Provisional Maturity Science Review For NOAA-20 Temperature, Water Vapor and Ozone

Beta Maturity Science Review for NOAA-20 Carbon Trace Gases

Presented by Antonia Gambacorta on behalf of the NUCAPS team

Date: 2018/06/15

PROVISIONAL MATURITY REVIEW MATERIAL for NOAA-20 Temperature, Water Vapor and Ozone

BETA MATURITY REVIEW MATERIAL for NOAA-20 Carbon Trace gases and OLR

Outline

- Algorithm Cal/Val Team Members
- Product Requirements
- Evaluation of algorithm performance to specification requirements
  - Evaluation of the effect of required algorithm inputs
  - Quality flag analysis/validation
  - Error Budget
- Identification of Processing Environment
- User Feedback
- Downstream Product Feedback
- Documentations (Science Maturity Check List)
- Conclusion
- Path Forward

NOAA-20 Algorithm Cal/Val Team

Name	Organization	Major Task
Lihang Zhou	STAR	Team Lead
Antonia Gambacorta	STC	Science Lead
Nick Nalli	IMSG	Validation Lead
Changyi Tan	IMSG	Team Member
Flavio Iturbide-Sanchez	IMSG	Team Member
Cally Bloch	IMSG	Team member
Mike Wilson	IMSG	Team Member
Juying Warner	Univ. of Maryland, CP	Team Member
Larrabee Strow	Univ. Of Maryland, BC	Team Member
Chris Barnet	STC	Collaborator
Tony Reale	STAR	Collaborator
Lori Borg	Univ. Of Wisconsin	Collaborator

JPSS Specification Performance Requirements
CrIS/ATMS Temperature and Moisture Profile EDR Uncertainty

CrIS/ATMS Atmospheric Vertical Temperature Profile (AVTP) Measurement Uncertainty – Layer Average Temperature Error	
PARAMETER	**REQUIREMENTS**
AVTP, Cloud fraction < 50%, surface to 300 hPa	1.6 K / 1-km layer
AVTP, Cloud fraction < 50%, 300–30 hPa	1.5 K / 3-km layer
AVTP, Cloud fraction < 50%, 30–1 hPa	1.5 K / 5-km layer
AVTP, Cloud fraction < 50%, 1–0.5 hPa	3.5 K / 5-km layer
AVTP, Cloud fraction ≥ 50%, surface to 700 hPa	2.5 K / 1-km layer
AVTP, Cloud fraction ≥ 50%, 700–300 hPa	1.5 K / 1-km layer
AVTP, Cloud fraction ≥ 50%, 300–30 hPa	1.5 K / 3-km layer
AVTP, Cloud fraction ≥ 50%, 30–1 hPa	1.5 K / 5-km layer
AVTP, Cloud fraction ≥ 50%, 1–0.5 hPa	3.5 K/ 5-km layer

CrIS/ATMS Atmospheric Vertical Moisture Profile (AVMP) Measurement Uncertainty – 2-km Layer Average Mixing Ratio % Error	
PARAMETER	**REQUIREMENTS**
AVMP, Cloud fraction < 50%, surface to 600 hPa	Greater of 20% or 0.2 $g \cdot kg^{-1}$ / 2-km layer
AVMP, Cloud fraction < 50%, 600–300 hPa	Greater of 35% or 0.1 $g \cdot kg^{-1}$ / 2-km layer
AVMP, Cloud fraction < 50%, 300–100 hPa	Greater of 35% or 0.1 $g \cdot kg^{-1}$ / 2-km layer
AVMP, Cloud fraction ≥ 50%, surface to 600 hPa	Greater of 20% of 0.2 $g \cdot kg^{-1}$ / 2-km layer
AVMP, Cloud fraction ≥ 50%, 600–400 hPa	Greater of 40% or 0.1 $g \cdot kg^{-1}$ / 2-km layer
AVMP, Cloud fraction ≥ 50%, 400–100 hPa	Greater of 40% or 0.1 $g \cdot kg^{-1}$ / 2-km layer

"Clear to Partly-Cloudy"
(Cloud Fraction < 50%)
⇕
IR retrieval

"Cloudy"
(Cloud Fraction >= 50%)
⇕
MW-only retrieval

Global requirements defined for lower and upper atmosphere subdivided into 1-km and 2-km layers for AVTP and AVMP, respectively.

Source: (L1RD, 2014, pp. 41, 43)

CrIS Infrared Trace Gases Specification Performance Requirements	
PARAMETER	**REQUIREMENTS**
O_3 (Ozone) Profile Precision, 4–260 hPa (6 statistic layers)	20%
O_3 (Ozone) Profile Precision, 260 hPa to sfc (1 statistic layer)	20%
O_3 (Ozone) Profile Accuracy, 4–260 hPa (6 statistic layers)	±10%
O_3 (Ozone) Profile Accuracy, 260 hPa to sfc (1 statistic layer)	±10%
O_3 (Ozone) Profile Uncertainty, 4–260 hPa (6 statistic layers)	25%
O_3 (Ozone) Profile Uncertainty, 260 hPa to sfc (1 statistic layer)	25%
CO (Carbon Monoxide) Total Column Precision	15% (CrIS FSR)
CO (Carbon Monoxide) Total Column Accuracy	±5% (CrIS FSR)
CO_2 (Carbon Dioxide) Total Column Precision	0.5% (2 ppmv)
CO_2 (Carbon Dioxide) Total Column Accuracy	±1% (4 ppmv)
CH_4 (Methane) Total Column Precision	1% (≈20 ppbv)
CH_4 (Methane) Total Column Accuracy	±4% (≈80 ppmv)

Source:
(L1RD, 2014, pp. 45-49)

JPSS Data Products Maturity Definition

JPSS/GOES-R Data Product Validation Maturity Stages – COMMON DEFINITIONS (Nominal Mission)
1. <u>Beta</u> o Product is minimally validated, and may still contain significant identified and unidentified errors. o Information/data from validation efforts can be used to make initial qualitative or very limited quantitative assessments regarding product fitness-for-purpose. o Documentation of product performance and identified product performance anomalies, including recommended remediation strategies, exists.
2. <u>Provisional</u> o 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. o Product analyses are sufficient for qualitative, and limited quantitative, determination of product fitness-for-purpose. o Documentation of product performance, testing involving product fixes, identified product performance anomalies, including recommended remediation strategies, exists. o Product is recommended for potential operational use (user decision) and in scientific publications after consulting product status documents.
3. <u>Validated</u> o Product performance has been demonstrated over a large and wide range of representative conditions (i.e., global, seasonal). o 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. o Product analyses are sufficient for full qualitative and quantitative determination of product fitness-for-purpose. o Product is ready for operational use based on documented validation findings and user feedback. o Product validation, quality assurance, and algorithm stewardship continue through the lifetime of the instrument.

Status of NUCAPS:

- NUCAPS Temperature, water vapor and ozone have reached validated maturity
- In this review, we will compare NUCAPS NOAA-20 to SNPP Temperature, water vapor and ozone statistical results products to prove its readiness for provisional status.
- More in-depth analysis will be made as larger NOAA-20 validation ensembles will be acquired with time.
- We will show preliminary results of NOAA-20 NUCAPS carbon trace gases to prove beta maturity.

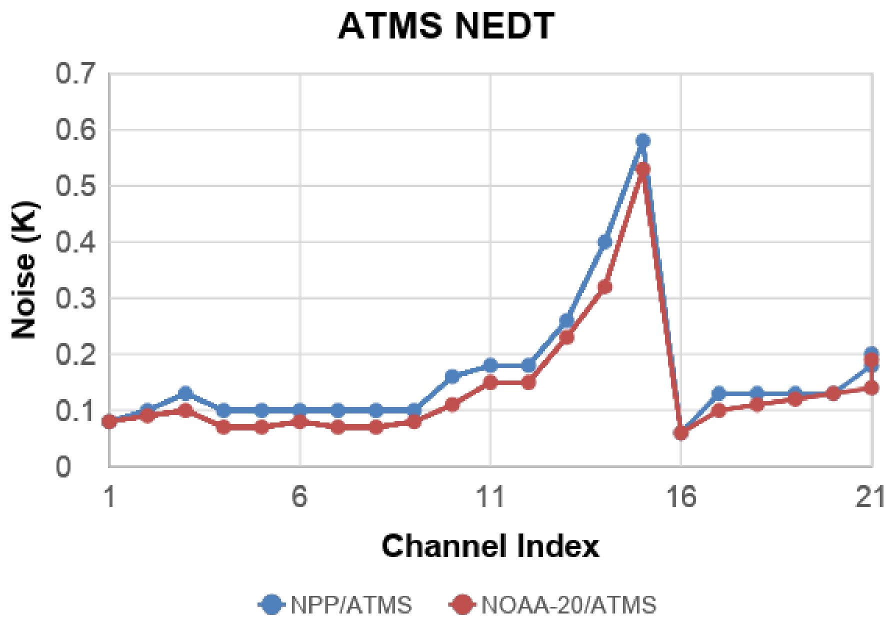
History of NUCAPS NOAA-20:

- **January 2018**: Operational SNPP NUCAPS applied to NOAA-20 – First Light Results
- **April 27 2018**: First DAP to ASSISTT – Implementation of NOAA-20 CrIS and ATMS NEDT; Base-lined SNPP, NOAA-20, MetOp NUCAPS system ported in the HEAP
- **June 22 2018**: Second DAP to ASSISTT – See next slide

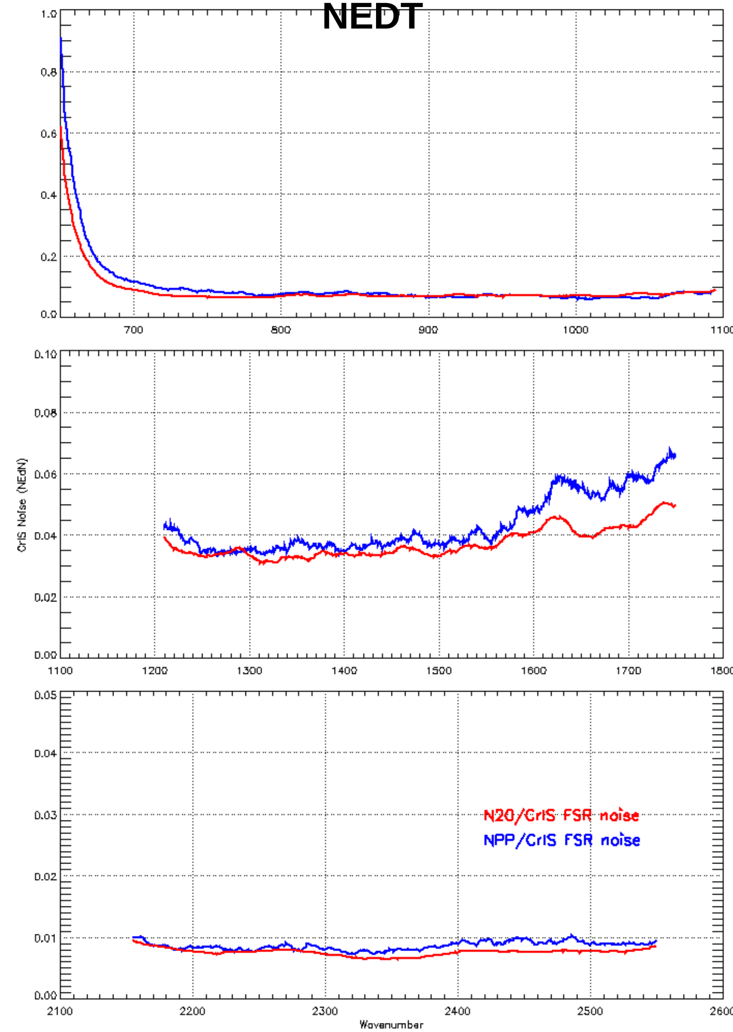
Improvements since last operational delivery approved by NUCAPS Phase 4 Algorithm Readiness Review (July 2017)

- **Algorithm Improvements**
  - An improved carbon monoxide quality control methodology (slide 17)
  - Work is in progress to improve training methodology of statistical regression by removing cloud contamination and supersaturation cases
  - Work is in progress to improve surface emissivity algorithm
- **LUT updates**
  - NOAA-20 CrIS and ATMS instrument noise files (slide 12)
  - Optimized temperature, water vapor, cloud clearing and carbon monoxide channel selection (slide 13 and 14)
  - An improved RTA bias correction in the carbon monoxide band (slide 15)
  - An improved carbon monoxide a priori climatology (slide 16)
  - Work in progress to improve methane and nitrous oxide retrieval modules

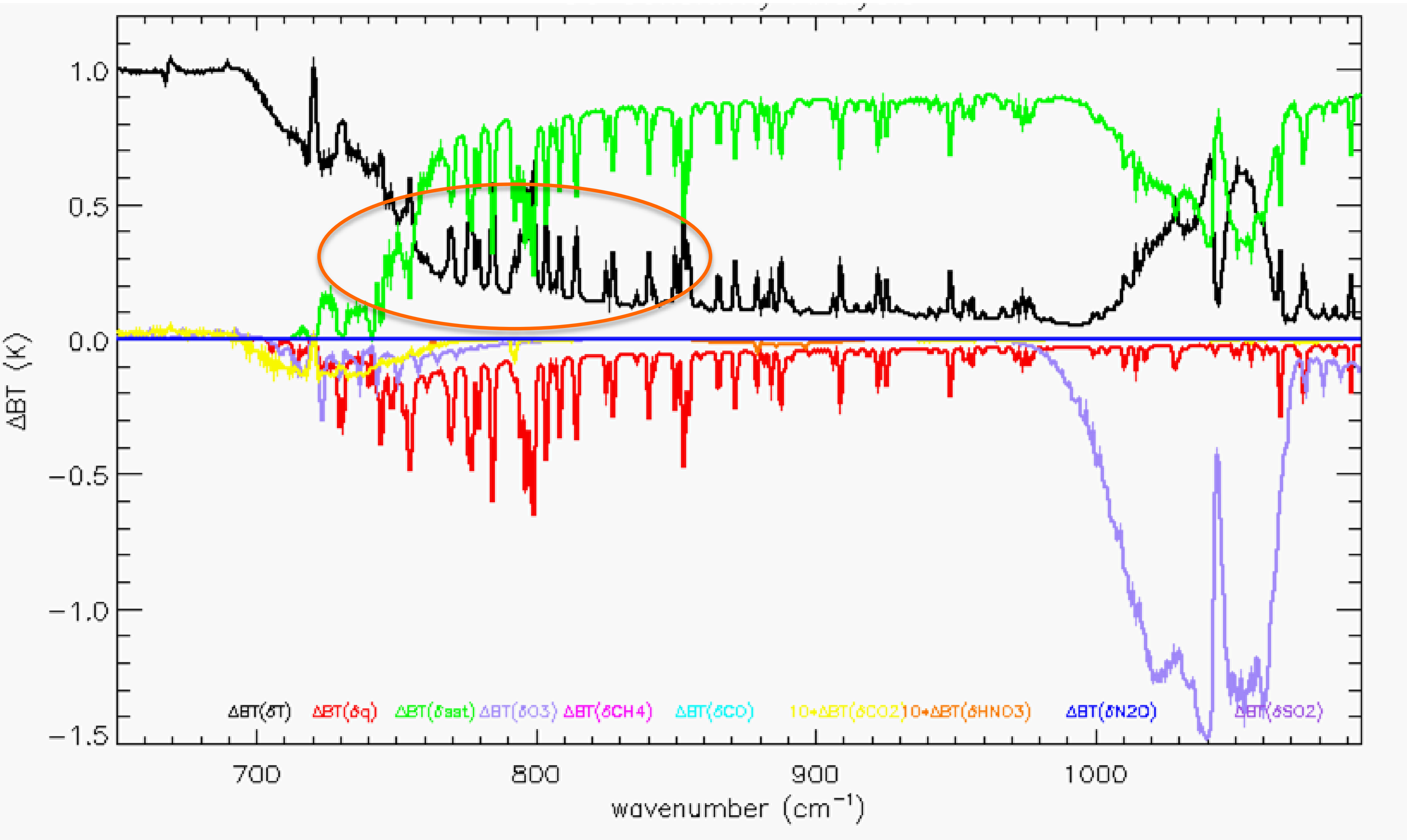
NOAA-20 CrIS and ATMS instrument noise files



