Provisional Maturity Science Review
For NOAA-20 NUCAPS Ozone, trace gases and OLR

Presented by Antonia Gambacorta and Nick Nalli

Date: 2018/10/02

JPSS Data Products Maturity Definition

1. Beta

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

2. Provisional

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

3. Validated

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

Provisional Maturity Review - Entry Criteria

- Product Requirements
- Pre-launch Performance Matrix/Waivers
- Provisional Maturity Performance Validation
  - On-orbit instrument performance assessment
    - Identify all of the instrument and product characteristics you have verified/validated as individual bullets
    - Identify pre-launch concerns/waivers, mitigation and evaluation attempts with on-orbit data
- Users/EDRs feedback
- Risks, Actions, Mitigations
  - Potential issues, concerns
- Path forward to Validated Maturity
- Summary

Provisional Maturity Review - Exit Criteria

- Provisional Maturity Performance is well characterized and meets/exceeds the requirements:
  - On-orbit instrument performance assessment
    - Provide summary for each identified instrument and product characteristic you have validated/verified as part of the entry criteria
    - Provide summary of pre-launch concerns/waivers mitigations/evaluation and address whether any of them are still a concern that raises any risk.
- Updated Provisional Maturity Slide Package addressing review committee's comments for:
  - Cal/Val Plan and Schedules
  - Product Requirements
  - Provisional Maturity Performance
  - Risks, Actions, Mitigations
  - Path forward to Validated Maturity

PROVISIONAL MATURITY REVIEW MATERIAL FOR NUCAPS OZONE, TRACE GASES AND OLR

Outline

- Algorithm Cal/Val Team Members
- Product Overview/Requirements
- Evaluation of algorithm performance to specification requirements
  - Algorithm version, processing environment
  - Evaluation of the effect of required algorithm inputs
  - Quality flag analysis/validation
  - Error Budget
- User Feedback
- Downstream Product Feedback
- Risks, Actions, and Mitigations
- Documentation (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 Trace Gas EDR Uncertainty (O3, CO, CO2, CH4)

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 Specification Performance Requirements
CrIS OLR

Attribute	Threshold	Objective
Geographic coverage	At least 90% coverage of the globe every 12 hours (monthly average) (once/daytime; once/nighttime)	
Vertical Coverage	N/A	
Horizontal Cell Size	25 km at Nadir	10 km at Nadir
Mapping Uncertainty (3σ)	5 km at Nadir	2 km at Nadir
Measurement Range	0 – 500 W/m^2	0 – 500 W/m^2
Measurement Accuracy	5 W/m^2	3 W/m^2
Measurement Precision	12 W/m^2	6 W/m^2

Processing Environment and Algorithms

- Description of processing environment and algorithms used to achieve Provisional maturity stage:
  - Algorithm version
  - Version of LUTs used
  - Effective date

Processing Environment and Algorithm Versions

August 20, 2018
Enterprise NUCAPS update to newly calibrated NOAA-20 SDRs and new nedt (Version 2.2)
NOAA-20 Provisional Maturity Review for ozone, trace gases and OLR

August 7th, 2018
NUCAPS MetOp B goes live in CSPP (Version 2.1.12c)

June 22nd, 2018
Enterprise NUCAPS Delivery of Algorithm Package (DAP) to ASSIST (Version 2.1.12c)
NUCAPS Enterprise algorithm delivery to UW for implementation in CSPP (Version 2.1.12c)

June 15th, 2018
NUCAPS NOAA-20 Temperature and Water Vapor Provisional Maturity review (Version 2.1.12c)

April 27th, 2018
First NOAA-20 NUCAPS Delivery of Algorithm Package (DAP) (Version 2.1.7)

April 4th, 2018
Implementation of NUCAPS Enterprise Algorithm (SNPP, NOAA-20, MetOp) in the HEAP (Version 2.1.7)

January 5th, 2018
NUCAPS NOAA-20 first Light results (Version 2.1.4)

August 31st, 2017
NUCAPS Phase 4 delivered to UW for implementation in CSPP (Version 2.0.5.4)

July 7th, 2017
NUCAPS Phase 4 Algorithm Readiness Review
NUCAPS Phase 4 Delivery of Algorithm Package (DAP) to ASSIST (Version 2.0.5.4)

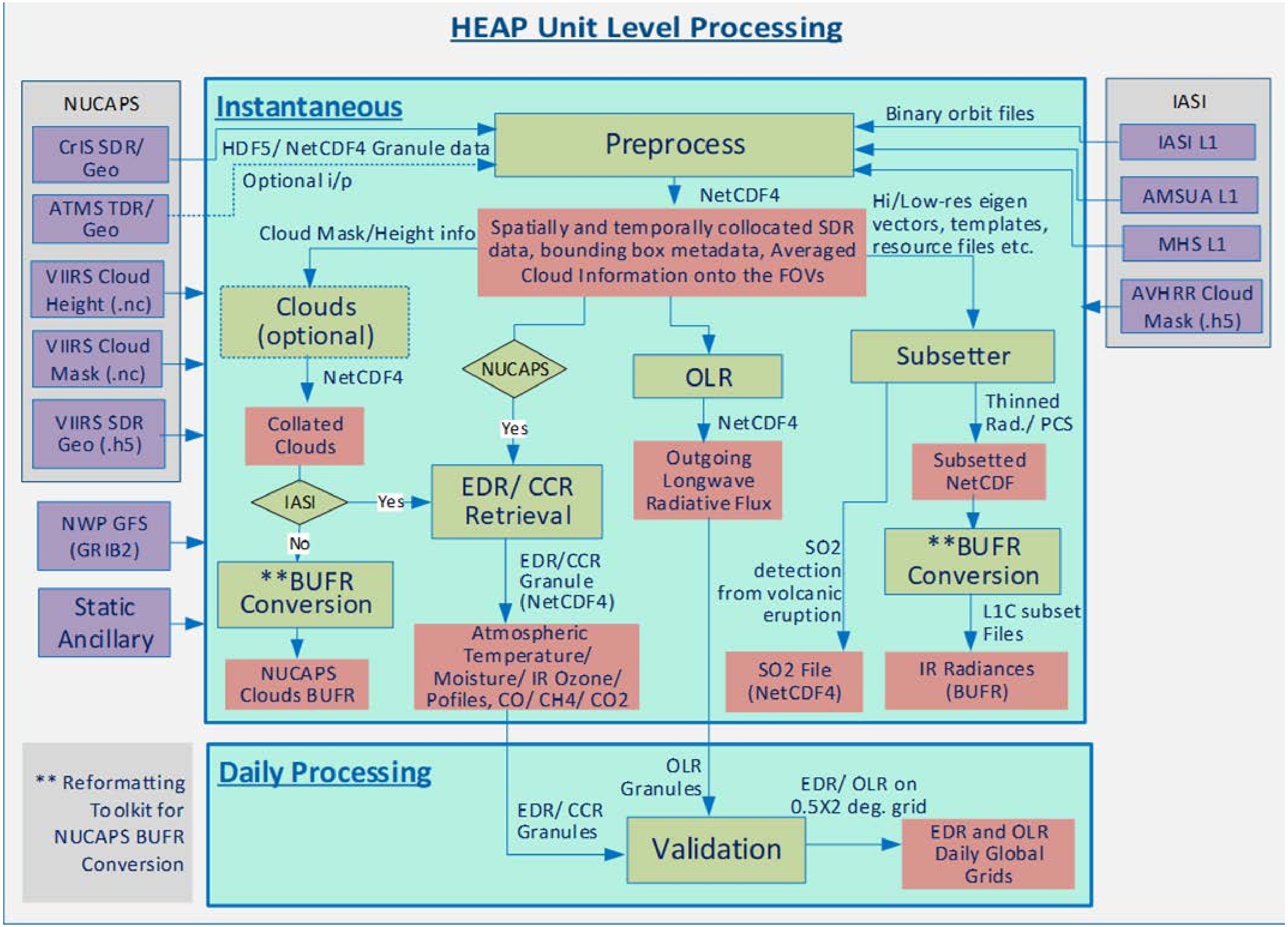
FY2018 NUCAPS test version history

- V2.0.5.4
  - NUCAPS Phase 4 delivery
- V2.1.4
  - New regression and CCR channels
- V2.1.7 (builds on v2.1.4)
  - NOAA-20 new nedt for ATMS and CrIS
- V2.1.9 (builds on v2.1.4)
  - New *T, Q*, CCR channels
- V2.1.10a
  - New CO *a priori*
- V2.1.10n (builds on v2.1.9)
  - New CO *a priori*
  - New *T, Q*, CCR channels
  - CO QC
  - Old Tuning
- V2.1.11a
  - New CO channels to 2200 cm-1
  - New CO Tuning (“patched” tuning)
- V2.1.11b
  - New CO channels to 2200 cm-1
  - New CO and CH4 Tunings
- V2.1.12
  - Modified “preferred” CO QC from Juying into a new “relaxed” CO QC, allowing regions over Africa (for example) to pass where they previously failed
- V2.1.12b
  - Used 11a moving forward, again with new tuning/rtaerr from Changyi using 326-327. instead of being a partial patch, this was a full tuning/rtaerr change. This version returned to the truncated 35 channel CO list ending at 2191.25.
  - These tuning sets caused more issues than they solved.
- V2.1.12c
  - Partial compromise between the issues in the V2.1.12 namelists and the improvements in V2.1.11 and the code changes. Uses V2.1.11a, but included the truncated CO channels (35) in the ozone namelists and the new “relaxed” CO tuning introduced at NUCAPS V2.1.12.
- V2.2
  - NOAA-20 new NEDT
- V2.3
  - Enterprise SARTA IR bias correction (March and April 2018 focus days)

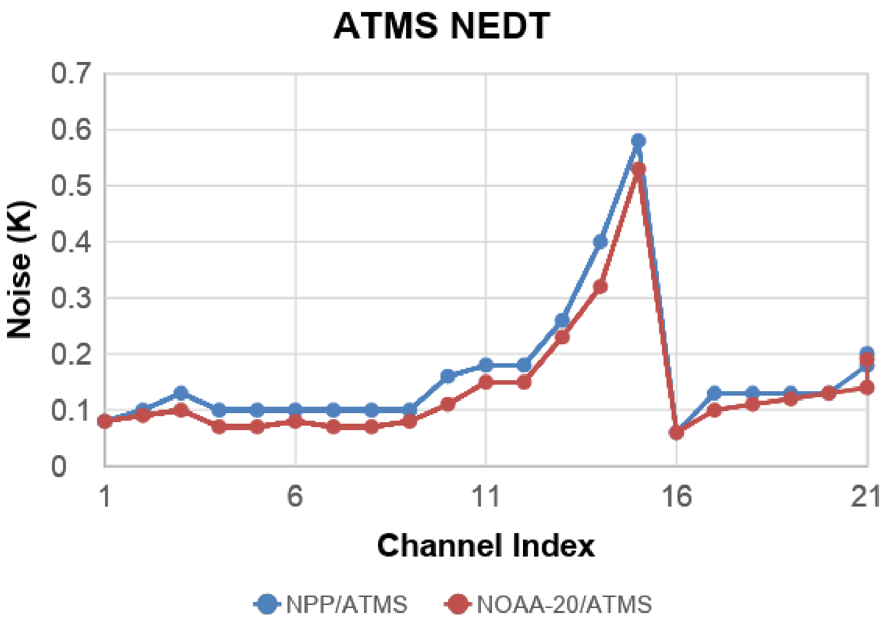
Status of NUCAPS

- NUCAPS SNPP Temperature, water vapor, ozone and OLR have reached validated maturity
- Significant upgrades affecting temperature and water vapor were validated and approved for provisional status on June 15th, 2018.
- Significant carbon trace gases upgrades were made in FY18 on the NUCAPS enterprise system but only tested on SNPP due to lack of comprehensive validation ensembles available for NOAA-20 at the time of the beta maturity review (June 15th, 2018). Only qualitative comparisons could be shown.
- In this review,
  - We continue comparing NUCAPS NOAA-20 to SNPP ozone, trace gases and OLR.
  - We show validation of NOAA-20 products against independent truth data sets as well.
- More in-depth analysis will be made as larger dedicated NOAA-20 validation ensembles are acquired with time.
- We will continue making unified upgrades to the NUCAPS enterprise system towards the final validation maturity review for NUCAPS SNPP and NOAA-20 (Spring 2019).

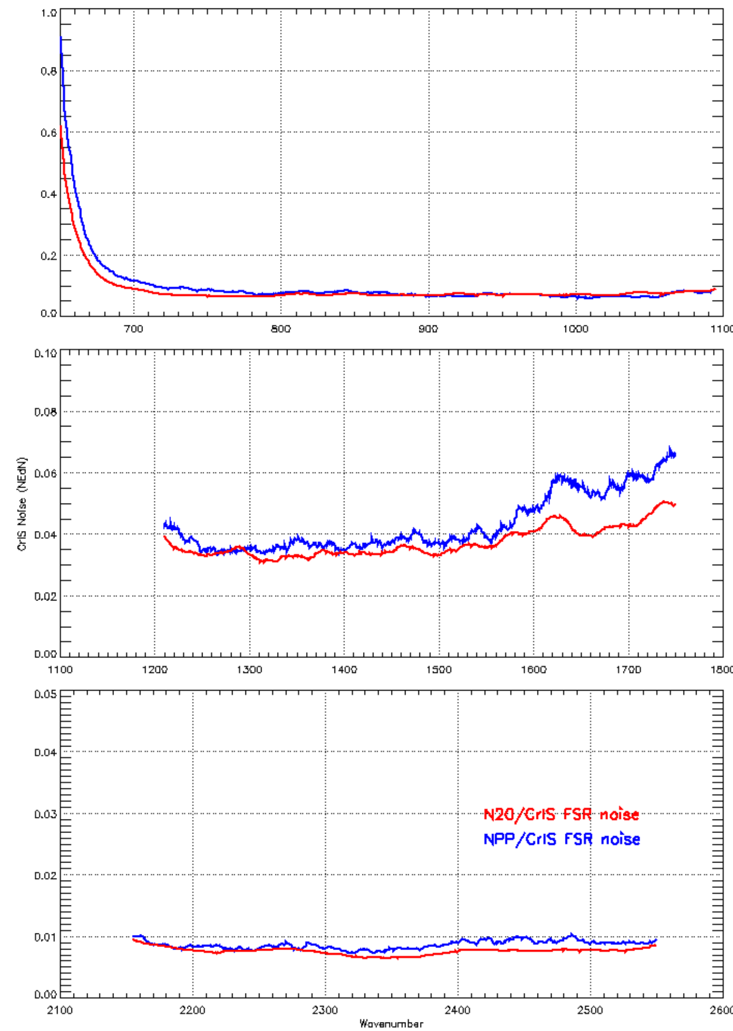
April 4th, 2018:
NUCAPS is implemented in the Hyperspectral Enterprise Algorithm Package (HEAP): one executable, one machine, one LUT methodology, multiple instruments



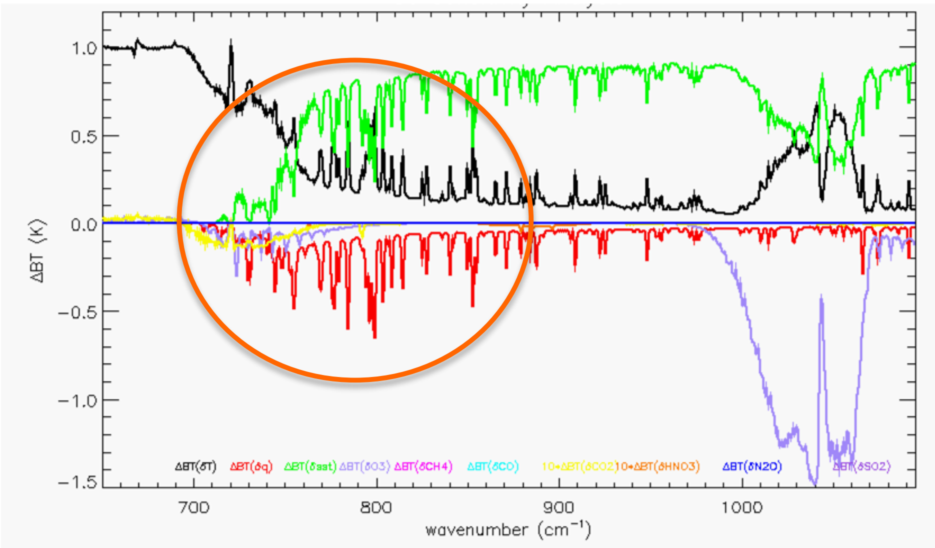
NUCAPS Version 2.1.7 (NOAA-20 only upgrade)



