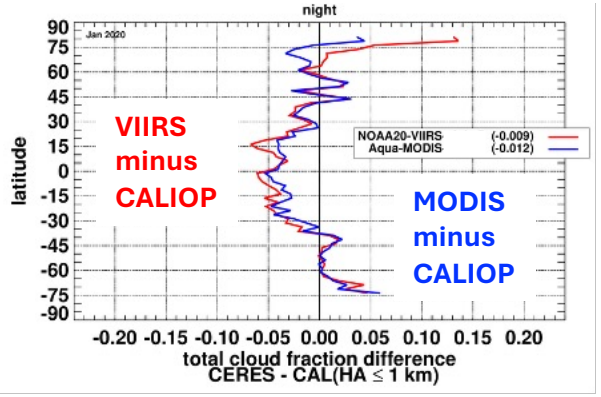
CERES Ed5 Aqua MODIS - CALIOP



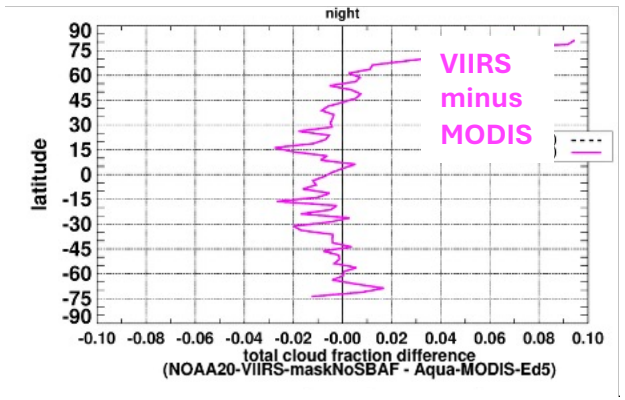
CERES NOAA-20 VIIRS - CALIOP



CERES Ed5 Zonal Means



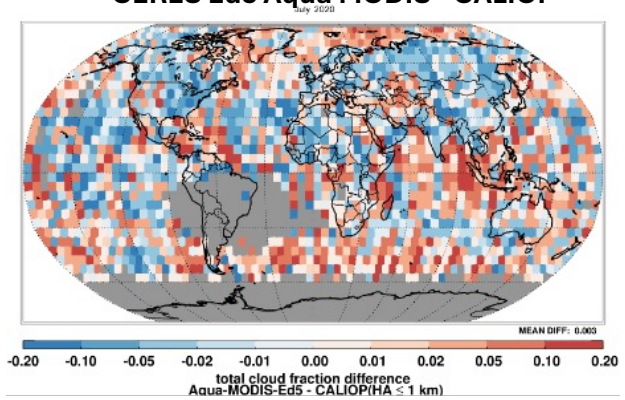
CERES Ed5 Zonal Mean Differences



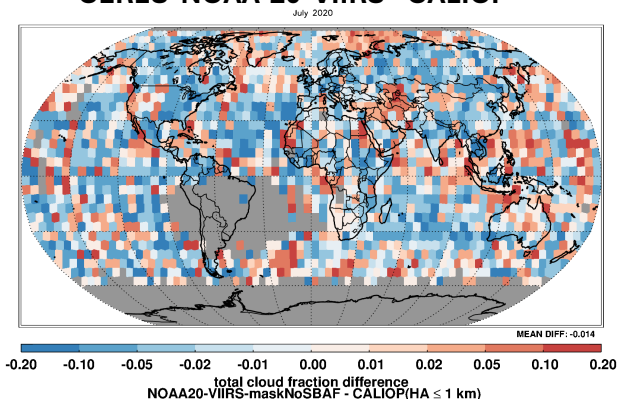
Zonal mean differences quite consistent from pole to pole in January, small latitude dependencies

