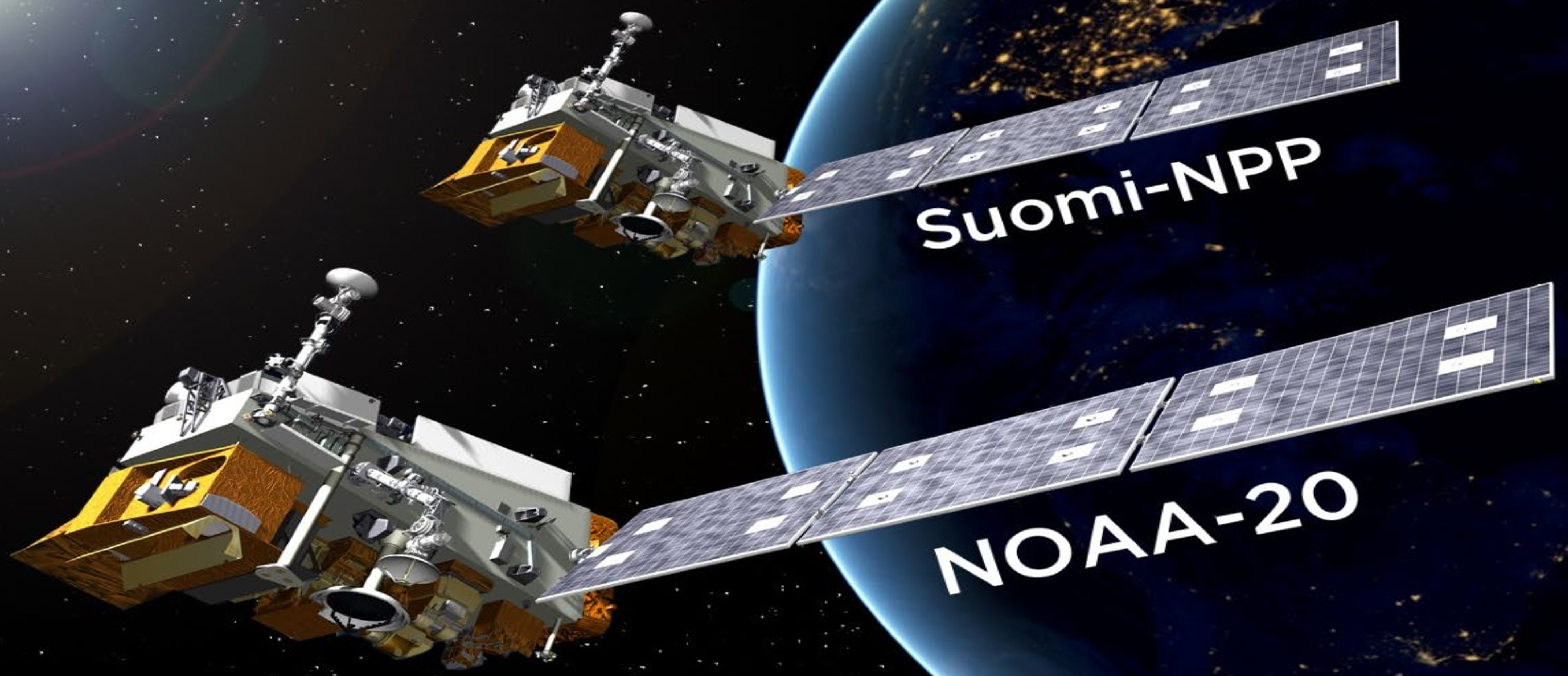
RFA Responses to
NUCAPS CO2 Validated Maturity Science Review



RFA Responses to
NOAA-20 & S-NPP CO2 EDR Validated Maturity
Date: 2021/02/03

JPSS NOAA NASA

RFA RESPONSES
NUCAPS CO2 EDR VALIDATED MATURITY REVIEW
FEBRUARY 3, 2021

RFA Responses to Validated Maturity:

NOAA-20 & S-NPP NUCAPS CO2 Product

Section	Outline for Maturity Review Presentation	Time
1	**Management updates**	**5 minutes (9:35 – 9:40)** • Presented Ken Pryor
2	**Address RFA from December 2020 Maturity Review** • Address RFAs from December 2020 Maturity Review	**20 minutes (9:40 – 10:00)** **Slides 4-36** • Juying Warner • Murty Divakarla • Ken Pryor
3	**Summary and Conclusions**	• Ken Pryor **Slides 37-38**
3	**Supplemental Slides** • None	**Slides 39-55**

NUCAPS Operational Products and Current Maturity Status

NUCAPS Products	
Cloud Cleared Radiances	
Atmospheric Vertical Temperature Profile (AVTP)	In AWIPS
Atmospheric Vertical Moisture Profile (AVMP)	In AWIPS
Cloud Fraction and Top Pressure	In AWIPS
Ozone	
CO	
CH_4	
CO_2	
Volcanic SO_2	Experimental Viable Products
HNO_3	Experimental Viable Products
N_2O	Experimental Viable Products
NH3	Experimental Viable Products
Isoprene	Experimental Viable Products
PAN	Experimental Viable Products

Data Product	Priority	Current Maturity Status	
		S-NPP	NOAA-20
AVTP/AVMP	3	✓ Validated	✓ Validated
Ozone (p)	3	✓ Validated	✓ Validated
OLR	3	✓ Validated	✓ Validated
CO (p)	4	✓ Validated	✓ Validated
CH4 (p)	4	✓ Validated	✓ Validated
CO2 (p)	4	• Validated*	• Validated*

***pending addressing RFAs from December 17 Maturity Review**
S-NPP/NOAA-20 Validated Maturity Review
https://www.star.nesdis.noaa.gov/jpss/AlgorithmMaturity.php

Validated Maturity CO2 (S-NPP & NOAA-20)	Dec-20	FY21

- Processing Environment, validation of NUCAPS products at STAR:
  - Linux servers running f90, IDL, bash, C/C++, libraries (hdf5 and netCDF4)
  - Product validation using a hierarchy of validation data sets
  - Once operationalized, NUCAPS products available through STAR SCDR are used as part of regular evaluation. The JSTAR Mapper and JSTAR LTM websites provide visualization of the products produced.
  - We also leverage NPROVS system for NUCAPS operational product evaluations

RFAs from December 2020 NUCAPS CO2 Validated Maturity Review

RFA	Review Panel RFA Recommendations	Response
1. More quantitative comparisons with OCO-2 needed (initiator: James Gleason)	• Slide: Slide 48, one image of OCO-2 vs NUCAPS. • Science panel would like to see more quantitative comparisons of the NUCAPS CO2 vs the OCO2 CO2 product. OCO2 CO2 has become the standard satellite CO2 product and the first question everyone will ask is how does NUCAPS compare to OCO2? • Correlations, monthly mean difference by latitude band, Land vs ocean, etc. • The TCCON and AirCore comparisons are useful and indicate that the NUCAP-OCO2 comparison shouldn't be too bad. • The validated maturity would be pending on the more quantitative OCO2 comparisons were done and found to be acceptable.	• Addressed in detail through slides 6-31
2. README Files update to reflect the changes of operational CO2 products related to the algorithms upgrades	• The results showed significant improvements of the provisional and validated versions of the algorithms, compared with those from the operational version. These changes need to be documented in the README file so the users are aware of these changes, and the timeline of the changes, to differentiate the changes of the CO2 products due to the real environmental changes vs. the changes due to the algorithm updates.	• REDAME files updated and posted.
3. Routine monitoring capability of the operational trace gas products	• As the quality assurance of the products performance and long term stabilities, recommend to extend the routine monitoring capabilities for NUCAPS trace products under the long term science maintenance of the cal/val phase. These capabilities should include the trending of the statistics and routine monitoring of the data qualities.	Details of work plan presented as part of NUCAPS on-going activities. Slides:33-36

RFA# 1: NUCAPS CO2 Quantitative Comparisons with OCO-2

- Supplemental slides provide additional maps of consistency

NUCAPS Product Validation Methodology Hierarchies

Carbon Trace Gas Validation Hierarchy
(*Nalli et al.* 2020)

1. **Numerical Model Global *Comparisons***
   - Examples: ECMWF **CAMS**, **CarbonTracker**
   - Large, truly global samples acquired from Focus Days
   - Limitation: Not independent truth data
2. **Satellite Sounder EDR *Intercomparisons***
   - Examples: **AIRS, TROPOMI, 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)
   - **ATom**, FIREX, WE-CAN, ACT-America

Focus Day Data Sets in Possession for December Maturity Review

Review Dec 2020	CrIS/SDRs ATMS/TDRs		ECMWF		CAMS		TCCON			Metop		
Focus Day	**SNPP**	**N-20**	**SNPP**	**N-20**	**SNPP**	**N-20**	**SNPP**	**N-20**	**Metop**	**-A**	**-B**	**-C**
20180401	√		√		√	√				√	√	Data started From 20190707 We can use 04/30/2020 Metop-A/B/C SNPP/NOAA-20 as a transfer standard
20180415	√						√					
20180516	√		√		√	√	√		√	√	√	
20180615	√	√	√	√	√	√	√	√	√	√	√	
20180716	√	√	√	√	√	√	√	√	√	√	√	
20180816	√	√	√	√	√	√	√	√	√	√	√	
20180820	√	√	√	√	√	√			√	√	√	
20180916	√	√	√	√	√	√	√	√	√	√	√	
20181015	√	√	√	√	√	√	√	√	√	√	√	
20181114	√	√	√	√	√	√	√	√	√	√	√	
20181215	√	√	√	√	√	√	√	√	√	√	√	
20190115	√	√	√	√	√	√	√	√	√	√	√	
20190215	√	√	√	√	√	√	√	√	√	√	√	
20190316	√	√	√	√	√	√	√	√	√	√	√	
20190415		√		√	√	√		√				
20190515		√		√	√	√		√				
20200123	√	√	√	√								
20200430	√	√	√	√	√	√						

RFA # 1 Response: Used the above focus day compilation for quantitative evaluation of S-NPP/NOAA-20 NUCAPS CO2 with OCO-2

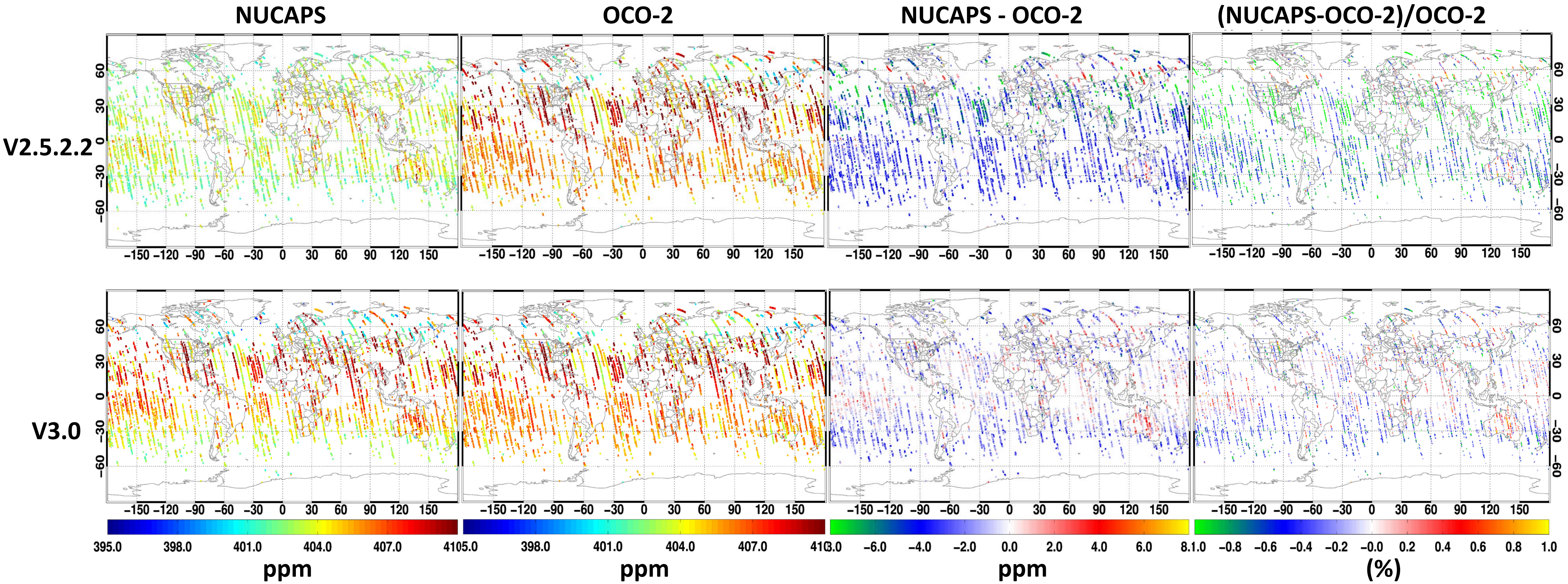
Carbon Dioxide (CO_2) Quantitative Comparisons Between NUCAPS CrIS and OCO-2 V9

- We examined the differences:
  - ✓ NUCAPS S-NPP/NOAA-20 CrIS versus OCO-2 V9:
    - Maps
    - Correlations
    - Histograms of the differences
  - ✓ Between OCO-2 V9 versus V10
    - Maps, Correlations, Histograms
- Results of quantitative evaluation with OCO-2 show
  - ✓ The differences between NUCAPS V3.0 CrIS and OCO-2 V9 are less than 0.5%, an improvement of more than 2.5 ppm closer to OCO-2 V9 from the current operational version V2.5.2.2.
  - ✓ The NUCAPS CO2 products from S-NPP and NOAA-20 are consistent with OCO-2 evaluations
  - ✓ The NUCAPS CO2 quantitative evaluations over land and ocean do not differ significantly with OCO-2

CO2 Quantitative Comparisons: NUCAPS S-NPP CrIS *vs*. OCO-2 V9

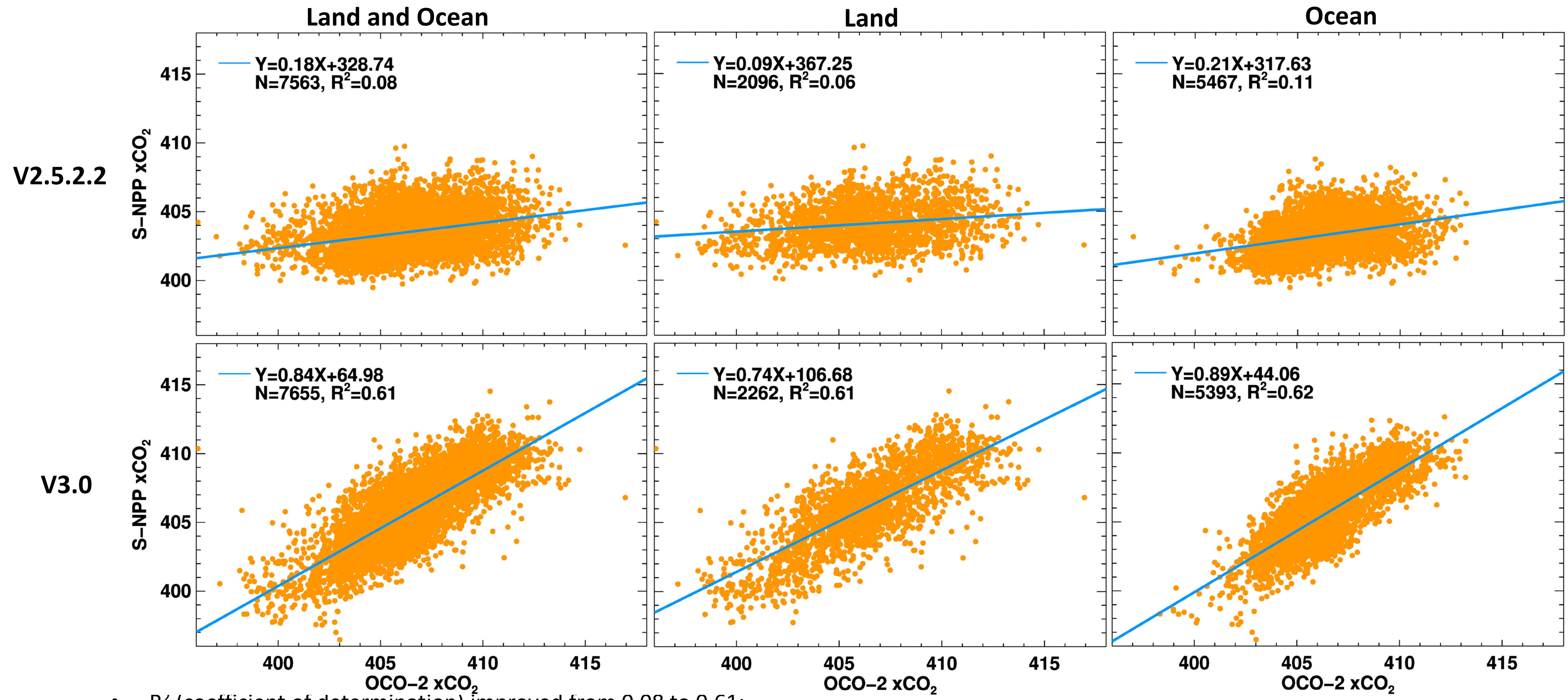
- Supplemental slides provide additional maps presented during the CO2 Validated maturity (December 2020)

CO2 (xCO2 ppm) Quantitative Comparisons: NUCAPS **S-NPP** CrIS *vs.* OCO-2 V9
Summary of 11 Focus days over 1-year, all Seasons



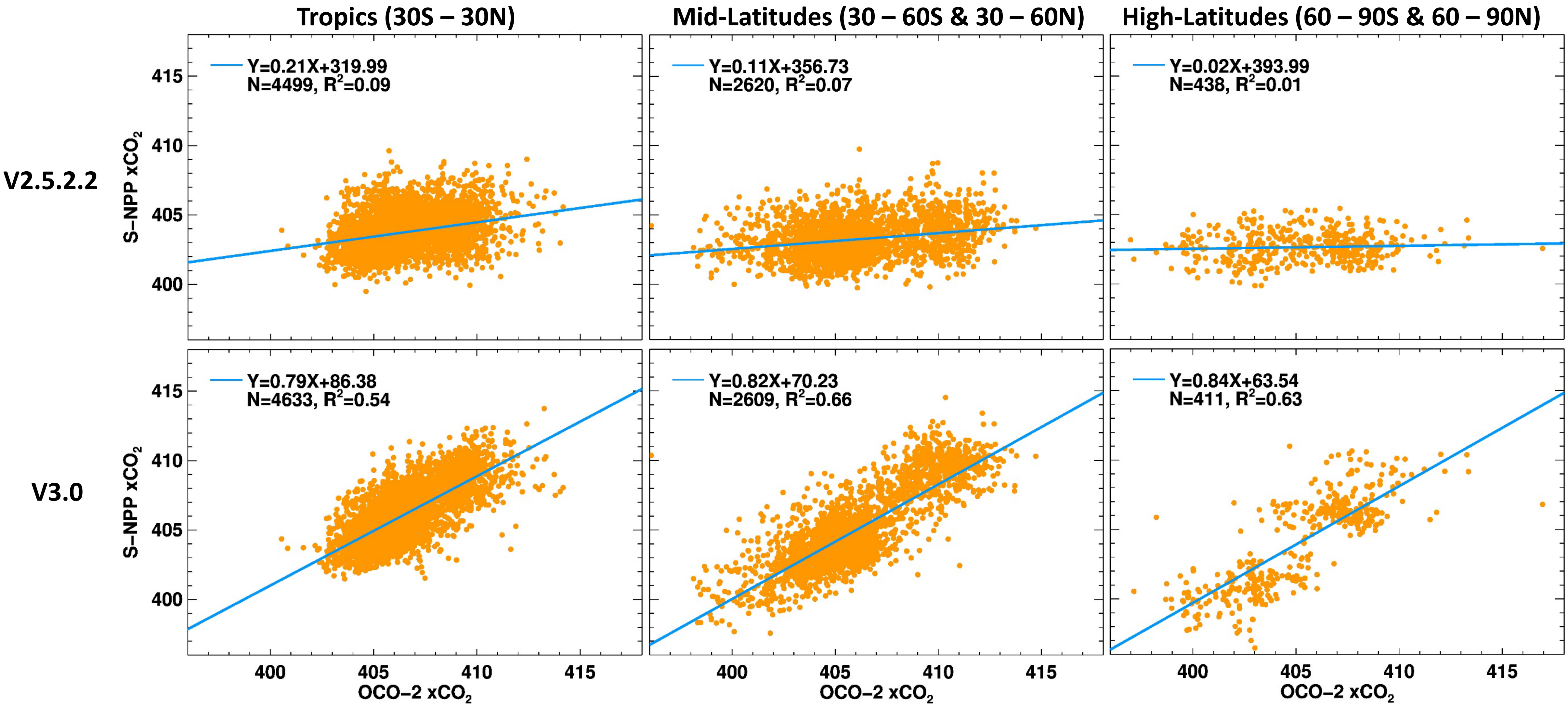
- Above figures are summary of the 11 days: 20180615, 20180716, 20180816, 20180916, 20181015, 20181215, 20190115, 20190215, 20190316, 20190415, 20190515 (OCO-2 not available on 20181115).
- Differences of NUCAPS V3.0 - OCO-2 V9 are approximately -2 to 2, which is less than 0.5%, while for V2.5.2.2 is primarily negative up to 1%.

CO2 (xCO2 ppm) Quantitative Comparisons: v2.5.2.2 and v3.0
NUCAPS S-NPP CrIS *vs.* OCO-2 V9 All 11 days, Stratified as Land, Ocean



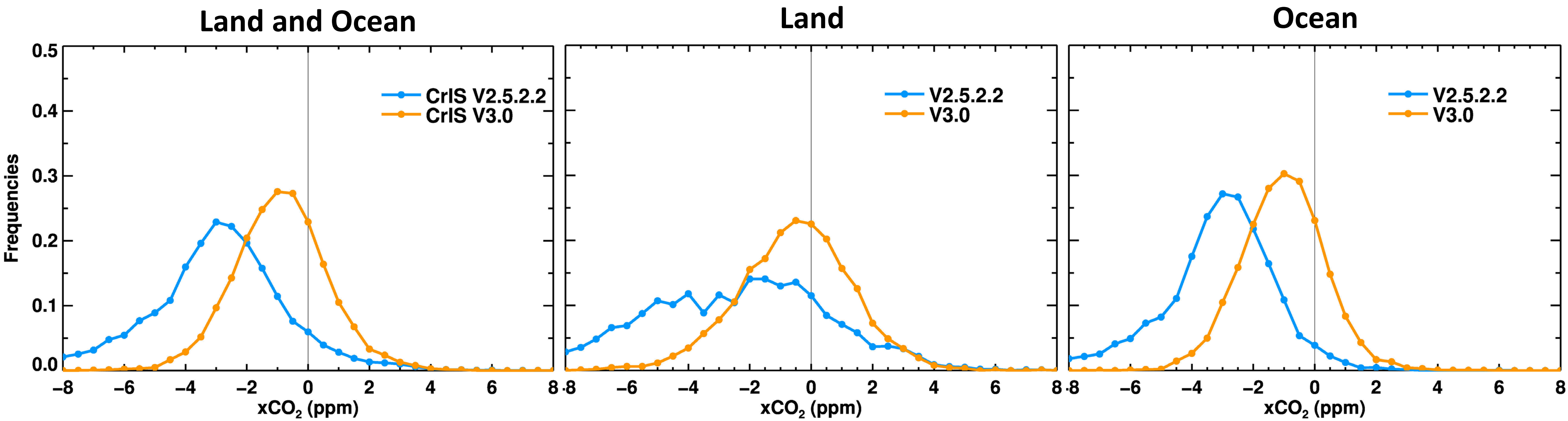
- R^2 (coefficient of determination) improved from 0.08 to 0.61;
- Slopes improved from 0.09 (land) and 0.21 (ocean) for V2.5.2.2 to 0.74 (land) and 0.89 (ocean) for V3.0.
- Conclusions do not differ significantly between land and ocean, so later results are for global only.

CO2 (xCO2 ppm) Quantitative Comparisons: v2.5.2.2 and v3.0
NUCAPS S-NPP CrIS *vs.* OCO-2 V9 All 11 days, Stratified by Latitude Bands



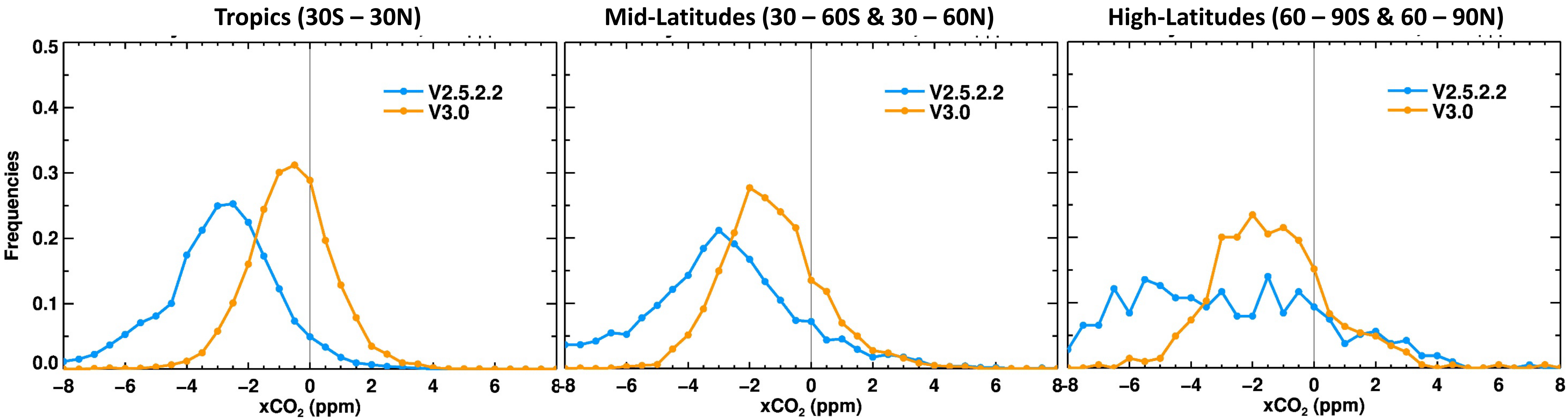
- R^2 (coefficient of determination) improved from 0.09 to 0.54 for the Tropics, 0.07 to 0.66 for the mid-latitudes, and 0.01 to 0.63 for the high-latitudes;
- Slopes improved from 0.21 (tropics), 0.11 (mid-latitudes), and 0.02 (high-latitudes) for V2.5.2.2 to 0.79 (tropics), 0.82 (mid-latitudes) and 0.84 (high-latitudes) for V3.0, respectively.

CO2 (xCO2 ppm) Quantitative Comparisons: NUCAPS **S-NPP** CrIS and OCO-2 V9, All 11 days, Stratified as Land, Ocean



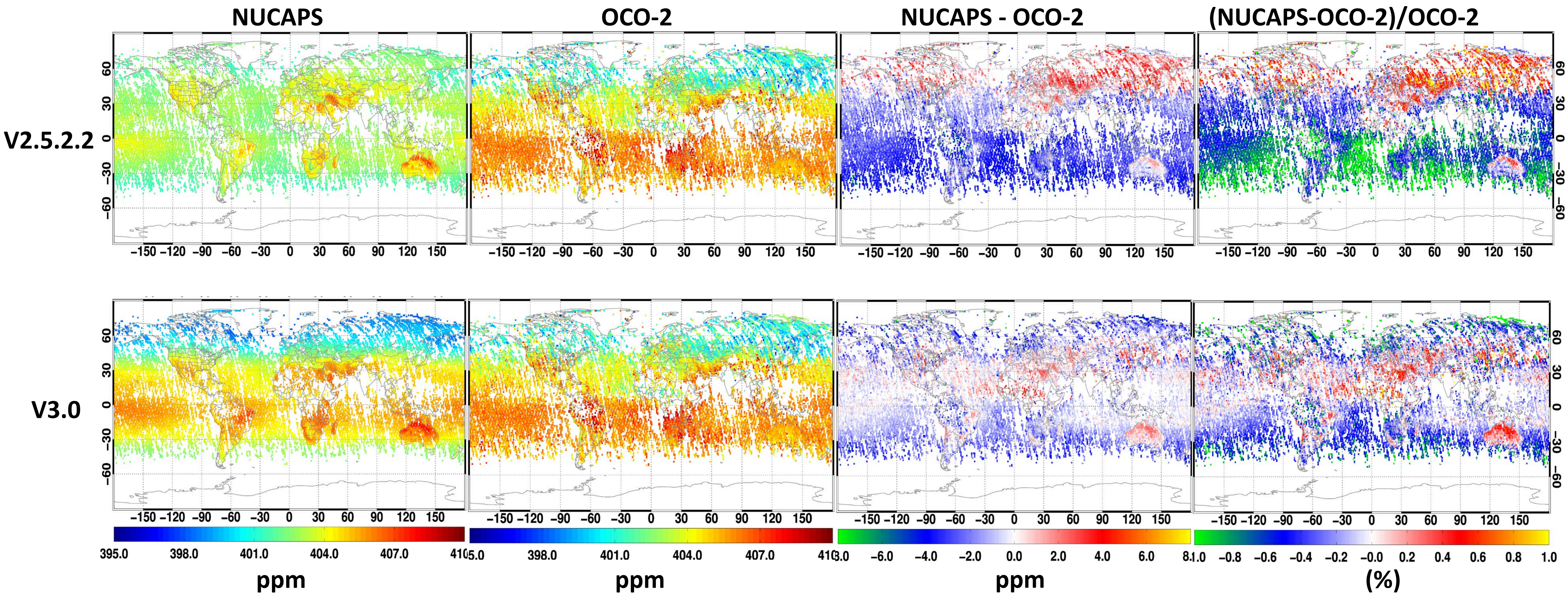
- The differences to OCO-2 V9 improved by 2.5 ppm from V2.5.2.2 to V3.0;
- Land and ocean do not differ significantly, so will only show land & ocean ensemble for follow up individual days.

CO2 (xCO2 ppm) Quantitative Comparisons: NUCAPS S-NPP CrIS and OCO-2 V9, All 11 days, Stratified by Latitude Bands



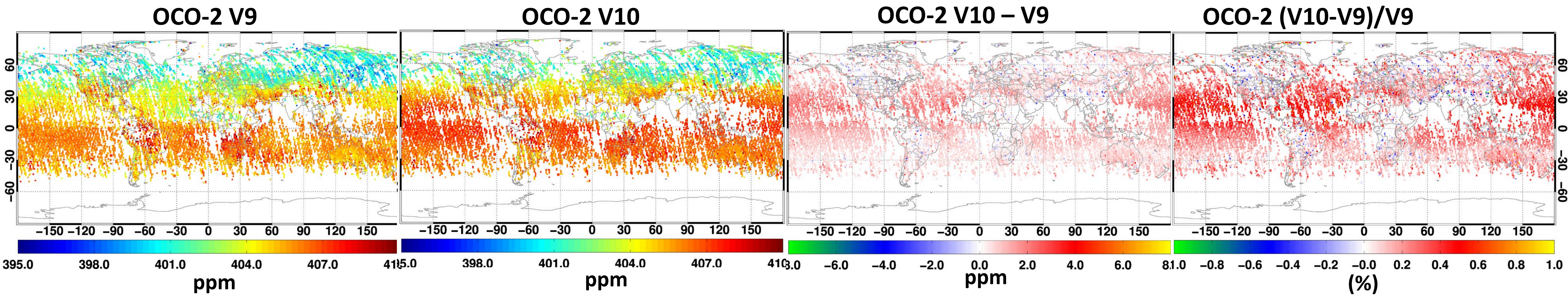
- The differences to OCO-2 V9 improved the most in the tropics, slightly less in the mid-latitudes, from V2.5.2.2 to V3.0.
- The high-latitude values were primarily from the Northern Hemisphere.

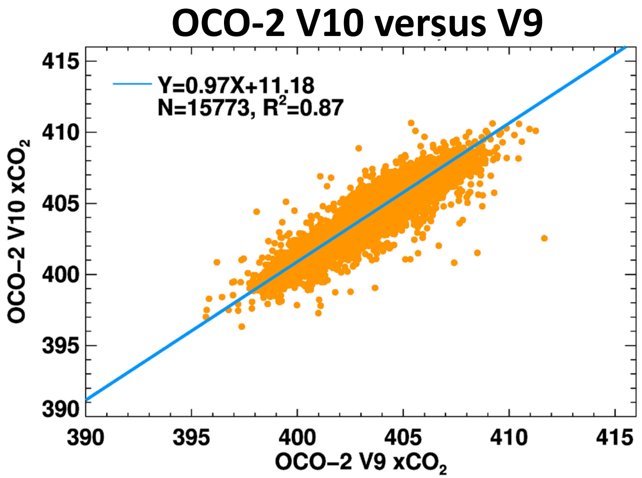
CO2 (xCO2 ppm) Quantitative Comparisons: NUCAPS **S-NPP** CrIS *vs.* OCO-2 V9 - August 2018 Monthly Means

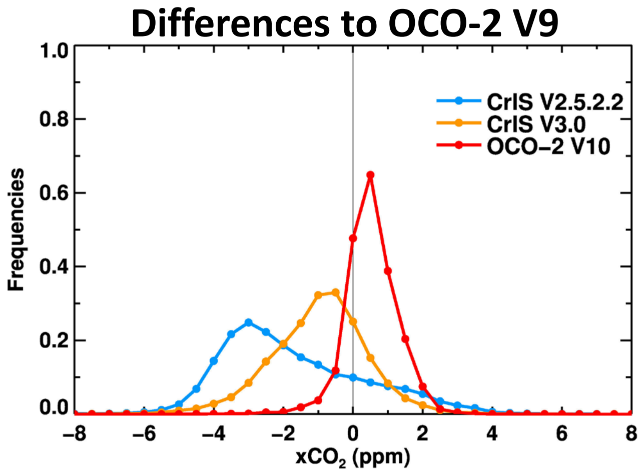


- Differences of NUCAPS V3.0 - OCO-2 V9 are approximately -2 to 2, which is less than 0.5%, while for V2.5.2.2 is primarily negative up to 1%.

CO2 (xCO2 ppm) Quantitative Comparisons: OCO-2 V9 *vs.* V10 - August 2018 Monthly Means

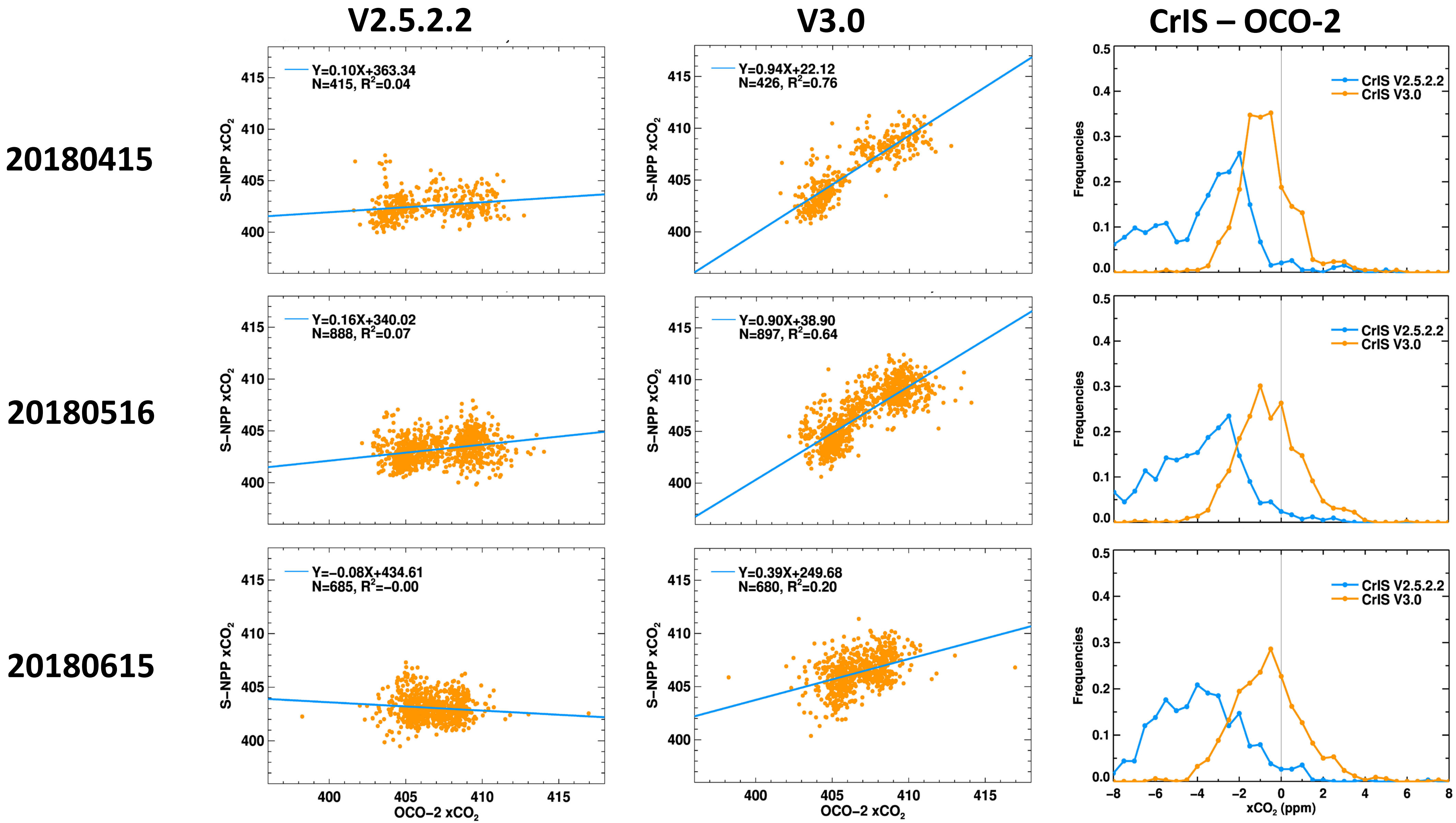




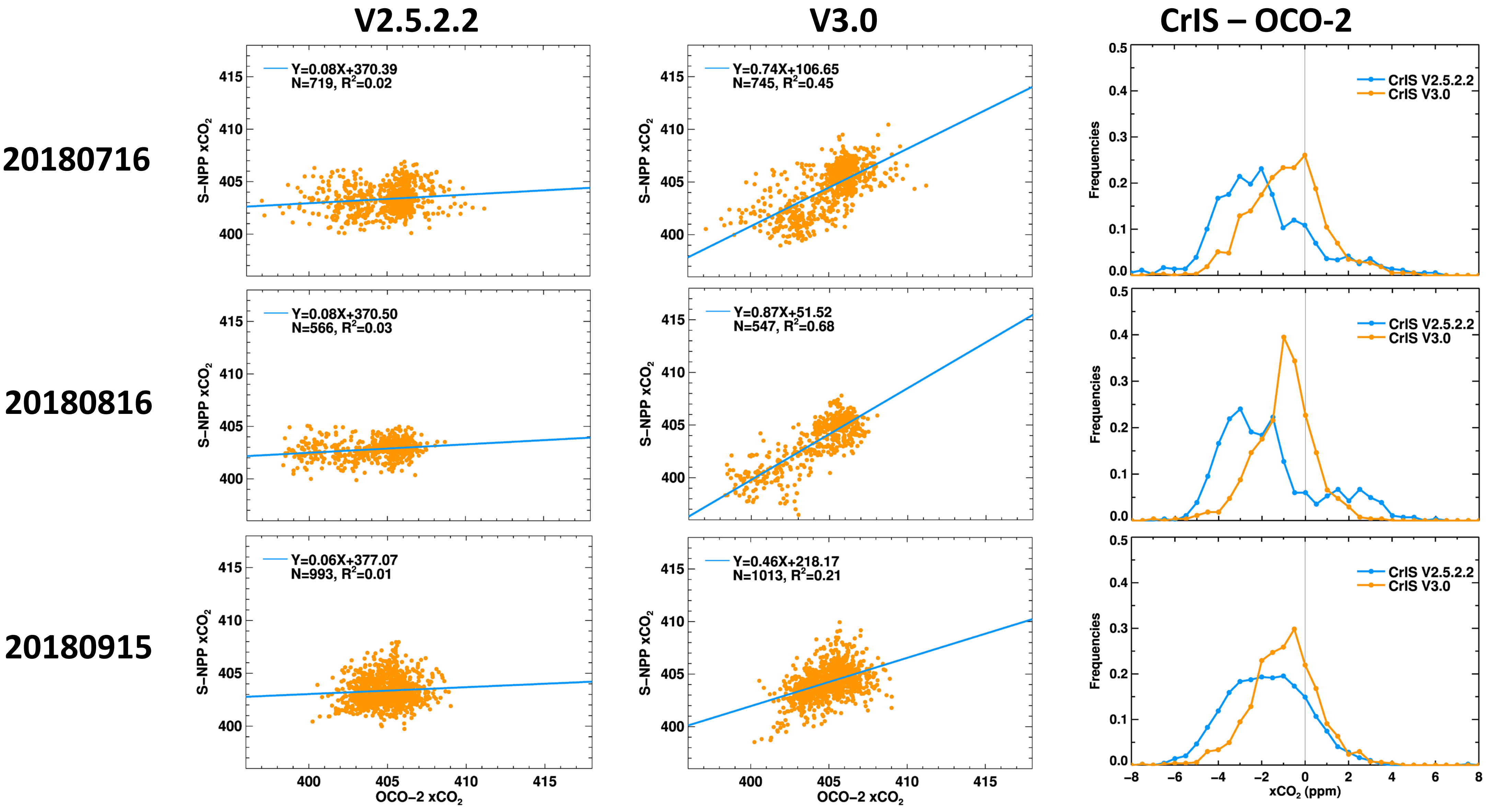


- Differences of OCO-2 V9 and V10 are approximately -2 to 2 ppm, which is less than 0.5%.
- This is in the same magnitude as the differences between NUCAPS CrIS and OCO-2.
- OCO-2 products are retrievals, not in situ, so the comparison results should be viewed differently from the product standard, set for in situ validations.

CO2 (xCO2 ppm) Quantitative Comparisons:
NUCAPS CO2 (xCO2 ppm): S-NPP *vs*. OCO-2 V9 – Global (Land & Ocean)



CO2 (xCO2 ppm) Quantitative Comparisons:
NUCAPS CO2 (xCO2 ppm): **S-NPP** *vs*. OCO-2 V9 - Global



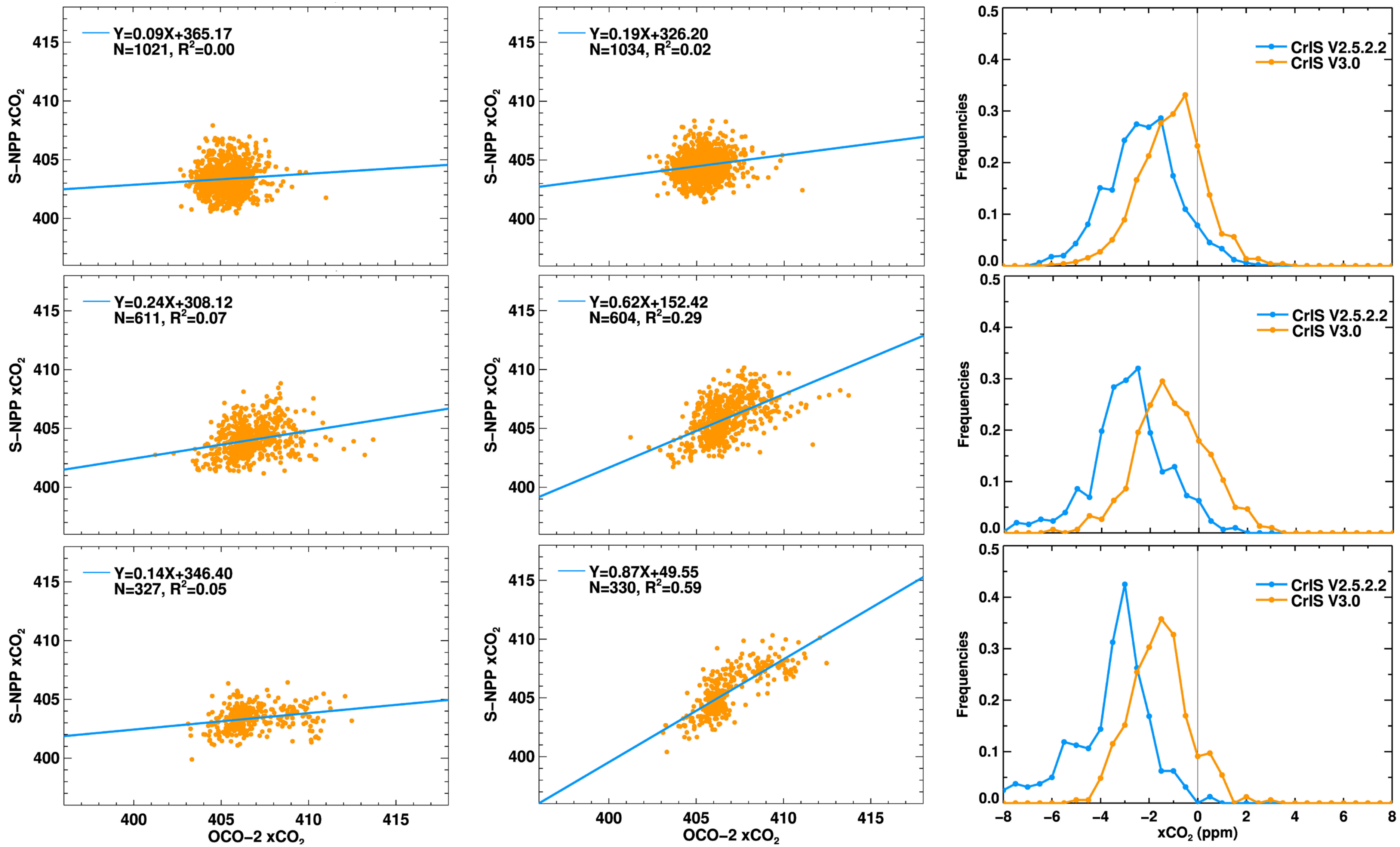
CO2 (xCO2 ppm) Quantitative Comparisons:
NUCAPS CO2 (xCO2 ppm): **S-NPP** *vs*. OCO-2 V9 - Global

V2.5.2.2 | **V3.0** | **CrIS – OCO-2**

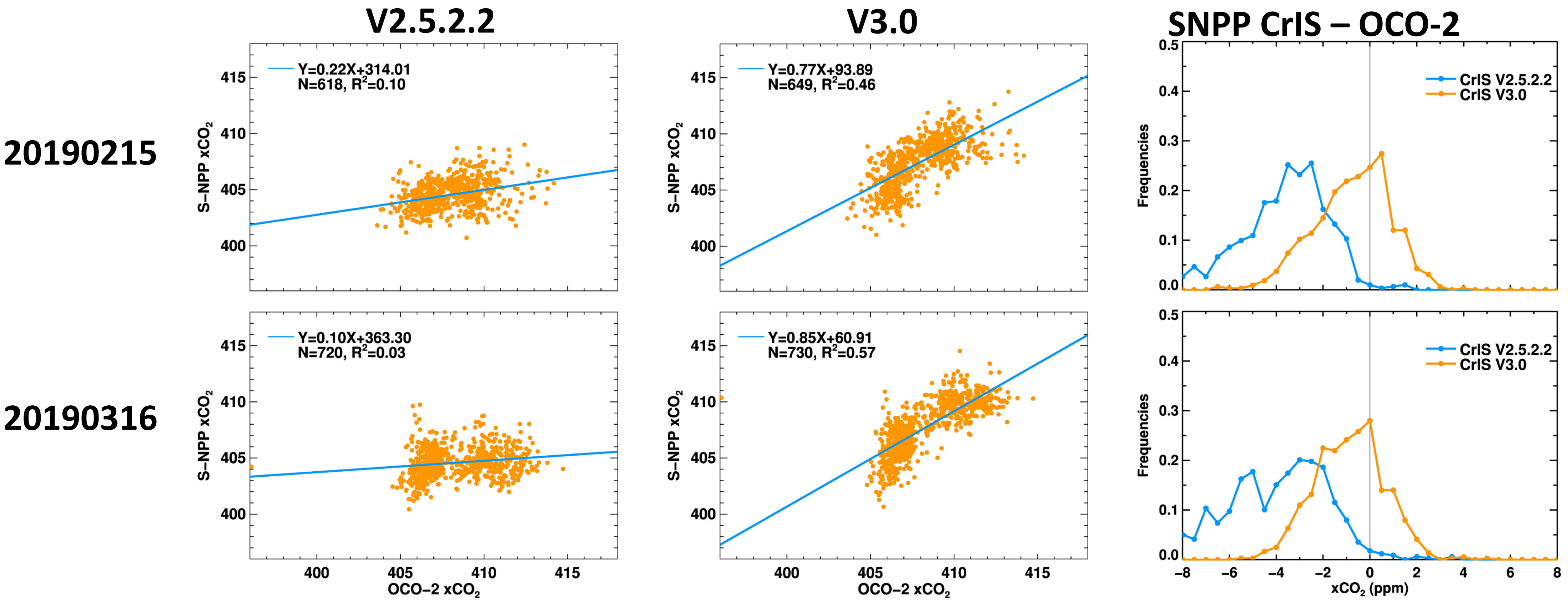
20181015

20181215

20190115



CO2 (xCO2 ppm) Quantitative Comparisons:
NUCAPS CO2 (xCO2 ppm): **S-NPP** *vs*. OCO-2 V9 - Global



- The correlation fits are meant to show differences between V2.5.2.2 and V3.0, so simple IDL fit routine (LINFIT) is used.
- More sophisticated methods of using initial guesses with error estimates to minimize a model are possible for future publication studies.
- Significant improvements from V2.5.2.2 to V3.0 to the agreements to OCO-2 V9 are shown in all days.

CO2 Quantitative Comparisons: NUCAPS NOAA-20 CrIS *vs*. OCO-2 V9

CO2 (xCO2 ppm) Quantitative Comparisons: NUCAPS **NOAA-20** CrIS *vs.* OCO-2 V9
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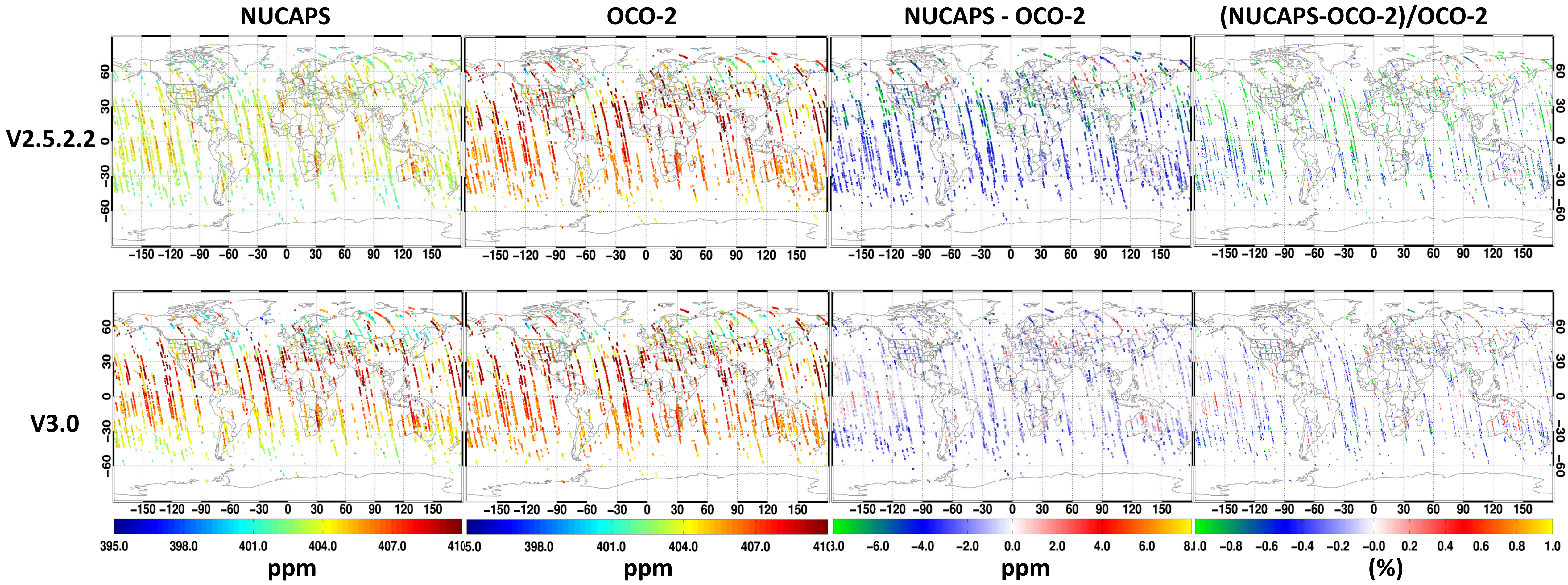

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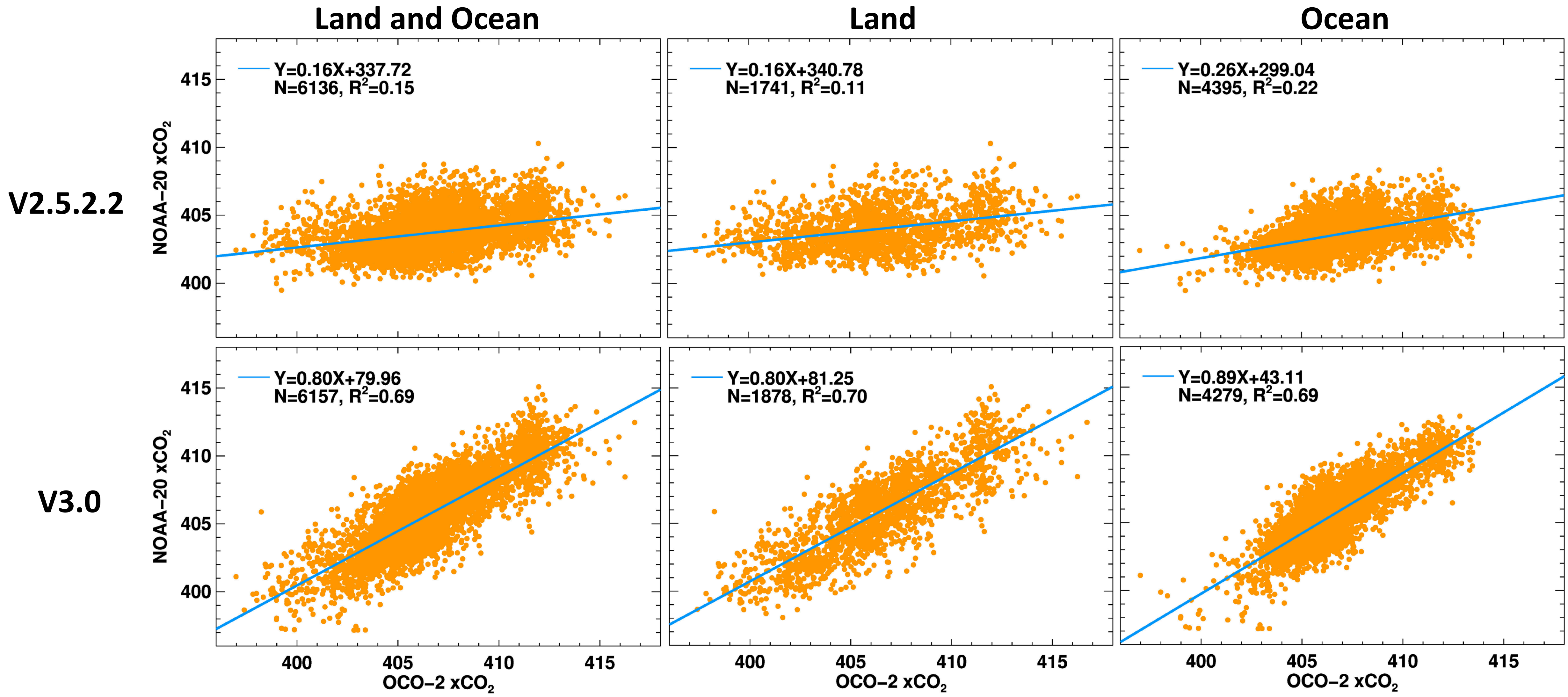
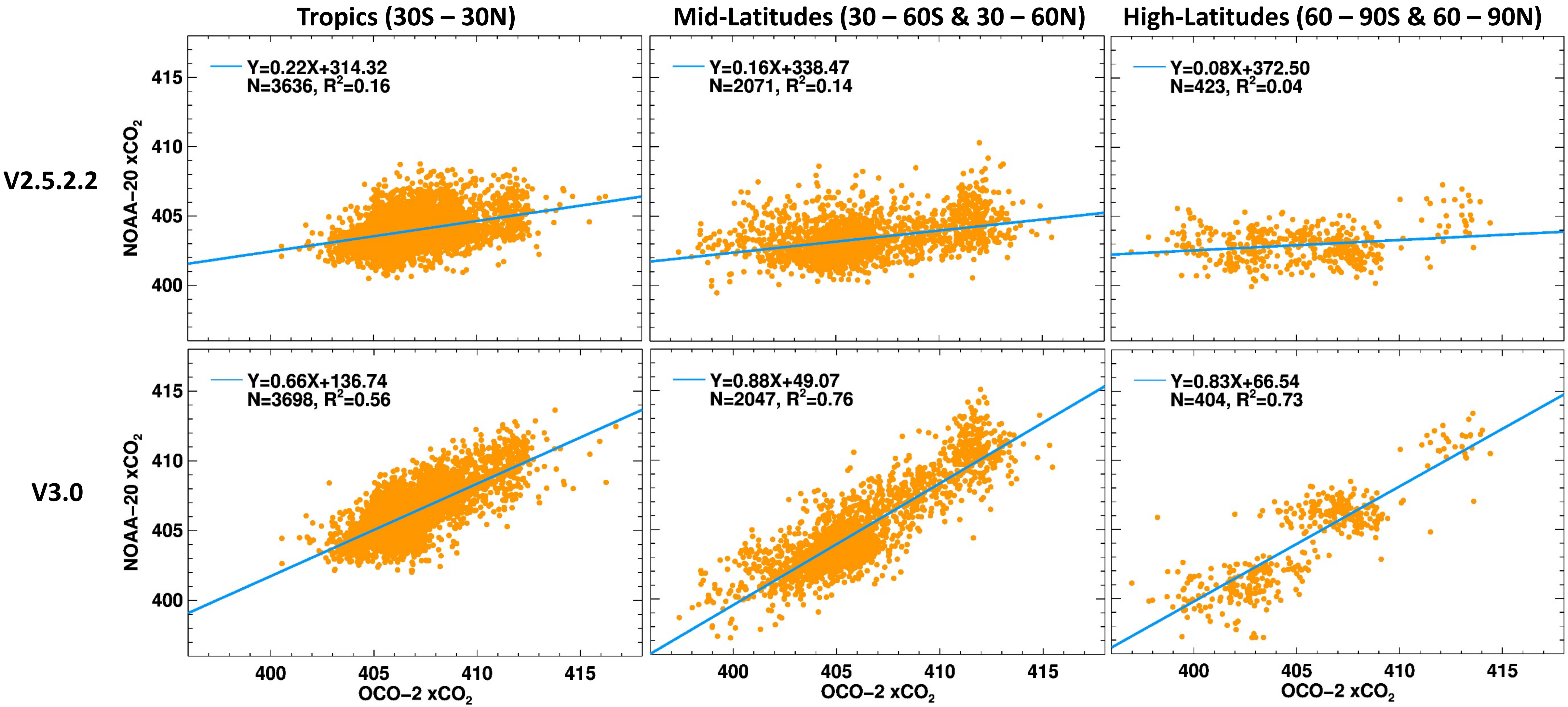


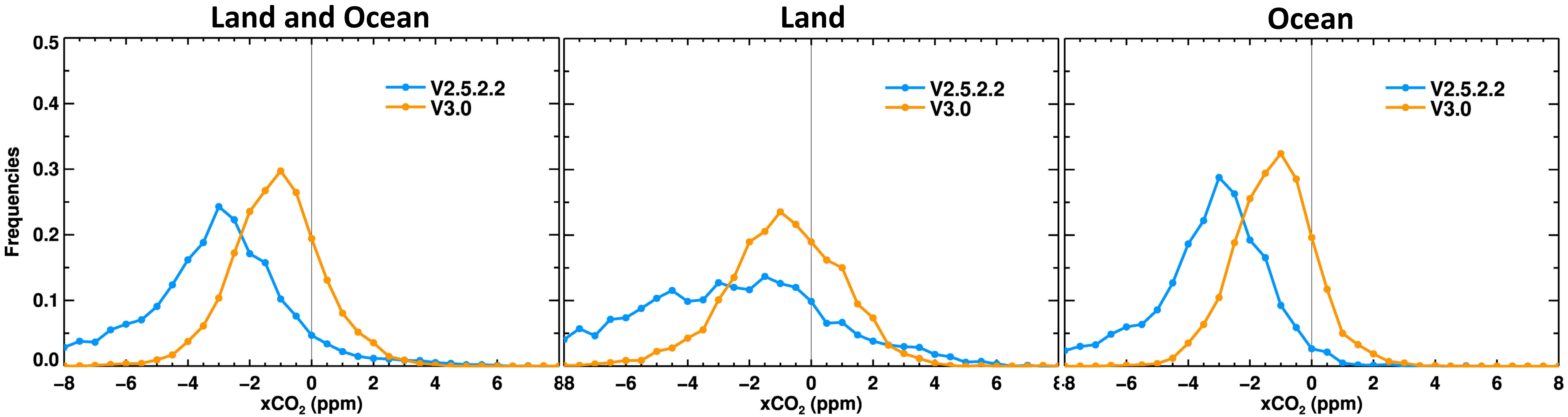
- R^2 (coefficient of determination) improved from 0.15 to 0.69;
- Slopes improved from 0.16 (land) and 0.26 (ocean) for V2.5.2.2 to 0.80 (land) and 0.89 (ocean) for V3.0.

CO2 (xCO2 ppm) Quantitative Comparisons: v2.5.2.2 and v3.0
NUCAPS **NOAA-20** CrIS *vs.* OCO-2 V9 All 11 days, Stratified by Latitude Bands



- R^2 (coefficient of determination) improved from 0.16 to 0.56 for the Tropics, 0.14 to 0.76 for the mid-latitudes, and 0.04 to 0.73 for the high-latitudes;
- Slopes improved from 0.22 (tropics), 0.16 (mid-latitudes), and 0.04 (high-latitudes) for V2.5.2.2 to 0.66 (tropics), 0.88 (mid-latitudes) and 0.83 (high-latitudes) for V3.0, respectively.

CO2 (xCO2 ppm) Quantitative Comparisons: NUCAPS NOAA-20 CrIS and OCO-2 V9, All 11 days, Stratified as Land, Ocean



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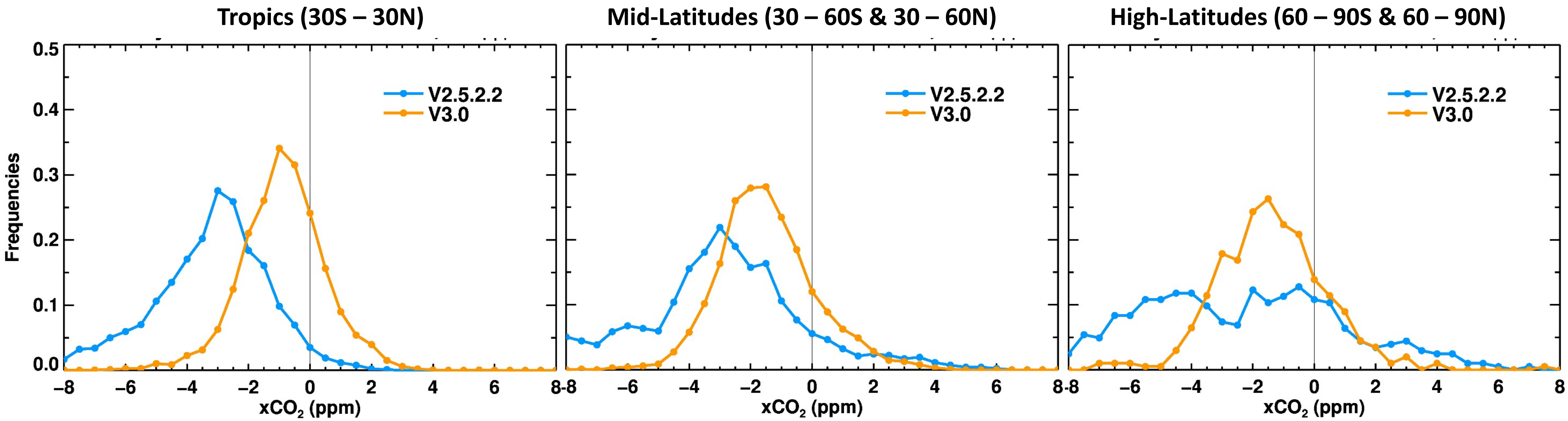

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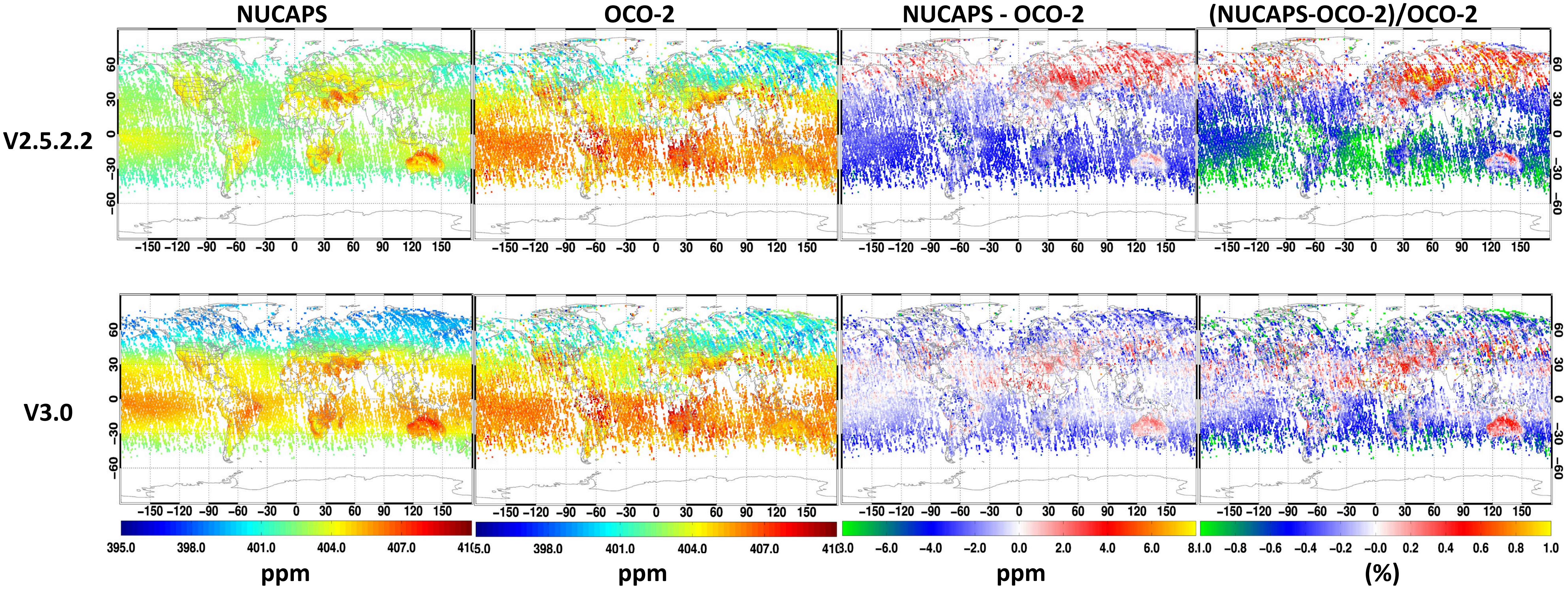
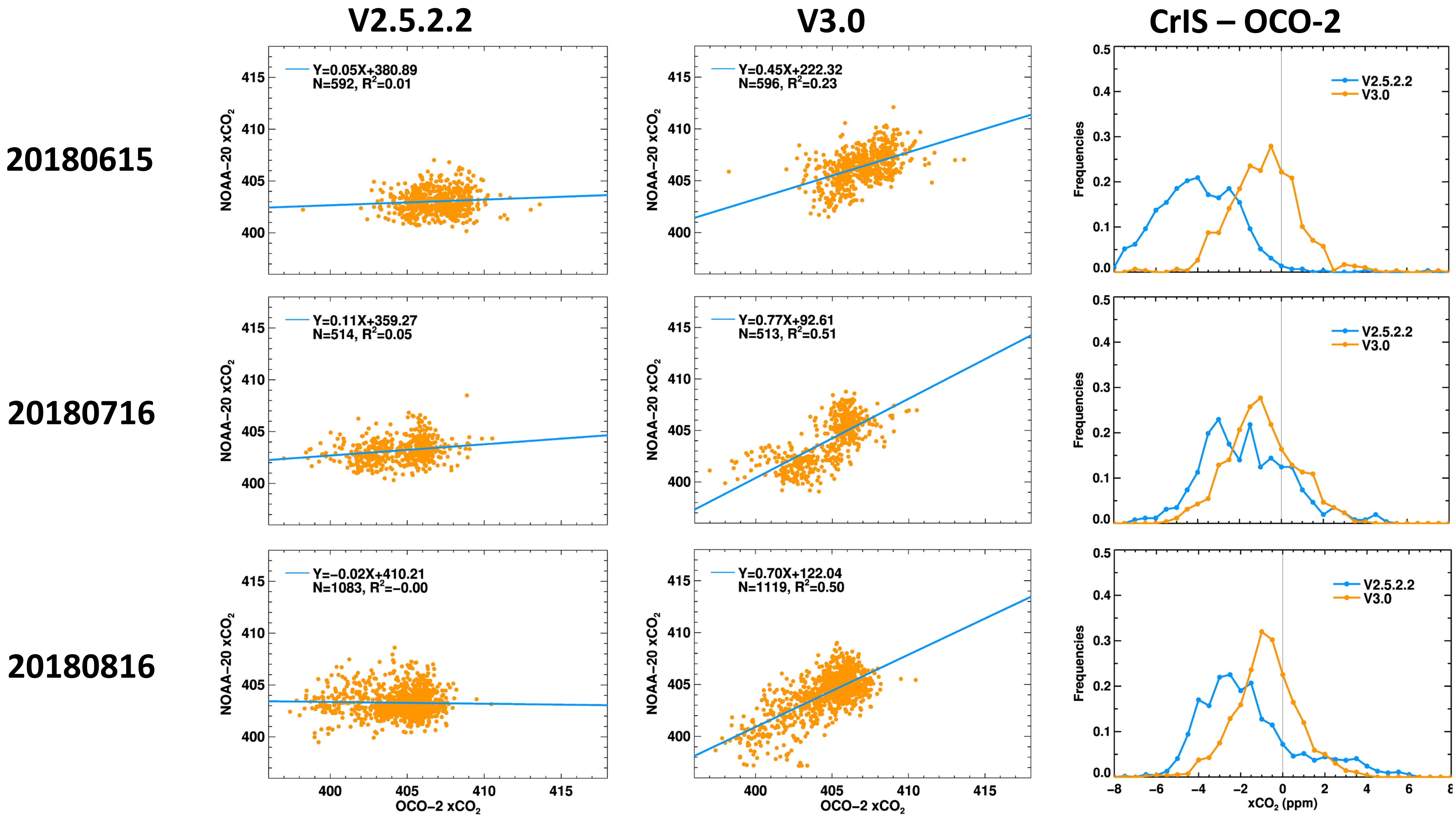


- Differences of NUCAPS NOAA-20 V3.0 - OCO-2 V9 are slightly larger than S-NPP, but the comparison conclusions still apply.

