Provisional Maturity Science Review
For NOAA-21 NUCAPS

Presented by
NUCAPS Team Members
Date: January 25, 2024

NOAA-21 NUCAPS PROVISIONAL MATURITY REVIEW

JANUARY 25, 2024

10:45 AM – 12:10 PM EDT

NUCAPS EDR Products

ATMOSPHERIC VERTICAL TEMPERATURE PROFILE (AVTP)

ATMOSPHERIC VERTICAL MOISTURE PROFILE (AVMP)

ATMOSPHERIC OZONE PROFILE (O_3)

OUTGOING LONGWAVE RADIATION (OLR)

CARBON MONOXIDE (CO)

METHANE (CH_4)

CARBON DIOXIDE (CO_2)

Outline

- NUCAPS Algorithm team members
- Product maturity definitions
- Entry/Exit Criteria
- Algorithm version(s), processing environment
- Evaluation of NOAA-21 products to specification requirements
- Documentation
- Summary
- Path forward for Validated Maturity
- Supplemental Slides

NUCAPS Algorithm Team Members

Name	Organization	Major Task
Ken Pryor, Laurie Rokke	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	Science/Technical lead
Tong Zhu	IMSG at NOAA/NESDIS/STAR	Algorithm development, ATMS, CrIS bias tuning, and maintenance
Margarita Kulko	IMSG at NOAA/NESDIS/STAR	OLR Algorithm development and maintenance
Juying Warner	Univ. of Maryland College Park	Trace Gases algorithm(s) development and maintenance
Wei Li	IMSG at NOAA/NESDIS/STAR	Trace Gas product validations with TCCON and VALAR processing
Mike Wilson, Tish Soulliard	GAMA-1 at NOAA/NESDIS/STAR	STAR-ASSISTT POC for Unified NUCAPS package
Rebekah Esmaili, Chris Barnet, Nadia Smith	STC	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)
Nick Nalli*		Formerly with IMSG, thanks for his suggestions on TCCON processing

JPSS Data Products Maturity Definition

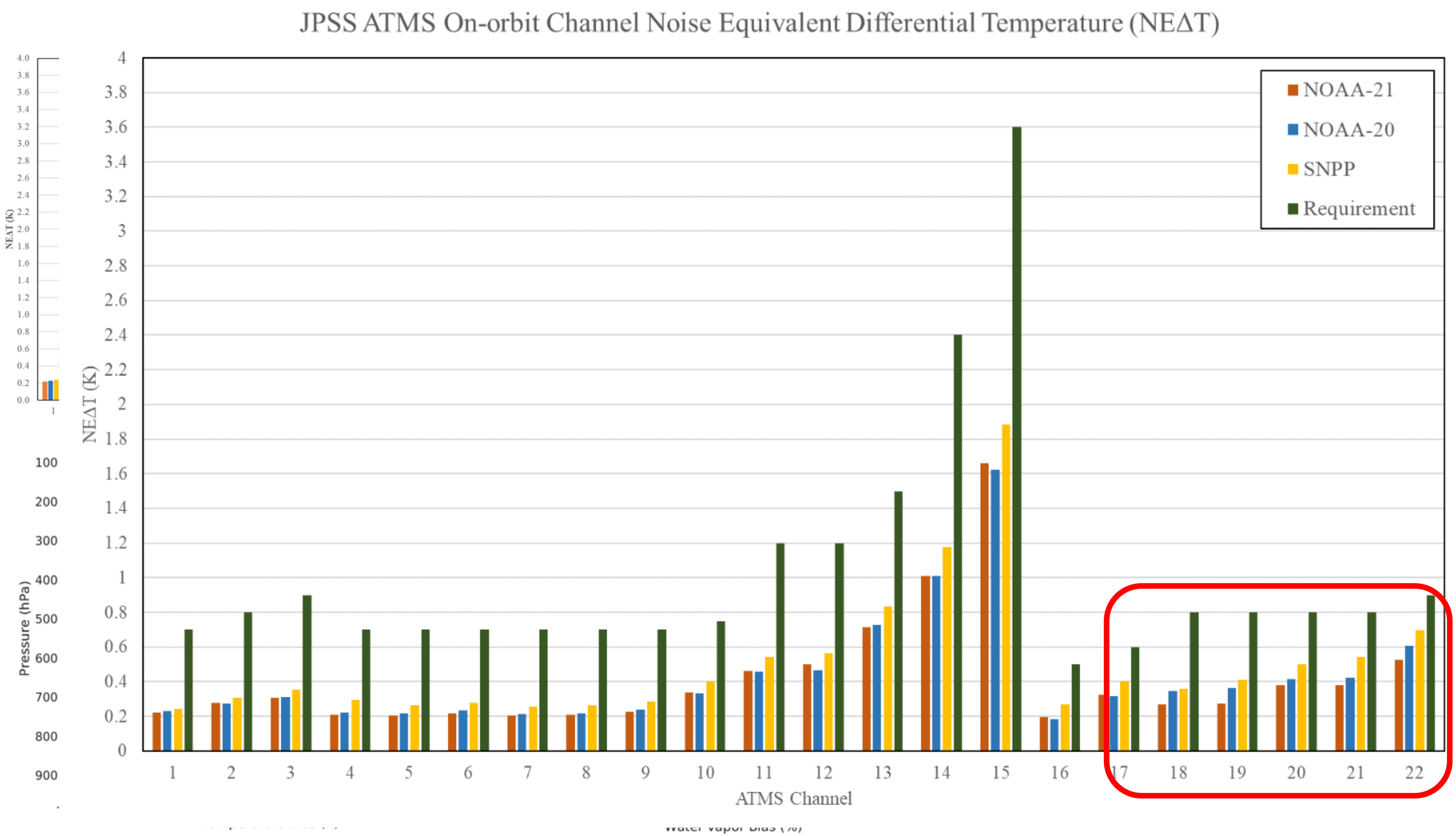
1. **Beta**
   - Product is minimally validated, and may still contain significant identified and unidentified errors.
   - Information/data from validation efforts can be used to make initial qualitative or very limited quantitative assessments regarding product fitness-for-purpose.
   - Documentation 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.

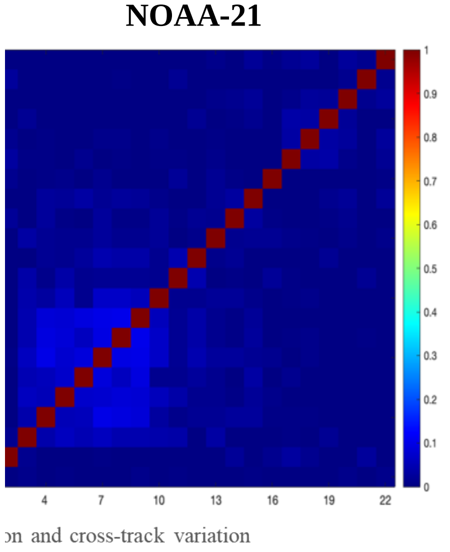
- This presentation showcases NOAA-21 NUCAPS EDR products for Provisional maturity for AVTP, AVMP, O_3, OLR, CO, CH_4, and CO_2 and and path forward for Validated maturity

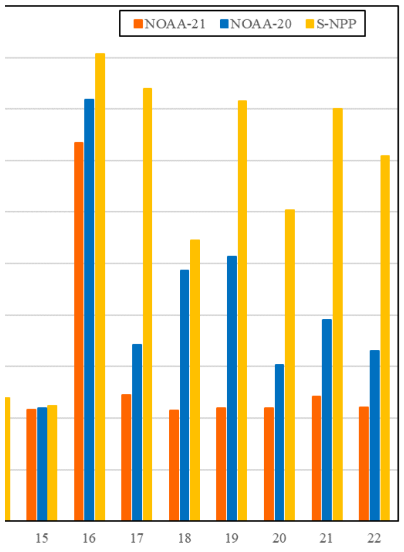
Maturity Review – Entry Criteria

- Product Requirements
- Pre-launch Performance Matrix/Waivers
- Provisional Maturity Performance Validation
  - On-orbit instrument performance assessment
    - Identify all of the instrument and product characteristics you have verified/validated as individual bullets
      - CrIS SDR/GEO, ATMS TDR/GEO are of Provisional/Validated Maturity
      - NUCAPS EDRs: AVTP (*T*), AVMP (H_2O), O_3, CO, CH_4, CO_2, OLR
    - Identify pre-launch concerns/waivers, mitigation and evaluation attempts with on-orbit data
      - None
- Users/Downstream-Products feedback
- Risks, Actions, Mitigations
  - Potential issues, concerns
- Path forward (to the next maturity stage)
- Summary

NOAA-21 ATMS SDR Validated Maturity Highlights (from ATMS SDR Provisional Maturity)

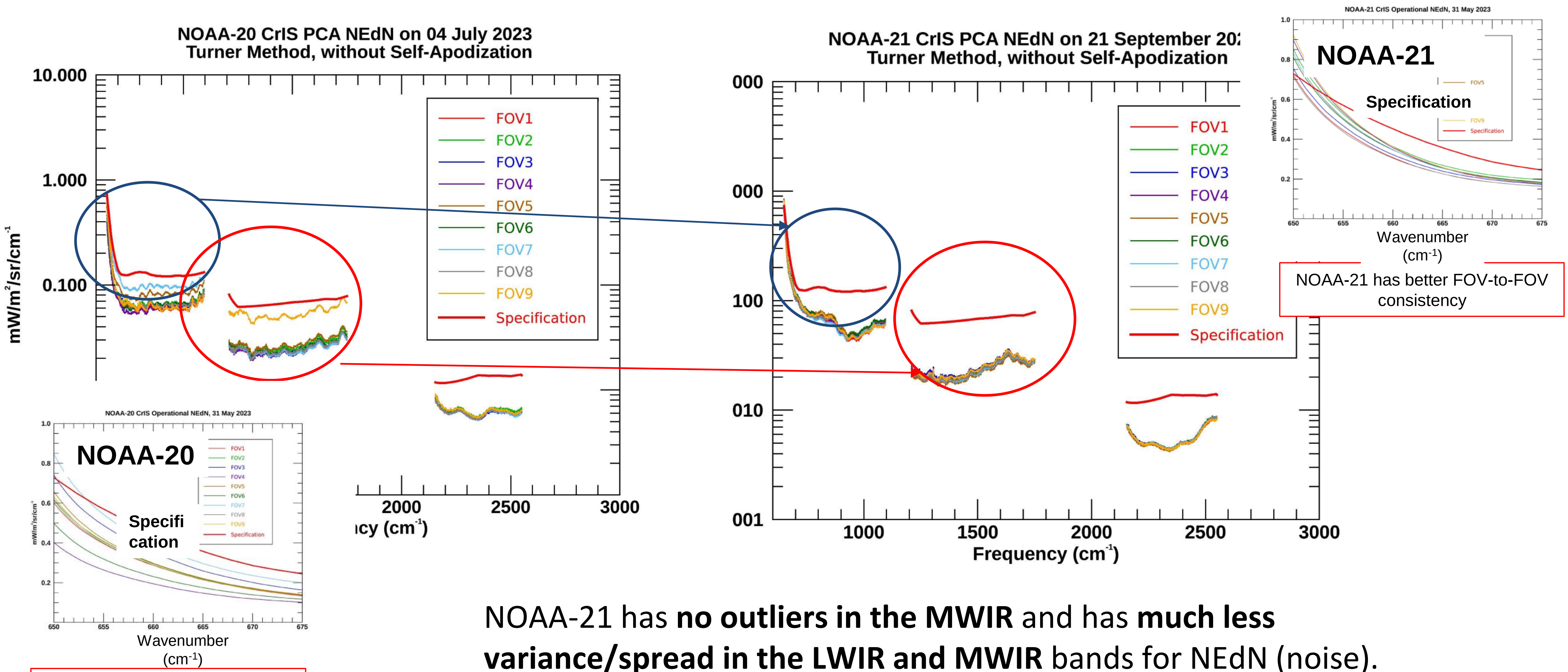






NOAA-21 CrIS EP 212 On-orbit Noise Performance vs NOAA-20 (from CrIS SDR Provisional Maturity)

NOAA-20 | **NOAA-21**



NOAA-20 CrIS has, in general, lower noise than NOAA-21 near the Longwave IR edge

NOAA-21 has **no outliers in the MWIR** and has **much less variance/spread in the LWIR and MWIR** bands for NEdN (noise). **Improved consistency in noise levels between the FOVs.**

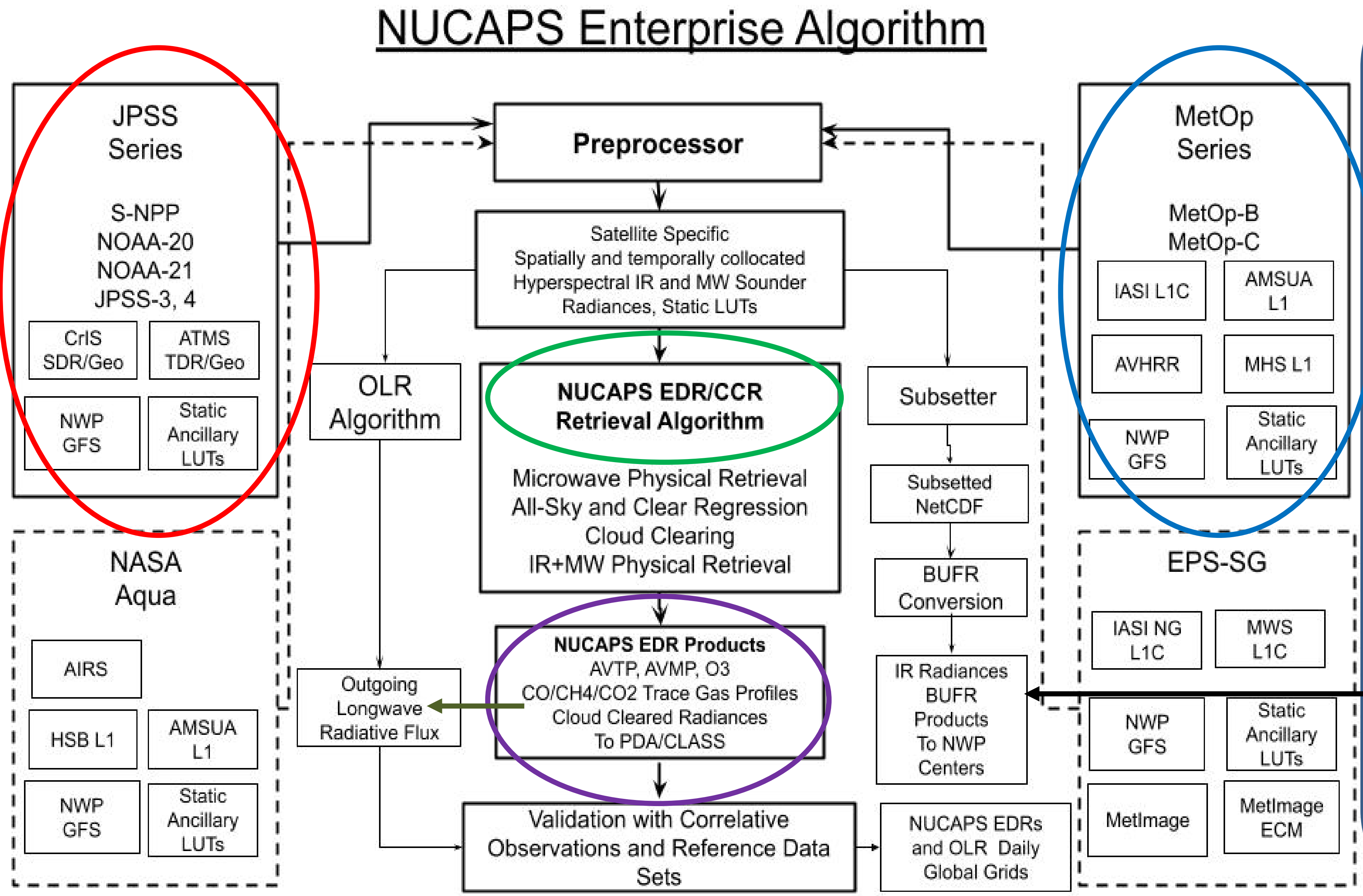
Provided by Denis Tremblay

Maturity Review – Exit Criteria

- Provisional Maturity Performance is well characterized and meets/exceeds the requirements:
  - On-orbit instrument performance assessment
    - Provide summary for each identified instrument and product characteristic you have validated/verified as part of the entry criteria
      - NUCAPS EDRs: AVTP (*T*), AVMP (H_2O), O_3, CO, CH_4, CO_2, OLR
    - Provide summary of pre-launch concerns/waivers mitigations/evaluation and address whether any are still a concern that raises a risk.
      - None
- Updated Maturity Review Slide Package addressing review committee's comments for:
  - Cal/Val Plan and Schedules: Yes
  - Product Requirements: Yes, in the Supplement
  - Beta Maturity Performance: Yes
  - Risks, Actions, Mitigations: Yes
  - Path forward (to the next maturity stage): Yes, Validated Maturity

NOAA Unique Combined Atmospheric Processing System (NUCAPS)

Algorithm Version, Processing Environment, Inputs, Outputs



- NUCAPS runs within the Hyperspectral Enterprise Algorithm Package (HEAP v2.3) and operationally generates AVTP, AVMP, O_3, OLR, CO, CH_4 and CO_2 products from JPSS NOAA-20 CrIS and Metop-B/C IASI hyperspectral infrared sounding instruments.
- HEAP (NUCAPS) v3.0 is currently in operations. Algorithm updates, sensor-independent LUTs, QC/QA are all updated for MetOp-C/B/ using the latest baseline version of NOAA-20
- NUCAPS v3.1 with AKs will be in NCCF operations by January 31
- BUFR product with NOAA-21 CrIS full spectral radiances, thinned radiance data sets
- **NUCAPS V3.2** 'NOAA-21' algorithm will be delivered to operations by February 2024.

Evaluation of the effect of required algorithm inputs

- Required Algorithm Inputs
  - Primary Sensor Data: NUCAPS requires (1) CrIS SDRs (2) ATMS TDRs, and (3) geolocation files for retrieval.
  - CrIS/ATMS sensor noise characteristics
  - MIT MW fast model for Microwave Retrievals.
  - All-sky and cloud-cleared PC regression coefficients (generated offline using focus day data sets)
  - Static tables/files needed for sarta radiative transfer algorithm:
    - No change (as provided for CrIS by UMBC->STC->STAR)
  - MW and IR bias-tuning LUTs: NOAA-21 specific LUTs developed at STAR
  - Ancillary Data: GFS data to provide surface pressure as initial boundary
  - *A priori* for O_3, CO, CH_4, CO_2, and other trace gases: Developed at STAR
- Upstream algorithms: None (if/when TDR/SDR processing changes, we evaluate impacts and update MW and IR bias tuning/corrections if needed)
- Evaluation of the effect of required algorithm inputs
  - Input static LUTs are all verified. Only dynamic inputs are the TDR/SDR/GEO data.

Evaluation of Algorithm Performance to Specification Requirements

- Findings/Issues from NOAA-21 Beta Review
  - ✔ NOAA-21 products show very good performance and high degree of agreement with NOAA-20 products, consistent with Beta Maturity criteria.
  - ✔ Preliminary validations of NOAA-21 products show very good promise.
  - ✔ No NOAA-21 specific caveats or risks observed
- Improvements since Beta Review
  - NOAA-21 specific LUTs using NOAA-21 ATMS/CrIS Noise files
    - NOAA-21 LUTs: IR & MW tuning; Cloudy and Clear regression
  - Algorithm Improvements: CH_4 a-priori updates and code changes
- Validation strategies/methods performed for Provisional Maturity
  - NOAA-20 vs NOAA-21 product consistency & Hierarchy of validation data sets
    1) Focus-day data sets, global ECMWF matches, global RAOB matches (NPROVS), correlative satellite products (TROPOMI, OCO-2): Evaluation for all NUCAPS products
    2) Validation Archive (VALAR) RAOB matches: AVTP, AVMP validation
    3) NOAA-GML O3SND matches over Boulder, CO and South Pole: O3 validation
    4) Total Carbon Column Observing Network - TCCON matches: CO, CH4, CO2 validation
    5) Daily NOAA-20/21 OLR validations with NOAA-20 CERES **for 7 months**

NUCAPS Algorithm
NOAA-21 Beta to Provisional Maturity

NUCAP EDRs

AVTP, AVMP, O_3

CO, CO_2, CH_4

OLR

Mission Effectivity

S-NPP

NOAA-20

NOAA-21

MetOp-C

Operational Version 3.0

NCCF UAT Version 3.1

Version 3.2 R_2O to ASSISTT*

EDR Reprocessing Version

NCIS Cloud

NOAA-20 Products (Validated)
NOAA-21 (Beta)

Averaging Kernels
CO_2 updates
O_3 Improvements
Surface Corrections

Includes NOAA-21 Specific LUTs
CH_4 updates applicable for both NOAA-20/21

NOAA-20 LUTs Used for NOAA-21 Beta Maturity
Product Consistency
v3.0 vs v3.1

NOAA-21 **Provisional**
Product Consistency Between NOAA-20 & 21
Validation with Truth Measurements

Cloud Containerization of NUCAPS v3.2 Provisional/Validated

Mission Effectivity

SNPP

NOAA-20

NOAA-21

MetOp-C

*R_2O: NUCAPS v3.2 Delivery to the ASSISTT: 1/25/2024.

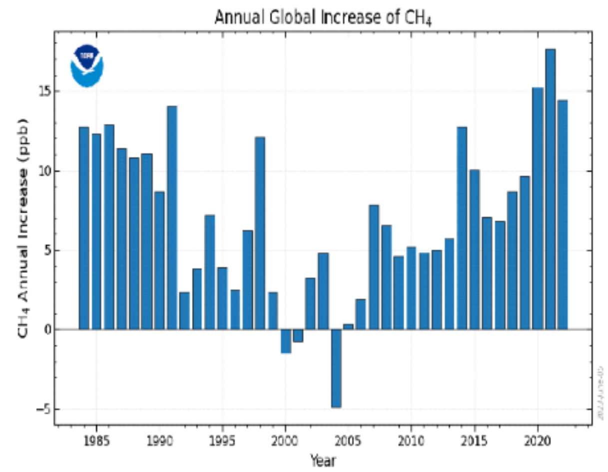
- ASSISTT's CCAP Delivery to NCCF: 3 weeks
    - Software Code Review (SCR) NOT Required; only LUT updates & few lines of code change.

Improvements Since Beta Maturity Review

- NOAA-21 specific LUTs
  - AVTP and AVMP first guess regression LUT updates (Cloudy and Clear Regression)
  - ATMS and CrIS radiance bias tuning

Regression/Tuning Data for Cloudy and Clear Regression						
NOAA-20 Operational	20190115 January	20190415 April		20180715 July		20181015 October
NOAA-21	**20230227 Feb**	**20230417 April**	**20230619 June**	**20230719 July**		**20231016 October**

- Algorithm Improvements: CH_4 a-priori updates and code changes

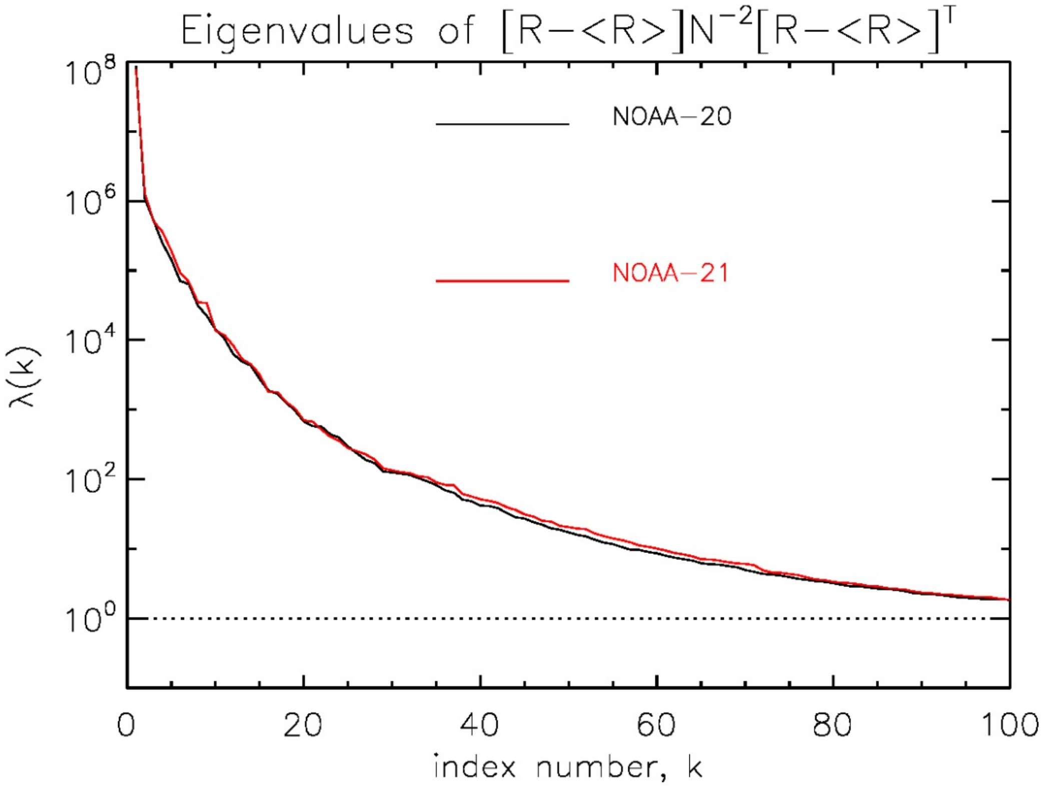


NUCAPS NOAA-21 EDR Algorithm v3.2

First Guess Regression Updates
IR and Microwave Tuning
NOAA-20 vs. NOAA-21 CrIS Noise

NOAA-21 NUCAPS: First Guess Regression

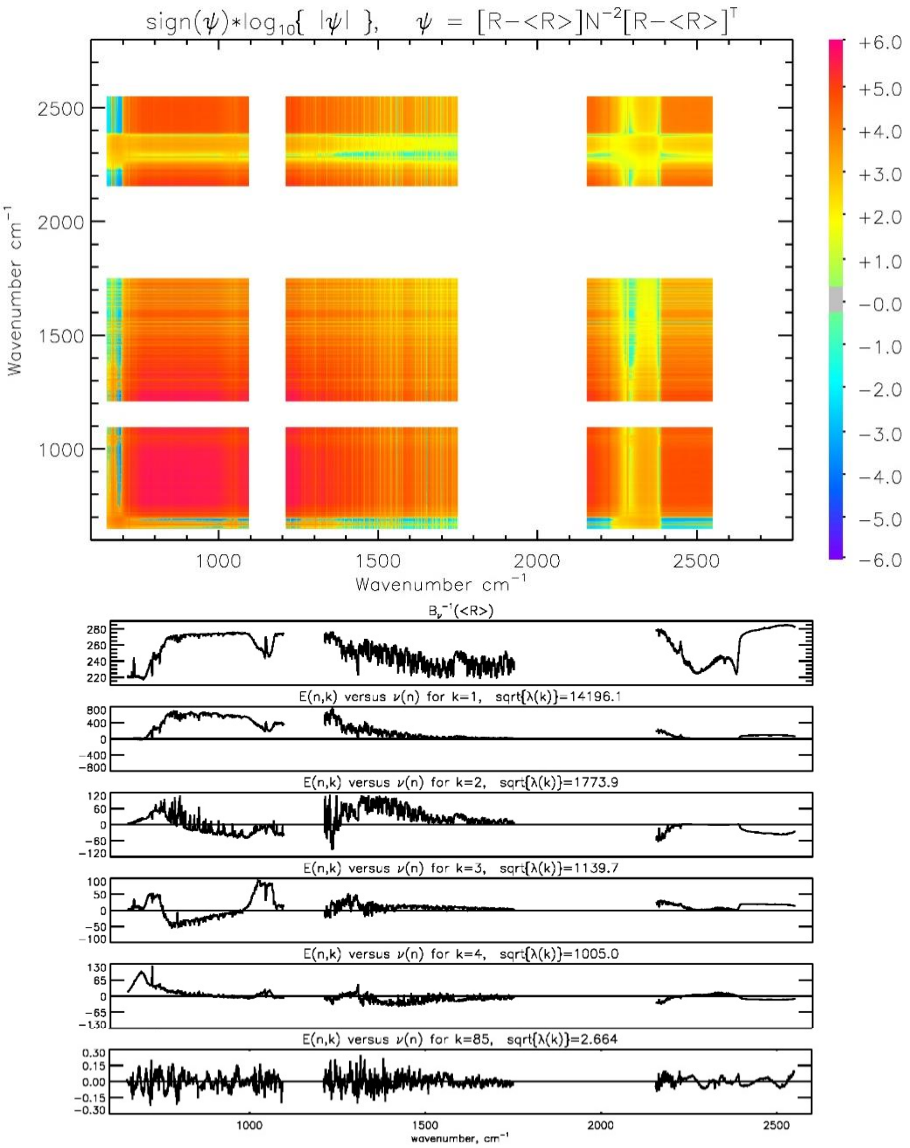
- Regression setup and preliminary evaluations completed
- Used Five Focus Days (2/27, 4/17, 06/19, 07/19, 10/16) for NOAA-21
  - Generated Cloudy and Clear Regression LUTs for NOAA-21 (CrIS and ATMS)
  - Applied these coefficients on a different day and generated retrievals for both NOAA-20 and NOAA-21
  - Compared the FG vs ECMWF for NOAA-21 and NOAA-20 OPS using 03/24, 09/21, 12/18 for global and ocean cases



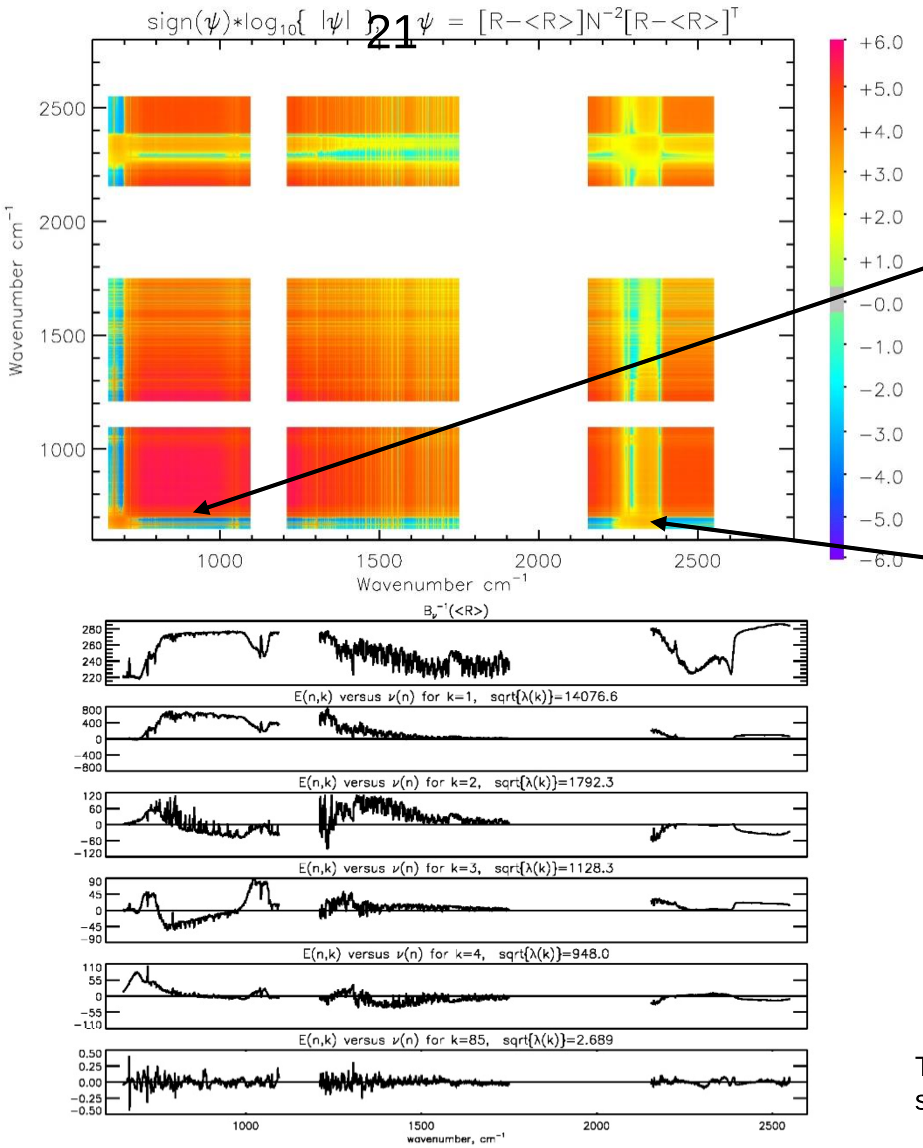
The 1st 100 significant eigenvectors from the NUCAPS regression training normalized at λ(k=200)

NOAA-21 NUCAPS: First Guess Regression

NOAA-



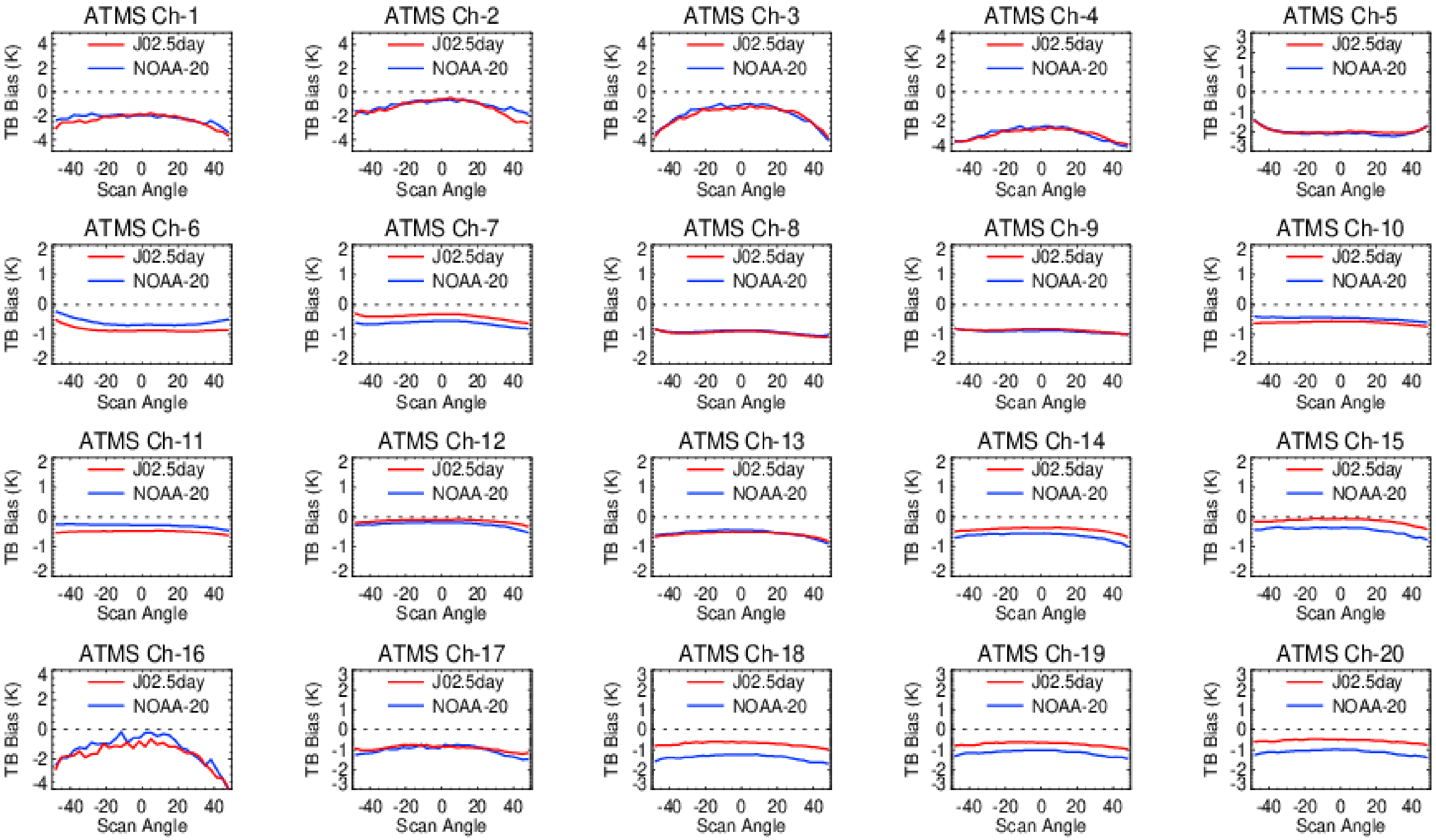
NOAA-21

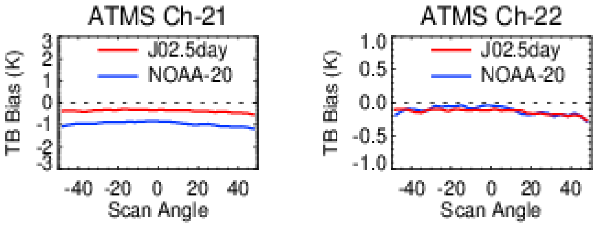


- Average of the CrIS radiance ensemble as BT
- Stratospheric channel is anticorrelated with tropospheric channels
- 4.3 μm and 15 μm bands are correlated
- Strong signal to noise ratio for all 85 eigenvectors

Thanks to Chris Barnet for the BT covariance script.

NUCAPS NOAA-20 vs. NOAA-21 ATMS Tuning





- Five focus days used for NOAA-21 MW tuning: 02/27, 04/17, 06/19, 07/19, 10/16, 2023

NUCAPS V3.2 has NOAA-21 bias and error tuning.

- Five Focus Days, ocean, nighttime only, and within +/- 60°Lats

NOAA-21 vs. NOAA20 MW Tuning

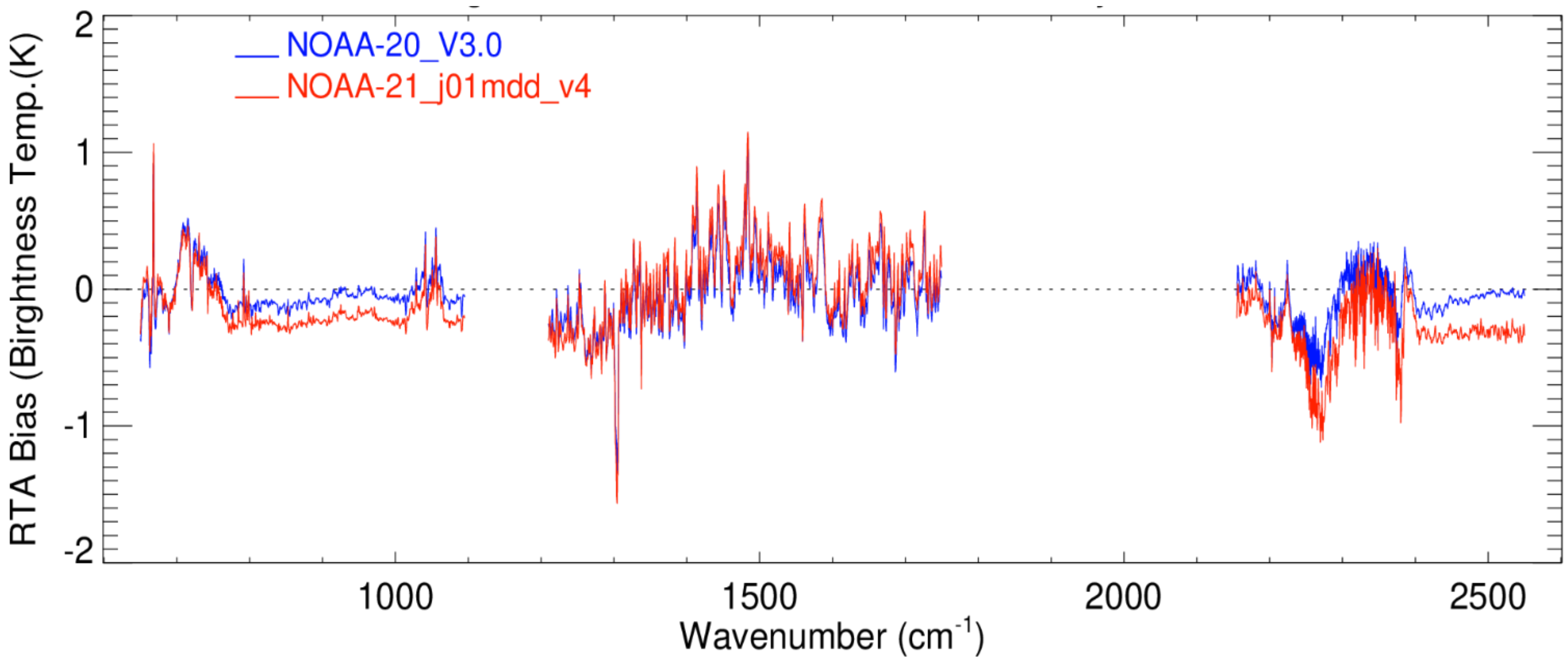
- Both have similar tuning biases for most of the temperature sounding channels.
- Some notable differences can be found at water vapor channels.

Note on MW retrievals

- MW retrieval is a product by itself. When IR+MW retrieval fails, the MIT retrieval is available.
- The regression retrieval replaces T(p) and q(p) microwave retrievals
- Nevertheless the NUCAPS downstream retrievals use microwave emissivities, surface classification (ice, sea, land, etc.) as well as in QC.

NOAA-21 CrIS Double-Difference Tuning

Tuning Biases of NOAA-20 and NOAA-21



- ECMWF analysis and 3-hour forecast data are used, and adjust of O3 above 110-hPa with NUCAPS retrieval
- Data Selection Criteria: VIIRS Cloud Mask, within ±60° Lat, Ocean only, Nighttime
- Calculated double-differences of OBS-SIM for NOAA-20 and NOAA-21 on 07/19 and 08/23, 2023
- Generated NOAA-21 tuning by adding double-difference to NOAA-20 tuning
- IR and MW tunings improved retrieval bias and RMS characteristics

NUCAPS NOAA-21 Version 3.2 for Provisional Maturity

Item	V3.0 (December 2020) HEAP 2.3	V3.1 (June 2023) HEAP 2.4	V3.2 NOAA-21 Algorithm
	NOAA-20/Metop-C **Currently in Operations**	NOAA-20/Metop-C NCCF Operations: Jan 2024	Changes Implemented for NOAA-21 Provisional Maturity
MW a-priori	✔ 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 NOAA-20	✔ No changes – as is for NOAA-20
MW Tuning	✔ Two focus days (20190215, 20190815) and MIT forward model	✔ NOAA-20	• **Updated for NOAA-21**
Cloudy Regression	✔ PC regression using NOAA-20 all-sky radiances matched with ECMWF, Updated with STC regression code; used four Focus Days	✔ No change – as is for NOAA-20	• **Updated for NOAA-21**
Clear Regression	✔ PC regression using NOAA-20 CCR radiances matched with ECMWF ✔ Used four Focus Days (20180415, 20180715, 20181015, 20190115)	✔ No change – as is for NOAA-20 ✔ Updated regression code	• **Updated for NOAA-21**
Emissivity Regression	✔ NO change from the operational version (V2.1.12d)	✔ No change – as is for NOAA-20	✔ No changes – as is for NOAA-20 ✔ Experiments on-going to update with CAMEL
IR Tuning	✔ Double Difference Method using NOAA-20 radiances and ECMWF SARTA simulations	✔ No change – as is for NOAA-20	• **Updated for NOAA-21**
CO climatology/QC	✔ No Change from the operational version (V2.1.12d)	✔ No change – as is for NOAA-20	✔ No changes – as is for NOAA-20
CH_4/N2O a-priori	✔ Updated CH_4/N_2O a-priori; QC flag updates to CH_4	✔ No change – as is for NOAA-20	✔ Updated, Effectivity NOAA-20/21
SO_2	✔ Climatology	✔ Retrieval turned on	✔ Retrieval turned on
CO_2 a-priori	✔ Updated CO_2 a-priori and QC flag updates	✔ CO_2 a-priori updates and QC flags	✔ Carried forward – as is for NOAA-20
CrIS Noise File	✔ No change from the operational version (V2.1.12d)	✔ No change – as is for NOAA-20	• **Updated for NOAA-21**
Channel Selection for cloud-clearing, T(p),q(p)	✔ Minor updates of channels ✔ Super saturation QC flag implemented	✔ No change – as is for NOAA-20	✔ No changes – as is for NOAA-20
Channels selection for trace gases	✔ No change from the operational version (V2.1.12d)	✔ No change – as is for NOAA-20	✔ No changes – as is for NOAA-20
Averaging Kernels and other product improvements	✔ None in the output file	✔ Added Averaging Kernels to the NUCAPS Product File ✔ Updated ozone a-priori ✔ Surface corrections to alleviate product use ✔ Damping factor update to improve boundary layer biases	✔ Carried forward these additional improvements ✔ No changes – as is for NOAA-20

NOAA-21 NUCAPS Provisional Maturity Review

NUCAPS EDR Products

Atmospheric Vertical Temperature Profile (AVTP)
Atmospheric Vertical Moisture Profile (AVMP)
Atmospheric Ozone Profile (O_3)
Outgoing Longwave Radiation (OLR)
Carbon Monoxide (CO)
Methane (CH_4)
Carbon Dioxide (CO_2)

NUCAPS Product Validation Methodology Hierarchies

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

T/H_2O/O_3 Profiles

1. **Numerical Model (e.g., ECMWF, NCEP/GFS) Global Comparisons**

Large, truly global samples acquired from Focus Days
Useful as "transfer standard" (via double-differences), bias tuning and regression
Limitation: Not independent truth data

2. **Satellite Sounder EDR (e.g., AIRS, COSMIC) *Intercomparisons***

Global samples acquired from Focus Days (**NOAA-20/NOAA-21**)
Limitation: Similar error characteristics

3. **Conventional PTU/O3 Sonde Matchup Assessments**

WMO/GTS operational sondes (NPROVS) or O3-sonde network (e.g., SHADOZ)
Representation of global zones, long-term monitoring (*Reale et al.* 2012; *Sun et al.* 2017)
Large samples after a couple months (e.g., *Divakarla et al.,* 2006)
Limitations: Skewed distributions; mismatch errors; non-uniform radiosondes, assimilated

4. **Dedicated/Reference PTU/O_3 Sonde Matchup *Assessments***

Dedicated for the purpose of satellite validation
Reference sondes: CFH, **GRUAN** corrected RS92/RS41
ARM sites (e.g., *Tobin et al.,* 2006), **AEROSE**, **HUBC**; collocations facilitated via NPROVS (*Reale et al.* 2012; *Sun et al.* 2017)
Limitation: Small sample sizes, geographic coverage

5. **Intensive Field Campaign *Dissections***

Include dedicated sondes, some *not* assimilated into NWP models
Include ancillary datasets, ideally funded aircraft campaign(s)
E.g., **SNAP, AEROSE, RIVAL, CalWater**, JAIVEX, AWEX-G, EAQUATE

Carbon Trace Gases

1. **Numerical Model Global *Comparisons***

Examples: ECMWF CAMS
Large, truly global samples acquired from Focus Days
Limitation: Not independent truth data

2. **Satellite Sounder EDR *Intercomparisons***

Examples: **TROPOMI, OCO-2**
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, WE-CAN, FIREX, ACT-America

Validation Strategies/Methods

NOAA-20 vs NOAA-21 product consistency & Hierarchy of validation data sets

1) Focus-day data sets, global ECMWF matches, global RAOB matches (NPROVS), correlative satellite products (TROPOMI, OCO-2):
   - ✔ Evaluation for all NUCAPS products
2) Global RAOB matches (NPROVS Team)
   - ✔ AVTP, AVMP validation
3) NOAA-GML O3SND matches
   - ✔ Over Boulder, CO and South Pole: O_3 Profile validation
4) Total Carbon Column Observing Network - TCCON matches:
   - ✔ CO, CH_4, CO_2 validation
5) Outgoing Longwave Radiation (OLR)
   - ✔ Daily NOAA-20/21 OLR validations with NOAA-20 CERES for 7 months
6) NUCAPS - MetOp-C product evaluations for all the NUCAPS products

NOAA-21 NUCAPS EDR Products Evaluation – Focus Day Datasets

Focus Days	CrIS Eng Pckg	NOAA-20 (v3.2)	NOAA-21 (v3.2)	ECMWF Matches	RAOB NPROVS	TROPOMI	OCO-2	TCCON	AIRS OLR	MetOp-C
03/24/2023	✔ EP v211*	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes
09/21/2023	✔ EP v212**	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	
12/18/2023	✔ EP v212**	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	

* CrIS SDR with EP v211 cal/val engineering package (Provisional); ** CrIS SDR with EP v212 cal/val engineering package (validated)

- Product consistency between NOAA-20/21
  - ✔ NOAA-21/20 NUCAPS v3.2 (v3.1 Operational version + NOAA-21 updates + CH_4 updates)
- AVTP, AVMP, **O_3**
  - ✔ NOAA-20,-21 global maps and statistical metrics versus **ECMWF** baseline
  - ✔ NPROVS Global RAOB collocations
- CO, CH4, and CO_2:
  - ✔ NOAA-20,-21 global maps versus **TROPOMI** (CO, CH_4), and **OCO-2** v11 (CO_2) baselines
  - ✔ Available TCCON measurement matches (lag-time between measurement time and availability)
- OLR:
  - ✔ NOAA-21 global maps versus NOAA-20 CrIS and Aqua CERES OLR baselines
    - NOAA-20 CERES OLR reference data matchups

NOAA-21 NUCAPS EDR Products Evaluation – Focus Day Datasets

O_3 Profile Validation with NOAA-GML Ozonesondes					
Focus Days	NOAA-20 (v3.2)	NOAA-21 (v3.2)	O_3SNDs Boulder, CO	O_3SNDs South Pole	✔ Validation of NUCAPS O_3 profiles over Boulder CO, and South Pole ✔ NOAA-GML team provided independent validations Irina Petropavlovskikh, Miyagawa Koji
07/17/2023	✔ Yes	✔ Yes	✔ Yes	✔ Yes	
08/23/2023	✔ Yes	✔ Yes	✔ Yes	✔ Yes	
09/12/2023	✔ Yes	✔ Yes	✔ Yes	✔ Yes	
10/03/2023	✔ Yes	✔ Yes	✔ Yes	✔ Yes	

OLR Product Validation with NOAA-20 CERES						
Time Period	NOAA-21 CrIS	NOAA-20 CrIS	NOAA-20 CERES	AIRS OLR	MetOp-C OLR	
Seven months of NOAA-20/21 OLR products	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Validation with NOAA-20 CERES ✔ OLR Applications ✔ **We consider this product to be of validated maturity**

NOAA-21 NUCAPS EDR Products Evaluation – Focus Day Datasets

Trace Gas Product Validations with TCCON Data

NOAA-20	✔ Yes	• Validation of Trace Gas Products w/o Averaging Kernels • Validation of Trace Gas Products with Averaging Kernels
NOAA-21	✔ Yes	

Focus Days	TCCON Stations									
	CI	**DF**	**ET**	**GM**	**HW**	**KA**	**LR**	**OC**	**SO**	**WG**
02/27/2023	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
03/24/2023	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
04/17/2023	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No
05/15/2023	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No
05/22/2023	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No
06/19/2023	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No	No
07/17/2023	No	No	Yes	No	Yes	No	No	No	No	No
07/19/2023	No	No	Yes	No	Yes	No	No	No	No	No
08/21/2023	No	No	Yes	No	Yes	No	No	No	No	No
08/23/2023	No	No	Yes	No	Yes	No	No	No	No	No
09/12/2023	No	No	Yes	No	Yes	No	No	No	No	No

CrIS OUTGOING LONGWAVE RADIATION (OLR) EDR

NUCAPS-OLR Reference Data & Time Periods

NUCAPS OLR	Reference Data & Source	Data Format	Time Period	Validation status
• NOAA-21 daily OLR	• NOAA-20 CriS • Aqua AIRS • NOAA-20 CERES	1° lat/lon	• 03/24/2023 • 09/21/2023	✓ Meets the requirement
• NOAA-21 monthly OLR • Seven months of NOAA-21 OLR products	• NOAA-20 CERES	Averaged 1° lat/lon	• 04-10/2023	✓ Meets the requirement

About OLR CERES.

https://www.earthdata.nasa.gov/learn/articles/ceres-instrument-primary-source-for-observing-heat-budget

"If people are analyzing the 20-plus years of CERES data, right now they're using Terra and Aqua. The record starts with [CERES data from] Terra, and then goes to Terra plus Aqua," said Loeb. "The plan was to transition to NOAA-20 and we were going to do that in July [2020], but with the Aqua anomaly that we had in April [2020], we figured we'd just do it then. So, NOAA-20 has taken over from Terra and Aqua, so the [climate data] record will be Terra only from March 2000 to June 2002, Terra and Aqua from July 2002 to March 2022, and then NOAA-20 from April 22 onward."