MODIS and VIIRS Cloud Fraction Consistency Assessment
July 2020 Daytime

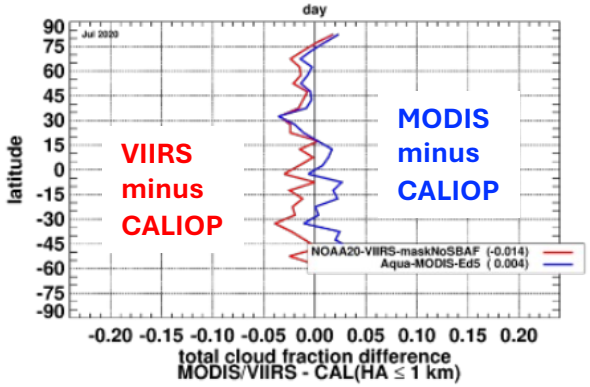
CERES Ed5 Aqua MODIS - CALIOP



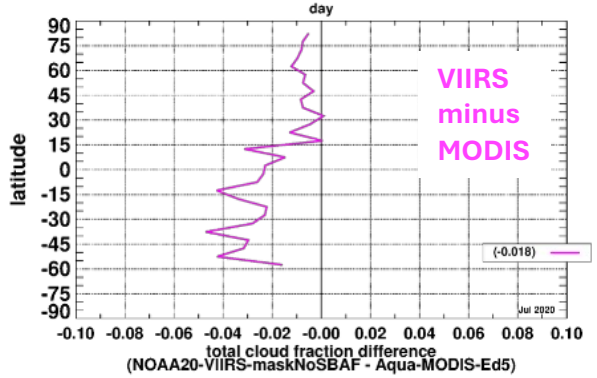
CERES NOAA-20 VIIRS - CALIOP



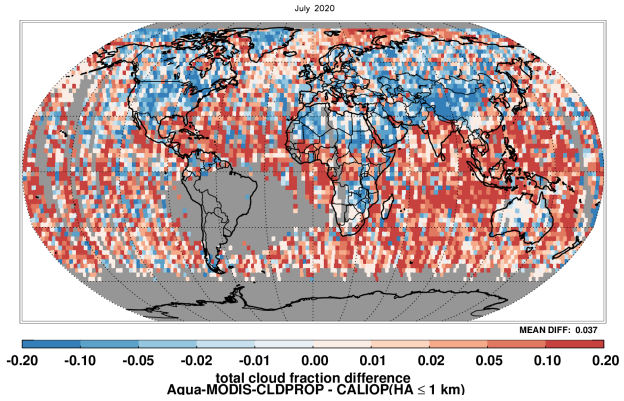
CERES Ed5 Zonal Means vs CALIOP



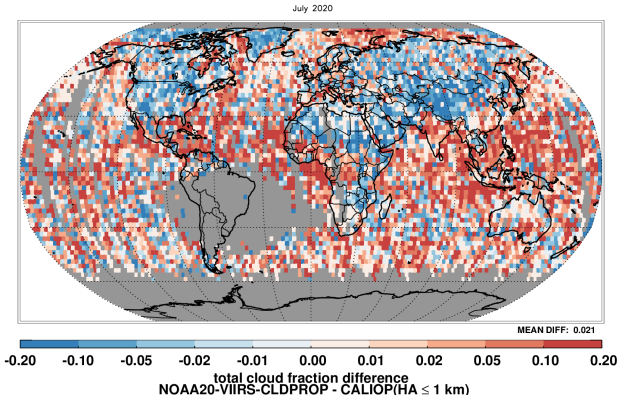
CERES Ed5 Zonal Mean Differences



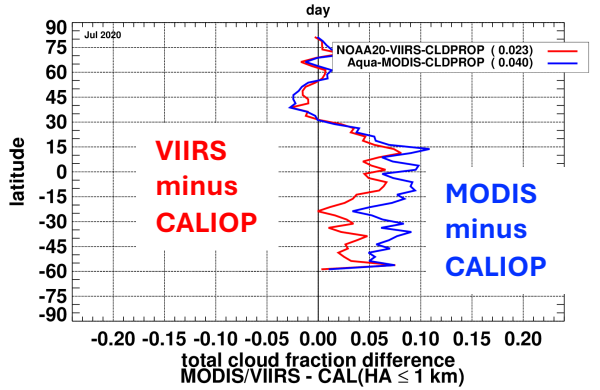
CLDPROP Aqua MODIS - CALIOP



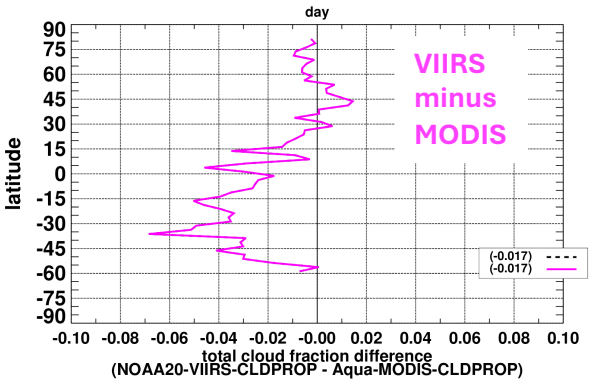
CLDPROP NOAA-20 VIIRS - CALIOP



CLDPROP Zonal Means



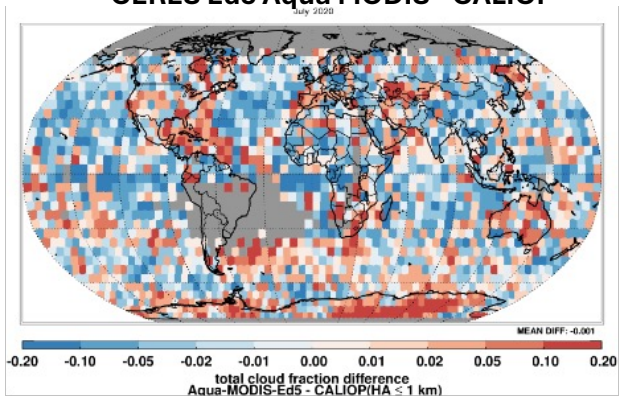
CLDPROP Zonal Mean Differences



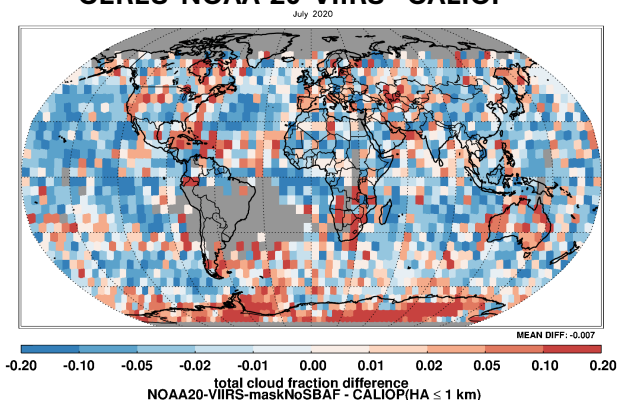
CERES Ed5 and CLDPROP V01.1 have remarkable consistency in the zonal mean differences despite accuracy differences for MODIS and VIIRS relative to CALIOP.

