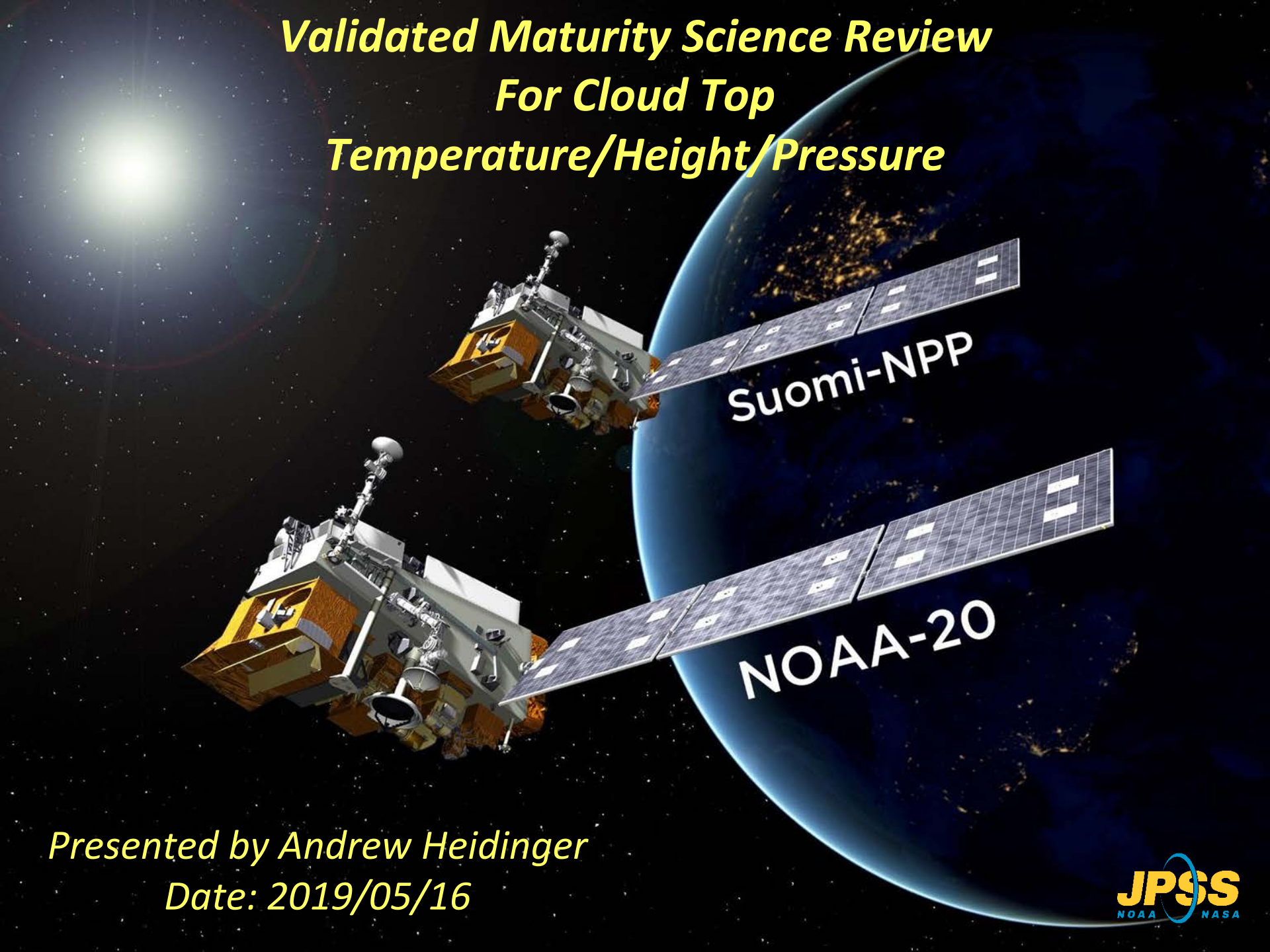
Validated Maturity Science Review For Cloud Top Temperature/Height/Pressure



Presented by Andrew Heidinger

Date: 2019/05/16

JPSS Data Products Maturity Definition

1. Beta

- Product is minimally validated, and may still contain significant identified and unidentified errors.
- Information/data from validation efforts can be used to make initial qualitative or very limited quantitative assessments regarding product fitness-for-purpose.
- Documentation of product performance and identified product performance anomalies, including recommended remediation strategies, exists.

2. Provisional

- Product performance has been demonstrated through analysis of a large, but still limited (i.e., not necessarily globally or seasonally representative) number of independent measurements obtained from selected locations, time periods, or field campaign efforts.
- Product analyses are sufficient for qualitative, and limited quantitative, determination of product fitness-for-purpose.
- Documentation of product performance, testing involving product fixes, identified product performance anomalies, including recommended remediation strategies, exists.
- Product is recommended for potential operational use (user decision) and in scientific publications after consulting product status documents.

3. Validated

- Product performance has been demonstrated over a large and wide range of representative conditions (i.e., global, seasonal).
- Comprehensive documentation of product performance exists that includes all known product anomalies and their recommended remediation strategies for a full range of retrieval conditions and severity level.
- Product analyses are sufficient for full qualitative and quantitative determination of product fitness-for-purpose.
- Product is ready for operational use based on documented validation findings and user feedback.
- Product validation, quality assurance, and algorithm stewardship continue through the lifetime of the instrument.

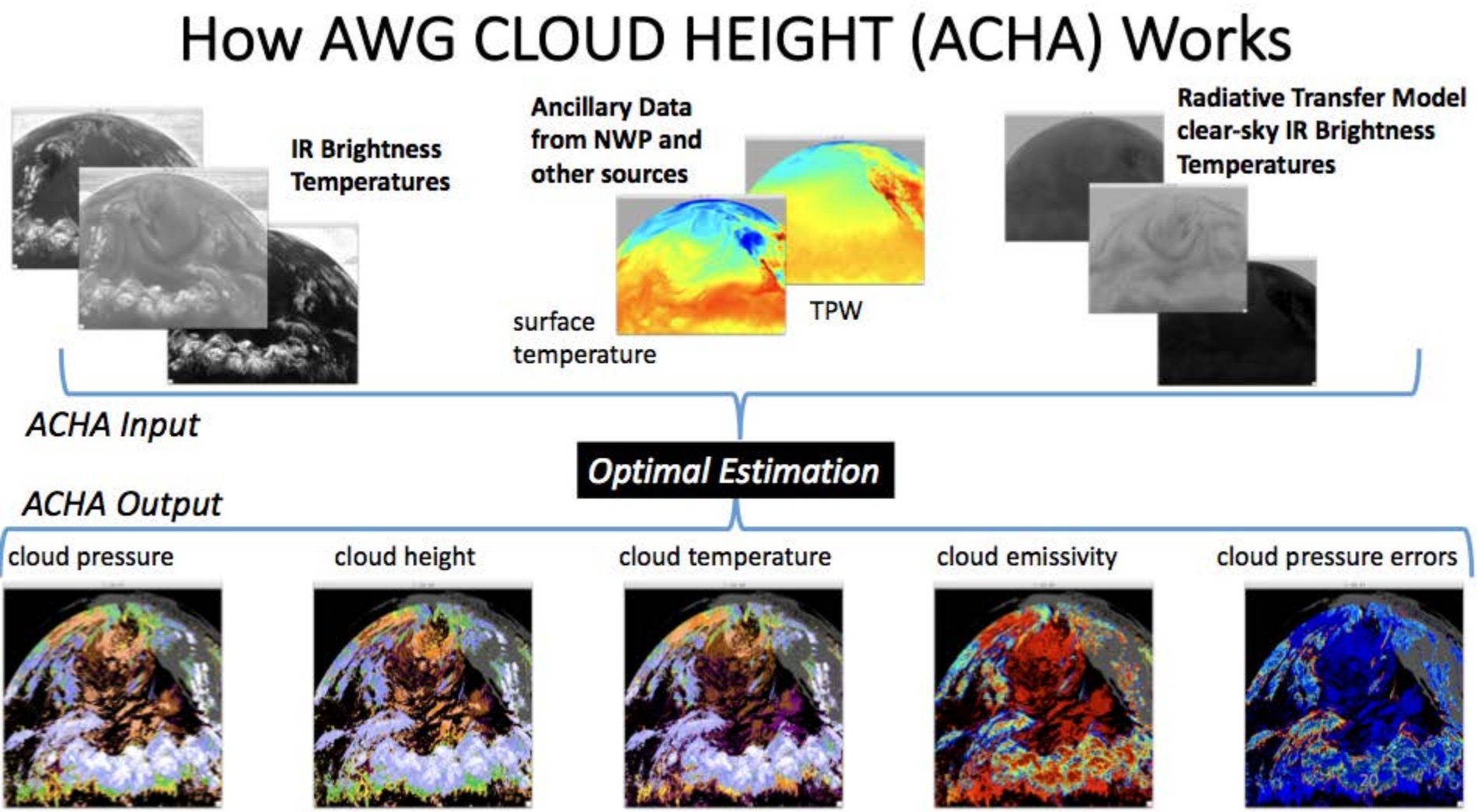
VALIDATED MATURITY REVIEW MATERIAL

ACHA Cal/Val Team

Algorithm Cal/Val Team Members

Name	Organization	Major Task
Andrew Heidinger	NOAA STAR	Team Lead
Yue Li	UW SSEC/CIMSS	Algorithm development and maintenance
Steve Wanzong	UW SSEC/CIMSS	Algorithm development and maintenance
William Straka	UW SSEC/CIMSS	ASSISTT Liaison
David Donahue	OSPO	Cloud Algorithm PAL
Shuang Qiu	OSPO	PAL

Product Overview



Product Requirements (JRED, consistent with Beta and Provisional; CCL is based on GOES-R)

Attribute	Threshold	Observed/validated	GOES-17 Prov
Geographic coverage	global	global	West Domain
Vertical Coverage	n/a	n/a	n/a
Vertical Cell Size	n/a	n/a	n/a
Horizontal Cell Size	0.8 km	n/a	n/a
Mapping Uncertainty	4 km	n/a	n/a
Measurement Range	160-320K (CTT) 0-20,000m (CTH) 50-1,100hPa (CTP) 0-1.0 (CCL fraction)	Same	180-300K (CTT/FD) 0-15,000m (CTH/FD) 100-1000hPa (CTP/FD)
Measurement Accuracy GOES-R requirements in red	6K when $\tau \geq 1$ (CTT) 1km when $\tau \geq 1$ (CTH) 100 hPa when $\tau \geq 1$ (CTP) 60% correct classification (CCL)	Validated against CALIPSO using all data/ phase matching and single layer 6.7K/0.3K -0.8km/0.2km 33hPa/-23hPa 60.9%/70.6%	Validated against CALIPSO using data outside of 0830-1930 UTC. Phase matching and single layer shown. 1.6K (3) (CTT/FD) -0.1km (0.5) (CTH/FD) 4.1hPa (50) (CTP/FD)
Measurement Precision	6K when $\tau > 1$ (CTT) 1km when $\tau > 1$ (CTH) 100 hPa when $\tau > 1$ (CTP)	18.4K/6.0K 2.7km/1.0km 170 hPa/78hPa	10.2K (5) (CTT/FD) 2.2km (1.5) (CTH/FD) 144.2hPa (150) (CTP/FD)
Measurement Uncertainty	Not specified	0-30K (CTT) 0-4000m (CTH) 0-400hPa (CTP)	Not specified

Processing Environment and Algorithms

- ACHA currently being processed within SAPF at NDE:
  - Operational Code base **v2r0** (February 2018 Science code delivery).
  - Current code (**v2r0**) running in NDE Operational String since March 2019 for NOAA-20
  - CCL will be split into a seperate output file as soon as NDE-specified metadata is defined (likely v2r2)

- Findings/Issues from Provisional Review
  - ACHA meets all specs for single-layer clouds of known phase for $\tau > 1$
  - There are unrealistic values for cloud height and pressure, but not for cloud temperature

- Improvements since Provisional Review
  - The unrealistic value issue was mostly fixed. Certain pixels still show 0 pressure and large height (less than 2 granules per day and less than 0.001% of pixels in the affected granules) and will be fixed in v2r2 updates

Algorithm performance evaluation

We have chosen independent sources of cloud top properties that provide qualitative and quantitative analysis of the performance more than 30 days spread between May 2018 and March 2019.

We also compare to non-NDE generation ACHA data to diagnose NDE-specific issues.

Our Specific Validation Strategies are:

1. Visual inspection of NDE ACHA against CLAVR-x ACHA.
2. Validation against NASA CALIPSO/CALIOP
3. Comparison between NDE and NASA MODIS MYD06

For CCL products, CALIPSO/CALIOP cloud layer products were used as validation datasets. Cloud top pressures from both N20 VIIRS and CALIPSO are converted to flight levels, and correct classification rates are computed by dividing the number of agreed pixels between VIIRS and CALIPSO at predefined FLs to the total number of pixels

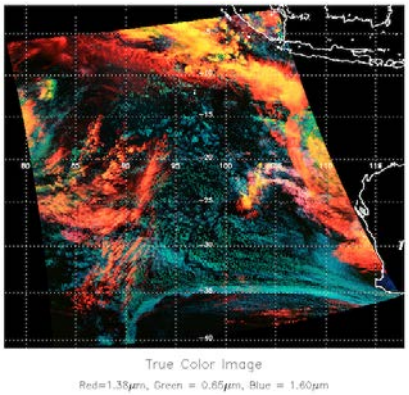
Data Used in this Analysis

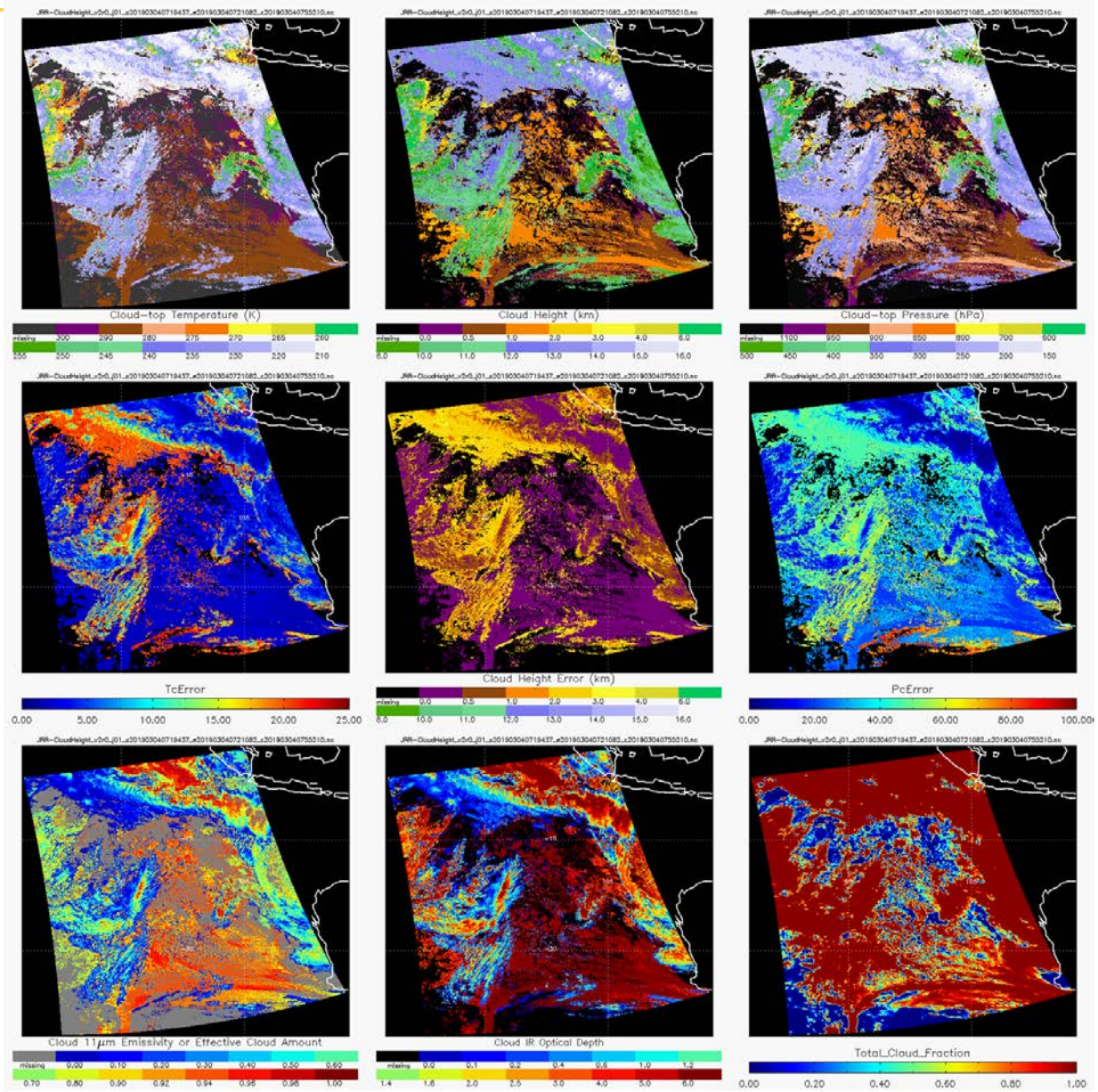
- NOAA-20 NDE v1r2 from 20 days between May and September, 2018, v2r0 from 3 days in October, 2018, and 15 days between January and March, 2019
- NASA CALIPSO from the same period.
- NASA AQUA/MODIS from the same period.

