# *Beta/Provisional Maturity Science Review For NOAA-21 Cloud Cover Layers (CCL) and Cloud Base Height (CBH)*

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*NOAA Cloud Science Team Lead: Mark Kulie*

*Presented by*
*John Haynes*
*Date: 10/26/2023*

# JPSS/GOES-R Data Product Validation Maturity Stages - COMMON DEFINITIONS (Nominal Mission)

## 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.

# BETA/PROVISIONAL/ MATURITY REVIEW
# Cloud Base Height (CBH)
# Cloud Cover Layers (CCL)

# Executive Summary

- NOAA-21 Cloud Base Height (CBH) and Cloud Cover Layers (CCL) products were evaluated visually and quantitatively with other observations
- Issues
  - upstream cloud product errors (CM, ACHA cloud top height, DCOMP) and NWP data issues directly inherited into CBH and CCL
  - sometimes blocky features appeared in nighttime CBH (using NWP-CWP input)
  - limited eval data resources: CloudSat/CALIPSO - no longer operational
- Quantitative assessments against ARM ground active sensor measurements and CALIPSO confirm that N21 CBH / CCL products perform well, especially optimal for single layer clouds, and meet all requirement
- Team recommends algorithm Beta/Provisional maturity (effective March 30, 2023)

## Algorithm Cal/Val Team Members

| Name | Organization | Major Task |
|---|---|---|
| Yoo-Jeong Noh | CSU/CIRA | Algorithm development/evaluation, CIRA Team Lead |
| John Haynes | CSU/CIRA | Algorithm development/evaluation, CIRA Co-Lead |
| Brandon Daub | CSU/CIRA | Algorithm development/evaluation |
| Mark Kulie | NOAA-NESDIS | NOAA Cloud Team Lead |
| Yue Li | UW-Madison/CIMSS | Algorithm development/evaluation |
| William Straka | UW-Madison/CIMSS | ASSISTT integration/data acquisition |
| Andrew Heidinger | NOAA-NESDIS-GEO | Algorithm development |
| David Donahue | OSPO | Cloud Algorithm PAL |
| Shuang Qiu | OSPO | Product Area Lead |

# Product Overview/Requirements

- **Cloud Base Height**
- Product performance requirements from JPSS Data Product Specification (DPS)

| Attribute | DPS | Requirement/Threshold | Performance |
|---|---|---|---|
| Coverage | DPS-481 | The Cloud Height product shall provide geolocated cloud top and base heights per cell, for the highest cloud in the column, globally, day and night, whenever detectable clouds are present, at the refresh rates of the instrument. | |
| Accuracy | DPS-485 | The algorithm shall produce a cloud base height product that has a measurement accuracy of **2.0 km for COT >=1 and 3.0 km for COT < 1** | |
| Precision | DPS-482 | The algorithm shall produce a cloud base height product that has a measurement precision of **2.0 km for COT >=1 and 3.0 km for COT < 1** | |
| Uncertainty | DPS | The algorithm shall produce a cloud height product that has a mapping uncertainty, (3 sigma) of 4 km. | |

*Note : Cloud Mask, CTH, DCOMP are used as input for CBH. CBH performance is impacted by the upstream product performance, and thus affects CCL performance.*

# Requirement Check List – VIIRS Cloud Cover Layer

| DPS | Requirement | Performance |
|---|---|---|
| DPS-458 | The Cloud Cover/Layers product shall provide geolocated fractional cloud cover per cell, for three atmospheric layers and for the total of all layers, globally, day and night, whenever detectable clouds are present, at the refresh rates of the instrument. | |
| DPS-591 | The Cloud Cover/Layers product shall provide geolocated fractional cloud cover per cell at the three atmospheric layers of 0 to 350 millibars (mb), 350 to 642 mb, and 642 to 1100 mb.* | |
| DPS-459 | The Cloud Cover/Layers product shall provide fractional cloud cover per cell with a measurement uncertainty of 15%. | |
| DPS-461 | The Cloud Cover/Layers product shall provide fractional cloud cover with a horizontal cell size of 10 kilometers. | |
| DPS-462 | The Cloud Cover/Layers product shall geolocate the center of the fractional cloud cover cell with a 3-sigma mapping uncertainty of 4 kilometers. | |

*** Cloud Cover Layers - 60%** correct classification for unobscured fraction in each layer (total, SFC-FL050, FL050-FL100, FL100-FL180, FL180-FL240, FL240-TOA)

* Cloud Layers - Note that five flight-level based cloud layers will be displayed/assessed for (H+M+L)

# Processing Environment and Algorithms

- Cloud Base Height (CBH): NDE v3r2,
- Cloud Cover layers (CCL): NDE v2r0 from Spring 2022 Super DAP

- S-NPP and NOAA-20 Validated Maturity Review completed (May 16, 2019)
  - Beta (July 2018), Provisional (Oct 2018)
  - CCL (*identical algorithm*) for G16/G18 Peer Stakeholder Provisional Validation Review completed (May 2023)

# Evaluation of algorithm performance to specification requirements

- **New since last review**
  - CCL (v2r0) now includes CBH (v3r2) as input
  - Nighttime cloud optical properties with DNB are incorporated into CBH/CCL
- **Required Algorithm Inputs**
  - Upstream algorithms: CM/CTH/DCOMP/NLCOMP for CBH, CTH/CBH for CCL
  - Ancillary data: Cloud Water Path from NWP when DCOMP/NLCOMP output is not valid
- **Algorithm performance evaluation**
  - Validation data sets
    - ARM surface radar/lidar/ceilometer (Apr-Jul 2023), CALIPSO, sensor intercomparisons
  - Long term monitoring readiness
    - CIRA's VIIRS LTM webpage (global comparisons with S-NPP, NOAA-20, and CLAVR-x currently, ready for NOAA-21 addition)
- **Inter-sensor comparison**
  - Compare with S-NPP and NOAA-20
  - Compare with GOES-16 and GOES-18

# Quality flag analysis/validation

- Quality Flags for CBH and CCL

| Flag Value | CldBaseQF Description |
|---|---|
| 0 | Valid retrieval from the statistical method |
| 1 | Invalid due to the upstream input being invalid or clear |
| 2 | CBH = Terrain due to CBH lower than Terrain |
| 3 | Out of range due to CBH < minCbh (0 km) or CBH > maxCbh (20 km) |
| 4 | Invalid due to CBH >= CTH |
| 5 | Valid retrieval from the extinction method |
| 6 | Valid retrieval from NWP for deep convection |

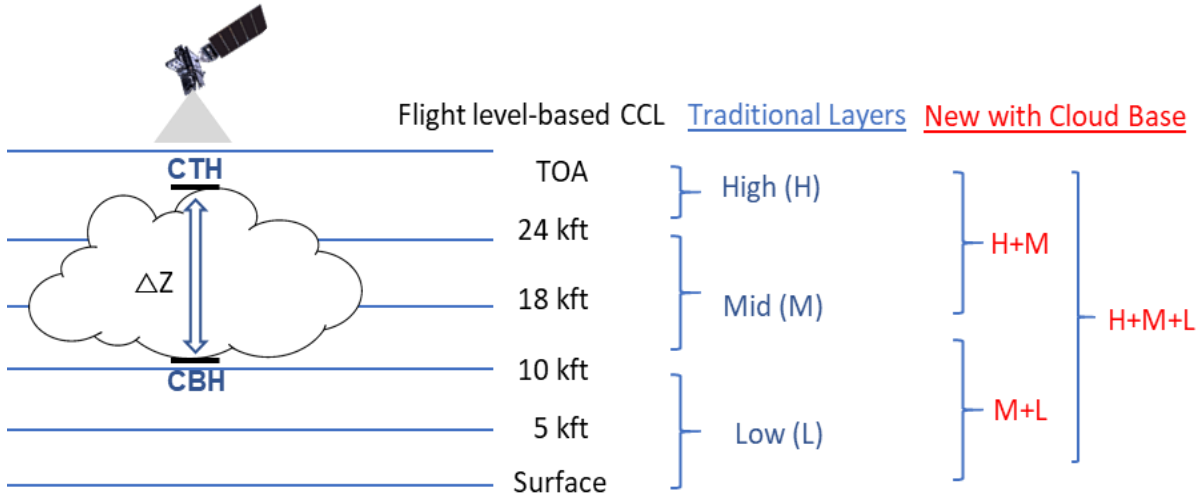
| Flag Value | CCL_DQF Description |
|---|---|
| 0 | Valid retrieval |
| 1 | Degraded (due to upstream errors) |
| 2 | Bad (Invalid) |

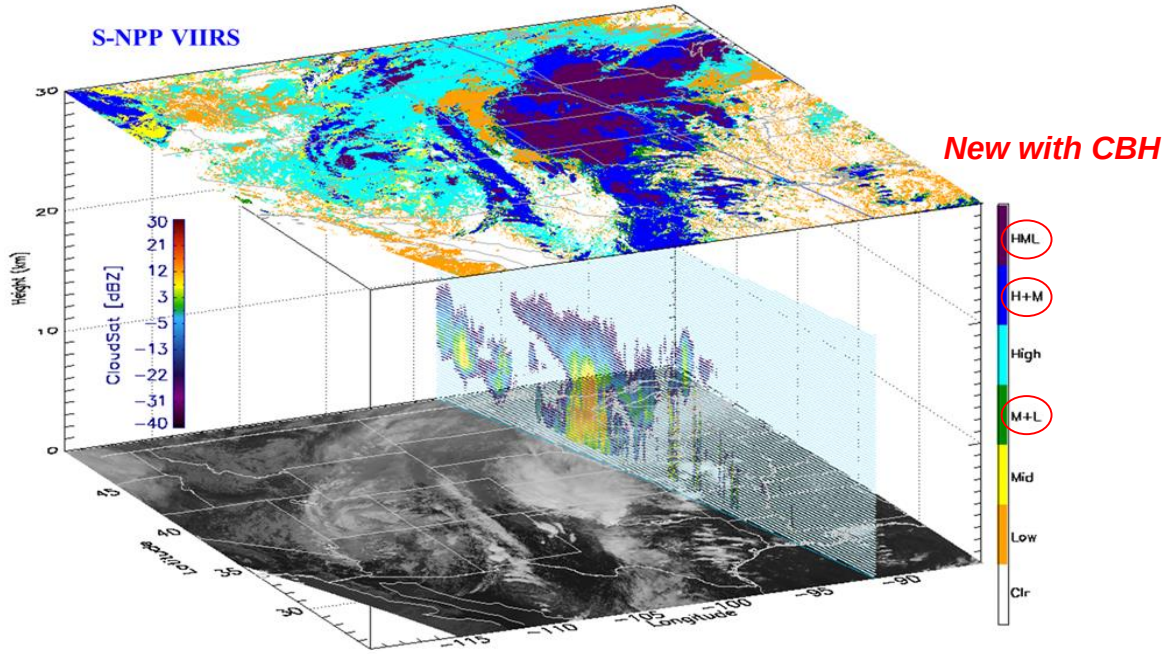
Diagnostic metadata output provided for each granule → More effective long-term monitoring

- Percentages of Valid and Invalid Retrievals per QF
- Mean / Min / Max / StdDev

# Introduction: CBH and CCL Products

- To provide satellite-based vertical cloud layer information
  - *CBH = CTH – CGT* (Cloud Geometric Thickness; statistical LUT using NASA A-Train data)
  - Seaman et al. 2017; Noh et al. 2017, 2022; Haynes et al. 2021
- Started with S-NPP VIIRS and now operational for ABI as well



# Introduction: CBH and CCL Products

| dec | binary | layers | meaning | poss (*)? |
|---|---|---|---|---|
| 0 | 00000000 | | clear | X |
| 1 | 00000001 | 1 | L | X |
| 2 | 00000010 | 2 | L | X |
| 3 | 00000011 | 12 | L | X |
| 4 | 00000100 | 3 | M | X |
| 5 | 00000101 | 1 3 | LM | |
| 6 | 00000110 | 23 | LM | X |
| 7 | 00000111 | 123 | LM | X |
| 8 | 00001000 | 4 | M | X |
| 9 | 00001001 | 1 4 | LM | |
| 10 | 00001010 | 2 4 | LM | |
| 11 | 00001011 | 12 4 | LM | |
| 12 | 00001100 | 34 | M | X |
| 13 | 00001101 | 1 34 | LM | |
| 14 | 00001110 | 234 | LM | X |
| 15 | 00001111 | 1234 | LM | X |
| 16 | 00010000 | 5 | H | X |
| 17 | 00010001 | 1 5 | L H | |
| 18 | 00010010 | 2 5 | L H | |
| 19 | 00010011 | 12 5 | L H | |
| 20 | 00010100 | 3 5 | MH | |
| 21 | 00010101 | 1 3 5 | LMH | |
| 22 | 00010110 | 23 5 | LMH | |
| 23 | 00010111 | 123 5 | LMH | |
| 24 | 00011000 | 45 | MH | X |
| 25 | 00011001 | 1 45 | LMH | |
| 26 | 00011010 | 2 45 | LMH | |
| 27 | 00011011 | 12 45 | LMH | |
| 28 | 00011100 | 345 | MH | X |
| 29 | 00011101 | 1 345 | LMH | |
| 30 | 00011110 | 2345 | LMH | X |
| 31 | 00011111 | 12345 | LMH | X |

(*) 'poss' column indicates that the combination is possible for the statistical (non-machine learning) algorithm. Statistical algorithm cannot produce broken cloud layers.

## Cloud Layers


**CBH (Version 3.2)**

Checked the output variable formats and structures

- Both no format issues

**CCL (Version 2.0)**

Cloud Layers - Note that five flight-level based cloud layers will be displayed/assessed for (H+M+L)

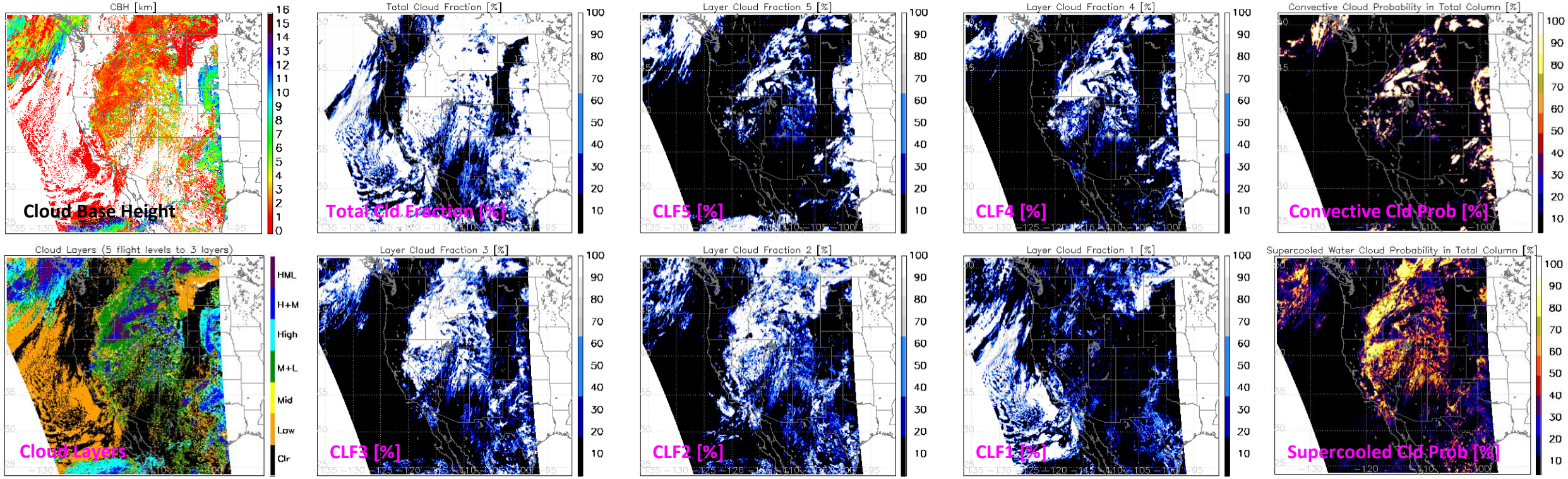
Layered cloud fractions (total+ each layer)

Additional fields (total + each layer; *future capability*)

- Supercooled water cloud probabilities
- Convective cloud probabilities

# VIIRS CBH and CCL Products

## NOAA-21 VIIRS CBH and CCL Products (2032 UTC 20231001)

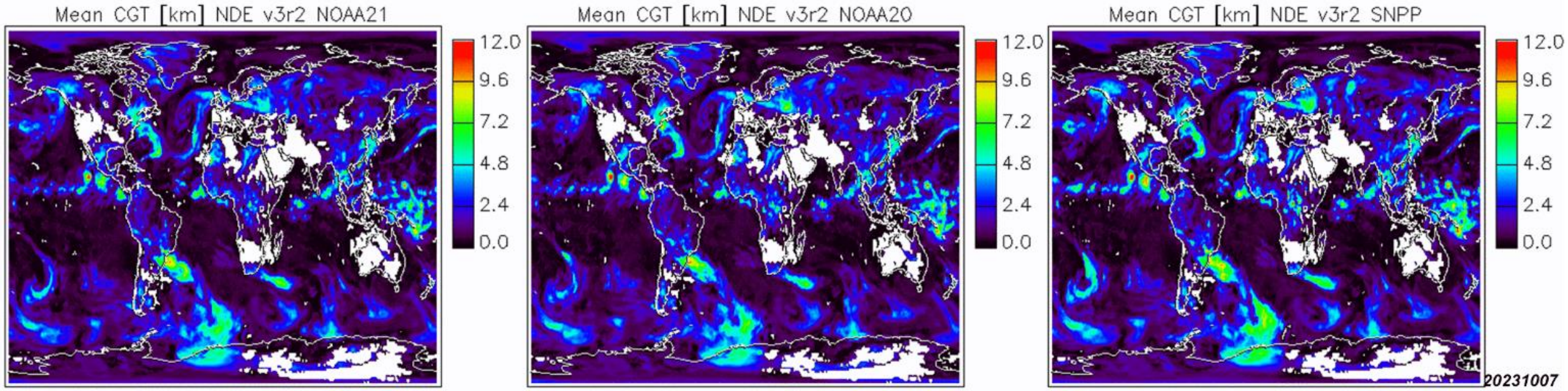



**Cloud Base Height (CBH)**

**Cloud Cover Layers (CCL)**

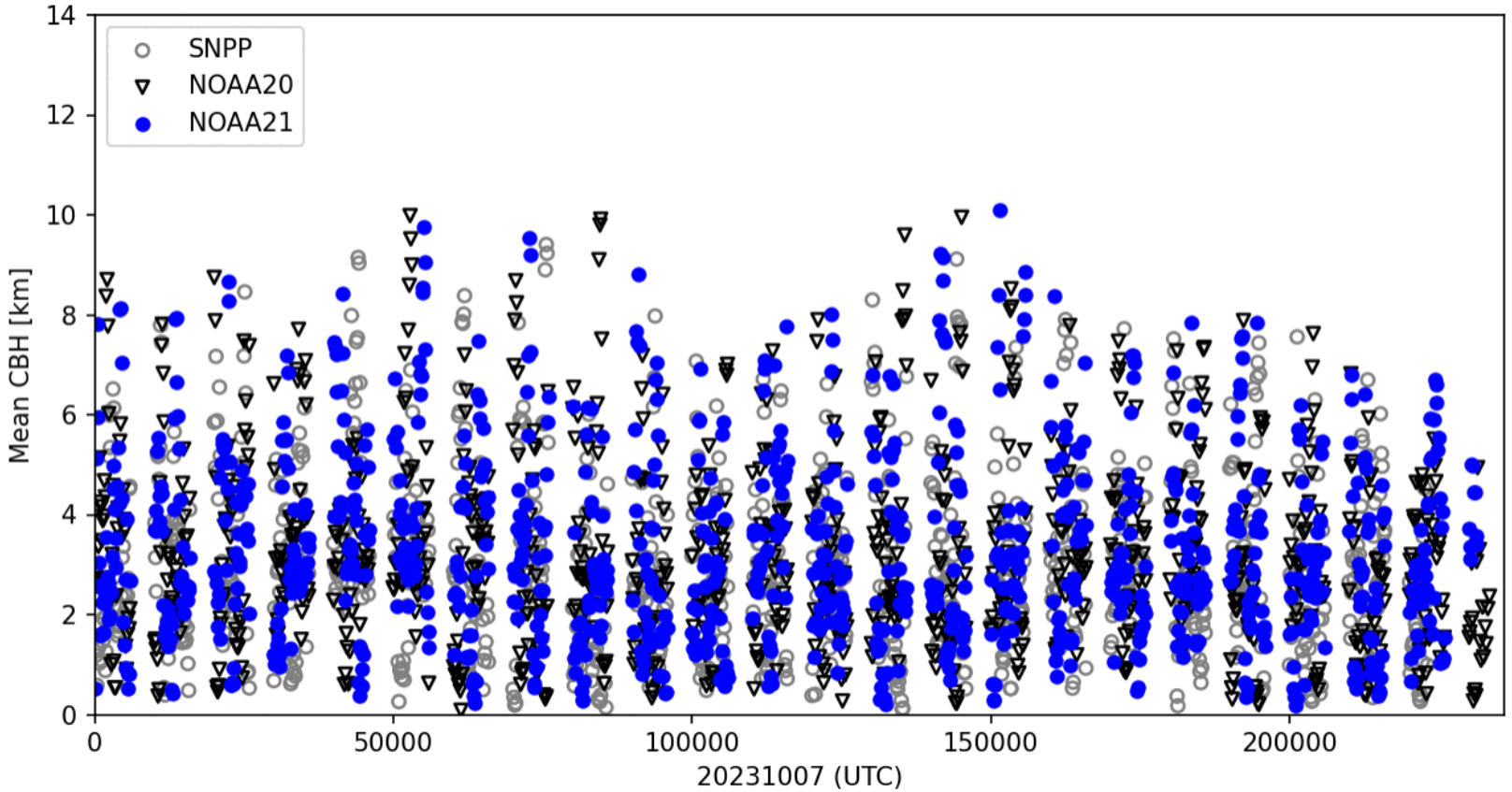
- ➔ Cloud Layers - Note that five flight-level based cloud layers will be displayed/assessed for (H+M+L)
- ➔ Layered cloud fractions (total+ each layer - CLF1 lowest)
- ➔ Additional fields (*future capability*): Supercooled water cloud probabilities, Convective cloud probabilities

# Global Cloud Geometric Thickness (CTH - CBH)




- CIRA's VIIRS LTM webpage (global comparisons with S-NPP, NOAA-20, and CLAVR-x currently, ready for NOAA-21 addition)
- Similar performance globally (all three VIIRS)

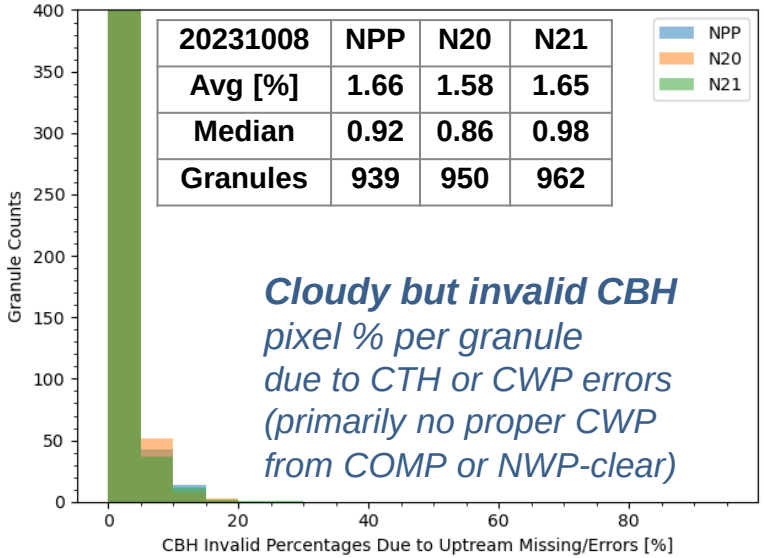
# Global CBH Timeseris (NOAA-20, NOAA-21, S-NPP)




Similar performance globally (all three VIIRS)

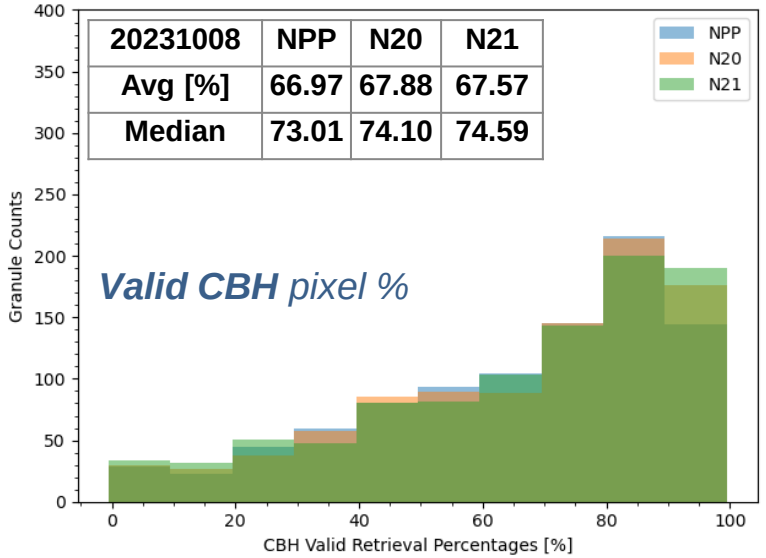
# Global Daily CBH and CCL Valid Retrievals (S-NPP/NOAA-20/NOAA-21)

| 20231008 | NPP | N20 | N21 |
|---|---|---|---|
| Avg [%] | 1.66 | 1.58 | 1.65 |
| Median | 0.92 | 0.86 | 0.98 |
| Granules | 939 | 950 | 962 |



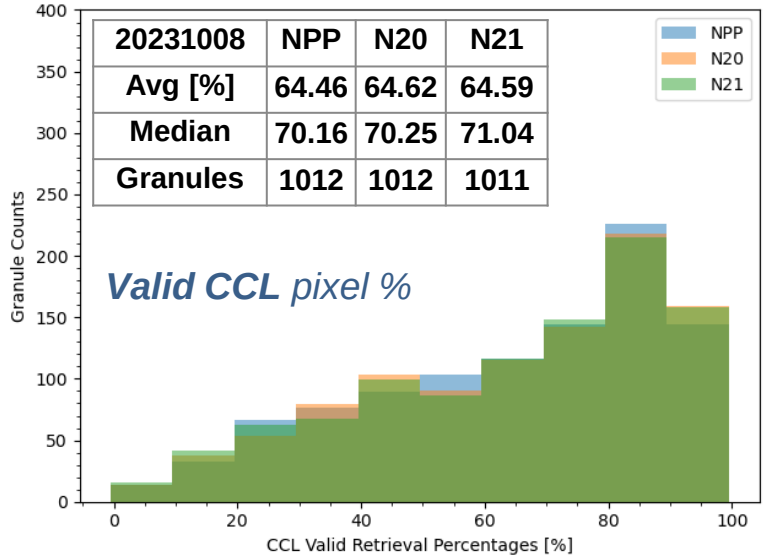

***Cloudy but invalid CBH*** *pixel % per granule due to CTH or CWP errors (primarily no proper CWP from COMP or NWP-clear)*

| 20231008 | NPP | N20 | N21 |
|---|---|---|---|
| Avg [%] | 66.97 | 67.88 | 67.57 |
| Median | 73.01 | 74.10 | 74.59 |



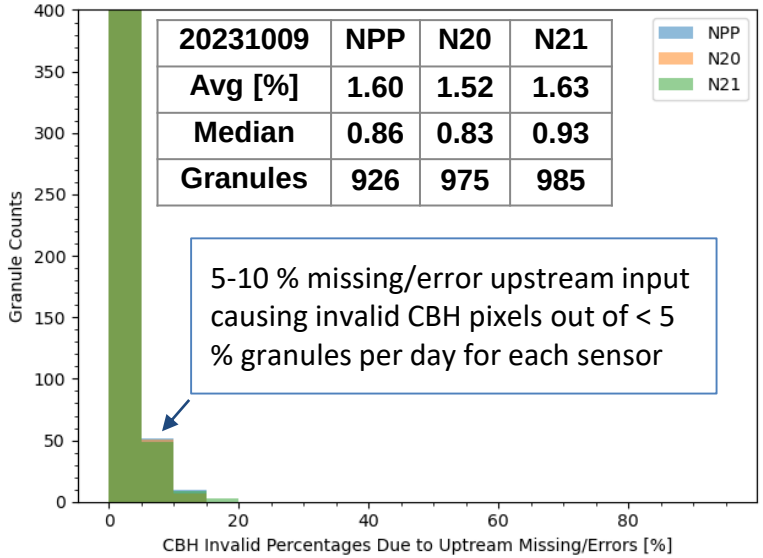

***Valid CBH*** *pixel %*

| 20231008 | NPP | N20 | N21 |
|---|---|---|---|
| Avg [%] | 64.46 | 64.62 | 64.59 |
| Median | 70.16 | 70.25 | 71.04 |
| Granules | 1012 | 1012 | 1011 |



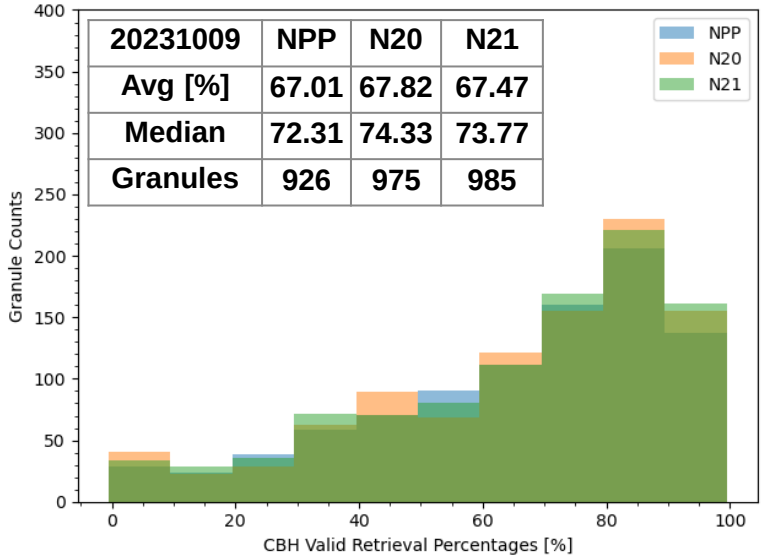

***Valid CCL*** *pixel %*

| 20231009 | NPP | N20 | N21 |
|---|---|---|---|
| Avg [%] | 1.60 | 1.52 | 1.63 |
| Median | 0.86 | 0.83 | 0.93 |
| Granules | 926 | 975 | 985 |

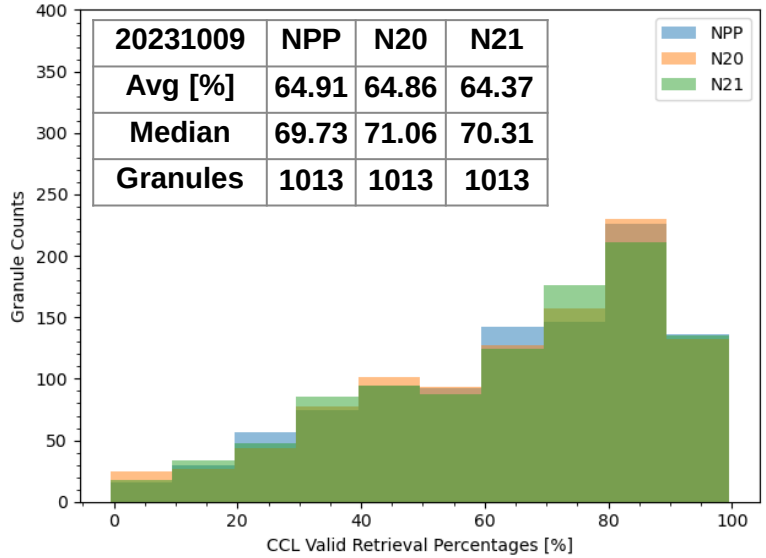



5-10 % missing/error upstream input causing invalid CBH pixels out of < 5 % granules per day for each sensor

| 20231009 | NPP | N20 | N21 |
|---|---|---|---|
| Avg [%] | 67.01 | 67.82 | 67.47 |
| Median | 72.31 | 74.33 | 73.77 |
| Granules | 926 | 975 | 985 |



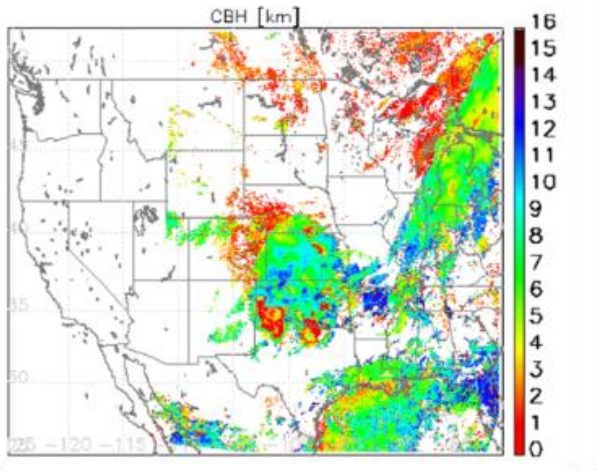

| 20231009 | NPP | N20 | N21 |
|---|---|---|---|
| Avg [%] | 64.91 | 64.86 | 64.37 |
| Median | 69.73 | 71.06 | 70.31 |
| Granules | 1013 | 1013 | 1013 |