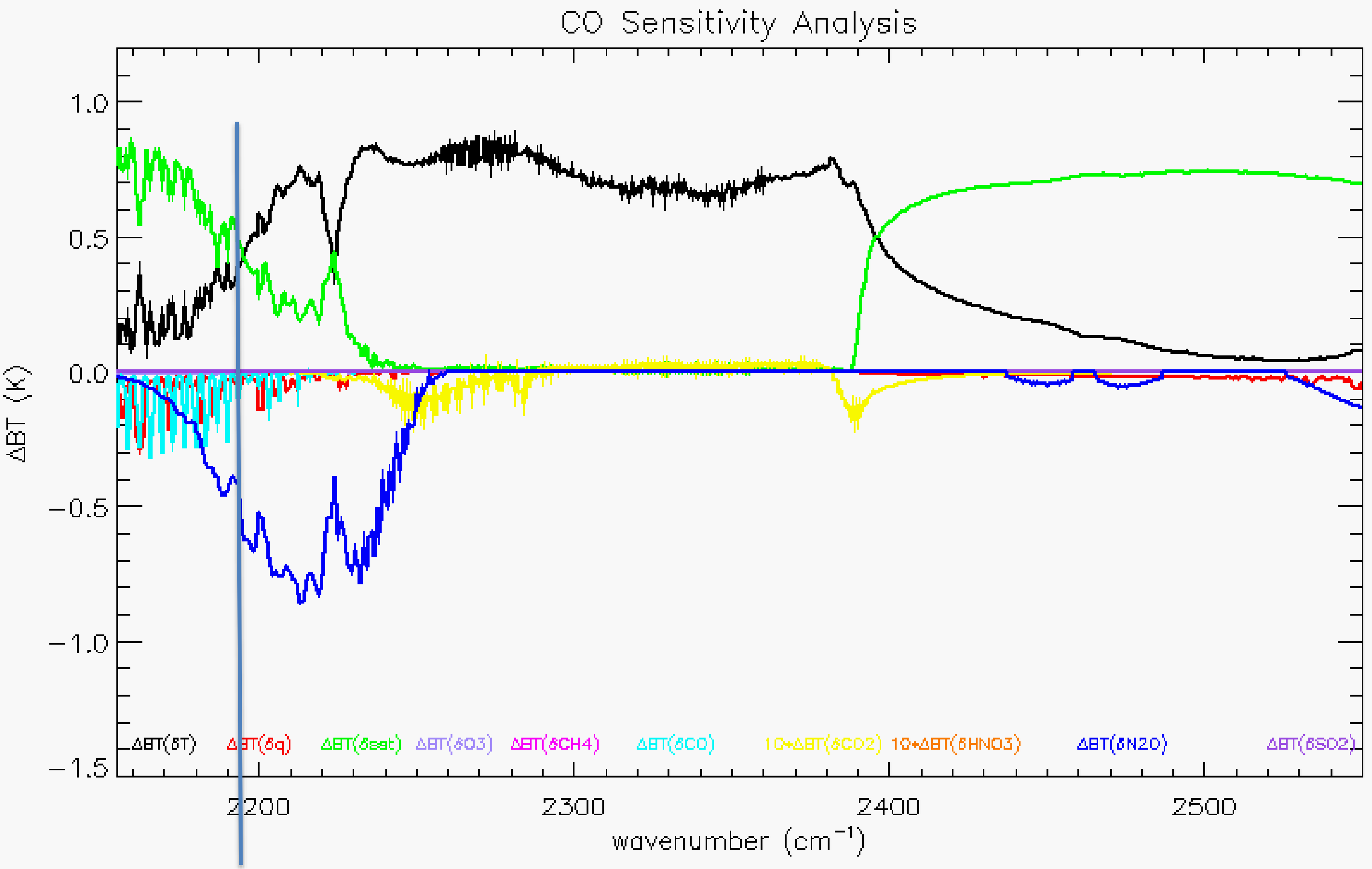
CrIS NEDT



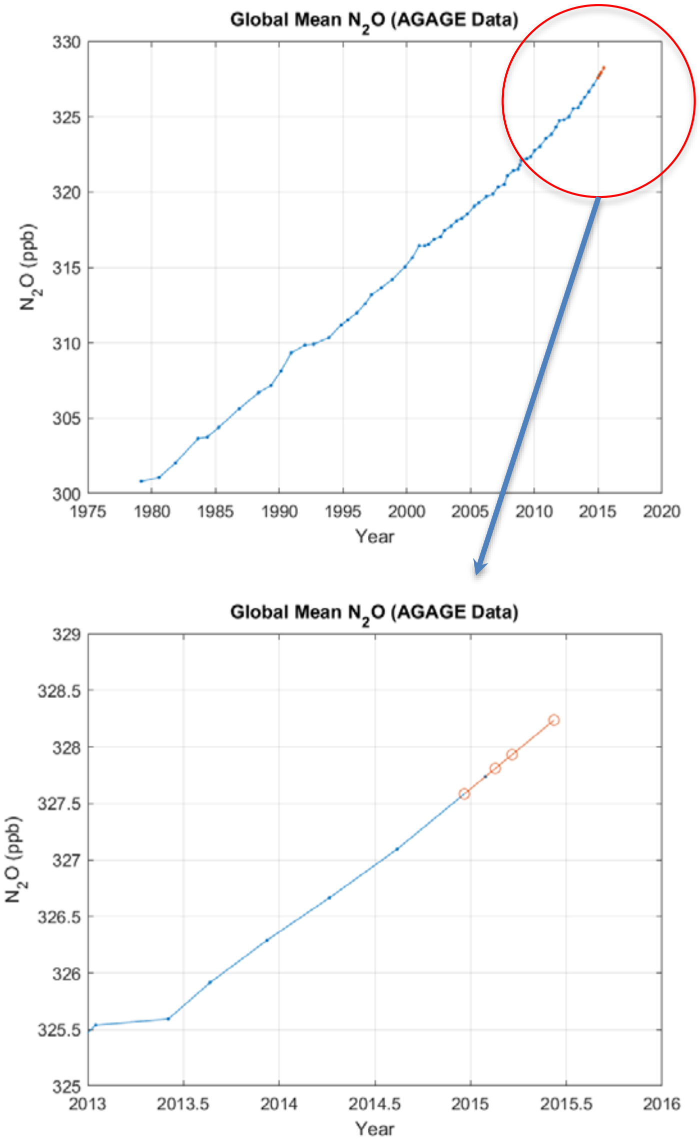
Optimized T, q, CCR channel selection

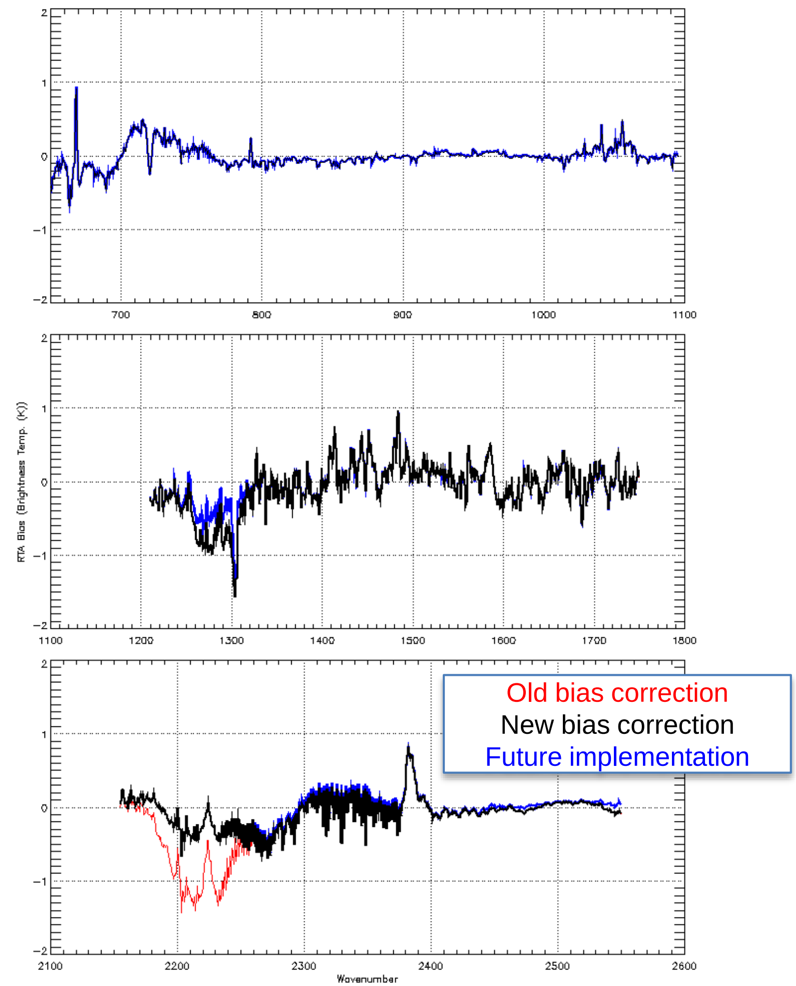


Optimized CO channel selection

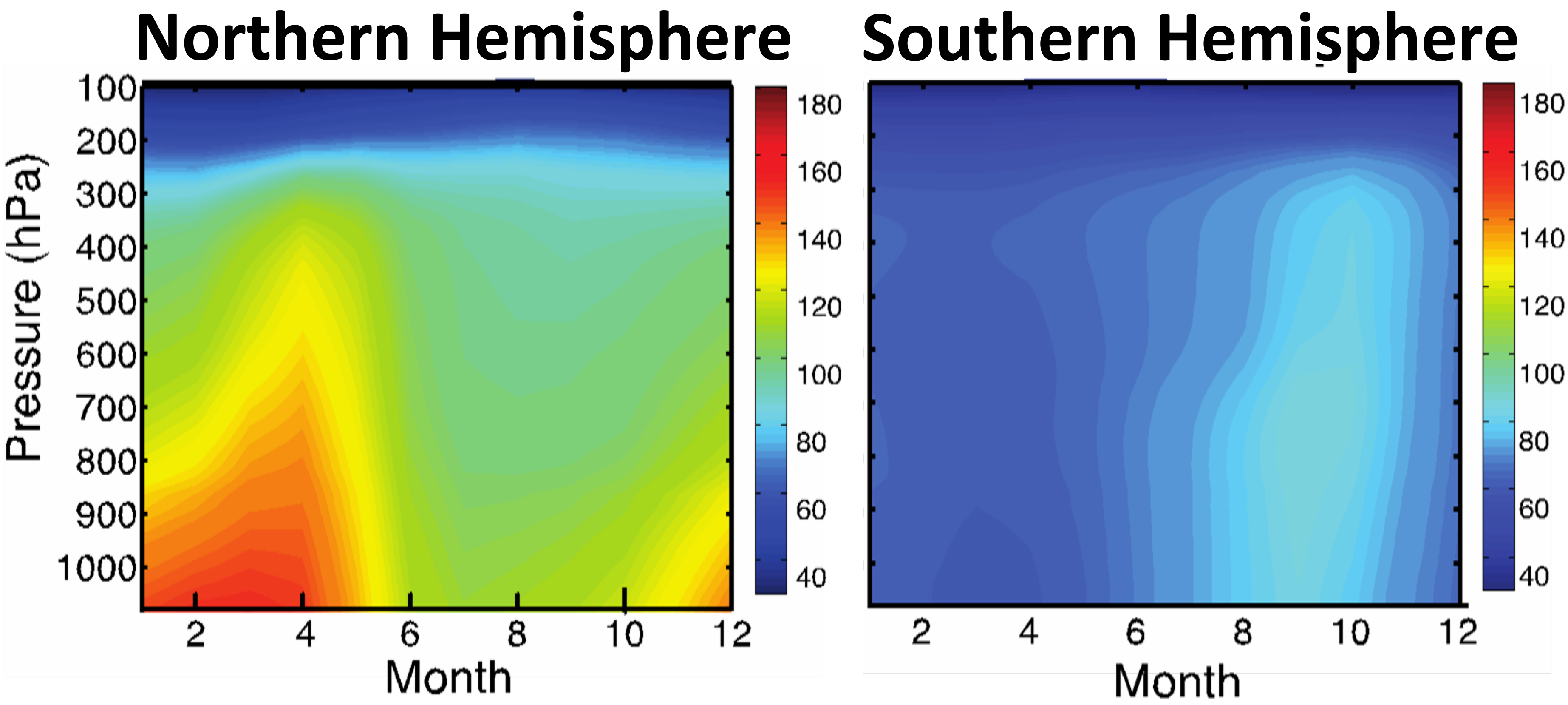


Optimized SARTA bias correction in the CO band



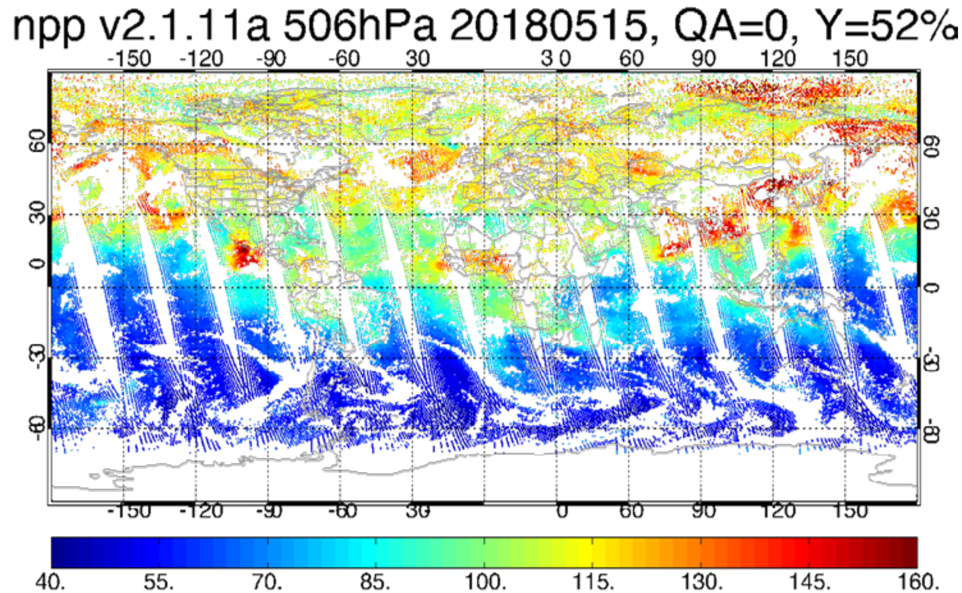


Improved carbon monoxide a priori climatology



- Two hemispheric CO profiles (ppbv) developed from NCAR MOZART-GEOS5 model;
- Linear transition between 15N and 15S;
- Monthly varying, but no year-to-year variations;
- Same approach as for AIRS, but updated to current values.

Reduced noise and cloud contaminations, but reduced yield



Module	Lower Limit	Upper Limit
Chi-square	0.0	1.0
DOFS	0.3	9.9
CO Retrievals	0.0	1.1
Cloud Amplifier Limit	0.3	1.8
Cloud-clearing residual	0.0	0.7
Number of iteration	0.0	5.0
Total cloud fraction	0.0	0.7

Validation Methodology Hierarchies

$T/H_2O/O_3$ Profiles

(e.g., *Nalli et al., JGR Special Section,* 2013)

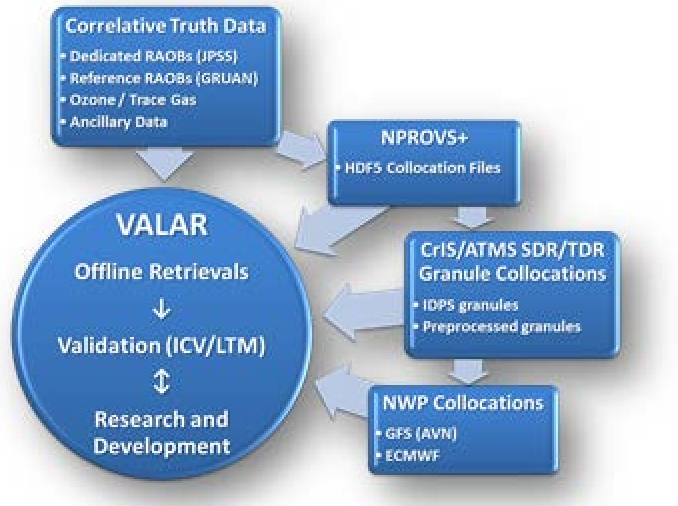
1. **Numerical Model (e.g., ECMWF, NCEP/GFS) Global *Comparisons***
   - Large, truly global samples acquired from Focus Days
   - Useful for sanity checks, bias tuning and regression
   - Limitation: Not independent truth data
2. **Satellite Sounder EDR (e.g., AIRS, ATOVS, COSMIC) *Intercomparisons***
   - Global samples acquired from Focus Days (e.g., AIRS)
   - Limitation: Similar error characteristics
3. **Conventional PTU/O3 Sonde Matchup *Assessments***
   - WMO/GTS operational sondes or O3-sonde network (e.g., SHADOZ)
   - Representation of global zones, long-term monitoring
   - Large samples after a couple months (e.g., *Divakarla et al.*, 2006; *Reale et al.* 2012)
   - Limitations: Skewed distributions; mismatch errors; non-uniform radiosondes, assimilated into NWP
4. **Dedicated/Reference PTU/O3 Sonde Matchup *Assessments***
   - *Dedicated* for the purpose of satellite validation
   - Reference sondes: CFH, **GRUAN** corrected RS92/RS41
   - E.g., **ARM sites** (e.g., *Tobin et al.*, 2006), **AEROSE**, **CalWater/ACAPEX**, BCCSO, PMRF
   - Limitation: Small sample sizes, geographic coverage
5. **Intensive Field Campaign *Dissections***
   - Include dedicated sondes, some *not* assimilated into NWP models
   - Include ancillary datasets, ideally funded aircraft campaign(s)
   - E.g., **SNAP, SNPP, AEROSE, CalWater**, JAIVEX, AWEX-G, EAQUATE

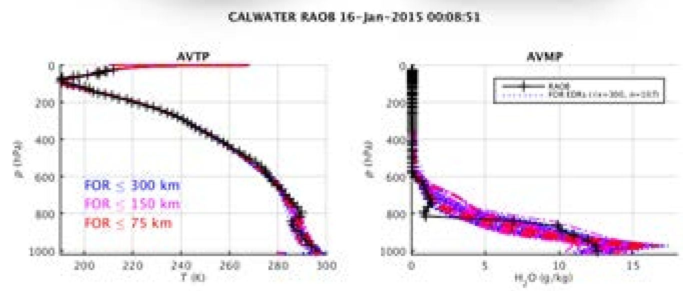
Carbon Trace Gases

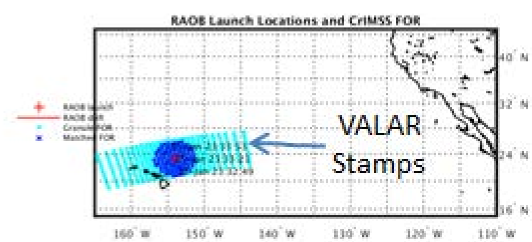
1. **Numerical Model Global *Comparisons***
   - Examples: **NOAA CarbonTracker** (*Lan et al.* 2017), **ECMWF**, NCEP/GFS
   - Large, truly global samples acquired from Focus Days
   - Limitation: Not independent truth data
2. **Satellite Sounder EDR *Intercomparisons***
   - Examples: **AIRS**, OCO-2, MLS
   - Global samples acquired from Focus Days (e.g., AIRS)
   - Limitation: Similar error characteristics
3. **Surface-Based Network Matchup *Assessments***
   - **Total Carbon Column Observing Network (TCCON)** spectrometers (*Wunch et al.* 2010, 2011)
   - **AirCore balloon-borne *in situ* profile observations** (*Membrive et al.* 2017)
   - Provide routine independent measurements representing global zones akin to RAOBs
   - Limitations: Small sample sizes, uncertainties in unit conversions, different sensitivities to atmospheric layers
4. **Intensive Field Campaign *In Situ* Data *Assessments***
   - Include ancillary datasets, ideally funded aircraft campaign(s)
   - E.g., **ATom**, **ACT-America**, FIREX, HIPPO

NOAA Validation Datasets and Tools

- **STAR Validation Archive (VALAR)**
  - Dedicated/reference and intensive campaign RAOBs
  - SDR/TDR granule-based collocations within 500 km radius acquired off SCDR (past 90 days) or CLASS (older than 90 days)
  - Carbon Trace Gas and O_3 EDR validation
  - Rigorous coarse-layer (1-km, 2-km) product performance measures based on statistical metrics corresponding to Level 1 Requirements as detailed in *Nalli et al.* (2013)
- **NOAA Products Validation System (NPROVS)** (*Reale et al.,* 2012)
  - Performs global RAOB collocations for multiple satellite platforms
    - Conventional WMO RAOBs
    - Dedicated/reference (*Sun et al.* 2017)
  - HDF5-formatted Collocation Files facilitates GRUAN RAOB matchups within VALAR
  - NRT monitoring capability
  - Satellite EDR intercomparison capability
  - Java based graphical user interface tools for monitoring (PDISP, NARCS, ODS)