CO2 (xCO2 ppm) Quantitative Comparisons:
NUCAPS CO2 (xCO2 ppm): **NOAA-20** *vs*. OCO-2 V9 – Global (Land & Ocean)



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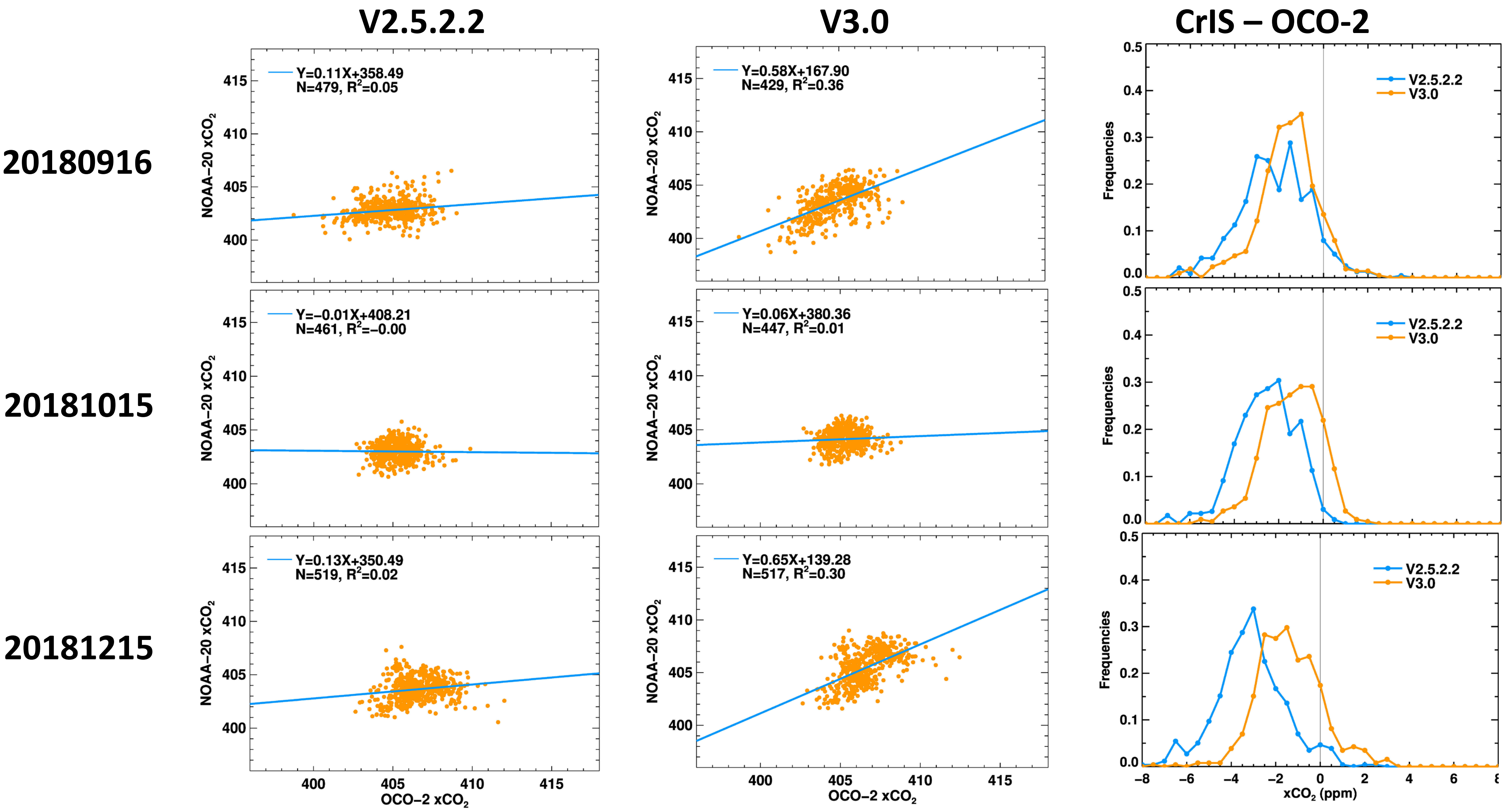
NUCAPS CO2 (xCO2 ppm): NOAA-20 *vs*. OCO-2 V9 – Global (Land & Ocean)



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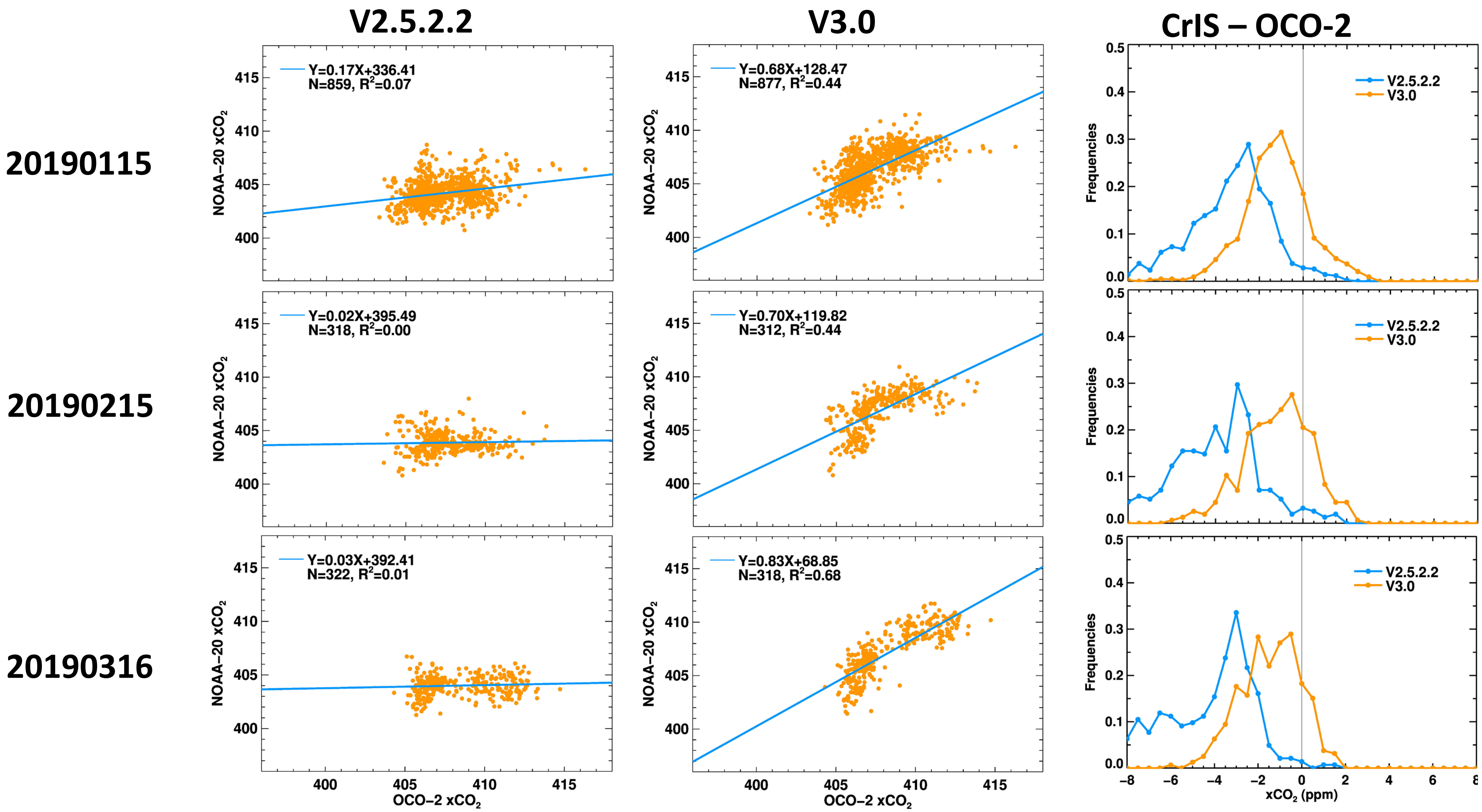

CO2 (xCO2 ppm) Quantitative Comparisons:
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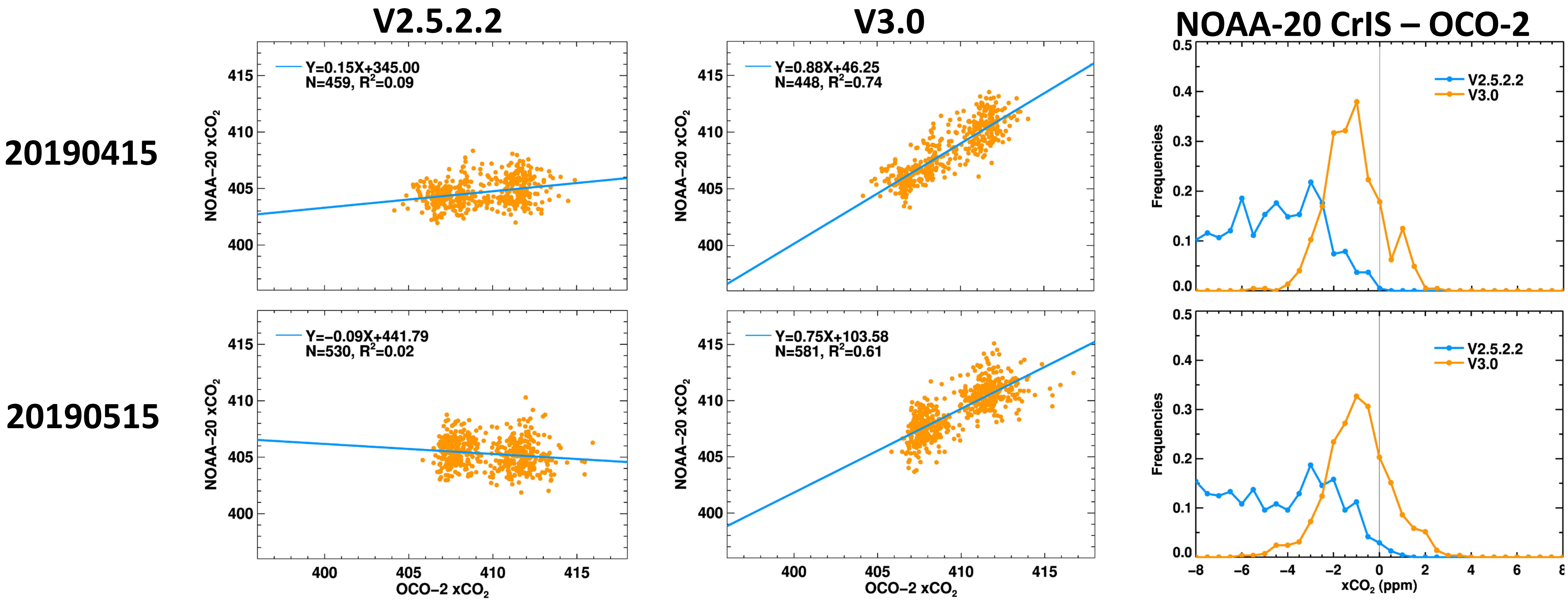


RFA# 2: README Files update to reflect the changes of operational CO2 products related to the algorithms upgrades

- Updated README Files and posted onto the google drive.

RFA# 3: Routine monitoring capability of the operational trace gas products

Need for Routine Monitoring of NUCAPS Products

- NUCAPS Team discussed the need for routine monitoring of other NUCAPS Products
  - RFA #3 CO_2 Validated Maturity: Routine monitoring capability of the operational trace gas products
    - As the quality assurance of the products performance and long term stabilities, recommend to extend the routine monitoring capabilities for NUCAPS trace products under the long term science maintenance of the cal val phase. These capabilities should include the trending of the statistics and routine monitoring of the data qualities.
      - IR Ozone with model analysis fields (e.g. ECMWF, CAMS), and OMPS EDR products
      - CO, CH_4, CO_2 trace gas products with model analysis fields (CAMS), other satellite products from Sentinel-TROPOMI, OCO-2.
  - Facilitates easy compilation of ‘focus-day data sets’, for NUCAPS team research activities, and in support of NOAA-STAR GML collaborations.
  - Support NOAA-STAR GML collaborations
    - Recent NOAA-GML workshop discussed the need for more ‘focus day’ datasets from 2020 and 2021. These data sets would be useful for all the three themes (trace gases, ozone and water vapor, aerosol products)
  - Provide support for user needs for future intensive field campaigns and case studies.
  - Support needs for active collaboration with the JPSS SDR (CrIS) and EDR (OMPS, AOD/ADP)

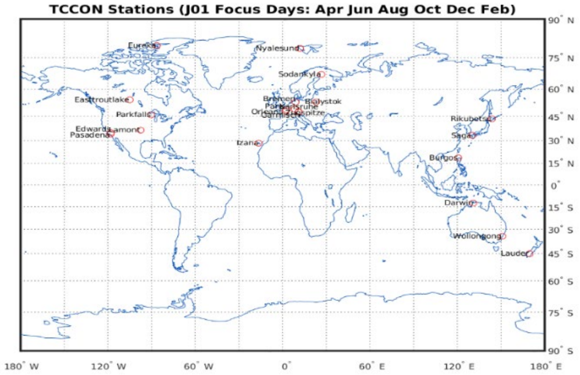
Routine Monitoring Capability for Operational Trace Gas Products

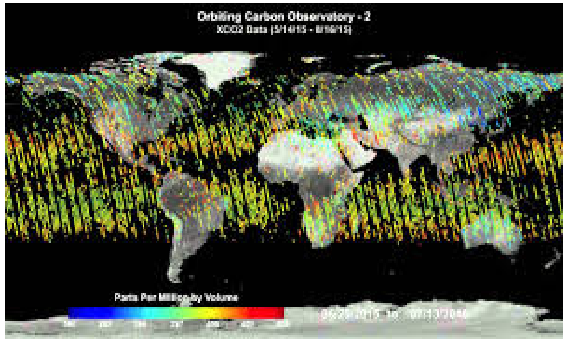
GML Theme 1

- TCCON data
  - Global network of ground-based FTS that accurately measure total column abundances of CO2, CO, CH4, N2O trace gases
  - Station locations are relatively stable, possible to extract tar balls updated from time to time and generate comparisons for routine evaluations
- OCO-2 Data
  - https://disc.gsfc.nasa.gov/datasets?keywords=OCO2&sort=endDate&page=1
  - OCO-2 Level 2 spatially ordered geolocated retrievals. Version 10 is the current version of the data set. V10 Level-1 and Level-2 products are available on a routine basis, sometimes with a latency of 3 days.
  - “Retrospective" run (v10r, they need to do bias correction) and those products are science quality and we have about <2 month lag (similar to MERRA-2 data)

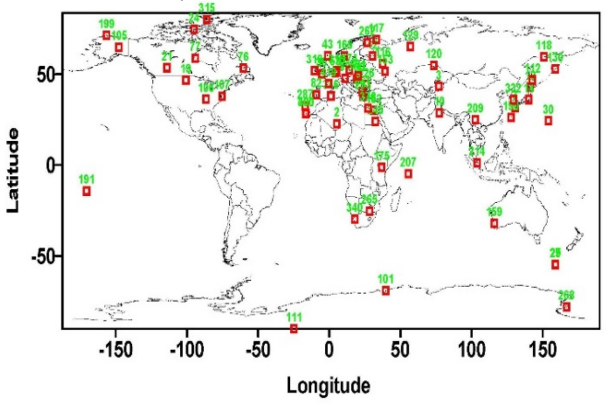
GML Theme 2

- BD/WOUDC - NOAA STAR/GML ozone and water vapor collaborative effort identified the need to get NUCAPS products at the specific O3SND locations
- Some of the BD total ozone may be available from the sites, but the WOUDC data has a lag time.
- https://woudc.org/contact.php



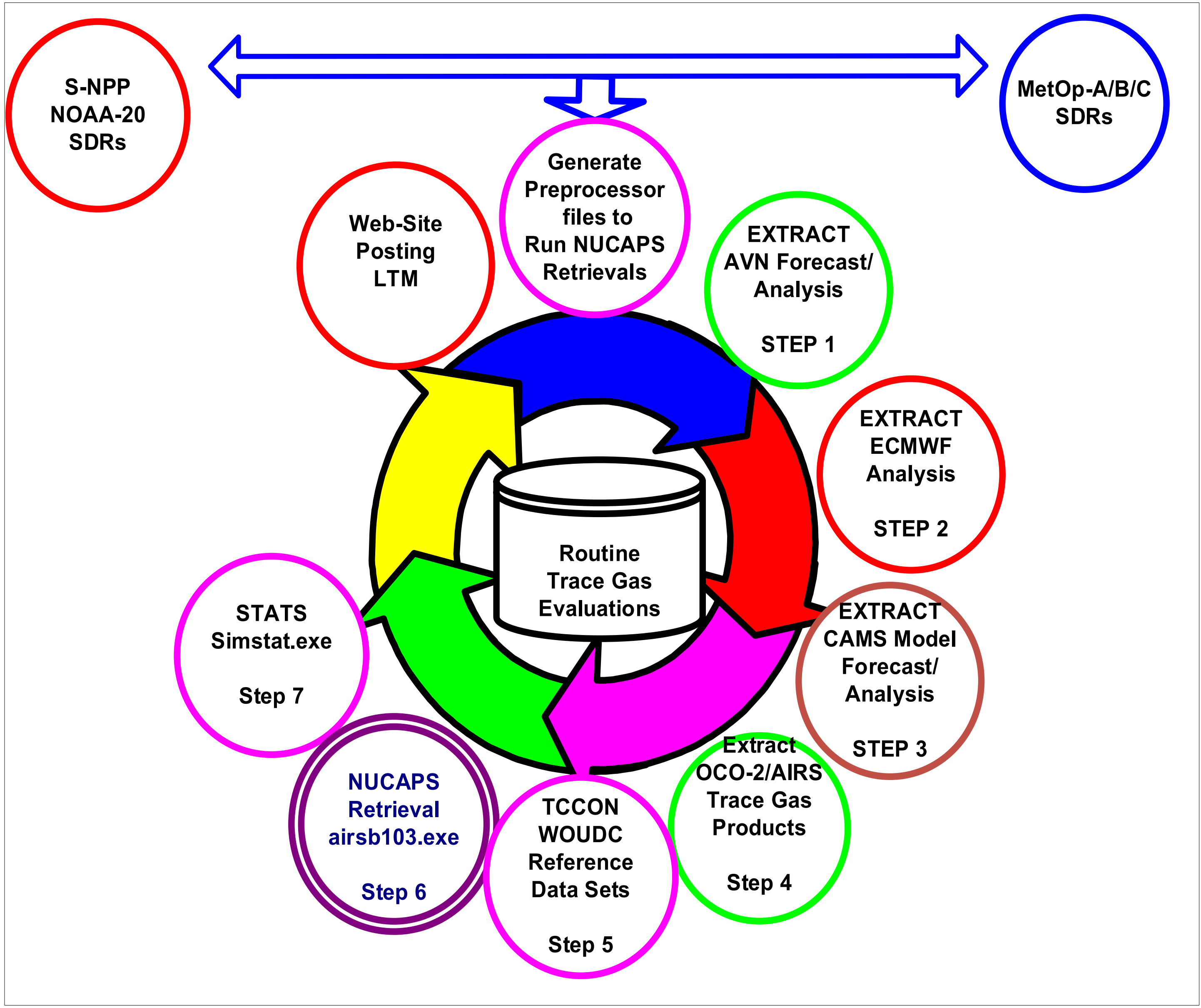


BD/WOUDC Ozone stations



Addressing RFA #3: Plans for Routine Trace Gas Monitoring

- Capability to run and generate individual components for routine monitoring exists
- NUCAPS team need to work on an automated (completely scripted) wrap-up scripts for daily monitoring with additional plots of trends, statistical metrics with other correlative observations.
- Should include automated FTP pull of correlative observations (AIRS, OCO-2, Sentinel) and ancillary data (GFS, CAMS, ECMWF, ..), and ability to extract SDR/EDRs at specific reference data locations.
- Generate NUCAPS products from JPSS and MetOp series on a daily basis using NUCAPS v3.0 until the NDE commissions the latest v3.0 version to operations. (ASSISTT Cluster can also provide this capability)
- Automate Matlab scripts for trace gas product validations
- Generate global maps (ascending/descending), difference maps, trends, and statistical metrics
- Leverage on NOAA LTM and JSTAR Mapper websites for website posting of plots/figures (NUCAPS team held a meeting with the ASSISTT, and the JSTAR/LTM team members (2/1/2021) and discussed plans of action.



Summary

- **Candidate NUCAPS version (V3.0)** is
  - Producing consistent results between SNPP and NOAA-20
  - Did not adversely impacted any NUCAPS products that are of validated maturity. Producing results of equal or better quality than the current operational version
  - Producing results generally meeting JPSS Data Product Specification (DPS) with independent correlative datasets (model outputs, satellite EDRs, OCO-2, in situ reference data TCCON, ATom, etc.)
- Delivered **v3.0** to ASSISST team for cluster integration to produce SNPP/NOAA-20 NUCAPS products
  - Currently verifying pre-operational products generated by the ASSISST cluster runs
- NUCAPS trace gas products are available on the JPSS STAR EDR LTM and JSTAR Mapper websites.
  - https://www.star.nesdis.noaa.gov/jpss/mapper
  - https://www.star.nesdis.noaa.gov/jpss/EDRs/products_Soundings_N20.php
- User feedback is positive
  - Many PGRR Initiatives are using NUCAPS products and found them extremely useful for their applications

Conclusions

- The CO_2 validated maturity review presented on 17 December 2020 provided a comprehensive validation of CO_2 product using a hierarchy of validation datasets
- This presentation provides an additional evaluation of the NUCAPS CO_2 product based on satellite EDR global intercomparisons (Hierarchy Method #2) with the OCO-2
    - The NUCAPS CO_2 product shows good global spatial coherence and consistency with OCO-2
    - The statistical analyses versus OCO-2 complements and corroborates those obtained from the *in situ* reference data presented in the Maturity Review (TCCON, AirCore, and ATom)
- The Team thus recommends NUCAPS algorithm Validated Maturity for the SNPP/NOAA-20 CO_2 Trace Gas EDR

SUPPLEMENTAL SLIDES

Set	List of Supplemental Slides	Slide Numbers
A	Supplemental slides on CO2 product evaluations from December Maturity Review.	36-48
B	Supplemental slides on routine Monitoring of NUCAPS products with other correlative data sets.	49-51

NUCAPS Carbon Trace Gas EDR Reference data, Time Periods

Observation Type	Reference Data	Time Period	Validation	Remarks
Atmospheric Tomography Mission (ATom)	• DC-8 aircraft based *in situ* air samples • Profiles of volume mixing ratios (ppmv) obtained using NOAA/GML Picarro G2401m analyzer	ATom-1,-2: Jul 2016 to Feb 2017 ATom-4: Apr-May 2018	✓ CO_2 meets bias and precision requirements throughout column	ATom (*Wofsy et al.* 2018) acknowledgment • Kathryn McCain, Colm Sweeney (NOAA/GML) • https://doi.org/10.3334/ORNLDAAC/1581
Total Carbon Column Observing Network (TCCON)	• Ground-based network of uplooking spectrometers • Total column DMF retrieved from near-IR solar spectrum	12 Focus Days: 2018-2019	✓ CO_2 meets total column requirements	TCCON (*Wunch et al.* 2010, 2011) acknowledgment • Debra Wunch (CalTech)
AirCore	• Balloon-borne *in situ* profiling system	Launches from 2018-2020	✓ CO_2 meets bias and precision requirements throughout column	AirCore (*Membrive et al.* 2017) acknowledgment • Bianca Baier (NOAA/GML)

CO and CH_4

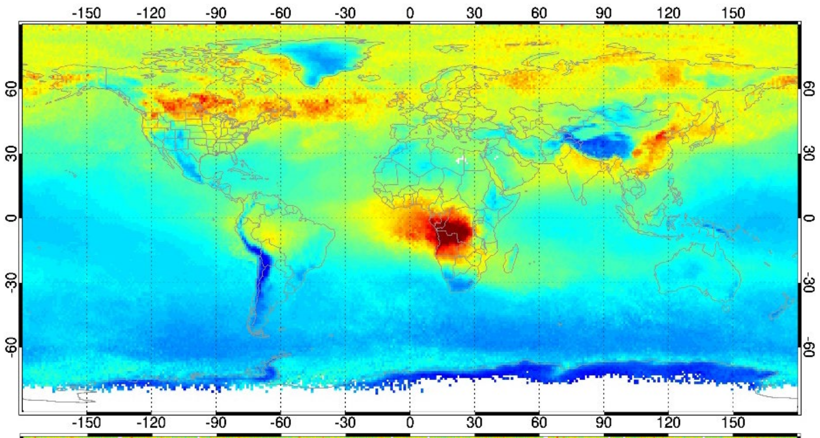
- Update on NUCAPS V3.0 CO and CH_4

CO_2

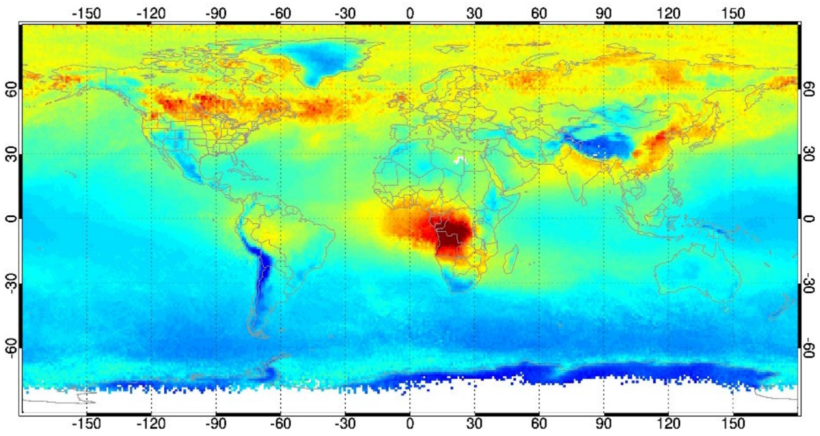
- Findings/Issues from Beta Review
  - Current operational version V2.5.2.2
  - Value ranges, distributions, and trends were incorrect;
- Improvements Beta-Provisional
  - Primarily new a priori
- Algorithm performance evaluation for Validated Maturity
  - Quality assurance
  - Channel examination
  - Expanded truth data sets – ATom 1 – 4
  - Comparing against OCO-2

Comparisons of V3.0 CO Column (x10^{17} mols/cm^2) Aug. 2018

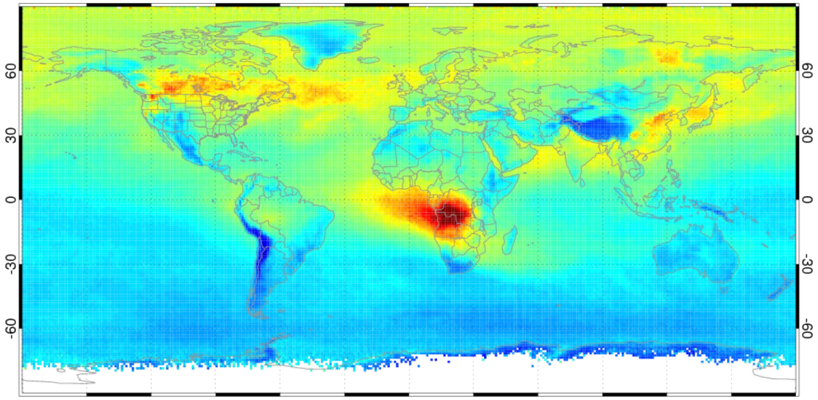
NUCAPS
S-NPP CrIS



NUCAPS
NOAA-20 CrIS

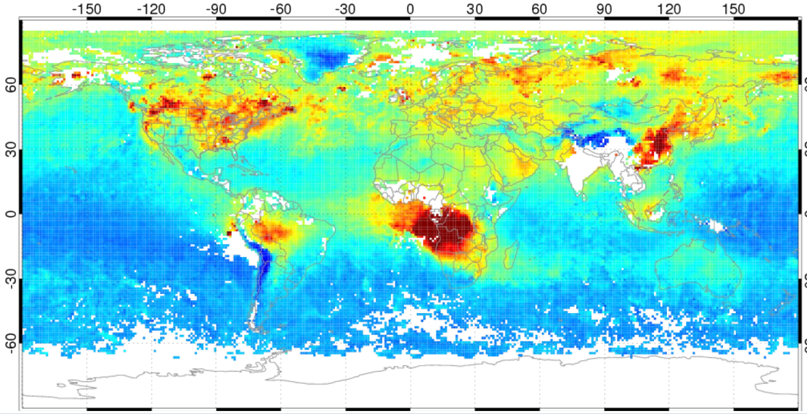


AIRS

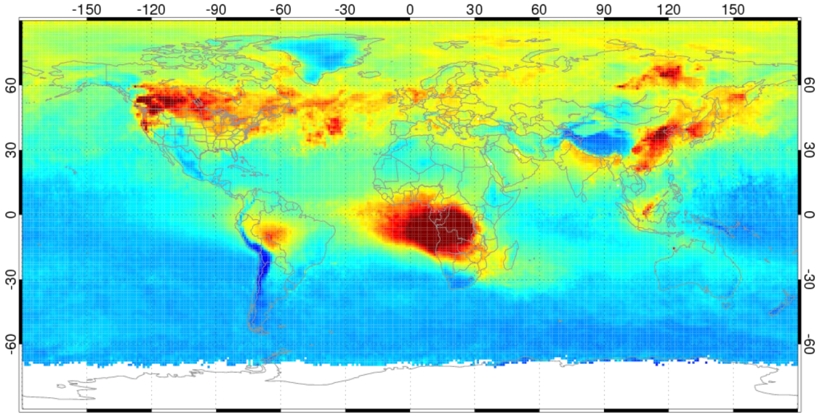


x10^{17} mols/cm^2

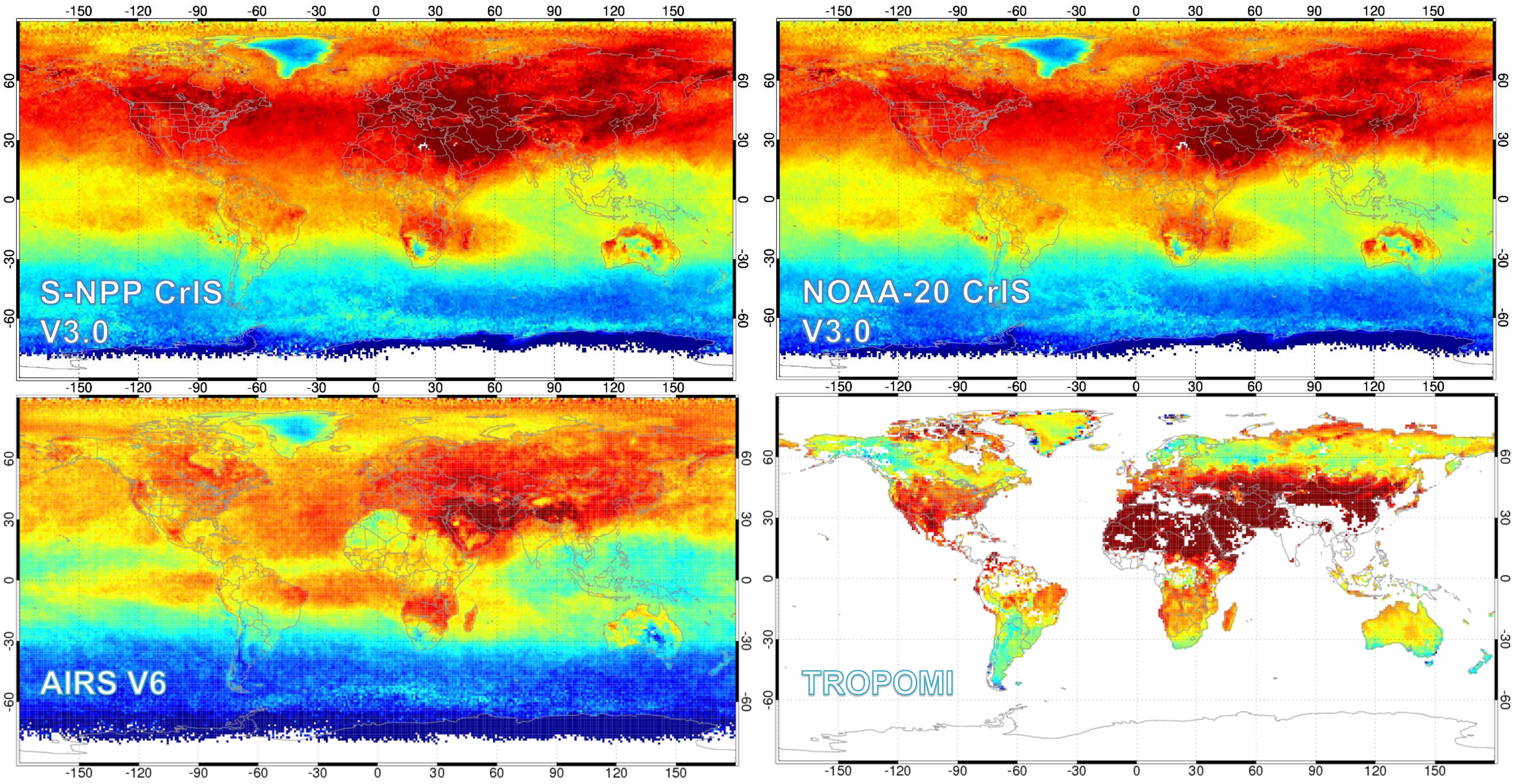
MOPITT



TROPOMI

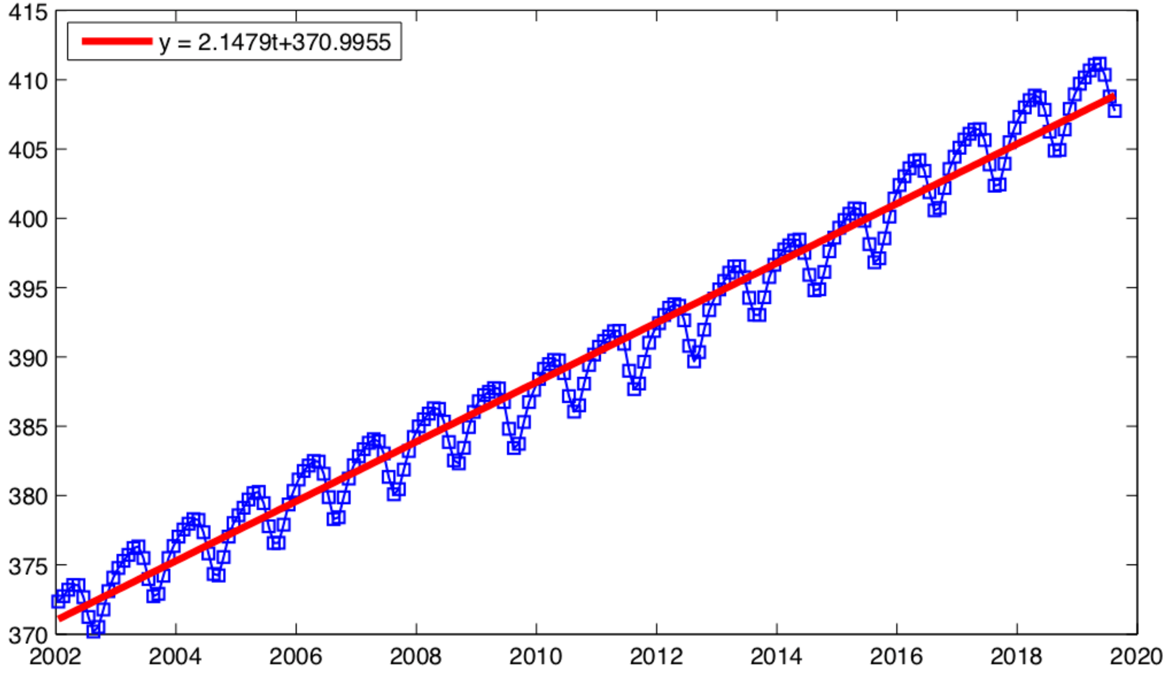


NUCAPS xCH_4 V3.0 Compared to AIRS and TROPOMI Aug. 2018 Monthly Mean



- CrIS CH_4 is slightly higher than AIRS; but agree with TROPOMI mid- and low- latitudes better.

NUCAPS CO_2 Improvements - a priori and Quality Assurance



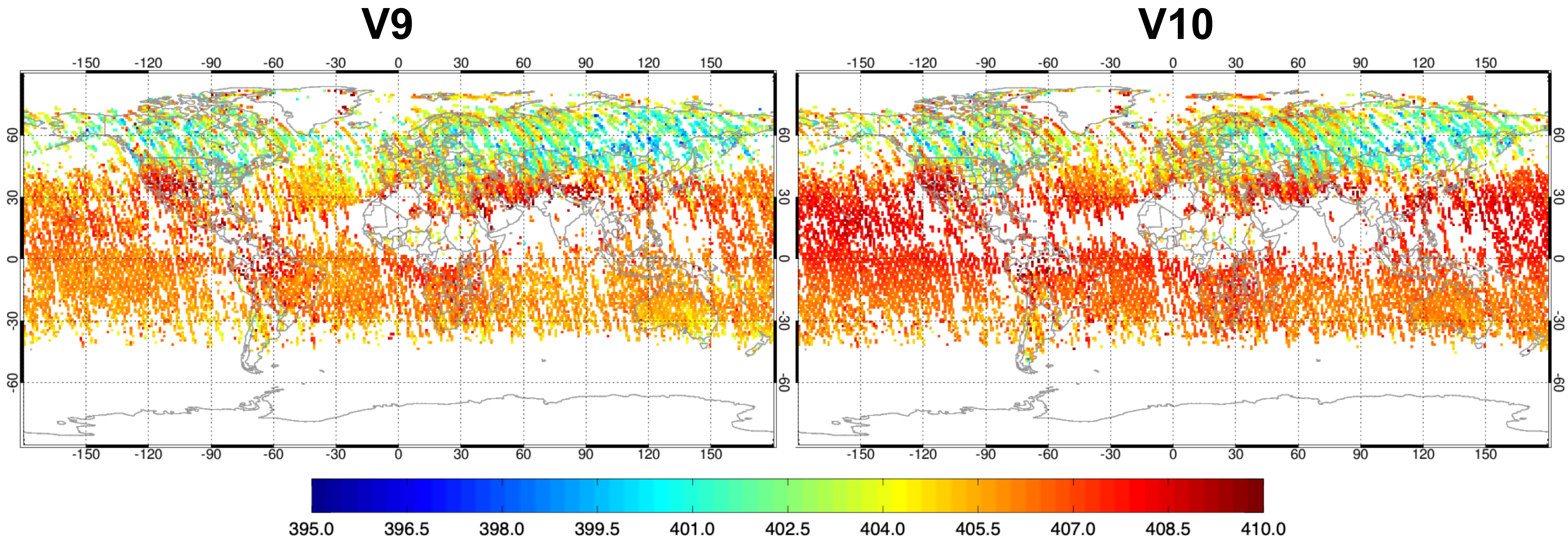
*Linear trend from ESRL surface measurements.

CO_2 a priori Using Carbon Tracker Distributions and NOAA/ESRL Trends

1. Latitudinal variations, and;
2. Seasonality from Carbon Tracker;
3. Linear trend from ESRL surface measurements;
4. Climatology uses anomaly from ESRL data.

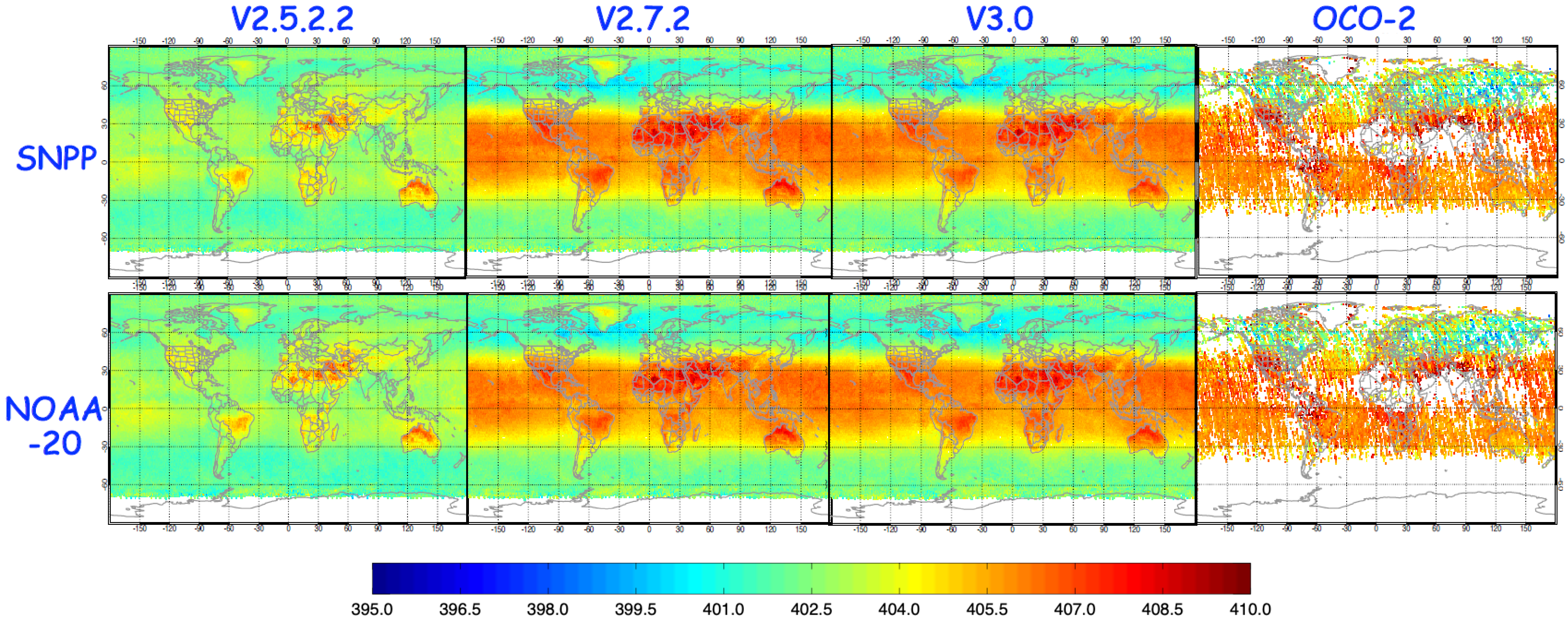
OCO-2 CO_2 to Compare Against

Orbiting Carbon Observatory-2
xCO2 (ppm) for July 2018



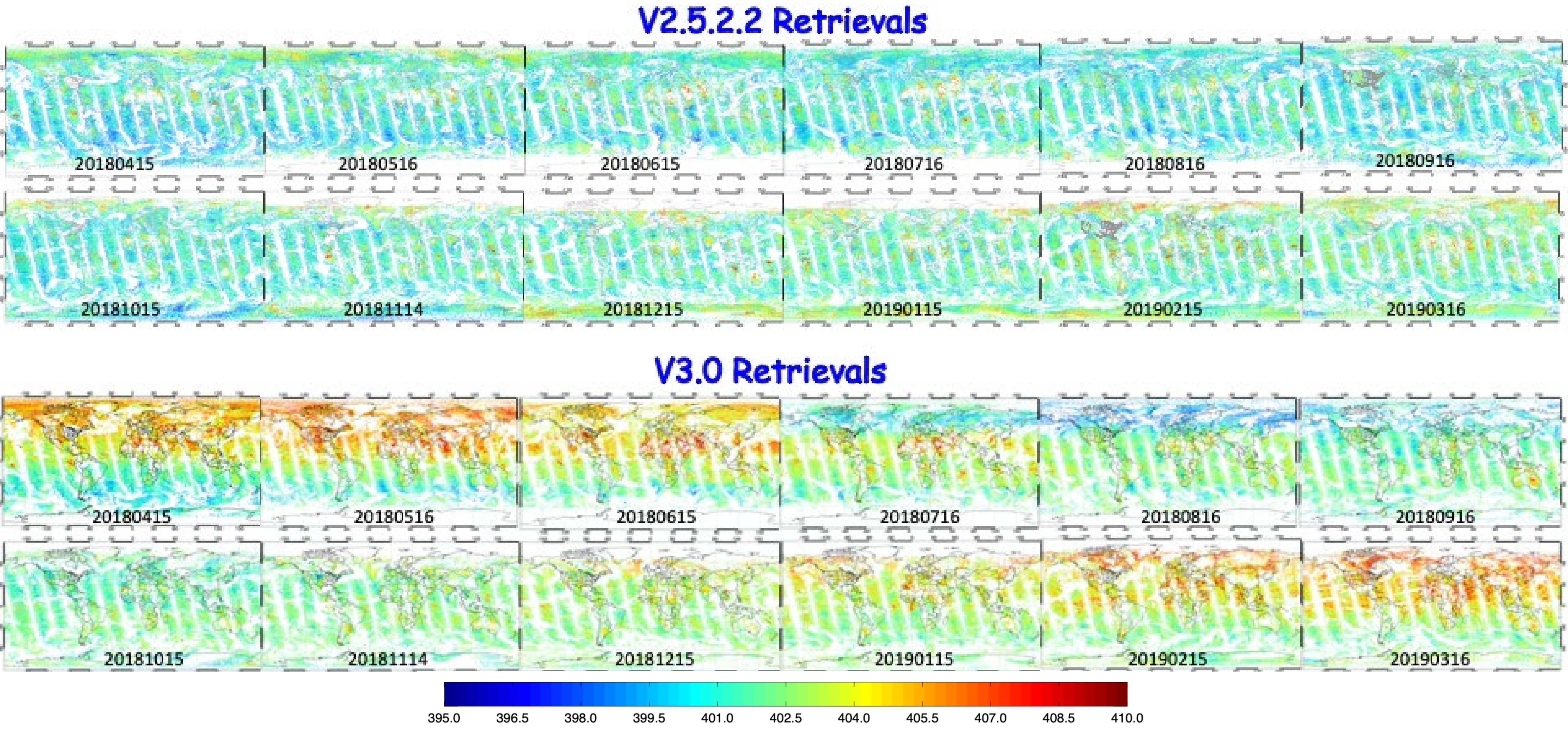
- xCO_2 – column averaged CO_2 mixing ratios
- OCO-2 – A CO_2 satellite mission. We use V9 except for the year of 2020 in the trends, which results in a discontinuity.

NUCAPS xCO_2 Retrievals Comparison with OCO-2 July 2018 Monthly Mean

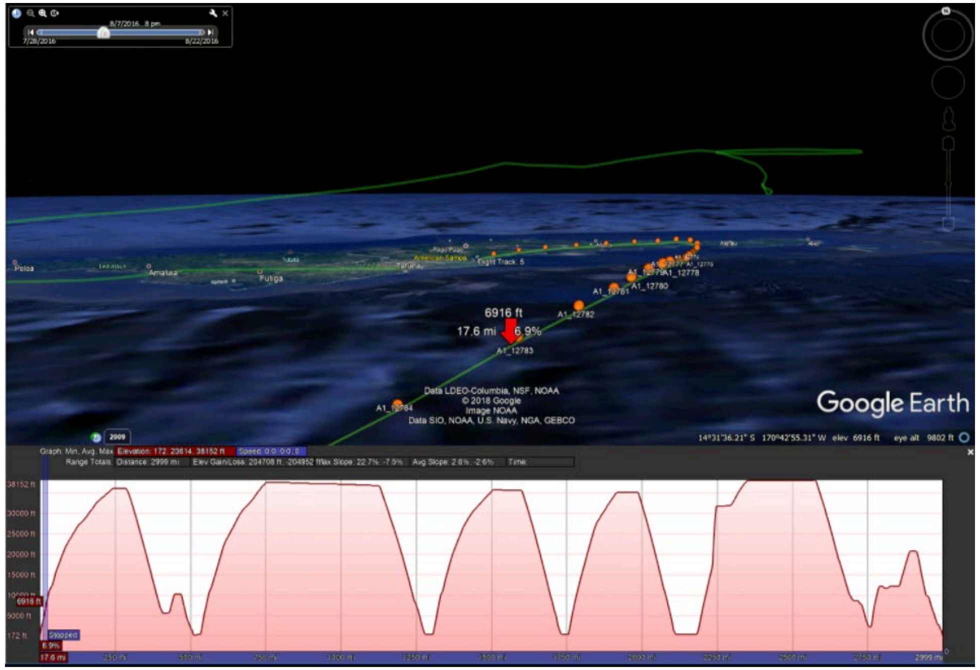


- OCO-2 – A CO_2 satellite mission
- The V3.0 CO_2 agrees much better with the OCO-2 than V2.5.2 did!

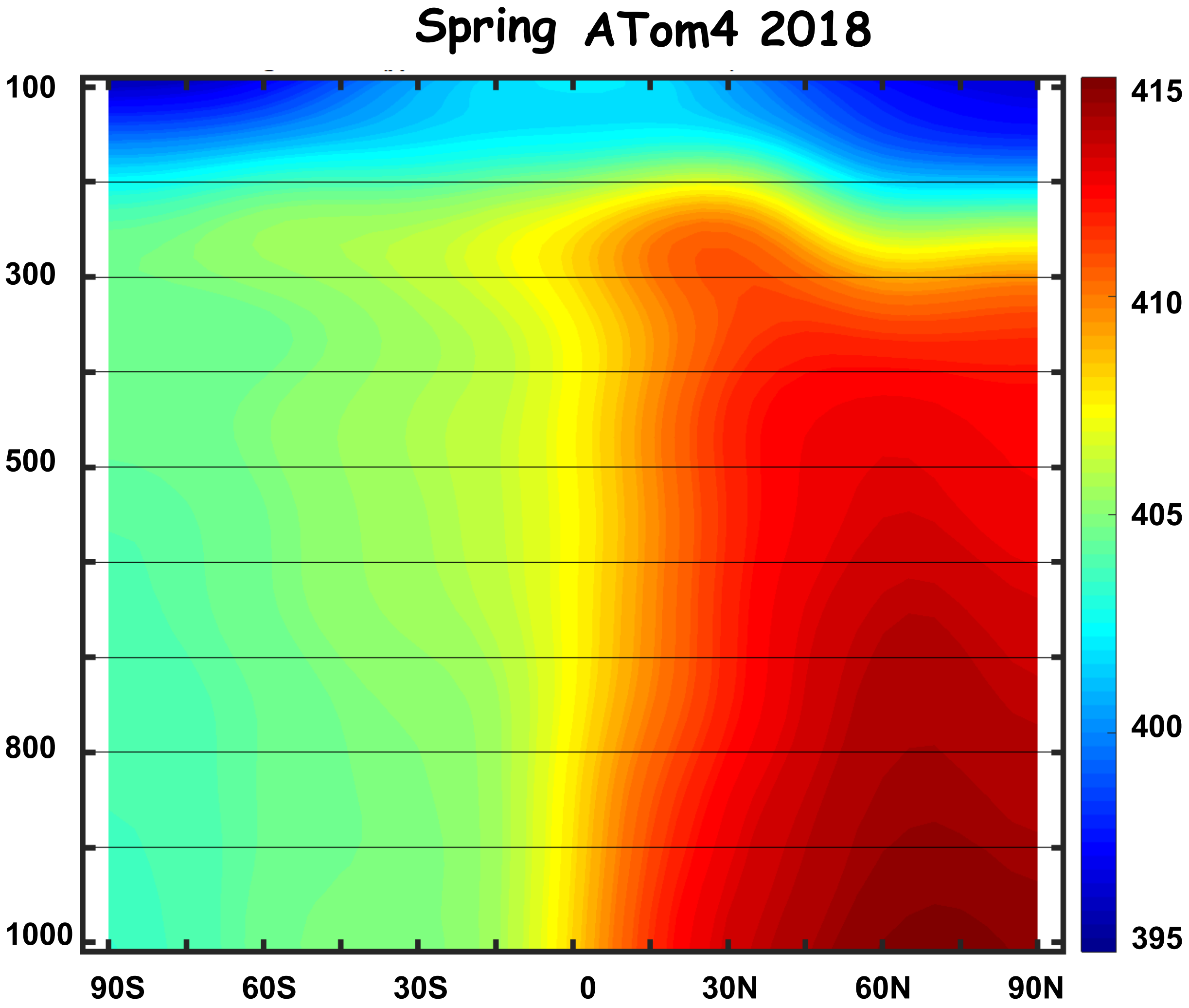
NUCAPS S-NPP CO2 V2.5.2.2 vs V3.0 at 307 hPa 12-Months Seasonality



ATom (Atmospheric Tomography Mission) 1-4 Seasonal Curtains

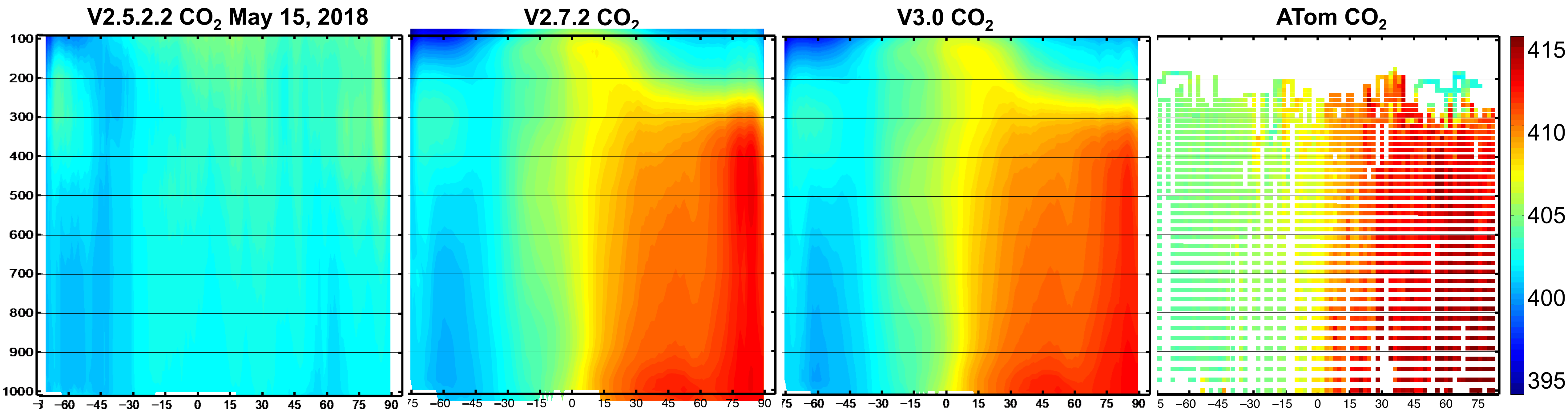


Deployment	Date Range
ATom-1	July 29 - August 23, 2016
ATom-2	January 26 - February 21, 2017
ATom-3	September 28 - October 26, 2017
ATom-4	April 24 - May 21, 2018



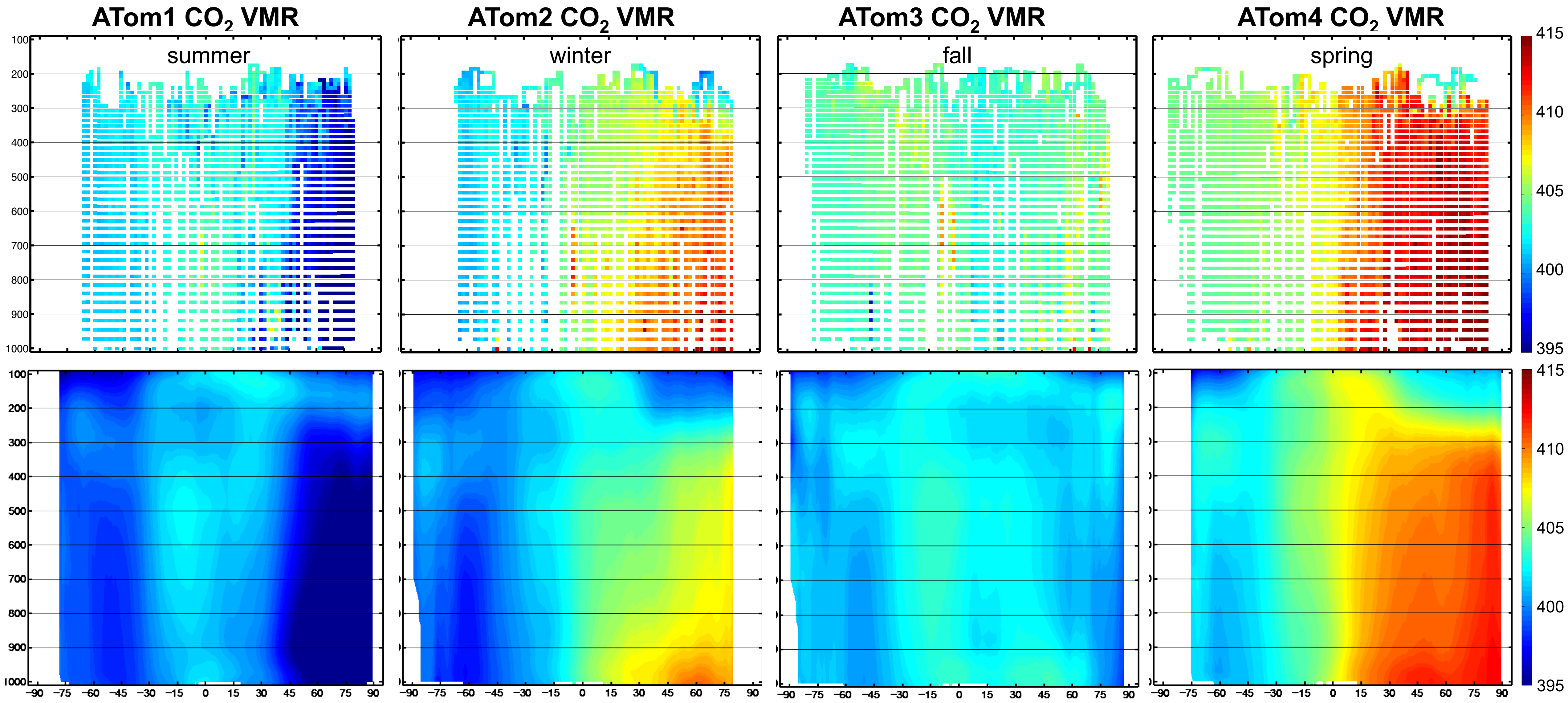
NUCAPS CO_2 VMR (ppbv) V2.5.2.2 vs V2.7.2 vs V3.0 Retrievals Against ATom4

ATom4 Apr. 24 – May 21, 2018



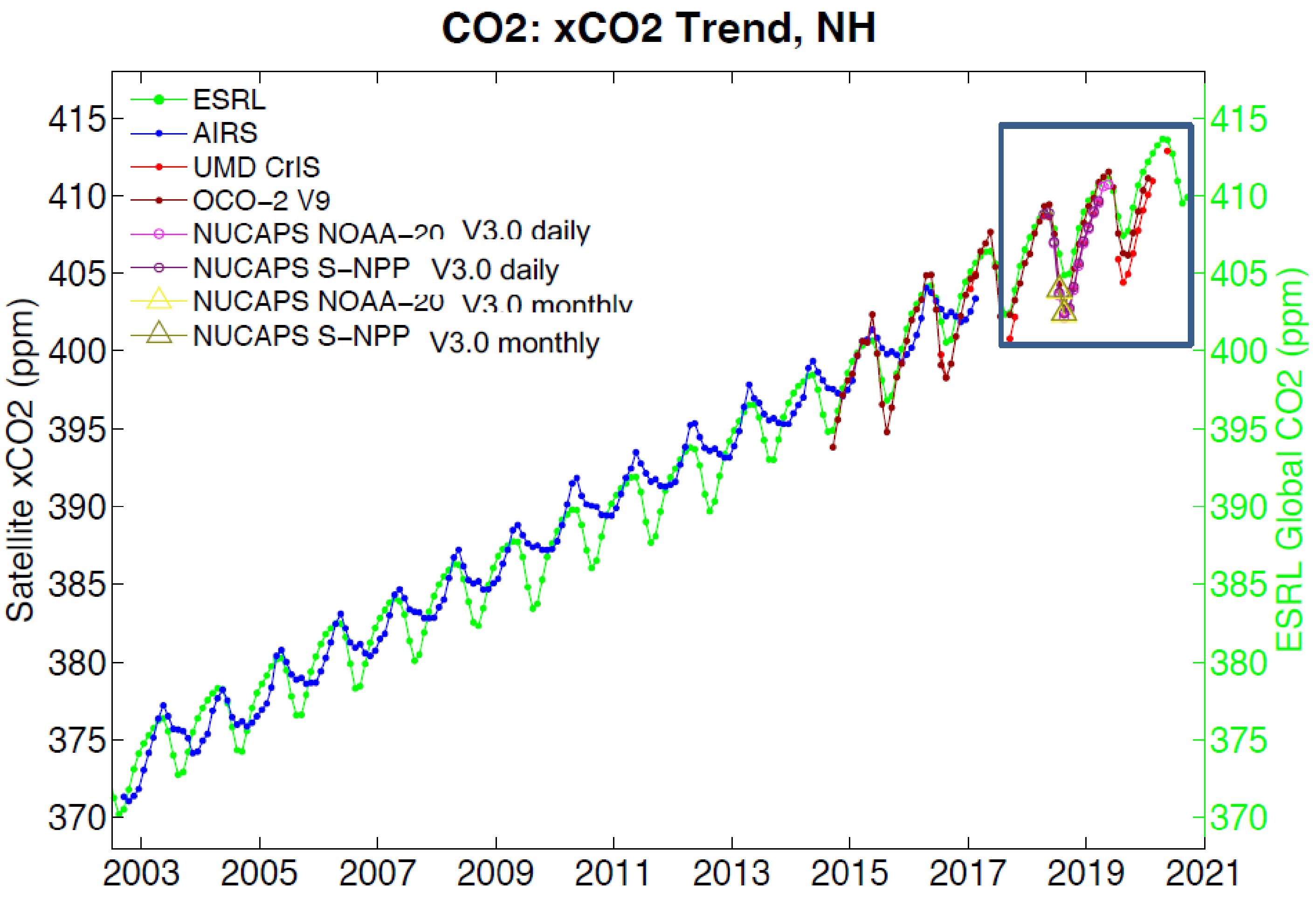
- Note V2.5.2.2 (left) is a single day curtain, while V2.7.2, V3.0 and ATom4 are entire mission period;
- V2.7.2 and V3.0 agrees with in situ measurements significantly better.

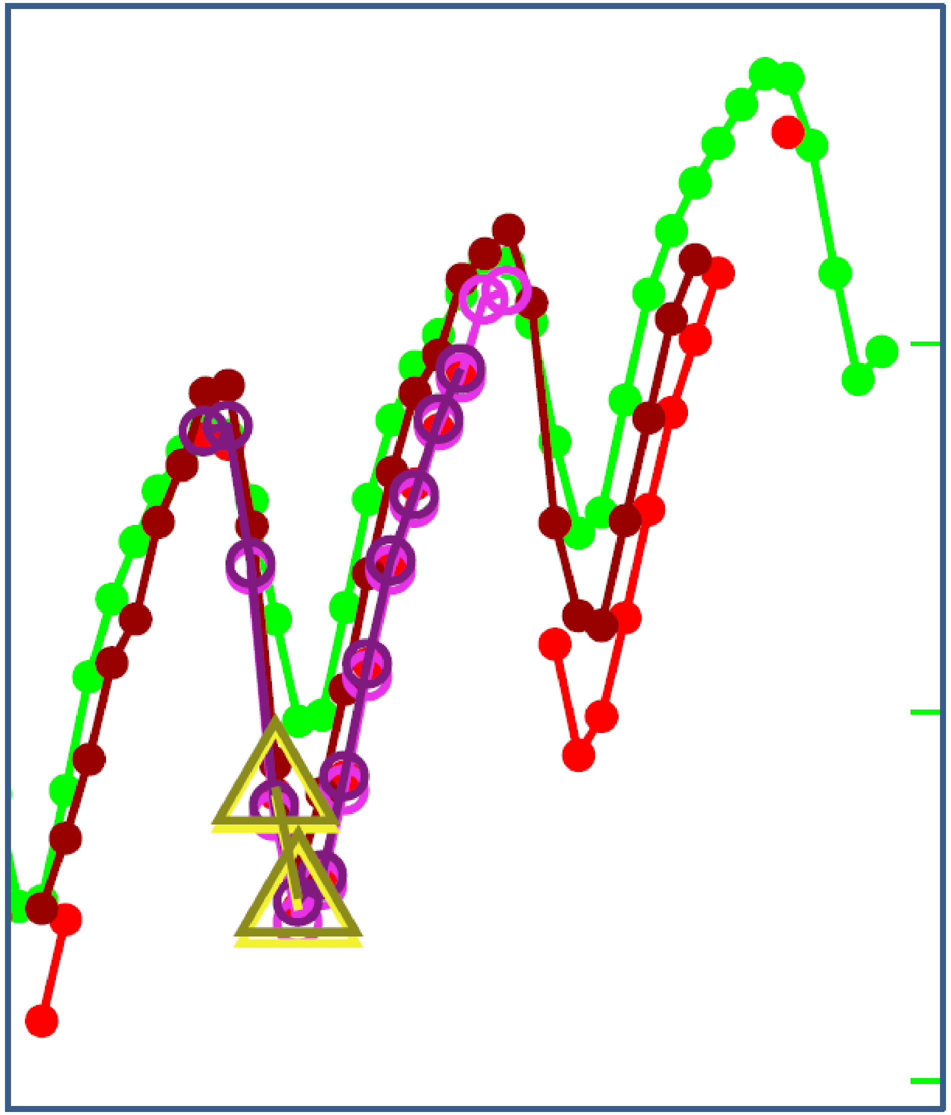
S-NPP CrIS CO_2 V2.9.1 Validate Against ATom1-4 All Sensors



- Main reason for the differences are: ATom are single tracks, primarily over ocean, but CrIS is global zonal mean, with both land and ocean.

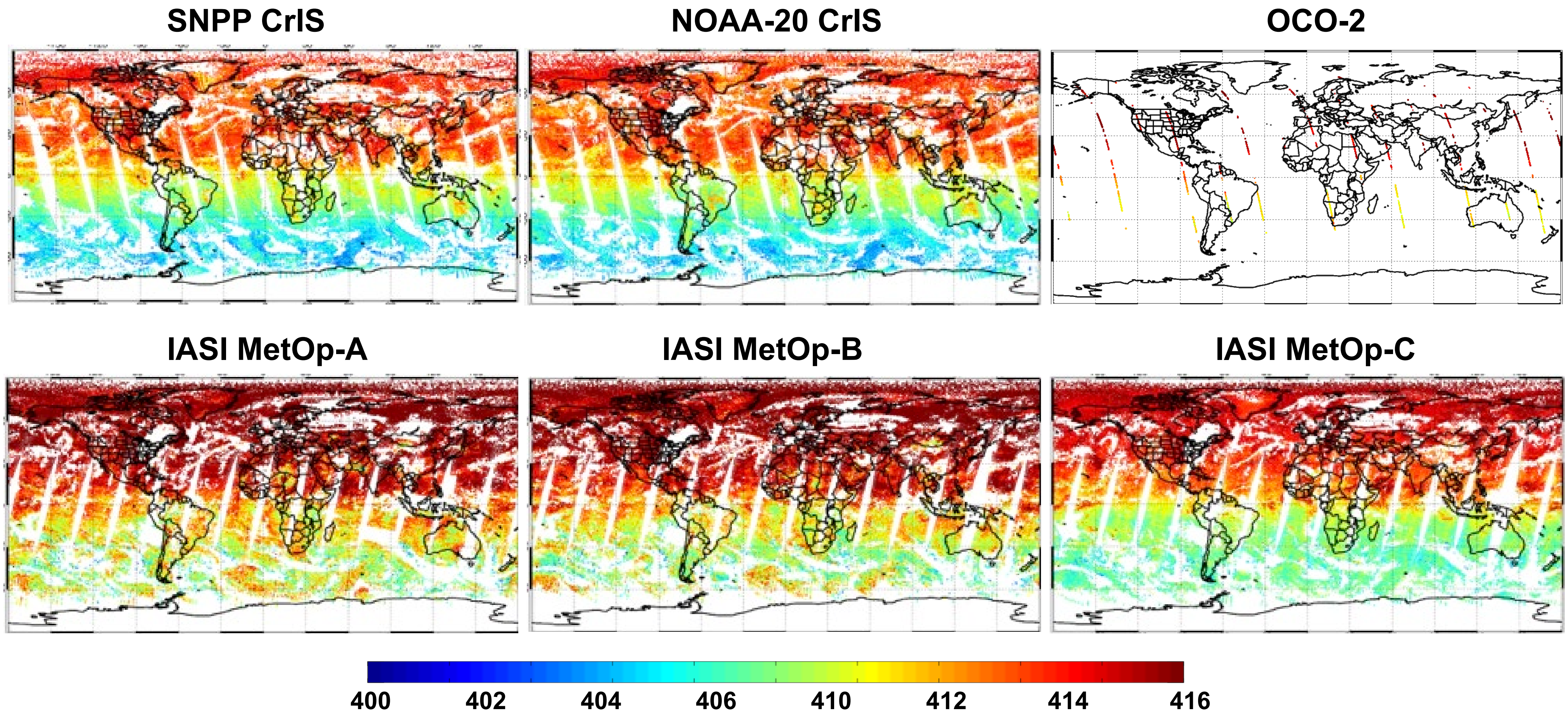
NUCAPS SNPP xCO_2 Trends V3.0 Compared with OCO-2 and AIRS





- NUCAPS CO_2 retrievals agree very well with OCO-2 trends and magnitudes, as well as the trends from ESRL!
- An improvement over AIRS

CO2 (xCO2) Comparison between CrIS (Upper) and IASI (lower)



- All MetOp IASI maps are pre Quality Assurance

Collaborations with GML: Theme 2

Example
Focus Day: 04/30/2020
MetOp–C (MetOp-B/A)

- ✓ IASI, AMSU-A, MHS level-1 Data Sets
- ✓ NUCAPS EDRs for each satellite configuration
- ✓ ECMWF and Copernicus Atmosphere Monitoring Service (CAMS) model data matches for each satellite configuration
- ✓ OLR products

S-NPP/NOAA-20

- ✓ CrIS/ATMS SDRs
- ✓ NUCAPS EDRs for both S-NPP/NOAA-20
- ✓ OMPS NM and NP Products
- ✓ **CLIMCAPS EDRs for JPSS**
- ✓ CAMS model data matches for each satellite configuration
- ✓ OLR Products

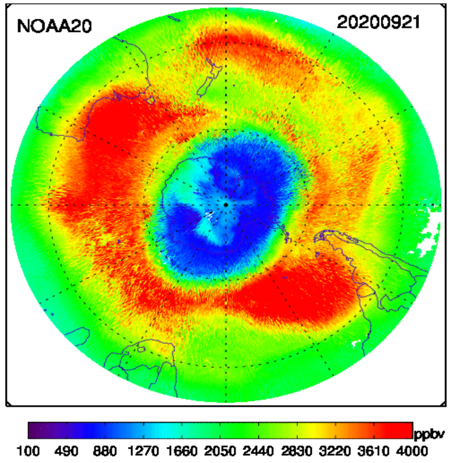
This focus day data set with CLIMCAPS and NUCAPS Averaging Kernels, and OMPS Ozone retrievals are being used for an assessment of NUCAPS, CLIMCAPS, and OMPS O3 retrievals.