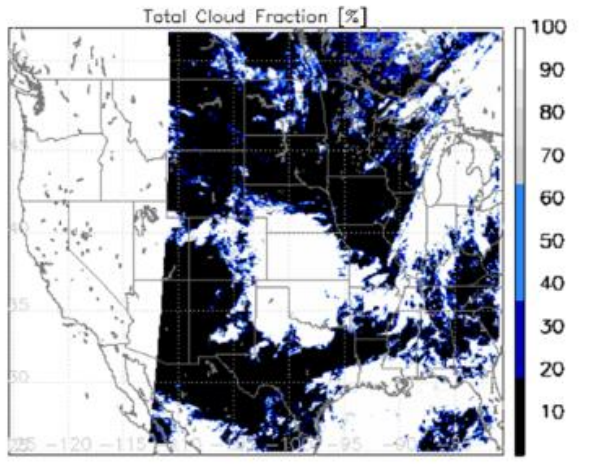


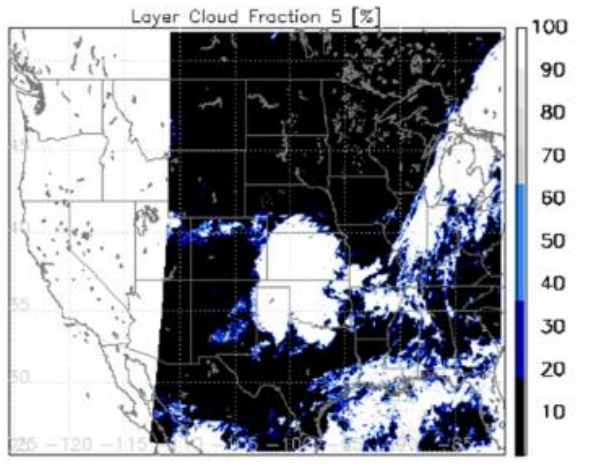

Diagnostic metadata output and quality flags provided for each granule (similar for all three VIIRS)

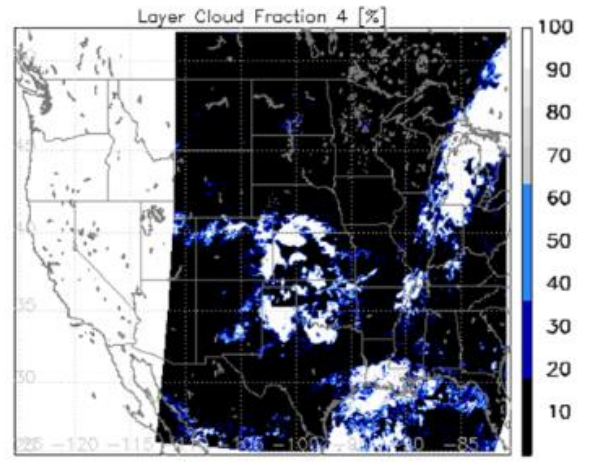
# Nighttime CBH (Full Moon)

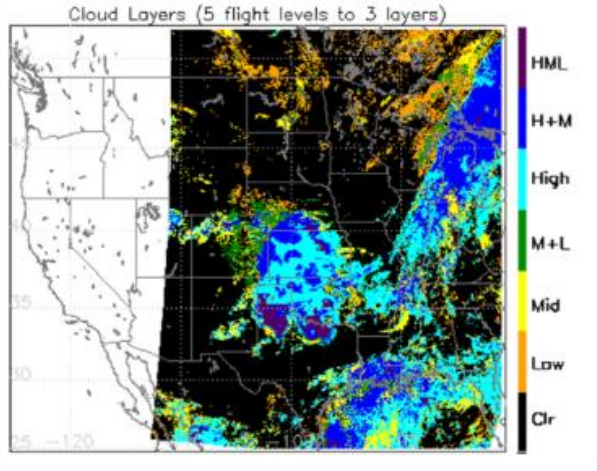
**20230706 (0830 UTC, near full moon/ DNB COMP-CWP input for CBH)**

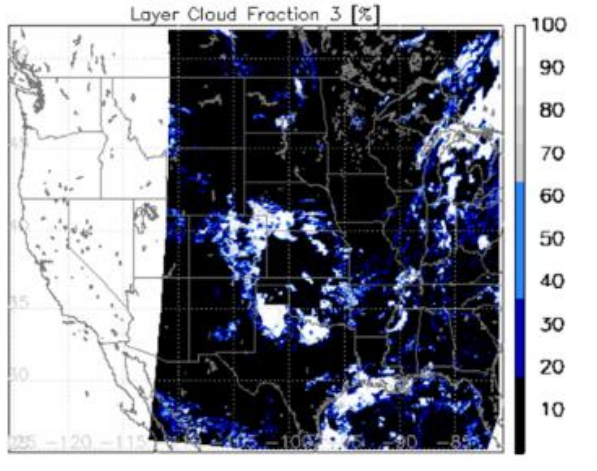


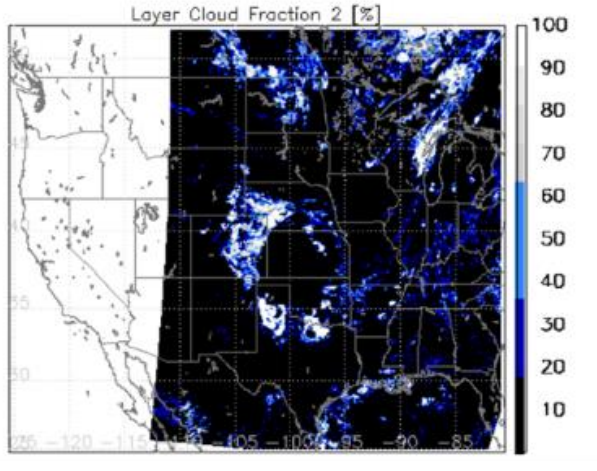



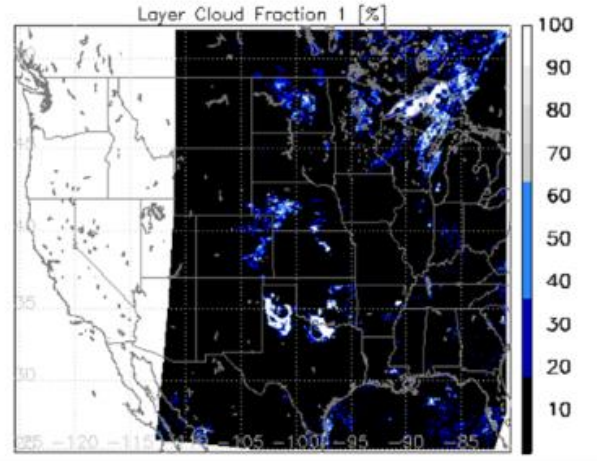



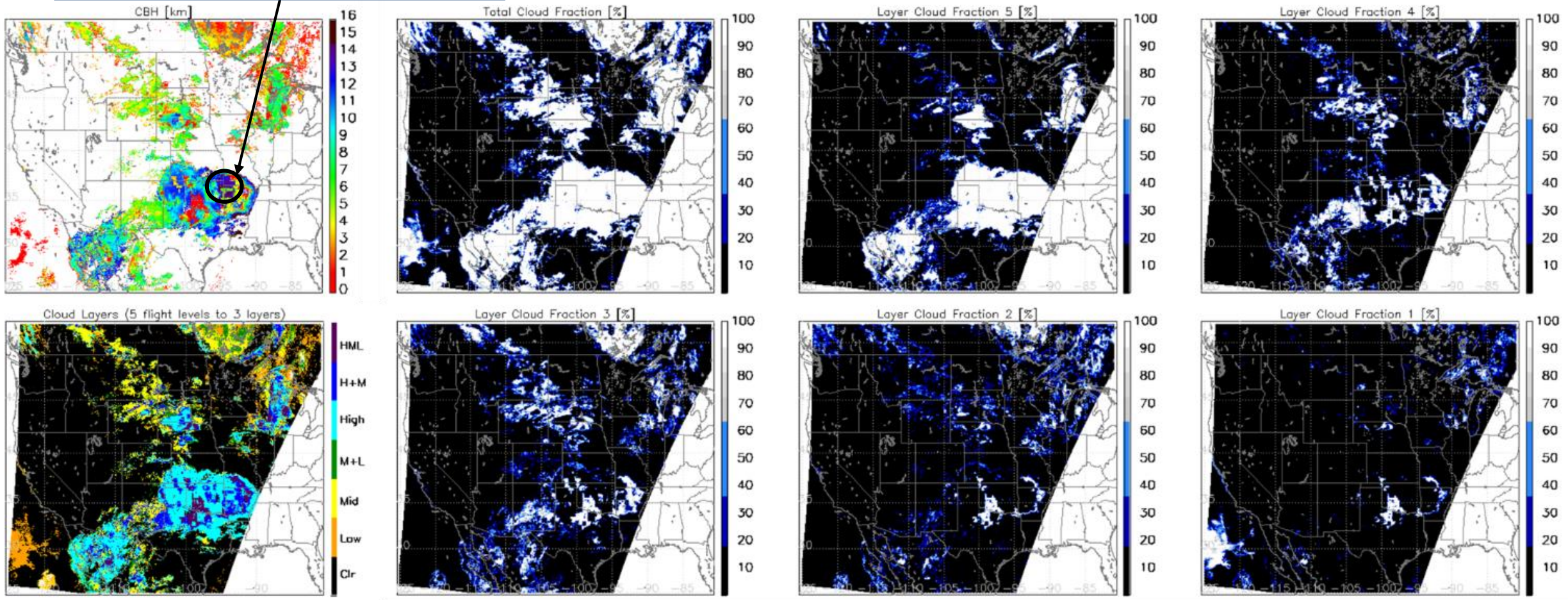



# Nighttime CBH (New Moon)

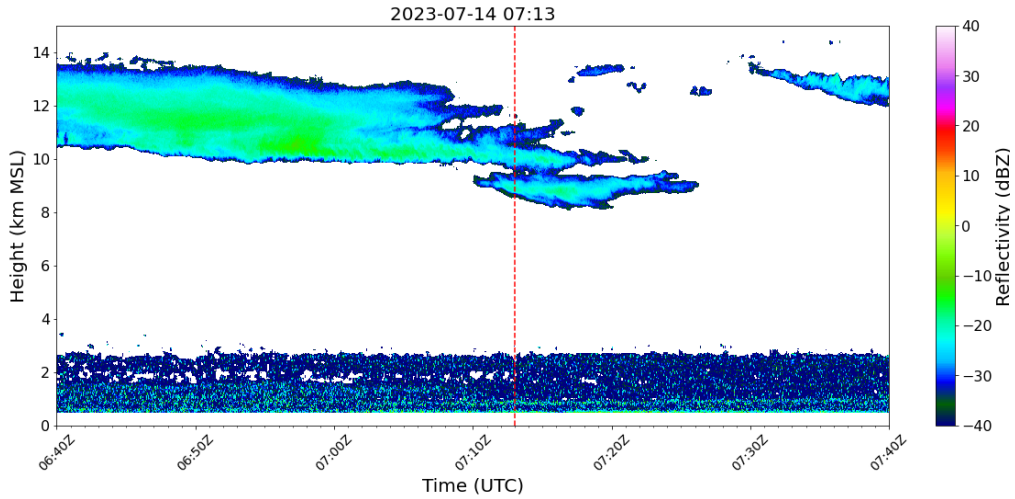
Blocky features due to NWP data input

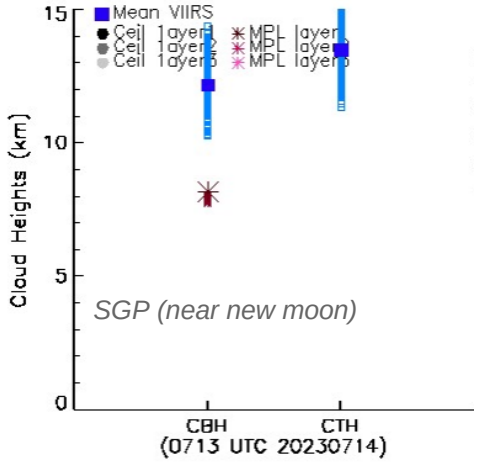
**20230714 (0713 UTC, near new moon/ NWP-CWP input for CBH)**



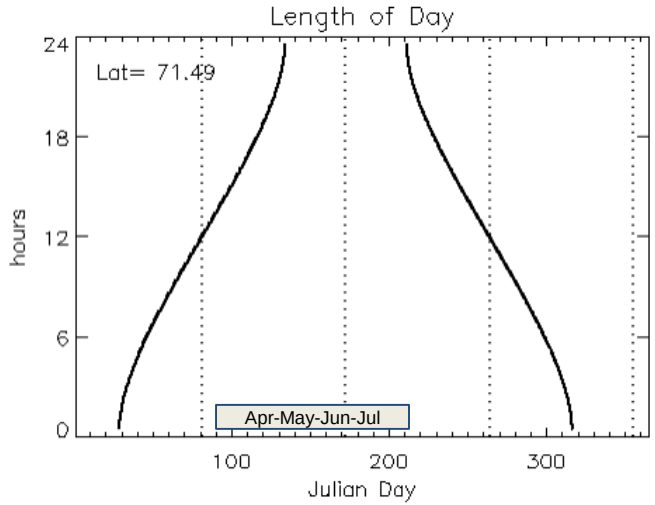
# CBH VIIRS-ARM data comparisons

- ARM site surface observations
- Target eval period: Apr - July 2023
- SGP/Oklahoma and NSA/Alaska sites
- Radar, micro-pulse lidar, ceilometer (KAZR, MPL, Ceil with MET-precip filter)
- “Within spec” comparisons:  validate CBHs when CTHs from VIIRS are within 2 km of CTHs from ground measurements (to avoid CTH errors directly inherited into CBH/CCL)




(All VIIRS dots in +- 3 min/10 km)

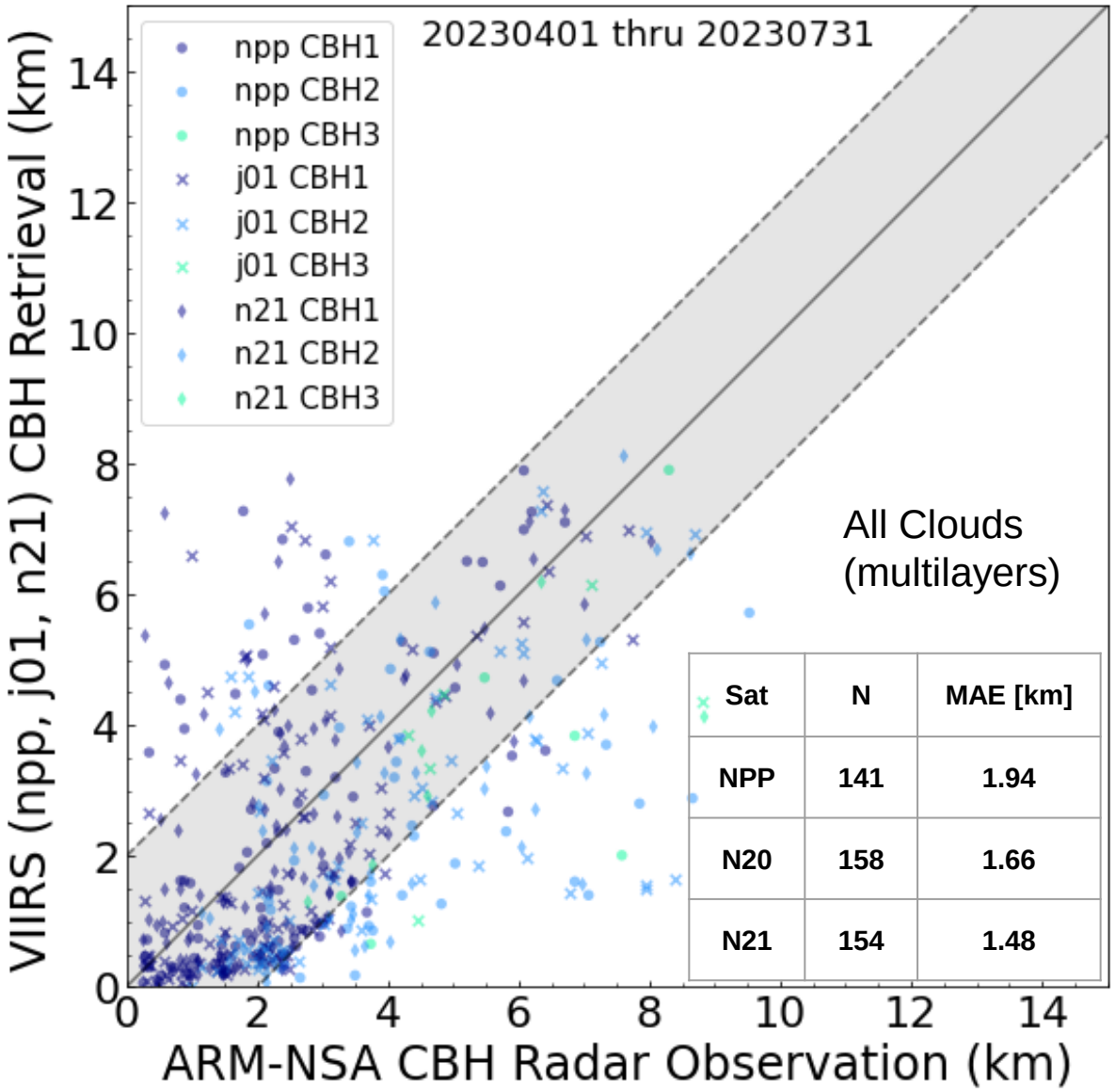



*At NSA site, part of this period is in 24 hr daylight*

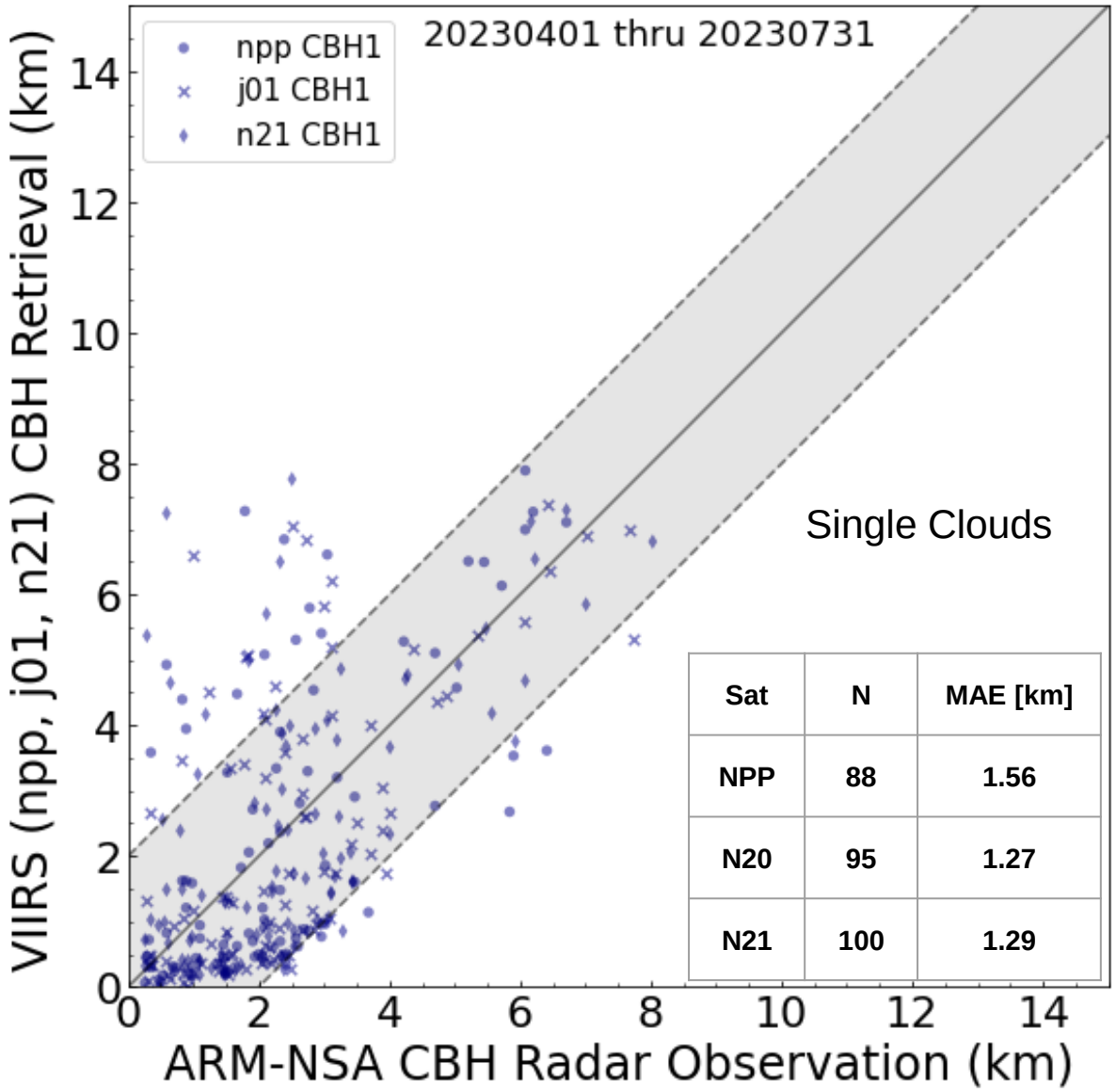
*Matchups and collocation analyses are challenging, given limited data resources*

# CBH (ARM-NSA site)

*removed first height gate from radar



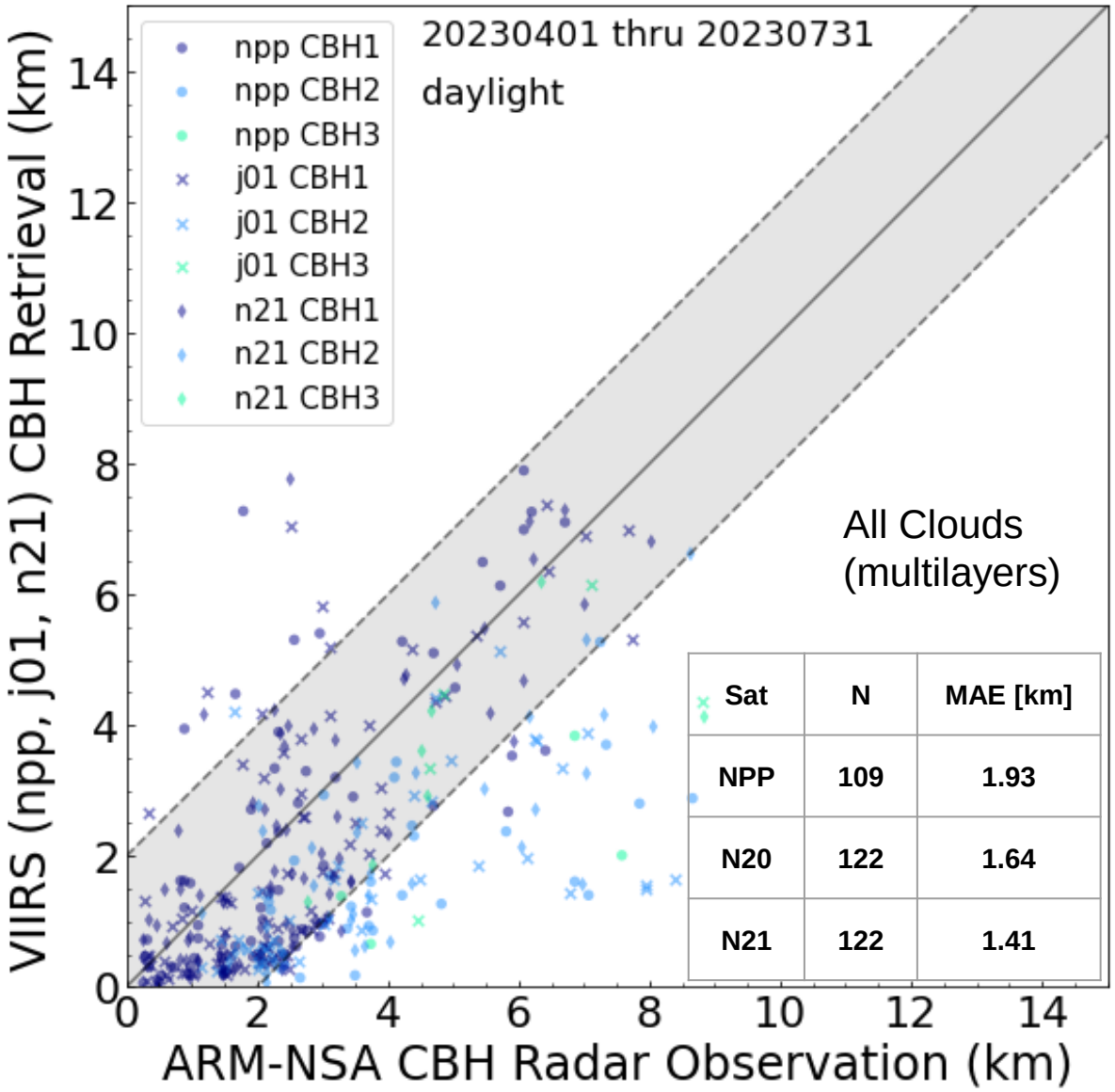

| Sat | N | MAE [km] |
|---|---|---|
| NPP | 141 | 1.94 |
| N20 | 158 | 1.66 |
| N21 | 154 | 1.48 |



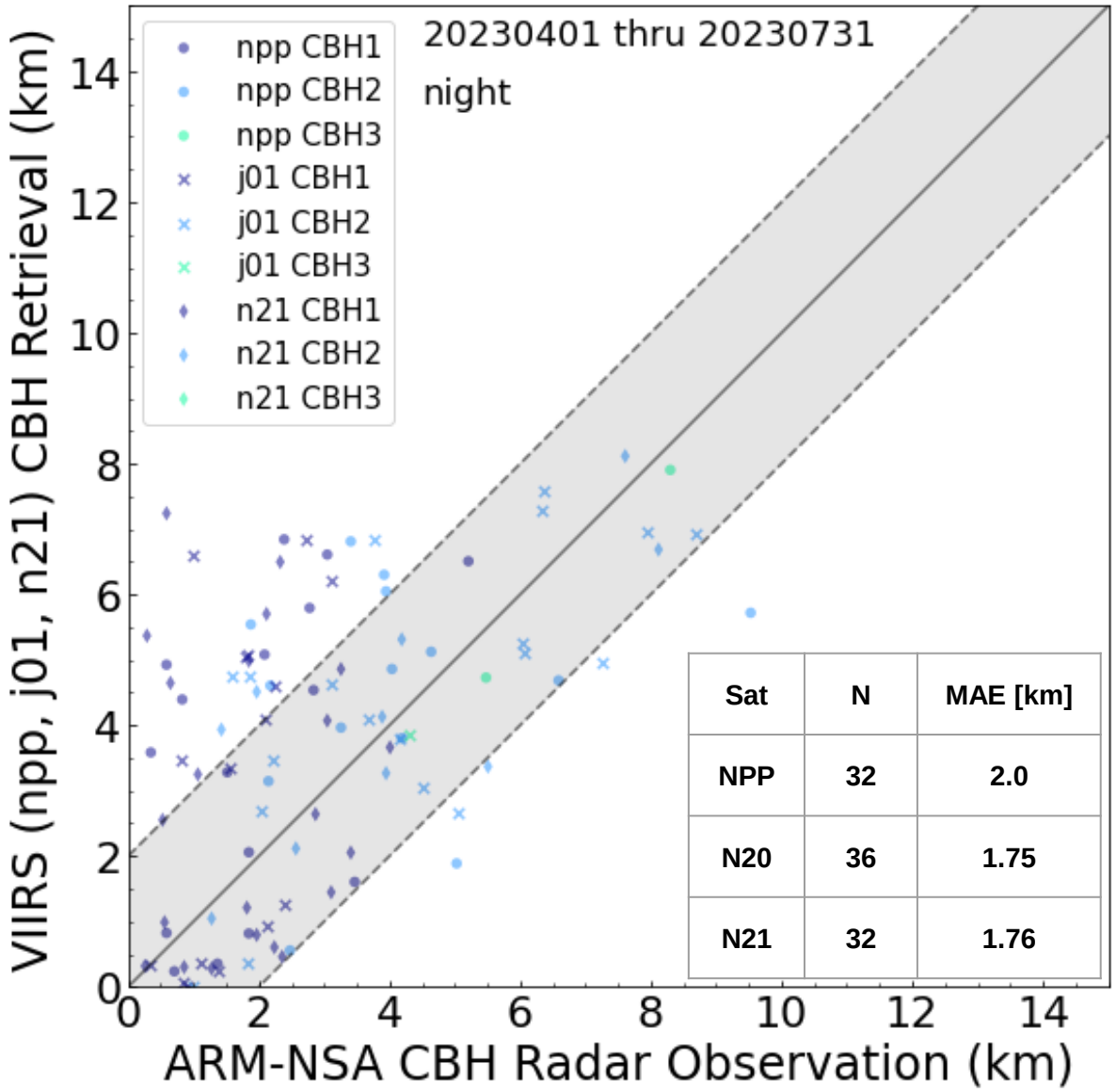

| Sat | N | MAE [km] |
|---|---|---|
| NPP | 88 | 1.56 |
| N20 | 95 | 1.27 |
| N21 | 100 | 1.29 |

# CBH (ARM-NSA site)

*removed first height gate from radar



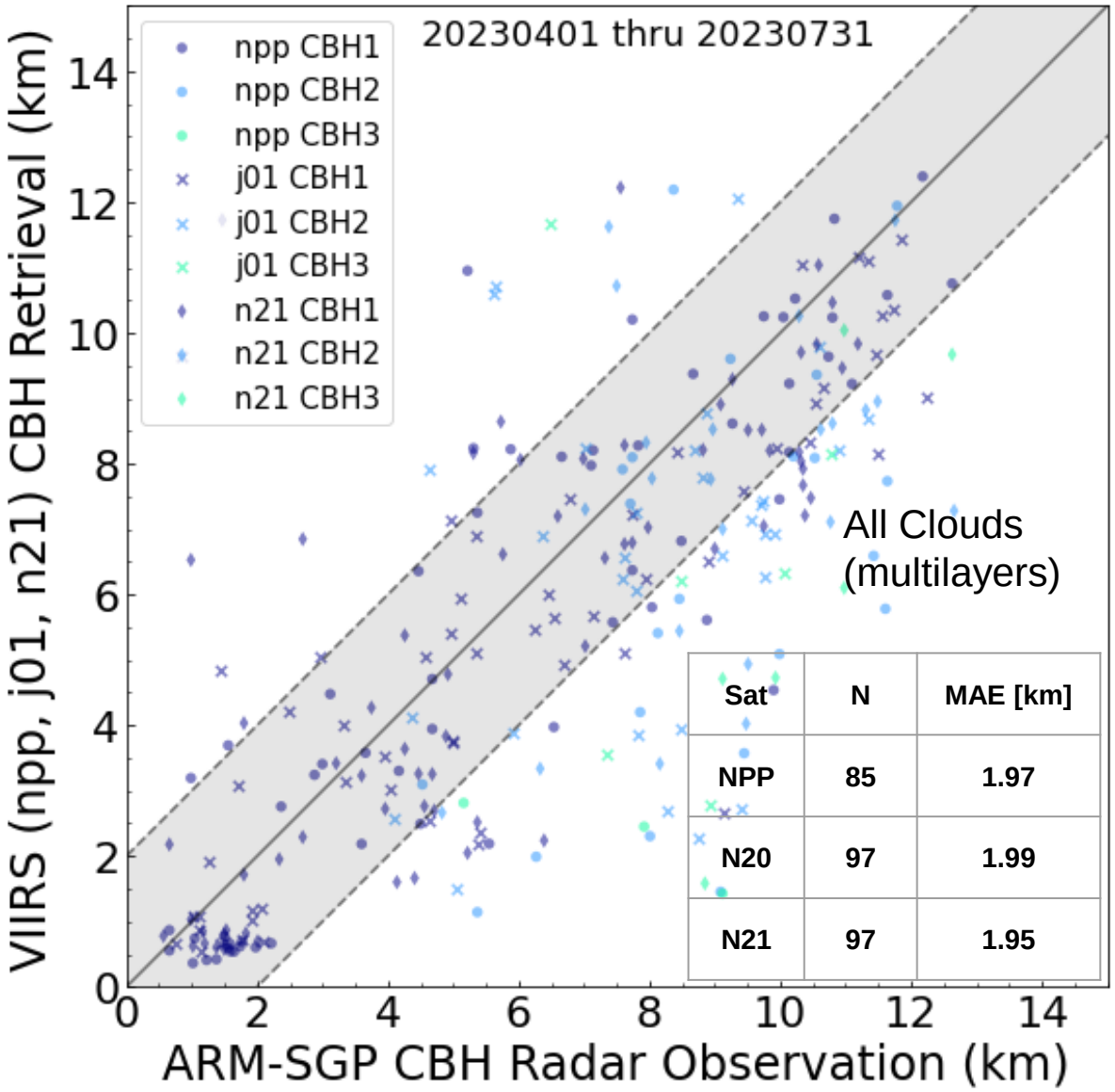

| Sat | N | MAE [km] |
|---|---|---|
| NPP | 109 | 1.93 |
| N20 | 122 | 1.64 |
| N21 | 122 | 1.41 |