January 26, 2018: NASA has been developing a next-generation sensor to collect this type of data – the **RBI** (Radiation Budget Instrument). However, RBI has experienced significant technical issues and substantial cost growth over the past two years. Because of these challenges, and the low risk of experiencing a gap in this data record over the next eight years due to having two relatively new instruments presently in orbit, NASA has decided to discontinue development of RBI. [10)]

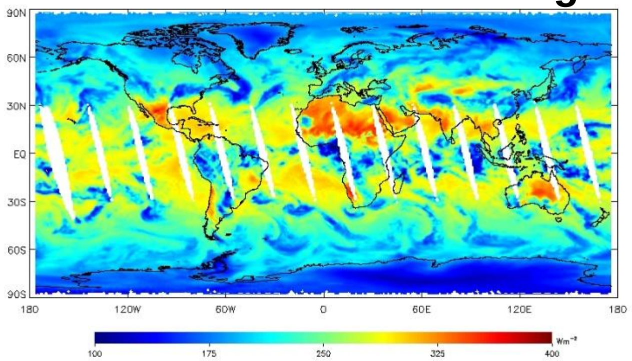
NASA's newest sensor measuring Earth's radiation budget in orbit — CERES (Clouds and the Earth's Radiant Energy System) — was launched on Nov. 18, 2017, aboard the National Oceanic and Atmospheric Administration's JPSS-1 (Joint Polar Satellite System-1), now named NOAA-20. CERES instruments are currently collecting data on four different U.S. spacecraft, including the joint NASA/NOAA Suomi NPP launched in 2011. Two other CERES instruments have been operating well for more than a decade.

https://www.eoportal.org/satellite-missions/jpss-2#mission-status

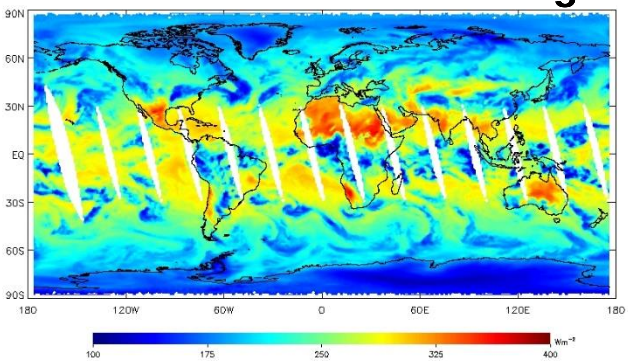
NOAA-20 CrIS vs NOAA-21 CrIS OLR for **24 March 2023**

✔ NOAA-21 CrIS OLR agrees well with NOAA-20 for both ascending and descending orbits.

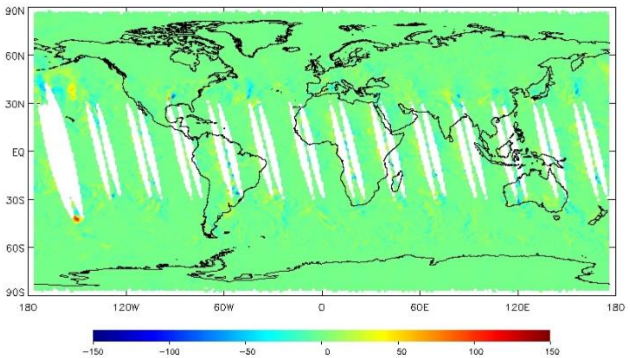
NOAA-21 CrIS Ascending



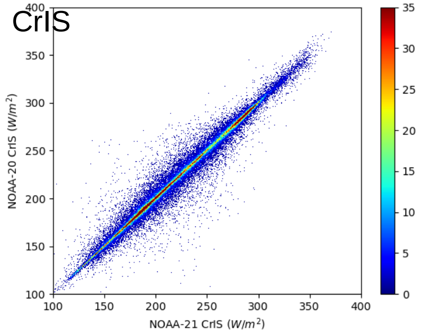
NOAA-20 CrIS Ascending



OLR Differences

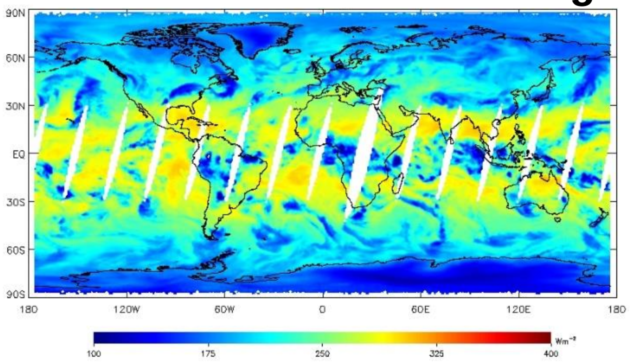


NOAA-20 CrIS vs NOAA-21 CrIS

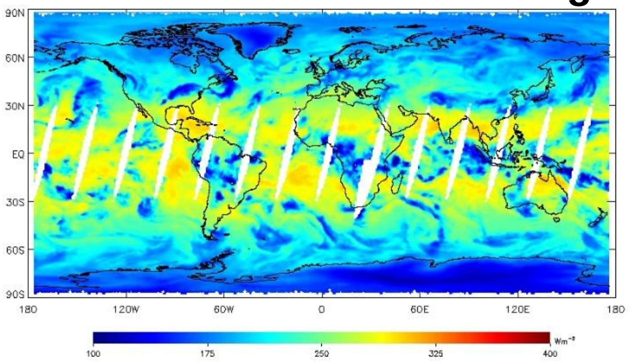


Mean Diff (W/m²)	0.1
STDev (W/m²)	8.1

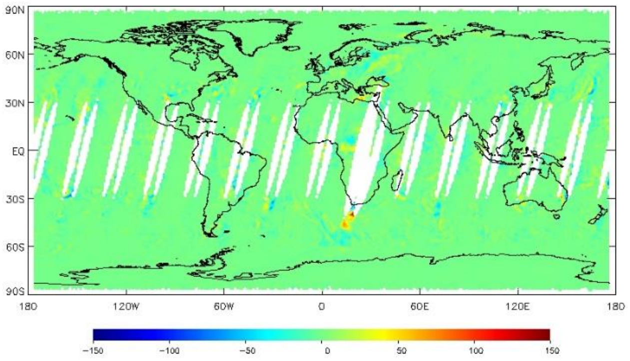
NOAA-21 CrIS Descending



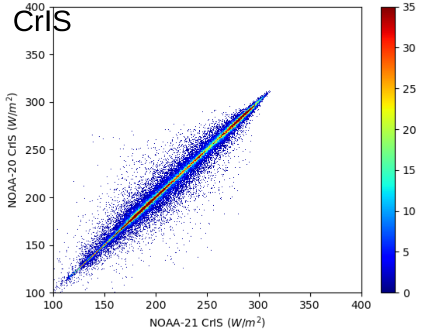
NOAA-20 CrIS Descending



OLR Differences



NOAA-20 CrIS vs NOAA-21 CrIS

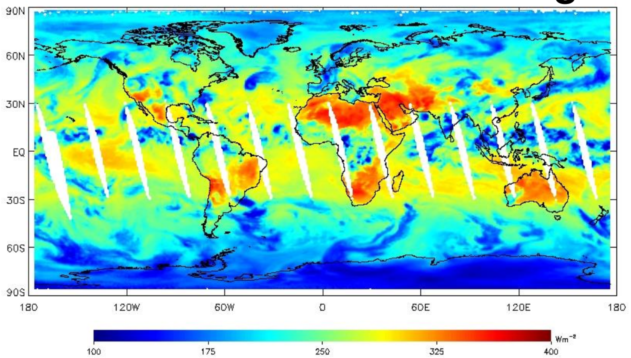


Mean Diff (W/m²)	0.1
STDev (W/m²)	7.7

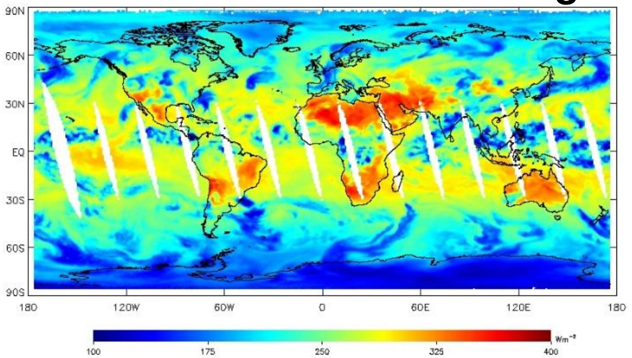
NOAA-20 CrIS vs NOAA-21 CrIS OLR for **21 Sept 2023**

✔ NOAA-21 CrIS OLR agrees well with NOAA-20 for both ascending and descending orbits.

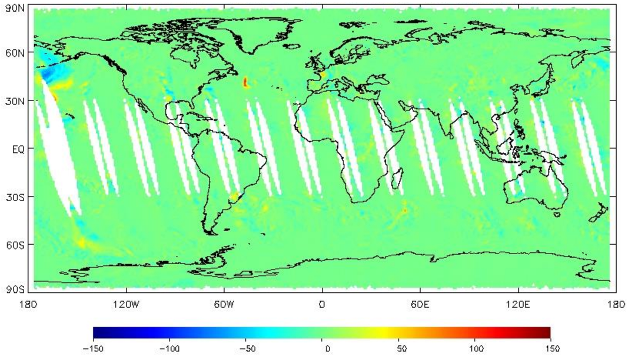
NOAA-21 CrIS Ascending



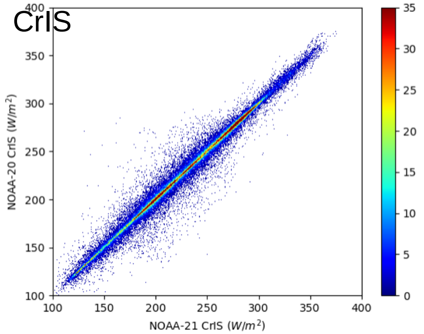
NOAA-20 CrIS Ascending



OLR Differences

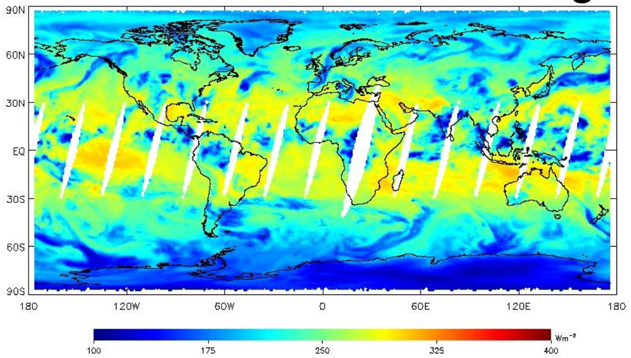


NOAA-20 CrIS vs NOAA-21 CrIS

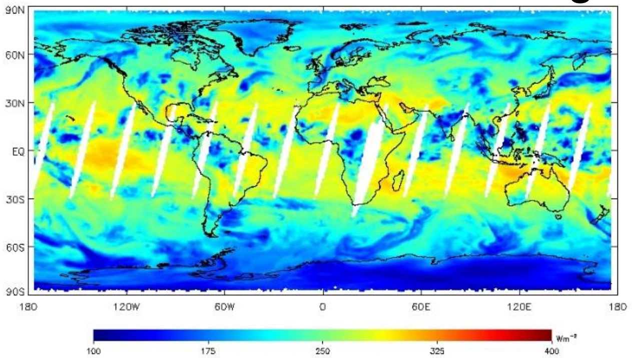


Mean Diff (W/m^2)	0
STDev (W/m^2)	7.6

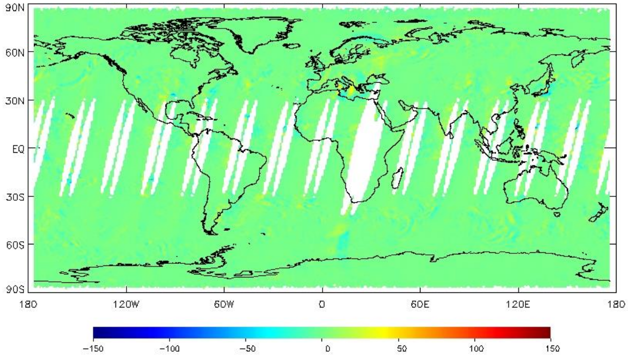
NOAA-21 CrIS Descending



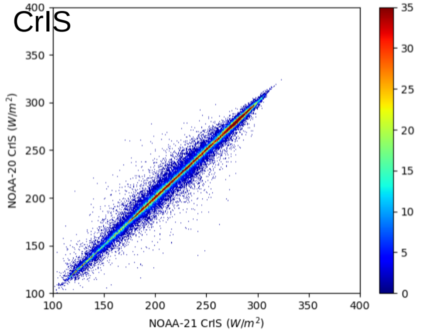
NOAA-20 CrIS Descending



OLR Differences



NOAA-20 CrIS vs NOAA-21 CrIS

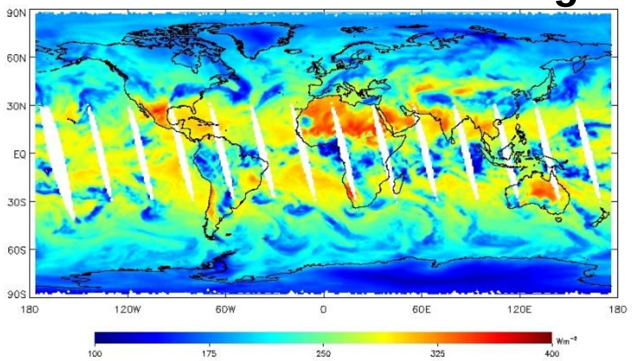


Mean Diff (W/m^2)	0.2
STDev (W/m^2)	6.4

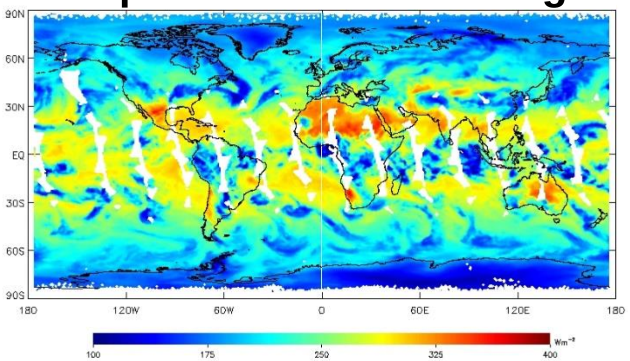
Aqua CERES vs NOAA-21 CrIS OLR for **24 March 2023**

✔ NOAA-21 CrIS OLR agrees well with Aqua CERES for both ascending and descending orbits.

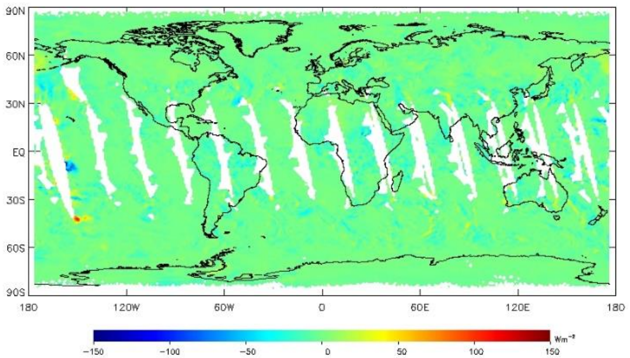
NOAA-21 CrIS Ascending



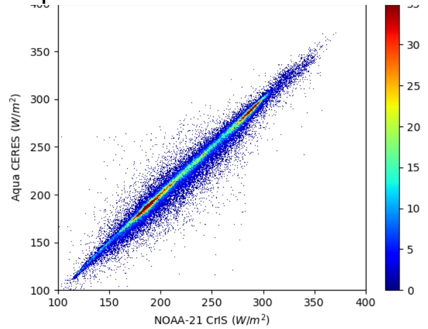
Aqua CERES Ascending



OLR Differences

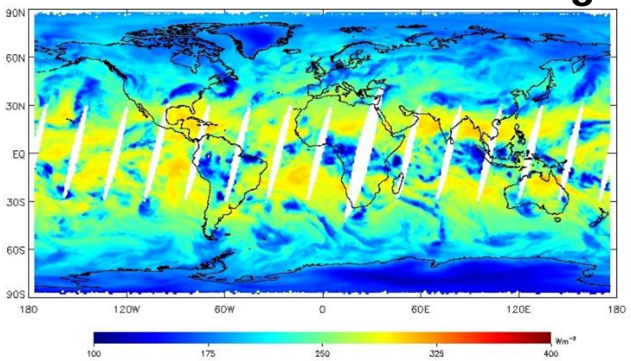


Aqua CERES vs NOAA-21 CrIS

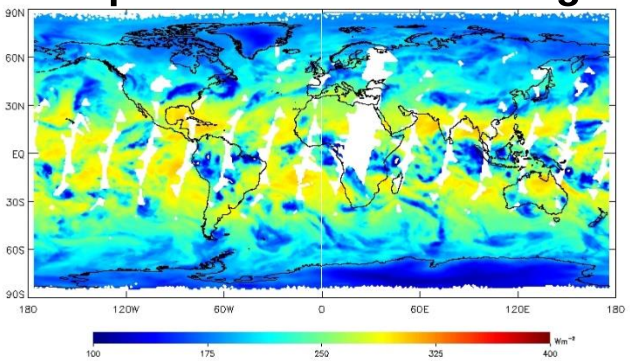


Mean Diff (W/m²)	-1.8
STDev (W/m²)	9.1

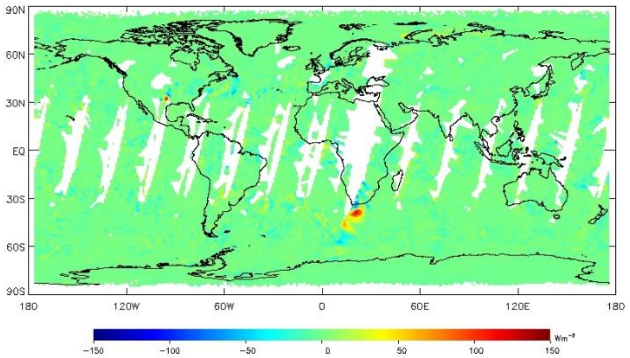
NOAA-21 CrIS Descending



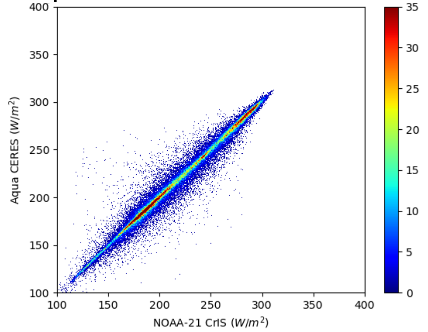
Aqua CERES Descending



OLR Differences



Aqua CERES vs NOAA-21 CrIS

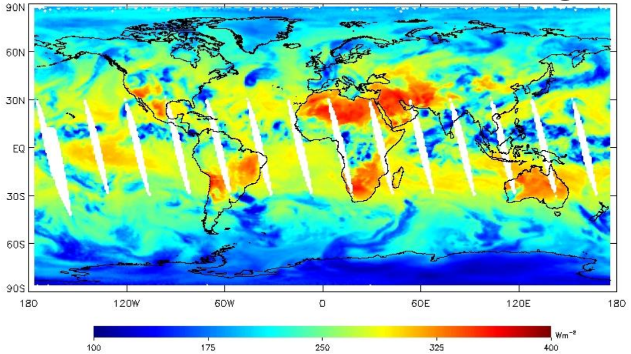


Mean Diff (W/m²)	-0.4
STDev (W/m²)	8.0

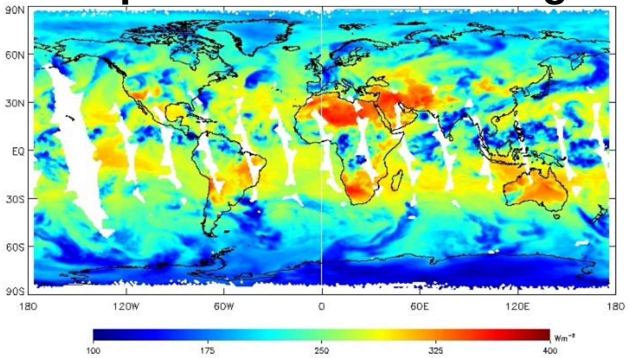
Aqua CERES vs NOAA-21 CrIS OLR for **21 Sept 2023**

✔ NOAA-21 CrIS OLR agrees well with Aqua CERES for both ascending and descending orbits.

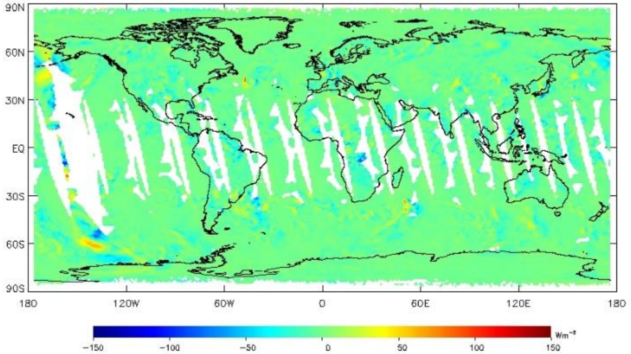
NOAA-21 CrIS Ascending



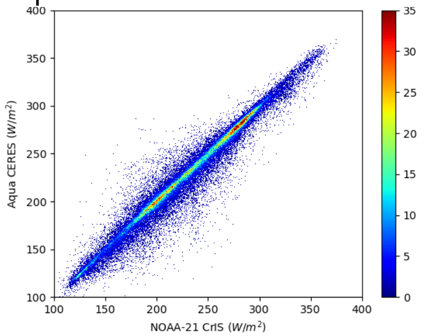
Aqua CERES Ascending



OLR Differences

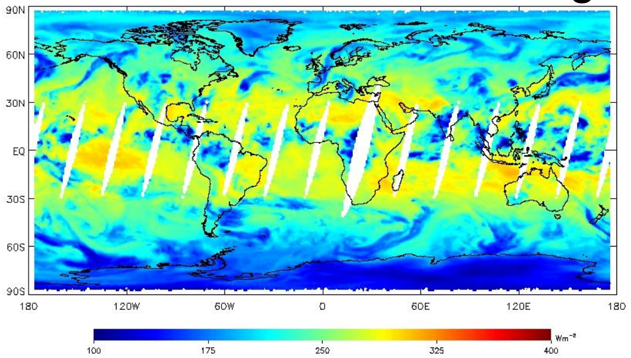


Aqua CERES vs NOAA-21 CrIS

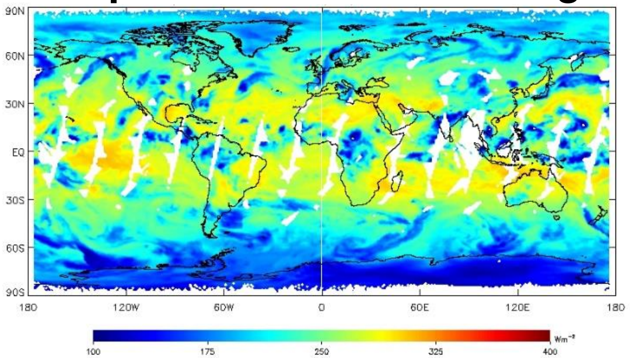


Mean Diff (W/m²)	-2.7
STDev (W/m²)	10.8

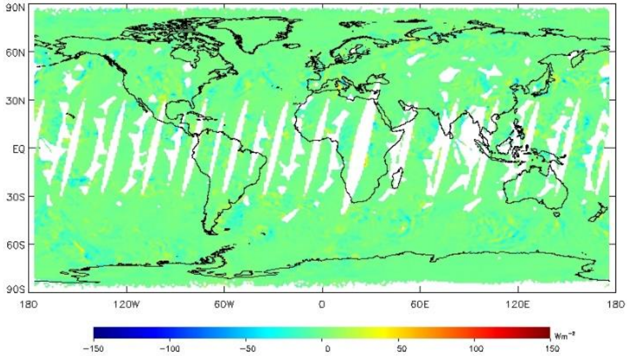
NOAA-21 CrIS Descending



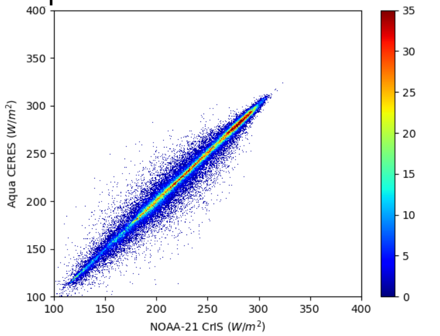
Aqua CERES Descending



OLR Differences

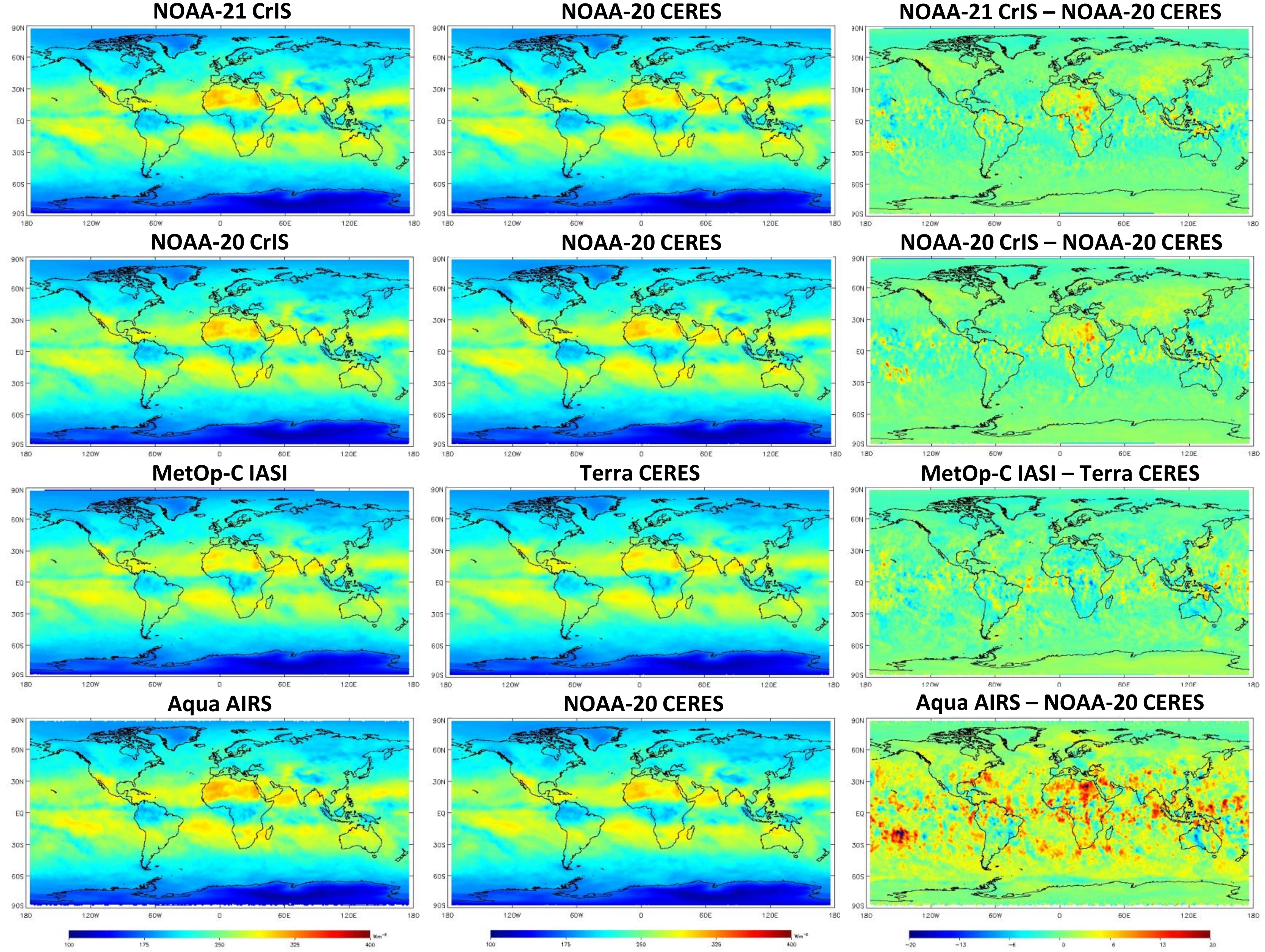


Aqua CERES vs NOAA-21 CrIS



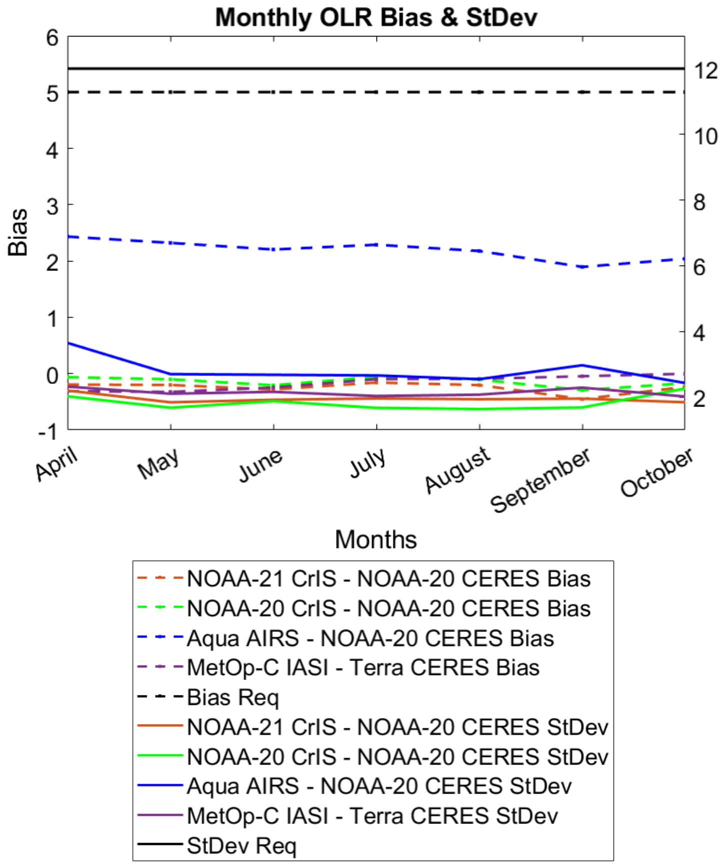
Mean Diff (W/m²)	-0.4
STDev (W/m²)	8.6

CrIS, IASI, AIRS 04-10/2023 Monthly OLR Mean *vs* CERES



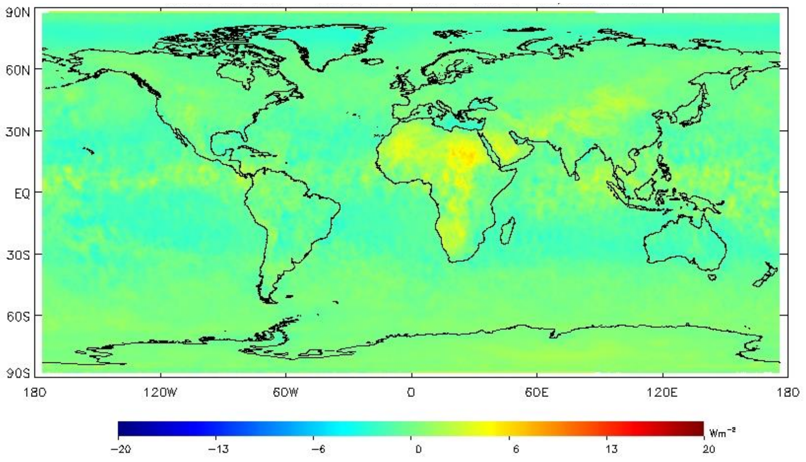
NOAA-20 CrIS (Operational Product)
Aqua AIRS (Operational Product)
Terra CERES (Operational Product)
NOAA-20 CERES (Operational Product)
NOAA-21 CrIS (Beta, not in operations)

The NOAA-21 OLR product meets the requirement as evidenced by the validations performed.

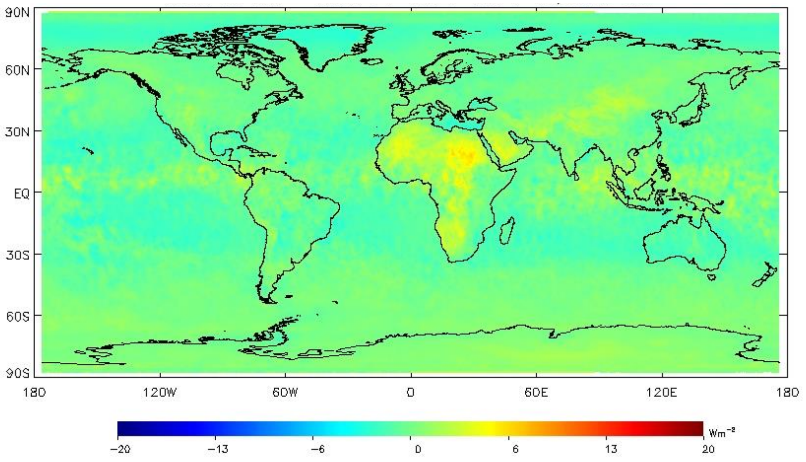


Total Monthly Mean Difference Between CrIS, IASI, AIRS and CERES

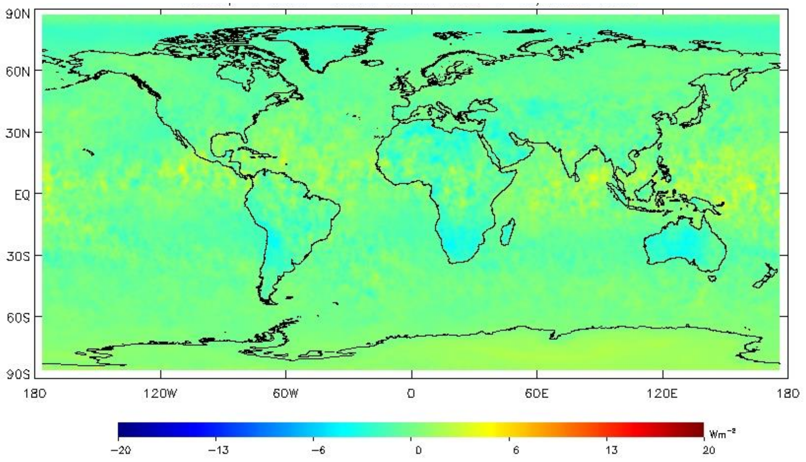
NOAA-21 CrIS – NOAA-20 CERES OLR Mean 04-10/2023



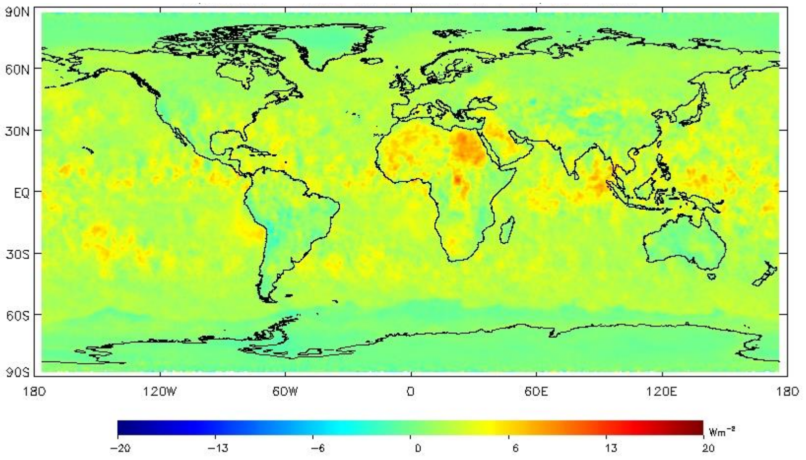
NOAA-20 CrIS – NOAA-20 CERES OLR Mean 04-10/2023



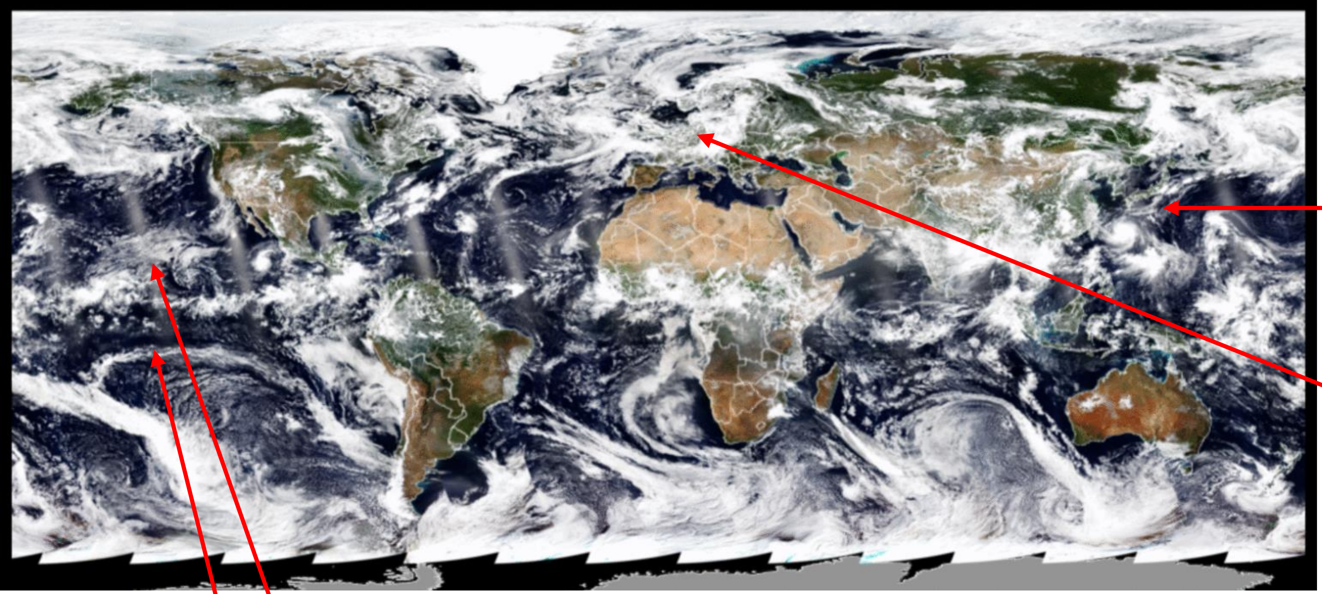
MetOp-C IASI - Terra CERES OLR Mean 4-10/2023



Aqua AIRS – NOAA-20 CERES OLR Mean 04-10/2023

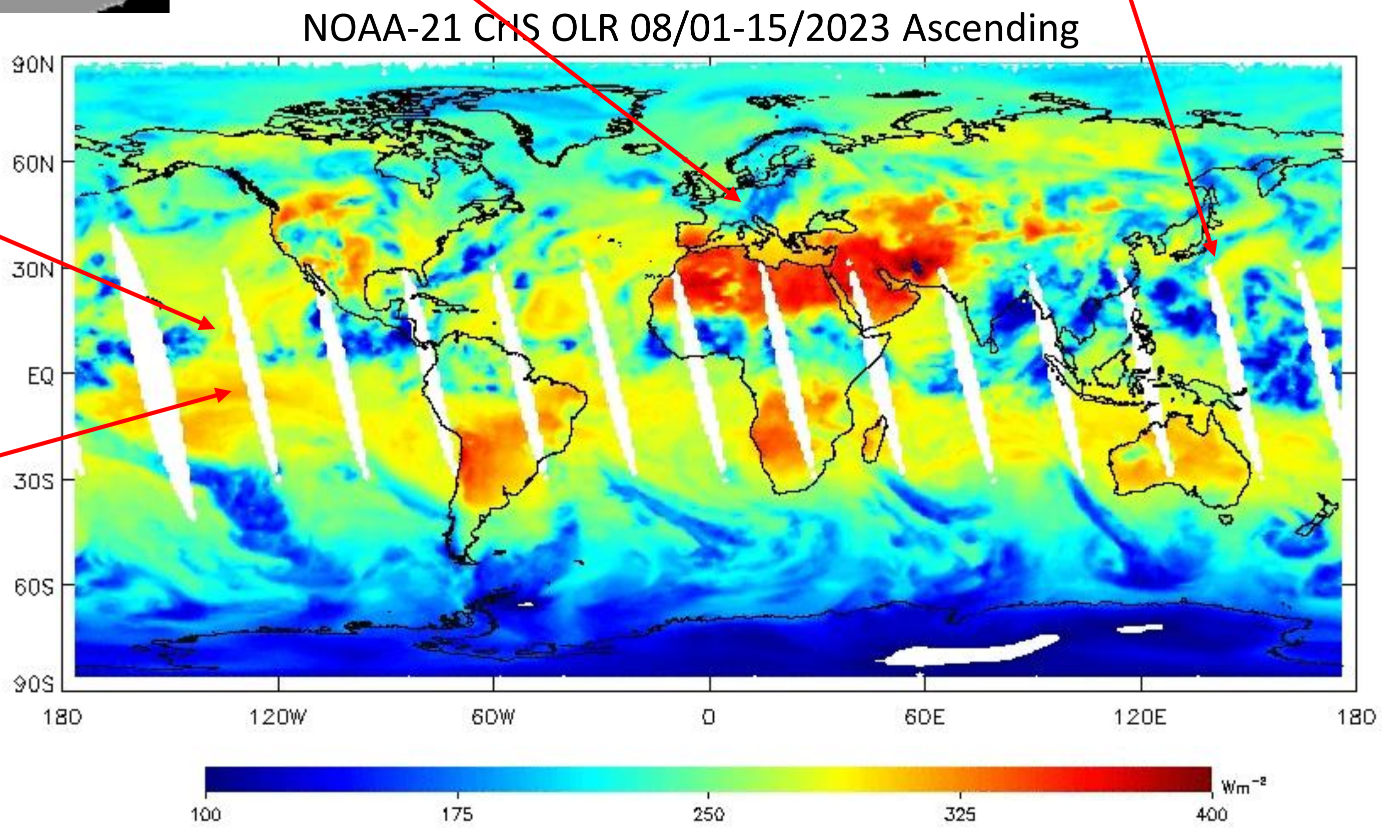


- NOAA-21 OLR is consistent with NOAA-20 CrIS and shows good agreement with NOAA-20 CERES.
- The larger value differences can be attributed to the viewing and scanning properties of the sensors and a lack of scene uniformity due to daytime solar radiation.



Typhoon Lan was a category 4-equivalent tropical cyclone, made a landfall over Japan, causing flooding, landslides, widespread damage to infrastructure, and injuries.

A **heavy thunderstorm** brought over a foot of hail in Germany, resulting in blocked drainage systems, flooding, and snowploughs.



Hurricane Dora was a powerful tropical cyclone that travelled across all three North Pacific cyclone basins. Gradient winds caused by the hurricane facilitated the spread of the **Hawaii wildfires**.

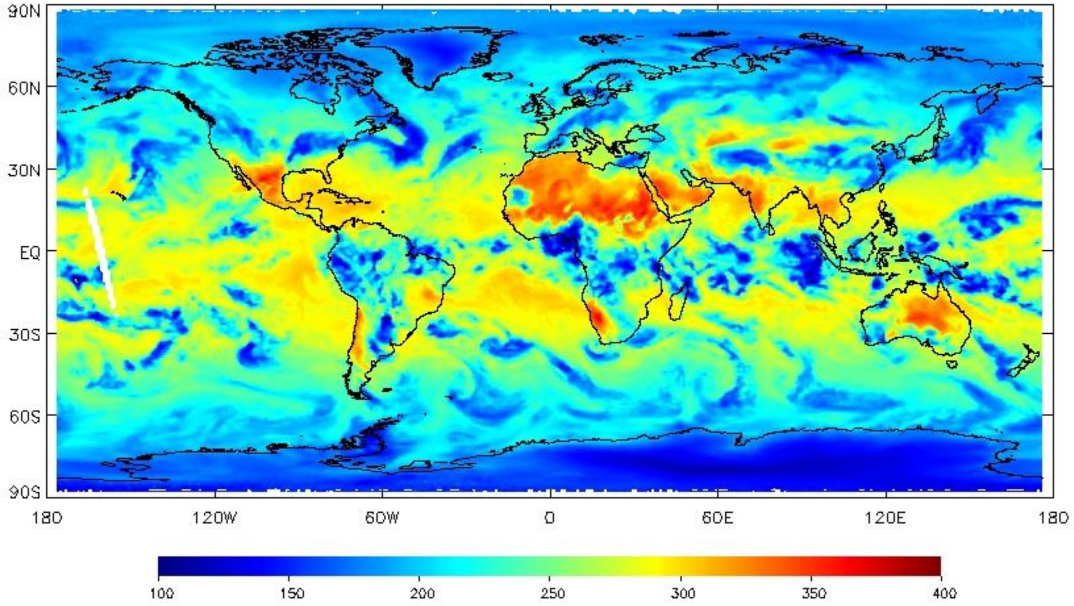
El Nino conditions remained in place, as warm waters displaced eastward over the central and eastern tropical Pacific.

Thanks to Tom Atkins for the JSTAR Mapper tiles script.

Summary

- The NUCAPS system produces consistent daily and monthly OLR products from NOAA-20, NOAA-21, and MetOp-C.
- The NUCAPS NOAA-21 and NOAA-20 OLR are consistent with each other and show good agreement with NOAA-20 CERES and AIRS.
- NOAA-21 OLR meets all JPSS requirements for provisional maturity level.
- A few differences are seen on the edge of the scans and in the tropical and subtropical regions and may be cause by the angular, temporal, and spatial sampling differences of the sensors.
- The hotspots do not significantly affect the OLR validation performance, as they do not persist over extended periods, and no hotspots of the same intensity are observed in the monthly mean OLR.
- OLR coupled with NOAA-20 VIIRS True-Color facilitates monitoring of global weather activities.
- Future OLR work includes yearly OLR analysis, blended OLR product, CFS comparisons, and CPC collaboration

NOAA-21 & NOAA-20 CrIS Merged 03/24/2023 Ascending



NUCAPS EDR Products

ATMOSPHERIC VERTICAL TEMPERATURE PROFILE (AVTP)
ATMOSPHERIC VERTICAL MOISTURE PROFILE (AVMP)
ATMOSPHERIC OZONE PROFILE (O_3)

Focus Days	CrIS Eng Pckg	NOAA-20 (v3.2)	NOAA-21 (v3.2)	ECMWF Matches	RAOB NPROVS	TROPOMI	OCO-2	TCCON	AIRS OLR	MetOp-C
03/24/2023	✔ EP v211*	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes
09/21/2023	✔ EP v212**	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	
12/18/2023	✔ EP v212**	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	✔ Yes	
01/01/2024	✔ EP v212**	✔ Used for the verification of NCCF (v3.1) operational run vs offline run								

- Product consistency between NOAA-20/21
  - ✔ NOAA-21/20 NUCAPS v3.2 (v3.1 Operational version + NOAA-21 updates + CH_4 updates)
- AVTP, AVMP, **O_3**
  - ✔ NOAA-20,-21 global maps and statistical metrics versus **ECMWF** baseline
  - ✔ NPROVS Global RAOB collocations
  - ✔ O3 Validations with NOAA-GML O_3SNDS

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

Temperature Profile

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

"Clear to Partly-Cloudy"
(Cloud Fraction < 50%)
↕
IR+MW retrieval

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

Moisture Profile

CrIS/ATMS Atmospheric Vertical Moisture Profile (AVMP) Measurement Uncertainty – 2-km Layer Average Mixing Ratio % Error		
PARAMETER	**THRESHOLD**	**OBJECTIVE**
AVMP, Cloud fraction < 50%, surface to 600 hPa	Greater of 20% or 0.2 g·kg^{-1} / 2-km layer	10%
AVMP, Cloud fraction < 50%, 600–300 hPa	Greater of 35% or 0.1 g·kg^{-1} / 2-km layer	10%
AVMP, Cloud fraction < 50%, 300–100 hPa	Greater of 35% or 0.1 g·kg^{-1} / 2-km layer	10%
AVMP, Cloud fraction ≥ 50%, surface to 600 hPa	Greater of 20% of 0.2 g·kg^{-1} / 2-km layer	10%
AVMP, Cloud fraction ≥ 50%, 600–400 hPa	Greater of 40% or 0.1 g·kg^{-1} / 2-km layer	10%
AVMP, Cloud fraction ≥ 50%, 400–100 hPa	Greater of 40% or 0.1 g·kg^{-1} / 2-km layer	NS

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

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

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)

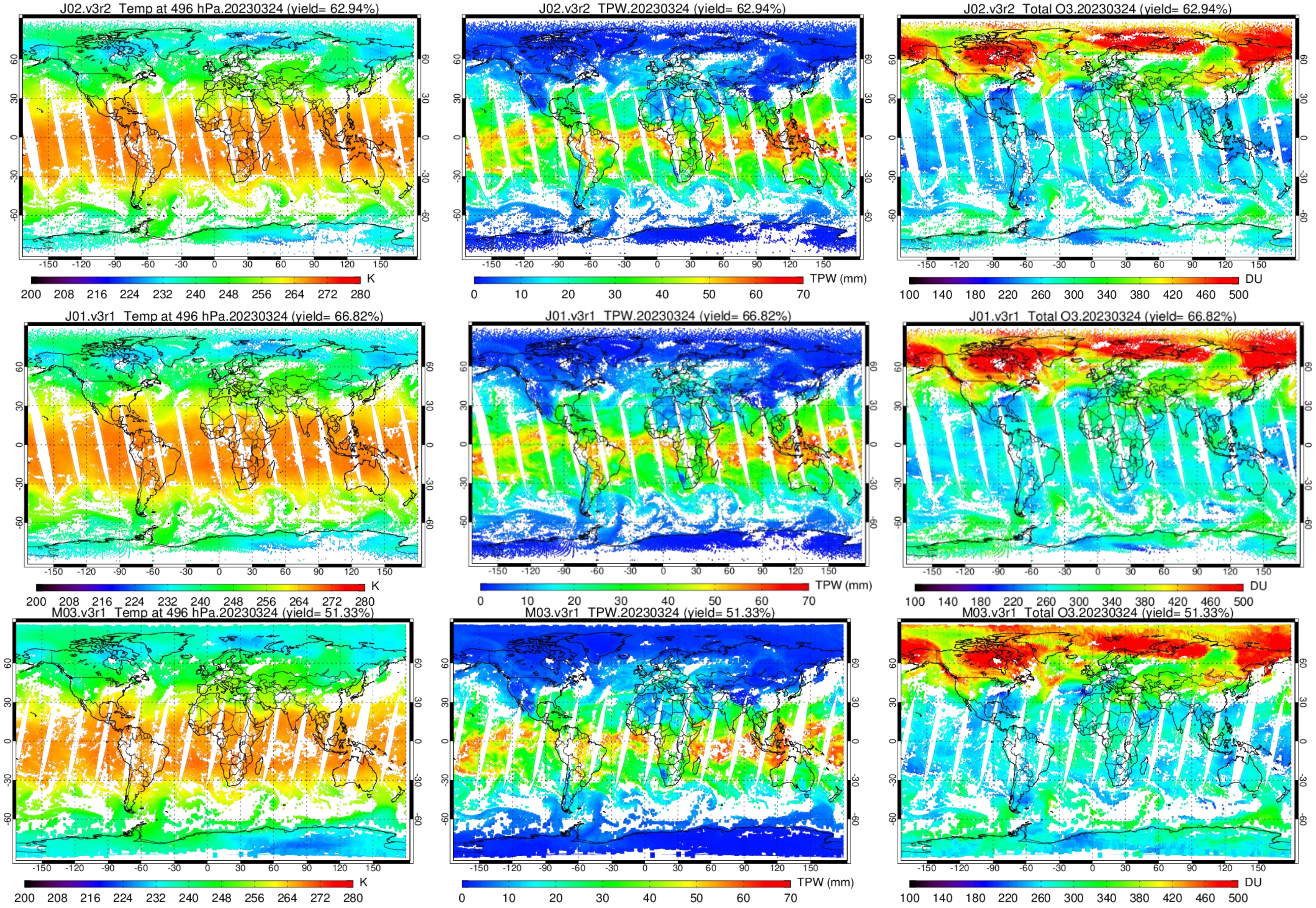
NUCAPS EDR Retrievals for 24 March 2023

Temperature at 496 hPa | TPW (mm) | Total Ozone (DU)