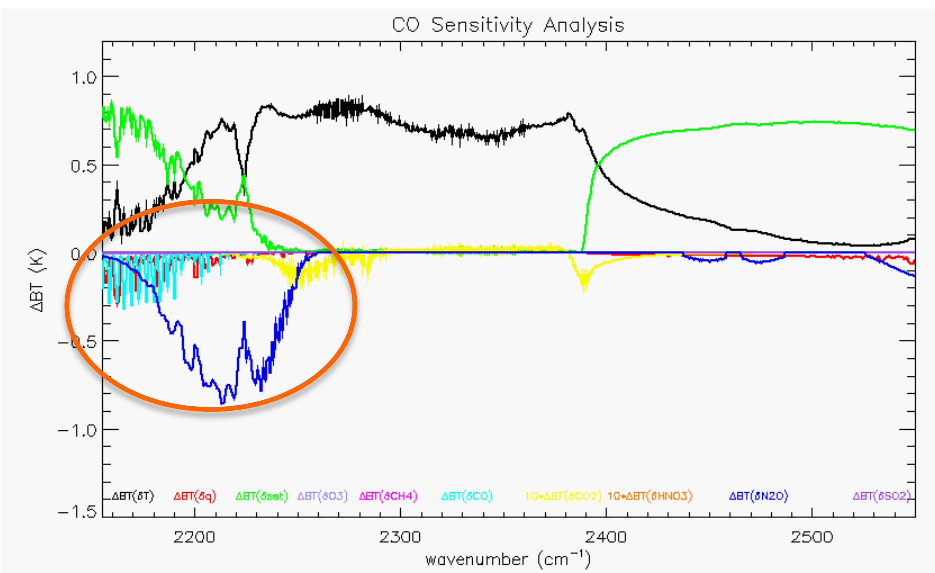
CrIS NEDT



NUCAPS Version 2.1.9 and 2.1.11a

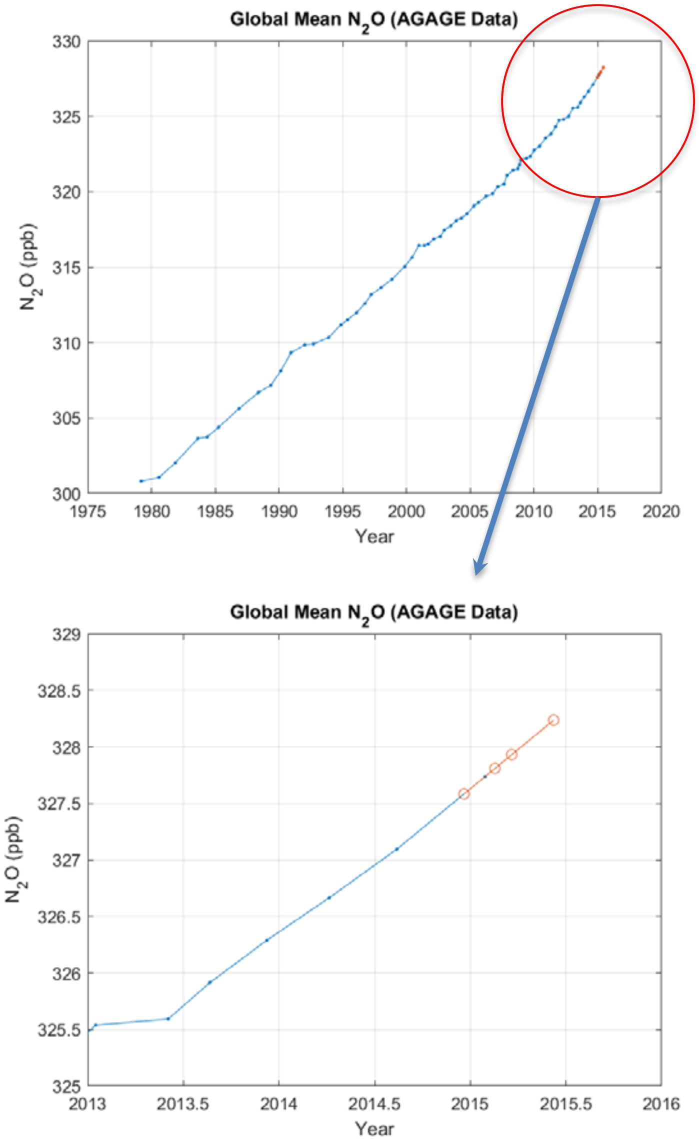


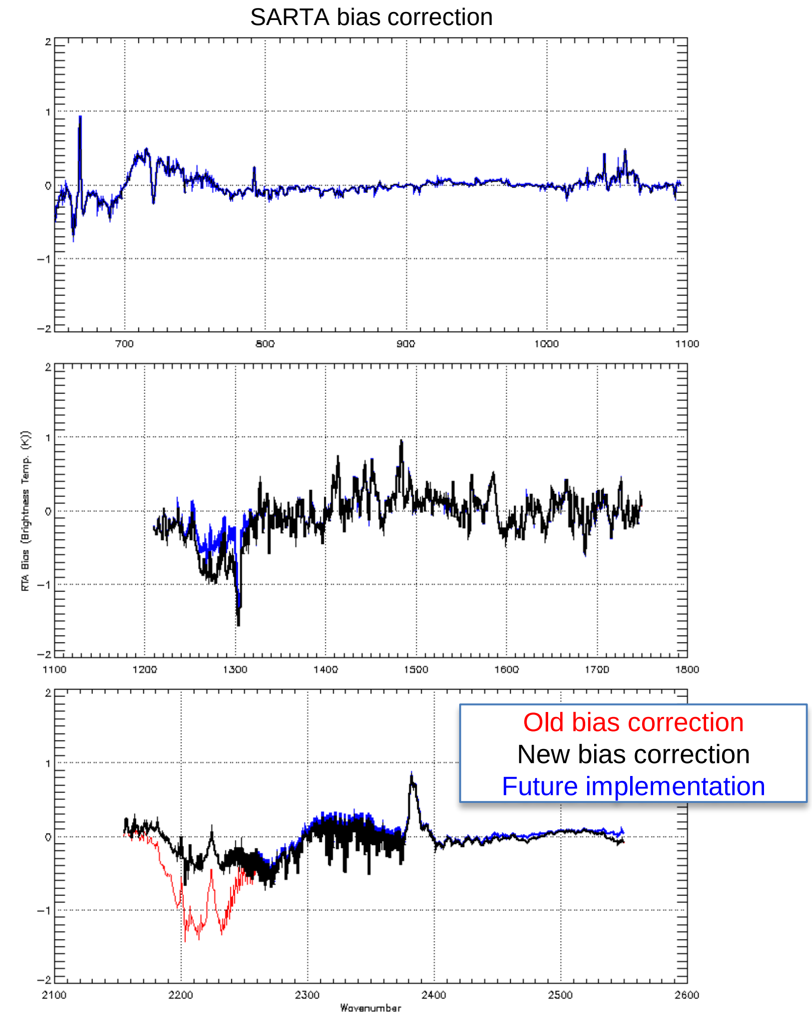
NUCAPS V2.1.9
Optimized T, q, CCR channel selection



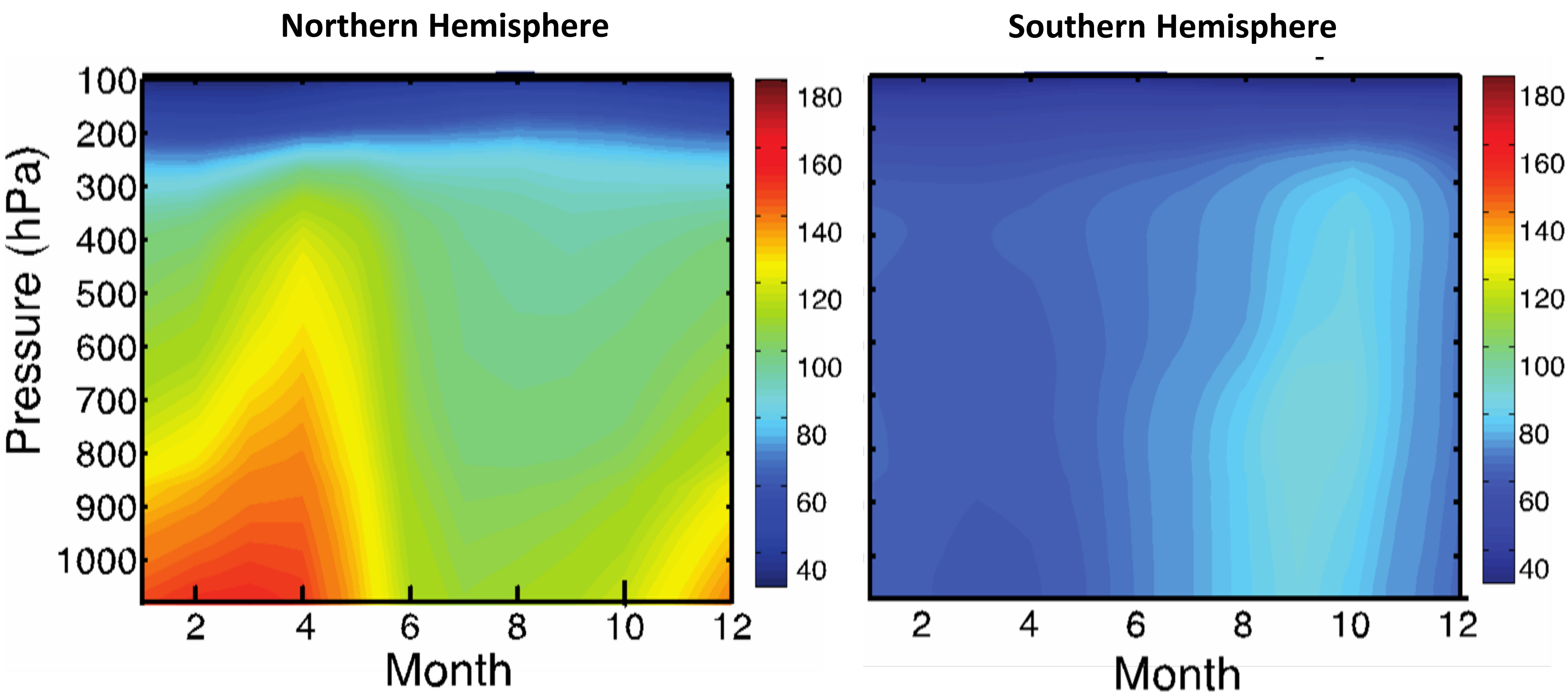
NUCAPS V2.1.11a
Optimized CO channel selection

NUCAPS version 2.1.11a: optimized SARTA bias correction in the CO band





NUCAPS version 2.1.10a: improved carbon monoxide a priori



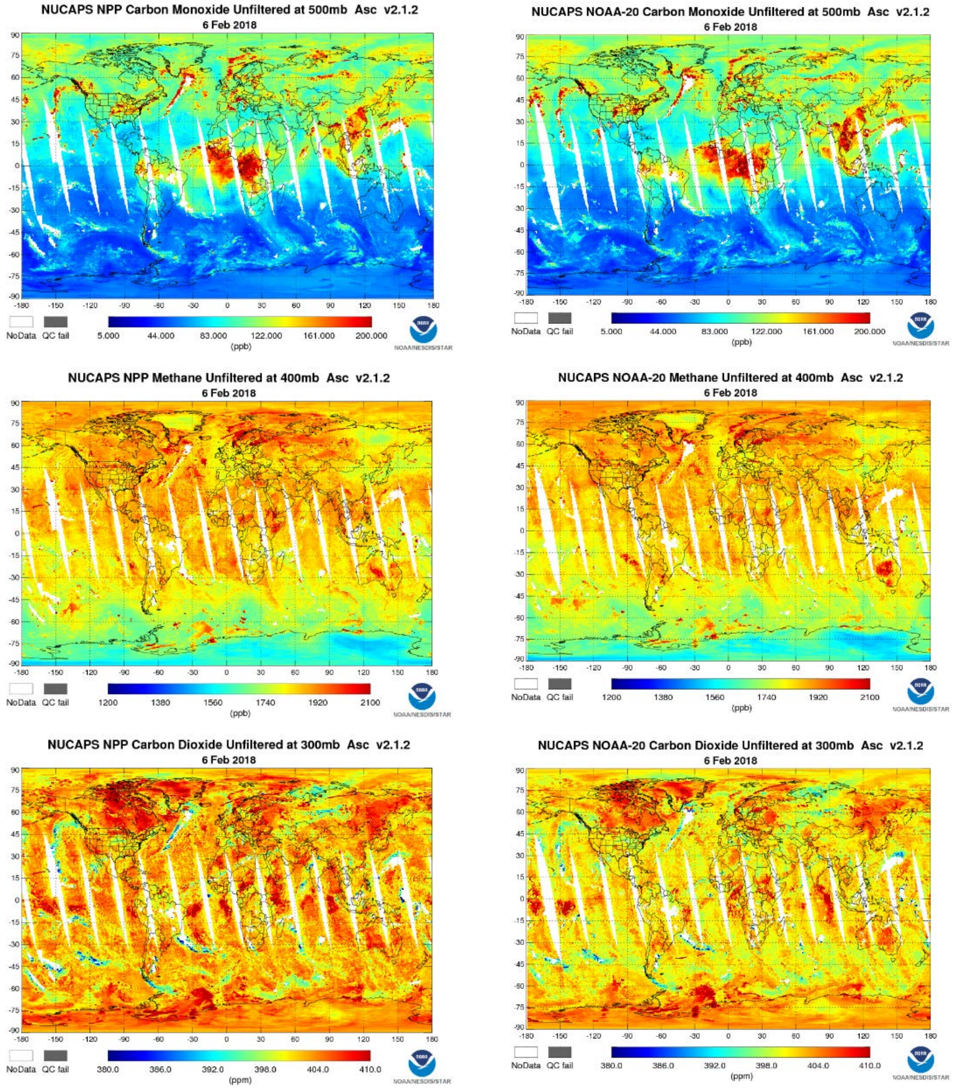
- Two hemispheric CO profiles (ppbv) developed from NCAR MOZART-GEOS5 model;
- Linear transition between 15N and 15S;
- Monthly varying, but no year-to-year variations;
- Same approach as for AIRS, but updated to current values.

Evaluation of algorithm performance to specification requirements

- **Findings/Issues from Beta Review**
  - Ozone
    - needed to show multiple global focus days and comparisons against ozone sondes
  - Carbon trace gases
    - CH_4 and CO_2 appeared consistently negatively biased wrt SNPP
    - needed to show more comprehensive and quantitative validation
    - Requirements appeared too stringent
  - OLR
    - needed to show more comprehensive and quantitative validation

- **Improvements since Beta Review**
  - Algorithm Improvements
    - none
  - LUT updates
    - Upgrade to newest NOAA-20 CrIS NEDT (August 14th 2018 release)
    - Computed new SARTA IR bias correction – still preliminary
    - Now processing newly calibrated NOAA-20 CrIS SDRs
  - Acquired necessary validation ensembles for provisional maturity review

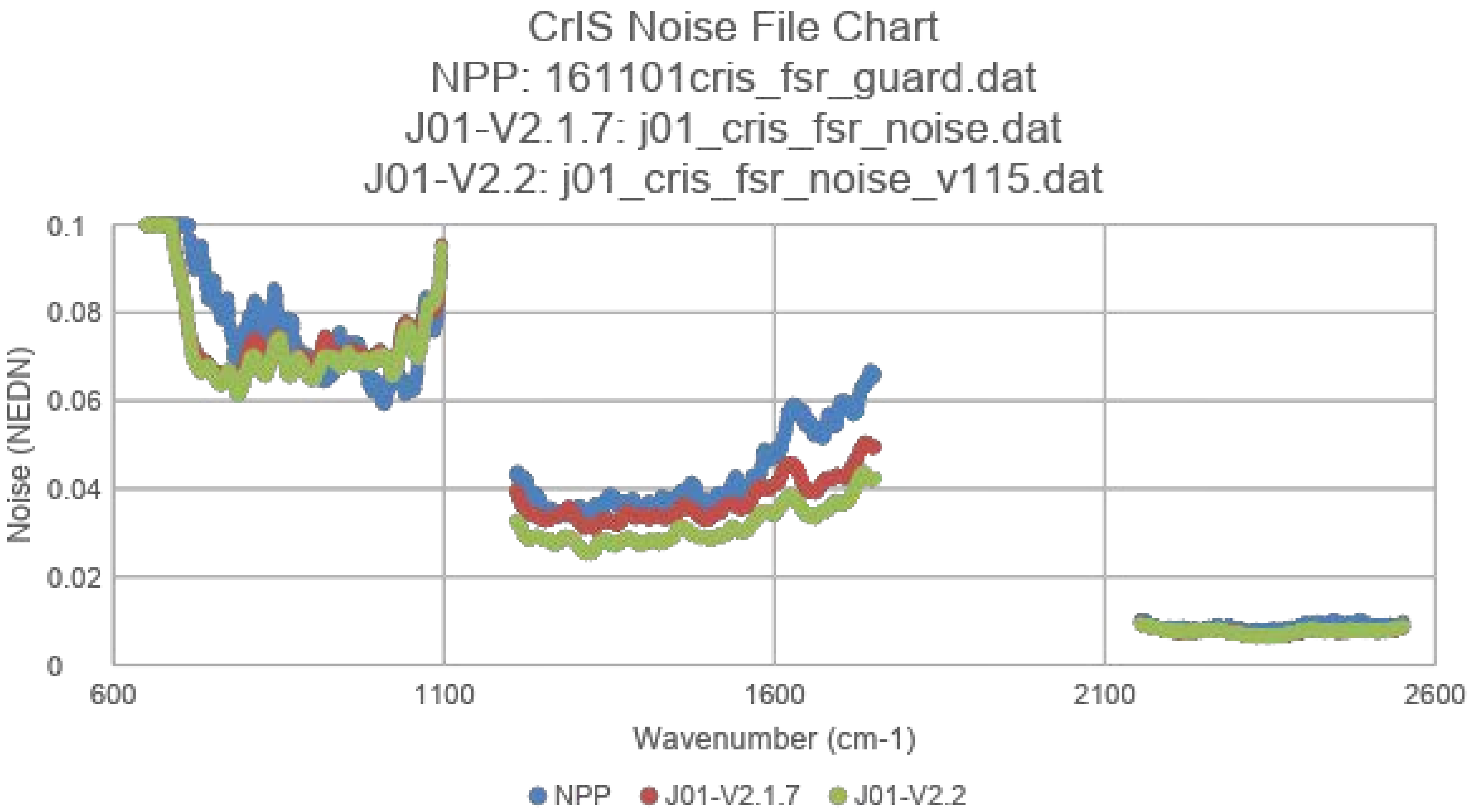
Findings/issues from beta review



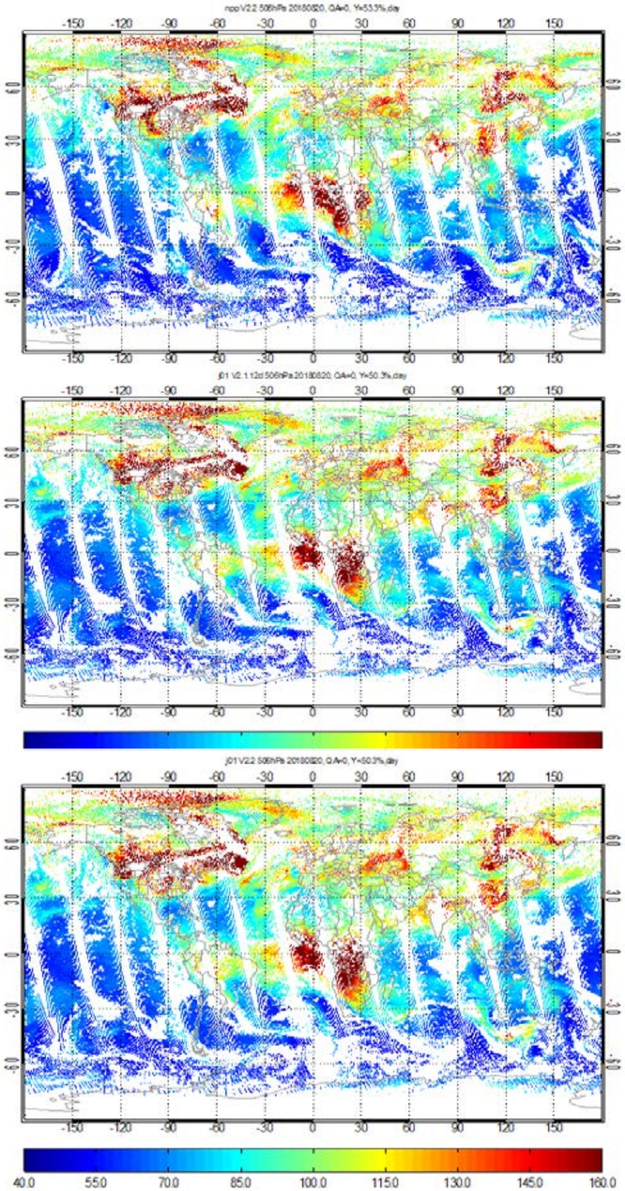
Left: SNPP NUCAPS
Right: NOAA20 NUCAPS

CH4 and CO2 appeared consistently negatively biased wrt SNPP

NOAA-20 CrIS NEDT (August 14th, 2018)



August 20th, NUCAPS v2.2: newly calibrated NOAA-20 CrIS SDRs and NOAA-20 CrIS instrument noise equivalent delta temperature (NEDT) upgrades



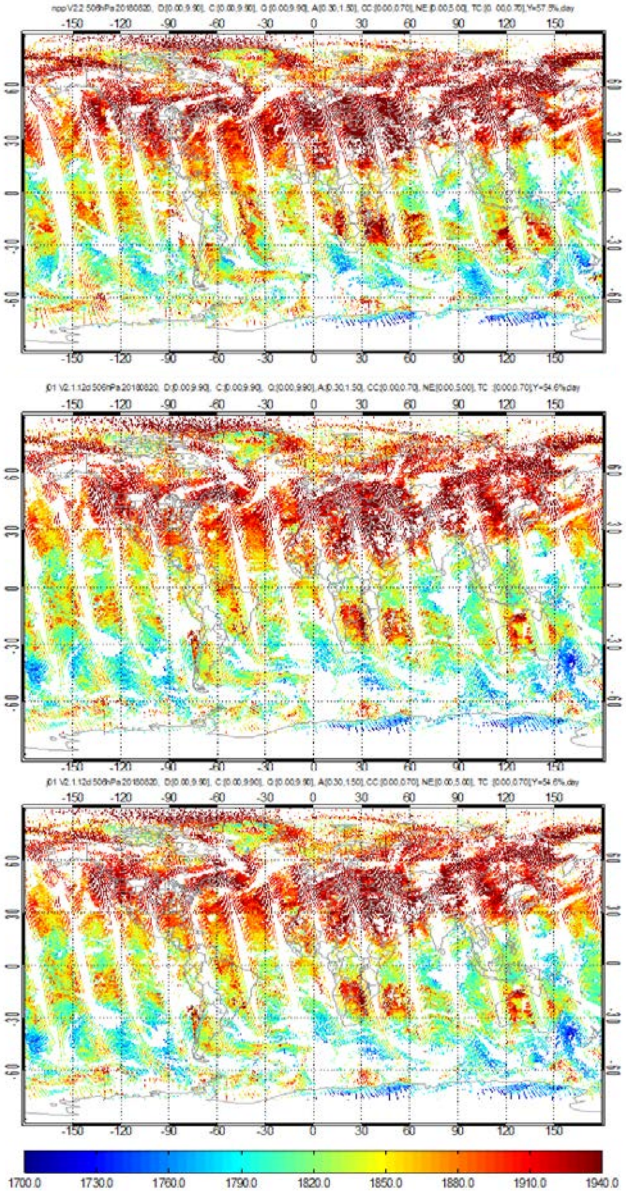
Carbon Monoxide

- **Top:** NUCAPS SNPP operational
- **Centre:** NUCAPS N-20 operational
- **Bottom:** NUCAPS N-20 V2.2

*SNPP operational and V2.2 are the same
*N-20 V2.2 system has newest NEDT

- NUCAPS SNPP and NOAA-20 carbon monoxide products are remarkably consistent. Differences are attributable to transport.
- NOAA-20 nedt upgrade does not show significant changes.