Objectives

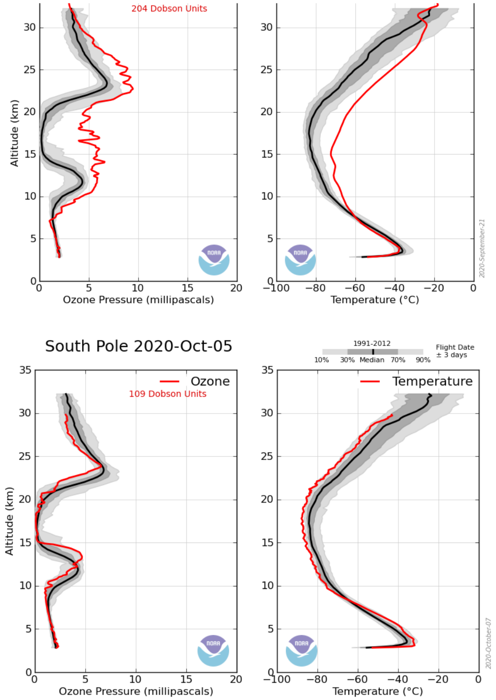
- Focus Day Evaluations through compilation of
  - S-NPP/NOAA-20, MetOp-B/C/A NUCAPS products
  - S-NPP/NOAA-20 OMPS Products
  - NUCAPS IR Ozone with OMPS 21 layer Ozone product;
  - NUCAPS vs. CLIMCAPS Products
  - Collocations of O3SND data sets with NUCAPS/OMPS data sets for inter-comparison and validation of NUCAPS, OMPS, and CLIMCAPS products
  - Alleviate S-NPP/NOAA-20 OMPS product differences
  - Ability to provide NUAPS products over reference dataset locations
    - NPROVS Provides T(p), q(p) routine validations
    - The attempt here is to do for trace gases

Collaborations with GML: Theme 2 (Ozone and Water Vapor)

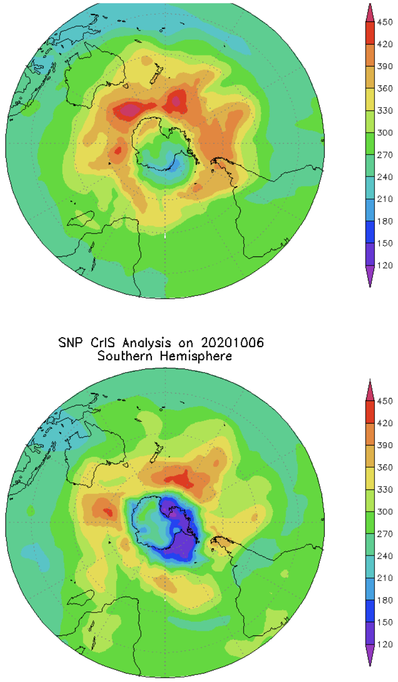
- Continued working with the GML collaborators on the NUCAPS and OMPS ozone products evaluations.
- Participation in NASA/NOAA Ozone hole discussions and collocations of O3SND and NUCAPS ozone products to study the progression and cover up ozone hole.
- Ozone Hole Research – O3SND launches vs. NUCAPS Ozone products
- Collocations of O3SND data sets with NUCAPS/OMPS data sets for inter-comparison of NUCAPS and CLIMCAPS products



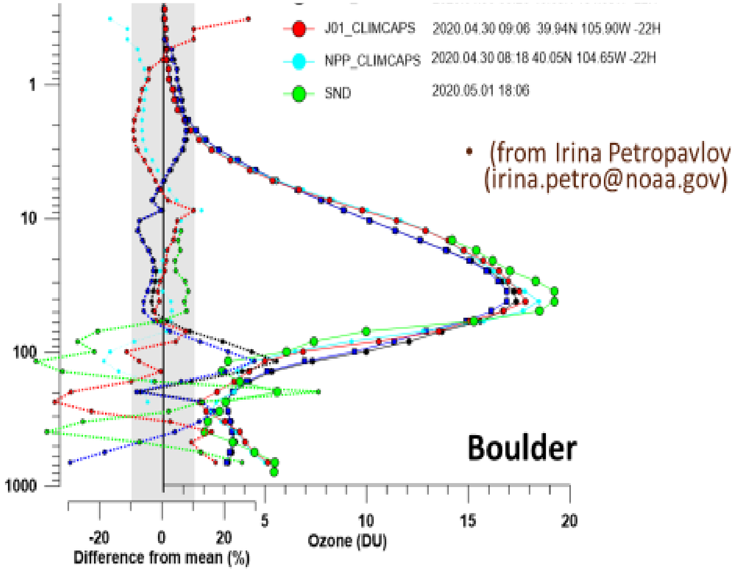
NUCAPS Ozone Product: Depiction of Ozone hole



NOAA/GML O3SNDs



OMPS Team TOAST Product

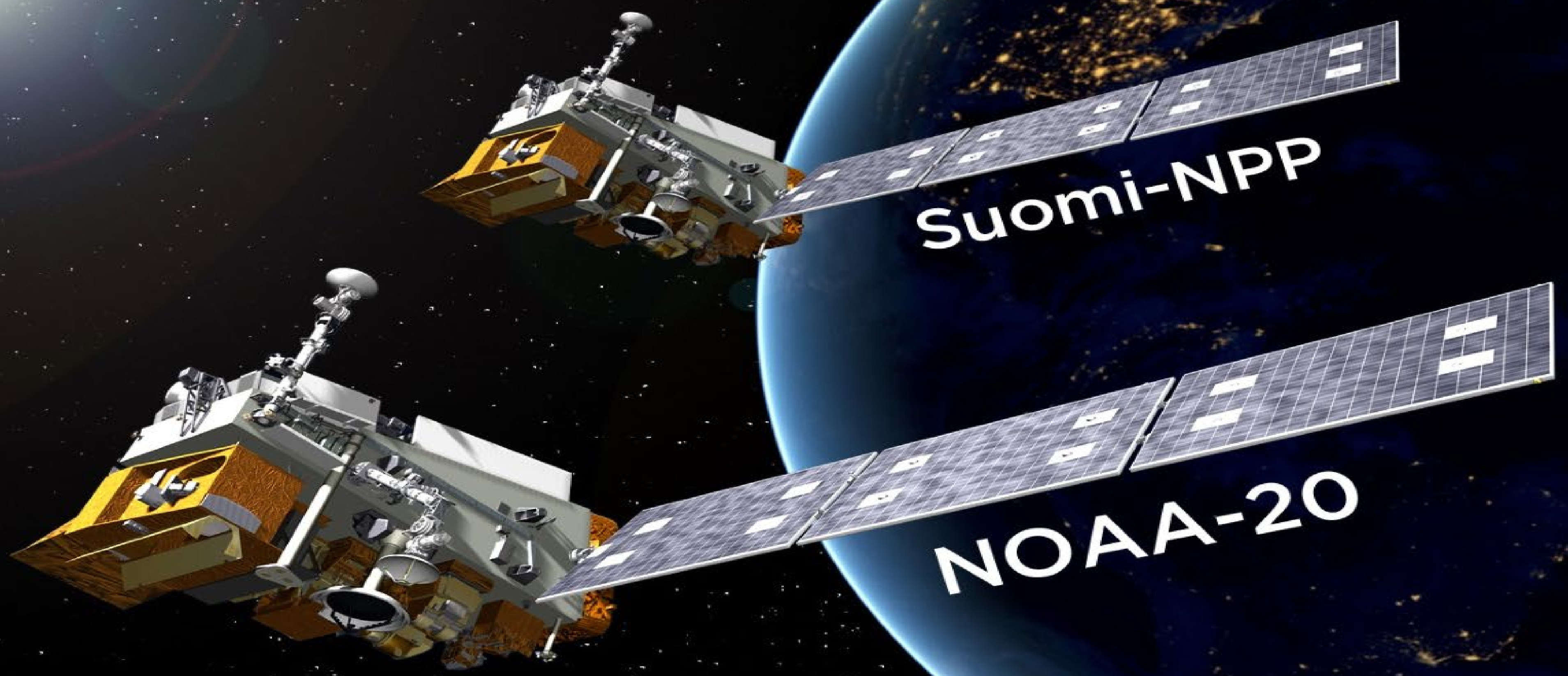


Preliminary evaluation of NUCAPS and CLIMCAPS products O3SND Measurements

Combining Efforts from NUCAPS team with JPSS Mapper/LTM and ASSISTT

- How can we bring these items together – using available resources (ASSISTT, JSTAR LTM/Mapper, currently available scripts) to tailor a routine monitoring system?
  - NUCAPS Algorithm produces AVTP, AVMP, O3, CO, CH4, CO2, and many other product from JPSS (S-NPP and NOAA-20) and MetOp series (MetOp-A/B/C). Retrieved products span from surface to 0.01mb (100 layers) .
    - JPSS Mapper and LTM websites provide NUCAPS products from S-NPP/NOAA-20
  - NUCAPS team(s) have scripts maintained by individuals to collocate various data sets (pre-processor for SDRs), EDRs, model data sets, statistics generation, etc. How these can be automated? NUCAPS team can provide these plots on a routine basis.
  - Adding additional data sets routinely (e.g. model ECMWF, CAMS, other satellite data sets) for inter-comparison, statistical analysis, and science applications. These are currently generated for ‘focus days’.
  - Discussed with JSTAR Mapper/LTM team and ASSISTT team members on routine processing, and website posting of statistical plots (inter-comparisons,

Validated Maturity Science Review
For NOAA-20 NUCAPS Algorithm



NOAA-20 & S-NPP CO2 EDR Validated Maturity
Presented by NUCAPS Team
Date: 2020/12/17

JPSS NOAA NASA

NUCAPS MATURITY REVIEW
CO2 EDR VALIDATED MATURITY REVIEW
DECEMBER 17, 2020
9:30 – 11:00 EDT

Validated Maturity:

NOAA-20 & S-NPP NUCAPS CO2 Product

Section	Outline for Maturity Review Presentation	Time
1	**Management updates** • Algorithm Team Members	**5 minutes (9:35 – 9:40)** • Presented Ken Pryor
2	**NUCAPS System, Candidate Version, Product Consistency, Requirements, Documentation.** • Maturity Definitions • Processing Environment, Entrance and Exit Criteria • Algorithm Versions; NUCAPS Candidate Version: Improvements from Operational Version • Address RFA from April 2020 Maturity Review; Product consistency • Requirements, Documentation (Science Maturity Check List) • Algorithm Performance to Specification Requirements. • **Supplemental slides on product consistency - at end of presentation**	**20 minutes (9:40 – 10:00)** • Presented by Murty Divakarla
3	**NUCAPS Trace Gas Product Evaluations** • *A priori*, Quality Assurance, and Evaluation with other correlative data sets (AIRS, TROPOMI, OCO) • Product consistency of trace gas products • CO2 validation and statistical metrics with Truth Data (TCCON, AirCore, ATOM, time series) • **Validation Results (supplemental slides at end of presentation)**	40 minutes (10:00 – 10:40) Presented by • Juying Warner • Nick Nalli
4	• **User Feedback** • **NUCAPS Trace Gas Products in Environmental Monitoring - mainly for CO2** • **Risks, Actions, and Mitigations** • **Conclusions** • **Path Forward**	**20 minutes (10:40 – 11:00)** • Presented by Ken Pryor
5	**Supplemental Slides** • Product consistency and validation plots not presented in the review • NUCAPS Team collaborations with external agencies for Risk Mitigation	

Algorithm Team Members

Name	Organization	Major Task
Satya Kalluri, Ken Pryor, Walter Wolf, and Alisa Young	NOAA/NESDIS/STAR	Lead budget/schedule planning/coordination. Provide government oversight for soundings cal/val activities, documentations, deliveries
Murty Divakarla	IMSG at NOAA/NESDIS/STAR	NUCAPS Science/Technical lead
Nick Nalli	IMSG at NOAA/NESDIS/STAR	NUCAPS Validation lead
Changyi Tan	IMSG at NOAA/NESDIS/STAR	Algorithm development, integration, and maintenance
Mike Wilson, Tish Soulliard	IMSG at NOAA/NESDIS/STAR	STAR-ASSISTT POC for Unified NUCAPS package optimization
Tianyuan Wang	IMSG at NOAA/NESDIS/STAR	Algorithm development and maintenance
Tong Zhu	IMSG at NOAA/NESDIS/STAR	Algorithm development and maintenance
Juying Warner	Univ. of Maryland College Park	Trace Gases algorithm(s) development
Chris Barnet, Nadia Smith, Rebekah Esmaili	STC	Algorithm development, CAMEL emissivity, user feedback via PGRR initiatives
Tony Reale, Bomin Sun, Mike Pettey, Charlie Brown	STAR, IMSG at STAR	NUCAPS vs. Global RAOB Validations
Larrabee Strow	UMBC	IR SARTA model development and maintenance
Lori Borg	Univ. of Wisconsin	ARM Site RAOBs dedicated launches
Robert Knuteson	Univ. of Wisconsin	Surface Emissivity collaborator
Xu Liu	NASA/LaRC	NUCAPS product assessment, single CrIS FOV retrieval development
A.K. Sharma	NOAA/OSPO	Product Area Lead (PAL)

MATURITY REVIEW MATERIAL – SECTION 2

NUCAPS System, Candidate Version, Product Consistency, Requirements, and Documentation
Presented by Murty Divakarla

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.

NUCAPS Operational Products and Current Maturity Status

NUCAPS Products	
Cloud Cleared Radiances	
Atmospheric Vertical Temperature Profile (AVTP)	In AWIPS
Atmospheric Vertical Moisture Profile (AVMP)	In AWIPS
Cloud Fraction and Top Pressure	In AWIPS
Ozone	
CO	
CH_4	
CO_2	
Volcanic SO_2	Experimental Viable Products
HNO_3	Experimental Viable Products
N_2O	Experimental Viable Products
NH3	Experimental Viable Products
Isoprene	Experimental Viable Products
PAN	Experimental Viable Products

Data Product	Priority	Current Maturity Status	
		S-NPP	NOAA-20
AVTP/AVMP	3	✓ Validated	✓ Validated
Ozone (p)	3	✓ Validated	✓ Validated
OLR	3	✓ Validated	✓ Validated
CO (p)	4	✓ Validated	✓ Validated
CH4 (p)	4	✓ Validated	✓ Validated
CO2 (p)	4	• Provisional	• Provisional

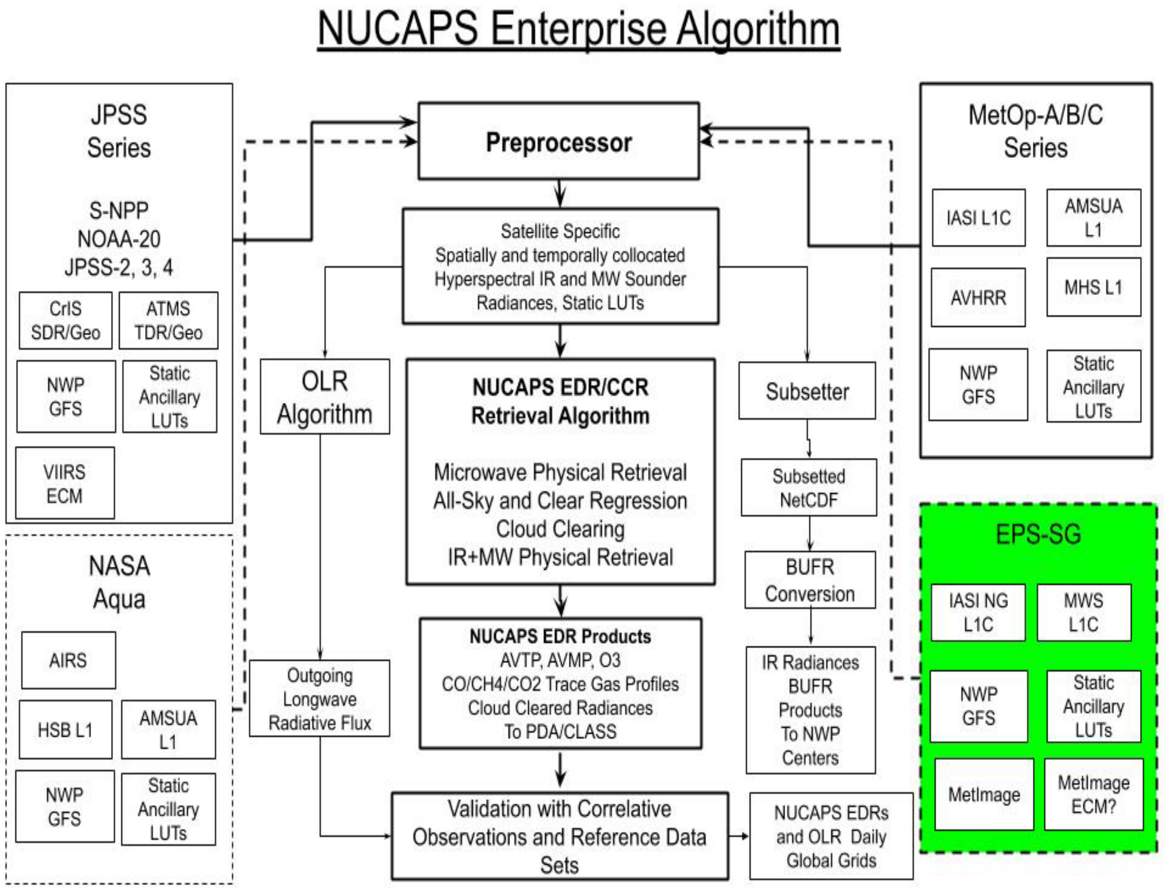
S-NPP/NOAA-20 Validated Maturity Review
https://www.star.nesdis.noaa.gov/jpss/AlgorithmMaturity.php

Validated Maturity CO2 (S-NPP & NOAA-20)	Dec-20	FY21

- Processing Environment, validation of NUCAPS products at STAR:
  - Linux servers running f90, IDL, bash, C/C++, libraries (hdf5 and netCDF4)
  - Product validation using a hierarchy of validation data sets
  - Once operationalized, NUCAPS products available through STAR SCDR are used as part of regular evaluation. The JSTAR Mapper and JSTAR LTM websites provide visualization of the products produced.
  - We also leverage NPROVS system for NUCAPS operational product evaluations

NUCAPS in HEAP High-level Flow Diagram

NUCAPS runs within the Hyper-Spectral Enterprise Algorithm Package (HEAP) and operationally produces AVTP, AVMP, O3, CO, CH4 and CO2 products from JPSS S-NPP/NOAA-20 CrIS and MetOp-A/B/C IASI Hyperspectral Infrared sounding instruments.



The HEAP provides the pre and post-processing capability for The NUCAPS retrieved products and generates

1) NUCAPS products
2) Principal Components
3) OLR
4) Thinned radiance preparation
5) Daily grid generation
6) BUFR product file containing CrIS FSR (2211 channels) and IASI (8461 channels), collocated VIIRS cloud height and cloud fraction, thinned radiances CrIS FSR: 431 channel radiances; IASI: 616 channel radiances; CrIS collocated VIIRS cloud height and cloud fraction.
7) PC reconstruction scores for OSPO product monitoring/quality control tool.

Satellite	Instrument
JPSS (S-NPP, NOAA-20, J2,J3)	CrIS/ATMS (currently S-NPP/NOAA-20)
MetOp-A, B, C	IASI/AMSU-A/MHS (total 3 currently)
EPS-SG Augmentation	IASI-NG/MWS
Total data volume	2x 49GB/day (JPSS) + 3x 67GB/day (MetOp)

Algorithm updates, sensor independent LUTs, QC/QA are all updated for MetOp-C/B/A using the latest baseline version of S-NPP/NOAA-20

Entrance and Exit Criteria

Entrance Criteria

- Upstream algorithms: None
- pre-launch concerns, waivers, and mitigations: None.
- Evaluation of the effect of required algorithm inputs
  - Input static LUTs are all verified.
  - Dynamic inputs are ATMS TDR/CrIS SDR/GEO data.
- Except CO2 EDR, all other S-NPP/NOAA-20 NUCAPS products have reached validated maturity
- Current status of product maturity:

Data Product	Priority	Current Maturity Status S-NPP/NOAA-20	Maturity Review
AVTP/AVMP	3	✓ Validated	✓ October 2019
Ozone (p)	3	✓ Validated	✓ October 2019
OLR	3	✓ Validated	✓ October 2019
CO (p)	4	✓ Validated	✓ October 2019
CH4 (p)	4	✓ Validated	✓ April 2020
CO2 (p)	4	• Provisional	• April 2020

https://www.star.nesdis.noaa.gov/jpss/AlgorithmMaturity.php

Validated Maturity CO2 (S-NPP & NOAA-20)	Dec-20	FY21

Exit Criteria

- Aiming for CO2 validated maturity
- Show qualitatively and quantitatively that the candidate version v3.0 produces products that are equal or better than the operational version
- S-NPP and NOAA-20 retrieval products are consistent
- T/H2O/O3/CO/CH4 have not suffered any degradation
- CO2 (CO and CH4) retrievals improve the a priori in the layers of sensitivity, and meets the requirements
- Demonstrate **enterprise** nature of the algorithm with product consistency between JPSS and MetOp series
- Provide updated Validated Maturity Slide Package addressing review committee's comments for
  - Addressing RFAs
  - Product Requirements
  - Product Consistency
  - Validated Maturity Performance
  - Risks, Actions, Mitigations
  - Path forward

NUCAPS Retrieval Algorithm Deliveries to OPS

Internal Version	OPS Phase	Approximate Delivery / Start Time	Comments
NUCAPS V1.0	Phase 2	• Delivered December 3, 2012. • Became Operational in October 2013	• Designed for only S-NPP nominal spectral resolution.
NUCAPS V1.5	Phase 3	• Delivered May 12, 2015. • Became Operational in October 2015.	• Maturity update for S-NPP AVTP/AVMP • Converted to GNU compilers.
NUCAPS V2.0.5.4	Phase 4	• Delivered July 20, 2017. • Part 1 Operational: Sept. 13, 2017. • Part II Operational on May 03, 2018.	• Updated to CrIS Full Spectral resolution. • (NUCAPS v1r0 became v2r0 in NOAA CLASS) • Can run NOAA-20 using S-NPP Namelists. • Included updates to several LUTs and Namelists (channel selection, tuning, regression, trace gas climatology, etc.).
NUCAPS V2.1.12d	V4.3	• Delivered August 15, 2018. • NOAA-20 became Operational on March 7, 2019.	• Trace gas updates (CO retrieval, tuning in N_2O region); Added new LUTs to differentiate S-NPP/NOAA-20 (e.g. instrument noise)
NUCAPS V2.5.2.2	HEAP 2.1	• Delivered October 29, 2019 • Became Operational, June 2020	• Trace gas updates (CO, CH4, QC) • NOAA-20 specific LUTs.
NUCAPS V2.7.2	HEAP 2.2	• Delivered to ASSISTT – April 16, 2020 • NDE DEV and I&T OPS	• Maturity Review (April 23, 2020) • CH4 Validated, CO2 Provisional
NUCAPS V3.0	HEAP 2.3	• Delivery to ASSISTT – December 21, 2020 • ASSISTT Next Deliver to NDE: Jan 2021	• CO2 Validated Maturity Review (Dec. 17, 2020) • All products reached validated maturity

Primary changes in Realizing NUCAPS Candidate Version 3.0

Item	V2.5.2.2 (October 2019) – HEAP 2.1		V2.7.2 (April 2020) HEAP 2.2	V3.0 (December 2020) HEAP 2.3
	S-NPP	NOAA-20	S-NPP/NOAA-20	
MW A-priori	✓ Zonal monthly climatology composed of NCEP and UARS Upper Tropo/Stratosphere measurements. (V2.1.12d)	✓ Zonal monthly climatology composed of NCEP and UARS Upper Tropo/Stratosphere measurements.(V2.1.12d)	✓ MiRS Climatology as A-priori. One year of ECMWF (2012), T(p), WV(p) ✓ Evenly spaced 5 days/month averaged to represent monthly average; Lat /Lon by 5 degrees);0, 6, 12, and 18 UTC.	✓ No changes – as is for S-NPP/NOAA-20
MW Tuning	✓ **Two focus days (20190215, 20190815) and SNPP radiances, and MIT forward model.**	✓ Two focus days (20190215, 20190815) NOAA-20 radiances and MIT forward model.	✓ No change – as is for S-NPP/NOAA-20	✓ No change – as is for S-NPP/NOAA-20
Cloudy Regression	✓ NO Change from the operational Version (V2.1.12d)	✓ PC regression using NOAA-20 all-sky radiances matched with ECMWF ✓ Used four Focus Days	✓ No change – as is for S-NPP/NOAA-20 ✓ Updated with Chris' regression code, statistically same	✓ No change – as is for S-NPP/NOAA-20 ✓ Updated with Chris' regression code
Clear Regression	✓ NO change from the operational version (V2.1.12d)	✓ PC regression using NOAA-20 CCR radiances matched with ECMWF ✓ Used four Focus Days (20180415, 20180715, 20181015, 20190115)	✓ No change – as is for S-NPP/NOAA-20 ✓ Updated with Chris's regression code, statistically same	✓ No change – as is for S-NPP/NOAA-20 ✓ Updated with Chris's regression code
Emissivity Regression	✓ NO Change from the operational version (V2.1.12d)	✓ NO change from the operational version (V2.1.12d)	✓ No change – as is for S-NPP/NOAA-20	✓ No change – as is for S-NPP/NOAA-20
IR Tuning	✓ "Full tuning" method using SNPP radiances and ECMWF SARTA simulations	✓ Double Difference Method using NOAA-20 radiances and ECMWF SARTA simulations.	✓ No change – as is for S-NPP/NOAA-20	✓ No change – as is for S-NPP/NOAA-20
CO climatology/QC	✓ NO Change from the operational version (V2.1.12d)	✓ NO Change from the operational version (V2.1.12d)	✓ No change – as is for S-NPP/NOAA-20	✓ No change – as is for S-NPP/NOAA-20
CH4/N2O A-priori	✓ Updated CH4/N2O a-priori	✓ Updated CH4/N2O A-priori	✓ No change – as is for S-NPP/NOAA-20 ✓ QC flag updates to CH4	✓ No change – as is for S-NPP/NOAA-20
SO2	✓ climatology	✓ climatology	✓ climatology	✓ Retrieval turned on
CO2 A-priori	✓ No Change from the OPS (V2.1.12d)	✓ No change from the OPS (V2.1.12d)	✓ Updated CO2 a-priori and QC flag updates	✓ CO2 QC flags optimized
CrIS Noise File	✓ NO change from the operational version (V2.1.12d)	✓ NO change from the operational version (V2.1.12d)	✓ No change – as is for S-NPP/NOAA-20	✓ No change – as is for S-NPP/NOAA-20
Channel Selection for cloud-clearing, T(p),q(p)	✓ Minor updates of channels	✓ Minor updates of channels	✓ No change – as is for S-NPP/NOAA-20 ✓ Super saturation QC flag implemented, RH threshold 110%	✓ No change – as is for S-NPP/NOAA-20 ✓ Super saturation QC flag, RH threshold 103%
Channels selection for trace gases	✓ NO change from the operational version (V2.1.12d)	✓ NO change from the operational version (V2.1.12d)	✓ No change – as is for S-NPP/NOAA-20	✓ No change – as is for S-NPP/NOAA-20

Algorithm Performance to Specification Requirements

Cal/Val Activities for NUCAPS Algorithm Performance (v3.0)

Items		Slides
• Address RFA from April 2020 Maturity Review • Product consistency • Requirements Check List	• RFA-1, 2 &3 from April maturity reviews are addressed. • Ensure latest algorithm produces consistent product quality and did not adversely affect retrieval products that are already of validated maturity ▪ T(p), q(p), O3(p) product consistency - S-NPP/NOAA-20 and MetOp series ▪ V3.0 (candidate version, December 2020) vs. v.2.7.2 (April 2020)	13–27
• Product consistency of trace gases products. • Validation of CO2 and other trace gas products	• Ensure latest algorithm produces consistent product quality and did not adversely affect trace gas products that are already of validated maturity ▪ V3.0 (candidate version, Dec. 2020) vs. v.2.7.2 (April 2020) CO(p), CH4(p), and CO2 (p) ▪ Validation with Focus Days: Depiction of Seasonality ▪ NUCAPS Product evaluations with other correlative data • Validation CO2 (CO and CH4) with reference data sets ▪ Statistical metrics and time series	13-75
• NUCAPS Trace Gas Products in Environmental Monitoring, • User Applications and Feedback	• Coronavirus studies using NUCAPS CO2 as a Tracer • CO2, CO and CH4 user applications and feedback • User Testimonials	76-87
• Risks, Summary and Conclusions	• Mitigation to identified risks • CH4 and CO2 requirements are all met. • NUCAPS team recommends CO2 Validated Maturity.	88-93
• Path Forward	• Potential future work • NUCAPS Milestones	97-101
• Supplemental slides	• Additional slides T(p), q(p), O3(p), and CO(p) Product Consistency • NUCAPS Team Collaborations with External Agencies for Risk Mitigation	102-134

RFAs from April 2020 Maturity Review

NUCAPS- Product Consistency Among S-NPP/NOAA-20, MetOp Series

- Supplemental slides provide additional maps of consistency not presented in the review for the focus day 20200430 (NOAA-20, S-NPP, MetOP Series), 20200123 (OLR products for S-NPP/NOAA-20, MetOp Series)

RFAs from April 2020 NUCAPS Maturity Review

RFA-2:

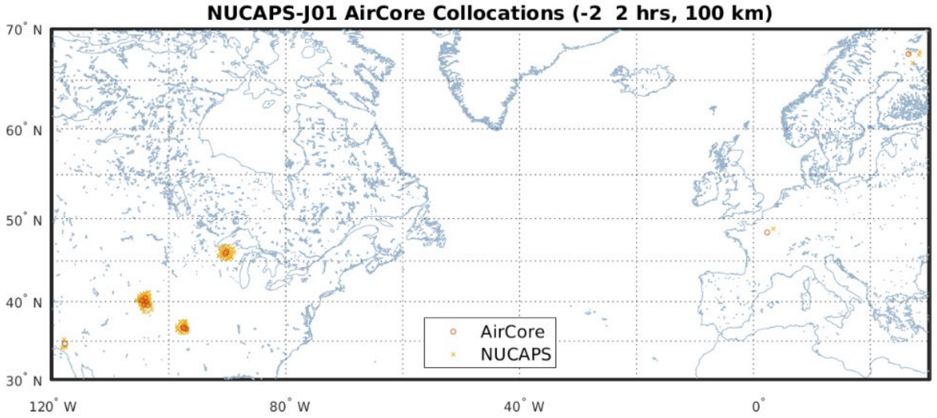
Further extend the validation data source for the trace gases, including the *in situ* and field campaign data if possible.

- Qualitative and quantitative evaluations of two focus-day retrievals to show product consistency between S-NPP/NOAA-20, and evaluations with Aqua-AIRS, TROPOMI (Details in Section 3)
- **Expanded reference data** collocations to **12 Focus Days** across the year (both S-NPP/NOAA-20) to show CO2 product meets the requirements, depict seasonality and time series. Evaluations with OCO, and other satellite observations. (Details Section 3)
- **GML Collaborations (Theme 1 for Trace gases)** has helped to add additional data sets like the **Carbon Tracker, AirCore** data sets

Expanded 12 Focus Day TCCON Dataset

Review Dec 2020	CrIS/SDRs ATMS/TDRs		ECMWF		CAMS		TCCON			Metop		
Focus Day	SNPP	N-20	SNPP	N-20	SNPP	N-20	SNPP	N-20	Metop	-A	-B	-C
20180401	√		√		√	√				√	√	Data started From 20190707 We can use 04/30/2020 Metop-A/B/C SNPP/NOAA-20 as a transfer standard
20180415	√						√					
20180516	√		√		√	√	√		√	√	√	
20180615	√	√	√	√	√	√	√	√	√	√	√	
20180716	√	√	√	√	√	√	√	√	√	√	√	
20180816	√	√	√	√	√	√	√	√	√	√	√	
20180820	√	√	√	√	√	√			√	√	√	
20180916	√	√	√	√	√	√	√	√	√	√	√	
20181015	√	√	√	√	√	√	√	√	√	√	√	
20181114	√	√	√	√	√	√	√	√	√	√	√	
20181215	√	√	√	√	√	√	√	√	√	√	√	
20190115	√	√	√	√	√	√	√	√	√	√	√	
20190215	√	√	√	√	√	√	√	√	√	√	√	
20190316	√	√	√	√	√	√	√	√	√	√	√	
20190415		√		√	√	√		√				
20190515		√		√	√	√		√				
20200123	√	√	√	√								
20200430	√	√	√	√	√	√						

SNPP, NOAA-20 GML AirCore Profile Collocations



RFAs from April 2020 NUCAPS Maturity Review

RFA-3(a): Suggest the team to update the MetOp-B/C and make it compatible with the retrievals from N20/S-NPP

- Optimized and delivered MetOp-C DAP to ASSISTT for Cloud implementation
  - ✓ Used NUCAPS v3.0 trace a-priori and QC as the baseline for MetOp-C DAP
- Evaluated focus-day retrievals (04/30/2020) for product consistency among JPSS and MetOp series, and other satellite retrievals (Aqua-AIRS, TROPOMI, OCO-2)
- Validated JPSS and MetOp trace gas products with TCCON reference data sets for 12 focus days

Focus Day: 04/30/2020
MetOp–C (MetOp-B/A)

- ✓ IASI, AMSU-A, MHS level-1 Data Sets
- ✓ NUCAPS EDRs for each satellite configuration
- ✓ ECMWF and Copernicus Atmosphere Monitoring Service (CAMS) model data matches for each satellite configuration
- ✓ OLR products

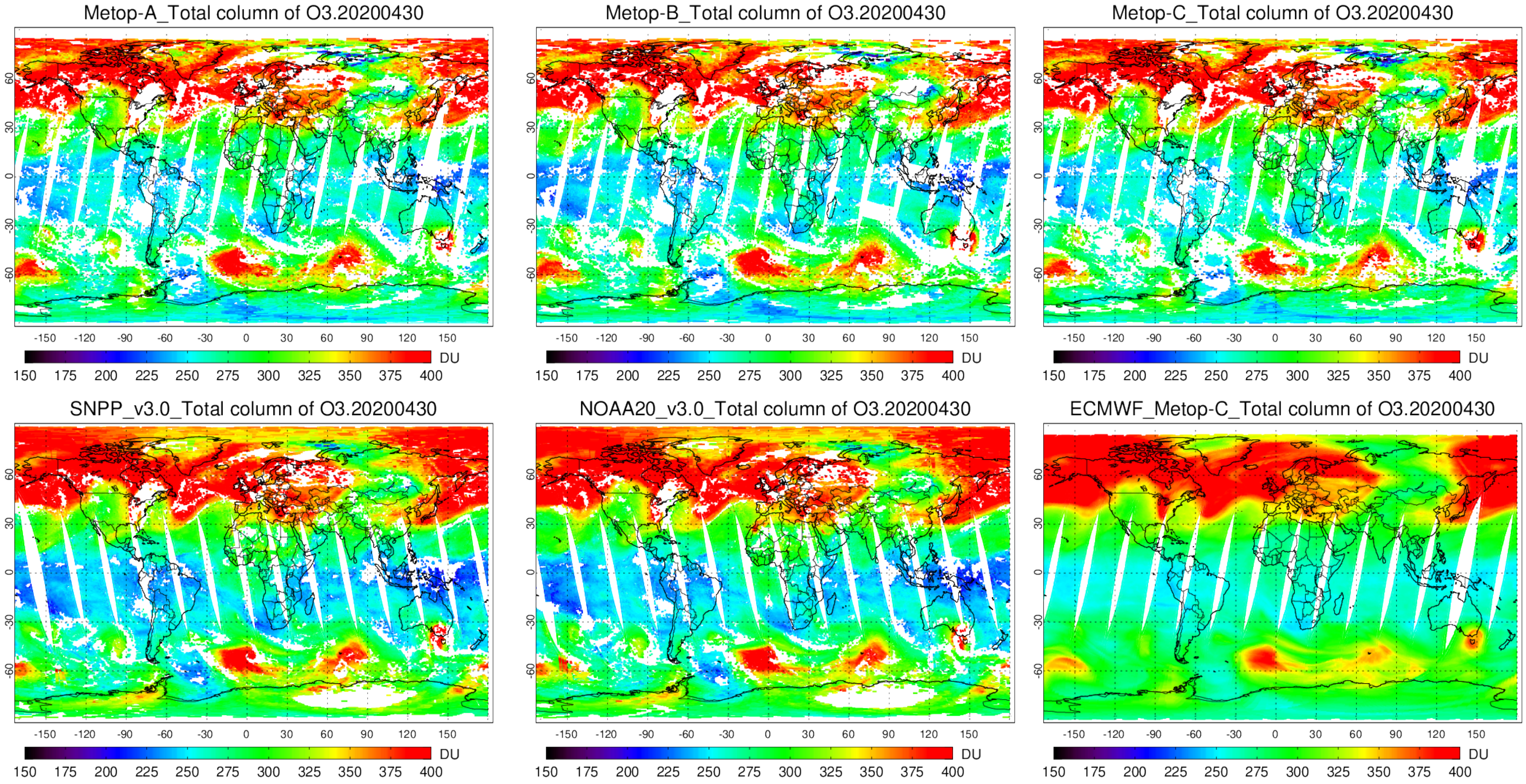
S-NPP/NOAA-20

- ✓ CrIS/ATMS SDRs
- ✓ NUCAPS EDRs for both S-NPP/NOAA-20
- ✓ **CLIMCAPS EDRs for JPSS**
- ✓ CAMS model data matches for each satellite configuration
- ✓ OLR Products

Item	MetOp-C IASI/AMSU-A/MHS
MW a-priori	• MiRS Climatology as A-priori. One year of ECMWF (2012), T(p), WV(p) • Adapted from S-NPP/NOAA-20 research
MW Tuning	• MetOp-C specific tuning LUTs
Cloudy Regression	✓ **MetOp-C Four Focus Days 20190715 20191015 20200116 20200415**
Clear Regression	✓ **MetOp-C Four Focus Days 20190715 20191015 20200116 20200415**
Emissivity Regression	• Currently as MetOp-B
IR Tuning	• Currently as MetOp-B
CO/CH4/CO2 Apriori	• Adapted from S-NPP/NOAA-20
Channel Selection for cloud-clearing	• Same as MetOp-B
Channels selection for trace gases	• Same as MetOp-B
IASI Noise File	• MetOp-C

GML Collaborations: This focus day data set with CLIMCAPS and NUCAPS Averaging Kernels, and OMPS Ozone retrievals are being used for an assessment of NUCAPS, CLIMCAPS, and OMPS O3 retrievals.

Total Ozone: Metop-A/B/C, S-NPP/NOAA-20, ECMWF

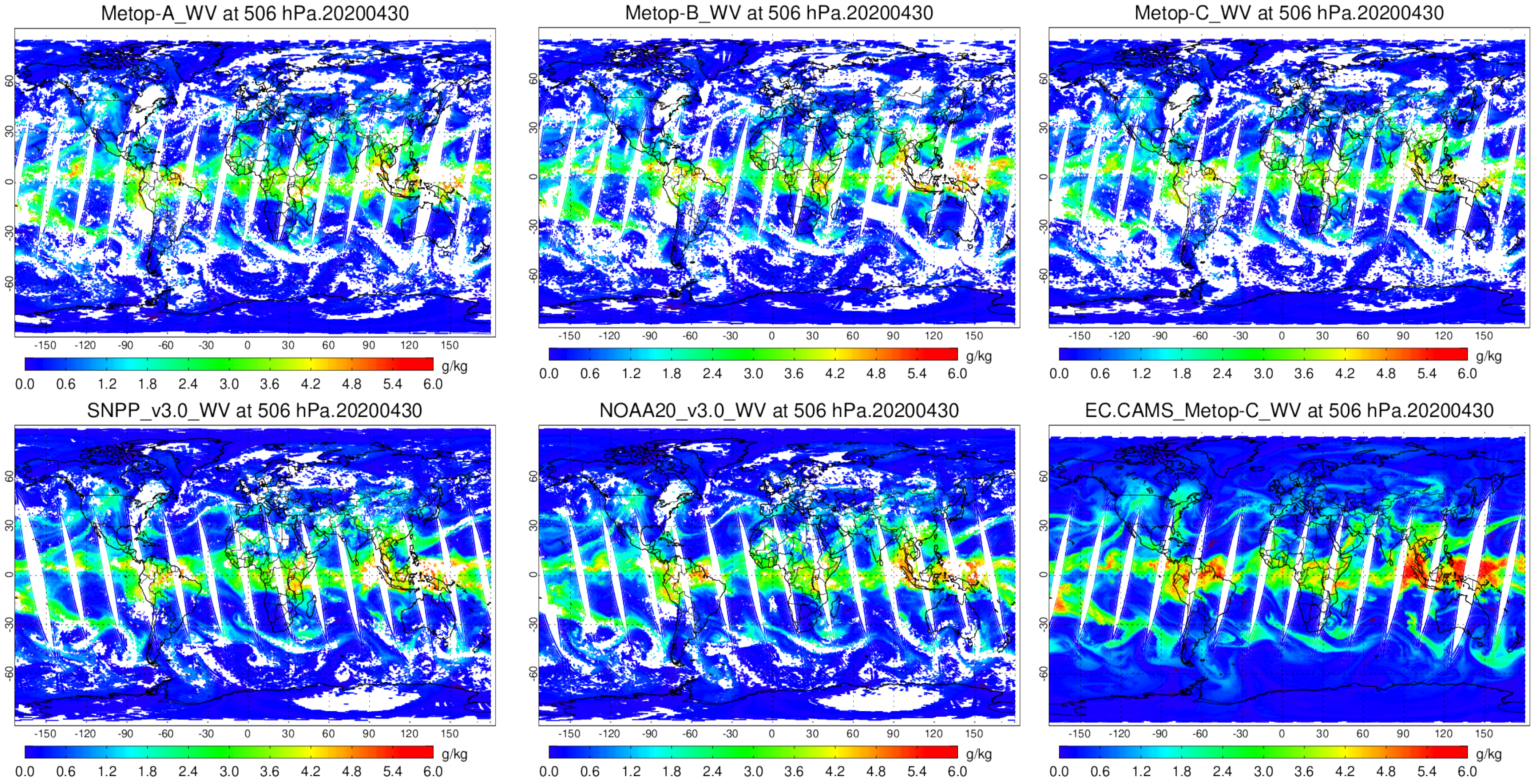


MetOp Yields (IR+MW)
A: 54%
B: 53%
C: 56%

S-NPP/NOAA20 Yield (IR+MW)
S-NPP: 70.4%
NOAA20: 69.7%

NUCAPS Algorithm produces consistent Ozone profile (O3) product from JPSS (S-NPP and NOAA-20) and MetOp series (MetOp-A/B/C). Retrieved O3 product (100 layers) spans from surface to 0.01mb, and has reached validated maturity. Validation of Ozone is performed using a hierarchy of validation data sources, e.g. models (ECMWF), correlative data sets (e.g. AIRS), and time and space collocated matches of dedicated O3SNDS from campaigns of opportunity (e.g. AEROSE) and WOUDC network. **See Supplemental slides for other products**

500 hPa Water Vapor Maps: Metop-A/B/C, S-NPP/NOAA20, ECMWF

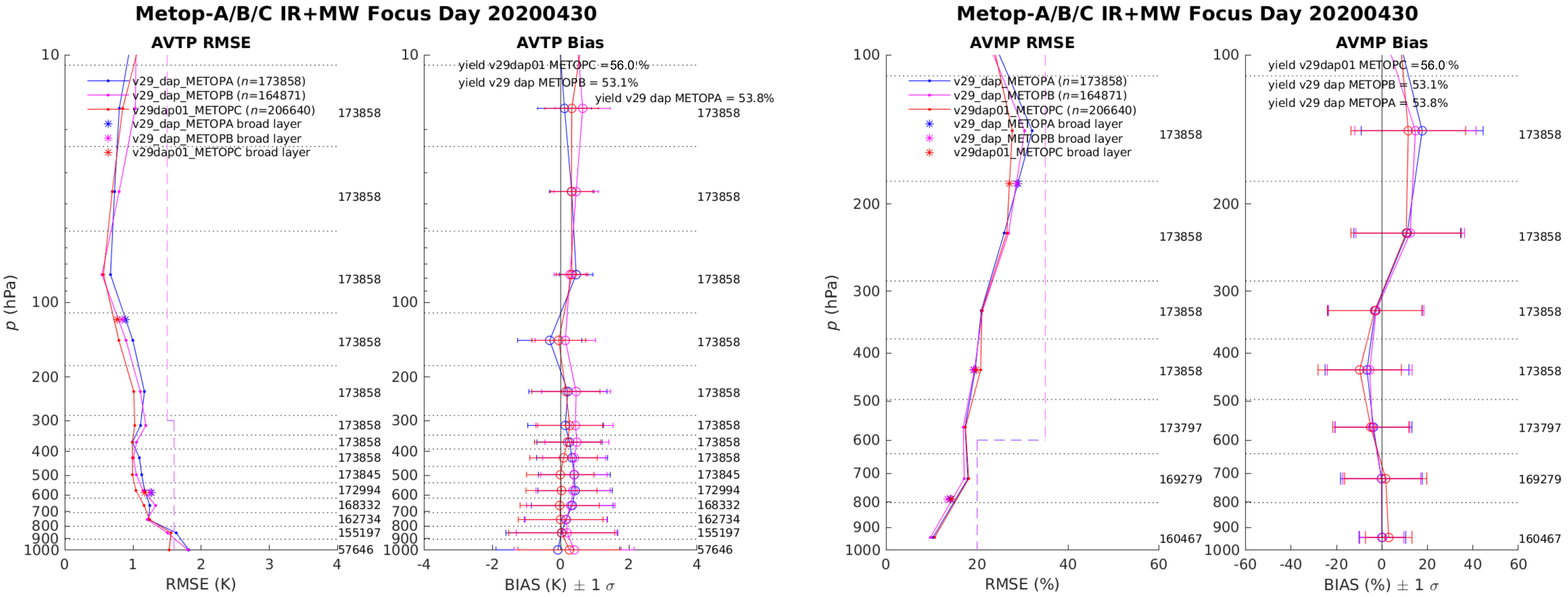


MetOp Yields (IR+MW)
A: 54%
B: 53%
C: 56%

S-NPP/NOAA20 Yield (IR+MW)
S-NPP: 70.4%
NOAA20: 69.7%

NUCAPS Algorithm produces consistent Atmospheric Vertical Moisture Profile (AVTP) product from JPSS (S-NPP and NOAA-20) and MetOp series (MetOp-A/B/C). Retrieved AVMP product (100 layers) spans from surface to 0.01mb, and has reached validated maturity. Validation of AVMP is performed using a hierarchy of validation data sources, e.g. models (ECMWF), correlative data sets (e.g. AIRS), and time and space collocated matches of dedicated RAOBS, campaigns (e.g. AEROSE), and global RAOB network (**Supplemental slides for other products)**

MetOp-A/B/C AVTP & AVMP Global Statistics with ECMWF

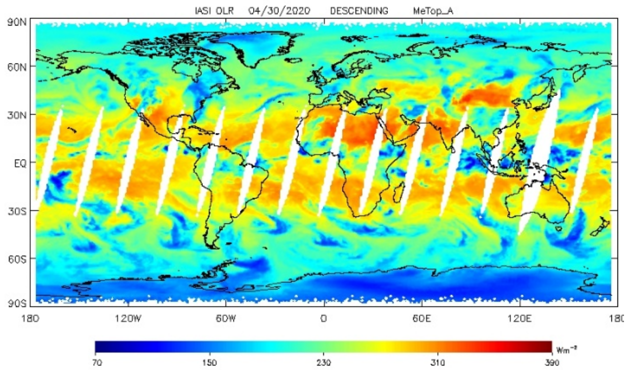


	Metop-A	Metop-B	Metop-C
Yield	54%	53%	56%

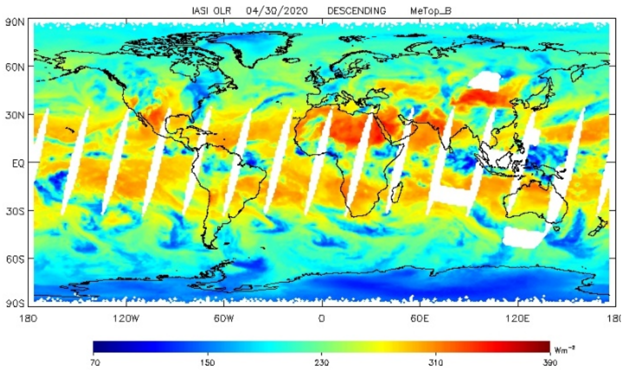
Trace gas retrieval consistency among S-NPP/NOAA-20 and MetOp-Series, and Validations discussed in Section 3.

NUCAPS Products:
Daily NUCAPS CrIS NOAA-20 OLR VS. IASI MetOP OLR (Day time 04/30/2020)

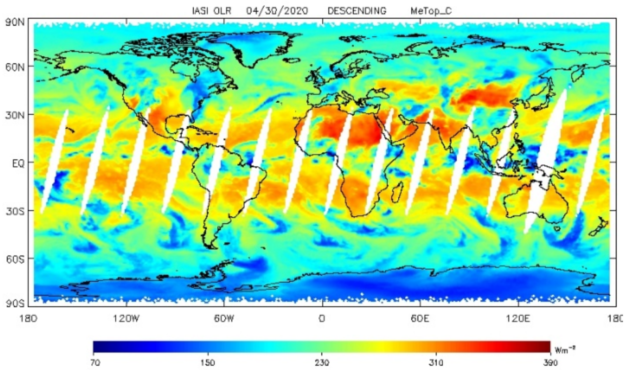
MetOp-A IASI



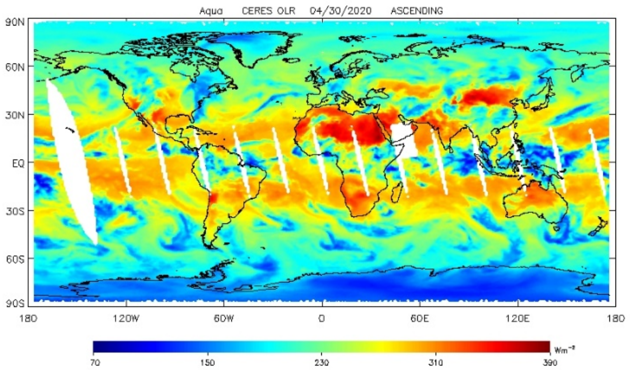
MetOp-B IASI



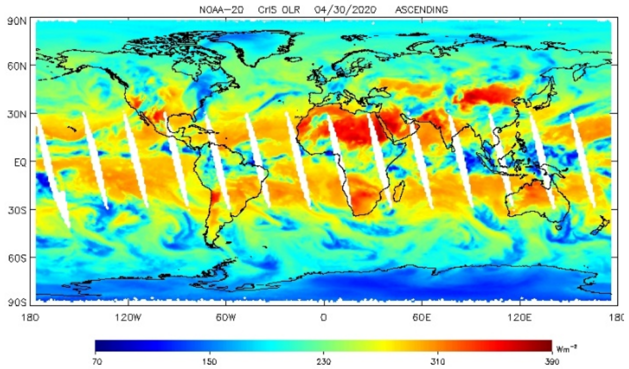
MetOp-C IASI



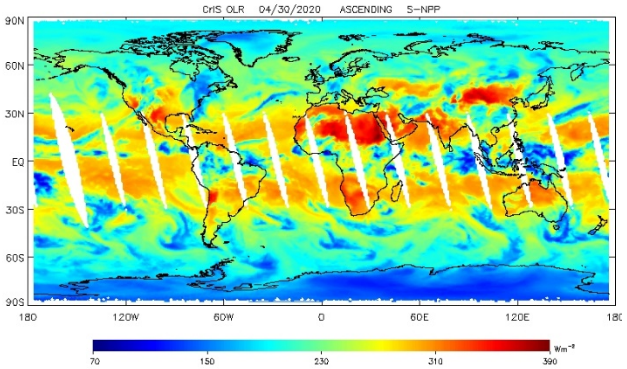
Aqua CERES



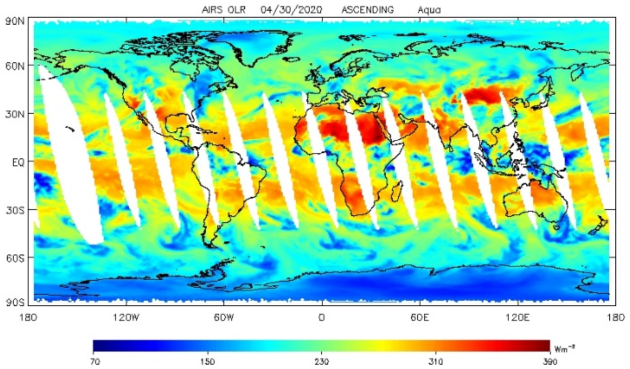
NOAA-20 CrIS



S-NPP CrIS



Aqua AIRS



MetOp IASI vs NOAA-20 CrIS

	BIAS	STD	CC
A	-0.82	24.41	0.87
B	0.07	21.61	0.89
C	0.27	23.18	0.89

MetOp IASI vs Aqua CERES

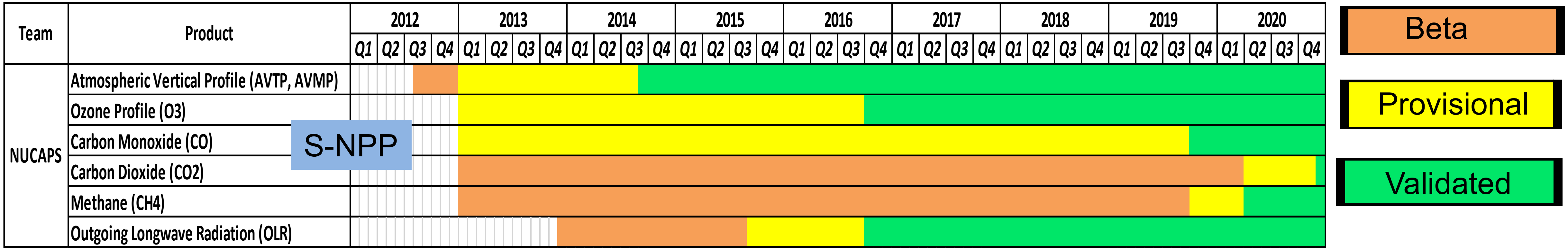
	BIAS	STD	CC
A	1.58	24.74	0.87
B	0.72	23.16	0.89
C	0.99	23.62	0.88

- NUCAPS JPSS CrIS-OLR has reached validated maturity.
- Evaluated IASI OLR products for consistency among MetOp-A/B/C and with other correlative observations.
- See supplemental for additional maps, Asc/Desc, 01/23/2020.

W/m^2	BIAS	STD
Requirement	5.0	12.0
CrIS NOAA-20	0.2	8.7

Action Items from April 2020 NUCAPS Maturity Review

RFA-3: (b) Suggest to put together plans for reprocessing the S-NPP mission long data sets with the Validated Maturity Algorithms.



- EDR products get impacted both by upstream SDR product changes (due to uncovered deficiencies and improved sensor characterizations in SDR algorithms) as well as EDR algorithm changes
- Without reprocessing, data products in the archive would have varying accuracy due to periodic updates of algorithms (to fix shortfalls in SDRs, Beta, Provisional, and Validated status) used for real-time product generation and OPS.
- Science Benefits, Addressing User Needs
  - Consistent mission-long high quality products
  - Enable users retroactively evaluate impacts on user applications.

NUCAPS EDR Reprocessing Viability

	Queries	Y/N	Remarks
1	Most matured algorithm that is of **validated maturity**?	Yes	With this maturity review, all of the NUCAPS products reach validated maturity (CO2)
2	Algorithm satisfies the **enterprise nature** of working on multiple satellite sources	Yes	NUCAPS EDR products show consistency among S-NPP/NOAA-20, MetOp series and is getting augmented for EPS-SG
3	Algorithm developer considers the algorithm as a 'matured version' and expects to remain stable for foreseeable future ready to warrant reprocessing' ?	Yes	NUCAPS team is very close in implementing Averaging Kernels as part of the NUCAPS output product **(! User requirements from JPSS/EUMETSAT Convention, February 2020).** STAR NUCAPS team can demonstrate a viable version for to roll-on for S-NPP reprocessing by February 2021.
4	Upstream SDR products required by the EDR algorithm are reprocessed or ready with a 'reprocessed' version?	Yes	Reprocessed S-NPP CrIS/ATMS SDRs are available for the S-NPP mission-long period
5	'Algorithm version for reprocessing' can use the Delivered Algorithm Packages (DAP) for operations (e.g. Maturity Reviews - - > SPSRB review)	Yes	SPSRB review process will follow after the review panel recommendations on the maturity review
6	Resources required for reprocessing are identified and are in place? User requests for reprocessed data sets?	Yes	STAR NUCAPS team require, (a) Enhanced computing power, (b) disk storage, and (c) a half time FTE to attend reprocessing. Juying Warner, member of the NUCAPS team, affiliate of UMD has resources to run reprocessing

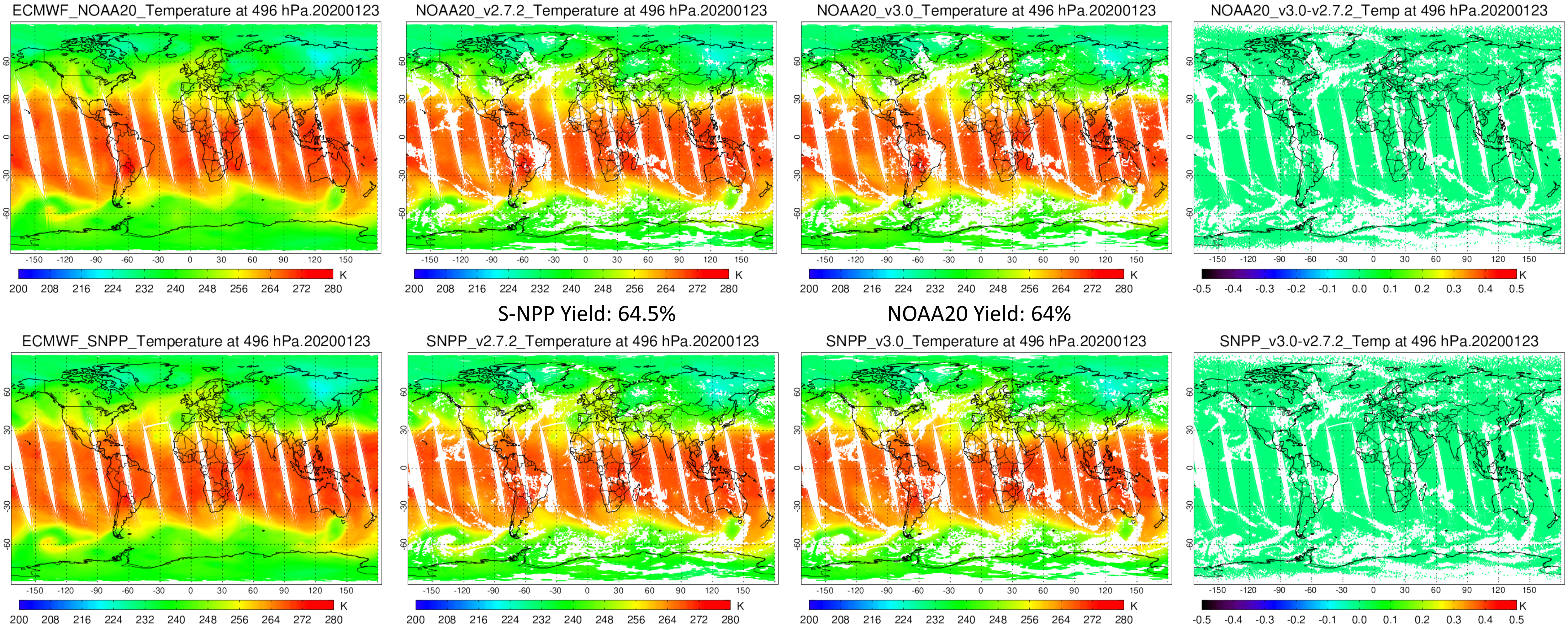
CrIS SDR ATMS TDR Data	GFS and other ancillary data/day	NUCAPS EDR Storage/Day
Reprocessed SDRs	2 GBs	64 GB

Satellite	Days on orbit	Storage
S-NPP	3338	221 TBs
NOAA-20	1125	75 TBs

T(p), q(p), O3(p), Product Consistency

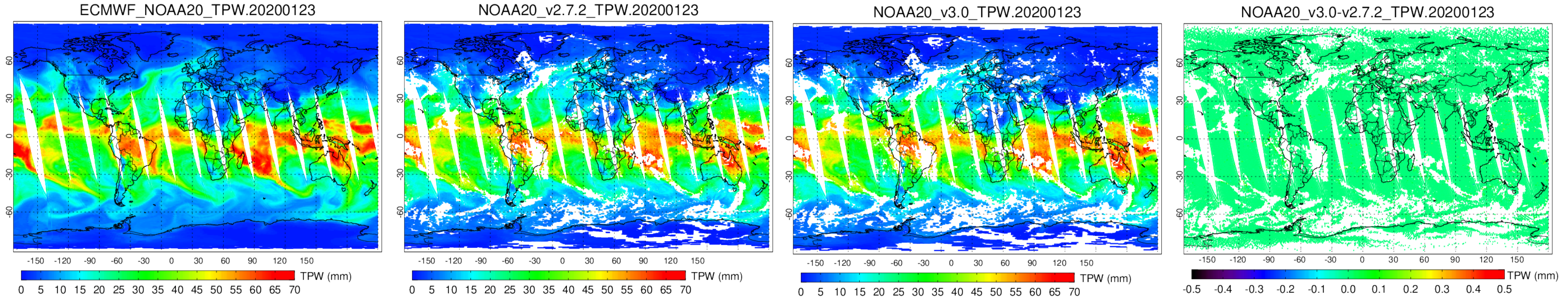
- **Ensure latest algorithm changes did not adversely affect retrieval products that are already of validated maturity.**
  - Performed evaluations of NUCAPS products (Latest v3.0) vs. V2.7.2 (April 2020 DAP) using two focus day data sets (20200123, 04302020).
  - Presented here are a couple of global maps, and supplemental slides provide evaluations for all the products for the focus day 20200430 (NOAA-20, S-NPP)

Product Consistency: v2.7.2 vs. v3.0 Temperature at 496 hPa (20200123)



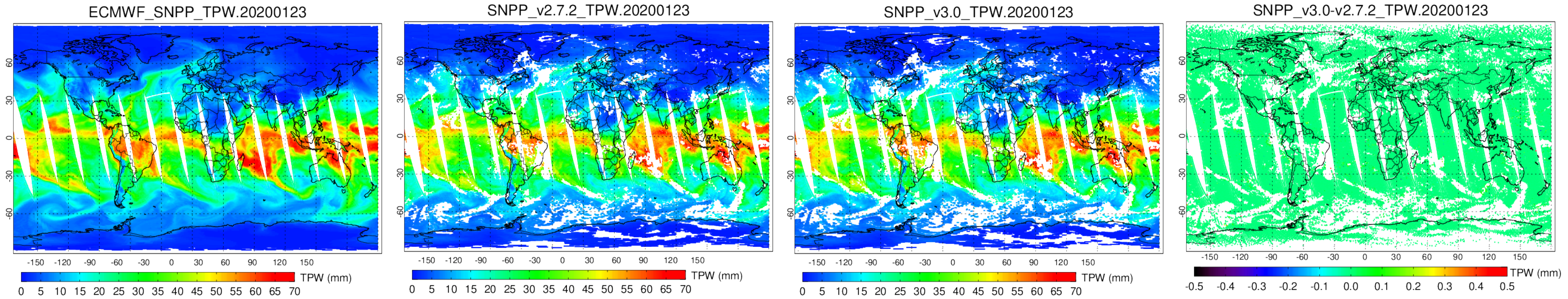
Supplemental slides provide additional evaluations of S-NPP/NOAA-20 v2.7.2 vs. v3.0 to ensure that the latest algorithm changes did not adversely affect retrieval products that are already of validated maturity. Consistency of Trace gas retrievals discussed in Section 3.

Product Consistency: v2.7.2 vs. v3.0 Total Precipitable Water (20200123)



S-NPP Yield: 64.5%

NOAA20 Yield: 64%

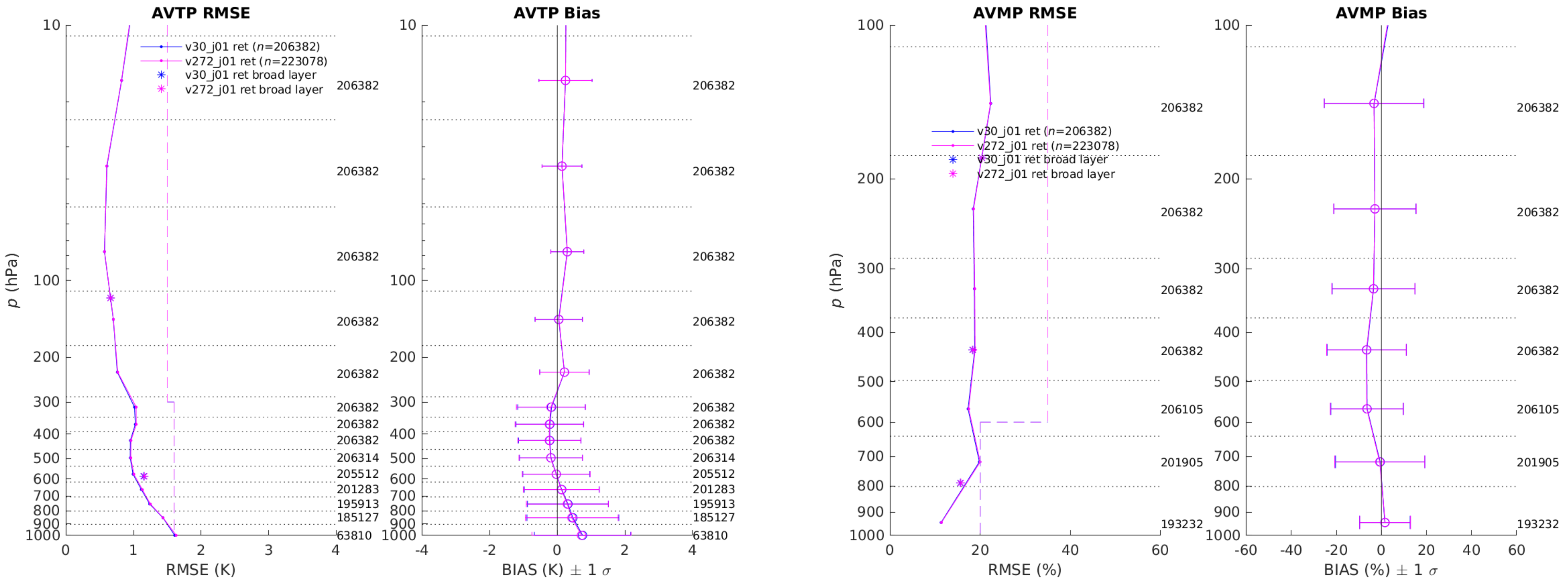


Supplemental slides provide additional evaluations of S-NPP/NOAA-20 v2.7.2 vs. v3.0 to ensure that the latest algorithm changes did not adversely affect retrieval products that are already of validated maturity. Consistency of Trace gas retrievals discussed in Section 3.