NOAA-21 V3.2

NOAA-20 Operational

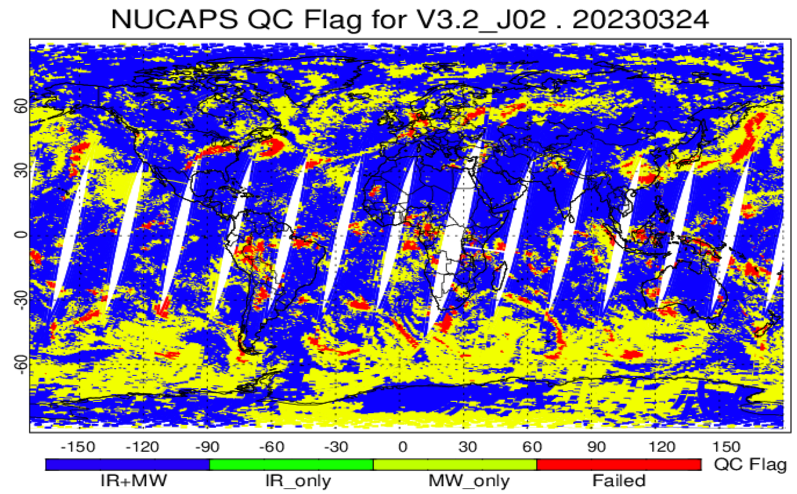
MetOp-C Operational



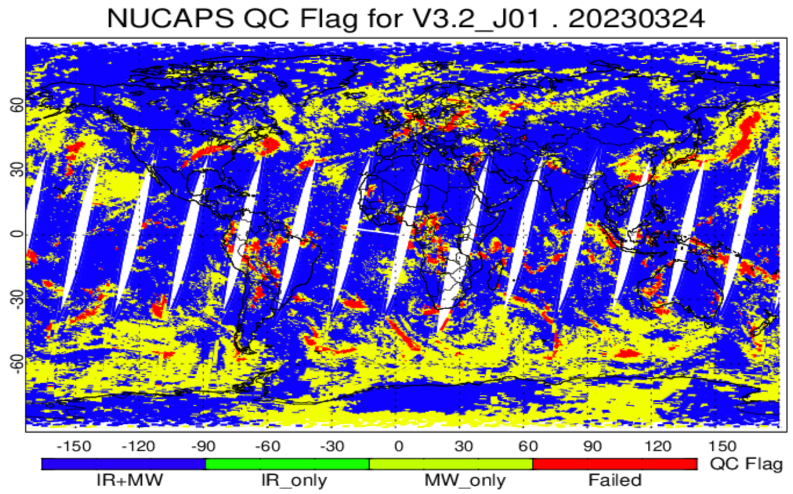
- NUCAPS produces vertical profiles of: Temperature, Water vapor, O_3, CO, CH_4, CO_2 and Outgoing Longwave Radiation (OLR)
- Figures shown are for **Temperature, Water Vapor, and Ozone.**
- V3.2 NOAA-21 products are consistent with the NOAA-20 operational products (v3.1)
- Retrieved profiles (100 layers) span from surface to 0.01 hPa.
- NUCAPS enterprise version produces products from both JPSS NOAA-21/20 and MetOp –C/B Satellites.
- Yield: 66% (NOAA-20/21)
- Yield: 51% (MetOp-C)

NUCAPS QC Flags for NOAA-20/21 V3.0/V3.1 (24 Mar 2023)

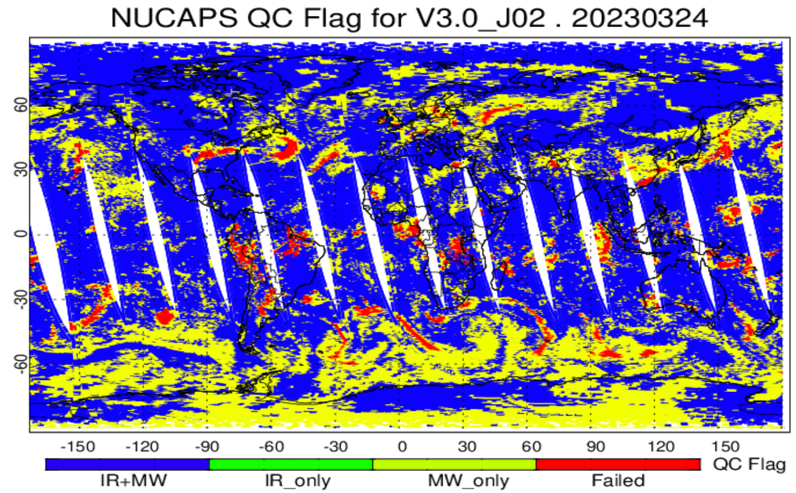
NOAA-21 v3.2



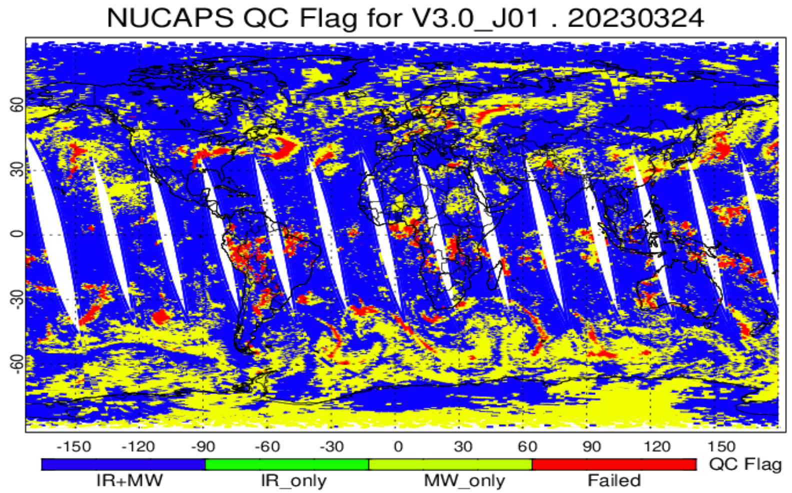
NOAA-20 v3.2



NOAA-21 v3.0 (OPS)



NOAA-20 v3.0 (OPS)



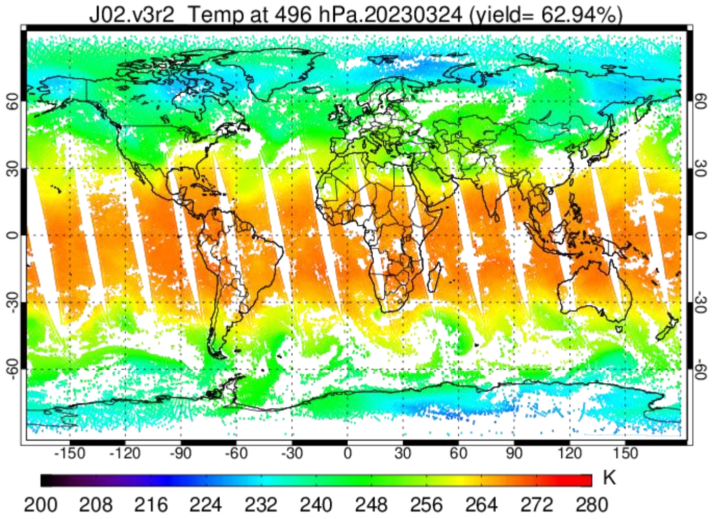
QC Flag	NOAA-20	NOAA-21
IR+MW Pass	66.8%	62.9%
IR Failed, MW Pass	30.0%	34.0%
Both IR, MW Failed	3.2%	3.1%

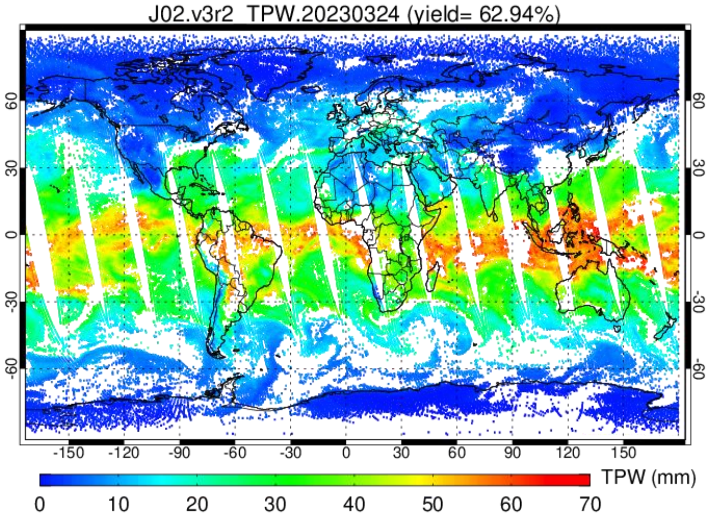
- ✔ NUCAPS v3.2, v3.1 (to be in OPS), and v3.0 (OPS) are consistent in QC flags and products.
- ✔ V3.2 has no detrimental impact to the operational NOAA-20 NUCAPS products (v3.1) (supplemental slides).
- ✔ $T(p)$, $q(p)$, $O_3(p)$ use IR+MW QC for accepted cases; trace gas products include an additional set QC flags (DoF)

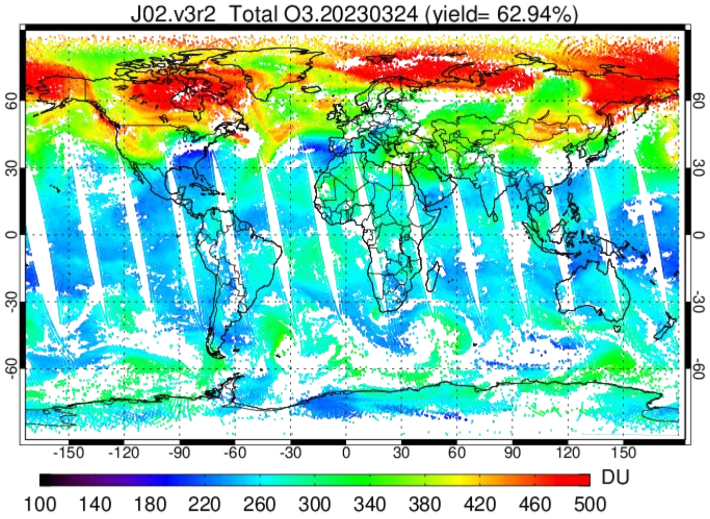
NOAA-21 vs NOAA-20 NUCAPS EDR Retrievals for **24 March 2023**

Temperature at 496 hPa | **TPW (mm)** | **Total Ozone (DU)**

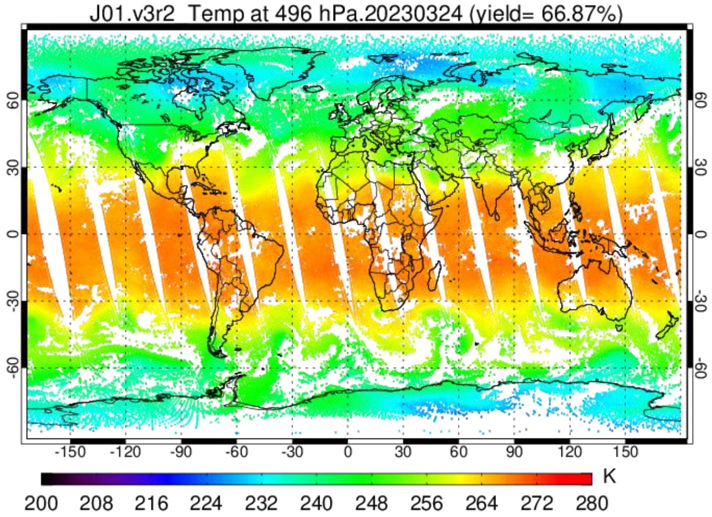
NOAA-21 V3.2

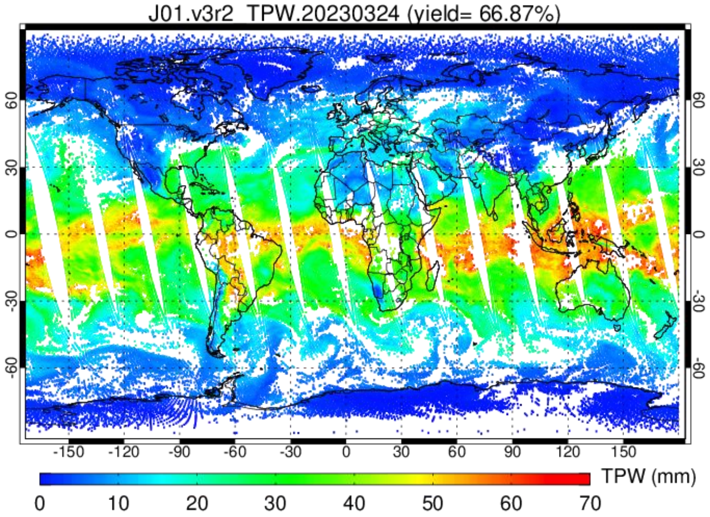


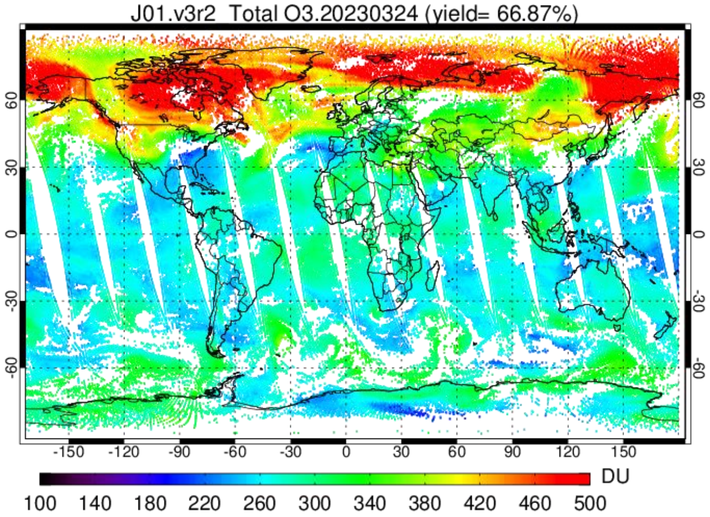




NOAA-20 V3.2







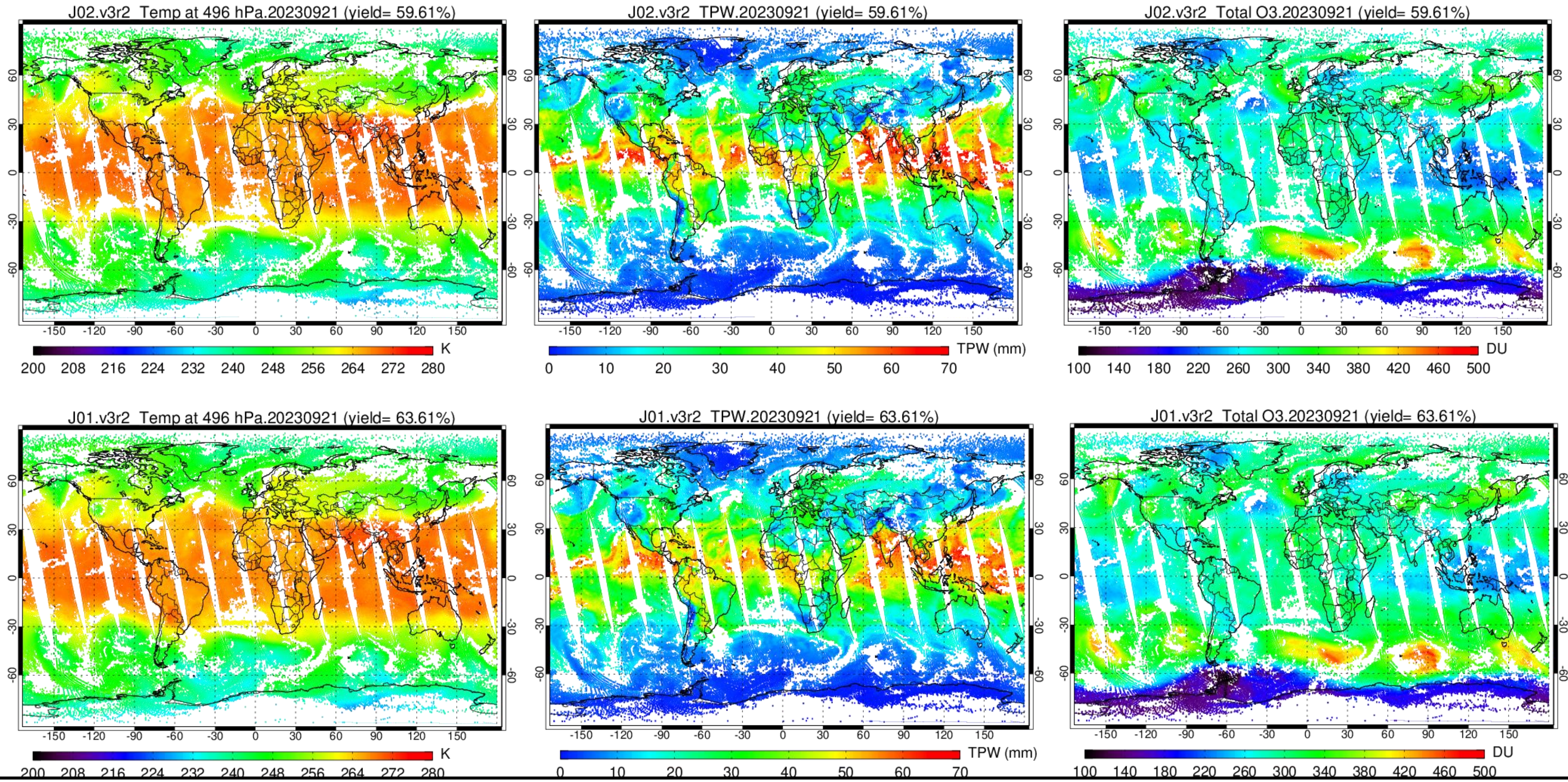
NUCAPS EDR retrievals from NOAA-21 Provisional algorithm matches very well both qualitatively and quantitatively with the NOAA-20 NUCAPS EDRs. The algorithm produces vertical profiles of temperature, water vapor, O_3, OLR, CO, CH_4, and CO_2. Retrieved profiles (100 layers) span from surface to 0.01 hPa.

NOAA-21 vs NOAA-20 NUCAPS EDR Retrievals for **21 Sep 2023**

	Temperature at 496 hPa	TPW (mm)	Total Ozone (DU)

NOAA-21 V3.2

NOAA-20 V3.2

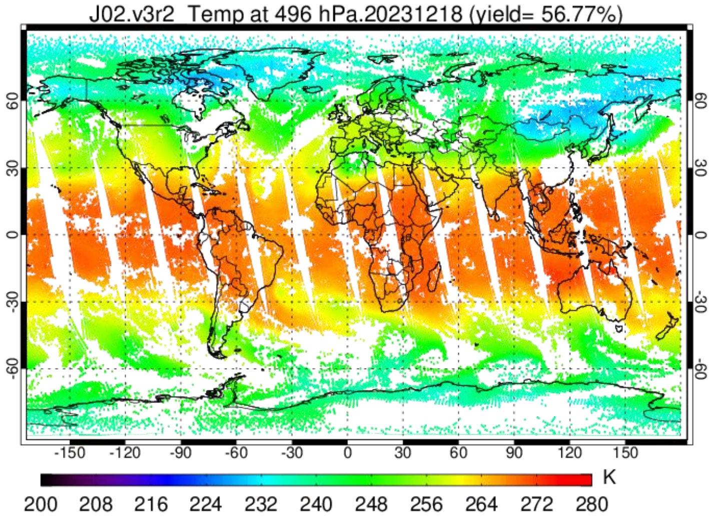


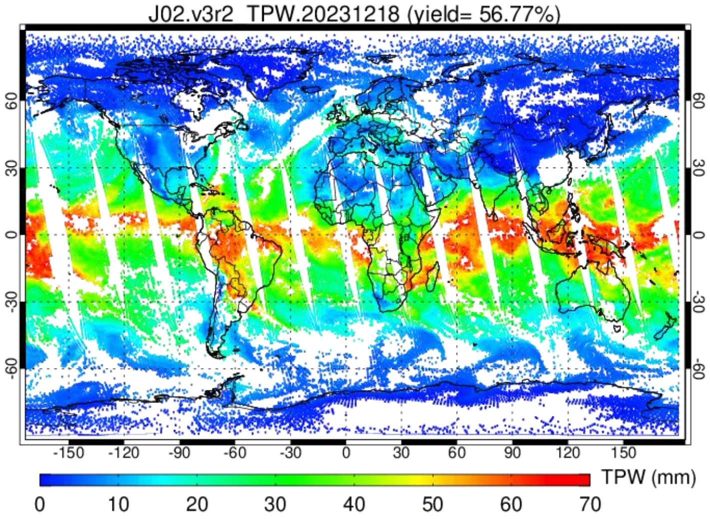
NUCAPS EDR retrievals from NOAA-21 Provisional algorithm matches very well both qualitatively and quantitatively with the NOAA-20 NUCAPS EDRs. The algorithm produces vertical profiles of temperature, water vapor, O_3, OLR, CO, CH_4, and CO_2. Retrieved profiles (100 layers) span from surface to 0.01 hPa.

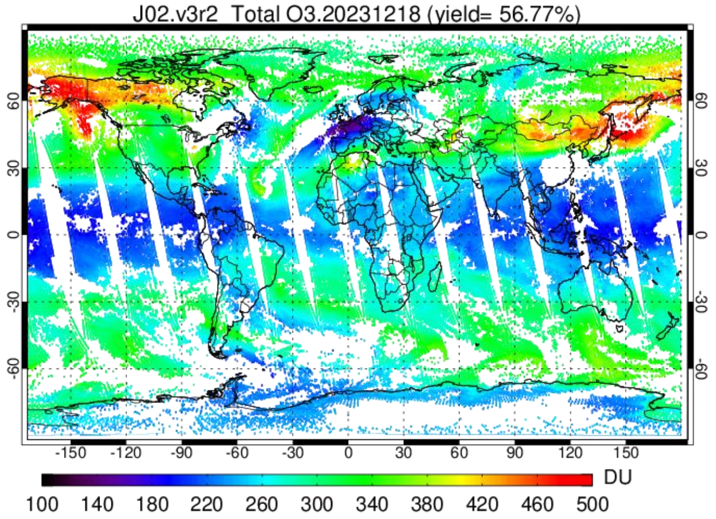
NOAA-21 vs NOAA-20 NUCAPS EDR Retrievals for **18 Dec 2023**

	Temperature at 496 hPa	TPW (mm)	Total Ozone (DU)

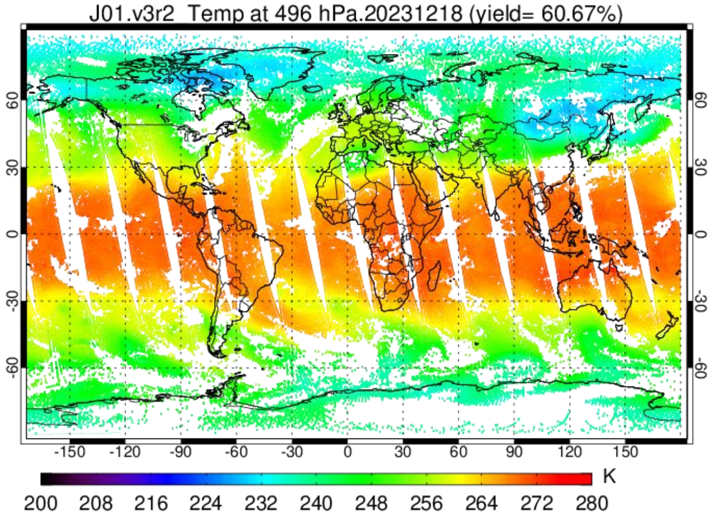
NOAA-21 V3.2

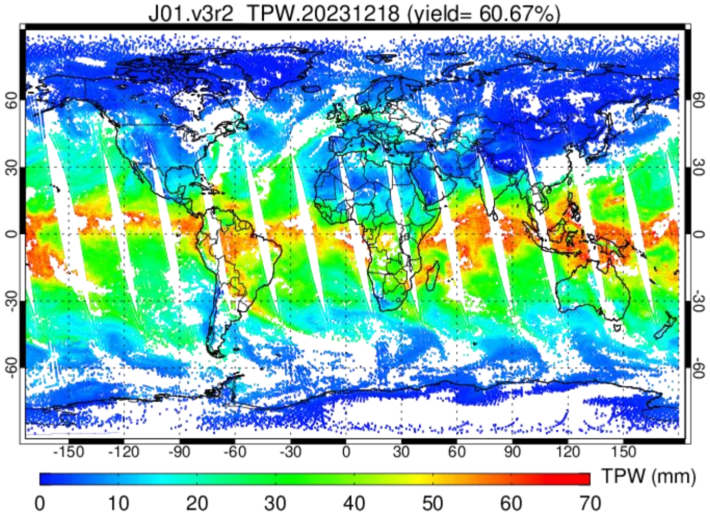


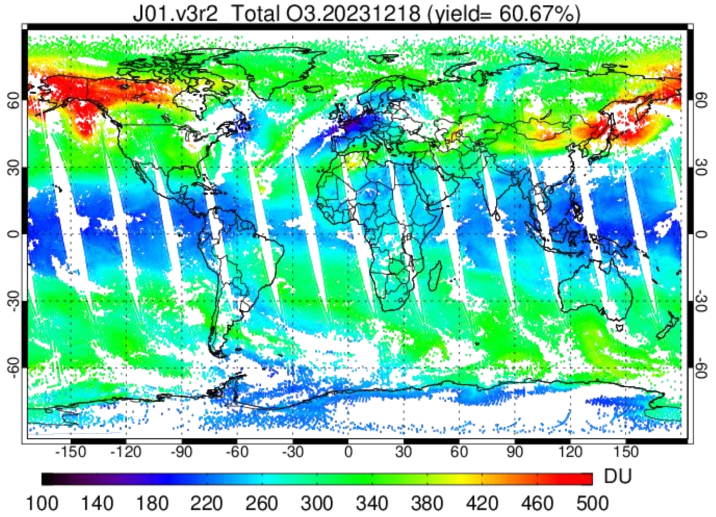




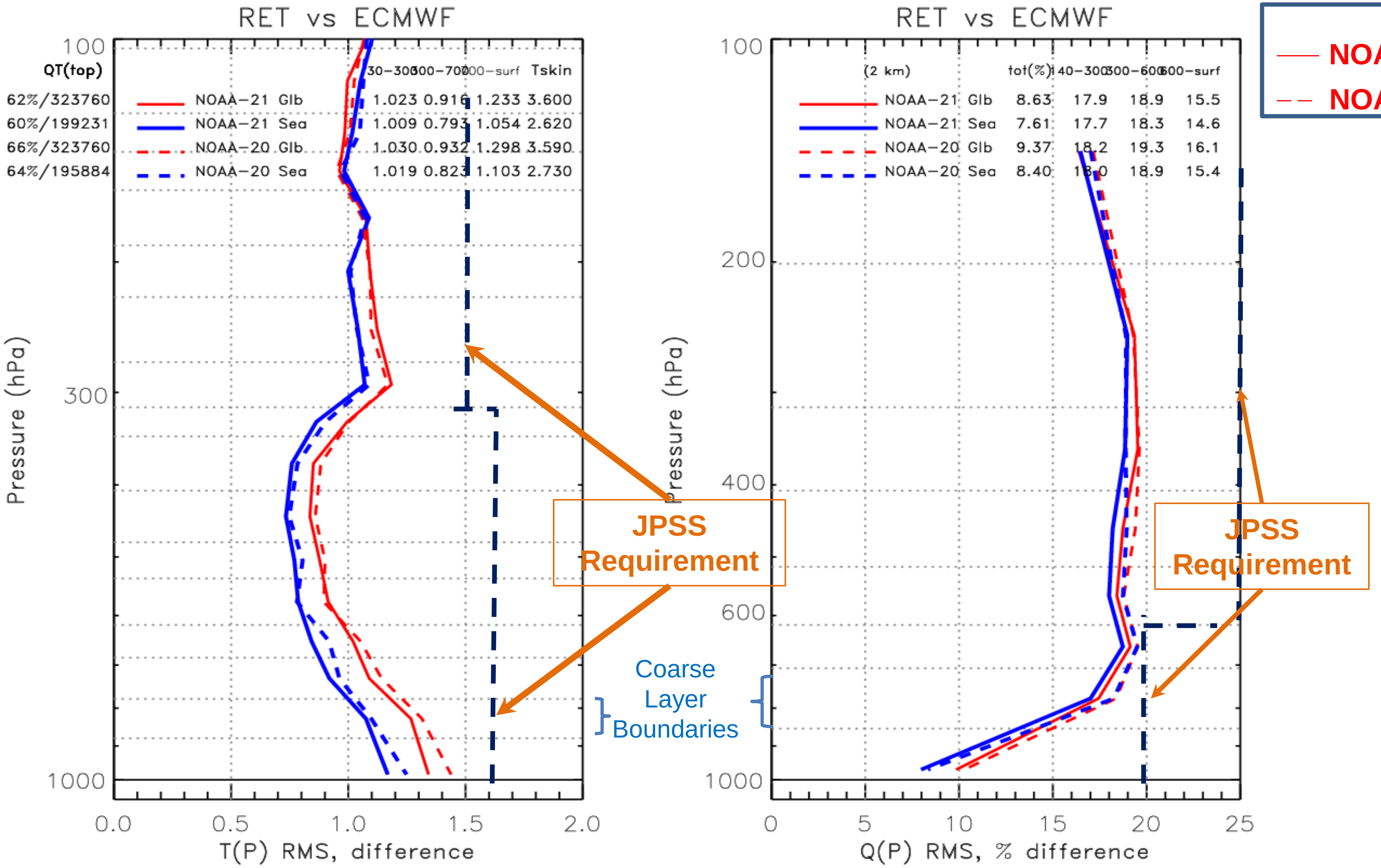
NOAA-20 V3.2







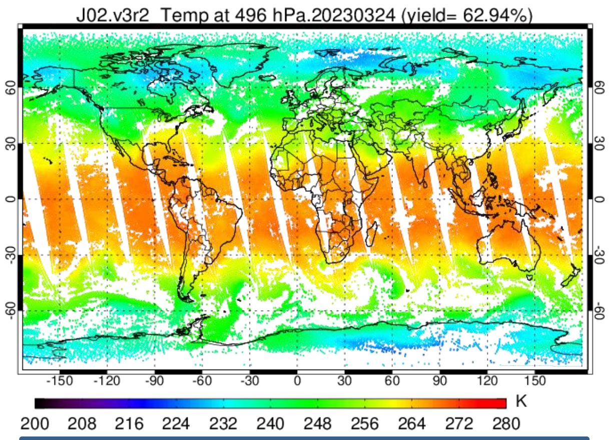
NUCAPS EDR retrievals from NOAA-21 Provisional algorithm matches very well both qualitatively and quantitatively with the NOAA-20 NUCAPS EDRs. The algorithm produces vertical profiles of temperature, water vapor, O_3, OLR, CO, CH_4, and CO_2. Retrieved profiles (100 layers) span from surface to 0.01 hPa.



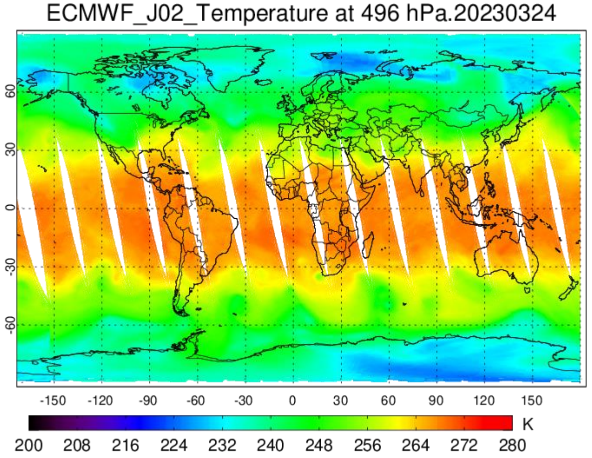
NOAA-21 Global — NOAA-21 Sea-only

NOAA-20 Global — NOAA-20 Sea-only

NOAA-21 Ret Temp at 500 hPa

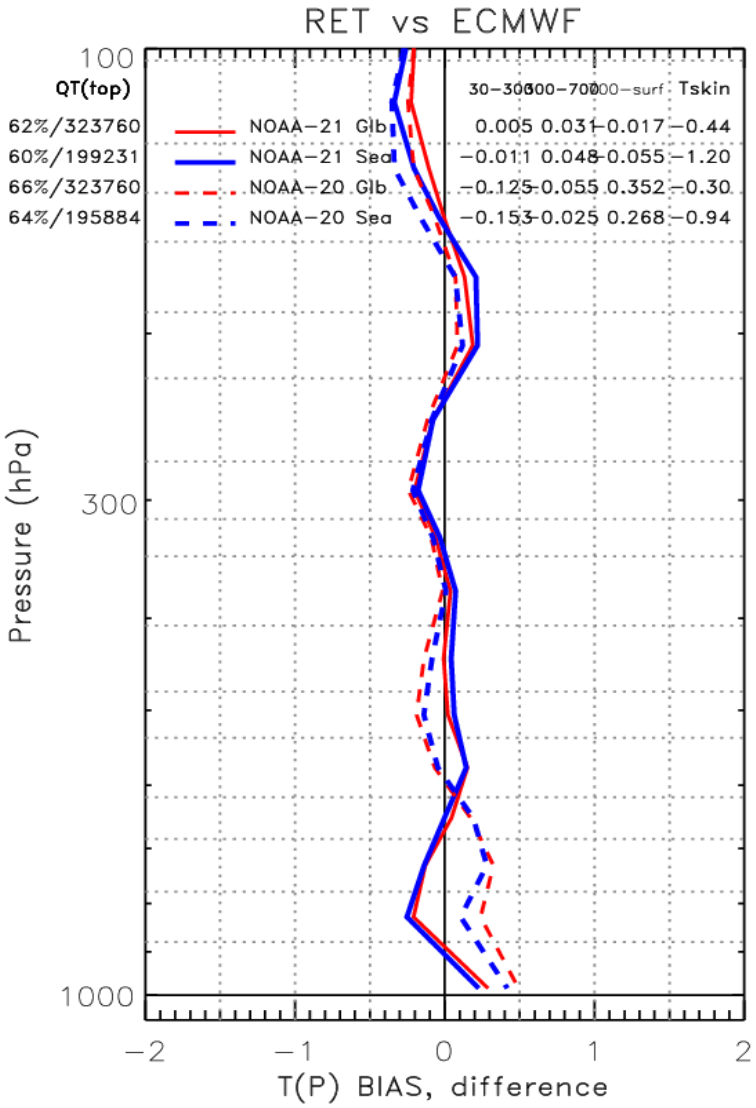


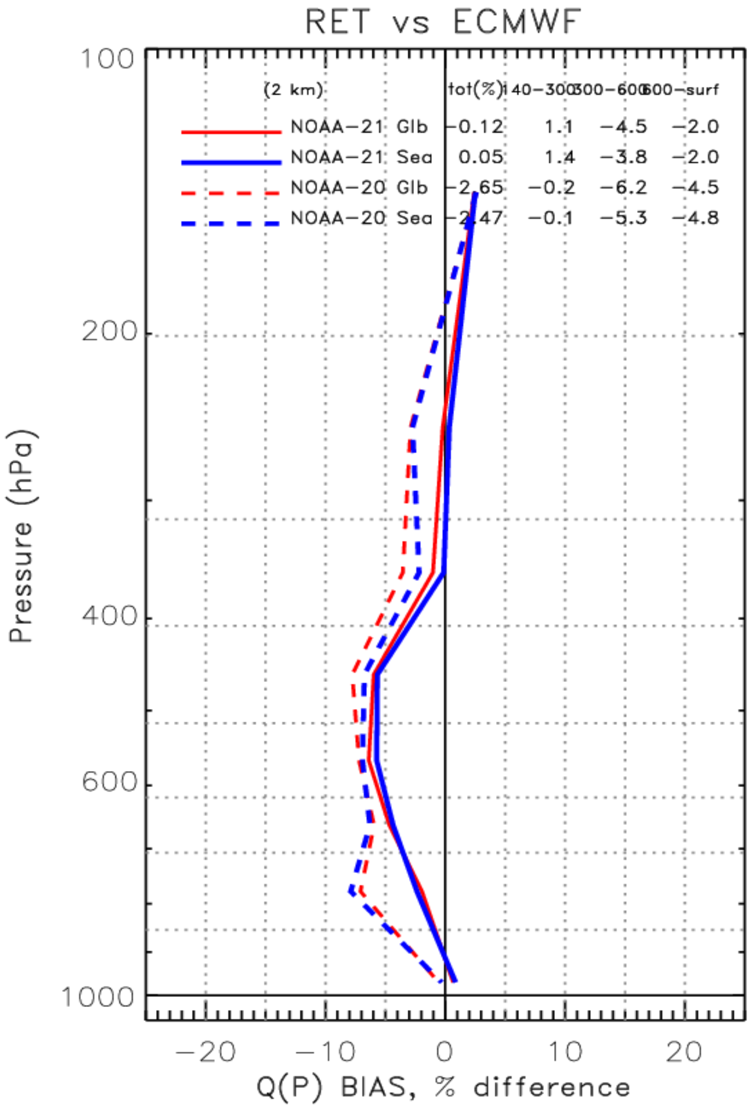
ECMWF Temp at 500 hPa



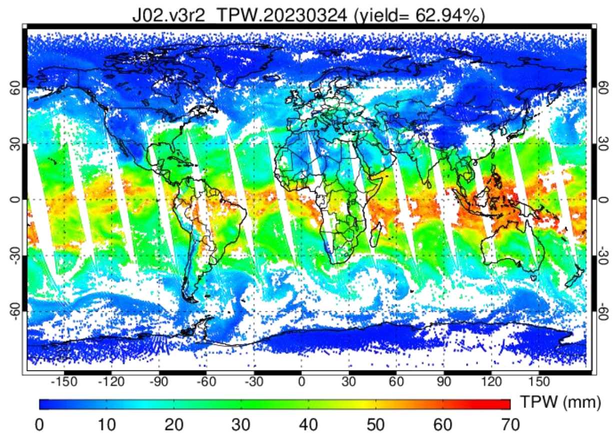
NOAA-21 AVTP & AVMP show good agreement with NOAA-20 and reveals a marginal improvement in RMS difference with ECMWF

NOAA-21 Global — NOAA-21 Sea-only
NOAA-20 Global — NOAA-20 Sea-only

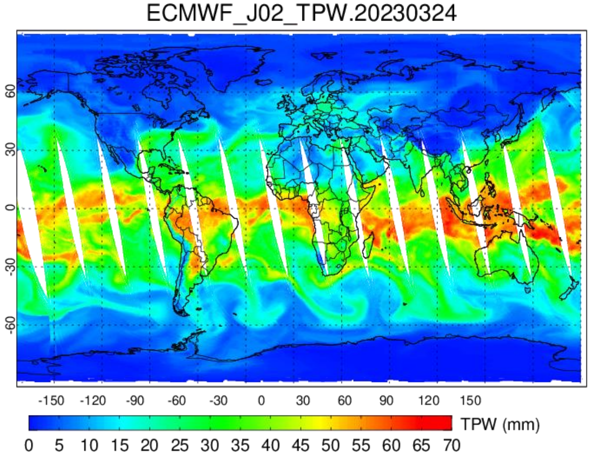




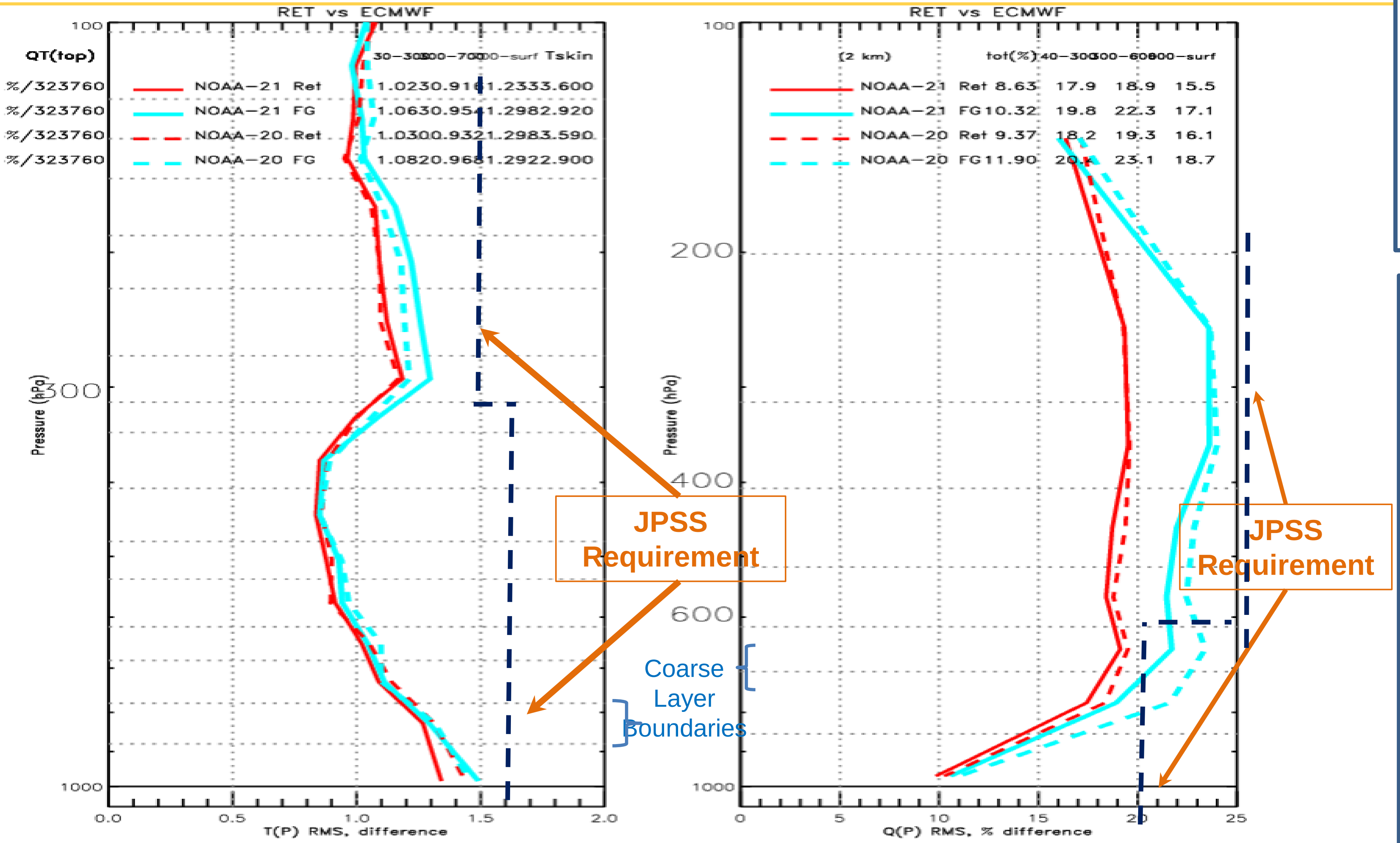
NOAA-21 Computed TPCW (mm)



ECMWF TPCW (mm)



NOAA-21 AVTP & AVMP show good agreement with NOAA-20 and reveals a marginal improvement in Bias with ECMWF



NOAA-21 Global Ret
NOAA-21 Global FG

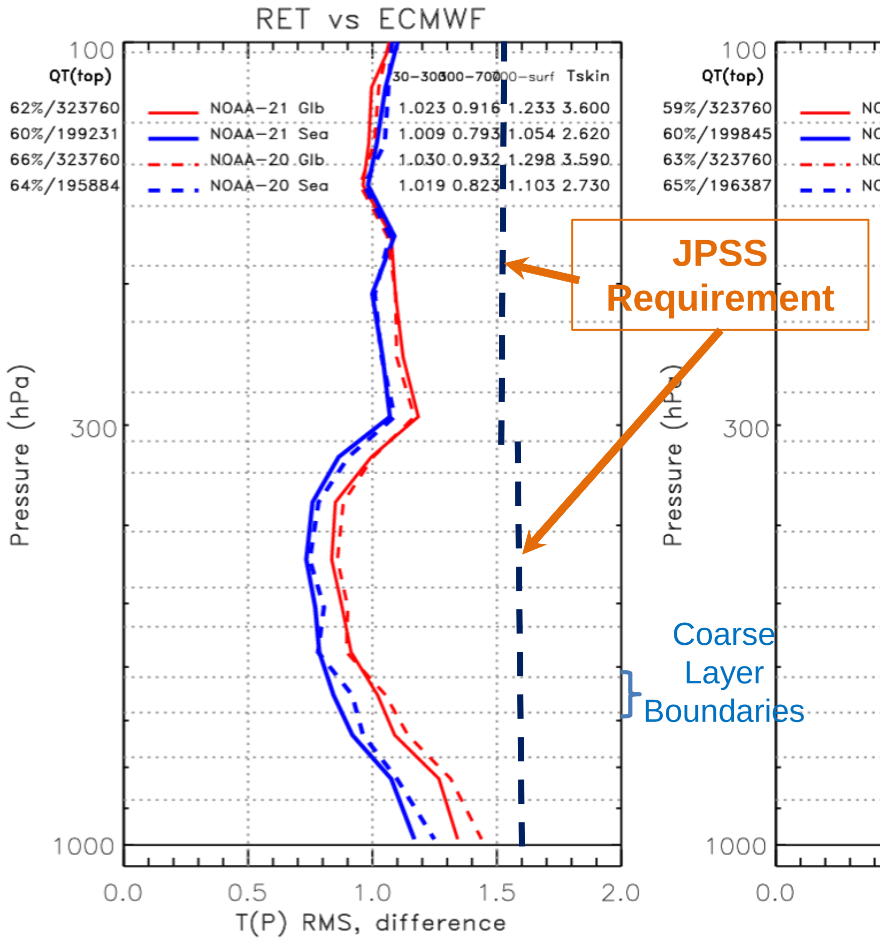
NOAA-20 Global Ret
NOAA-20 Global FG
Provisional Maturity

- NUCAPS algorithm uses cloudy and clear PC regression to generate the first guess of AVTP and AVMP for the final physical retrieval.
- NOAA-21 cloudy and clear regression LUTs are derived using 5 focus days spanning around the year to capture seasonality (20230227, 20230417, 20230619, 20230719, 20231016).

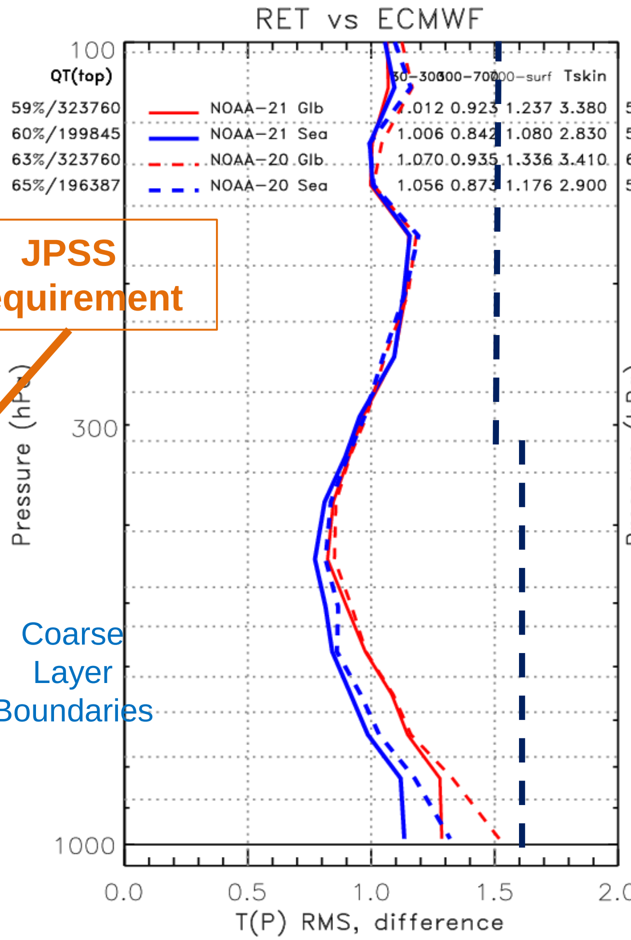
NOAA-21 AVTP & AVMP physical retrieval vs First Guess

JPSS NOAA NASA

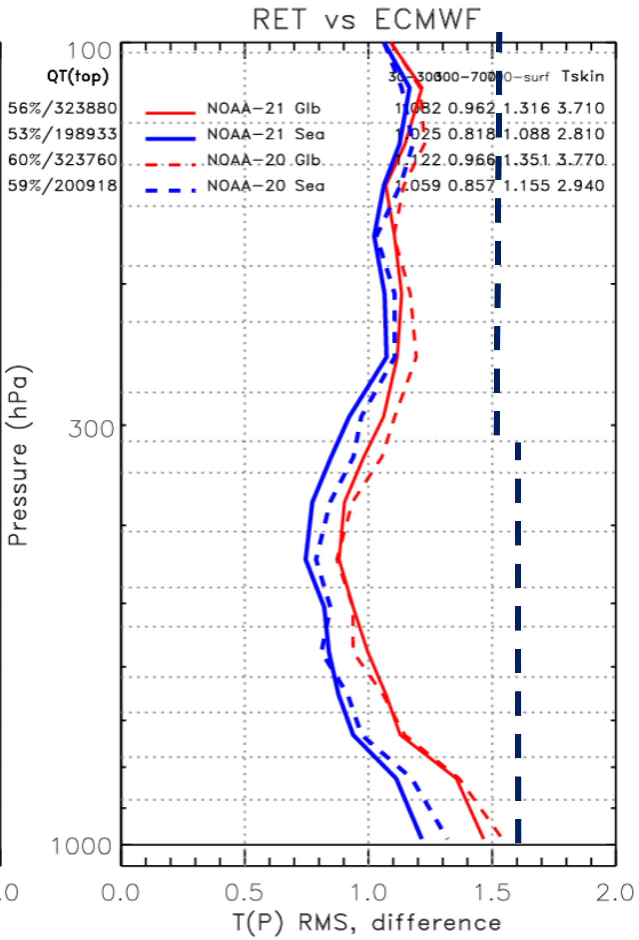
24 Mar 2023



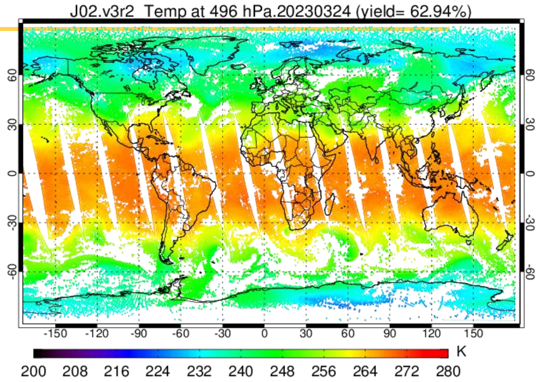
21 Sep 2023



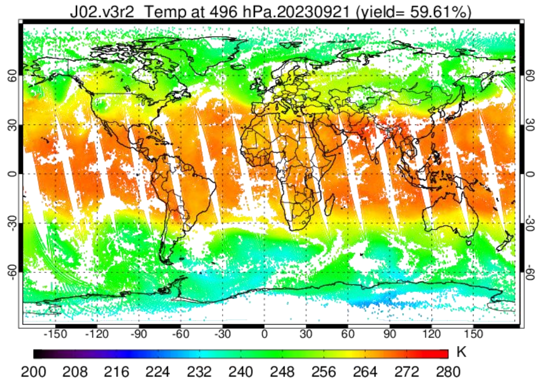
18 Dec 2023



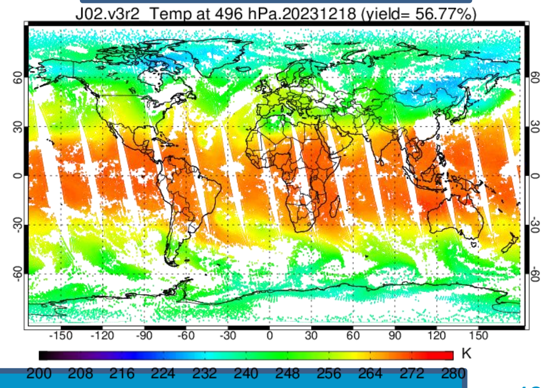
NOAA-21 24 Mar 2023



NOAA-21 21 Sep 2023



NOAA-21 12 Dec 2023



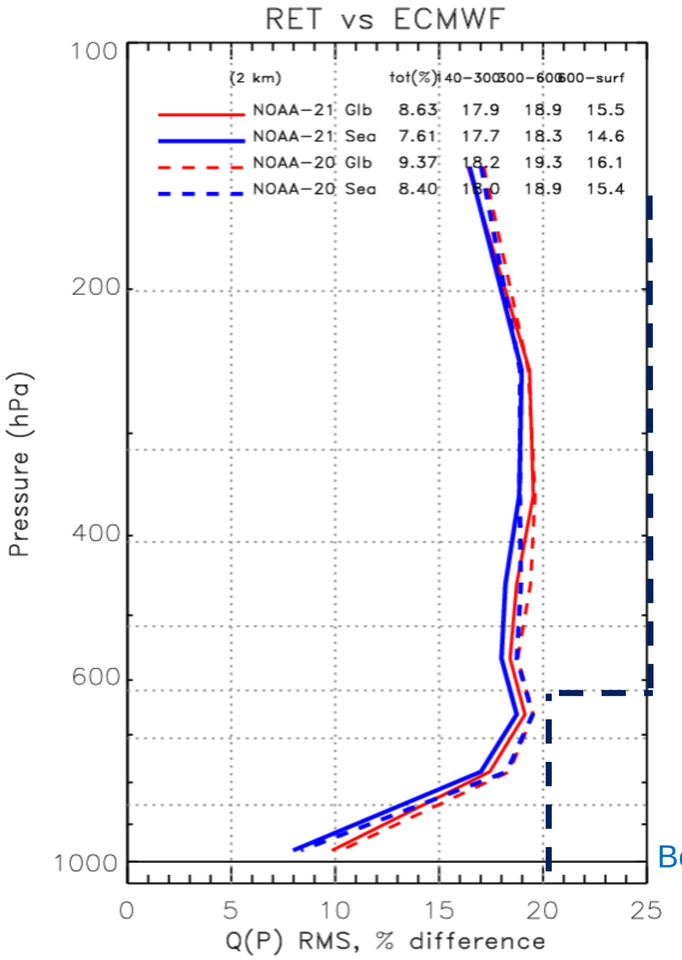
NOAA-21 Global — **NOAA-21 Sea-only**

NOAA-20 Global — **NOAA-20 Sea-only**

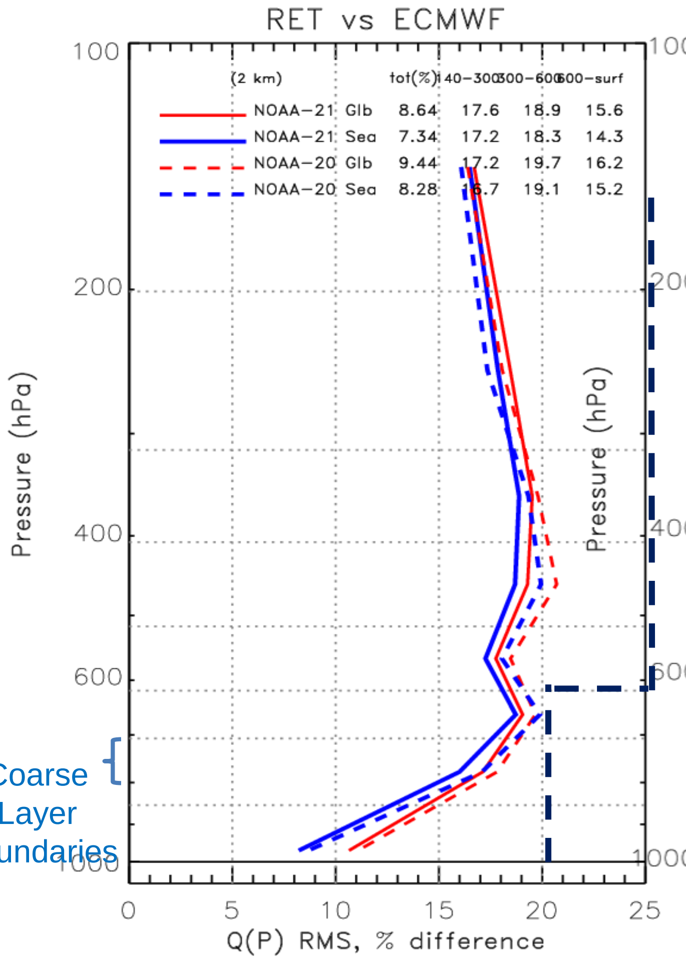
NOAA-21 AVTP show good agreement with NOAA-20 and reveals a marginal improvement in RMS difference with ECMWF