August 20th, NUCAPS v2.2: newly calibrated NOAA-20 CrIS SDRs and NOAA-20 CrIS instrument noise equivalent delta temperature (NEDT) upgrades



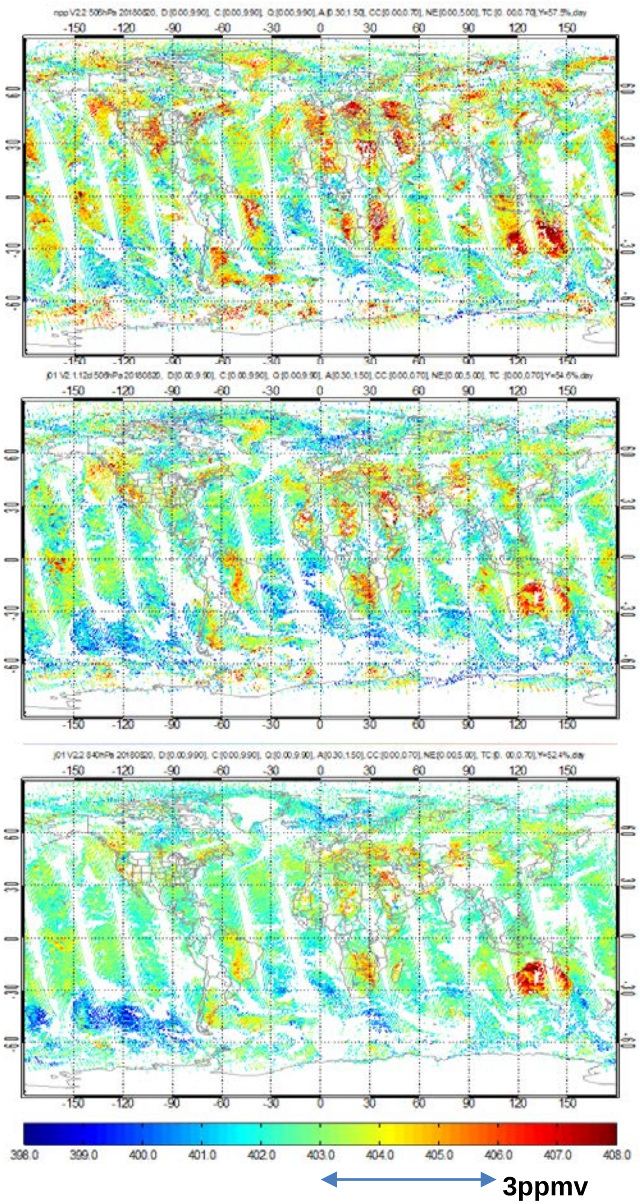
Methane

- **Top:** NUCAPS SNPP Operational
- **Centre:** NUCAPS N-20 Operational
- **Bottom:** NUCAPS N-20 V2.2

*SNPP operational and V2.2 are the same
*N-20 V2.2 system has newest NEDT

- NUCAPS SNP methane has reached provisional maturity already
- NUCAPS SNPP and NOAA-20 methane are now more consistent
- NUCAPS NOAA-20 methane slightly negatively biased wrt SNPP
- NOAA-20 LUTs relevant to methane are being tested: IR SARTA model bias correction; regression coefficients.
- Those upgrades will be part of final delivery (validated maturity review)

August 20th, NUCAPS v2.2: newly calibrated NOAA-20 CrIS SDRs and NOAA-20 CrIS instrument noise equivalent delta temperature (NEDT) upgrades



Carbon Dioxide

- **Top:** NUCAPS SNPP Operational
- **Centre:** NUCAPS N-20 Operational
- **Bottom:** NUCAPS N-20 V2.2

*SNPP operational and V2.2 are the same

*N-20 system has newest NEDT

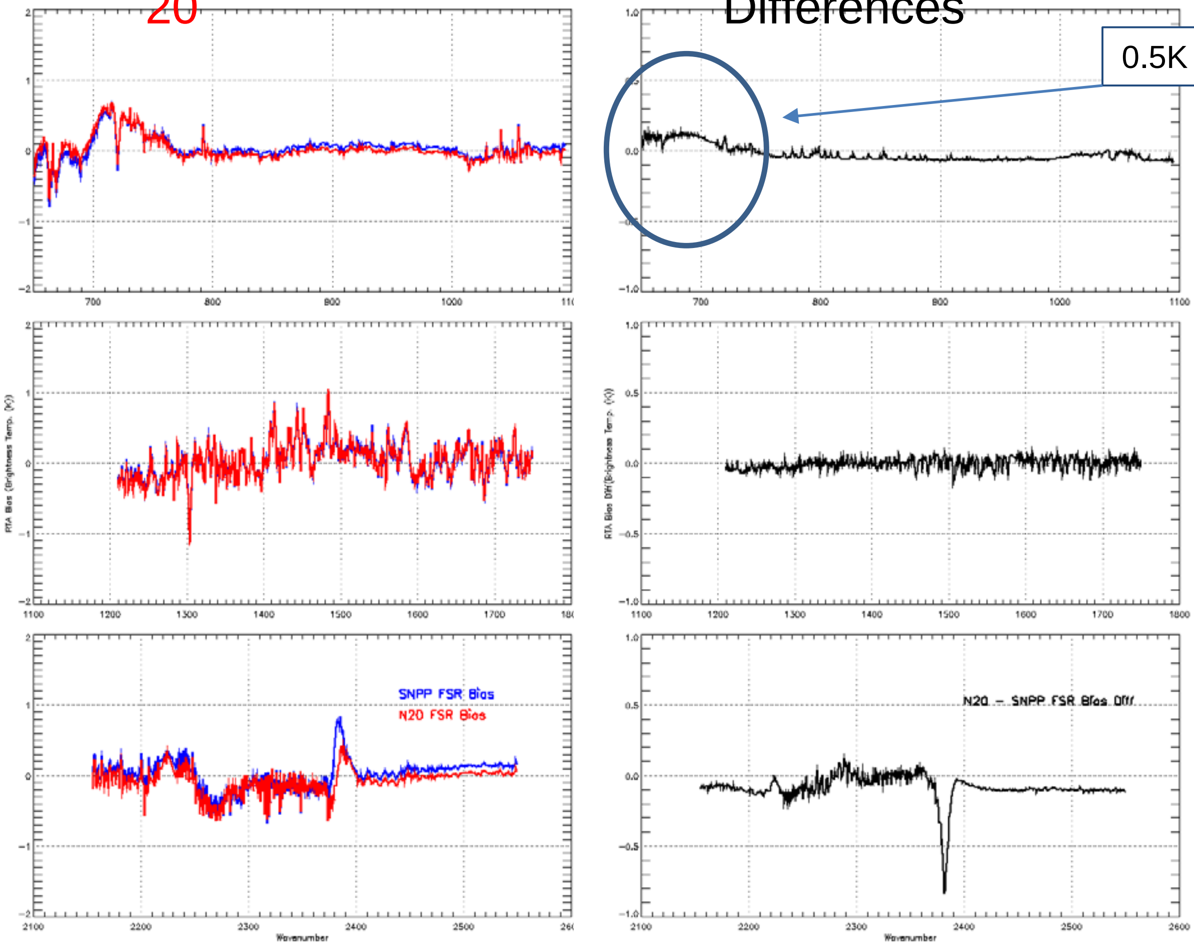
- NUCAPS SNPP and NOAA-20 carbon monoxide are now significantly more consistent wrt each other
- NOAA-20 carbon dioxide still shows a negative bias wrt SNPP (see slide 19)
- We think we need to update the SARTA bias correction (see next slide)
- **0.1K difference in the OBS translates to 3ppmv in CO_2!**

SNPP vs NOAA-20 CrIS inter-calibration OBS- CALC using SARTA Forward Model(*)

SNPP vs NOAA-20

Double Differences

0.5K -> 3ppmv in CO_2

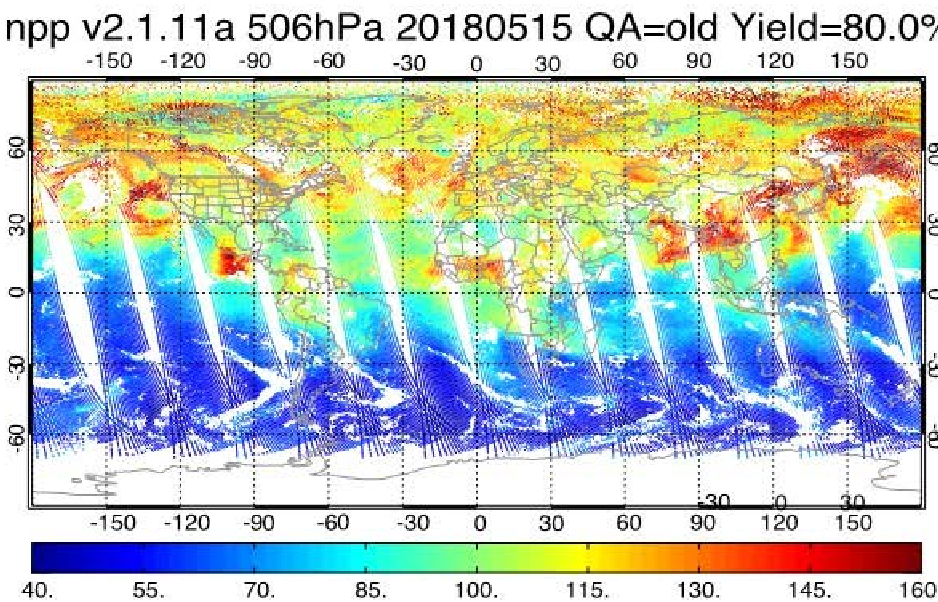


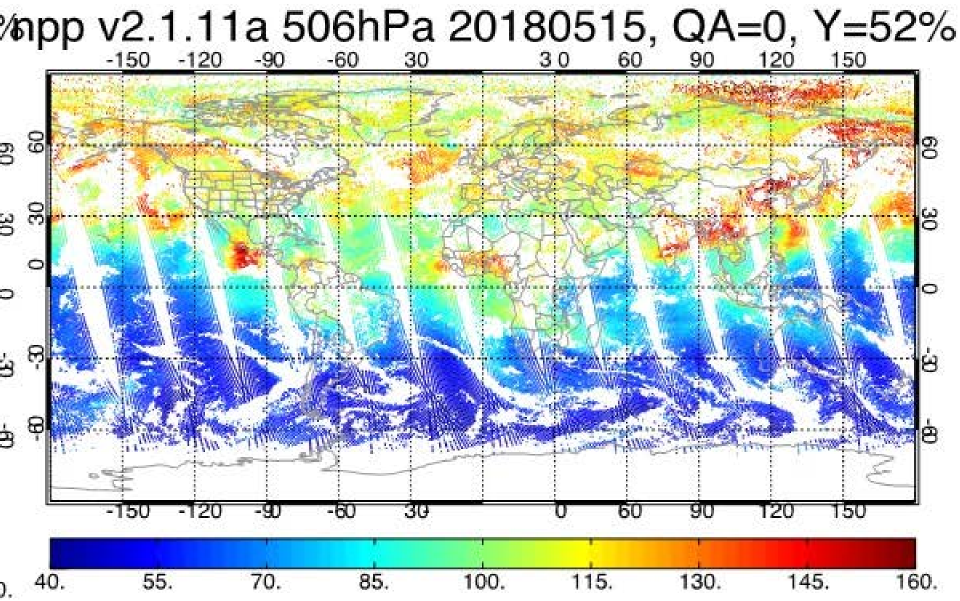
(*) Ocean, night, mid latitude, clear sky cases from two Spring 2018 focus days

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

NUCAPS 2.1.12c: new CO quality control





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

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

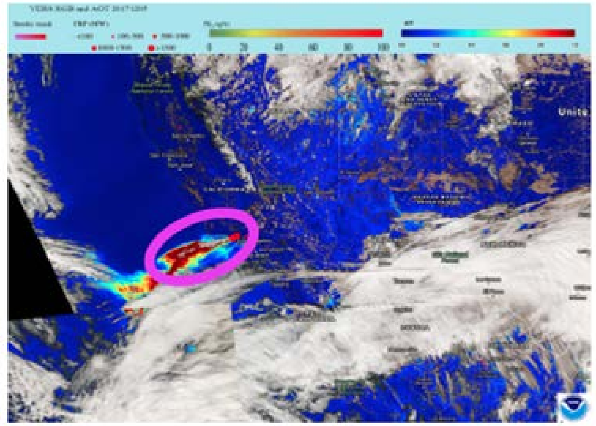
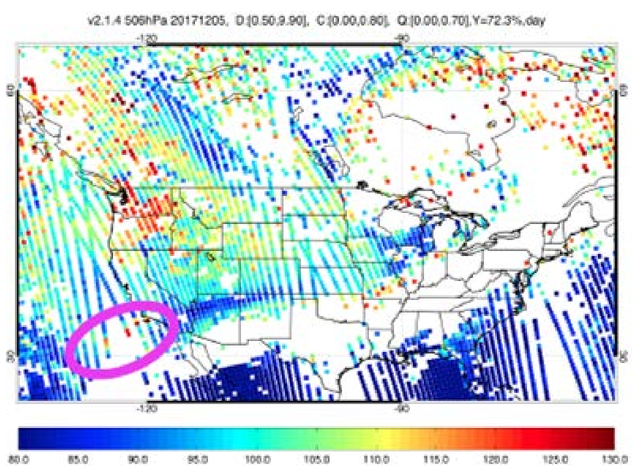
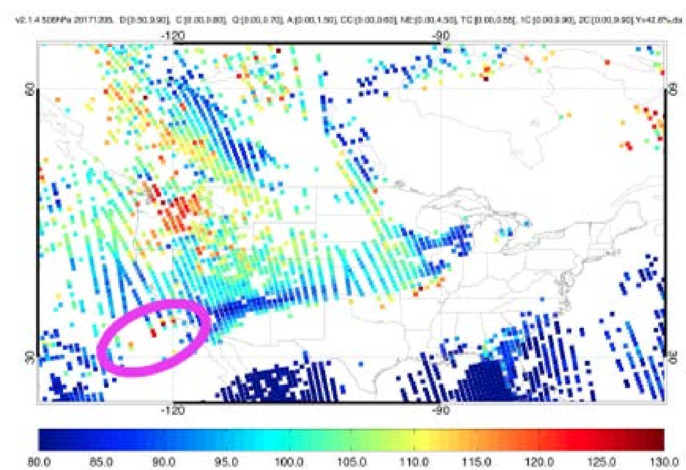