MODIS and VIIRS Cloud Fraction Consistency Assessment
July 2020 Nighttime

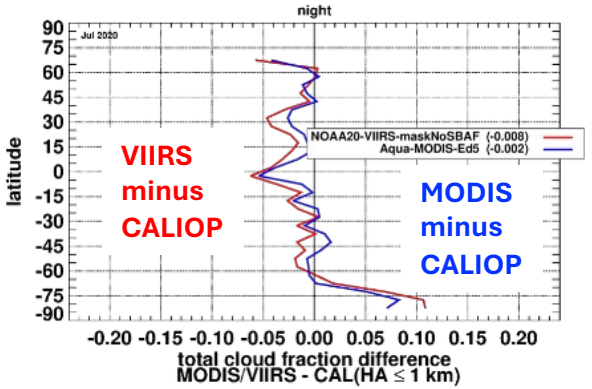
CERES Ed5 Aqua MODIS - CALIOP



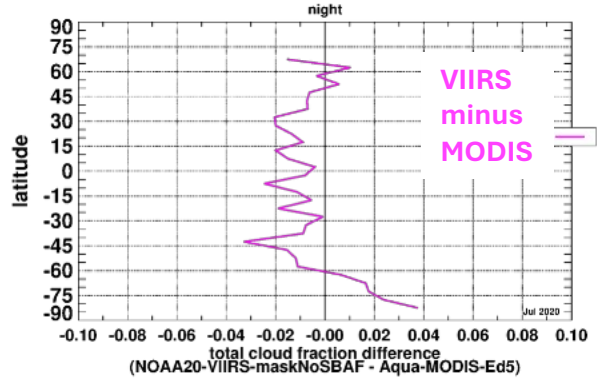
CERES NOAA-20 VIIRS - CALIOP



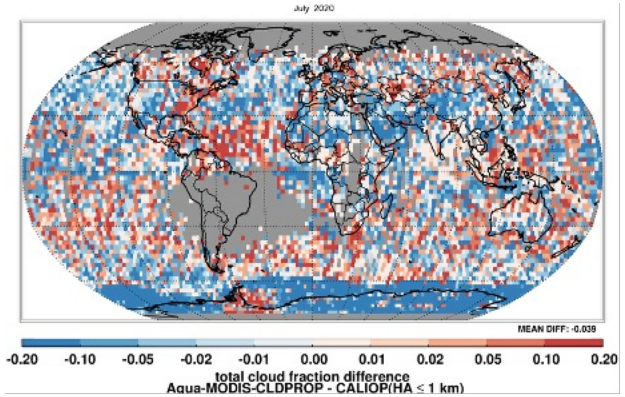
CERES Ed5 Zonal Means vs CALIOP



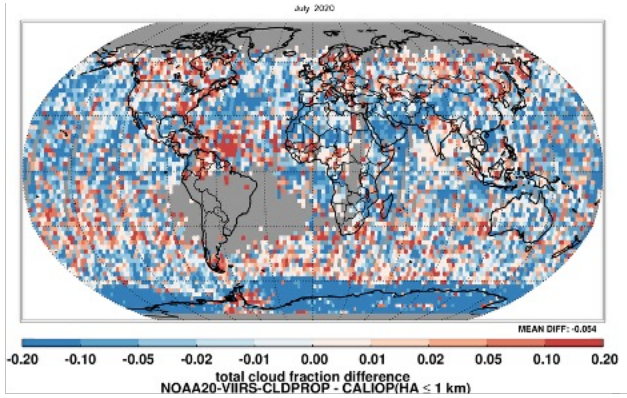
CERES Ed5 Zonal Mean Differences



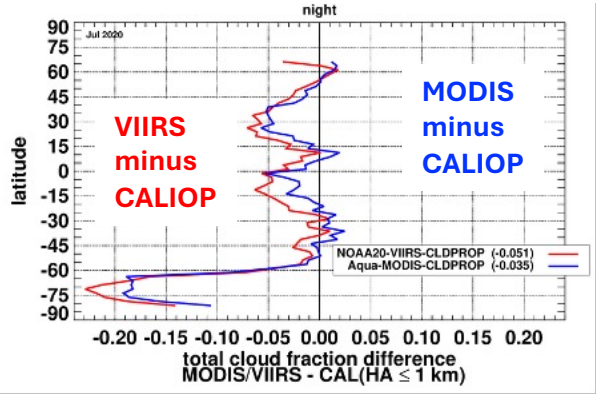
CLDPROP Aqua MODIS - CALIOP



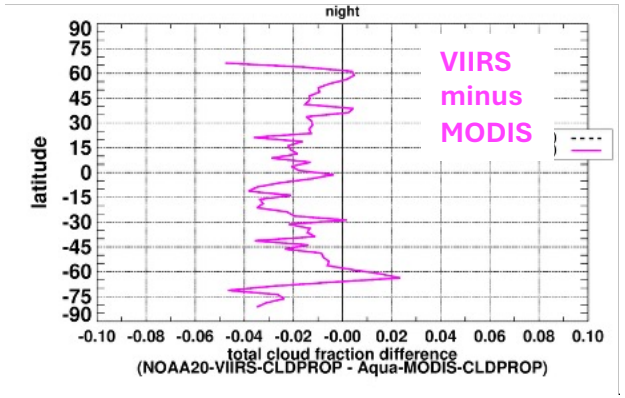
CLDPROP NOAA-20 VIIRS - CALIOP



CLDPROP Zonal Means

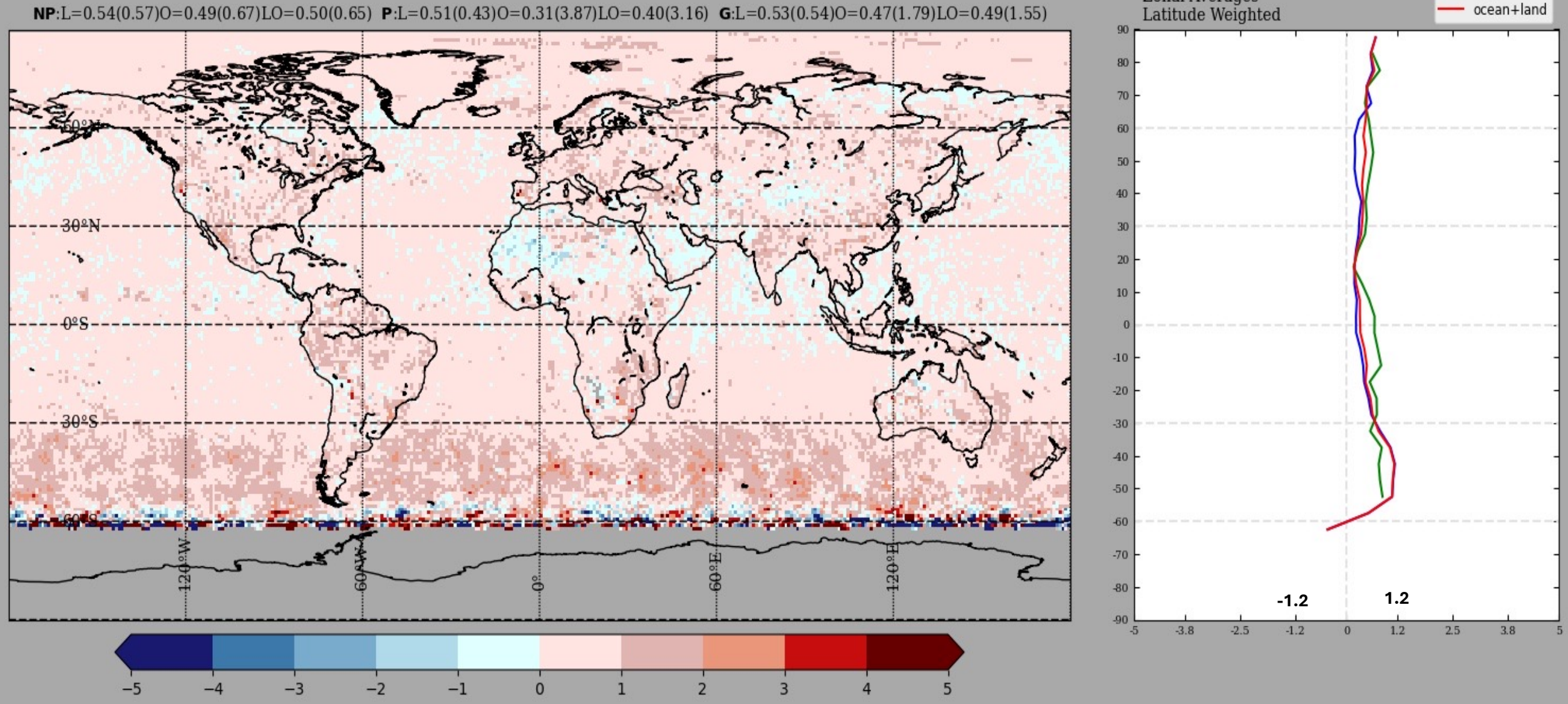


CLDPROP Zonal Mean Differences



CERES Ed5 and CLDPROP V01.1 have remarkable consistency in the zonal mean differences despite accuracy differences for MODIS and VIIRS relative to CALIOP

Daytime Total Cloud Optical Depth Difference
VIIRS minus Ed5 MODIS
July 2020



LEO Summary

- The CERES Clouds Working Group has revised and delivered the MODIS algorithm for Edition 5
  - Substantial improvements found for nighttime and for polar clouds over Antartica
- Neural networks help refine/improve:
  - cloud heights, cloud top phase, nighttime cloud detection over Antarctica and nighttime cloud optical depth (shown in previous meetings)
- For Ed5, a common cloud mask was developed and successfully applied to MODIS and VIIRS
  - Ed5 MODIS/VIIRS consistency in cloud fraction similar to that found in GSFC CLDPROP
- Ed5 MODIS level-2 cloud properties (CLDPIX) publicly available in early 2027

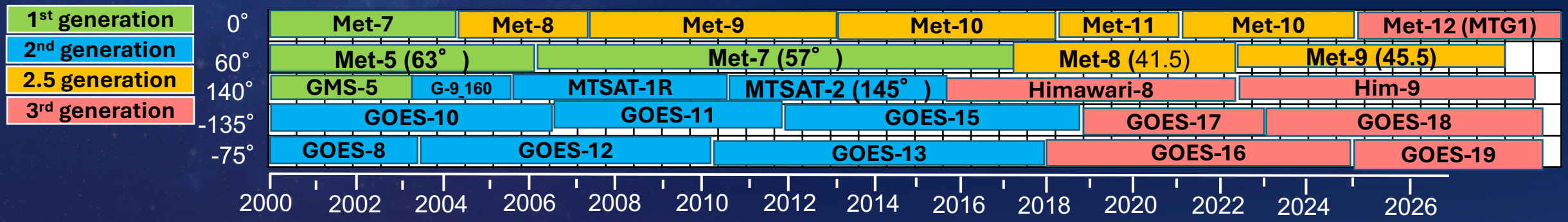
Future Work

- VIIRS algorithms to be delivered in Spring 2027 are currently being revised to ensure proper calibration, neural net development, clear-sky radiative closure, etc.

GEO Edition 5 updates

- 3-channel algorithm and 2-channel (1st generation GEO)
- Updates (consistent with LEO):
  - Replace GEOS-IT analysis with ERA5 reanalysis for characterizing atmospheric composition
  - Develop new cloud optical lookup tables and CKD that account for the specific instrument spectral response function
  - Skin temp from model is corrected over land using neural net
- Time-dependent machine learning method (KDT) for improving cloud detection and some retrievals for sun-glint conditions, high SZA, and nighttime (based on ~6.7 μm and 11 μm bands)

Geostationary Time Series



- 1st generation GEO: 0.65μm, 6.2μm, and 11μm channels
- 2nd generation GEO: 0.65μm, 3.9μm, 6.2μm, 11μm and 12μm/13.3μm channels
- 2.5 generation Meteosat: 3 visible channels and 8 IR channels
- 3rd generation GEO: MODIS-like with 16 channels

- For Edition 5 (Ed5), algorithms have been adapted to ingest common channels across the record:

3 channel algorithm:

- 2nd and newer GEO generations
- 0.64 μm (cloud optical depth), 3.9 μm (water particle size), and 11 (cloud temp and height).
- ~6.7 μm for nighttime

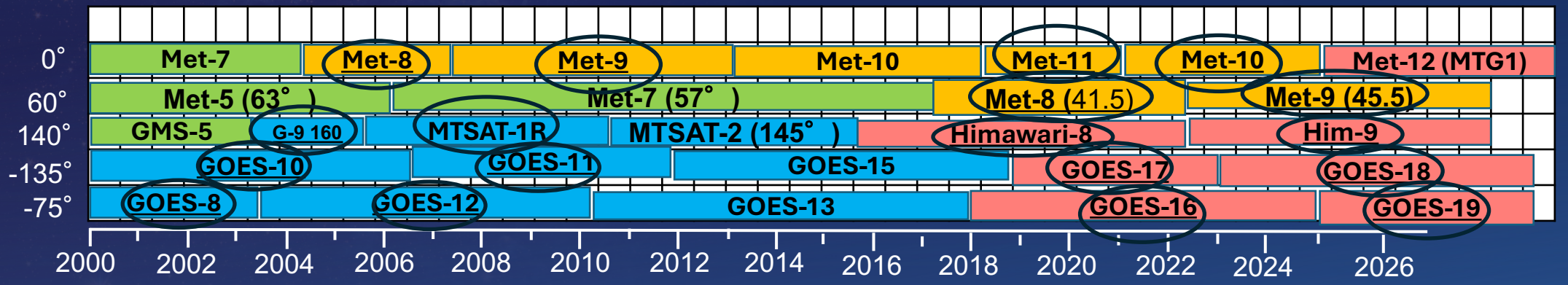
2 channel algorithm:

- 1st generation GEO: Met-7, Met-5, and GMS-5
- 0.64, ~6.7 (nighttime), 11 μm channels: limited cloud phase detection, optical depth and temperature/height.