NOAA-20 IR+MW (23 January 2020) v3.0 vs v2.7.2

AVTP

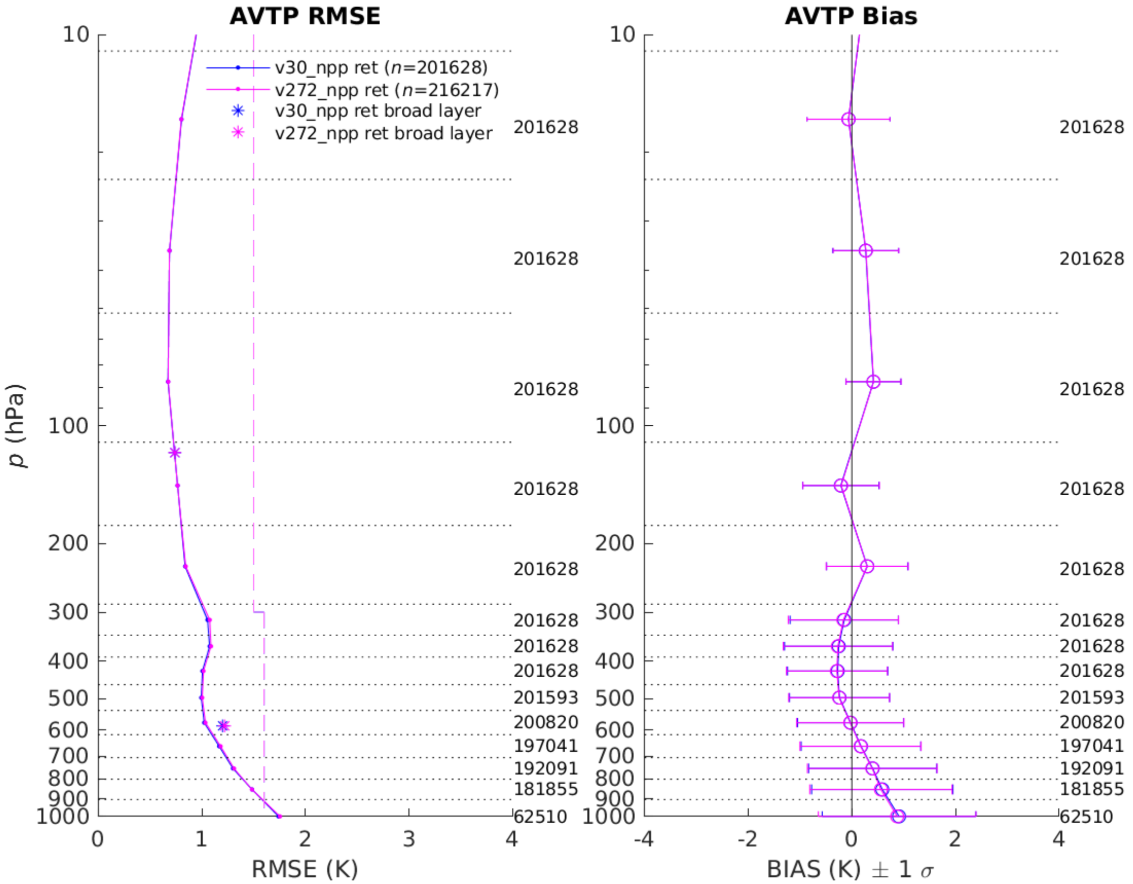
AVMP



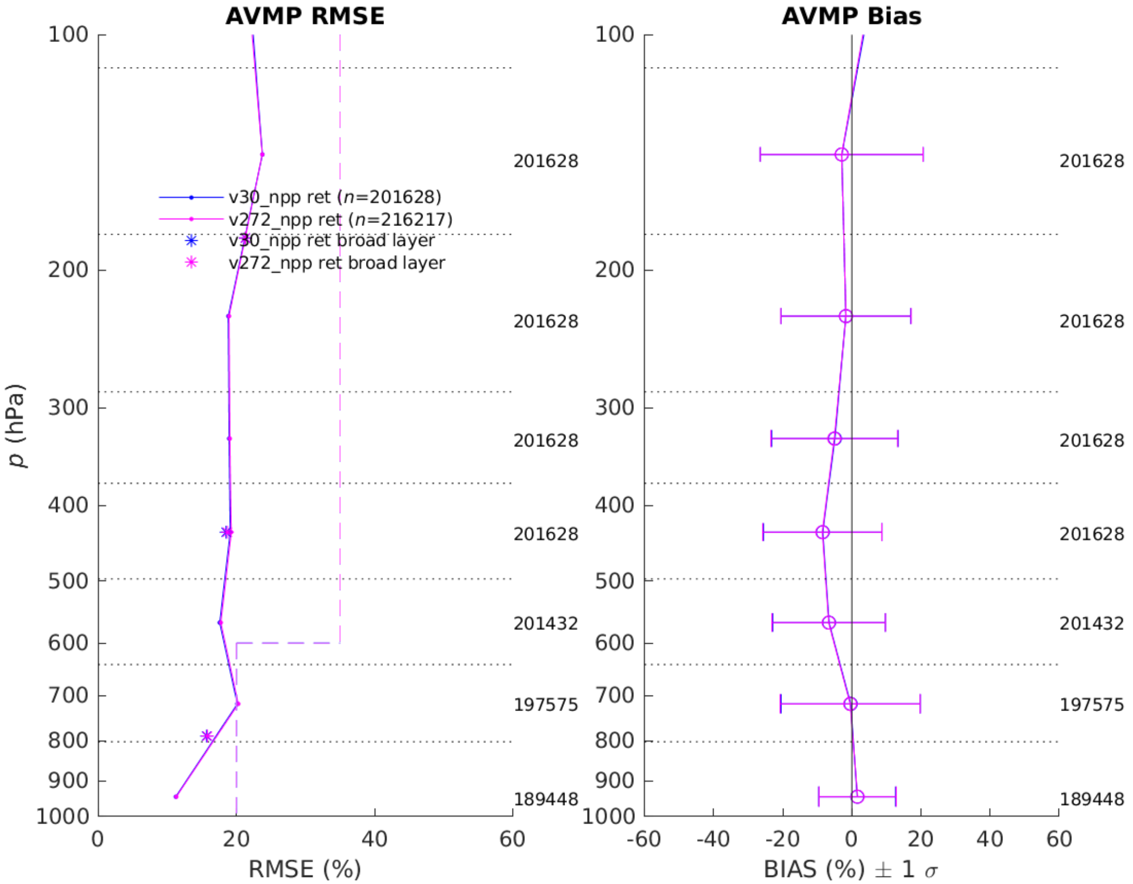
Section 3 and supplemental slides discuss S-NPP/NOAA-20 Trace gas retrievals, evaluations with TROPOMI, OCO and reference data sets

S-NPP IR+MW (23 January 2020) v3.0 vs v2.7.2

AVTP



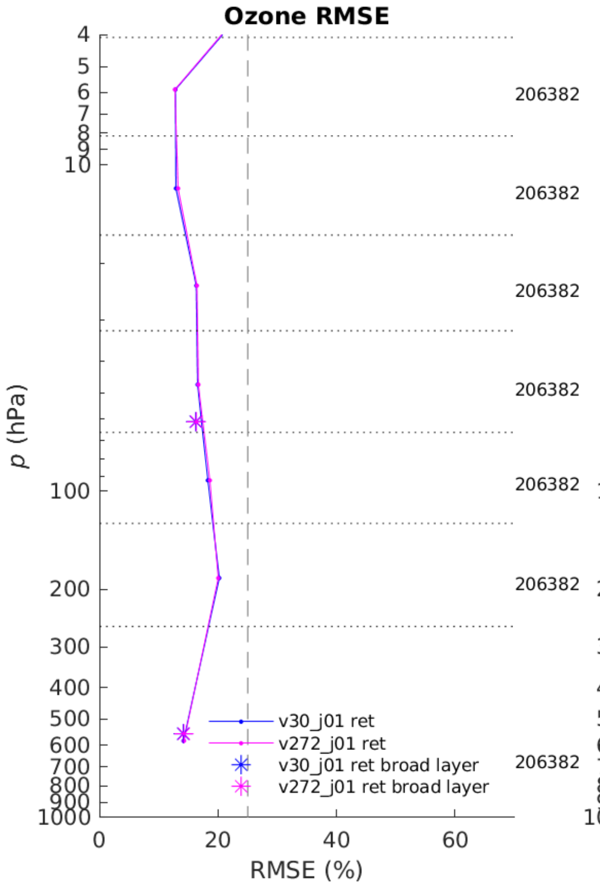
AVMP

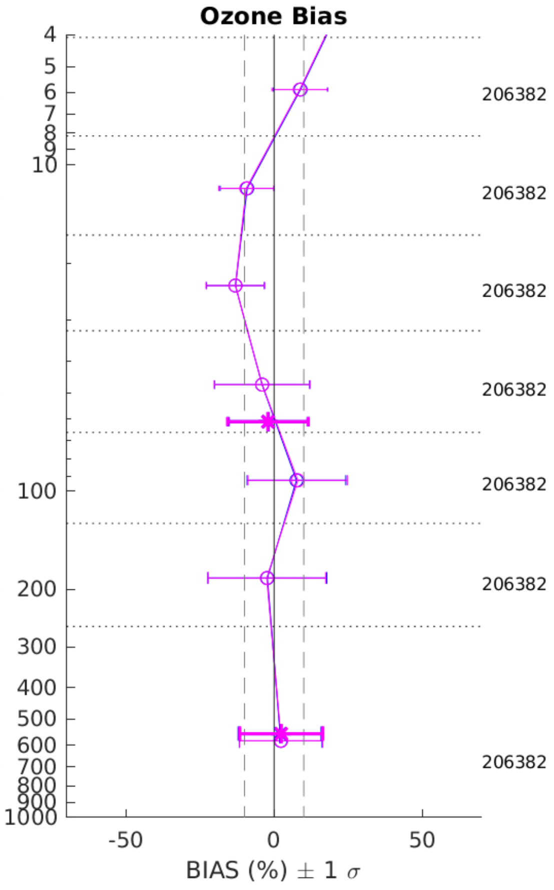


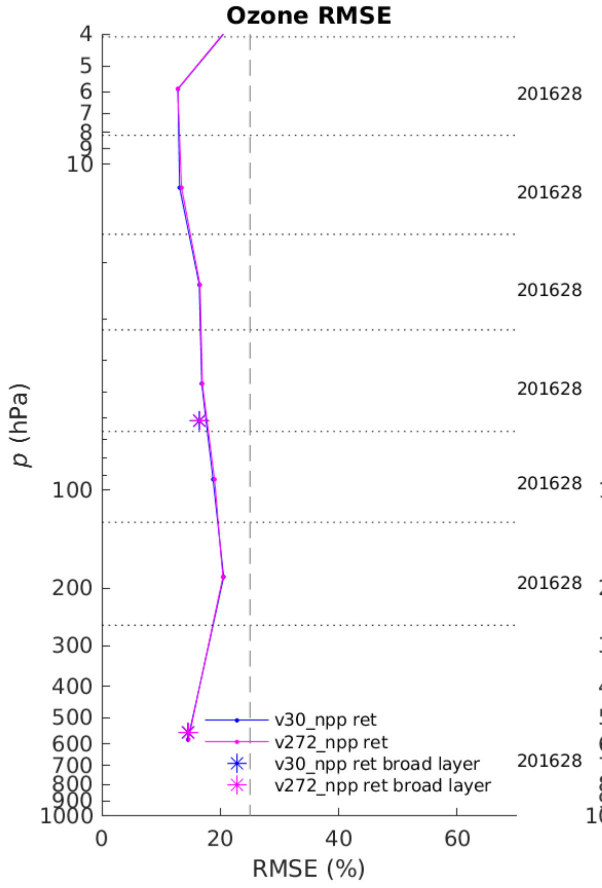
Section 3 and supplemental slides discuss S-NPP/NOAA-20 Trace gas retrievals, evaluations with TROPOMI, OCO and reference data sets

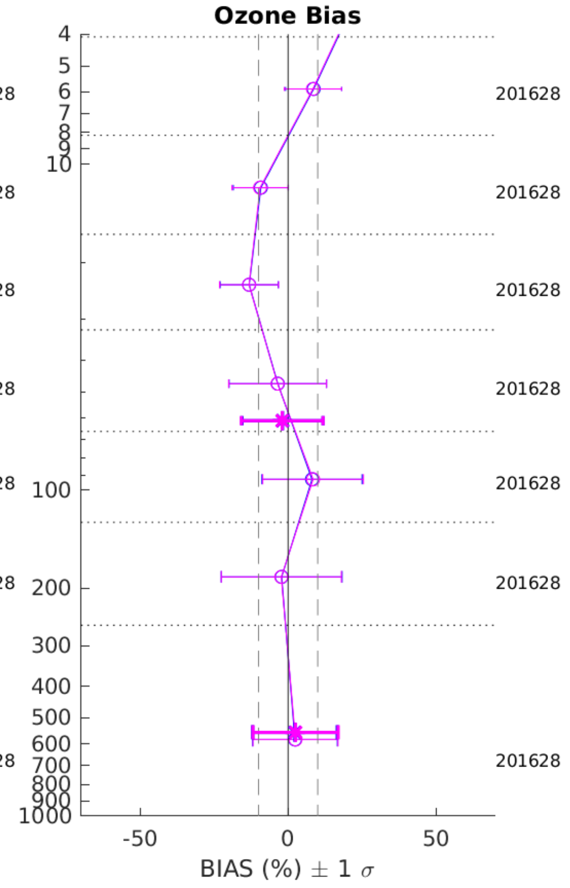
NOAA-20 and S-NPP IR Ozone Profile - v3.0 vs v2.7.2

NOAA-20 23 Jan 2020 S-NPP









REQUIREMENTS CHECK LIST

S-NPP and NOAA-20 Validated Maturity for CO_2

Validated Maturity End State	Assessment
Product performance has been demonstrated over a large and wide range of representative conditions (i.e., global, seasonal).	Yes. See slides 32-75
Comprehensive documentation of product performance exists that includes all known product anomalies and their recommended remediation strategies for a full range of retrieval conditions and severity level.	Yes. See slides 32-75
Product analyses are sufficient for full qualitative and quantitative determination of product fitness-for-purpose.	Yes. See slides 32-75
Product is ready for operational use based on documented validation findings and user feedback.	Yes. See slides 76-87
Product validation, quality assurance, and algorithm stewardship continue through the lifetime of the instrument	Yes. See slides 88-101

Requirement Check List – Carbon Dioxide (CO_2)

DPS	Requirement	Performance
DPS-389	The Carbon Dioxide product shall provide carbon dioxide volume density, geolocated, globally, for the total vertical column, in all weather conditions, day and night, at the refresh rates of the instrument	Yes. The NUCAPS algorithm produces a CO2 product geolocated, globally, for the total vertical column, in all weather conditions, day and night, at the refresh rates of the instrument. See Slides 41, 78-79.
DPS-390	The Carbon Dioxide product shall provide carbon dioxide volume density with a measurement range of 300 to 500 parts per million by volume (ppmv)	Yes. The algorithm has the capability to satisfy the range (min and max) as per the requirement. But the min and max shown depends on the focus day observed product used for validation. See Slide 104.
DPS-391	The Carbon Dioxide product shall provide carbon dioxide volume density with a horizontal resolution of 100 km	Yes. The NUCAPS algorithm produces a CO2 product on a field-of-regard consisting of 3 x 3 CrIS fields-of-view, constituting a nominal nadir spatial resolution of 45 km.
DPS-393	The Carbon Dioxide product shall provide carbon dioxide volume density with a measurement precision of 0.5% or 2 ppmv	Yes. Global validation of carbon trace gases requires acquisition periods for *in situ* data collection, with AirCore, TCCON and aircraft campaigns (e.g., ATom) having a lag time between observation and pubic release of QA products. The team also recommends proper use of averaging kernels (AKs) as part of assessments.
DPS-394	The Carbon Dioxide product shall provide carbon dioxide volume density with a measurement accuracy of 1% or 4 ppmv	As above regarding in situ data collection.

Documentation

Science Maturity Check List	Yes ?
Readme for Data Product Users	Yes
*Algorithm Theoretical Basis Document (ATBD)	Yes, reformatted in accordance with SBSRB template, and updated with latest algorithm version and validation results.
Algorithm Calibration/Validation Plan	Yes, updated for JPSS-2
*(External/Internal) Users Manual	Yes
System Maintenance Manual (for ESPC products)	Yes
Peer Reviewed Publications (Demonstrates algorithm is independently reviewed)	Published one paper in *Remote Sensing*, three more publications are in various phases of manuscript preparations – see Slides 94, 98
Regular Validation Reports (at least annually) (Demonstrates long-term performance of the algorithm)	Yes, NOAA-20 and SNPP carbon trace gas validation has been published in MDPI *Remote Sensing* Special Issue.

*ATBD, External/Internal Users Manual, System Maintenance Manual available upon request, and as part of DAP

MATURITY REVIEW MATERIAL – SECTION 3

NUCAPS Trace Gas Product Evaluations

- Validation Datasets (Presented by Nick Nalli)
- **NUCAPS CO_2 product evaluation with other correlative data sets (AIRS, TROPOMI) (Presented by Juying Warner)**
- Expanded truth data sets and statistical analysis for validation of CO_2 (Presented by Nick Nalli)

NUCAPS Product Validation Methodology Hierarchies

Carbon Trace Gas Validation Hierarchy
(*Nalli et al.* 2020)

1. **Numerical Model Global** ***Comparisons***
   - Examples: ECMWF **CAMS**, **CarbonTracker**
   - Large, truly global samples acquired from Focus Days
   - Limitation: Not independent truth data
2. **Satellite Sounder EDR** ***Intercomparisons***
   - Examples: **AIRS, TROPOMI, 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)
   - **ATom**, FIREX, WE-CAN, ACT-America

Focus Day Data Sets in Possession for December Maturity Review

Review Dec 2020	CrIS/SDRs ATMS/TDRs		ECMWF		CAMS		TCCON			Metop		
Focus Day	**SNPP**	**N-20**	**SNPP**	**N-20**	**SNPP**	**N-20**	**SNPP**	**N-20**	**Metop**	**-A**	**-B**	**-C**
20180401	√		√		√	√				√	√	Data started From 20190707 We can use 04/30/2020 Metop-A/B/C SNPP/NOAA-20 as a transfer standard
20180415	√						√					
20180516	√		√		√	√	√		√	√	√	
20180615	√	√	√	√	√	√	√	√	√	√	√	
20180716	√	√	√	√	√	√	√	√	√	√	√	
20180816	√	√	√	√	√	√	√	√	√	√	√	
20180820	√	√	√	√	√	√			√	√	√	
20180916	√	√	√	√	√	√	√	√	√	√	√	
20181015	√	√	√	√	√	√	√	√	√	√	√	
20181114	√	√	√	√	√	√	√	√	√	√	√	
20181215	√	√	√	√	√	√	√	√	√	√	√	
20190115	√	√	√	√	√	√	√	√	√	√	√	
20190215	√	√	√	√	√	√	√	√	√	√	√	
20190316	√	√	√	√	√	√	√	√	√	√	√	
20190415		√		√	√	√		√				
20190515		√		√	√	√		√				
20200123	√	√	√	√								
20200430	√	√	√	√	√	√						

NUCAPS Carbon Trace Gas EDR Reference data, Time Periods

Observation Type	Reference Data	Time Period	Validation	Remarks
Atmospheric Tomography Mission (ATom)	• DC-8 aircraft based *in situ* air samples • Profiles of volume mixing ratios (ppmv) obtained using NOAA/GML Picarro G2401m analyzer	ATom-1,-2: Jul 2016 to Feb 2017 ATom-4: Apr-May 2018	✓CO2 meets bias and precision requirements throughout column	ATom (*Wofsy et al.* 2018) acknowledgment • Kathryn McCain, Colm Sweeney (NOAA/GML) • https://doi.org/10.3334/ORNLDAAC/1581
Total Carbon Column Observing Network (TCCON)	• Ground-based network of uplooking spectrometers • Total column DMF retrieved from near-IR solar spectrum	12 Focus Days: 2018-2019	✓CO2 meets total column requirements	TCCON (*Wunch et al.* 2010, 2011) acknowledgment • Debra Wunch (CalTech)
AirCore	• Balloon-borne *in situ* profiling system	Launches from 2018-2020	✓CO2 meets bias and precision requirements throughout column	AirCore (*Membrive et al.* 2017) acknowledgment • Bianca Baier (NOAA/GML)

NUCAPS Trace Gas Products in V3.0 and CO_2 Validate Maturity

CO and CH_4

- Update on NUCAPS V3.0 CO and CH_4

CO_2

- Findings/Issues from Beta Review
  - Current operational version V2.5.2.2
  - Value ranges, distributions, and trends were incorrect;
- Improvements Beta-Provisional
  - Primarily new a priori
- Algorithm performance evaluation for Validated Maturity
  - Quality assurance
  - Channel examination
  - Expanded truth data sets – ATom 1 – 4
  - Comparing against OCO-2

Comparisons of V3.0 CO Column (x10^{17} mols/cm^2) Aug. 2018

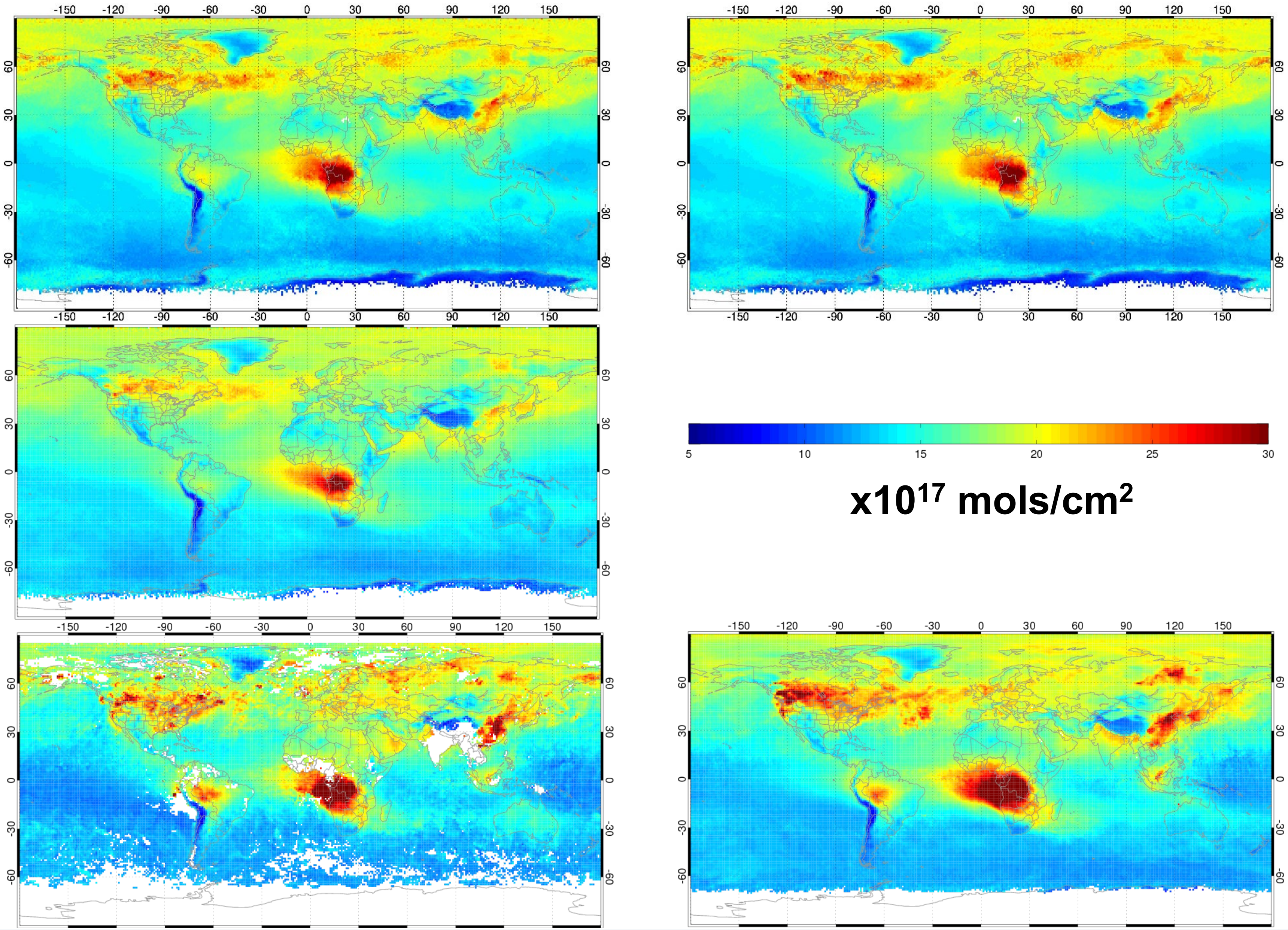
NUCAPS S-NPP CrIS

NUCAPS NOAA-20 CrIS

AIRS

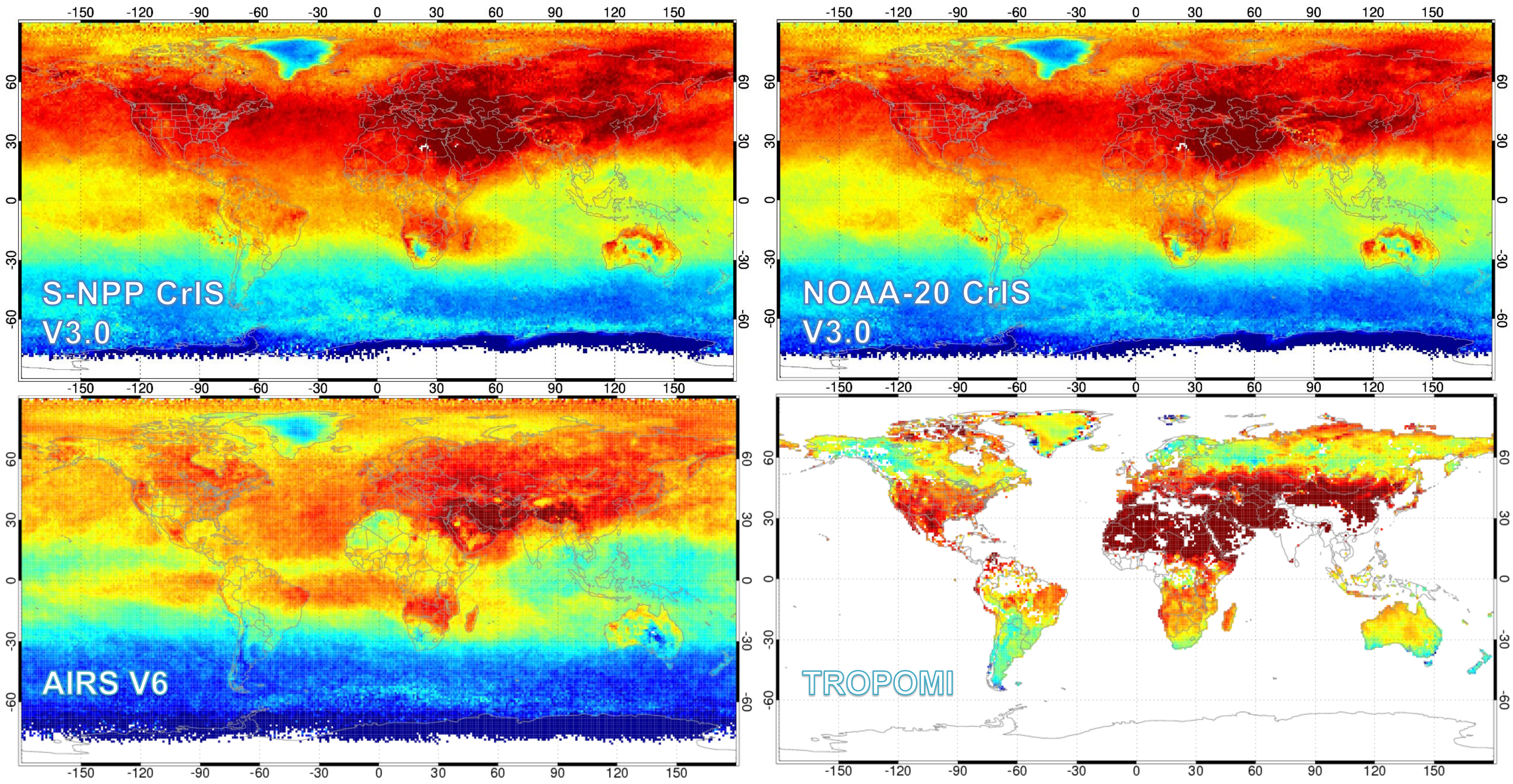
MOPITT

TROPOMI



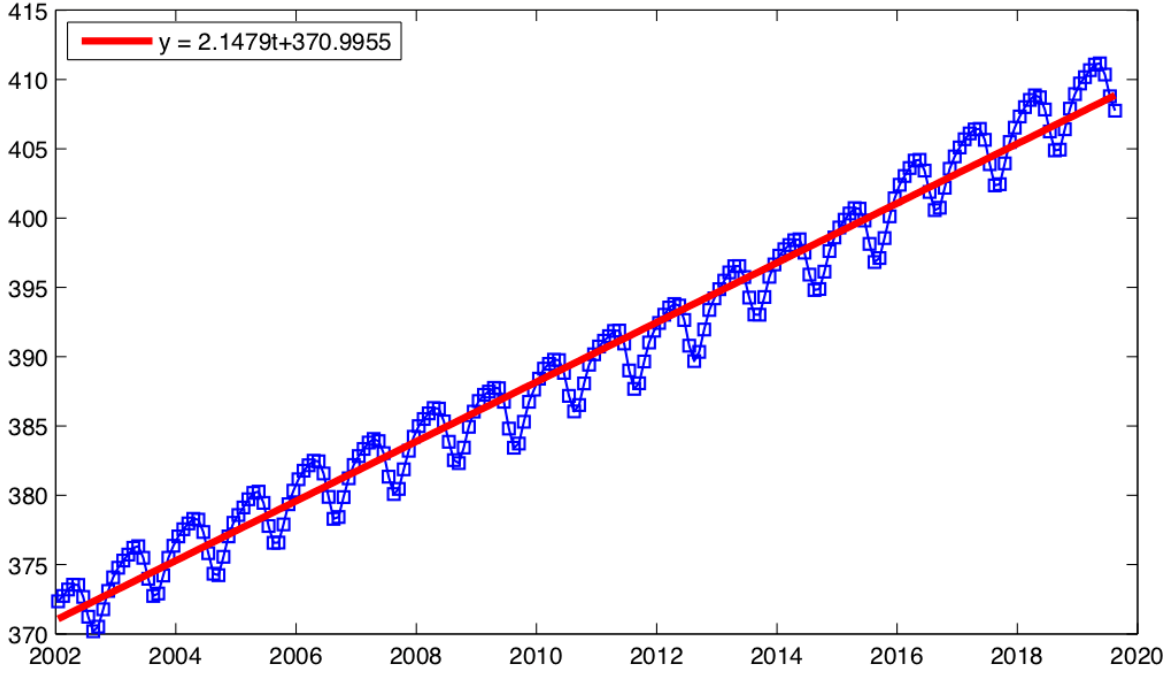
x10^{17} mols/cm^2

NUCAPS xCH_4 V3.0 Compared to AIRS and TROPOMI Aug. 2018 Monthly Mean



- CrIS CH_4 is slightly higher than AIRS; but agree with TROPOMI mid- and low- latitudes better.

NUCAPS CO_2 Improvements - a priori and Quality Assurance



*Linear trend from ESRL surface measurements.

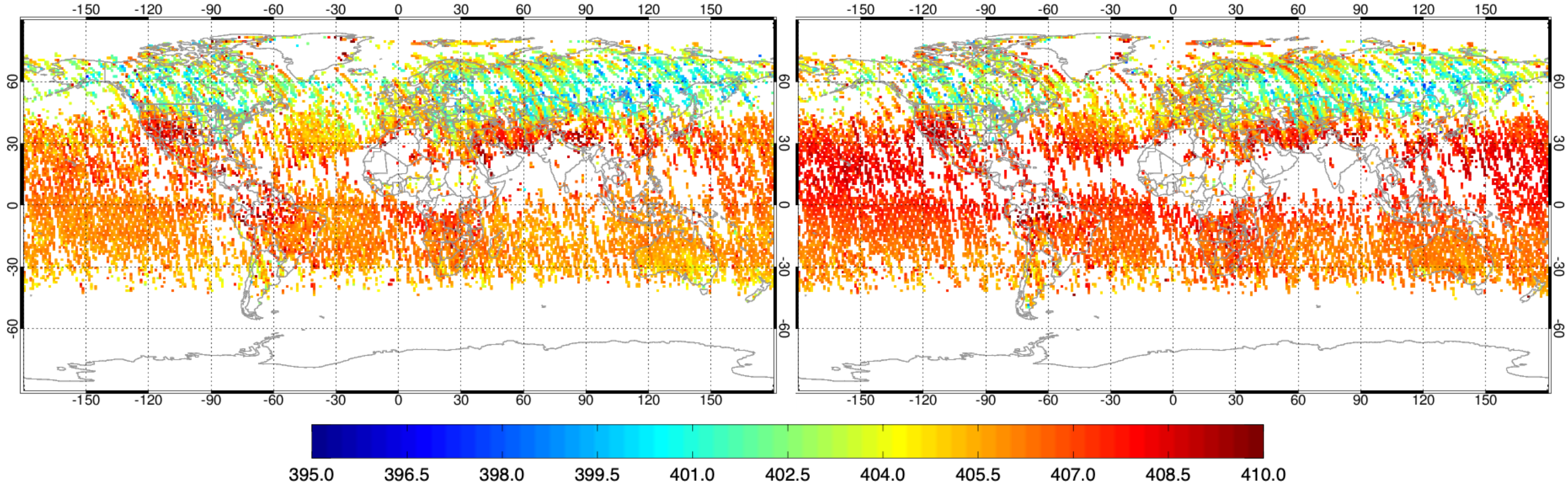
CO_2 a priori Using Carbon Tracker Distributions and NOAA/ESRL Trends

1. Latitudinal variations, and;
2. Seasonality from Carbon Tracker;
3. Linear trend from ESRL surface measurements;
4. Climatology uses anomaly from ESRL data.

OCO-2 CO_2 to Compare Against

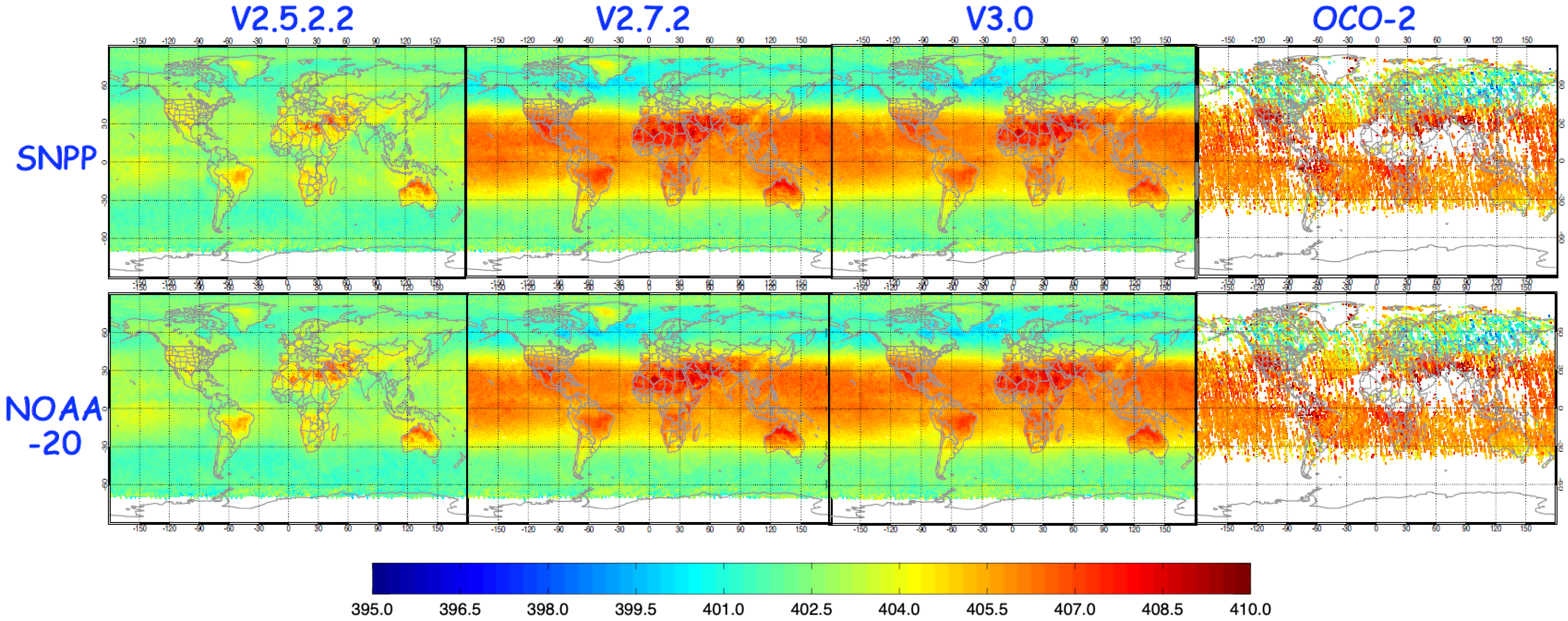
Orbiting Carbon Observatory-2
xCO2 (ppm) for July 2018

V9 **V10**



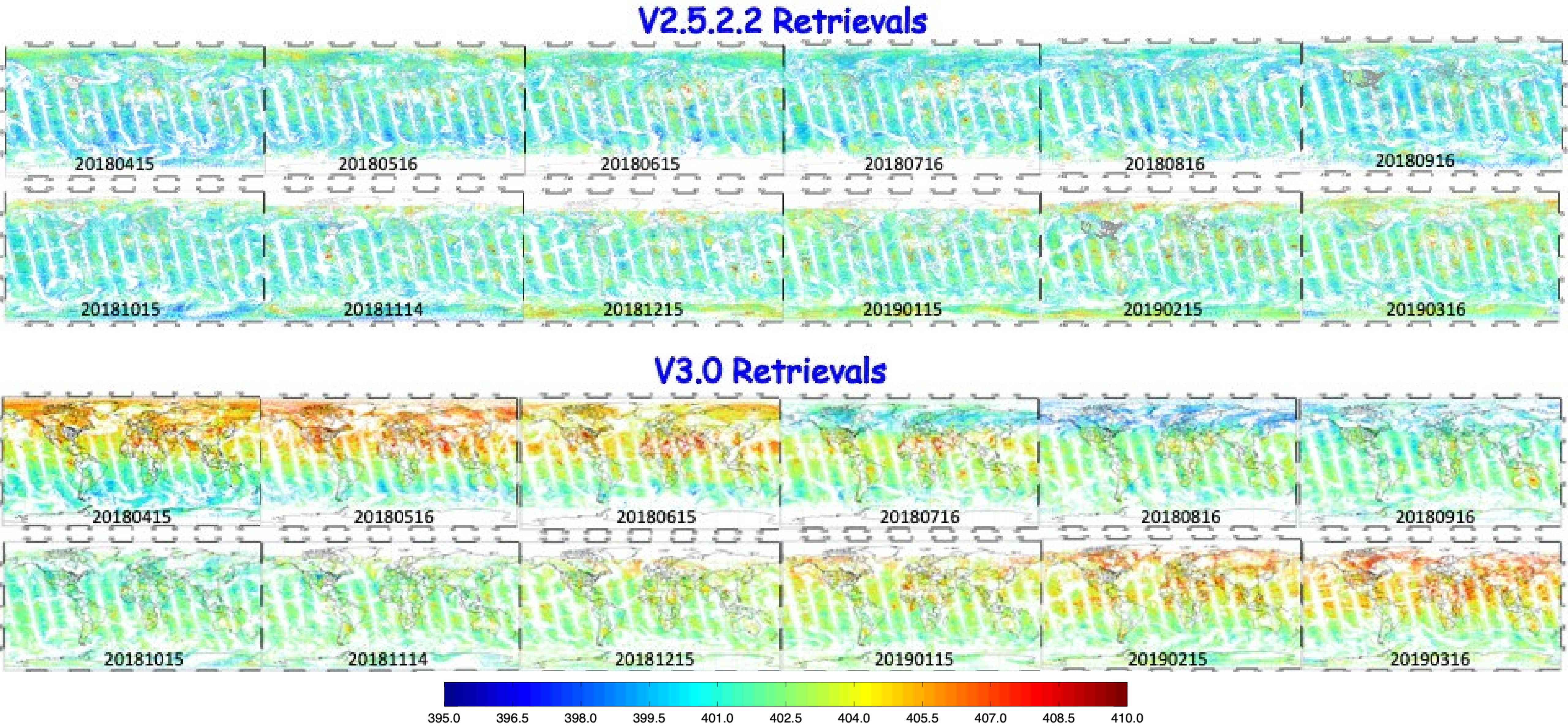
- xCO_2 – column averaged CO_2 mixing ratios
- OCO-2 – A CO_2 satellite mission. We use V9 except for the year of 2020 in the trends, which results in a discontinuity.

NUCAPS xCO_2 Retrievals Comparison with OCO-2 July 2018 Monthly Mean

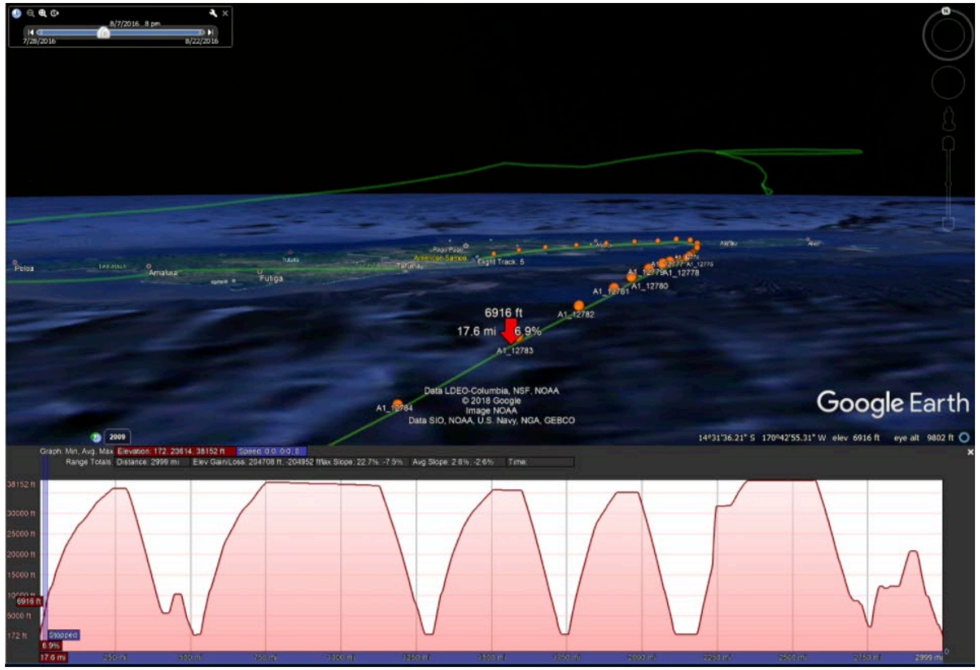


- OCO-2 – A CO_2 satellite mission
- The V3.0 CO_2 agrees much better with the OCO-2 than V2.5.2 did!

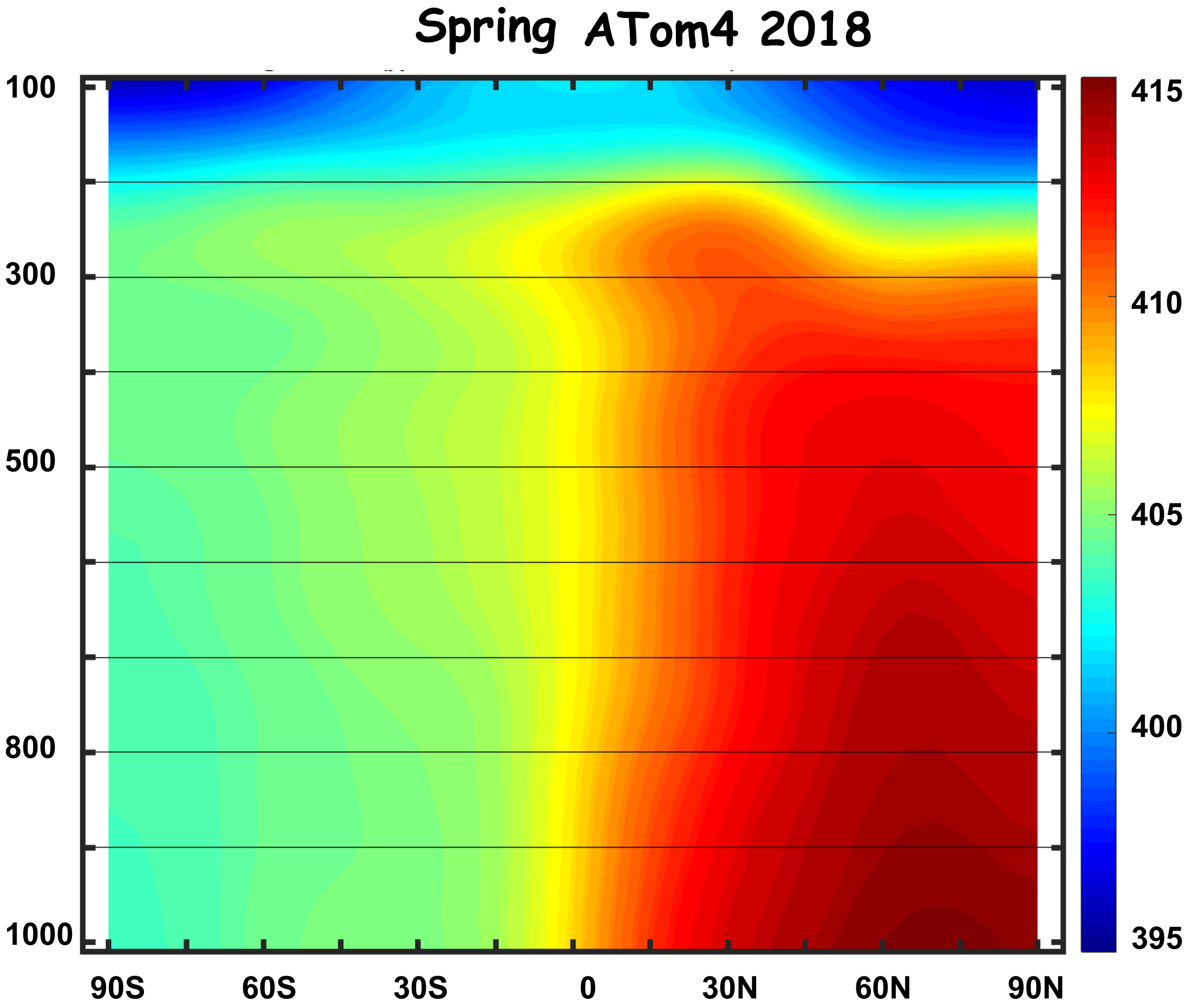
NUCAPS S-NPP CO2 V2.5.2.2 vs V3.0 at 307 hPa 12-Months Seasonality



ATom (Atmospheric Tomography Mission) 1-4 Seasonal Curtains

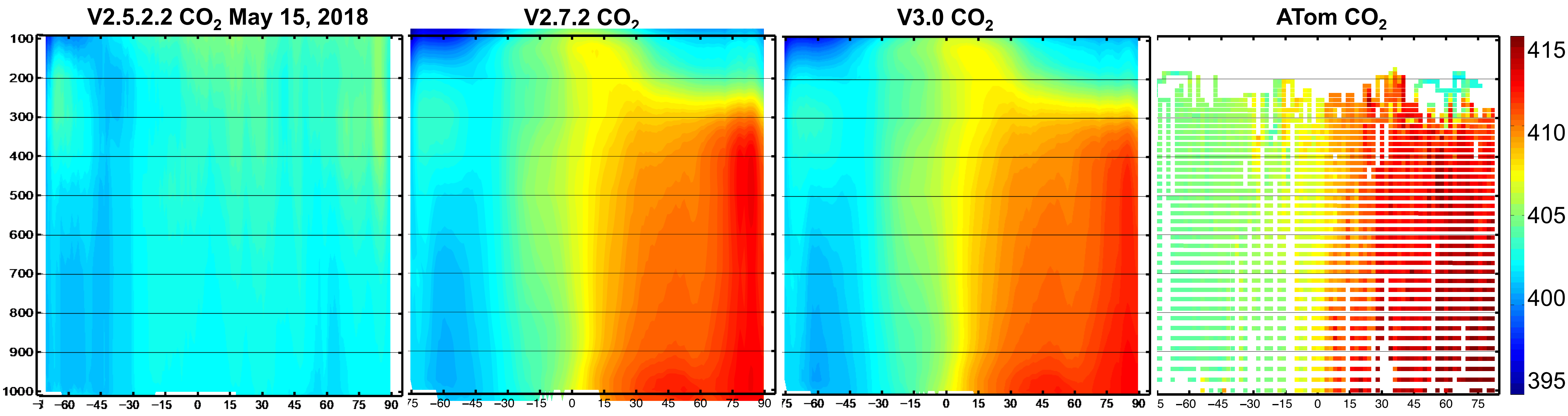


Deployment	Date Range
ATom-1	July 29 - August 23, 2016
ATom-2	January 26 - February 21, 2017
ATom-3	September 28 - October 26, 2017
ATom-4	April 24 - May 21, 2018



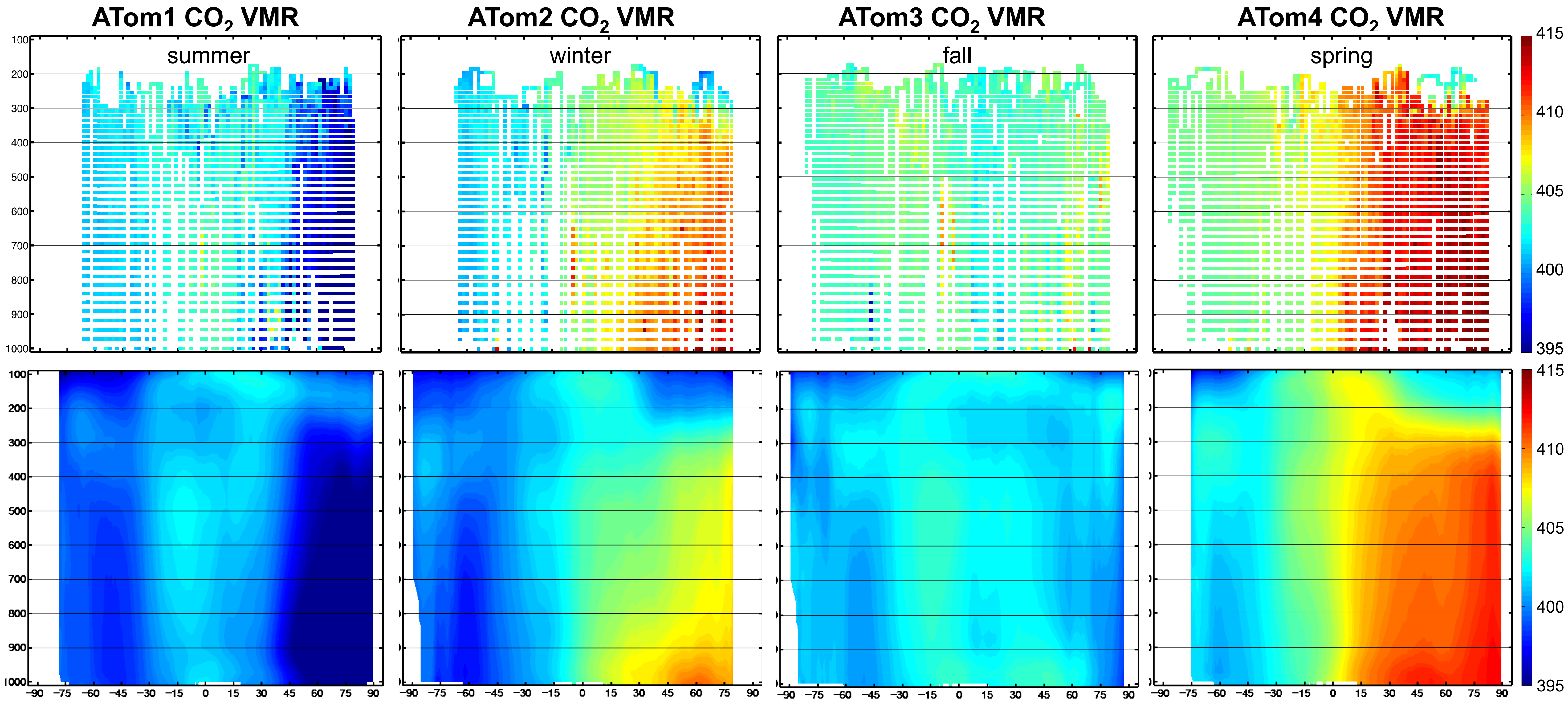
NUCAPS CO_2 VMR (ppbv) V2.5.2.2 vs V2.7.2 vs V3.0 Retrievals Against ATom4

ATom4 Apr. 24 – May 21, 2018



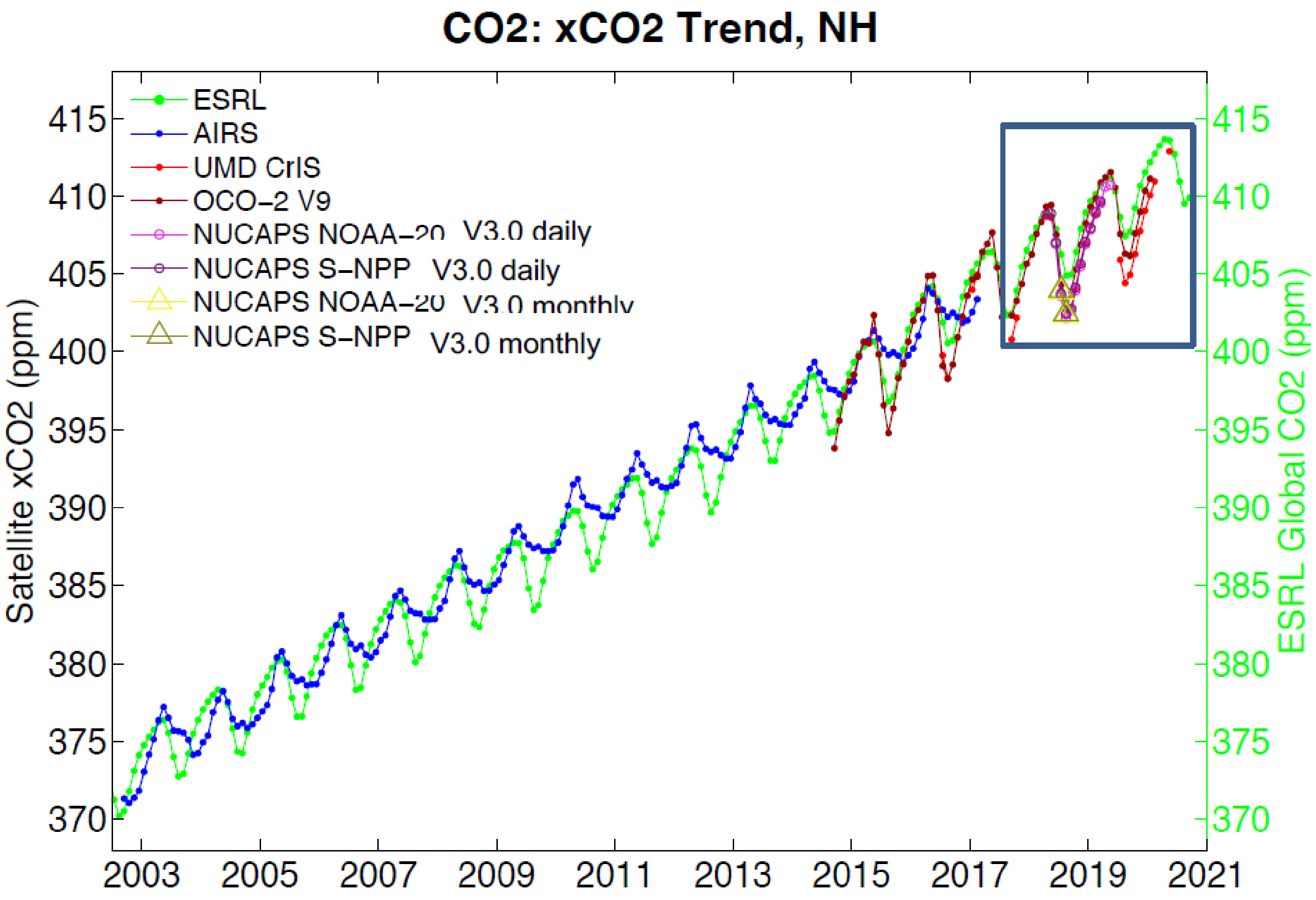
- Note V2.5.2.2 (left) is a single day curtain, while V2.7.2, V3.0 and ATom4 are entire mission period;
- V2.7.2 and V3.0 agrees with in situ measurements significantly better.

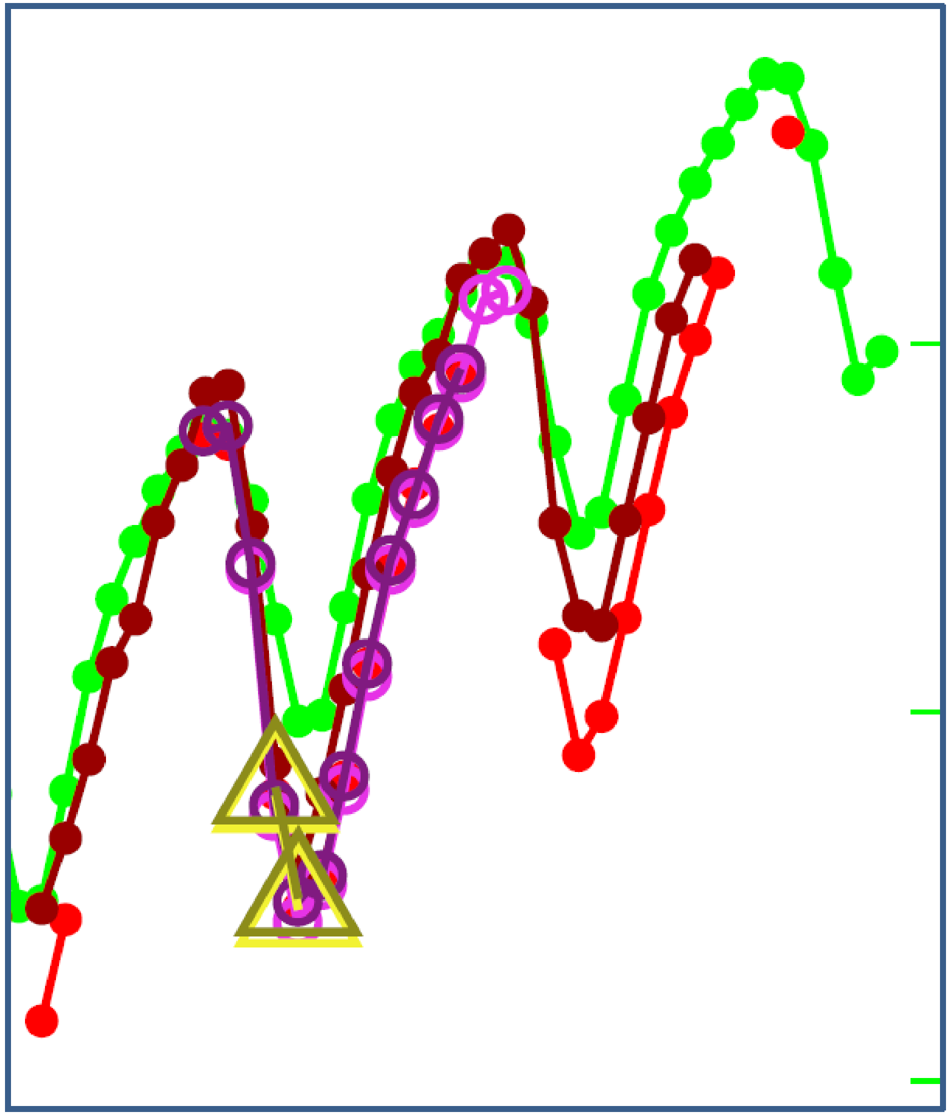
S-NPP CrIS CO_2 V2.9.1 Validate Against ATom1-4 All Sensors



- Main reason for the differences are: ATom are single tracks, primarily over ocean, but CrIS is global zonal mean, with both land and ocean.

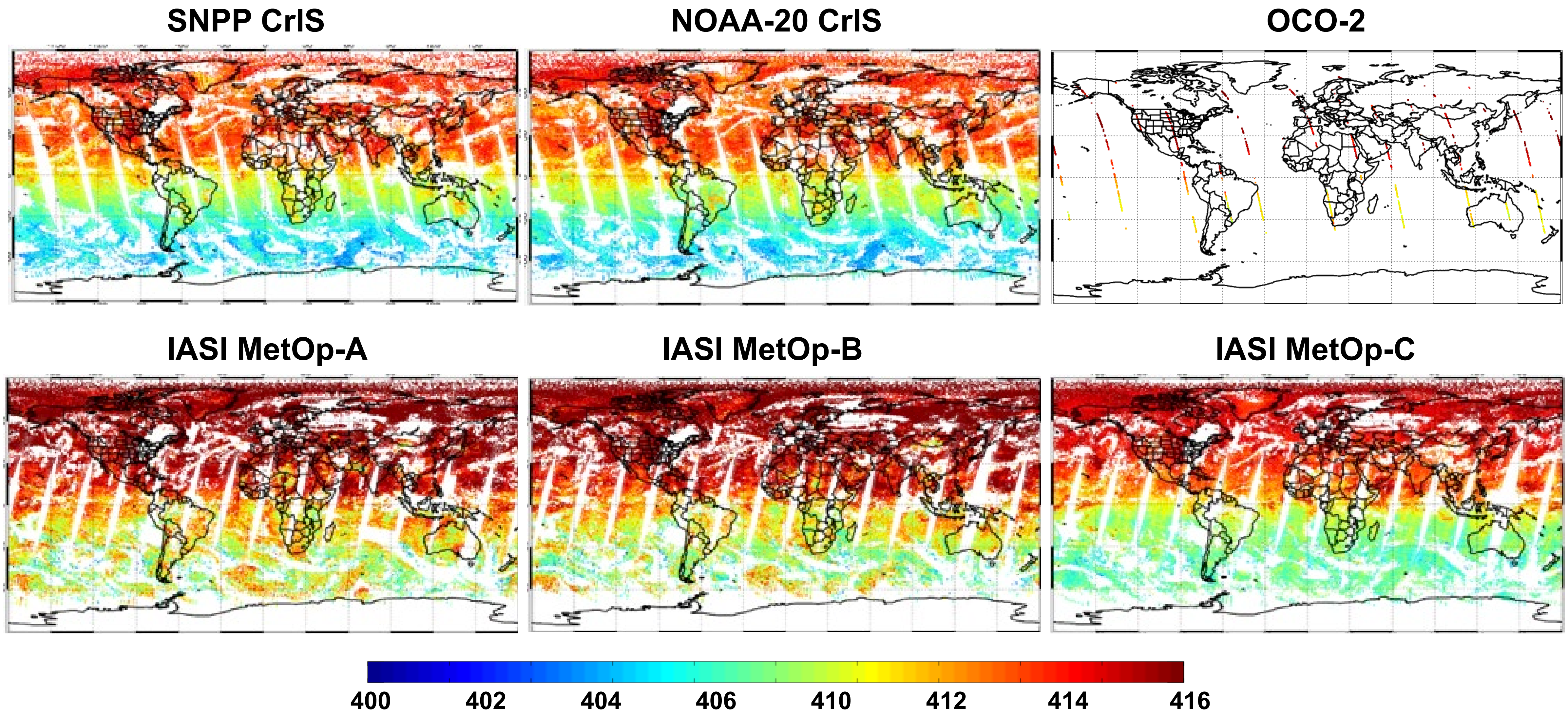
NUCAPS SNPP xCO_2 Trends V3.0 Compared with OCO-2 and AIRS





- NUCAPS CO_2 retrievals agree very well with OCO-2 trends and magnitudes, as well as the trends from ESRL!
- An improvement over AIRS

CO2 (xCO2) Comparison between CrIS (Upper) and IASI (lower)



- All MetOp IASI maps are pre Quality Assurance

MATURITY REVIEW MATERIAL – SECTION 3

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- Validation Datasets (Presented by Nick Nalli)
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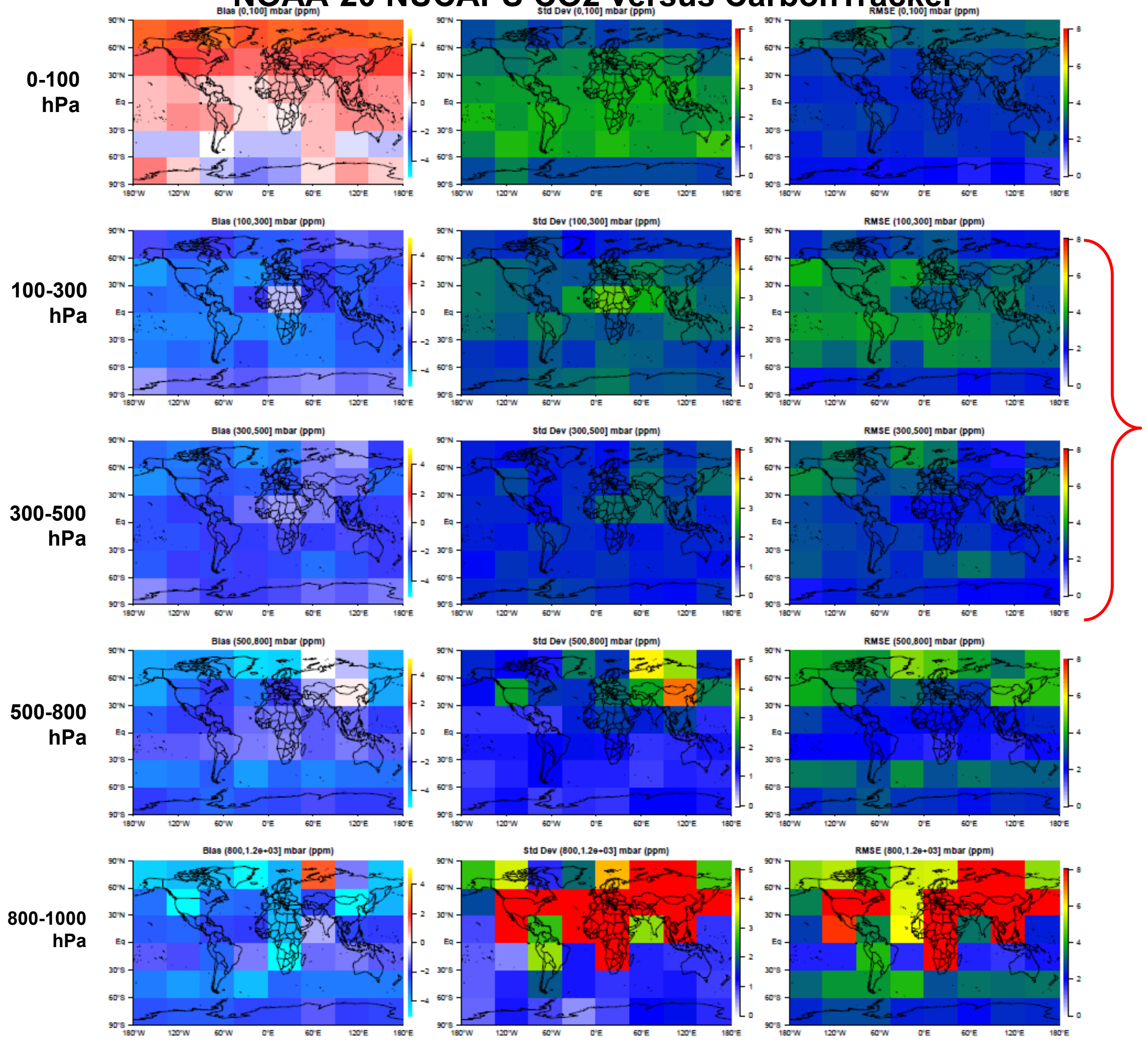
- **Expanded truth data sets and statistical analysis for validation of CO_2 (Presented by Nick Nalli)**

GML CarbonTracker Model Intercomparison (GML-NESDIS Theme 1)

NOAA-20 NUCAPS CO2 versus CarbonTracker



- As part of the **GML-NESDIS Theme 1** collaboration, GML (Andy Jacobson) provided a first-cut global model intercomparison of NUCAPS versus CarbonTracker CO2 for the Focus Day 15-Jun-2018.
- These figures (courtesy of A. Jacobson, GML) provide an indication of the global distribution of deviations of the NUCAPS CO2 retrieval from the CarbonTracker model.
- Agreement between the two is best in the layers where NUCAPS has sensitivity.