ACHA Cloud Top Products

Example level 2 products from NDE NOAA-20 on between 0710 and 0720 UTC on 03/04/2019 showing:

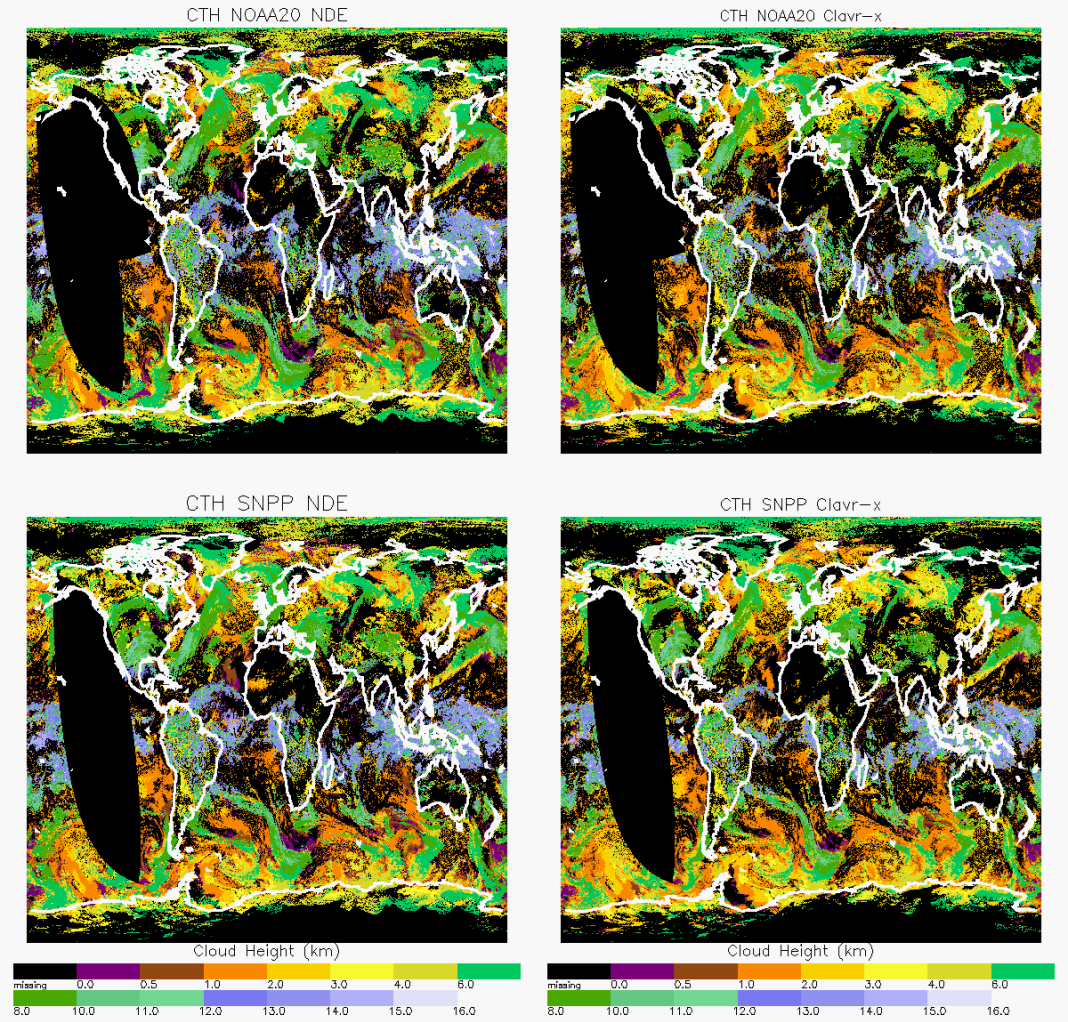
- Cloud top temperature, height and pressure (top row);
- Uncertainties for cloud top temperature, height and pressure (middle row);
- Cloud effective emissivity, infrared cloud optical depth and total cloud fraction (bottom row).





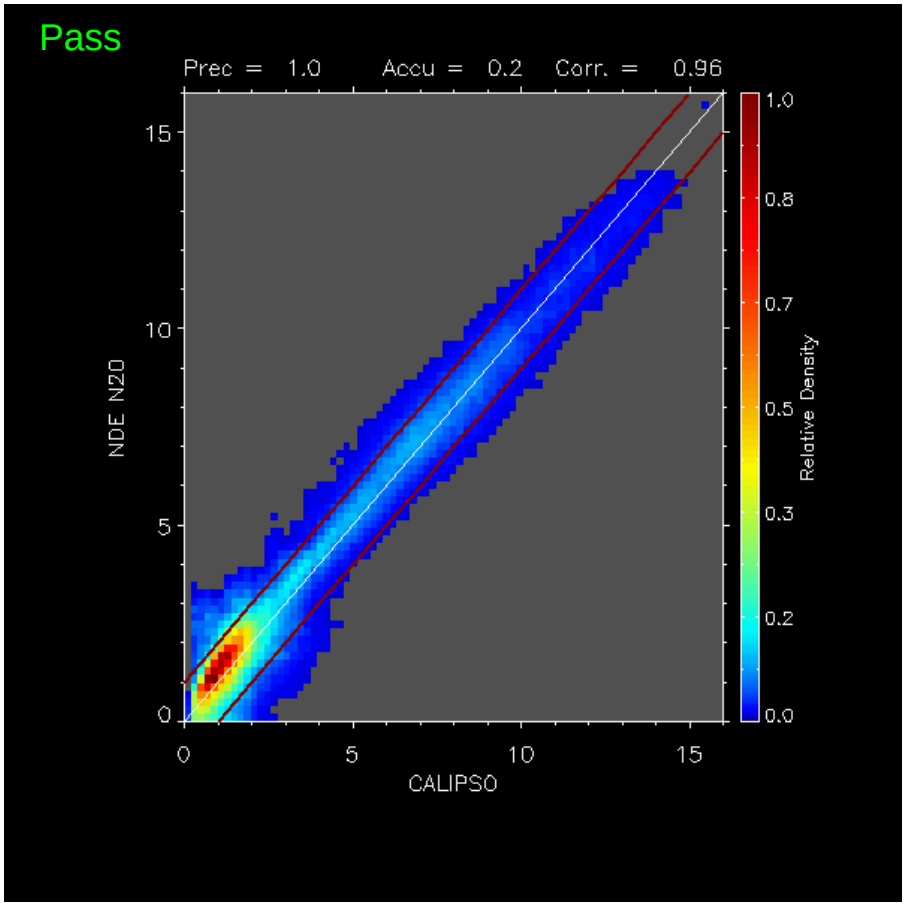
Visual Comparison to Clavr-x

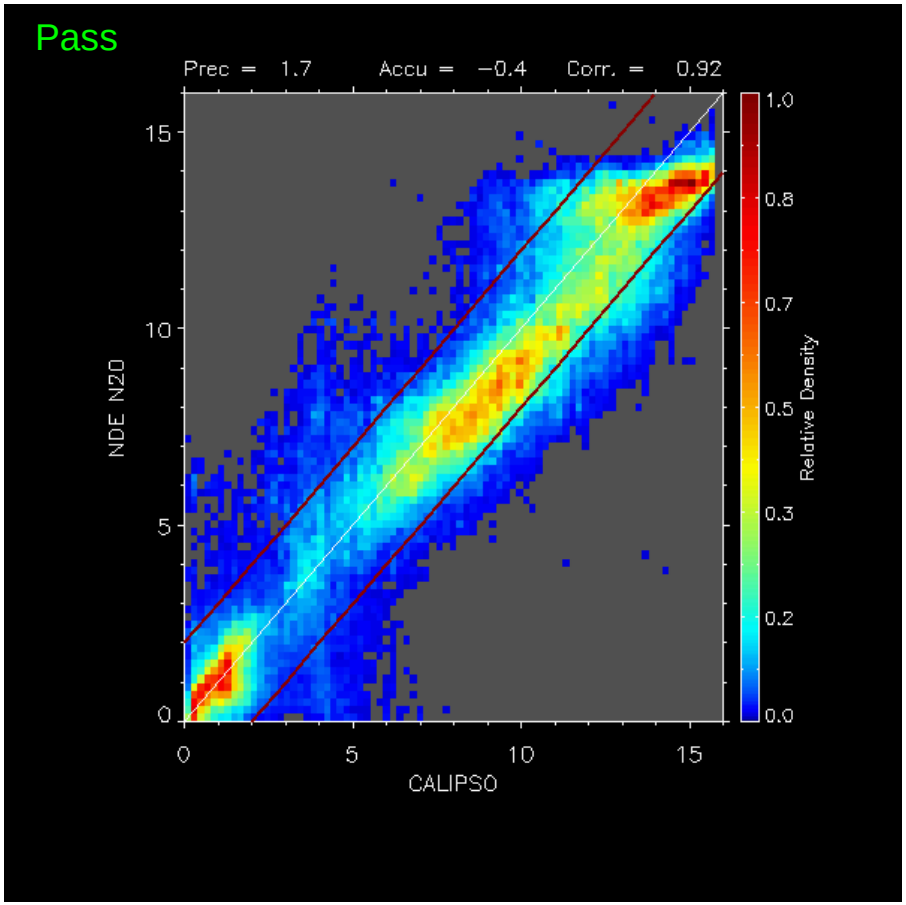
- Figure on the right shows global cloud top height for the ascending mode on day 3/12/2019
- Results from NOAA-20 NDE and Clavr-x, as well as SNPP NDE and Clavr-x are presented
- Visually the results show very good consistency across sensors