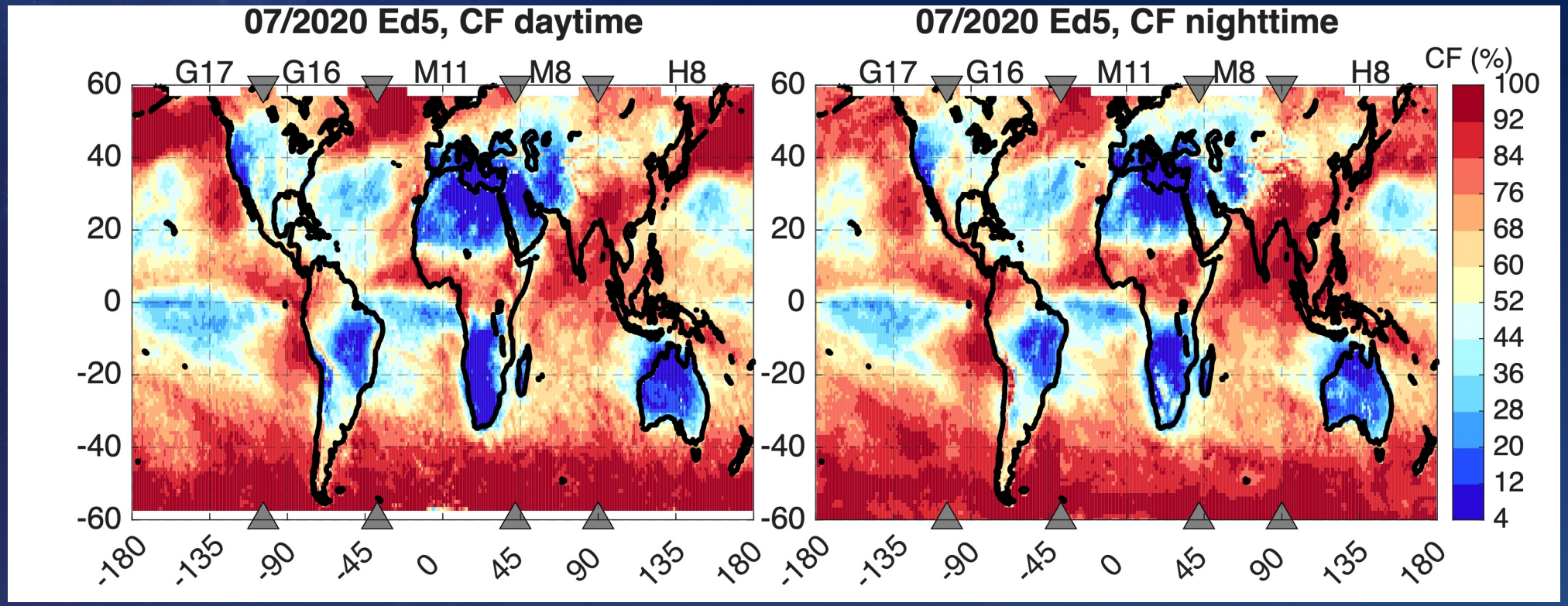
Geostationary Time Series: Progress toward Ed5

1st generation
2nd generation
2.5 generation
3rd generation

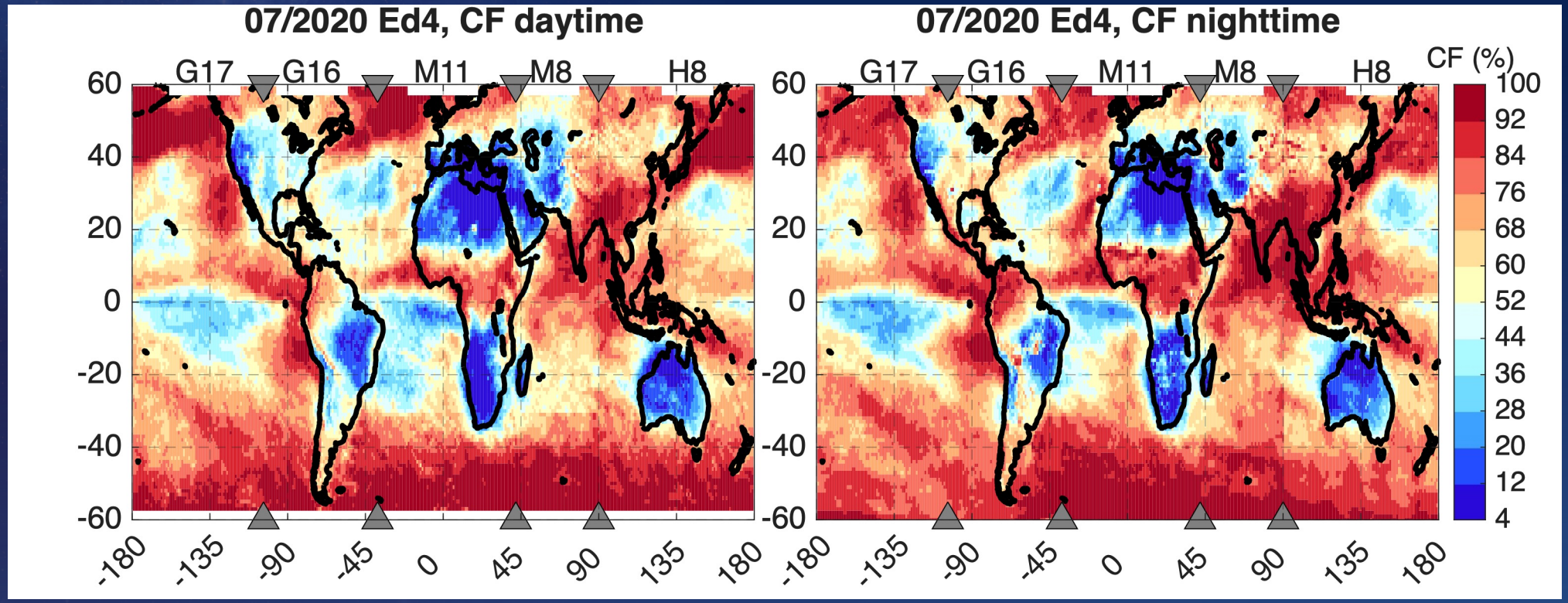
- Edition 5 code (2026 version) applied to GEOs highlighted in **CIRCLES**



GEO Edition 5 Cloud mask (Cloud Fraction)



GEO Edition 4 Cloud mask (Cloud Fraction)

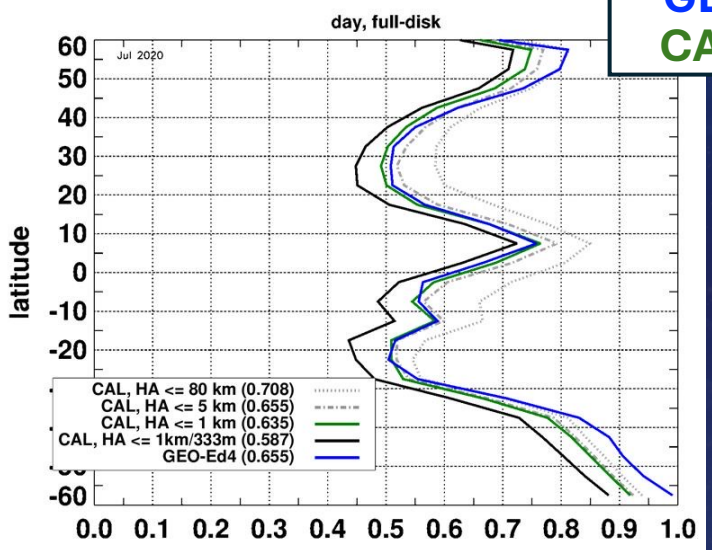


GEO vs CALIPSO (July 2020)