Figure courtesy of Shobha Kondragunta

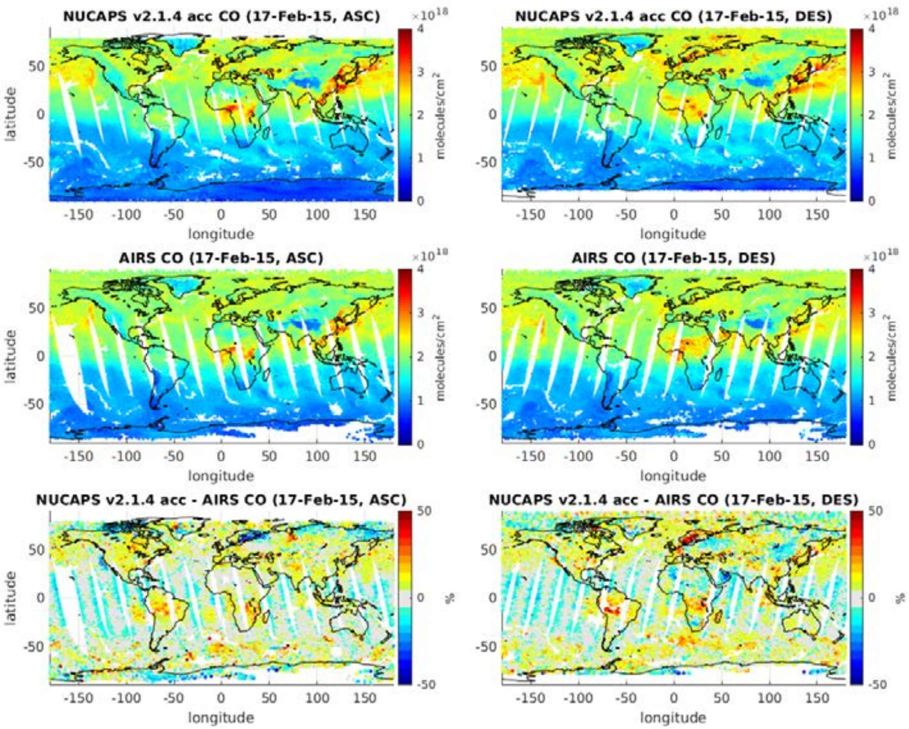




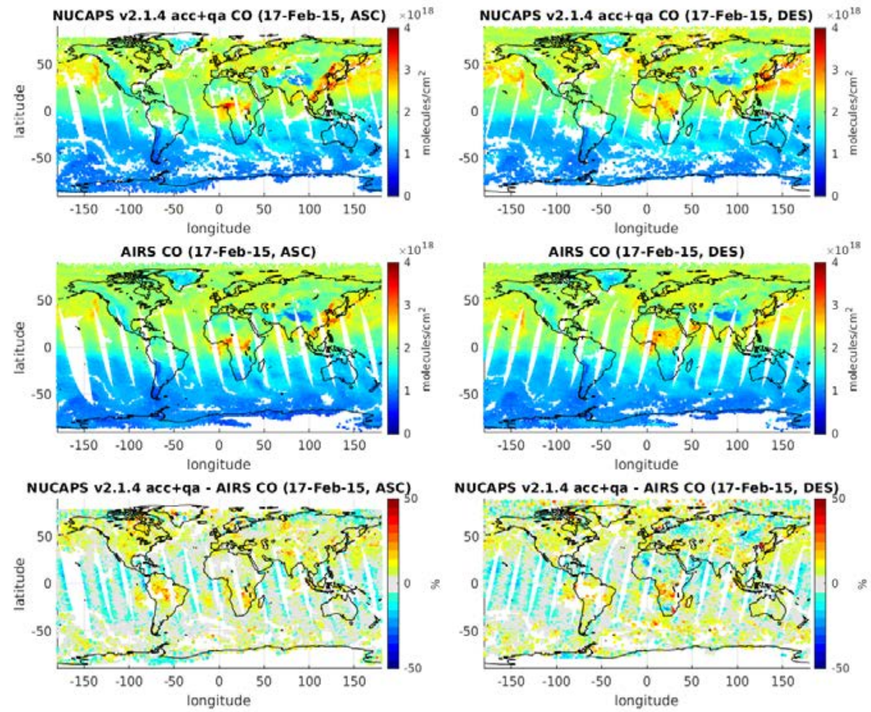
- CO tailored QC removes spurious spikes in CO due to poor cloud clearing while preserving the real signal of interest (CA Thomas Fire, Dec. 5th, 2017)

Quality flag analysis/validation: carbon monoxide
Comparison against AIRS carbon monoxide

IR+MW Accepted Cases

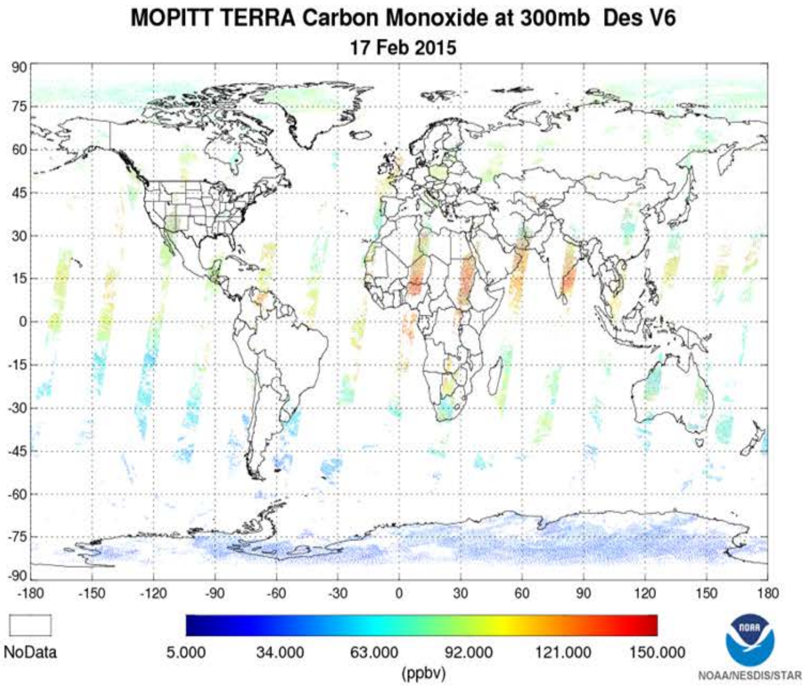


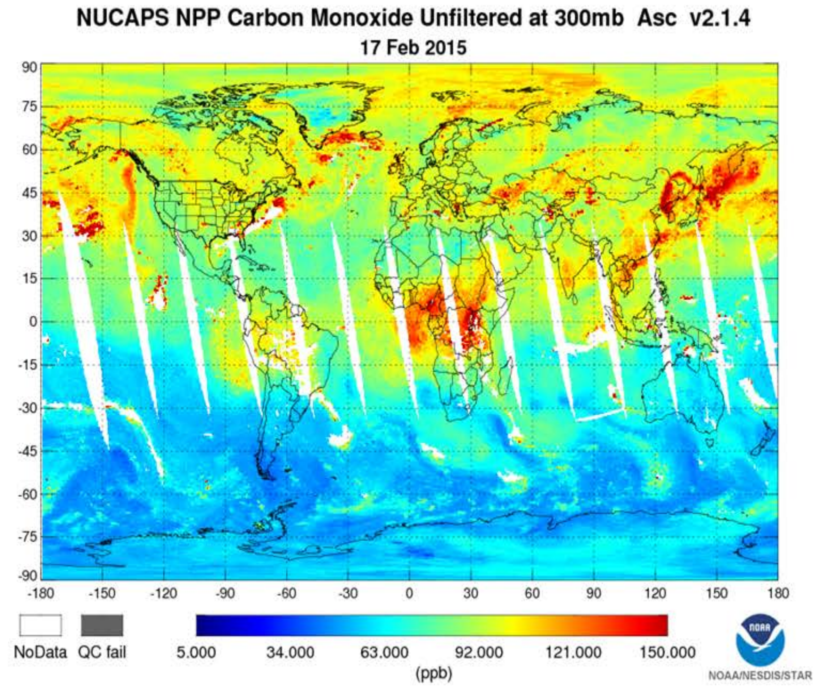
IR+MW Accepted Cases + Trace Gas QA



- 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**.

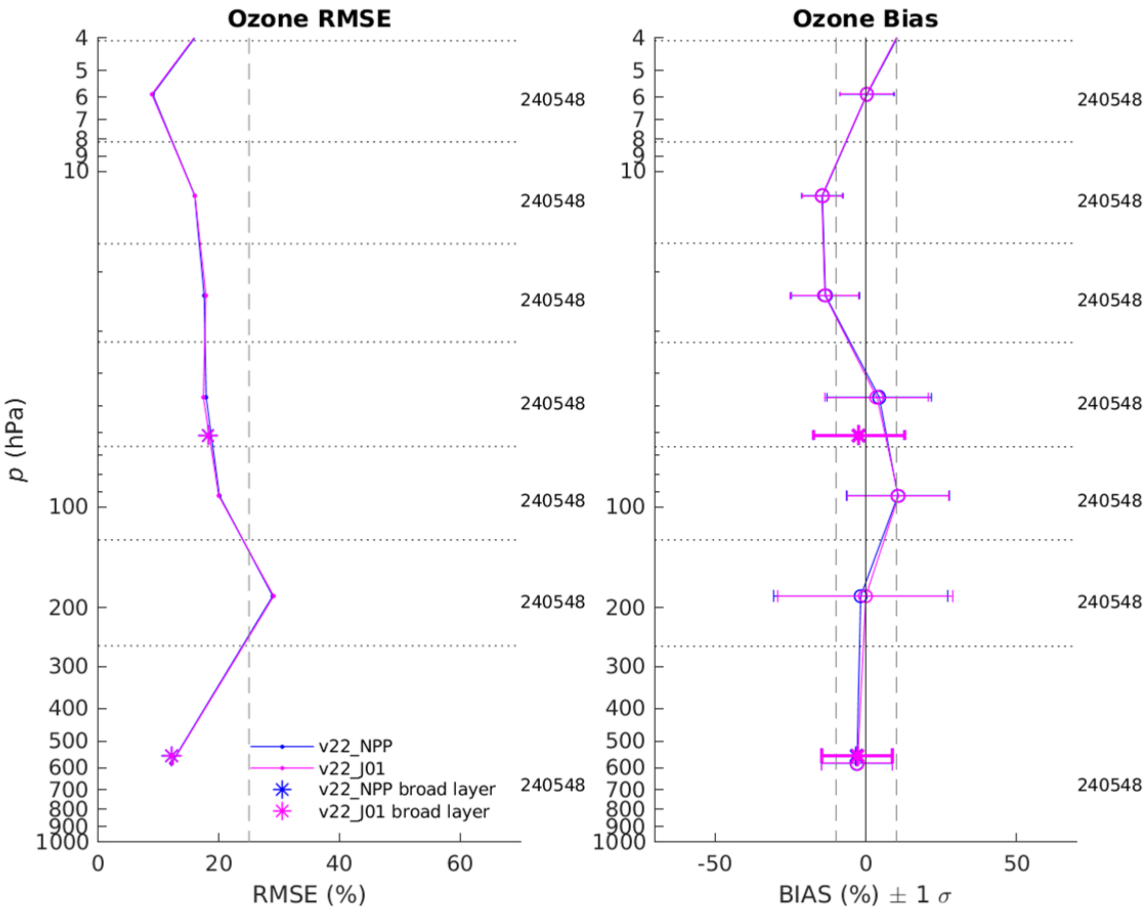
Algorithm performance evaluation

- Validation data sets (type, periods, coverage)
- Validation strategies / methods
- Validation results
- Long term monitoring readiness

- **Part I: Ozone Validation**
- **Part II: Carbon Trace Gases Validation**
- **Part III: OLR Validation**

NUCAPS NOAA-20 IR Ozone Profile EDR versus ECMWF and Ozonesondes

Ozone Global Focus Day (20 Aug 2018) Validation Versus ECMWF Ozone



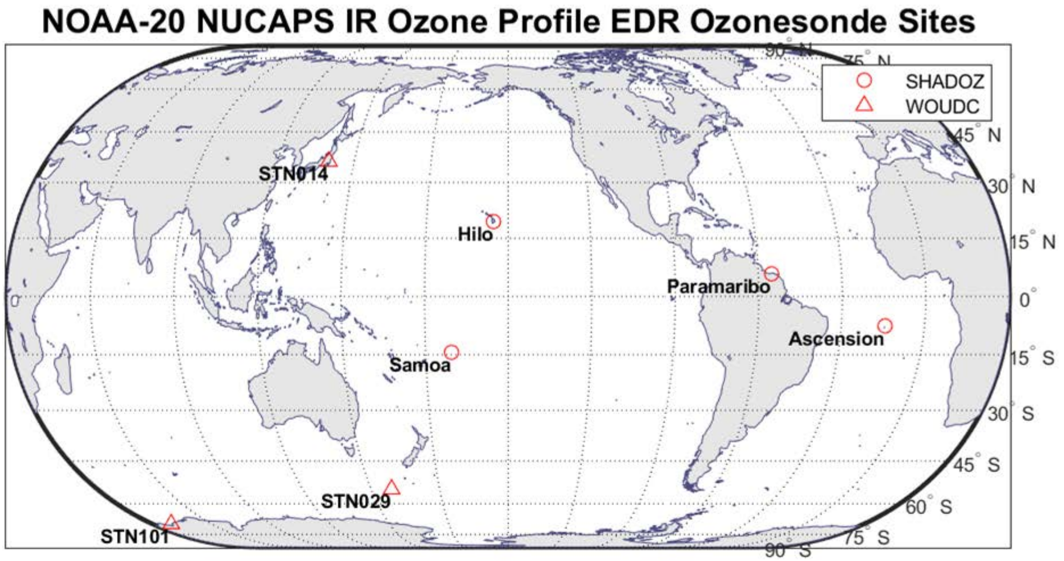
Ozone

- **Blue**: NUCAPS SNPP operational
- **Magenta**: NUCAPS N-20 V2.2

* SNPP operational and V2.2 are the same
* N-20 system has newest N-20 NEDT

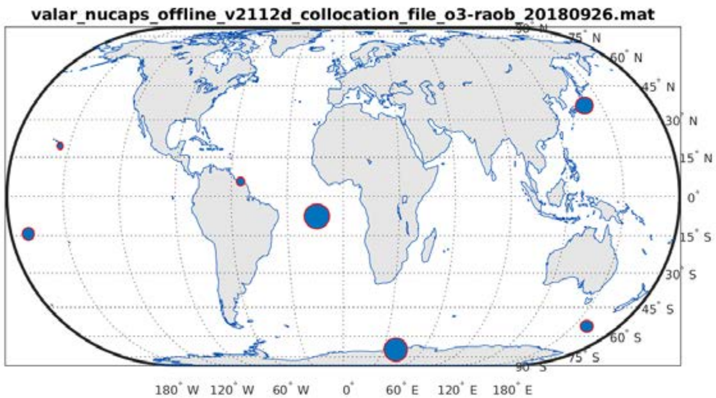
- NUCAPS SNPP ozone is a validated mature product
- NUCAPS SNPP and NOAA-20 remarkably consistent
- NUCAPS NOAA-20 ozone fully meets spec

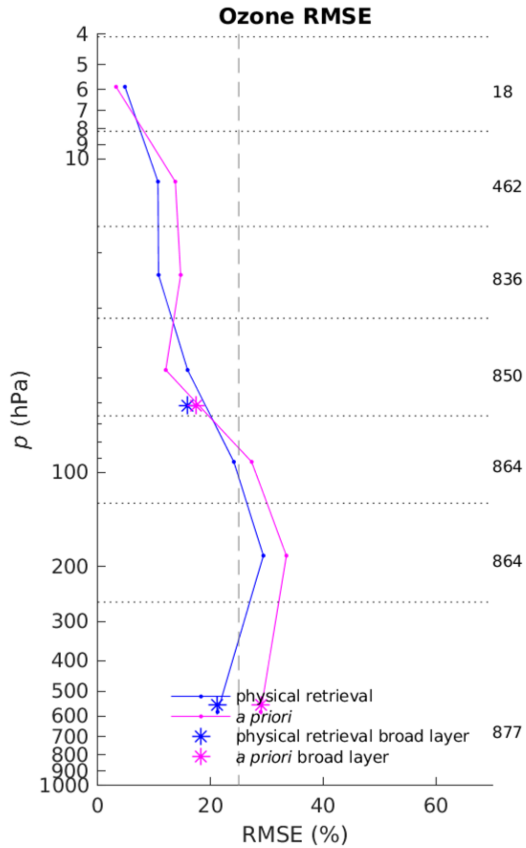
- **NOAA-20 collocated ozonesondes**
  - **Sites of Opportunity**
    - **SHADOZ** (*Thompson et al.* 2007)
      - Paramaribo
      - Hilo, Hawaii
      - Ascension Island
      - American Samoa
    - **WOUDC**
      - STN014
      - STN029
      - STN101

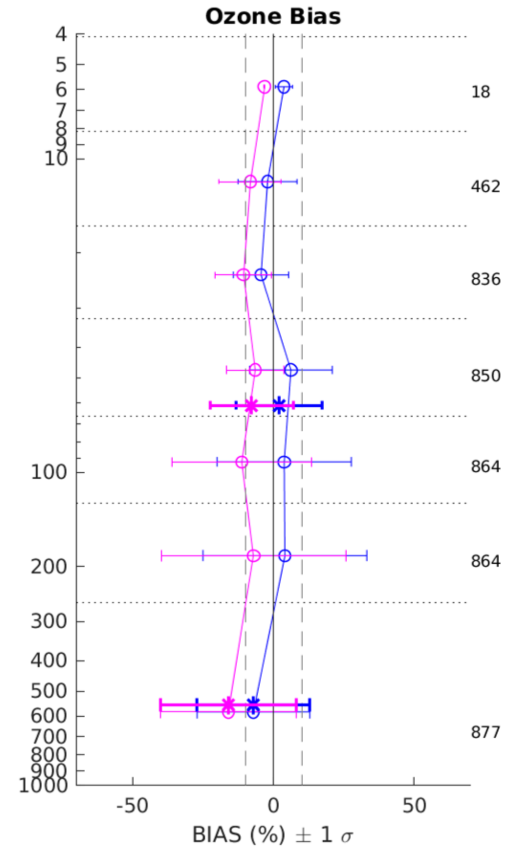


NOAA-20 Ozonesonde Collocations

(125 km, −4 to +2 hours)



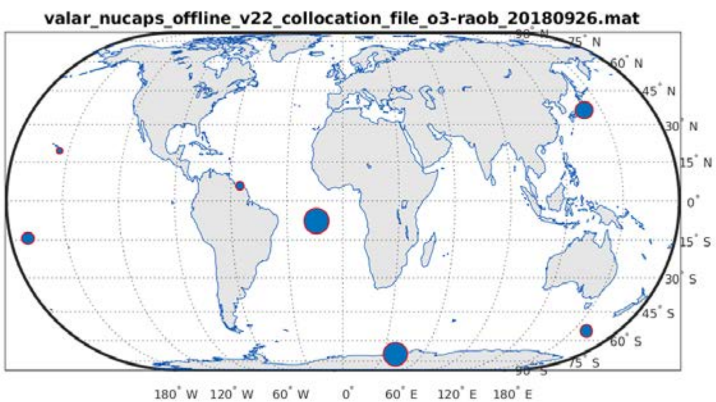


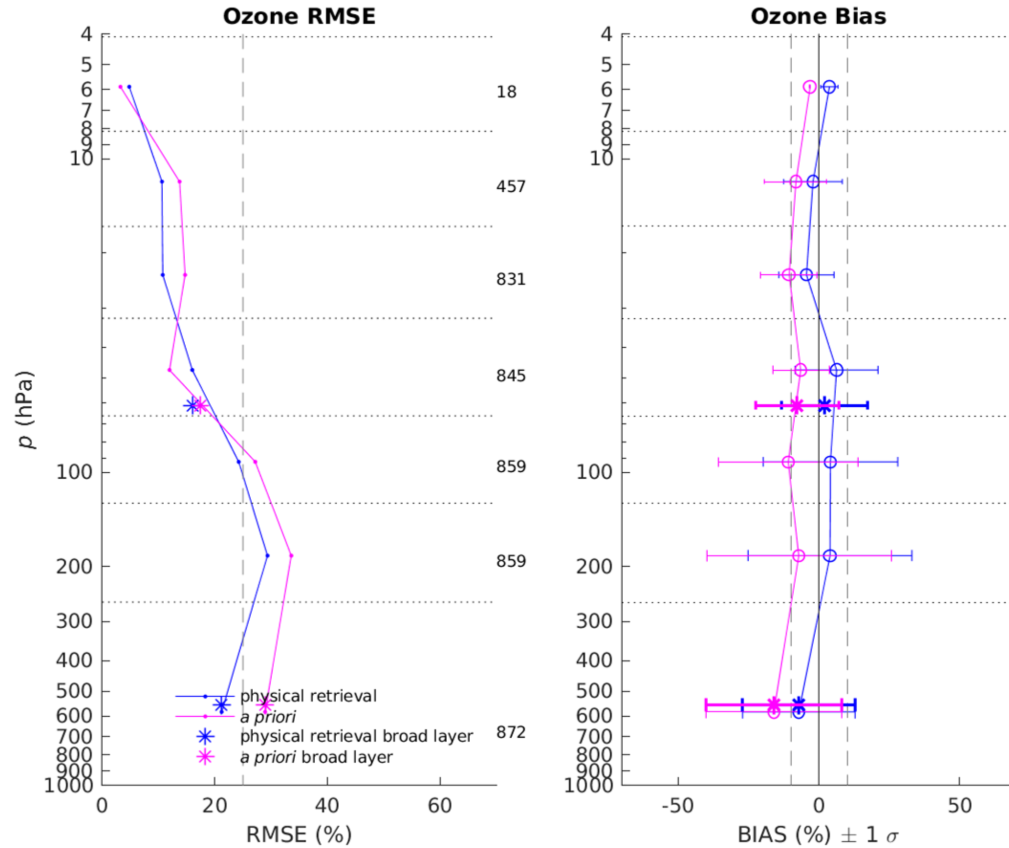


NOAA-20 v2.2 O_3 vs Collocated Ozonesondes

NOAA-20 Ozonesonde Collocations

(125 km, −4 to +2 hours)