VERIFICATION AGAINST NASA CALIPSO/CALIOP

CTH - Phase Matching and Single Layer



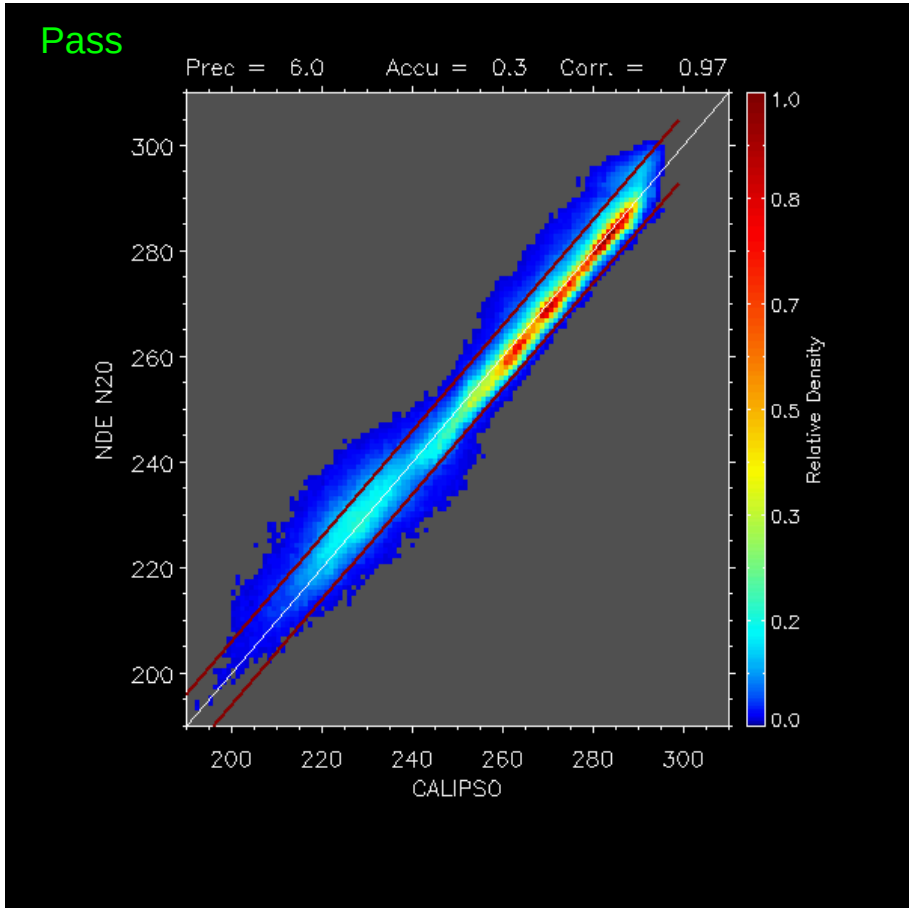


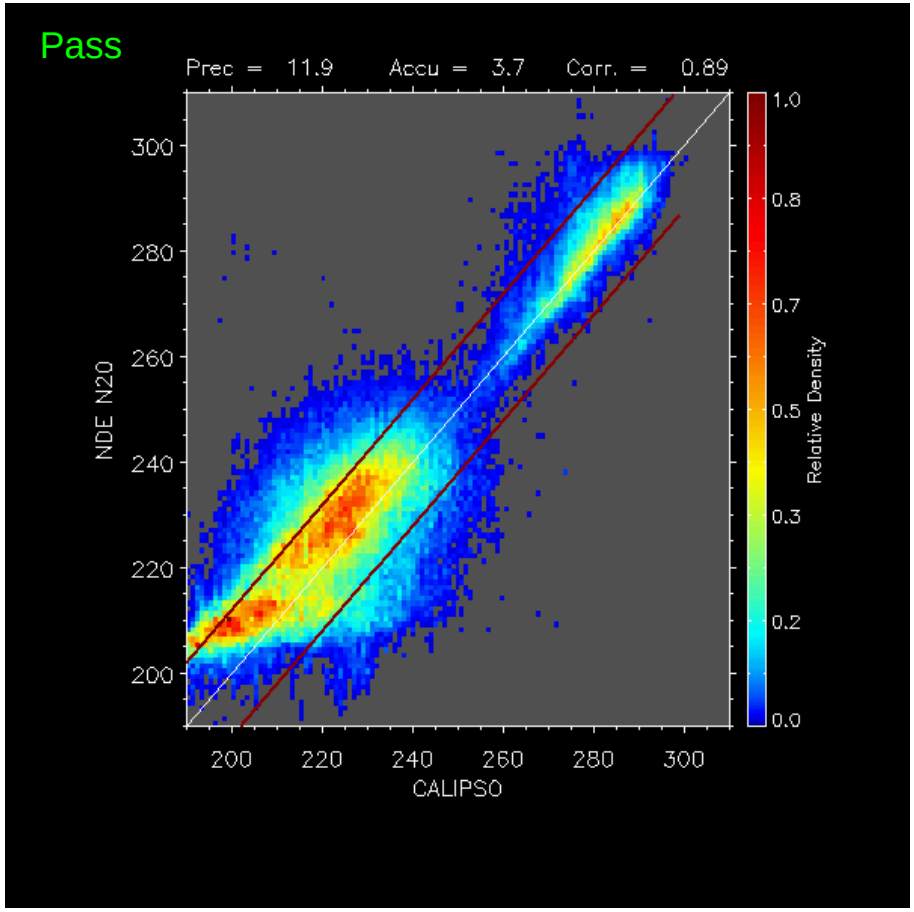
COT >=1

COT < 1

1km when $\tau \geq 1$, 2km when $\tau < 1$

CTT - Phase matching and single layer



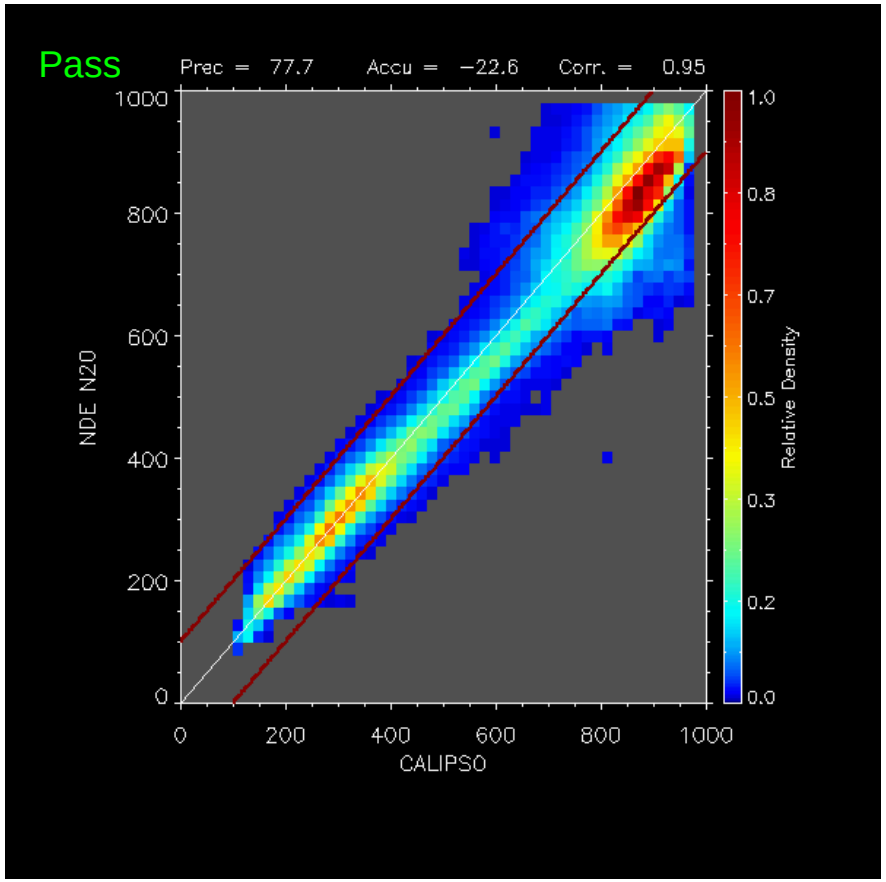


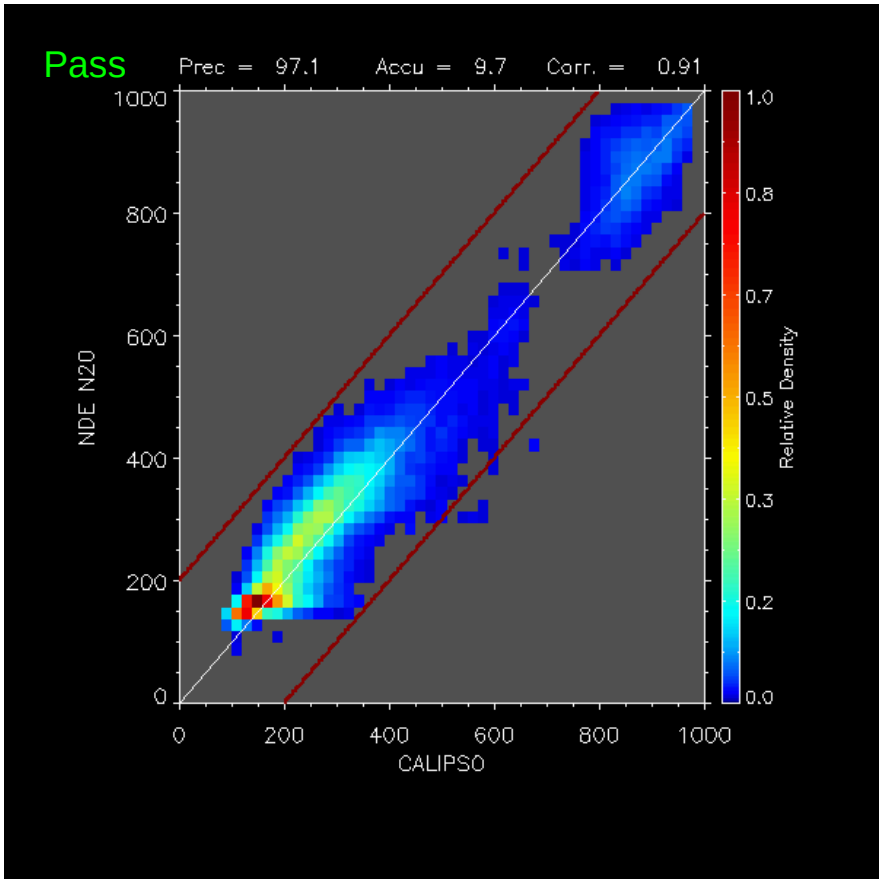
COT >=1

6K when $\tau \geq 1$, 12K when $\tau < 1$

COT < 1

CTP - Phase matching and single layer





COT >=1

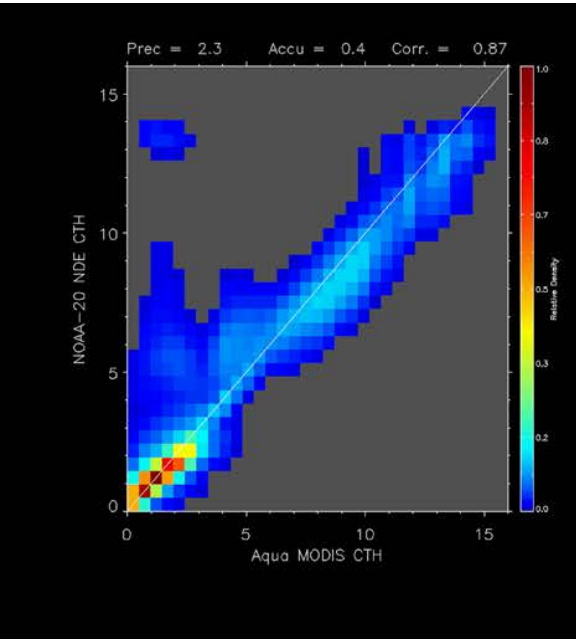
100 hPa when $\tau \geq 1$, 200 hPa when $\tau < 1$

COT < 1

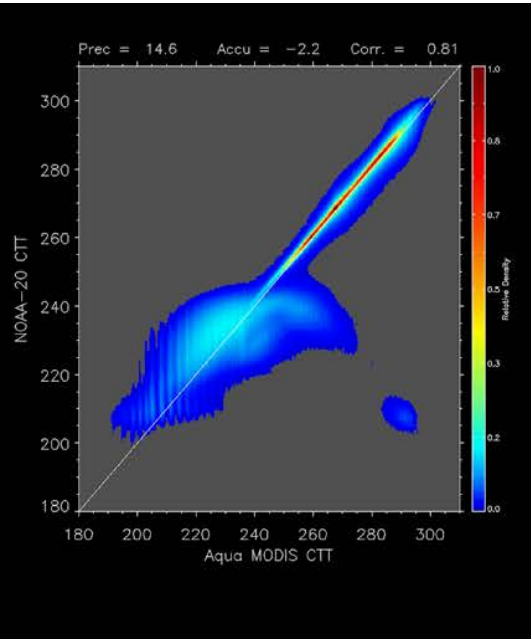
VERIFICATION AGAINST NASA AQUA/MODIS

MODIS Comparison: Phase-Matched

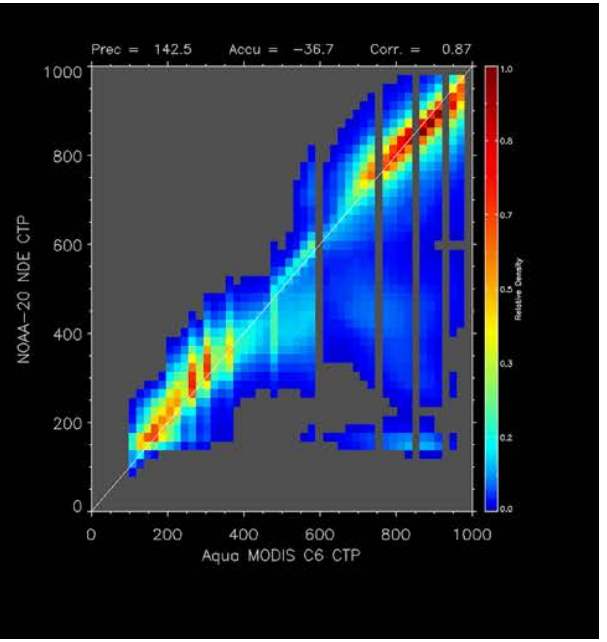
CTH



CTT



CTP

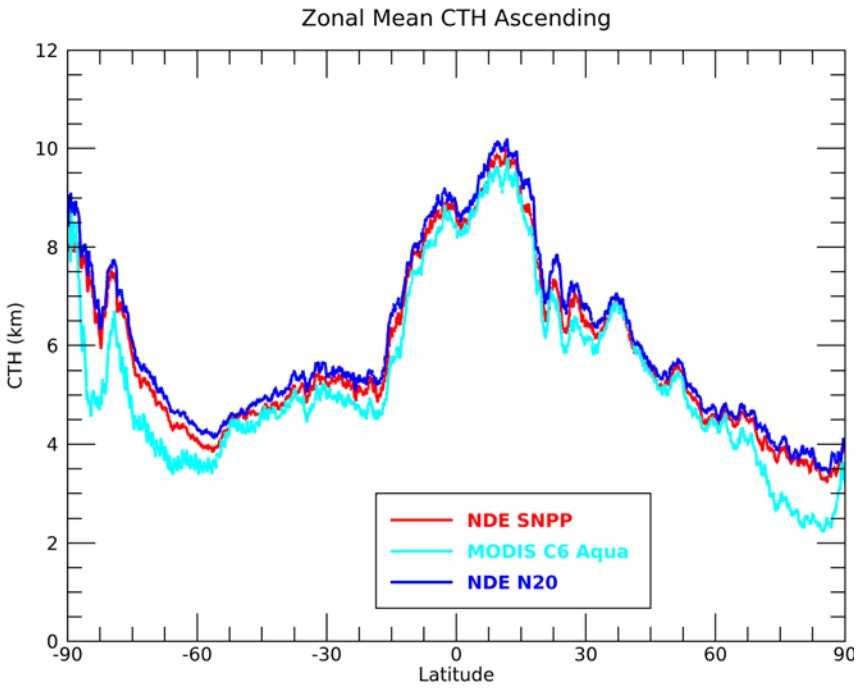


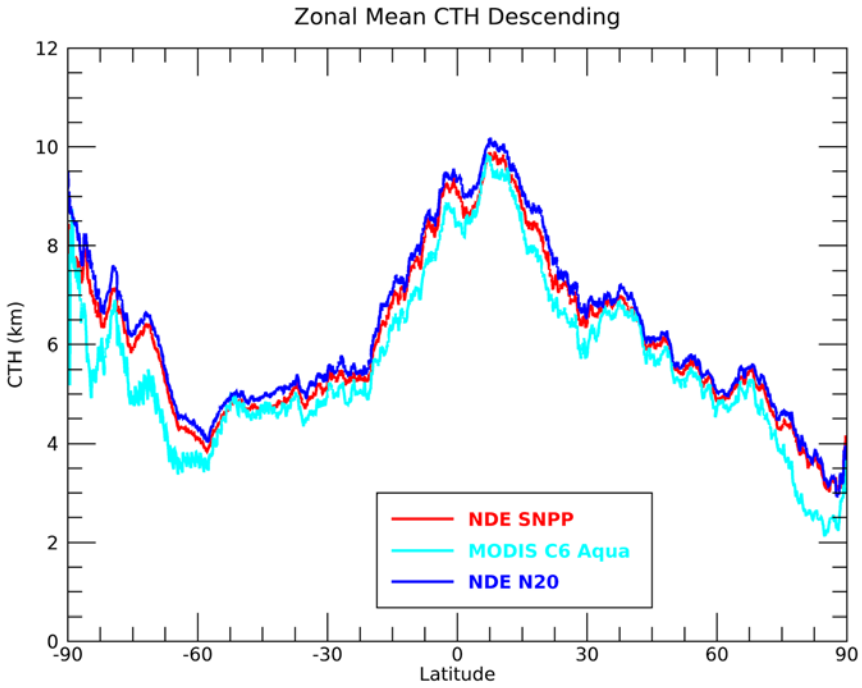
- Not separating thick and thin clouds due to lack of truth COD
- Single layer filtering isn't available
- Considering NASA MODIS as truth, all three variables meet the specs for accuracy; CTP also meets precision specs while CTH and CTT are close assuming COT>=1

Evaluation Against NASA MODIS - Phase matched

		Against MODIS C6	Against MODIS C6 (Provisional)	Against Caliop	Against Caliop (Provisional)
CTH (km)	Bias	0.45	0.2	-0.49	-0.6
	Std Dev	2.27	2.1	1.62	1.7
CTT (K)	Bias	-2.17	0.2	4.69	5.4
	Std Dev	14.56	13.8	11.14	11.5
CTP (hPa)	Bias	-36.71	-27.3	13.68	18.2
	Std Dev	142.47	139.7	93.74	95.1