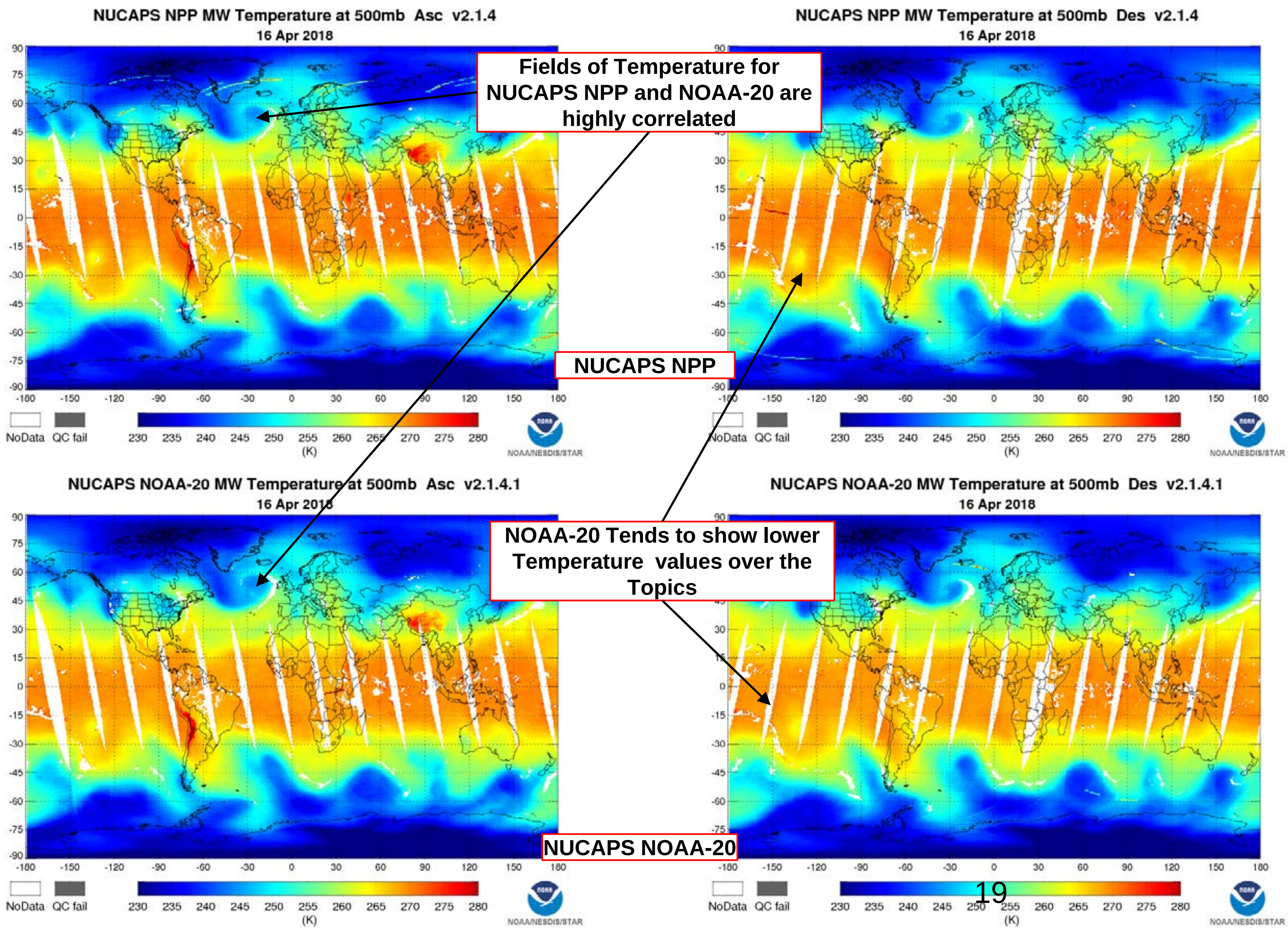




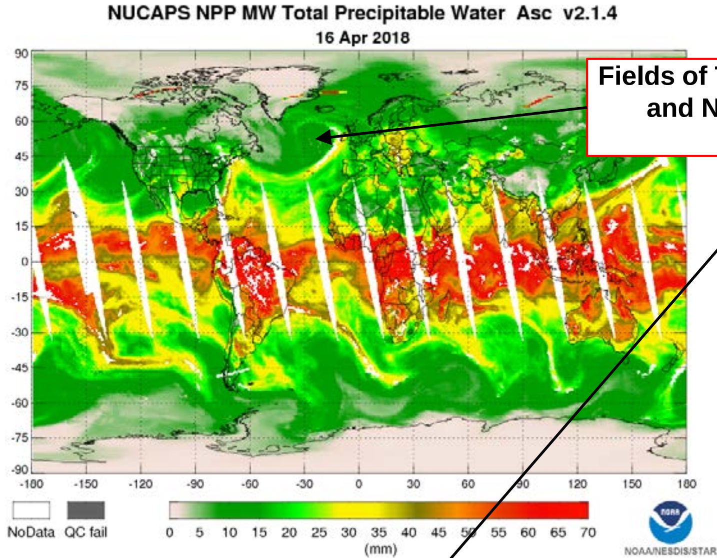
NUCAPS NOAA-20 & NPP AVTP and AVMP

PART I: MW-Only Temperature and Water Vapor

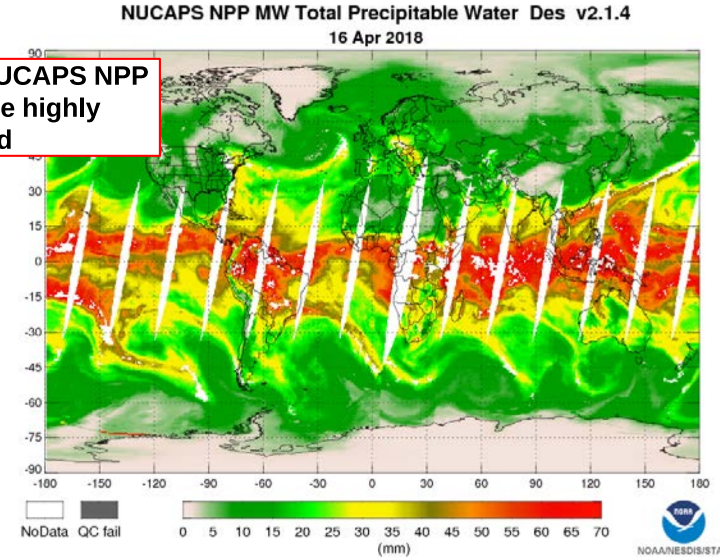
NUCAPS NPP and NOAA-20 MW-Only: Temperature at 500 hPa

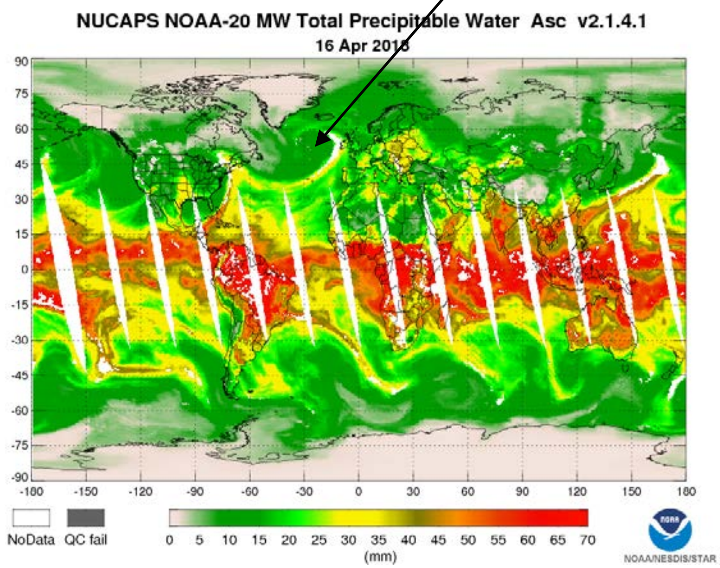


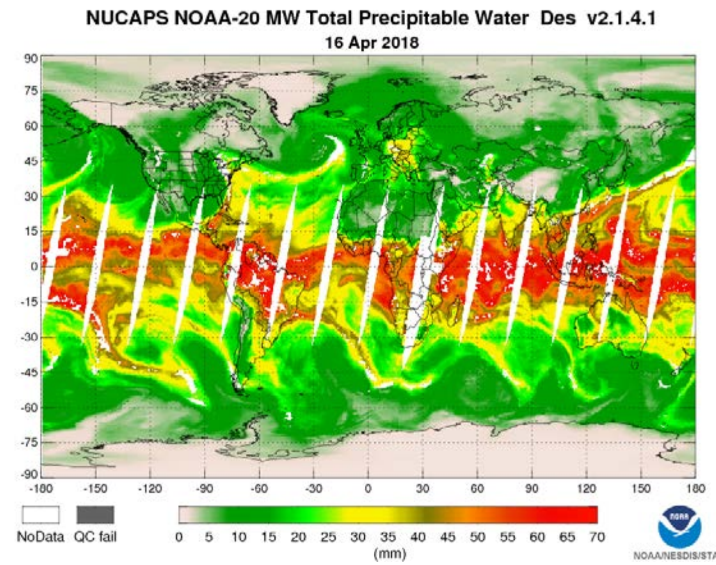
NUCAPS NPP and NOAA-20 MW-Only: TPW



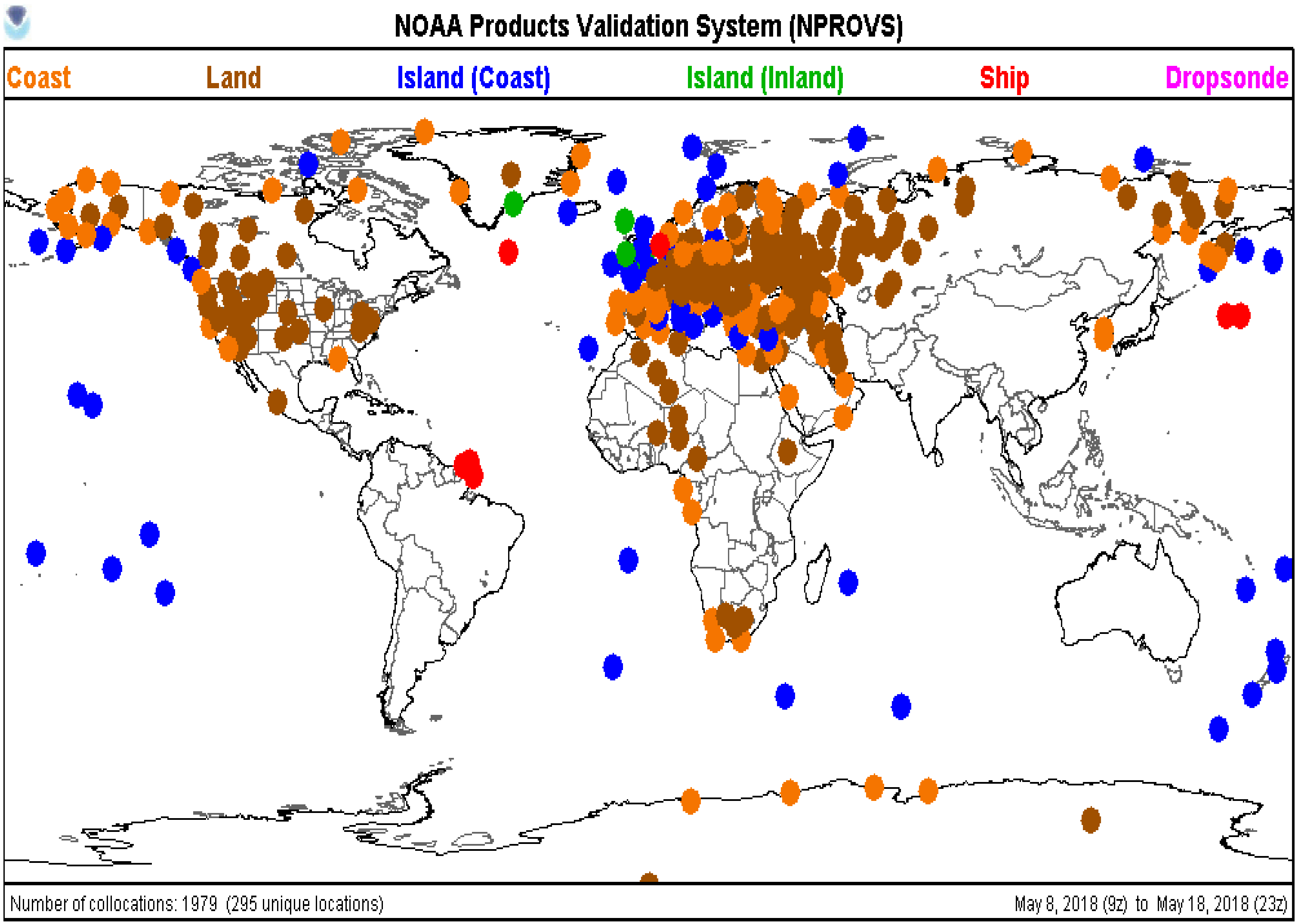
Fields of TPW for NUCAPS NPP and NOAA-20 are highly correlated





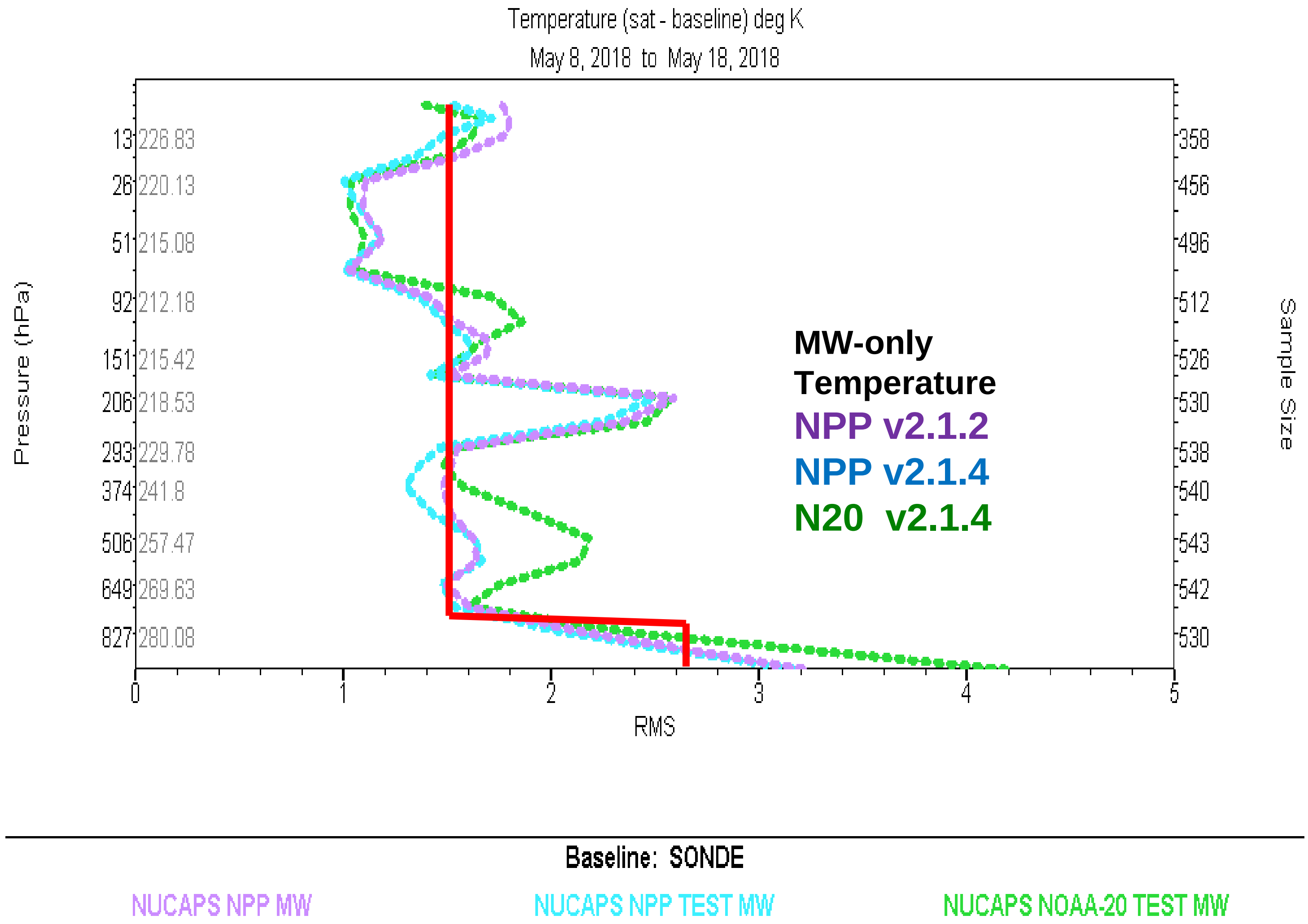


Comparison against conventional RAOBs using NPROVS



NPP 2.1.2, NPP 2.1.4 and N20 2.1.4 @ -2 to +3 hr, 50km

Comparison against conventional RAOBs using NPROVS



Sample: IR+MW Pass QC; -2,+3hr; 50km

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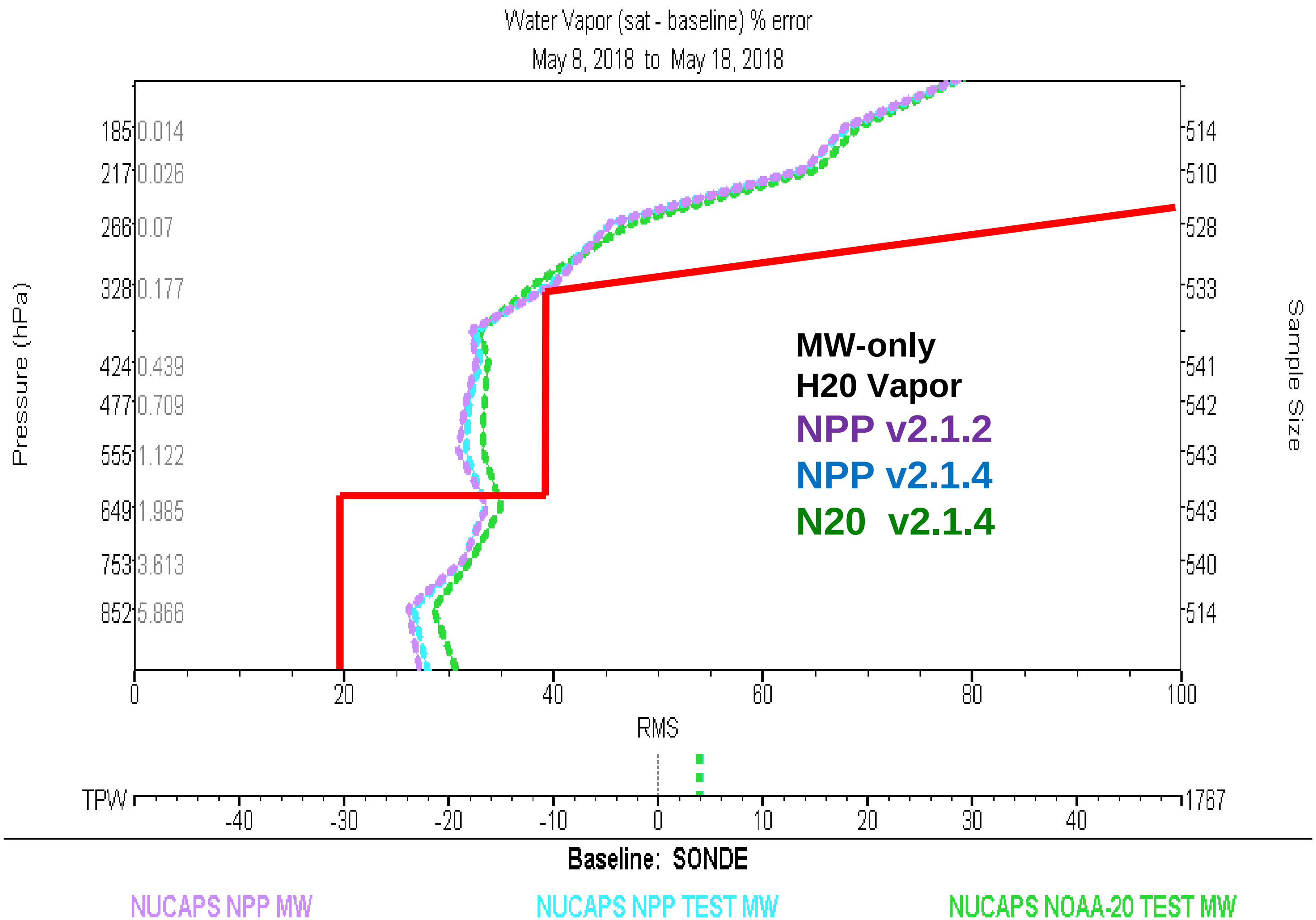
Comparison against conventional RAOBs using NPROVS