Ozone Error Budget

green = passed   yellow = close   red = failed

ECMWF Baseline

Summary on IR+MW Results vs JPSS L1RD Requirements			
Ozone			
Pressure Range (hPa)	JPSS L1RD Requirement RMS (%)	SNPP RMS (%)	N-20 RMS (%)
4-260	25	18.2	18.2
260-Psfc	25	12.1	12.2

SHADOZ and WOUDC Ozonesonde Baseline

Summary on IR+MW Results vs JPSS L1RD Requirements			
Ozone			
Pressure Range (hPa)	JPSS L1RD Requirement RMS (%)	SNPP (v1.5) RMS (%)	N-20 RMS (%)
4-260	25	18.9	15.9
260-Psfc	25	23.2	21.2

NUCAPS Carbon Trace Gas Validation

Atmospheric Tomography (ATom) Mission
(*Wofsy et al.* 2018)

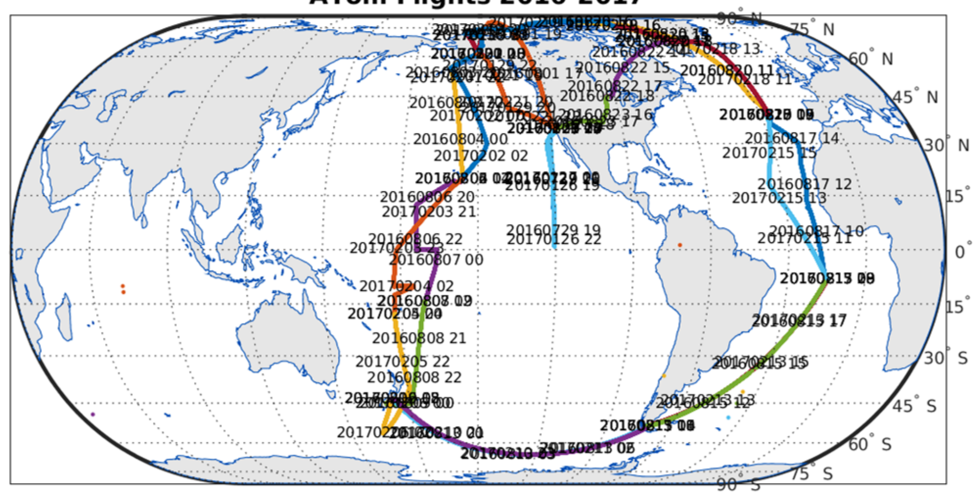
- **ATom** deployed extensive gas and aerosol payloads on the **NASA DC-8** aircraft for global-scale sampling of the atmosphere, profiling continuously from 0.2–12 km altitude

- **Flights** occurred in each of 4 seasons over a 4-year period, originating from the Armstrong Flight Research Center in Palmdale, California
  - North to western Arctic, south to South Pacific, east to the Atlantic, north to Greenland, and return to California across central North America
  - ATom established a single, contiguous global-scale data set

- In this work we use the **NOAA PICARRO** ATom-1 and -2 datasets
  - PIs: Kathryn McKain and Colm Sweeney (CIRES, U. of Colorado, NOAA/ESRL

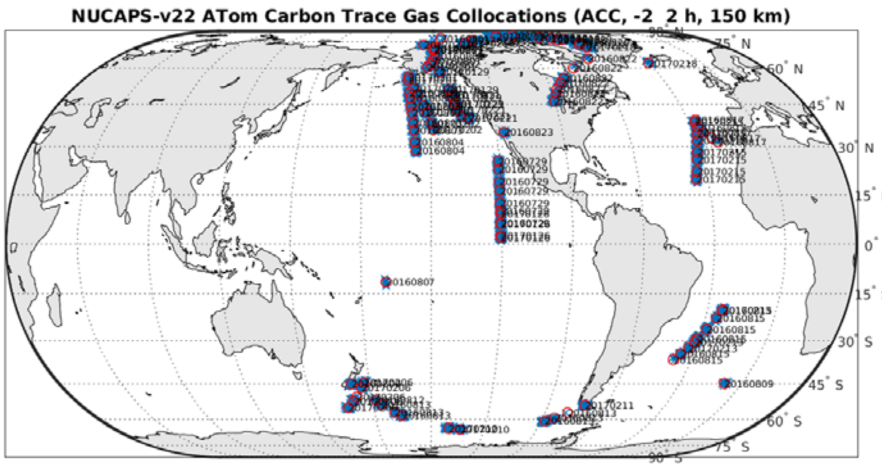
- **Source:** https://espo.nasa.gov/atom/

ATom Flights 2016-2017

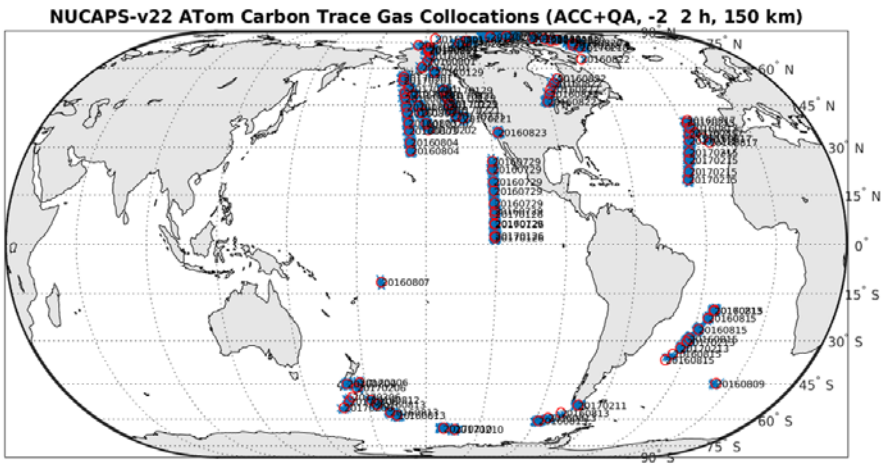


SNPP NUCAPS-ATom Collocations

Accepted Cases

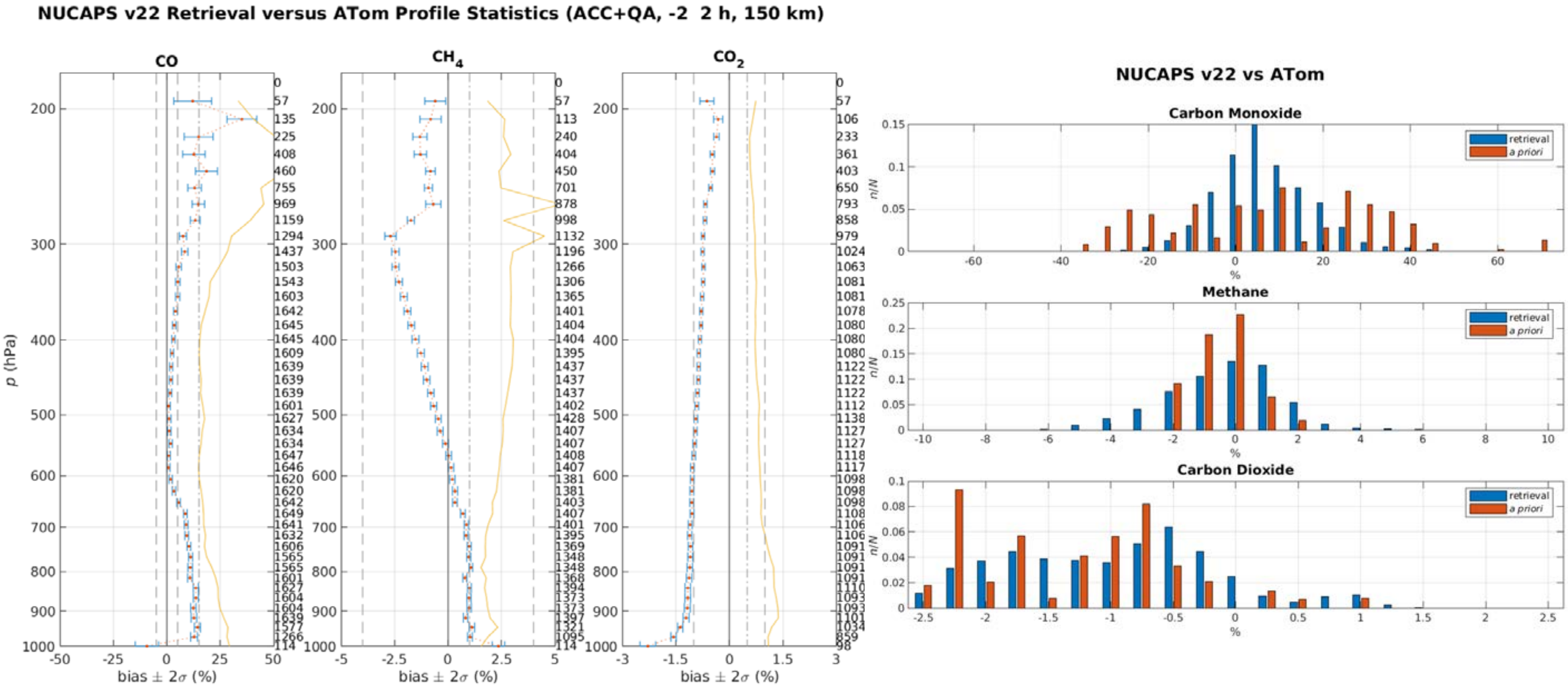


Accepted + CO Trace Gas QA

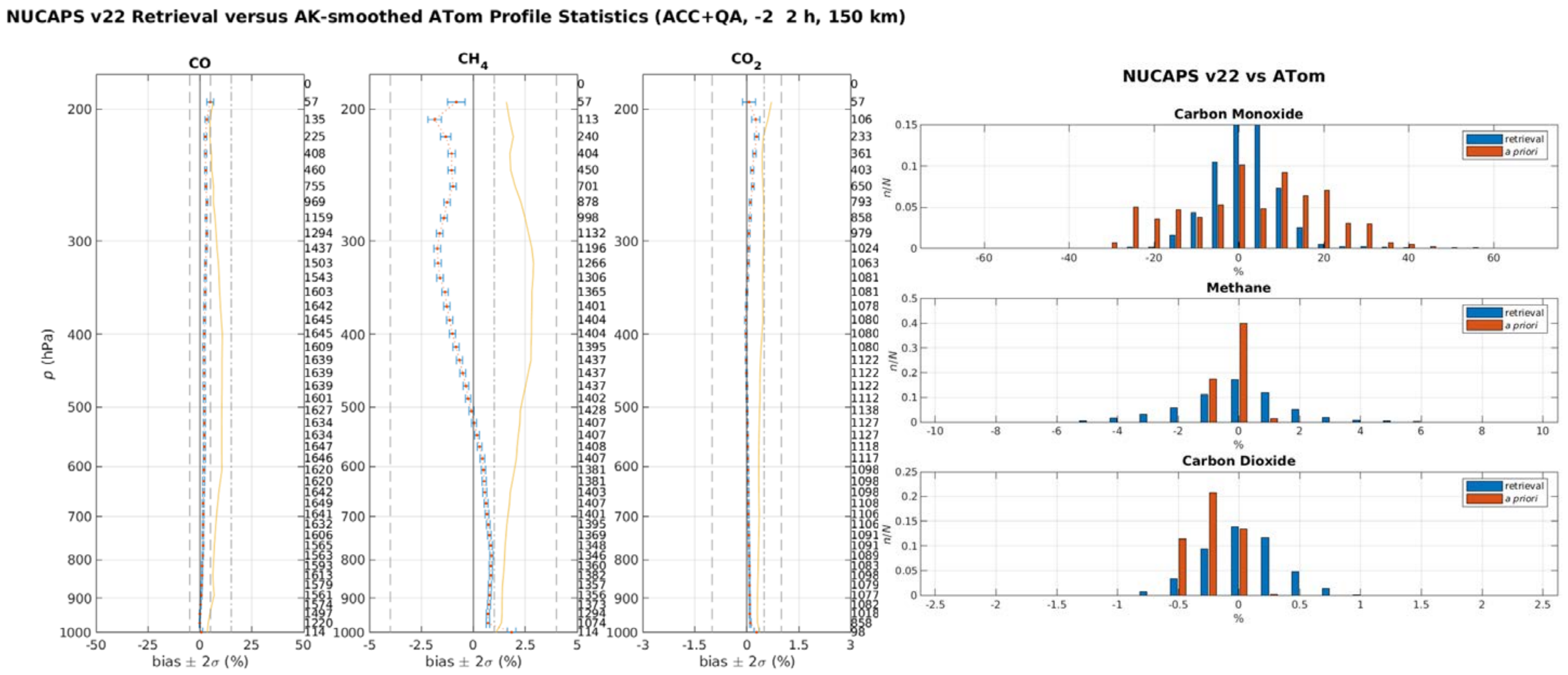


NUCAPS SNPP (v2.2) versus ATom

Accepted+QA, ±2 hr, 150 km

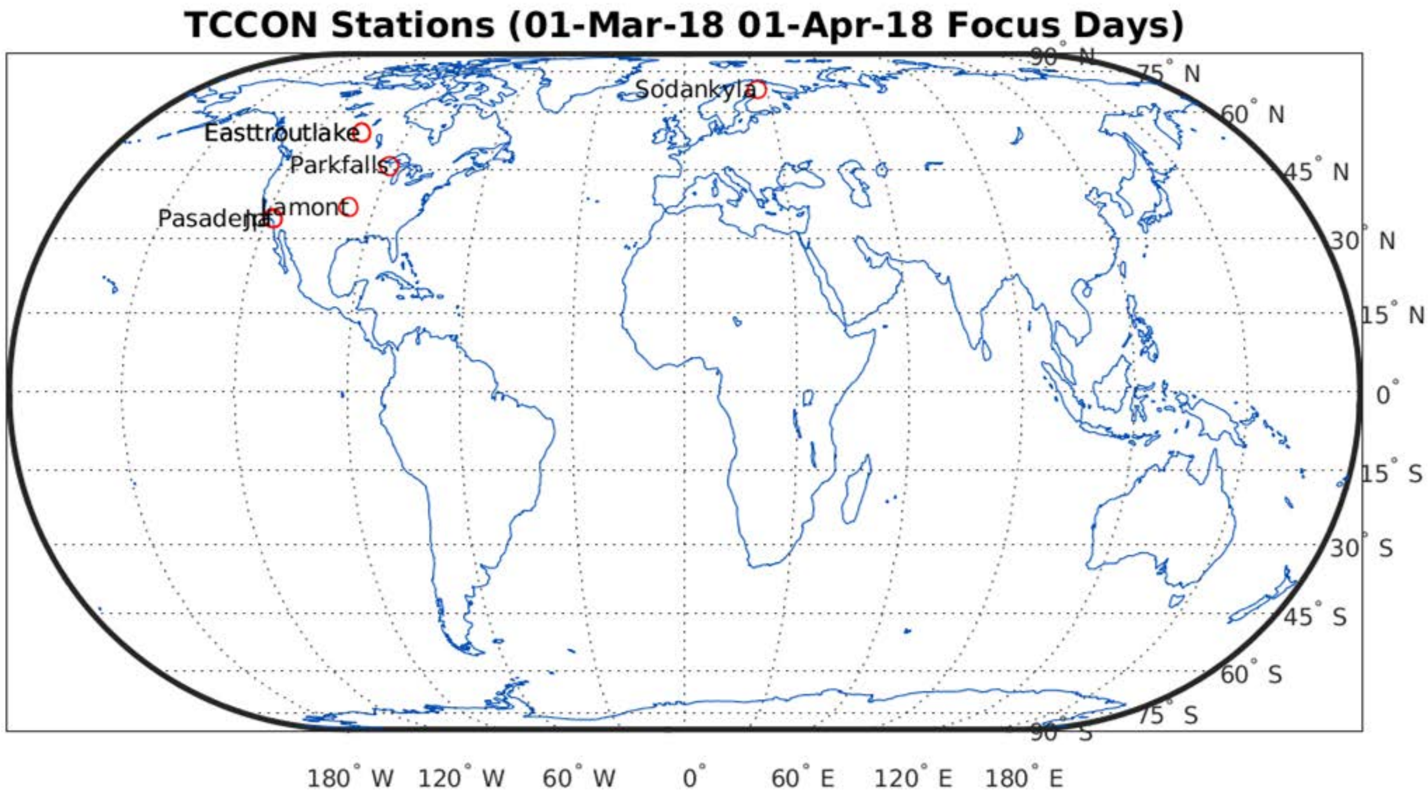


NUCAPS SNPP (v2.2) versus ATom AK-Smoothed Accepted+QA, ±2 hr, 150 km

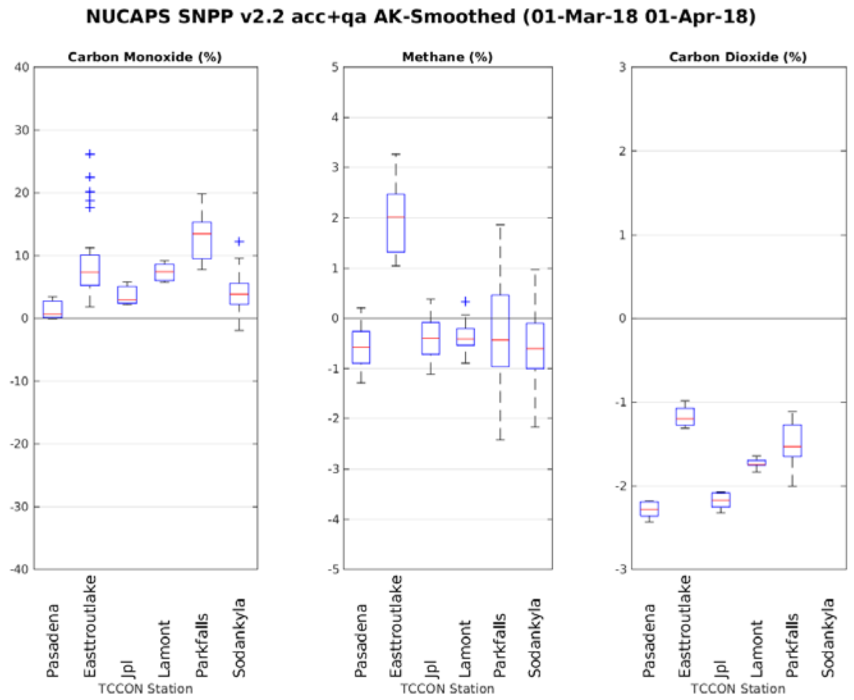


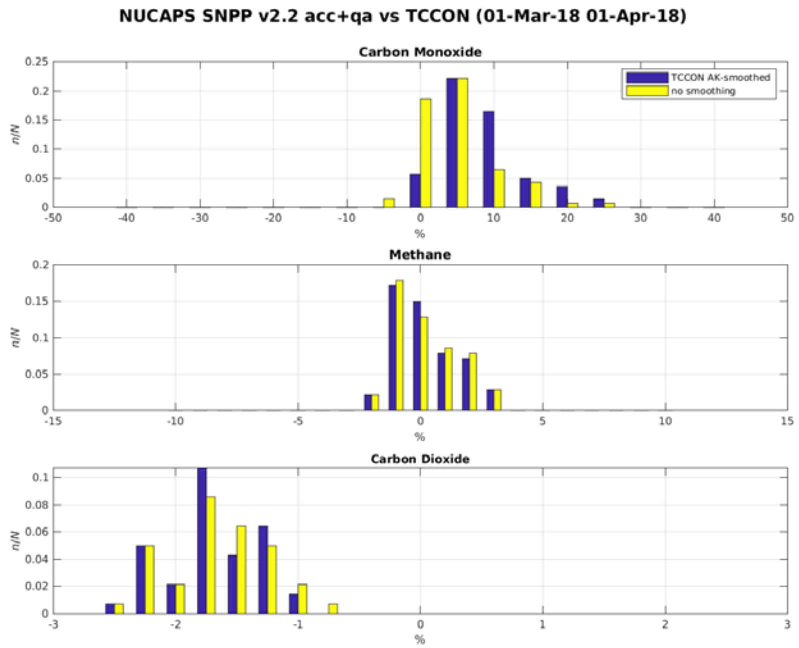
Total Carbon Column Observing Network (TCCON) Stations NOAA-20 Focus Days: 1-Mar-18, 1-Apr-18