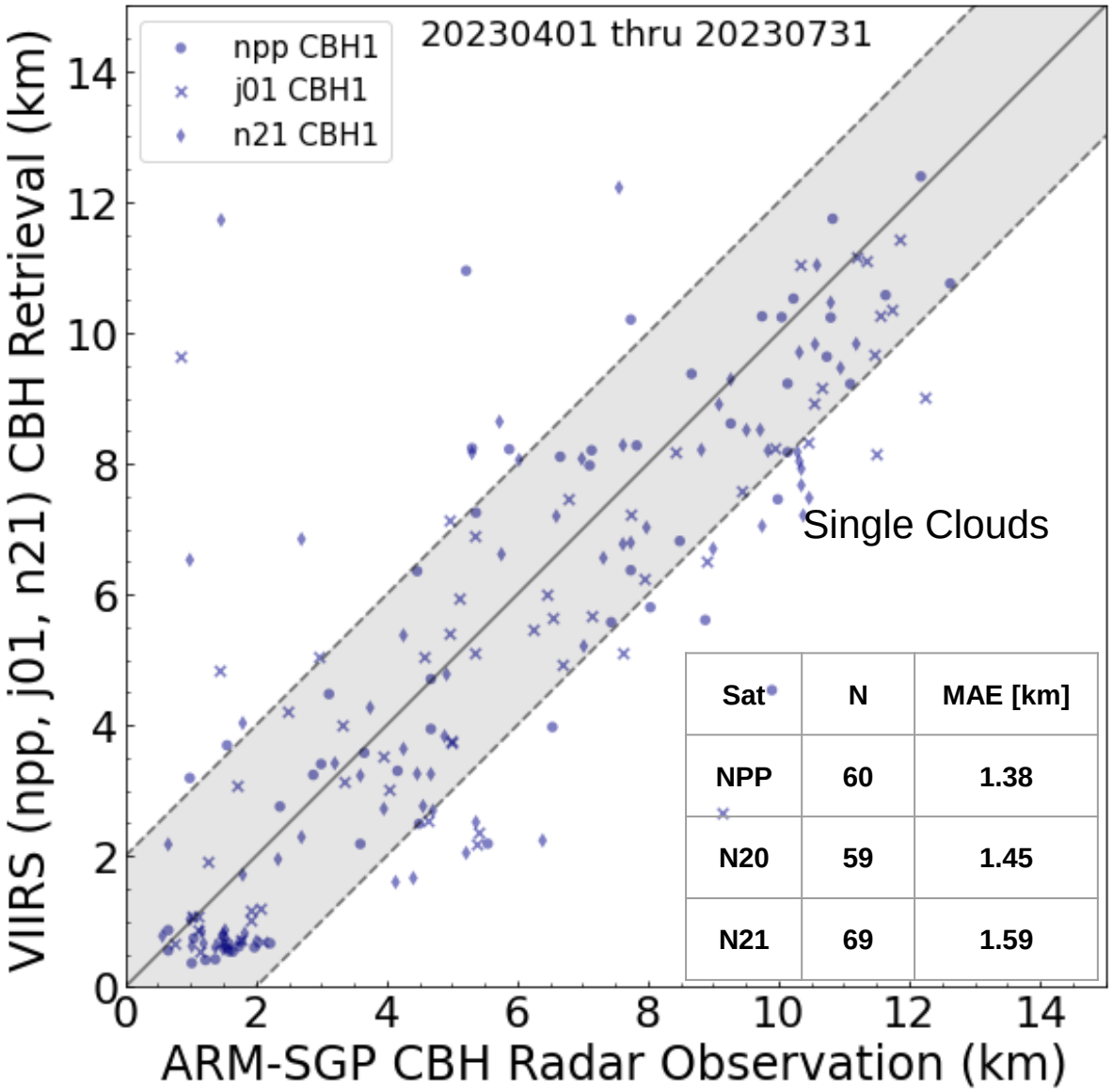

| Sat | N | MAE [km] |
|---|---|---|
| NPP | 32 | 2.0 |
| N20 | 36 | 1.75 |
| N21 | 32 | 1.76 |

# CBH (ARM-SGP site)

*removed first height gate from radar



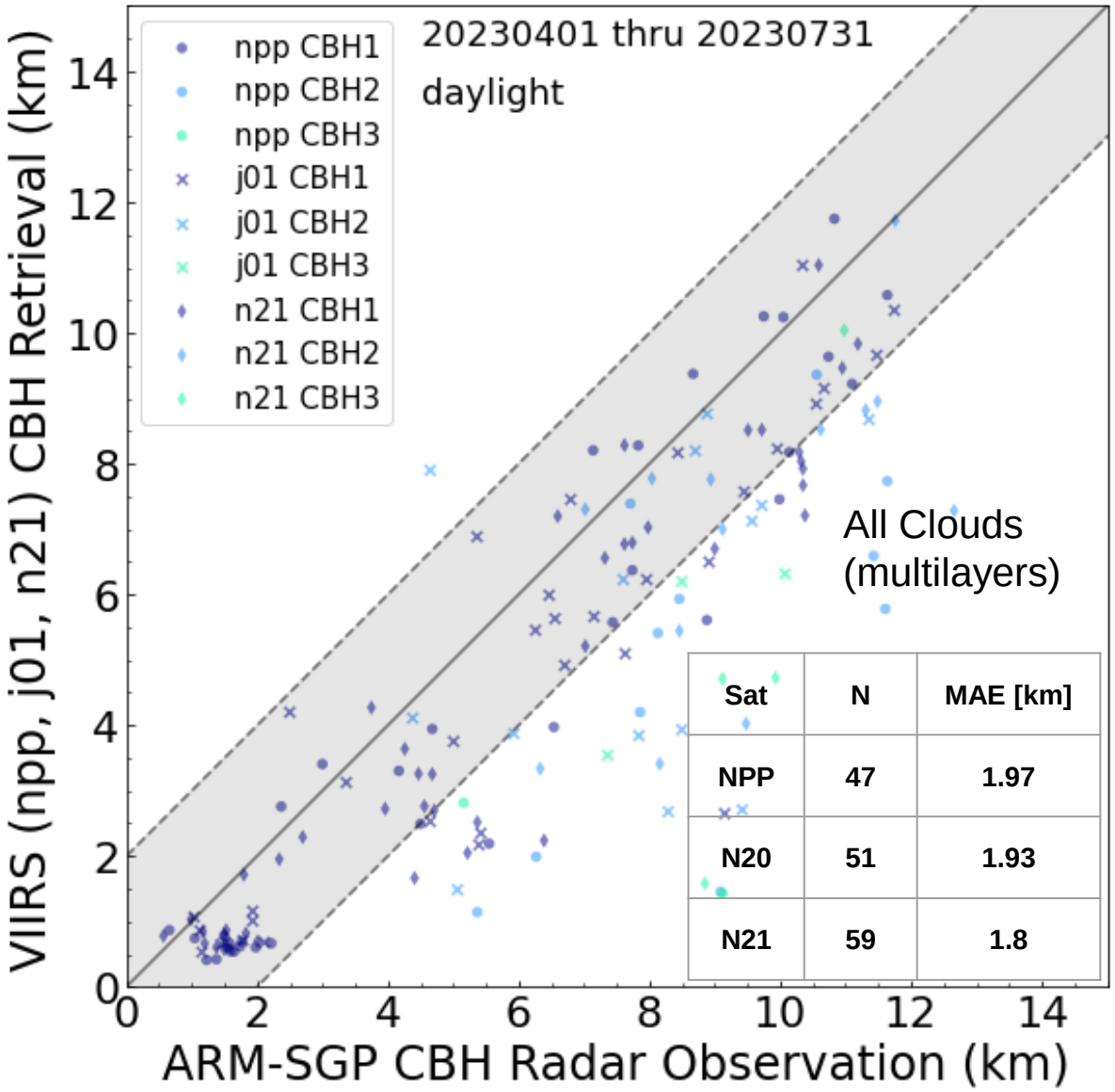

| Sat | N | MAE [km] |
|---|---|---|
| NPP | 85 | 1.97 |
| N20 | 97 | 1.99 |
| N21 | 97 | 1.95 |



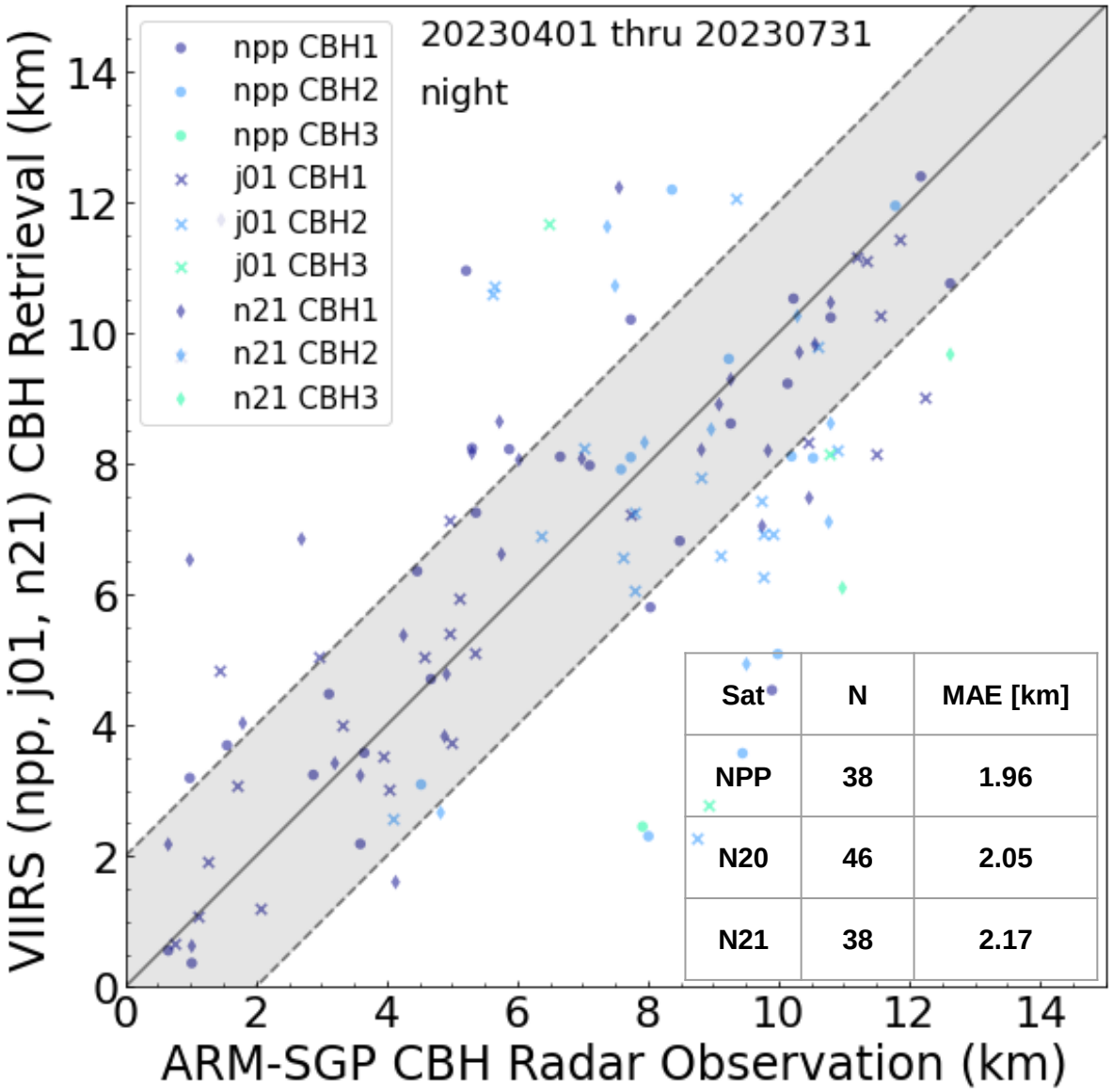

| Sat | N | MAE [km] |
|---|---|---|
| NPP | 60 | 1.38 |
| N20 | 59 | 1.45 |
| N21 | 69 | 1.59 |

# CBH (ARM-SGP site)

*removed first height gate from radar

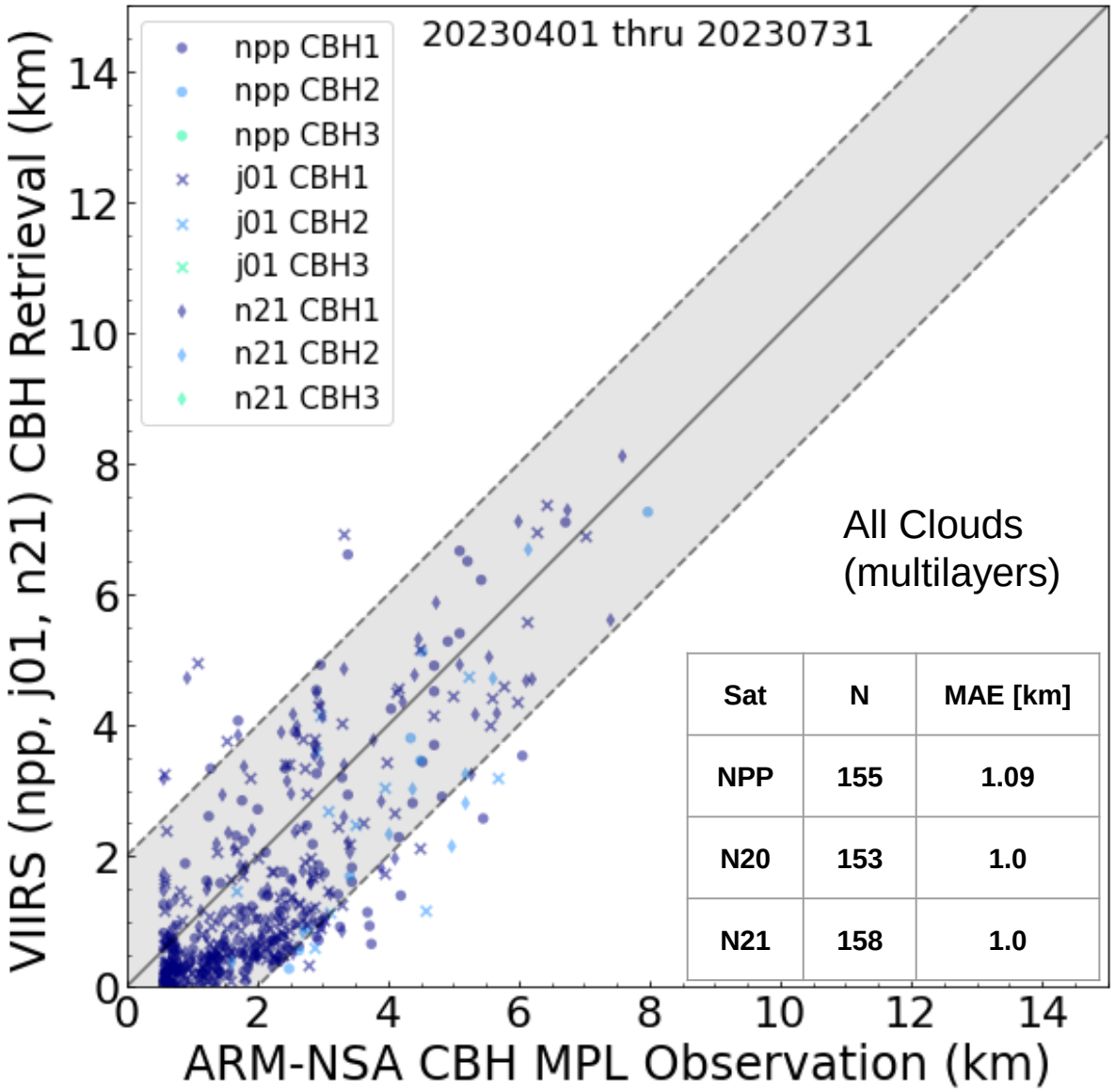



| Sat | N | MAE [km] |
|---|---|---|
| NPP | 47 | 1.97 |
| N20 | 51 | 1.93 |
| N21 | 59 | 1.8 |



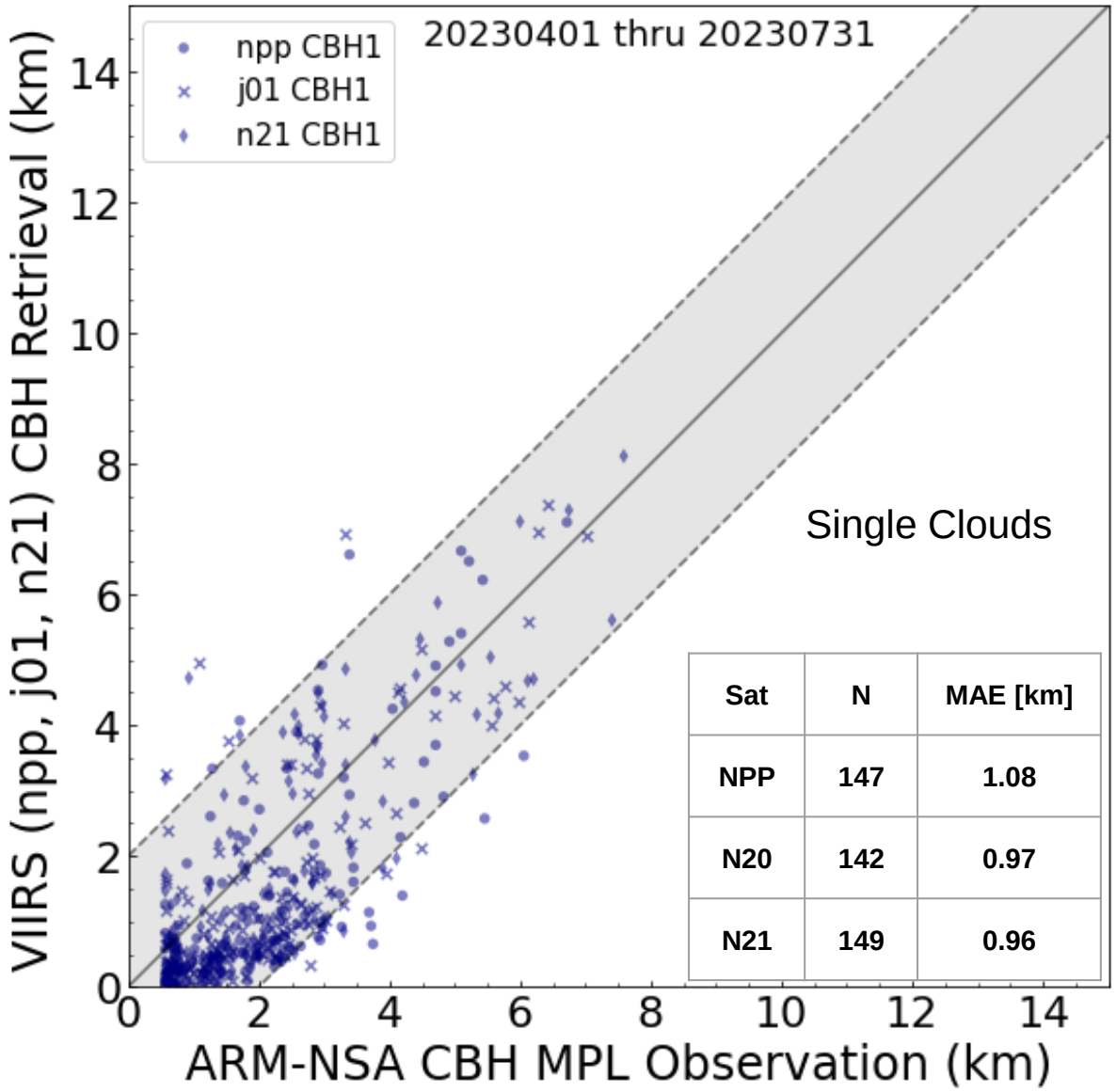

| Sat | N | MAE [km] |
|---|---|---|
| NPP | 38 | 1.96 |
| N20 | 46 | 2.05 |
| N21 | 38 | 2.17 |

# CBH (ARM-NSA site) - Lidar




All Clouds (multilayers)

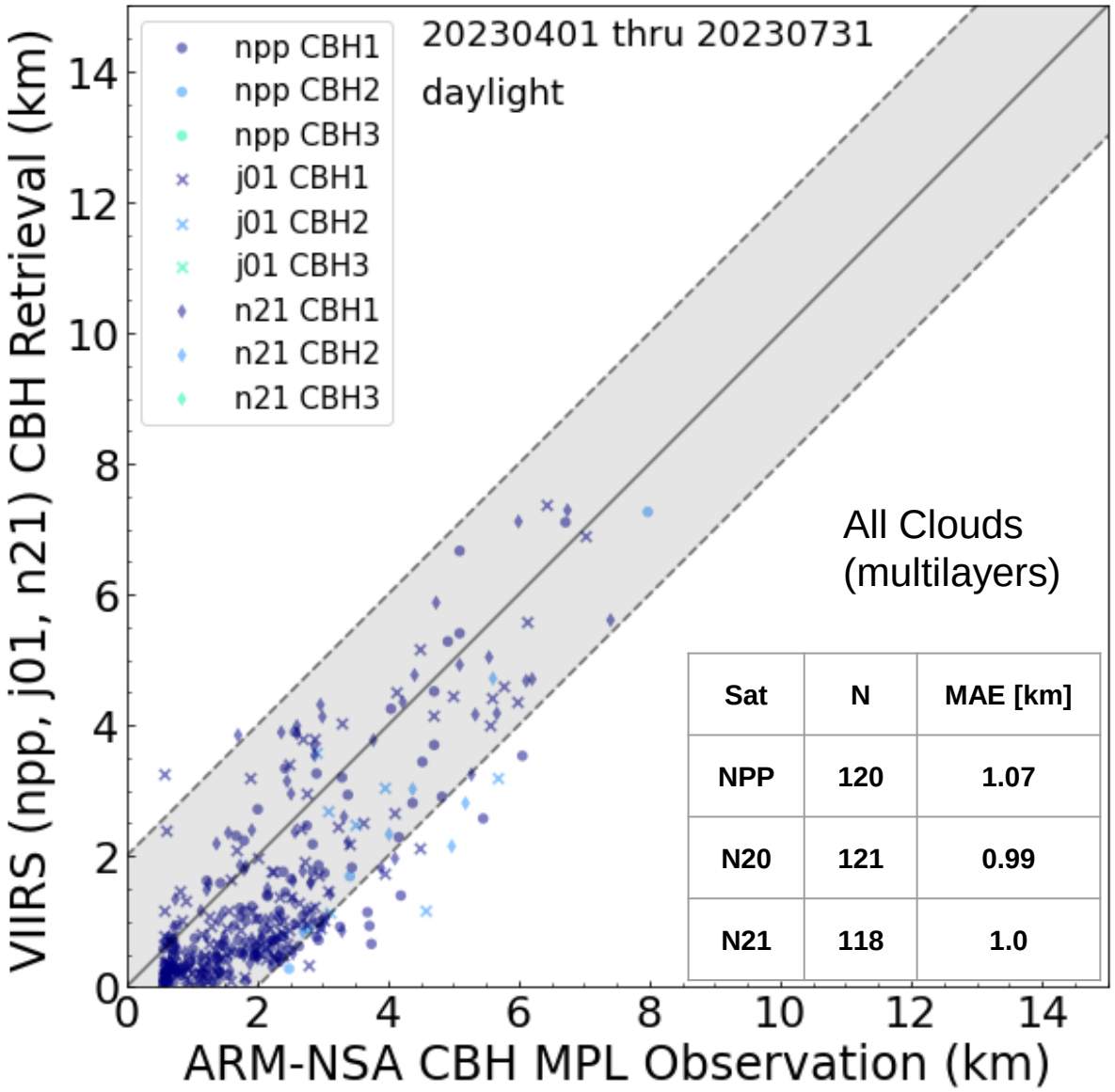
| Sat | N | MAE [km] |
|---|---|---|
| NPP | 155 | 1.09 |
| N20 | 153 | 1.0 |
| N21 | 158 | 1.0 |



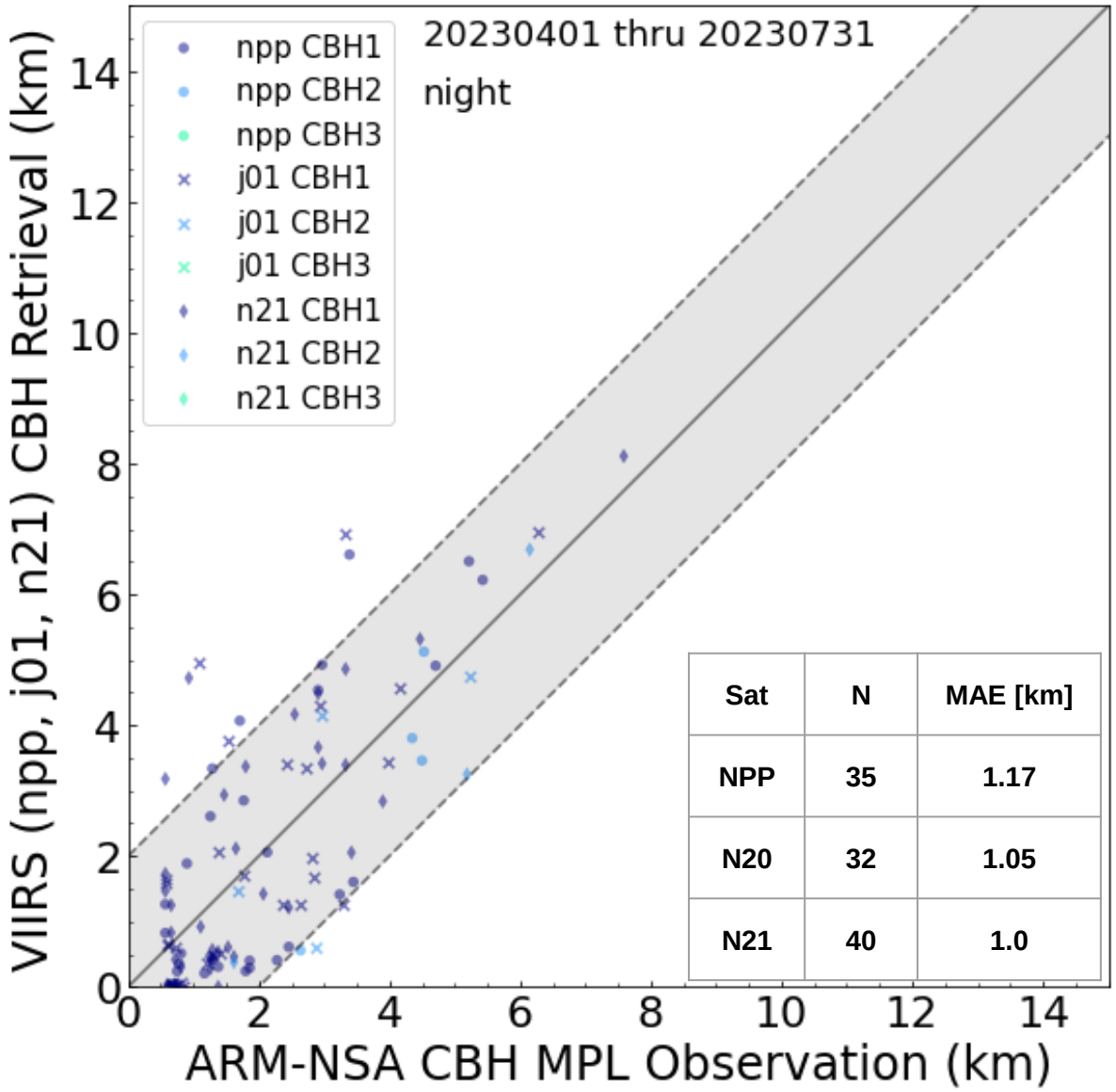

Single Clouds

| Sat | N | MAE [km] |
|---|---|---|
| NPP | 147 | 1.08 |
| N20 | 142 | 0.97 |
| N21 | 149 | 0.96 |

# CBH (ARM-NSA site) - Lidar

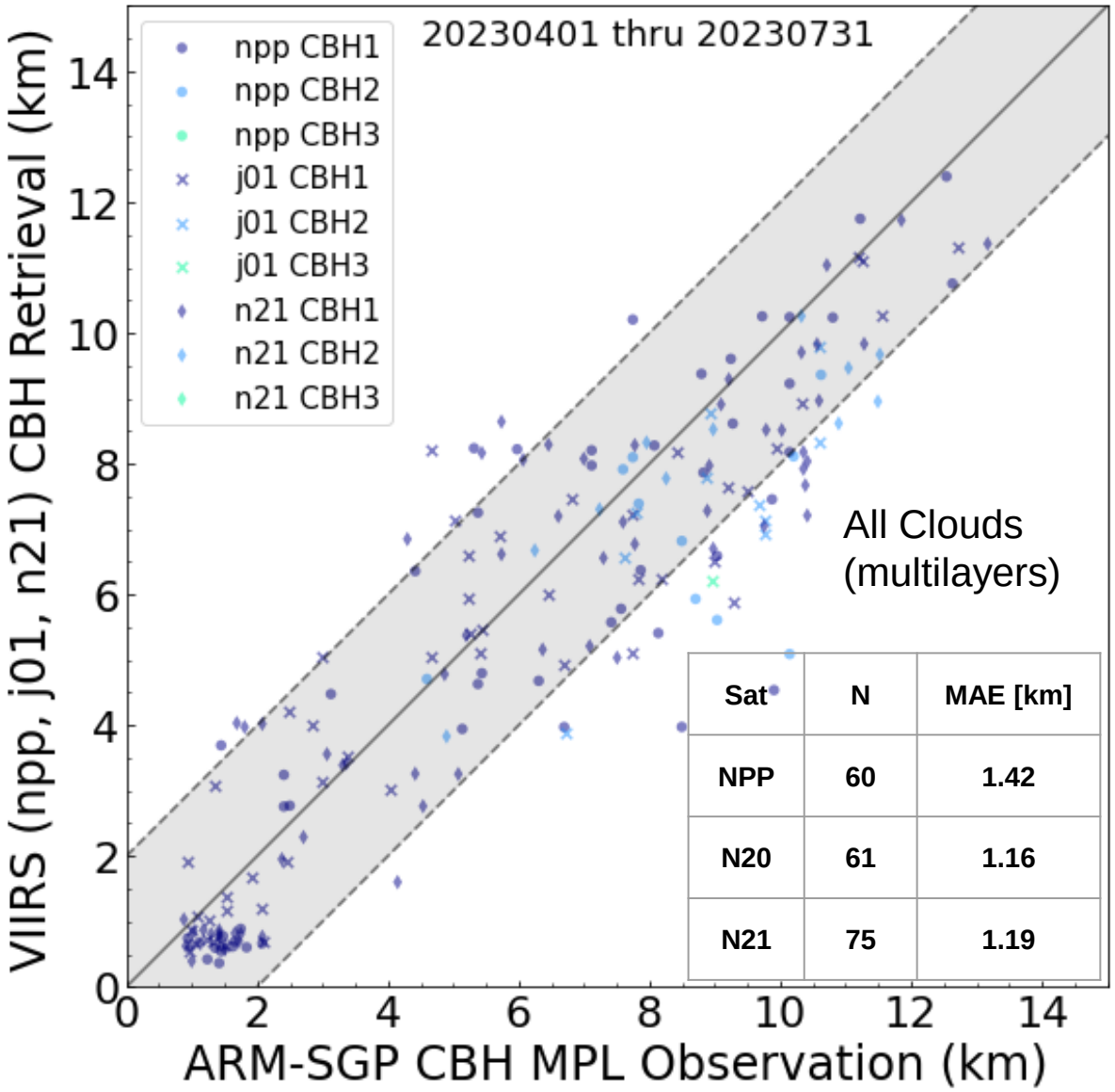



| Sat | N | MAE [km] |
|---|---|---|
| NPP | 120 | 1.07 |
| N20 | 121 | 0.99 |
| N21 | 118 | 1.0 |

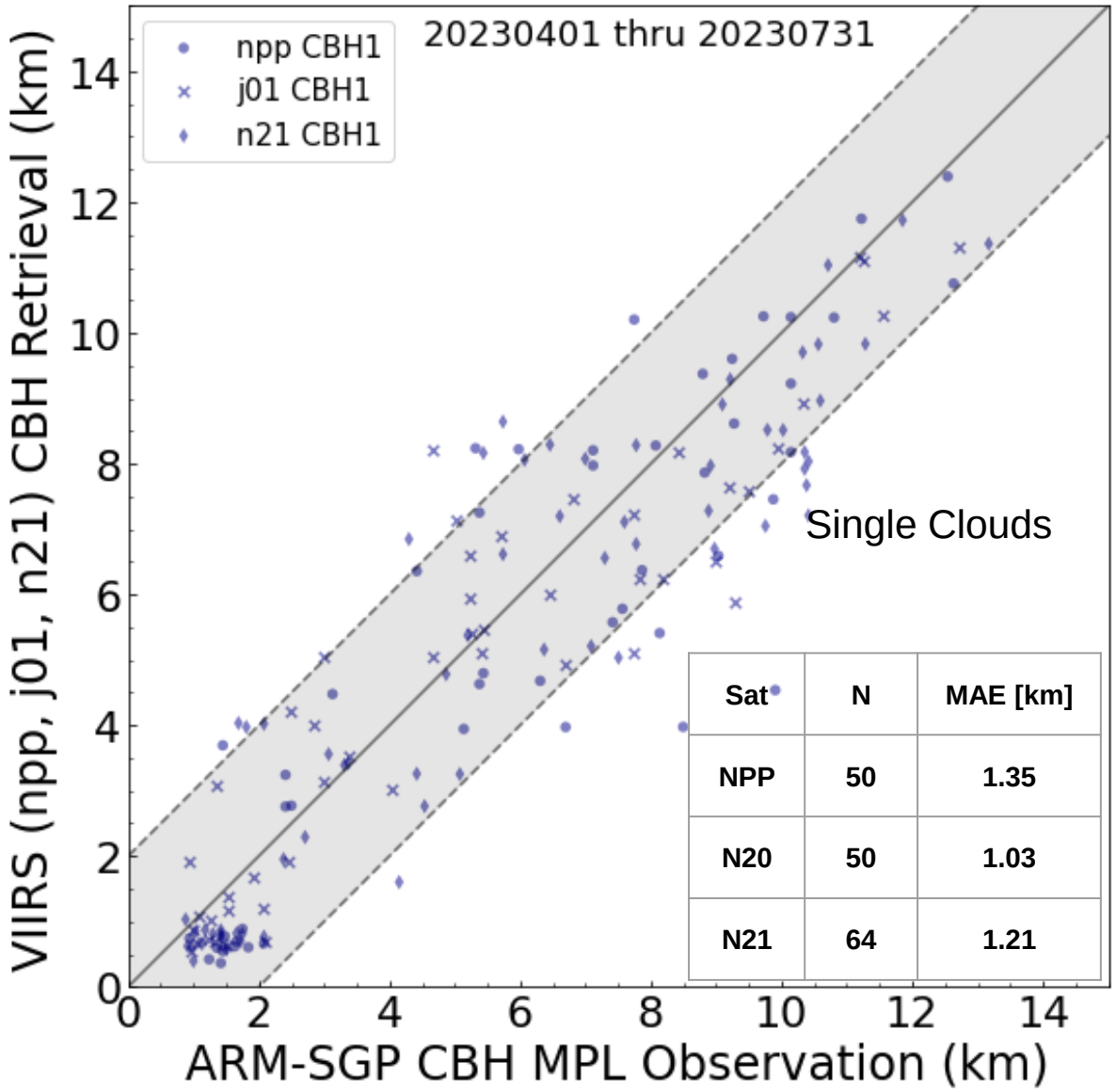



| Sat | N | MAE [km] |
|---|---|---|
| NPP | 35 | 1.17 |
| N20 | 32 | 1.05 |
| N21 | 40 | 1.0 |