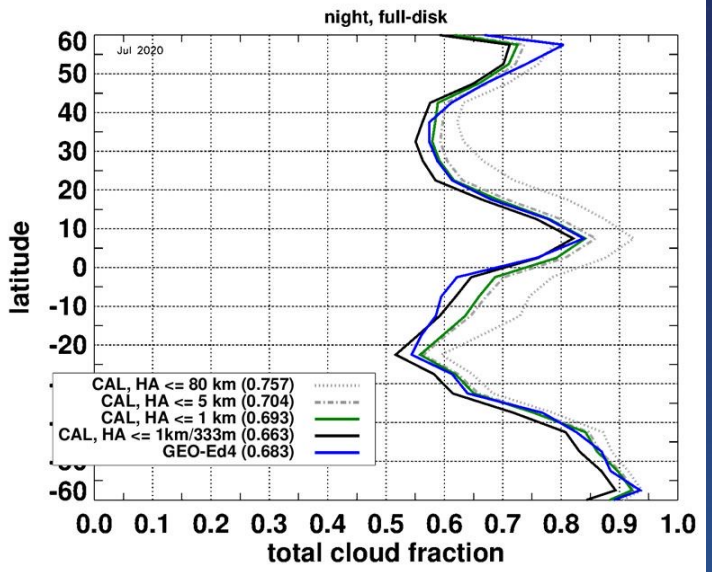
Edition 4

GEO Ed4
CALIPSO

Day



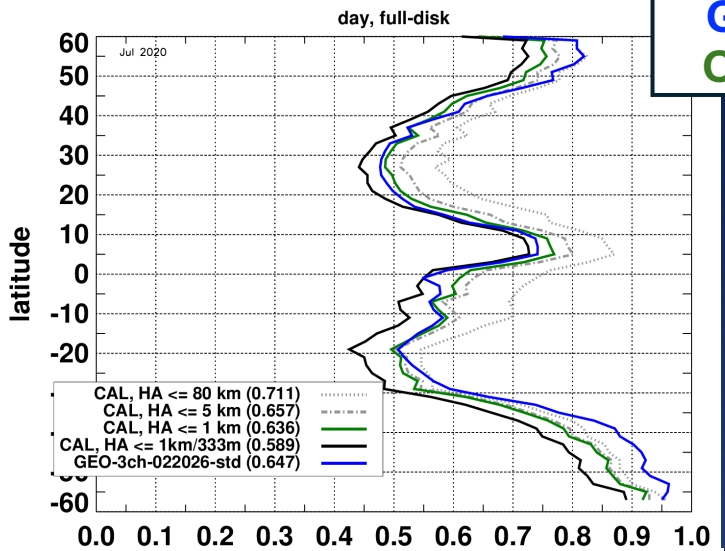
Night



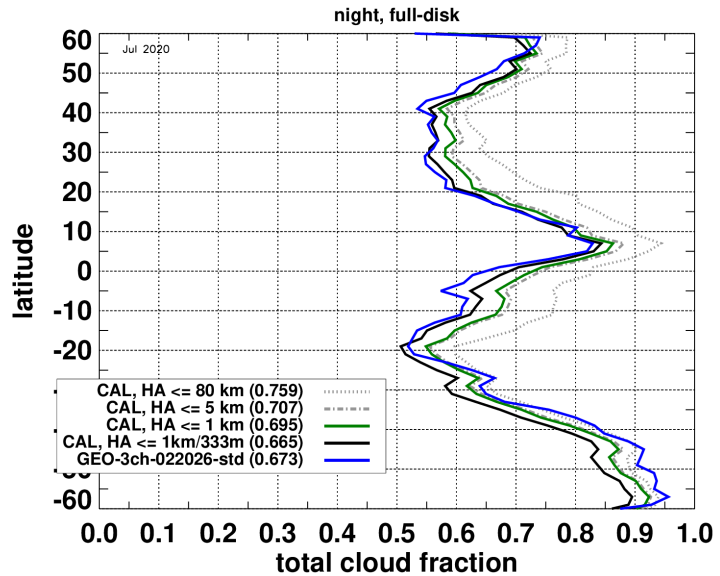
Edition 5

GEO Ed5
CALIPSO

Day

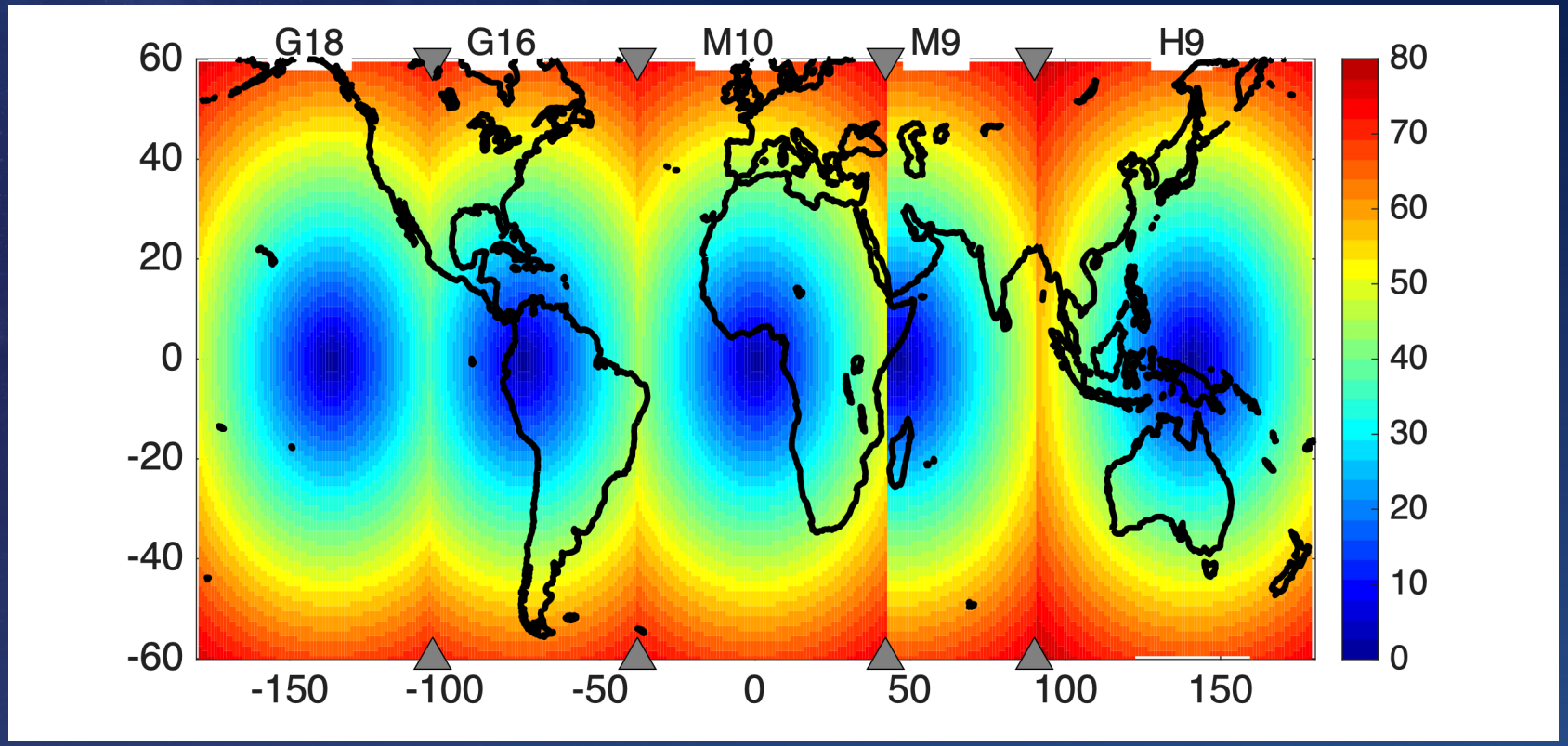


Night



Viewing zenith angle for the merged GEO map

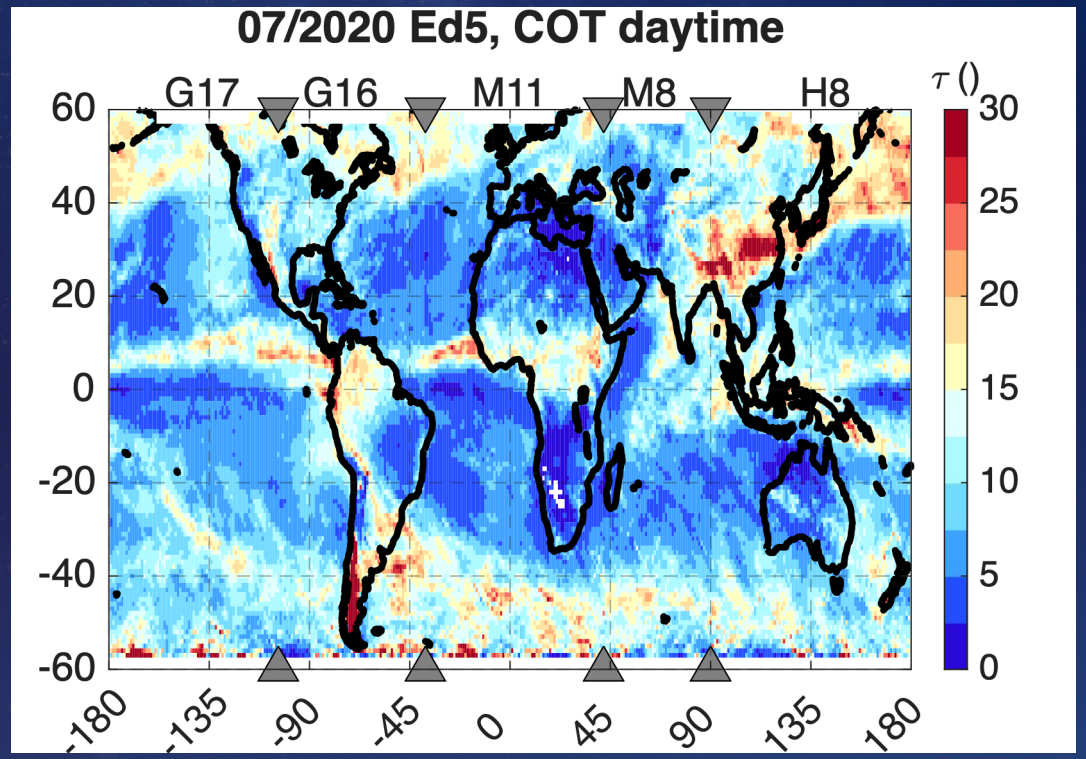
Viewing zenith angle of the combined GEO maps