Global Zonal Mean CTH - N20, SNPP and MODIS

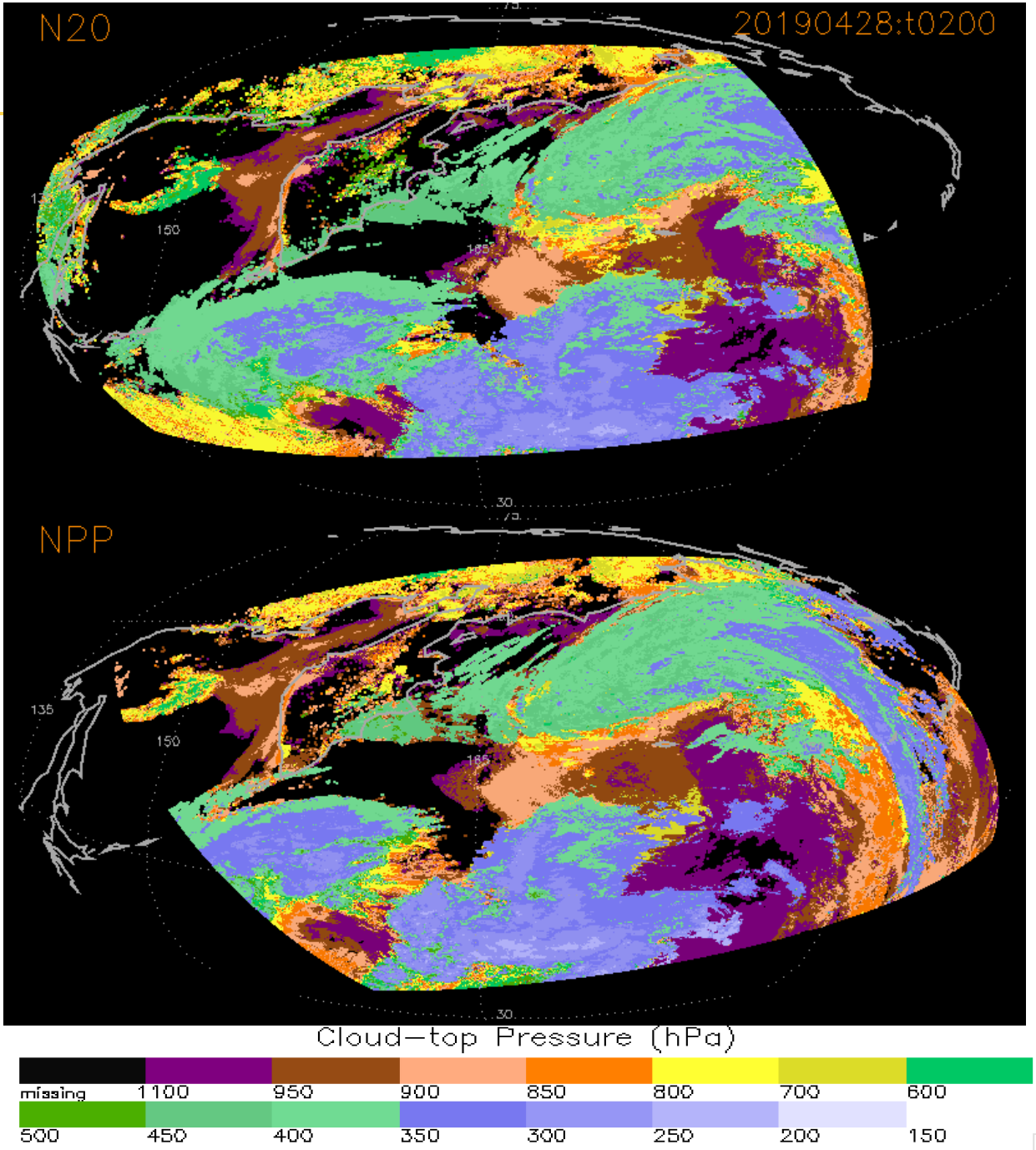




- Zonal plots computed from selected 11 days of ACHA products from 2018 and 2019 as well as NASA MODIS.
- The zonal mean patterns show reasonably well consistency between N20 and SNPP.
- Discrepancies between NASA MODIS and NDE products over higher latitudes are caused by both overdetection of clouds and failed CO_2 slicing retrieval in NASA MODIS C6.

NOAA-20 vs SNPP

- April 28, 2019
- Image shows CTP for NOAA-20 and SNPP 51 minutes earlier.
- Inspection of all images for this day showed no major inconsistencies.
- Animation on next page.



NOAA-20 vs SNPP (animation)

- April 28, 2019
- Image shows CTP for NOAA-20 and SNPP 51 minutes earlier.
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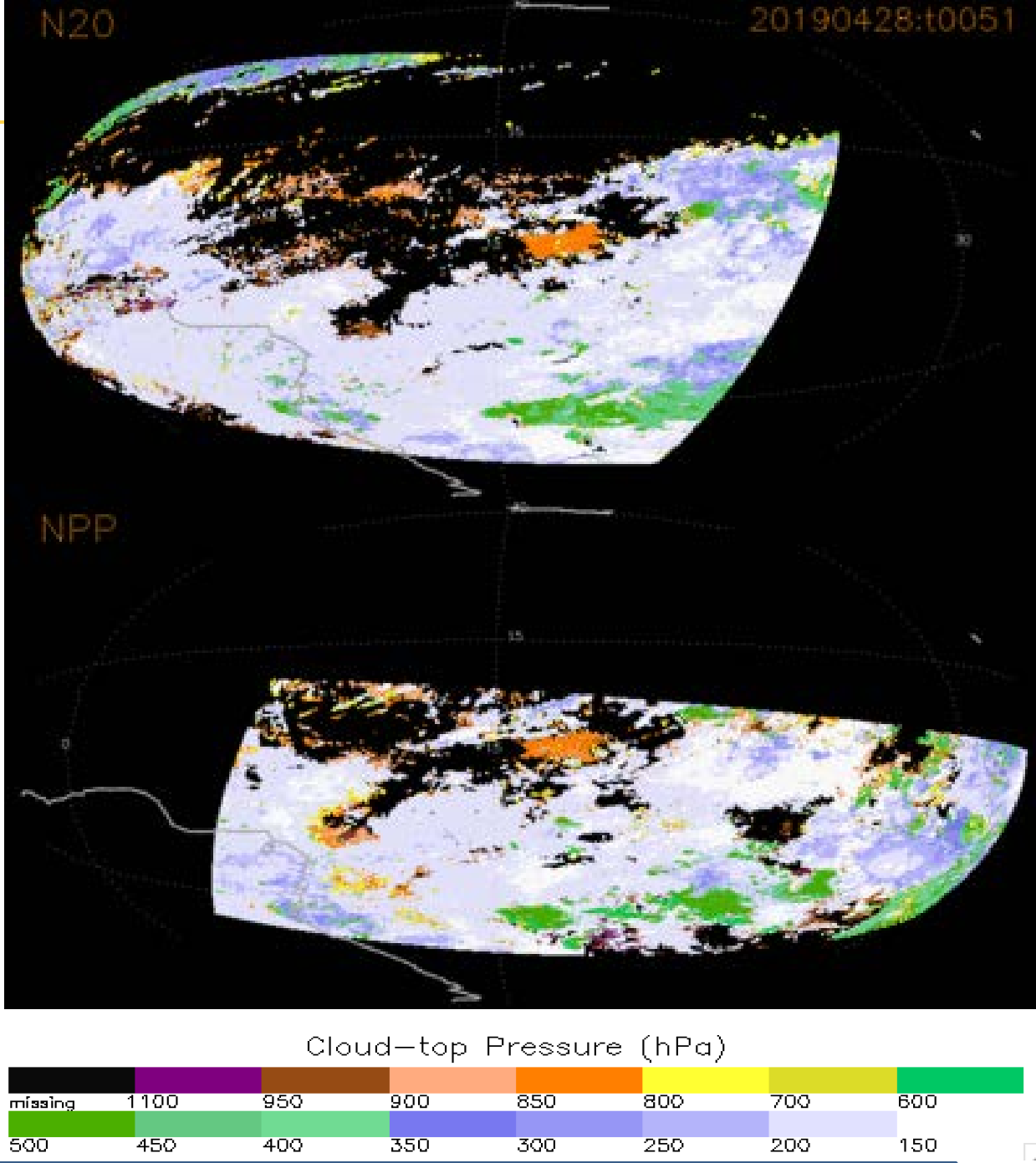
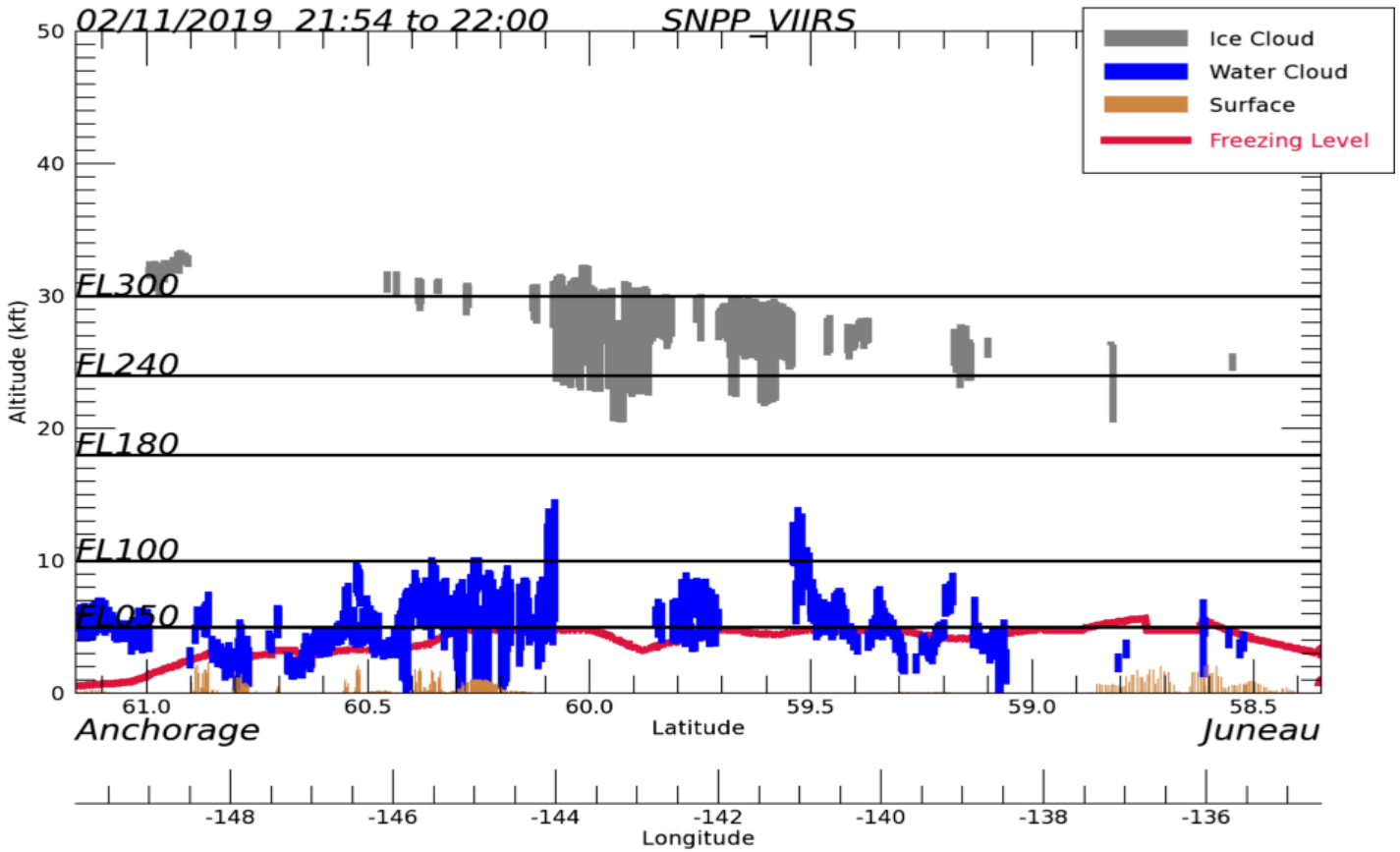


Cloud Cover Layers

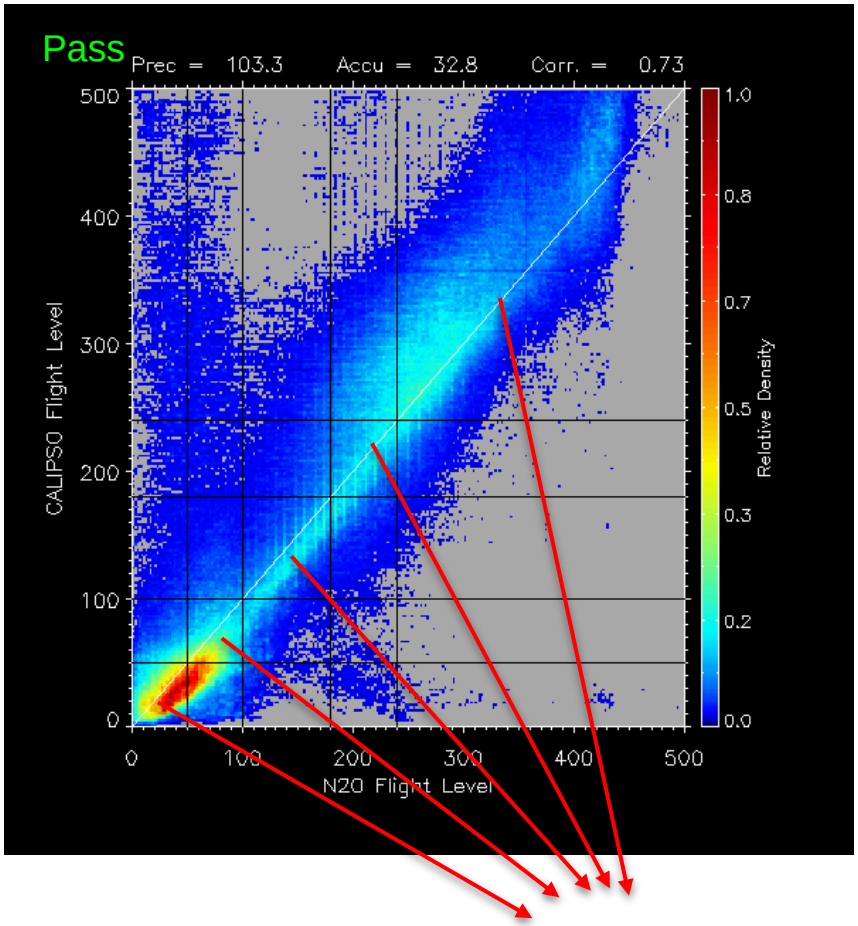
Cloud Cover Layer



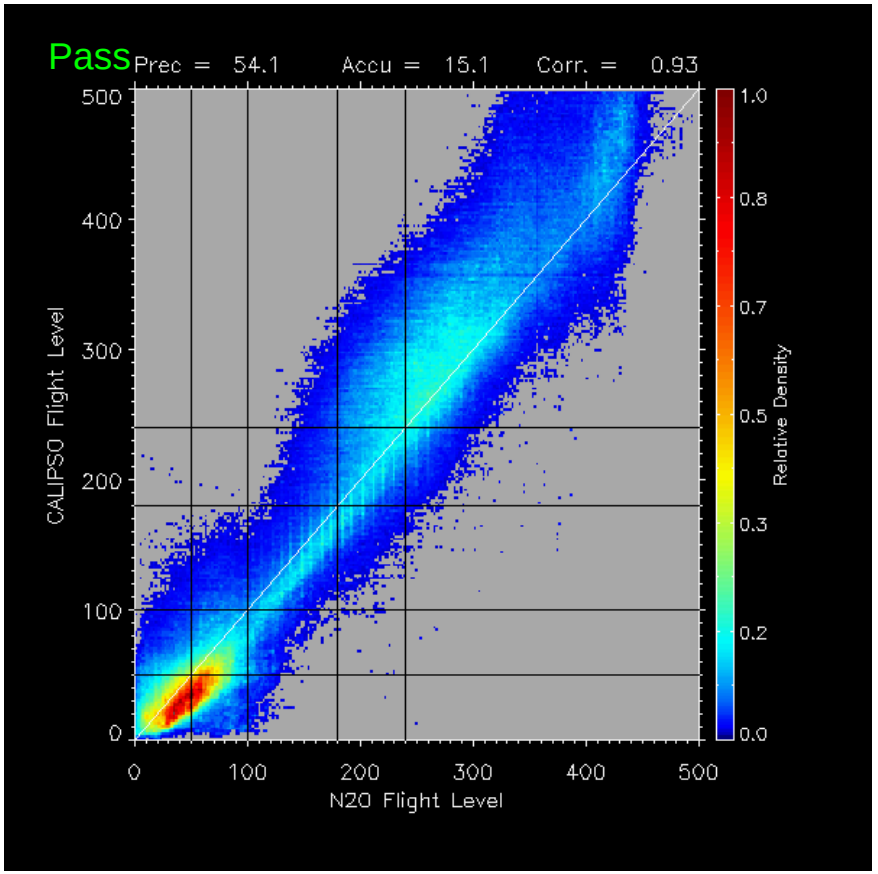
- An example shows the cloud cover layer cross section based on flight levels between Anchorage and Juneau. Made for Alaska Cloud Product Demo (killed by Federal Shutdown but will be done in summer)
- CCL is the amount of cloud between the flight levels (FLs).
- Image draws from mask, phase, height, optical props and base.