NUCAPS v3.0 versus TCCON Statistical Analysis

NOAA-20 and SNPP

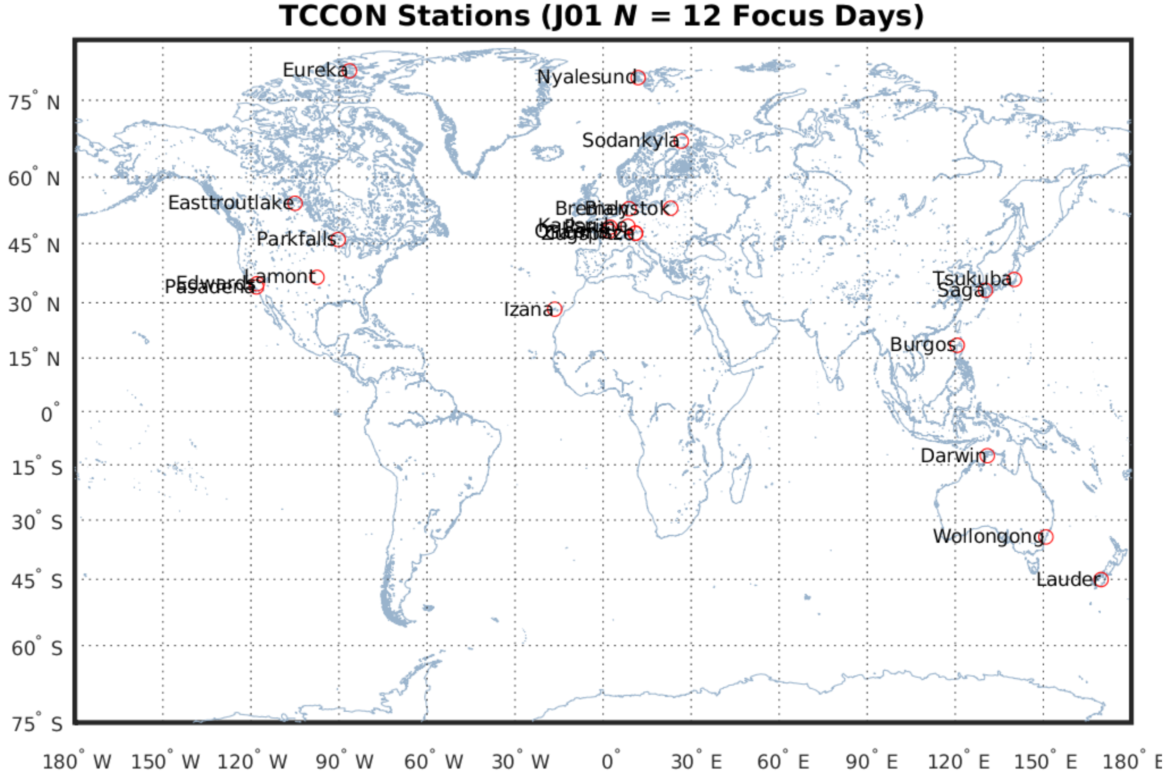
Metop-A and-B

Collocations from 12 Focus Days

TCCON Stations and Averaging Kernels (AKs)

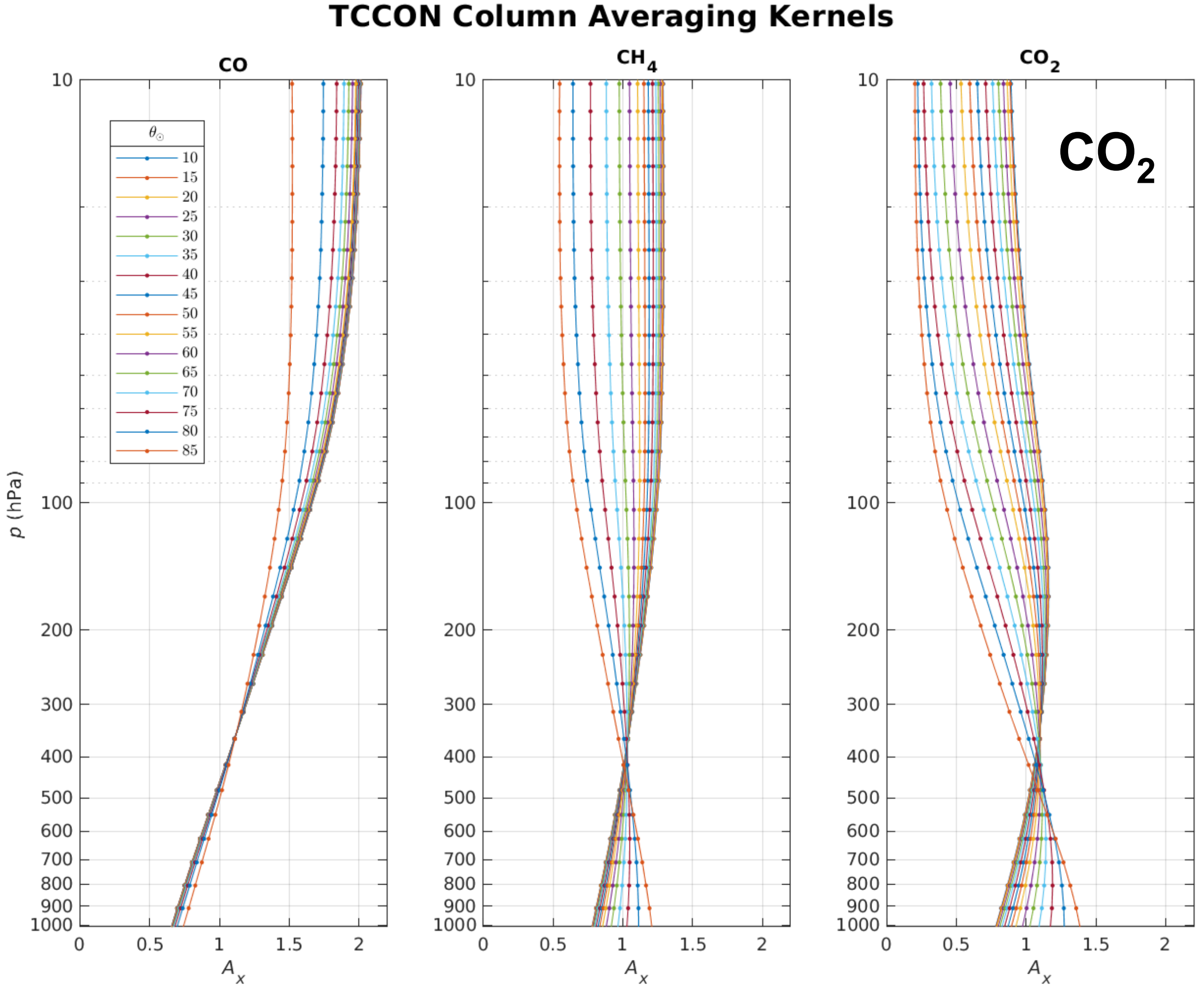
Total Carbon Column Observing Network
TCCON (*Wunch et al.* 2011)

Collocated Focus Day Stations
NOAA-20 Trace Gas QA, ±2 hr, 125 km



- **Global network of ground-based FTS** that accurately measure total column abundances of CO_2, CO, CH_4, N_2O trace gases
- Serves as **SNPP ↔ NOAA-20 transfer standard**, complementing the ATom analysis

Column AKs

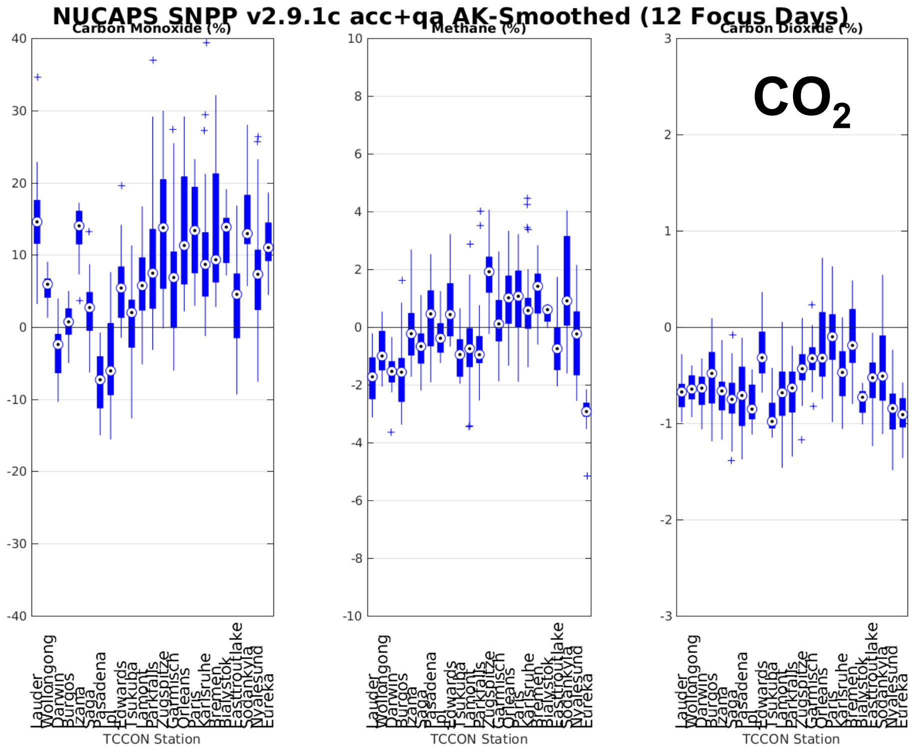


NUCAPS v3.0 Total Column Trace Gases vs TCCON: Statistical Analysis JPSS

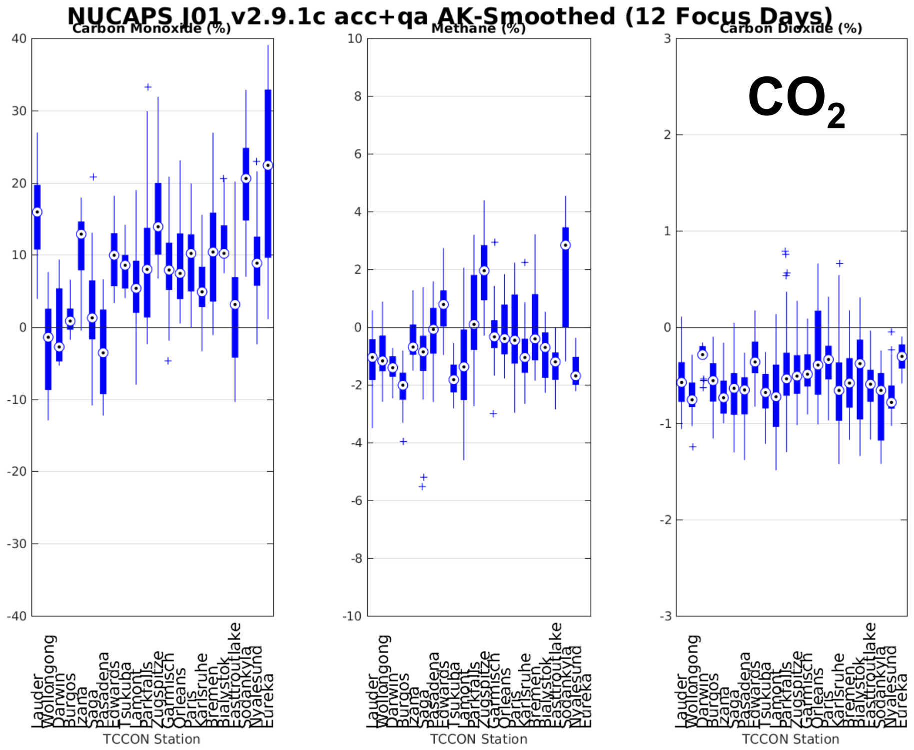
Box-Whisker Statistics by TCCON Station

(Sorted in order of latitude)

SNPP



NOAA-20



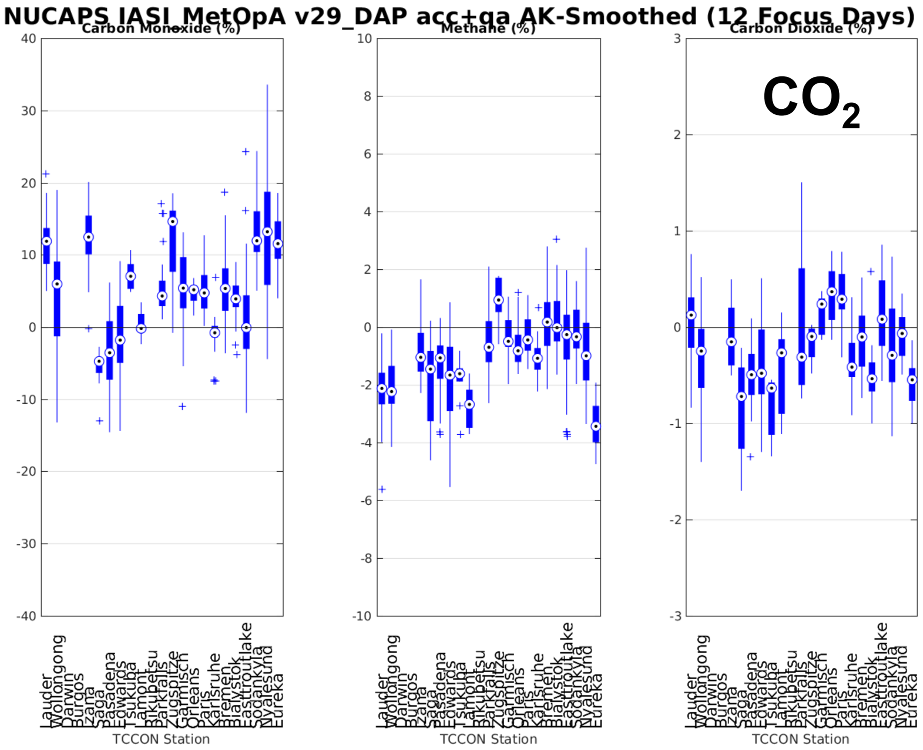
NUCAPS – TCCON

NUCAPS v3.0 Total Column Trace Gases vs TCCON: Statistical Analysis Metop

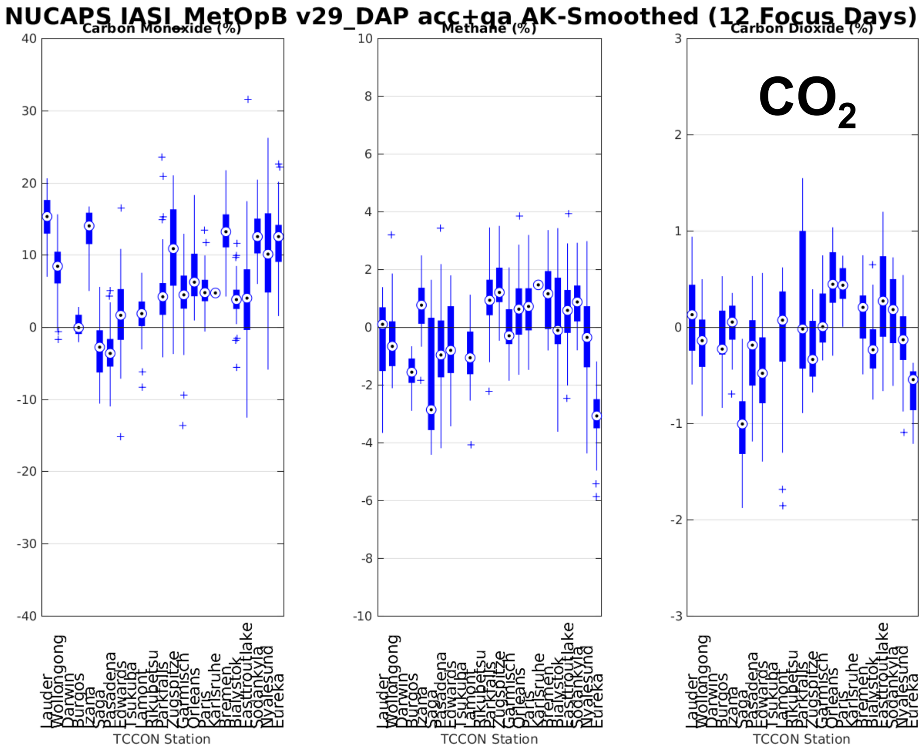
Box-Whisker Statistics by TCCON Station

(Sorted in order of latitude)

Metop-A



Metop-B

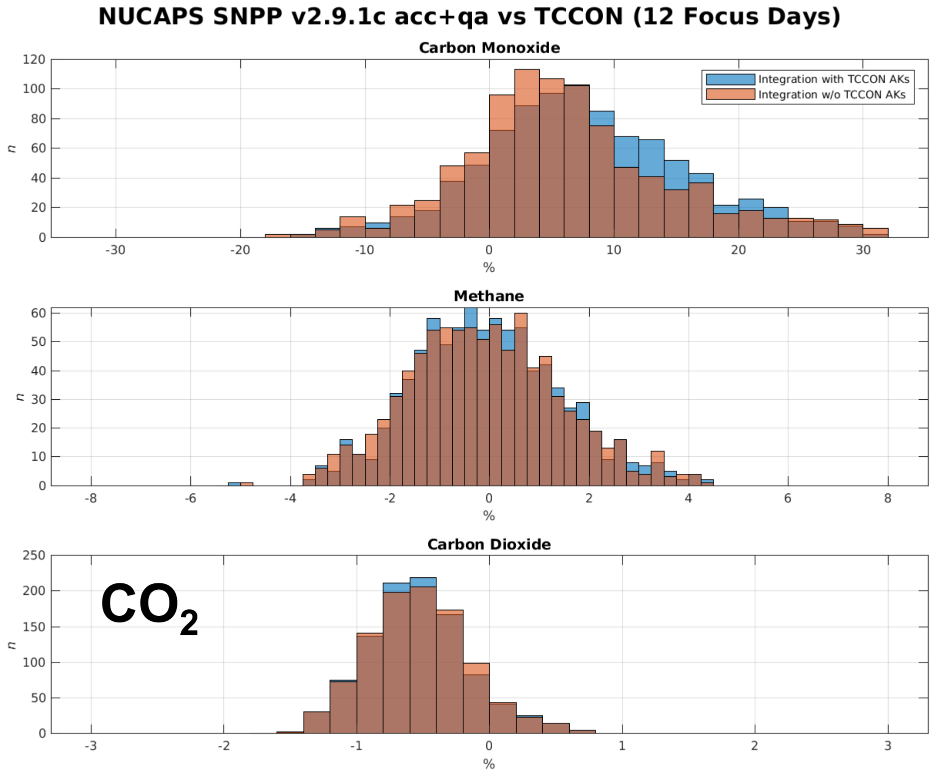


NUCAPS – TCCON

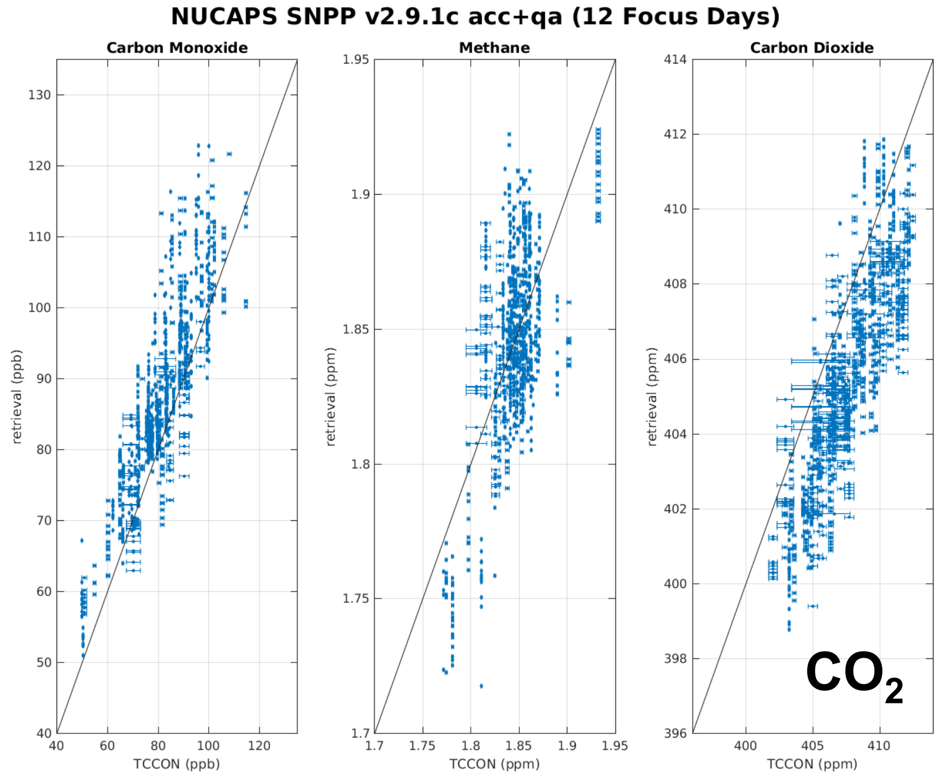
SNPP NUCAPS v3.0 Total Column Trace Gases vs TCCON

Statistical Analysis 12 Focus Days

Histograms



Scatterplots

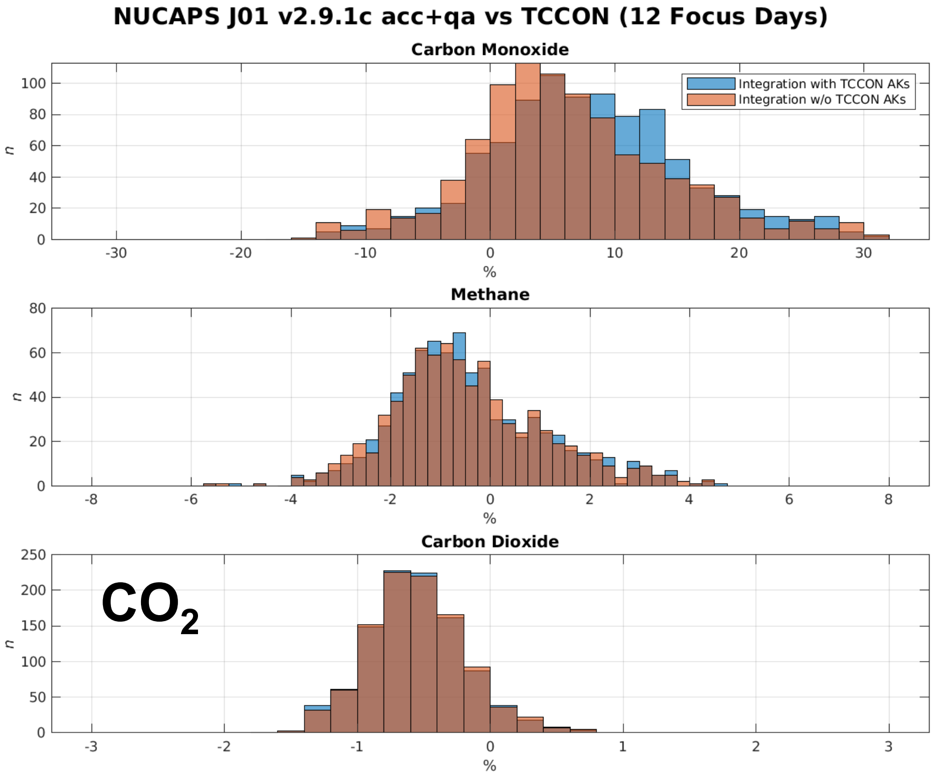


NUCAPS – TCCON

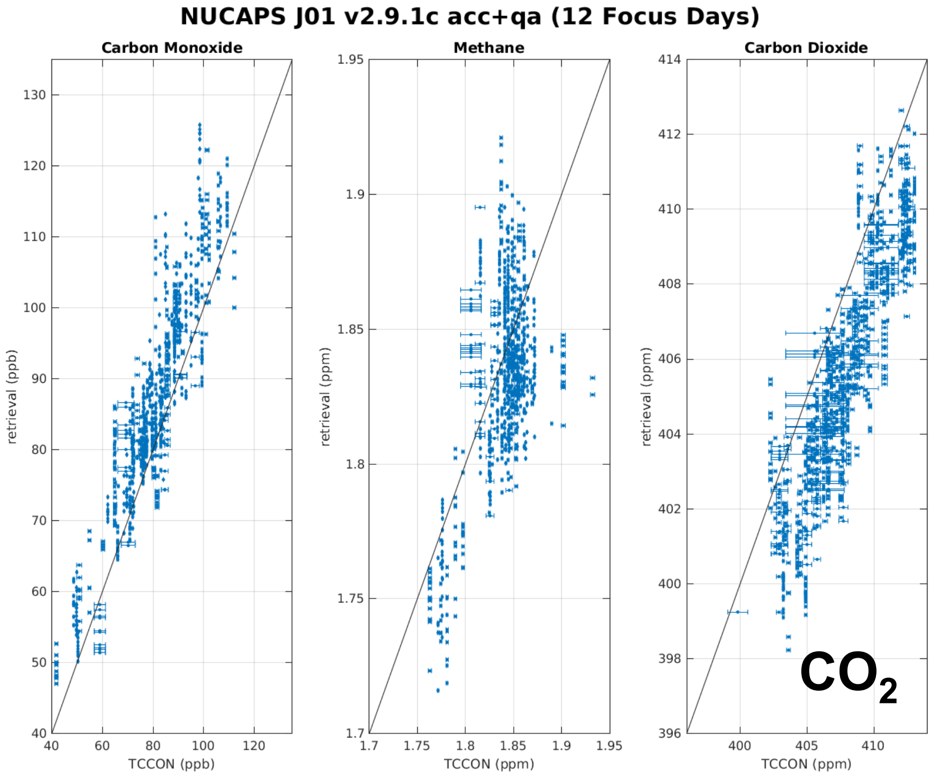
NOAA-20 NUCAPS v3.0 Total Column Trace Gases vs TCCON

Statistical Analysis for 12 Focus Days

Histograms



Scatterplots

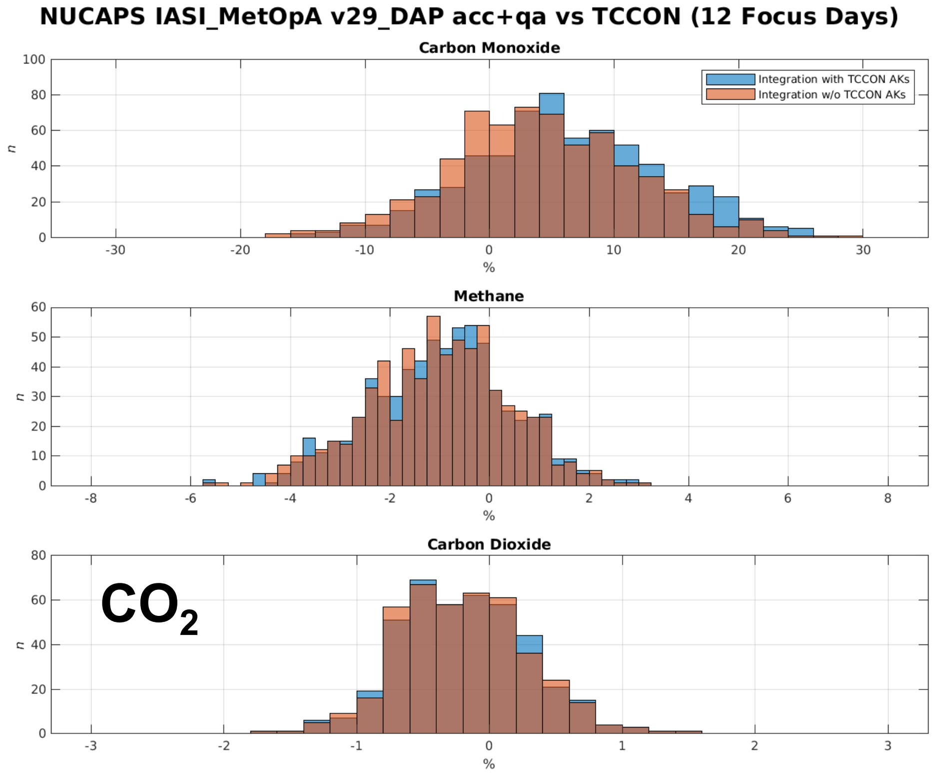


NUCAPS – TCCON

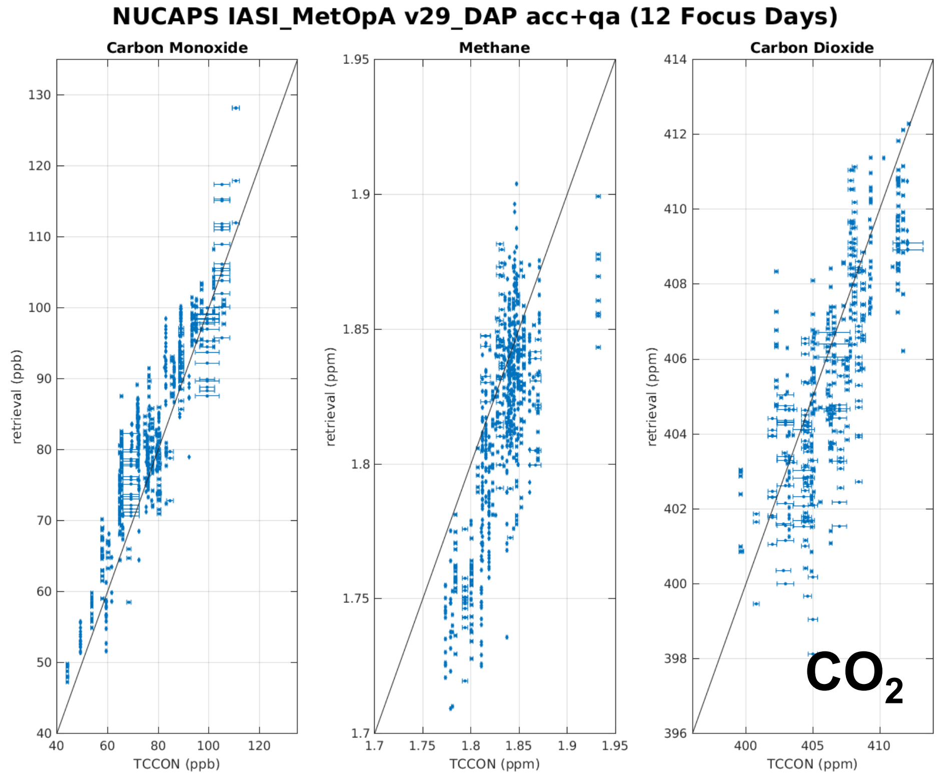
Metop-A NUCAPS v3.0 Total Column Trace Gases vs TCCON

Statistical Analysis 12 Focus Days

Histograms



Scatterplots

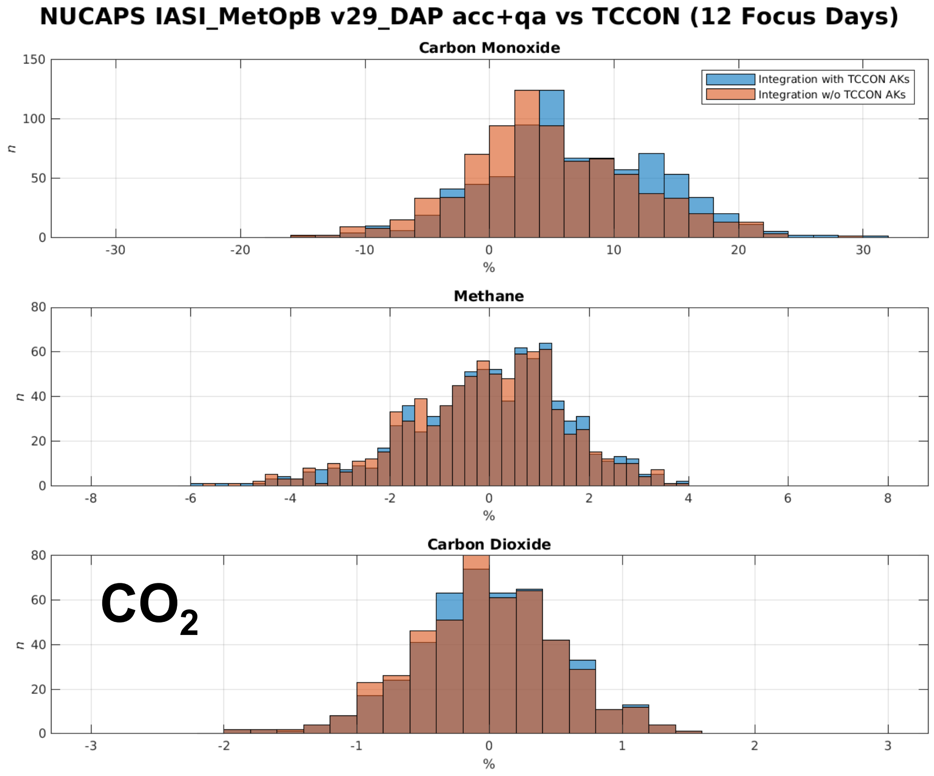


NUCAPS – TCCON

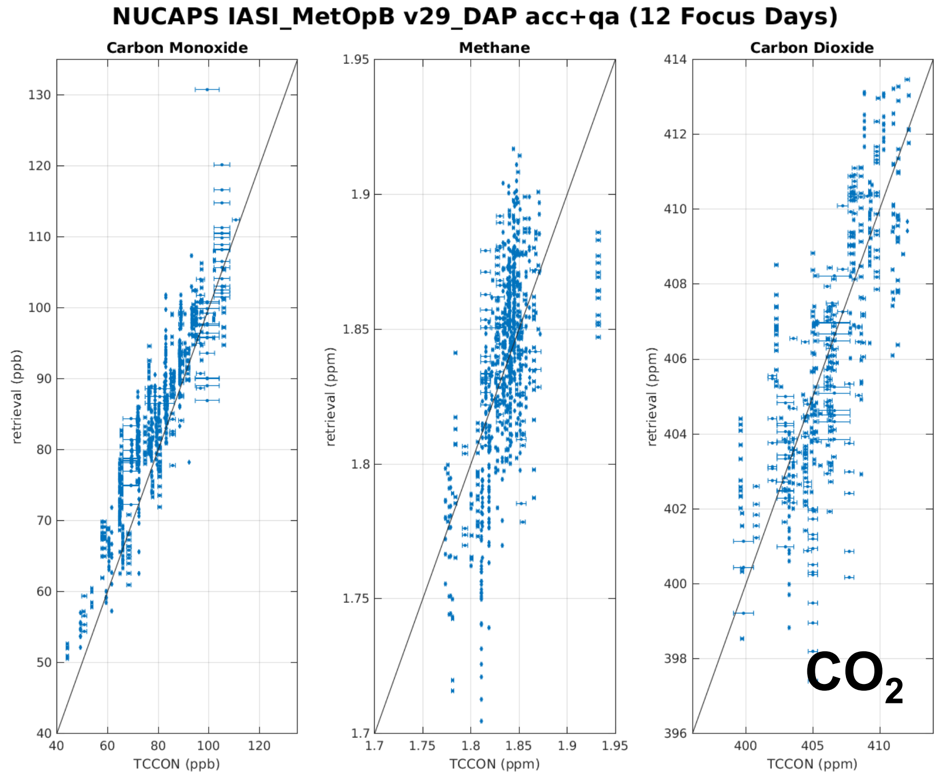
Metop-B NUCAPS v3.0 Total Column Trace Gases vs TCCON

Statistical Analysis 12 Focus Days

Histograms



Scatterplots

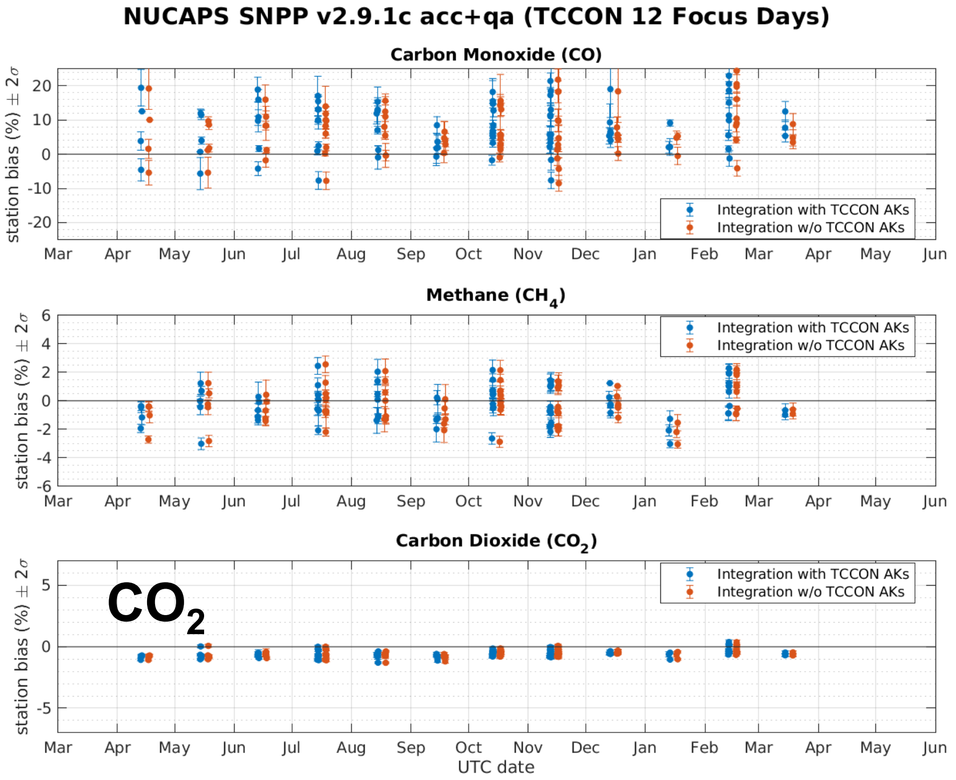


NUCAPS – TCCON

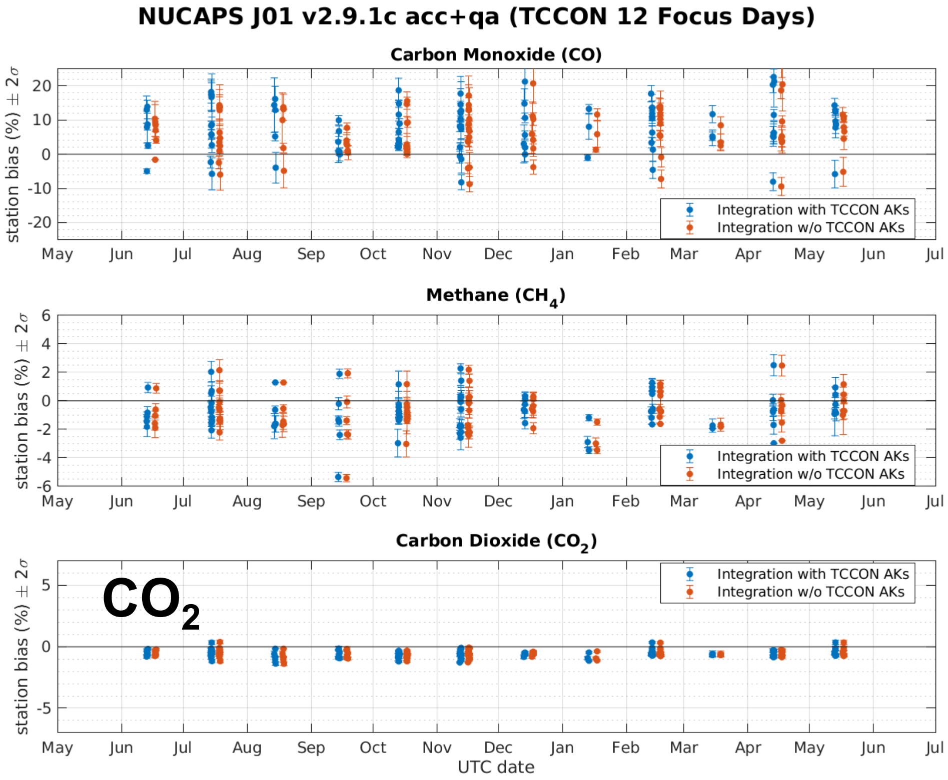
NUCAPS v3.0 Total Column Trace Gases vs TCCON: Statistical Analysis JPSS

12 Focus Day Time Series Spanning Annual Cycle

SNPP



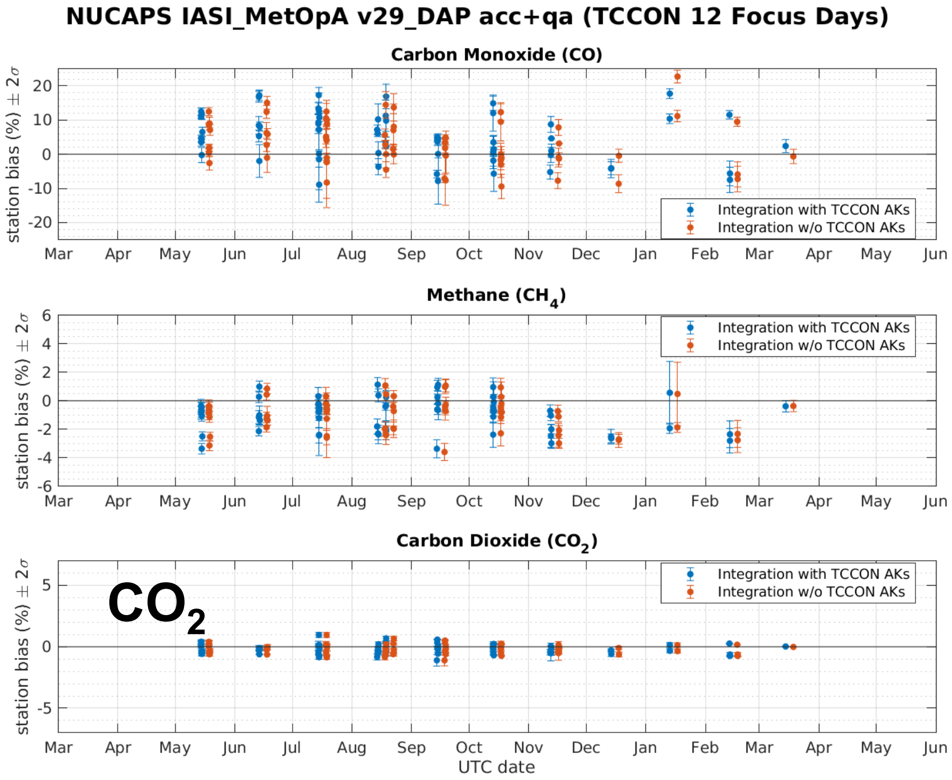
NOAA-20



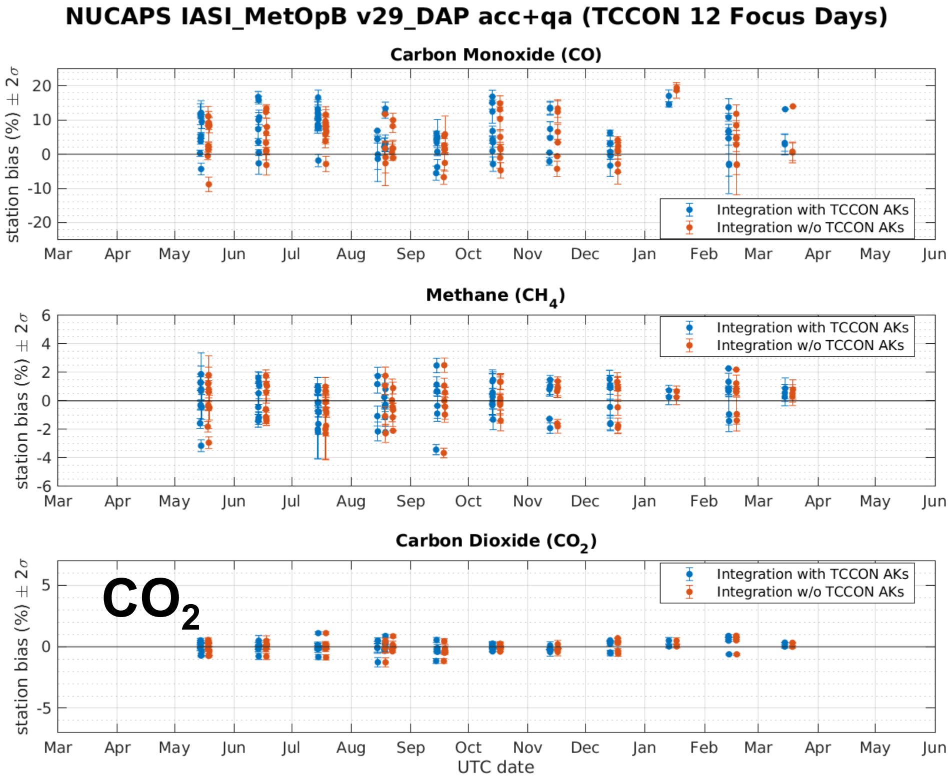
NUCAPS – TCCON

12 Focus Day Time Series Spanning Annual Cycle

Metop-A



Metop-B



NUCAPS – TCCON

NOAA-20 and SNPP NUCAPS V3.0 versus TCCON: Statistical Summary

SNPP ↔ NOAA-20 Transfer Standard

Parameter	Stat	Raw Total Column		TCCON AKs applied	
		NUCAPS	Req	NUCAPS	Req
CO	Precision	8.4 (8.7)	15%	8.2 (8.4)	15%
	Accuracy	+6.5 (+6.5)	±5%	+8.0 (+7.9)†	±5%
CH4	Precision	1.6 (1.5)*	1%* (20 ppmv)	1.5 (1.5)*	1% (20 ppmv)
	Accuracy	−0.4 (−0.1)	4% (80 ppmv)	−0.6 (+0.0)	4% (80 ppmv)
CO2	Precision	0.4 (0.4)	0.5% (2 ppmv)	0.4 (0.5)	0.5% (2 ppmv)
	Accuracy	−0.5 (−0.5)	±1% (4 ppmv)	−0.6 (−0.5)	±1% (4 ppmv)

Values in ( ) indicates SNPP

- Meets requirement
- Marginal (± 25%)
- Outside Requirement (with explanation)

NOTES
*Precision requirements for CH4 are now known to be too stringent and will require waver.
†NUCAPS CO sensitivity peaks in mid-troposphere whereas TCCON peaks above 100 hPa.

NOAA-20, SNPP V3.0 Global Yields:
CO = 69.5 (70.7)%, *N* = 922 (923)
CH4 = 60.2 (67.7)%, *N* = 799 (884)
CO2 = 76.9 (77.5)%, *N* = 1020 (1011)

Metop-A and -B NUCAPS V3.0 versus TCCON: Statistical Summary

Metop ↔ SNPP ↔ NOAA-20 Transfer Standard

Parameter	Stat	Raw Total Column		TCCON AKs applied	
		NUCAPS	Req	NUCAPS	Req
CO	Precision	7.5 (6.8)	15%	7.7 (7.0)	15%
	Accuracy	+4.2 (+4.8)	±5%	+6.1 (+6.7)†	±5%
CH4	Precision	1.4 (1.5)*	1%* (20 ppmv)	1.4 (1.6)*	1% (20 ppmv)
	Accuracy	−1.0 (−0.1)	4% (80 ppmv)	−1.0 (+0.0)	4% (80 ppmv)
CO2	Precision	0.5 (0.6)	0.5% (2 ppmv)	0.5 (0.5)	0.5% (2 ppmv)
	Accuracy	−0.2 (0.0)	±1% (4 ppmv)	−0.2 (0.0)	±1% (4 ppmv)

Values in ( ) indicates Metop-B

- Meets requirement
- Marginal (± 25%)
- Outside Requirement (with explanation)

NOTES

*Precision requirements for CH4 are now known to be too stringent and will require waver.

†NUCAPS CO sensitivity peaks in mid-troposphere whereas TCCON peaks above 100 hPa.

Metop-A (-B) V3.0 Global Yields:

CO = 61.1 (66.3)%, *N* = 643 (788)

CH4 = 65.1 (68.3)%, *N* = 686 (812)

CO2 = 40.0 (39.4)%, *N* = 421 (468)

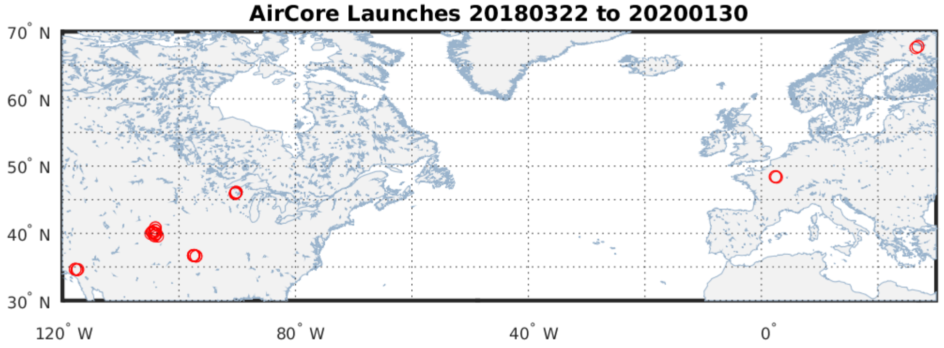
NUCAPS v3.0 Versus AirCore Statistical Analysis

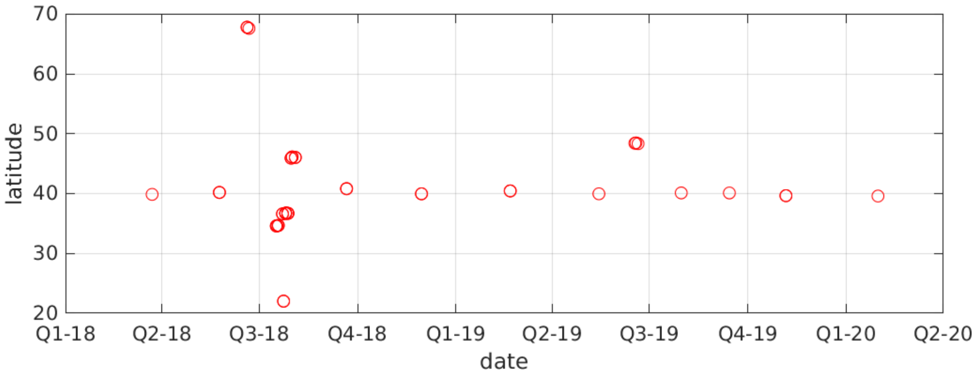
SNPP and NOAA-20

NOAA/GML AirCore Launches 2016-2018

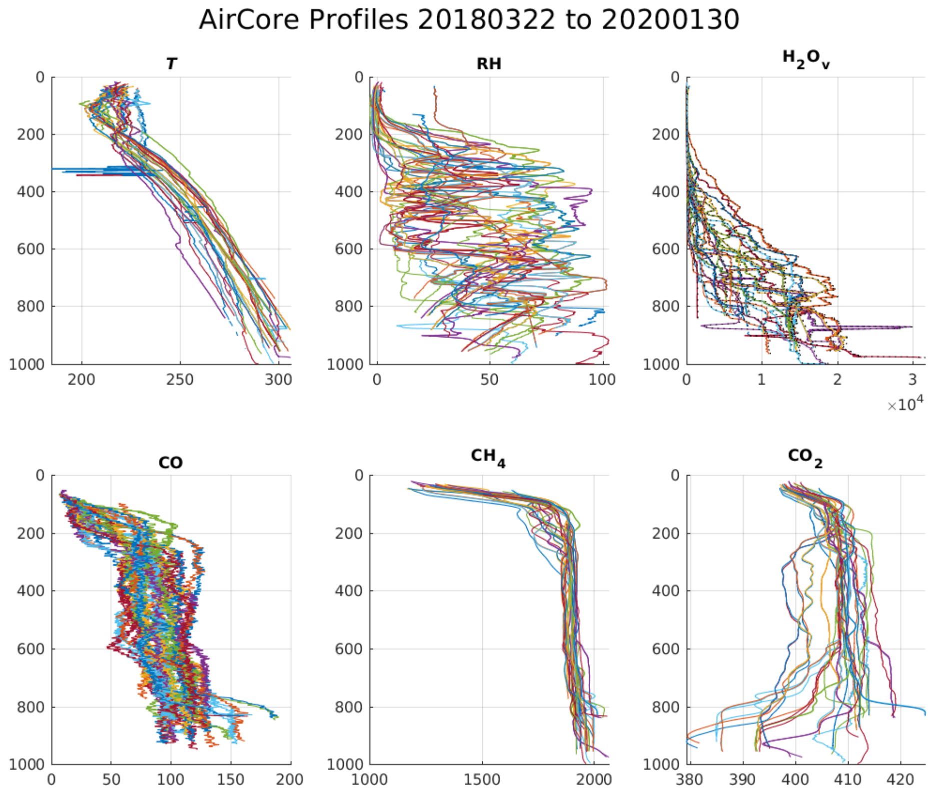
NOAA-20 NUCAPS v3.0 AirCore Sample Collocations

Space-Time Collocations

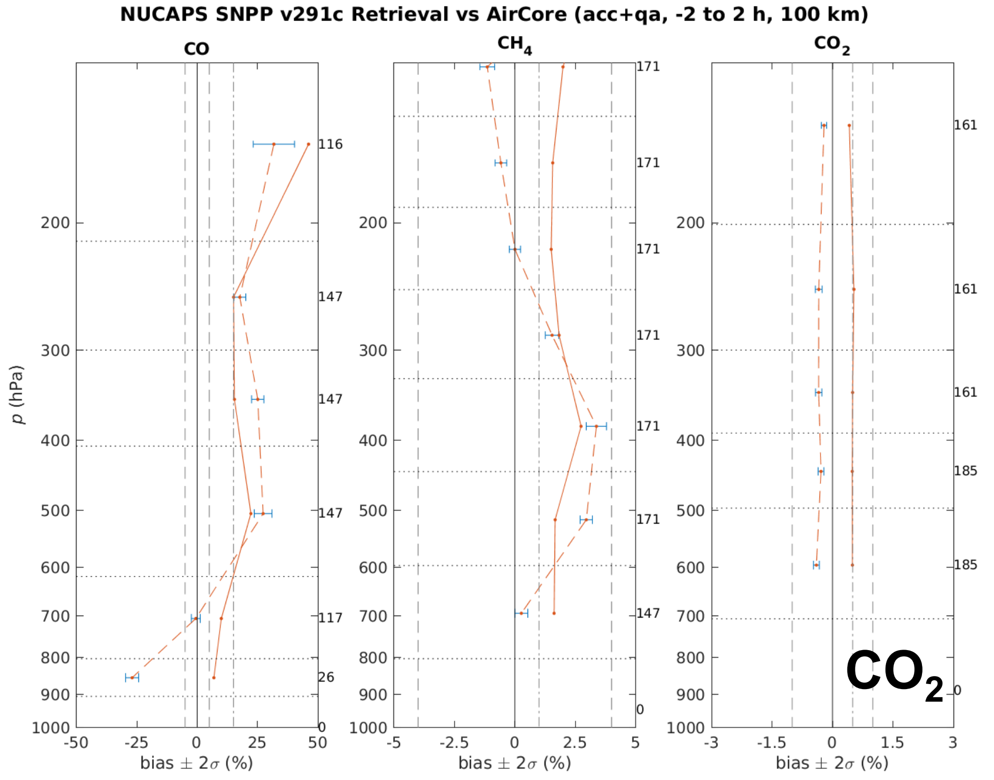




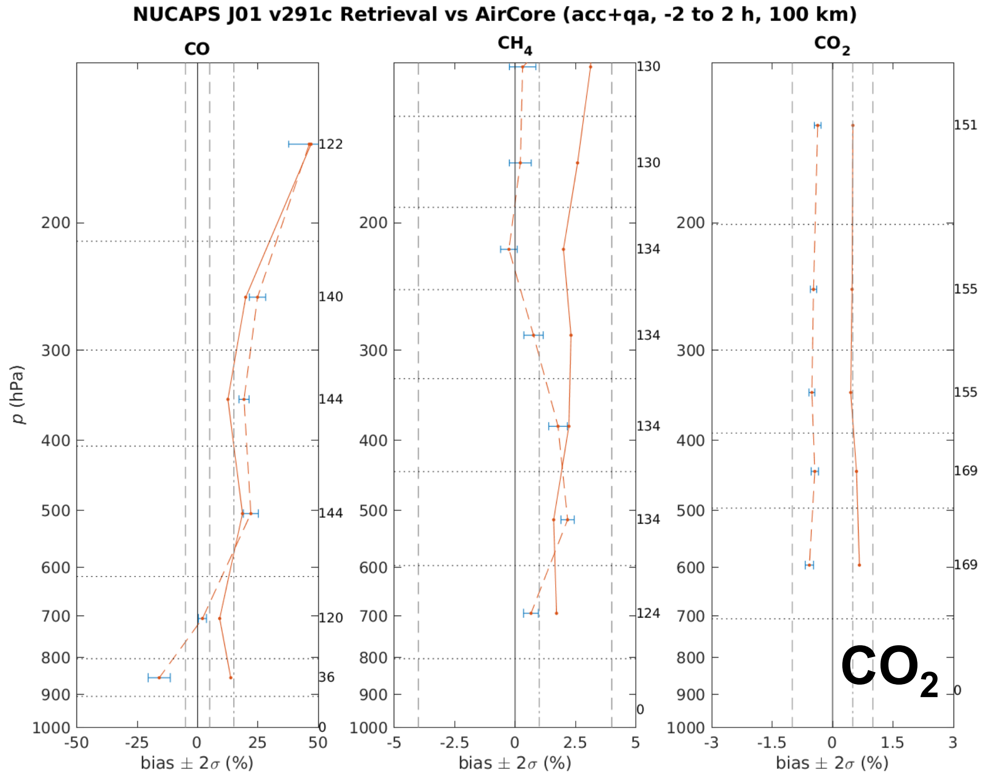
Profiles



SNPP

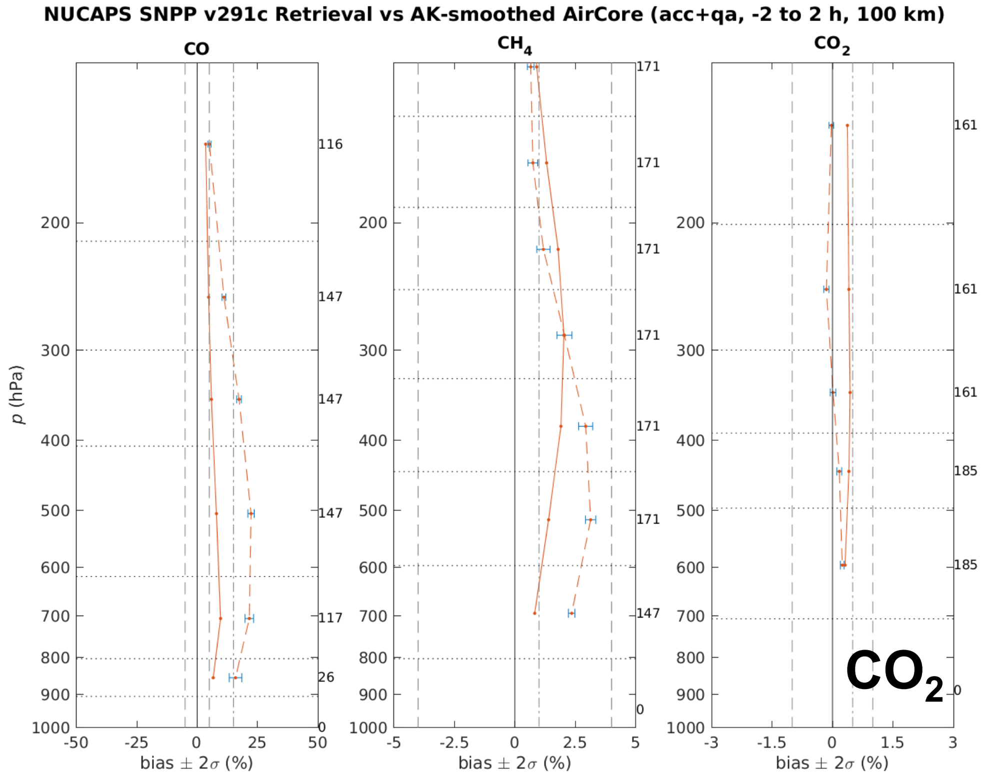

NUCAPS SNPP v291c Retrieval vs AirCore (acc+qa, -2 to 2 h, 100 km)
CO
CH_4
CO_2
p (hPa)
bias ± 2σ (%)
CO_2

NOAA-20

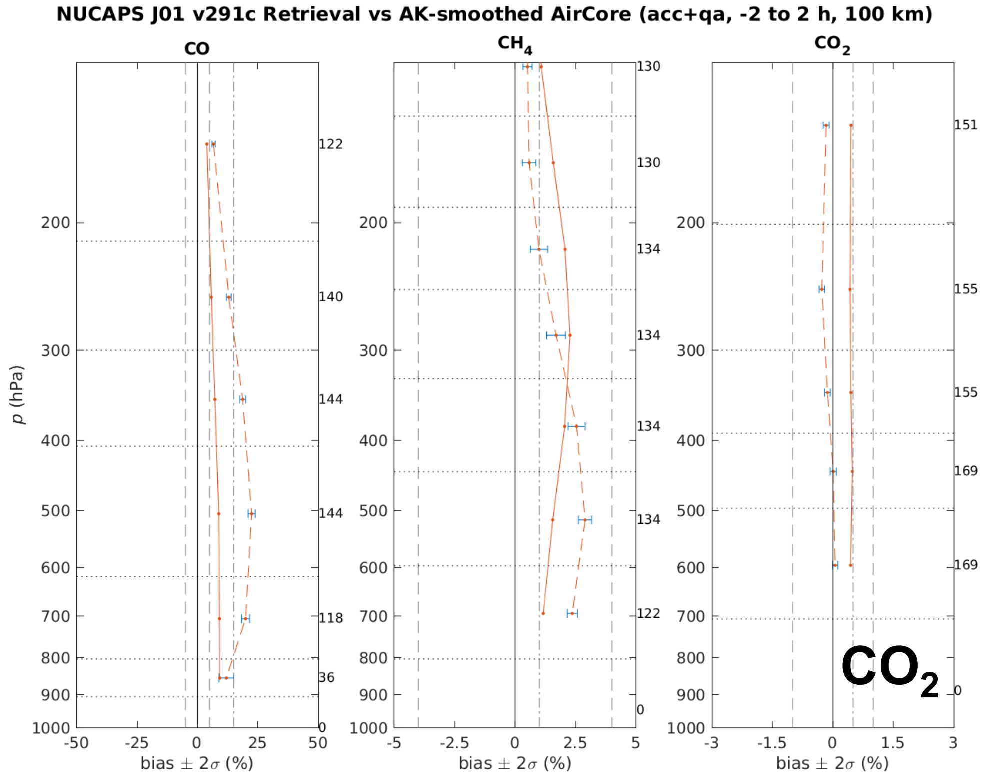

NUCAPS J01 v291c Retrieval vs AirCore (acc+qa, -2 to 2 h, 100 km)
CO
CH_4
CO_2
p (hPa)
bias ± 2σ (%)
CO_2

NUCAPS v3.0 Retrieval vs AirCore w AKs Profile Statistics

SNPP



NOAA-20



NUCAPS v3.0 Versus ATom Statistical Analysis

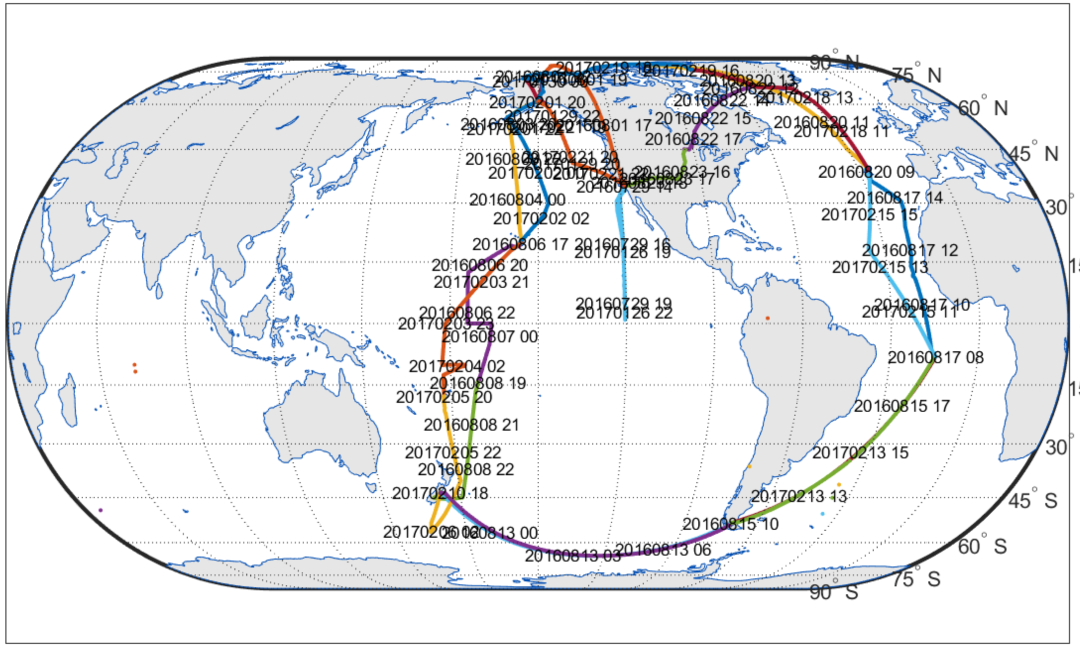
SNPP and NOAA-20

ATom-1,-2 and -4 Aircraft Campaigns 2016-2018

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 spanning 4 seasons originating from the Armstrong Flight Research Center, Palmdale, California
- We use the **NOAA Picarro ATom-1, -2** and **-4** datasets (2016-2018)
  - We have fully implemented the **ATom VALAR dataset for NOAA-20**, based upon **2018 ATom-4**
  - Additionally, we have enhanced the **SNPP ATom VALAR dataset**
    - **Updated the ATom-1,-2** truth profiles with the latest release versions
    - Included the **ATom-4** along with the **ATom-1,-2** data, creating a larger collocation ensemble

ATom Flights 2016-2017 (Wofsy et al. 2018)



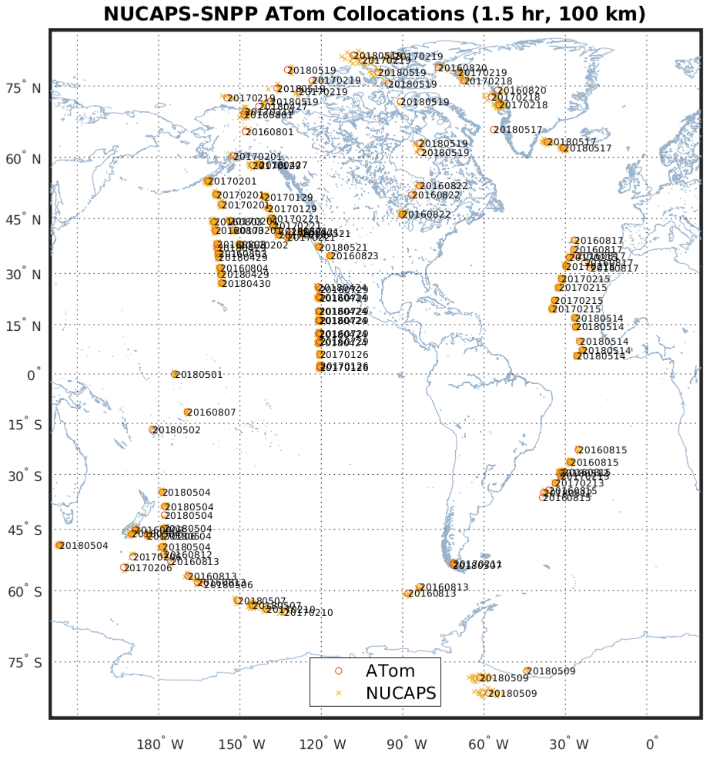
Source: [*https://espo.nasa.gov/atom/*](https://espo.nasa.gov/atom/)

NUCAPS ATom CO_2 Trace Gas Statistical Summary

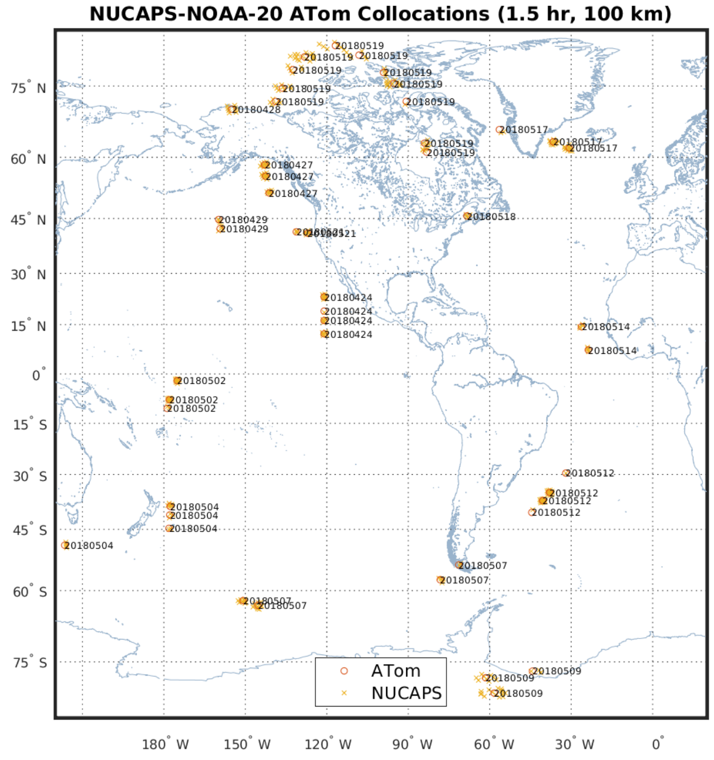
- **SNPP** and **NOAA-20** retrievals are comparable
- *T*/H_2O/O_3 favorably compare with ATom truth, are comparable with OPS and have not suffered any degradation
- **NUCAPS CO_2 trace gas retrievals improve the *a priori*** in the layers of sensitivity
- **CO_2 retrievals** and ***a priori*** are **significantly improved** over OPS
- **CO_2 retrievals** are "near-perfect" after applying AKs to the ATom data
- **NUCAPS CO_2 trace gas retrievals meet JPSS L1 Requirements**

ATom-NUCAPS v3.0 Extended Sample Collocations (ATom-1,-2,-4)

SNPP Extracted ATom Profile Collocations



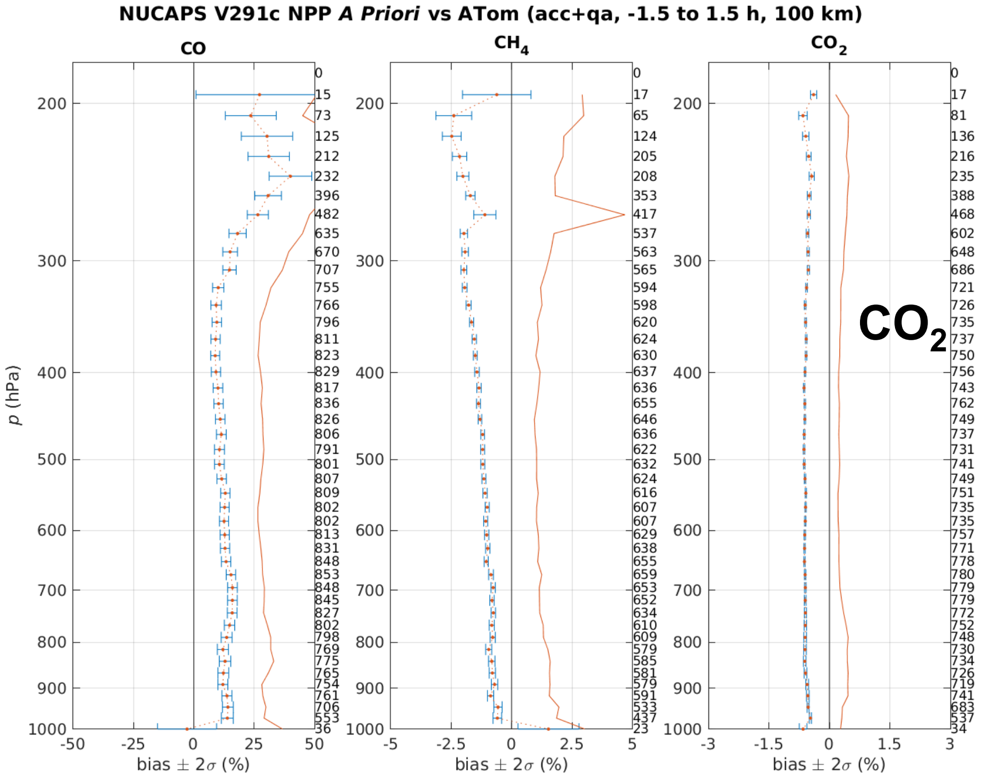
NOAA-20 Extracted ATom Profile Collocations



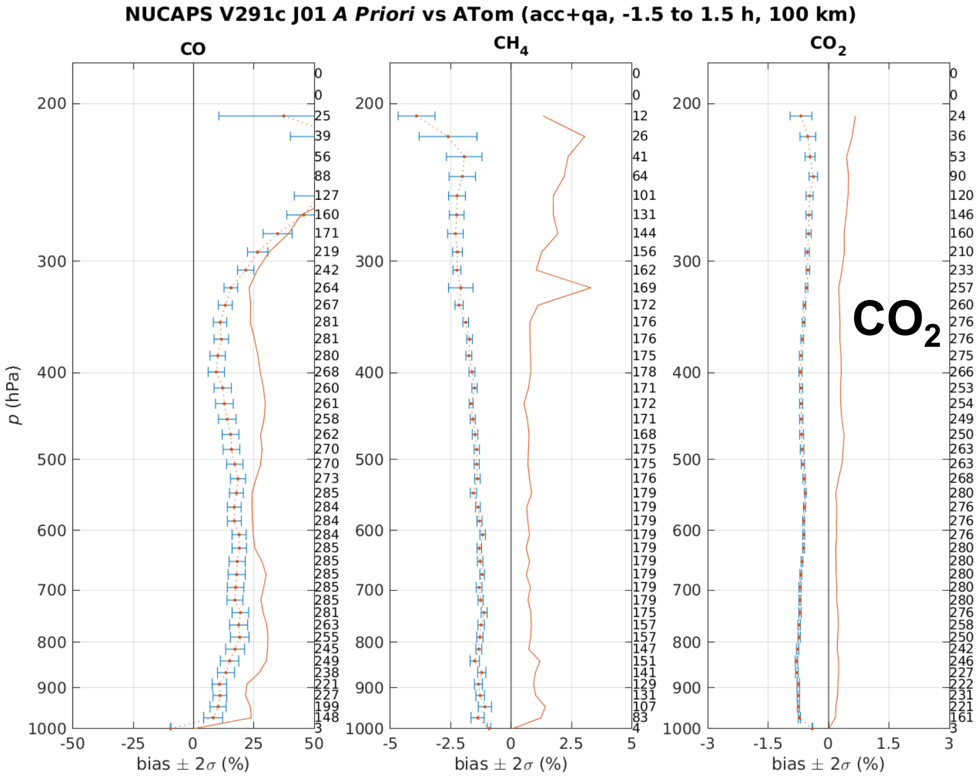
NUCAPS v3.0 *A Priori* vs ATom: 100 Layer Profile Statistical Analysis