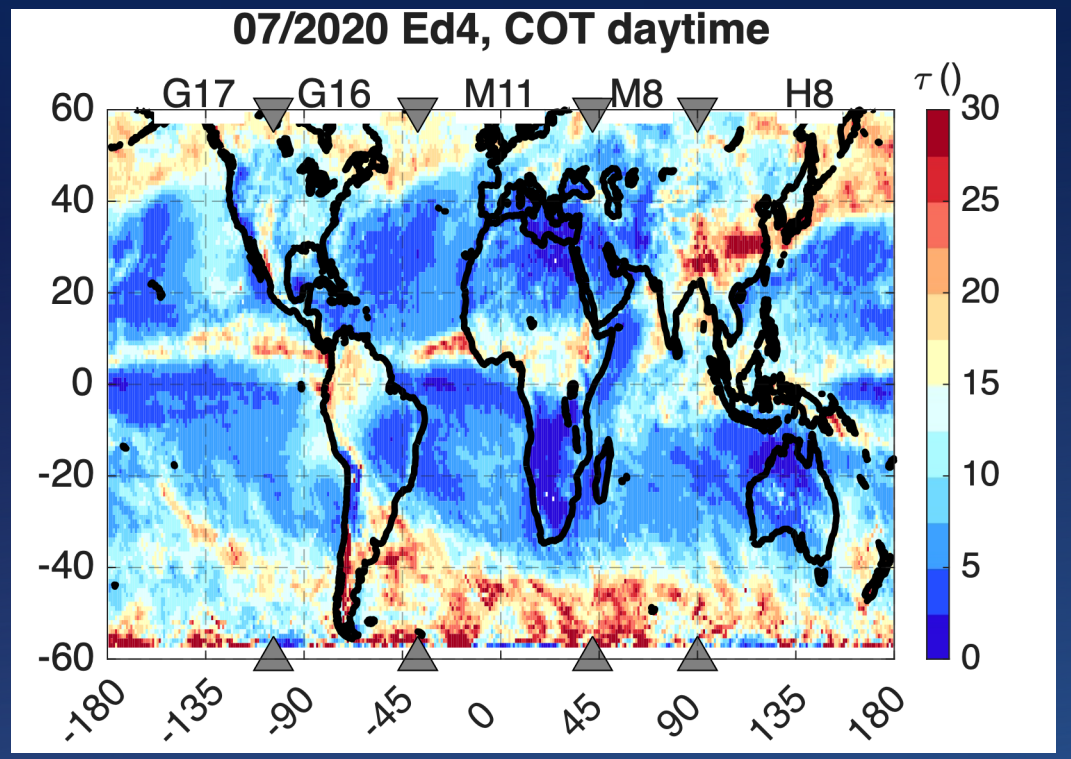
- Pixel coarsening at high latitudes and high solar zenith angle might contribute to biases, especially in the Southern Ocean

GEO Cloud optical thickness (COT)

Ed 5



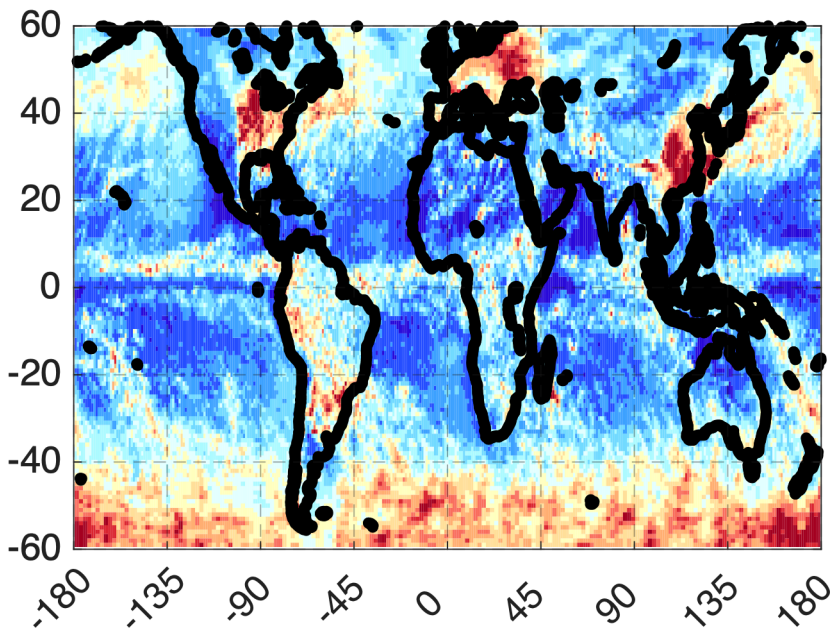
Ed 4



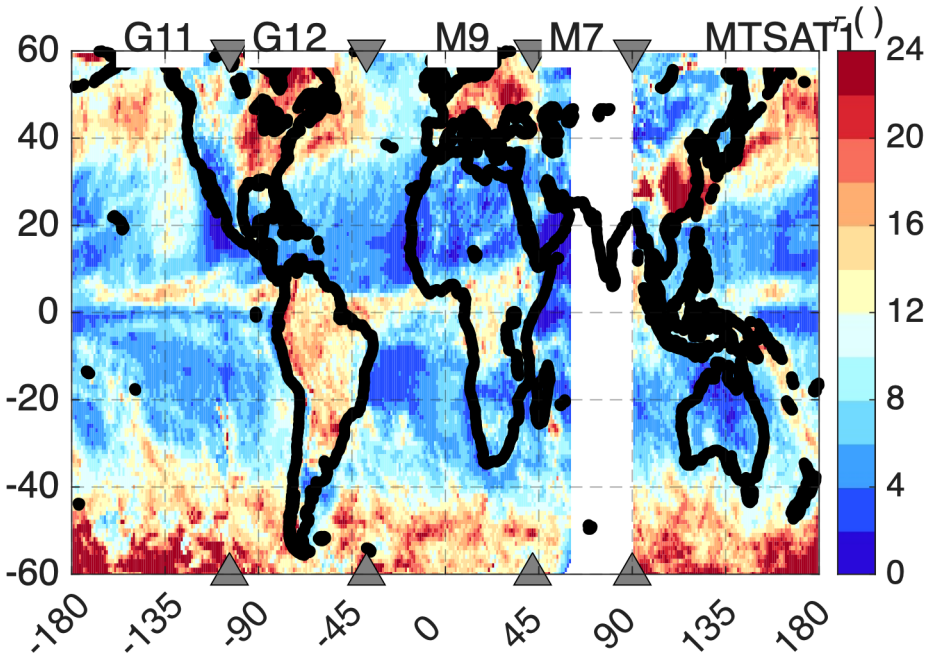
- Ed5 and Ed4 COT are consistent
- Discrepancies primarily attributed to different ice cloud optical models
  - 2-habit ice model in Ed5 vs rough hexagonal in Ed4.