# CBH (ARM-SGP site) - Lidar

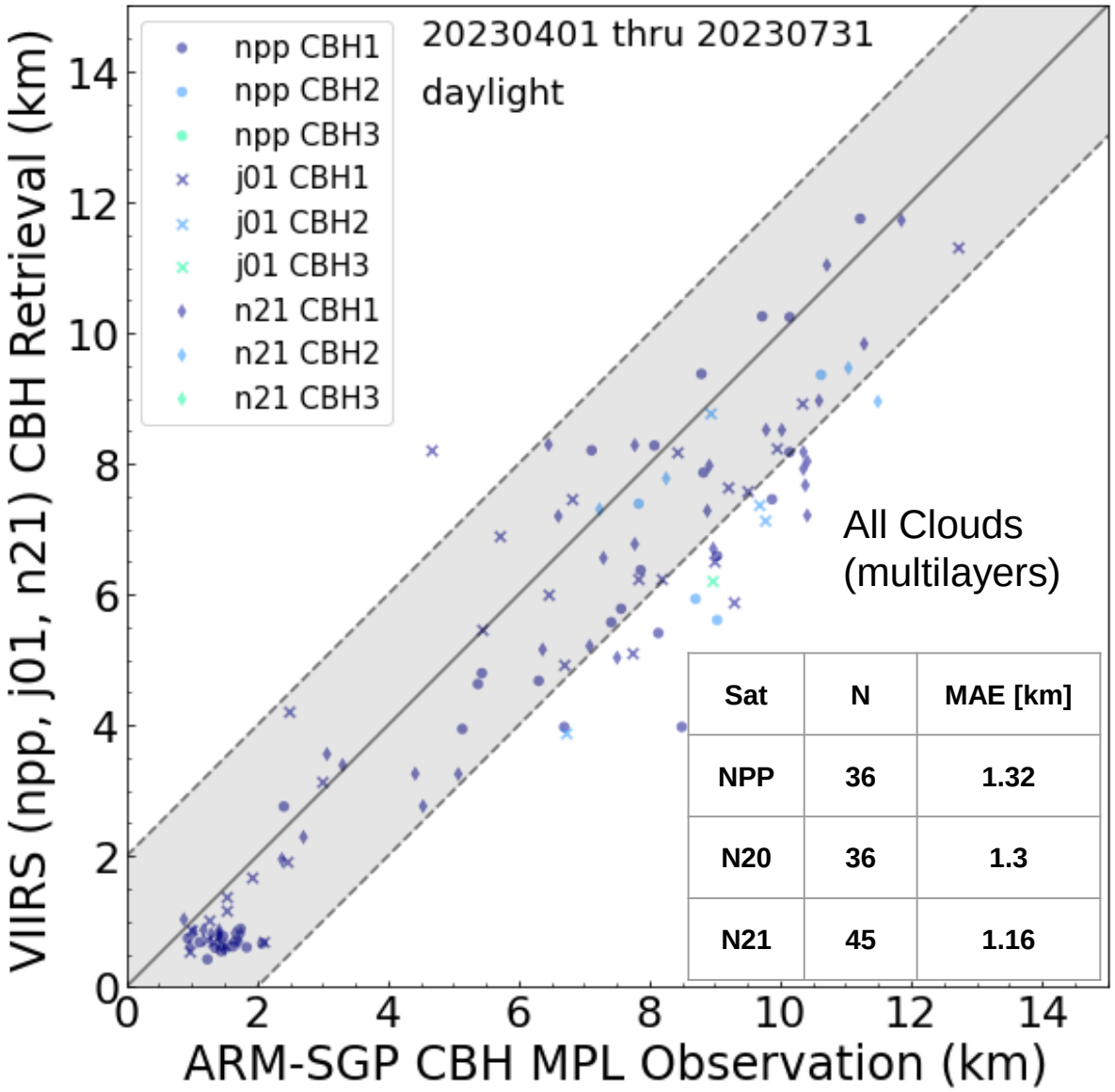



| Sat | N | MAE [km] |
|---|---|---|
| NPP | 60 | 1.42 |
| N20 | 61 | 1.16 |
| N21 | 75 | 1.19 |

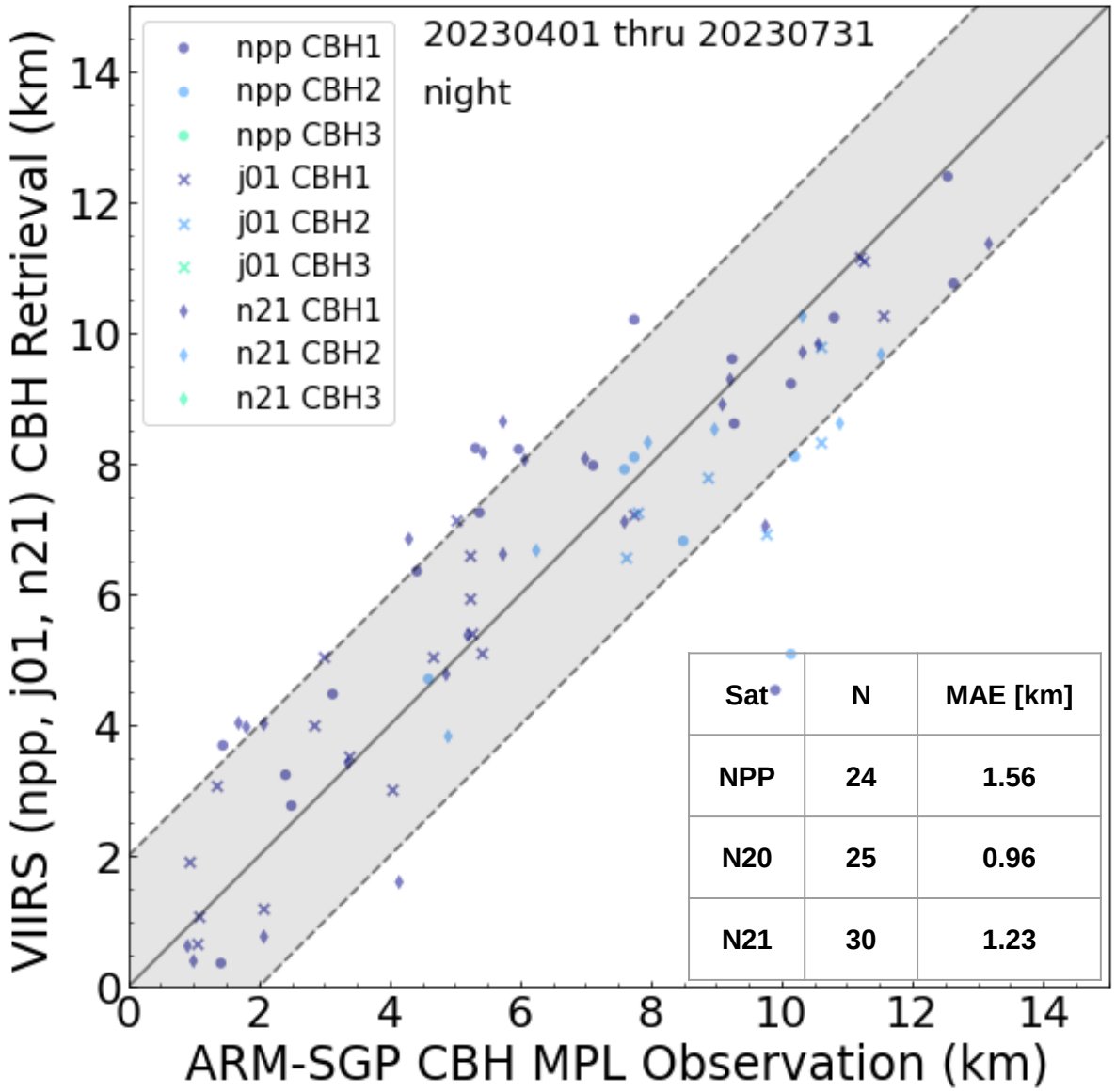



| Sat | N | MAE [km] |
|---|---|---|
| NPP | 50 | 1.35 |
| N20 | 50 | 1.03 |
| N21 | 64 | 1.21 |

# CBH (ARM-SGP site) - Lidar

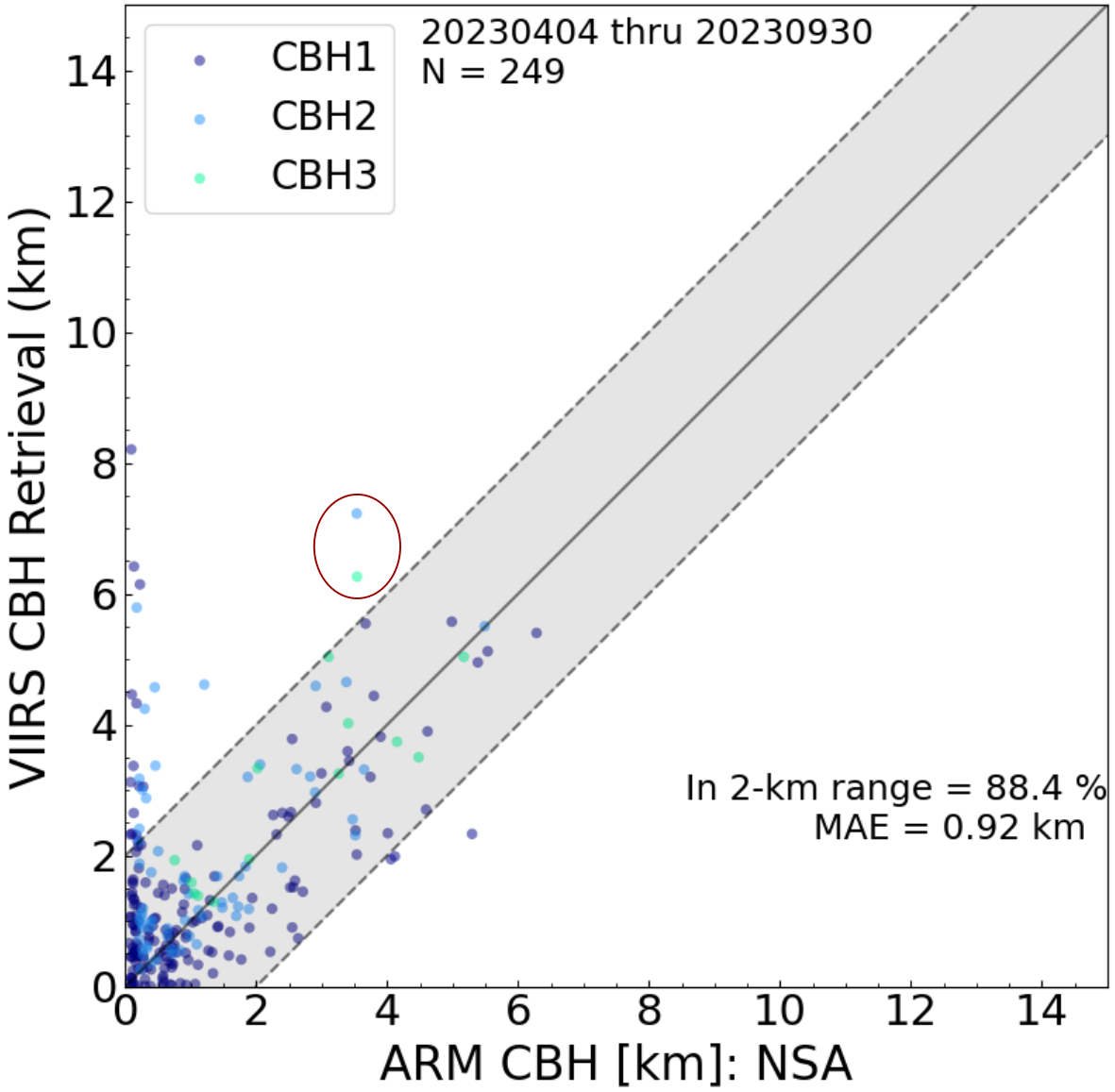


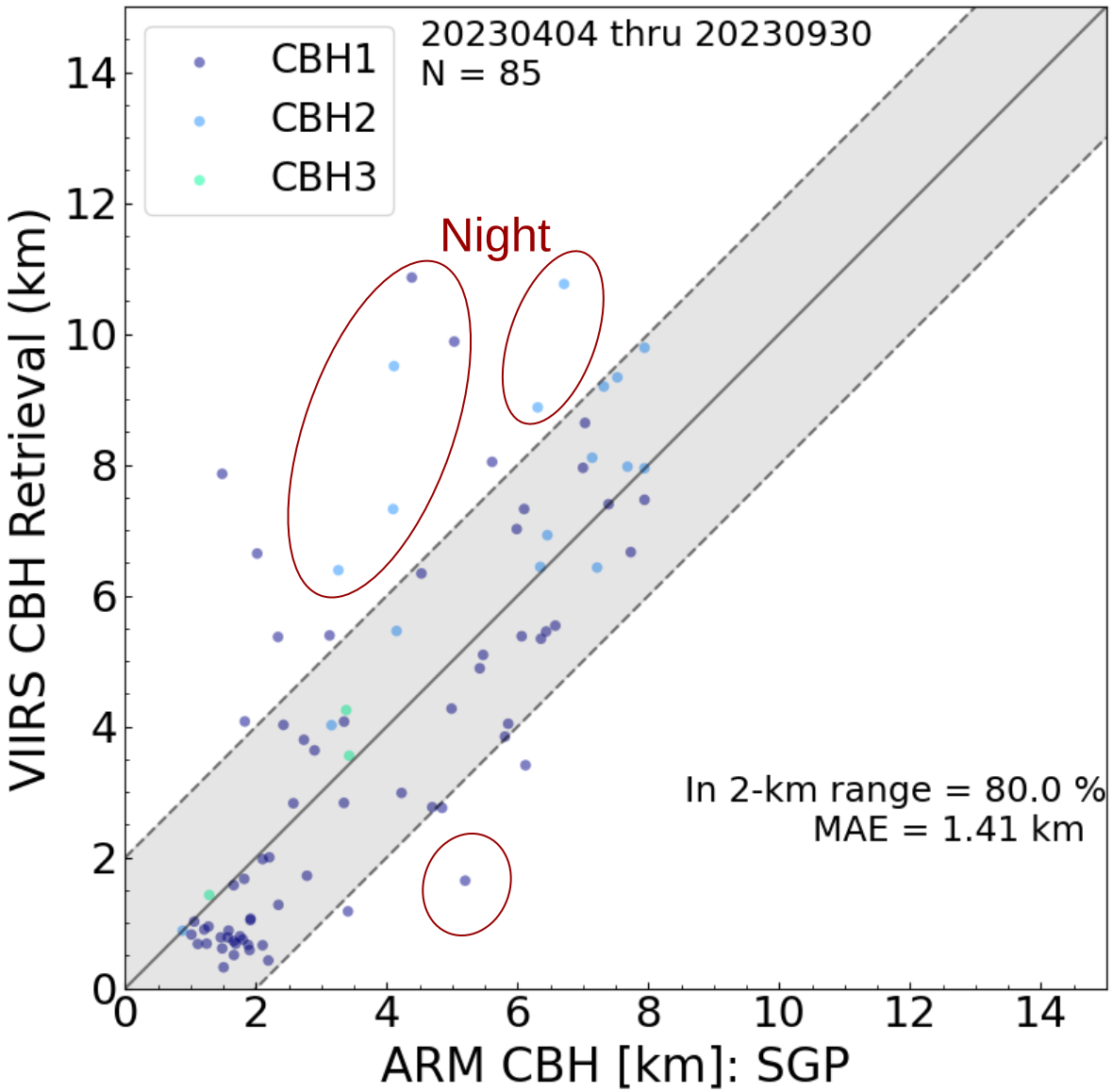

| Sat | N | MAE [km] |
|---|---|---|
| NPP | 36 | 1.32 |
| N20 | 36 | 1.3 |
| N21 | 45 | 1.16 |




| Sat | N | MAE [km] |
|---|---|---|
| NPP | 24 | 1.56 |
| N20 | 25 | 0.96 |
| N21 | 30 | 1.23 |

# N21 VIIRS CBH with ARM Ceilometer



# Cloud Cover Layers (CCL) - v2r0

| dec | binary | layers | meaning | poss (*)? |
|---|---|---|---|---|
| 0 | 00000000 | | clear | X |
| 1 | 00000001 | 1 | L | X |
| 2 | 00000010 | 2 | L | X |
| 3 | 00000011 | 12 | L | X |
| 4 | 00000100 | 3 | M | X |
| 5 | 00000101 | 1 3 | LM | |
| 6 | 00000110 | 23 | LM | X |
| 7 | 00000111 | 123 | LM | X |
| 8 | 00001000 | 4 | M | X |
| 9 | 00001001 | 1 4 | LM | |
| 10 | 00001010 | 2 4 | LM | |
| 11 | 00001011 | 12 4 | LM | |
| 12 | 00001100 | 34 | M | X |
| 13 | 00001101 | 1 34 | LM | |
| 14 | 00001110 | 234 | LM | X |
| 15 | 00001111 | 1234 | LM | X |
| 16 | 00010000 | 5 | H | X |
| 17 | 00010001 | 1 5 | L H | |
| 18 | 00010010 | 2 5 | L H | |
| 19 | 00010011 | 12 5 | L H | |
| 20 | 00010100 | 3 5 | MH | |
| 21 | 00010101 | 1 3 5 | LMH | |
| 22 | 00010110 | 23 5 | LMH | |
| 23 | 00010111 | 123 5 | LMH | |
| 24 | 00011000 | 45 | MH | X |
| 25 | 00011001 | 1 45 | LMH | |
| 26 | 00011010 | 2 45 | LMH | |
| 27 | 00011011 | 12 45 | LMH | |
| 28 | 00011100 | 345 | MH | X |
| 29 | 00011101 | 1 345 | LMH | |
| 30 | 00011110 | 2345 | LMH | X |
| 31 | 00011111 | 12345 | LMH | X |

(*) 'poss' column indicates that the combination is possible for the statistical (non-machine learning) algorithm. Statistical algorithm cannot produce broken cloud layers.

## Cloud Layers

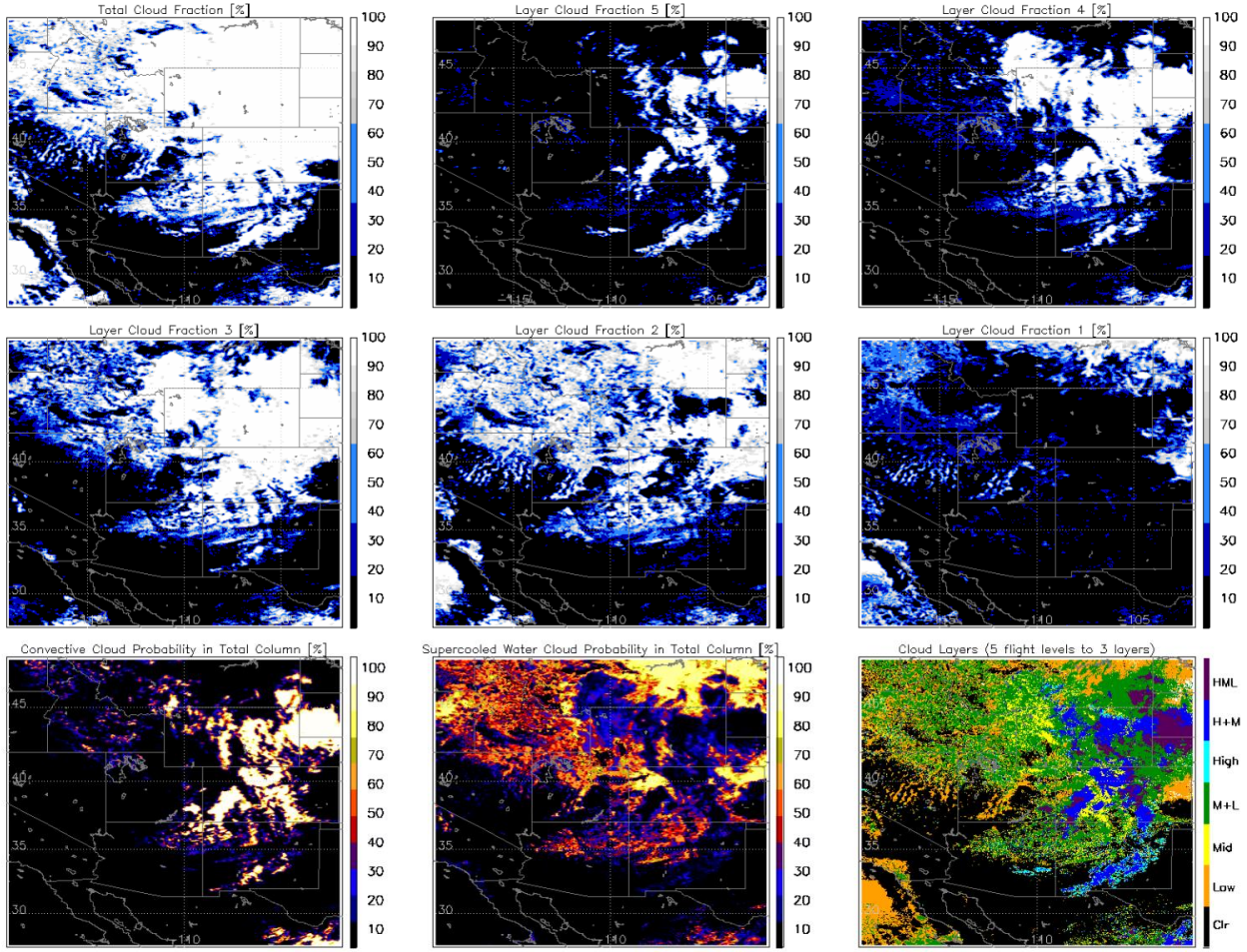

**CCL (Version 2.0)**

- Cloud Layers - Note that five flight-level based cloud layers will be displayed/assessed for (H+M+L)
- Layered cloud fractions (total+ each layer)
- Checked the output variable formats and structures
  - Both no format issues
- CALIPSO and ARM radar data for evaluation

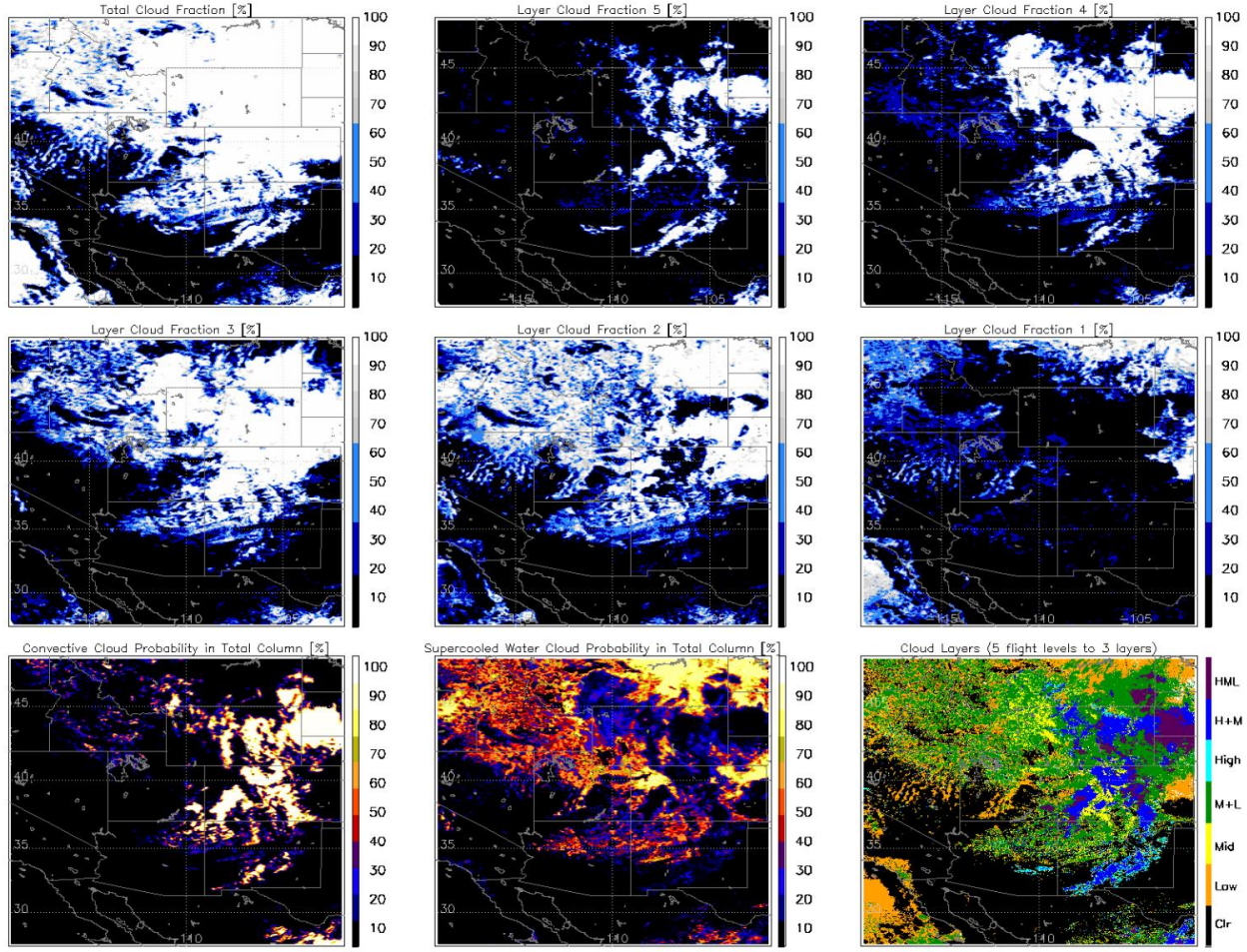
*** Cloud Cover Layers - 60%** correct classification for unobscured fraction in each layer (total, SFC-FL050, FL050-FL100, FL100-FL180, FL180-FL240, FL240-TOA)