TCCON
(*Wunch et al.* 2011)

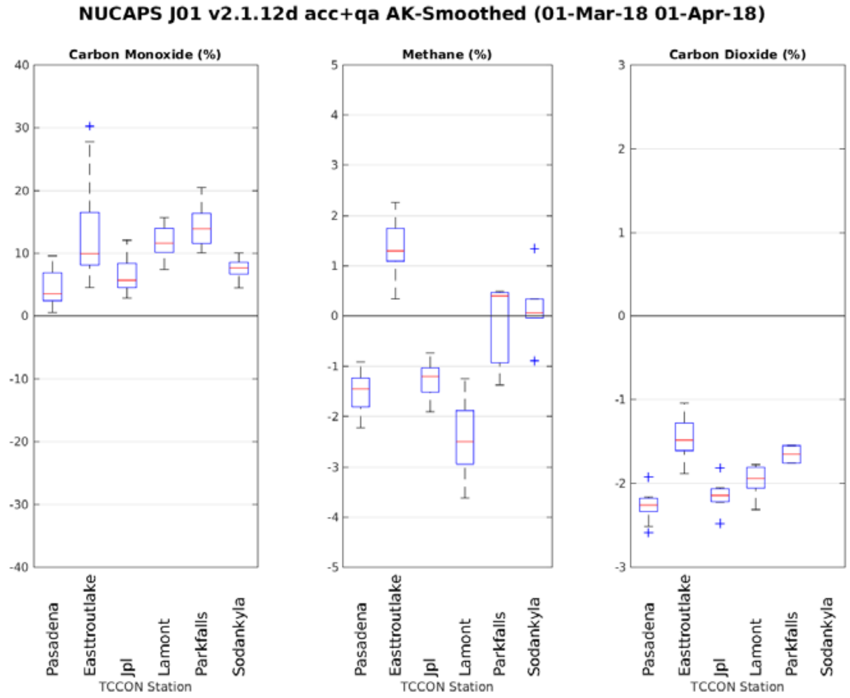


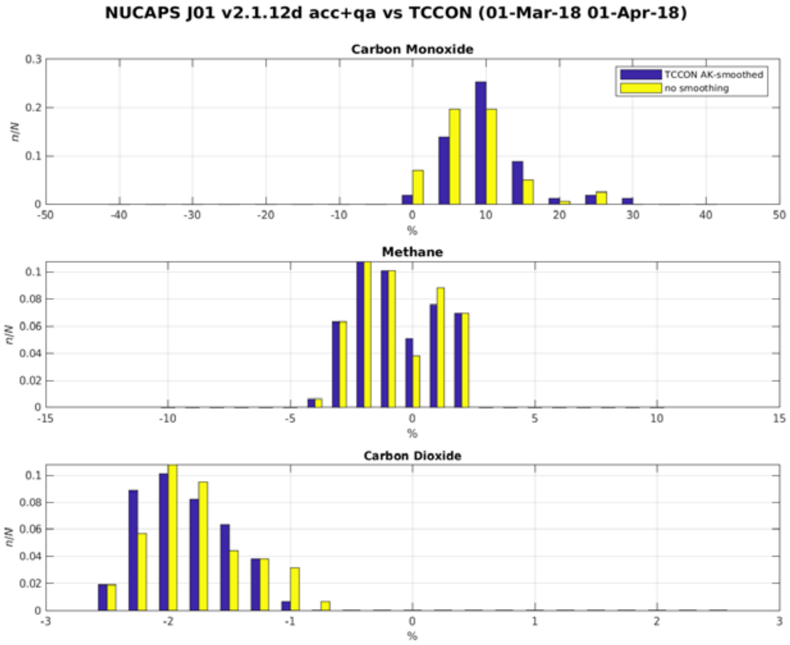
SNPP v2.2 (v2.1.12d) vs TCCON



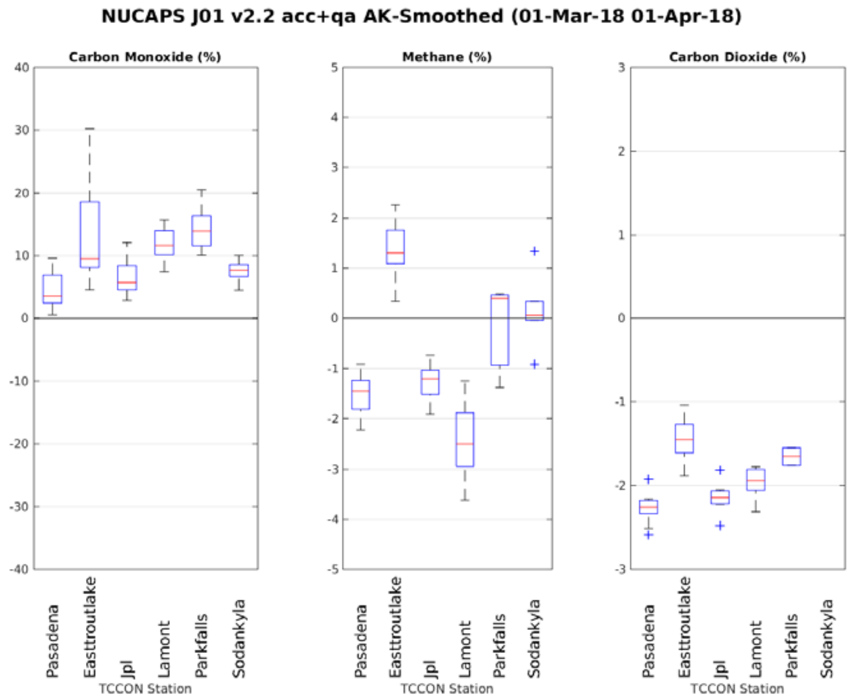


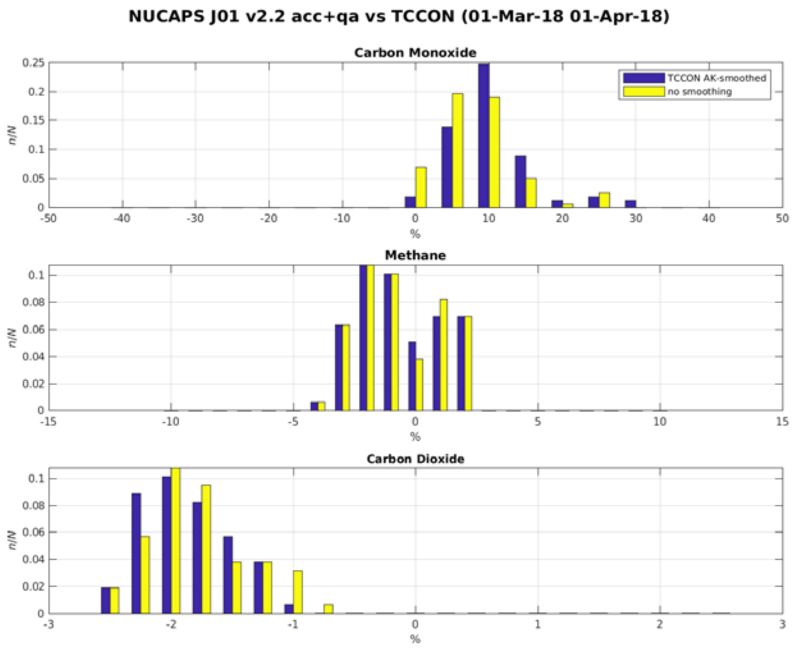
NOAA-20 v2.1.12d vs TCCON



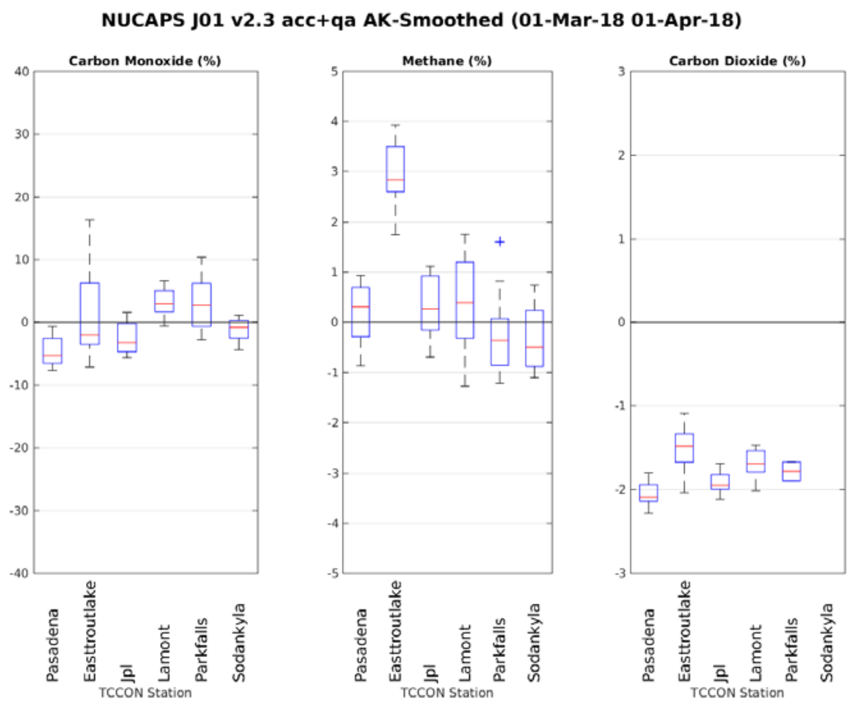


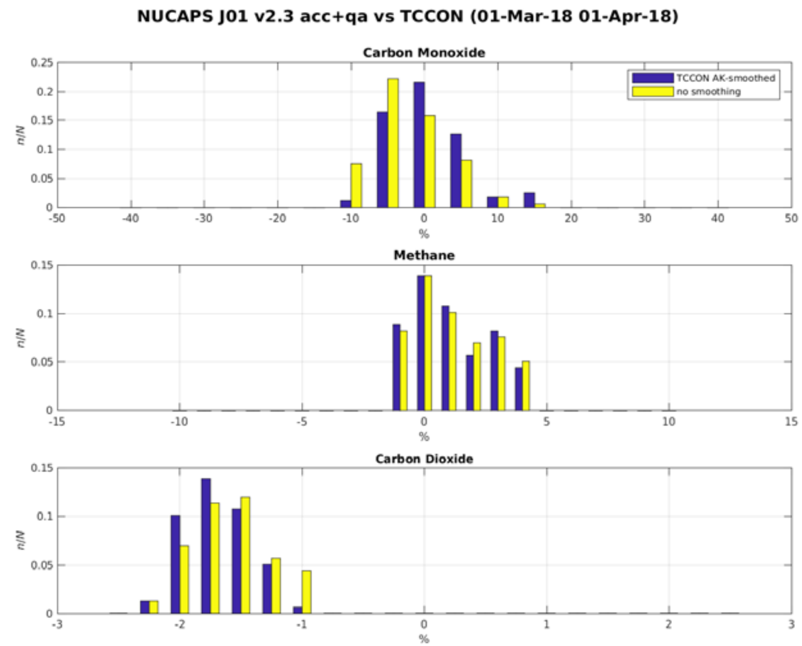
NOAA-20 v2.2 vs TCCON





NOAA-20 v2.3 vs TCCON





NUCAPS versus TCCON Total Column IR+MW Accepted Cases + Trace Gas QA

	TCCON Baseline N-20 V2.1.12d *Trace Gas QA*			TCCON Baseline SNPP V2.2 *Trace Gas QA*			TCCON Baseline N-20 V2.2 *Trace Gas QA*			TCCON Baseline N-20 V2.3 *Trace Gas QA*		
Trace Gas EDR	BIAS (%)	STD (%)	RMS (%)	BIAS (%)	STD (%)	RMS (%)	BIAS (%)	STD (%)	RMS (%)	BIAS (%)	STD (%)	RMS (%)
CO	**+10.7** **+8.3** (±5.0)	**5.7** **5.4** (15.0)	12.1 9.9	**+8.1** **+5.2** (±5.0)	**5.6** **5.5** (15.0)	9.9 7.6	**+10.7** **+8.3** (±5.0)	**5.7** **5.5** (15.0)	12.1 9.9	**+0.6** **−2.2** (±5.0)	**5.0** **4.9** (15.0)	5.1 5.4
CO_2	**−1.9** **−1.8** (±1.0)	**0.4** **0.4** (0.5)	1.9 1.8	**−1.7** **−1.6** (±1.0)	**0.4** **0.4** (0.5)	1.8 1.7	**−1.9** **−1.8** (±1.0)	**0.4** **0.4** (0.5)	1.9 1.8	**−1.7** **−1.6** (±1.0)	**0.3** **0.3** (0.5)	1.7 1.6
CH_4	**−0.7** **−0.6** (±4.0)	**1.7** **1.7** (1.0)	1.8 1.8	**+0.2** **+0.2** (±4.0)	**1.3** **1.3** (1.0)	1.3 1.3	**−0.7** **−0.7** (±4.0)	**1.7** **1.7** (1.0)	1.8 1.8	**+1.0** **+1.1** (±4.0)	**1.5** **1.5** (1.0)	1.8 1.8
	Yield CO = 76.6%, *n* = 121 Yield CO2 = 62.0%, *n* = 98 Yield CH4 = 69.6%, *n* = 110			Yield CO = 79.3%, *n* = 111 Yield CO2 = 45.7%, *n* = 64 Yield CH4 = 71.4%, *n* = 100			Yield CO = 76.6%, *n* = 121 Yield CO2 = 61.4%, *n* = 97 Yield CH4 = 69.6%, *n* = 110			Yield CO = 79.7%, *n* = 126 Yield CO2 = 63.3%, *n* = 100 Yield CH4 = 74.7%, *n* = 118		

NUCAPS NOAA-20 OLR Validation

CrIS OLR Algorithm Review

Least-squares regression Algorithm

- Broadband radiometer CERES OLR as ‘truth’.
- Eight sets of regression coefficients are trained to account for view angle dependence of AIRS and CrIS radiances.
- OLR is expressed as weighted linear combination of **pseudo channel** radiances.
- AIRS is used as a transfer instrument.
- CrIS – AIRS pseudo radiances are regressed against CrIS pseudo radiances. Regression database is derived with theoretical radiative transfer model simulations given ‘noaa88’ and ‘noaa89’ sounding collections.

Ref: Kexin Zhang, Mitchell D. Goldberg, Fengying Sun, Lihang Zhou, Walter W. Wolf, Changyi Tan, Nicholas R. Nalli, and Quanhua Liu, Estimation of Near-Real-Time Outgoing Longwave Radiation from Cross-Track Infrared Sounder (CrIS) Radiance Measurements, JTECH, 2017. DOI: http://dx.doi.org/10.1175/JTECH-D-15-0238.1

CrIS HSR OLR methodology

• For each pseudo channel, AIRS and CrIS spectrally convolved radiance (R) is defined as,

$$R(i,\theta) = \frac{1}{\nu_{2i} - \nu_{1i}} \int_{\nu_{1i}}^{\nu_{2i}} r(\nu,\theta) d\nu$$

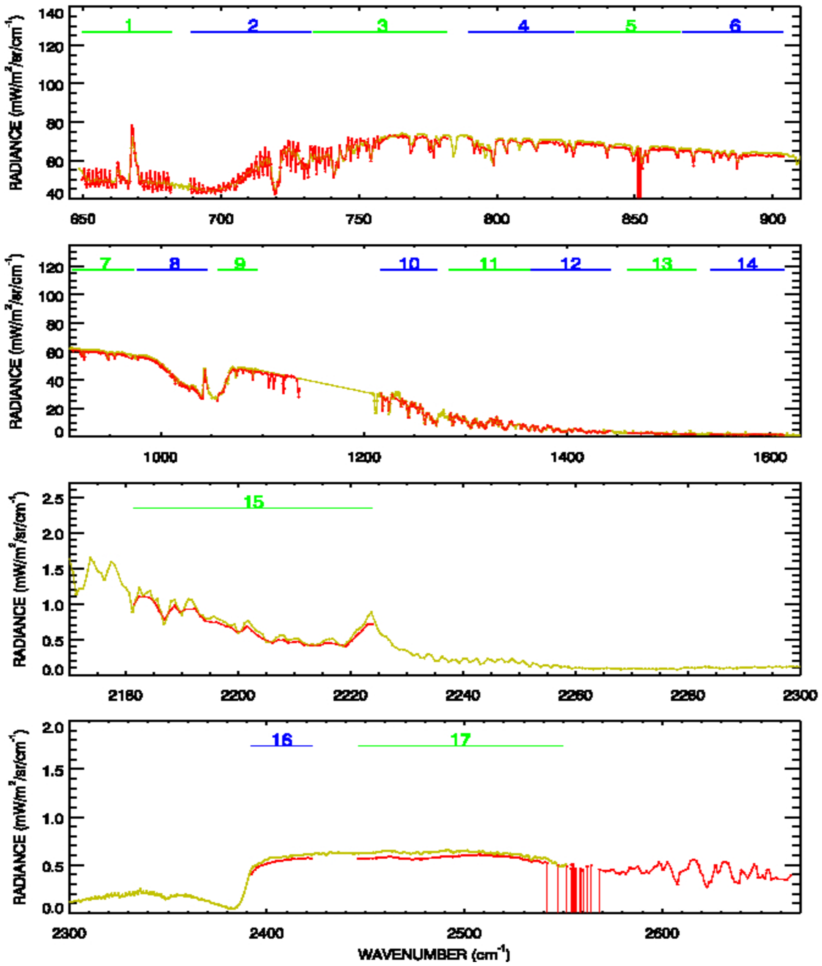
• For each pseudo channel, the radiance difference (ΔR) between AIRS and CrIS pseudo channel radiances, is computed using regression coefficients (“a_k”):

$$\Delta R(i) = a_0 + \sum_{k=1}^{K} a_k r_{CrIS}(\nu_k)$$

•CrIS OLR is a liner combination of the pseudo channel corrected radiances, using AIRS OLR regression coefficients “b_i”:

$$F_{CrIS} = b_0(j) + \sum_{i=1}^{n} b(i,j)[R(i,\theta_j) + \Delta R(i)]$$

CrIS OLR Pseudo-Channels



Pseudo channels range within simulated CrIS (yellow) and AIRS (red) radiance spectra calculated from SARTA simulated radiances using US standard atmospheric profiles.