CO / CH_4 / CO_2

SNPP



NOAA-20

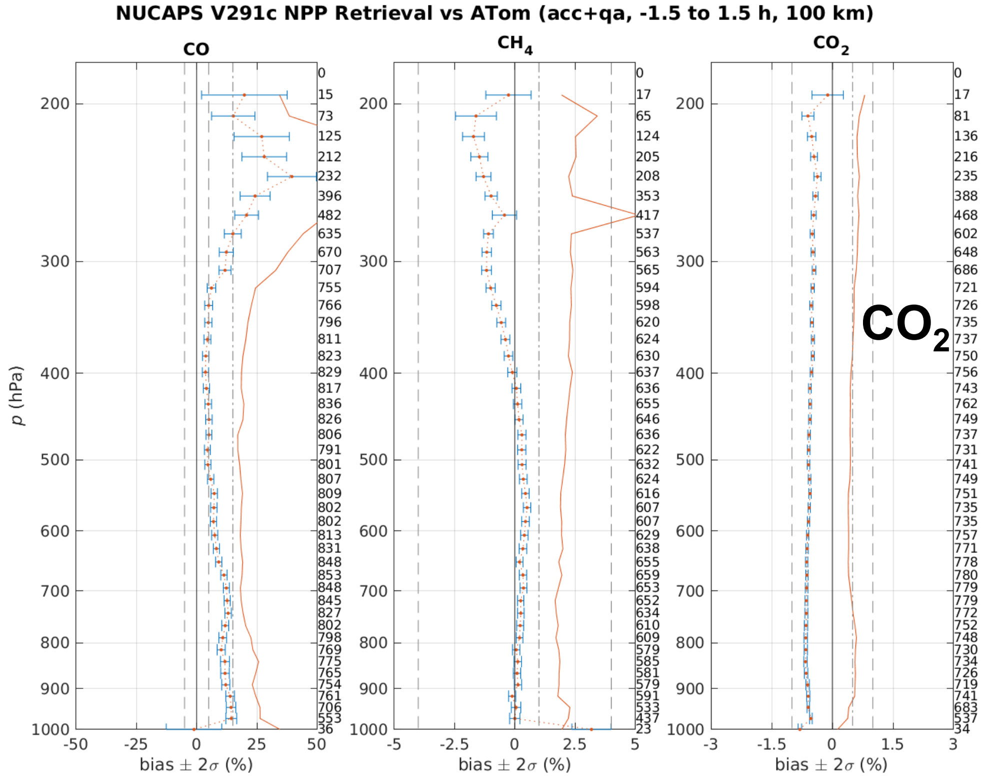


NUCAPS – ATom

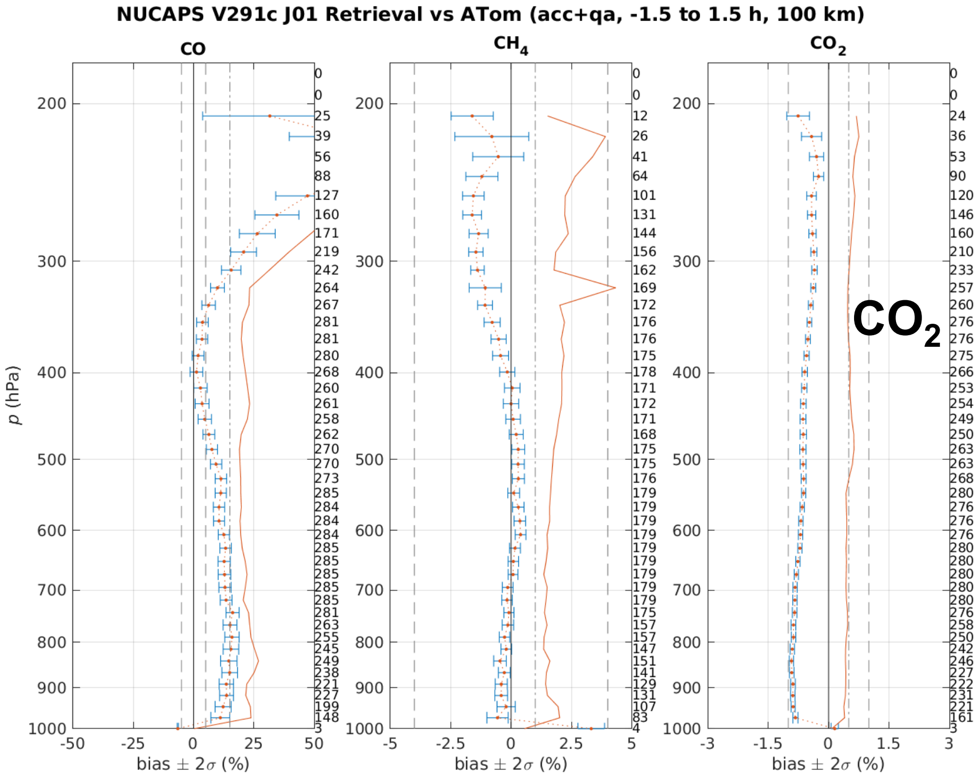
NUCAPS v3.0 Retrieval vs ATom: 100 Layer Profile Statistical Analysis

CO / CH_4 / CO_2

SNPP



NOAA-20

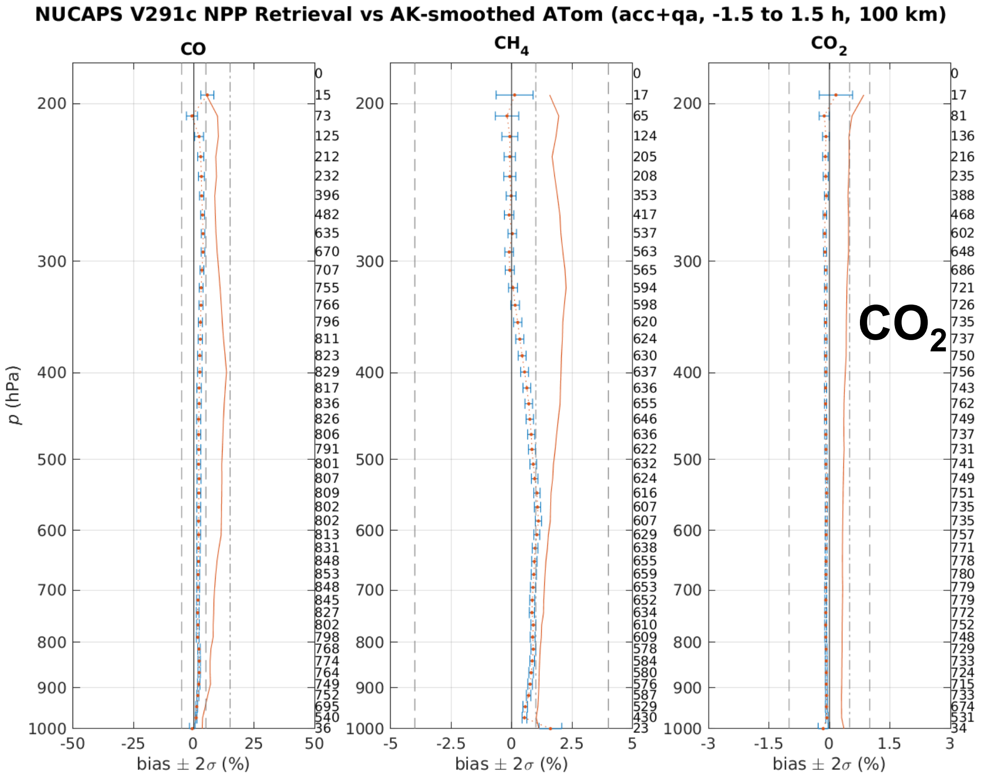


NUCAPS – ATom

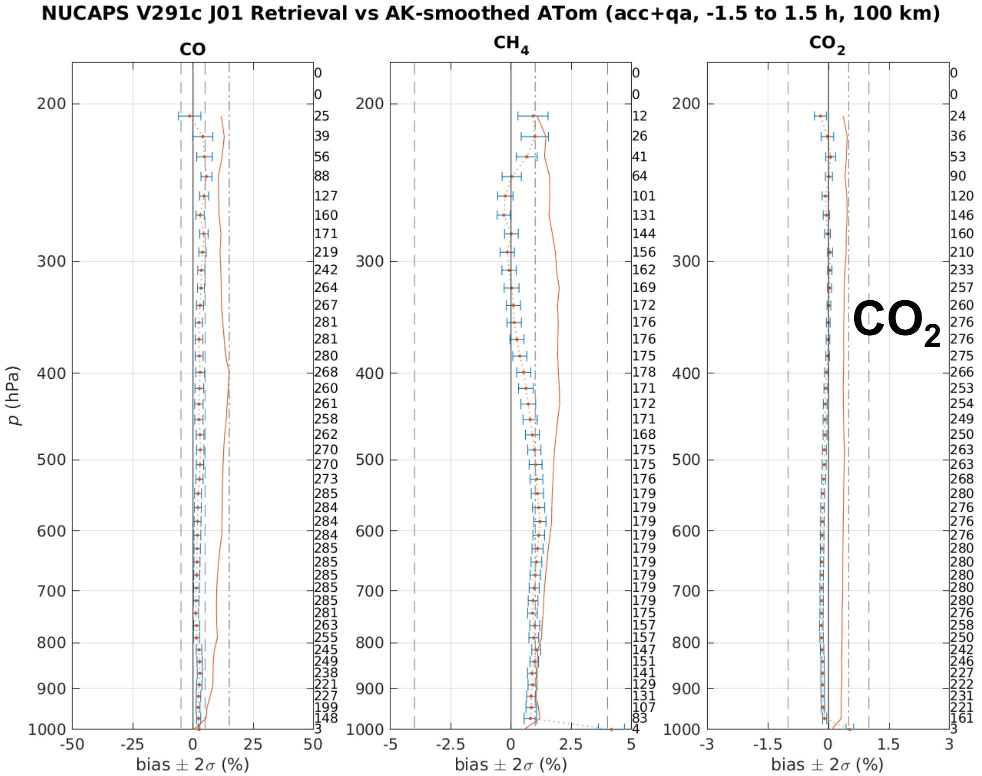
NUCAPS v3.0 Retrieval vs ATom w AKs: 100 Layer Profile Statistical Analysis

CO / CH_4 / CO_2

SNPP



NOAA-20

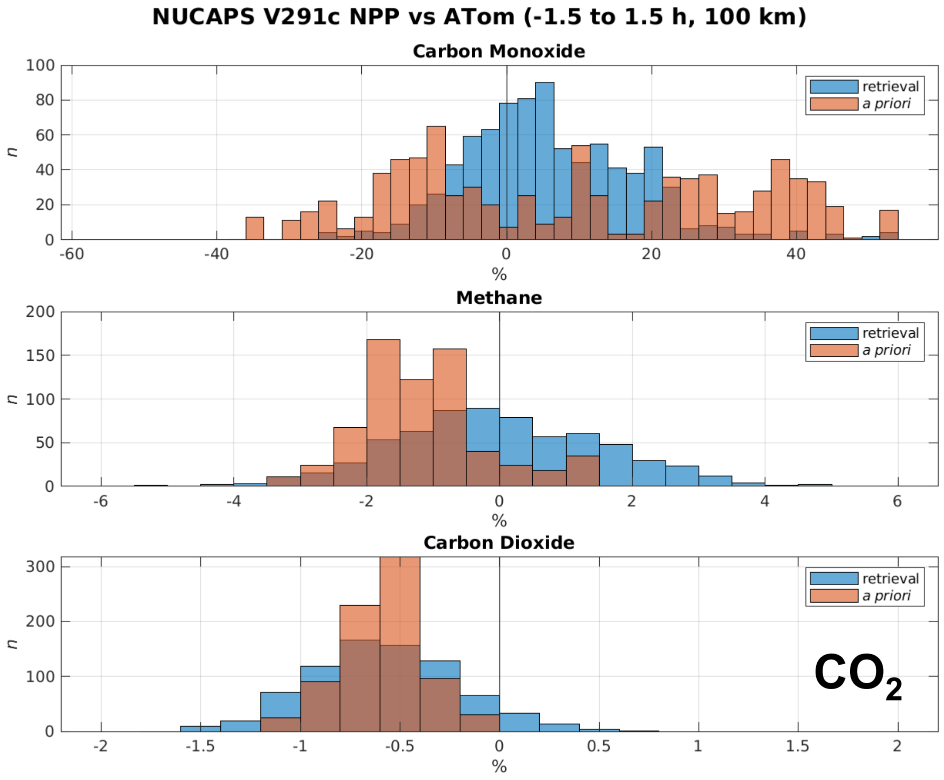


NUCAPS – ATom

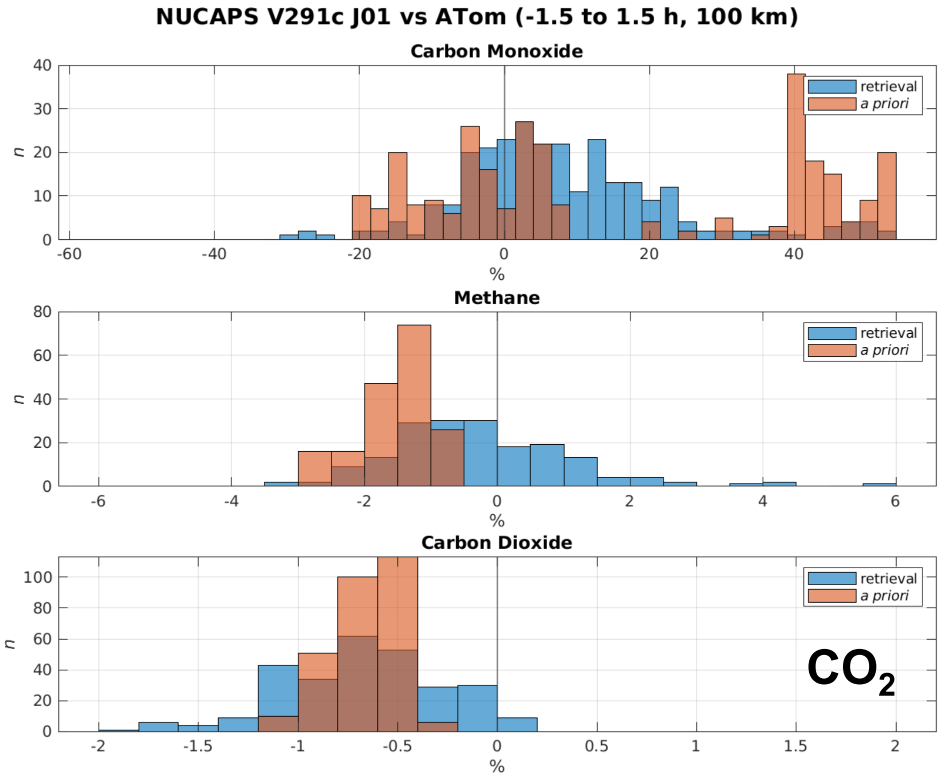
NUCAPS v3.0 *A Priori* & Retrieval vs ATom: Total Column Statistical Analysis

CO / CH_4 / CO_2

SNPP



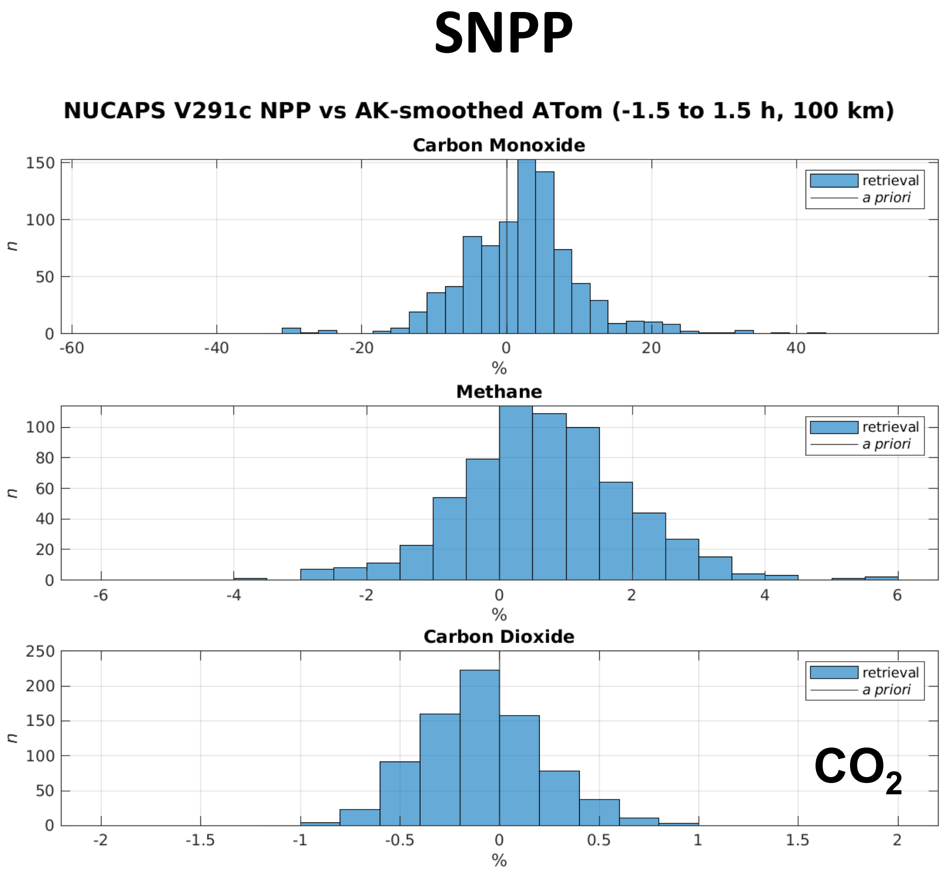
NOAA-20

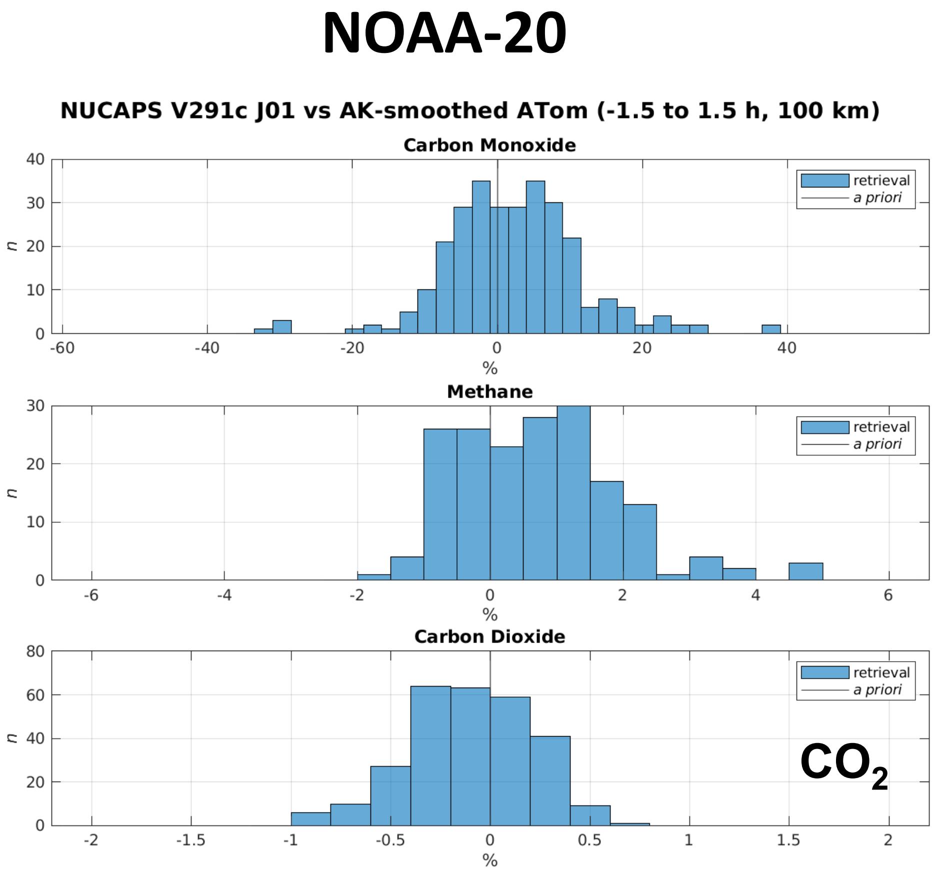


NUCAPS – ATom

NUCAPS v3.0 Retrieval vs ATom w AKs: Total Column Statistical Analysis

CO / CH_4 / CO_2





NUCAPS – ATom

NOAA-20 and SNPP NUCAPS V3.0 versus ATom: Statistical Summary

Parameter	Stat	Raw Total Column		NUCAPS AKs applied	
		NUCAPS	Req	NUCAPS	Req
CO	Precision	18.7 (15.8)	15%	9.5 (8.2)	15%
	Accuracy	+10.6 (+7.8)†	±5%	+2.2 (+2.1)	±5%
CH4	Precision	1.4 (1.6)*	1%* (20 ppmv)	1.3 (1.3)*	1% (20 ppmv)
	Accuracy	−0.3 (+0.0)	4% (80 ppmv)	+0.7 (+0.7)	4% (80 ppmv)
CO2	Precision	0.4 (0.4)	0.5% (2 ppmv)	0.3 (0.3)	0.5% (2 ppmv)
	Accuracy	−0.7 (−0.6)	±1% (4 ppmv)	−0.1 (−0.1)	±1% (4 ppmv)

Values in ( ) indicates SNPP

- Meets requirement
- Marginal (± 30%)
- Outside Requirement (with explanation)

NOTES

*Precision requirements for CH4 are now known to be too stringent and will require waver.

†NUCAPS CO sensitivity peaks in mid-troposphere, so the AK results are more reflective of the algorithm performance..

V3.0 Global Yields:

CO = 56 (61)%, *N* = 285 (861)
CH4 = 35 (47)%, *N* = 179 (666)
CO2 = 55 (60)%, *N* = 280 (846)

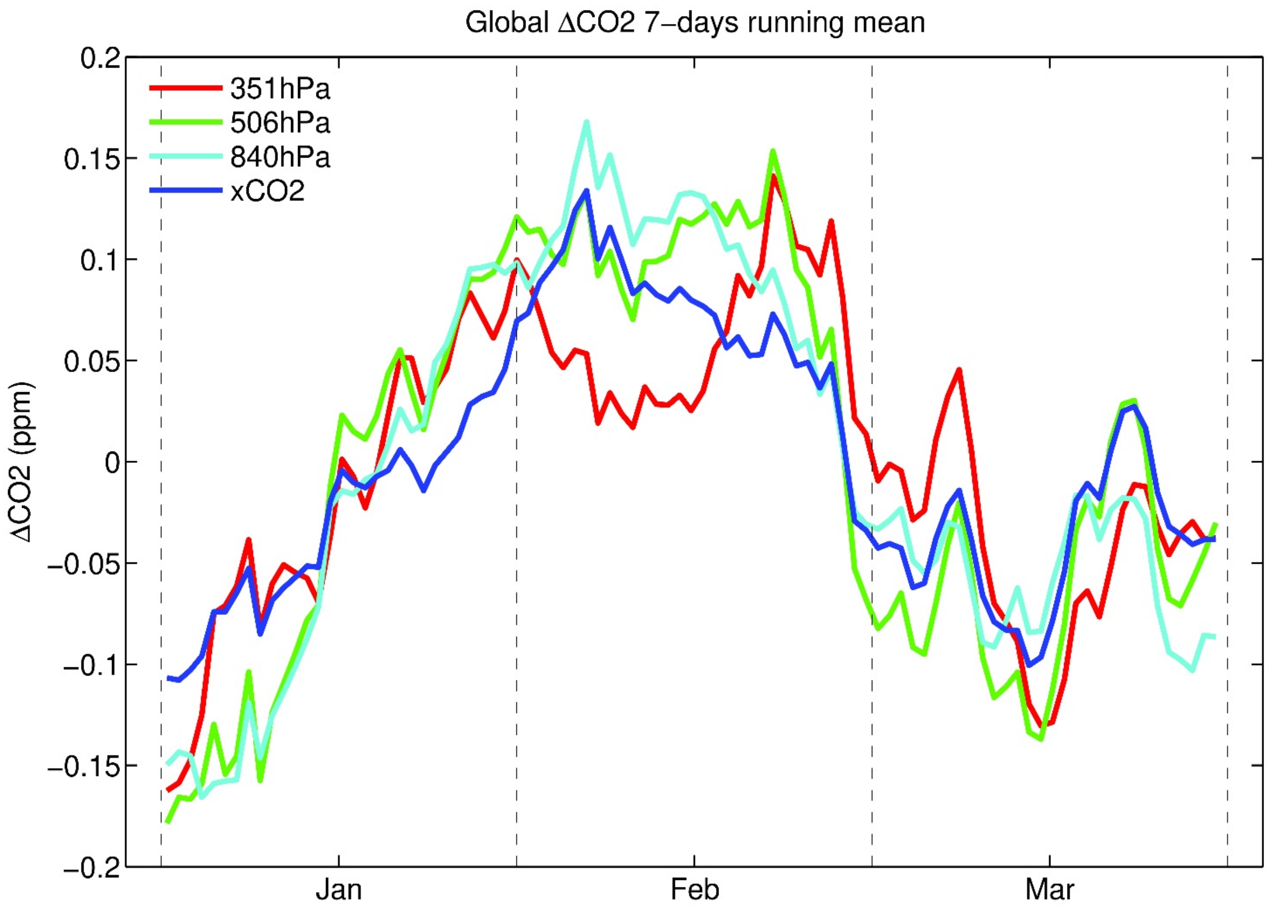
Error Budget: CO_2

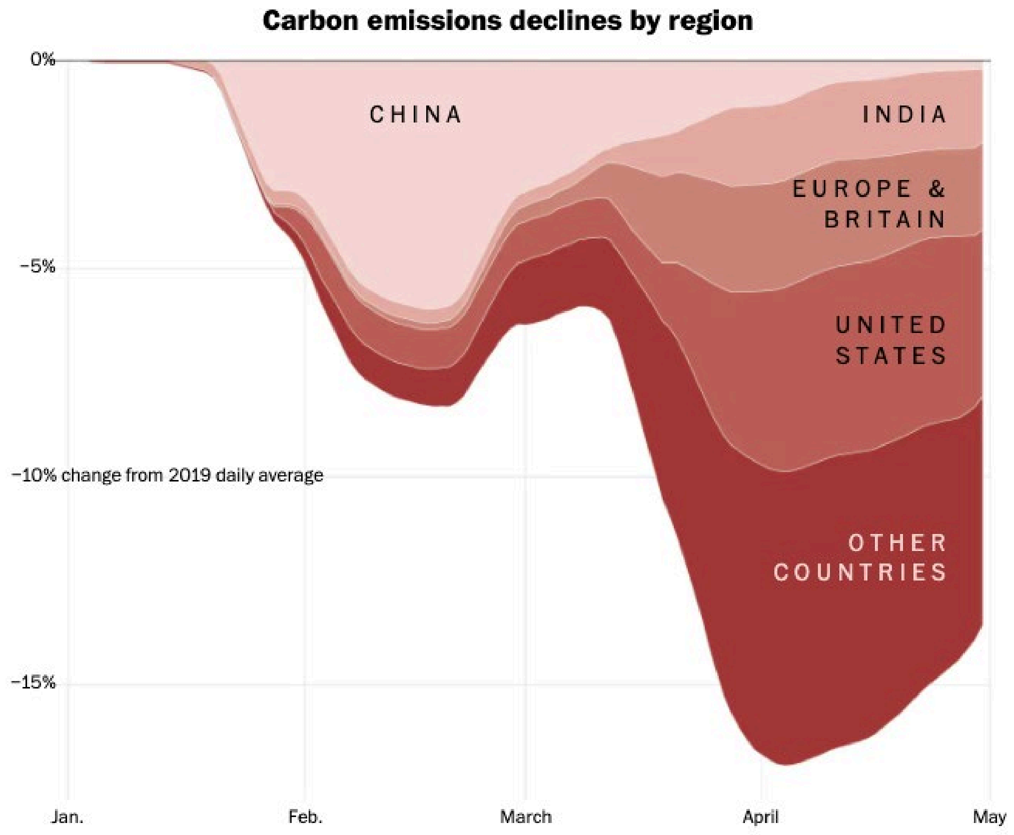
Attribute Analyzed	JPSS Data Product Specifications	Maturity Status	Analysis/Validation Result	Error Summary	Support Artifacts
SNPP/NOAA-20 CO2	See Slides 29-30, 120	Validated	Meets requirements	See Slides 59-60, 74	

NUCAPS Trace Gas Products in Environmental Monitoring
User Applications and Feedback

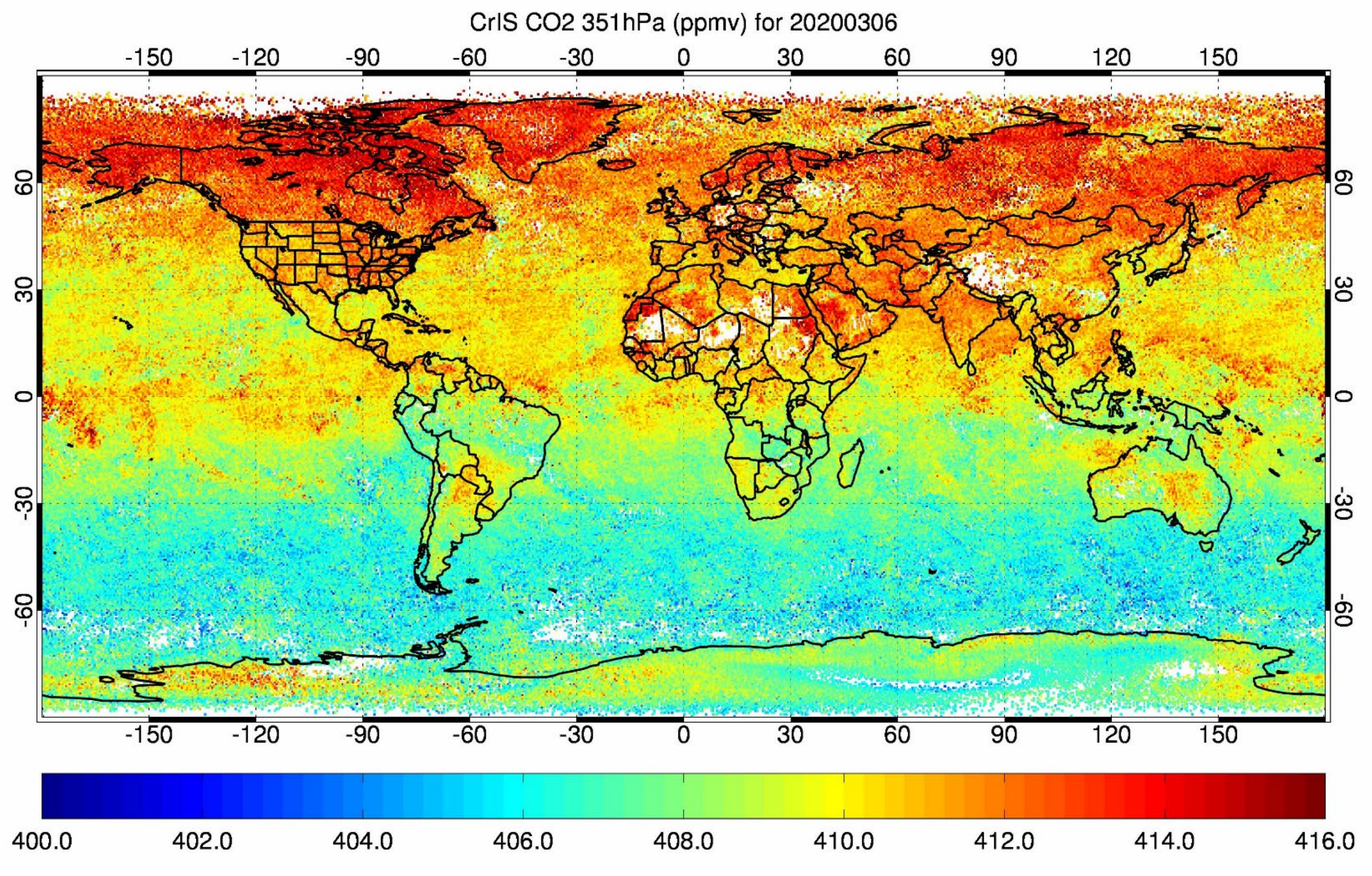
CORONAVIRUS STUDY

Global Carbon Emissions Trend



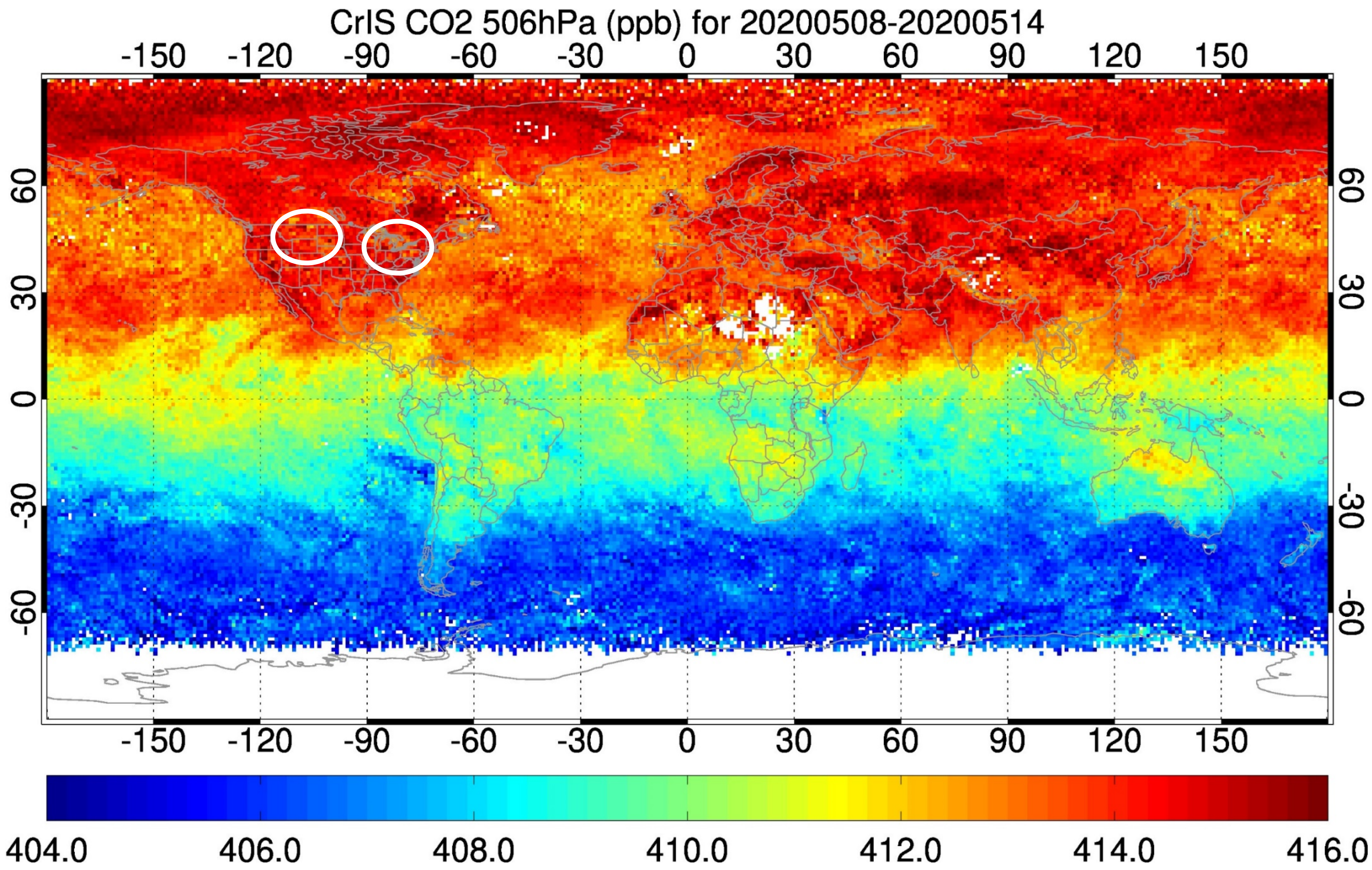


Mar 3-9 2020



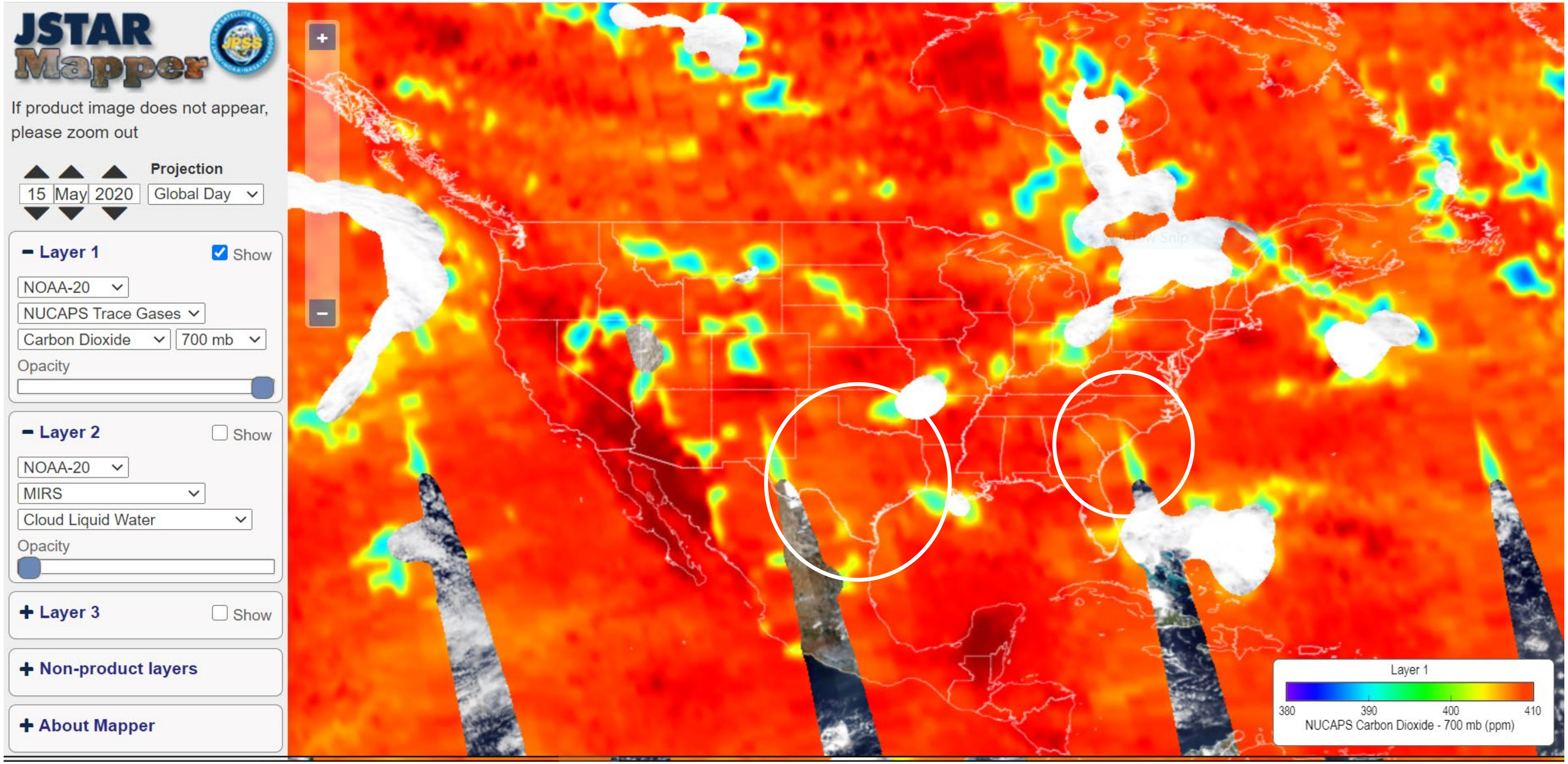
CrIS CO2 351hPa (ppmv) for 20200306
-150
-120
-90
-60
-30
0
30
60
90
120
150
60
30
0
-30
-60
400.0
402.0
404.0
406.0
408.0
410.0
412.0
414.0
416.0

May 2020


CrIS CO2 506hPa (ppb) for 20200508-20200514
-150 -120 -90 -60 -30 0 30 60 90 120 150
60 30 0 -30 -60
404.0 406.0 408.0 410.0 412.0 414.0 416.0

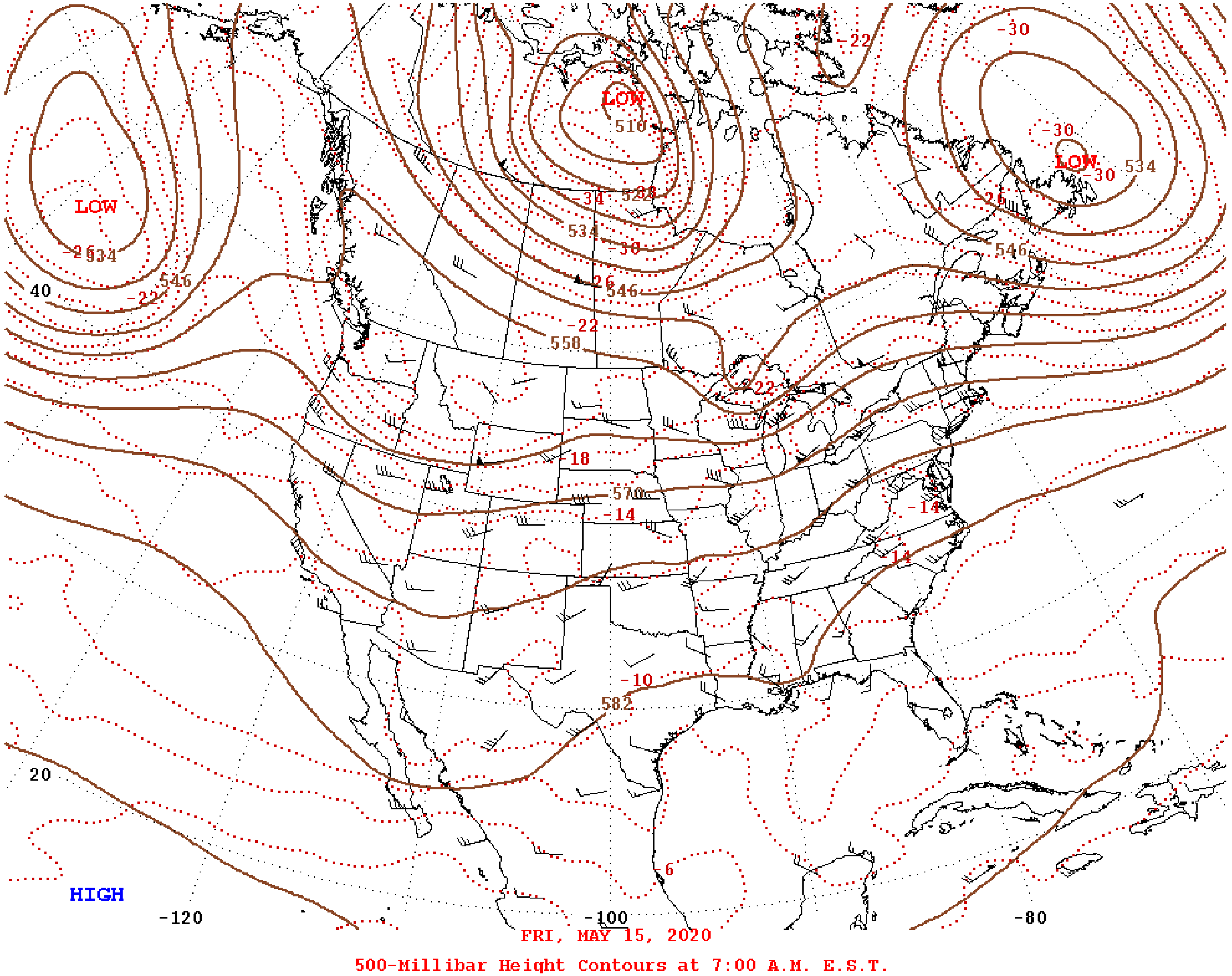
NUCAPS Retrievals on JSTAR Mapper
COVID-19 Impacts over North America

https://www.star.nesdis.noaa.gov/jpss/mapper



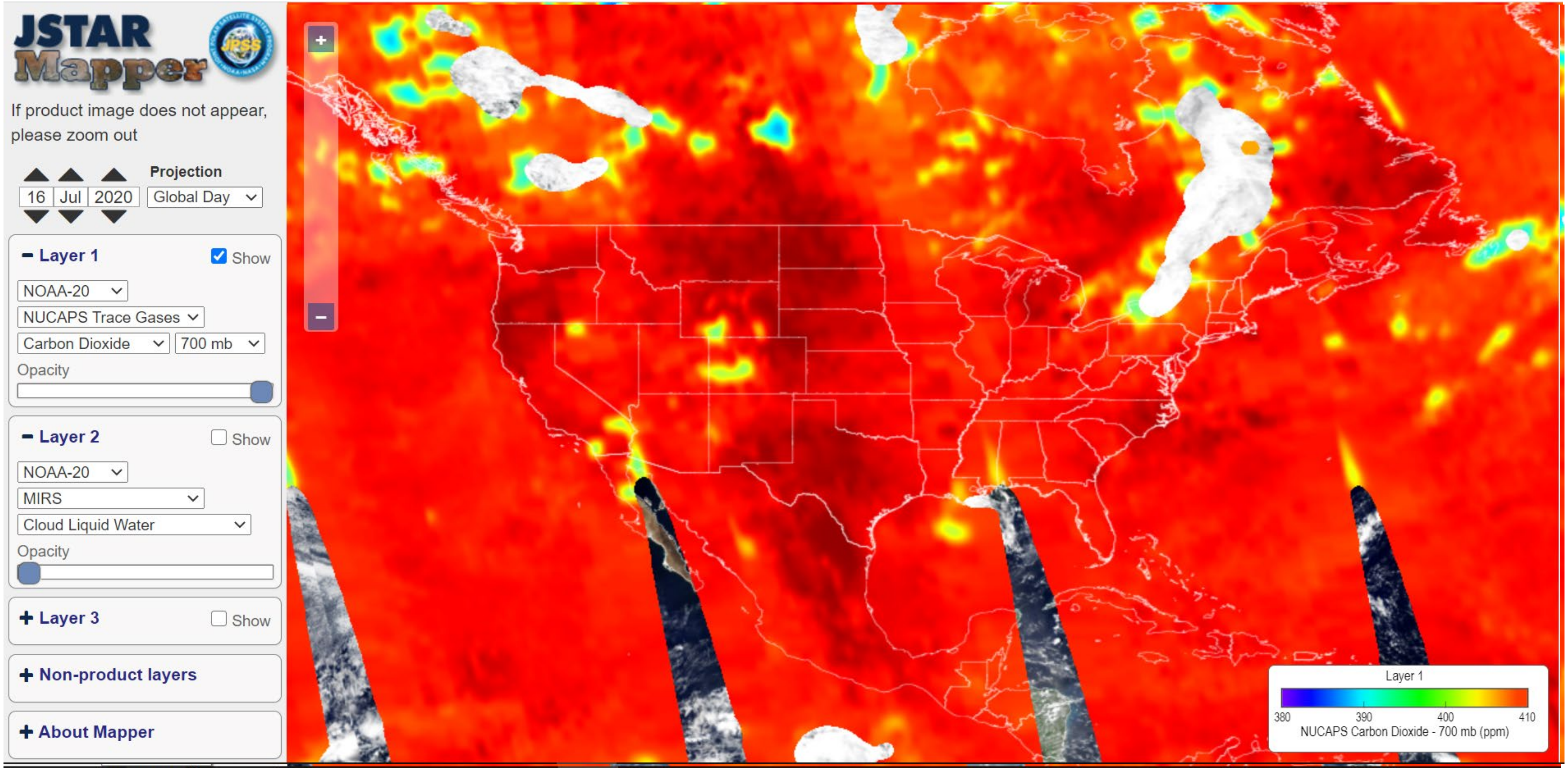
NUCAPS Retrievals on JSTAR Mapper
COVID-19 Impacts over North America

500-mb Height/Wind Analysis

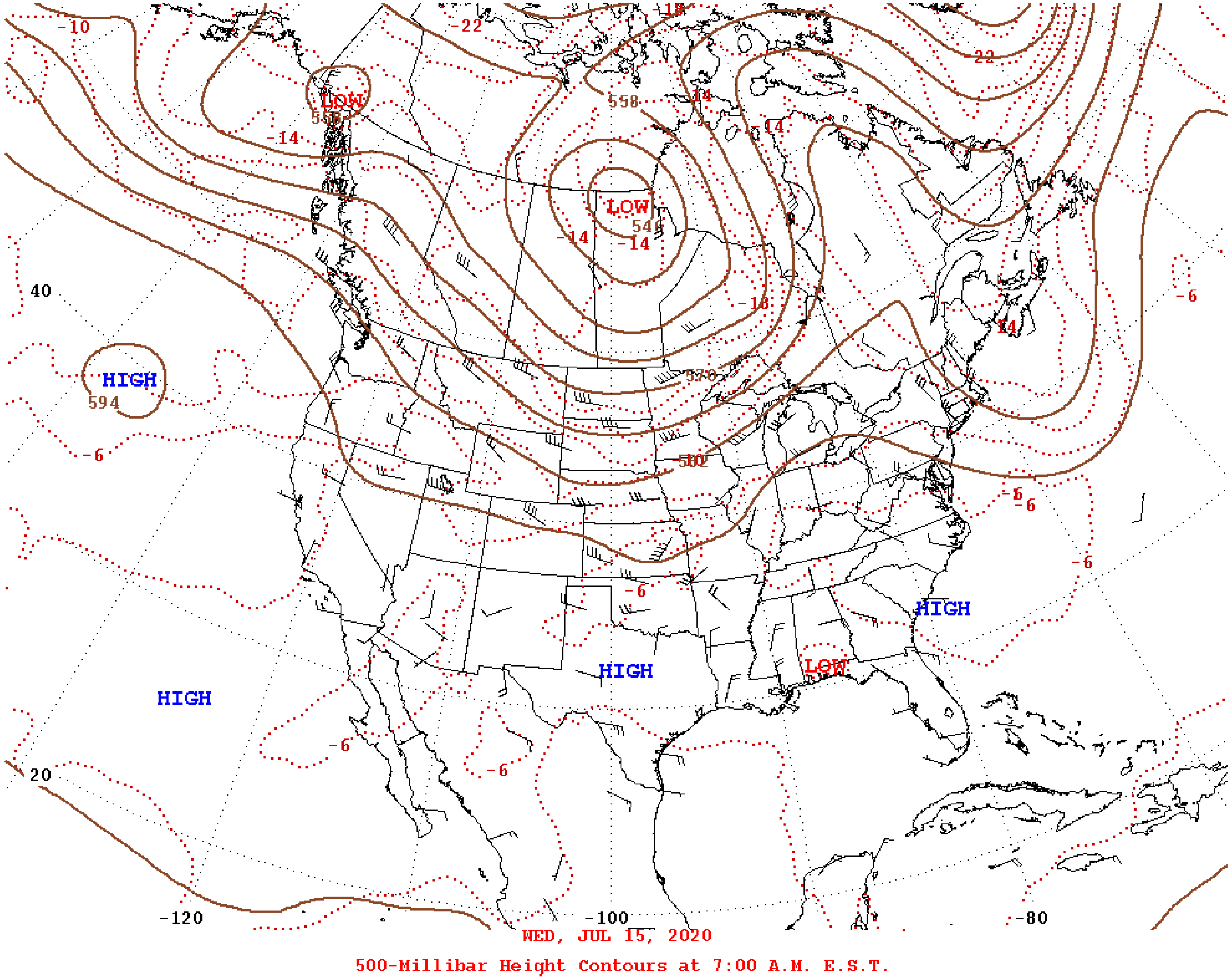


NUCAPS Retrievals on JSTAR Mapper
COVID-19 Impacts over North America

https://www.star.nesdis.noaa.gov/jpss/mapper



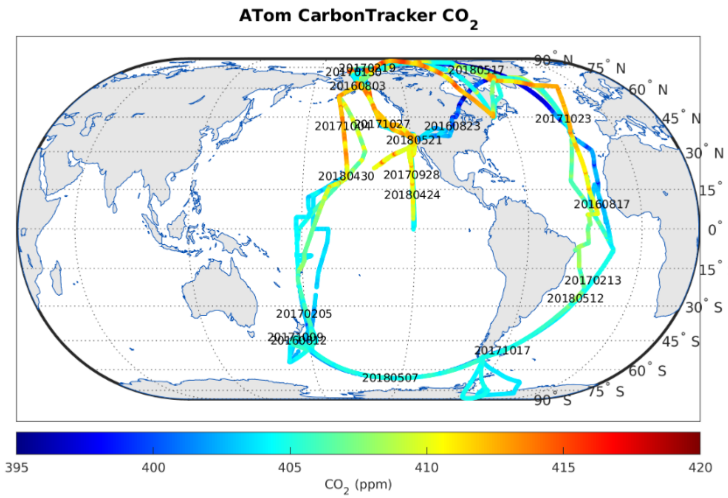
500-mb Height/Wind Analysis

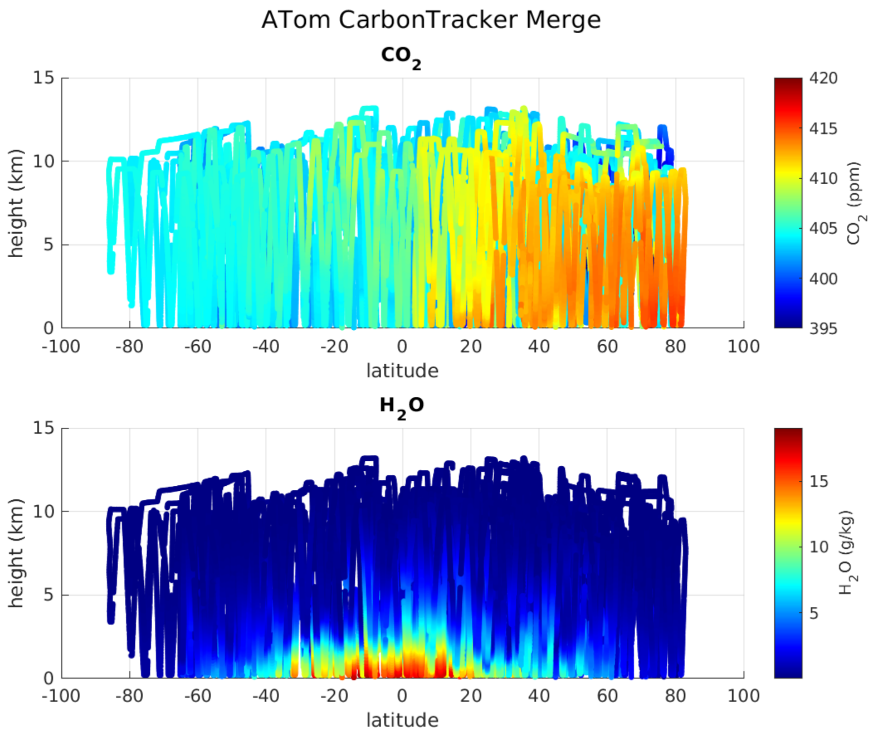


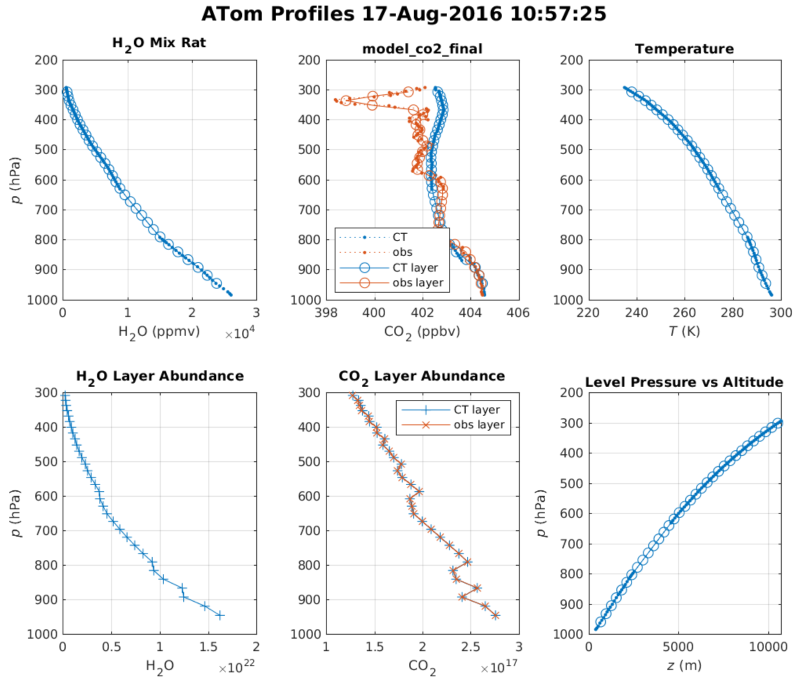
Collaborations with GML: Theme 1

Continued working with the GML collaborators on the NUCAPS carbon trace gas EDR product evaluations based on GML in situ datasets. Provided a set of focus day SNPP/NOAA-20 NUCAPS EDR products to the GML Theme 1 team for familiarity with the NUCAPS output products.

- **Participation in Quarterly Tag-Up Meeting; work in progress on collaborative Elsevier reference book**
- **Commenced work on merged ATom-CarbonTracker dataset for statistical intercomparison of NUCAPS, ATom and CarbonTracker CO_2 profiles**



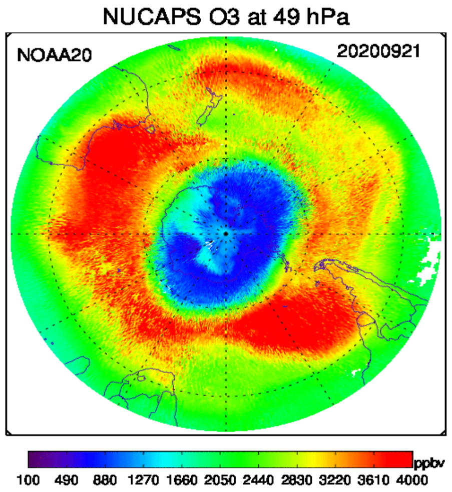




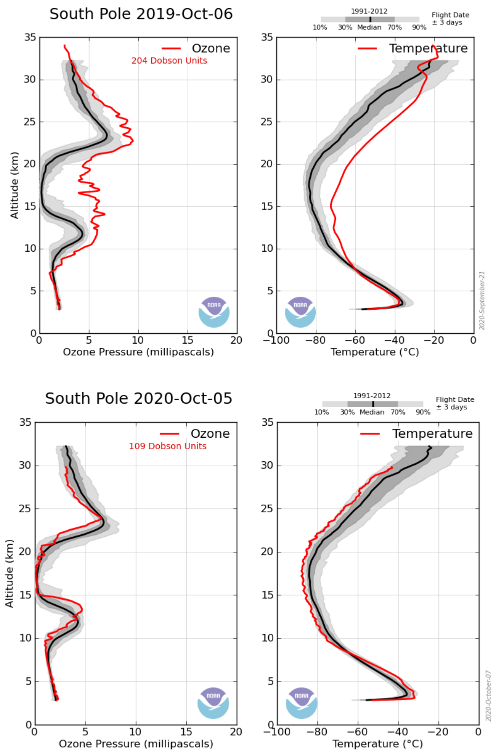
Collaborations with GML: Theme 2

Continued working with the GML collaborators on the NUCAPS and OMPS ozone products evaluations.

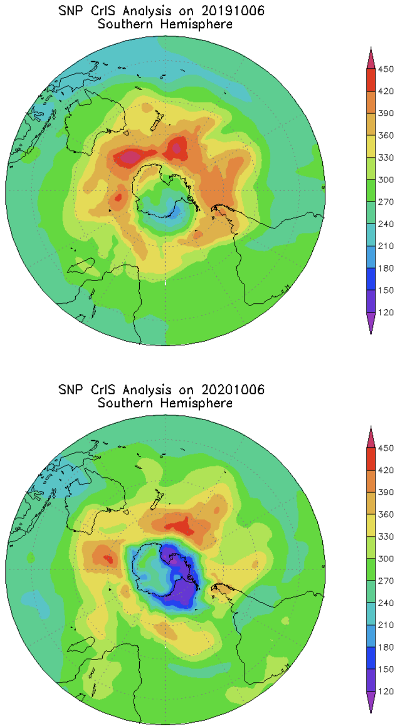
- **Participation in NASA/NOAA Ozone Ozone hole discussions and collocations of O3SND and NUCAPS ozone products to study the progression and cover up ozone hole.**
- **Collocations of O3SND data sets with NUCAPS/OMPS data sets for inter-comparison of NUCAPS and CLIMCAPS products**



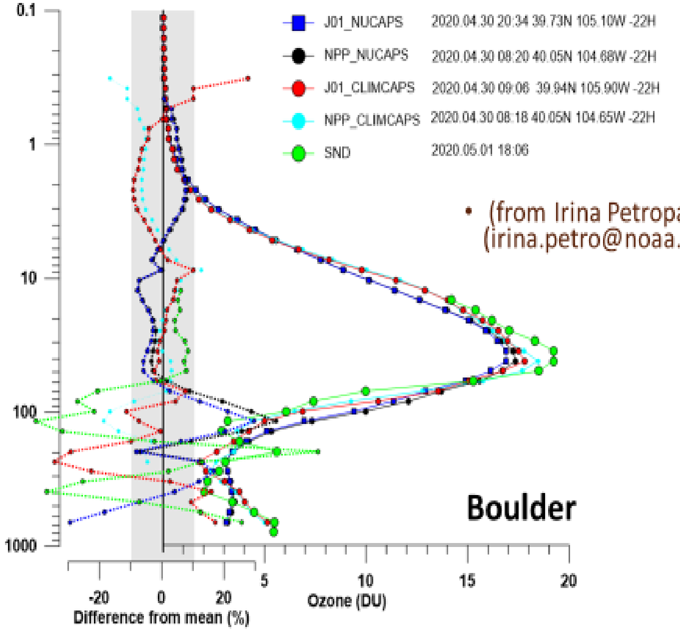
NUCAPS Ozone Product: Depiction of Ozone hole



NOAA/GML O3SNDs



OMPS Team TOAST Product



• (from Irina Petropavlov (irina.petro@noaa.gov)

Preliminary evaluation of NUCAPS and CLIMCAPS products O3SND Measurements

Other Types of Satellite Observations that Can Help Constrain Carbon Budgets

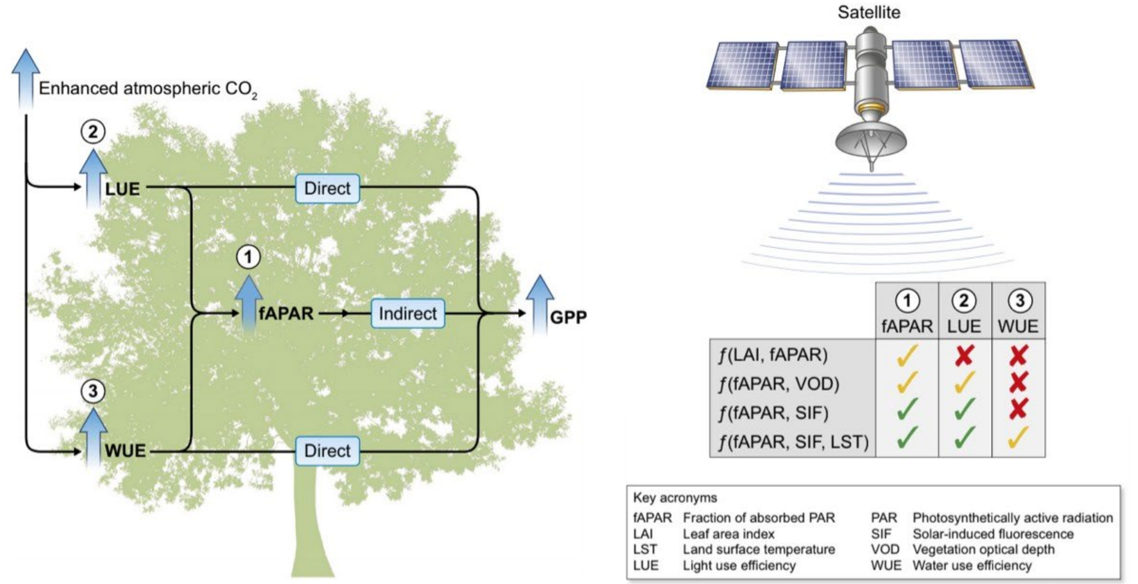


Fig. 1 Schematic of the pathways by which CO_2 fertilization effects (CFE) can increase gross primary productivity (GPP) and the potential ways satellite observations could be combined to constrain the CFE pathways. We define CFE pathways to include increases in light use efficiency (LUE), increases in water use efficiency (WUE), and increases in the fraction of photosynthetically active radiation (fAPAR). Satellite indices include leaf area index (LAI) and fAPAR, land surface temperature (LST), vegetation optical depth (VOD) and solar-induced Chl fluorescence (SIF). We show different combinations of these satellite records and indicate their potential to globally constrain (green ticks), regionally constrain (yellow ticks) or fail to constrain (red crosses) a given CFE pathway. Regional constraints (yellow ticks) are most often limited by atmospheric effects and/or signal saturation in dense canopies, such as tropical forest ecosystems.

NUCAPS CO2 product will serve as an important independent data source for carbon budget monitoring.

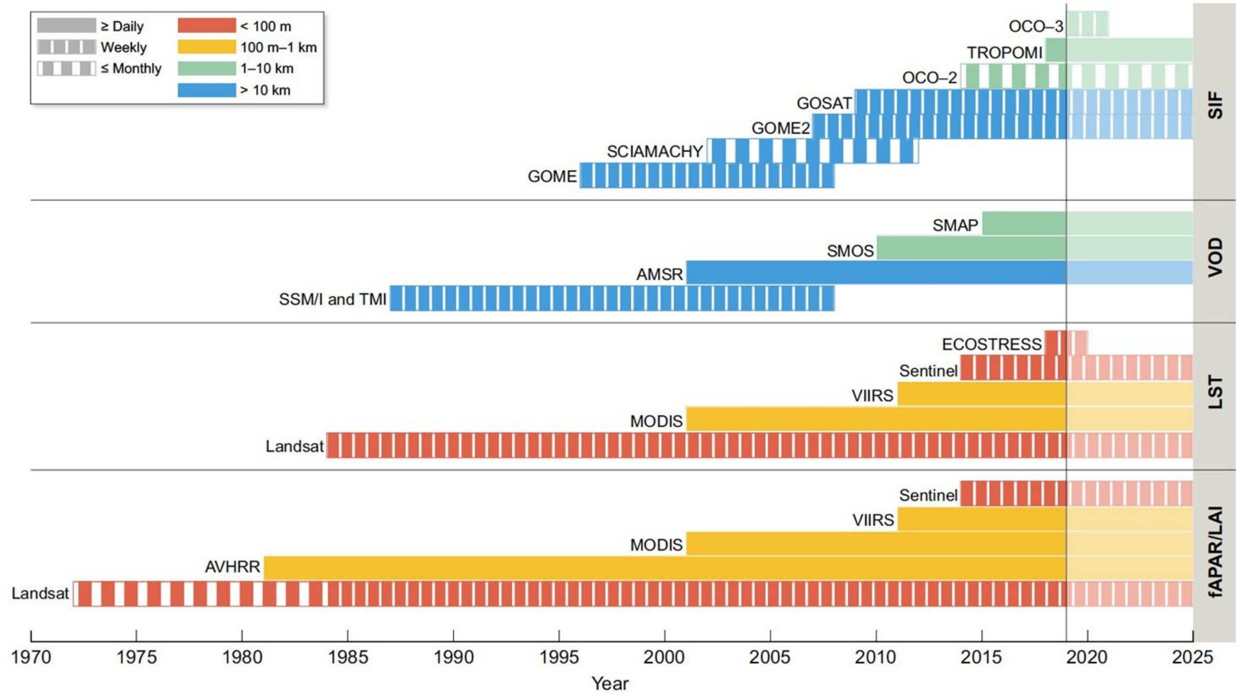


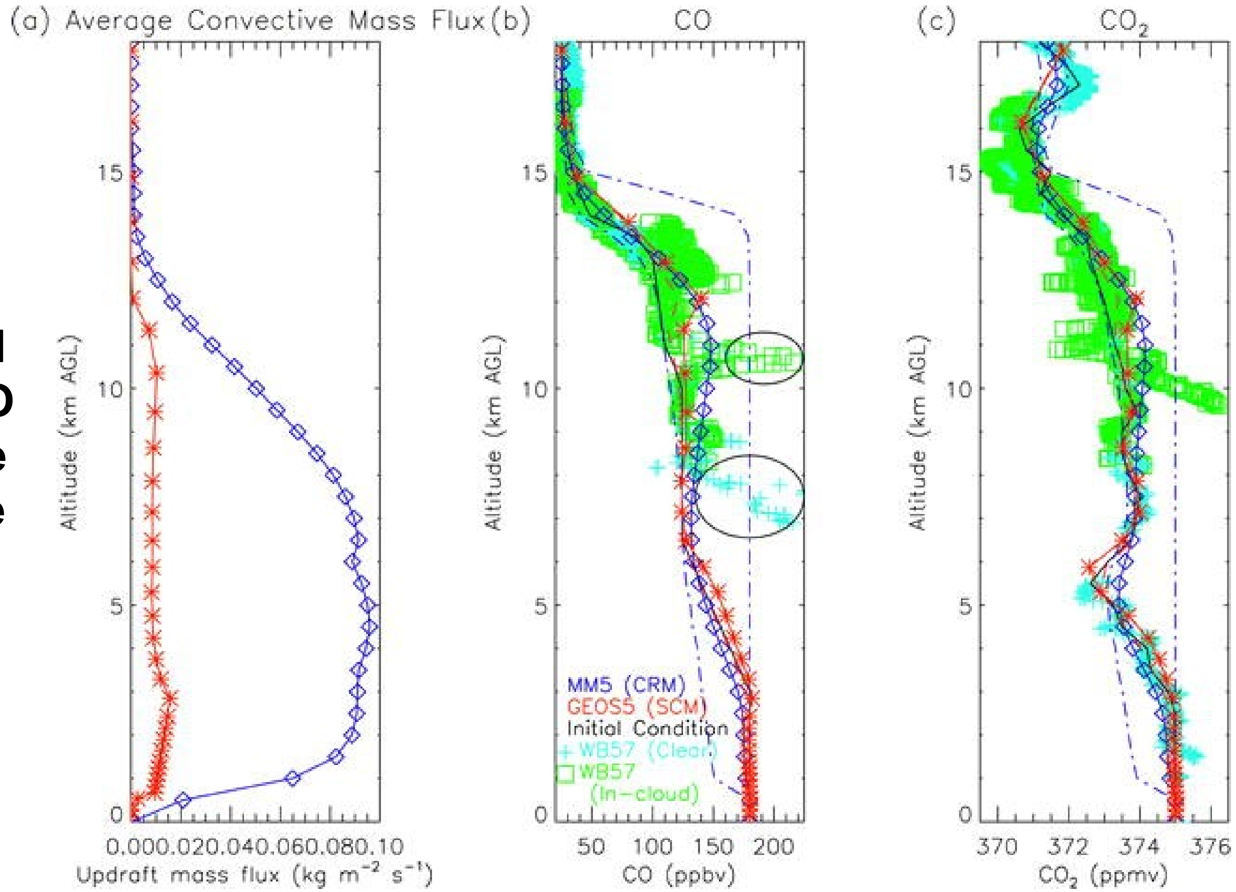
Fig. 2 A timeline of satellite observations of leaf area index (LAI) and fraction of photosynthetically active radiation (fAPAR), land surface temperature (LST), vegetation optical depth (VOD) and solar-induced fluorescence (SIF). Observation timelines are provided for context and are not meant to provide a comprehensive overview of all available sensors. This timeline clearly demonstrates the availability of diverse, multidecadal satellite observation records that are rapidly increasing in spatiotemporal resolution.