# NOAA-21 vs. NOAA-20

## NOAA-21 VIIRS 20:22-20:23 UTC (Day)

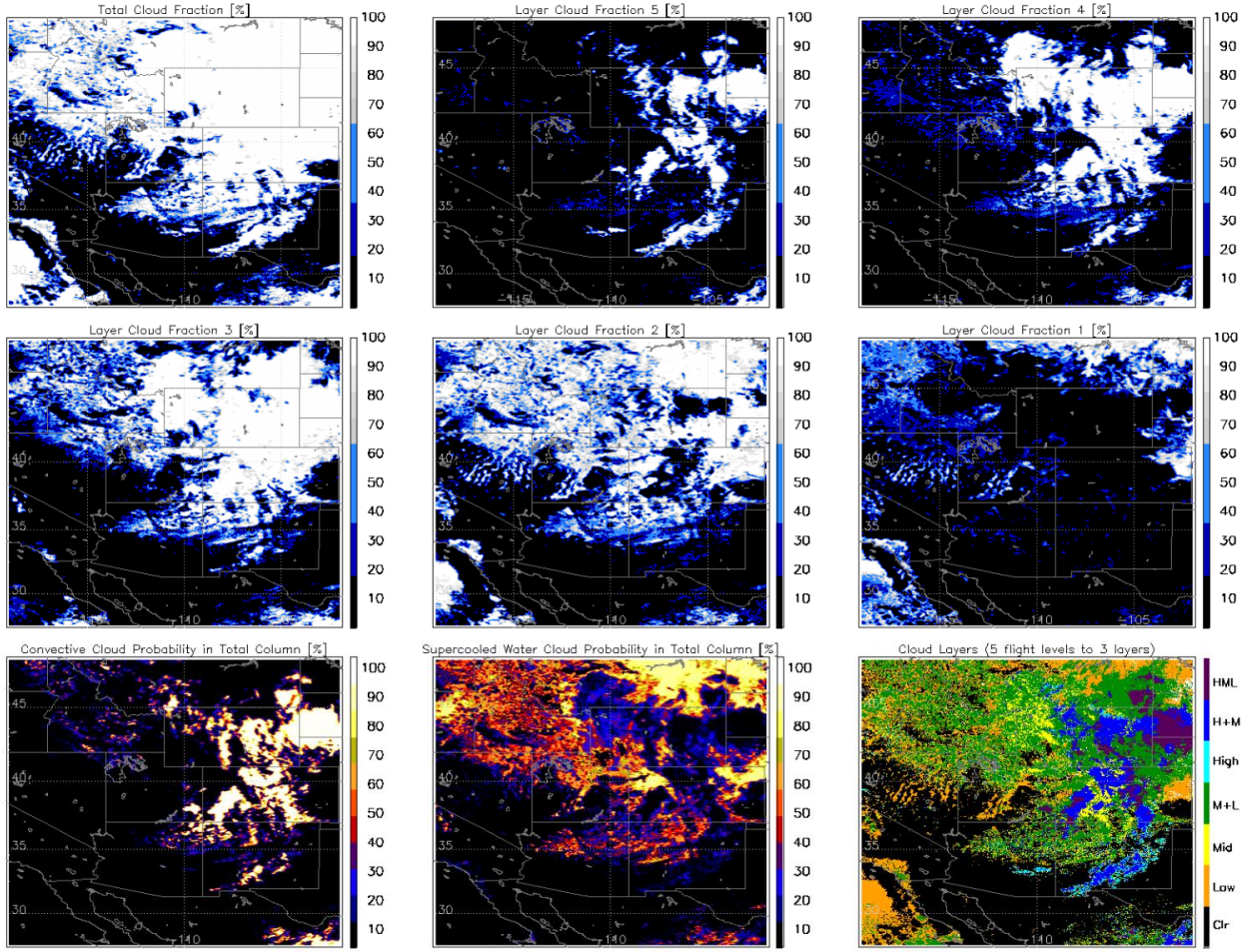



## NOAA-20 VIIRS 19:57-19:59 UTC 2023/04/14

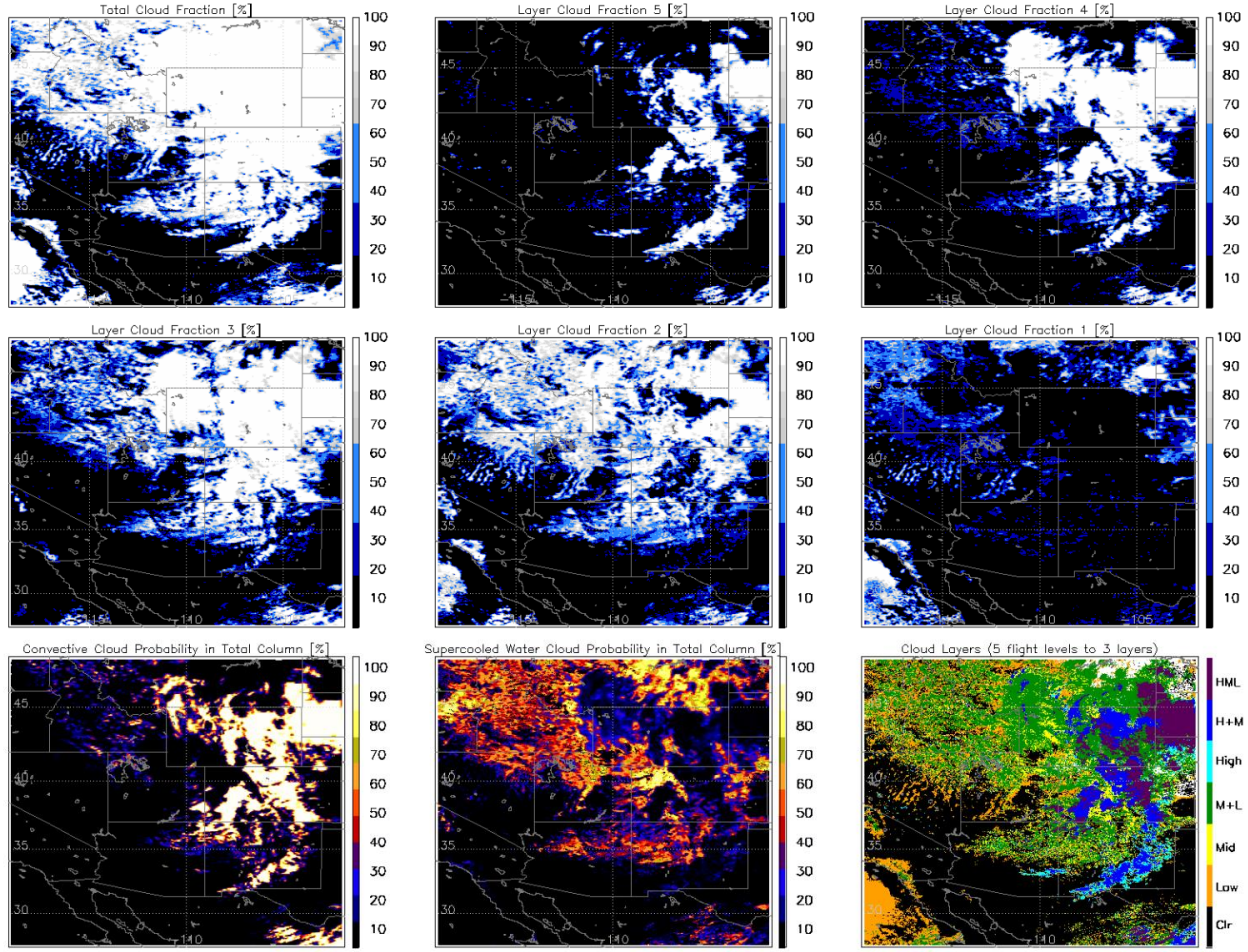


# NOAA-21 vs. S-NPP

## NOAA-21 VIIRS 20:22-20:23 UTC (Day)

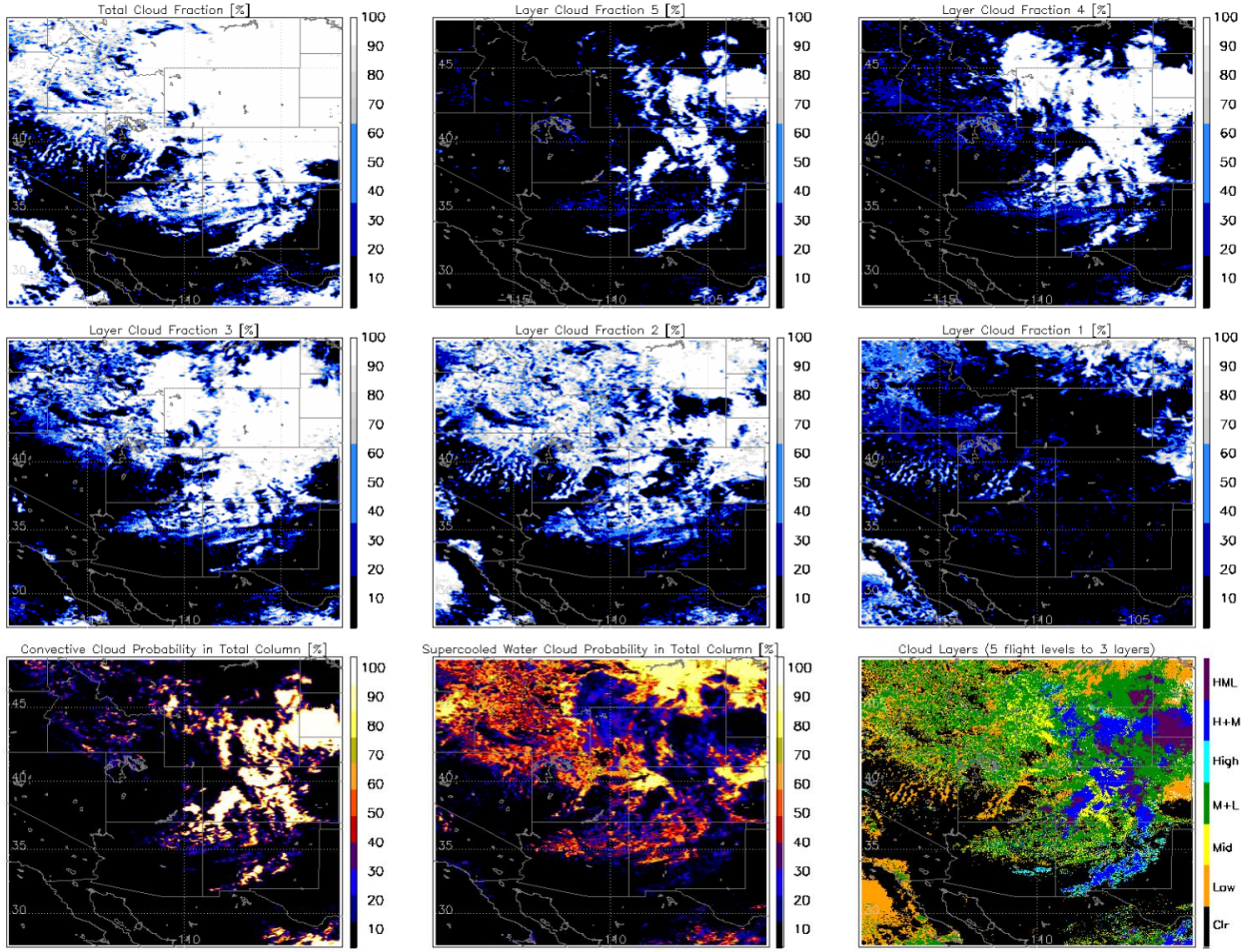



## S-NPP VIIRS 20:50-20:51 UTC 2023/04/14

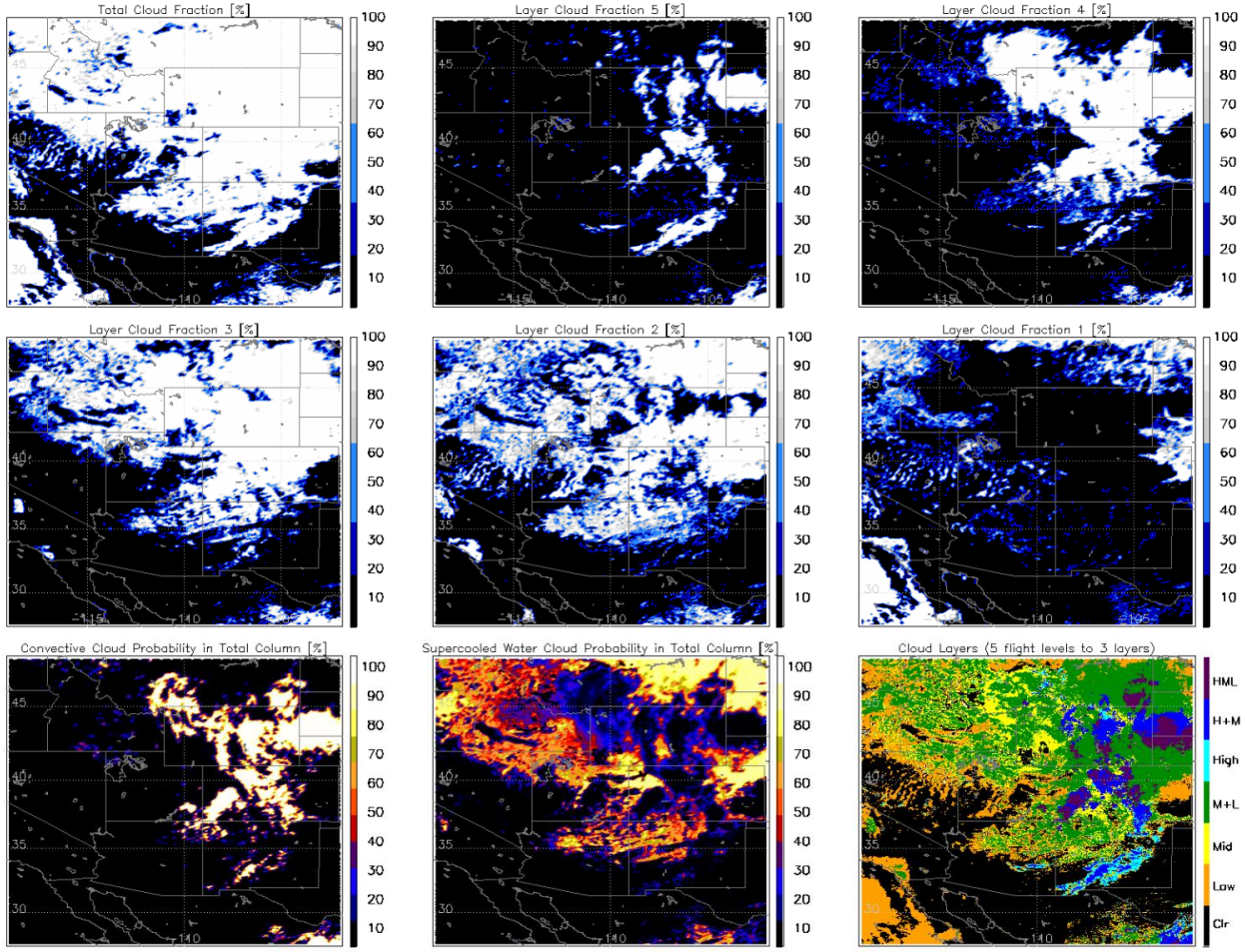


# NOAA-21 vs. GOES-18

## NOAA-20 VIIRS 20:22-20:23 UTC (Day)

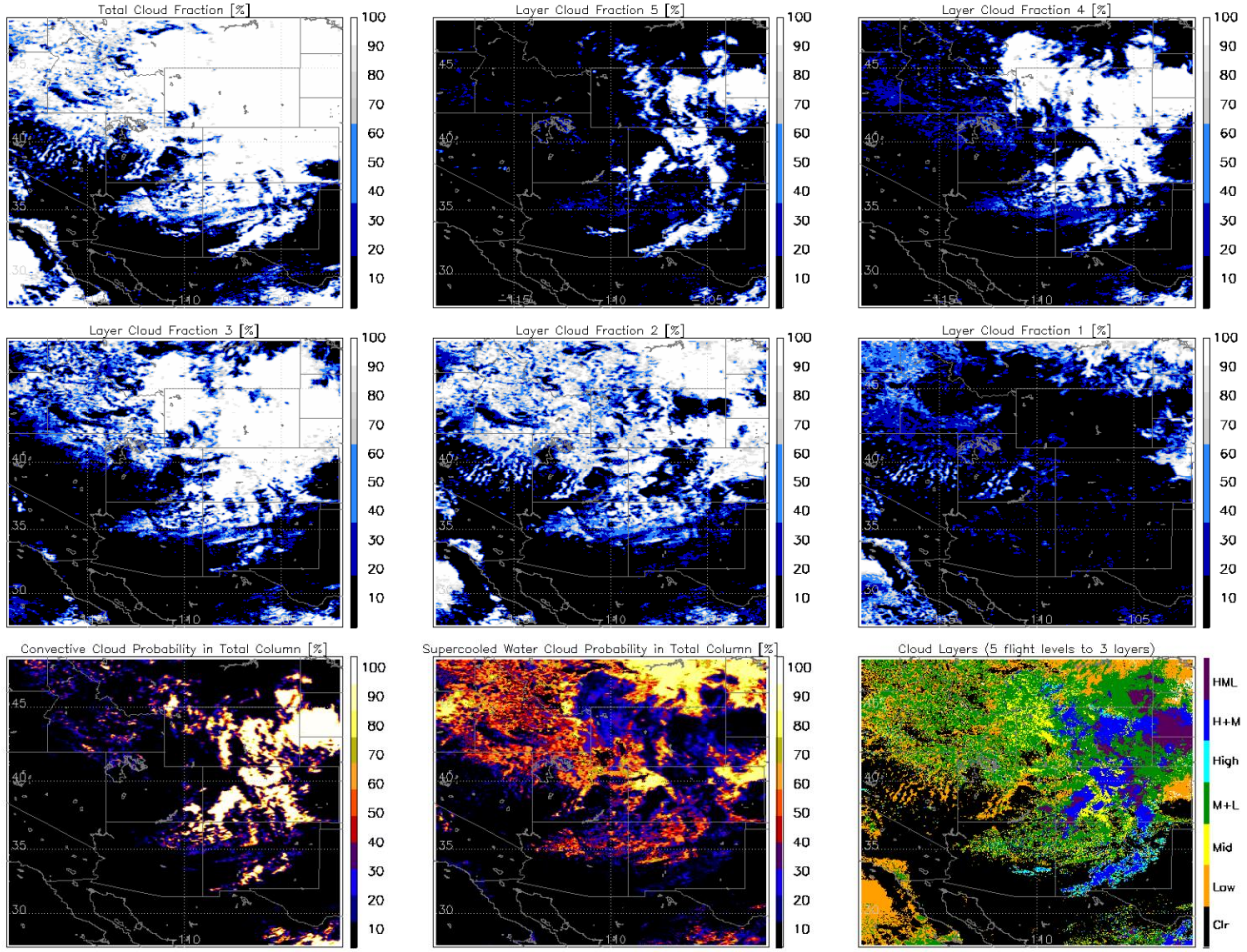



## G18 ABI 20:00 UTC 2023/04/14 (full disk DE 2km)

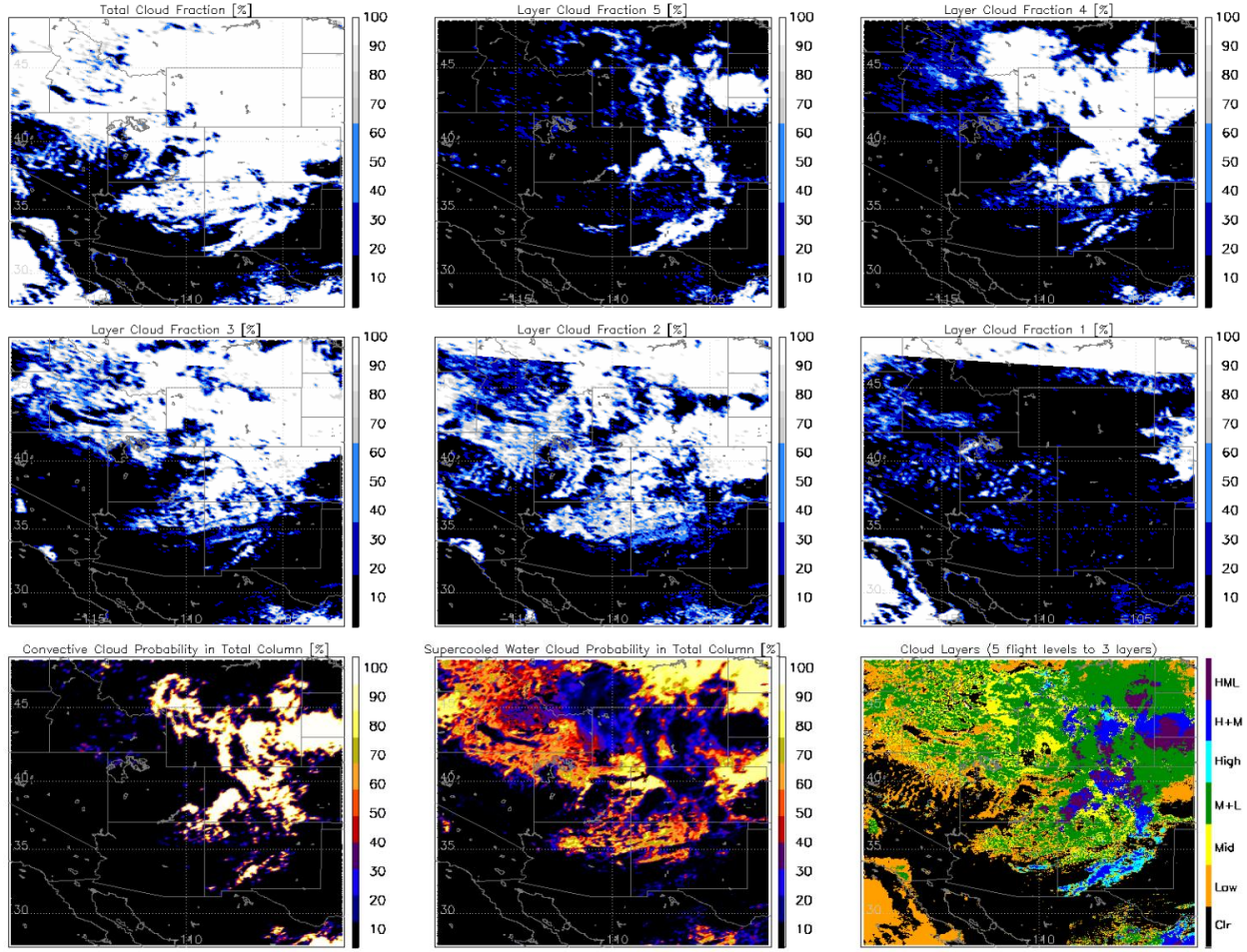


# NOAA-21 vs. GOES-16

## NOAA-20 VIIRS 20:22-20:23 UTC (Day)




## G16 ABI 20:00 UTC 2023/04/14 (full disk DE 2km)



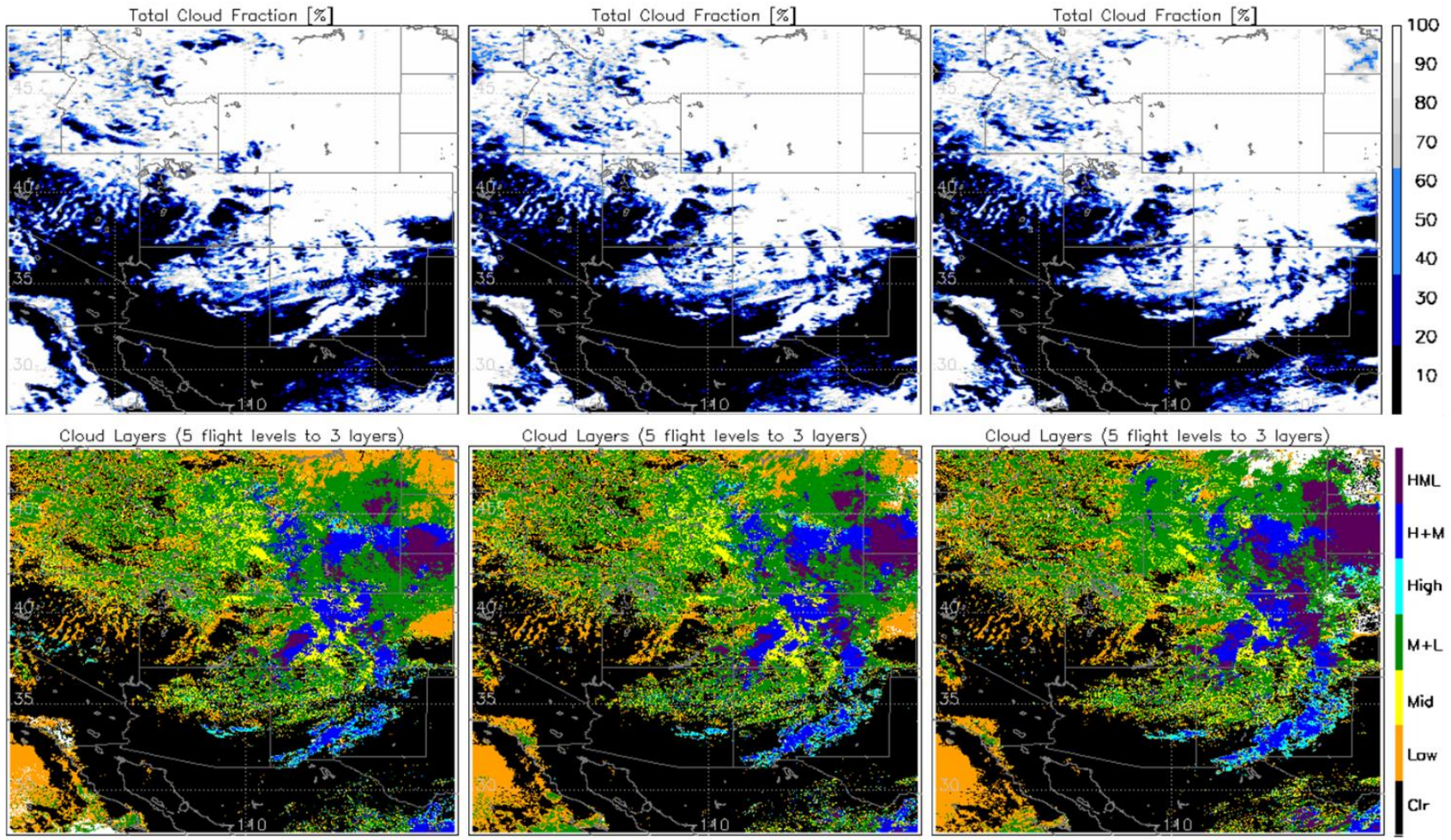

*Note ABI CCL errors in low layer CFs are in old PRO-DE system*

# NOAA-21 compared with NOAA-20 and S-NPP

NOAA-20 19:57-19:59 UTC

NOAA-21 20:22-20:23 UTC

S-NPP 20:50-20:51 UTC




2023/04/14
(W. CONUS)

**Total Cloud Fraction**

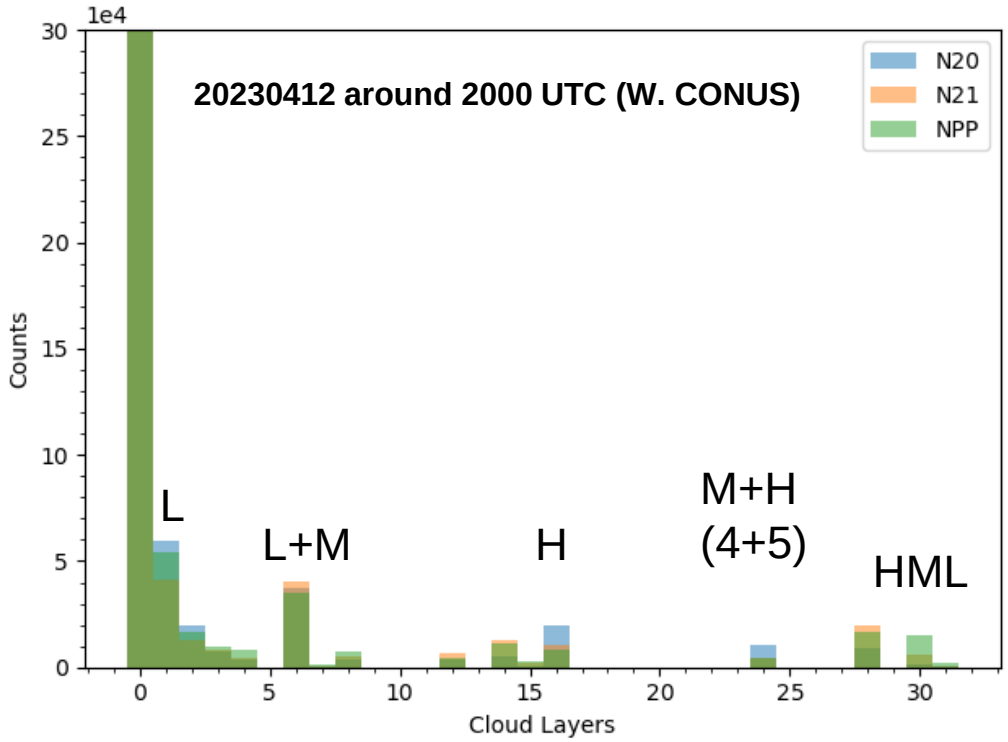
**Cloud Layers**

# NOAA-21 compared with NOAA-20 and S-NPP

NOAA-20 1957-1959 UTC NOAA-21 2022-2023 UTC S-NPP 2050-2051 UTC

**Comparisons of full-disk Cloud Layer Flags (0-31 for five flight-level based layers)**

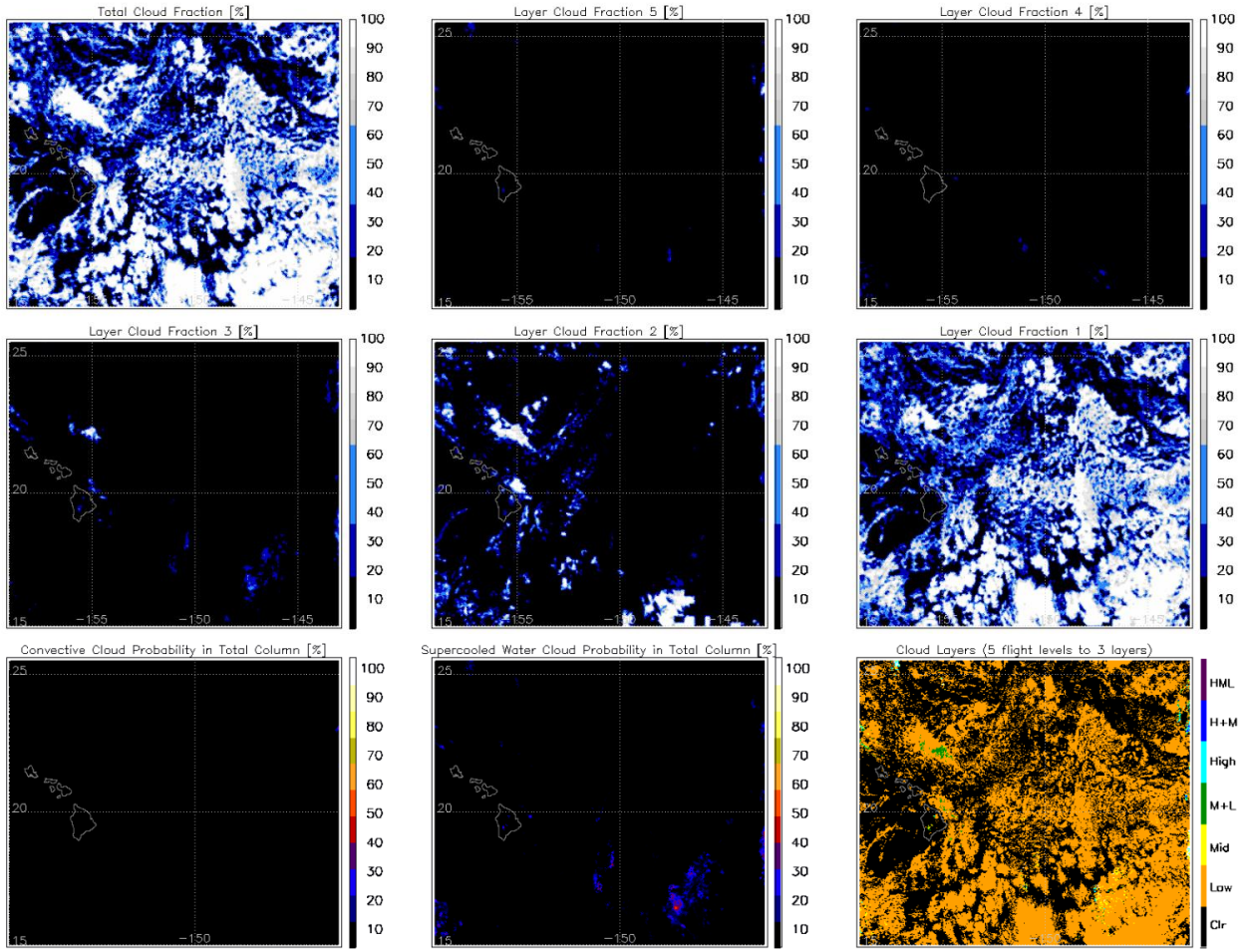
| dec | binary | layers | meaning | poss |
|---|---|---|---|---|
| 0 | 00000000 | | clear | X |
| 1 | 00000001 | 1 | L | X |
| 2 | 00000010 | 2 | L | X |
| 3 | 00000011 | 12 | L | X |
| 4 | 00000100 | 3 | M | X |
| 5 | 00000101 | 1 3 | LM | |
| 6 | 00000110 | 23 | LM | X |
| 7 | 00000111 | 123 | LM | X |
| 8 | 00001000 | 4 | M | X |
| 9 | 00001001 | 1 4 | LM | |
| 10 | 00001010 | 2 4 | LM | |
| 11 | 00001011 | 12 4 | LM | |
| 12 | 00001100 | 34 | M | X |
| 13 | 00001101 | 1 34 | LM | |
| 14 | 00001110 | 234 | LM | X |
| 15 | 00001111 | 1234 | LM | X |
| 16 | 00010000 | 5 | H | X |
| 17 | 00010001 | 1 5 | L H | |
| 18 | 00010010 | 2 5 | L H | |
| 19 | 00010011 | 12 5 | L H | |
| 20 | 00010100 | 3 5 | MH | |
| 21 | 00010101 | 1 3 5 | LMH | |
| 22 | 00010110 | 23 5 | LMH | |
| 23 | 00010111 | 123 5 | LMH | |
| 24 | 00011000 | 45 | MH | X |
| 25 | 00011001 | 1 45 | LMH | |
| 26 | 00011010 | 2 45 | LMH | |
| 27 | 00011011 | 12 45 | LMH | |
| 28 | 00011100 | 345 | MH | X |
| 29 | 00011101 | 1 345 | LMH | |
| 30 | 00011110 | 2345 | LMH | X |
| 31 | 00011111 | 12345 | LMH | X |



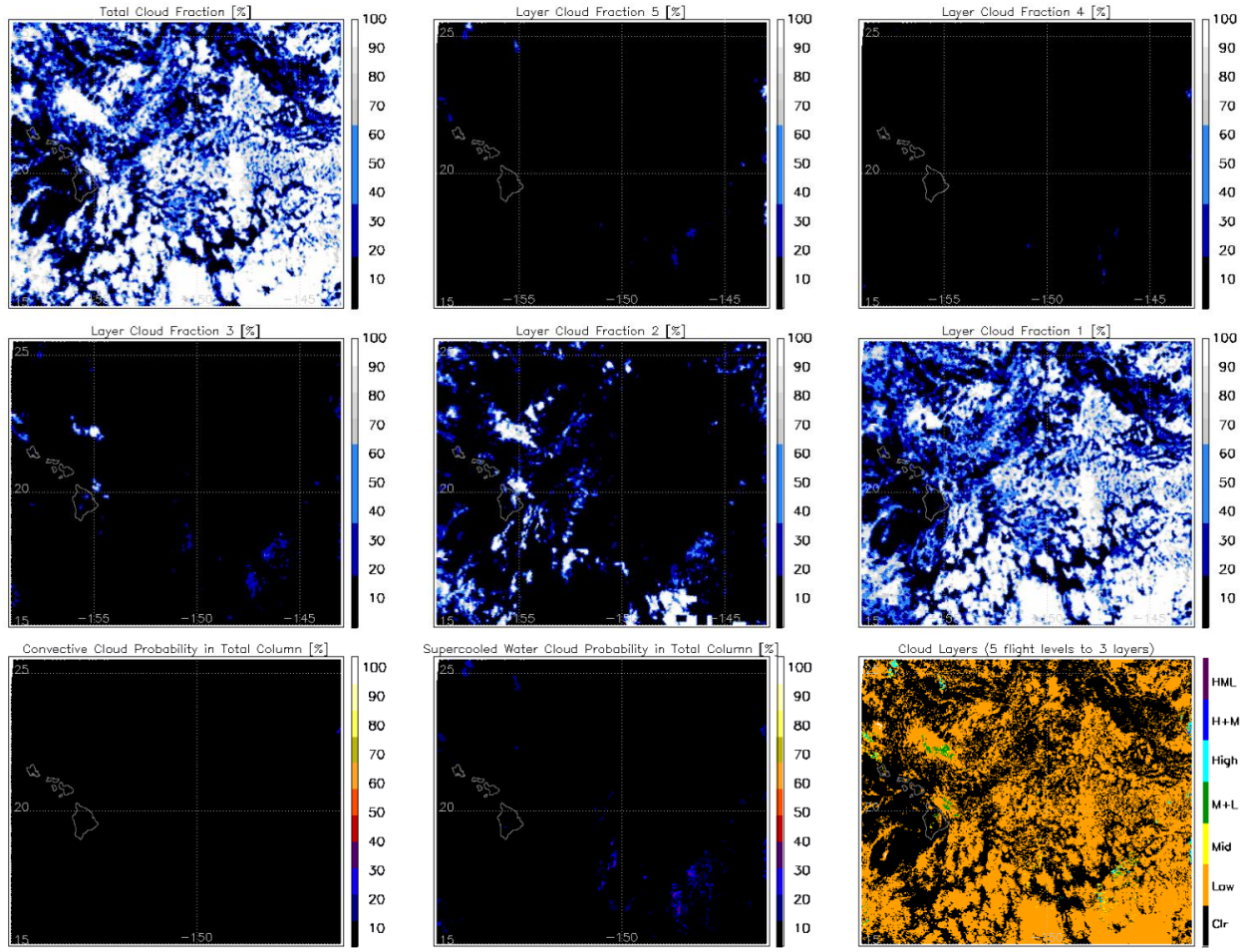
# NOAA-21 vs. NOAA-20

Hawaii example (closer to new moon)