CrIS OLR Pseudo-Channels

- **AIRS, CrIS low-res, hi-res Pseudo channels**

Pseudo Channel	Center Wavenumber (cm^{-1})	Width (cm^{-1})	No. of CrIS Channels (low-res)	No. of CrIS Channels (hi-res)	No. of AIRS Channels
1	665.81	32.37	52	52	124
2	710.79	43.68	70	70	151
3	757.71	48.35	78	78	88
4	808.68	38.68	61	61	52
5	847.70	37.57	60	60	67
6	885.45	36.66	59	59	64
7	943.04	60.06	96	96	77
8	1011.43	69.53	111	111	107
9	1075.52	38.89	62	62	45
10	1244.78	55.61	45	89	80
11	1323.68	78.67	63	126	119
12	1403.84	78.47	63	125	121
13	1493.64	66.74	53	107	83
14	1577.48	72.77	59	117	77
15	2202.72	42.44	17	68	42
16	2407.46	30.78	13	49	29
17	2497.91	103.42	41	166	94

Simulation of AIRS and CrIS HSR radiances

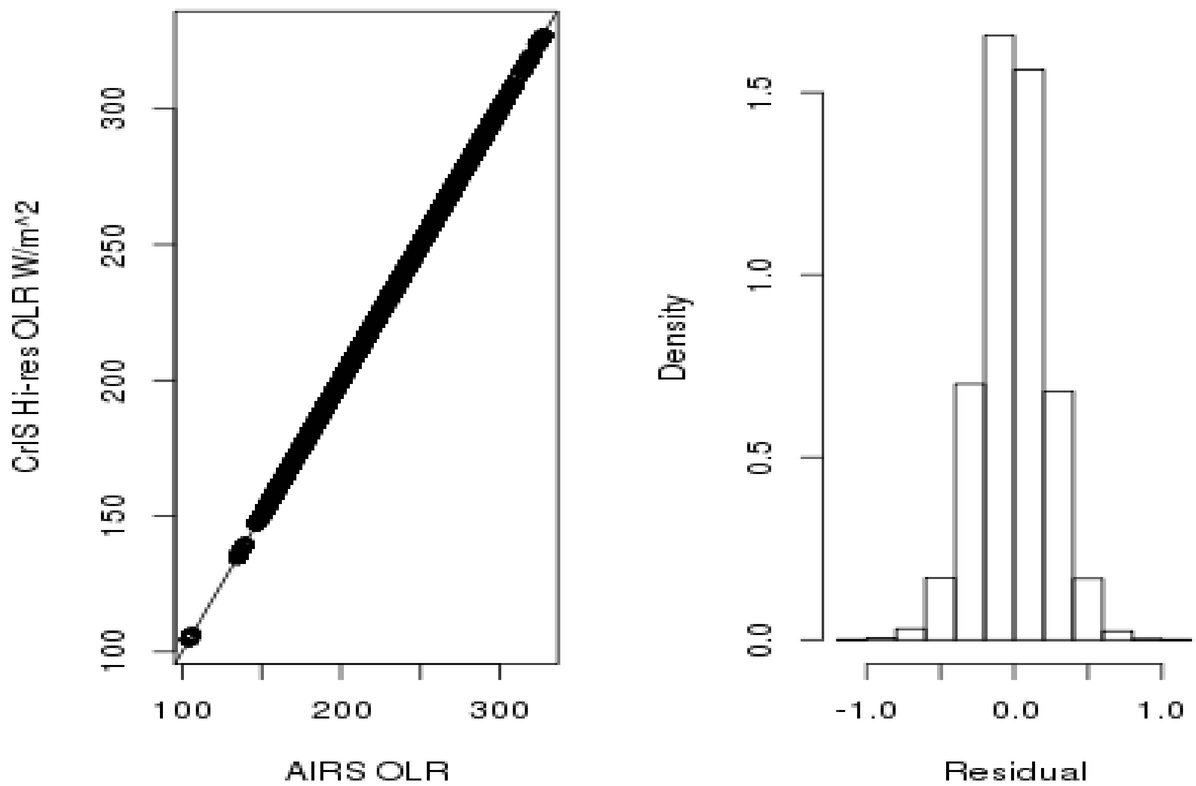
- CrIS HSR OLR radiance correction training dataset of “noaa89b” (nprof=7622).
- CrIS HSR OLR radiance correction coefficient testing dataset of “noaa88b” (nprof=7547).
- AIRS version 10ab RTA. Instrument noise added.
- CrIS version 11a High Res RTA. Instrument noise added.
- 90 CrIS view angles. No. of samples=90*nprof.

Evaluation of algorithm performance

- Cal/Val Activities for evaluating algorithm performance:
  - Testing trained correction regression coefficient
    - Training dataset of “noaa89b” (nprof=7622)
    - Testing dataset of “noaa88b” (nprof=7547)
  - Compared estimated CrIS OLR with simultaneous CERES SSF products on NPP and NOAA-20
    - Compared over 0.5 deg lat/lon global grids

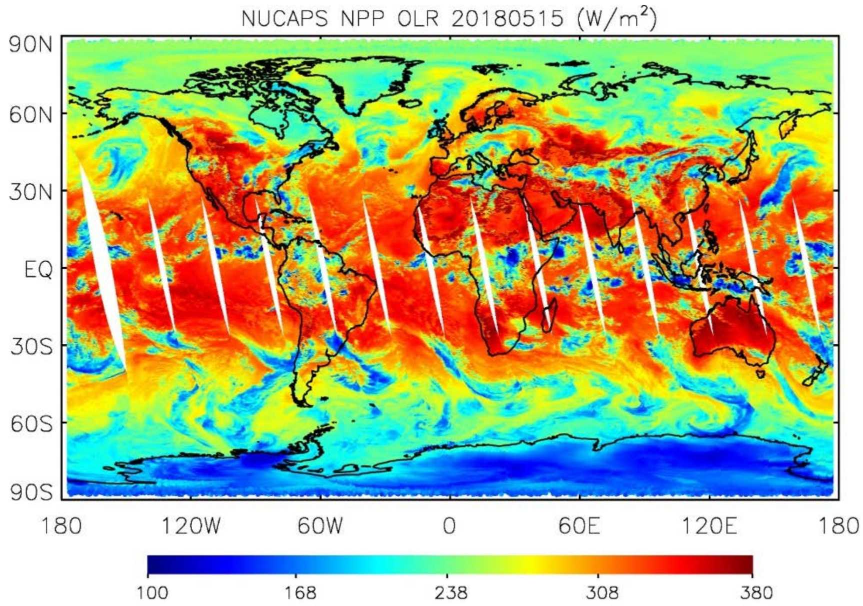
Testing CrIS OLR regression coefficient

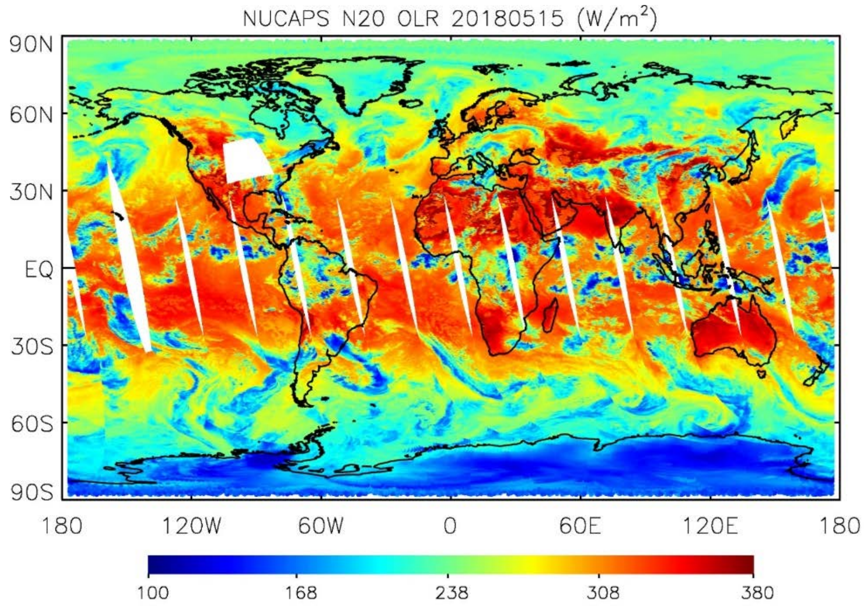
OLR is computed from simulated radiances using NOAA88 profiles.



Mean = -0.004118296, standdev = 0.2265357

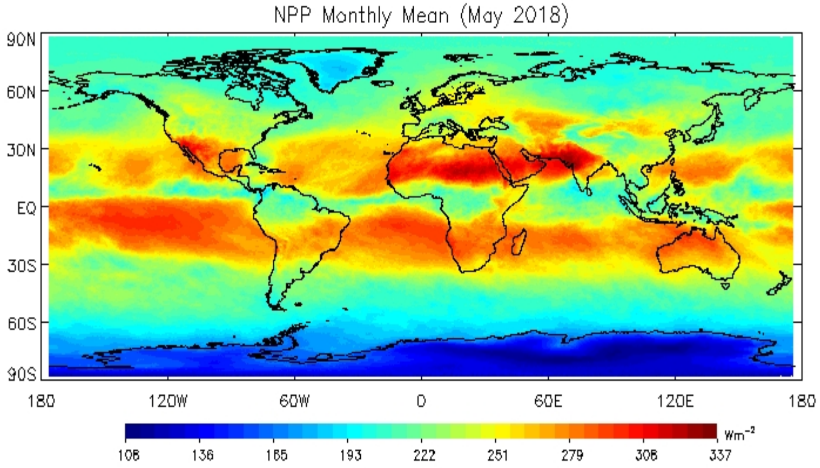
NPP and NOAA-20 CrIS OLR Comparison Focus day May 15th, 2018

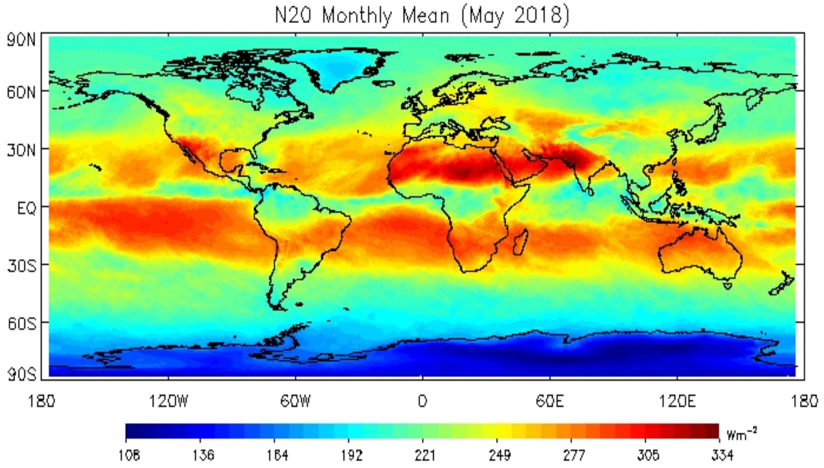


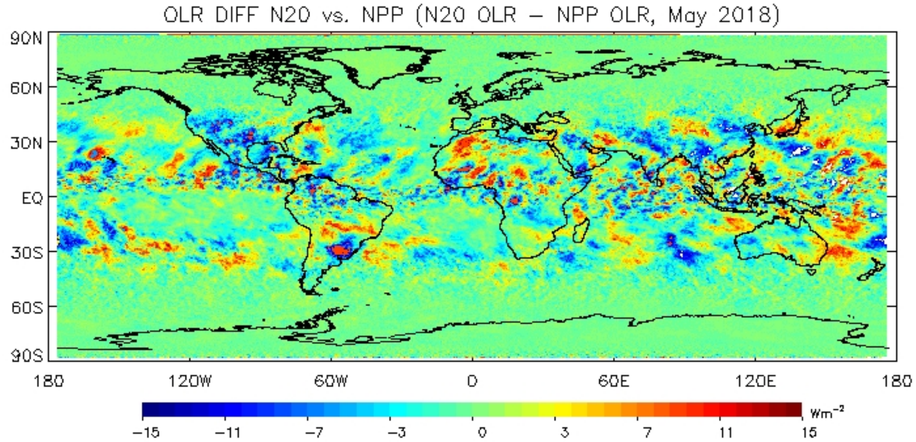


- ✓ SNPP and NOAA-20 OLR are strongly consistent.
- ✓ Results have been derived by applying the SNPP OLR module to NOAA-20.
- ✓ Based on the strong consistency between SNPP and NOAA-20 CrIS and these preliminary results, the outcome of the beta review was of NOT computing NOAA-20 OLR radiance correction coefficients.

NPP and NOAA-20 CrIS OLR Monthly Mean (May 2018)







	SNPP OLR monthly mean (May, 2018 in W/m^2)	NOAA-20 OLR monthly mean (May, 2018 in W/m^2)
60 N to 90 N	210.77	210.77
60 S to 60 N	245.43	245.19
60 S to 90 S	164.44	163.36

CrIS OLR Validation – Test data description

- **CERES data**
  - NPP and NOAA-20 CERES products:

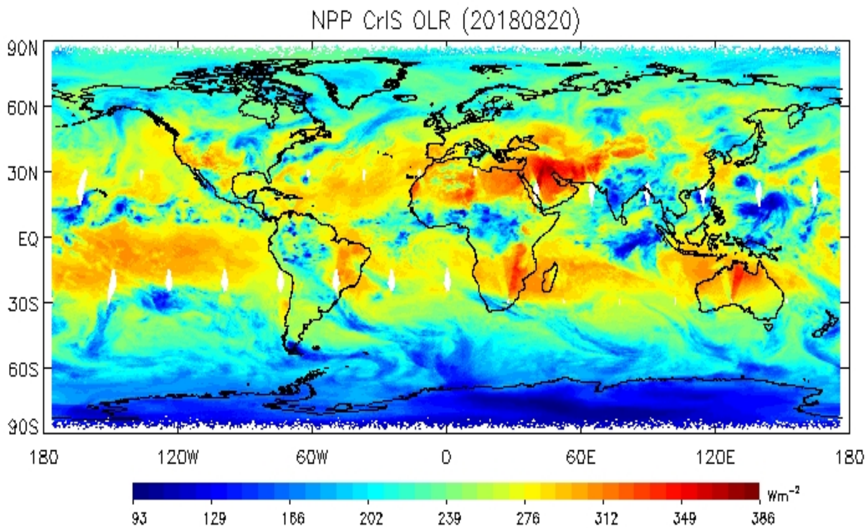
    https://eosweb.larc.nasa.gov/project/ceres/es8_npp-fm5_ed1-cv_table

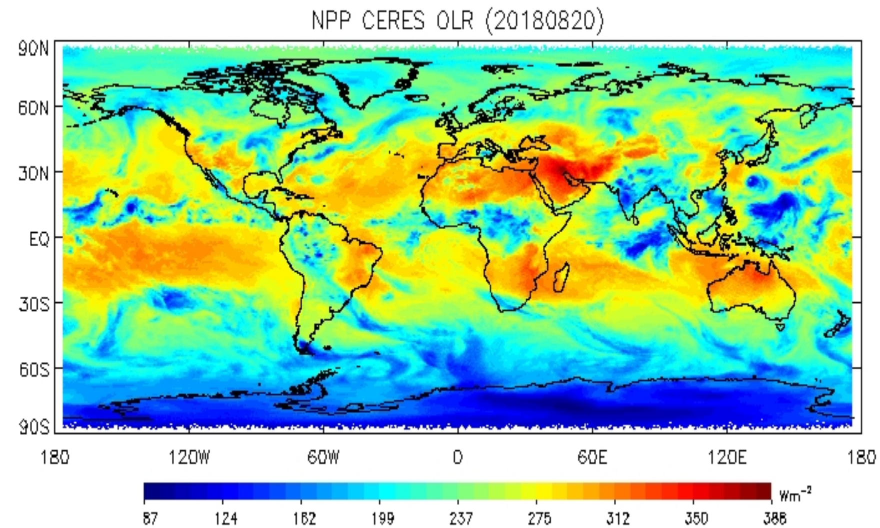
    https://eosweb.larc.nasa.gov/project/ceres/es8_j01_fm6_ed1_cv
  - Averaged CERES OLR on 0.5 deg lat/lon grids.

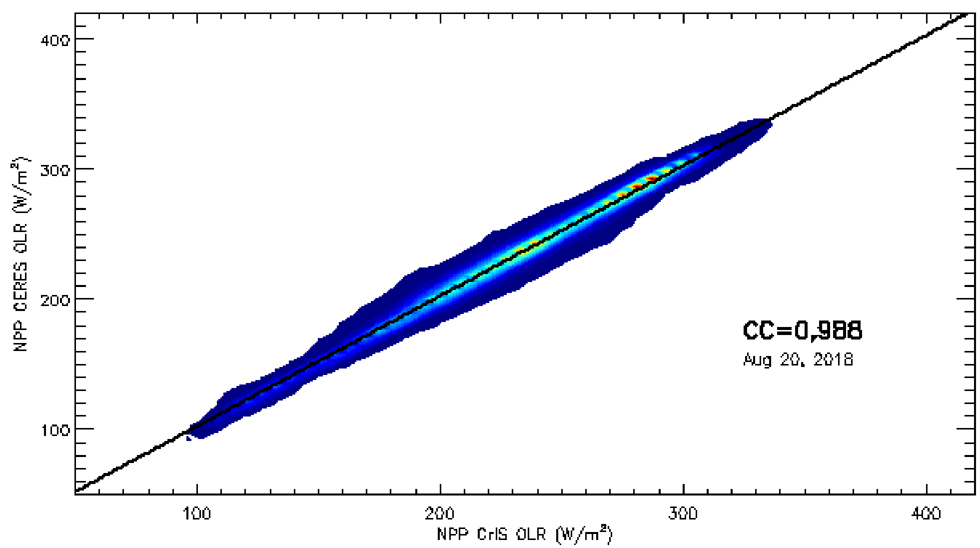
CrIS OLR Validation – Test data description

- **CrIS SDR data**
  - Hamming apodization performed by NUCAPS preprocessor.
  - Applied CrIS OLR algorithm to calculate CrIS OLR for each FOV, generated netCDF file for each granule.
  - Averaged CrIS OLR at 0.5 deg lat/lon grids.