Sample: IR+MW Pass QC; -2,+3hr; 50km

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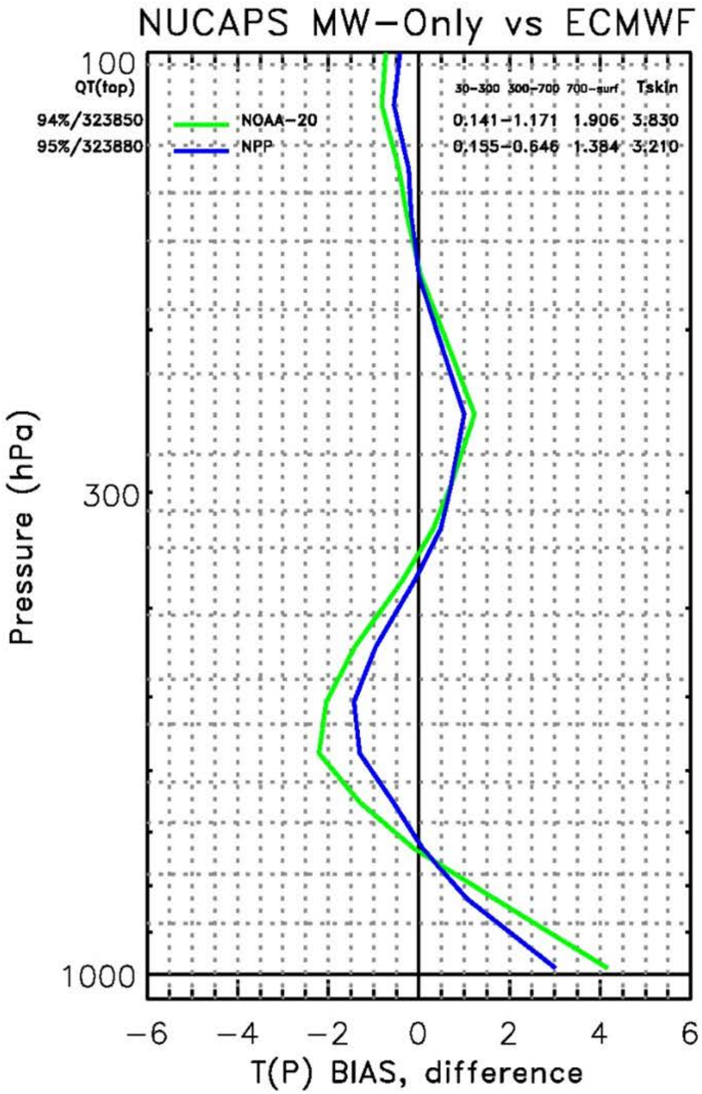
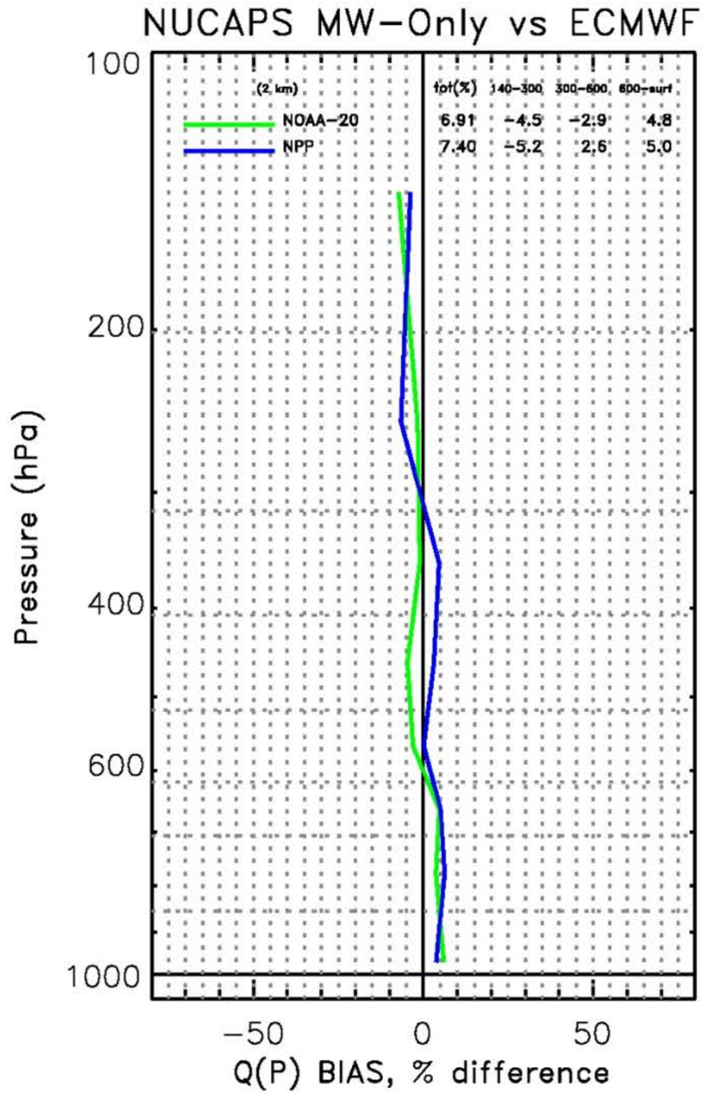
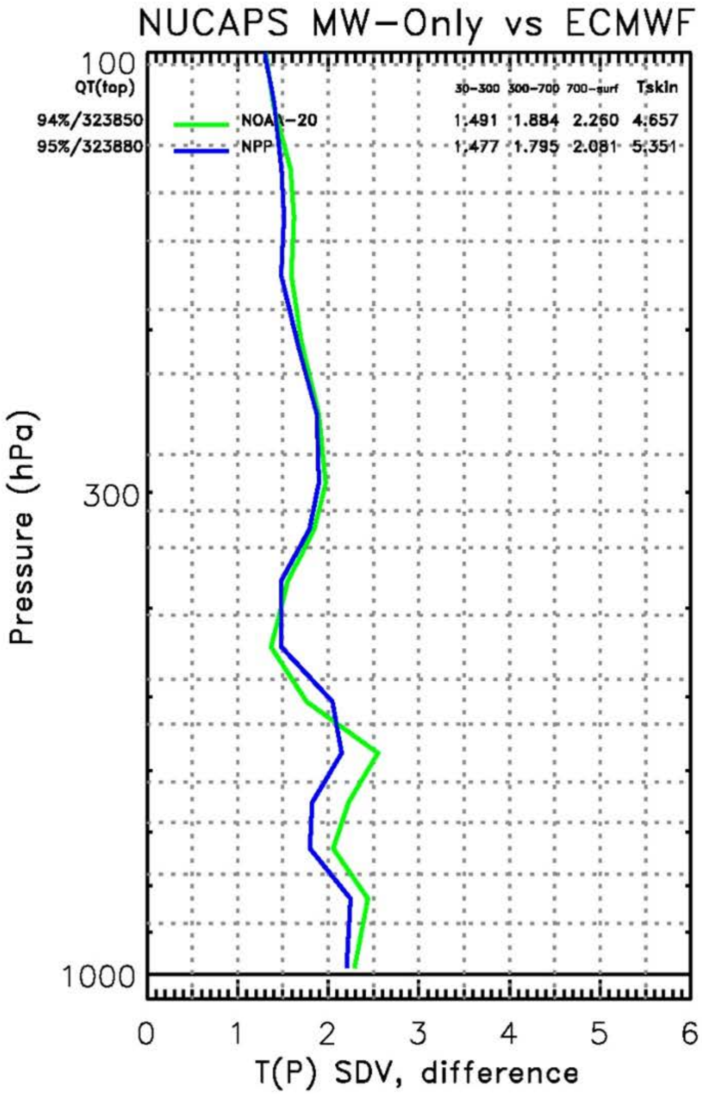
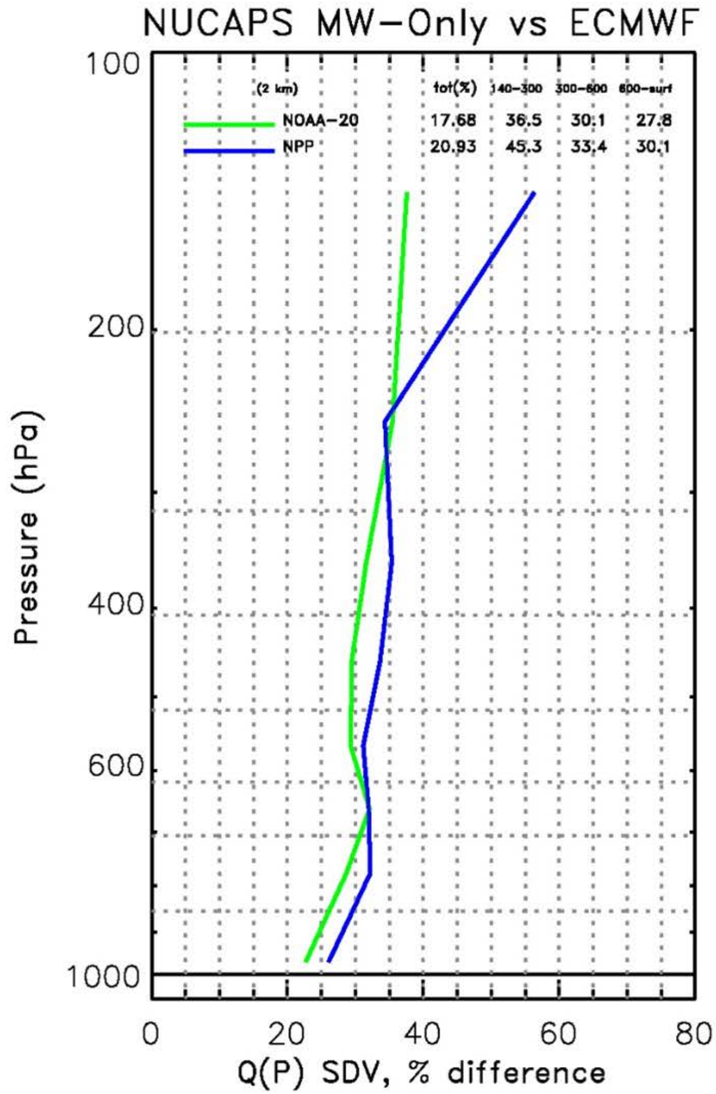
Comparison of NUCAPS NPP and NOAA-20 against ECMWF MW-Only Accepted: Bias



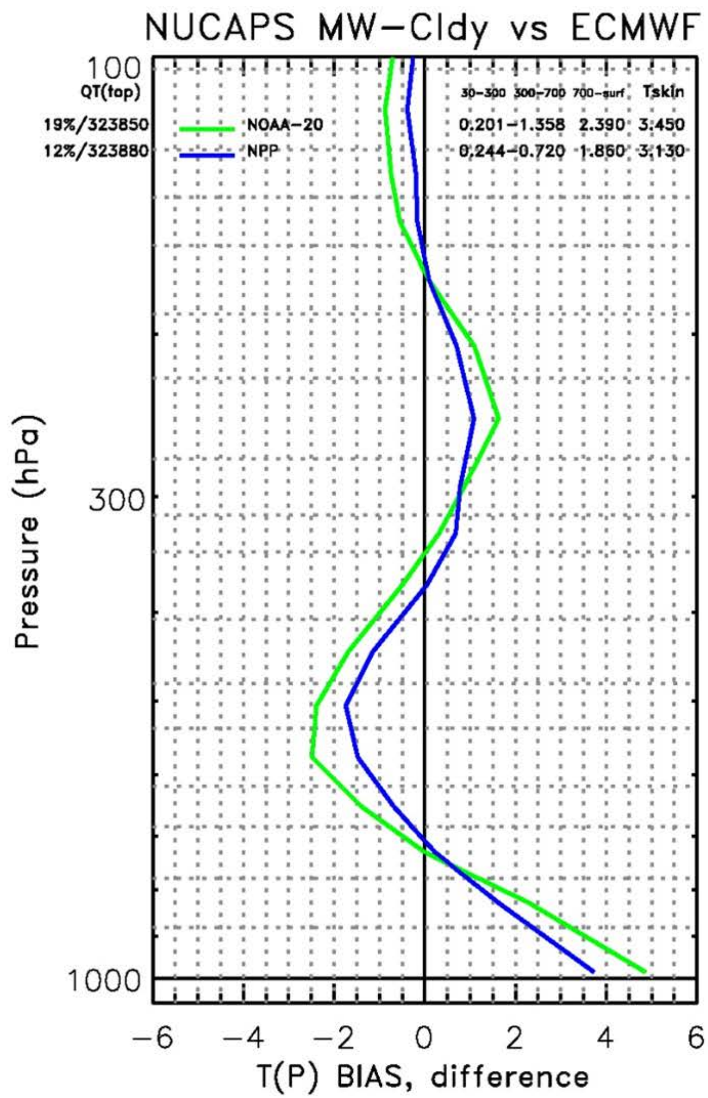


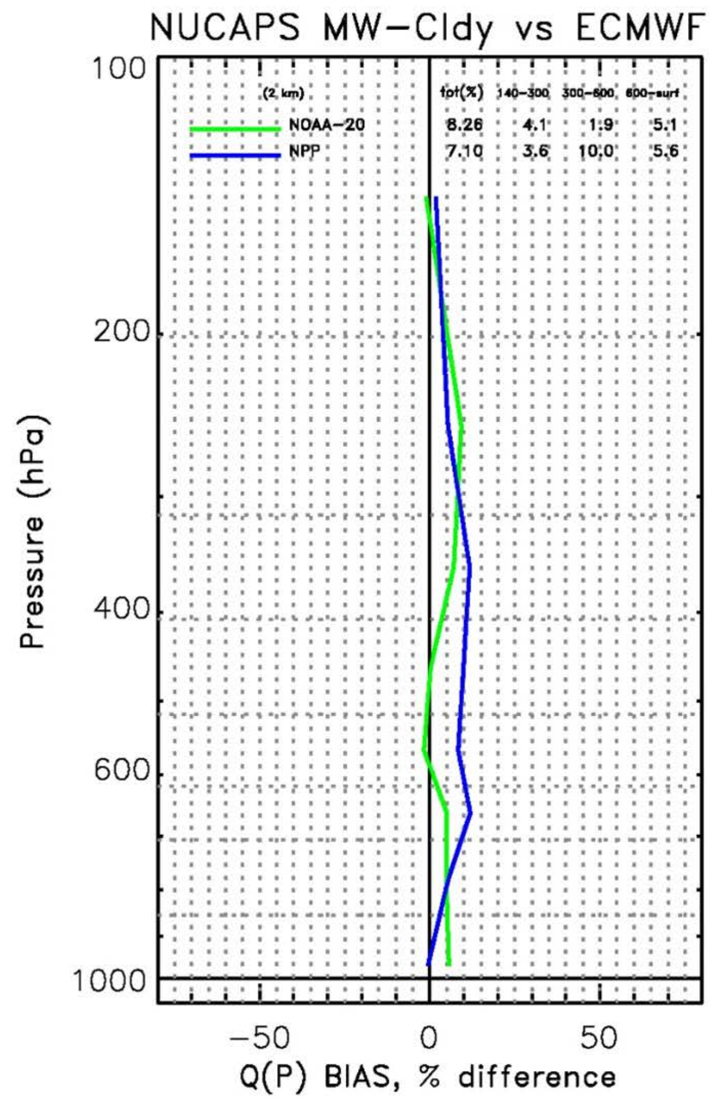
Comparison of NUCAPS NPP and NOAA-20 against ECMWF
MW-Only Accepted: StDev



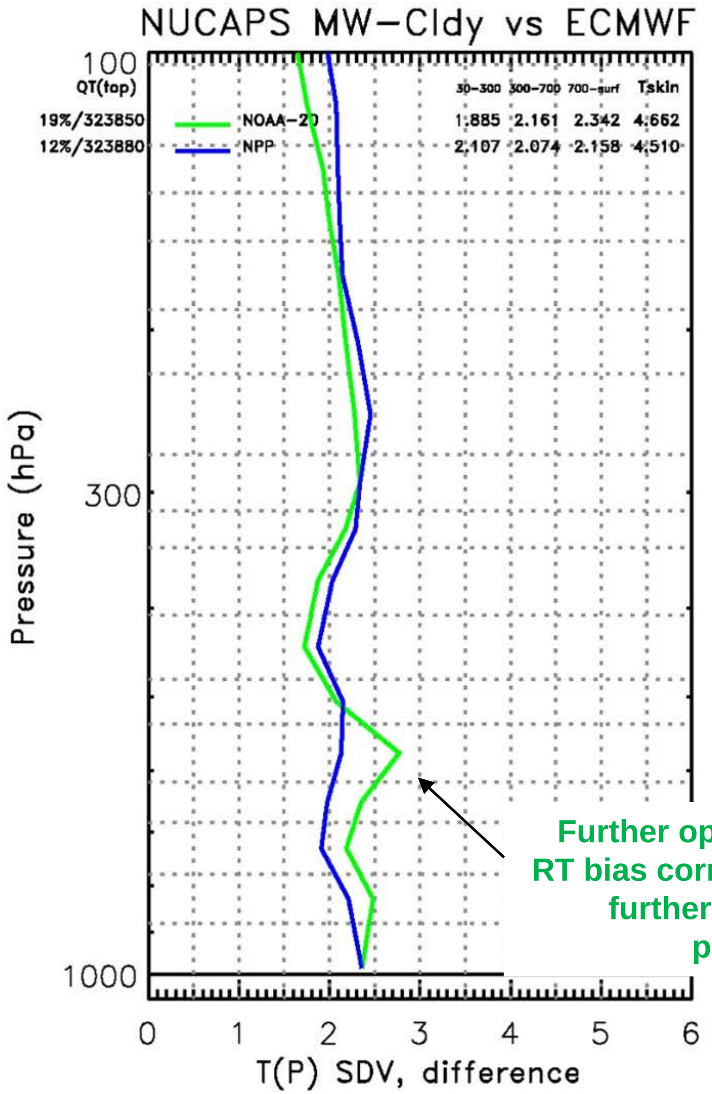


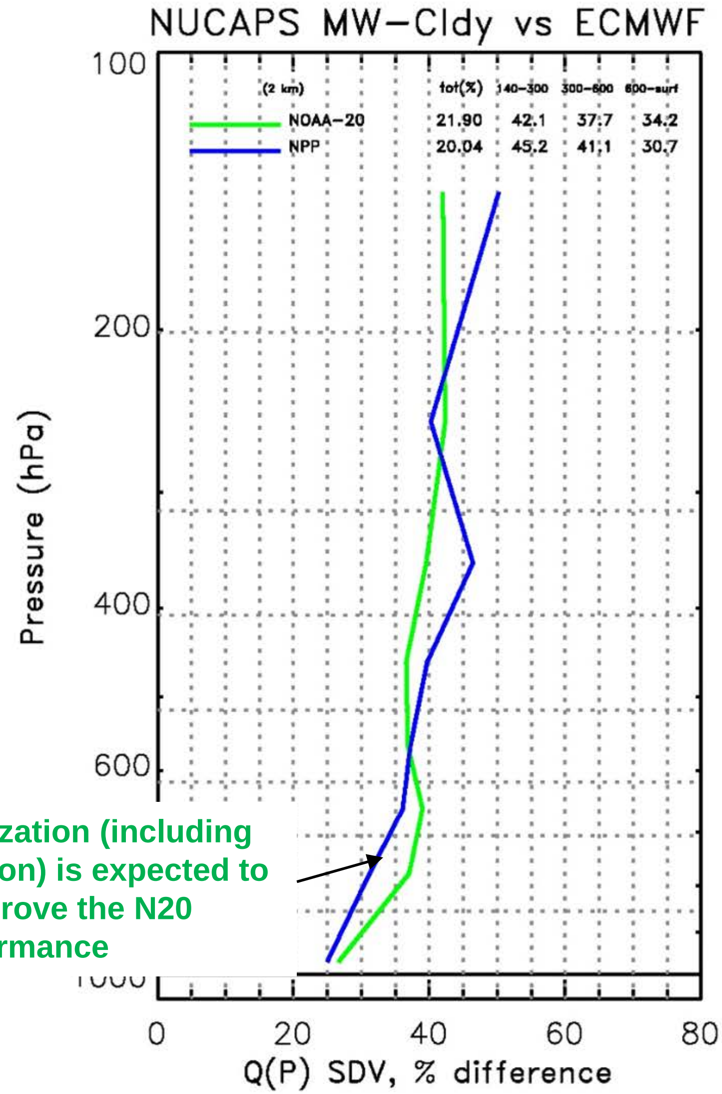
Comparison of NUCAPS NPP and NOAA-20 against ECMWF
MW-Only Accepted, MW+IR rejected: Bias





Comparison of NUCAPS NPP and NOAA-20 against ECMWF
MW-Only Accepted, MW+IR rejected: StDev





Further optimization (including RT bias correction) is expected to further improve the N20 performance

Summary on the NUCAPS NOAA-20 MW-only Retrieval Performance

✓ Actual instrument noise of NOAA-20/ATMS has been obtained and used as part of the NUCAPS/NOAA-20 MW-Only retrieval system.

✓ Qualitative comparison demonstrates that fields of Temperature (at 500 hPa) and Total Precipitable Water Vapor of NUCAPS/NOAA-20 MW-only are highly correlated against corresponding fields derived from the NUCAPS/NPP MW-Only.

✓ A global comparison against conventional RAOBs and ECMWF shows that:

- NUCAPS/NOAA-20 MW-Only holds similar temperature performance to NUCAPS/NPP MW-Only with bias differences no larger than 1K and standard deviation differences close to 0.5K.

- NUCAPS/NOAA-20 and NPP MW-Only show nearly the same bias water vapor performance, while NUCAPS/NOAA-20 shows improved standard deviation by about 5%.