## NOAA-21 VIIRS 11:38-11:40 UTC (Night)



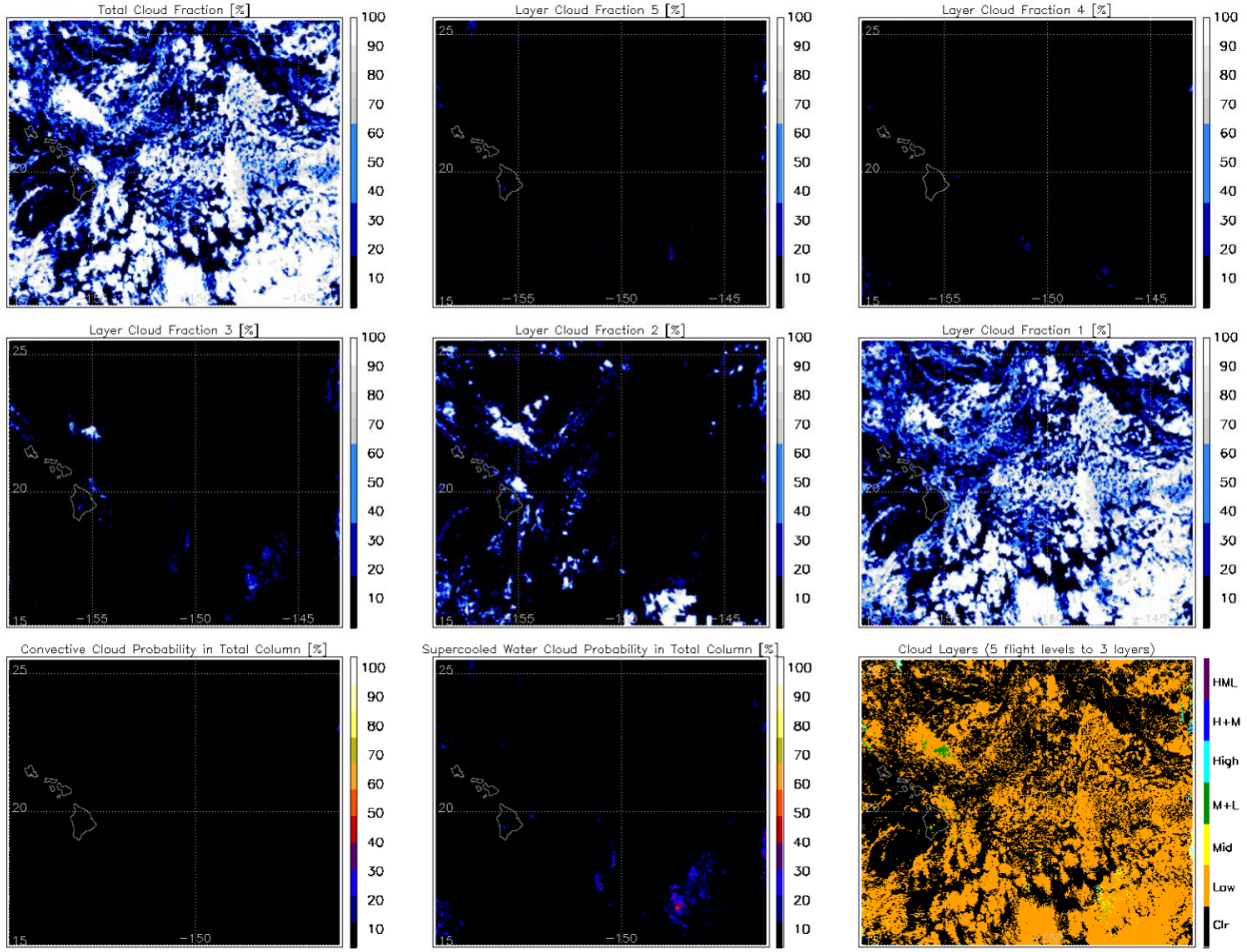

## NOAA-20 VIIRS 11:16-11:73 UTC 2023/04/14



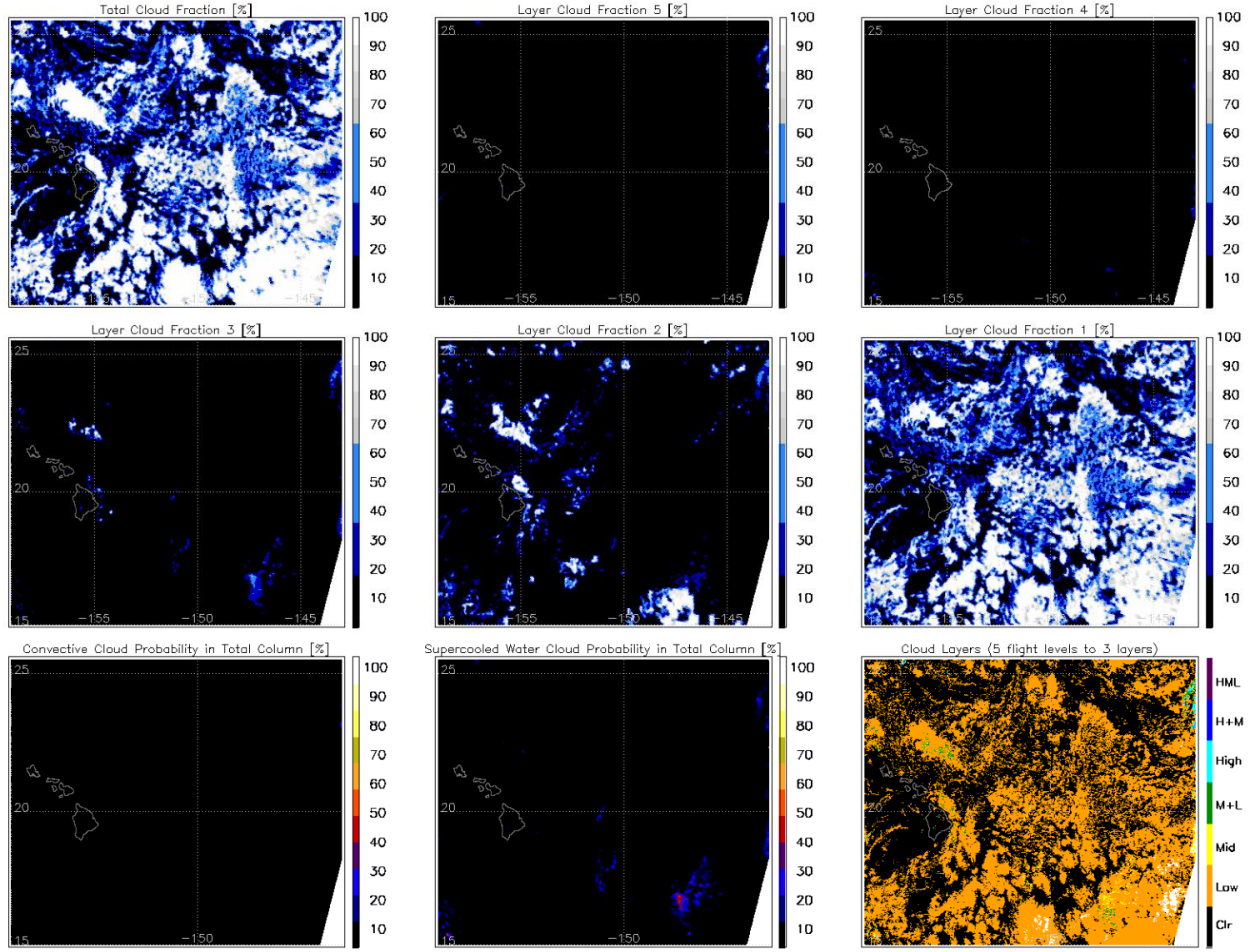
# NOAA-21 vs. S-NPP

Hawaii example (closer to new moon)

## NOAA-21 VIIRS 1138-1140 UTC (Night)




## S-NPP VIIRS 12:05-12:07 UTC 2023/04/14

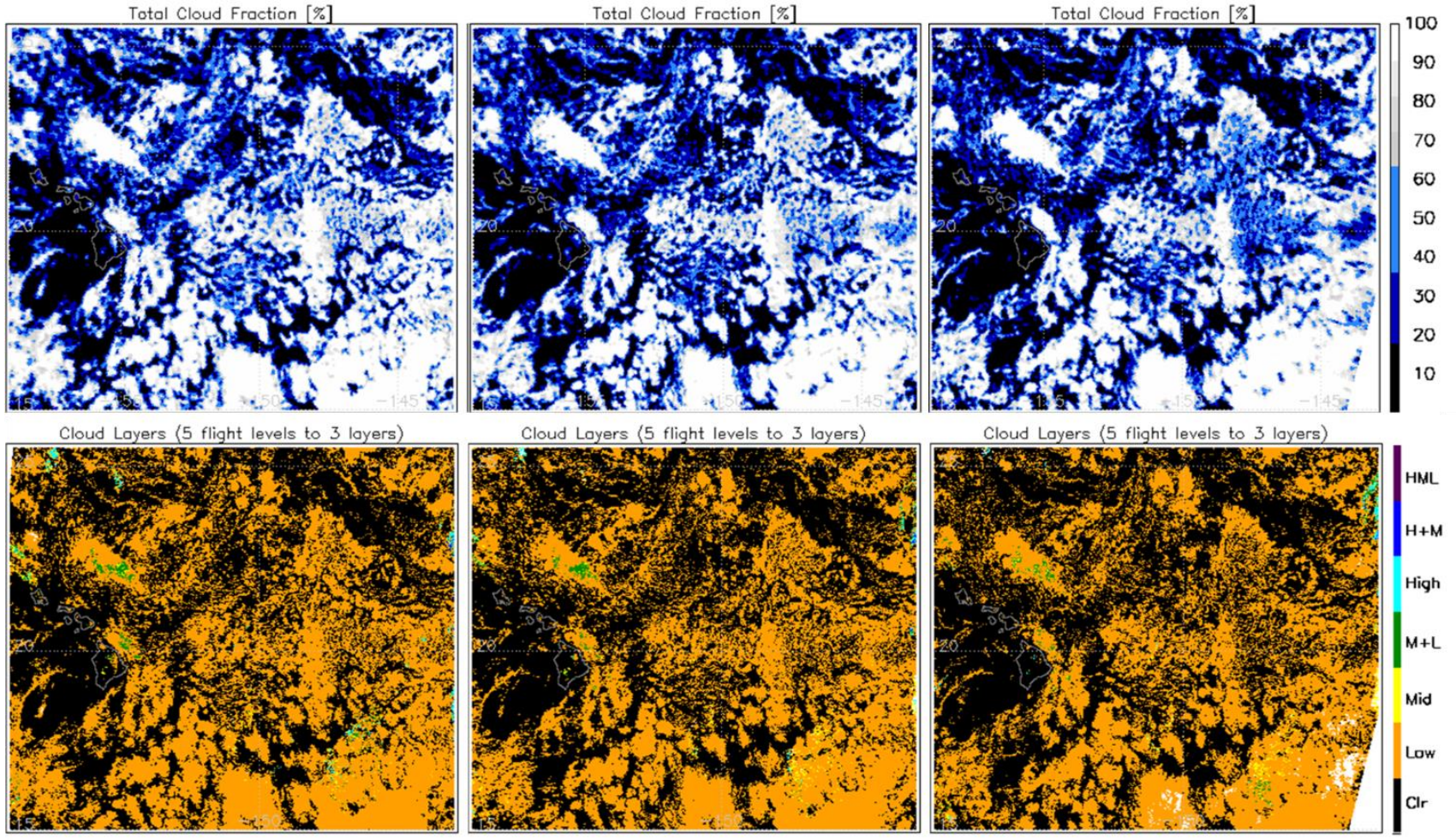


# NOAA-21 compared with NOAA-20 and S-NPP

NOAA-20 11:16-11:73 UTC

NOAA-21 11:38-11:40 UTC

S-NPP 12:05-12:07 UTC




2023/09/29
(Hawaii, full moon)

**Total Cloud Fraction**

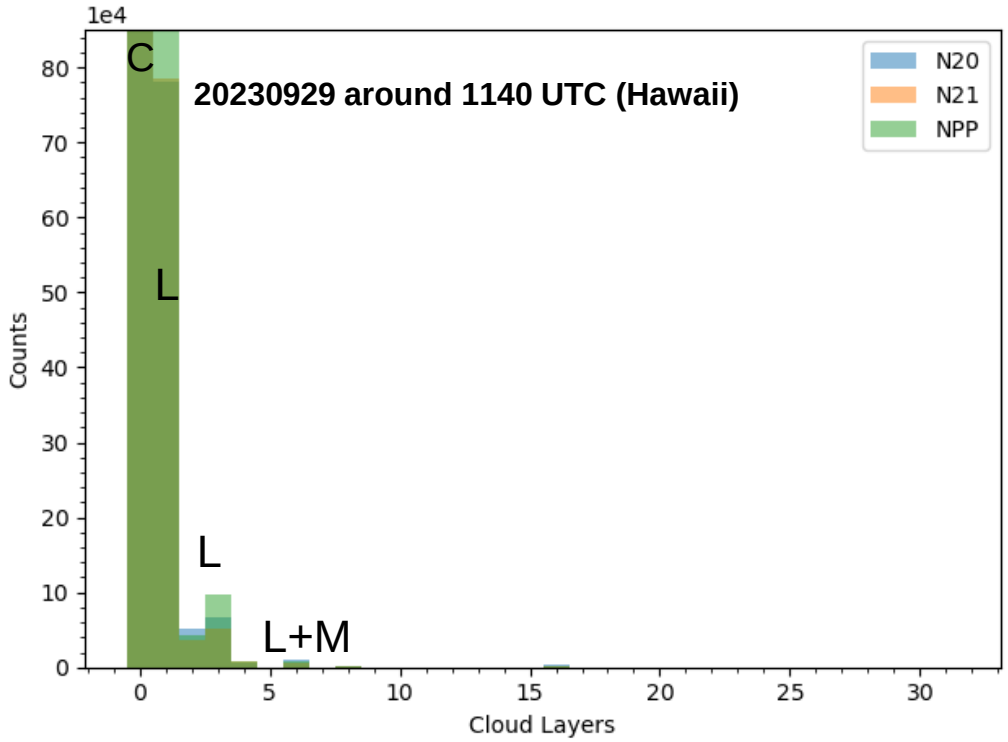
**Cloud Layers**

# NOAA-21 compared with NOAA-20 and S-NPP

NOAA-20 1116-1173 UTC  NOAA-21 1138-1140 UTC  S-NPP 1205-1207 UTC

**Comparisons of full-disk Cloud Layer Flags (0-31 for five flight-level based layers)**

| dec | binary | layers | meaning | poss |
|---|---|---|---|---|
| 0 | 00000000 | | clear | X |
| 1 | 00000001 | 1 | L | X |
| 2 | 00000010 | 2 | L | X |
| 3 | 00000011 | 12 | L | X |
| 4 | 00000100 | 3 | M | X |
| 5 | 00000101 | 1 3 | LM | |
| 6 | 00000110 | 23 | LM | X |
| 7 | 00000111 | 123 | LM | X |
| 8 | 00001000 | 4 | M | X |
| 9 | 00001001 | 1 4 | LM | |
| 10 | 00001010 | 2 4 | LM | |
| 11 | 00001011 | 12 4 | LM | |
| 12 | 00001100 | 34 | M | X |
| 13 | 00001101 | 1 34 | LM | |
| 14 | 00001110 | 234 | LM | X |
| 15 | 00001111 | 1234 | LM | X |
| 16 | 00010000 | 5 | H | X |
| 17 | 00010001 | 1 5 | L H | |
| 18 | 00010010 | 2 5 | L H | |
| 19 | 00010011 | 12 5 | L H | |
| 20 | 00010100 | 3 5 | MH | |
| 21 | 00010101 | 1 3 5 | LMH | |
| 22 | 00010110 | 23 5 | LMH | |
| 23 | 00010111 | 123 5 | LMH | |
| 24 | 00011000 | 45 | MH | X |
| 25 | 00011001 | 1 45 | LMH | |
| 26 | 00011010 | 2 45 | LMH | |
| 27 | 00011011 | 12 45 | LMH | |
| 28 | 00011100 | 345 | MH | X |
| 29 | 00011101 | 1 345 | LMH | |
| 30 | 00011110 | 2345 | LMH | X |
| 31 | 00011111 | 12345 | LMH | X |



# Data (CALIPSO - CCL matchups)

- **Global analysis**
- SAPF N21 CCL products retrieved from for 9 days in May/June 2023
- CALIPSO/CALIOP cloud layer products at 5 km resolution were used as validation datasets
- CALIPSO Version 3 were used, instead of Version 4, due to data availability

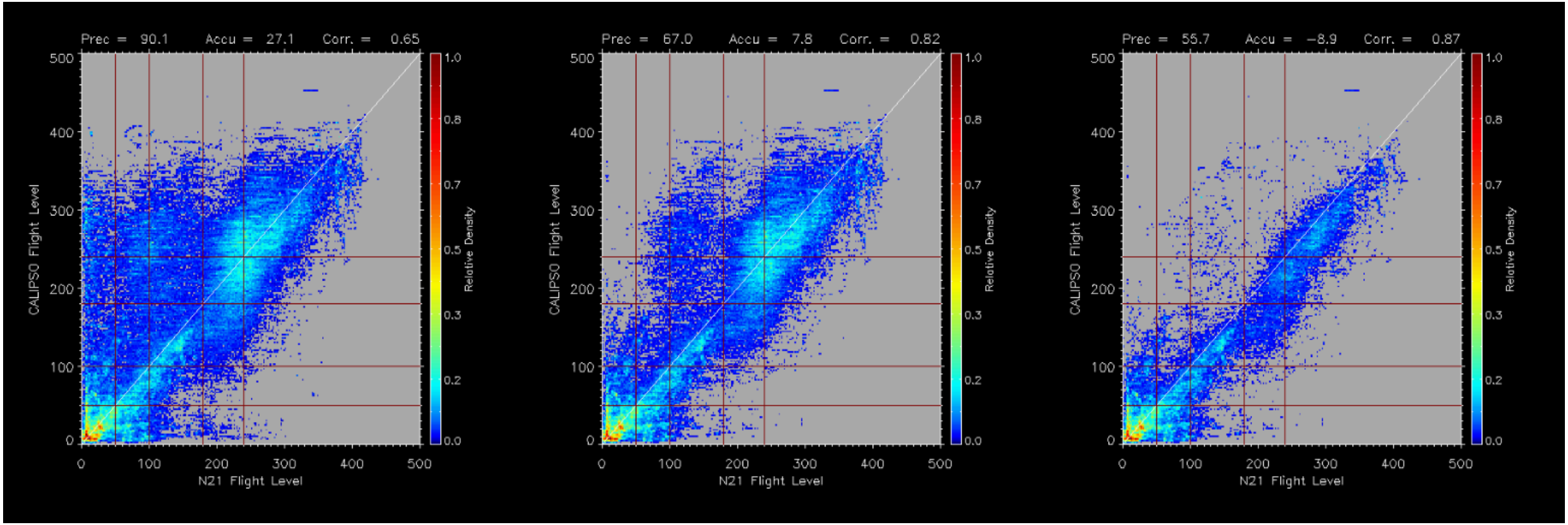
*(led by Yue Li, CIMSS)*

# Data and Methods

- Space and time collocations between CALIPSO and N21 were conducted
- Cloud top pressures are converted to flight levels, and correct classification ratios are computed by dividing the number of agreed pixels between N21 and CALIPSO at predefined FLs to the total number of pixels
- Cloud phase matching between N21 and CALIPSO is applied to account for retrieval differences in cloud phase that impacts upstream ACHA products
- Overlapping detection also affects ACHA and CCL retrieval, so additional filtering to remove multilayer clouds is also applied
- Note that CALIPSO has its limitations in detecting cloud base, so primarily cloud top information is used here

*(led by Yue Li, CIMSS)*

# N21 May/June 2023




No filtering

Phase matched

Phase matched and single layer

# **Total** Correct classification percentage (Spec is 60% correct)

| % | No filtering | Phase matched | Phase matched and single layer |
|---|---|---|---|
| SAPF | 59.2 | 69.0 | 75.0 |

# **Layered** correct classification percentage

| % | No filtering | Phase matched | Phase matched and single layer |
|---|---|---|---|
| Layer1<br>Sfc-5 kft | 84.8 | 86.3 | 86.8 |
| Layer2<br>5-10 kft | 52.3 | 51.6 | 52.7 |
| Layer3<br>10-18 kft | 55.3 | 60.2 | 64.7 |
| Layer4<br>18-24 kft | 54.5 | 70.2 | 76.6 |
| Layer5<br>> 24 kft | 53.6 | 68.5 | 82.5 |

1) The total number of CALIPSO pixels within each FL range is considered as truth to compute the layered classification percentage
2) The lower accuracy numbers might be caused by 1) limited data; 2)upstream algorithms; 3) cloud base not accounted for using CALIPSO
3) CCL is directly impacted by upstream algorithms, particularly cloud height (ACHA). ACHA and hence CCL's performances improve significantly as cloud phase matching and/or single layer filtering are applied

# Contingency Table Evaluation

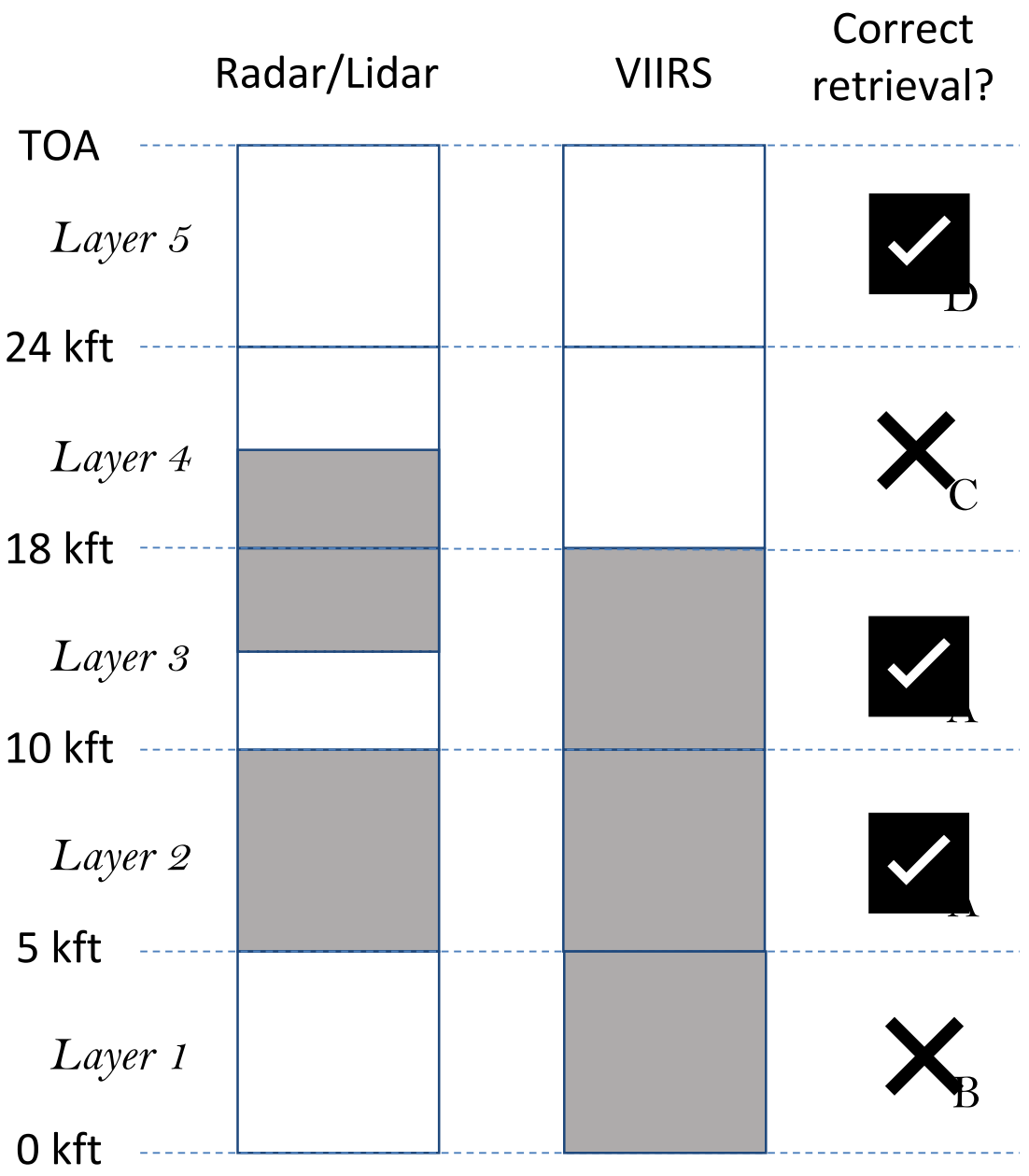
For each of 5 CCL layers ($j$=1 to 5), create a *contingency table* with 4 counts ($A_j$, $B_j$, $C_j$, $D_j$):

**Observed by ARM (or CloudSat/CALIPSO)?**

| **Retrieved by VIIRS?** | Y | N |
|---|---|---|
| Y | $A_j$ | $B_j$ |
| N | $C_j$ | $D_j$ |

For each matched set of obs/retrieval, if the observations show cloud **in any radar/lidar bin within the bounds of that layer**, then observed=Yes; else observed=No.

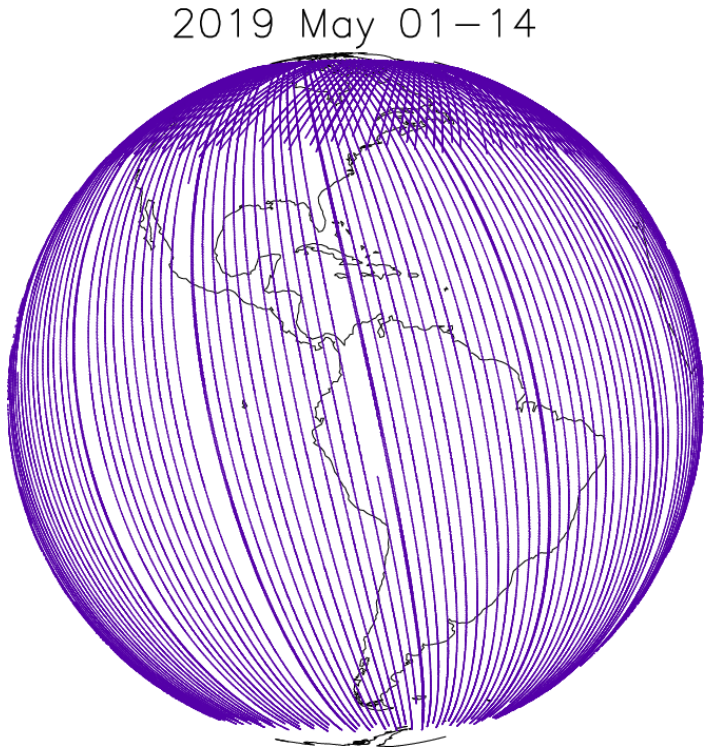
Prob. of detection for layer $j$ = $A_j$/ ($A_j$+$C_j$)
False alarm ratio for layer $j$ = $B_j$/ ($A_j$+$B_j$)
Accuracy for layer $j$ = ($A_j$+$D_j$)/ ($A_j$+$B_j$+$C_j$+$D_j$)



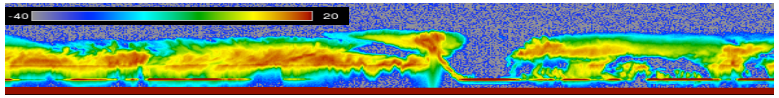
*Previous example with the same algorithm*

# GOES-16 (ASSISTT retrospect) vs. CloudSat

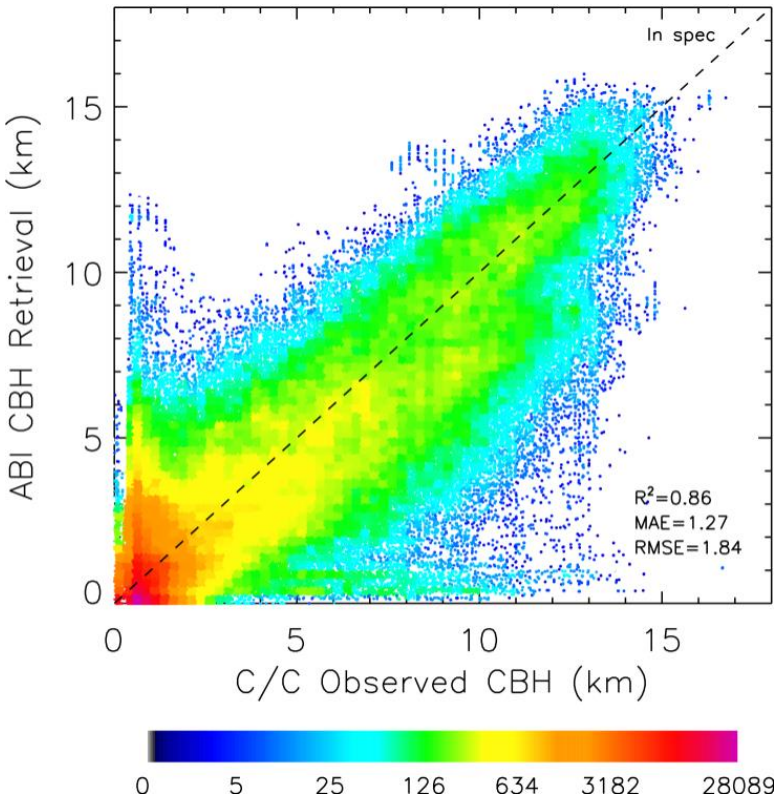
(May 1-14, 2019)



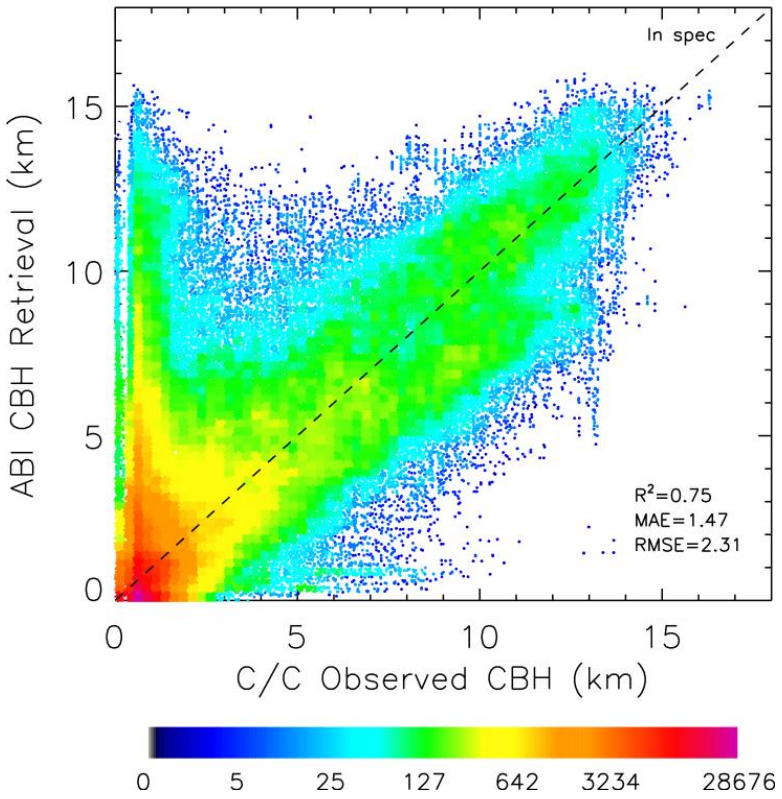

**CloudSat vertical resolution 240 m**




## Topmost Layer CBH




## Lowest CBH (all clouds)




*Measurement accuracy requirements for VIIIRS CBH: 2 km for COT ≥ 1 & 3 km for COT < 1*

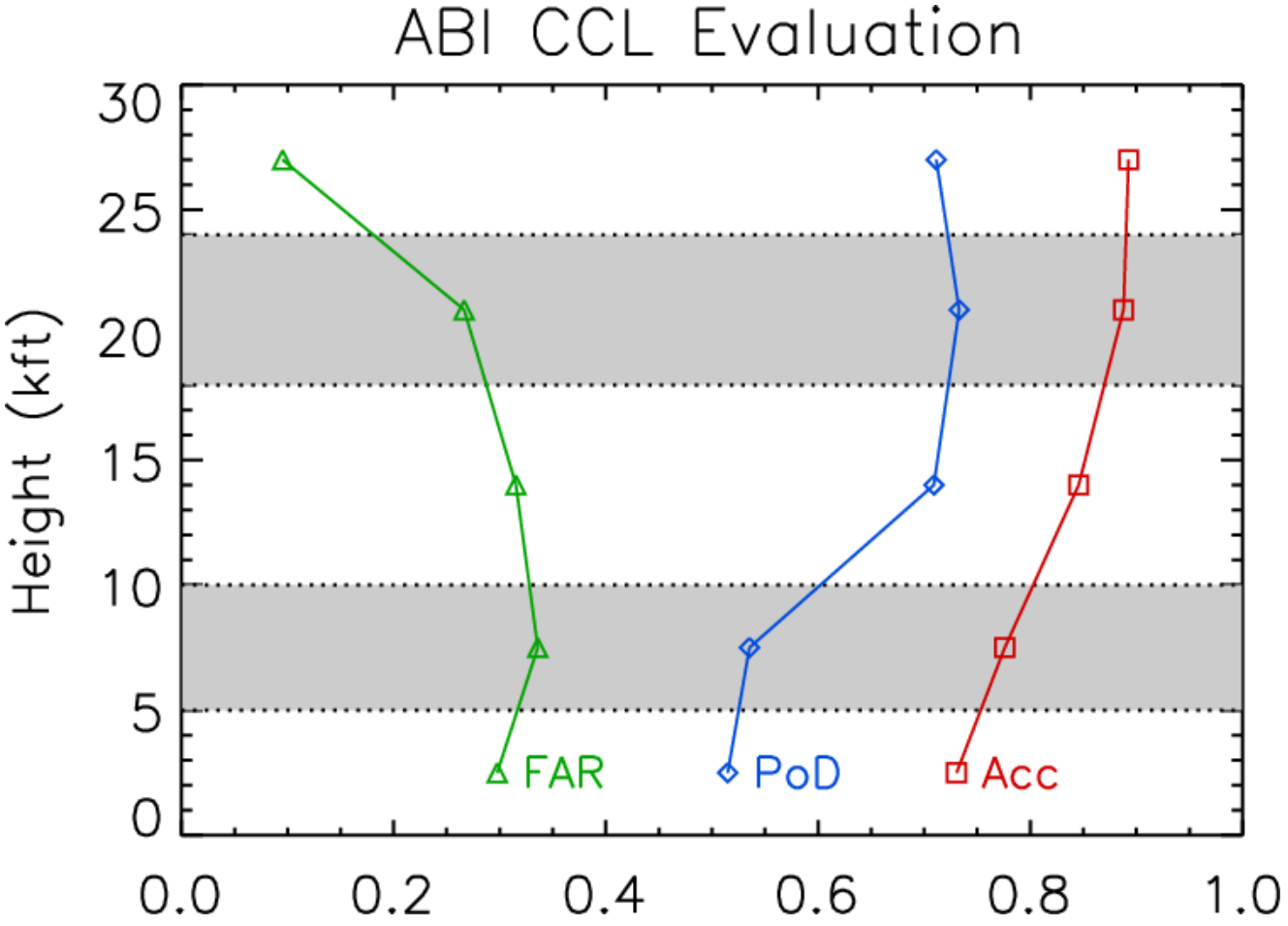
*Previous example with the same algorithm*