MODIS and GEO consistency

CERES MODIS Ed5 (daytime) 04/2008



CERES GEO Ed5 (daytime) 04/2008



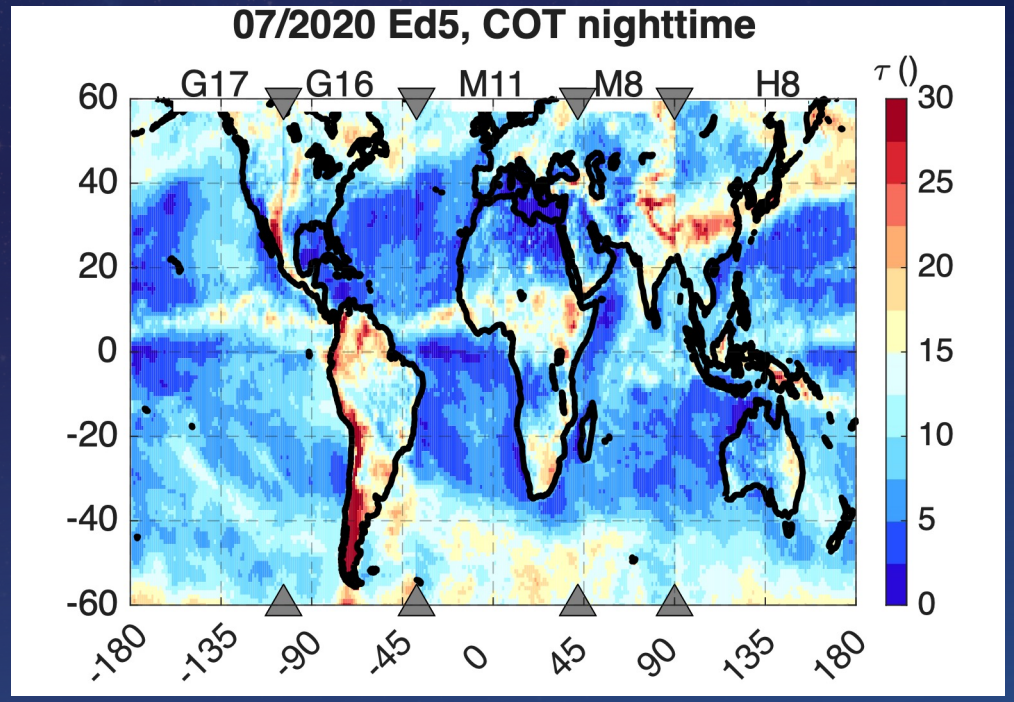
- Both MODIS and GEO cloud optical depth are qualitatively consistent.

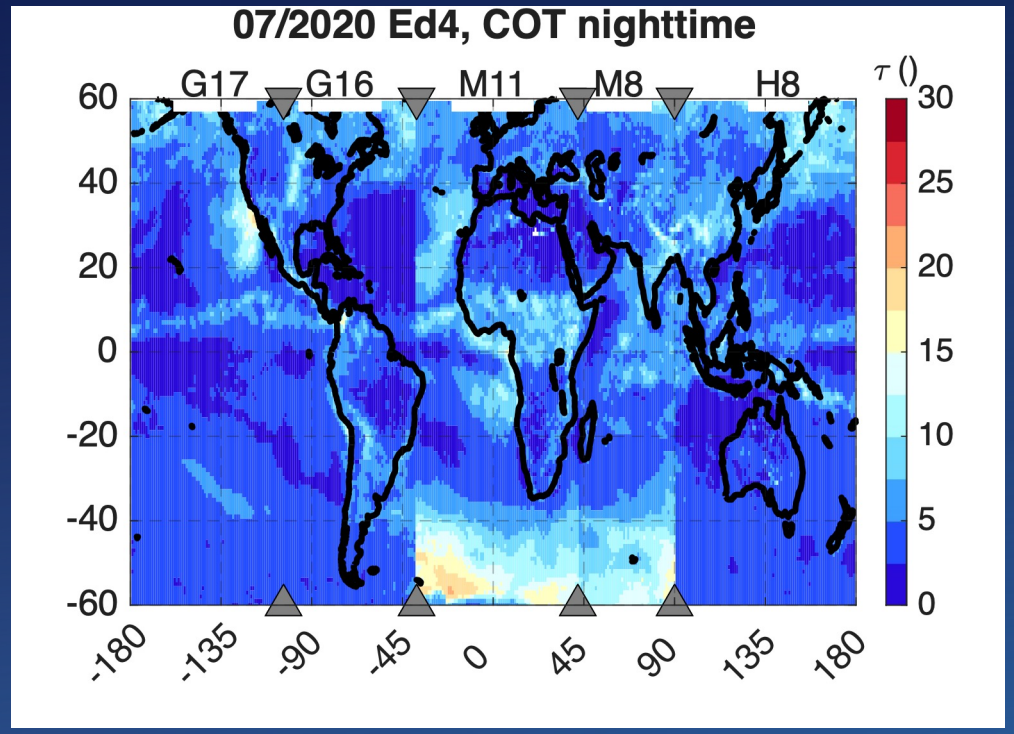
Cloud reconstruction with KDT: Optical thickness (COT)

Night

- Method searches for donor optical depth from an earlier daytime retrieval map using 11 μm and ~6.7 μm channels?