Cloud Cover Layer

No Filtering - 60.9% correct



Phase matched - 70.6% correct



Pixels fall within boxes along the diagonal are correct identified

Error Budget - N20 Compared to CALIPSO

Attribute Analyzed	JERD Threshold (Accuracy)	On-orbit Performance from CALIOP		Meet Requirement?
CTT	6K when $\tau \geq 1$	No filtering	6.7K	Almost
		Phase matching	4.1K	Yes
		Phase matching and single layer	0.3K	Yes
CTH	1km when $\tau \geq 1$	No filtering	-0.8km	Yes
		Phase matching	-0.4km	Yes
		Phase matching and single layer	0.2km	Yes
CTP	100 hPa when $\tau \geq 1$	No filtering	32.8hPa	Yes
		Phase matching	8.4hPa	Yes
		Phase matching and single layer	-22.6hPa	Yes
CCL	60% correct classification	No filtering	60.9%	Yes
		Phase matching	70.6%	Yes

Error Budget - N20 Compared to CALIPSO

Attribute Analyzed	JERD Threshold (Precision)	On-orbit Performance from CALIOP		Meet Requirement?
CTT	6K when $\tau \geq 1$	No filtering	18.4K	No
		Phase matching	10.4K	No
		Phase matching and single layer	6.0K	Yes
CTH	1km when $\tau \geq 1$	No filtering	2.7km	No
		Phase matching	1.5km	No
		Phase matching and single layer	1.0km	Yes
CTP	100 hPa when $\tau \geq 1$	No filtering	169.7hPa	No
		Phase matching	91.4hPa	Yes
		Phase matching and single layer	77.7hPa	Yes

Error Budget - SNPP Compared to CALIPSO

Attribute Analyzed	JERD Threshold (Accuracy)	On-orbit Performance from CALIOP		Meet Requirement?
CTT	6K when $\tau \geq 1$	No filtering	5.1K	Yes
		Phase matching	2.7K	Yes
		Phase matching and single layer	0.1K	Yes
CTH	1km when $\tau \geq 1$	No filtering	-0.6km	Yes
		Phase matching	-0.2km	Yes
		Phase matching and single layer	0.1km	Yes
CTP	100 hPa when $\tau \geq 1$	No filtering	25.0hPa	Yes
		Phase matching	-0.2hPa	Yes
		Phase matching and single layer	-23.2hPa	Yes
CCL	60% correct classification	No filtering	62.2%	Yes
		Phase matching	72.0%	Yes

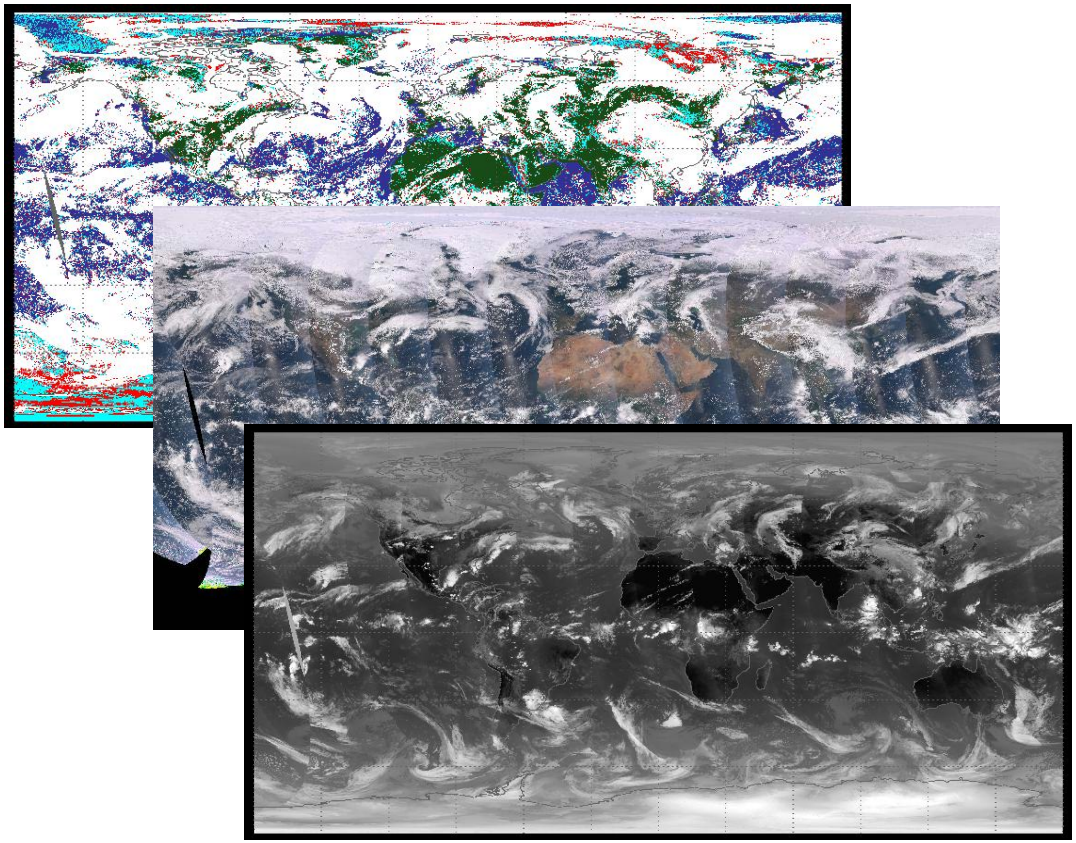
Error Budget - SNPP Compared to CALIPSO

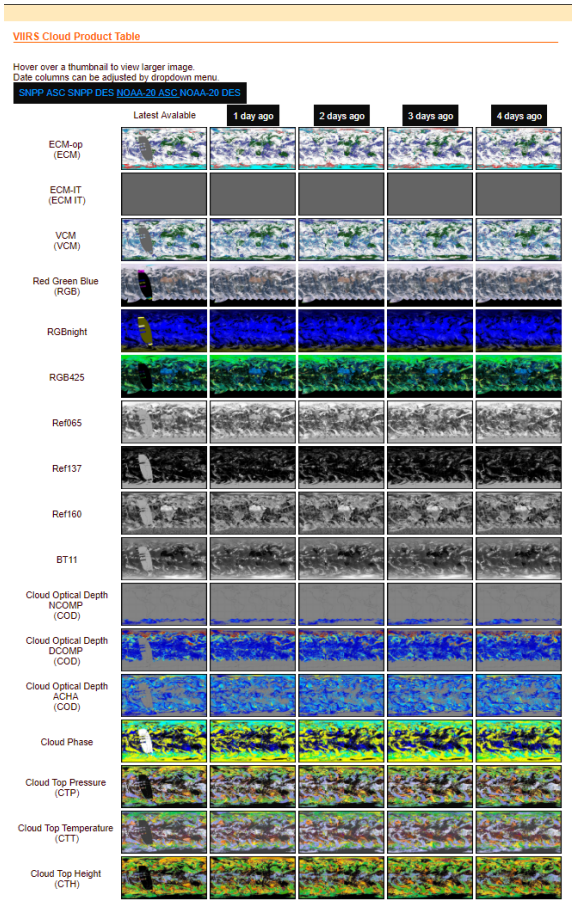
Attribute Analyzed	JERD Threshold (Precision)	On-orbit Performance from CALIOP		Meet Requirement?
CTT	6K when $\tau \geq 1$	No filtering	16.6K	No
		Phase matching	9.0K	No
		Phase matching and single layer	5.9K	Yes
CTH	1km when $\tau \geq 1$	No filtering	2.5km	No
		Phase matching	1.3km	No
		Phase matching and single layer	1.0km	Yes
CTP	100 hPa when $\tau \geq 1$	No filtering	155.7hPa	No
		Phase matching	83.0hPa	Yes
		Phase matching and single layer	72.4hPa	Yes

Long-Term Monitoring

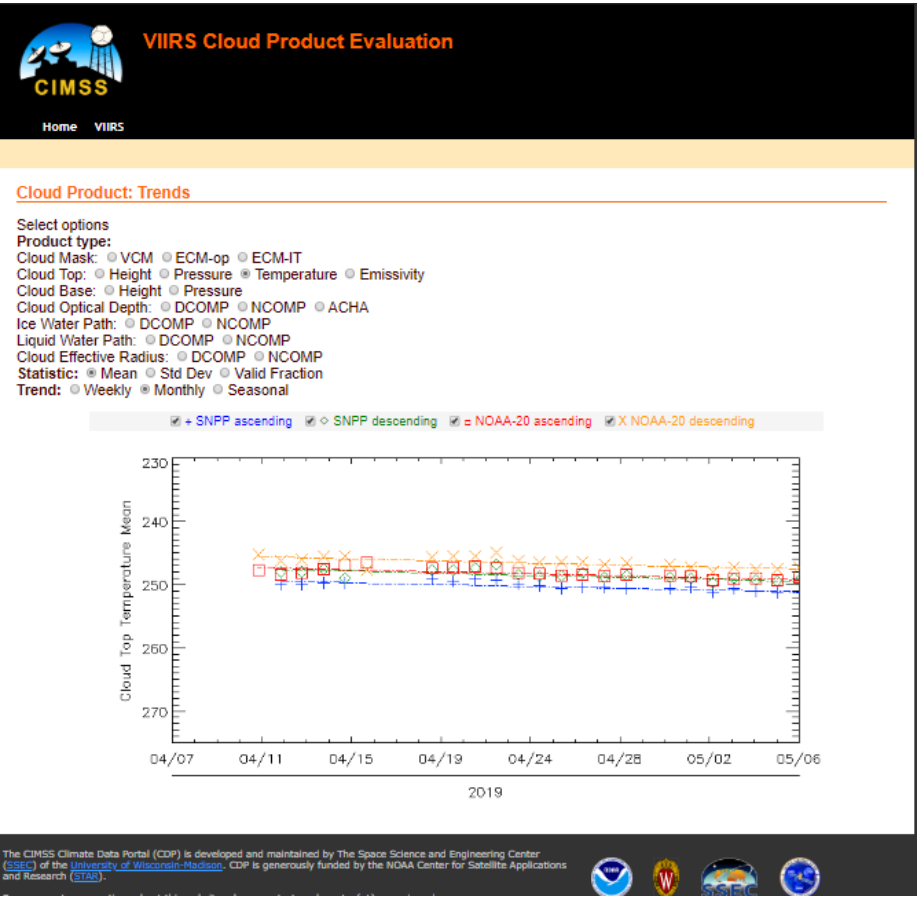
Long Term Monitoring

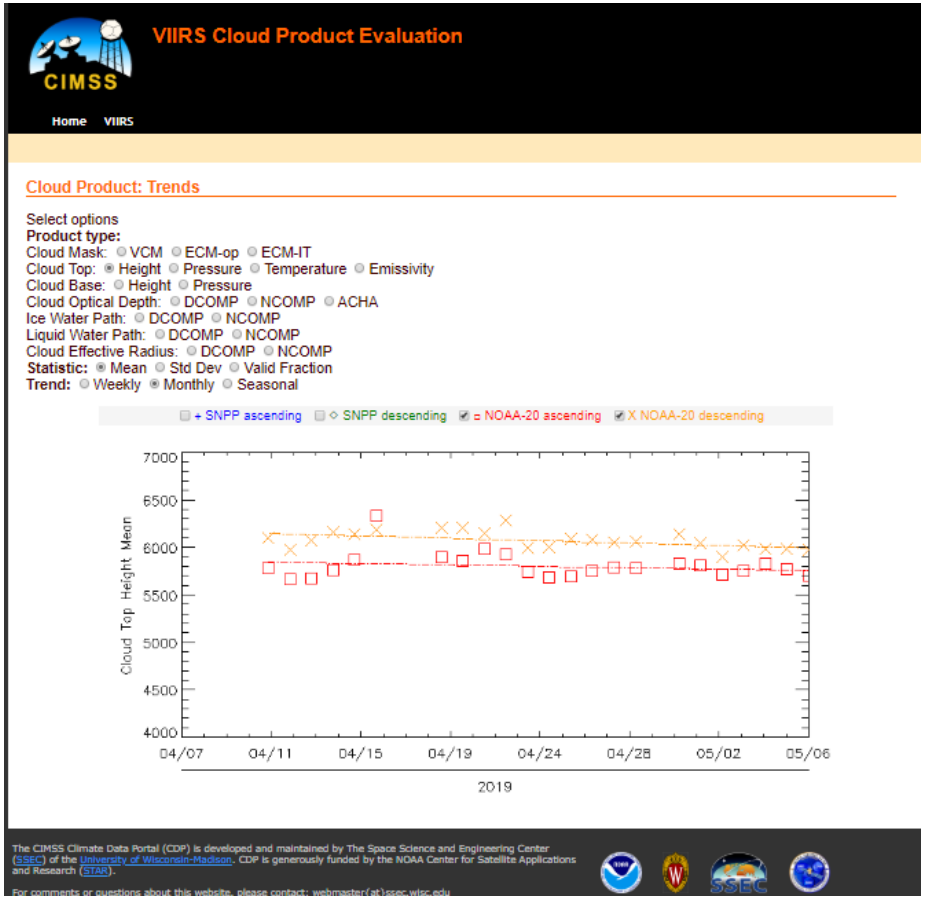
http://cimss.ssec.wisc.edu/clavrx/viirs_img/