# GOES-16 (ASSISTT retrospect) vs. CloudSat

(May 1-14, 2019)

Figure shows the following for each of the five levels evaluated:

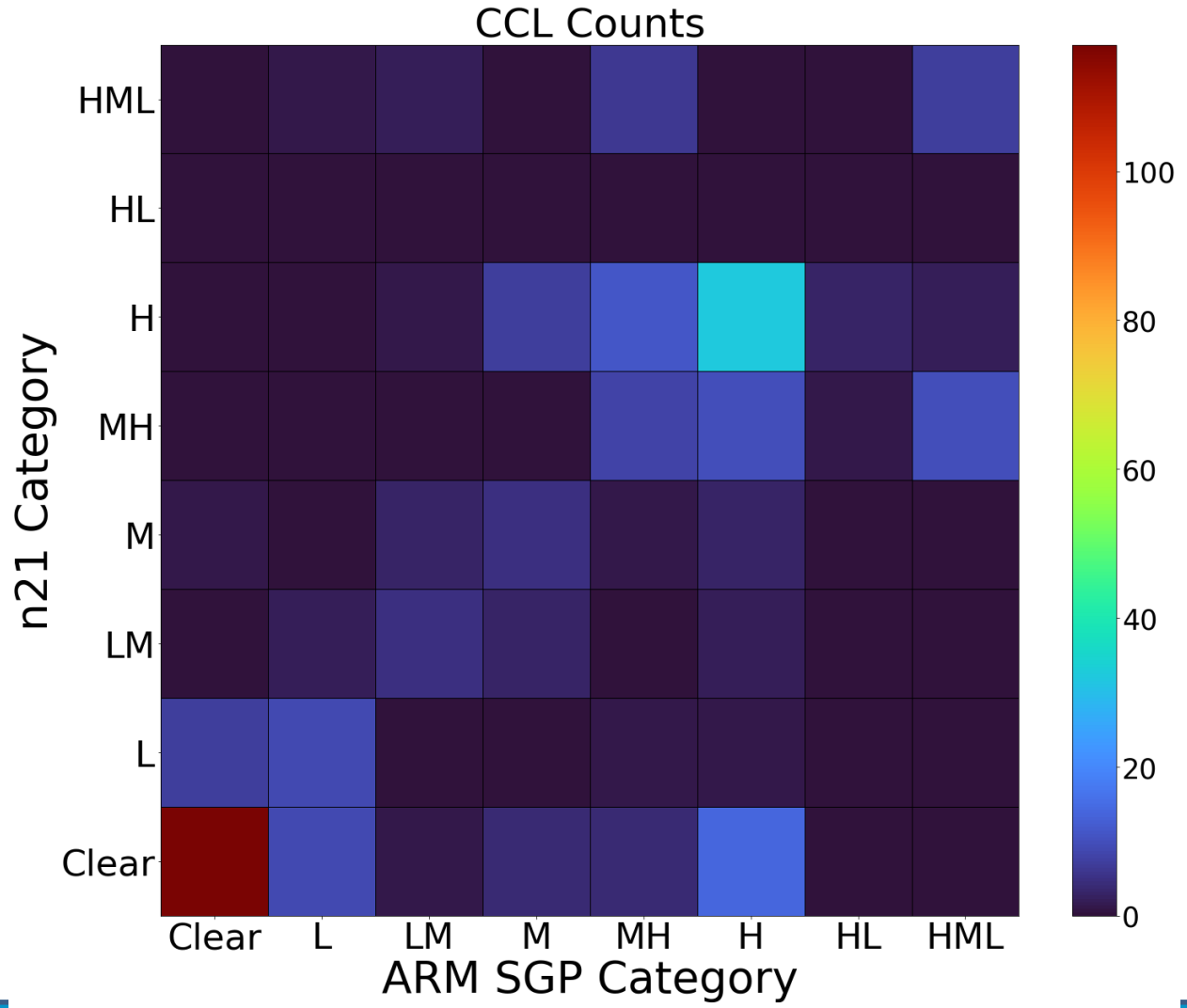
- Probability of detection (PoD)
  target=1
- False alarm ratio (FAR)
  target=0
- Accuracy (Acc)
  target=1

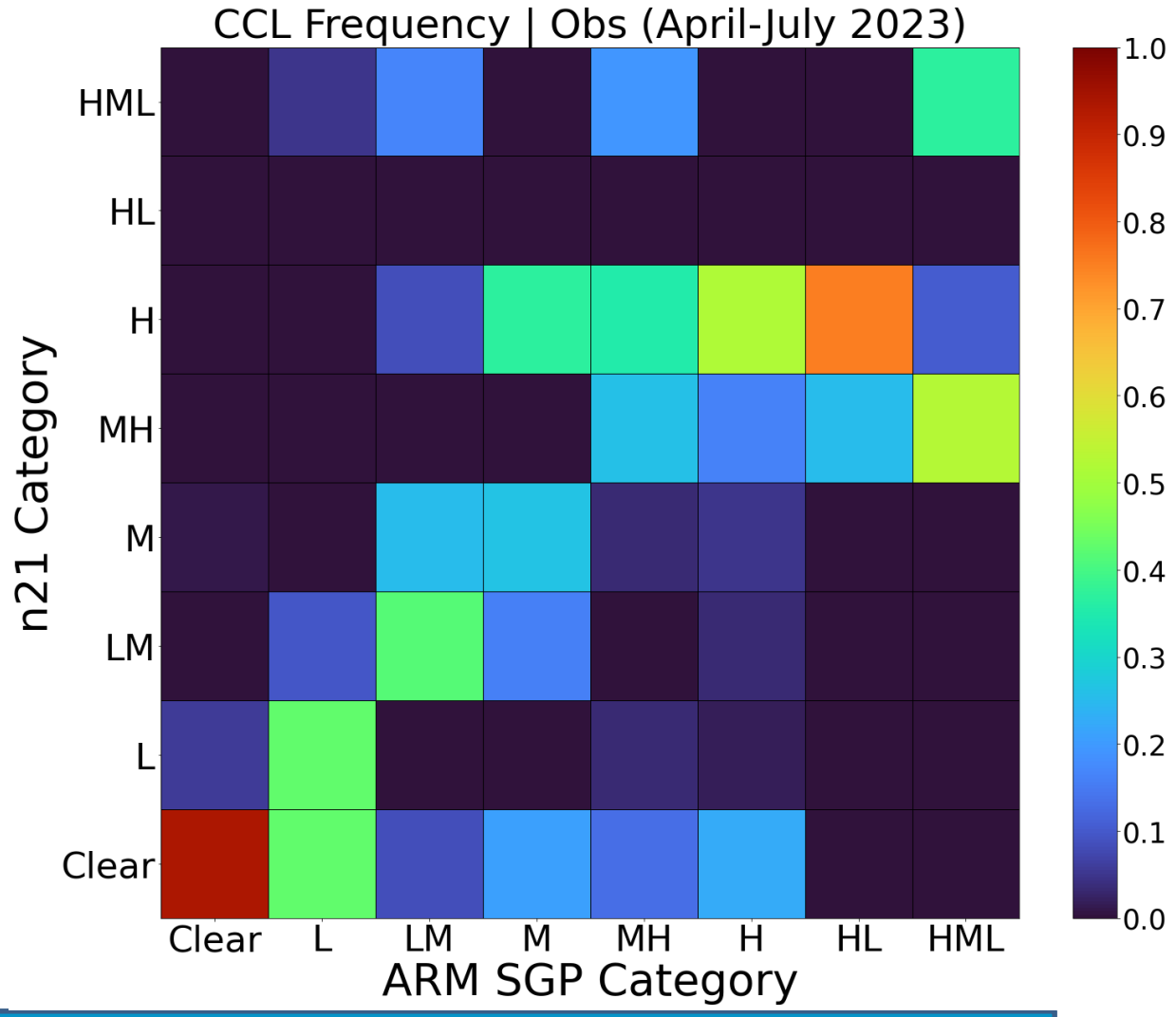


Radar comparison

*Still included radar first height gate in the analysis

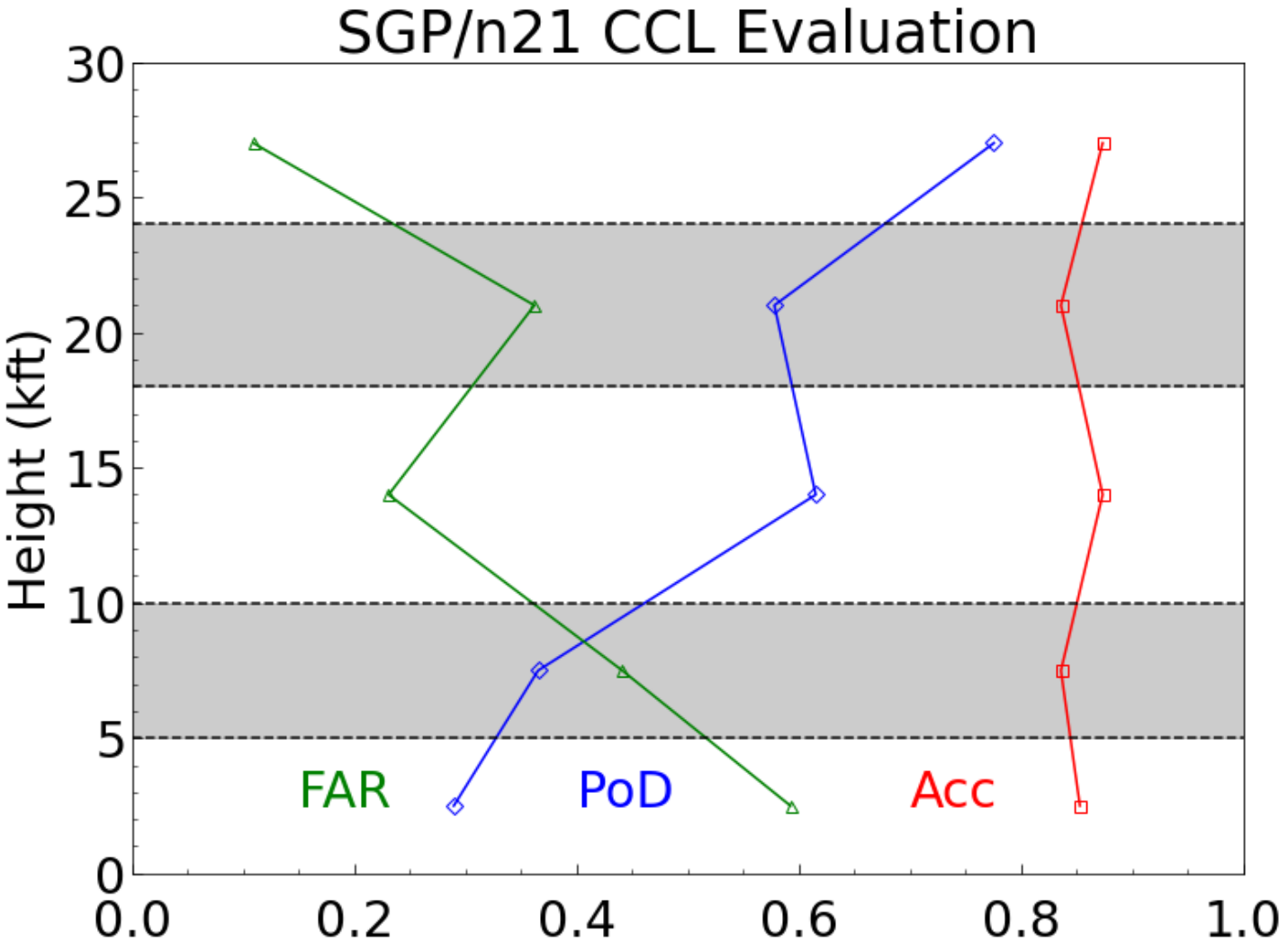
## CCL (ARM-SGP vs n21)



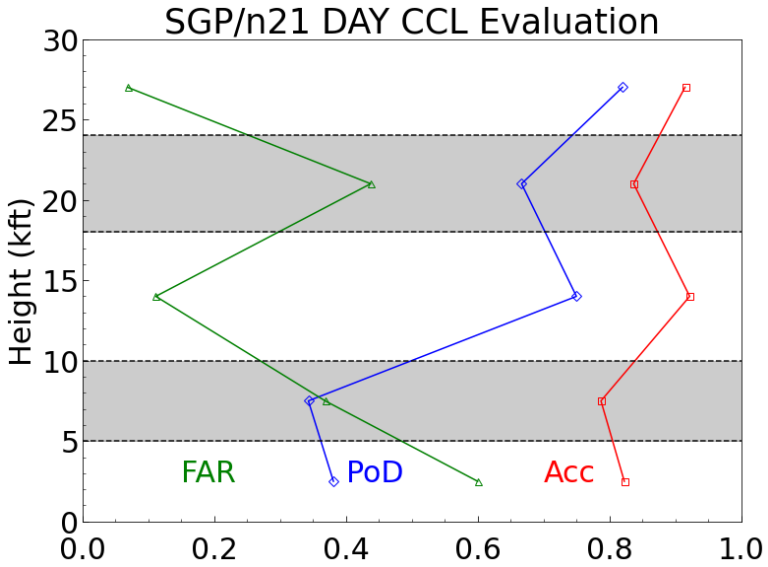



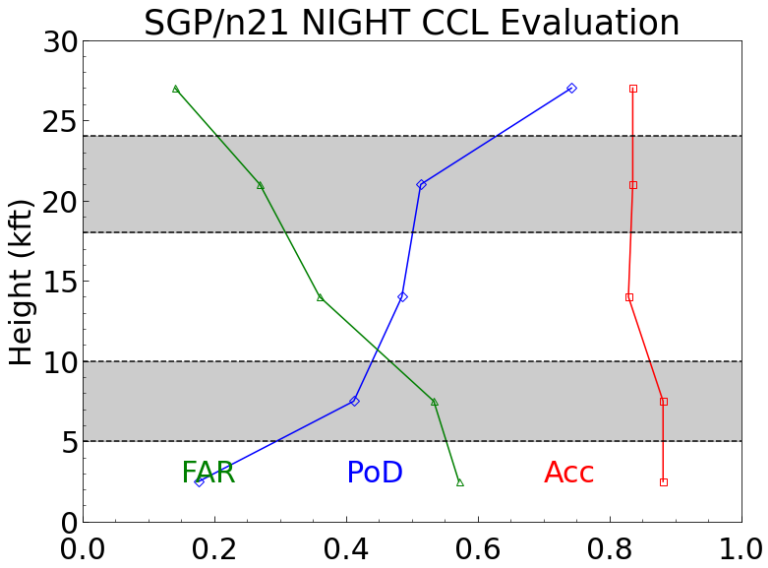
## *ARM SGP - NOAA-21 VIIRS*

CCL Flight Levels (ARM-SGP vs n21)



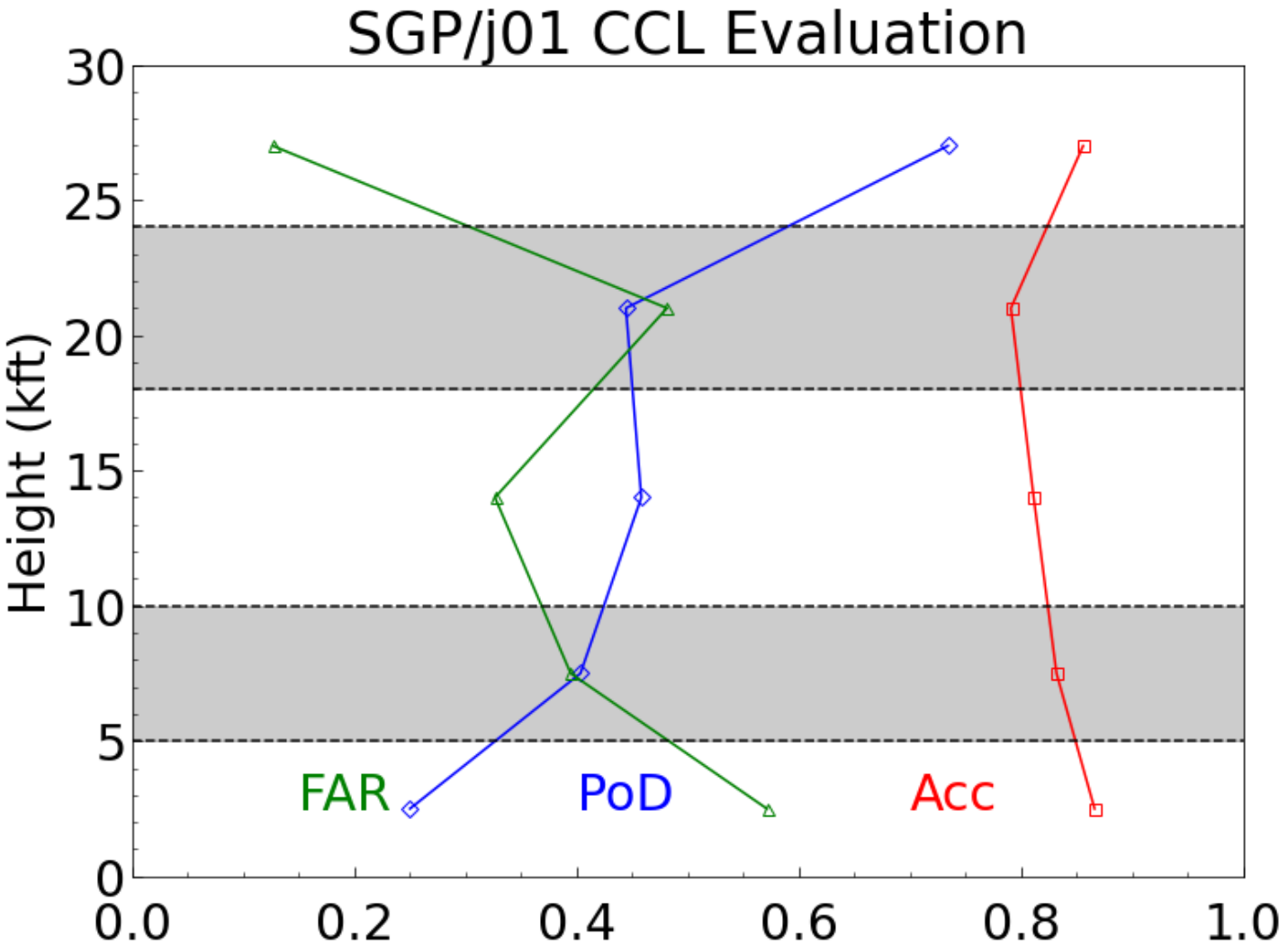

*Still included radar first height gate in the analysis



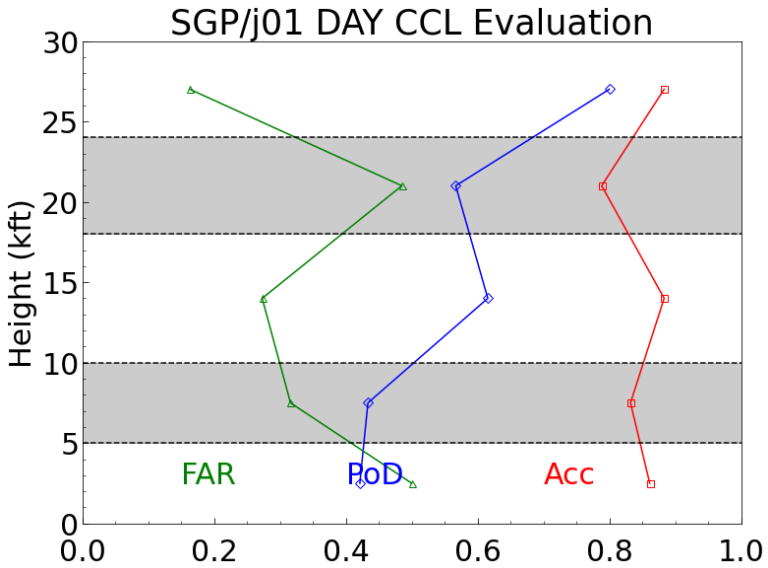



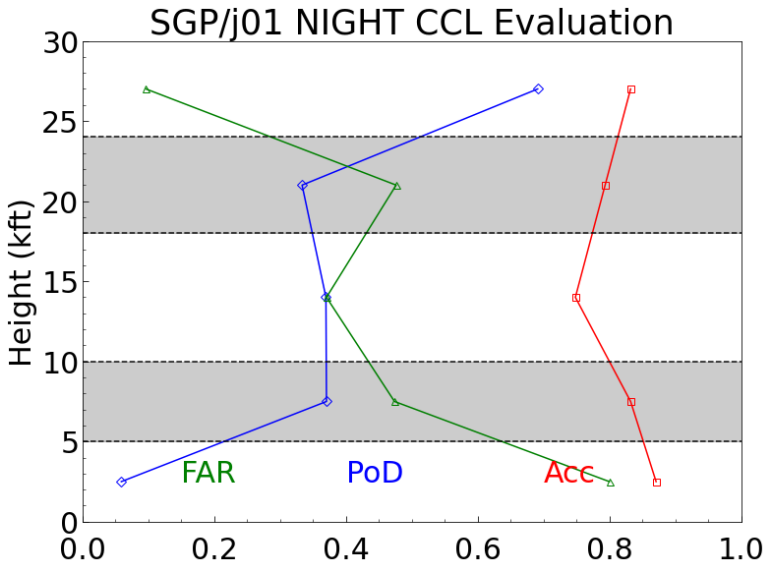
## *ARM SGP - NOAA-20 VIIRS*

CCL Flight Levels (ARM-SGP vs n20)



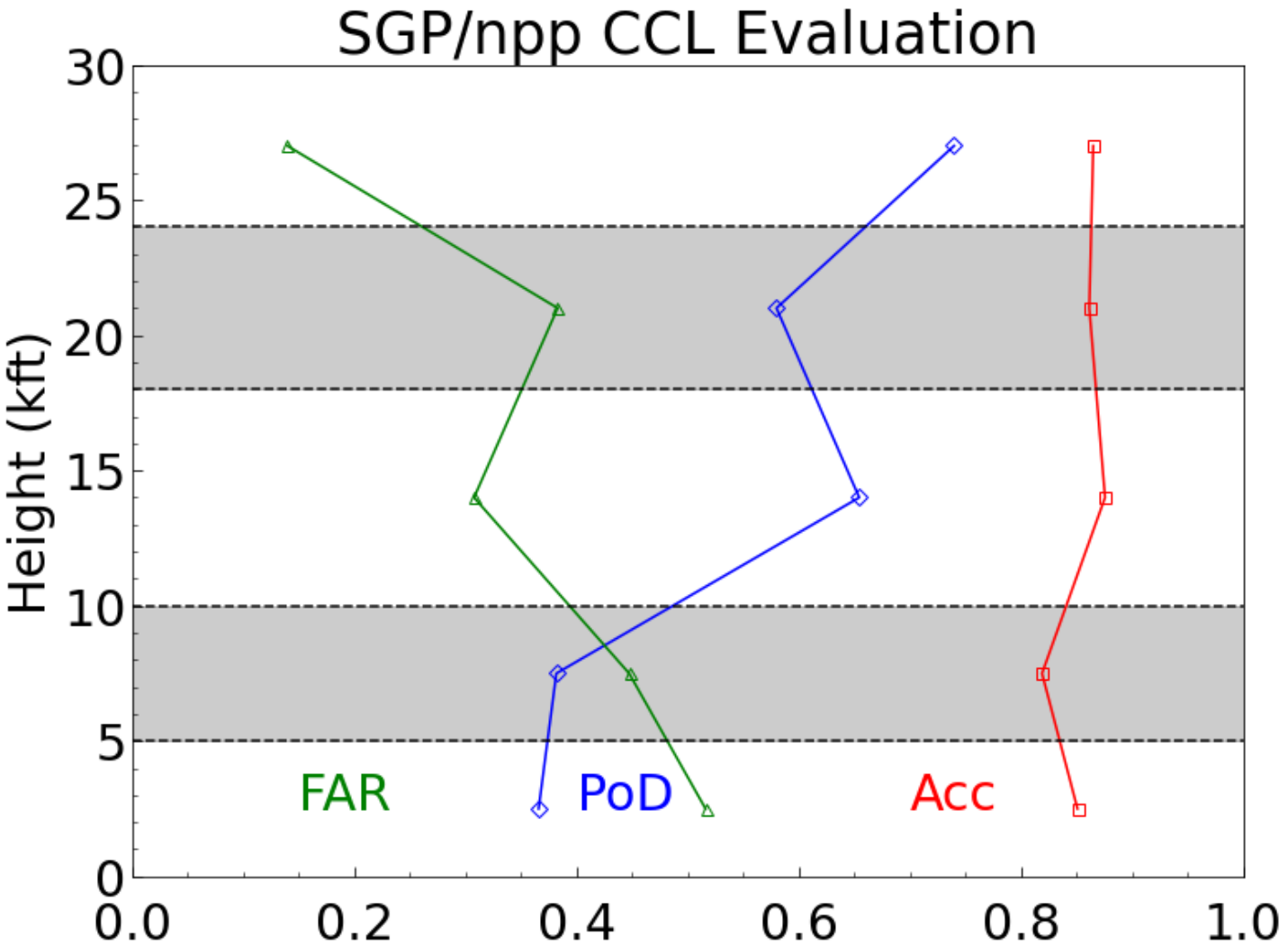

*Still included radar first height gate in the analysis



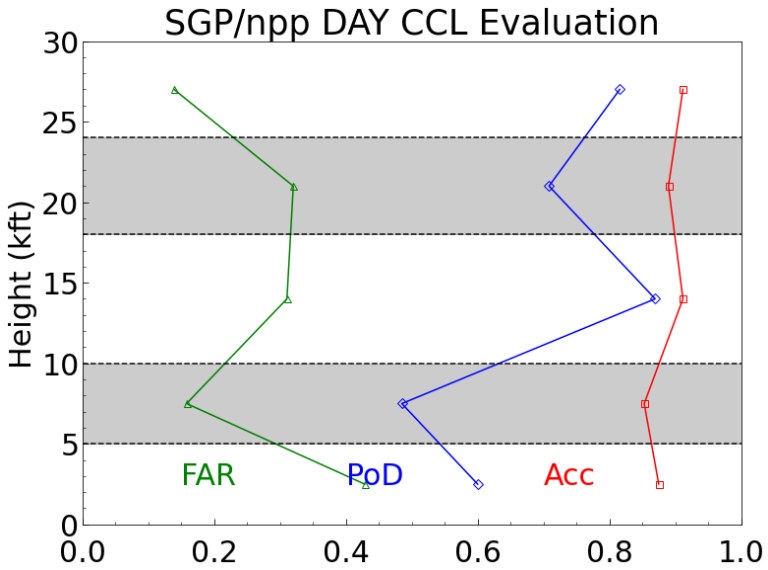



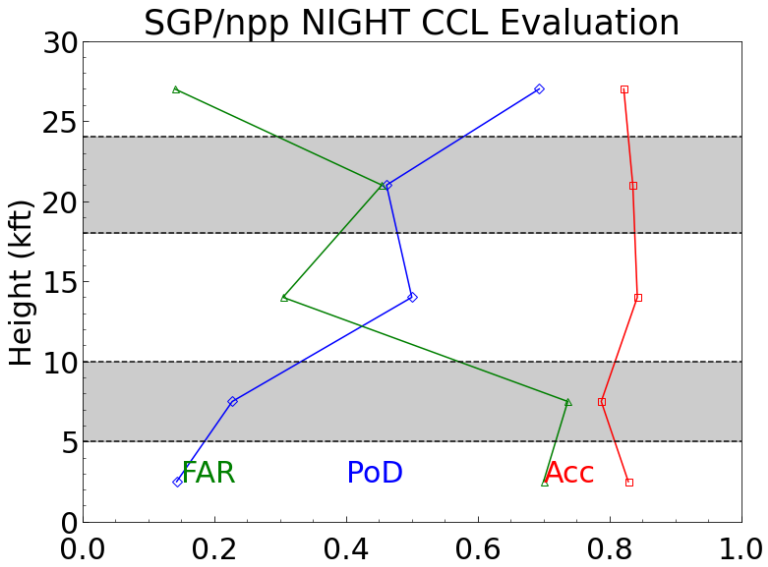
## *ARM SGP - S-NPP VIIRS*

CCL Flight Levels (ARM-SGP vs npp)