Greg Frost (ESRL/CSL): "...an interesting experiment to see how we might use CO2 assimilation along with OC/CO2 correlations to improve the model (GEFS-Aerosol) predictions."

*****With validated maturity, the NUCAPS CO2 product will be much better positioned to serve an operational and research resource for climate monitoring and prediction.*****

Potential Future Collaboration with NASA GMAO
In support of GEOS-5 model trace gas data assimilation

Lesley Ott (NASA/GMAO): “Having a product like this (NUCAPS CO2) would really help us, and probably other OCO users, because it would greatly reduce the amount of prep work that would be needed to use OCO and NUCAPS together.”



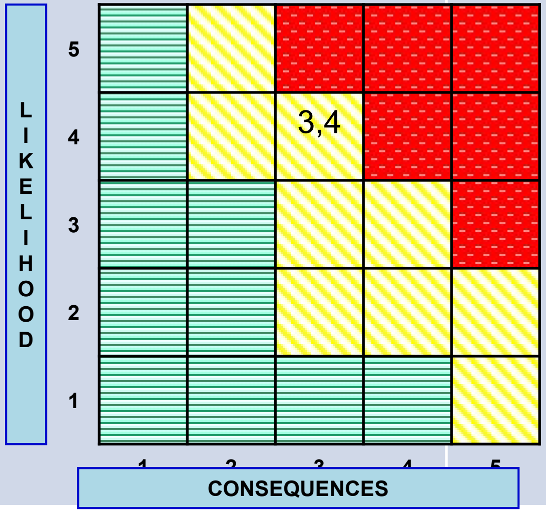
(a) Convective mass flux from the CRM (blue) and SCM (red) simulations of the 3 Jul CRYSTAL-FACE storm averaged over 210 min; (b) CO and (c) CO2 mixing ratios at the end of the 4-h simulations compared with observations from the WB57 aircraft. Solid (dashed) red line shows SCM CO and CO2 calculated with (without) advective tendencies derived from CRM output. The solid blue line indicates CRM results averaged over a 150 km × 150 km region; the dashed–dotted blue lines show the maximum and minimum values within the averaging area. Plus signs (squares) represent aircraft observations from the WB57 taken outside (inside) of the cloud. Circled areas in (b) indicate measurements that may be influenced by biomass burning or outflow from a previous convective event.

Ott, L. E., Bacmeister, J., Pawson, S., Pickering, K., Stenchikov, G., Suarez, M., Huntrieser, H., Loewenstein, M., Lopez, J., & Xueref-Remy, I. (2009). Analysis of Convective Transport and Parameter Sensitivity in a Single Column Version of the Goddard Earth Observation System, Version 5, General Circulation Model, Journal of the Atmospheric Sciences, 66(3), 627-646.

RISKS, SUMMARY, AND CONCLUSIONS

Risk(s)

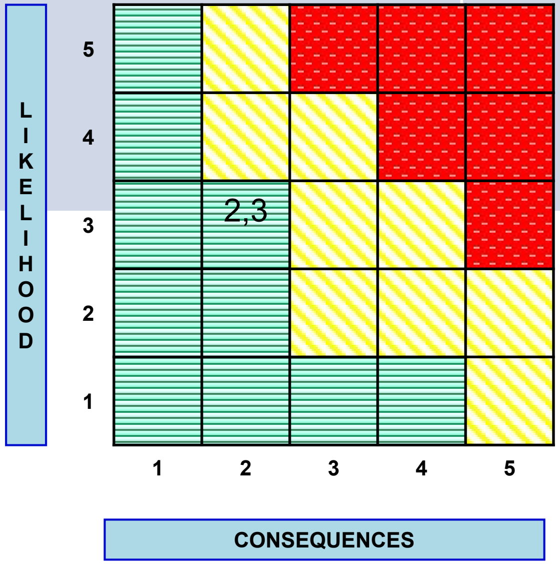
Risk ID & Rank	Risk ID	Risk Statement	Approach/Mitigation	Status
1. Reference data sets for NUCAPS trace gas product validation. **Medium**	NUCAPS-20-RSK-001	**Given that:** There is a time lag between acquisition of AirCore, TCCON, and aircraft *in situ* measurements and public release of QA products **There is a possibility:** of delay in validating NUCAPS products and time series and seasonal depiction of validations. **Resulting in :** Delays in reaching validated maturity of trace gas products from future JPSS-2, 3 satellites	Global validation of carbon trace gases requires acquisition periods for *in situ* data collection, with AirCore, TCCON and aircraft campaigns (e.g., ATom) having a lag time between observation and pubic release of QA products. TCCON sites provide routine measurements of total column trace gases. Other satellites can provide independent satellite-derived EDRs (e.g., AIRS, TROPOMI, OCO-2, etc.). AirCore soundings can provide in situ measurements, but they have not become a routine dataset yet, and they are still a rather new data source. These are datasets that can be used for cal/val without aircraft campaigns, but they not be of the same quality for this purpose.	NUCAPS team makes every effort to get the required data sets in time, and so far met all the deliverables and milestones of product validated maturity reviews.



Risk Owner(s): Nick Nalli, Murty Divakarla, Changyi Tan, Ken Pryor, NUCAPS team members

Risk(s)

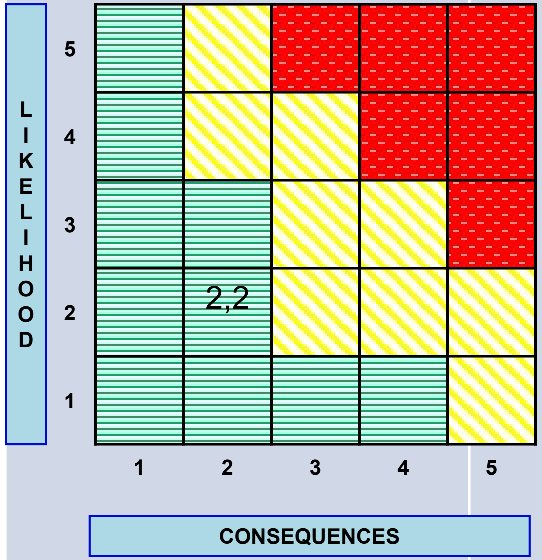
Risk ID & Rank	Risk ID	Risk Statement	Approach/Mitigation	Status
2. SARTA and MW fast forward models for future satellite instrument configurations (e.g. MetOp-SG IASI/MWS, JPSS-2,3) **Low Risk in Implementation**	NUCAPS-20-RSK-002	**Given that:** SARTA and MW radiative transfer algorithms and updates are provided by collaborating agencies (UMBC, STC) to generate fast forward models for NUCAPS **There is a possibility:** The NUCAPS team may not be able to implement these fast forward algorithms to future satellite systems **Resulting in :** Delivering NUCAPS products.	STAR NUCAPS team holds cross-training and technical interchange meetings (TIMs) Q&A sessions with STC and other agencies. Details are provided in the supplemental slides – Subset #2 NUCAPS Team Collaborations with External Agencies for Risk Mitigation".	Through these TIMs, the NUCAPS core team gained self sufficiency in working with the SARTA and MW RTAs, fast forward model implementation, and generation of LUTs for fast forward models. This risk has been addressed and effective measures were taken resolving this risk.



Risk Owner(s): Tong Zhu, Murty Divakarla, Changyi Tan, Ken Pryor, NUCAPS team members

Risk(s)

Risk ID & Rank	Risk ID	Risk Statement	Approach/Mitigation	Status
3. Averaging Kernels Implementation **Low Risk in Implementation**	NUCAPS-20-RSK-003	**Given that:** The users need averaging kernels for T(p), q(p), and O3(p), and other trace gases as part of NUCAPS output files, **There is a need:** to update the NUCAPS system with output files accommodating averaging kernels for T(p), q(p), and O3(p), and other trace gases as part of NUCAPS output files. Resulting in: Improved utility of NUCAPS products.	During the JPSS/GOES-R summit, many users have discussed the need for averaging kernels as part of NUCAPS output files. With the help from Nadia Smith and Chris Barnet, the NUCAPS team is developing FORTRAN code to output the Averaging Kernel to the final NUCAPS products.	STAR NUCAPS team is capable of producing and integrating averaging kernels as part of NUCAPS output files. This will eventually increase the NUCAP product output files by about 20%, and JPSS program needs to initiate a dialogue with CLASS and any necessary budget for archiving larger data volumes, and requires coordination with CLASS/NCEI. **This is an additional constraint.**

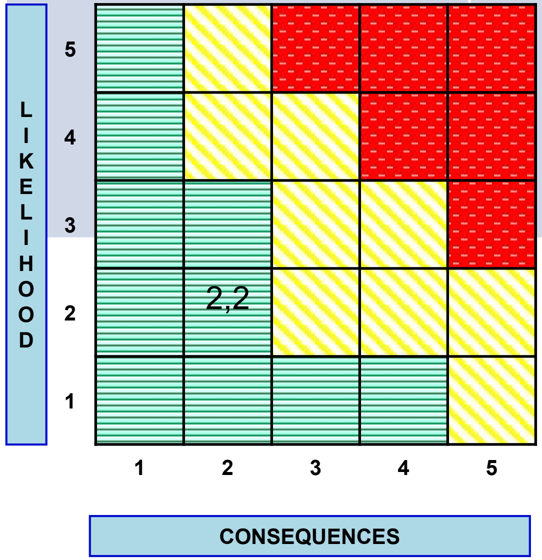


Risk Owner(s): Murty Divakarla, Tianyuan Wang, Changyi Tan, Nick Nalli, Chris Barnet, Ken Pryor, NUCAPS team members

Caveat(s)

Caveat	Caveat ID	Risk Statement	Approach/Mitigation	Status
1. Reactive maintenance for upstream SDR product anomalies	NUCAPS-20-CAV-001	**Given that:** S-NPP has been in the orbit for more 9 years, and NOAA-20 recently has shown some CrIS noise anomalies **There is a possibility:** The NUCAPS products may get impacted by the upstream SDR performance changes. **Resulting in :** Degraded NUCAPS products.	STAR NUCAPS team, in coordination with the CrIS and ATMS SDR teams, watch for sensor anomalies and associated SDR impacts. In the past, the NUCAPS team has adapted necessary measures of reactive maintenance (e.g. example CrIS Side-A to Side-B transition), and adapting CrIS/ATMS updated noise files in updating NUCAPS subcomponents and LUTs.	NUCAPS team is well prepared with necessary measures to account for any anomalies. The team knows how to address this caveat (removing MW channels, re-doing regressions, etc.). NUCAPS team is also optimizing the IR-only NUCAPS retrieval system as part of risk mitigation, and for future IR-only retrievals from GEO-CrIS or other LEO SmallSAT constellations.

Low Risk in Implementation

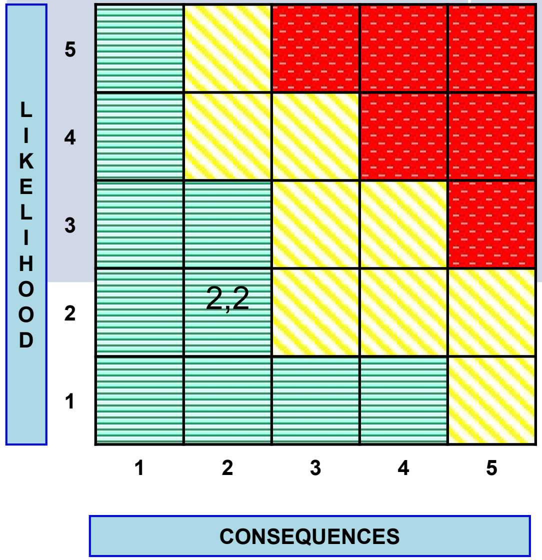


Risk Owner(s): Murty Divakarla, Changyi Tan, Ken Pryor, NUCAPS team members

Caveat(s)

Caveat	Caveat ID	Risk Statement	Approach/Mitigation	Status
2. GFS model changes affecting NUCAPS enterprise algorithm	NUCAPS-20-CAV-002	**Given that: NWP** global Forecast System (GFSv16) upgrades will have significant changes with respect to grid resolution (0.25° x 0.25°), **There is a possibility:** The NUCAPS product production may get impacted **Resulting in :** NUCAP product performance	The NUCAPS system uses GFS surface pressure to define the boundary conditions for the NUCAPS retrieval. The current NUCAPS GFS pre-processor has the capability to process both 0.5 and 0.25 degree GRIB files. In case, if there is a change in the vertical resolution from the GFSv16, the NUCAPS team has the capability to account for those changes based on the experience gained from ECMWF model data used for NUCAPS product evaluation.	NUCAPS team is well prepared with necessary measures to account for GFSv16 associated upgrades with respect to spatial grid resolution (0.25° x 0.25°), vertical resolution, and any product/algorithm updates to GFS GRIB attributes. The team has experience dealing with this change from before (grid resolution), and any upstream changes of GFS vertical resolution.

Low Risk in Implementation



Risk Owner(s): Changyi Tan, Murty Divakarla, Ken Pryor, NUCAPS team members

Publications and Upcoming Presentations

1. Nicholas R. Nalli, Changyi Tan, Juying Warner, Murty Divakarla, Antonia Gambacorta, Michael Wilson, Tong Zhu, Tianyuan Wang, Zigang Wei, Ken Pryor, Satya Kalluri, Lihang Zhou, Colm Sweeney, Bianca C. Baier, Kathryn McKain , DebraWunch, Nicholas M. Deutscher, Frank Hase, Laura T. Iraci , Rigel Kivi , Isamu Morino, Justus Notholt, Hirofumi Ohyama,David F. Pollard, Yao Té, Voltaire A. Velazco, Thorsten Warneke, Ralf Sussmann and Markus Rettinger, "Validation of Carbon Trace Gas Profile Retrievals from the NOAA-Unique Combined AtmosphericProcessing System for the Cross-Track Infrared Sounder", **Remote Sensing,** https://www.mdpi.com/2072-4292/12/19/3245

2. Tianyuan Wang, Lihang Zhou, Changyi Tan, Murty Divakarla, Ken Pryor, Juying Warner, Zigang Wei, Mitch Goldberg and Nicholas R. Nalli, "Validation of Near-Real-Time NOAA-20 CrIS Outgoing Longwave Radiation with Multi-satellite Datasets on Broad Timescales", manuscript under review at the STAR publication approval panel for submission **for Remote Sensing.**

3. Satya Kalluri, C. Barnett, M. Divakarla, R. Esmaili, N. Nalli, K. Pryor, T. Reale, N. Smith, C. Tan, T. Wang, J.Warner, M. Wilson, L. Zhou, T. Zhu, "Utility of Satellite Retrievals of Atmospheric Profiles in Detecting and Monitoring Severe Weather Events at NOAA", manuscript in draft and under review by authors for **submission for BAMS.**

4. Juying Warner, Z. Wei, NUCAPS team, "Tropospheric Carbon Gases Observed from the Cross-track Infrared Sounder (CrIS)" manuscript in preparation.

5. **AMS-2021** Presentations on NUCAPS related topics.
   a) *Murty Divakarla, IMSG, Rockville, MD; and S. Kalluri, K. Pryor, C. Barnet, C. Tan, M. Wilson, N. Nalli, T. Zhu, J. Warner, T. Wang, L. Soulliard, T. King, and L. Zhou, "*Joint 11.7 - NUCAPS Atmospheric Sounding Product System for JPSS-CrIS and MetOp-IASI Hyperspectral Sounders: Products, Performance, and Recent Advances", Thursday, January 14, 2021, 1:40 PM – 1:45 PM
   b) *Tong Zhu, IMSG, Rockville, MD; and C. Tan, M. Divakarla, C. Barnet, K. Pryor, M. Wilson, N. R. Nalli, T. Wang, J. Warner, S. Kalluri, L. Zhou, and M. Goldberg",* 662 - NUCAPS Microwave Tuning for MetOp-C AMSU-A/MHS", Wednesday, January 13, 2:00-3:30 PM
   c) *Nicholas R. Nalli, IMSG, College Park, MD; and C. Tan, J. Warner, M. Divakarla, A. Gambacorta, M. Wilson, T. Zhu, T. Wang, K. Pryor, S. Kalluri, L. Zhou, B. C. Baier, C. Sweeney, K. McKain, and D. Wunch,"* Joint 11.8 - Validation of Carbon Trace Gases from the NOAA Unique Combined Atmospheric Sounding System (NUCAPS), Thursday, January 14, 1:45 PM – 1:50 pm

Summary

- **Candidate NUCAPS version (V3.0)** is
  - Producing consistent results between SNPP and NOAA-20
  - Did not adversely impacted any NUCAPS products that are of validated maturity. Producing results of equal or better quality than the current operational version
  - Producing results generally meeting JPSS Data Product Specification (DPS) with independent correlative datasets (model outputs, satellite EDRs, in situ reference data TCCON, ATom, etc.)
- Delivered **v3.0** to ASSISST team for cluster integration to produce SNPP/NOAA-20 NUCAPS products
  - Currently verifying pre-operational products generated by the ASSISST cluster runs
- NUCAPS trace gas products are available on the JPSS STAR EDR LTM and JSTAR Mapper websites.
  - https://www.star.nesdis.noaa.gov/jpss/mapper
  - https://www.star.nesdis.noaa.gov/jpss/EDRs/products_Soundings_N20.php
- User feedback is positive
  - Many PGRR Initiatives are using NUCAPS products and found them extremely useful for their applications

Conclusions

- Team recommends NUCAPS algorithm **Validated Maturity** for the **SNPP/NOAA-20 CO_2 Trace Gas EDR**

NUCAPS Future Plans/Schedules/Milestones

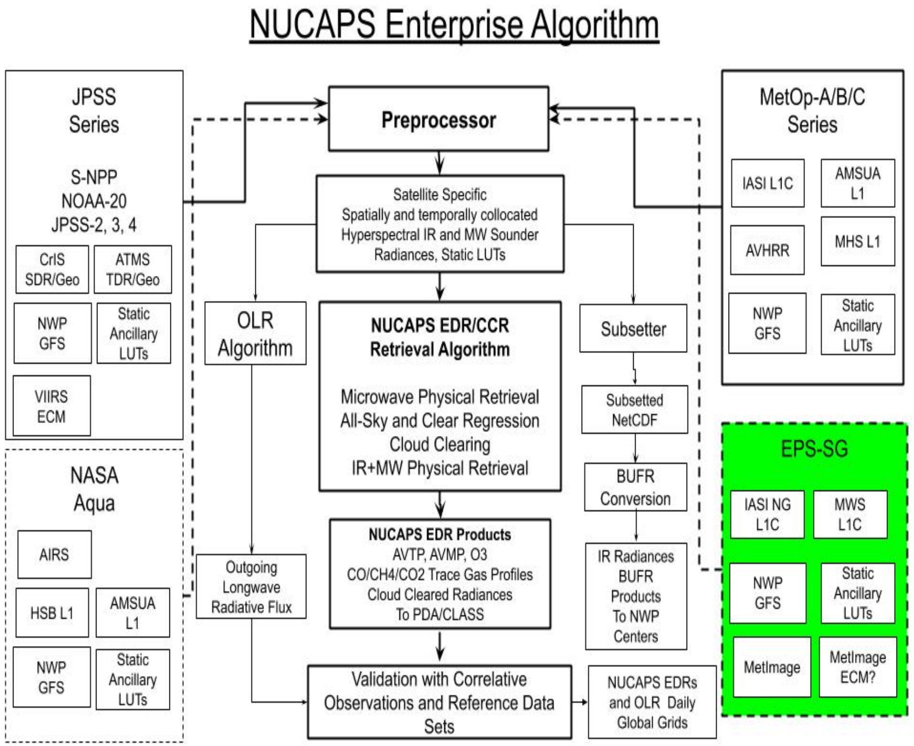
PATH FORWARD

- NUCAPS Accomplishments
- NUCAPS AOP Plan
- EPS-SG Augmentation
- GML Collaborations

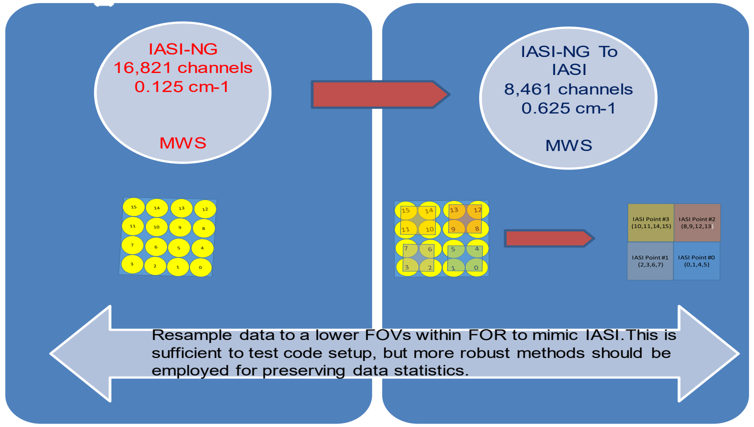
NUCAPS Accomplishments

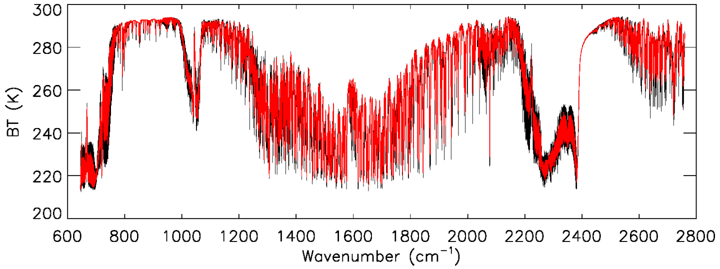
- **NUCAPS team finalized the candidate version for December CO2 Maturity Review**
  - Includes necessary fixes related rH clipping in the first guess and rH flag activation, and SO2 flag activation
  - Improved QC/QA for CO2 and other Trace Gas products.
  - Evaluation of trace gas products in progress with TCCON, AirCore and ATom reference data sets
- **NUCAPS team finalized the MetOp-C DAP delivery.**
  - **Global maps and statistical plots produced for MetOp-C products show consistency with MetOp-A/B IASI products**
- **NUCAPS team continued collaborations with NOAA-GML**
  - **Theme 2 Ozone: 2020 Ozone hole discussion and collocations of O3SND and NUCAPS ozone products to study the progression and cover up ozone hole**
  - **Theme 1 Carbon Gases: Began work on merged ATom-CarbonTracker dataset for CO2 validation provided by GML; provided GML with offline NUCAPS Focus Day run; continued collaborative work on Elsevier reference book**
- **Publications**
  - **Team members published the trace gas validation paper in Remote Sensing (https://www.mdpi.com/2072-4292/12/19/3245)**
  - **Team members finalized the OLR paper for routing through STAR review panel approval process.**
  - **Two more publications are in various stages of draft and editing.**

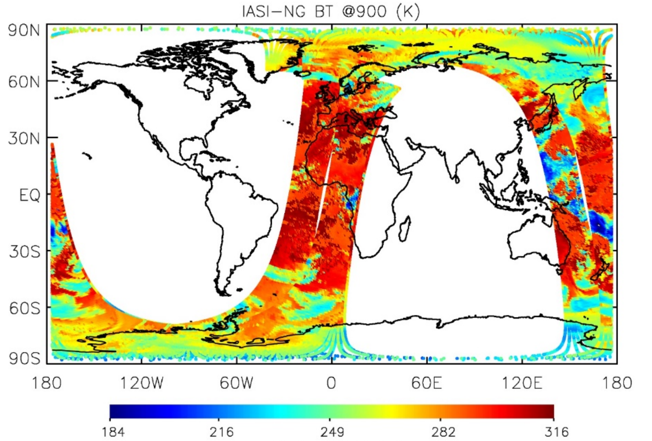
NUCAPS Updates to EPS-SG IASI-NG/MWS

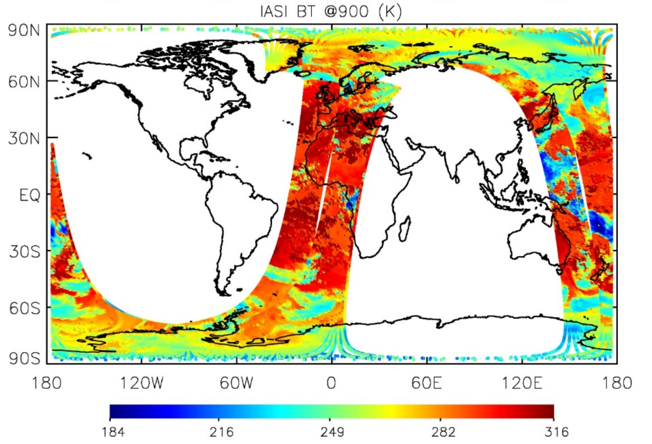


- LEO orbit, sun-synchro.
- Mertz interferometer
- 4x4 pixel detector
- 12-km pixel at Nadir
- 4 spectral bands
- Sampling 0.125 cm^{-1}
- Swath ~2000km
- Launch 2021









- Covert IASI-NG spectrum into an IASI spectrum to generate Day-1 products with 95% of NUCAPS code functioning as is, including using the existing forward model, channel selections, and all downstream components
- Follow MetOp-C system, use all usable components
  - Build Preprocessor for MWS/IASI-NG collocations
  - Build MW fast forward model for MWS
  - Use MetOp-C IASI SARTA RTA (Truncate IASI-NG to IASI)

FY-2021 JPSS Annual Operating Plan (AOP) Milestone

Activity	AOP
Maturity Reviews, DAP Deliverables	• Validated maturity for CO_2, Maintenance, monitoring, CO, CO_2, CH_4 algorithm improvements and reactive maintenance. • JPSS-2 final DAP Delivery, and final JPSS-2 Cal/Val Plan
Algorithm Improvements	• NUCAPS averaging kernels for T/H_2O/O_3/CO/CH_4/CO_2 and implementation into the NUCAPS OPS code, and product format improvements based on user requirements. Distribution of averaging kernels and apriori information an integral part of the operational products. • Improve trace gas retrievals and explore additional trace gas products (NH_3, HNO_3, N_2O, SO_2). Validate SO_2 product, implement Ammonia algorithm for CrIS. Algorithm to retrieve Ammonia product is readily available for hyperspectral sensors, and the product has user applications related to agriculture, fire emissions, and air quality. • Update NUCAPS code for stability index calculation and the use of ancillary data to improve boundary layer characterization. Explore assimilation of surface observations into the sounding retrieval process. • Land and Ocean spectral emissivity improvements • Land surface spectral emissivity retrieval with CAMEL emissivity lookup approach for the first guess. Improvements to snow/ice surface spectral emissivity.
Collaborations	• Support STAR-NUCAPS and GML collaborations on trace gases, ozone, and water vapor. • Collaborate with CrIS SDR team of GEO-CrIS EDR product, SNO studies, and data compression optimization studies
System Development	• NUCAPS augmentation for EPS-SG IASI-NG/MWS and development of necessary instrument specific LUTs. • Optimizing IR-only retrievals for risk mitigation and conceptual GEO-CrIS retrieval products • **Explore alternate technologies for (?)**
Case Studies	• Demonstrate the utility of NUCAPS products for environmental events and applications, support field campaigns
Publications	• Realize four publications that are currently in preparation.
Reprocessing	• Initiate mission-long reprocessing plans for S-NPP/NOAA-20 NUCAPS EDR products with the latest validated maturity algorithms.

NUCAPS Deliverables and Milestones

Milestones	Original Date	Forecast Date	Actual Completion Date	Variance Explanation
NOAA-20 Calibration/Validation				
Beta Maturity			06/15/18	
Provisional Maturity: AVTP, AVMP			06/15/18	
Provisional Maturity: Ozone, OLR, CO			10/02/18	
Validated Maturity: AVTP, AVMP, Ozone, OLR			10/28/19	
Validated Maturity: CO (S-NPP & NOAA-20)			10/28/19	
Provisional Maturity: CH4 (S-NPP & NOAA-20)			10/28/19	
Validated Maturity: CH4 (S-NPP & NOAA-20)	Feb-20	Apr-20	04/23/20	Combine review
Provisional Maturity: CO2 (S-NPP & NOAA-20)	Feb-20	Apr-20	04/23/20	Combine review
Validated Maturity: CO2 (S-NPP & NOAA-20)	Dec-20	Dec-20	12/17/20	
NOAA-20 Algorithm Adjustments				
Initial DAP			07/16/18	
Final DAP			11/01/19	
JPSS-2 Schedule				
J2 pre-launch test/proxy data review/analyze	Sep-20	Sep-20		
J2 Cal/Val Plan - draft delivery	Jun-20	Jun-20	06/05/20	
J2 Cal/Val Plan - final delivery	Dec-20	Dec-20		
Initial J2 ready DAP to ASSISTT	Jul-20	Jul-20	07/28/20	
Initial J2 ready DAP to NDE (include NPP/N20 updates)	Nov-20	Nov-20		
Final J2 ready DAP to ASSISTT	Mar-21	Mar-21		
Final J2 ready DAP to NDE (include NPP/N20 updates)	Aug-21	Aug-21		
Algorithm Updates Review	Sep-20	Sep-20		09/15/20
Algorithm Updates/Cal-Val Activities				
Algorithm update DAP to ASSISTT: ▪ Optimization of CO related look up tables ▪ Improve NOAA-20 CH4/CO2 algorithms ▪ J2 HEAP algorithm	Jul-20	Jul-20	07/28/20	With initial J2 DAP
Validation against NUCAPS SNPP trace gas EDRs, other instruments (MOPITT, AIRS, IASI) and in situ measurements (TCCON, ATom, WE-CAN, KORUS)	Sep-20	Sep-20		
Annual algorithms/products performance report	Feb-20	Feb-20	Feb-20	SJASTM: Feb-20
NOAA-20 and S-NPP cross-calibration/comparison	Sep-20	Sep-20		
Cal/Val visualization and LTM tool development/improvement	Sep-20	Sep-20		
Peer reviewed paper on NUCAPS HEAP cal/val	Sep-20	Sep-20		

NUCAPS Validated Maturity Review

SUPPLEMENTAL SLIDES

Set	List of Supplemental Slides	Slide Numbers
A	Supplemental Slides from Section 2	103-118
B	Supplemental Slides from Section 3	119-122
C	Supplemental Slides from Section 4	123
D	NUCAPS Team Collaborations with External Agencies	124-134

SET A. SUPPLEMENTAL SLIDES FROM SECTION 2

Set	List of Supplemental Slides	Slide Numbers
A.2.1	Sample Trace Gas Retrieval Ranges	104
A.2.2	RFA-1 AI Related work	105
A.2.3	MetOp-A/B/C statistical metrics Additional slides of product consistency (AVTP, AVMP, CO, CH4, CO2) among S-NPP/NOAA-20 and MetOp Series.	106-108
A.2.4	Additional slides of evaluation of v2.7.2 vs. v3.0 (to ensure that the latest algorithm changes did not adversely affect retrieval products that are already of validated maturity.	109-118

Sample Trace Gas Retrieval Ranges

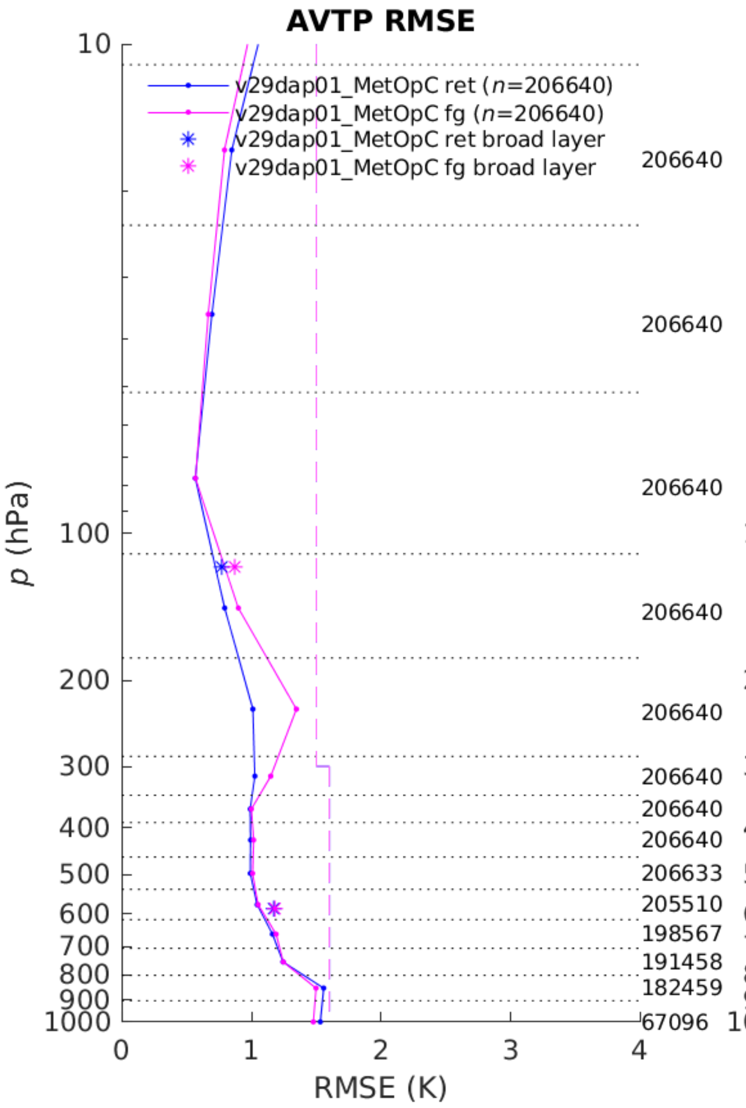
Sensor		SNPP		NOAA-20	
Date	Gas	min	max	min	max
20180820	CO (ppbv)	0	2081	0	2003
	CH4 (ppbv)	0	2334	0	2319
	O3 (ppbv)	0	16034	0	16270
	CO2 (ppmv)	373	450	372	443

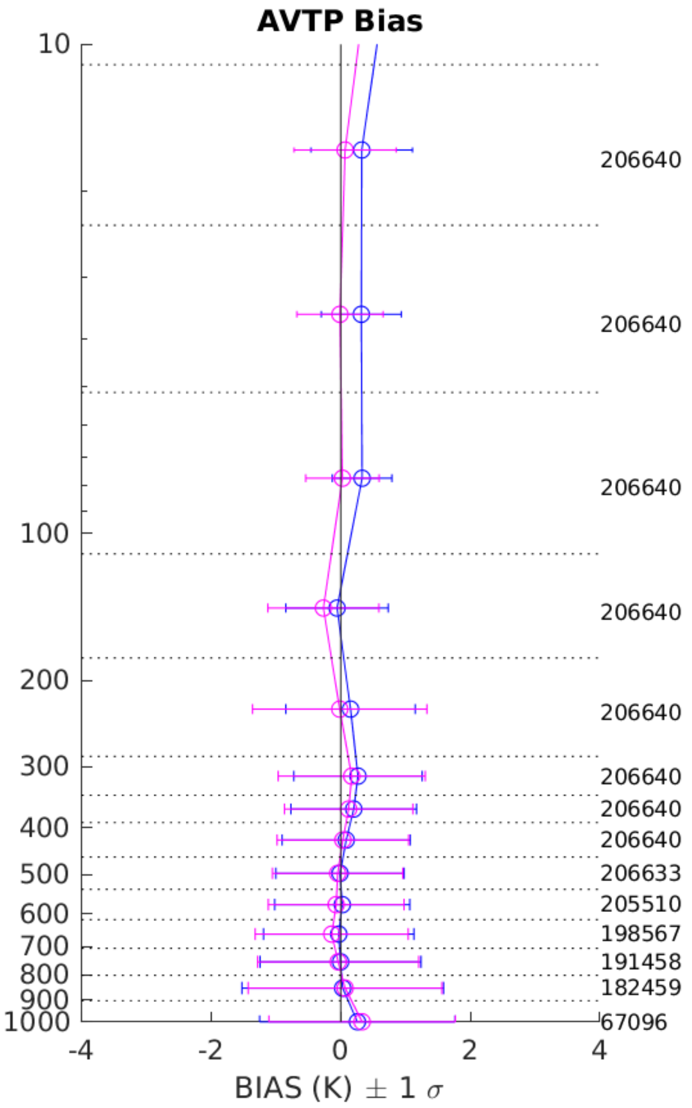
RFAs from April 2020 NUCAPS Maturity Review

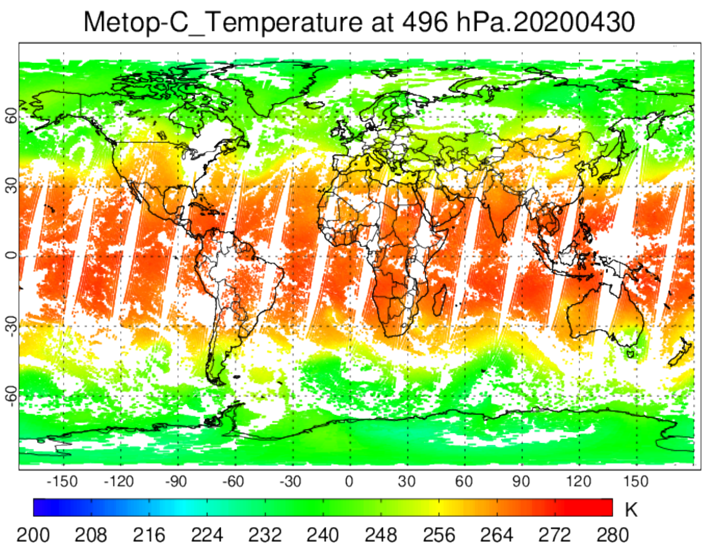
RFA-1: For the AI work, identify what is the problem the team is trying to use AI to solve, and why.

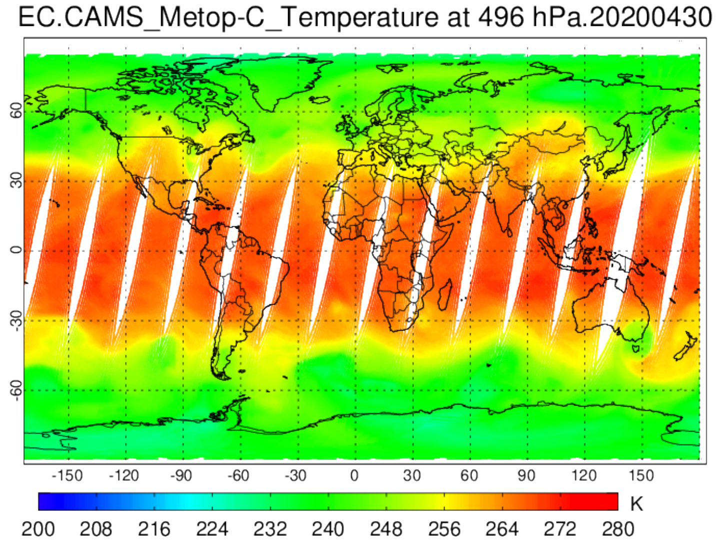
- **Improved Cloud Detection and/or Cloud-Clearing**
  - ❑ A remaining primary source of error in the NUCAPS algorithm EDR products lies in the problem of cloud-clearing. Cloud-clearing amplifies IR spectral noise and it is known that residual cloud-contamination often remains in the cloud-cleared radiance (CCR) spectra.
  - ❑ Additionally, RTA tuning requires the selection of clear-sky cases. Residual cloud-contamination will thus have a large impact on the quality of the tuning.
  - ❑ AI (Machine Learning) is well-suited to pattern recognition, including complex geophysical spatial patterns, and thus has promise for improved cloud-detection (e.g., *Liu et al.* 2020). We will explore Machine Learning techniques (e.g., Deep Neural Networks, DNN) for improving cloud-detection and cloud-clearing algorithms.
- **The OLR Regression**
  - ❑ The current OLR regression is supper channel based, with AIRS as a transfer instrument, linear regression. We can exclude the transfer instrument, and directly use DNN to train the OLR from CrIS/IASI radiance with the CERE OLR benchmark.
- **Improve Boundary Layer Retrievals**
  - ❑ Numerous investigations discussed possible improvements to boundary layer retrieval improvements through effective data fusion of multiple data sources and DNN. Will explore the best option

MetOp-C AVTP RMS and Bias - FG and Final Retrieval

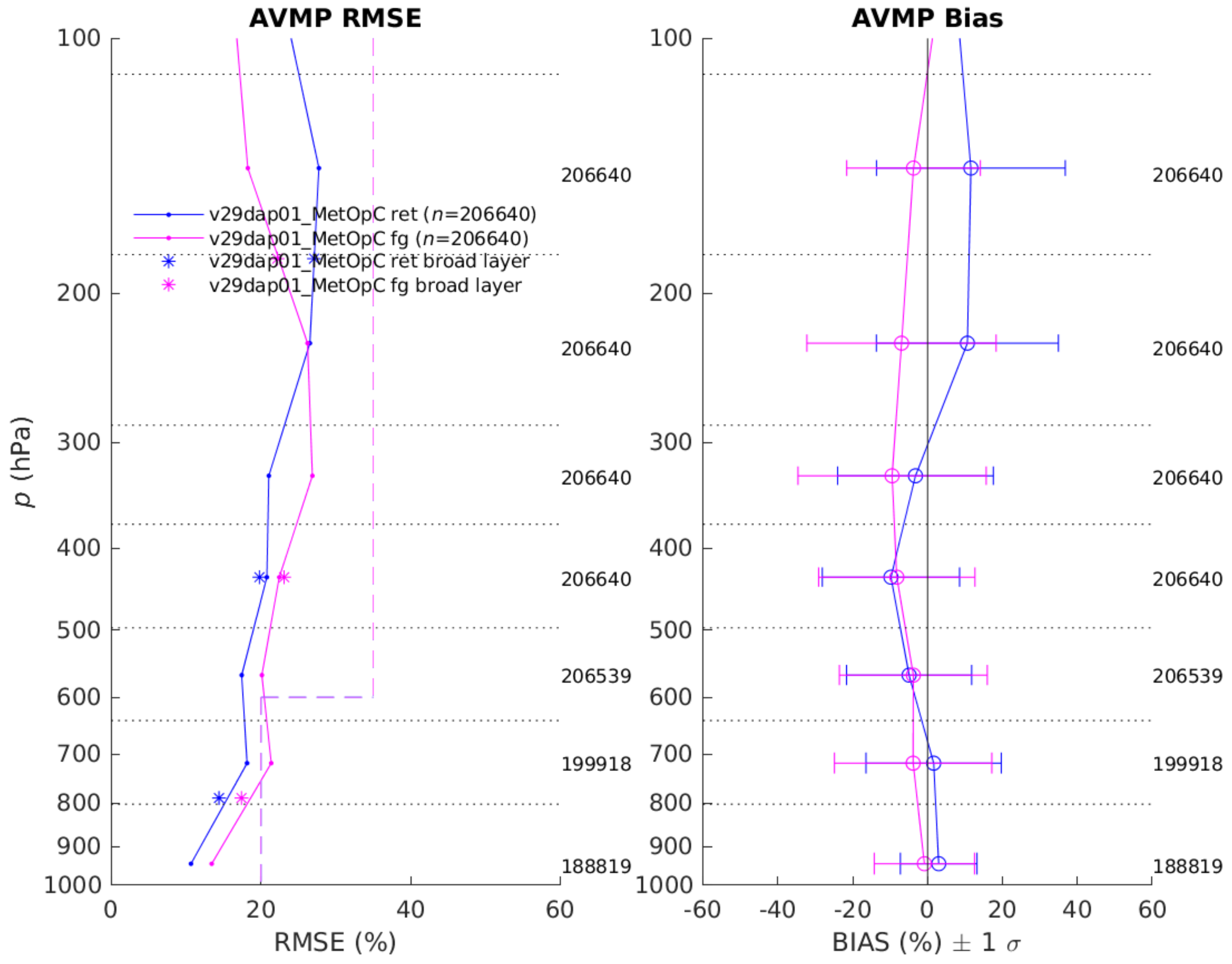


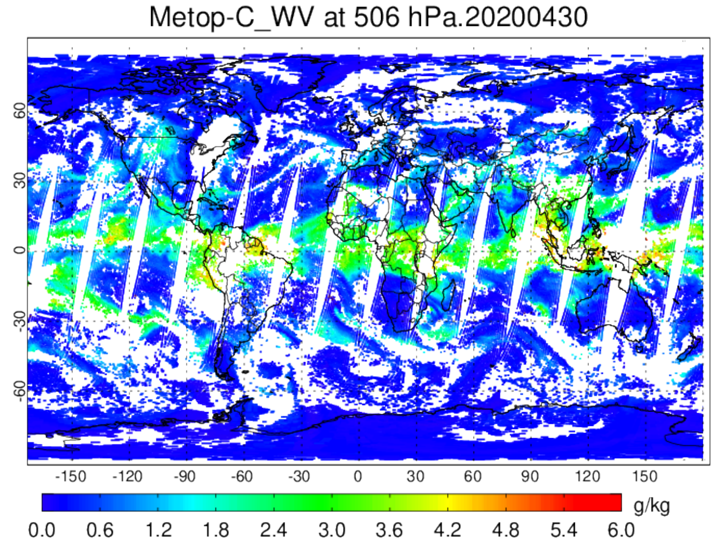


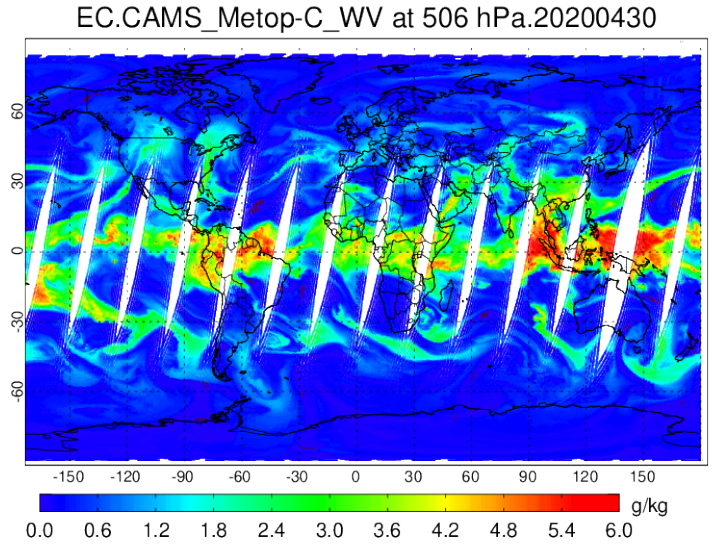




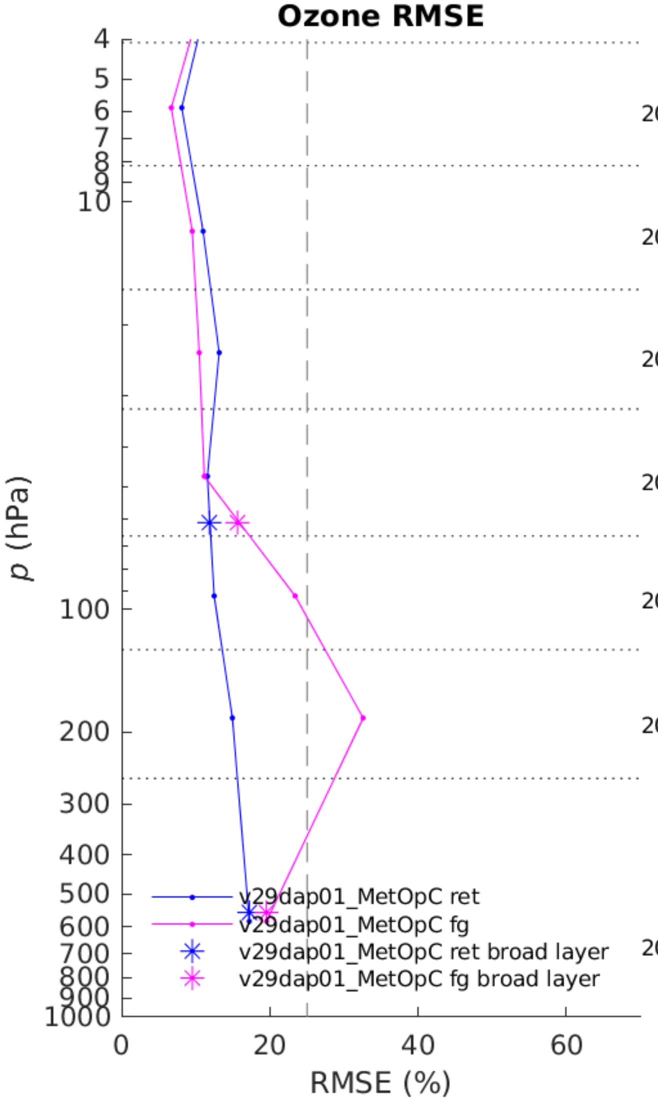
MetOp-C AVMP RMS and Bias wrt ECMWF - FG and Final Retrieval

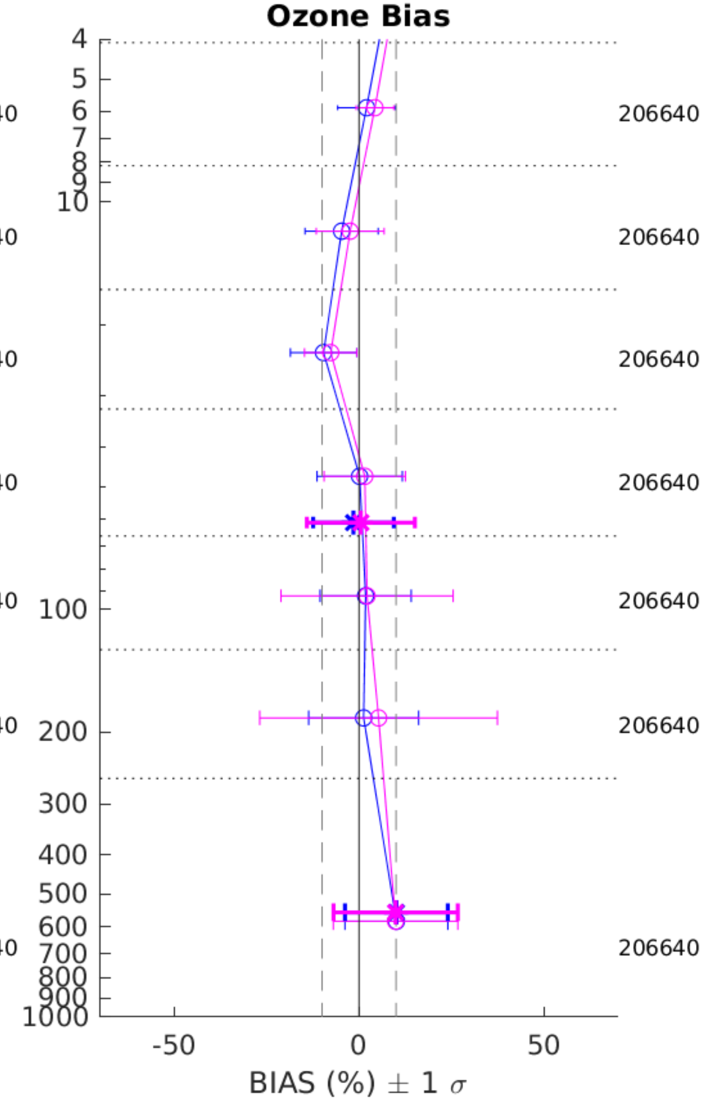


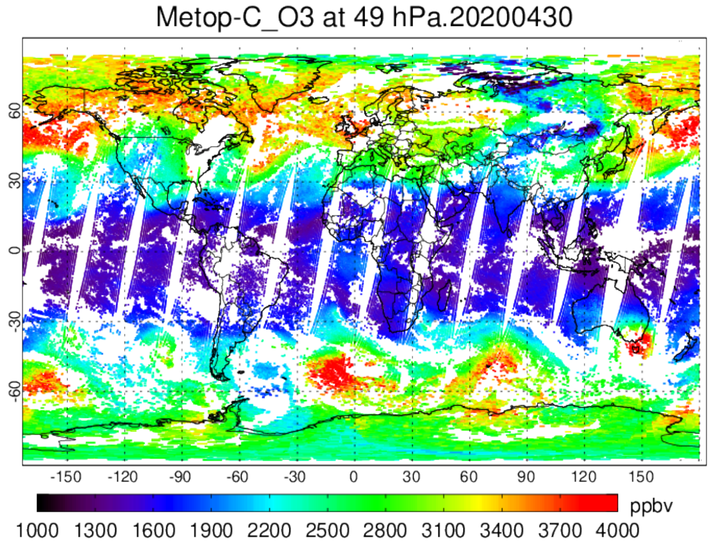


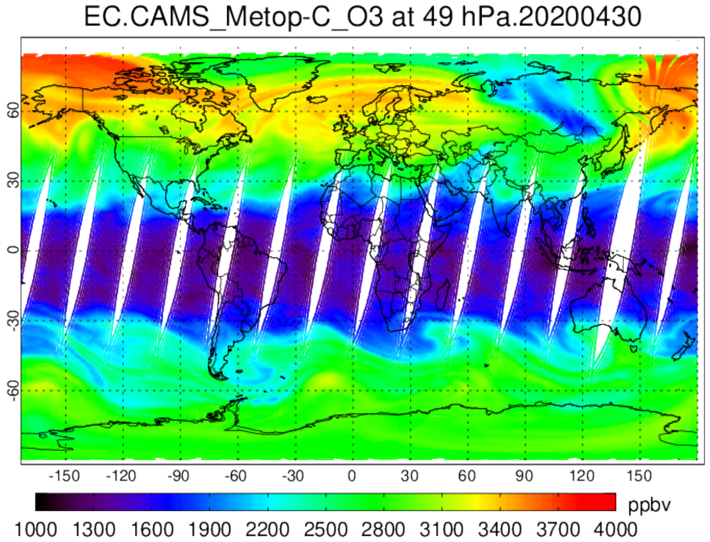


MetOp-C Ozone RMS and Bias wrt ECMWF - FG and Final Retrieval

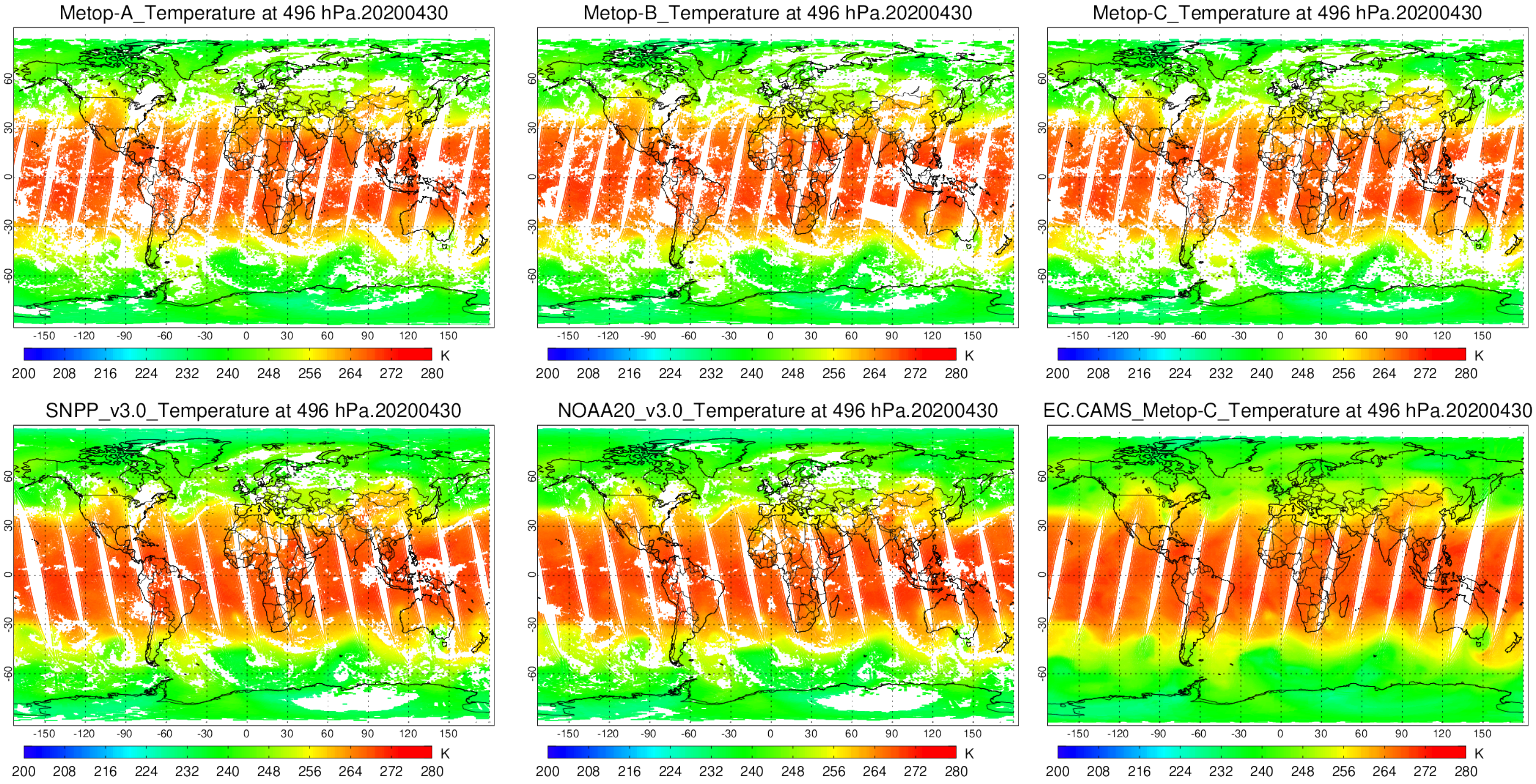








500 hPa Temperature Maps : MetOp-A/B/C, S-NPP/NOAA20, ECMWF

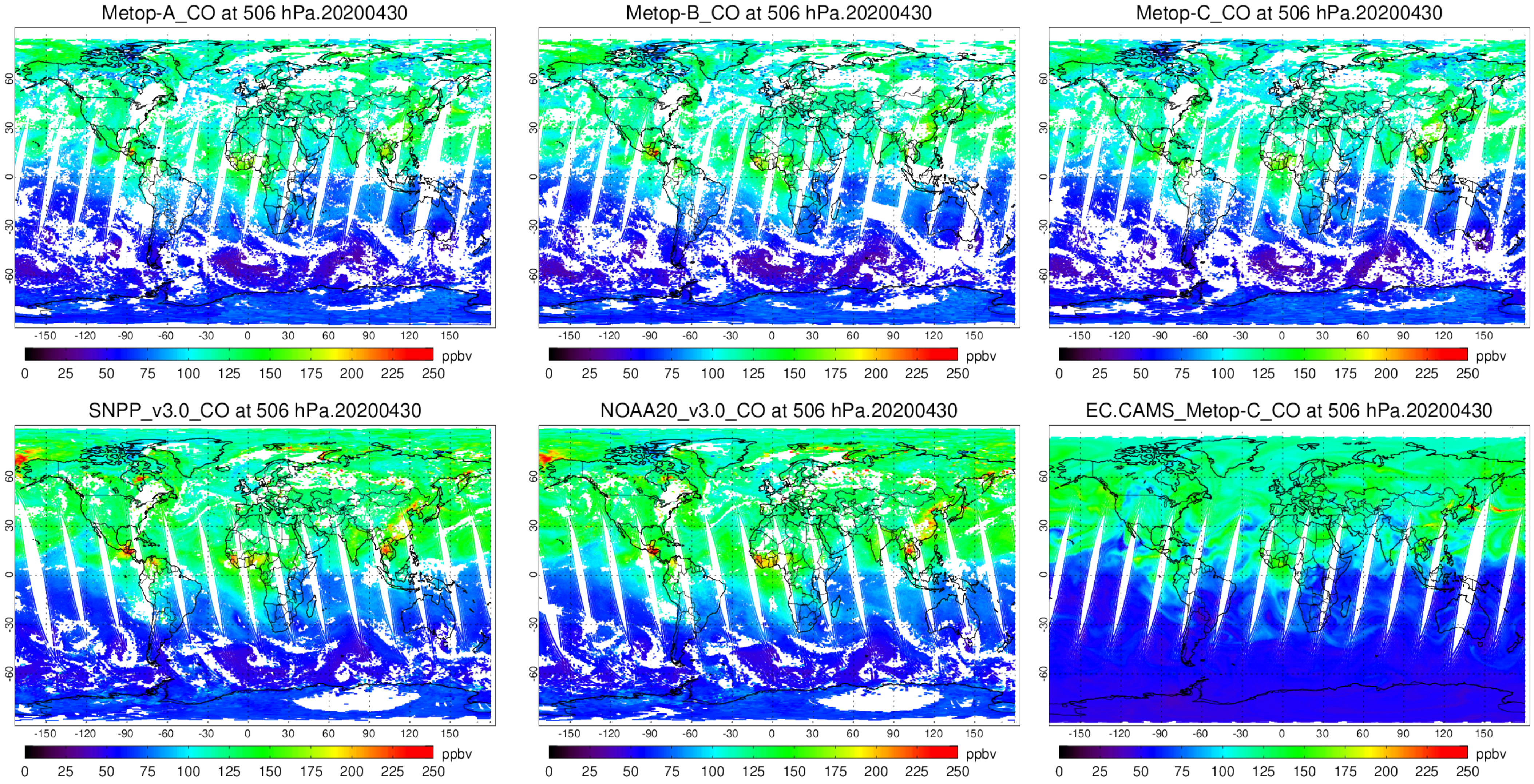


MetOp Yields (IR+MW)
A: 54%
B: 53%
C: 56%

S-NPP/NOAA20 Yield (IR+MW)
S-NPP: 70.4%
NOAA20: 69.7%

NUCAPS Algorithm produces consistent Atmospheric Vertical Temperature Profile (AVTP) product from JPSS (S-NPP and NOAA-20) and MetOp series (MetOp-A/B/C). Retrieved AVTP product (100 layers) spans from surface to 0.01mb, and has reached validated maturity. Validation of AVMP is performed using a hierarchy of validation data sources, e.g. models (ECMWF), correlative data sets (e.g. AIRS), and time and space collocated matches of dedicated RAOBS, global RAOB network, and campaigns of opportunity (e.g. AEROSE).

500 hPa Carbon Monoxide Maps: Metop-A/B/C, S-NPP/NOAA-20, ECMWF

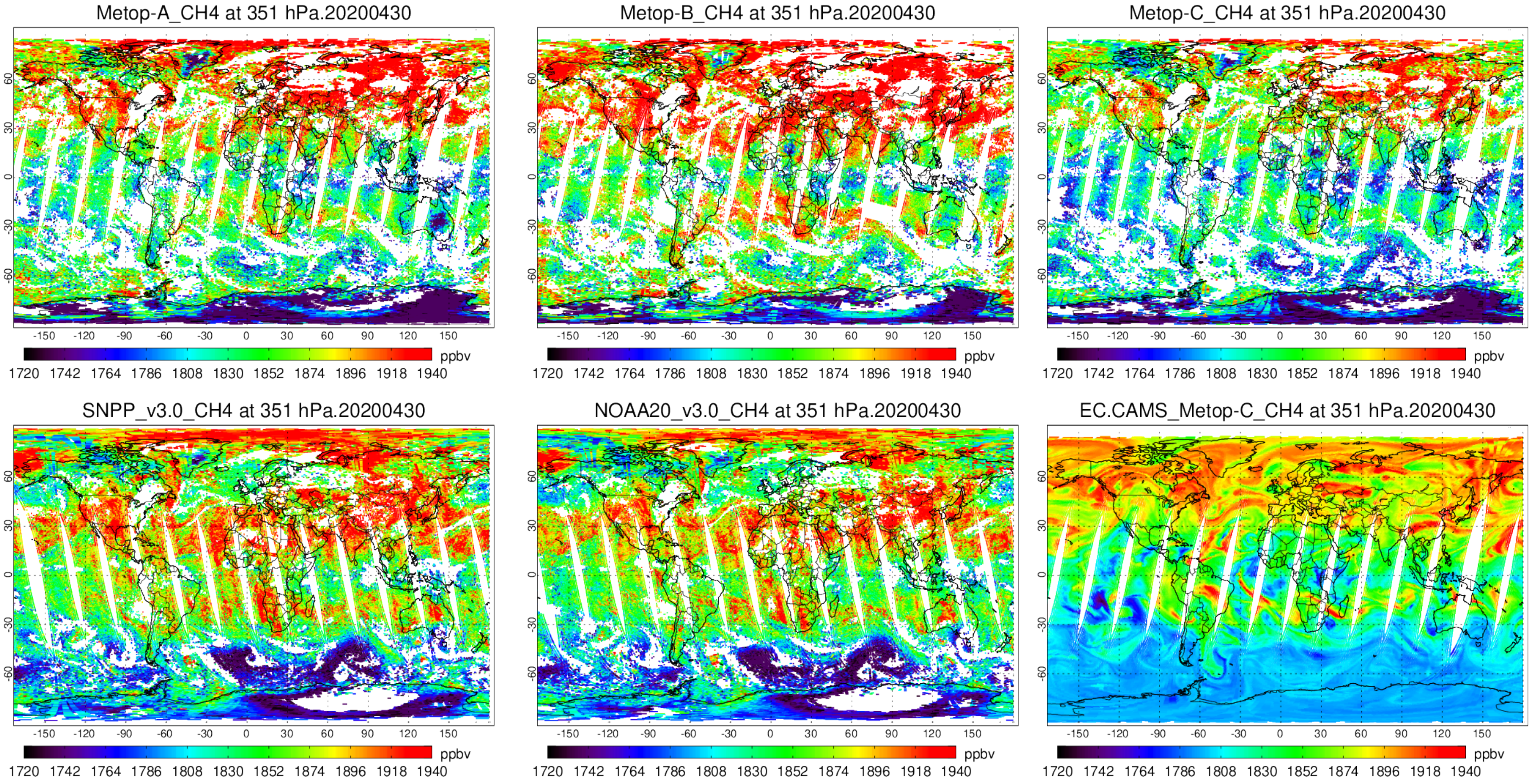


MetOp Yields (IR+MW)
A: 54%
B: 53%
C: 56%

S-NPP/NOAA20 Yield (IR+MW)
S-NPP: 70.4%
NOAA20: 69.7%

NUCAPS Algorithm produces consistent Carbon monoxide (CO) product from JPSS (S-NPP and NOAA-20) and MetOp series (MetOp-A/B/C). Retrieved CO product (100 layers) spans from surface to 0.01mb, and has reached validated maturity. Validation of CO is performed using a hierarchy of validation data sources, e.g. models (CAMS), correlative data sets (e.g. AIRS, TROPOMI), and time and space collocated matches of reference data sets such as TCCON, Atom, Aircore, and campaigns of opportunity (e.g.xxx).

350 hPa Methane (CH4) Maps: Metop-A/B/C, S-NPP/NOAA-20, ECMWF

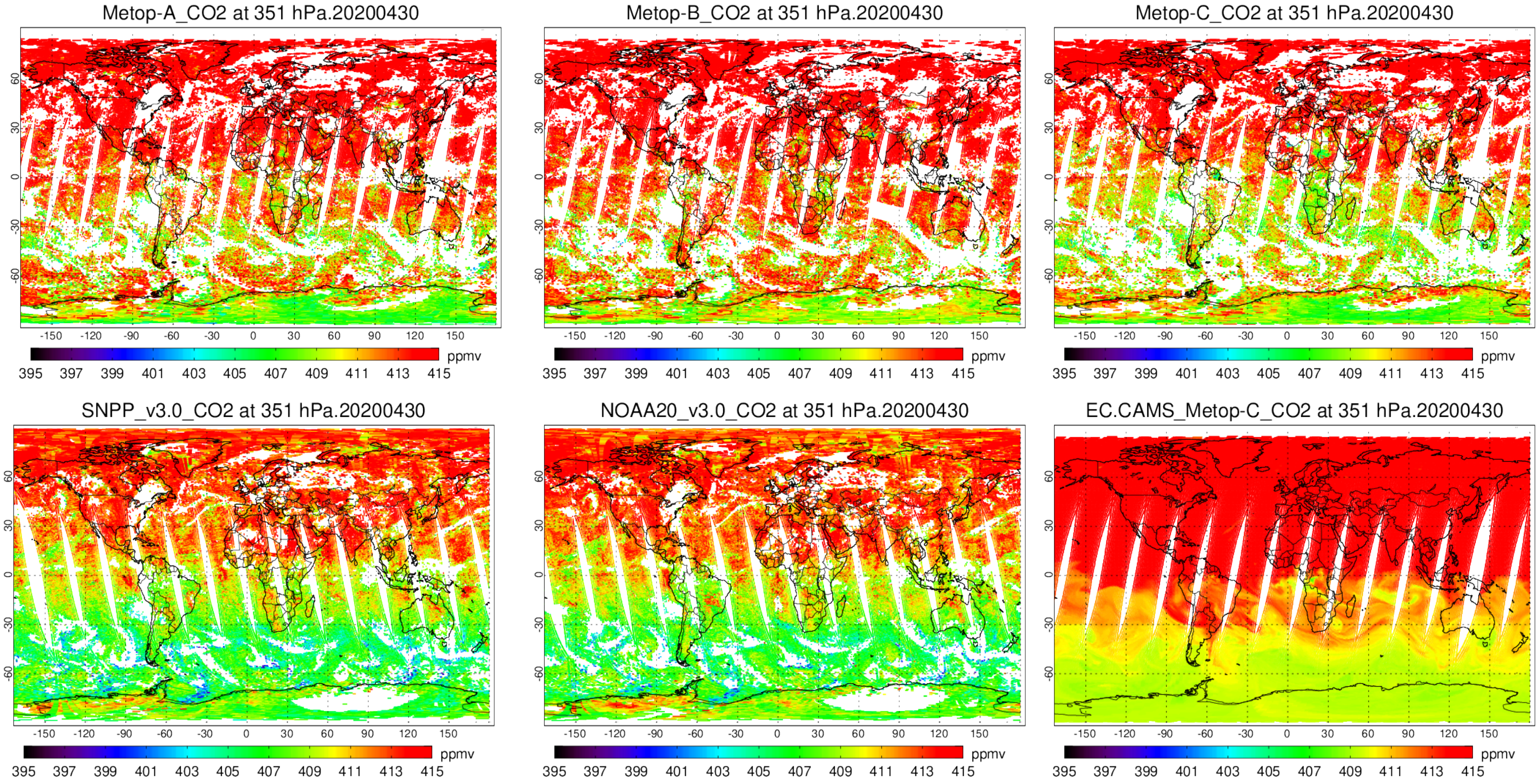


MetOp Yields (IR+MW)
A: 54%
B: 53%
C: 56%

S-NPP/NOAA20 Yield (IR+MW)
S-NPP: 70.4%
NOAA20: 69.7%

NUCAPS Algorithm produces consistent Methane (CH4) product from JPSS (S-NPP and NOAA-20) and MetOp series (MetOp-A/B/C). Retrieved CH4 product (100 layers) spans from surface to 0.01mb, and has reached validated maturity. Validation of CH4 is performed using a hierarchy of validation data sources, e.g. models (CAMS), correlative data sets (e.g. AIRS, TROPOMI), and time and space collocated matches of reference data sets such as TCCON, Atom, Aircore, and campaigns of opportunity (e.g.xxx).