NOAA-20 CTT and CTH Monitoring (Ascending Node)

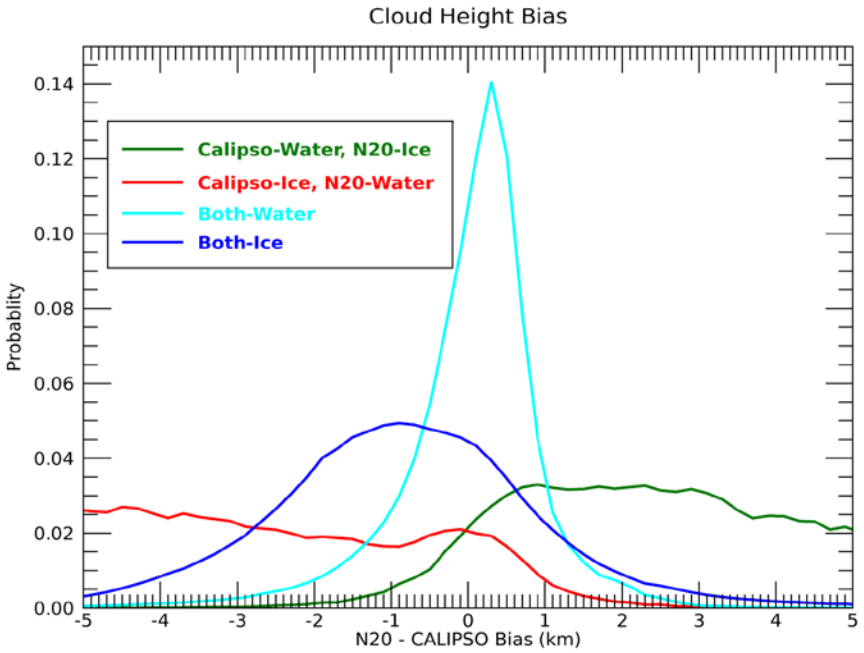




Required algorithm inputs

- Required Algorithm Inputs
  - Upstream Algorithms
    - Cloud Mask
    - Cloud Type/Phase
  - LUT (None)
  - Primary Sensor Data
    - Calibrated Brightness Temperatures, radiances for M14, M15 and M16
    - Satellite zenith angle and viewing zenith angle
    - Space Mask
    - Bad pixel mask for M14, M15 and M16
  - Static and Dynamic Ancillary Data
    - Surface emissivity from SEEBOR, surface elevation and type
    - NWP profiles
    - Clear-sky Infrared RTM Calculations for M14, M15 and M16 (transmission and radiance profiles, clear sky brightness temperatures and radiances)
    - Blackbody radiance profiles for M14, M15 and M16

Evaluation of the effect of upstream cloud type algorithm



	CALIPSO Water	CALIPSO Ice
NDE N20 Water	35%	12%
NDE N20 Ice	4%	49%

- When cloud phase (water/ice) is correctly identified, ACHA cloud top height performs well compared to CALIPSO
- If phase is incorrectly classified, ACHA tends to underestimate ice phase clouds and overestimate water phase clouds. These phase numbers confirm phase is in spec (80% correct).
- Numbers in the table shows percentages of NDE cloud phase in each category compared to CALIPSO

Quality Flags

- ACHA cloud top property outputs quality flags are set as follows:
  - Variable name: CloudHgtQF
  - Values
    - 0 (good)
    - 1 (marginal retrieval) if user selects to process clear/probably pixels
    - 2 (retrieval attempted) if retrieval fails from the optimal estimation algorithm
    - 3 (bad)
  - Quality flags are subject to the quality assurance checks and considered bad if:
    - M14 brightness temperature less than 170K or greater than 340K
    - Surface temperature less than 180K or greater than 340K
    - Tropopause temperature less than 160K or greater than 270K
- Another flag that explains the ACHA optimal estimation (OE) retrieval quality:
  - Variable name: CloudHgtFlag
  - This variable is a 3 dimensional array that sets retrieval quality for each of four direct OE output
  - Values
    - 0: failed
    - 1: low quality
    - 2: good quality
    - 3: high quality

User Feedback

Name	Organization	Application	User Feedback - User readiness dates for ingest of data and bringing data to operations
Jim Jung	CIMSS	VIIRS/CrIS Radiance Products for NWP Assimilation	
NASA NPP MODIS/VIIRS Continuity.	NASA	ACHA used as the cloud height in the NPP VIIRS/MODIS continuity cloud product suite.	None, but ACHA on VIIRS had to pass a parallel set of reviews and data is now available from NASA Lads and Atmospheric SIPS at SSEC.

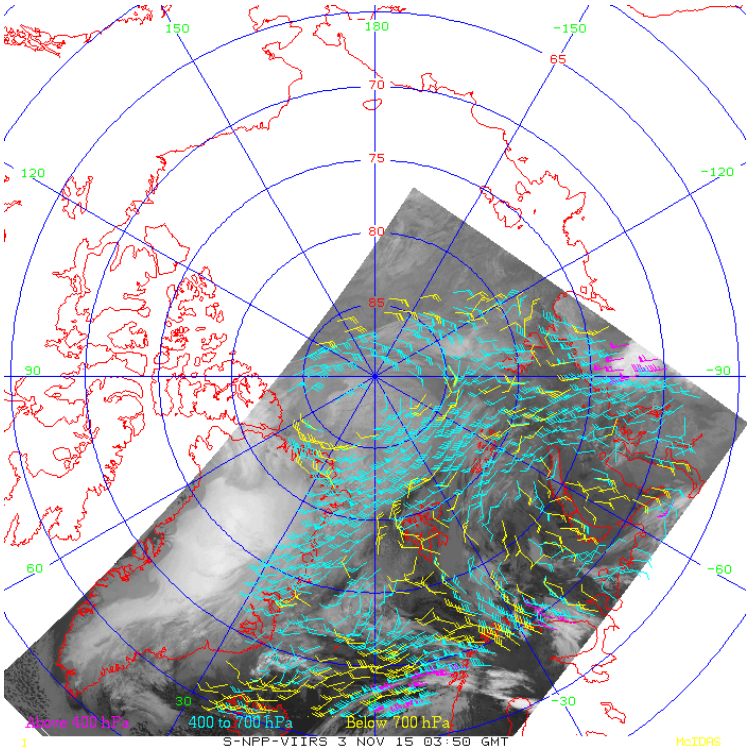
Downstream Product Feedback

Algorithm	Product	Downstream Product Feedback - Reports from downstream product teams on the dependencies and impacts
AMV (Winds)	Pressure, emissivity	See following slides

Downstream Product Feedback (AMVs)

VIIRS Polar Winds are derived by tracking clouds features in the VIIRS longwave infrared channel (clouds only)

- The algorithm utilizes the Enterprise pixel level cloud pressures to assign a final AMV height.
- The height assignment is the largest source of AMV error, so we work closely with the AMV team to ensure product compliance.



Attribute Analyzed	L1RD Threshold	On-orbit Performance	Meet Requirement?	Additional Comments
Accuracy	7.5 m/s	4.8-6.3 m/s	Yes	Raob, aircraft
Precision	4.2 m/s	2.8-4.3 m/s	Yes overall	Raob, aircraft

Courtesy of Jeff Key and Jaime Daniels

Risks, Actions, and Mitigations

Identified Risk	Description	Impact	Action/Mitigation and Schedule
NDE processing	Missing granules in NDE processing	Moderate	Closed - Issue fixed with sufficient time for full validation analyses,
Unrealistic values in CTH/CTP	The unrealistic values for cloud height and pressure, but not for cloud temperature output were found during beta and provisional	Low	Mostly fixed. A complete fix will be delivered in v2r2 update.
NDE Specific Metadata	Metrics including min, max, mean and std dev of height, temperature and pressure. Numbers are wrong or NaN in v2r0 output from NDE.	Low	Analysis of the SAPF standalone processing as well as analysis of the v1r2 and v2r1 DAP at ASSISTT do not show this issue. Analysis as to where the issue is occuring is currently ongoing. A verification of metadata will be performed during v2r1 I&T testing by the Cloud Team.

Example of Issues with Internal Metrics in Level-2

- Read from : JRR-CloudHeight_v2r0_j01_s201904282343136_e201904282344381_c201904290019410.nc

- Cloud Top Pressure : MinCldTopPres = 1100 ; MaxCldTopPres = 0 ; MeanCldTopPres = NaNf ; StdDevCldTopPres = NaNf ;

- Cloud Top Temperature: MinCldTopTemp = 340 ; MaxCldTopTemp = 180 ; MeanCldTopTemp = NaNf ; StdDevCldTopTemp = NaNf ;

- Cloud Top Height: MinCldTopHeight = 20000 ; MaxCldTopHeight = -300 ; MeanCldTopHeight = NaNf ; StdDevCldTopHeight = NaNf ;

Documentations

Science Maturity Check List	Yes ?
ReadMe for Data Product Users	Yes (Provisional. Full Validation ReadMe will be provided after review)
Algorithm Theoretical Basis Document (ATBD)	Yes
Algorithm Calibration/Validation Plan	Yes
(External/Internal) Users Manual	Yes
System Maintenance Manual (for ESPC products)	Yes
Peer Reviewed Publications (Demonstrates algorithm is independently reviewed)	Yes
Regular Validation Reports (at least annually) (Demonstrates long-term performance of the algorithm)	As requested. LTM of algorithm is performed regularly via Cloud Team website

Check List - Validated Maturity

Validated Maturity End State	Assessment
Product performance has been demonstrated over a large and wide range of representative conditions (i.e., global, seasonal).	All requirements have been met
Comprehensive documentation of product performance exists that includes all known product anomalies and their recommended remediation strategies for a full range of retrieval conditions and severity level.	Yes
Product analyses are sufficient for full qualitative and quantitative determination of product fitness-for-purpose.	Yes
Product is ready for operational use based on documented validation findings and user feedback.	Yes
Product validation, quality assurance, and algorithm stewardship continue through the lifetime of the instrument	Yes

Conclusion

- ACHA meets all specs for single-layer clouds of known phase.
- Accuracy spec is always met for all other clouds except for unfiltered cloud top temperature.
- The unrealistic values for cloud height and pressure, but not for cloud temperature were found during beta and provisional. This is mostly resolved but there are still a few pixels where this occurs. This has a minor impact and will be fixed in the next science code delivery (late 2019)
- ACHA appears to perform well enough for the AMV's to meet spec and we continue to try and optimize ACHA for that application.
- **The Cloud Team recommends Full Validated Maturity at this time.**

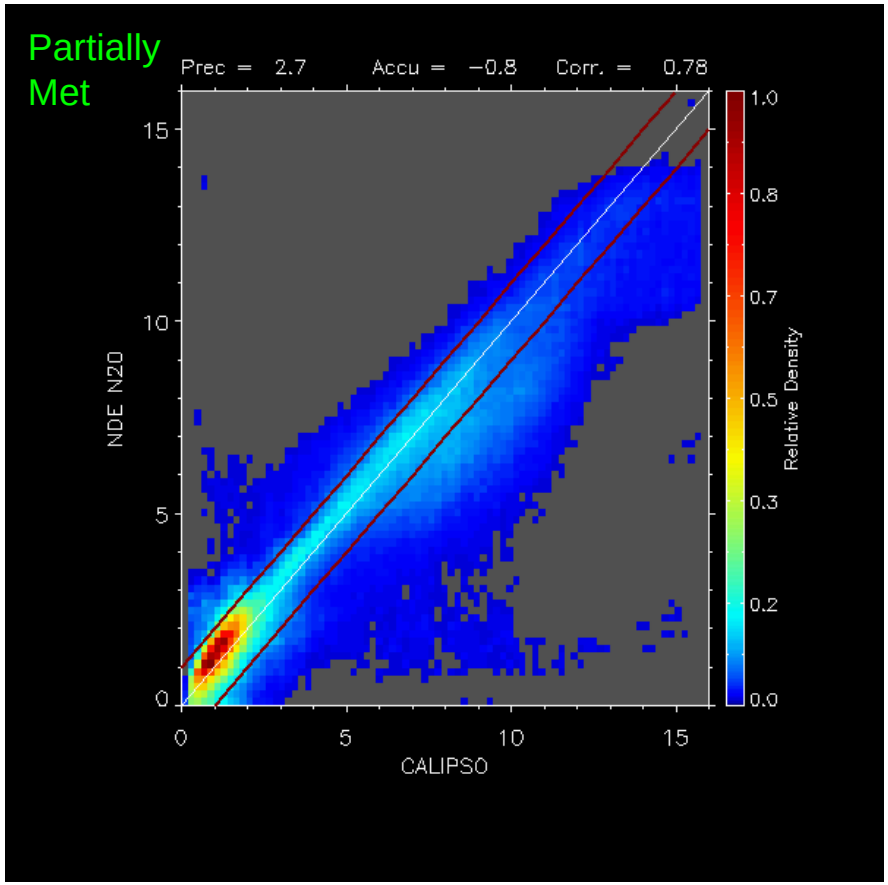
Path Forward

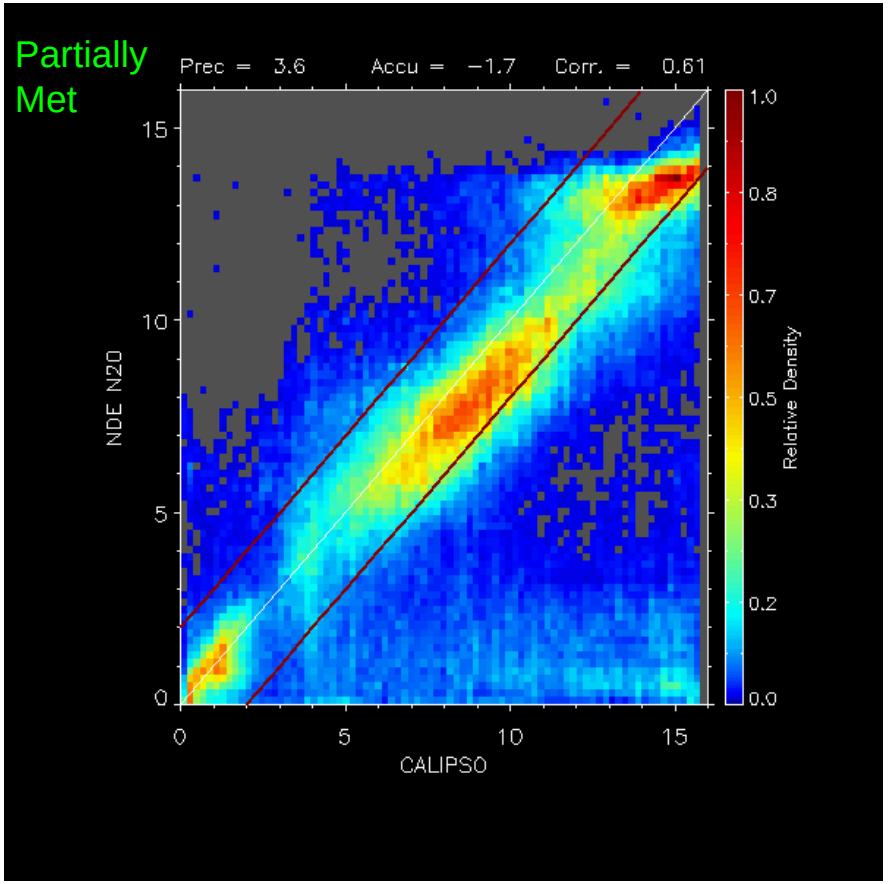
- Planned improvements
  - We will work with Phase team and explore methods that allow ACHA to try a different phase value when ACHA retrievals fail.
  - We will continue to expand the ACHA multi-layer capability but VIIRS provides limited spectral information for this.
  - If successful, our JPSS PG RR project should develop a capability to leverage off NUCAPS to improve the VIIRS height performance.
  - We will also continue to interact with the winds team to try and improve performance where possible