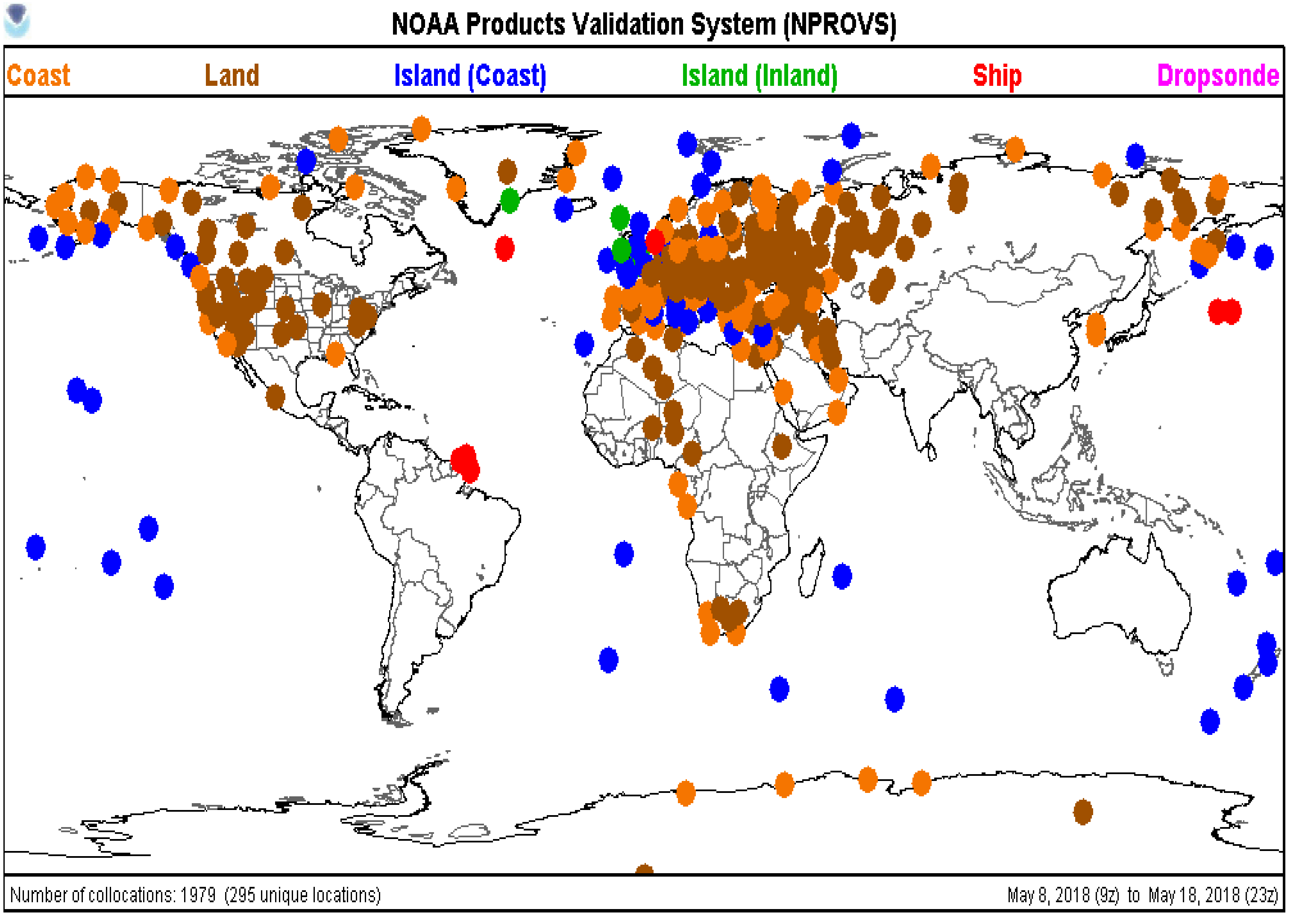
✓ MW-only products close to meet requirements – uncertainty in truth and collocation mismatch have a role. Need larger, multi-seasonal ensemble of dedicated RAOBs measurements.

✓ Future work: NOAA-20 MW RTA; improvement of MW surface classification;

NUCAPS NOAA-20 & NPP AVTP and AVMP

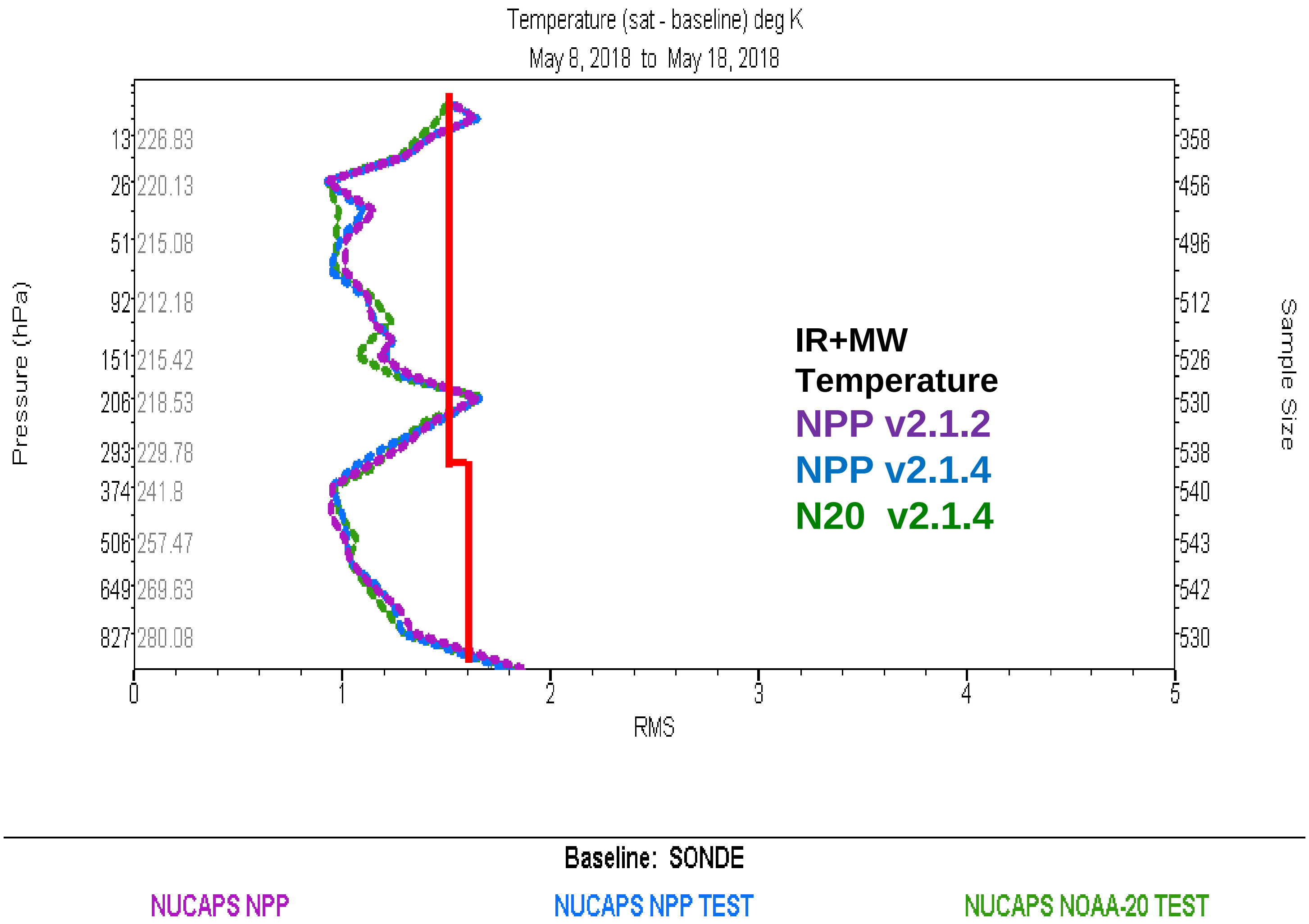
PART II: MW+IR Temperature, Water Vapor and Ozone

Comparison against conventional RAOBs using NPROVS



NPP 2.1.2, NPP 2.1.4 and N20 2.1.4 @ -2 to +3 hr, 50km

Comparison against conventional RAOBs using NPROVS



Sample: IR+MW Pass QC; -2,+3hr; 50km

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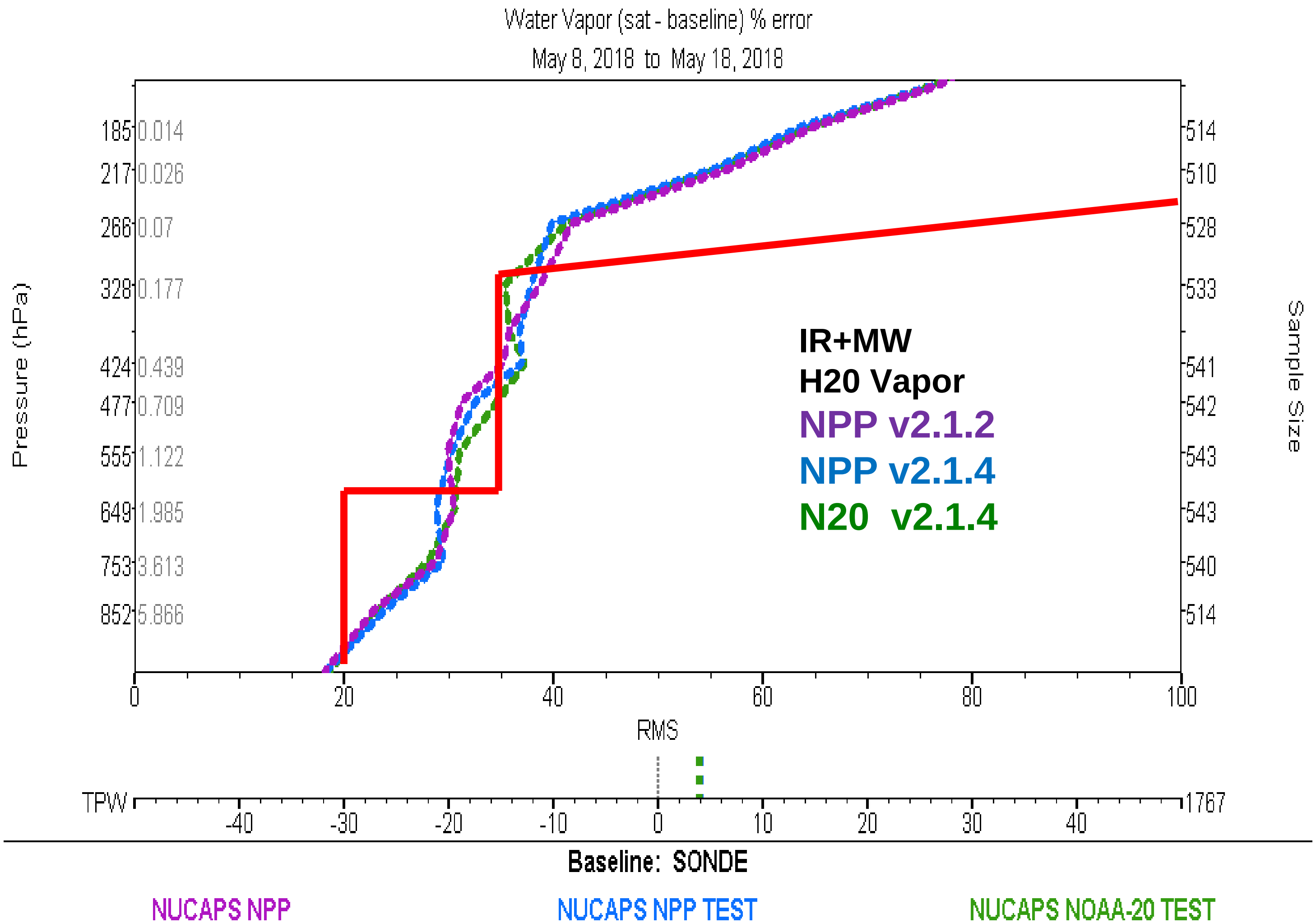
Comparison against conventional RAOBs using NPROVS



Sample: IR+MW Pass QC; -2,+3hr; 50km

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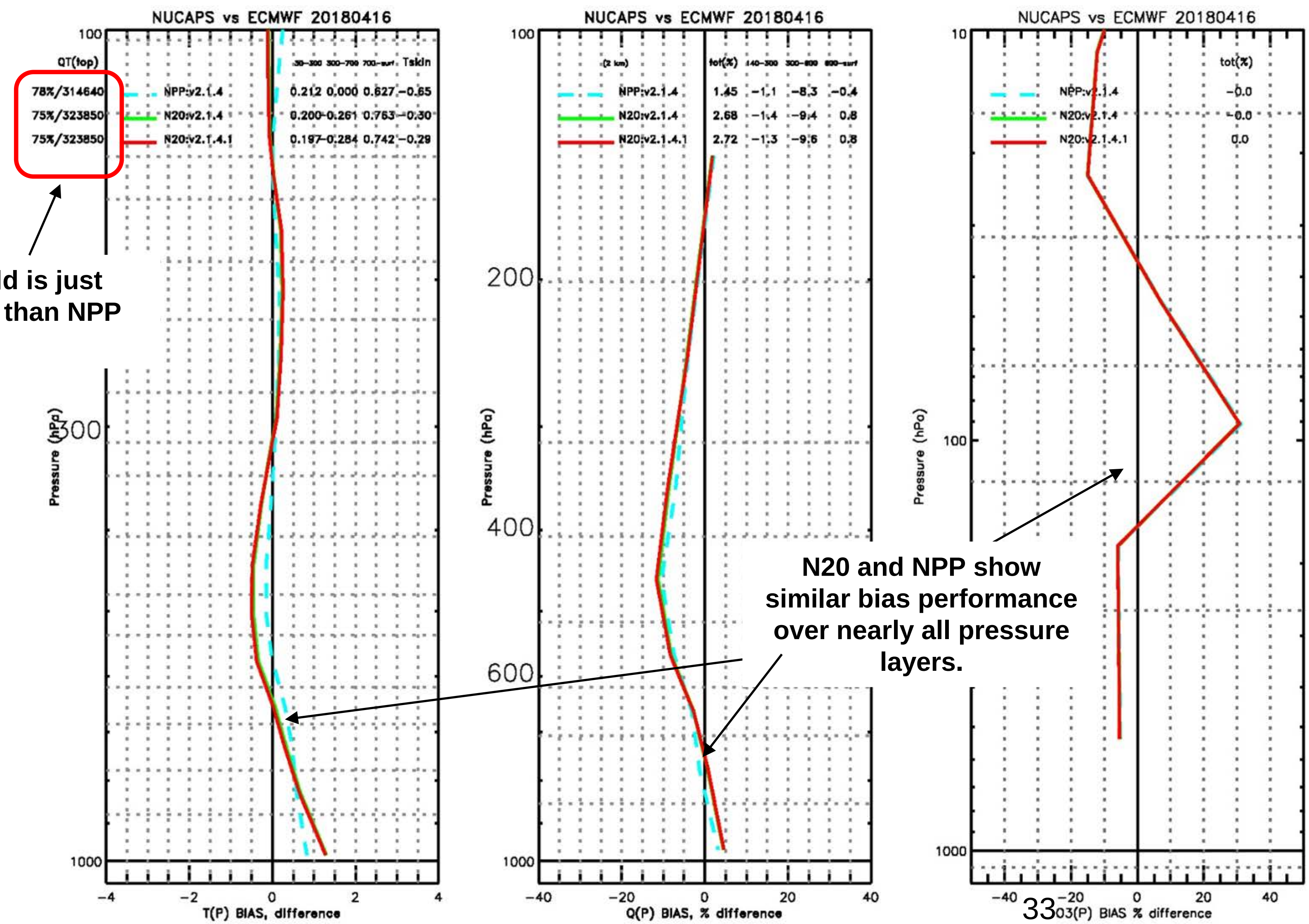
Comparison of NUCAPS NPP and NOAA-20 against ECMWF MW+IR: Bias

SNPP Operational | **First Light N20 (January 2018)** | **N20 (June 15 DAP)**



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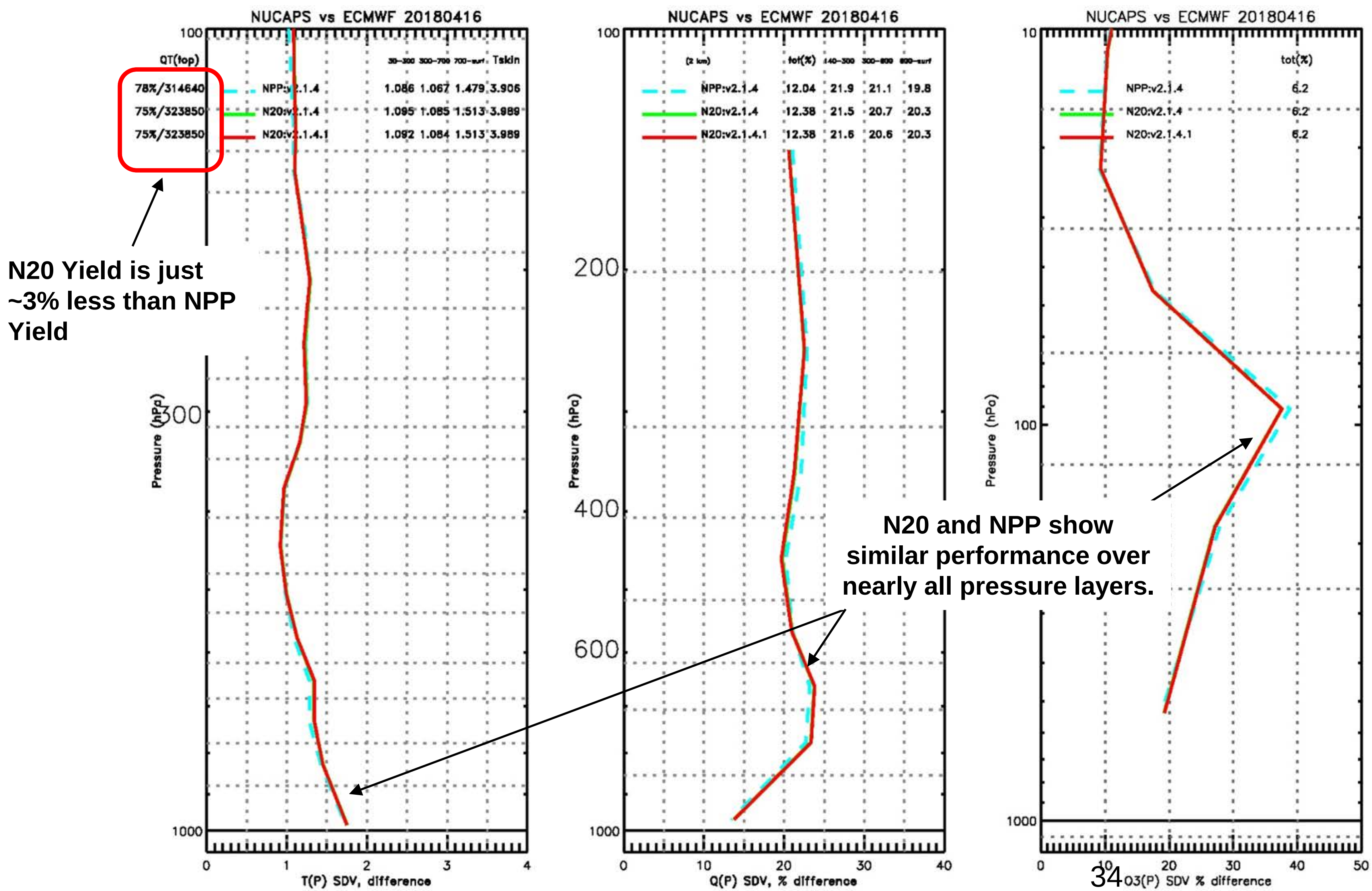
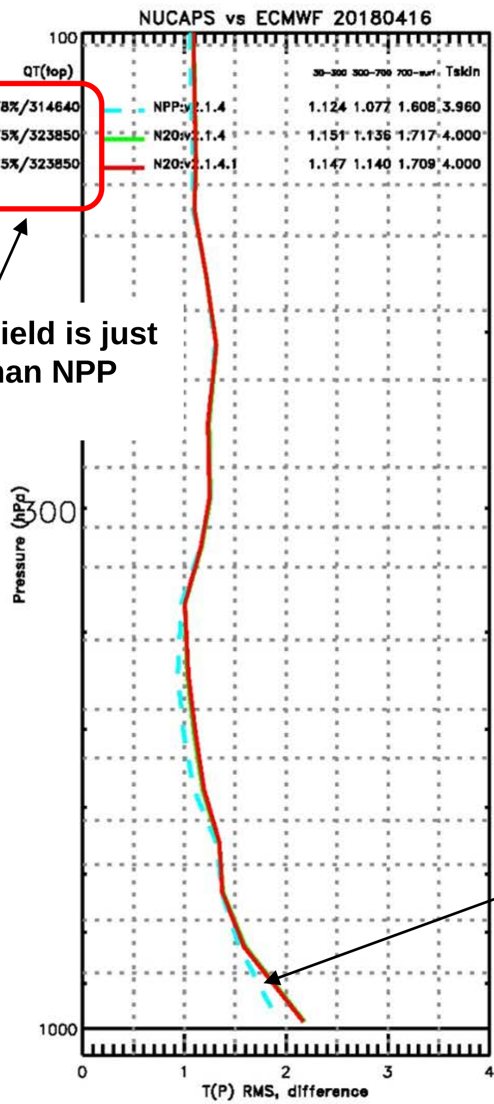
Comparison of NUCAPS NPP and NOAA-20 against ECMWF MW+IR: SDV