JPSS NOAA NASA

24 Mar 2023

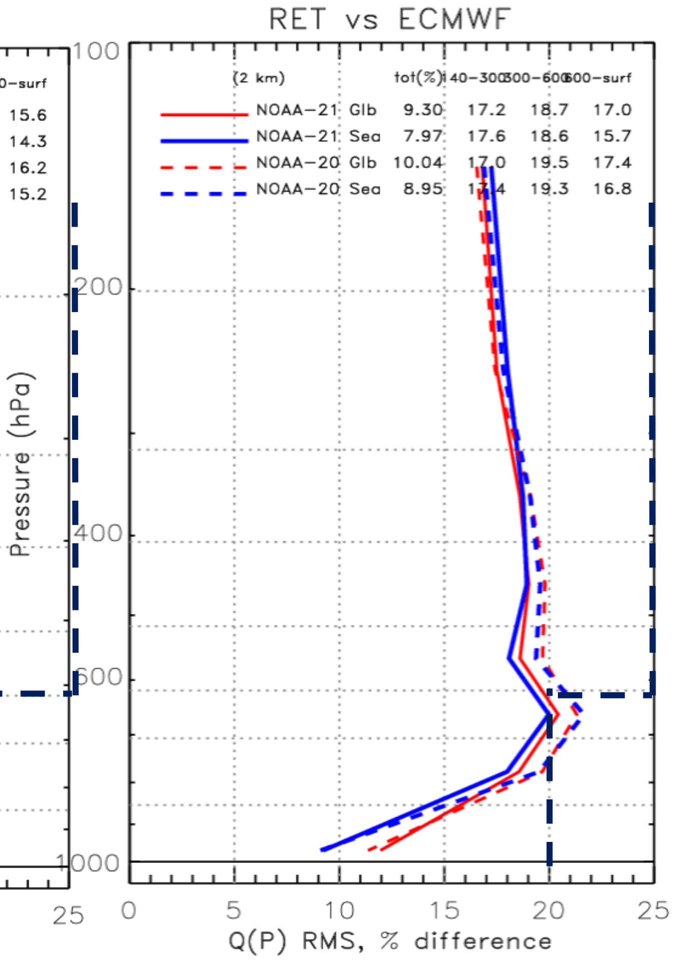


21 Sep 2023

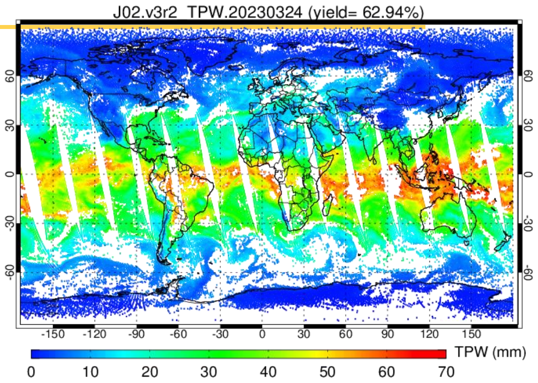


Coarse Layer Boundaries

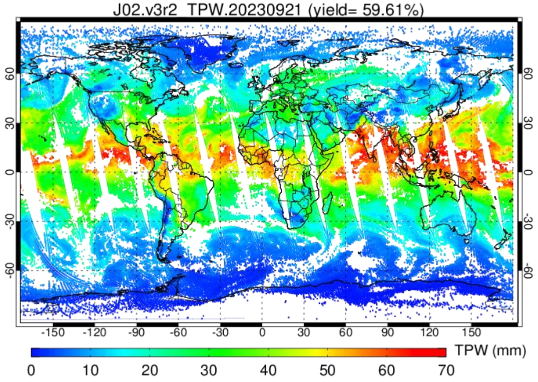
18 Dec 2023



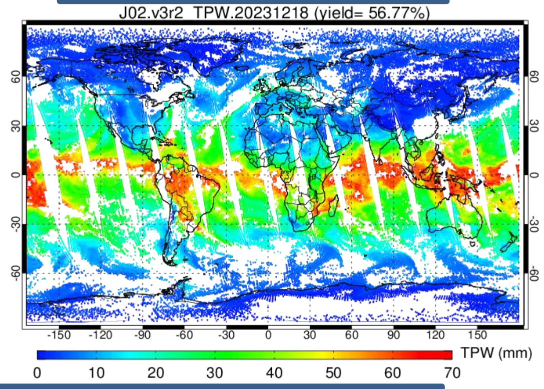
NOAA-21 24 Mar 2023



NOAA-21 21 Sep 2023



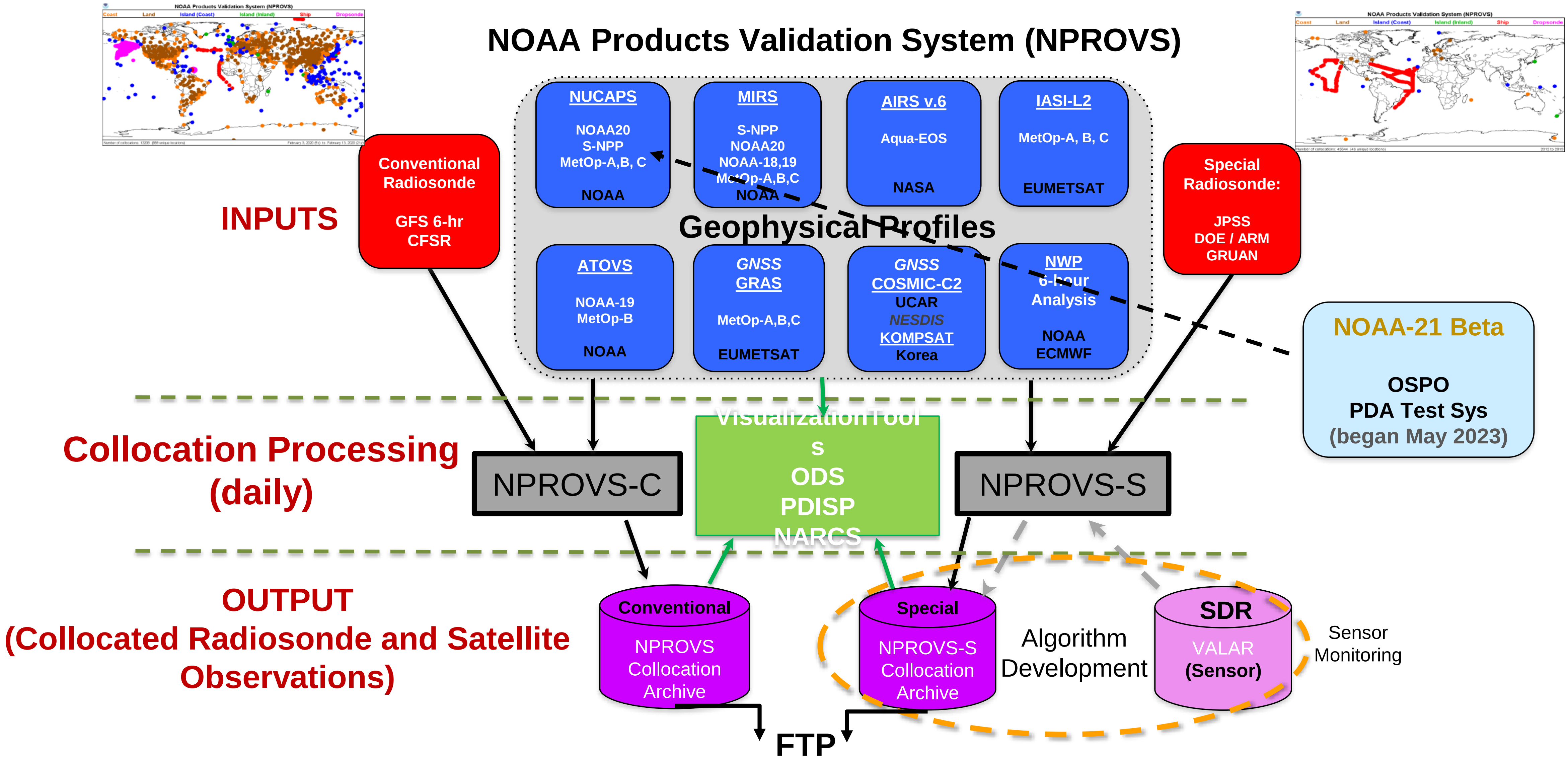
NOAA-21 12 Dec 2023



—— NOAA-21 Global —— NOAA-21 Sea-only
– – NOAA-20 Global – – – NOAA-20 Sea-only

NOAA-21 AVMP show good agreement with NOAA-20 and reveals a marginal improvement in RMS difference with ECMWF

AVTP, AVMP VALIDATIONS WITH GLOBAL RAOBS



https://www.star.nesdis.noaa.gov/smcd/opdb/nprovs/

Yields (%) of Successful NUCAPS "*IR+MW*" and "*MW-only*" Sounding for the 3-Focus Days

Sept 21 2023

NOAA21 v3.2
- Total retrievals: 323760
- **IR+MW yield: 59.6** ***(57.7, v3.1b)***
- MW-only yield: 37.2
- Both Fail: 3.2

NOAA20 v3.2
- Total retrievals: 323760
- **IR+MW yield: 63.6** ***(63.5, v3.1b)***
- MW-only retrieval: 33.2
- Both Fail: 3.2

Dec. 18 2023

NOAA21 v3.2
- Total retrievals: 323880
- **IR+MW yield: 56.8**
- MW-only yield: 40.4
- Both Fail: 2.8

NOAA20 v3.2
- Total retrievals: 323760
- **IR+MW yield: 60.7**
- MW-only yield: 36.5
- Both Fail: 2.8

March 24 2023

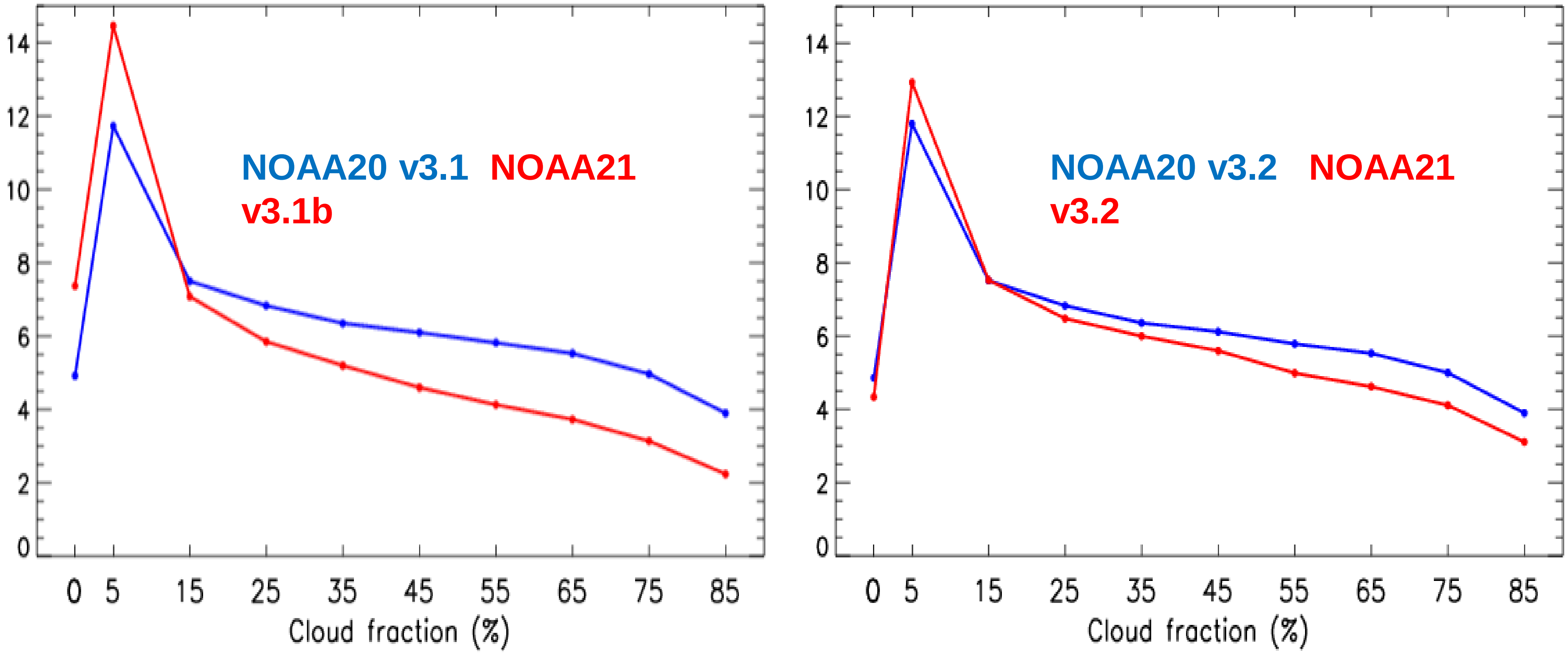
NOAA21 v3.2
- Total retrievals: 323760
- **IR+MW yield: 62.9**
- MW-only yield: 34.1
- Both Fail: 3.0

NOAA20 v3.2
- Total retrievals: 323760
- **IR+MW yield: 66.9**
- MW-only yield: 30.0
- Both Fail: 3.1

N21v3.2 on average has 4% lower IR+MW yield than N20v3.2

MetOp-C (not shown) has about 7-10% lower IR+MW yield than N20v3.2

PDF of IR+MW Pass QC vs Effective Cloud Faction 9/21/23

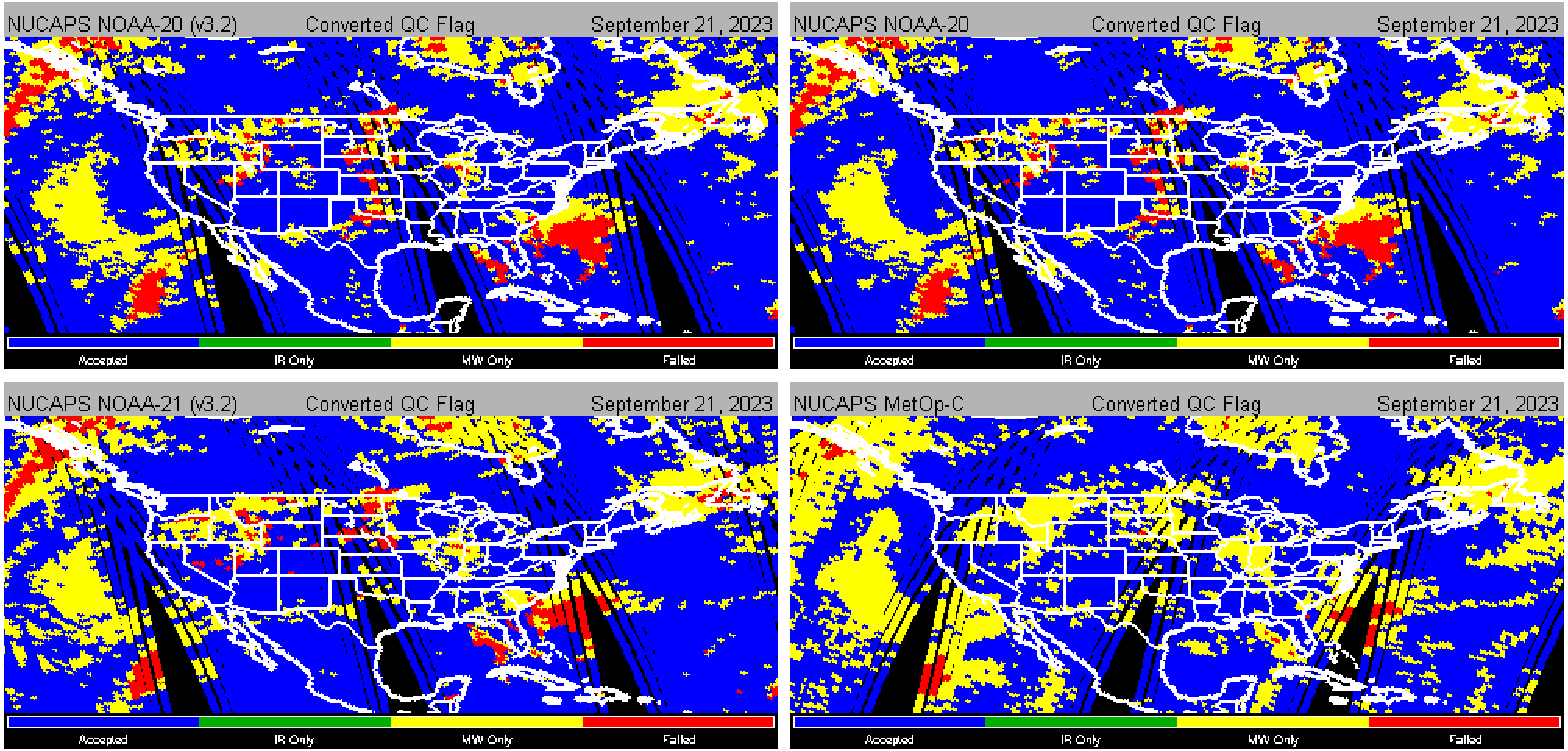


PDF's more similar for v3.2 (right) compared to v3.1 (left)

Sept 21

N20
V3.2
2PM

N20
Oper
2PM

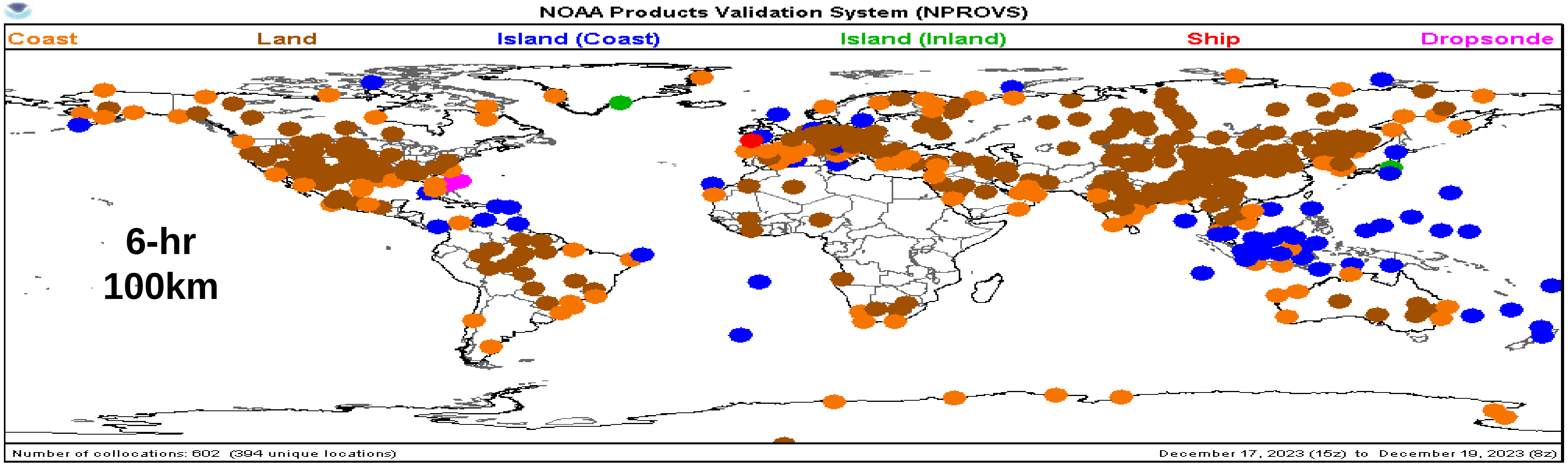


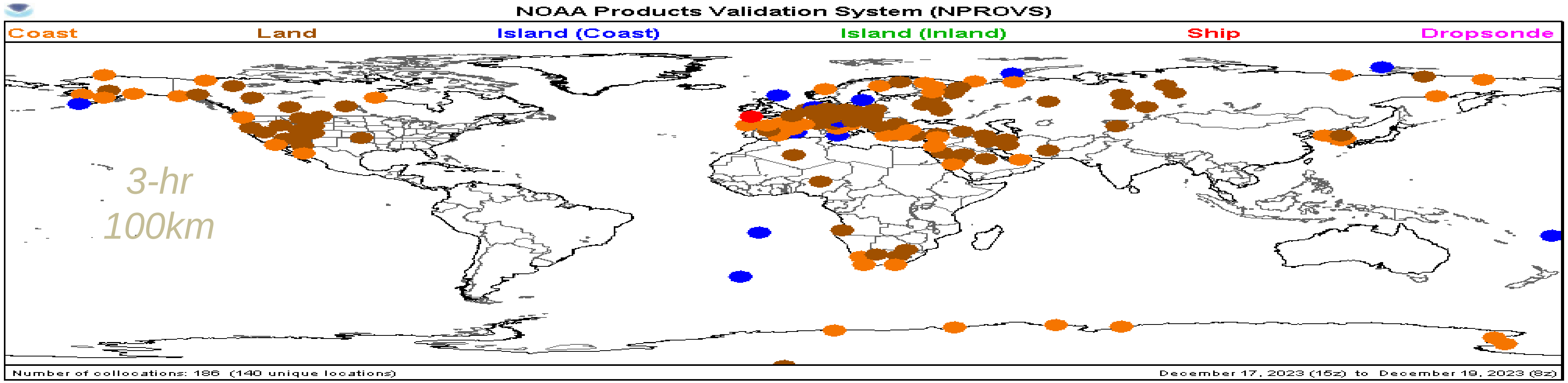
N21
v3.2
230 PM

MetOp-C
V3.2
10AM

IR+MW Pass **MW-only Pass** **Both Fail**

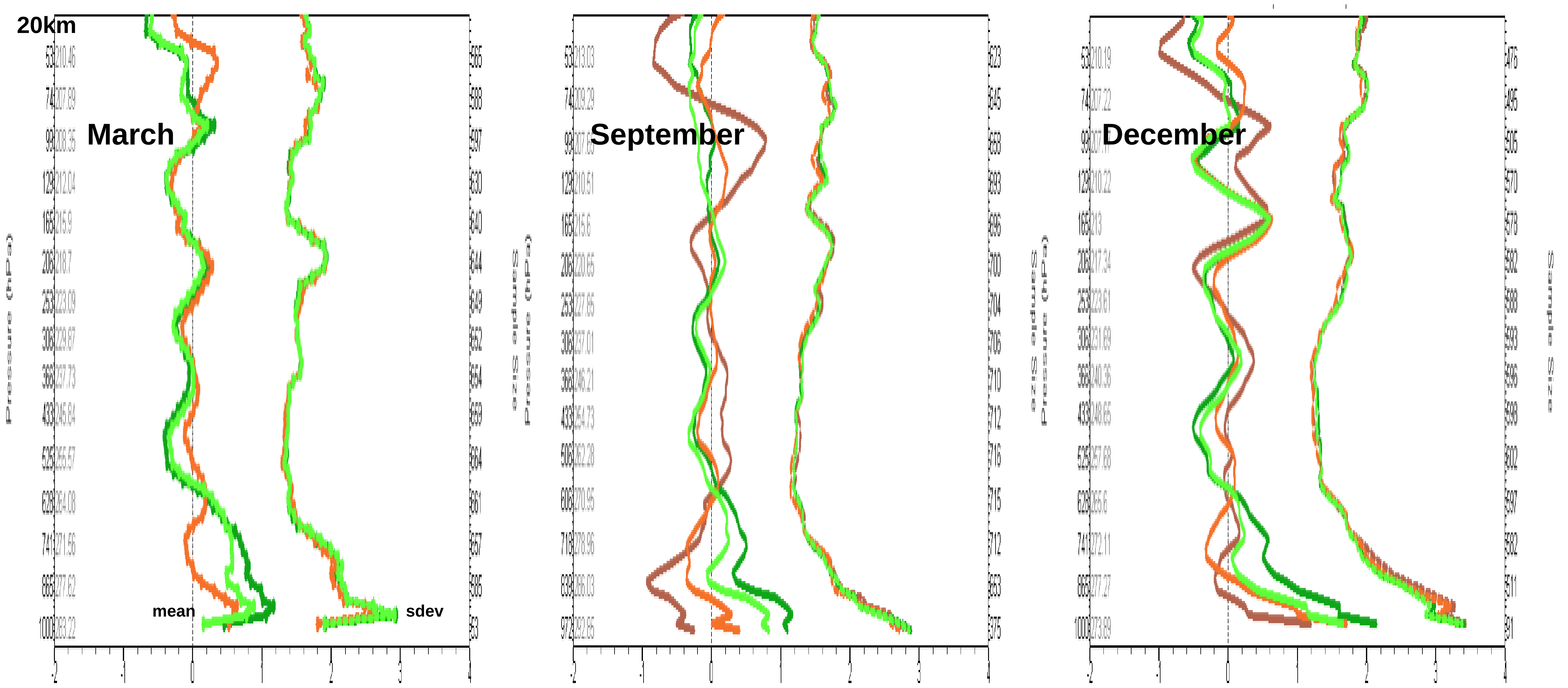
*





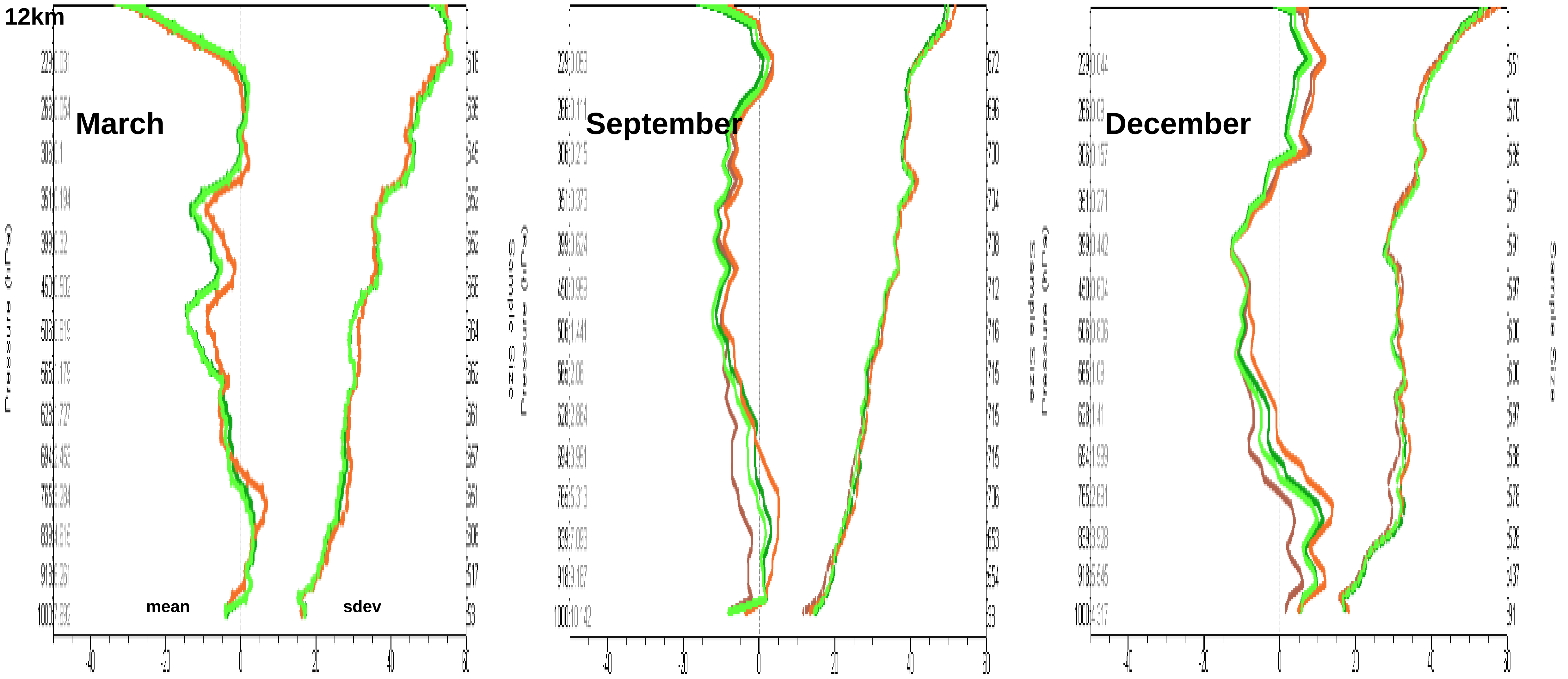
Collocated Raob and NUCAPS (IR+MW pass qc) for:

N20Oper N20v3.2 N21Beta N21v3.2



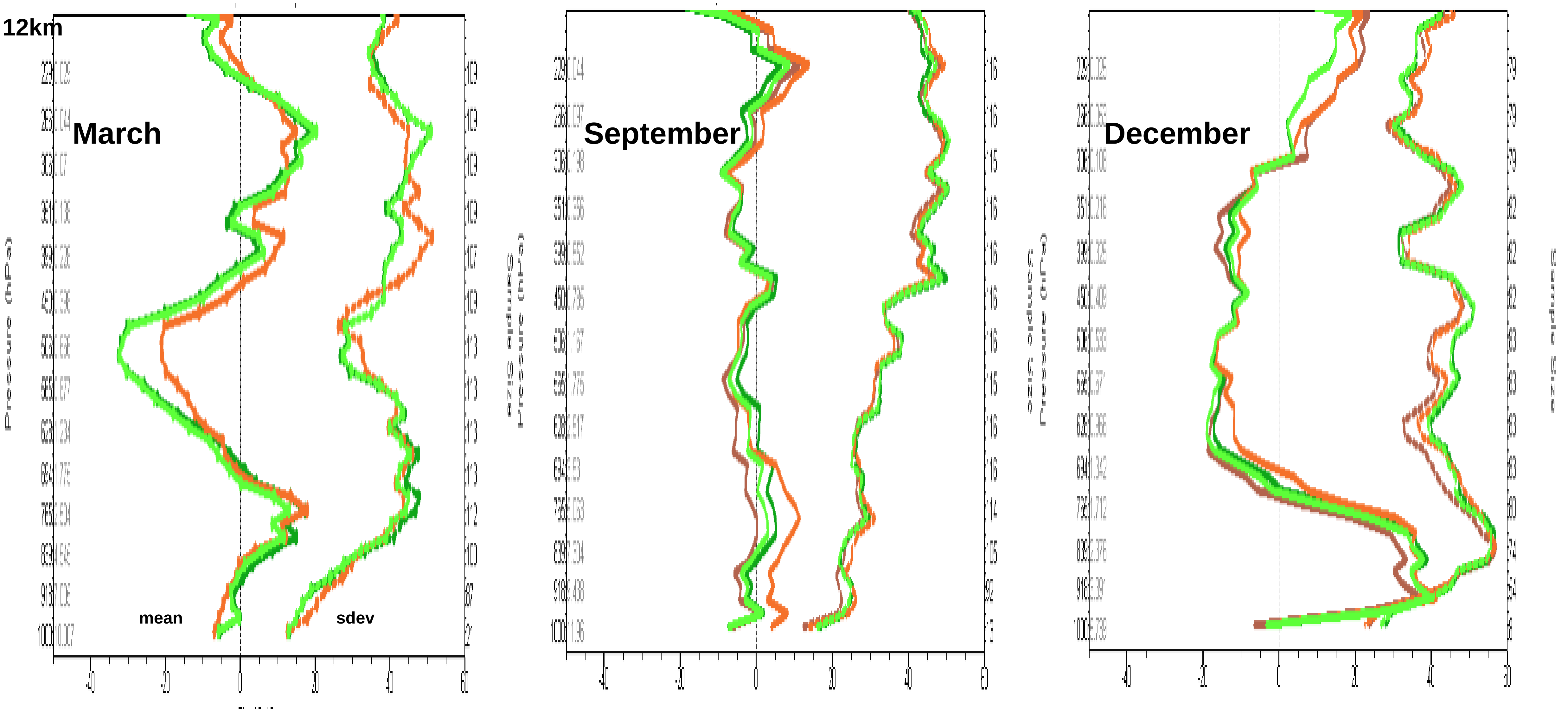
NUCAPS NOAA 20 Oper NUCAPS NOAA-20v3.2 NUCAPS NOAA-21 Beta NUCAPS NOAA-21 v3.2

Global: Temperature 100 Layers 6-hr



NUCAPS NOAA 20 Oper   NUCAPS NOAA-20v3.2   NUCAPS NOAA-21 Beta   NUCAPS NOAA-21 v3.2

Global: H20 Vapor Fraction (%) 100 Layers 6-hr



NUCAPS NOAA 20 Oper NUCAPS NOAA-20v3.2 NUCAPS NOAA-21 Beta NUCAPS NOAA-21 v3.2

CONUS: H20 Vapor Fraction (%) 100 Layers 6-hr

Summary

- NPROVS validation of NOAA-21 EDR Sounding using collocated Radiosonde and Satellite Observations from three Focus Days (March 24, September 21, December 18); *100 Layers*

- N21v3.2 appears overall compatible to N20v3.2, slightly better for Temperature and close for H20 vapor fraction; *improved compatibility with MetOp-C*

- The IR+MW yield for NOAA-21v3.2 is ~4% less than that for NOAA20v3.2.

- Recommend NOAA-21 (**and NOAA-20**) v3.2 suitable for operational implementation

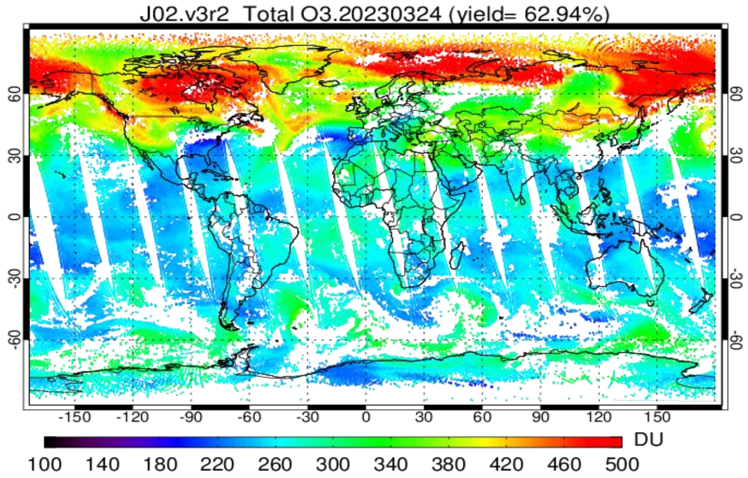
JPSS Specification Performance Requirements
CrIS Trace Gas EDR Uncertainty (O_3, CO, CO_2, CH_4)

	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

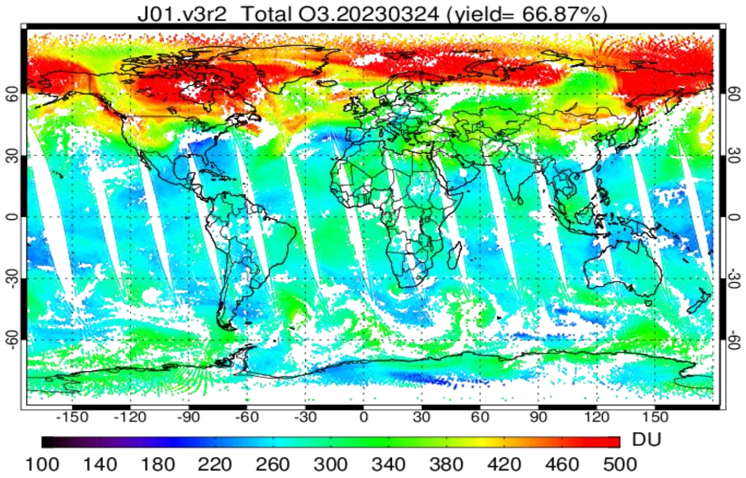
Source:
(L1RD, 2014, pp. 45-49)

NUCAPS Ozone Product Evaluations with ECMWF

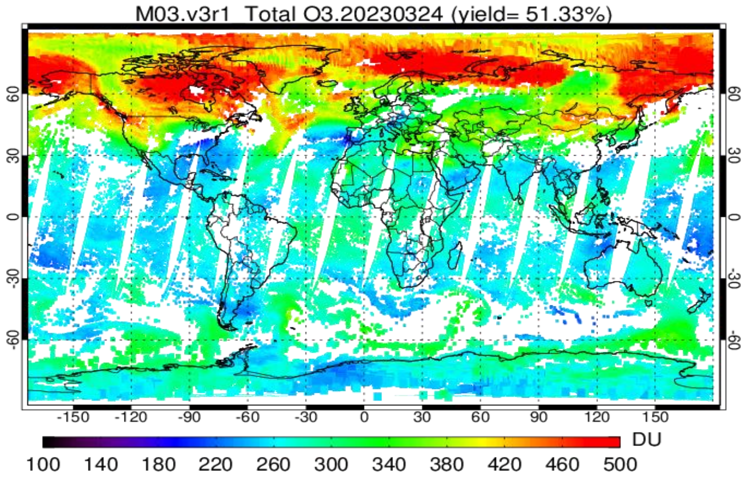
NOAA-21 (Provisional) v3.2



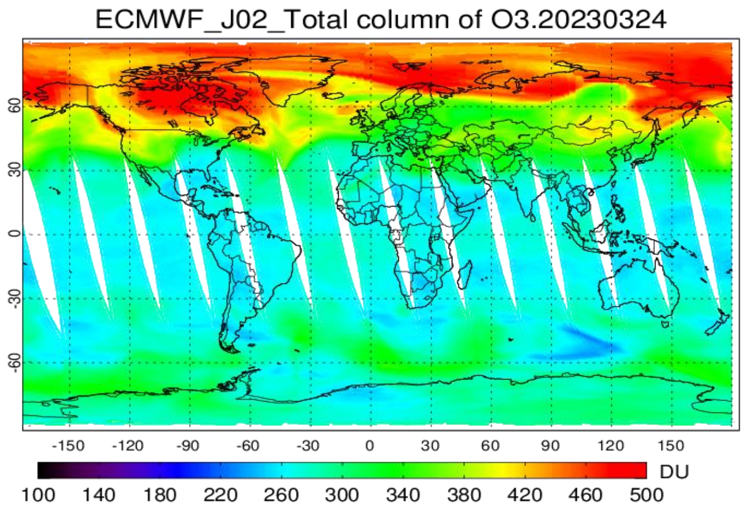
NOAA-20 v3.2



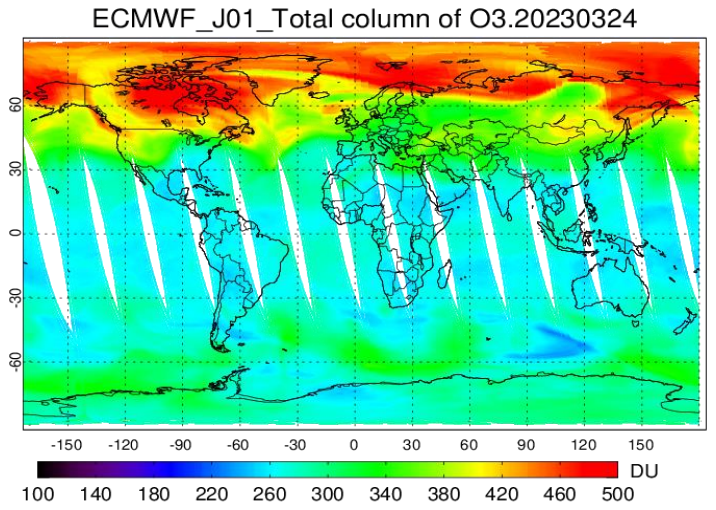
MetOp-C Operational



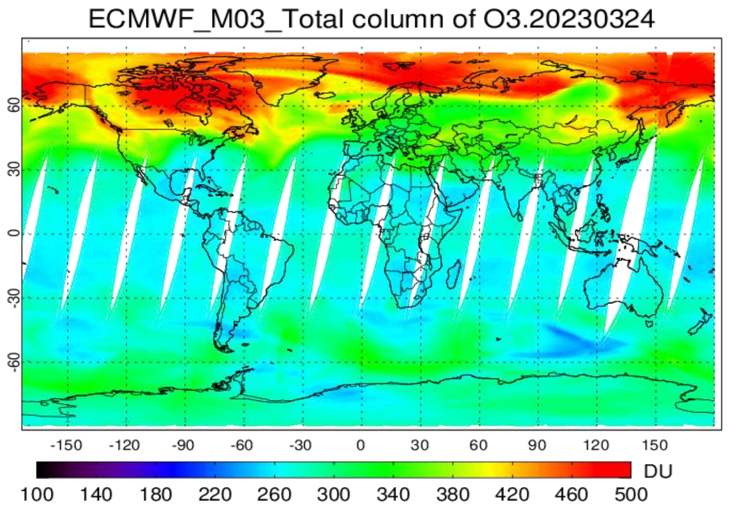
ECMWF

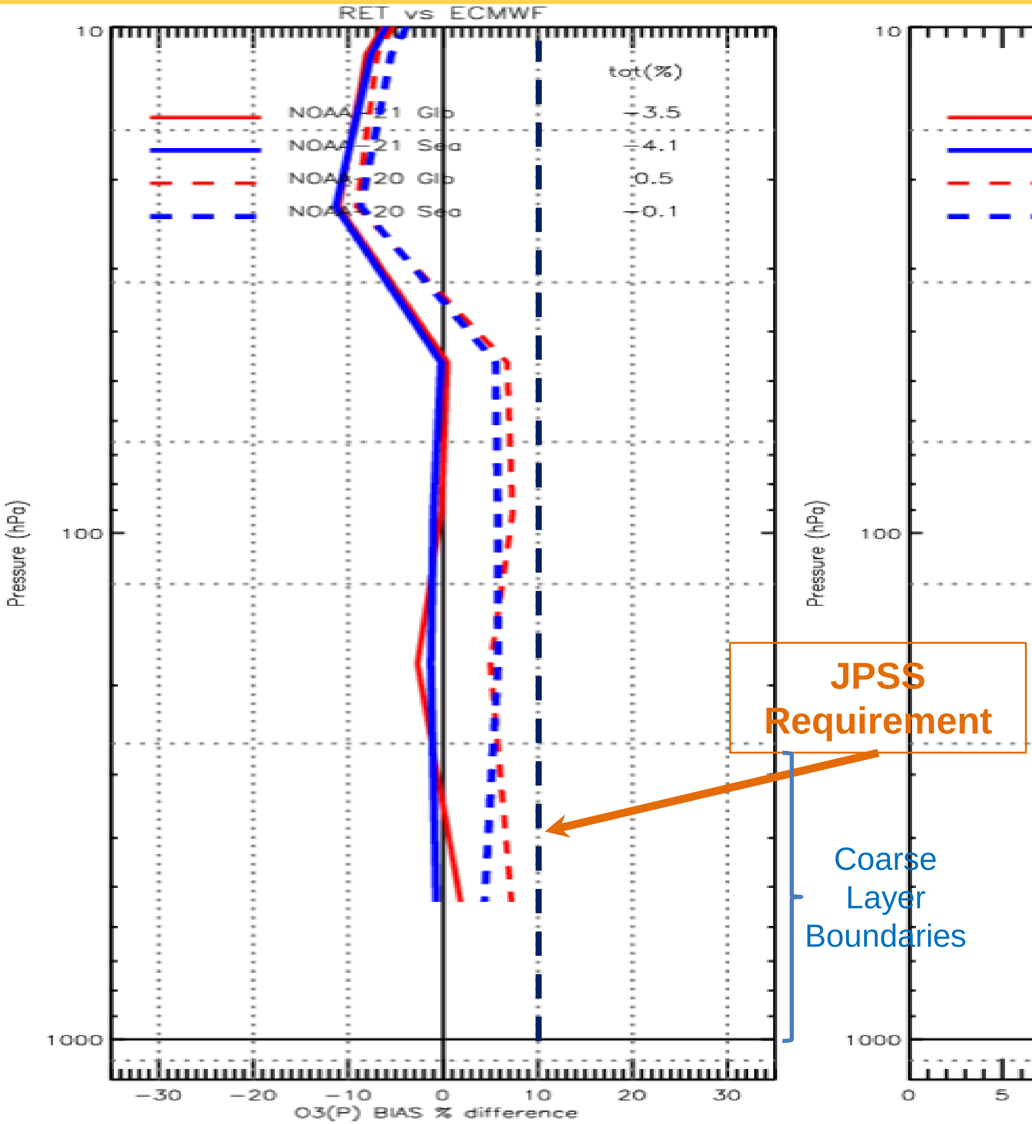


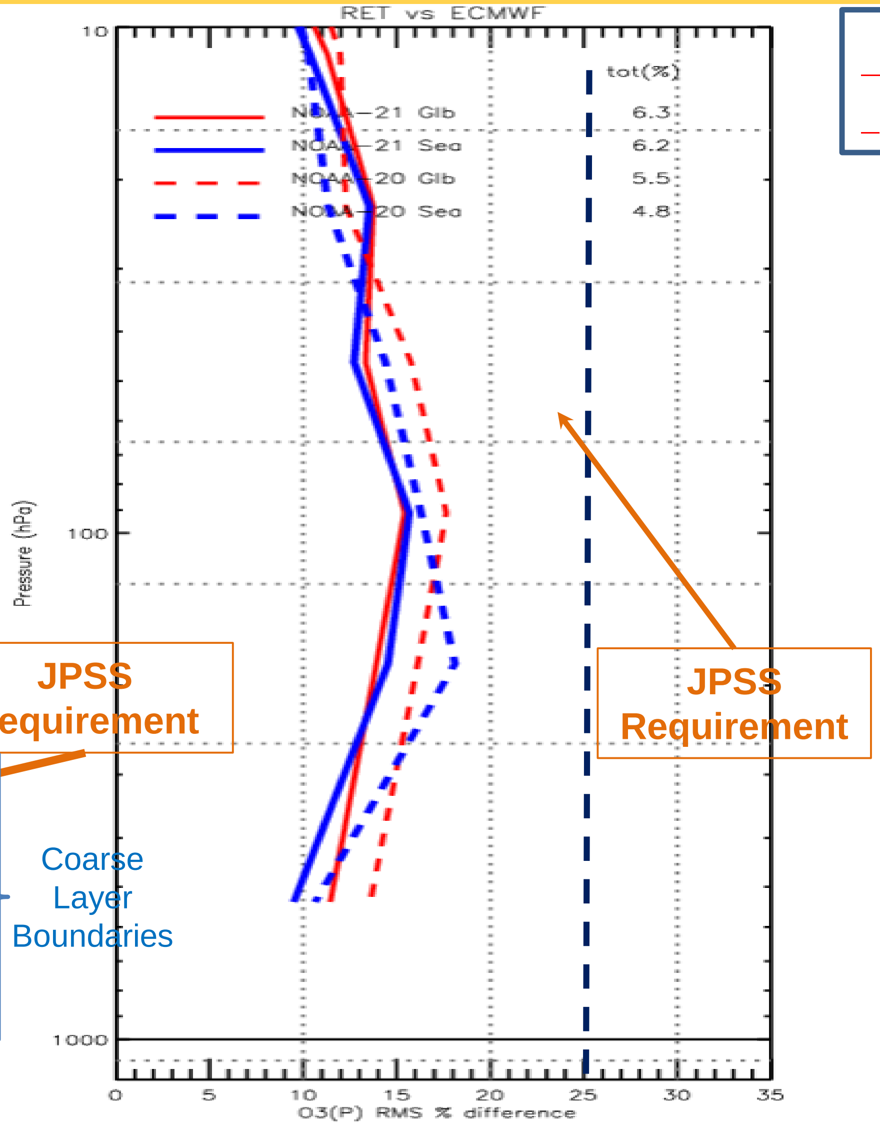
ECMWF



ECMWF



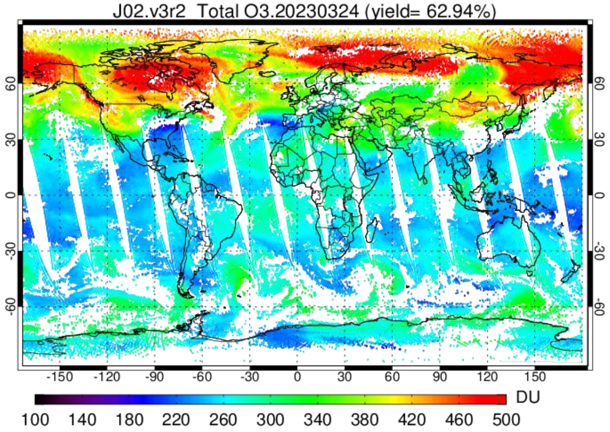




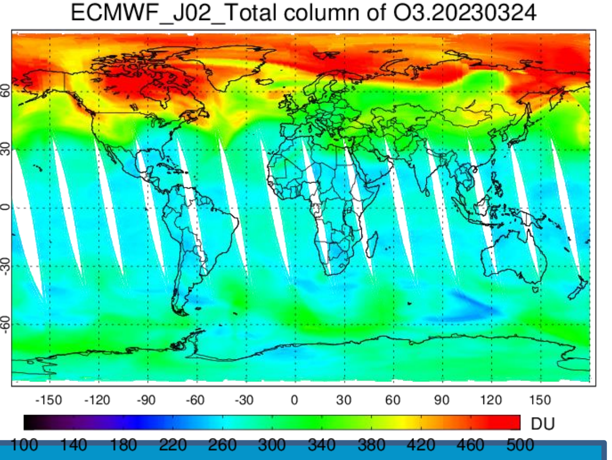
NOAA-21 Global — NOAA-21 Sea-only

NOAA-20 Global - - - NOAA-20 Sea-only

NUCAPS Total Ozone (DU)

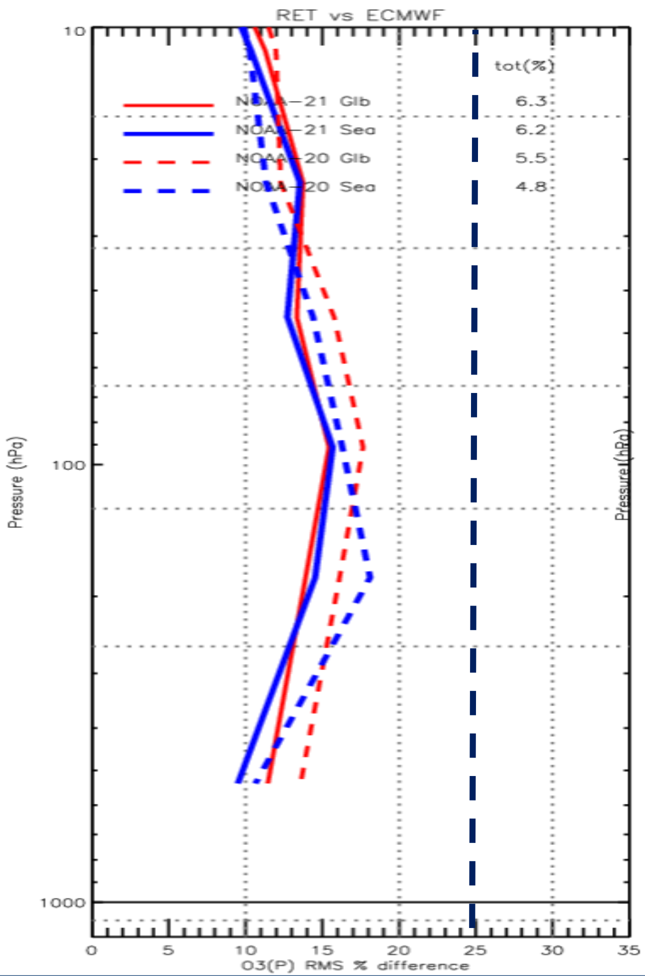


ECMWF Total Ozone (DU)