Ed 5

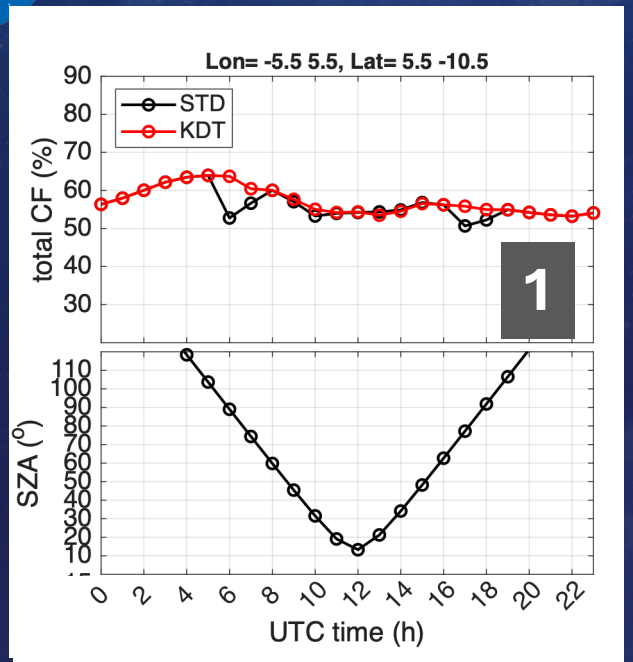


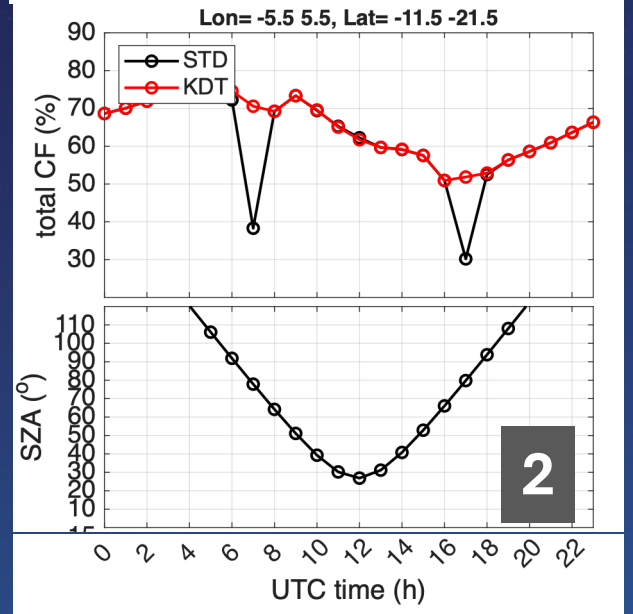


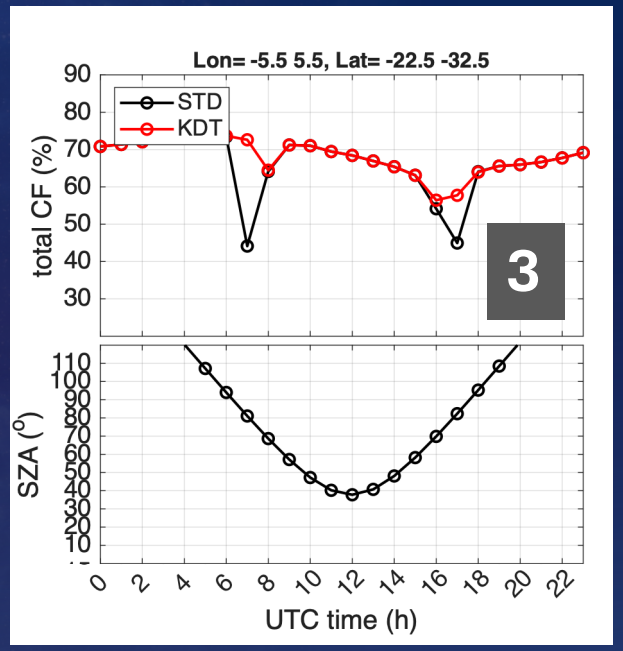
Ed 4

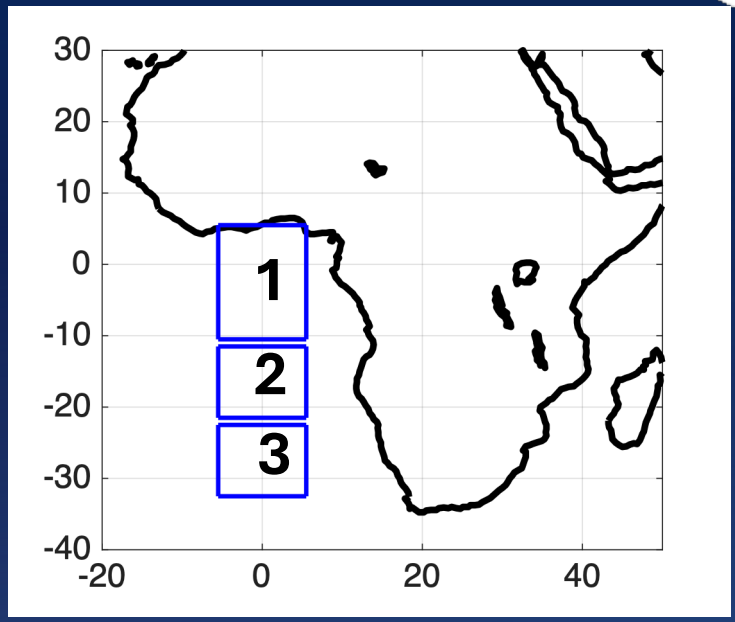
- New nighttime Ed5 COT is more consistent with daytime COT.

Cloud reconstruction with KDT: Cloud Fraction (mask)





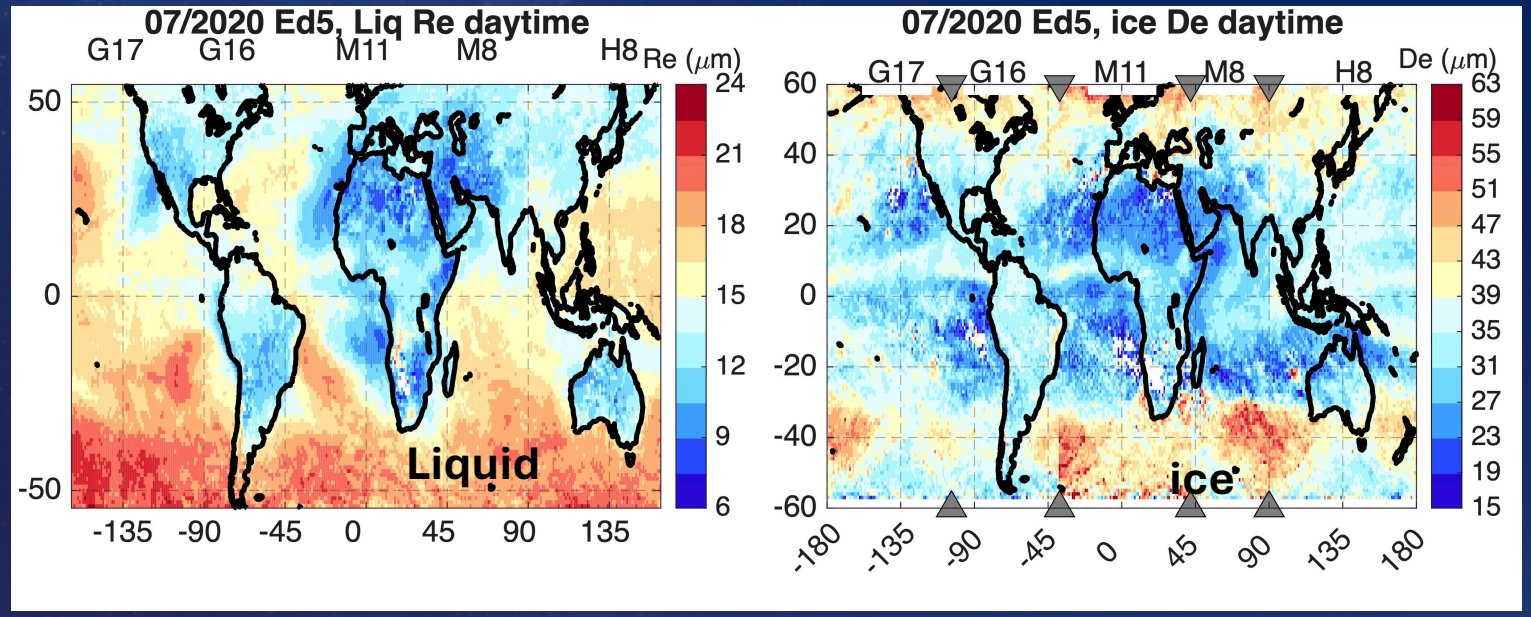




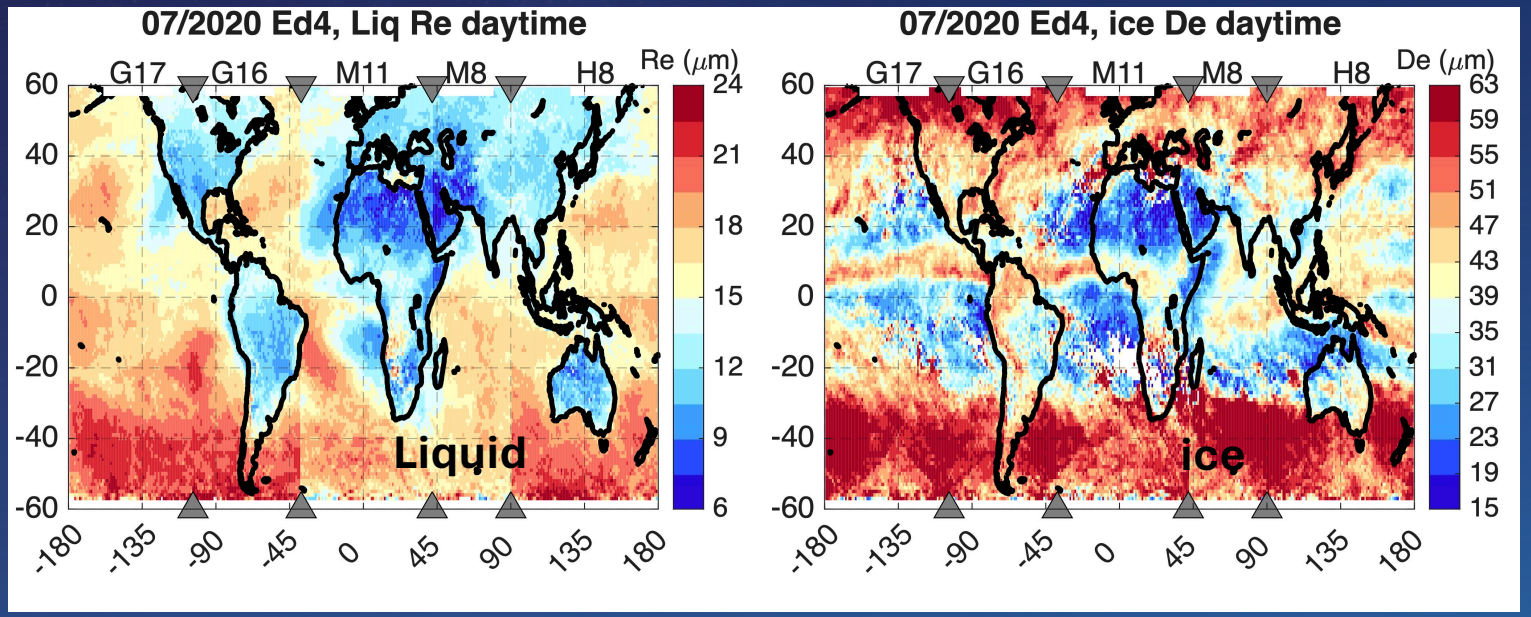
- KDT removes cloud fraction underestimation for $75^\circ < SZA \leq 90^\circ$
- KDT also mitigates artifacts over sun glint (not shown).

GEO cloud particle size (Re and De), July 2020

Ed 5



Ed 4



- Improved spatial consistency for Re.
- Large De differences are attributed to the adoption of a Two-Habit ice model in Ed5

GEO Summary

- The GEO record since 2000 will be reprocessed using a 3-channel algorithm (2-channel for Met-5, Met-7, and GMS-5).
- Key improvements include:
  - Satellite/instrument-specific cloud optical properties and gas absorption models generally result in more consistent retrievals across satellite domains
  - Nighttime optical depth and cloud mask reconstruction over sunglint and near terminator
- Reduction in the number of channels likely impact cloud detection over ice/snow surface (to be evaluated).
- Cloud mask algorithm is in the process of being tuned to increase accuracy
- 2-channel algorithm refinements are ongoing