SNPP Operational | **First Light N20 (January 2018)** | **N20 (June 15 DAP)**

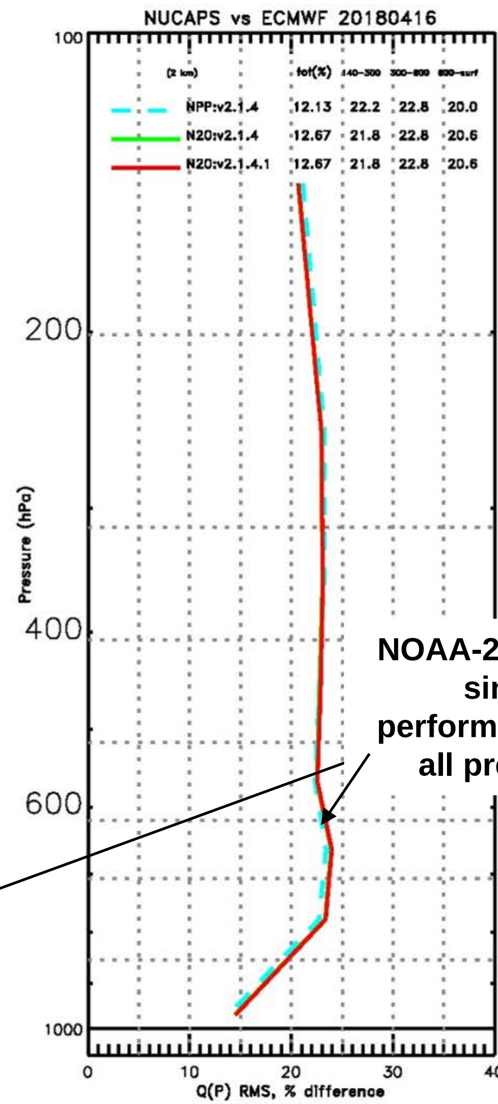


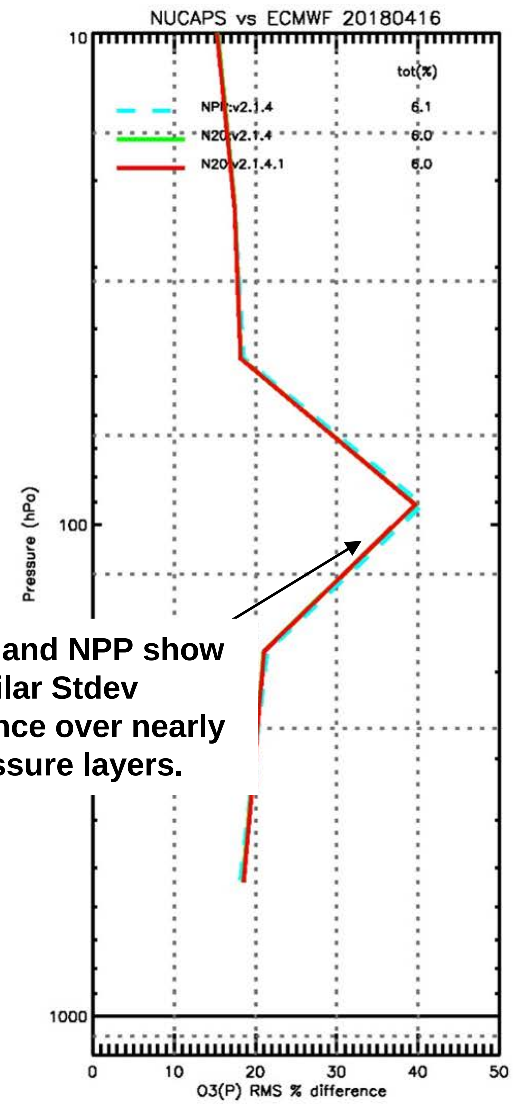
Comparison of NUCAPS NPP and NOAA-20 against ECMWF MW+IR: RMS

SNPP Operational | **First Light N20 (January 2018)** | **N20 (June 15 DAP)**



NOAA-20 Yield is just ~3% less than NPP Yield





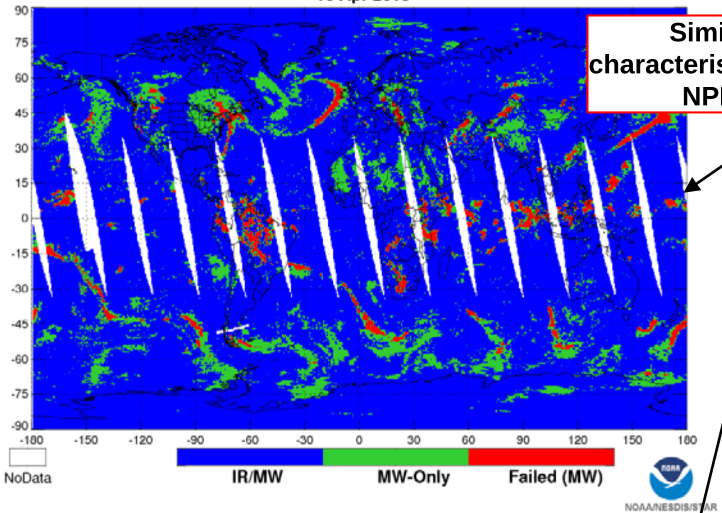
NOAA-20 and NPP show similar Stdev performance over nearly all pressure layers.

Quality flag analysis/validation

- Defined Quality Flags
  - Variable
  - Description
  - Value
- Quality flag analysis/validation
  - Test / example / ground truth data sets
  - Analysis / validation results
  - Analysis / validation plan

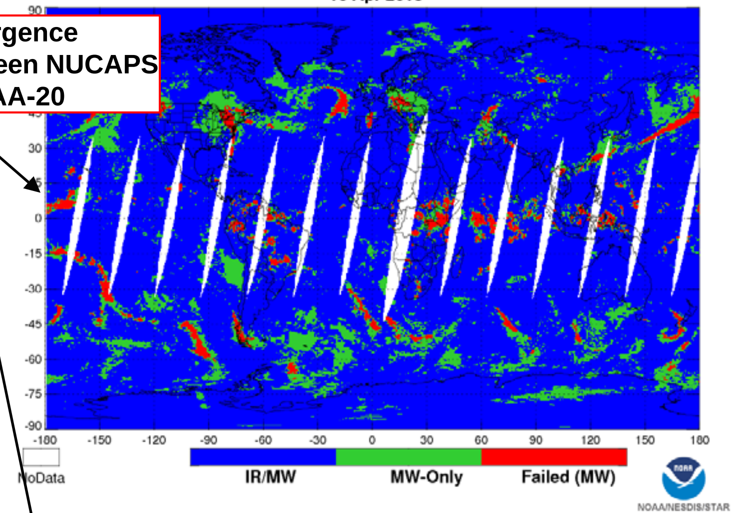
Quality flag analysis/validation

NUCAPS NPP Quality Control Flag Asc v2.1.4
16 Apr 2018

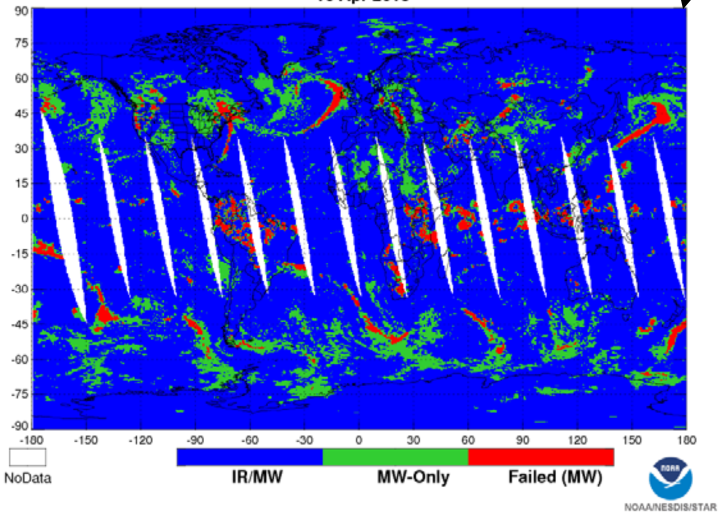


Similar convergence characteristics between NUCAPS NPP and NOAA-20

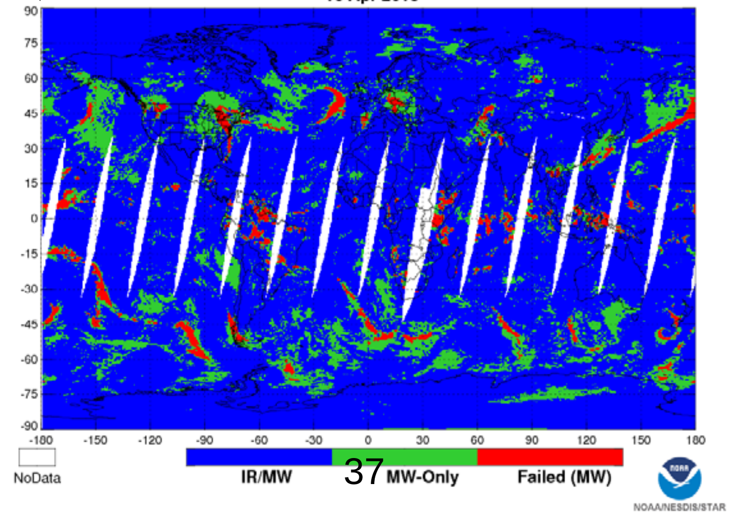
NUCAPS NPP Quality Control Flag Des v2.1.4
16 Apr 2018



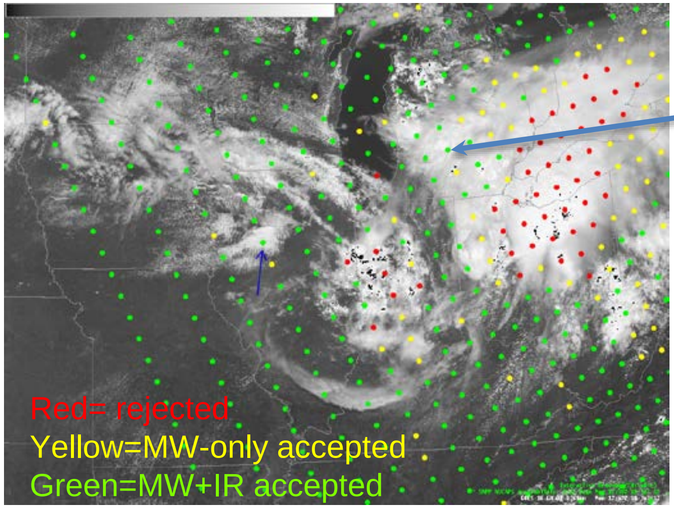
NUCAPS NOAA-20 Quality Control Flag Asc v2.1.4
16 Apr 2018



NUCAPS NOAA-20 Quality Control Flag Des v2.1.4
16 Apr 2018



Quality flag analysis/validation: Temperature, Water Vapor



How green is green?

- There have been several instances where green should have not been *green*. Forecasters can lose confidence in NUCAPS soundings when profiles corresponding to green dots do not appear representative of the weather regime that is being analyzed.
- This appears to be a long-standing issue as seen from the past years' HWT experiments and it proves that we need to improve on the existing NUCAPS quality control criteria and display.
- "*It would be nice to have some sort of display on the sounding that would highlight areas that may not be correct or had some QC issues. That would allow the forecaster to see that the sounding may not be accurate, since they may make the assumption that since the circle was green, it is good*." GOB, HWT Spring Experiment, Wed. July 12, 2017.
- Additional metrics need to be provided to add confidence in the NUCAPS soundings. These metrics will be vertically dependent, as opposed to the existing total column ones. This is work in progress and it will answer questions such as:
  - Can you still find a good use of NUCAPS soundings in the mid tropospheric levels above low level clouds? If yes…
  - What is the lowermost vertical pressure level where NUCAPS can confidently be trusted?
- A sample of test cases, a high quality ensemble of dedicated in situ measurements and HRRR profiles will be used to validate this vertically dependent retrieval quality indicator.

Error Budget

- Compare analysis/validation results against requirements, present as a table.

- Error budget limitations should be explained.

- Describe prospects for overcoming error budget limitations with future improvement of the algorithm, test data, and error analysis methodology.

Summary table of requirements verifications: SNPP & N20 MW+IR temperature and water vapor vs ECMWF

green = passed   yellow = close   red = failed

Summary on IR+MW Results vs JPSS L1RD Requirements							
Temperature				Water Vapor			
Pressure Range (hPa)	JPSS L1RD Requirement (K)	SNPP (K)	N20(K)	Pressure Range (hPa)	JPSS L1RD Requirement (%)	SNPP (%)	N20(%)
1-30	1.5	1.1	1.1	100-300	35	22.2	21.8
30-300	1.5	1.0	1.1	300-600	35	22.8	22.8
300-Psfc	1.6	1.6	1.7	600-Psfc	20	20.0	20.6

- ✓ Validation results are with respect to ECMWF, using a global focus day
- ✓ Comparison shows that NUCAPS SNPP and NOAA-20 temperature, water vapor are strongly consistent.

- ✓ **Future work (see also slide 57):**

  - Upgrade of NOAA-20 RTA MW and IR bias correction and regression module using a multi-seasonal training data set. Upgrade IR surface emissivity.
  - NUCAPS has been ported in the HEAP: one unified code for all instruments. All algorithm upgrades will be consistently applied to all platforms: MetOp, SNPP, NOAA-20.
  - Develop and validate a vertically dependent retrieval quality indicator.
  - Future field campaigns (RIVAL, AEROSE, NOAA MADIS) will augment validation analysis.

Summary table of requirements verifications: SNPP & N20 Ozone retrieval vs ECMWF

green = passed yellow = close red = failed

Summary on IR+MW Results vs JPSS L1RD Requirements			
Ozone			
Pressure Range (hPa)	JPSS L1RD Requirement RMS (%)	SNPP RMS (%)	N20 RMS (%)
4-260	25	16.8	16.8
260-Psfc	25	25.0	25.0

- ✓ Validation results are with respect to ECMWF, using a global focus day
- ✓ Comparison shows that NUCAPS SNPP and NOAA-20 ozone are strongly consistent.
- ✓ **Future work (see also slide 57):**

  - Upgrade of NOAA-20 RTA IR bias correction using a multi-seasonal training data set. Upgrade IR surface emissivity.
  - NUCAPS has been ported in the HEAP: one unified code for all instruments. All algorithm upgrades will be consistently applied to all platforms: MetOp, SNPP, NOAA-20.

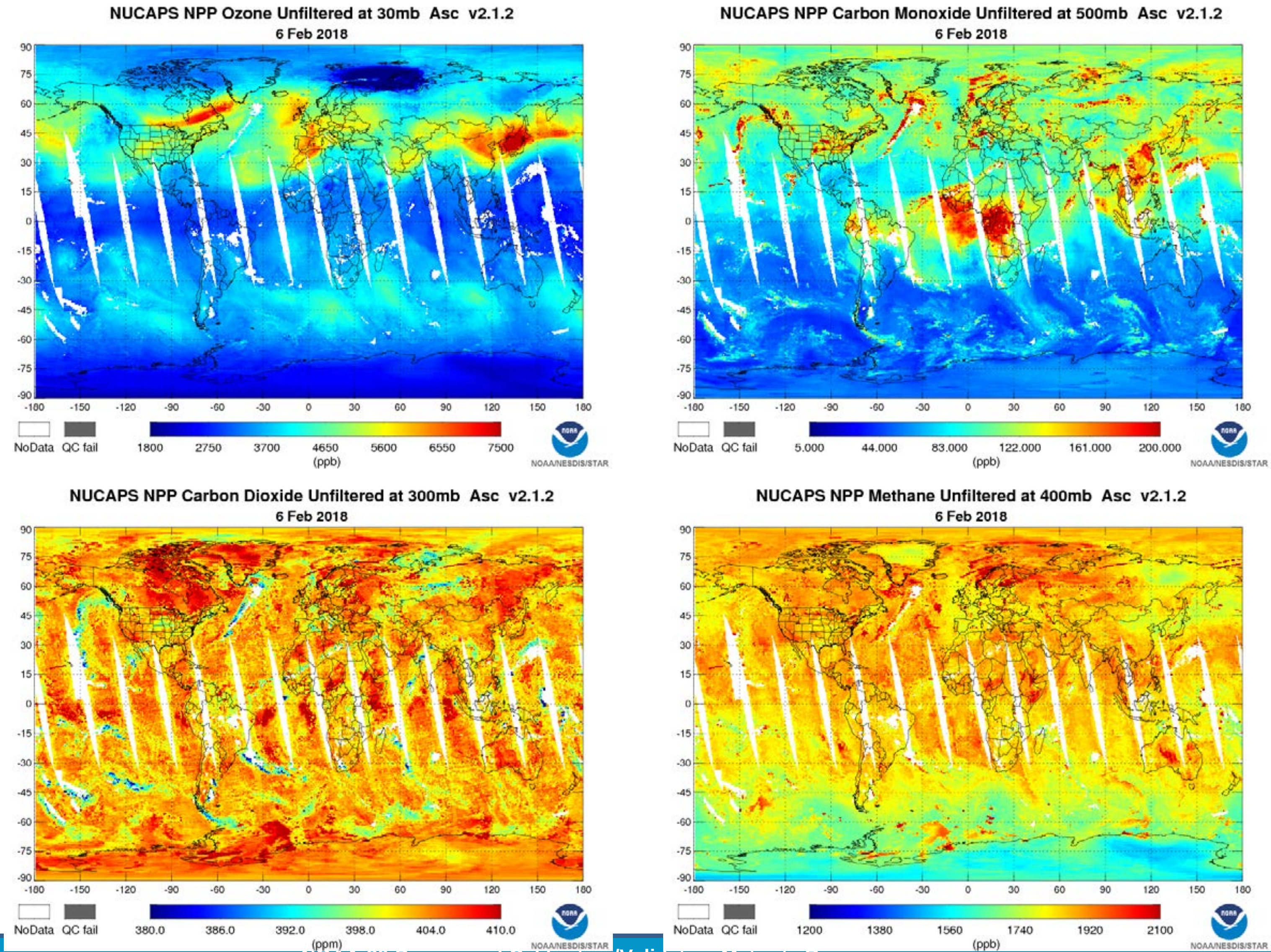
  - Future field campaigns and additional in situ measurements (AEROSE, SHADOZ) will augment validation analysis.