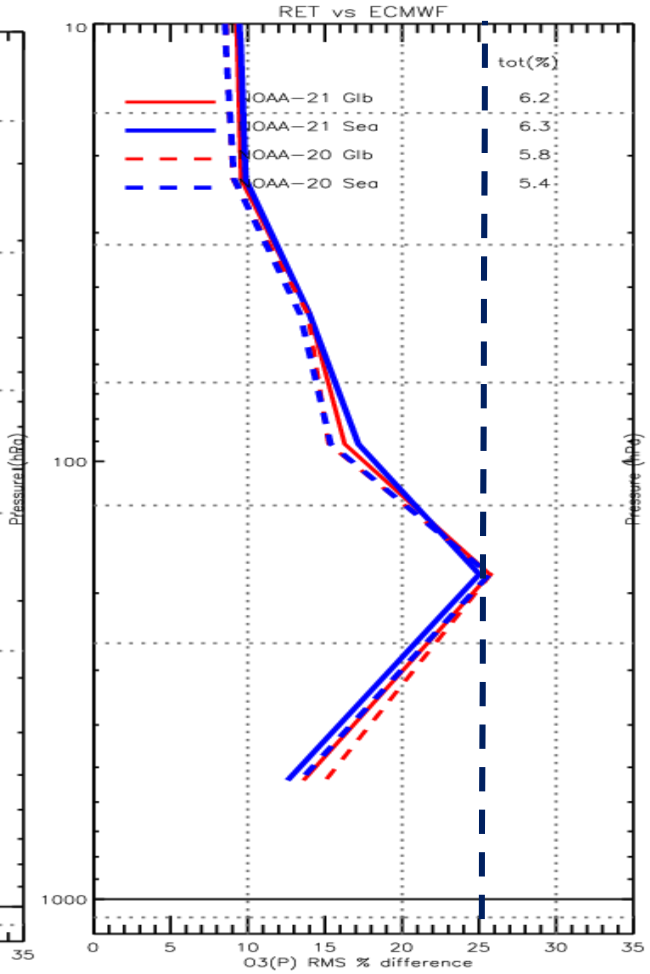


NOAA-21 Ozone shows good agreement with NOAA-20 and reveals a marginal improvement in Bias & RMS difference with ECMWF

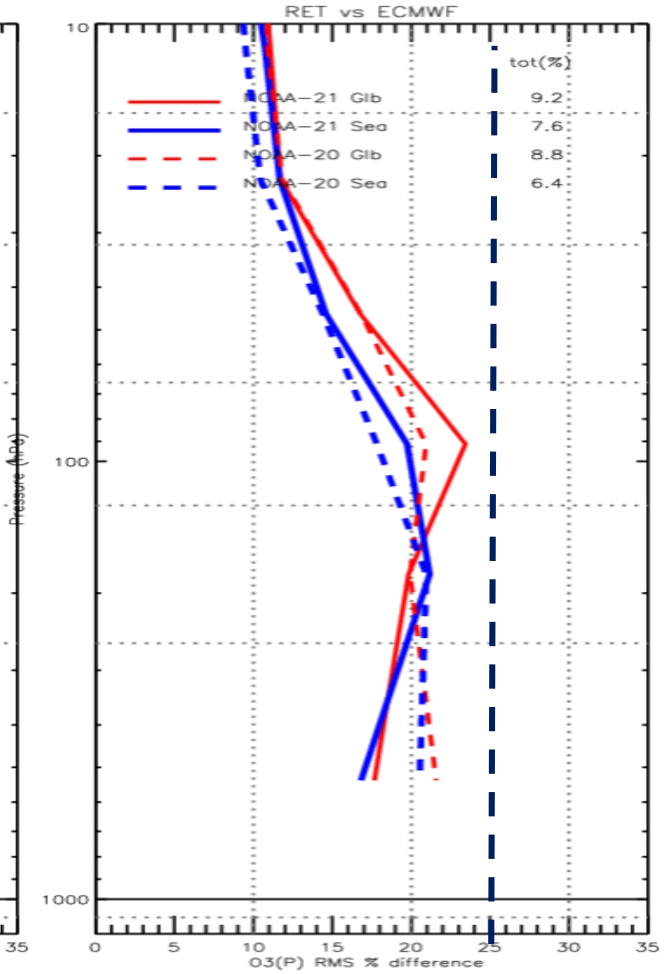
24 Mar 2023



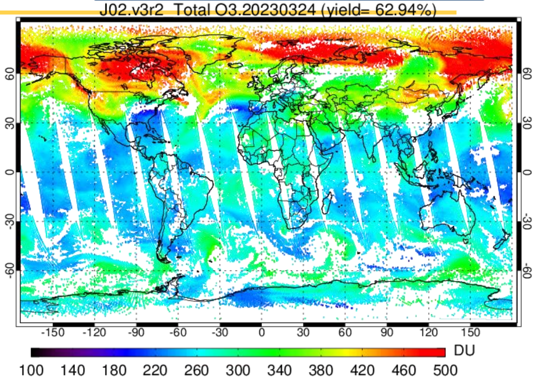
21 Sep 2023



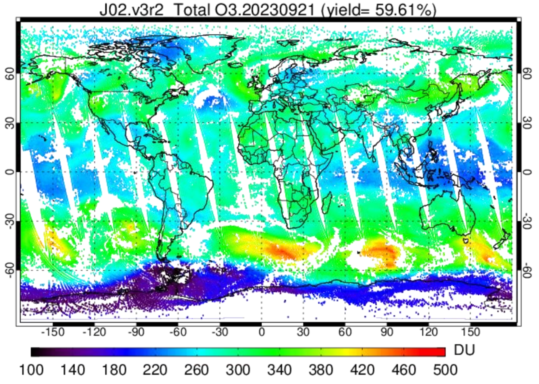
18 Dec 2023



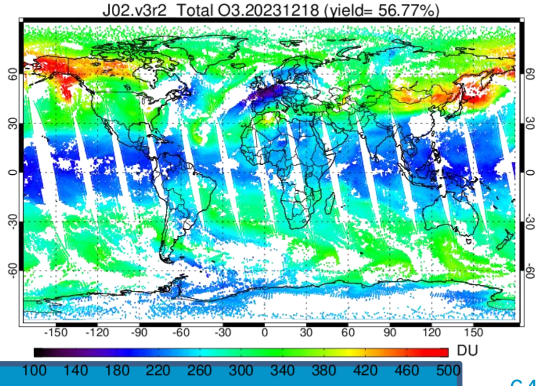
NOAA-21 24 Mar 2023



NOAA-21 21 Sep 2023



NOAA-21 12 Dec 2023



—— **NOAA-21 Global** —— **NOAA-21 Sea-only**

– – **NOAA-20 Global** – – – **NOAA-20 Sea-only**

NOAA-21 O_3 profiles show good agreement with NOAA-20 and reveals a marginal improvement in RMS difference with ECMWF

NUCAPS Ozone Retrieval Validation with GML O_3SNDs

- As part of NOAA-GML collaborations, performed many validations of NOAA-20 with NOAA-GML O3SNDS during Antarctica spring to summer transition (supplemental slides)
- NUCAPS NOAA-20 O3 retrievals match pretty well with NOAA-GML O3SNDS
- NOAA-21 and NOAA-20 O3 retrievals show very good agreement with each other, and as a ‘transfer standard’ prove NOAA-21 O_3 retrievals are good.
- In addition, validated NOAA-21/20 O_3 retrievals with NOAA-GML O_3SNDS over (a) Boulder, CO; and (b) South Pole

O_3 Profile Validation with NOAA-GML Ozonesondes

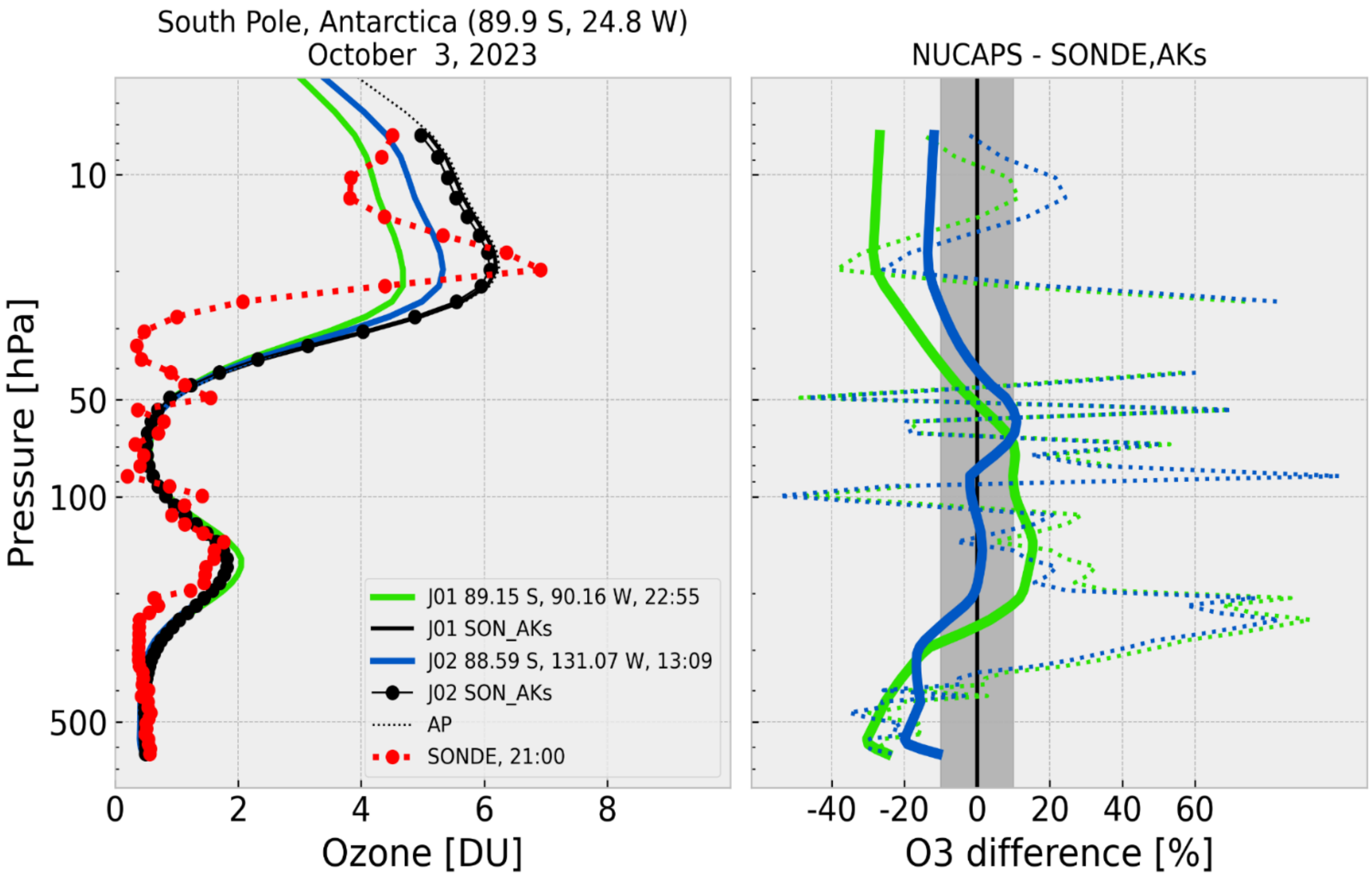
Focus Days	NOAA-20 (v3.2)	NOAA-21 (v3.2)	O_3SNDs Boulder, CO	O_3SNDs South Pole
07/17/2023	✔ Yes	✔ Yes	✔ Yes	✔ Yes
08/23/2023	✔ Yes	✔ Yes	✔ Yes	✔ Yes
09/12/2023	✔ Yes	✔ Yes	✔ Yes	✔ Yes
10/03/2023	✔ Yes	✔ Yes	✔ Yes	✔ Yes

- ✔ Validation of NUCAPS O_3 profiles over Boulder CO, and South Pole
- ✔ NOAA-GML team provided independent validations
- ✔ Thanks to:
  Irina Petropavlovskikh & Miyagawa Koji

Ozone Validations with NOAA-GML O_3SNDS

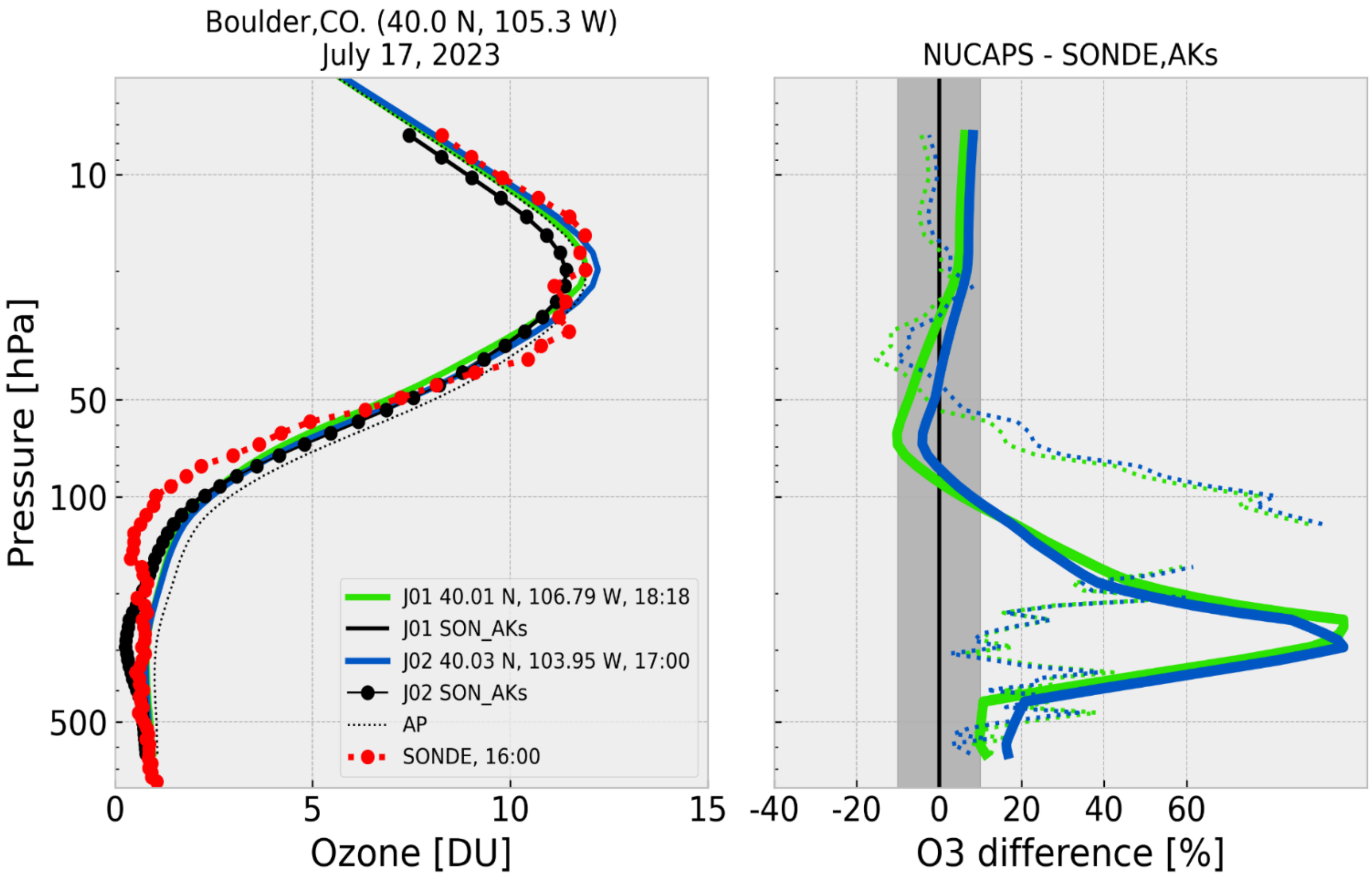
Irina Petropavlovskikh and Miyagawa Koji

NOAA-21/20 O3 Profile vs South Pole O_3SND: 3 Oct 2023



- Ozone hole conditions: co-located (+/- 1 degree latitude, +/- 50 degree longitude) NOAA-20 (green) and NOAA-21 (blue) ozone profiles show very good agreement with each other, including small differences due to ozone natural variability
- NUCAPS profiles also agree well between 200 and 50 hPa with the co-incident ozonesonde (red) launched from South Pole.
- The agreement is further improved after the 100-layer AK is applied to smooth ozonesonde high resolution profile (black). The bias is within +/-10 % between 300 and 30 hPa, which

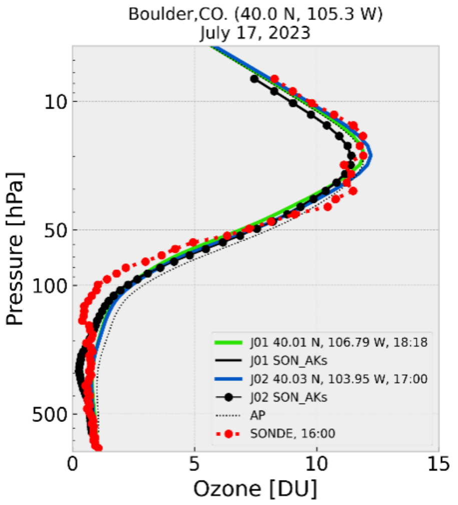
NOAA-21/20 O3 Profile vs Boulder, CO O_3SND: 17 Jul 2023

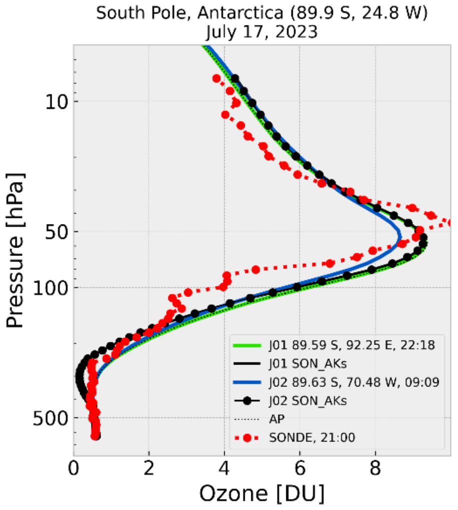


- Typical middle latitude: co-located (+/- 1 degree latitude, +/- 5 degree longitude) NOAA-20 (green) and NOAA-21 (blue) ozone profiles show very good agreement with each other,
- NUCAPS profiles also agree very well with the co-incident ozonesonde (red) launched from Boulder, CO.
- The agreement is further improved after the 100-layer AK is applied to smooth ozonesonde high resolution profile (black).
- The bias is within +/-10 % above 100 hPa.
- Larger bias below 100 hPa is due to limited sensitivity of the NUCAPS retrieval as defined by the AKs.

Boulder, CO (Top) and South Pole
Four Focus Days

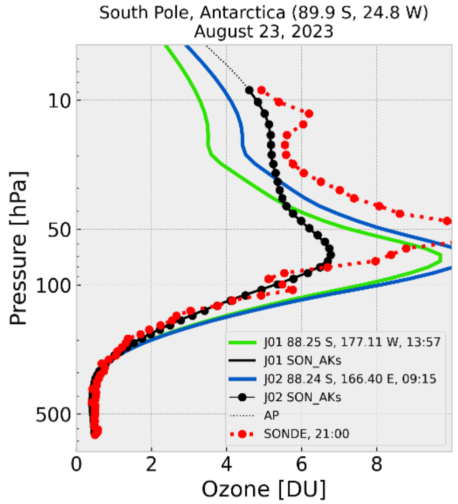
17 Jul 2023



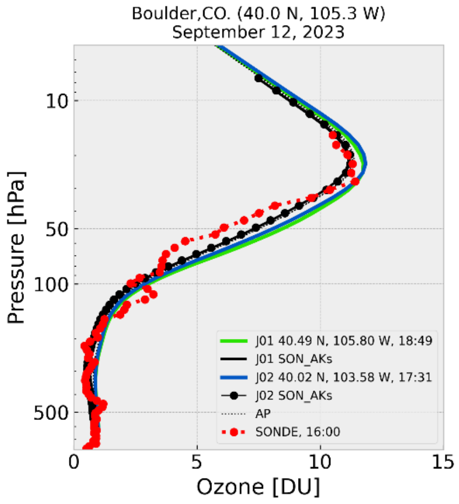


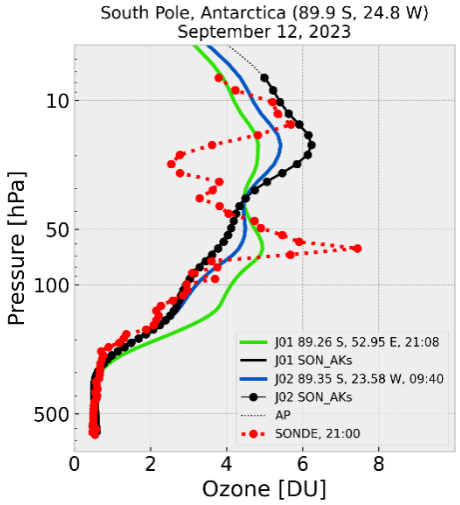
23 Aug 2023

No match

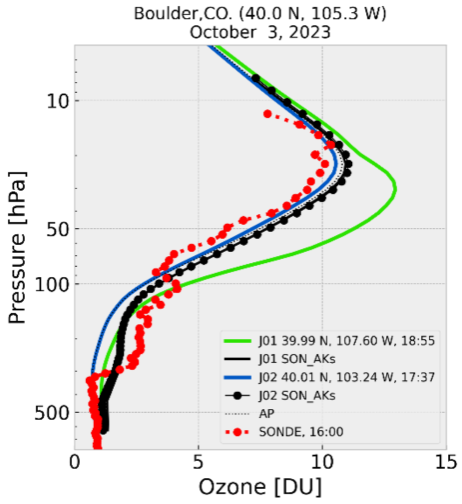


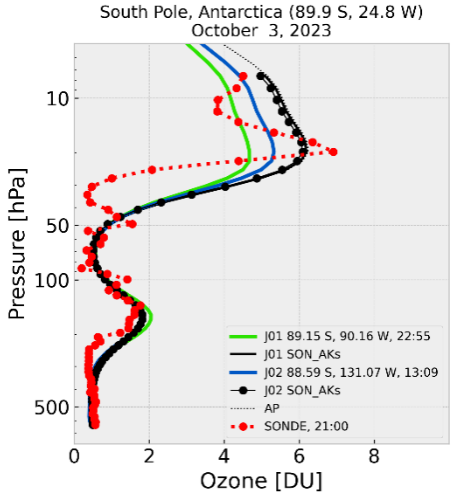
12 Sep 2023





03 Oct 2023



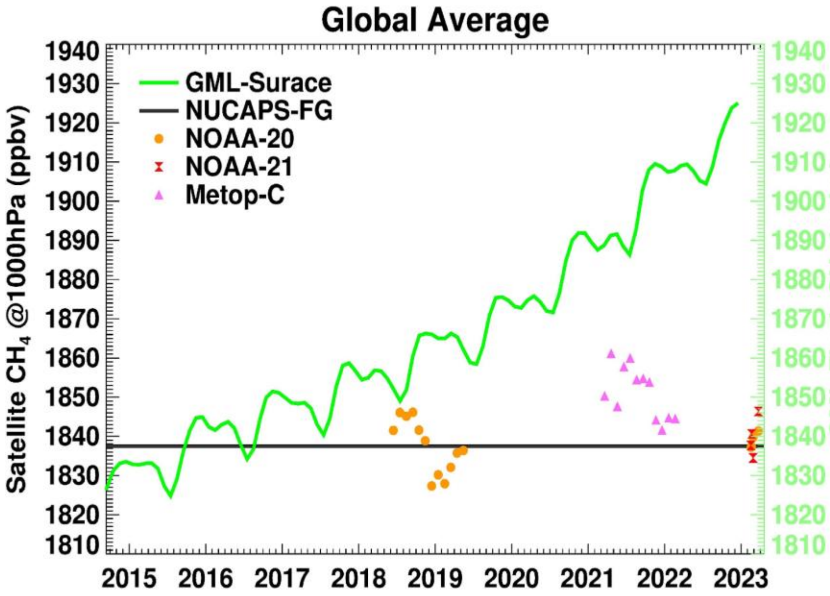


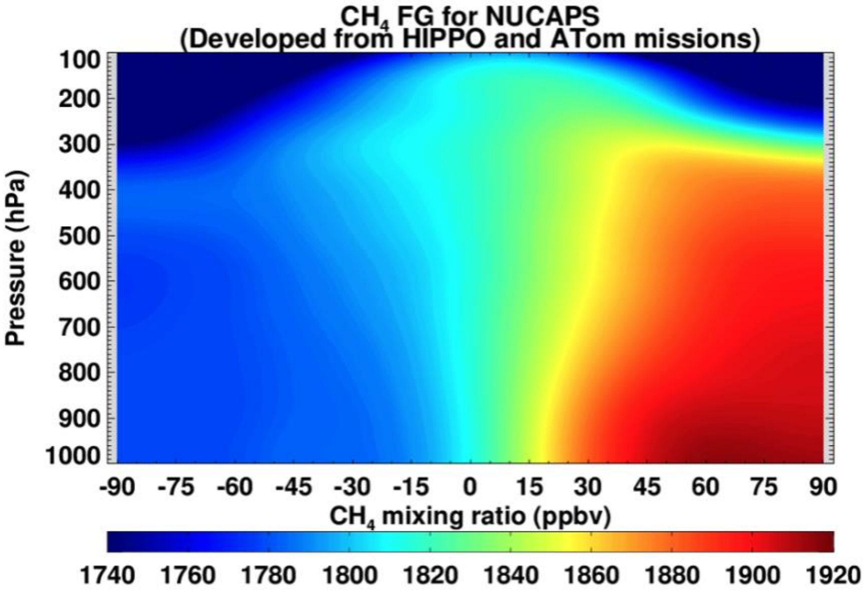
Focus Day Datasets

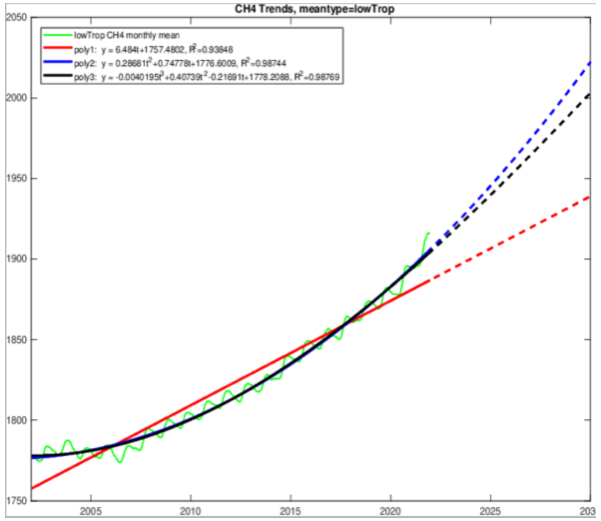
Trace Gas Products

CO, CO_2, CH_4

CH4 A-priori Update (v3.2)





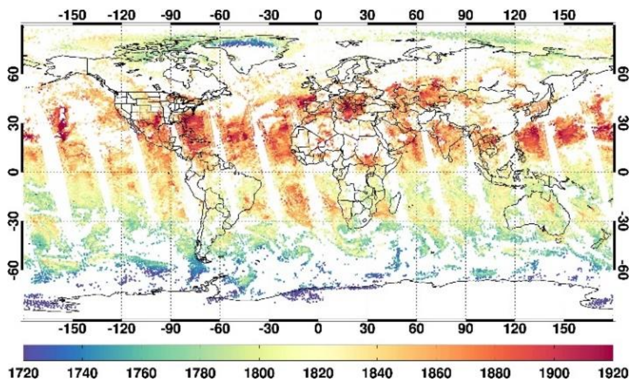


Previous v3.1 CH_4 a priori is shown as black horizontal line, whereas green line represents GML surface measurements showing high rate of increase. NUCAPS retrievals are biased low in later years due to this fixed *a priori*, see NOAA-20, NOAA-21, and MetOp-C.

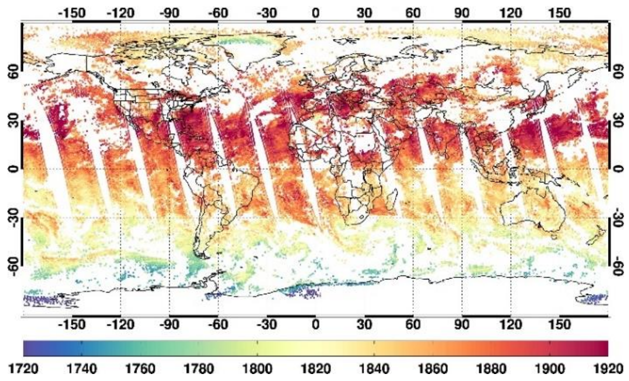
- V3.1 a priori was developed using HIPPO and ATom field campaign measurements reflecting vertical and latitudinal variations.
- NUCAPS team analyzed CH_4 NOAA-GML and CarbonTracker model data to identify the increased rate of CH_4 for a necessary change in the a-priori. A 2nd degree polynomial fit in the trend term was added in v3.2.

NOAA-20 and NOAA-21 xCH_4 (ppbv) with A-priori updates: 24 March 2023

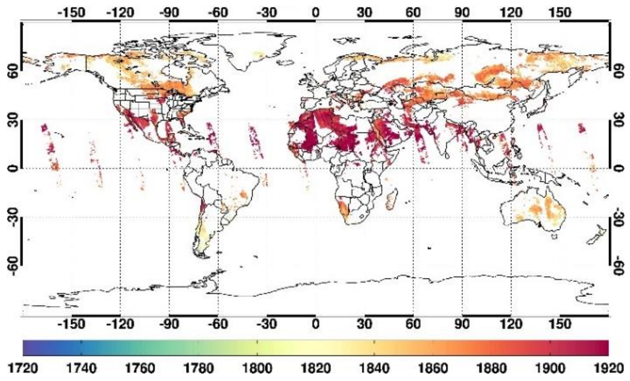
V3.1 CH_4 Retrievals
NOAA-20



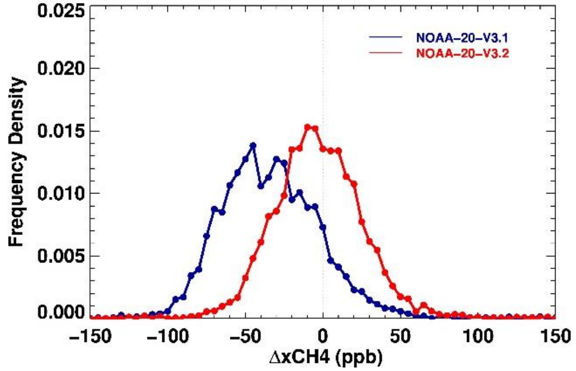
V3.2 CH_4 with new a-priori
NOAA-20



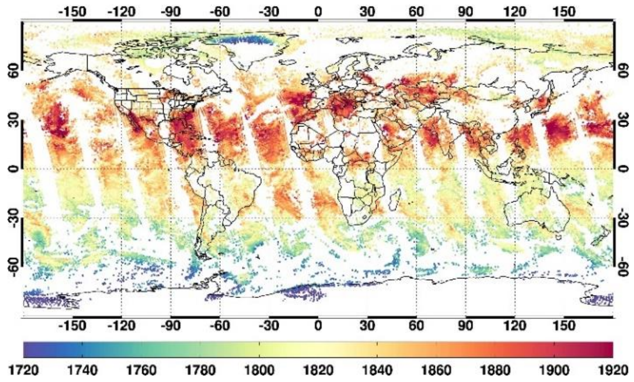
TROPOMI



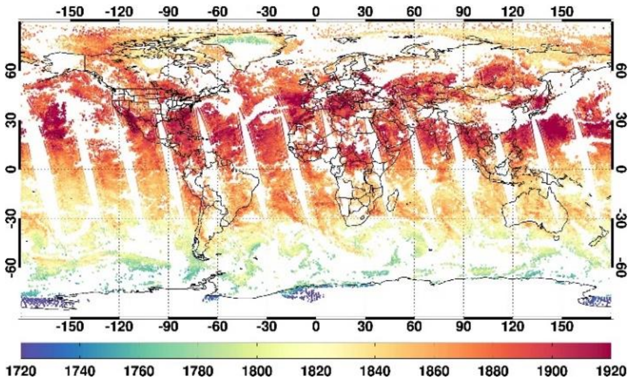
NOAA-20 – TROPOMI



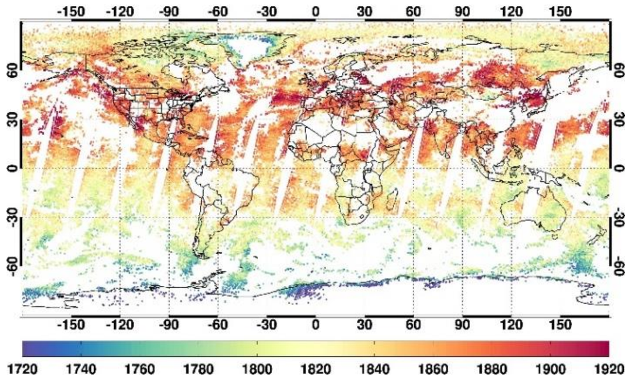
NOAA-21



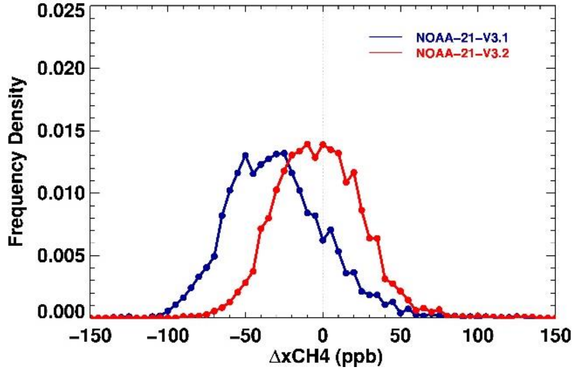
NOAA-21



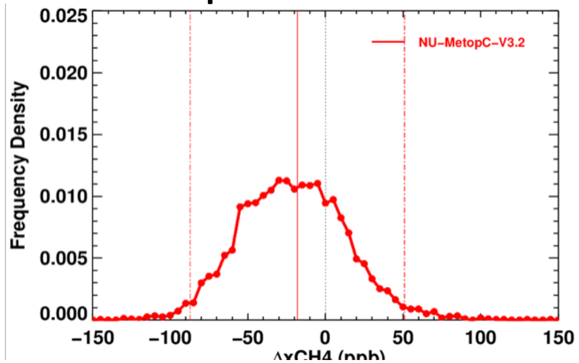
MetOp-C IASI



NOAA-21 – TROPOMI



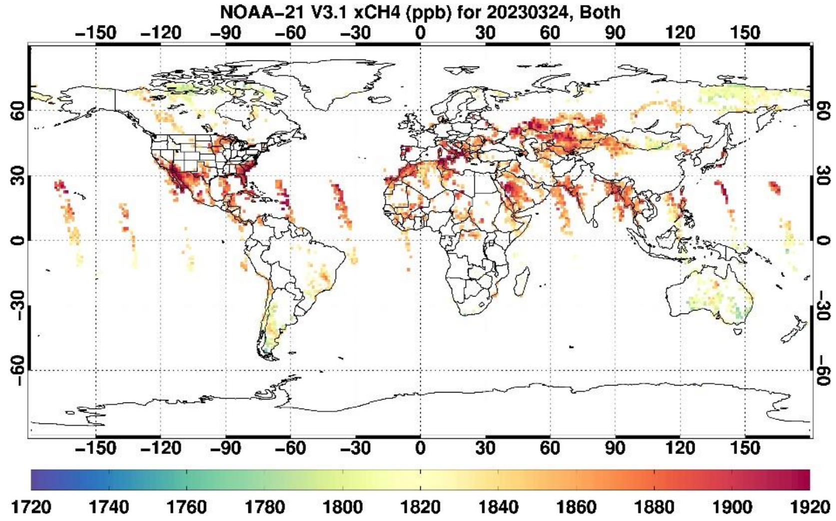
MetOp-C IASI – TROPOMI



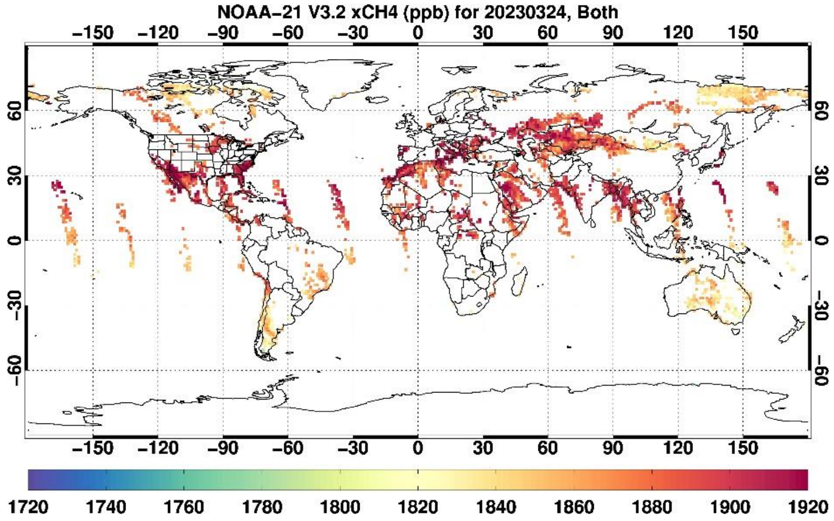
- NUCAPS CH4 was underestimating in v3.1 by approximately 50 ppbv, compared to TROPOMI, as shown in the histograms on the right.
- New v3.2 CH_4 a priori was adjusted by GML trends; the vertical and horizontal distributions in the a priori were developed by HIPPO and Atom, same as in v3.1.

Maps of NOAA-21 CH_4 Collocated with TROPOMI Pixels

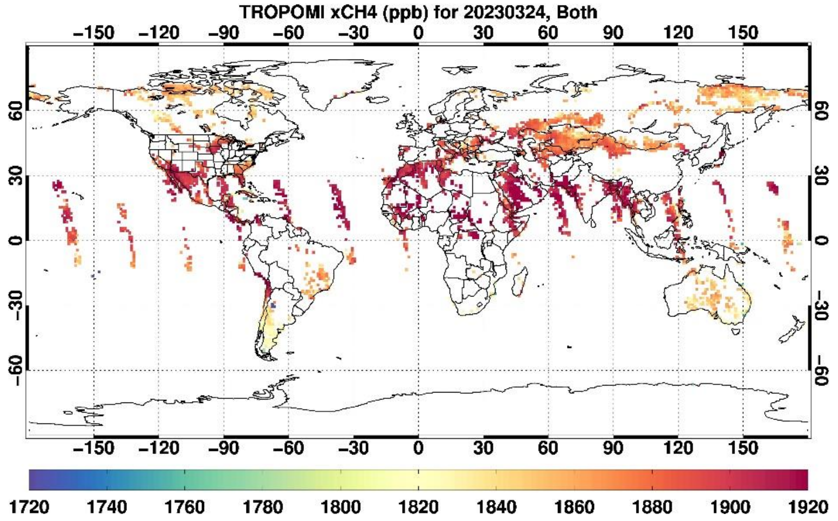
NOAA-21 V3.1 CH_4 Retrievals

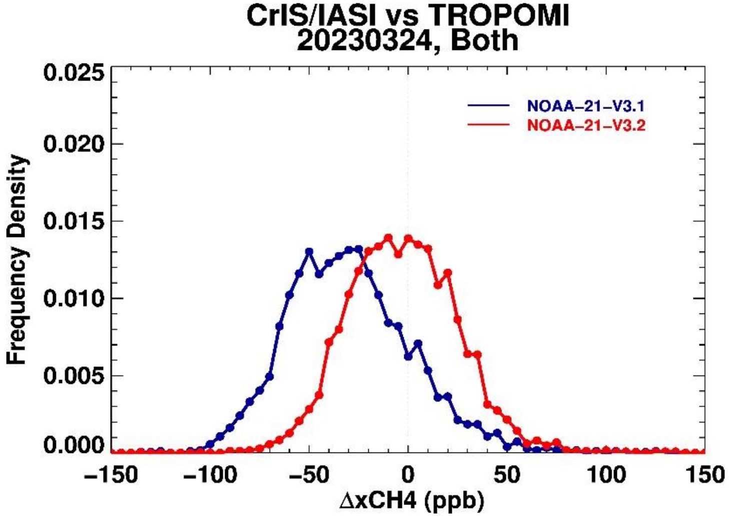


NOAA-21 V3.2 CH_4 with a-priori updates



TROPOMI

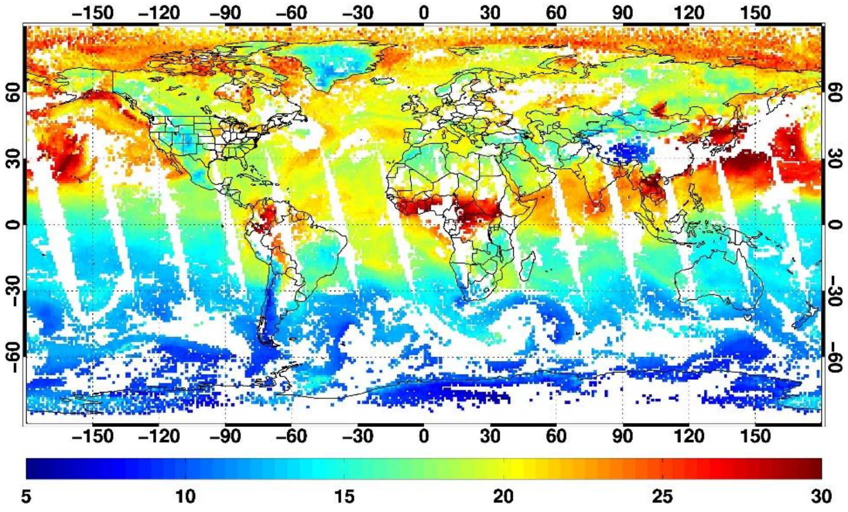




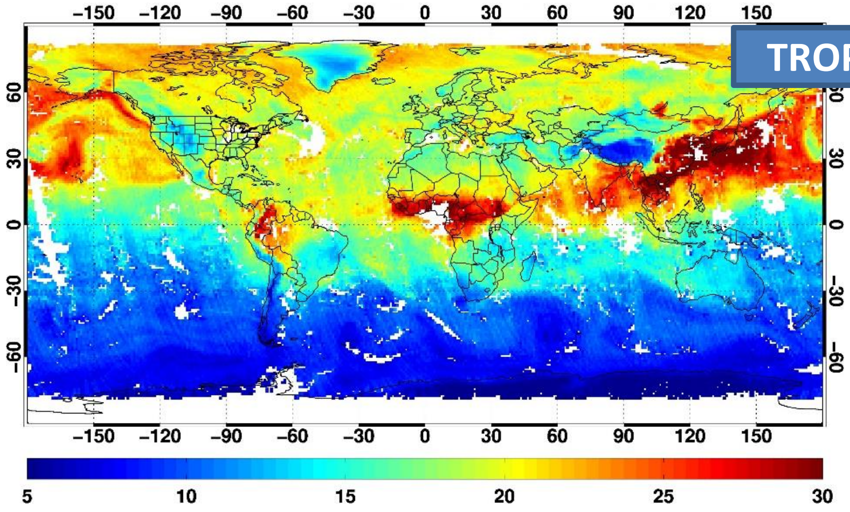
- NOAA-21 v3.2 results for 20230324 using TROPOMI coverage;
- New v3.2 NOAA-21 CH_4 agrees well to TROPOMI, a significant improvement compared to v3.1.

Total Column Carbon Monoxide NOAA-21,-20 NUCAPS 3.2 vs TROPOMI for **24 Mar 2023**

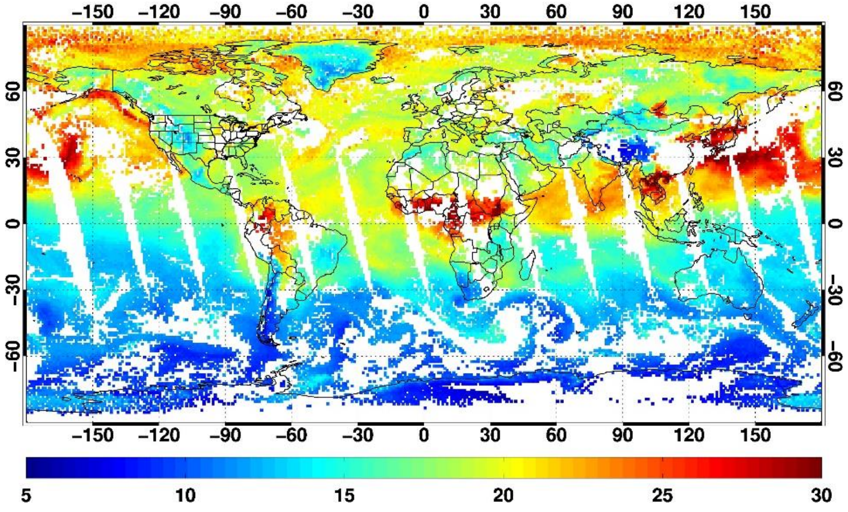
NOAA-21



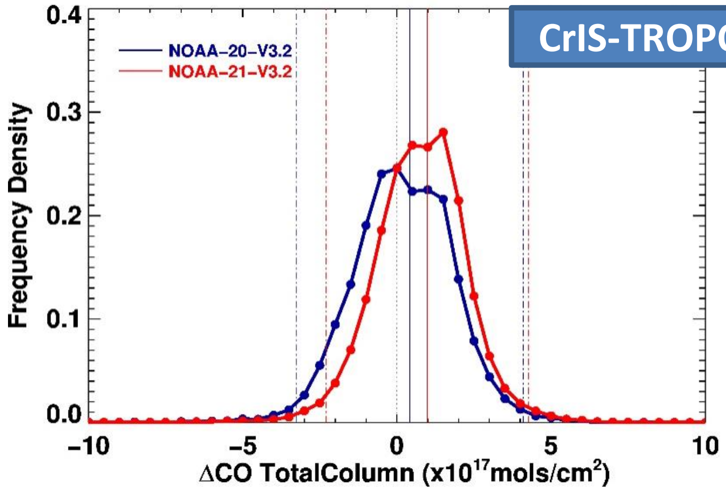
TROPOMI



NOAA-20



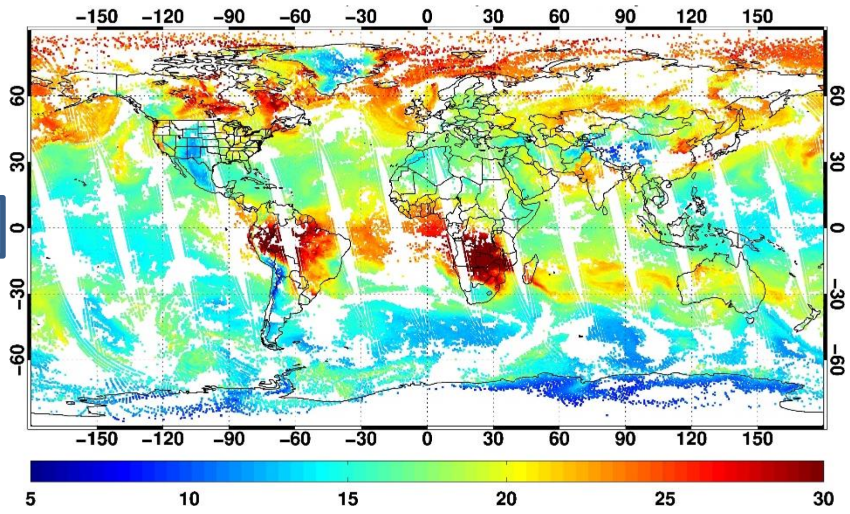
CrIS-TROPOMI



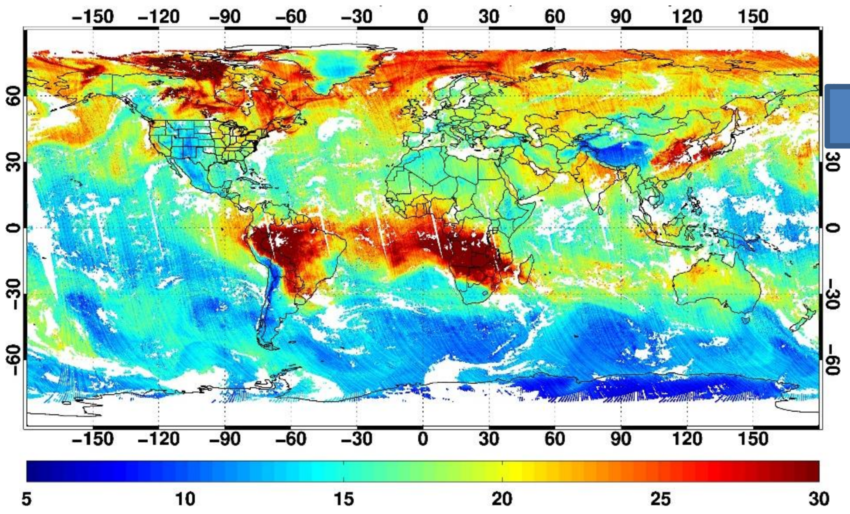
- NUCAPS total column CO, CrIS vs TROPOMI.
- NUCAPS EDR products are generated for both daytime and nighttime.
- TROPOMI uses solar spectrum to retrieve CO and comparisons are possible for daytime only.
- NOAA-21 CO is slightly higher than NOAA-20, by 0.5×10^{17}mols/cm^2 statistically.