- Future Cal/Val activities
  - We will continue routine long term monitoring via Cloud Team website to monitor for any anomalies which may occur
  - We will interact with the International Cloud and Winds Working Groups on their analysis of the enterprise Cloud Algorithm

Backup Materials

CTH - no filtering



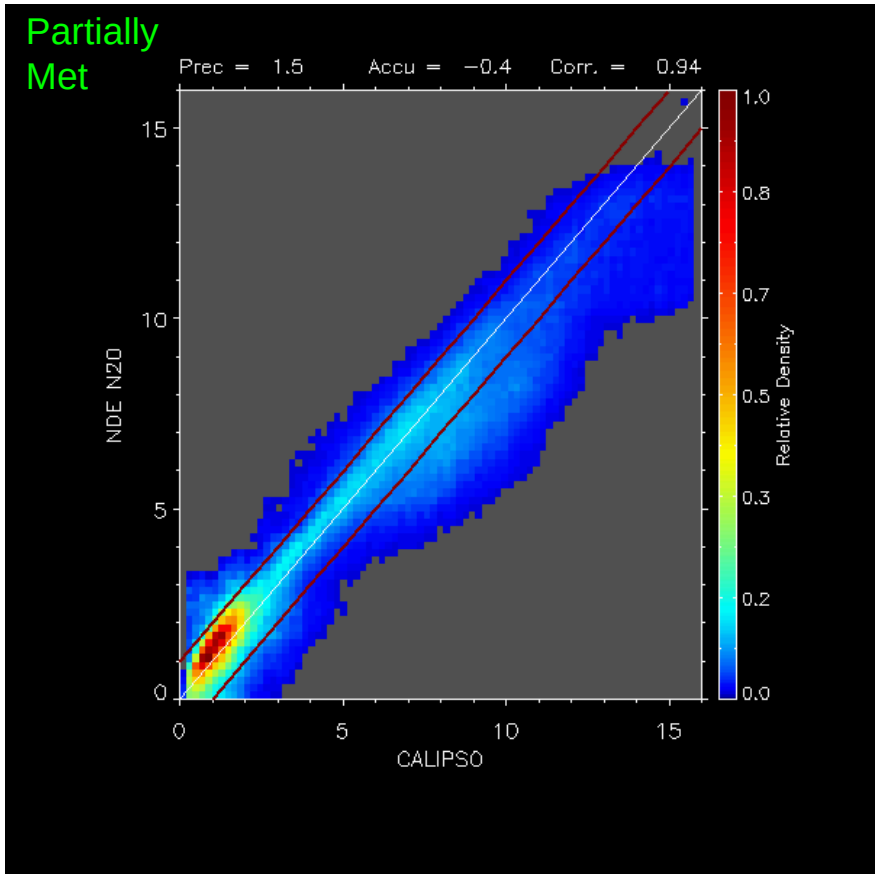


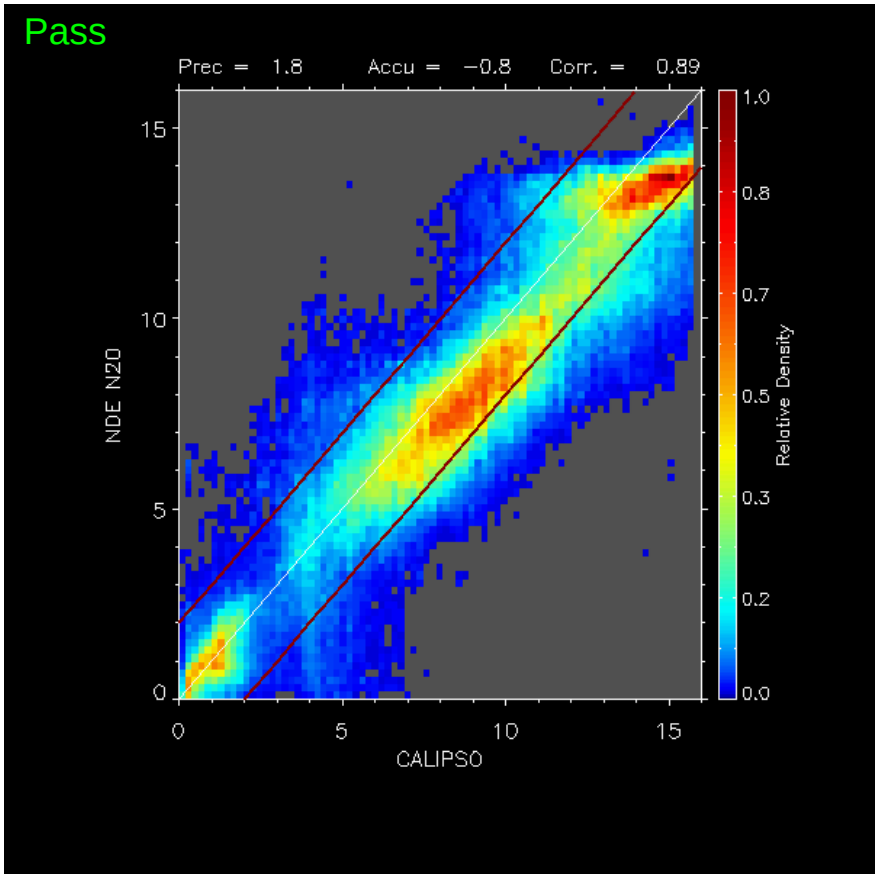
COT >=1

COT < 1

1km when $\tau \geq 1$, 2km when $\tau < 1$

CTH - Phase Matching



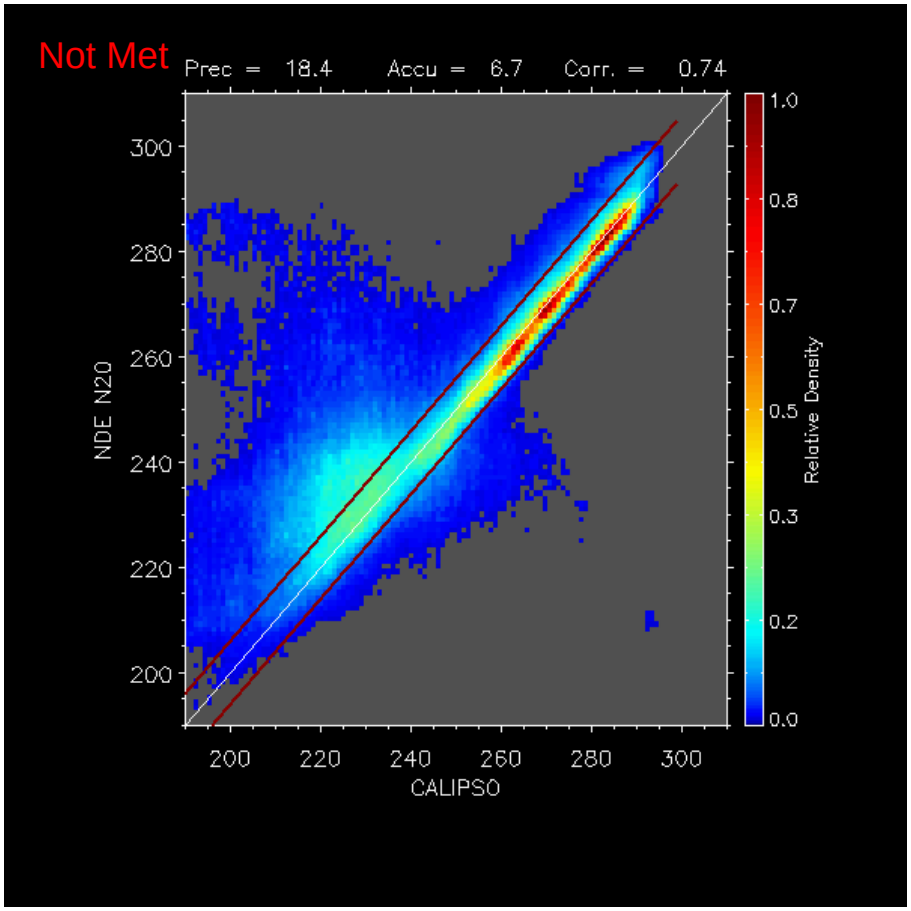


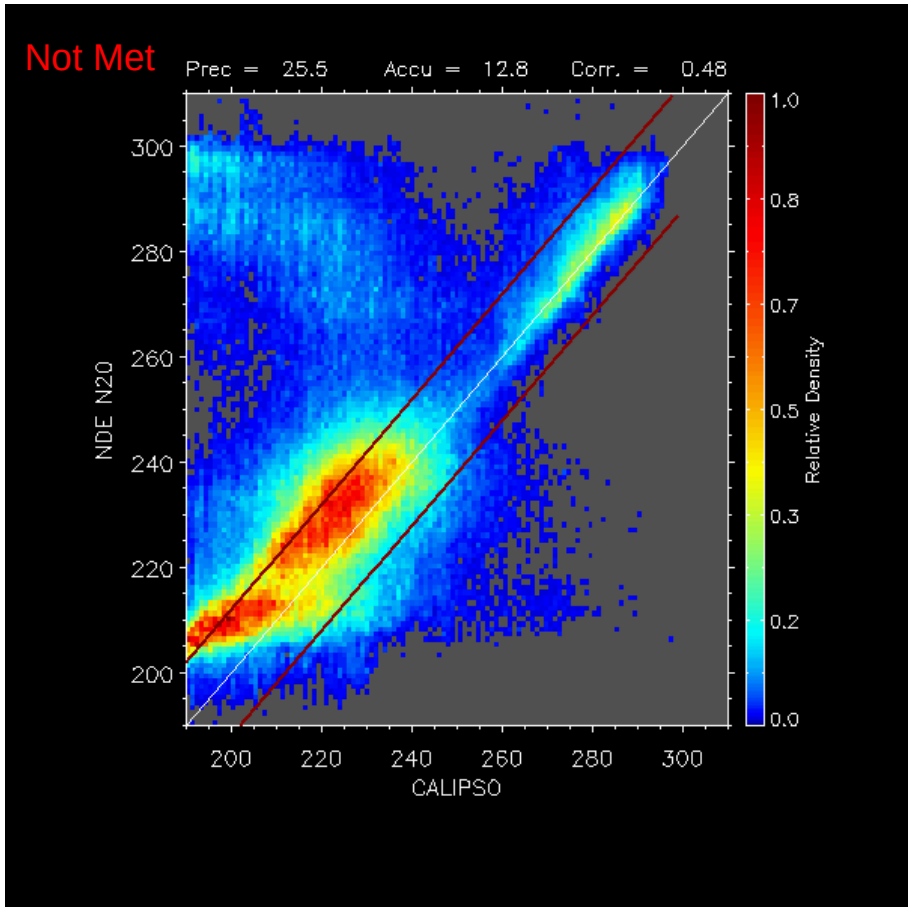
COT >=1

COT < 1

1km when $\tau \geq 1$, 2km when $\tau < 1$

CTT - no filtering



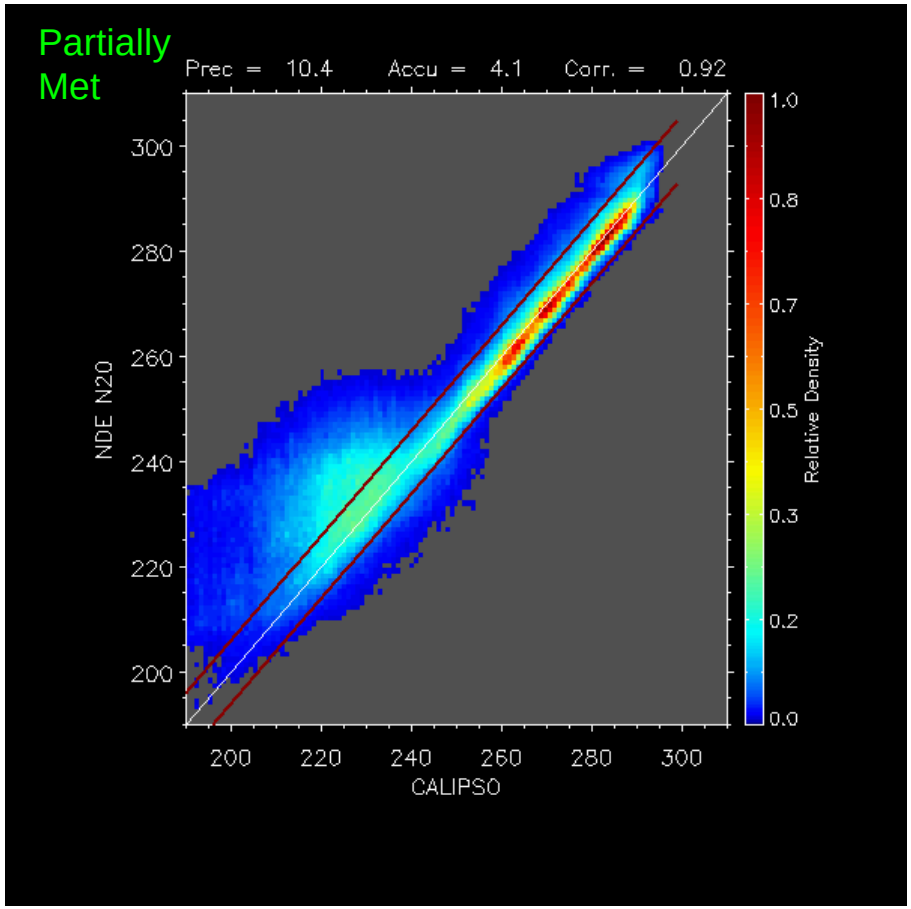


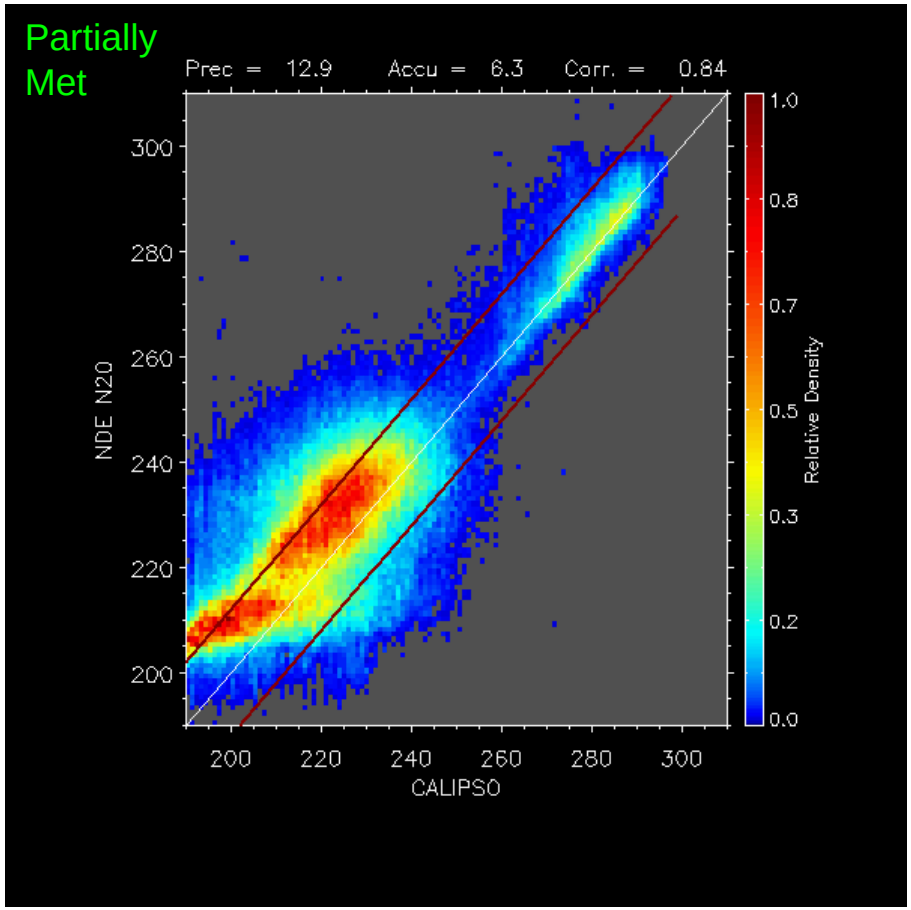