Check List - Provisional Maturity

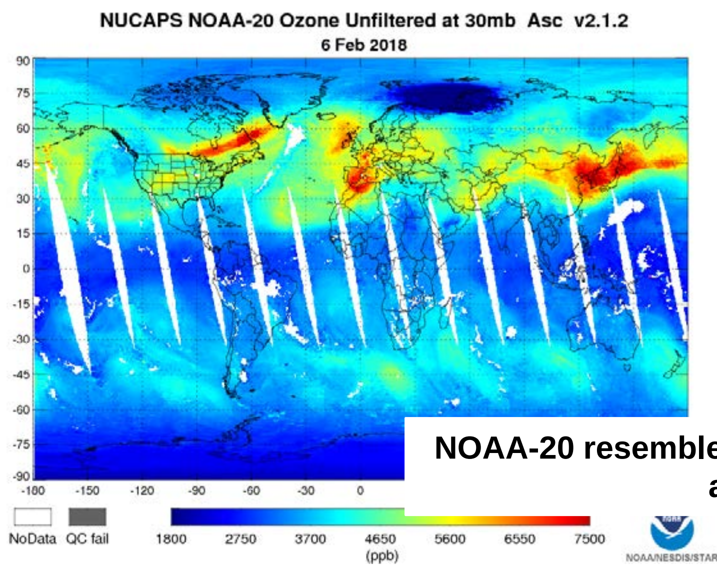
Provisional Maturity End State	Assessment
Product performance has been demonstrated through analysis of a large, but still limited (i.e., not necessarily globally or seasonally representative) number of independent measurements obtained from select locations, periods, and associated ground truth or field campaign efforts.	**YES**. Comparison shows that NUCAPS SNPP and NOAA-20 temperature, water vapor and ozone are strongly consistent.
Product analysis is sufficient to communicate product performance to users relative to expectations (Performance Baseline).	**YES**. Summary tables are available
Documentation of product performance exists that includes recommended remediation strategies for all anomalies and weaknesses. Any algorithm changes associated with severe anomalies have been documented, implemented, tested, and shared with the user community.	**YES**. Work is in progress to communicate changes to the users community.
Product is ready for operational use and for use in comprehensive cal/val activities and product optimization.	**YES**. Future work includes an optimization of the MW surface classification, regression module and IR surface emissivity.

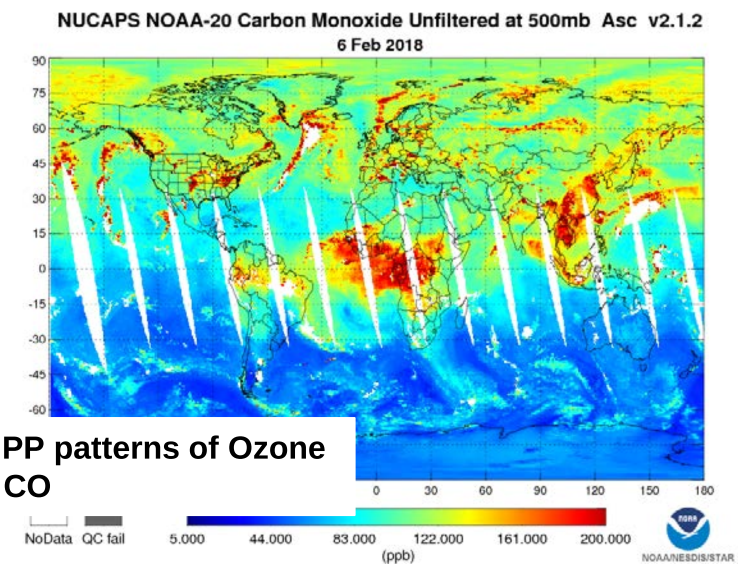
NUCAPS SNPP vs NOAA-20 Carbon Trace Gas EDRs and OLR qualitative comparison for beta maturity

NUCAPS NPP v2.12 Trace Gases at Pressure Levels where Higher Sensitivity is Expected

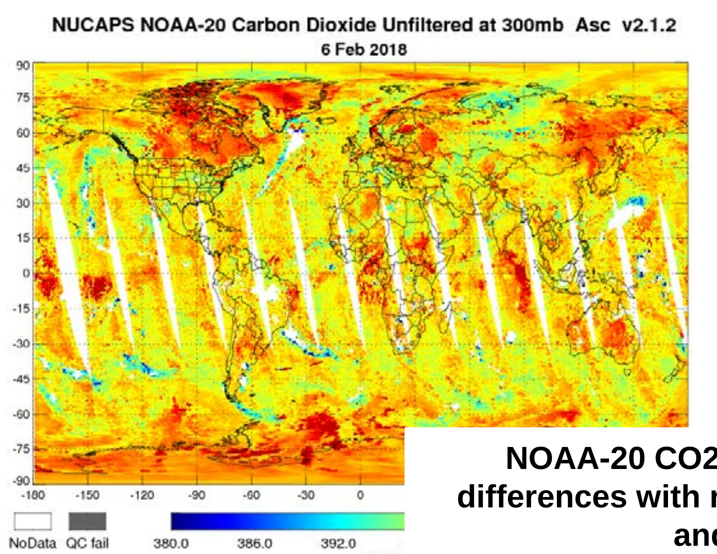


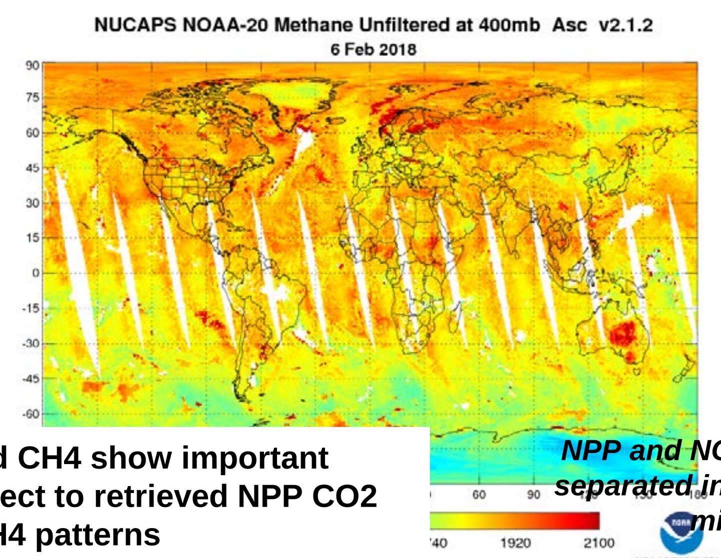
NUCAPS NOAA-20 v2.1.2 Trace Gases at Pressure Levels where Higher Sensitivity is Expected





NOAA-20 resembles NPP patterns of Ozone and CO





NOAA-20 CO2 and CH4 show important differences with respect to retrieved NPP CO2 and CH4 patterns

NPP and NOAA-20 are separated in time by 50 min

Summary of NOAA-20 Carbon Trace Gases

- ✓ NUCAPS NOAA-20 and NPP trace gases were compared at pressure levels where higher sensitivity is expected.
- ✓ Results show that NUCAPS NOAA-20 resembles NPP patterns of Ozone and CO.
- ✓ However, NUCAPS NOAA-20 CO_2 and CH_4 show important differences with respect to retrieved NUCAPS SNPP CO_2 and CH_4 fields. Generally lower values are found.
- ✓ These difference are under examination.
- ✓ Work in progress: NOAA-20 LUT upgrades: regression module, IR surface emissivity, MW and IR RTA bias corrections.
- ✓ Updates will presented in the NUCAPS Validated Trace Gas Maturity Review (~Fall 2018).

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Quality flag analysis/validation

- Defined Quality Flags
  - Variable
  - Description
  - Value
- Quality flag analysis/validation
  - Test / example / ground truth data sets
  - Analysis / validation results
  - Analysis / validation plan

Quality flag analysis/validation: carbon monoxide Thomas Fire, California December 5th, 2017.

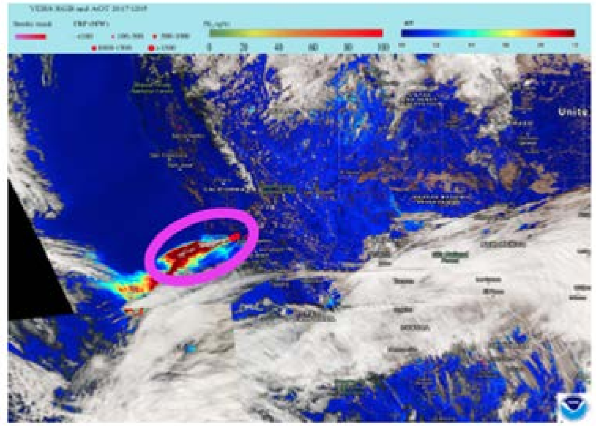
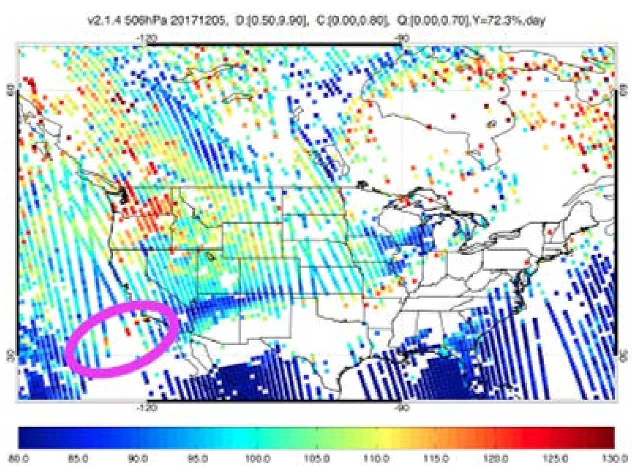
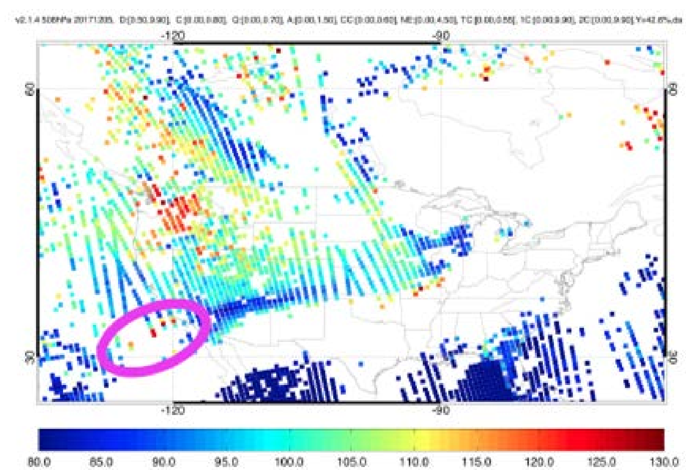


Figure courtesy of Shobha Kondragunta

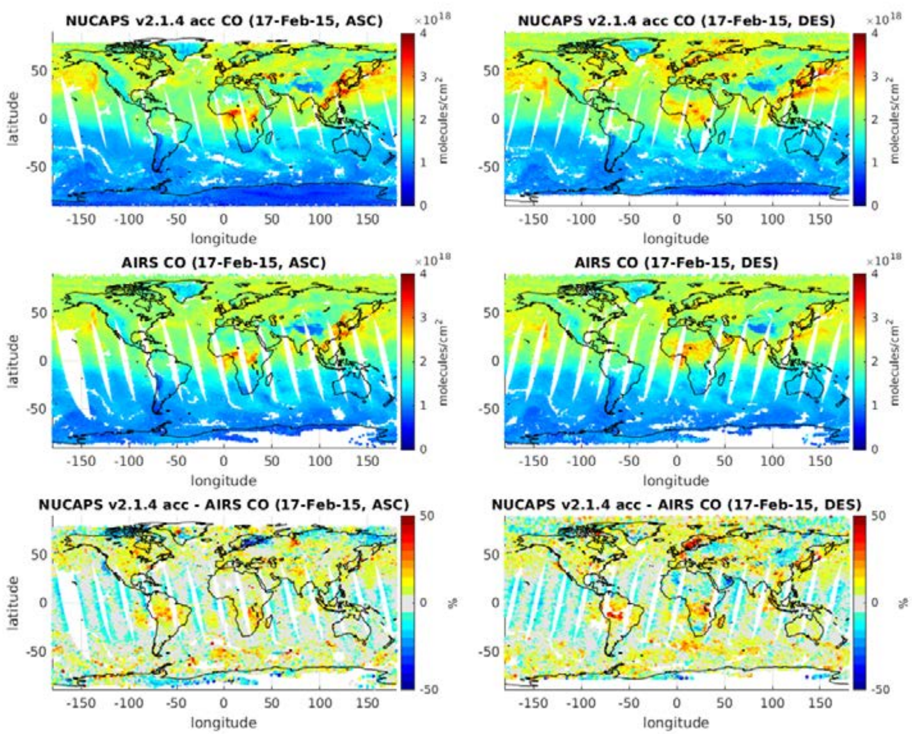




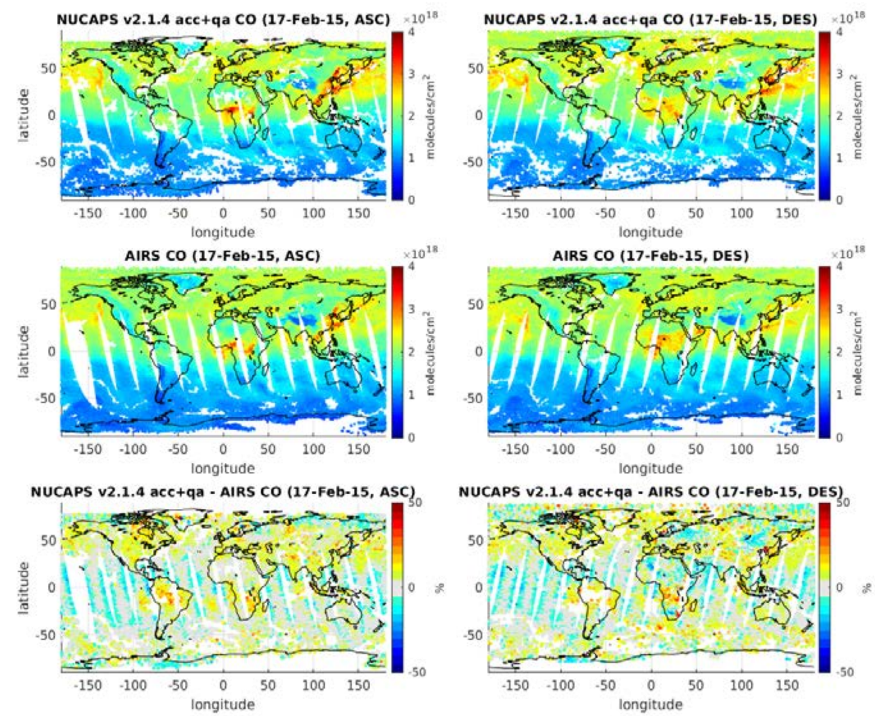
- CO tailored QC removes spurious spikes in CO due to poor cloud clearing while preserving the real signal of interest (CA Thomas Fire, Dec. 5th, 2017)

Quality flag analysis/validation: carbon monoxide

IR+MW Accepted Cases

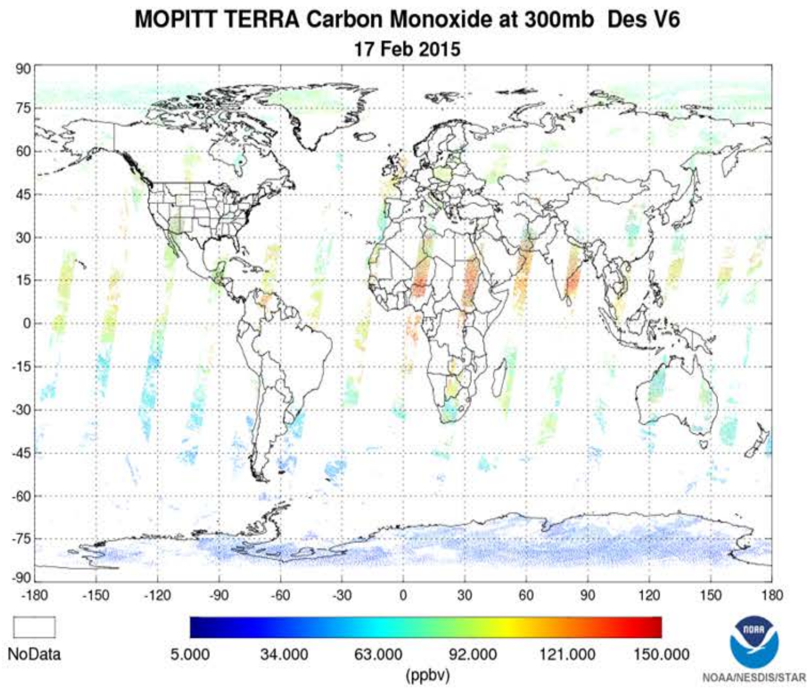


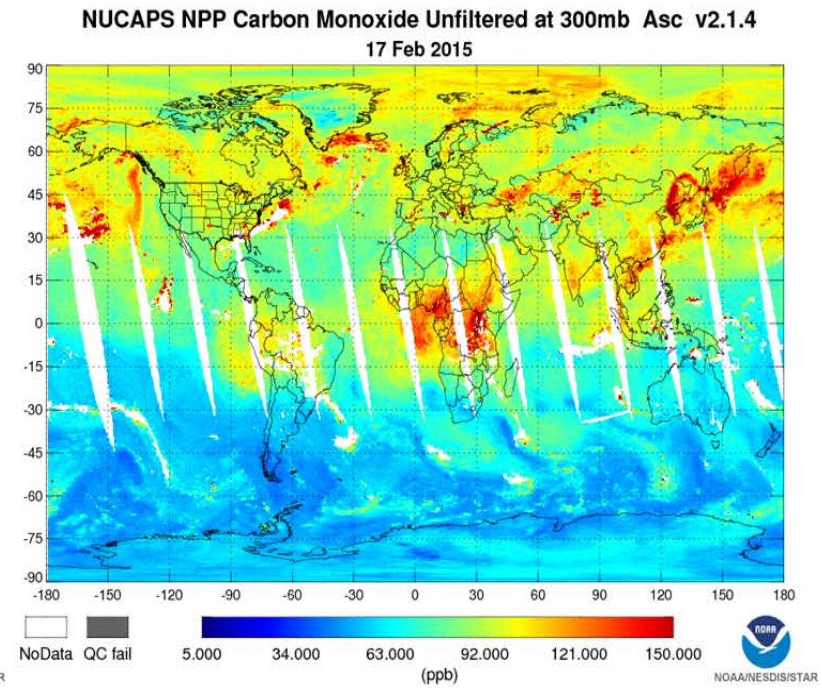
IR+MW Accepted Cases + Trace Gas QA



- CO tailored QC improves comparison with respect to AIRS v6

NUCAPS CO vs MOPITT CO





- Considered as the CO community reference, MOPITT CO retrieval is a IR+NIR, clear-sky only algorithm, with 10% accuracy requirement. Note: regions associated with high CO values are generally related to the presence of fires, which increases the presence or aerosols that could be degrading the cloud-mask used by MOPITT to define the clear-sky conditions.