Total Column Carbon Monoxide NOAA-21, -20 NUCAPS 3.2 vs TROPOMI for **21 Sep 2023**

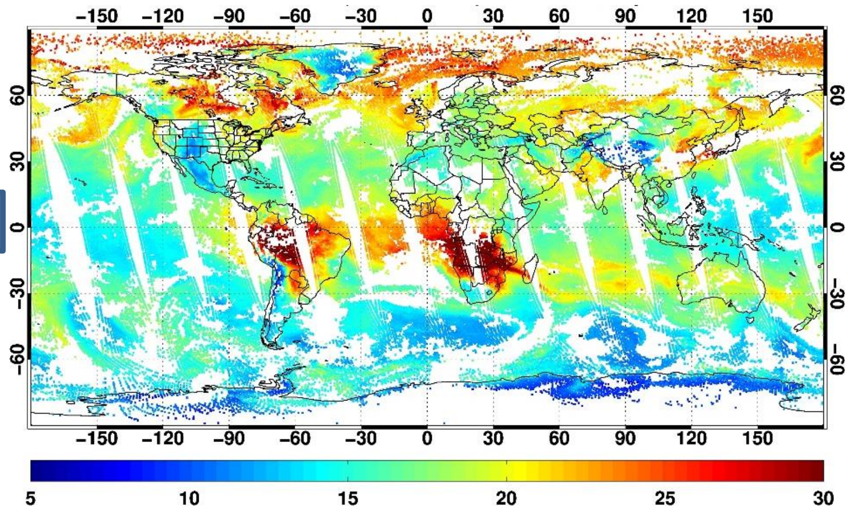
NOAA-21



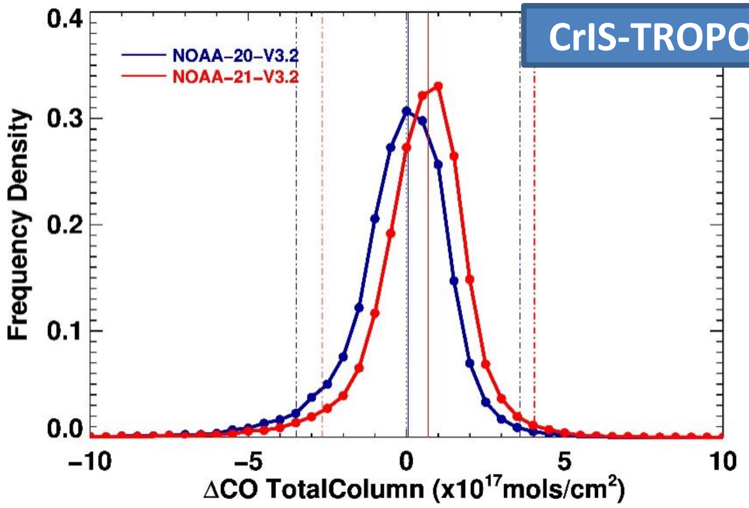
TROPOMI



NOAA-20



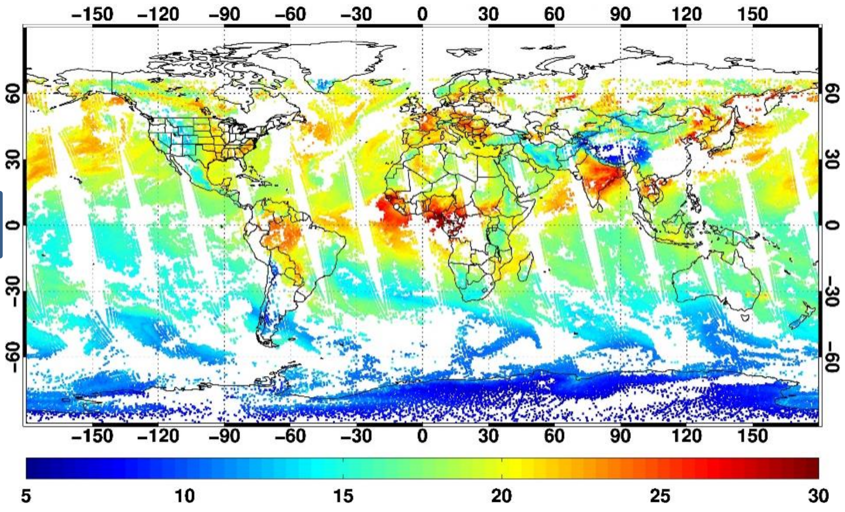
CrIS-TROPOMI



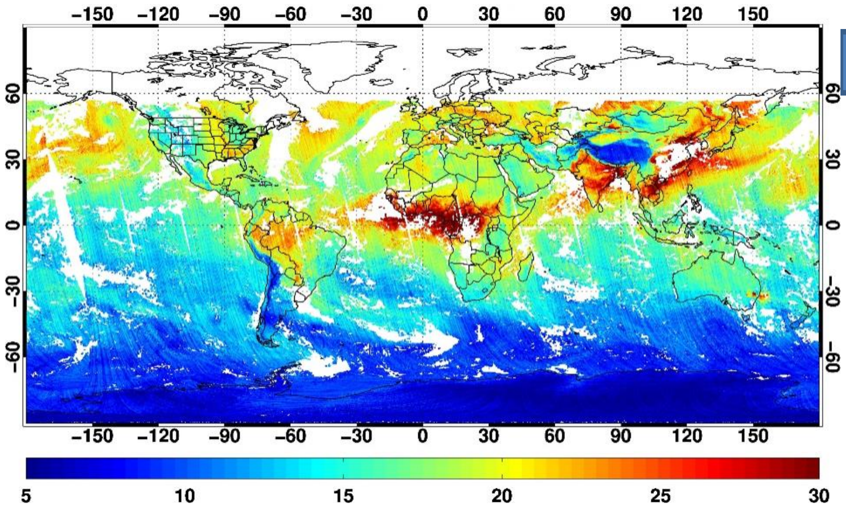
- NUCAPS total column CO, CrIS vs TROPOMI for Sept. 21, 2023.
- NOAA-21 NUCAPS CO product matches very well both qualitatively and quantitatively with the NOAA-20 NUCAPS product.
- NOAA-21 CO is slightly higher than NOAA-20, by 0.5×10^{17} mols/cm^2 statistically.

Total Column Carbon Monoxide NOAA-21, -20 NUCAPS 3.2 vs TROPOMI for **18 Dec 2023**

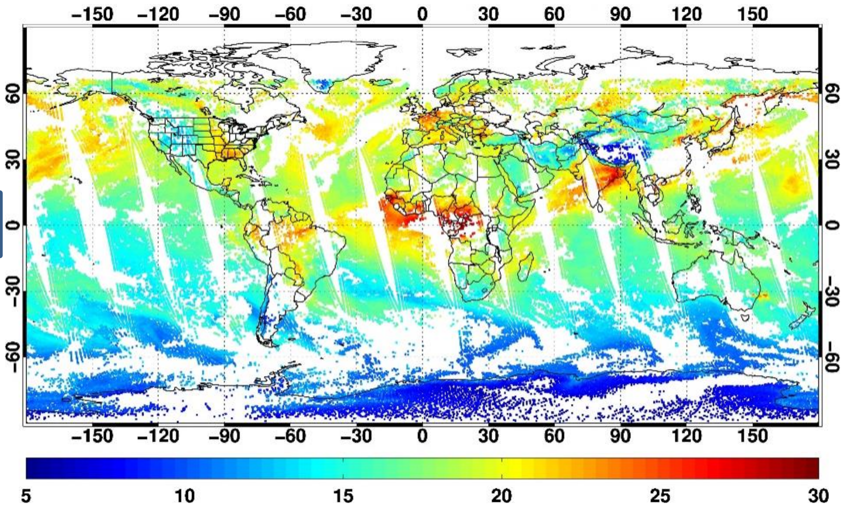
NOAA-21



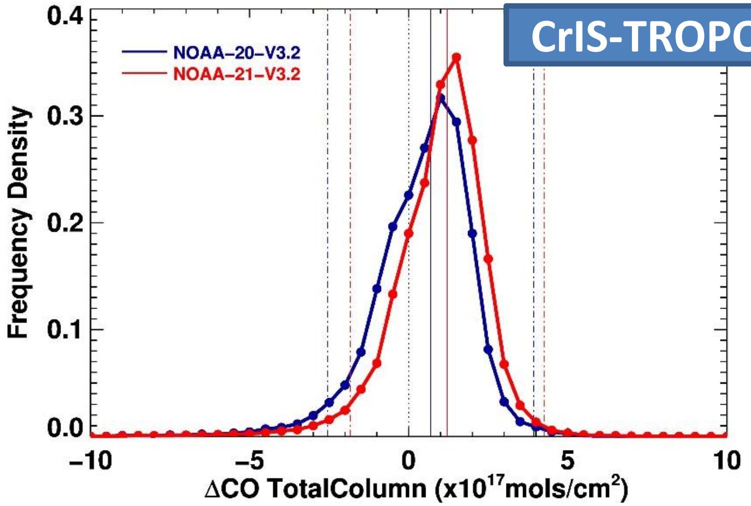
TROPOMI



NOAA-20



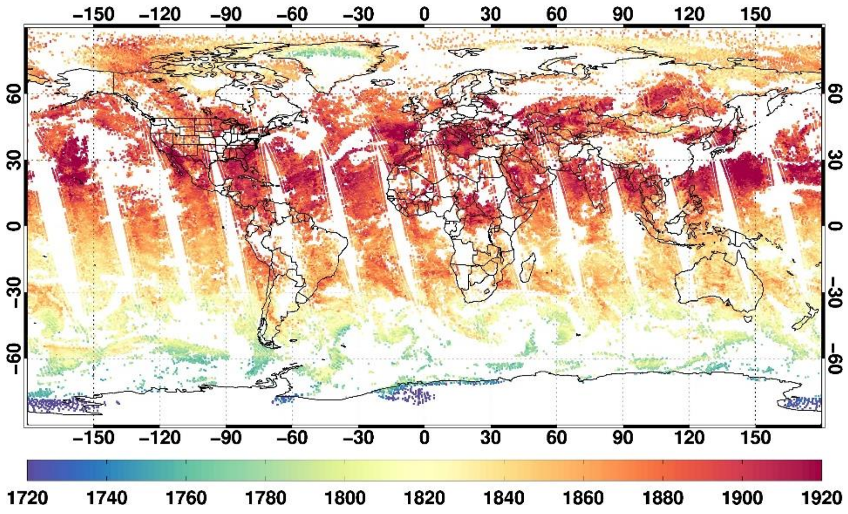
CrIS-TROPOMI



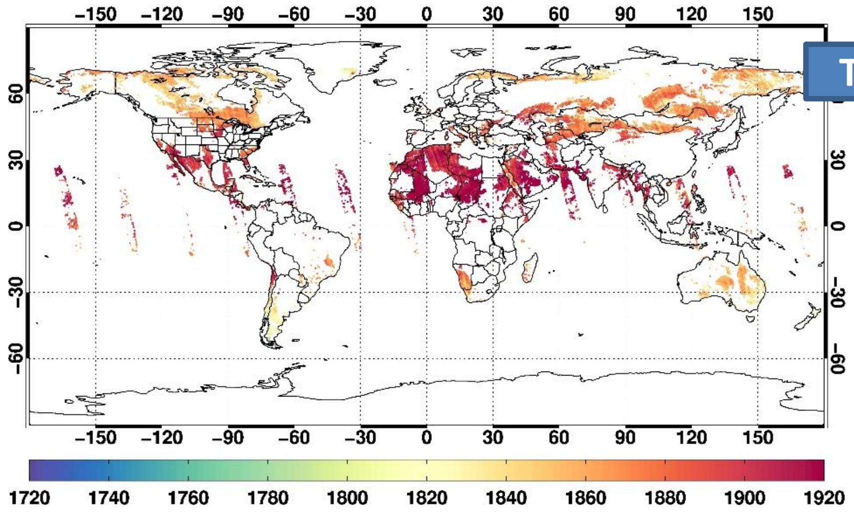
- Differences between NOAA-20 and NOAA-21 are slightly smaller in the winter.
- Missing data NH high latitudes is due to the lack of solar energy in the NH winter.

Column Averaged Methane NOAA-21,-20 NUCAPS 3.2 vs TROPOMI for **24 Mar 2023**

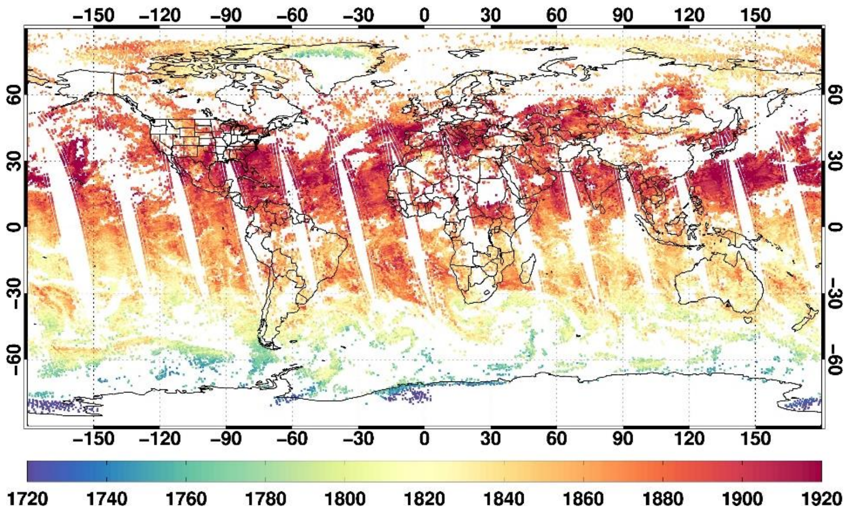
NOAA-21



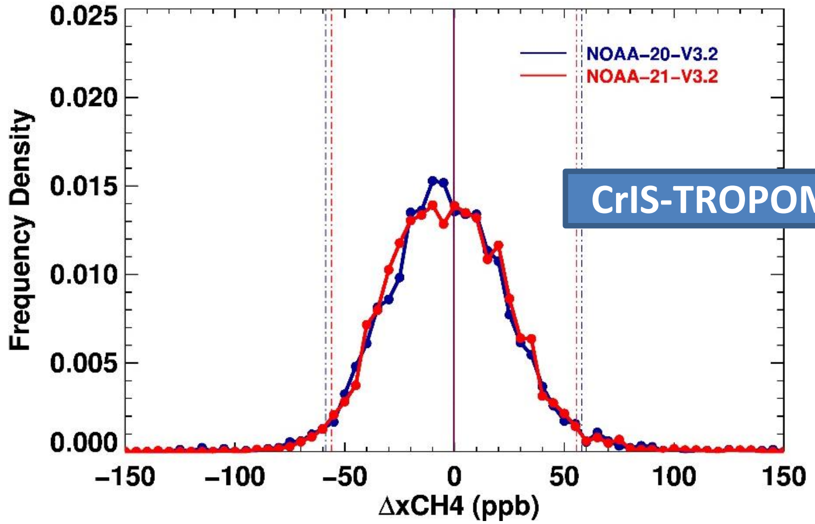
TROPOMI



NOAA-20



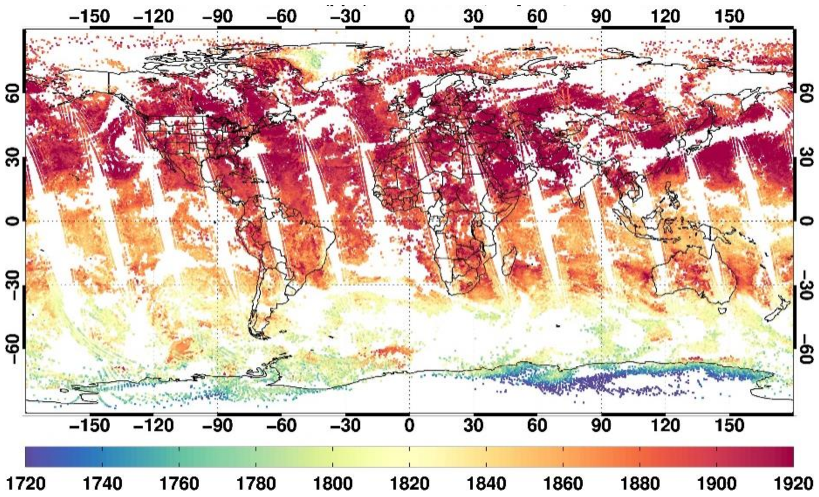
CrIS-TROPOMI



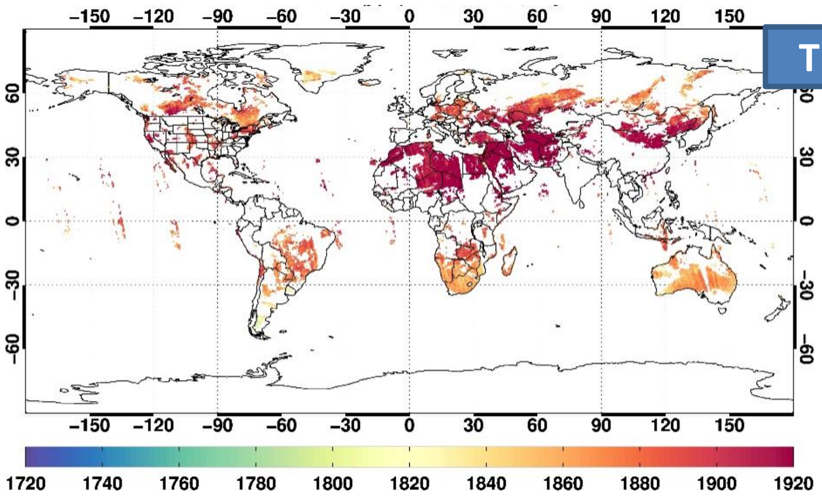
- NUCAPS column averaged CH_4, CrIS vs TROPOMI on Mar. 24, 2023.
- V3.2 CrIS CH_4 agree very well between NOAA-20 and NOAA-21, and against TROPOMI.
- CrIS coverages are significantly higher than that of TROPOMI.

Column Averaged Methane NOAA-21,-20 NUCAPS 3.2 vs TROPOMI for **21 Sep 2023**

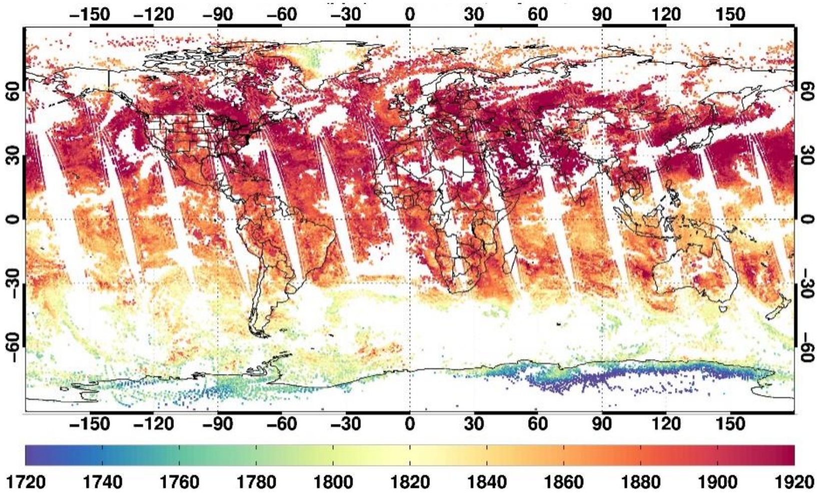
NOAA-21



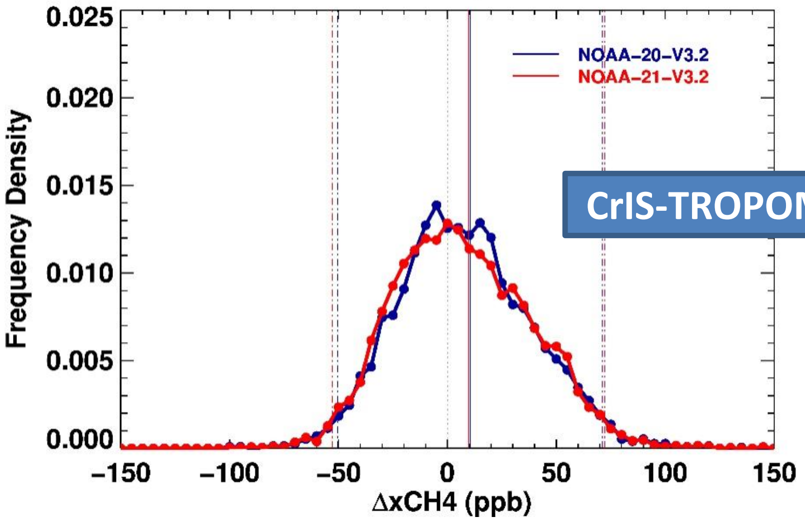
TROPOMI



NOAA-20



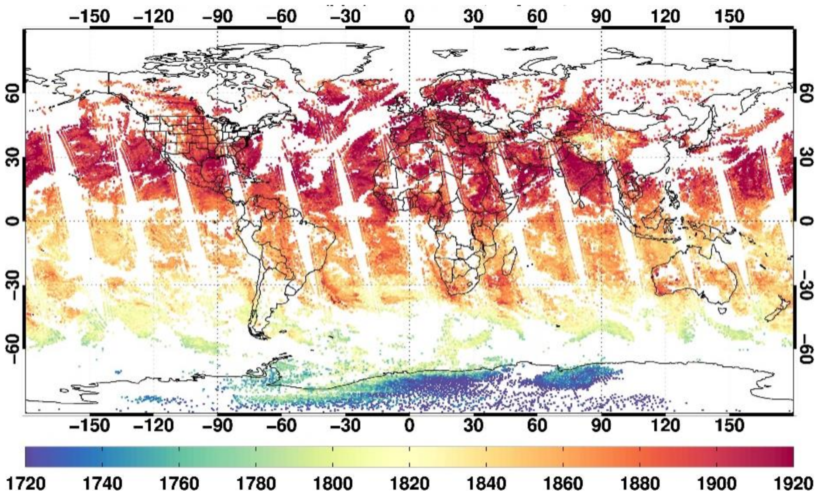
CrIS-TROPOMI



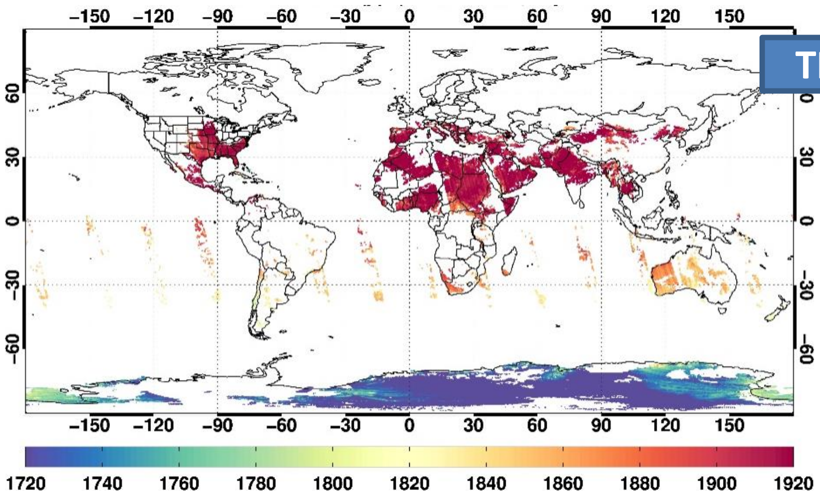
- NUCAPS column averaged CH_4, CrIS vs TROPOMI on Sept. 21, 2023.
- V3.2 CrIS CH_4 agree very well between NOAA-20 and NOAA-21, and against TROPOMI.
- CrIS coverages are significantly higher than that of TROPOMI.

Column Averaged CH_4 NOAA-21,-20 NUCAPS 3.2 vs TROPOMI for **18 Dec 2023**

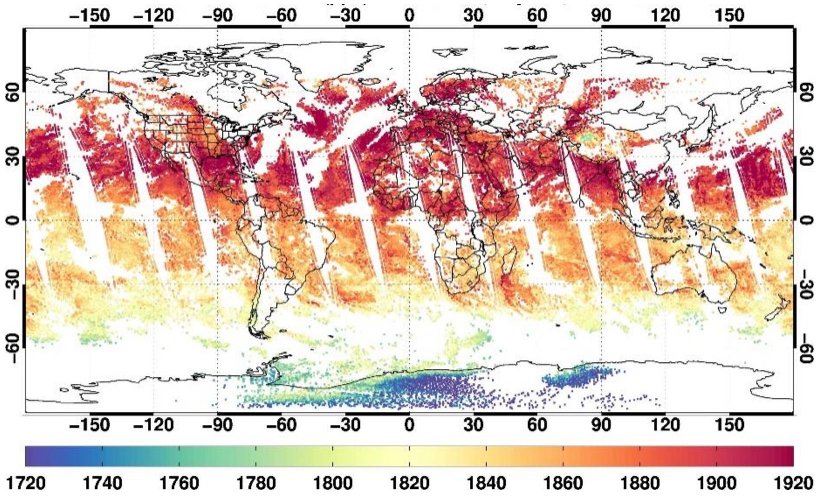
NOAA-21



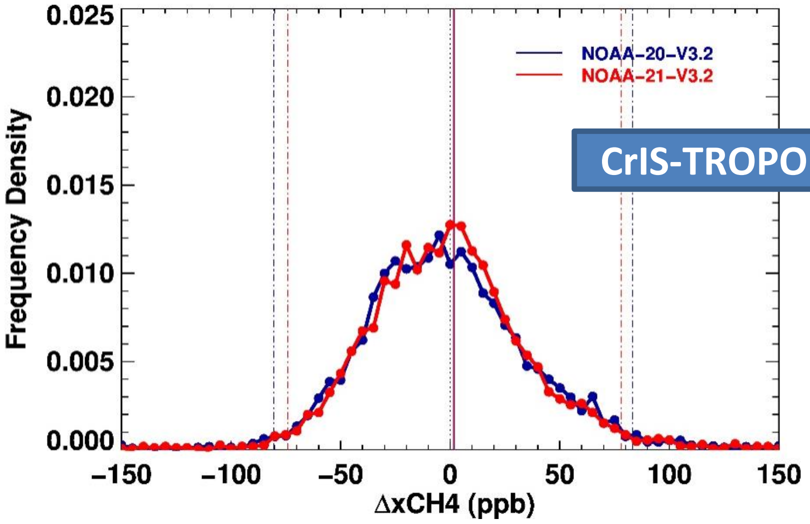
TROPOMI



NOAA-20



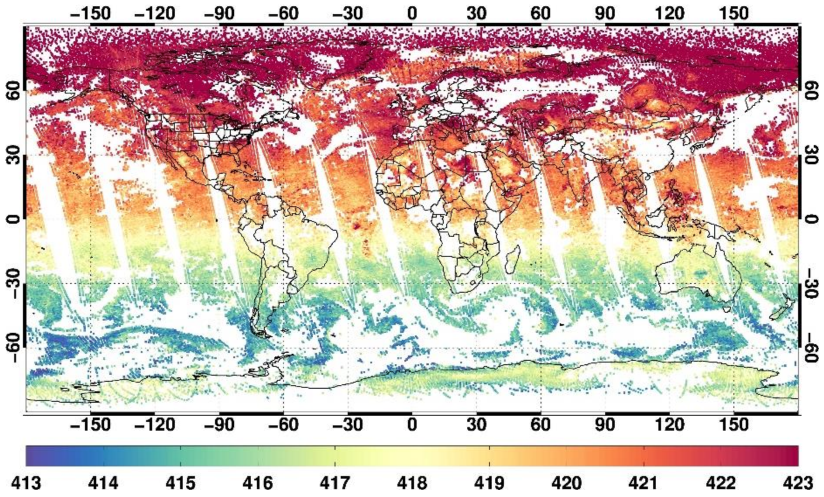
CrIS-TROPOMI



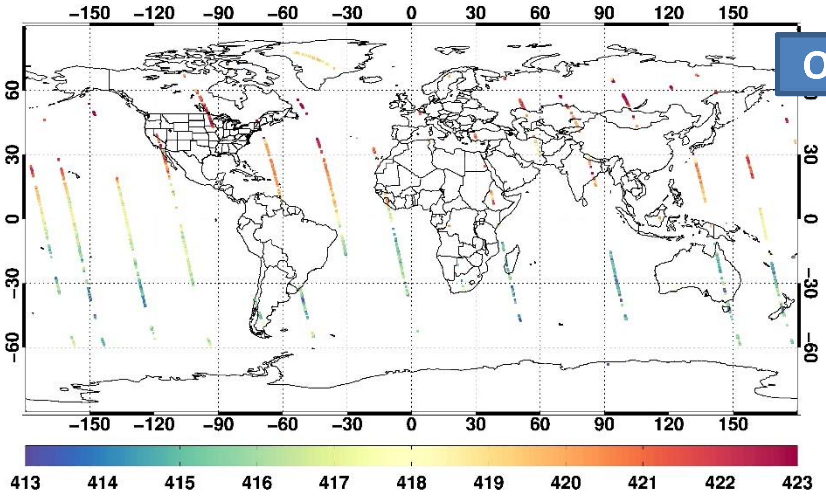
- NUCAPS column averaged CH_4, CrIS vs TROPOMI on Sept. 21, 2023.
- V3.2 CrIS CH_4 agree very well between NOAA-20 and NOAA-21, and against TROPOMI.
- CrIS coverages are significantly higher than that of TROPOMI.

Column Averaged Carbon Dioxide NOAA-21,-20 NUCAPS 3.2 vs OCO-2 for **24 Mar 2023**

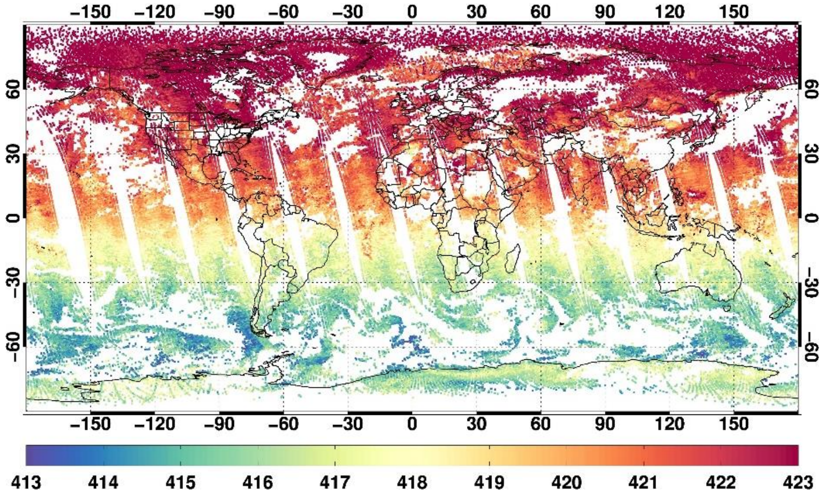
NOAA-21



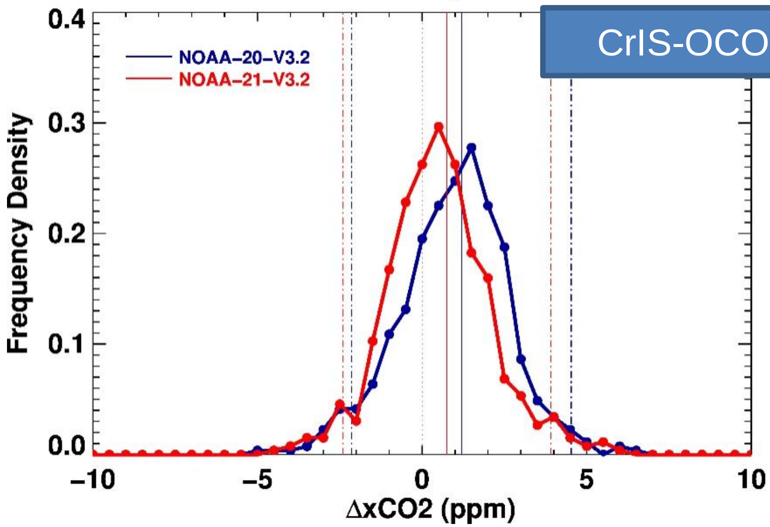
OCO-2 v11



NOAA-20



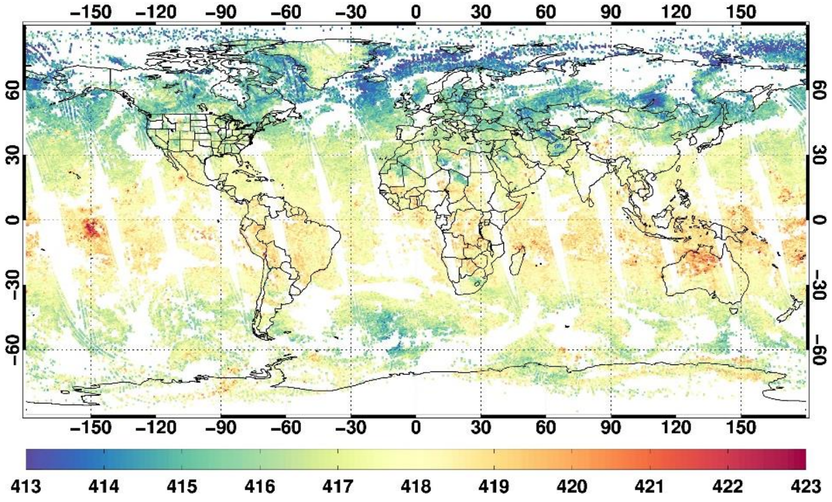
CrIS-OCO2



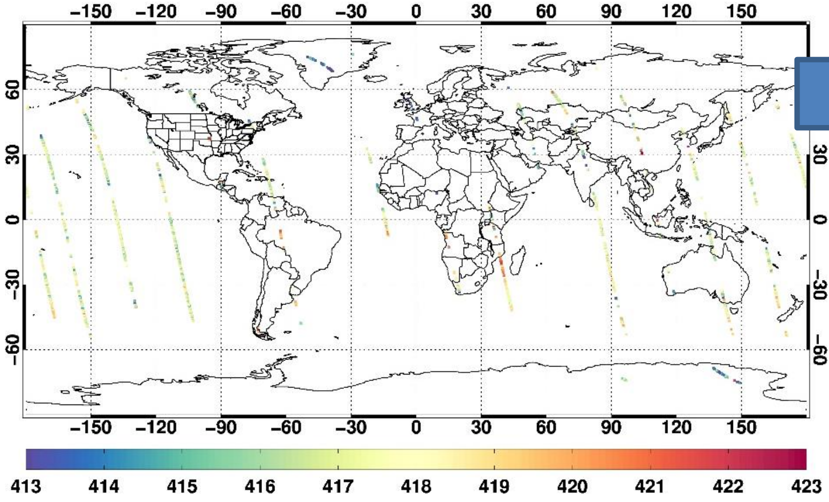
- NUCAPS products are generated for both daytime and nighttime.
- OCO-2 uses solar measurements to retrieve CO_2 and comparisons are possible for daytime only.
- NOAA-21 NUCAPS CO_2 retrievals agree very well both qualitatively and quantitatively with NOAA-20 NUCAPS CO_2.

Column Averaged Carbon Dioxide NOAA-21,-20 NUCAPS 3.2 vs OCO-2 for **21 Sep 2023**

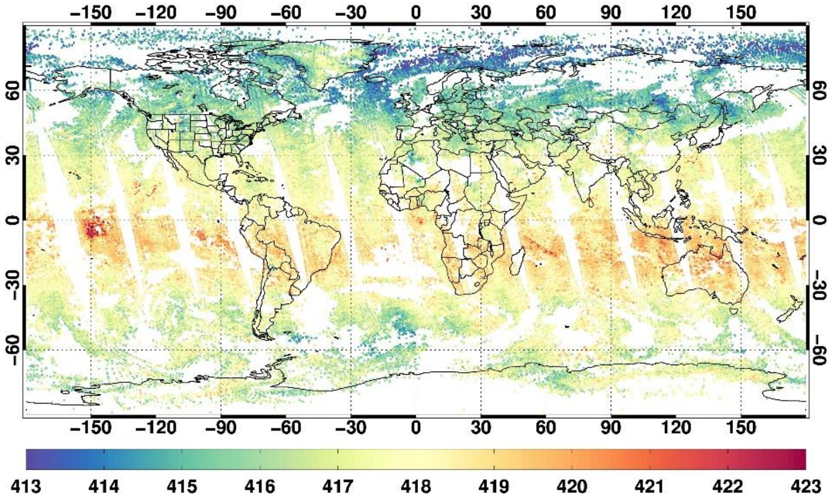
NOAA-21



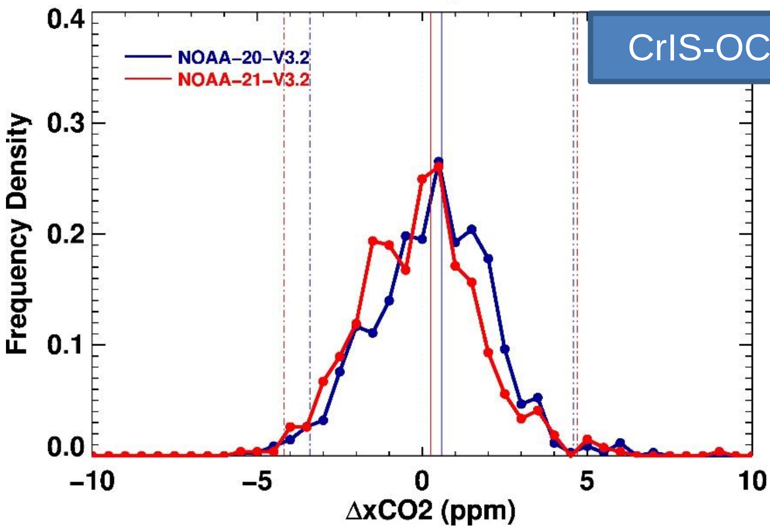
OCO-2 v11



NOAA-20



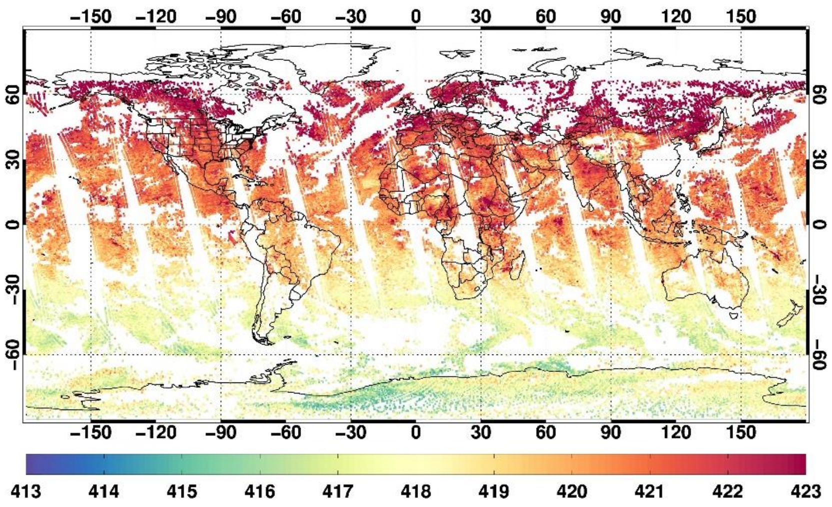
CrIS-OCO2



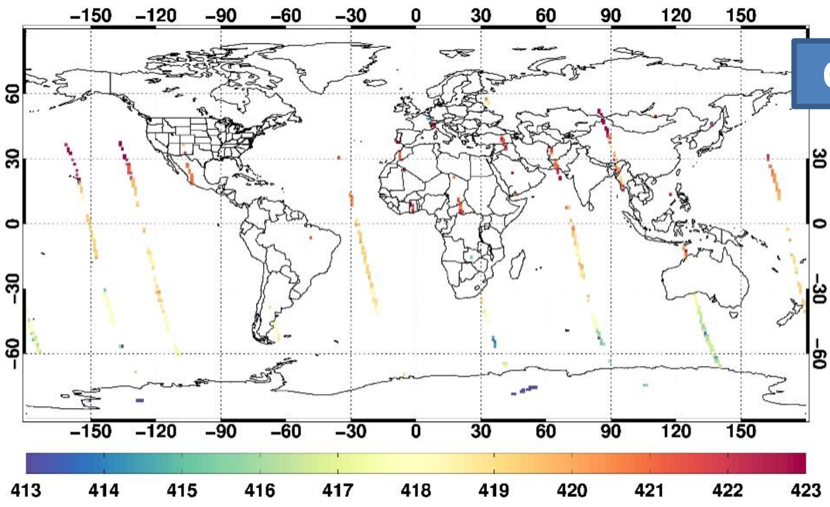
- NOAA-21 NUCAPS CO_2 retrievals from NOAA-21 match very well with NOAA-20 NUCAPS CO_2, as well as with OCO-2 v11.
- CO2 summer/full values are significantly lower, showing correct seasonality.

Column Averaged Carbon Dioxide NOAA-21,-20 NUCAPS 3.2 vs OCO-2 for **18 Dec 2023**

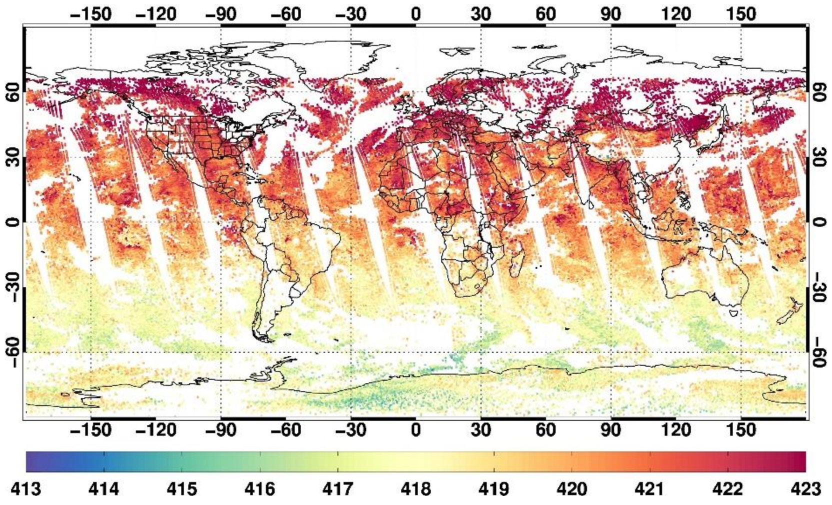
NOAA-21



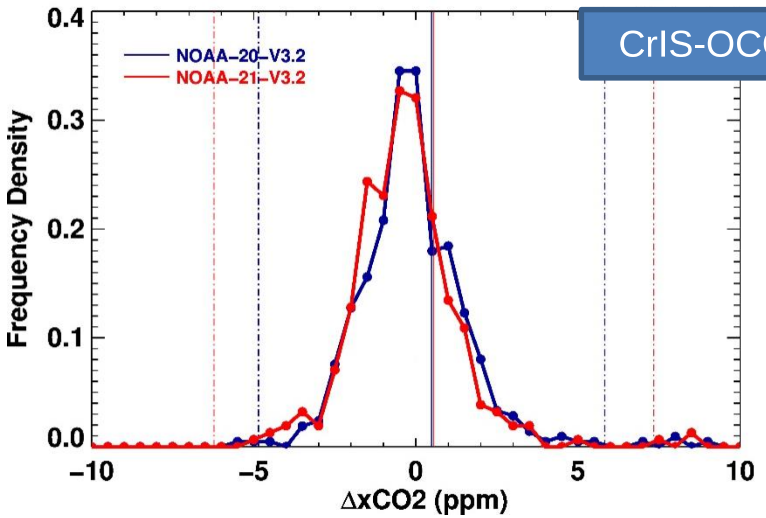
OCO-2 v11



NOAA-20



CrIS-OCO2

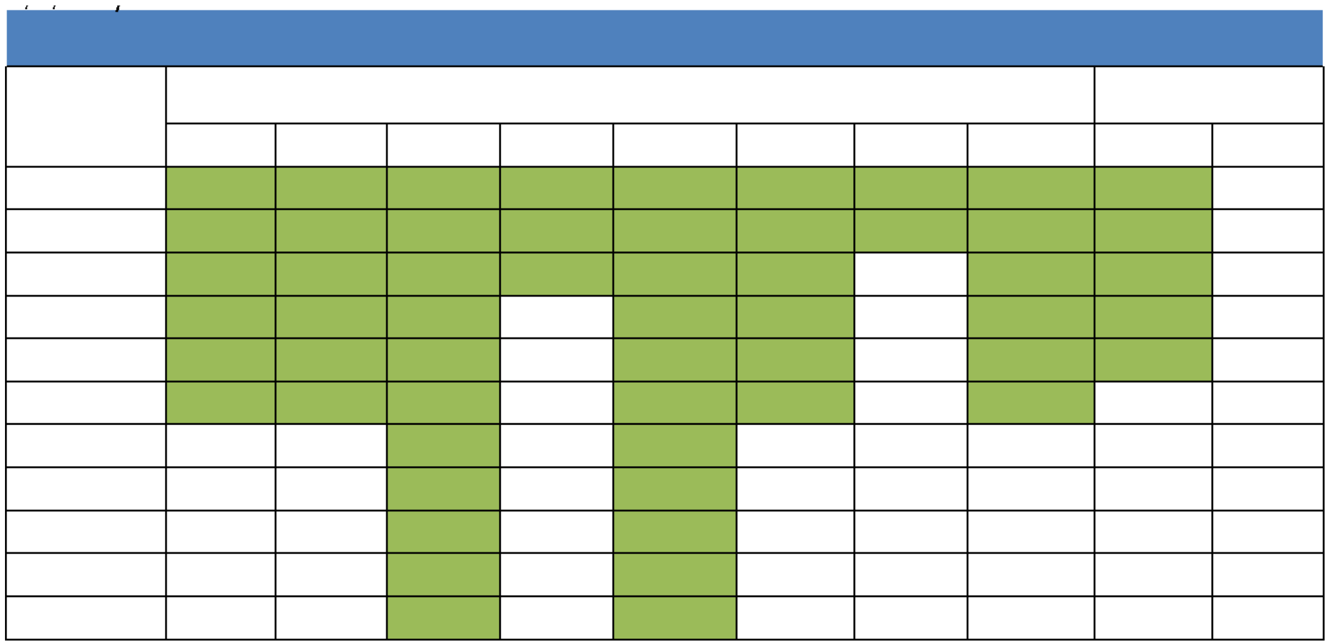


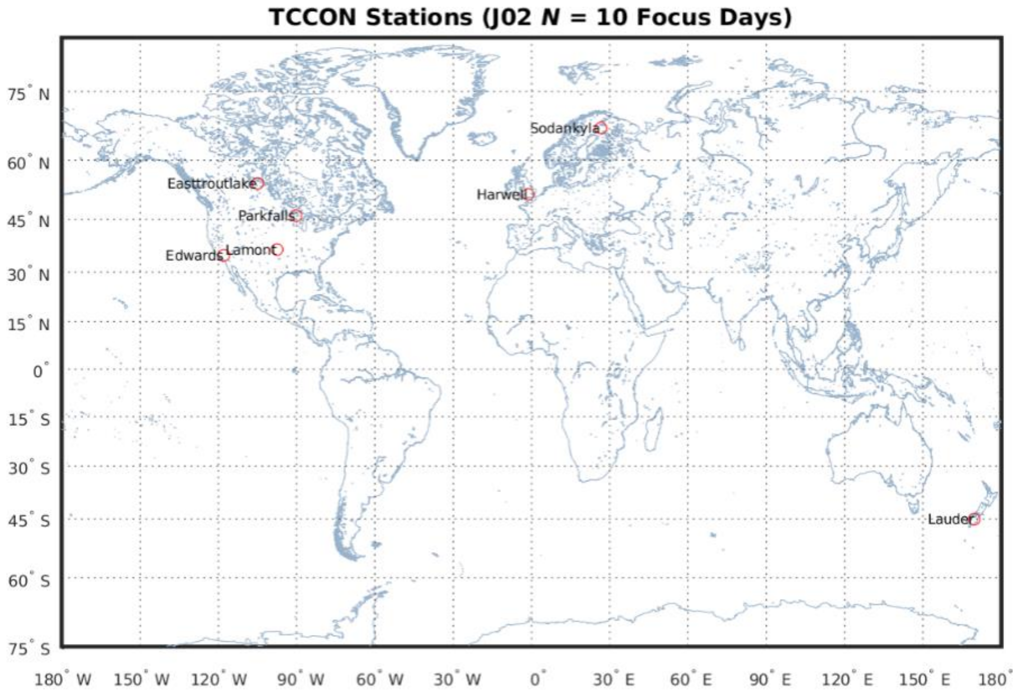
- NOAA-21 NUCAPS CO_2 retrievals from NOAA-21 match very well with NOAA-20 NUCAPS CO_2, as well as with OCO-2 v11.
- CO_2 winter values are higher than the summer but lower than the spring.

Trace Gas Product Validations

TCCON Measurements

The Total Carbon Column Observing Network (TCCON) Data





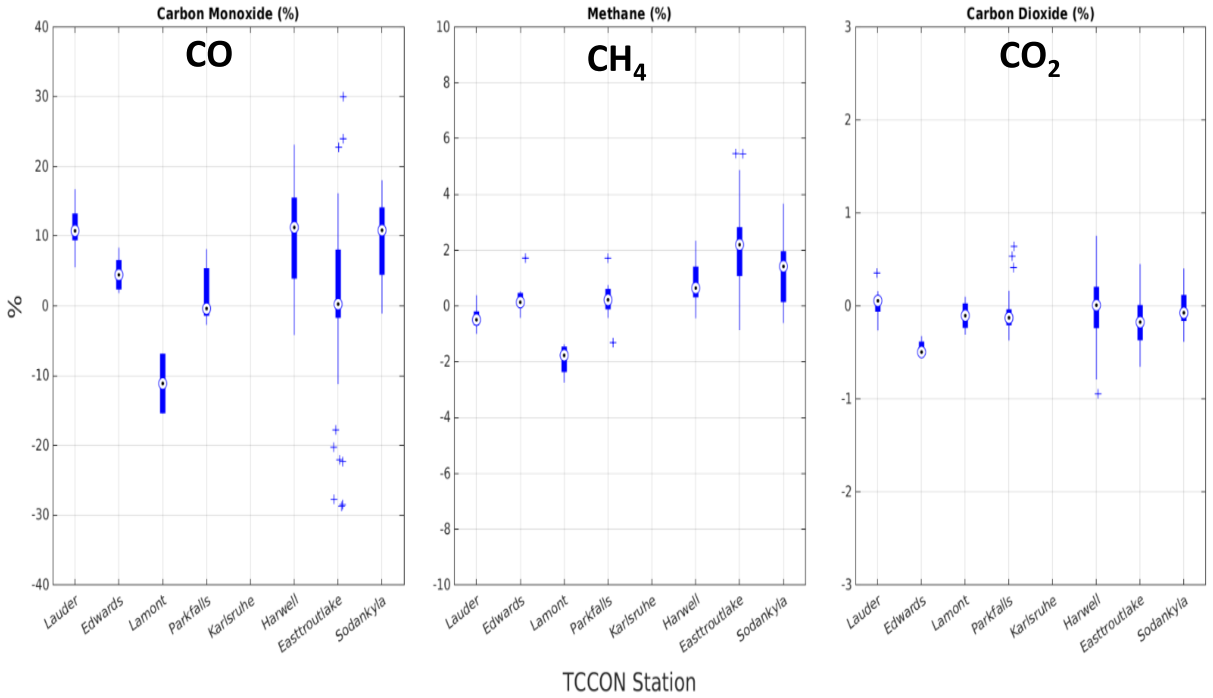
- **DF** --- Edwards, CA, USA
- **ET** --- East Trout Lake, Canada
- **GM** --- Garmisch, Germany
- **HW** --- Harwell, UK
- **KA** --- Karlsruhe, Germany
- **LR** --- Lauder, New Zealand
- **OC** --- Lamont, Oklahoma, USA
- **PA** --- Park Falls, Wisconsin, USA
- **SO** --- Sodankylä, Finland
- **WG** --- Wollongong, Australia

- TCCON reference measurements require time to collect due to lag-time between measurement time and availability (~5 months)

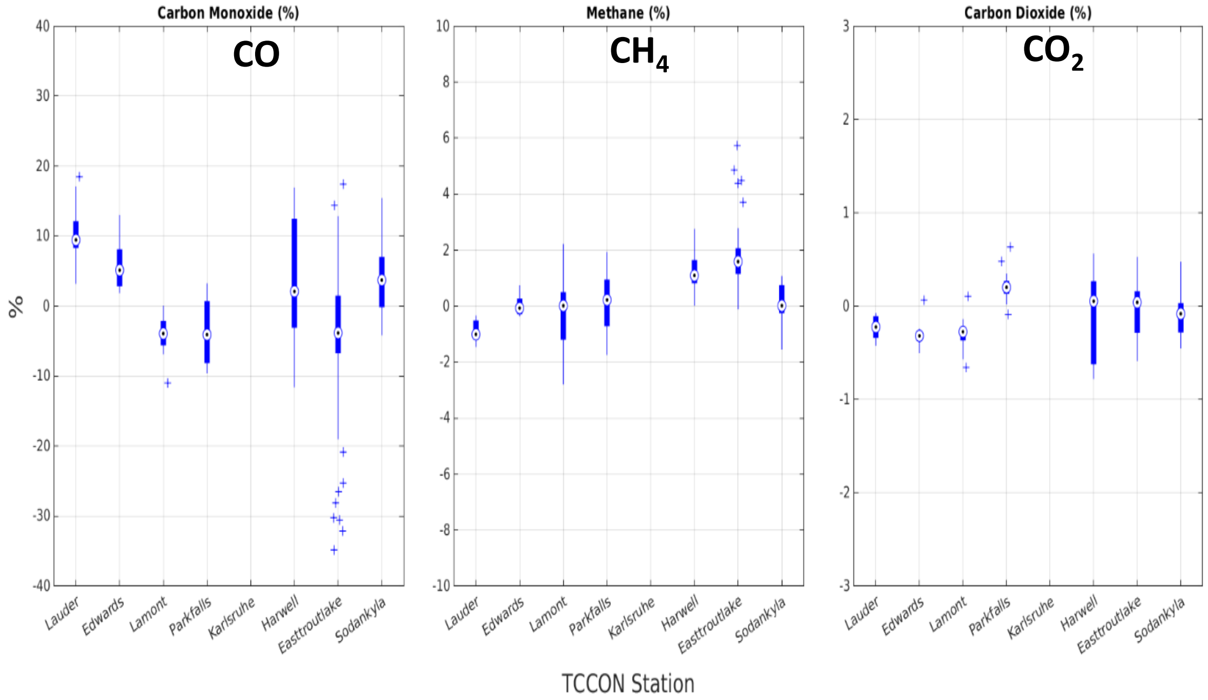
Box-Whisker Statistics by TCCON Station

(Sorted in order of latitudes)

NOAA-21 NUCAPS – TCCON

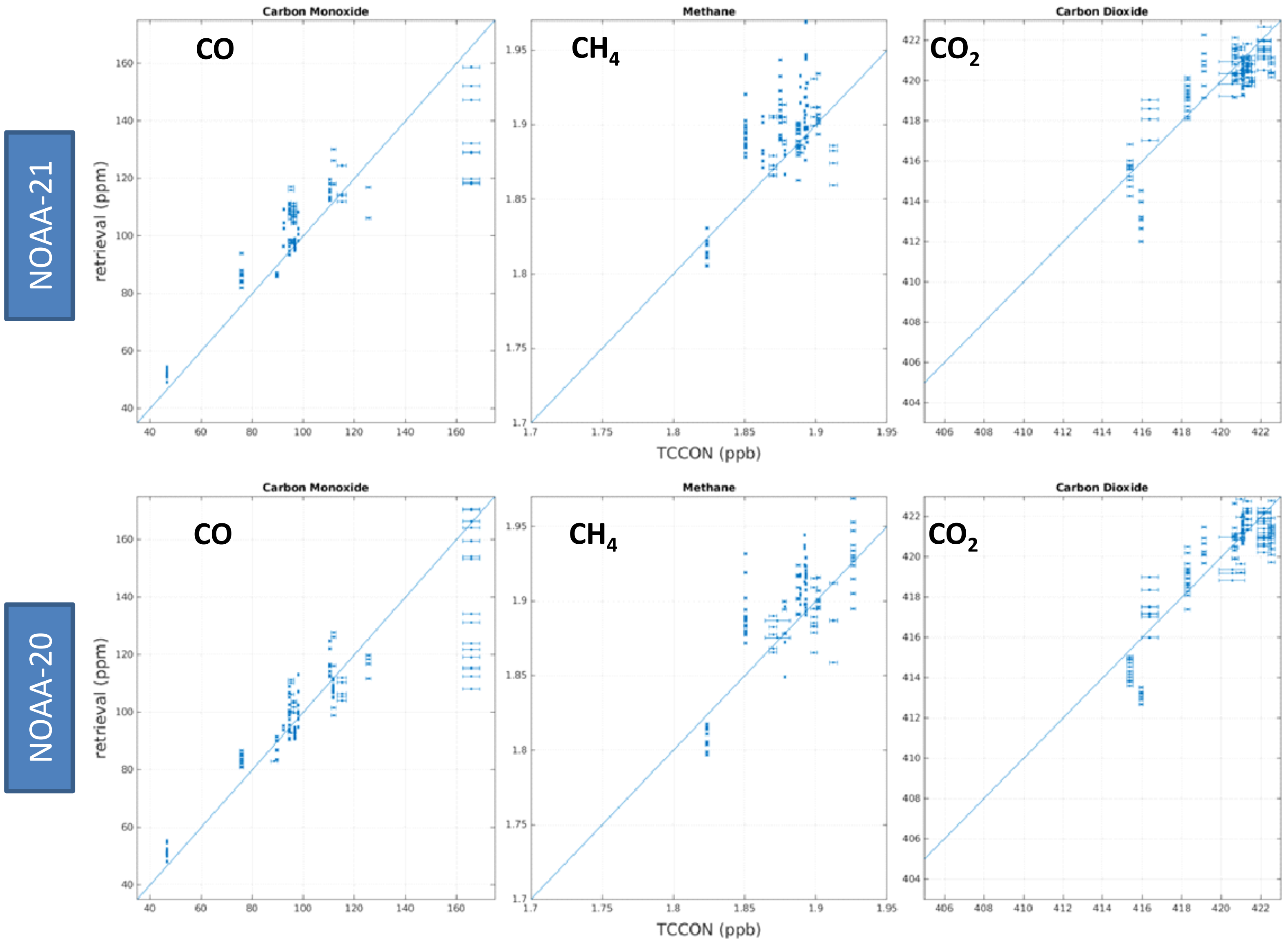


NOAA-20 NUCAPS – TCCON



- NOAA-21 results agree very well with those of NOAA-20

NOAA-21, 20 Collocated TCCON Matches



- NUCAPS correlation with TCCON for the focus days.
- NOAA-21 and NOAA-20 correlation results to TCCON are similar for NUCAPS CO, CH4, and CO_2.
- A simple linear fit correlation coefficients of 0.62 to 0.89 show good agreement between NUCAPS retrievals and TCCON measurements.
- Uncertainties partially due to difficulties matching samples.