*Still included radar first height gate in the analysis

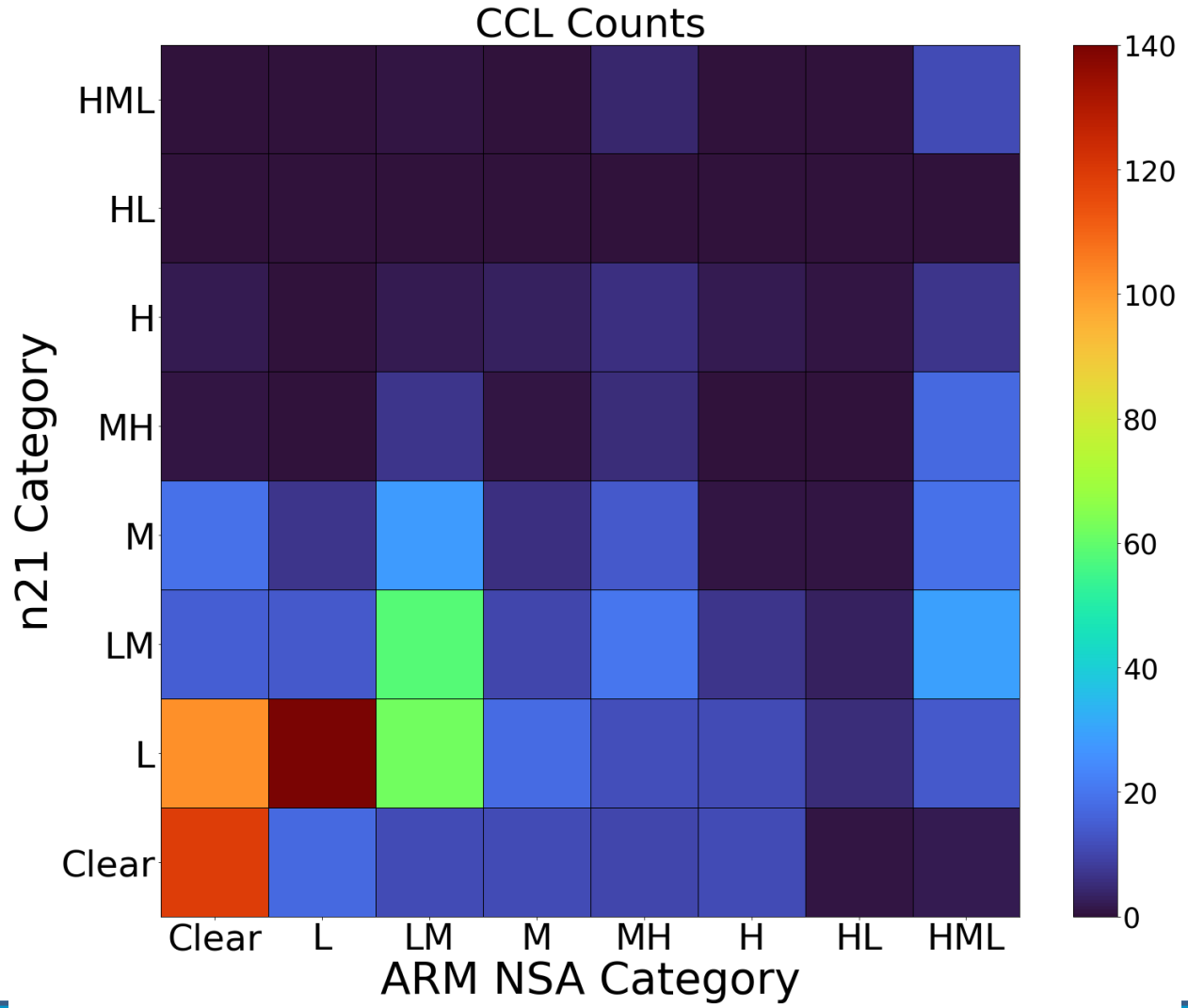


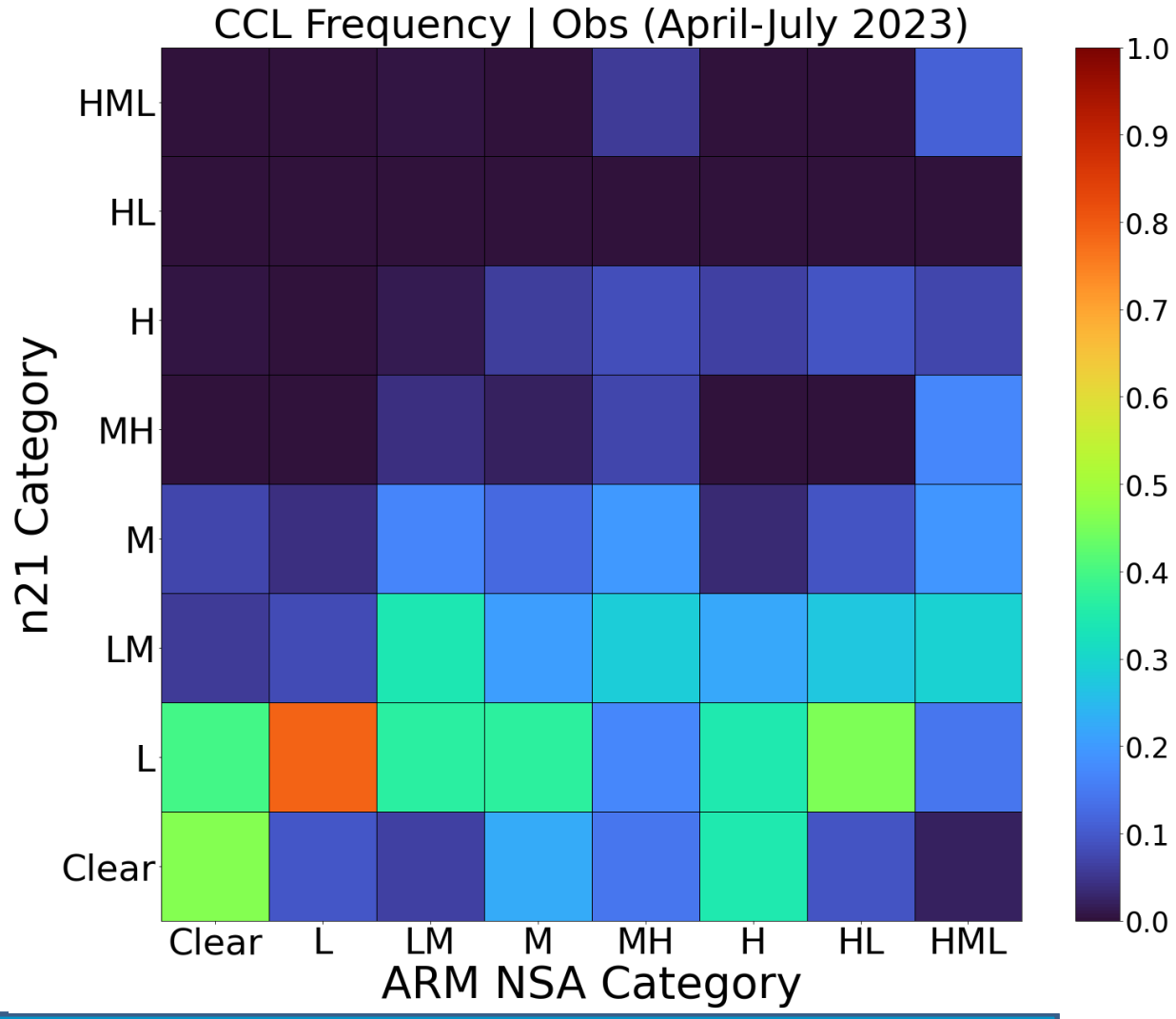



Radar comparison

*Still included radar first height gate in the analysis

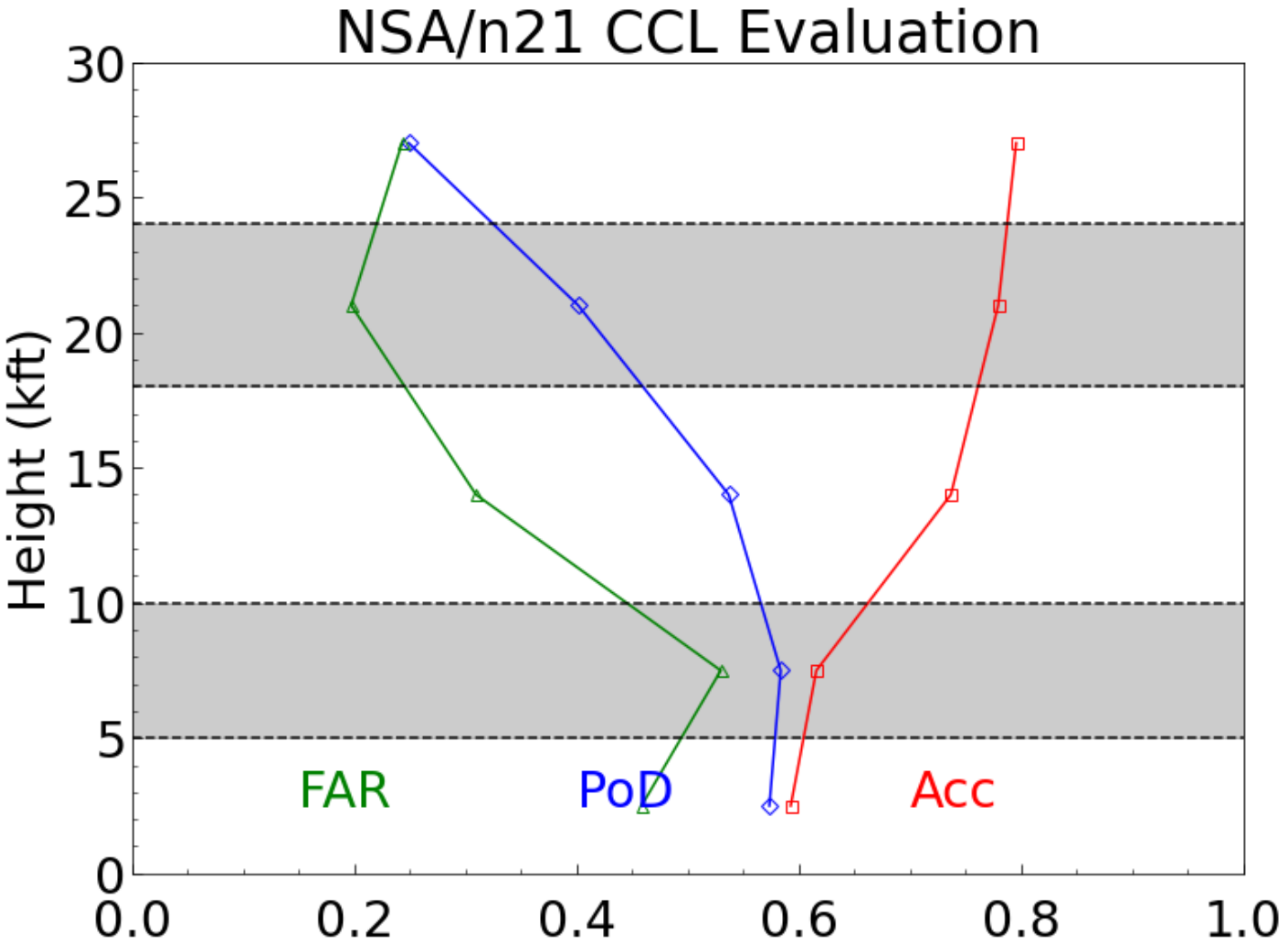
## CCL (ARM-NSA vs n21)



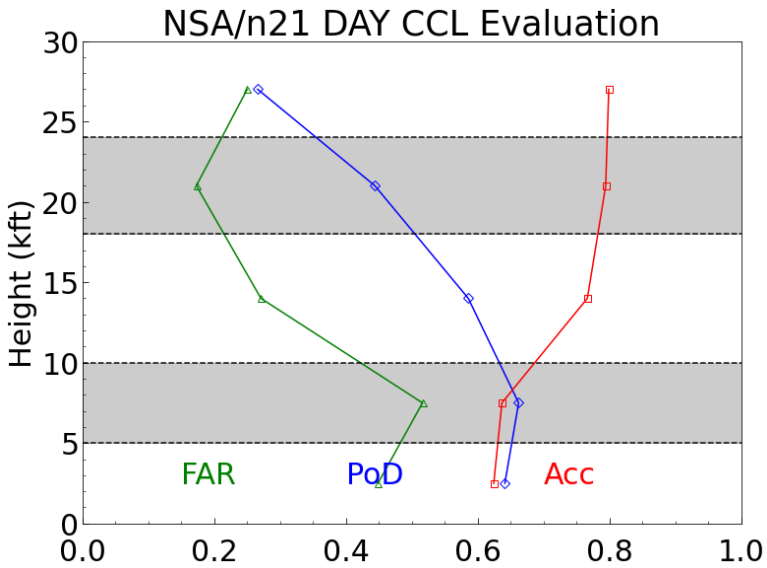



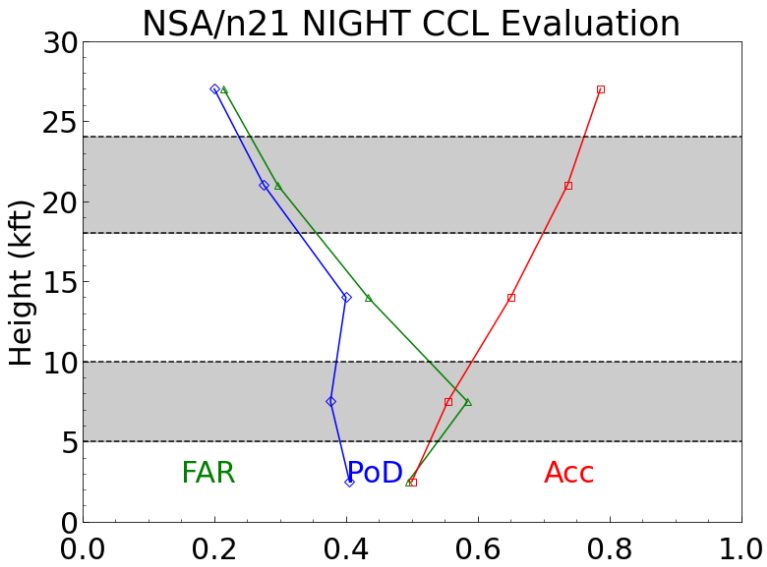
# *ARM NSA - NOAA-21 VIIRS*

CCL Flight Levels (ARM-NSA vs n21)



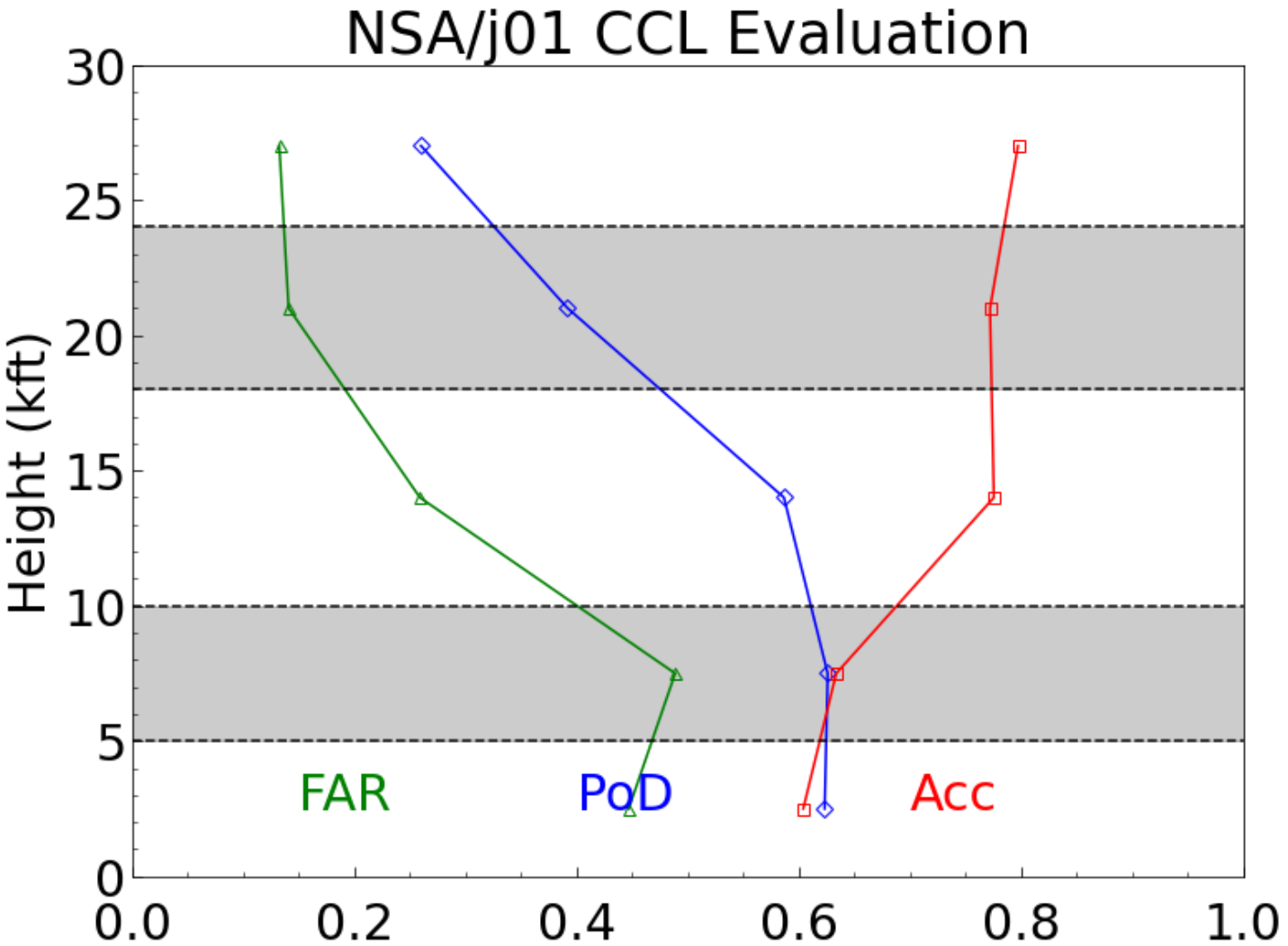

*Still included radar first height gate in the analysis



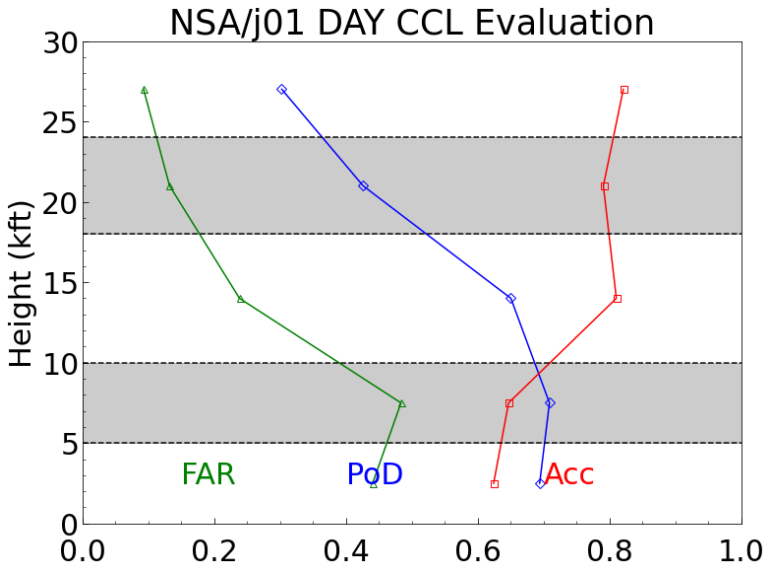



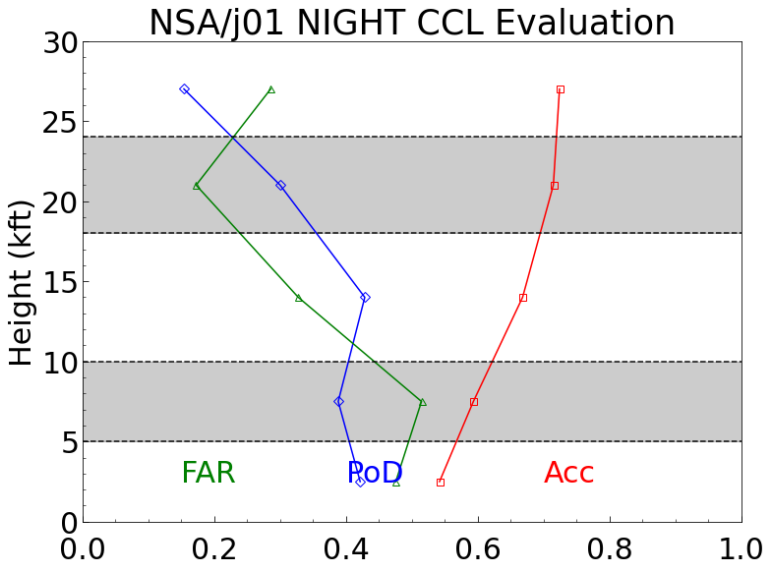
# *ARM NSA - NOAA-20 VIIRS*

CCL Flight Levels (ARM-NSA vs n20)



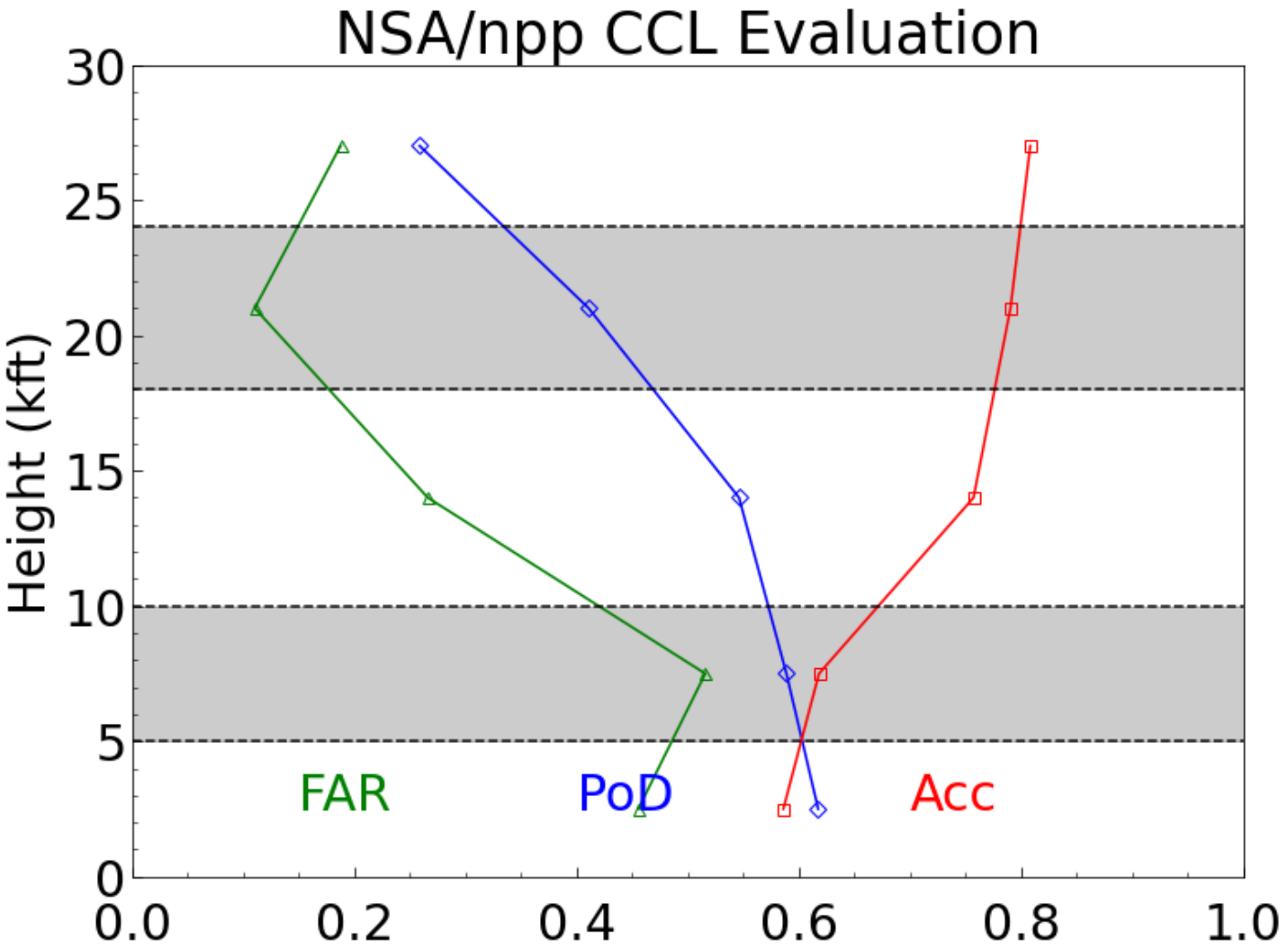

*Still included radar first height gate in the analysis



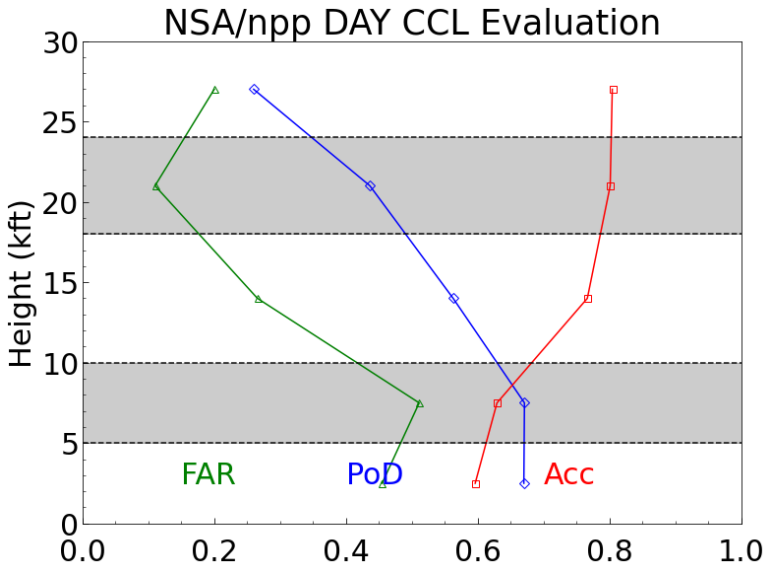



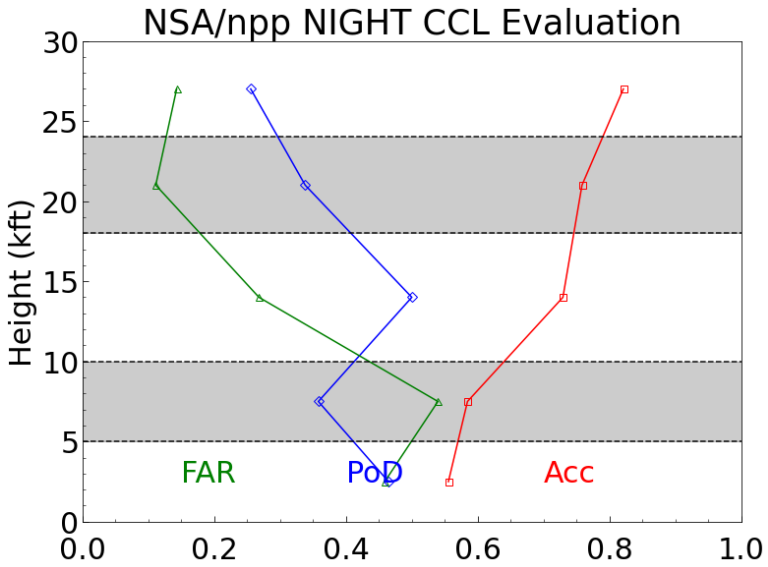
## *ARM NSA - S-NPP VIIRS*

CCL Flight Levels (ARM-NSA vs npp)




*Still included radar first height gate in the analysis



# Error Budget

## CBH

| Attribute Analyzed | DPS | Requirement /Threshold | Pre-Launch Performance | On-orbit Performance | | | Meet Requirement? | Additional Comments |
|---|---|---|---|---|---|---|---|---|
| | | | | NOAA-21 | NOAA-20 | S-NPP | | |
| Accuracy | 485 | 2 km (COT >= 1)<br>3 km (COT < 1) | - | **1.37**<br>**(single: 1.20)** | 1.45<br>(single: 1.14) | 1.58<br>(single: 1.29) | **Yes**<br>(all clouds including multilayers) | Represents values combined from ARM radar/lidar evaluations (Apr-Jul 2023) |
| Precision | 482 | 2 km (COT >= 1)<br>3 km (COT < 1) | - | **1.78**<br>**(single: 1.54)** | 2.01<br>(single: 1.46) | 2.22<br>(single:1.74) | **Yes**<br>**for N21** | Represents values obtained from radar and lidar evaluations (Apr-Jul 2023)<br><br>Limited eval data resources for a short time period (N20/NPP completed full-maturity)<br><br>Will improve eval for longer time period with multi data resources |

- Metrics shown represent the range of error statistics (MAE, RMSE) determined from the “all clouds” including multilayers or “single-layer clouds” from “within-spec” analyses conducted at ARM sites (SGP and NSA), showing combined values of the radar and lidar evaluations.

# Error Budget

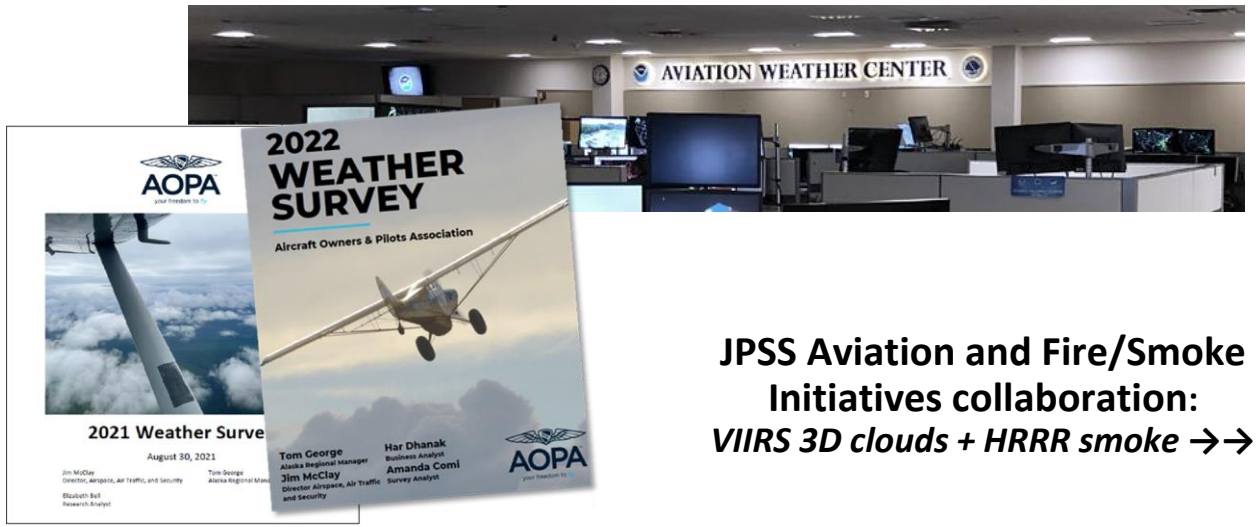
## CCL

| Attribute Analyzed | DPS | Requirement /Threshold | Pre-Launch Performance | On-orbit Performance | | | Meet Requirement? | Additional Comments |
|---|---|---|---|---|---|---|---|---|
| | | | | NOAA-21 | NOAA-20 | S-NPP | | |
| Accuracy | | 60% correct classification | - | 5 Layers: ~ 60–90%<br><br>Total: 69% - phase match 75% - phase match and single layer | 5 Layers: ~ 60–90% | 5 Layers: ~ 60–90% | Yes | Represents scores from ARM radar evaluations (Apr-Jul 2023) and CALIPSO (9 days May-Jun 2023) |

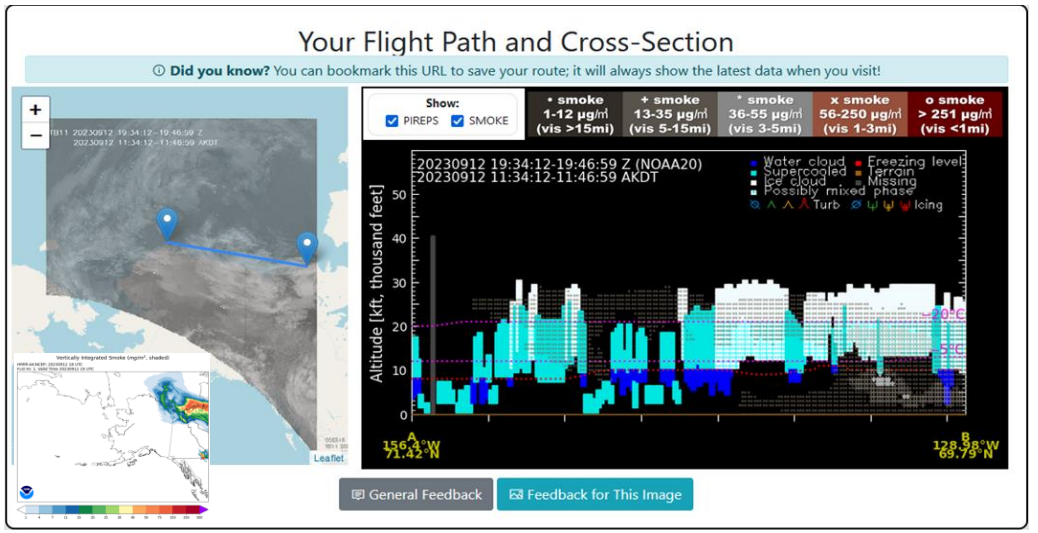
- Metrics represent the range of correct classifications for five flight-level based layers determined from radar analyses at the ARM sites (SGP and NSA). These numbers are consistent with the correct classification percentages determined from CALIPSO lidar-based validation for N21 (which also includes a total layer classification analysis).
- Precision - not specified

# User Feedback

| Name | Organization | Application | User Feedback |
|---|---|---|---|
| T. Higginbotham<br>A. Terborg | AWC | Cloud data monitoring/ preview before ABI CCL operation | Introduced the new satellite cloud products providing vertical cloud layer information beyond 2D imagery for forecasters |
| D. Uden<br>M. Wandishin | NOAA GSL | NWP model assessment | Using cloud top/base to examine NOAA's Rapid Refresh Forecast System (RRFS) model fields |
| T. George<br>A. White | AOPA, Alaska Airmen Assoc. | Cloud status overview for daily flight plan as supplementary data | Using VIIRS cloud data and cross-sections through CIRA's website, actively providing feedback for product improvement |
| P. Suffern | NTSB | Aircraft accident case investigation | Additional data source over data-sparse regions - AK |




**JPSS Aviation and Fire/Smoke Initiatives collaboration:**
***VIIRS 3D clouds + HRRR smoke →→***




**https://aviation.cira.colostate.edu**

# Downstream Product Feedback

| Algorithm | Product | Downstream Product Feedback<br>- Reports from downstream product teams on the dependencies and impacts |
|---|---|---|
| Cloud Base Height (CBH) | Cloud Cover Layers (CCL) | - Refined increasing lower level cloud fractions hidden under cloud top<br>- Need improvements for multilayered clouds |

# Risks, Actions, and Mitigations

- Provide updates for the status of the risks/actions identified during the previous maturity review(s); add new ones as needed

| Identified Risk | Description | Impact | Action/Mitigation and Schedule |
|---|---|---|---|
| Limited validation data | CloudSat and CALIPSO stopped operation, which have been providing critical information especially for cloud base and lower level clouds | Moderate | Still limited but will maximize the use of surface observations and continue to find more data resources (field campaigns, MRMS, GPM, upcoming EarthCARE) |
| Upstream cloud retrieval update | Cloud mask, ACHA cloud top, COMP algorithm changes directly impact on CBH and CCL performance | Moderate | Will continue monitoring the algorithm update status in collaboration with other cloud teams and address any changes in product eval. |

# Documentations (Check List)

| Science Maturity Check List | Yes ? |
|---|---|
| ReadMe for Data Product Users | Will be completed after the review |
| Algorithm Theoretical Basis Document (ATBD) | Yes<br>(will update for the Enterprise ATBD) |
| Algorithm Calibration/Validation Plan | Yes, but will update as requested<br>(the latest submitted in May 2020 for all JPSS including J2) |
| (External/Internal) Users Manual<br>*- User Quick Guides (CBH / CCL / CVC-cross-sections)* | Yes<br>(will add as requested) |
| System Maintenance Manual (for ESPC products) | Will be completed by OSPO |
| Peer Reviewed Publications<br>(Demonstrates algorithm is independently reviewed) | Yes |
| Regular Validation Reports (at least annually)<br>(Demonstrates long-term performance of the algorithm) | Will provide as requested |

# Check List - Provisional Maturity

| Beta/Provisional Maturity End State | Assessment |
|---|---|
| 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. | Yes |
| Product analyses are sufficient for qualitative, and limited quantitative, determination of product fitness-for-purpose. | Yes |
| Documentation of product performance, testing involving product fixes, identified product performance anomalies, including recommended remediation strategies, exists. | Will be completed after review |
| Product is recommended for potential operational use (user decision) and in scientific publications after consulting product status documents. | Yes |

# Provisional Maturity Conclusions

- The Cloud Team recommends that the NOAA-21 Cloud Base Height and Cloud Cover Layers products reach **Beta and Provisional** maturity status.

- Effective date:  March 30, 2023

# Conclusion

- Visual and quantitative assessments for VIIRS CBH and CCL products were conducted and checked all meet requirement
  - Lower level cloud validation is challenging with limited eval data resources (no more CloudSat/CALIPSO)
  - Quantitative assessments against 4-month ARM ground radar/lidar/ceilometer measurements and global CALIPSO case studies confirm that CBH and CCL products perform normally, best for single layer clouds
  - Upstream cloud product errors (CM, ACHA cloud top height, DCOMP) directly affect CBH and CCL performance
  - “Invalid CBH” pixels when CTH is valid - primarily due to no valid CWP input
  - Sometimes blocky features in nighttime CBH from NWP-CWP input for all three VIIRS -> need to further examine NWP data remapping/smoothing parts
- Further improvements on science algorithms will continue particularly for multilayers and nighttime products, and more user-oriented product demonstrations / user guidance materials will be pursued, actively interacting with users

# Path Forward

- The CBH (v3r2) and CCL (v2r0) algorithms with NOAA-21 VIIRS are working normally as long as upstream cloud retrievals and supplementary NWP data are valid
- Further improvements
  - *Nighttime*: further assessment for with/without DNB (near full moon), explore potentials to use AI-based CWP input for CBH
  - *Multilayers*: assessment of experimental lower layer CBH based on NWP condensation levels and adiabatic lapse rate data along with ACHA multilayer update (CrIS/NUCAPS), leverage AI/ML schemes (CIRA's GOES-R work - *Haynes et al. 2022*)
  - Evaluation of additional output (supercooled and convective layers), potentially utilizing ARM MW+radar LWC, NUCAPS/NWP temp, MRMS, and GPM L2 (convective vs. stratiform flag) data
  - Future possibility: explore Oxygen-A band use from EPS-SG METImage
- For "Full Maturity": continue to collect and perform longer-period product assessment, including regional/seasonal variations