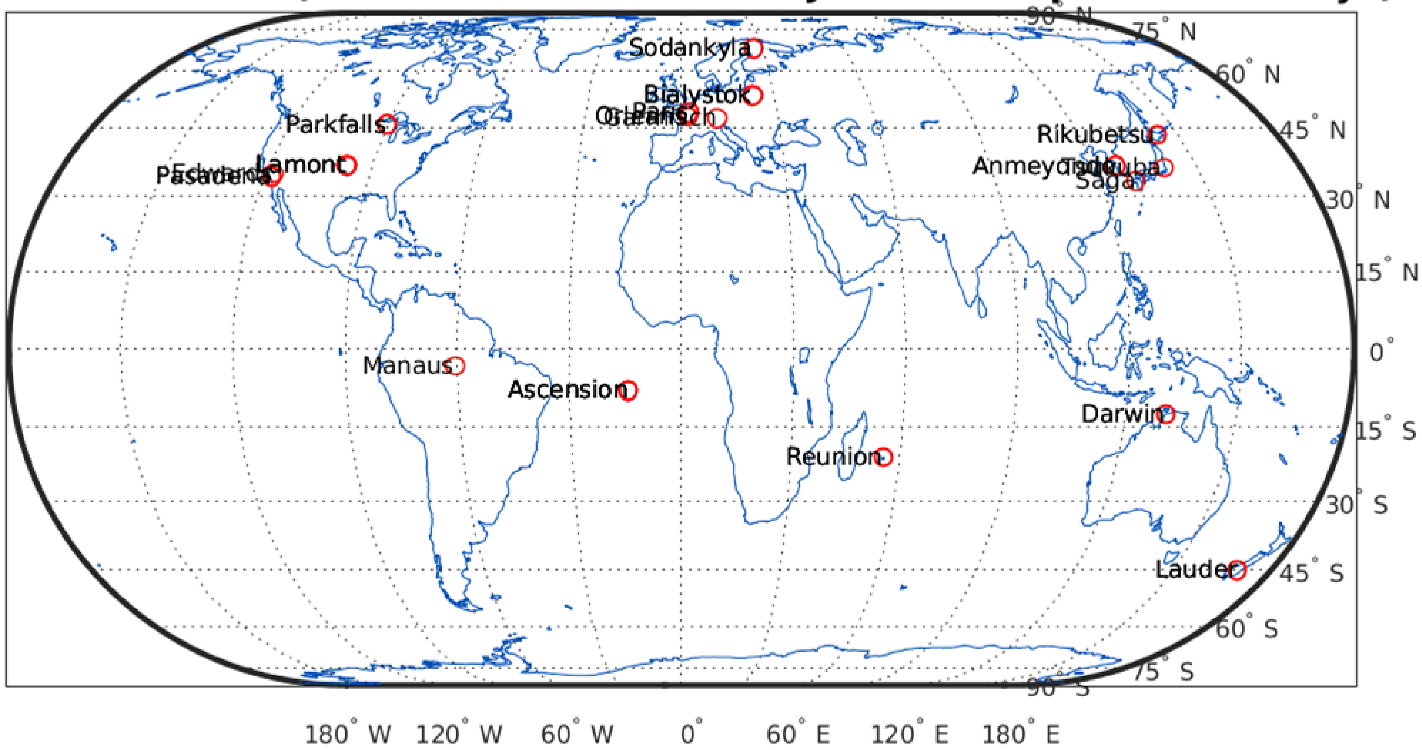
- NUCAPS is an all-sky, cloud-cleared based, MW+IR retrieval algorithm, with 5% accuracy requirement.

- NUCAPS all sky, total column CO requirement, by comparison, appears too stringent.

Error budget: Carbon trace gases

Total Carbon Column Observing Network (TCCON)
17 Feb, Mar, Jul, Sep 2015 Focus Days

TCCON Stations (17-Feb-15 17-Mar-15 17-Jul-15 17-Sep-15 Focus Days)

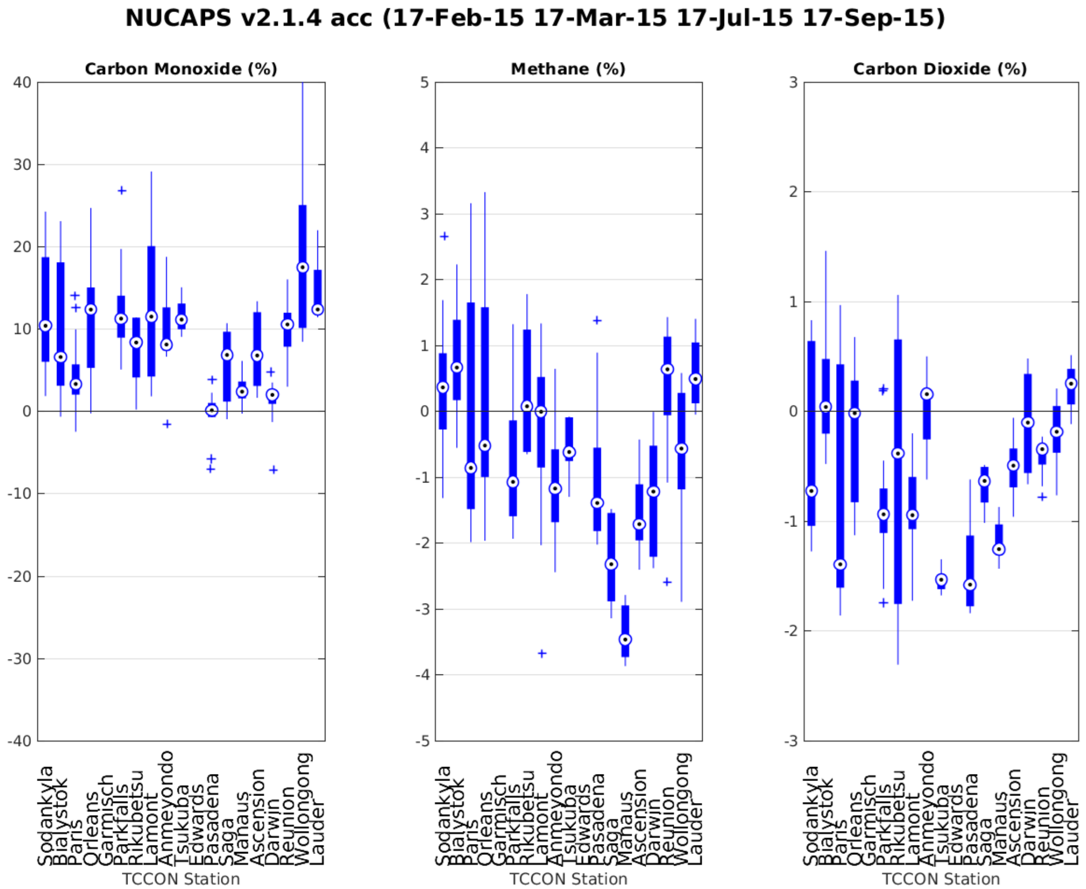


Error budget: Carbon trace gases vs TCCON

Accepted FOR within threshold radius (100 km)

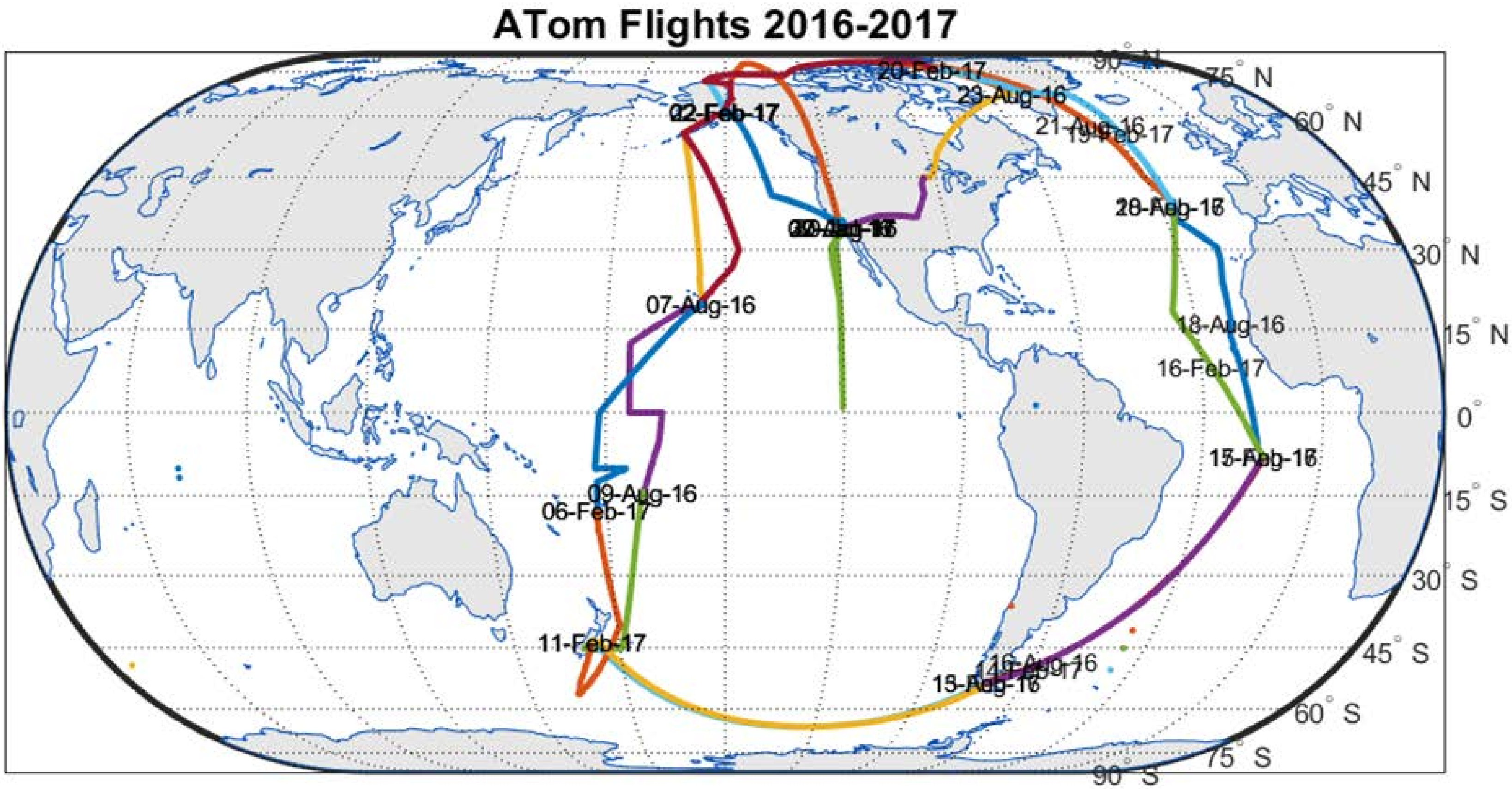
Time window (±6 hours) versus mean TCCON

Stations ordered from North to South



- We are aware that current operational CO product suffers from a bias and cloud clearing noise contamination (conclusion from the July 2017 ARR).
- Work has been done to improve CO and CH4 a priori, chn selection, RTA IR bias correction and QC.
- Changes are being tested for both SNPP and NOAA-20 and will be shown in the trace gas validated maturity review (Fall 2018).

Quality flag analysis/validation: carbon monoxide

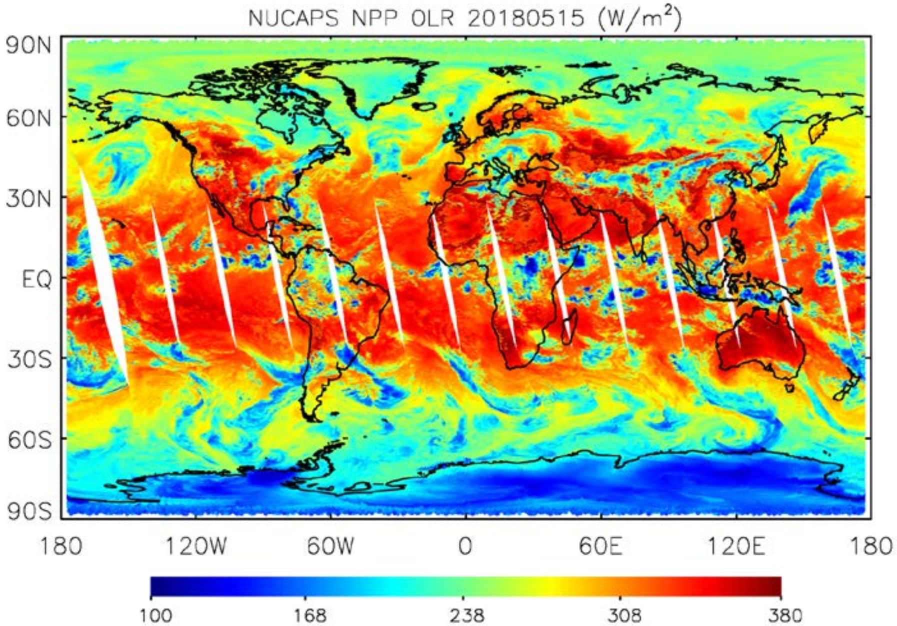


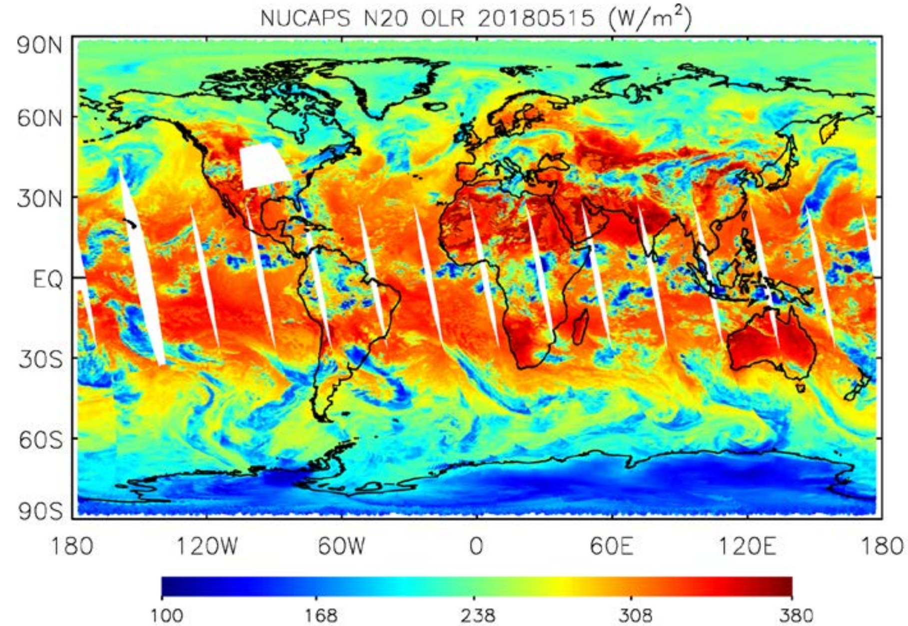
- In situ vertical profile measurements are key to test algorithm upgrades.
- Work is in progress to test:
  - New CO and CH4 climatology, RTA IR bias correction, QC methodology, chn selection

Error budget: NUCAPS Carbon trace

- We are aware that current operational CO product suffers from a bias and cloud clearing noise contamination
- Work has been done to improve CO and CH4 a priori, chn selection, RTA IR bias correction and QC.
- In situ vertical profile measurements are key to test algorithm upgrades.
- Changes are being tested for both SNPP and NOAA-20 and will be shown in the trace gas validated maturity review.
- Preliminary results show that layers where sensitivity to CO is high (400-500mb) are showing expected improvements over implementation of new CO LUT. Here NUCAPS CO meets requirement.
- It is recommended though to separate carbon trace gas requirements by coarse layers as opposed to total column, as it is done for temperature, water vapor and ozone. This is to take into account the vertical dependent carbon trace gas sensitivity.

SNPP vs NOAA-20 OLR





- ✓ SNPP and NOAA-20 OLR are strongly consistent.
- ✓ Results have been derived by applying the SNPP OLR module to NOAA-20.
- ✓ Work is in progress to deliver NOAA-20 derived OLR coefficients.

User Feedback

Name	Organization	Application	User Feedback - User readiness dates for ingest of data and bringing data to operations
AWIPS users	Regional WFOs	Temperature, water vapor in the BL	Need to improve Temperature and Water Vapor in the BL. Need better quality indicators. *Ongoing work.*
Brad Pierce, Shobha Kondragunta	NOAA/NESDIS/STAR	Carbon Monoxide	Spurious spikes of CO values at the edge of clouds indicate the need for better QC There seems to be a distinctive bias in the CO retrieval profile. *June 15 DAP addressed and mitigated both issues.*
Multiple from FIREX TIM (November 2016)	Multiple	Carbon Trace Gases	Need Averaging Kernels to be added to the operational product distribution. Need to add NH_3 to the operational product list. *Work is in progress to submit a formal user request.*
Multiple	Multiple	Atmospheric Composition	Need to correct for topography in the operational netcdf product; distribute total column quantities

Documentations (Check List, 1 slide)

Science Maturity Check List	Yes ?
ReadMe for Data Product Users	yes
Algorithm Theoretical Basis Document (ATBD)	Yes (NPP)
Algorithm Calibration/Validation Plan	Yes (NPP)
(External/Internal) Users Manual	Yes (NPP)
System Maintenance Manual (for ESPC products)	Yes (NPP)
Peer Reviewed Publications (Demonstrates algorithm is independently reviewed)	Yes (NPP)
Regular Validation Reports (at least. annually) (Demonstrates long-term performance of the algorithm)	Yes (NPP)

Path Forward

Planned improvements

- MW Surface Emissivity classification improvement
- MW RTA bias correction
- IR Surface Emissivity
- MW+IR Water Vapor Supersaturation issue
- Statistical regression improvement by removal of cloud contamination in the training ensemble
- Optimization of IR channel selection
- Development of vertically dependent retrieval quality indicators
- N2O and CH4 a priori improvement
- IR RTA bias correction improvement

Future Cal/Val activities / milestones

- RIVAL and ARM sites dedicated RAOBs
- AEROSE Field Campaign (~2019)
- WE-CAN campaign (July – September 2018)
- FIREX Campaign (~2019)
- Maturity Validated Review ~ September 2018.

Check List - Beta Maturity

Beta Maturity End State	Assessment
Product is minimally validated, and may still contain significant identified and unidentified errors	**YES**. NOAA-20 carbon products appear generally lower than SNPP products. As time progresses, we will be able to acquire additional focus days for improved LUT training.
Information/data from validation efforts can only be used to make initial qualitative or very limited quantitative assessments regarding product fitness-for-purpose	**YES**. As time progresses, we will be able to acquire more extensive validation ensembles.
Documentation of product performance and identified product performance anomalies, including recommended remediation strategies, exists	**YES**. All actions are recorded. Future plan activity is laid out.

Back up slides

- Required Algorithm Inputs
  - Primary Sensor Data: CrIS and ATMS SDRs
  - Ancillary Data: GFS surface pressure
  - Upstream algorithms: none
  - LUTs via namelists

- Evaluation of the effect of required algorithm inputs
  - Study / test cases
  - Results

MW-only Requirements Verification

Summary on GLOBAL validation vs ECMWF

green = passed yellow = close red = failed

Summary on MW-Only/Cloudy Results vs JPSS L1RD Requirements							
Temperature				Water Vapor			
Pressure Range (hPa)	JPSS L1RD Requirement (K)	NPP (K)	NOAA-20 (K)	Pressure Range (hPa)	JPSS L1RD Requirement (%)	NPP (%)	NOAA-20 (%)
30-300	1.5	2.1	2.0	100-300	40	45.4	42.7
300-700	1.5	2.3	2.6	300-600	40	42.3	37.9
700-Psfc	2.5	3.0	3.6	600-Psfc	20	31.5	34.6

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Preliminary error budget: testing intermediate SNPP NUCAPS upgrades (vs TCCON, 4 Focus Days)

Top: AKs

Bottom: No AKs

	TCCON Baseline V2.1.4 Full Res *Trace Gas QA*			TCCON Baseline V2.1.5 Full Res *Trace Gas QA*			TCCON Baseline V2.1.6 Full Res *Trace Gas QA*		
Trace Gas EDR	BIAS (%)	STD (%)	RMS (%)	BIAS (%)	STD (%)	RMS (%)	BIAS (%)	STD (%)	RMS (%)
CO	**+8.9** **+7.6** (±5.0)	**6.5** **6.4** (15.0)	11.1 9.9	**+4.0** **+2.3** (±5.0)	**6.9** **5.5** (15.0)	8.0 5.9	**+3.6** **+1.4** (±5.0)	**7.7** **7.4** (15.0)	8.5 7.5
CO_2	**−0.4** **−0.3** (±1.0)	**0.7** **0.7** (0.5)	0.8 0.8	**−0.4** **−0.3** (±1.0)	**0.7** **0.7** (0.5)	0.8 0.8	**−0.4** **−0.3** (±1.0)	**0.7** **0.7** (0.5)	0.8 0.8
CH_4	**−0.2** **−0.3** (±4.0)	**1.4** **1.4** (1.0)	1.4 1.4	**−0.2** **−0.3** (±4.0)	**1.4** **1.4** (1.0)	1.4 1.4	**−0.2** **−0.3** (±4.0)	**1.4** **1.4** (1.0)	1.4 1.4

	Yield	n
CO	63.5%	283
CO2	71.5%	319
CH4	74.9%	334

	Yield	n
CO	28.0%	125
CO2	71.5%	319
CH4	74.9%	334

	Yield	n
CO	26.9%	120
CO2	71.5%	319
CH4	74.9%	334