NOAA-21 and NOAA-20 NUCAPS V3.2 versus TCCON: Statistical Summary

NOAA-20 ↔ NOAA-21 Transfer Standard

Parameter	Stat	Raw Total Column		TCCON AKs applied	
		NUCAPS	Req	NUCAPS	Req
CO	Precision	12.7 (11.5)	15%	11.5 (10.3)	15%
	Accuracy	+1.2(-3.5)	±5%	+5.1 (0.1)	±5%
CH4	Precision	1.5 (1.4)*	1%* (20 ppmv)	1.5 (1.4)*	1% (20 ppmv)
	Accuracy	+1.1 (0.7)	4% (80 ppmv)	+1.1 (0.7)	4% (80 ppmv)
CO2	Precision	0.3 (0.3)	0.5% (2 ppmv)	0.3 (0.3)	0.5% (2 ppmv)
	Accuracy	-0.1 (0)	±1% (4 ppmv)	-0.1 (-0.1)	±1% (4 ppmv)

Values in ( ) indicates NOAA-20

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

NOTES

*Precision requirements for CH_4 are now known to be too stringent and will require waiver.

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

NOAA-21, NOAA-20 V3.2 Global Yields:

CO = 47.3 (54.5)%, *N* = 114 (132)

CH4 = 56.0 (46.7)%, *N* = 135(113)

CO2 = 67.2 (68.2)%, *N* = 162(165)

User Engagement/Readiness
Case Studies

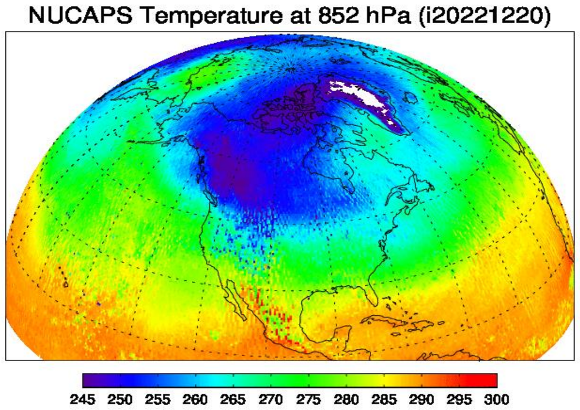
NUCAPS Users and Collaborations

Organization	NUCAPS Product(s)	Application
AWIPS WFO	AVTP, AVMP	Nowcasting, atmospheric instabilities, severe weather outbreaks
CSPP Direct Broadcast	AVTP, AVMP, other	Improved latency for regional applications, situational awareness
NOAA-GML	Trace Gas Products (CO, CH_4, CO_2)	Tracking Greenhouse Gases and Understanding Carbon Cycle Feedbacks: Annual Reports*, Publications
NOAA-GML	IR Ozone	Ozone and water vapor comparison of satellite retrievals and in situ measurements from ground and airborne sources. Ozone and water vapor - Annual Reports*, publications; TOAST Product (OSPO)
NOAA-CPC	CrIS OLR product	CPC gridded daily OLR analysis for improved climate monitoring and analysis; OLR is ingested into CPC Blended OLR (CBO) product.
NWP Centers (ECMWF)	Thinned radiance products	NWP Assimilation
Argentina Meteorological Service	AVTP, AVMP	Assimilation of NUCAPS temperature and water vapor into regional model. Active collaborations ongoing.

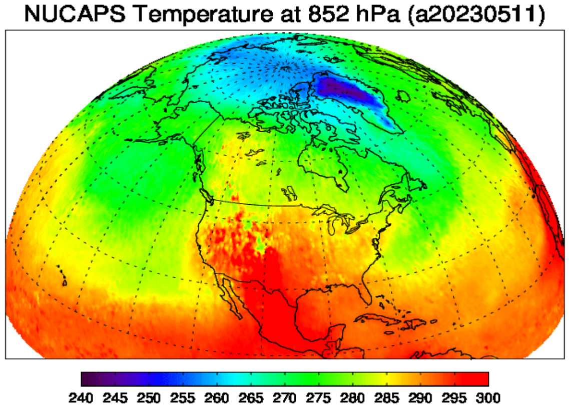
*Nalli, N., Baier, B., Jacobson, A.R., Warner, J., Bruhwiler, L., Lan, X., and Sweeney, C. (2022). *October 2022 NESDIS-GML Annual Report, "Synergies between OAR Observing Capabilities and NESDIS Satellite Missions for Trusted Data and Product Development.* Internal NOAA report: unpublished.

*Petropavlovskikh, I., Flynn, L., Divakarla, M., Johnson, B., McConville, G., Miyagawa, K., Beach, E., Wild, J., Nalli, N., Zhu, T., Prior, K., Niu, J., Hurst, D., and Morris, G. (2022). *October 2022 NESDIS-GML Annual Report, Ozone and Water Vapor Theme 2, Synergies between OAR Observing Capabilities and NESDIS Satellite Missions for Trusted Data and Product Development*. Internal NOAA report: unpublished

Monitoring Arctic Air Outbreak (Dec 20-26, 2022)

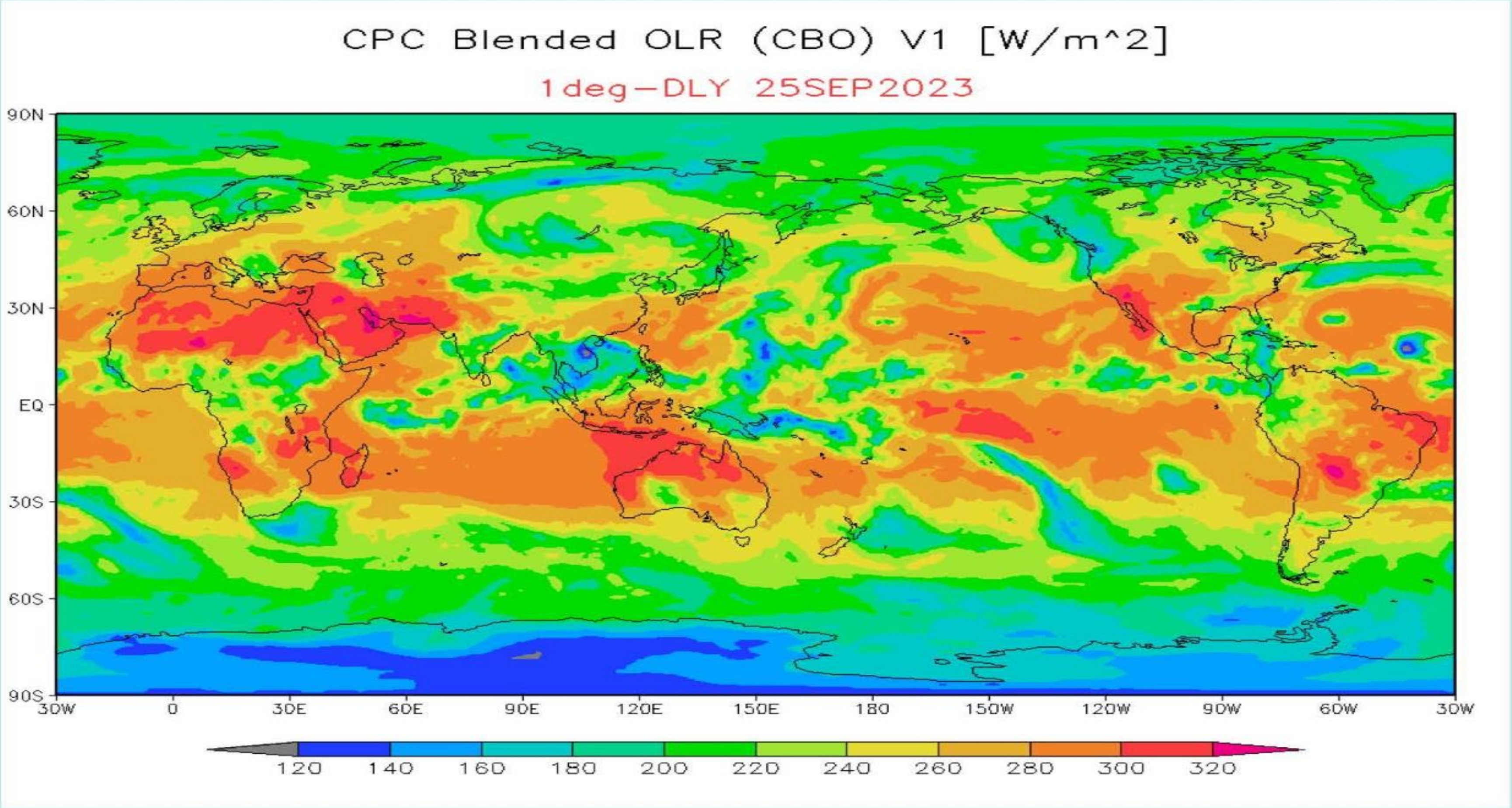


Heatwave in US Pacific Northwest (May 11 – 15, 2023)



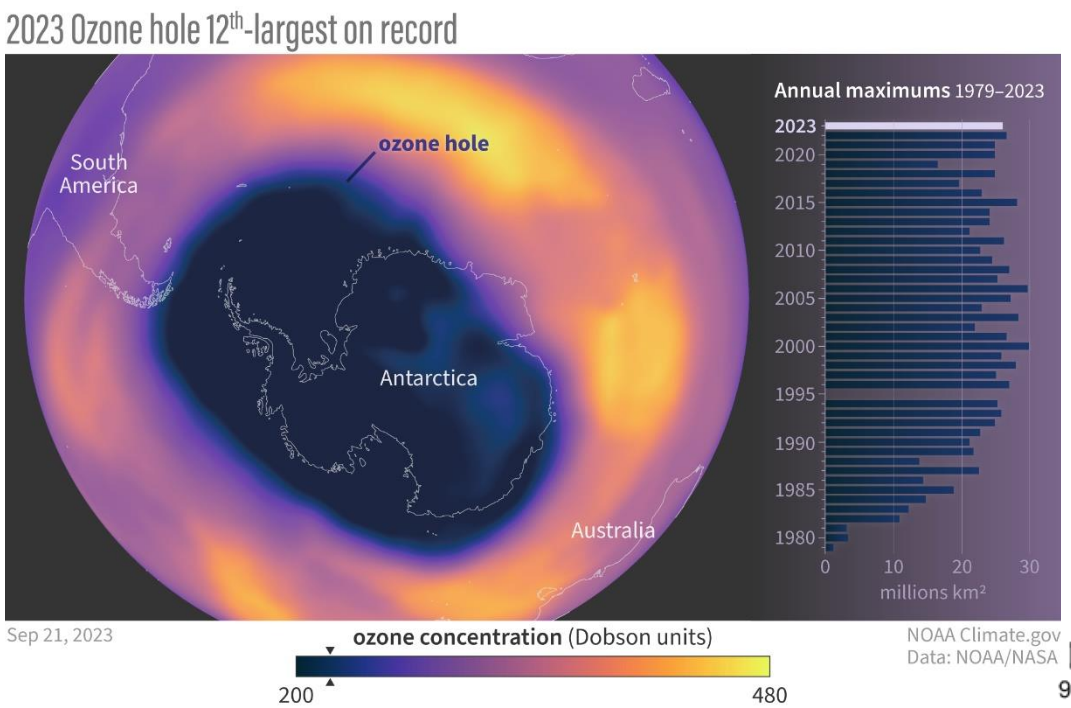
Use of NUCAPS Hyperspectral OLR Retrievals

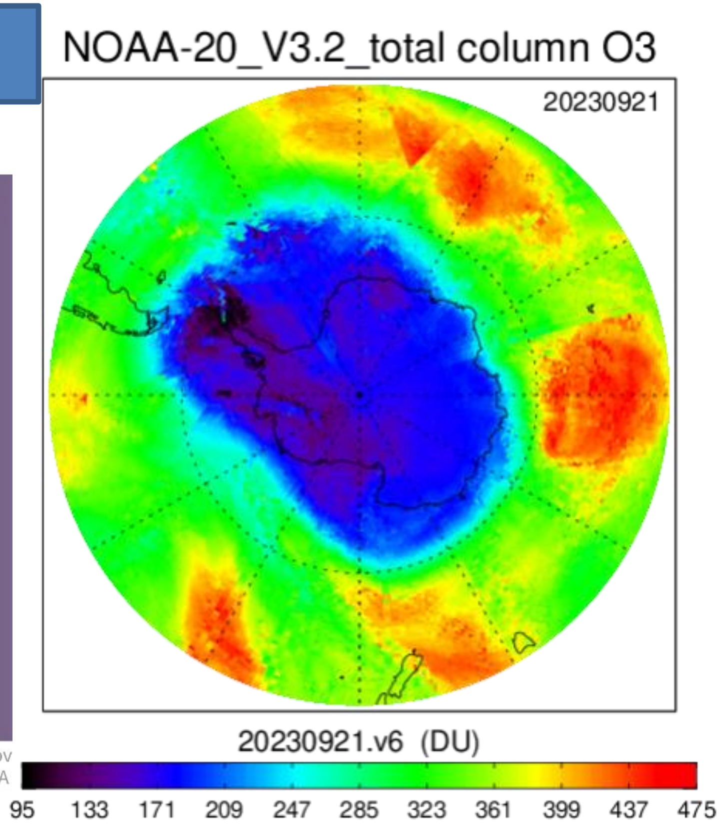
2) Sample Daily OLR derived from NUCAPS Retrievals

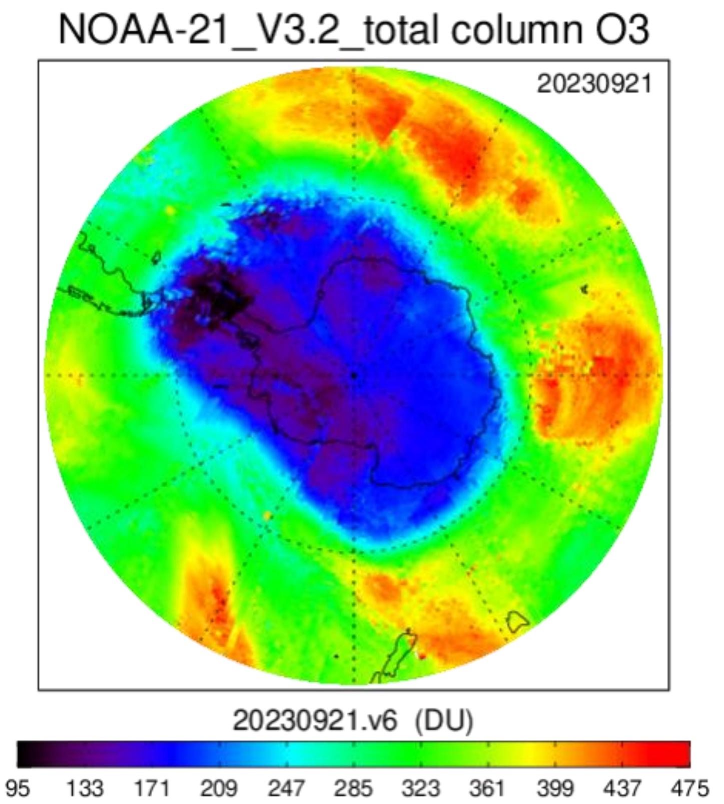


NUCAPS NOAA-21 Captured Ozone Hole at Its Maximum Size on September 21, 2023

2023 ozone hole ranks 12th largest on record

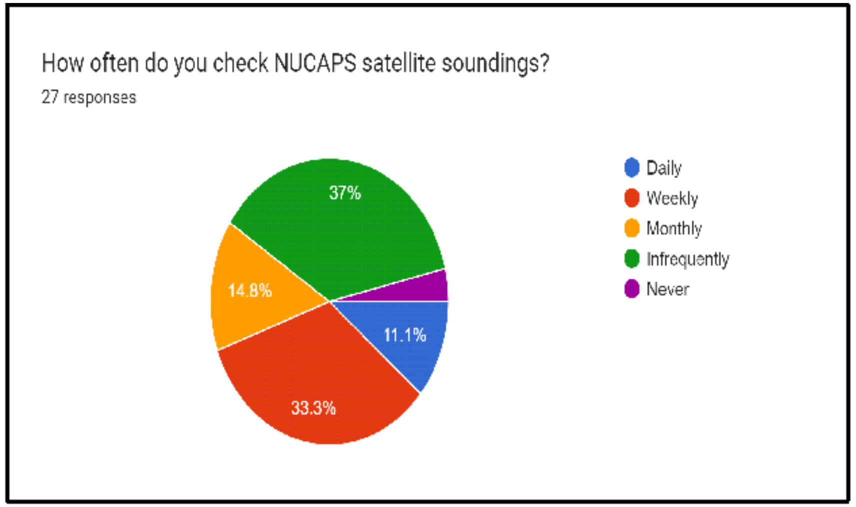


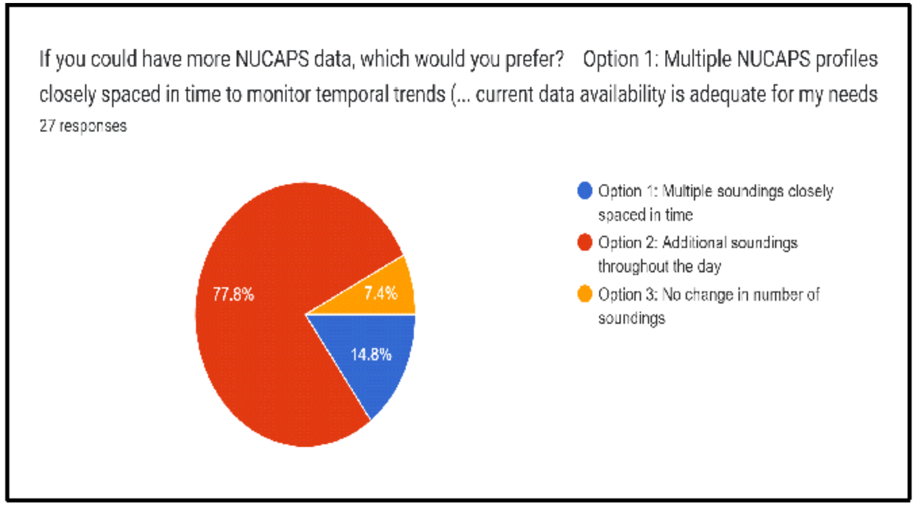


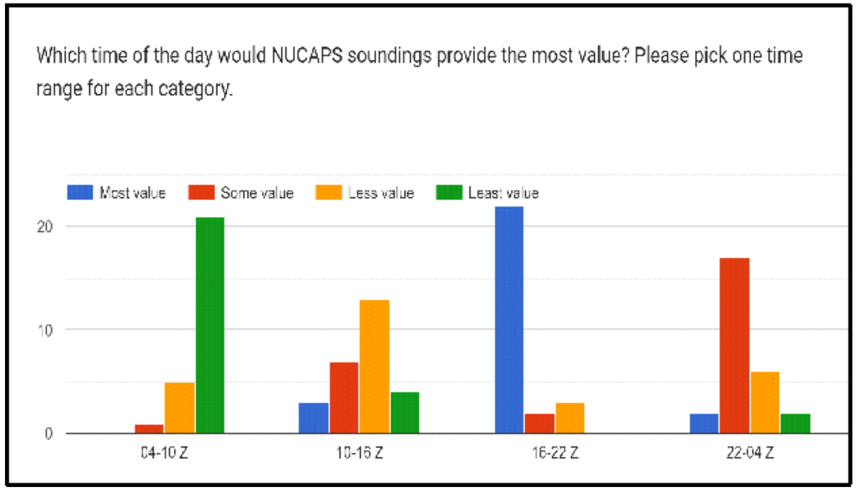


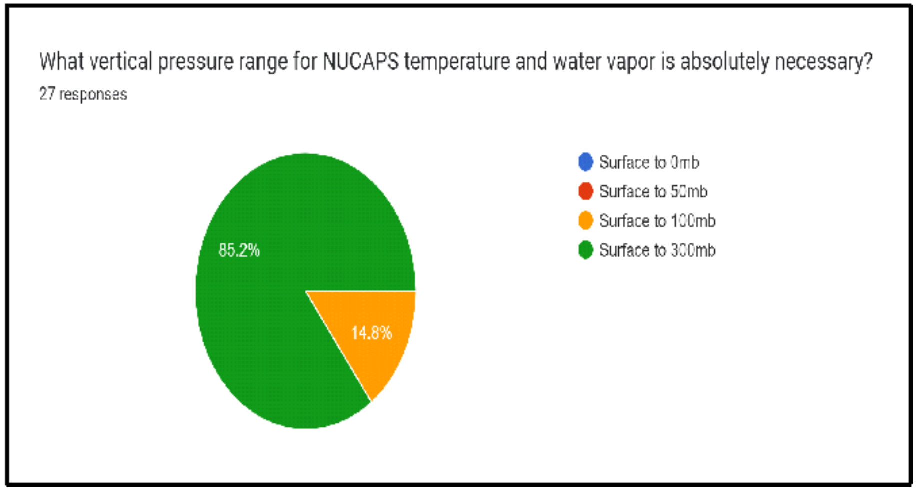
- The 2023 Antarctic ozone hole (the total area where ozone amounts are below 220 DU) reached its maximum size (26 million km^2) on September 21, which ranks as the 12th largest since 1979, according to annual satellite and balloon-based measurements made by NOAA and NASA. –by www.noaa.gov/news-release/ (11/01/2023)
- NUCAPS NOAA-20 and NOAA-21 V3.2 retrievals (IR+MW and MW_only) exhibit a comparable pattern and size in capturing the ozone hole. Further analysis is underway.

Results from 2023 Survey on NUCAPS utilization and interest in additional overpasses from satellites (Source: Rebekah Esmaili)









How can we prepare?

- Revisit file structure/users needs (STAR)
  - MetOp-B/-C and NOAA-20/-21 NUCAPS data file structure the same
- How can we reduce latency as much as possible (STAR/OSPO)
- Ensure that data are AWIPS friendly (STAR)
  - Surface correction a major issue, already being addressed
- Consider how NWS users want to display the data (PGRR)
  - An opportunity to have custom/upgradable AWIPS modules

UKMET NUCAPS User Community

Tornado and Storm Research Organisation

+ Create ▾ Ken Pryor ▾

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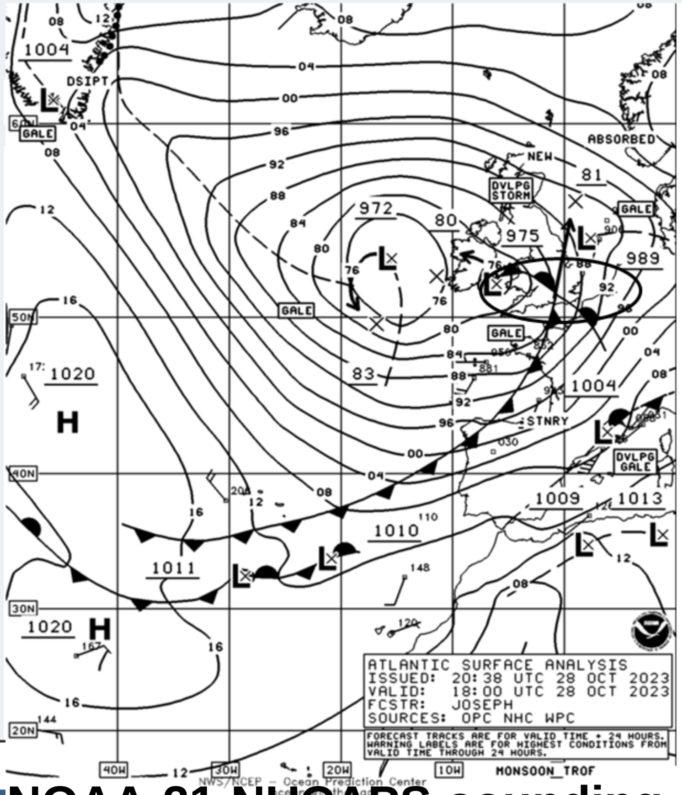
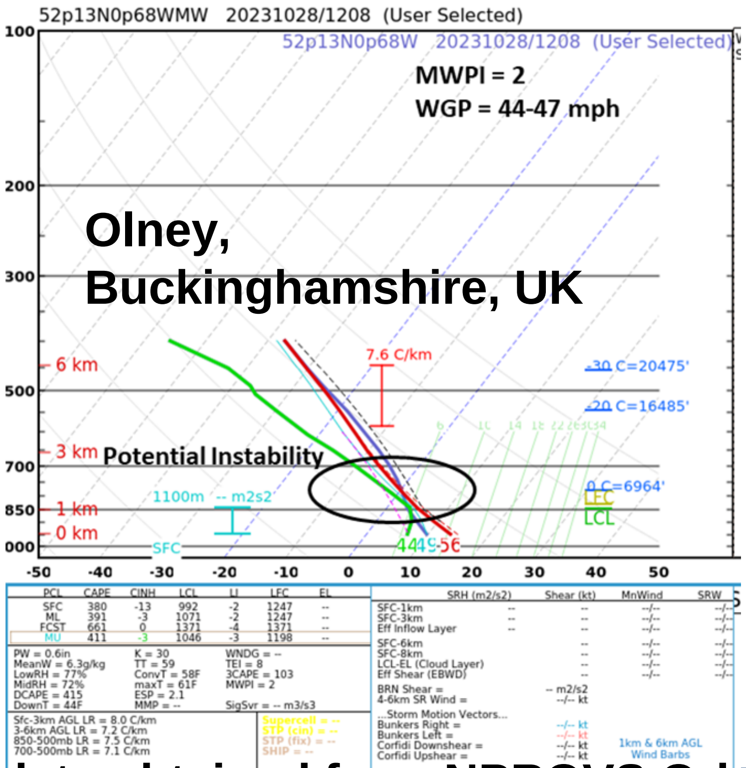
20231028 TN Condicote, Gloucestershire

By Jamie McBean
October 29, 2023 in Severe Weather Reports in Britain and Ireland

✔ Following ▾ 2





Ken Pryor

Members

43
LocationNew Market, Maryland, USA

Posted November 10, 2023 (edited)

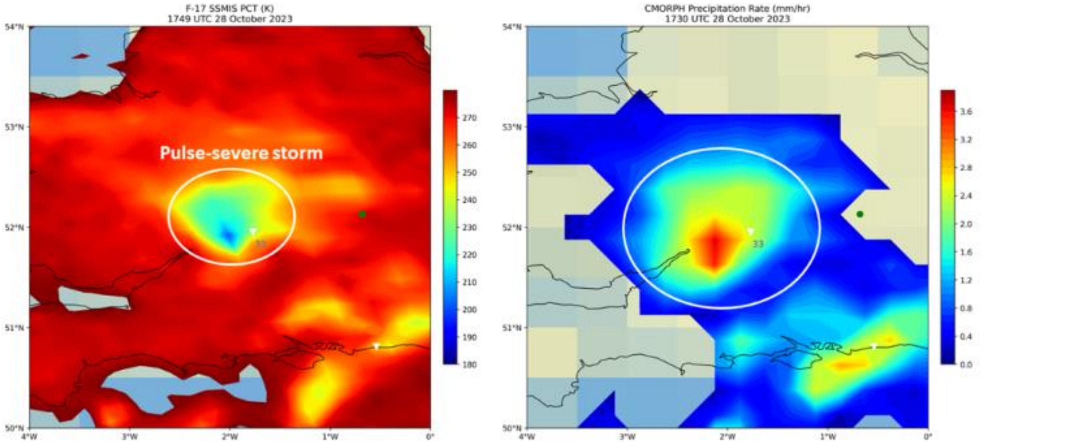
The parent storm of the Gloucestershire tornado appears impressively in satellite passive microwave imagery as a large pulse-type severe storm. Here's my official weekly report to NOAA administration on my preliminary findings of this event study.

NOAA-21 NUCAPS sounding profile observes severe wind and tornado potential over Great Britain: During the late afternoon and early evening of October 28, 2023, areas of intense thunderstorms developed over southwestern England and the English Channel downstream of a double-center extratropical cyclone over the northeastern Atlantic Ocean and Irish Sea. A particularly large and intense pulse-type storm developed in a potentially unstable air mass, containing a relatively deep and convective boundary layer, over Gloucestershire County between 1700 and 1800 UTC. Storm outflow wind and tornado damage near Cheltenham, Gloucestershire, United Kingdom (UK) is shown in Figure 1 that entails significant tree and structural damage. Shortly before the time of tornado occurrence, concurrent Defense Meteorological Satellite Program (DMSP) F-17 satellite Special Sensor Microwave Imager Sounder (SSMIS) 92 GHz polarization-corrected temperature ("PCT") and Climate Prediction Center (CPC) Morphing technique (CMORPH) rainfall rate product images at 1749 UTC and 1730 UTC, respectively, showed in Figure 2 storm structure and intensity and the location of tornado occurrence (white inverted triangle) near Cheltenham. In addition, this storm generated low-end outflow (downburst) winds measured at 33 mph at Little Rissington Royal Air Force station. Accordingly, Figure 3 highlights the closest NOAA-21 NOAA Unique Combined Atmospheric Processing System (NUCAPS) sounding profile over central England over five hours before the tornado event that exhibited a classic "inverted-V" signature, typically associated with warm-season severe downburst wind events over the Southern Great Plains region of the United States. Derived from the sounding profile, the microburst windspeed potential index ("MWPI", K. Pryor, developer) indicated downburst/outflow wind gust potential of 44 to 47 mph, sufficient to promote tornado generation. The NUCAPS sounding retrieval was obtained by the NOAA/NPROVS Orbital Display System (ODS). This preliminary satellite data analysis is a component of an ongoing study conducted by the UK-based Tornado and Storm Research Organisation (TORRO), and will be presented at the upcoming monthly JPSS PGRR Sounding Initiative meeting on November 16, 2023.

Captions:

Figure 1: Significant tree and structural damage associated with the tornado occurrence near Cheltenham, Gloucestershire County, UK on October 28, 2023. Site survey photographs are courtesy of @Matt Clark and @Kay Morrison, Tornado and Storm Research Organisation (TORRO).
Figure 2. Concurrent DMSP F-17 satellite 92 GHz channel polarization-corrected temperature ("PCT") (left) and CPC CMORPH rainfall rate product images on October 28, 2023 shortly before tornado occurrence in Gloucestershire County, UK. The inverted white triangle marks the location of tornado occurrence and the green circle marks the NOAA-21 NUCAPS sounding retrieval location over central England. "33" represents outflow (downburst) winds measured at 33 mph at Little Rissington Royal Air Force station.

Figure 3. The National Weather Service Ocean Prediction Center-produced surface analysis valid at 1800 UTC (left) and the NOAA-21 NUCAPS sounding profile over central England at 1208 UTC (right) October 28, 2023.

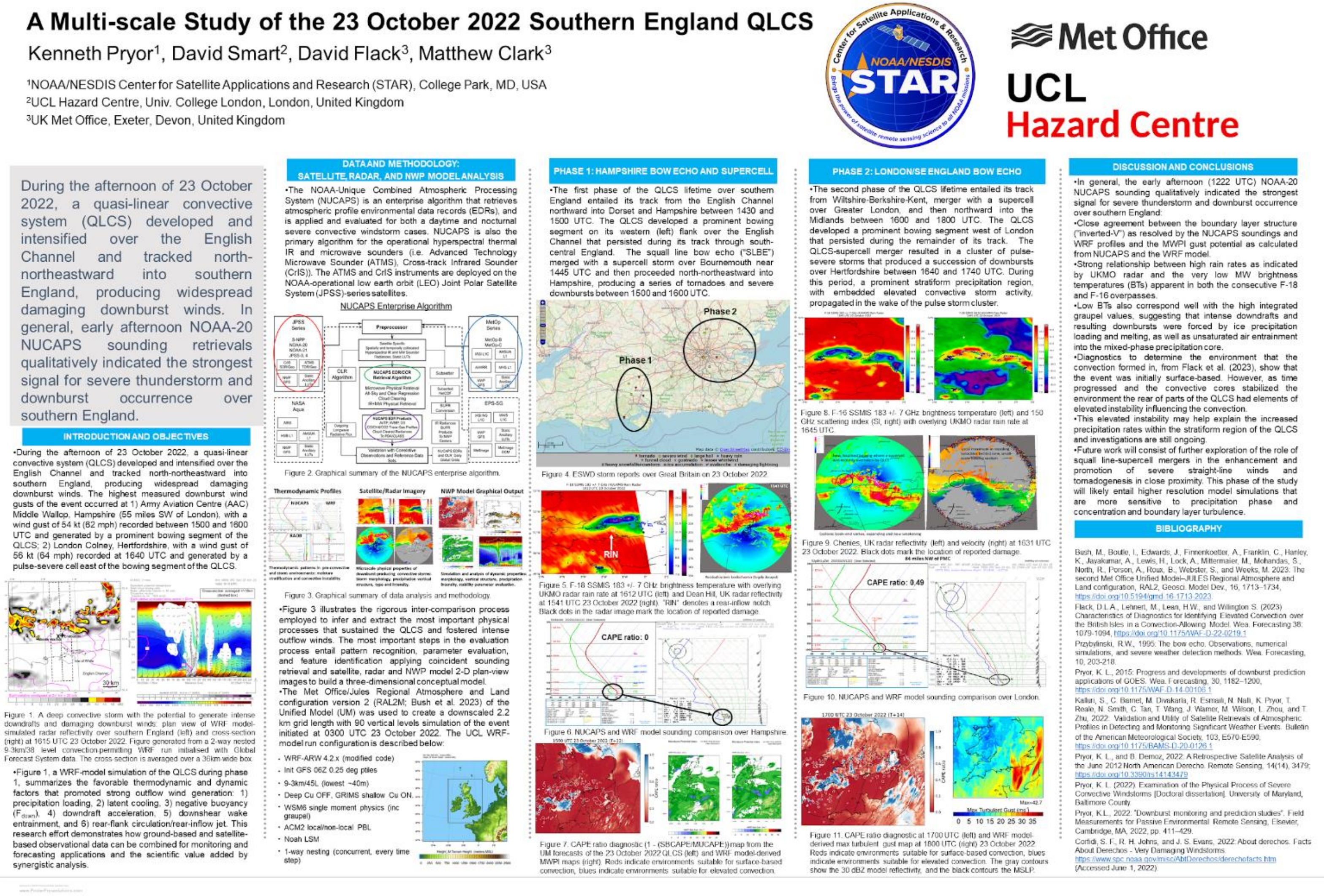


NOAA-21 NUCAPS sounding data obtained from NPROVS Orbital Display

UKMET NUCAPS User Community

Attendance and Presentation at the AMS 20th Conference on Mesoscale Processes:

- K. Pryor presented “A Multi-scale Study of the 23 October 2022 Southern England Quasi-linear Convective System (QLCS)”.
- The poster was viewed by scientists from National Center for Atmospheric Research (NCAR), University of Reading, UK, and University of Melbourne, Australia, with an Interest in NUCAPS sounding profiles of temperature and moisture and LEO satellite microwave image products.
- Presented important study results of cool-season elevated convective storm and mesoscale convective system (MCS) development over Great Britain and northwestern Europe.
- This poster contributed to filling a knowledge gap within the meteorological research community by showcasing the effectiveness of NUCAPS in severe storm environments.



https://ams.confex.com/ams/WAFNWPMS/meetingapp.cgi/Paper/424783

Documentation
Check List for Provisional Maturity

Error Budget

Attribute Analyzed	JPSS Data Product Specifications	Maturity Status	Analysis/Validation Result	Error Summary	Support Artifacts
NOAA-21/20 OLR	Supplemental slides	Provisional	Meets requirements	Slide 37 Slide 101	Slides 27-37
NOAA-21/20 AVTP, AVMP	Slides 39, 40; Supplemental slides	Provisional	Meets requirements	Slide 60 Slide 101	Slides 46-50 Slides 56-60
NOAA-21/20 O3	Slide 61; Supplemental slides	Provisional	Meets requirements	Slides 63-65 Slide 101	Slides 61-69
NOAA-21/20 CO, CH_4 & CO_2	Slide 61, Supplemental slides	Provisional	Meets requirements	Slide 87 Slide 101	Slides 70-86

Documentation

Science Maturity Check List	Yes ?
ReadMe for Data Product Users	✔ Yes
Algorithm Theoretical Basis Document (ATBD)	✔ Yes
Algorithm Calibration/Validation Plan	✔ Yes
(External/Internal) Users Manual	✔ Yes
System Maintenance Manual (for ESPC products)	✔ Yes
Peer Reviewed Publications (Demonstrates algorithm is independently reviewed)	✔ Yes (AMS, AGU presentations; Annual reports on STAR/NOAA-GML Theme 1 (Trace gases) and Theme 2 (Ozone and water vapor); peer reviewed (See below)
Regular Validation Reports (at least annually) (Demonstrates long-term performance of the algorithm)	✔ Yes

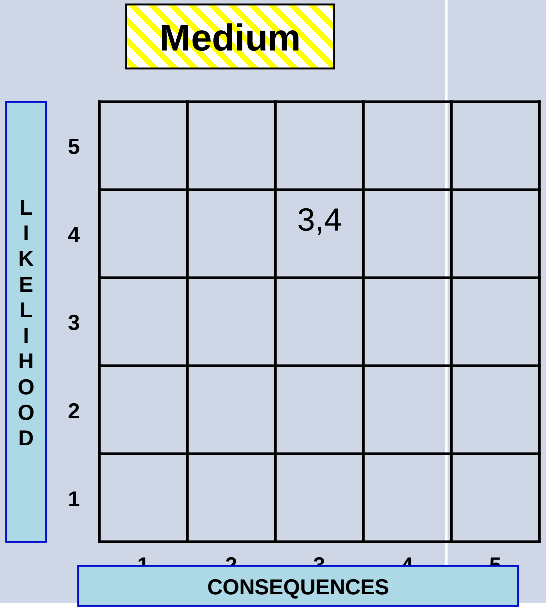
Peer Reviewed Publications and Conference Presentations

1. Nalli, N. R., et al., 2023: Validation of carbon trace gas profile retrievals from the NOAA-Unique Combined Atmospheric Processing System for the Infrared Atmospheric Sounding Interferometer, manuscript in prep for *Remote Sens*. special issue.
2. Kalluri, S., C. Barnet, M. Divakarla, R. Esmaili, N. R. Nalli, K. Pryor, T. Reale, N. Smith, C. Tan, T. Wang, J. Warner, M. Wilson, L. Zhou, and T. Zhu, 2022: Validation and Utility of Satellite Retrievals of Atmospheric Profiles in Detecting and Monitoring Significant Weather Events, *Bull. Amer. Meteorol. Soc., 103*(2), E570-E590, doi: 10.1175/BAMS-D-20-0126.1.
3. Kuciauskas, A., A. Reale, R. Esmaili, B. Sun, N. R. Nalli, and V. R. Morris, 2022: Investigating NUCAPS Skill in Profiling Saharan Dust for Near-Real-Time Forecasting, *Remote Sens., 14*(17), 4261, doi:10.3390/rs14174261.
4. Nalli, N. R., et al., 2020: Validation of carbon trace gas profile retrievals from the NOAA-Unique Combined Atmospheric Processing System for the Cross-Track Infrared Sounder, *Remote Sens.*, *12*(19), 3245, doi:10.3390/rs12193245
5. Nalli, N. R., et al., 2018b: Validation of atmospheric profile retrievals from the SNPP NOAA-Unique Combined Atmospheric Processing System. Part 2: Ozone, *IEEE Trans. Geosci. Remote Sens., 56*(1), 598-607, doi:10.1109/TGRS.2017.2762600.
6. Nalli, N. R., et al., 2018a: Validation of atmospheric profile retrievals from the SNPP NOAA-Unique Combined Atmospheric Processing System. Part 1: Temperature and moisture, *IEEE Trans. Geosci. Remote Sens., 56*(1), 180-190, doi:10.1109/TGRS.2017.2744558
7. Sun, B., A. Reale, F. H. Tilley, M. E. Pettey, N. R. Nalli, and C. D. Barnet, 2017: Assessment of NUCAPS S-NPP CrIS/ATMS sounding products using reference and conventional radiosonde observations, *IEEE J. Sel. Topics Appl. Earth Observ., 10*(6), 2499-2509, doi: 10.1109/JSTARS.2017.2670504
8. Numerous presentations given at domestic and international conferences (e.g. AMS, AGU, etc.)

Check List - Provisional Maturity

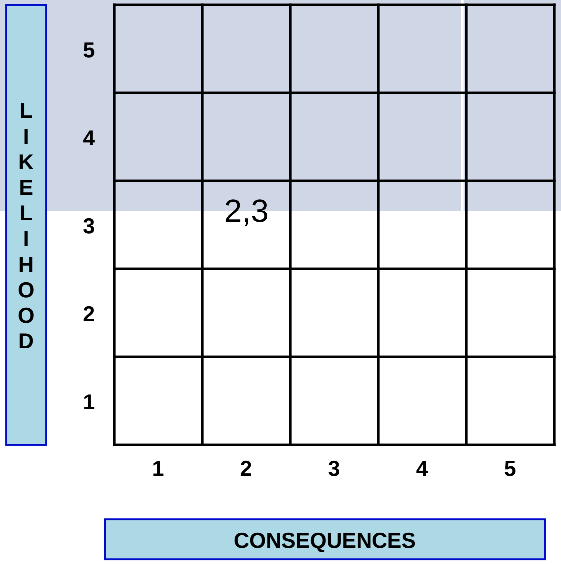
Provisional Maturity End State	Assessment
Product performance has been demonstrated through analysis of a large, but still limited (i.e., not necessarily globally or seasonally representative) number of independent measurements obtained from select locations, periods, and associated ground truth or field campaign efforts.	✔ Yes
Product analysis is sufficient to communicate product performance to users relative to expectations (Performance Baseline).	✔ Yes
Documentation of product performance exists that includes recommended remediation strategies for all anomalies and weaknesses. Any algorithm changes associated with severe anomalies have been documented, implemented, tested, and shared with the user community.	✔ Yes
Product is ready for operational use and for use in comprehensive cal/val activities and product optimization.	✔ Yes

Risk(s)

Risk ID & Rank	Risk ID	Risk Statement	Approach/Mitigation	Status
1. Reference data sets for NUCAPS trace gas product validation.  		**Given that:** There is a time lag between acquisition of 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 NOAA-21, J3	Global validation of carbon trace gases requires acquisition periods for *in situ* data collection, 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(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-NG/MWS) **Low Risk in Implementation**		**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.	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.



Summary

- Performed global evaluation of all the NOAA-21 NUCAPS products
  - ✔ Quality flags and data formats for consistency for both ascending and descending orbits.
  - ✔ Global maps (Asc/Desc) and statistical metrics (NOAA-20/21) *vs* ECMWF (*AVTP, AVMP,* O_3)
  - ✔ AVTP and AVMP assessment with global RAOB matches (NPROVS)
  - ✔ Ozone product assessment with NOAA-GML O_3SNDS
  - ✔ Global maps (Asc/Desc) of CO, CH_4, and CO_2 (NOAA-20 & 21 *vs* TROPOMI CO, CH_4, and OCO-2 v11)
  - ✔ CO, CH_4, and CO_2 assessment with TCCON measurement matches
  - ✔ OLR global (Asc/Desc) maps: NOAA-21 vs NOAA-20 with NOAA-20 CERES.
- Validations of NOAA-21 products show very good performance, and high degree of agreement with NOAA-20 products; **NOAA-21 NUCAPS EDRs (OLR, AVTP, AVMP, O_3, CO, CO_2, CH_4) meet JPSS requirements.**
- **NUCAPS v3.2 DAP has been delivered to the ASSISTT team (1/24/2024).**
- **NUCAPS Team recommends NOAA-21 Provisional Maturity, effective with the operational implementation date of NUCAPS v3.2 in NCCF.**

Path Forward for Validated Maturity

- Planned activities moving from “Provisional” to “Validated”
  - Continue validations exercises following the product validation methodology hierarchies to meet validated maturity requirements.
    - ✔ NOAA-21 OLR product has been validated with CERES and other satellite observations (AIRS) for about 7 months. Based on the presented results, the NUCAPS team recommends “Validated Maturity” for OLR.
  - Global evaluation of NUCAPS products with focus data sets spanned around a year and collocated ECMWF and other models; correlative satellite retrieved products (TROPOMI, OCO-2)
  - Time series of all NUCAPS products validations with truth measurements (global and seasonal)
  - Multi-satellite inter-comparisons and trend analysis for trace gas products
  - AVTP and AVMP validations using NPROVS global RAOB collocations and Validation Archive (VALAR) data sets (currently ongoing)
  - Ozone product validations with additional NOAA-GML, WOUDC-O3 measurements
  - Trace gas product validations with additional TCCON and other in situ measurements
- Near Future Plans: Reprocessing of S-NPP/NOAA-20 NUCAPS products on NCIS; CAMEL emissivity lookup, addition of physical emissivity for snow/ice; NUCAPS product applications: situational awareness, environmental applications.

Supplemental Slides

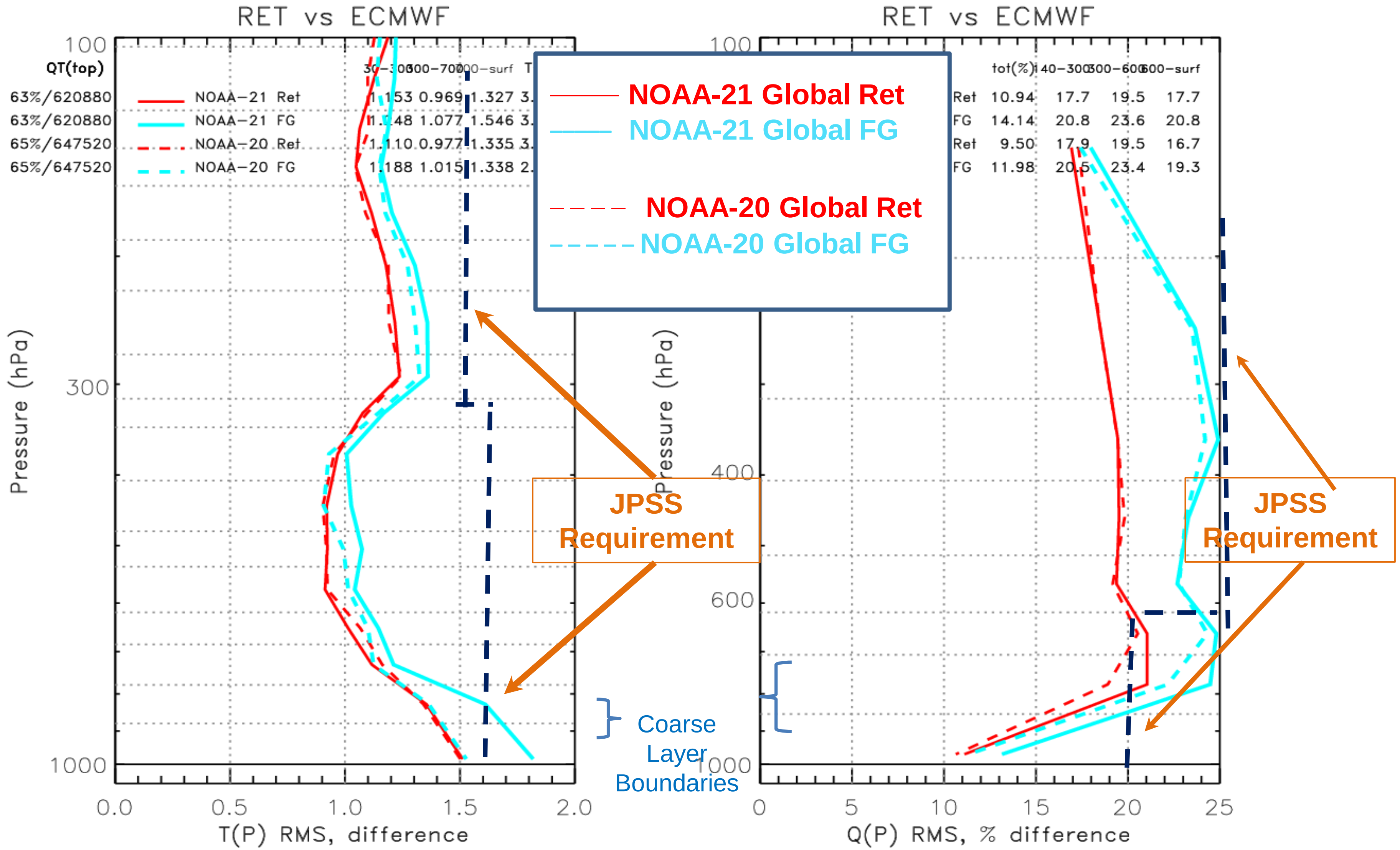
NUCAPS NOAA-21 Provisional Maturity Review

SUPPLEMENTAL SLIDES

Set	List of Supplemental Slides	Slide Numbers
S.1	NOAA-21 Product Evaluations – Additional Slides	
S.2	NPROVS Evaluations – Additional Slides	
S.3	NUCAPS v3.1 Improvements	
S.4	NUCAPS Products Requirements	

NUCAPS NOAA-21 Version 3.1 for Beta Maturity

Item	V3.0 (December 2020) HEAP 2.3	V3.1 (June 2023) HEAP 2.4	V3.1 NOAA-21 Algorithm
	NOAA-20/Metop-C **Currently in Operations**	NOAA-20/Metop-C NCCF Operations: Jan 2024	Version Used for NOAA-21 **Beta Maturity** (Required Changes)
MW a-priori	✔ 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 NOAA-20	✔ No changes – as is for NOAA-20
MW Tuning	✔ Two focus days (20190215, 20190815) and MIT forward model	✔ NOAA-20	✔ Currently using NOAA-20 LUT • **Requires an update for NOAA-21**
Cloudy Regression	✔ PC regression using NOAA-20 all-sky radiances matched with ECMWF, Updated with STC regression code; used four Focus Days	✔ No change – as is for NOAA-20	✔ Currently using NOAA-20 LUT • **Requires an update for NOAA-21**
Clear Regression	✔ PC regression using NOAA-20 CCR radiances matched with ECMWF ✔ Used four Focus Days (20180415, 20180715, 20181015, 20190115)	✔ No change – as is for NOAA-20 ✔ Updated regression code	✔ Currently using NOAA-20 LUT • **Requires an update for NOAA-21**
Emissivity Regression	✔ NO change from the operational version (V2.1.12d)	✔ No change – as is for NOAA-20	✔ No changes – as is for NOAA-20 ✔ Experiments on-going to update with CAMEL
IR Tuning	✔ Double Difference Method using NOAA-20 radiances and ECMWF SARTA simulations	✔ No change – as is for NOAA-20	✔ Currently using NOAA-20 LUT • **Requires an update for NOAA-21**
CO climatology/QC	✔ No Change from the operational version (V2.1.12d)	✔ No change – as is for NOAA-20	✔ No changes – as is for NOAA-20
CH_4/N2O a-priori	✔ Updated CH_4/N_2O a-priori; QC flag updates to CH_4	✔ No change – as is for NOAA-20	✔ No changes – as is for NOAA-20
SO_2	✔ Climatology	✔ Retrieval turned on	✔ Retrieval turned on
CO_2 a-priori	✔ Updated CO_2 a-priori and QC flag updates	✔ CO_2 a-priori updates and QC flags	✔ No changes – as is for NOAA-20
CrIS Noise File	✔ No change from the operational version (V2.1.12d)	✔ No change – as is for NOAA-20	✔ Currently using NOAA-20 LUT • **Requires an update for NOAA-21**
Channel Selection for cloud-clearing, T(p),q(p)	✔ Minor updates of channels ✔ Super saturation QC flag implemented	✔ No change – as is for NOAA-20	✔ No changes – as is for NOAA-20
Channels selection for trace gases	✔ No change from the operational version (V2.1.12d)	✔ No change – as is for NOAA-20	✔ No changes – as is for NOAA-20
Averaging Kernels and other product improvements	✔ None in the output file	✔ Added Averaging Kernels to the NUCAPS Product File ✔ Updated ozone a-priori ✔ Surface corrections to alleviate product use ✔ Damping factor update to improve boundary layer biases	✔ Carried forward these additional improvements ✔ No changes – as is for NOAA-20



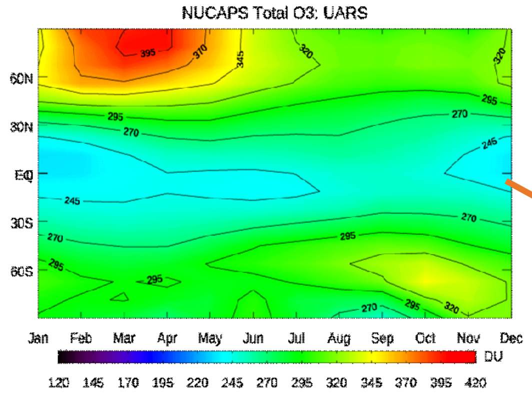
- **Slide from Beta Maturity**
- "NOAA-21-Ready" algorithm (Beta Maturity) used NOAA-20 regression LUTs to provide First Guess.
- "NOAA-21 algorithm" (Provisional Maturity) has updated FG LUTs generated with matched NOAA-21 and ECMWF collocations.