COT >=1

6K when $\tau \geq 1$, 12K when $\tau < 1$

COT < 1

CTT - Phase Matching



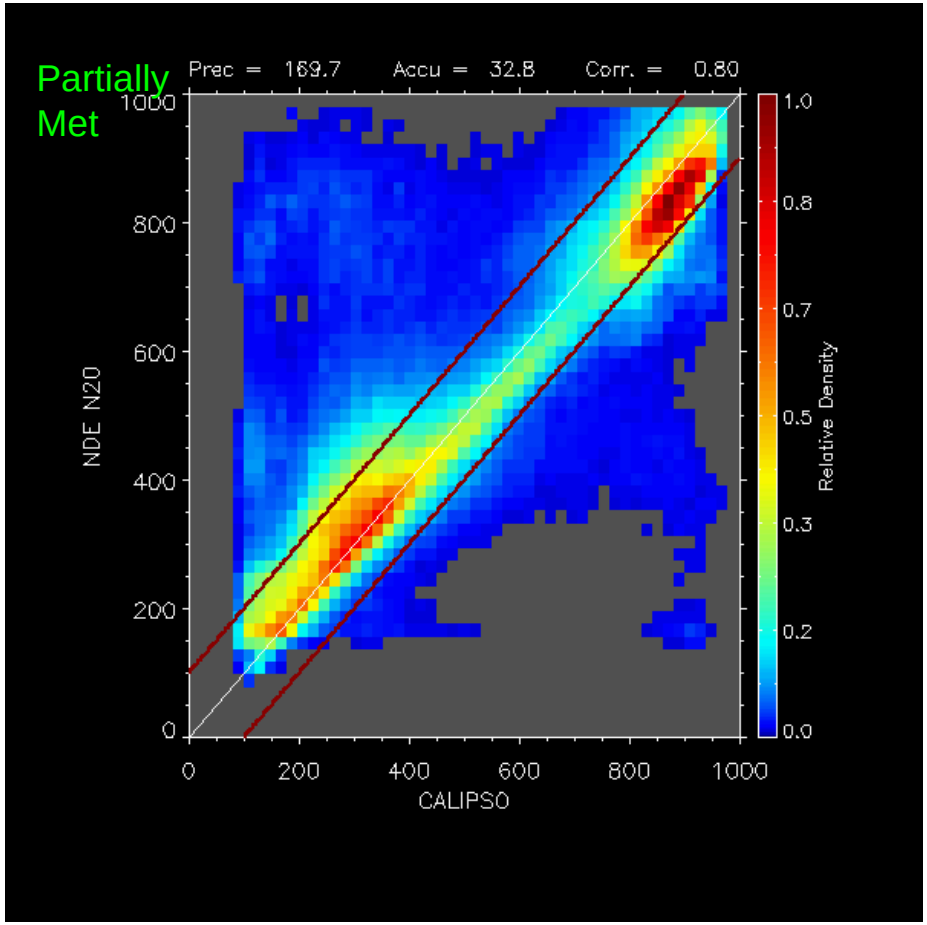


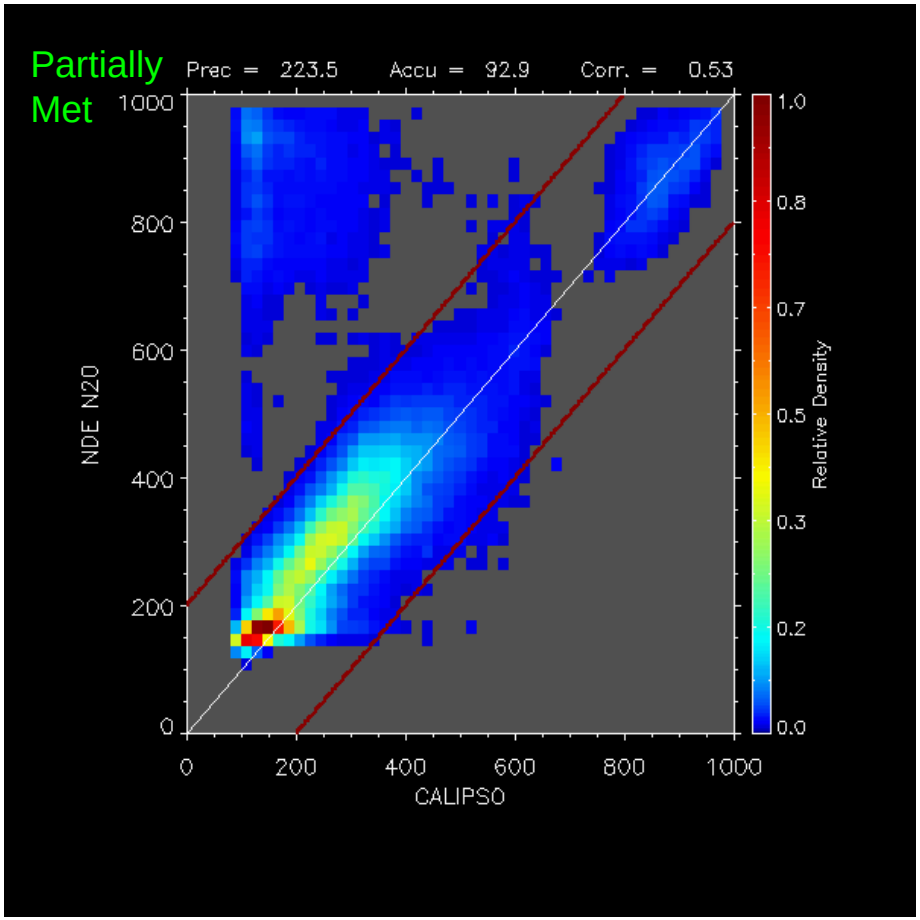
COT >=1

6K when $\tau \geq 1$, 12K when $\tau < 1$

COT < 1

CTP - no filtering



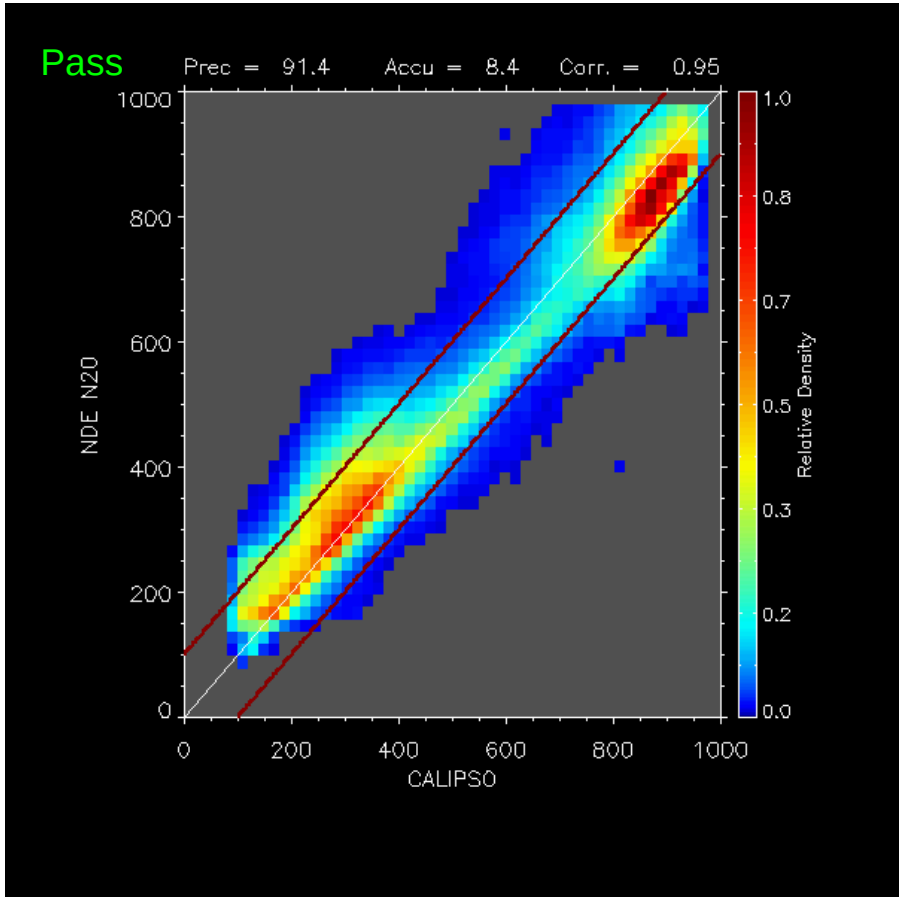


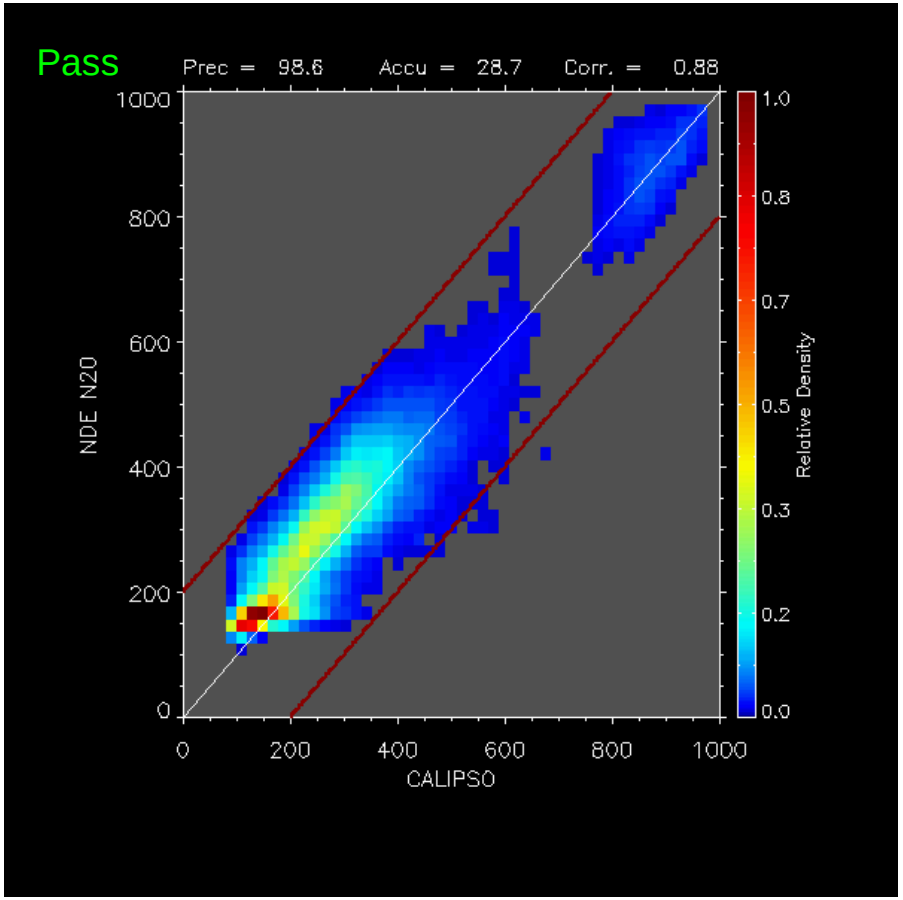
COT >=1

100 hPa when $\tau \geq 1$, 200 hPa when $\tau < 1$

COT < 1

CTP - Phase matching





COT >=1

100 hPa when $\tau \geq 1$, 200 hPa when $\tau < 1$

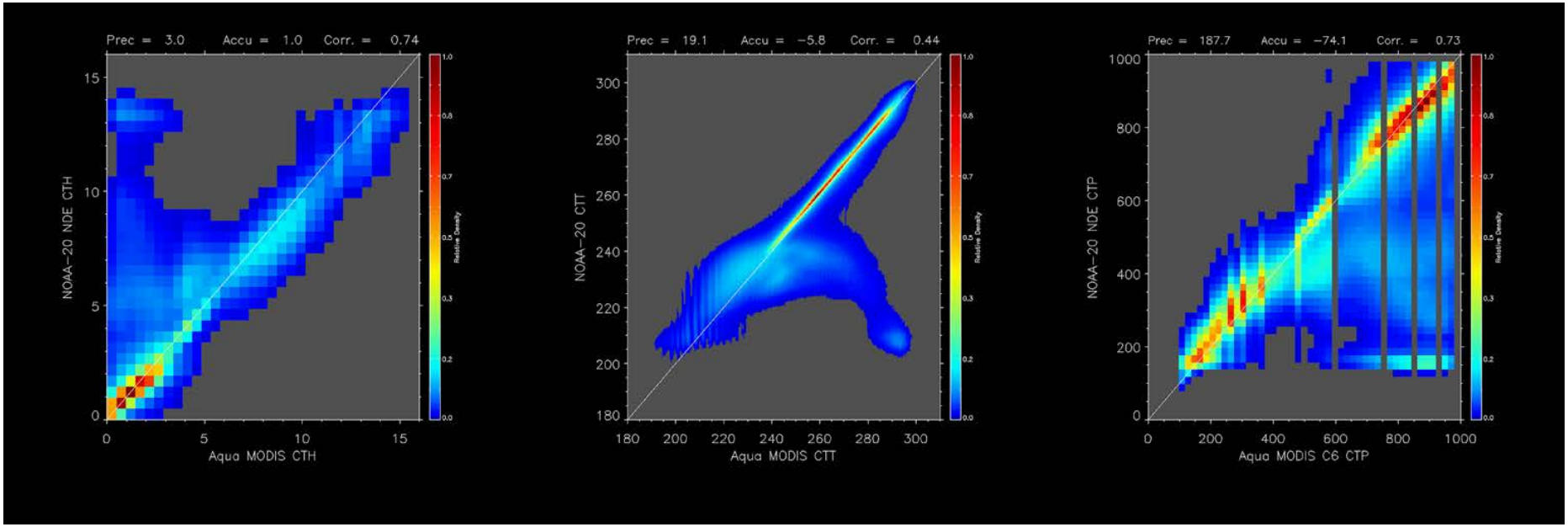
COT < 1

MODIS Comparison: no filtering

CTH

CTT

CTP



- Not separating thick and thin clouds due to lack of truth COD
- All data are used and no filtering applied