350 hPa Carbon Dioxide (CO2) Maps: Metop-A/B/C, S-NPP/NOAA-20, ECMWF

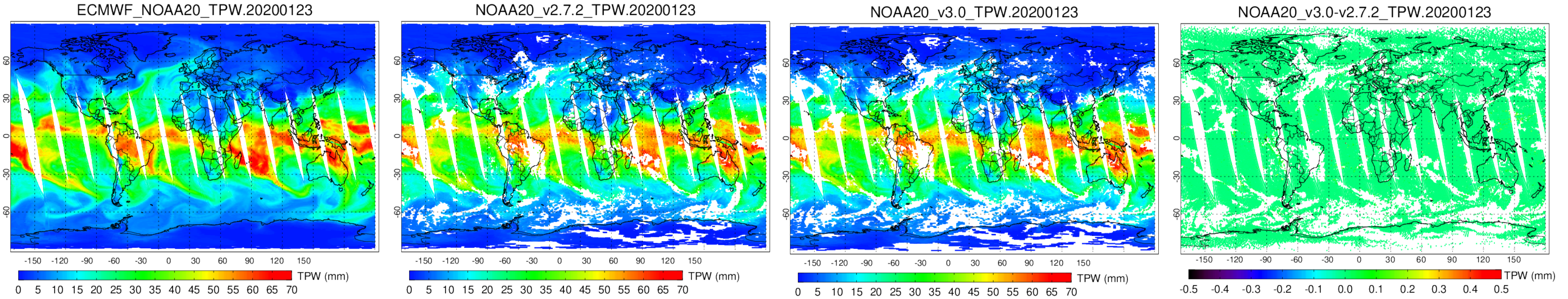


MetOp Yields (IR+MW)
A: 54%
B: 53%
C: 56%

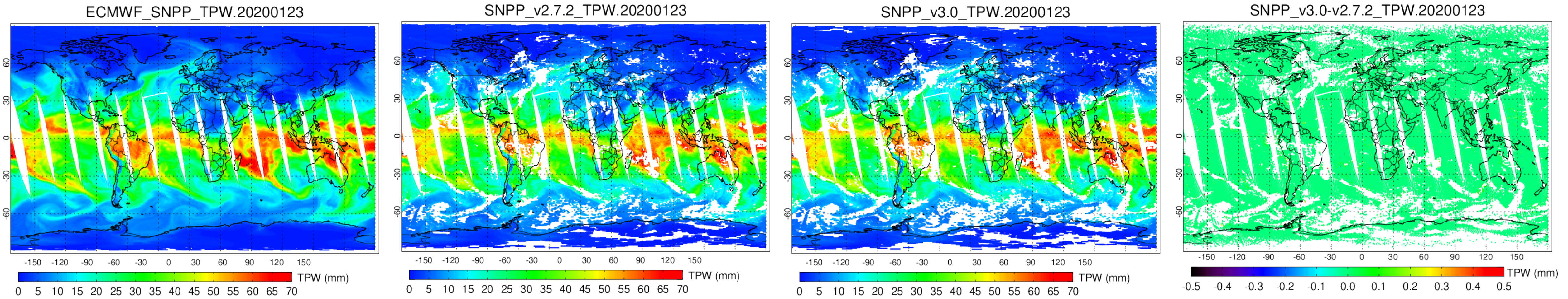
S-NPP/NOAA20 Yield (IR+MW)
S-NPP: 70.4%
NOAA20: 69.7%

NUCAPS Algorithm produces consistent Carbondioxide (CO2) product from JPSS (S-NPP and NOAA-20) and MetOp series (MetOp-A/B/C). Retrieved CO2 product (100 layers) spans from surface to 0.01mb, and has reached provisional maturity, and aimed to reach validated maturity. Validation of CH4 is performed using a hierarchy of validation data sources, e.g. models (CAMS), correlative data sets (e.g. AIRS, TROPOMI), and time and space collocated matches of reference data sets such as TCCON, Atom, Aircore, and campaigns of opportunity (e.g.xxx).

2.7.2 vs. v3.0 Total Precipitable Water (20200123)

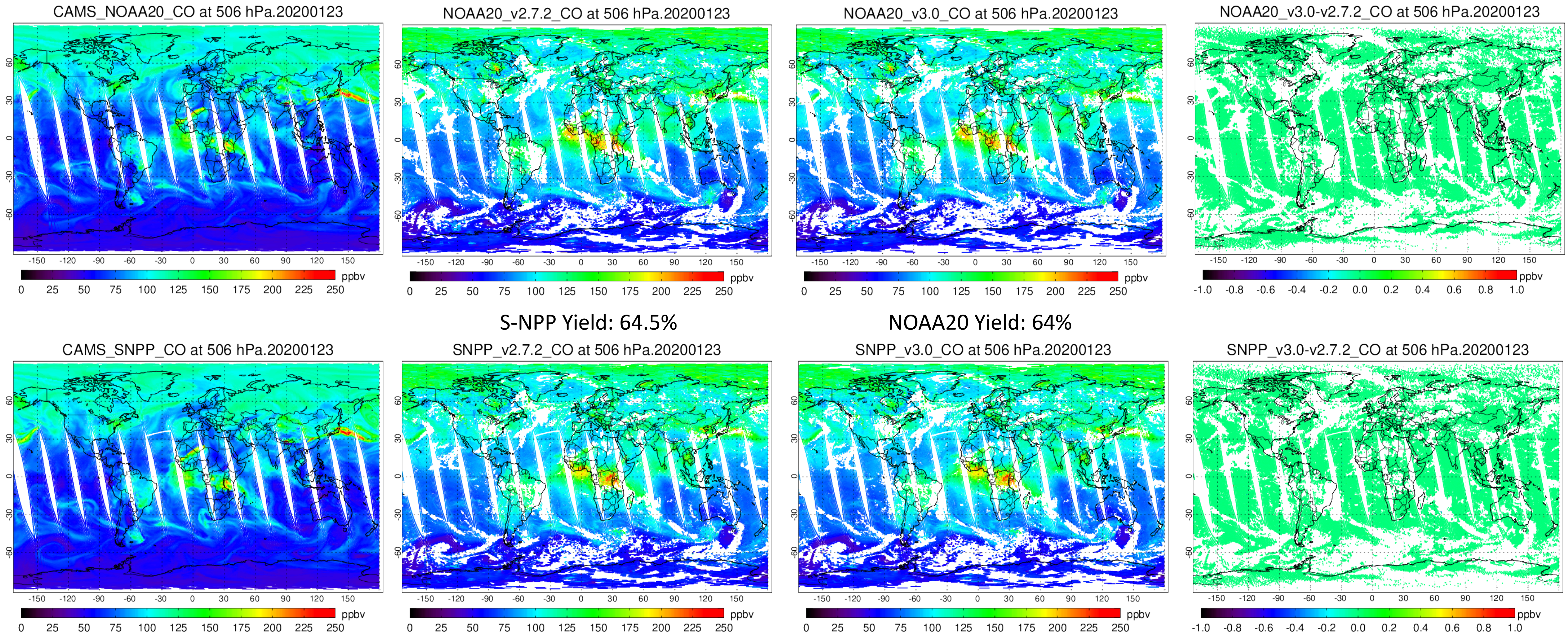


S-NPP Yield: 64.5%   NOAA20 Yield: 64%



These supplemental slides provide additional evaluations of S-NPP/NOAA-20 v2.7.2 vs. v3.0 to ensure that the **latest algorithm changes did not adversely affect retrieval products that are already of validated maturity.**

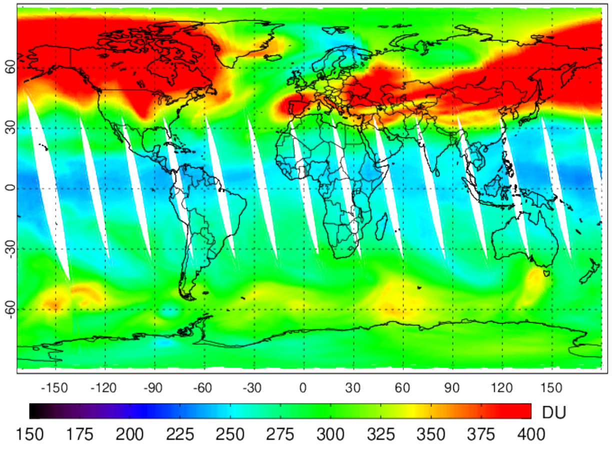
2.7.2 vs. v3.0 CO at 506 hPa (20200123)



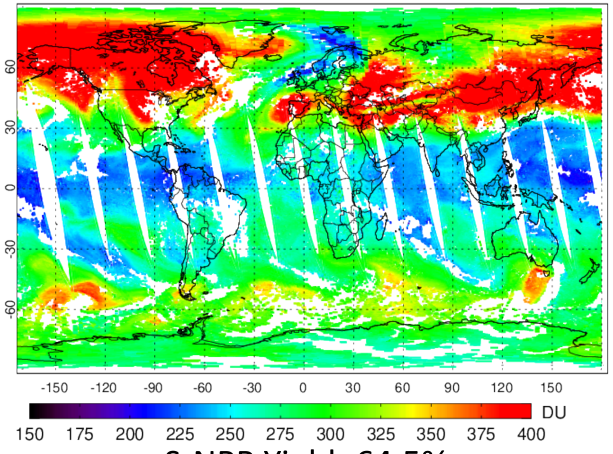
These supplemental slides provide additional evaluations of S-NPP/NOAA-20 v2.7.2 vs. v3.0 to ensure that the **latest algorithm changes did not adversely affect retrieval products that are already of validated maturity.**

2.7.2 vs. v3.0 Total Column Ozone (20200123)

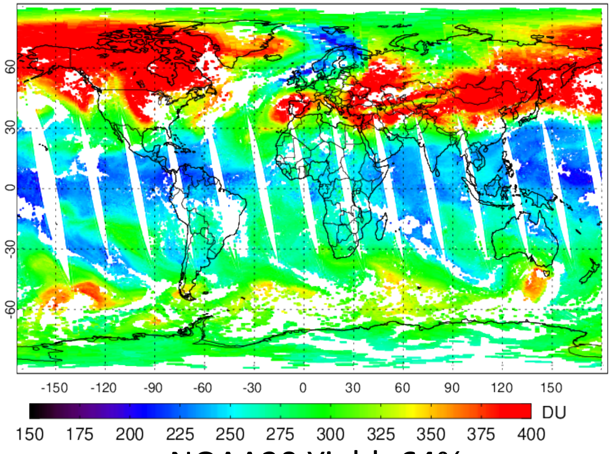
CAMS_NOAA20_Total column of O3.20200123



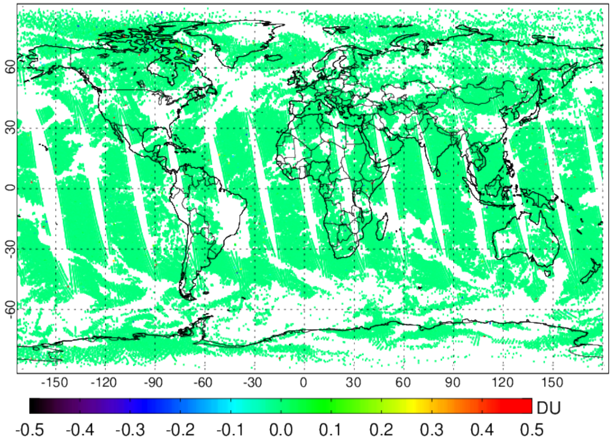
NOAA20_v2.7.2_Total column of O3.20200123



NOAA20_v3.0_Total column of O3.20200123



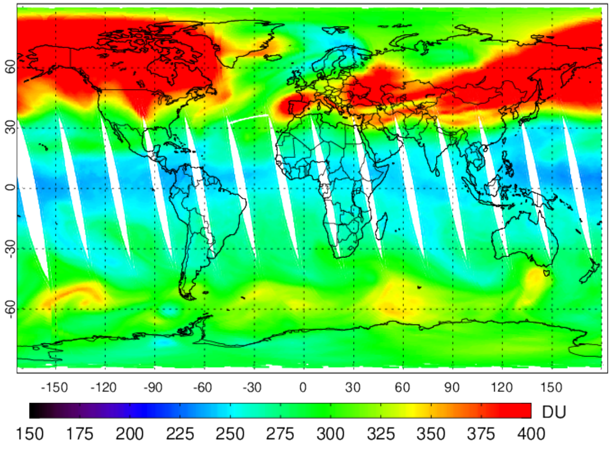
NOAA20_v3.0-v2.7.2_Total column of O3.20200123



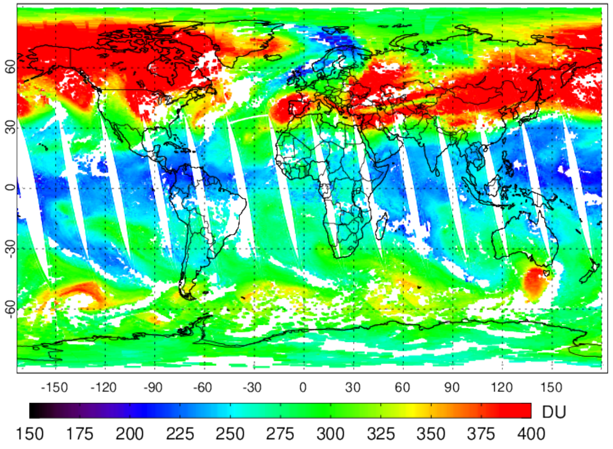
S-NPP Yield: 64.5%

NOAA20 Yield: 64%

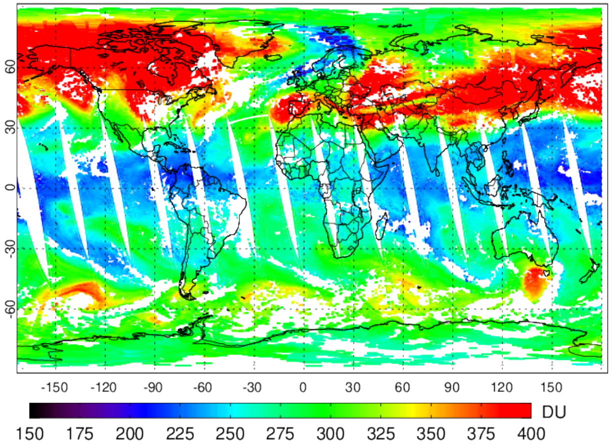
CAMS_SNPP_Total column of O3.20200123



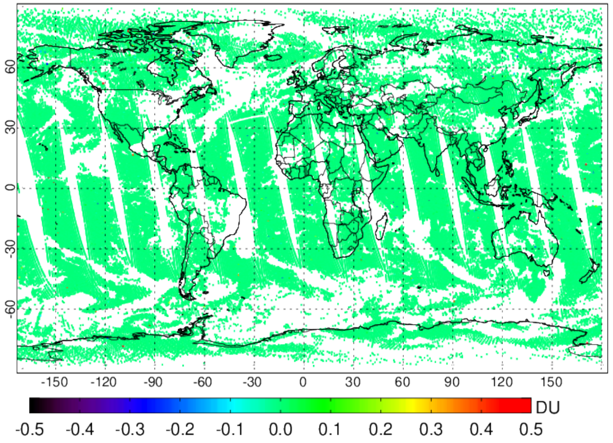
SNPP_v2.7.2_Total column of O3.20200123



SNPP_v3.0_Total column of O3.20200123



SNPP_v3.0-v2.7.2_Total column of O3.20200123

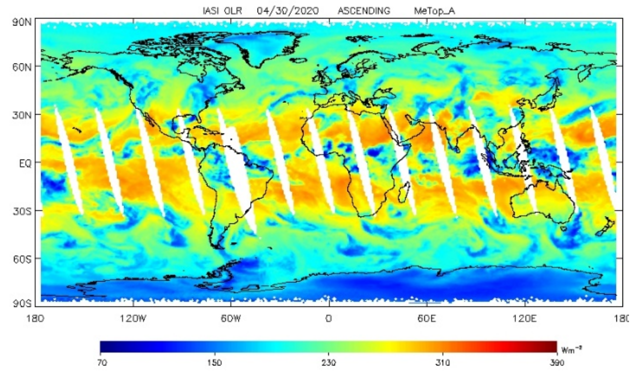


These supplemental slides provide additional evaluations of S-NPP/NOAA-20 v2.7.2 vs. v3.0 to ensure that the **latest algorithm changes did not adversely affect retrieval products that are already of validated maturity.**

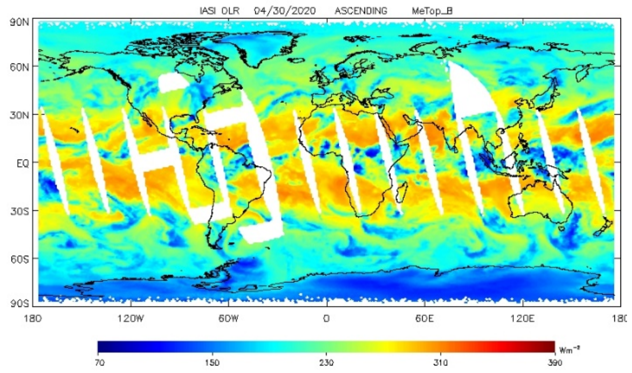
NUCAPS Products

Daily NUCAPS CrIS NOAA-20 OLR VS. IASI MetOP OLR (Night time 04/30/2020)

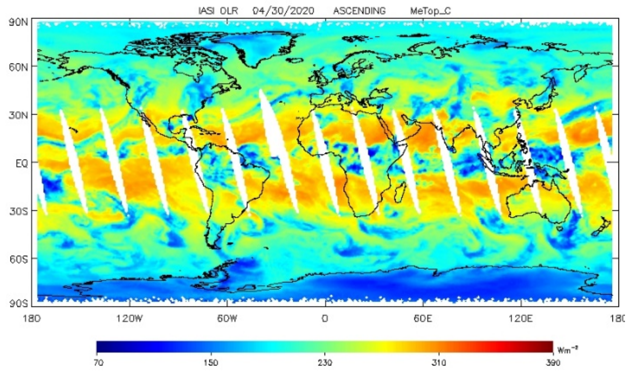
MetOp-A IASI



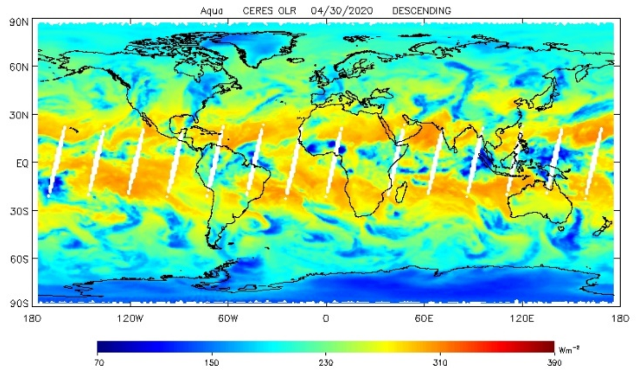
MetOp-B IASI



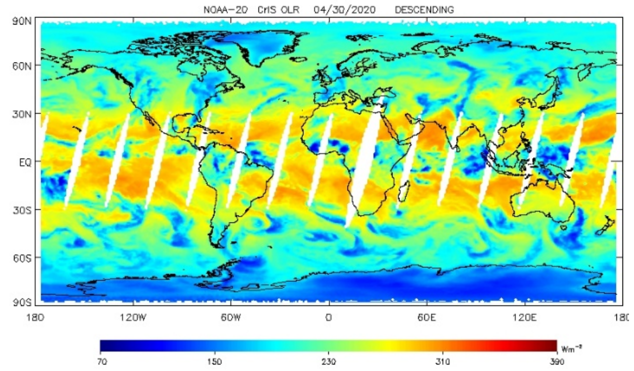
MetOp-C IASI



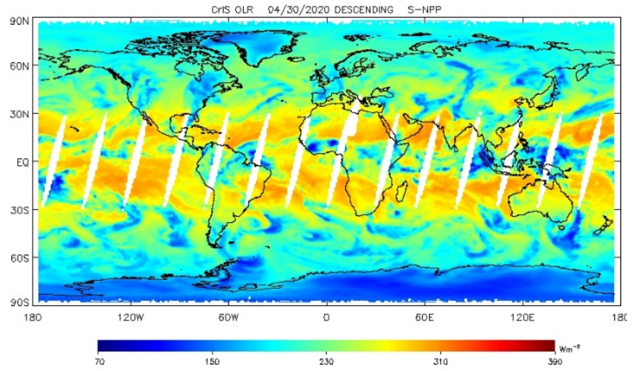
Aqua CERES



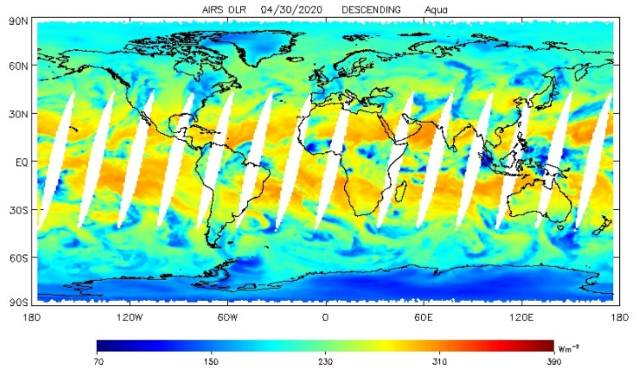
NOAA-20 CrIS



S-NPP CrIS



Aqua AIRS



MetOp IASI vs NOAA-20 CrIS

	BIAS	STD	CC
A	-1.14	23.17	0.87
B	-1.56	21.06	0.89
C	-0.79	21.07	0.89

MetOp IASI vs Aqua CERES

	BIAS	STD	CC
A	-1.20	23.75	0.87
B	-1.58	21.81	0.89
C	-0.74	21.80	0.89

- NUCAPS JPSS CrIS-OLR has reached validated maturity.
- IASI OLR products are being evaluated for consistency among MetOp-A/B/C and with other correlative observations.

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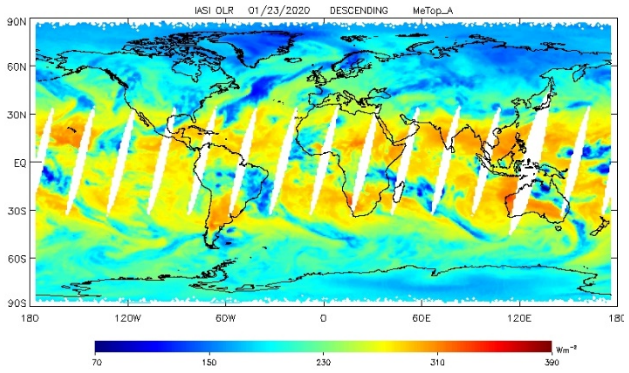
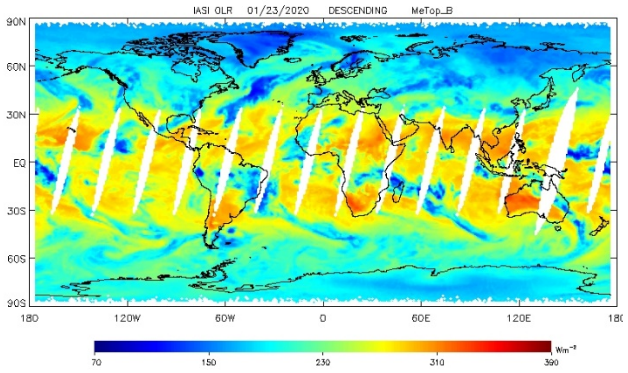
NUCAPS Products

Daily NUCAPS CrIS NOAA-20 OLR VS. IASI MetOp OLR (Day time 01/23/2020)

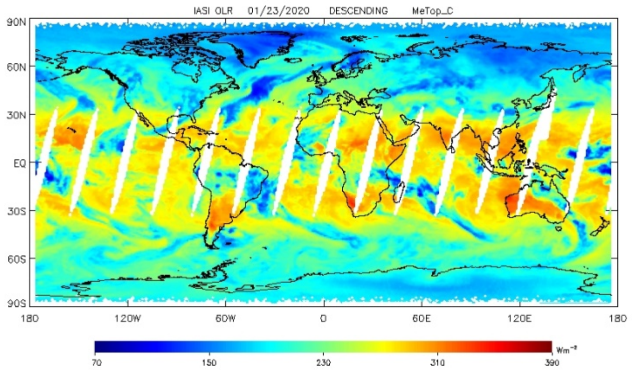
MetOp-A IASI



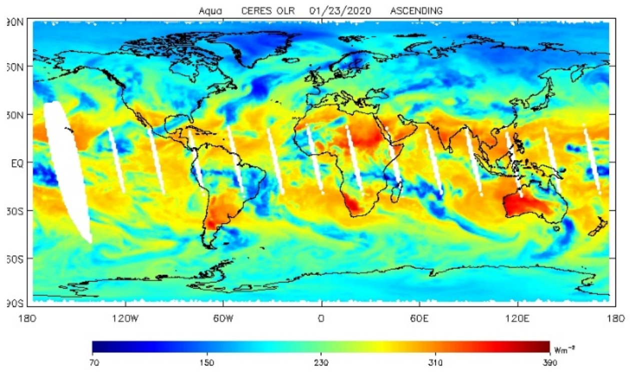
MetOp-B IASI



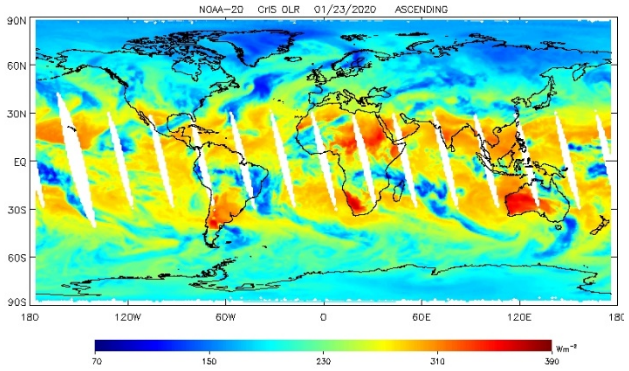
MetOp-C IASI



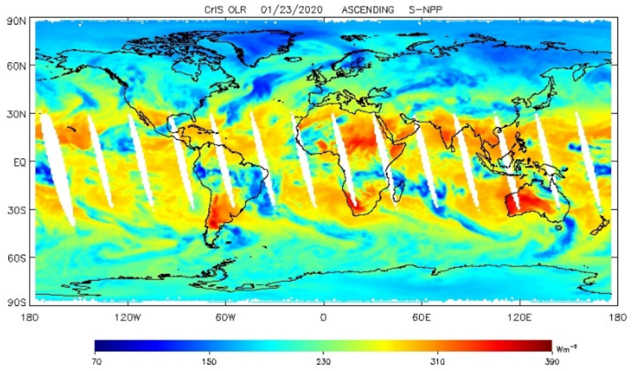
Aqua CERES



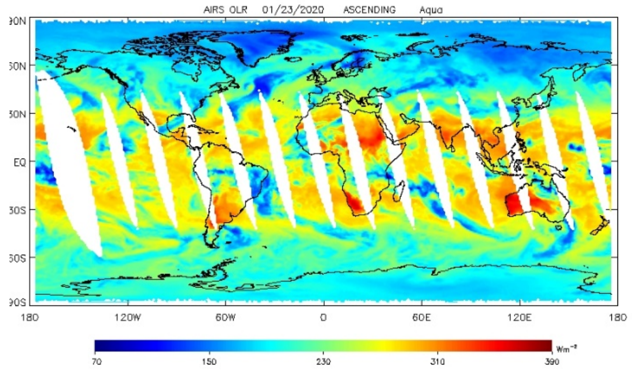
NOAA-20 CrIS



S-NPP CrIS



Aqua AIRS



MetOp IASI vs NOAA-20 CrIS

	BIAS	STD	CC
A	2.80	21.78	0.88
B	1.72	21.21	0.89
C	1.96	20.74	0.89

MetOp IASI vs Aqua CERES

	BIAS	STD	CC
A	3.69	22.20	0.88
B	2.55	21.31	0.89
C	2.83	21.05	0.89

- NUCAPS JPSS CrIS-OLR has reached validated maturity.
- IASI OLR products are being evaluated for consistency among MetOp-A/B/C and with other correlative observations.

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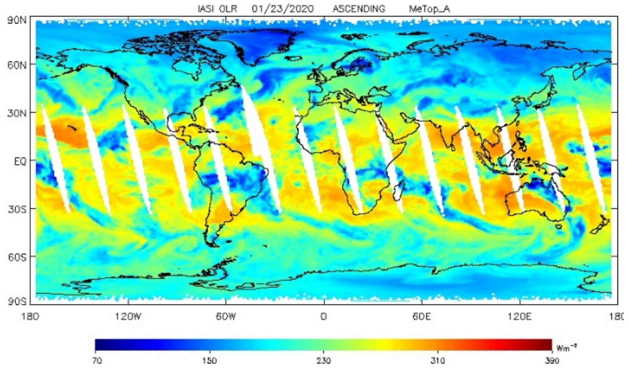
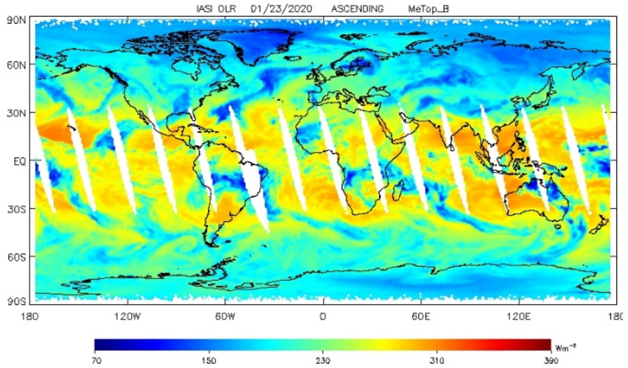
Daily NUCAPS CrIS NOAA-20 OLR VS. IASI MetOp OLR (Night time 01/23/2020)

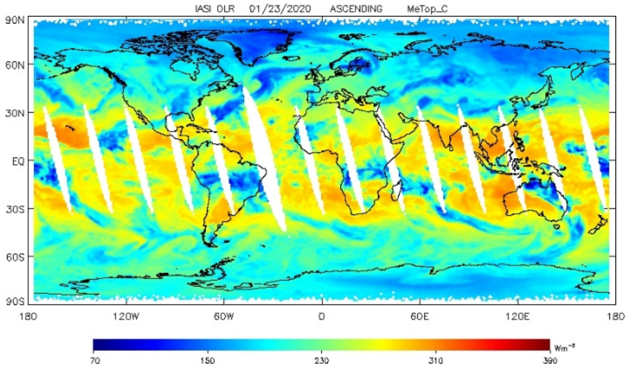
MetOp-A IASI



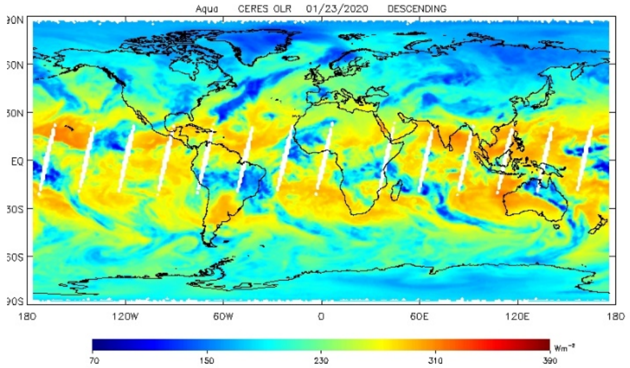
MetOp-B IASI



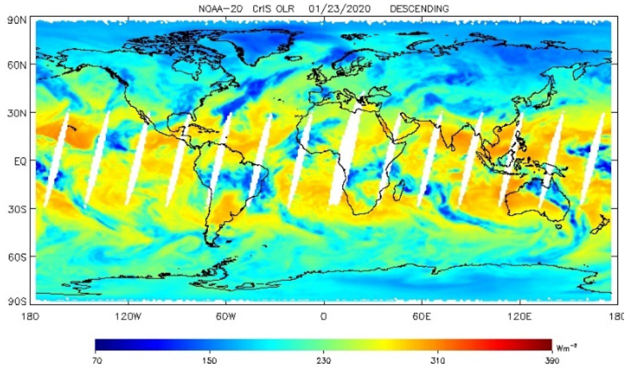
MetOp-C IASI



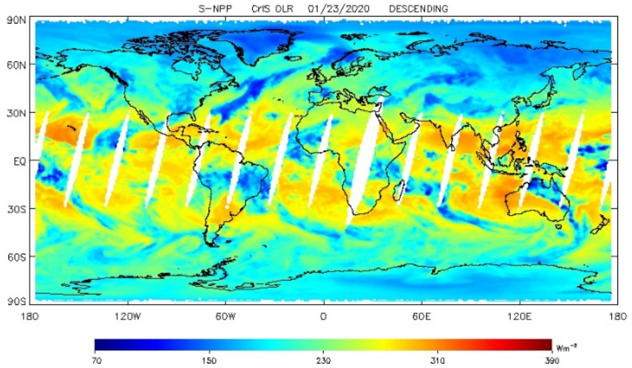
Aqua CERES



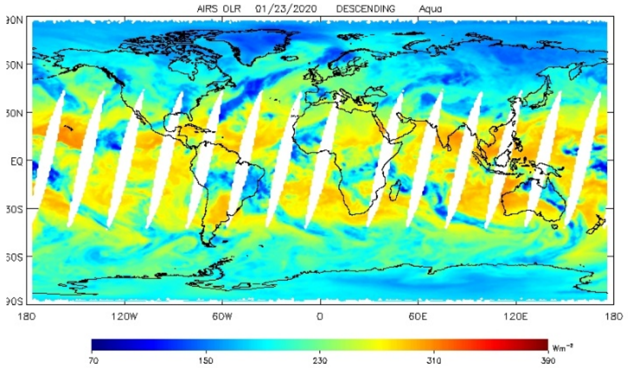
NOAA-20 CrIS



S-NPP CrIS



Aqua AIRS



MetOp IASI vs NOAA-20 CrIS

	BIAS	STD	CC
A	0.15	20.32	0.89
B	-0.12	19.05	0.90
C	-0.05	19.10	0.90

MetOp IASI vs Aqua CERES

	BIAS	STD	CC
A	0.20	20.64	0.89
B	-0.03	19.43	0.90
C	0.04	19.40	0.90

- NUCAPS JPSS CrIS-OLR has reached validated maturity.
- IASI OLR products are being evaluated for consistency among MetOp-A/B/C and with other correlative observations.

SET B. SUPPLEMENTAL SLIDES FROM SECTION 3

Set	List of Supplemental Slides	Slide Numbers
B.3.1	JPSS Level 1 Requirements for Trace Gases	120
B.3.2	SNPP NUCAPS v2.7.2 Column Trace Gases versus TCCON	121
B.3.3	NUCAPS AVTP/AVMP/O3 profiles versus ATom	122

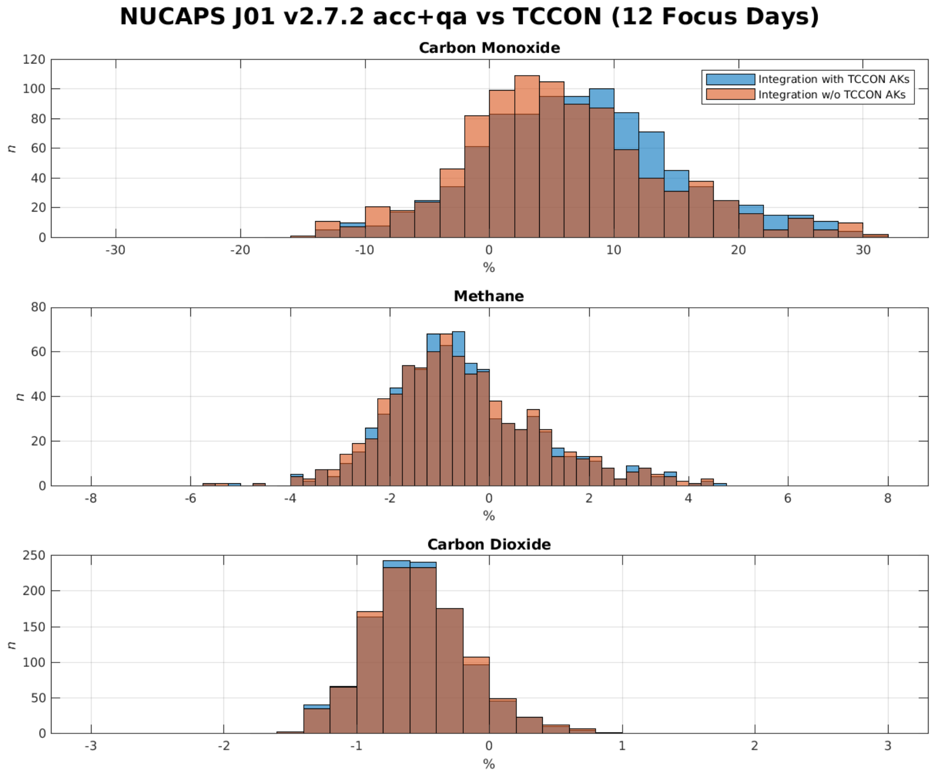
JPSS Specification Performance Requirements
CrIS Trace Gas EDR Uncertainty (O_3, CO, CO_2, CH_4)

	CrIS Infrared Trace Gases Specification Performance Requirements		
	PARAMETER	**THRESHOLD**	**OBJECTIVE**
Ozone Profile	**O_3 (Ozone)** Profile Precision, 4–260 hPa (6 statistic layers)	20%	10%
	O_3 (Ozone) Profile Precision, 260 hPa to sfc (1 statistic layer)	20%	10%
	O_3 (Ozone) Profile Accuracy, 4–260 hPa (6 statistic layers)	±10%	±5%
	O_3 (Ozone) Profile Accuracy, 260 hPa to sfc (1 statistic layer)	±10%	±5%
	O_3 (Ozone) Profile Uncertainty, 4–260 hPa (6 statistic layers)	25%	15%
	O_3 (Ozone) Profile Uncertainty, 260 hPa to sfc (1 statistic layer)	25%	15%
Carbon Gases	**CO (Carbon Monoxide)** Total Column Precision	15% (CrIS FSR)	3%
	CO (Carbon Monoxide) Total Column Accuracy	±5% (CrIS FSR)	±5%
	CO_2 (Carbon Dioxide) Total Column Precision	0.5% (2 ppmv)	1.05 to 1.4 ppmv
	CO_2 (Carbon Dioxide) Total Column Accuracy	±1% (4 ppmv)	NS
	CH_4 (Methane) Total Column Precision	1% (≈20 ppbv)	NS
	CH_4 (Methane) Total Column Accuracy	±4% (≈80 ppmv)	NS

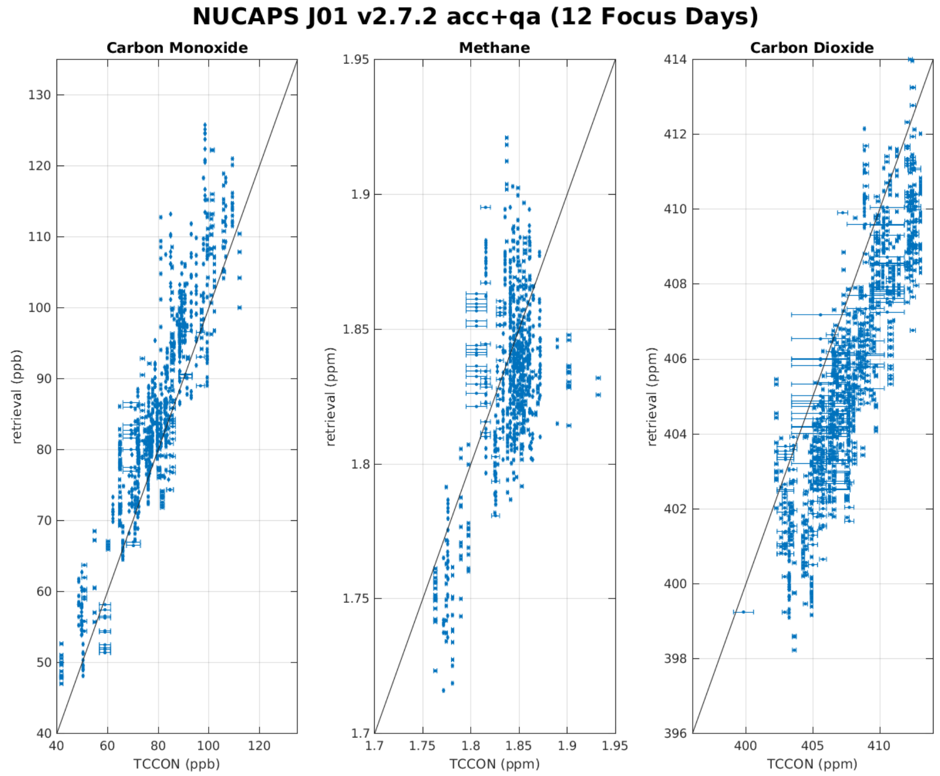
Source:
(L1RD, 2014, pp. 45-49)

Statistical Analysis 12 Focus Days

Histograms



Scatterplots

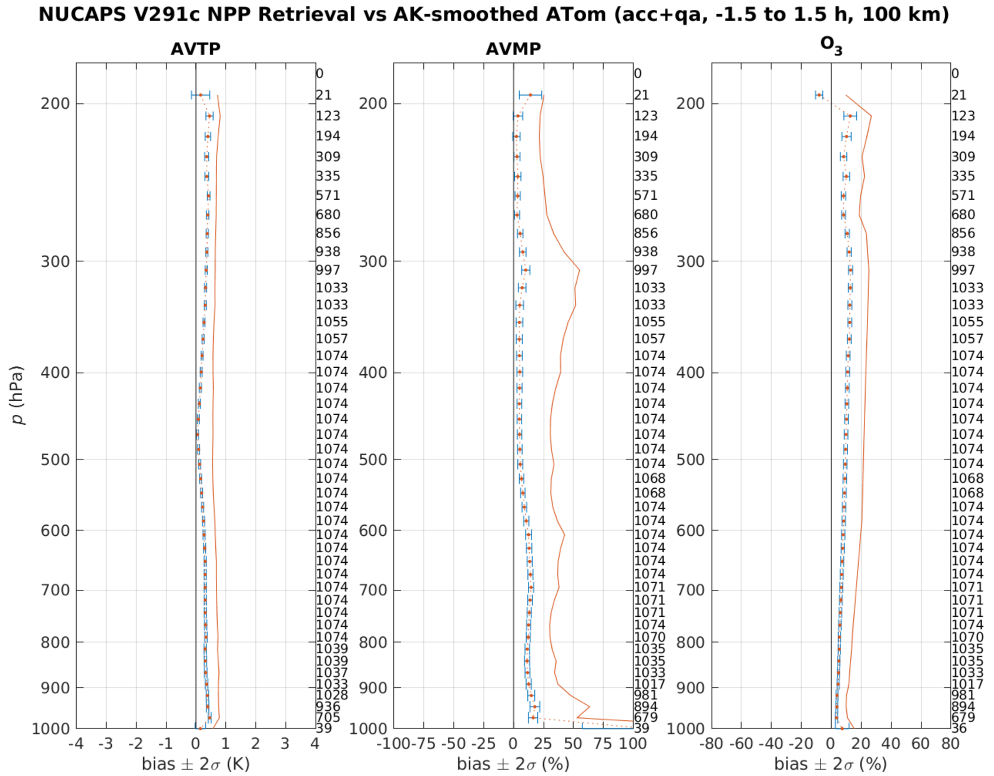


NUCAPS – TCCON

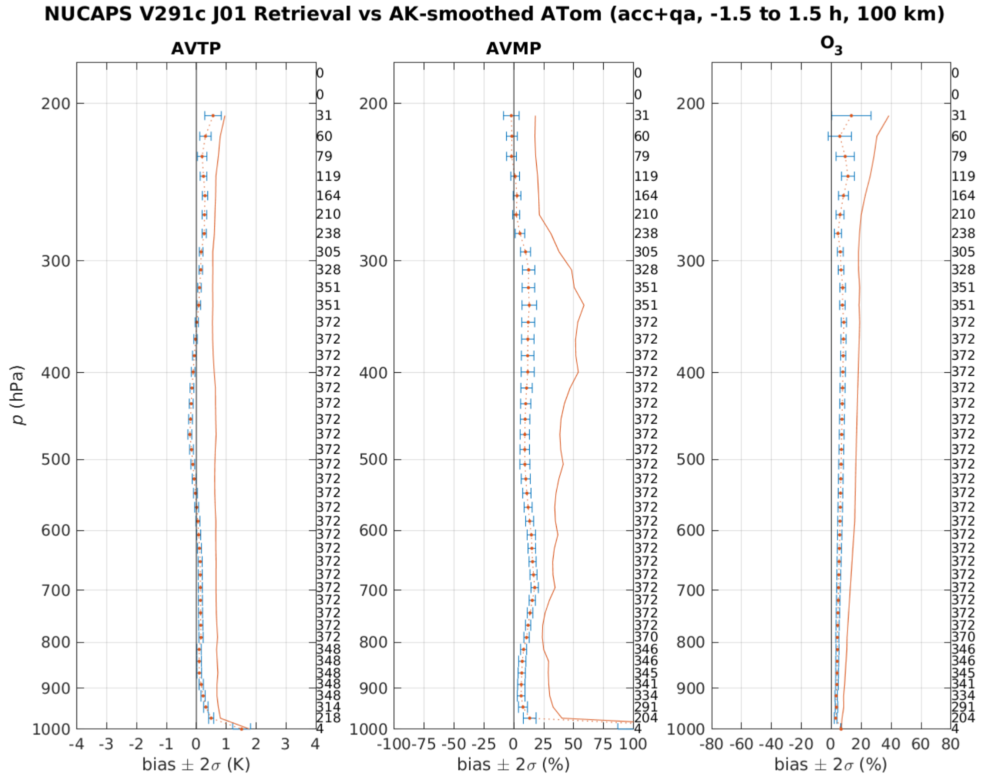
NUCAPS v3.0 Retrieval vs ATom w AKs: 100 Layer Profile Statistical Analysis

Temperature / H_2O / O_3

SNPP



NOAA-20



NUCAPS – ATom

SET C. SUPPLEMENTAL SLIDES FROM SECTION 4

Set	List of Supplemental Slides	Slide Numbers
B.3.1	N/A	N/A

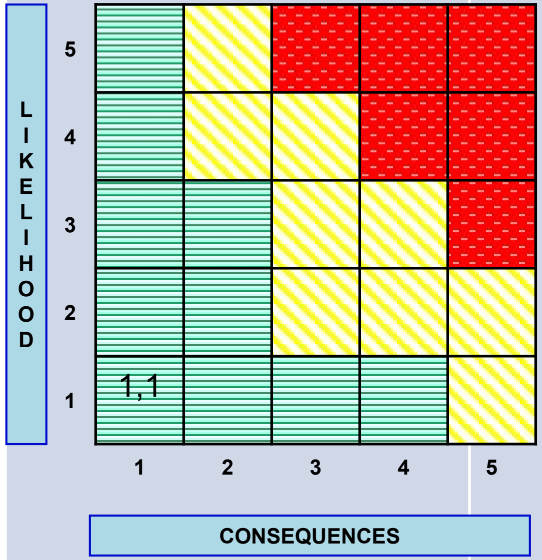
SET D. NUCAPS TEAM COLLABORATIONS WITH EXTERNAL AGENCIES FOR RISK MITIGATION, ALGORITHM IMPROVEMENT & DEVELOPMENT

Criticality

HIGH
MED
LOW

NUCAPS Team Collaborations with External Agencies
Risk(s)

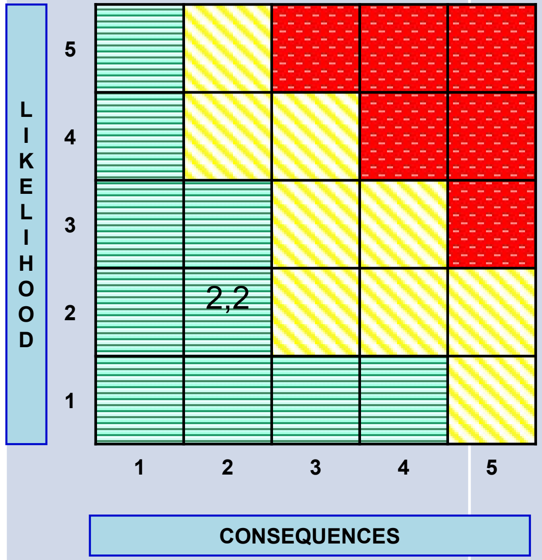
Risk ID & Rank	Risk ID	Risk Statement	Approach/Mitigation	Status
1. Sarta code updates, wrapper scripts. **Low Risk in Implementation and can be closed**	NUCAPS-20-RSKSUP-01	**Given that:** There is a wrapper script to convert SARTA RTA coefficients to NUCAPS RTA format **There is a possibility: that** without knowing the knowhow, it would be hard to generate NUCAPS RTA updates in future. **Resulting in :** the possibility of making SARTA code updates harder.	STAR NUCAPS team holds cross-training and technical interchange meetings (TIMs) Q&A sessions with STC and other agencies. Through TIMs, Chris Barnet, STC, has provided the knowhow to STAR NUCAPS team members (POC: Tong Zhu). STAR NUCAPS teams has been doing code-walk-through to look into any hard coded constants for QA, and discussions with Chris Barnet. NUCAPS team repeated the wrapper scripts and converted the updated SARTA coefficients to NUCAPS RTA format, and performed benchmark tests. STAR team worked with Chris Barnet, received and verified results (12/17/2019, Tong Zhu) Larrabee delivered updated code for MetOp-C. STAR team performed test runs to simulate Metop-C IASI, and create tuning coefficient.	STAR NUCAPS team is self sufficient and has the knowhow to receive future SARTA updates from Larrabee and implement for stand-alone radiance simulations (comprad), and implementation as part of NUCAPS algorithm. This risk can be closed since effective measures were all taken.



Risk Owner(s): Tong Zhu, Murty Divakarla, Changyi Tan, Ken Pryor, NUCAPS team members

NUCAPS Team Collaborations with External Agencies
Risk(s)

Risk ID & Rank	Risk ID	Risk Statement	Approach/Mitigation	Status
2. **All-sky and clear regression first guess algorithm/code** **Low Risk in Implementation**	NUCAPS-20-RSKSUP-02	**Given that:** The NUCAPS system has to generate All-sky and clear-regression first guess LUT for the current and future satellite systems (JPSS-2, 3, 4), MetOp-C, EPS-SG) **There is a possibility:** that without a robust and well documented code may Resulting in: inabilities for knowledge transfer for future NUCAPS team developers.	STAR NUCAPS team has the regression codes separated out for different systems (CrIS/ATMS, IASI/AMSU-A/MHS). STC Team has a robust, well documented code that can be used for different satellites. STAR NUCAPS team felt it good to have a better documented code. So, experimented with STC teams' code for future implementations.	STAR NUCAPS team is more or less self sufficient, and do not need any major assistance from the STC team. The "cleaned-up" code is nearly well documented. The team has been working on a deep dive to fully understand/maintain the code, and to complete all documentations. For future developments (for MetOp-C, IASI-NG and JPSS-x), we only need to modify the code slightly replacing the instrument specific variables. This risk has been addressed, and currently Low.

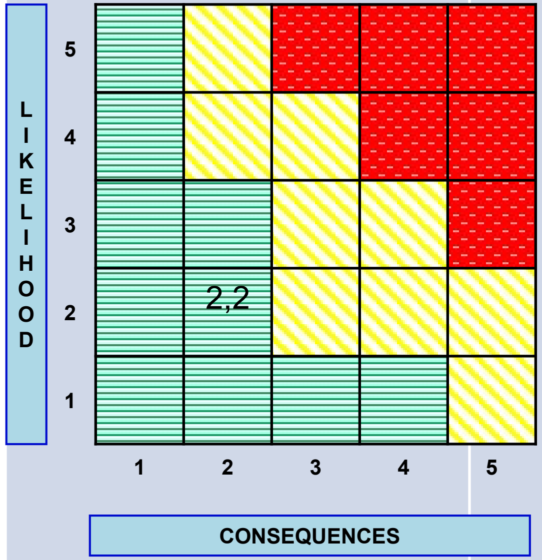


Risk Owner(s): Tianyuan Wang, Murty Divakarla, Changyi Tan, Ken Pryor, NUCAPS team members

NUCAPS Team Collaborations with External Agencies
Algorithm Improvement/Development

Algorithm Improvement Development	ALG_DEV ID	Risk Statement	Approach/Mitigation	Status
1. Implementation of Ammonia retrieval algorithm.	NUCAPS-20-ALGDEV-01	**Given that:** there are additional viable products retrievable from the hyper-spectral IR sounding instruments, **There is a possibility:** to integrate the retrieval of Ammonia to the NUCAPS operational system **Resulting in**: Increased use of NUCAPS products by ESRL, EPA, NFS, USDA	One of the highlighted new products is Ammonia (NH3), an experimental AIRS product that has demonstrated user applications related to agriculture, fire emissions and air quality, Earth System modeling (nitrogen cycling), aerosol formation and understanding fire effects on atmospheric composition. The algorithm to retrieve Ammonia (NH3) is readily available and compatible with the NUCAPS system through research efforts of Juying Warner, one of the NUCAPS team affiliates. Juying Warner provides necessary trace gas related improvements to the NUCAPS team and her expertise would suffice NUCAPS needs.	Implementation of the NH3 algorithm into NUCAPS and transition to operations require user requests/requirements from NWS, ARL and other user agencies. A "working group" meeting on this topic with other stake holders and users may resolve issues in moving forward.

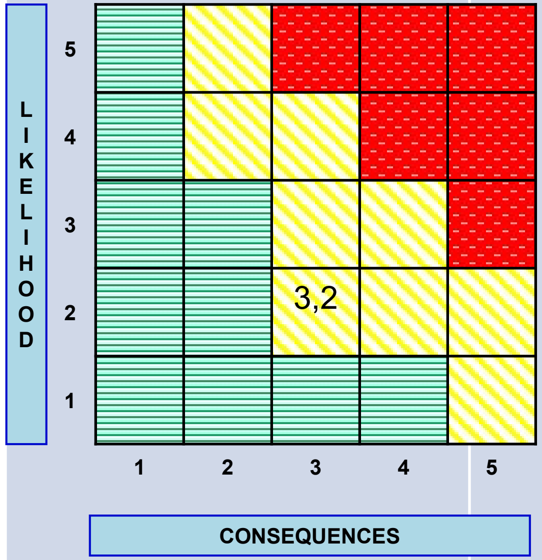
Low Risk in Implementation



Risk Owner(s): Juying Warner, Changyi Tan, Mike Wilson, Murty Divakarla, Ken Pryor, NUCAPS team members

Algorithm Improvement Development	ALG_DEV ID	Risk Statement	Approach/Mitigation	Status
2. Augmenting NUCAPS to IASI-NG/MWS	NUCAPS-20-ALGDEV-02	**Given that:** The NUCAPS system has to generate products using EPS-SG MetOp-IASI-NG/MWS **There is a need:** to update the HEAP pre-processor to map IASI-NG/MWS radiances, and generate satellite specific LUTs Resulting in: NUCAPS system for EPS-SG products generation meeting deliverables and milestones.	After a group discussion among STAR Management, NUCAPS team, Larrabee Strow (UMBC), Chris Barnet (STC), based on prons and cons, it was decided to implement NUCAPS for IASI-NG/MWS by transforming the IASI-NG (16,821 channels) to IASI (8461) channels. With IASI-NG transformed to IASI, the MetOp-C IASI SARTA can be implemented as the NUCAPS RTA to augment for IASI-NG. The team has the capability to generate MWS fast forward model. Mapping MWS to IASI is another important preprocessing steps that may require some suggestions and verifications from the STC team (see Risk topic 4)	NUCAPS team adapted IASI-NG to IASI transformation and evaluated the method using the synthetic data provided by the EUMETSAT. The team, thus have the capability to generate QA assured 'IASI-NG to IASI' radiances. The MetOp-C SARTA code is all optimized and can be directly used for truncated IASI-NG (16,821 channels) to IASI (8461 channels) The team is currently working on the MW fast forward model for the MWS (seek risk topic 4), and upgrade to NUCAPS-HEAP pre-processor for mapping of IASI-NG/MWS. We still need to understand mapping of IASI-NG/MWS and requires considerable amount of work to the HEAP preprocessor.

Medium Risk in NUCAPS Development for EPS-SG

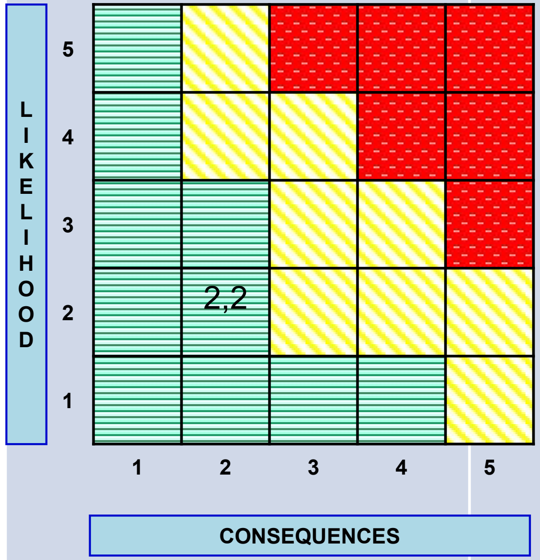


Risk Owner(s): Murty Divakarla, Changyi Tan, Chris Barnet, Ken Pryor, NUCAPS team members

NUCAPS Team Collaborations with External Agencies
Algorithm Improvement/Development

Algorithm Improvement Development	ALG_DEV ID	Risk Statement	Approach/Mitigation	Status
3. Rosenkranz's Microwave Line by Line Model and generation of NUCAPS MW-only Fast Forward Model	NUCAPS-20-ALGDEV-03	**Given that:** The NUCAPS system has to augmented for EPS-SG using MWS **There is a need:** to update the Rosenkranz's MicrowaveLine by Line model and generation of NUCAPS microwave-only fast forward model and updated MW retrieval Resulting in: NUCAPS system for optimized product generation from the current and future (EPS-SG MWS) satellite systems meeting deliverables and milestones.	The NUCAPS team has the capability to generate MW fast forward model, and the microwave-only retrievals for ATMS, AMSU-A and MHS, and have implemented successfully for the current JPSS (S-NPP/NOAA-20) and MetOp series of satellites (MetOp-C/B)	NUCAPS team adapted IASI-NG to IASI transformation and evaluated the method using the synthetic data provided by the EUMETSAT. The team, thus have the capability to generate QA assured 'IASI-NG to IASI' radiances. The MetOp-C SARTA code is all optimized and can be directly used for truncated IASI-NG (16,821 channels) to IASI (8461 channels) The team is currently working on the MW fast forward model for the MWS (seek risk topic 4), and upgrade to NUCAPS-HEAP pre-processor for mapping of IASI-NG/MWS.

Low Risk in Implementation

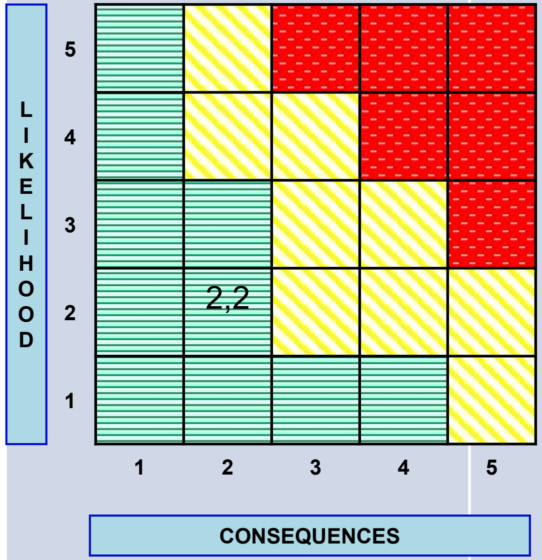


Risk Owner(s): Tong Zhu, Murty Divakarla, Chris Barnet, Ken Pryor, NUCAPS team members

NUCAPS Team Collaborations with External Agencies
Algorithm Improvement/Development

Algorithm Improvement Development	ALG_DEV ID	Risk Statement	Approach/Mitigation	Status
4. Preparing unified code for future NUCAPS development	NUCAPS-20-ALGDEV-04	**Given that:** The NUCAPS system has algorithm developers from different agencies (STAR, STC, UMBC, UMD, UW) **There is a need:** to generate unified code based on the research performed by various agencies, and combining improvements made by other agencies (e.g., STC, AIRS science team, UMD) Resulting in: NUCAPS system with up-to-date improvements.	STAR NUCAPS team holds cross-training and technical interchange meetings (TIMs) Q&A sessions, and hands-on workshops with STC and other agencies to prepare an unified code. The team requires further discussions with the STC team on the important upgrades based on the improvements observed through CLIMCAPS system. STAR team need knowhow to generate local angle correction LUT files for both JPSS and MetOP series.	STAR NUCAPS team has included updates provided by Chris Barnet from July 29, 2019. The NUCAPS team plans to have another TIM to know the important updates from the CLIMCAPS that may benefit the NUCAPS algorithm. This is just the nature of development from multiple groups. The NUCAPS version has reached matured stage and has very low risk.

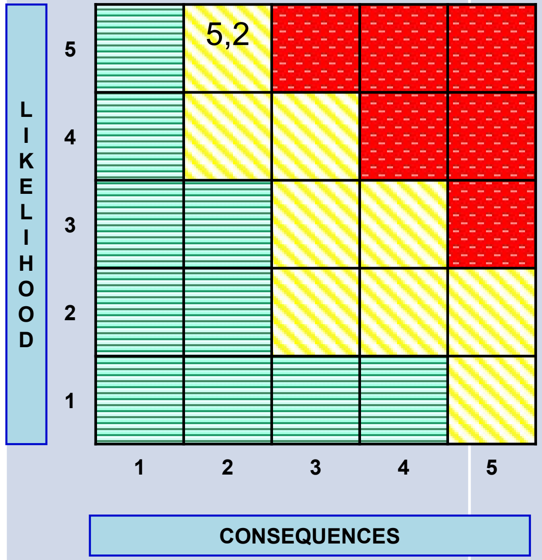
Low Risk in Implementation



Risk Owner(s): Mike Wilson, Changyi Tan, Murty Divakarla, Chris Barnet, Ken Pryor, NUCAPS team members

Algorithm Improvement Development	ALG_DEV ID	Risk Statement	Approach/Mitigation	Status
5. Improved IR sea surface effective-emissivity (IRSSE) physical model implementation in the NUCAPS SARTA RTA.	NUCAPS-20-ALGDEV-05	**Given that:** Sea surface emissivity is has a known dependence on surface temperature and is a critical parameter in forward modeling of window channel radiances, and snow/ice surfaces are also a known problem that can lead to even greater errors **There is a possibility:** There will latitudinal biases in forward calculations as much as 0.5 K, especially in cold waters, with even larger biases over snow/ice surfaces that has been seen in validation over such regions **Resulting in**: Unknown zonal bias artifacts in the NUCAPS lower tropospheric profile retrievals and skin temperature retrievals over oceans, with larger biases over snow/ice surfaces		

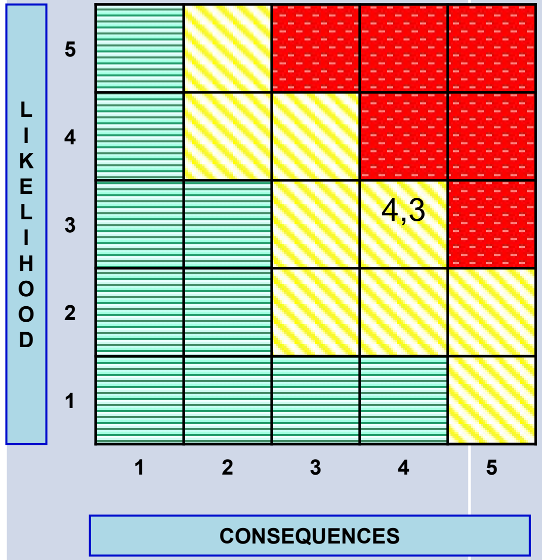
Likelihood High; Moderate Risk for Lower Tropospheric NUCAPS Retrieval Accuracy



Risk Owner(s): Nick Nalli, Changyi Tan, Murty Divakarla, Ken Pryor, NUCAPS team members

Algorithm Improvement Development	ALG_DEV ID	Risk Statement	Approach/Mitigation	Status
6. Algorithm improvements, implementation of new trace gas products (e.g. N2O, NH3)	NUCAPS-20-ALGDEV-06	**Given that:** there are additional viable products retrievable from the hyper-spectral IR sounding instruments, **There is a possibility:** to develop retrieval algorithms to produce new trace gas products such as N2O, HNO3, etc. **Resulting in**: Increased use of NUCAPS products by ESRL, EPA, NFS, USDA	During JPSS-CPO, and JPSS-MAPP technical interchange meetings, the NUCAPS has summarized the operational products as well as potential new science products derivable from current hyper-spectral sounding instruments (AIRS, IASI, and CrIS).	An in-depth discussion on producing additional viable trace gas products from NUCAPS would help future NUCAPS algorithm upgrades.

Moderate to High level of efforts in implementation

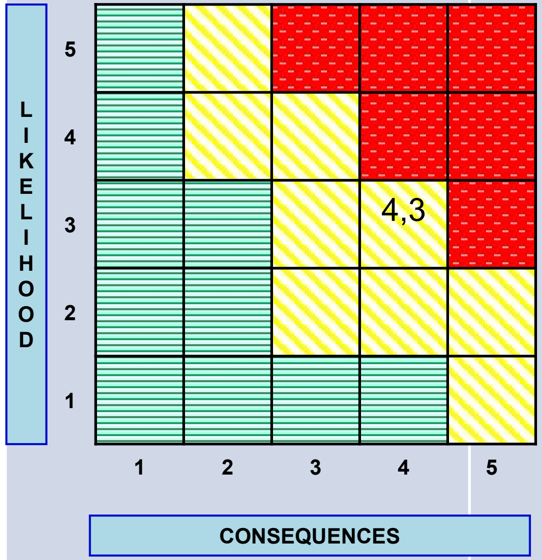


Risk Owner(s): Juying Warner, Changyi Tan, Mike Wilson, Murty Divakarla, Ken Pryor, NUCAPS team members

NUCAPS Team Collaborations with External Agencies
Algorithm Improvement/Development

Algorithm Improvement Development	ALG_DEV ID	Risk Statement	Approach/Mitigation	Status
7. NUCAPS augmentation for GEO hyperspectral sounding product development	NUCAPS-20-ALGDEV-07	**Given that:** there is every possibility for a hyper-spectral IR sounding instrument in the Geostationary orbit, **There is a need:** to develop NUCAPS retrieval algorithms optimized for IR-only retrieval due to non-availability of a microwave sounding instrument. **Resulting in**: NUCAPS products from GEO-CrIS augmentation.	The NUCAPS team has been involved with the CrIS SDR team on the GEO-TMP CrIS project and has used the GEO-CrIS proxy data generated by the CrIS SDR team to produce NUCAPS IR-only retrievals. Earlier results of IR-only implementations at STAR yielded larger RMS differences with very high yield, and Chris Barnet has implemented some quality flags mitigating the unavailability of microwave QC. Thus we need Chris's input on this. Examine cloud-clearing methodologies based on temporal sequence of hyper spectral radiance availability	An in-depth discussion on IR-only retrievals and supplementing the microwave retrievals/QC with GFS analysis fields is needed to move forward.

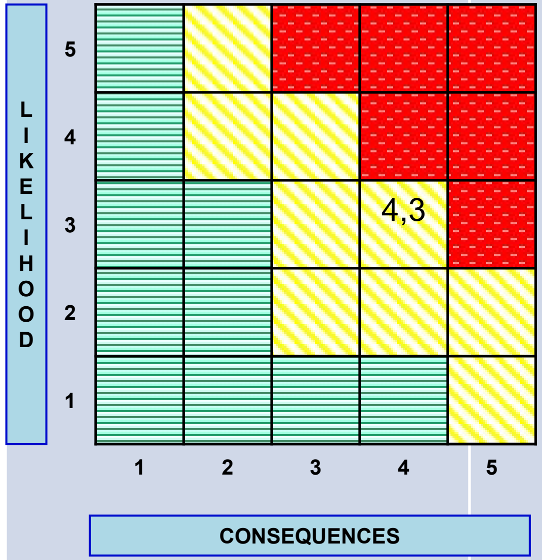
Moderate to High level of efforts in implementation



Risk Owner(s): Changyi Tan, Mike Wilson, Murty Divakarla, Ken Pryor, NUCAPS team members

Caveat

Caveat	Caveat ID	Risk Statement	Approach/Mitigation	Status
1. Field campaigns and user feedback **Moderate level of collaboration**	NUCAPS-20-CAVSUP-01	**Given that: NUCAPS trace gas products have all reached validated maturity** **There is a possibility:** to discuss potential applications and collaborative programs with user agencies and field campaigns to exploit the full length of utility of the NUCAPS products through DB/CSPP in support of real-time applications. **Resulting in**: increased user base and further improvements of NUCAPS products.	Rebekah Esmaili and Chris Barnet have been POC on field campaigns pertaining to the JPSS PGRR Initiatives, for example FIREX, ENRR, Hurricane dropsonde campaigns, among others. Originally there was division of tasks with STC taking the lead on JPSS PGRR and STAR taking the lead on cal/val, but we would benefit from more collaborations with CPO/AC4, ESRL/CSD, ESRL/GMD, GFDL, ARL on the user needs and fit-to-purpose product development attending to data time frame, latency, and special needs.	Discussion with Chris and the STC Team will be needed for establishing a “MOU” between STAR and STC regarding PGRR Initiatives and campaigns associated with them.



Risk Owner(s): Nick Nalli, Murty Divakarla, Juying Warner, Ken Pryor and NUCAPS team members.