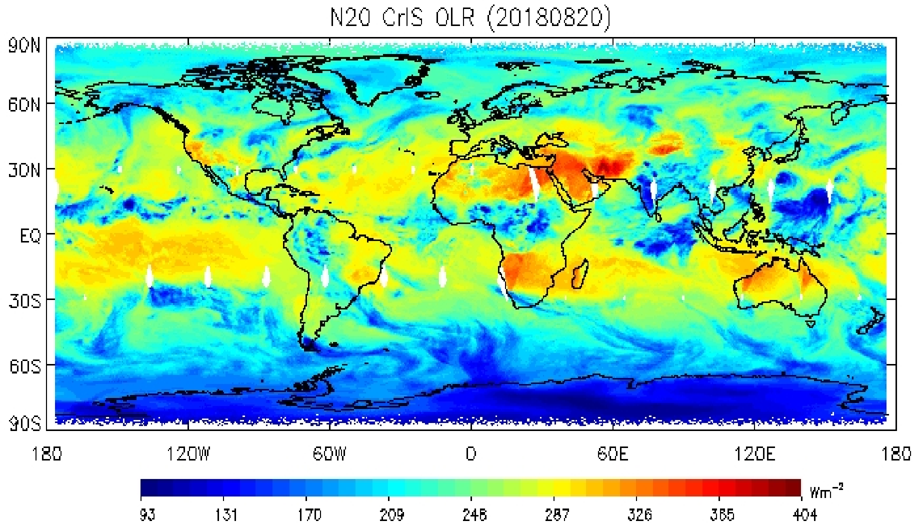
NPP CrIS OLR vs. NPP CERES OLR (August 20th, 2018)

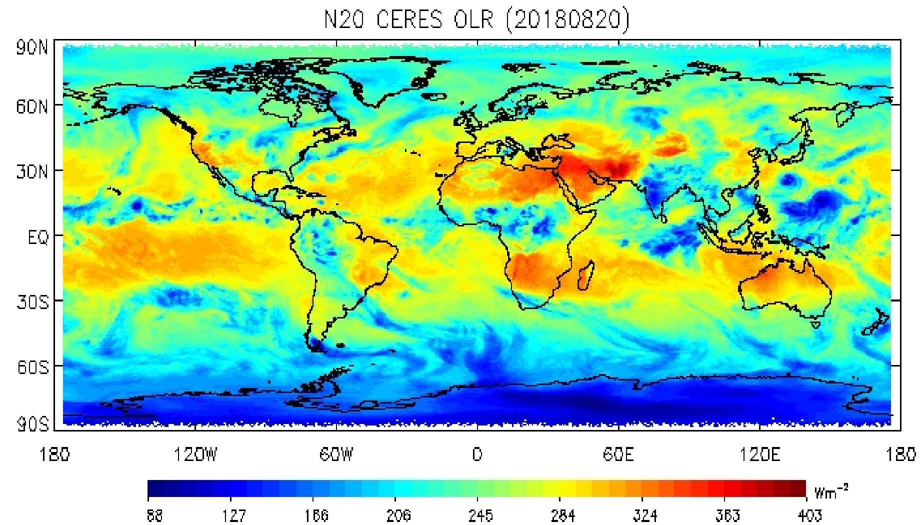


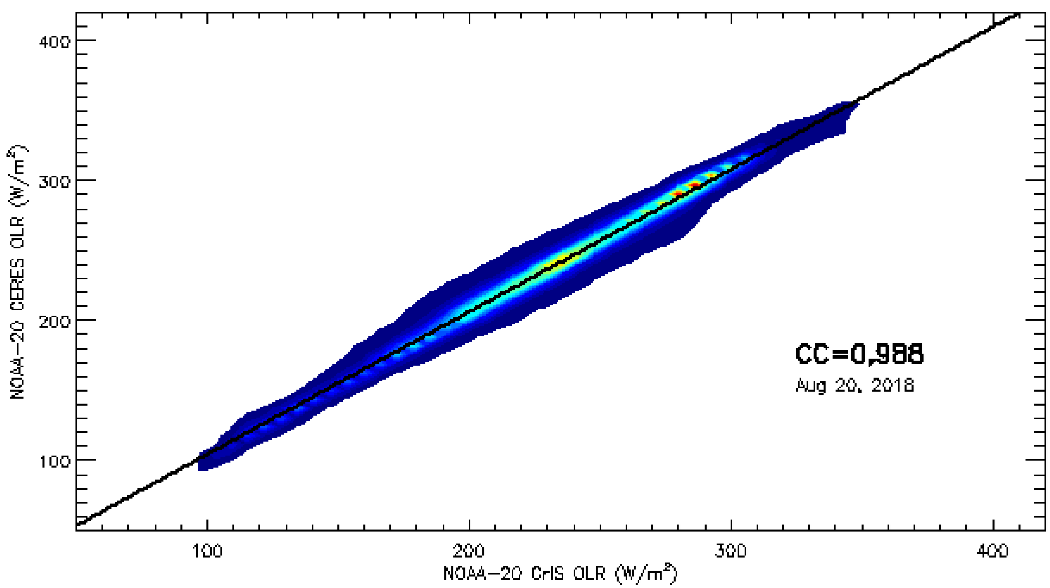




NOAA-20 CrIS OLR vs. NOAA-20 CERES OLR (August 20th, 2018)







Conclusion remarks on CrIS NOAA-20 OLR

- ✓ SNPP OLR is a mature product
- ✓ SNPP and NOAA-20 OLR are strongly consistent.
- ✓ Initial results shown at the beta maturity review were derived by applying the SNPP CrIS OLR coefficients to NOAA-20 CrIS.
- Difference in the monthly averages are very small where there is a great amount of overlapping orbits - north and south of 50 degrees latitude. So the change in clouds over 50 minutes coupled with less overlap of orbits produces a cloud signal.
- Based on the strong consistency between SNPP and NOAA-20 CrIS shown in those preliminary results, the outcome of the beta review and followed up analysis was of NOT computing NOAA-20 OLR radiance correction coefficients but just use SNPP coefficients.
- Additional analysis using multiple focus days and quantitative comparisons against CERES OLR data are confirming remarkable consistency and agreement with independent truth data.
- Future work is to compare CrIS SNPP and NOAA-20 OLR against a theoretical model and derive doble differences to assess homogeneity across the two platforms.

Requirement Check List – CrIS Infrared Ozone Profile

JERD	Requirement	Meet Requirement (Y/N)?
JERD-2191	The algorithm shall produce an infrared ozone profile product that has a horizontal cell size of 50 km at nadir	Y
JERD-2192	The algorithm shall produce an infrared ozone profile product on the native retrieval reporting interval (usually the forward model's vertical grid) such that users can vertically remap the product without the loss of vertical information content	Y
JERD-2193	The algorithm shall produce an infrared ozone profile product that has a mapping uncertainty (3 sigma) of 10 km	Y
JERD-2194	The algorithm shall produce an infrared ozone profile product that has a measurement precision of: 20% from 4 hPa to 260 hPa (6 statistic layers) and 20% form 260 hPa to the surface (1 statistic layer)	Y
JERD-2195	The algorithm shall produce an infrared ozone profile product that has a measurement accuracy of: 10% from 4 hPa to 250 hPa (6 statistic layers) and 10% from 260 hPa to the surface (1 statistic layer)	Y
JERD-2196	The algorithm shall produce an infrared ozone profile product that has a measurement uncertainty of: 25% from 4 hPa to 250 hPa (6 statistic layers) and 25% from 260 hPa to the surface (1 statistic layer)	Y

Requirement Check List – Carbon Monoxide (CO)

JERD	Requirement	Meet Requirement (Y/N)?
JERD-2164	The algorithm shall produce a CO product that has a vertical coverage of the total column	Y
JERD-2165	The algorithm shall produce a CO product that has a horizontal resolution of 100 km	Y
JERD-2166	The algorithm shall produce a CO product that has a mapping uncertainty (3 sigma) of 25 km	Y
JERD-2167	The algorithm shall produce a CO product that has a measurement range of 0 to 200 ppbv	Y
JERD-2168	The algorithm shall produce a CO product that has a measurement precision of 15%	Y
JERD-2169	The algorithm shall produce a CO product that has a measurement accuracy of +/-5%	N

Requirement Check List – Carbon Dioxide (CO_2)

JERD	Requirement	Meet Requirement (Y/N)?
JERD-2173	The algorithm shall produce a CO_2 product that has a vertical coverage of the total column	Y
JERD-2174	The algorithm shall produce a CO_2 product that has a horizontal resolution of 100 km	Y
JERD-2175	The algorithm shall produce a CO_2 product that has a mapping uncertainty (3 sigma) of 25 km	Y
JERD-2176	The algorithm shall produce a CO_2 product that has a measurement range of 300 to 500 ppmv	Y
JERD-2177	The algorithm shall produce a CO_2 product that has a measurement precision of 0.5% (2 ppmv)	Y
JERD-2178	The algorithm shall produce a CO_2 product that has a measurement accuracy of +/-1% (4 ppmv)	N

Requirement Check List – Methane (CH_4)

JERD	Requirement	Meet Requirement (Y/N)?
JERD-2182	The algorithm shall produce a CH_4 product that has a vertical coverage of the total column	Y
JERD-2183	The algorithm shall produce a CH_4 product that has a horizontal resolution of 100 km	Y
JERD-2184	The algorithm shall produce a CH_4 product that has a mapping uncertainty (3 sigma) of 25 km	Y
JERD-2185	The algorithm shall produce a CH_4 product that has a measurement range of 1100 to 2250 ppbv	Y
JERD-2186	The algorithm shall produce a CH_4 product that has a measurement precision of 1% (~ 20 ppbv)	N
JERD-2187	The algorithm shall produce a CH_4 product that has a measurement accuracy of +/-4% (~ 80 ppbv)	Y

Requirement Check List – Outgoing Longwave Radiation

JERD	Requirement	Meet Requirement (Y/N)?
JERD-2200	The algorithm shall produce an OLR product during daytime and nighttime, regardless of sky conditions	Y
JERD-2201	The algorithm shall produce an OLR product that has a horizontal cell size of 25 km at nadir	Y
JERD-2202	The algorithm shall produce an OLR product that has a mapping uncertainty (3 sigma) of 5 km at nadir	Y
JERD-2203	The algorithm shall produce an OLR product that has a measurement range of 0 to 500 W/m^2	Y
JERD-2204	The algorithm shall produce an OLR product that has a measurement precision of 12 W/m^2	Y
JERD-2205	The algorithm shall produce an OLR product that has a measurement accuracy of 5 W/m^2	Y

Users Feedback

Name	Organization	Application	User Feedback - User readiness dates for ingest of data and bringing data to operations
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 NH3 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
Larry Flynn	NOAA/NESDIS/STAR	TOAST	- pending
Pingping Xie	NOAA/NESDIS/STAR	OLR PI	- pending

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
Total column requirements for carbon trace gases	Total column requirements are not appropriate given the limited DOF of the trace gas retrieval products	Can't meet spec	Redefne requirements on coarse layer statistics similar to T, q, O3

Documentations (Check List, 1 slide)

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

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 ozone, CO, CH4 and OLR are strongly consistent. CO2 requires further optimization. Independent validations against truth data sets also show that the products meet spec or are close to do so.
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, SARTA bias correction, IR surface emissivity, CH4 and CO optimization.

Conclusion

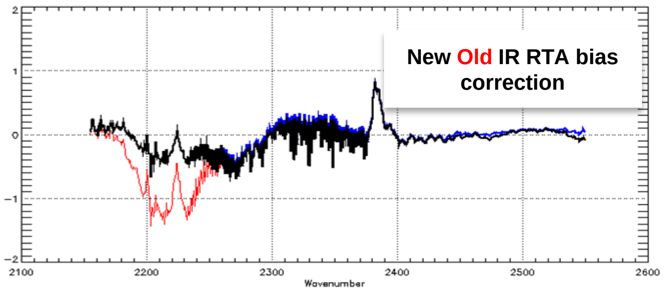
- Cal/Val results summary:
  - Team recommends algorithm provisional maturity
    - NOAA-20 NUCAPS Ozone meets spec
    - NOAA-20 NUCAPS CO is consistent with SNPP NUCAPS CO
    - NOAA-20 CH_4 and CO_2 products require optimization
    - NOAA-20 CrIS OLR meets spec

Path Forward

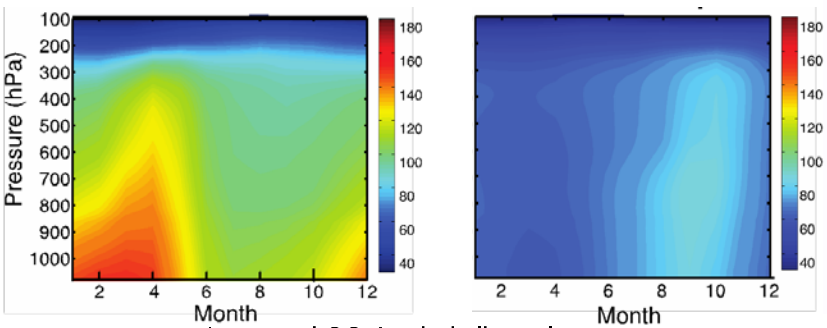
- Lessons learned for N20 Cal Val
  - Carbon trace gas total column requirements appear not appropriate. Could we think of redefining on coarse layers
  - Carbon trace gas requirements are too stringent
- Planned improvements
  - MW surface classification, regression module, SARTA bias correction, IR surface emissivity, CH4 and CO optimization
- Future Cal/Val activities / milestones
  - Acquire WE-CAN, FIREX and AirCore data sets
  - Validate NUCAPS NOAA-20 and SNPP OLR vs OLR theoretical model; apply doulbe differences.
  - Prepare validated maturity review

Back up slides

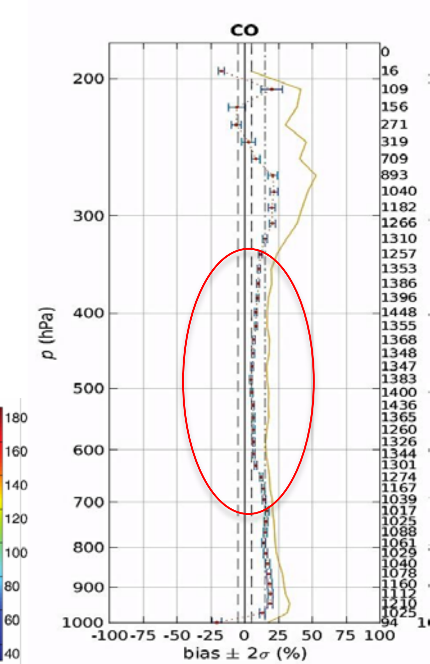
NUCAPS version 2.1.10a to 2.1.12d



Improved SARTA bias correction in the CO band



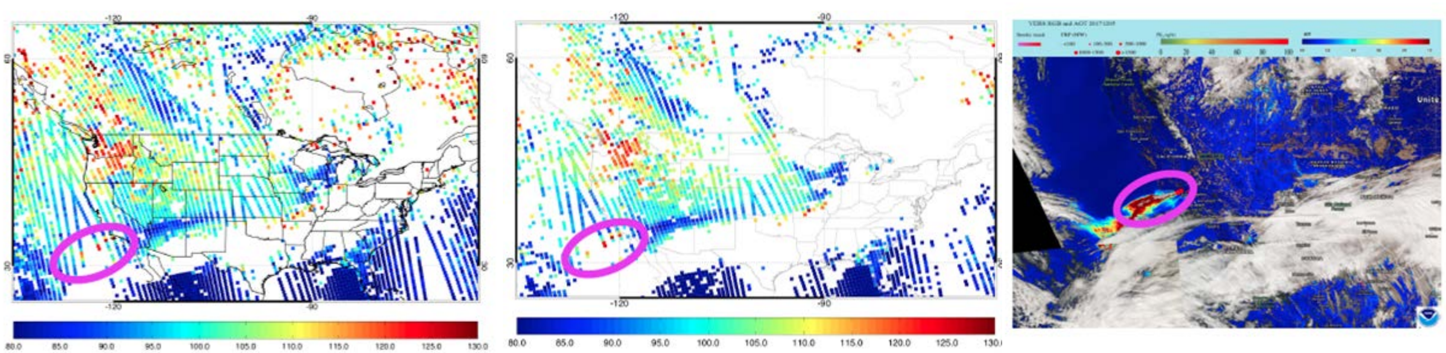
Improved CO A priori climatology



Comparisons against ATom

An improved IR RTA bias correction in the CO band, CO chn selection, CO a priori climatology and refined quality controls tailored to responding to users needs for an unbiased and stable CO product

Comparisons against the ATom ensemble shows that NUCAPS CO now meets accuracy (dash line) and precision (dot dash line) in the region where CrIS is sensitive to CO (350-750 mb)


Improved CO Quality Flag

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)

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NUCAPS: NOAA's Long term Strategy for Hyper Spectral Sounding

- Aqua (2002)

- MetOp A (2006), B (2012), C (2018)

- Suomi NPP (2011)

- JPSS 1,2,3,4 (2017 - 2038)

- EPS SG (2020, 2040)

NUCAPS
NOAA **U**nique **C**ombined **A**tmospheric **P**rocessing **S**ystem

CCR, CLD	• National Center Environmental Prediction • Data Assimilation
ST, T, WV	• AWIPS II - https://www.unidata.ucar.edu/software/awips2/ • RealEarth - https://realearth.ssec.wisc.edu/
O3	• TOAST https://www.ospo.noaa.gov/Products/atmosphere/etoast/index.html
CO, CH4, CO2	• IDEA I: https://www.star.nesdis.noaa.gov/smcd/spb/aq/ • Data Assimilation
HNO3, N2O, SO2	• Research products
OLR	• http://www.cpc.ncep.noaa.gov/products/global_precip/html/wpage.cams_opi.html
... HN3	• Future development areas

OLR Error Budget

Summary on CrIS SNPP and NOAA-20 OLR Results vs CERES SNPP and NOAA-20 OLR			
	JPSS L1RD Requirement (W/m^2)	SNPP OLR (W/m^2)	SNPP N20 (W/m^2)
SDV	12.0		
BIAS	5.0		