NOAA-21-Provisional' FG LUT updates perform better than the "NOAA-21-Ready" algorithm used for Beta Maturity

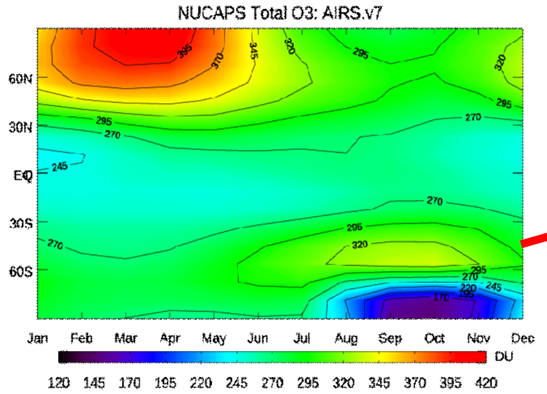
NUCAPS Ozone Product Improvements and Validations with NOAA-GML O_3SNDs Collocations

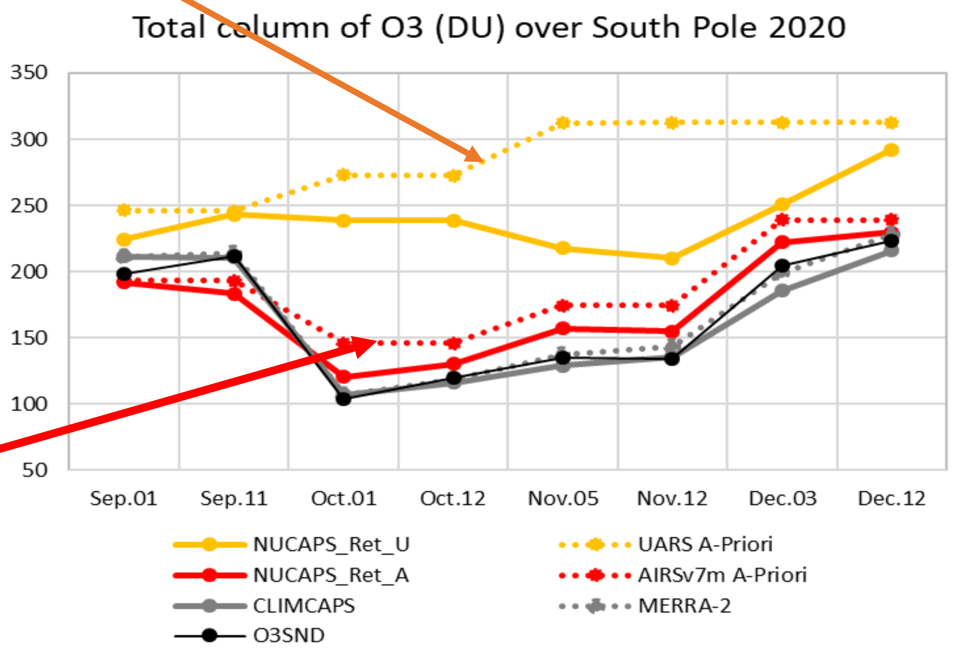
- Evaluated NUCAPS Ozone retrievals over Antarctica spring to summer transition
- Utilized collocated NUCAPS and CLIMCAPS retrievals with NOAA GML O_3SNDs to validate the algorithm improvements
- Evaluated relative merits of NUCAPS and CLIMCAPS a-prioris and final retrievals with collocated O3SNDS through three-way inter-comparison
- Provided matched NUCAPS retrievals with Averaging Kernels for NOAA GML evaluations

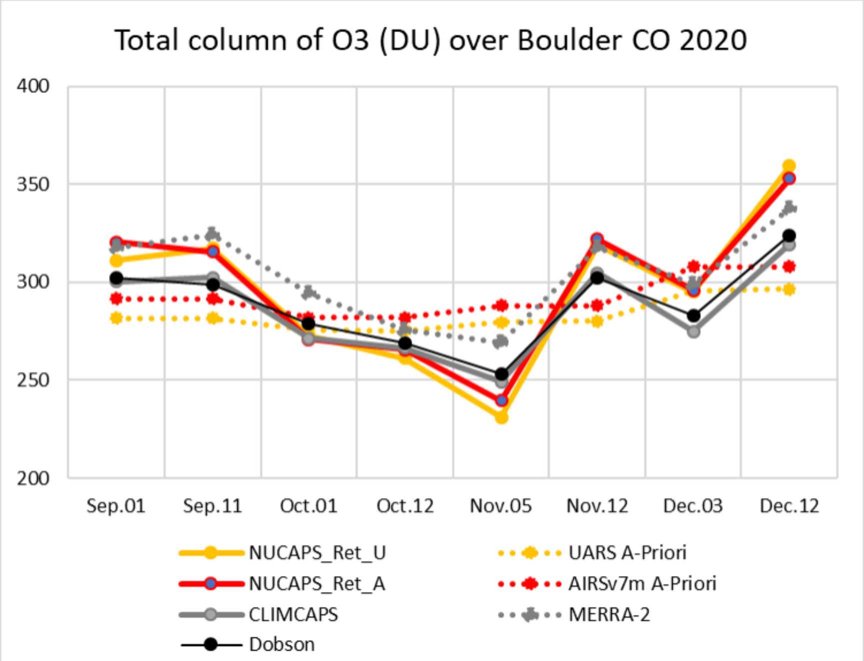
NUCAPS OPS: Ozone a-priori
Ozone Validated Maturity version



NUCAPS v3.1:
Ozone new a-priori







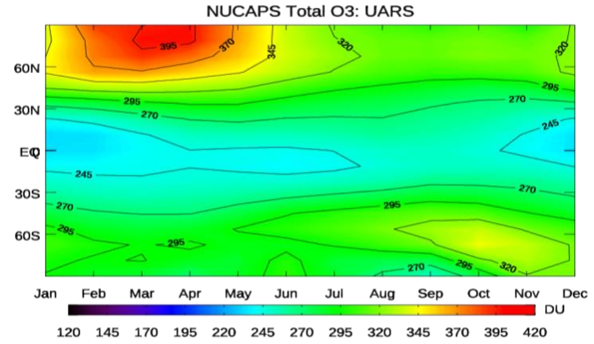
NUCAPS NOAA-20 Ozone Product Validations Using Focus Day Data Sets and ECMWF Collocations

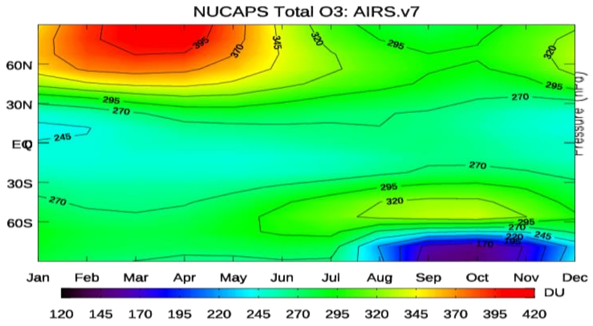
Focus Day Data Sets with ECMWF Collocations

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	√	√	√	√	√	√						

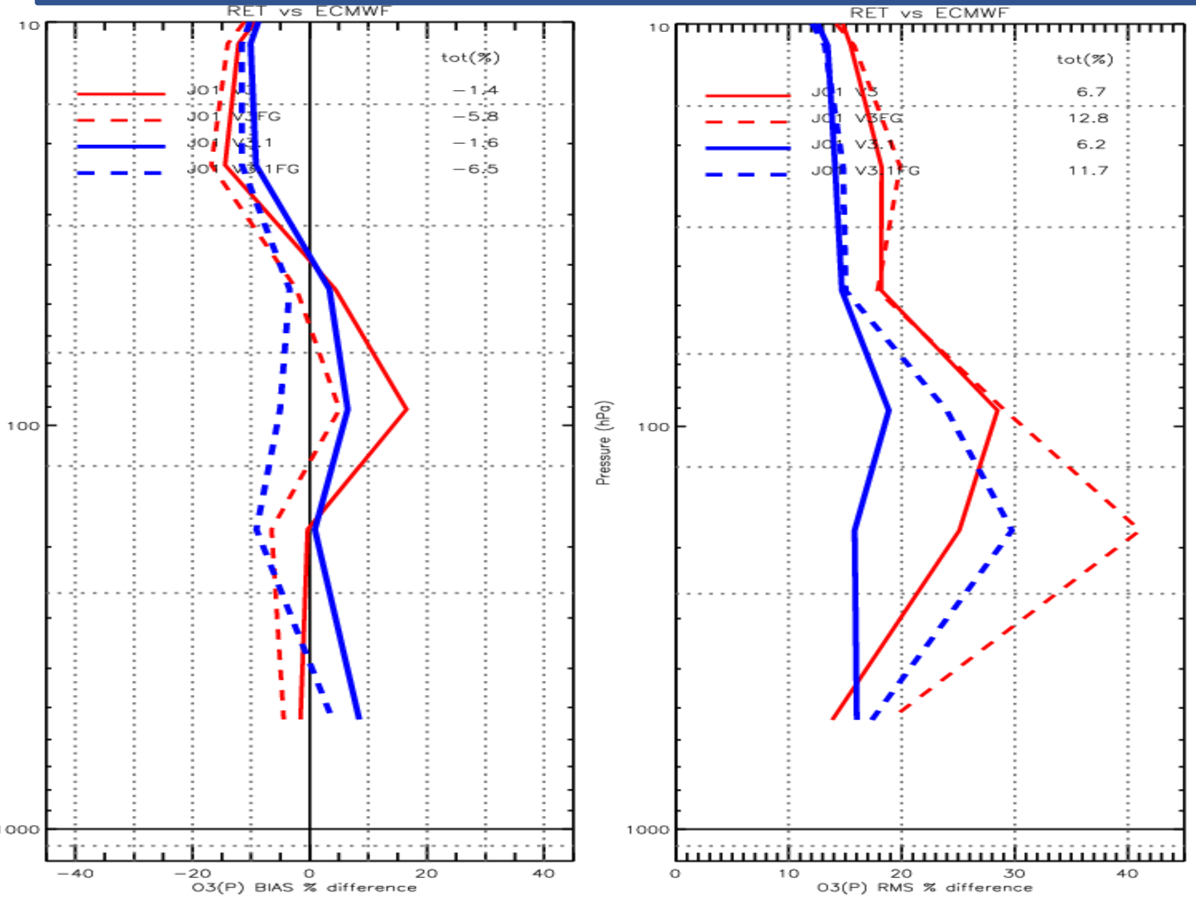
NUCAPS OPS: Ozone a-priori
Ozone Validated Maturity version

NUCAPS v3.1:
Ozone new a-priori





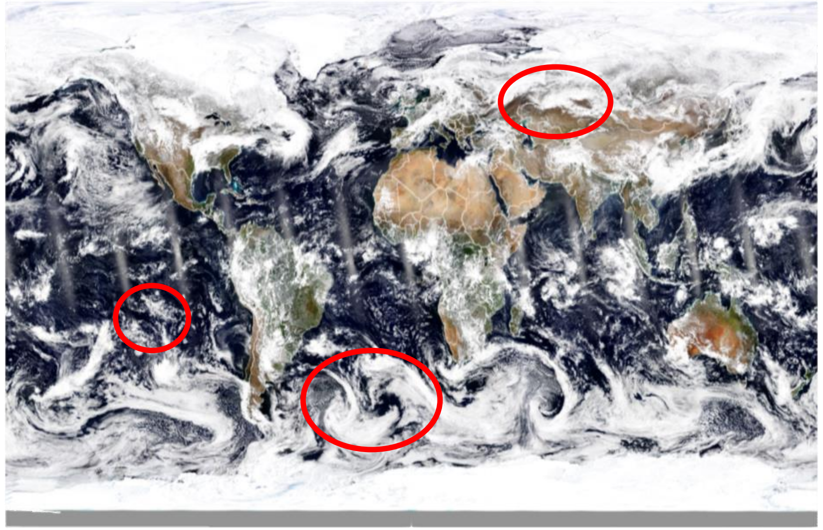
NUCAPS NOAA-20 Global Ozone Retrieval vs. ECMWF
Sample Size: 12 focus days: 3,856,560
Dashed Lines: v3.0: a-priori V3.1: new a-priori
Solid Lines: v3.0 Final Retrieval, v3.1 Final Retrieval
Bias **RMS**

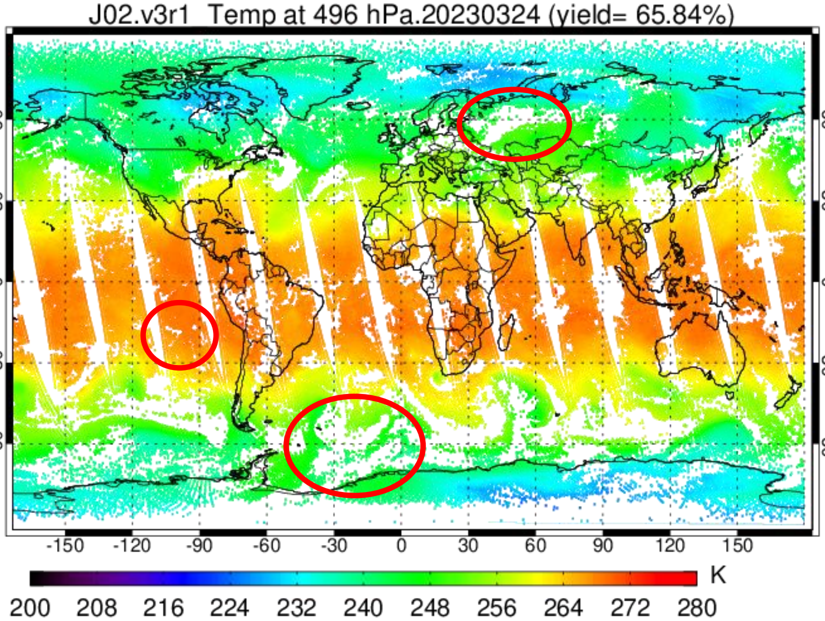


- NUCAPS v3.1 global O_3 profile retrievals show improved statistical metrics with ECMWF collocations.
- Currently going through NCCF operational implementation

NOAA-20 V3.1, NOAA-21 V3.1 NOAA-21 V3.2 (20230324)

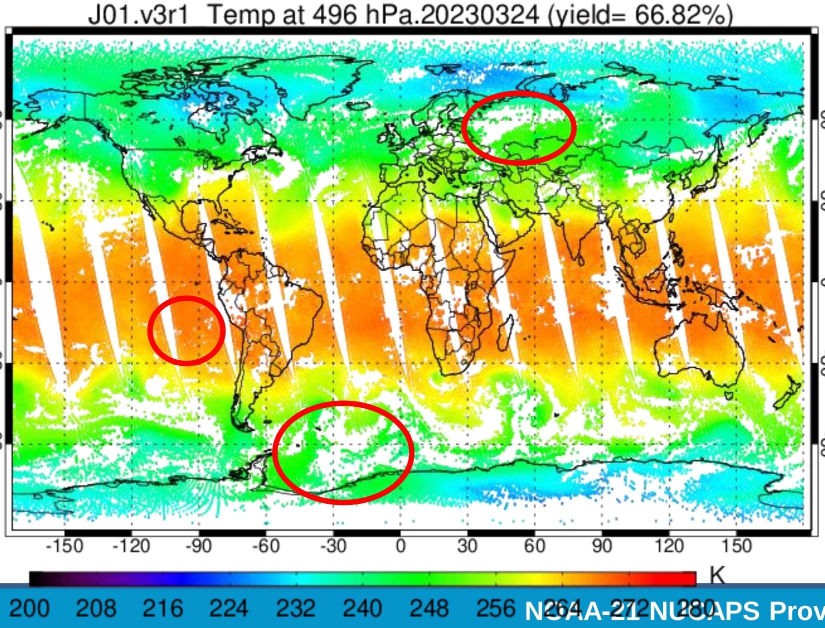
VIIRS J02
Cloud Mask

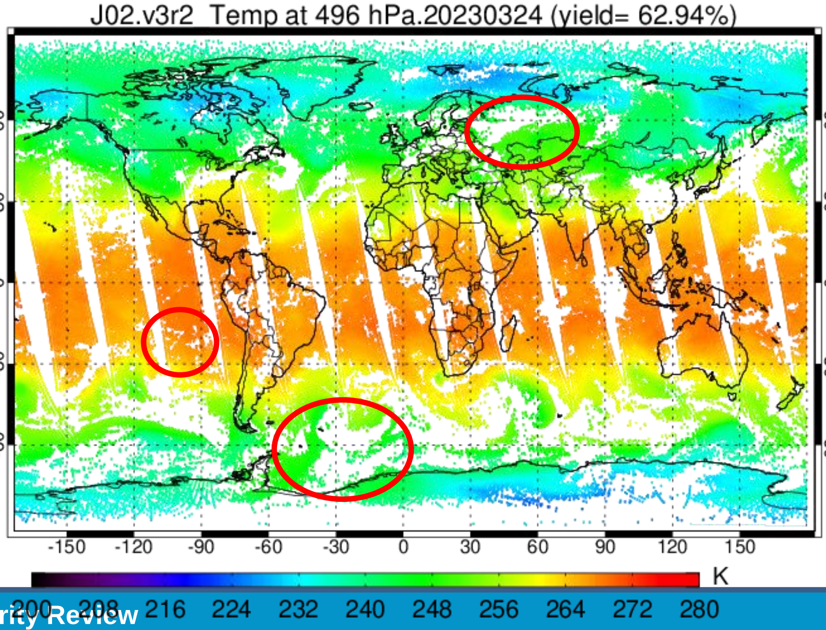




NOAA-21
V3.1

NOAA-20
V3.1



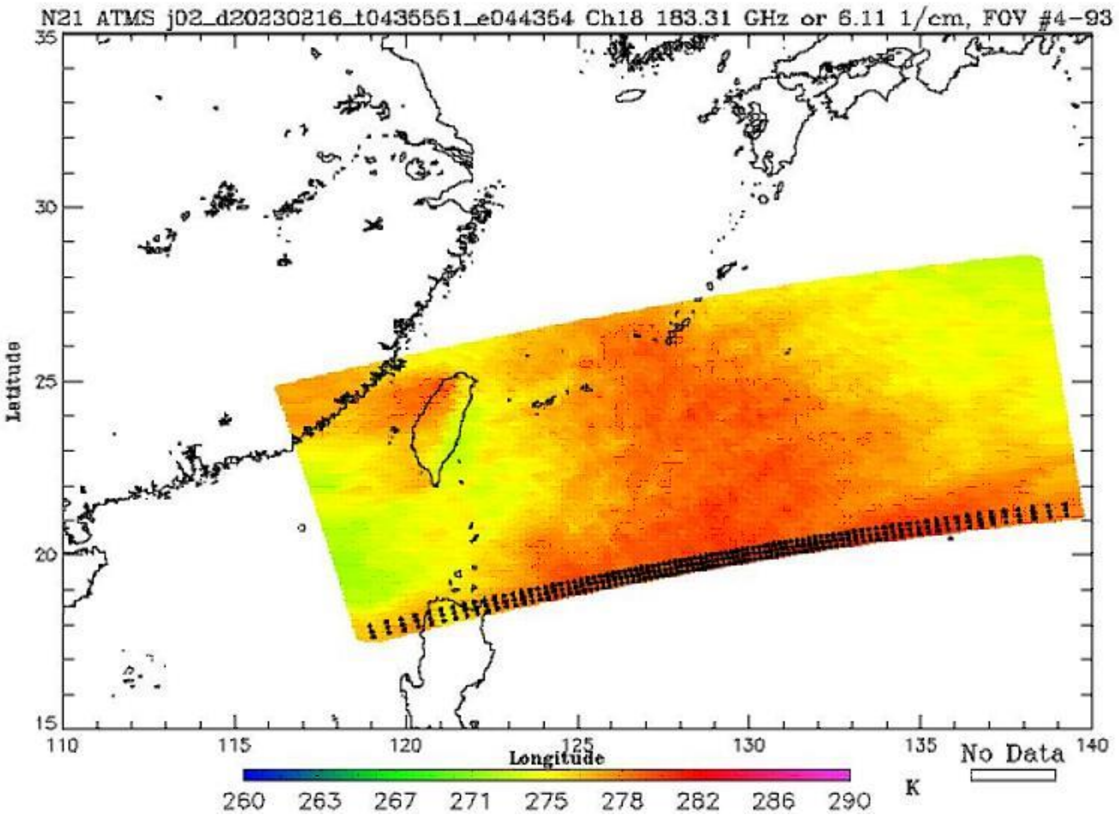


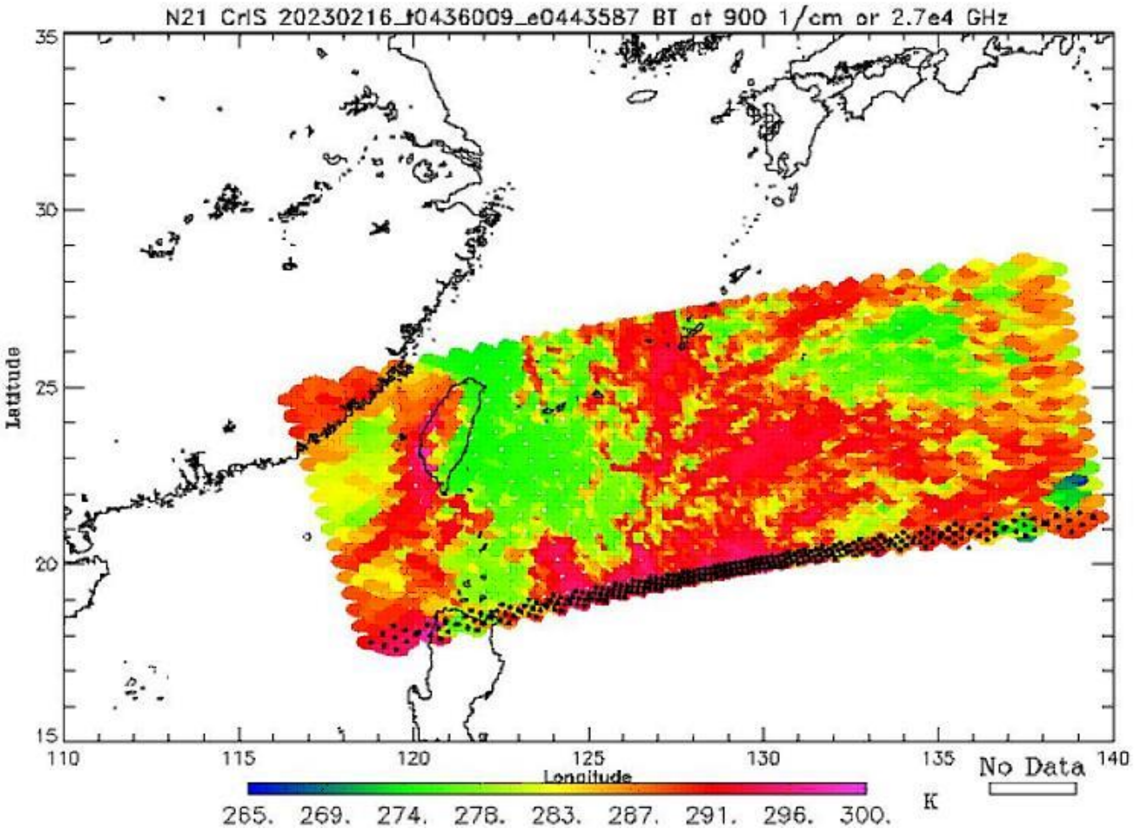
NOAA-21
V3.2

NOAA-20 vs NOAA-21 ATMS rotation and CrIS Matching

(Chris's email on February 24, 2023)

sub: on-orbit ATMS/CrIS footprints are perfectly aligned, as expected



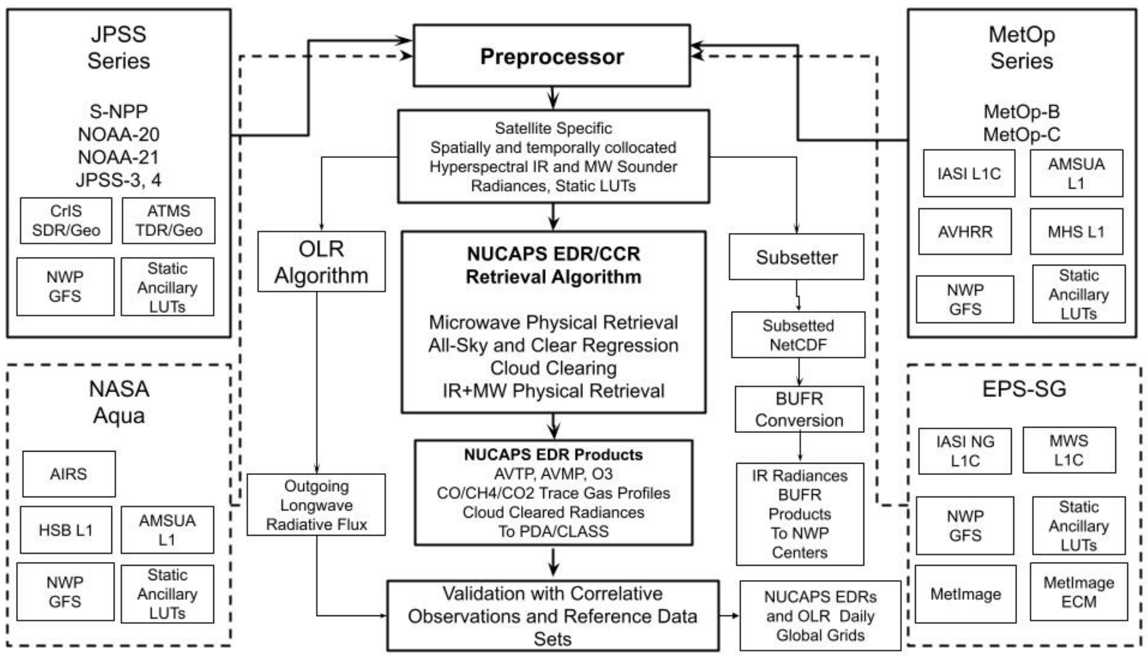


NOAA Unique Combined Atmospheric Processing System (NUCAPS)

Algorithm Version, Processing Environment, Inputs, Outputs

NUCAPS runs within the Hyperspectral Enterprise Algorithm Package (HEAP v2.3) and operationally produces AVTP, AVMP, O3, OLR, CO, CH_4 and CO_2 products from JPSS NOAA-20 CrIS and Metop-B/C IASI hyperspectral infrared sounding instruments.

NUCAPS Enterprise Algorithm



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), 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

Retrieved Parameter	Spectral Range Used (cm^{-1})
AVTP	**650-800** **2375-2395**
AVMP	**1200-1600**
Cloud P, T, fraction	**700-900**
O_3	**996-1068**
CO	**2155-2200**
CH_4	**1220-1370**
CO_2	**666-795**

- HEAP (NUCAPS) v3.0 is currently in operations. Algorithm updates, sensor-independent LUTs, QC/QA are all updated for MetOp-C/B/ using the latest baseline version of NOAA-20
- 'NOAA-21-Ready' NUCAPS algorithm uses NOAA-20 LUTs

Satellite	Instrument
JPSS NOAA-20/21, J3)	CrIS/ATMS; S-NPP products discontinued due to unavailability CrIS midwave band
MetOp-B, C	IASI/AMSU-A/MHS

About OLR CERES.

https://www.earthdata.nasa.gov/learn/articles/ceres-instrument-primary-source-for-observing-heat-budget

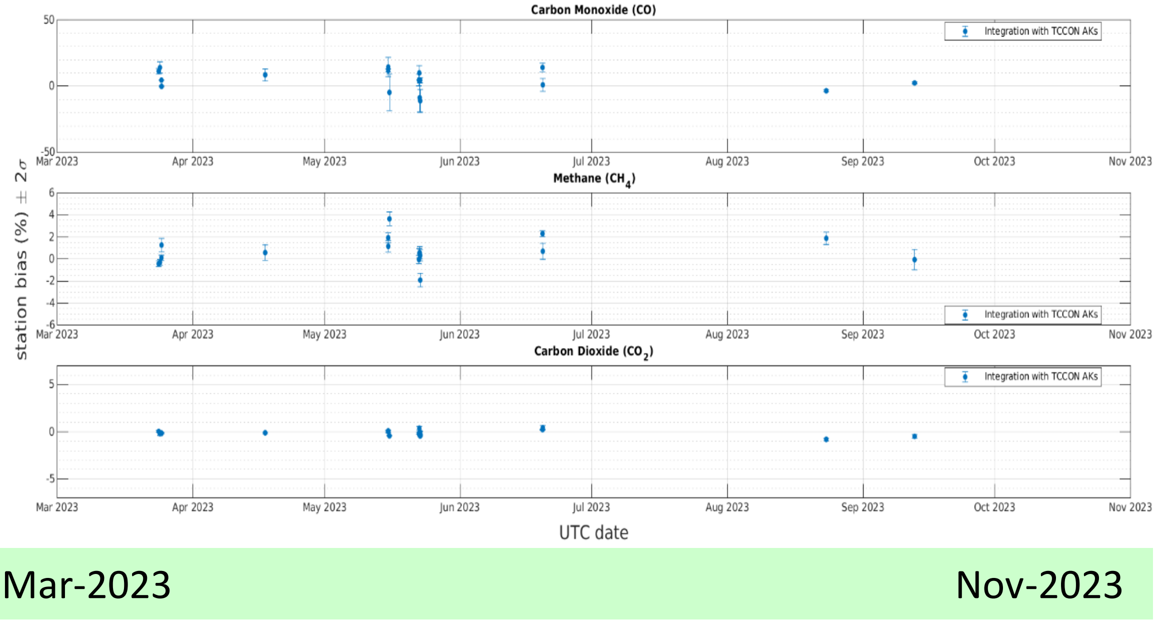
"If people are analyzing the 20-plus years of CERES data, right now they're using Terra and Aqua. The record starts with [CERES data from] Terra, and then goes to Terra plus Aqua," said Loeb. "The plan was to transition to NOAA-20 and we were going to do that in July [2020], but with the Aqua anomaly that we had in April [2020], we figured we'd just do it then. So, NOAA-20 has taken over from Terra and Aqua, so the [climate data] record will be Terra only from March 2000 to June 2002, Terra and Aqua from July 2002 to March 2022, and then NOAA-20 from April 22 onward.“

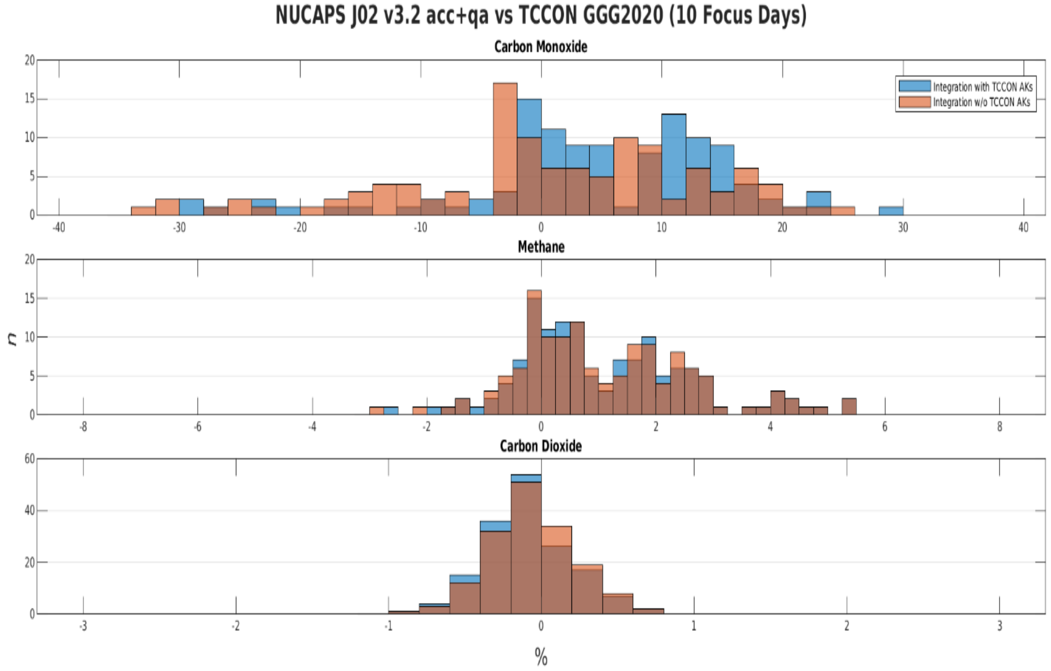
January 26, 2018: NASA has been developing a next-generation sensor to collect this type of data – the **RBI** (Radiation Budget Instrument). However, RBI has experienced significant technical issues and substantial cost growth over the past two years. Because of these challenges, and the low risk of experiencing a gap in this data record over the next eight years due to having two relatively new instruments presently in orbit, NASA has decided to discontinue development of RBI. [10)]

NASA's newest sensor measuring Earth's radiation budget in orbit — CERES (Clouds and the Earth's Radiant Energy System) — was launched on Nov. 18, 2017, aboard the National Oceanic and Atmospheric Administration's JPSS-1 (Joint Polar Satellite System-1), now named NOAA-20. CERES instruments are currently collecting data on four different U.S. spacecraft, including the joint NASA/NOAA Suomi NPP launched in 2011. Two other CERES instruments have been operating well for more than a decade.

https://www.eoportal.org/satellite-missions/jpss-2#mission-status

TCCON time series and NUCAPS-TCCON Differences





- The histograms show roughly Gaussian distributions in the errors.
- CH_4 and CO_2 basically show very little difference when TCCON AKs are applied.
- CO shows a larger bias with TCCON AKs applied, because the TCCON AKs for CO (unlike CH_4 and CO_2) all peak above the upper-troposphere/lower-stratosphere (UT/LS), whereas the NUCAPS AKs for CO peak in the mid-troposphere. Thus greater weight is given to the (UT/LS) when TCCON AKs are applied to NUCAPS, and given that NUCAPS has no skill above 100 hPa, we therefore would expect less agreement in the total column results.

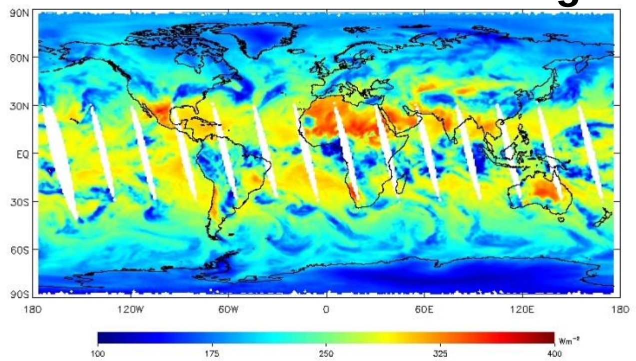
Supplemental Slides

(S.2) NOAA-21 PRODUCT EVALUATIONS – ADDITIONAL SLIDES

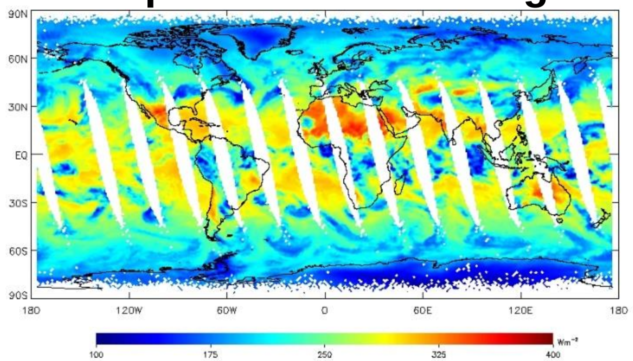
Aqua AIRS vs NOAA-21 CrIS OLR for **24 March 2023**

✔ NOAA-21 CrIS OLR agrees well with Aqua AIRS for both ascending and descending orbits.

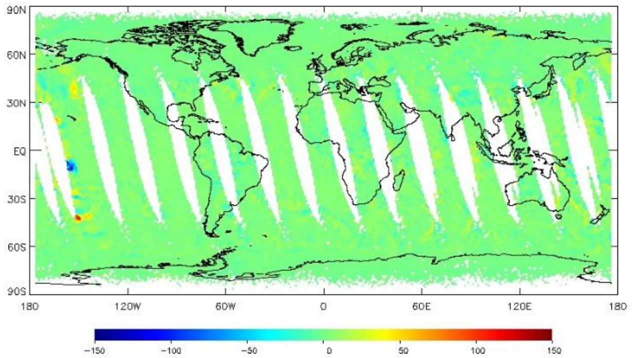
NOAA-21 CrIS Ascending



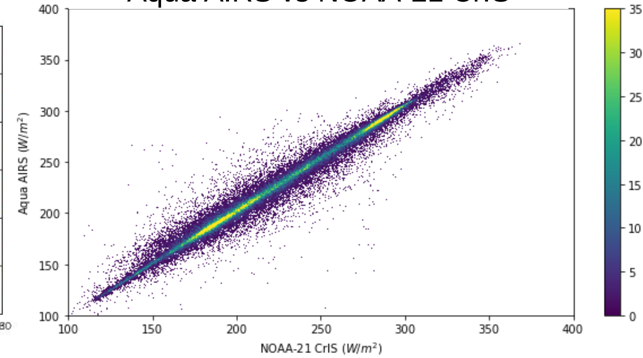
Aqua AIRS Ascending



OLR Differences

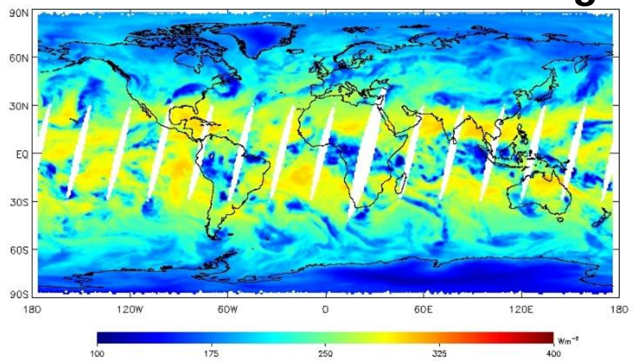


Aqua AIRS vs NOAA-21 CrIS

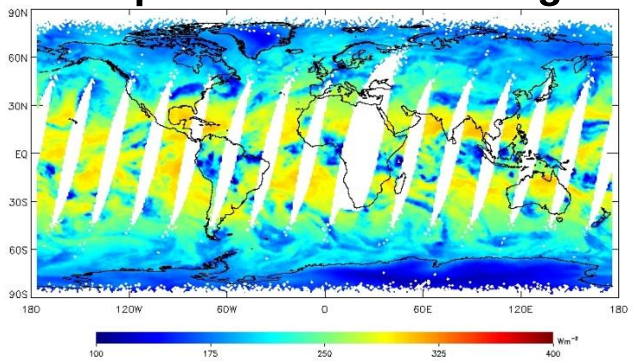


Mean Diff (W/m²)	**2.4**
STDev (W/m²)	**8.6**

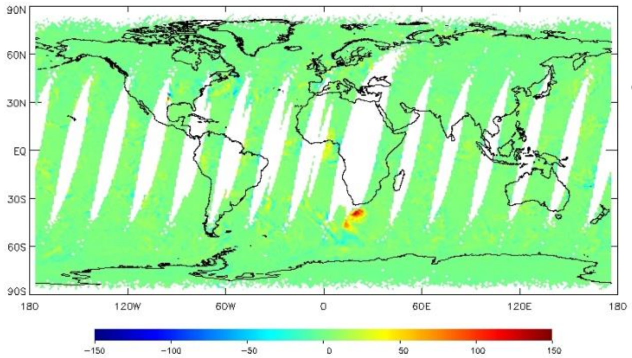
NOAA-21 CrIS Descending



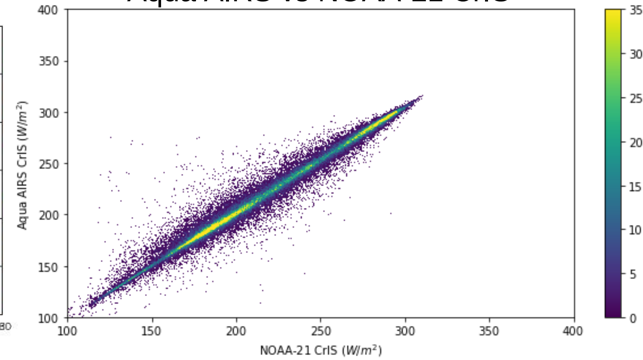
Aqua AIRS Descending



OLR Differences



Aqua AIRS vs NOAA-21 CrIS

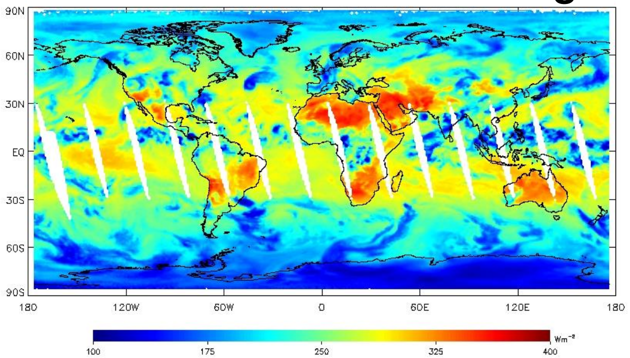


Mean Diff (W/m²)	**2.5**
STDev (W/m²)	**8.0**

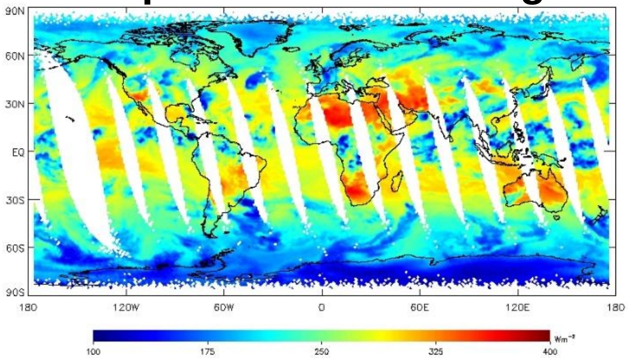
Aqua AIRS vs NOAA-21 CrIS OLR for **21 Sept 2023**

✔ NOAA-21 CrIS OLR agrees well with Aqua AIRS for both ascending and descending orbits

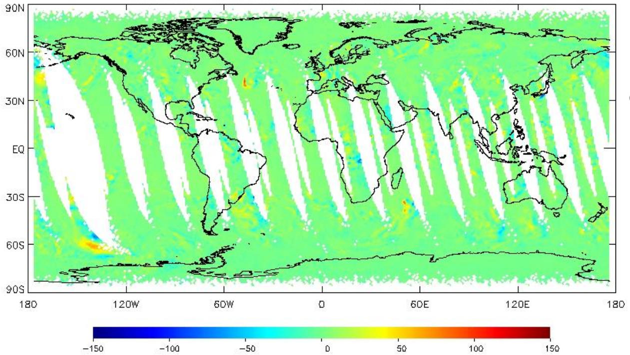
NOAA-21 CrIS Ascending

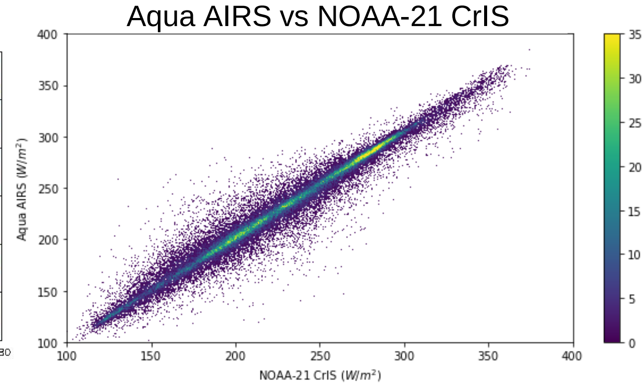


Aqua AIRS Ascending



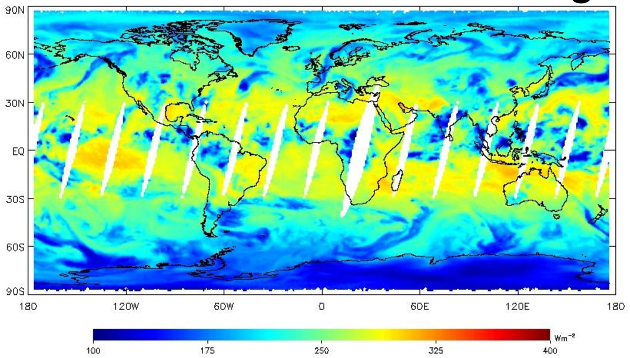
OLR Differences



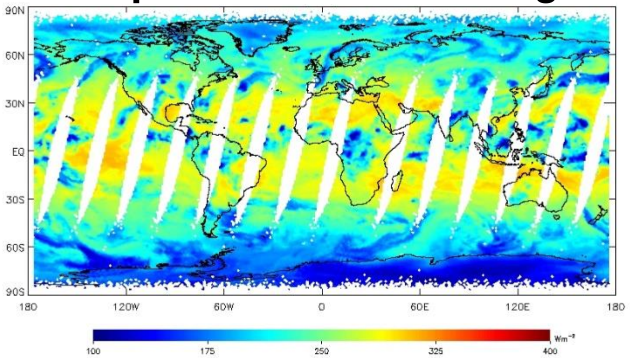


Mean Diff (W/m²)	2.0
STDev (W/m²)	10.3

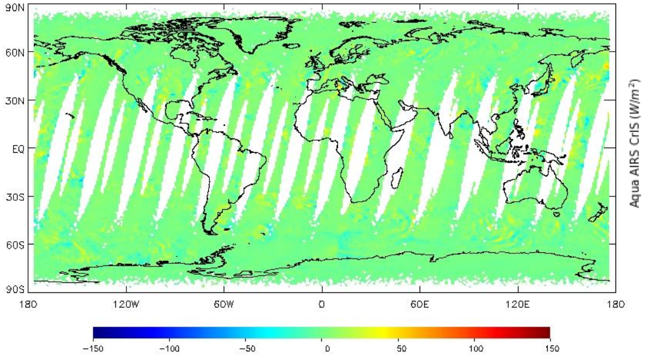
NOAA-21 CrIS Descending

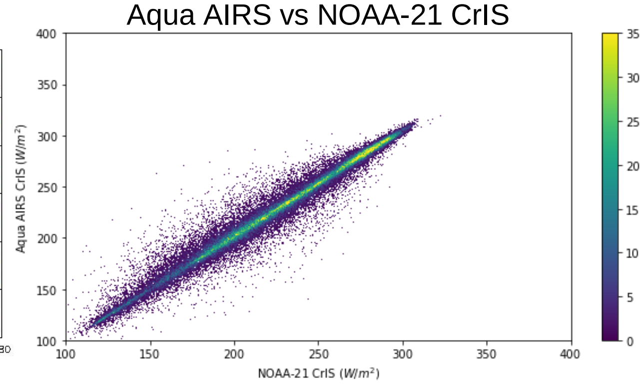


Aqua AIRS Descending



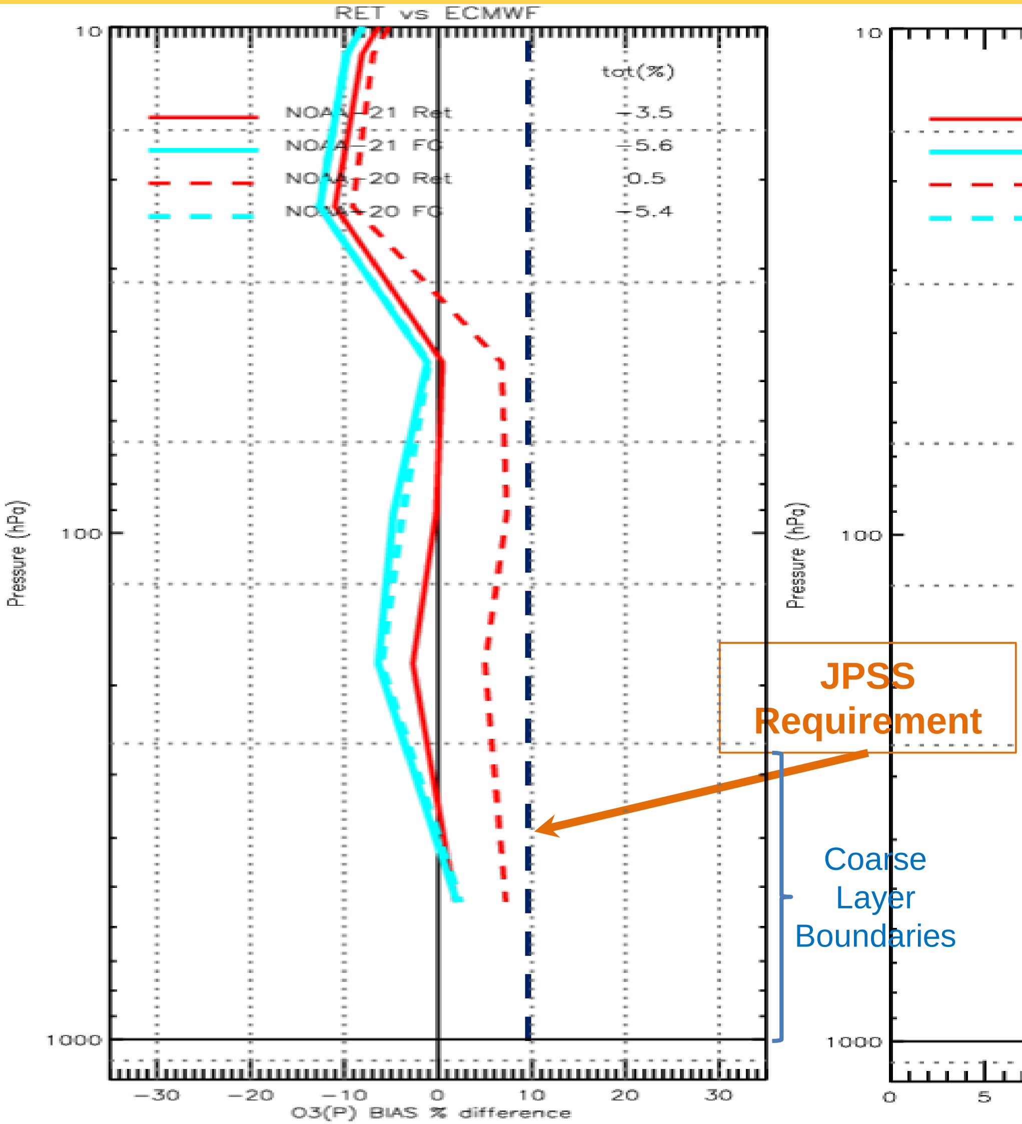
OLR Differences

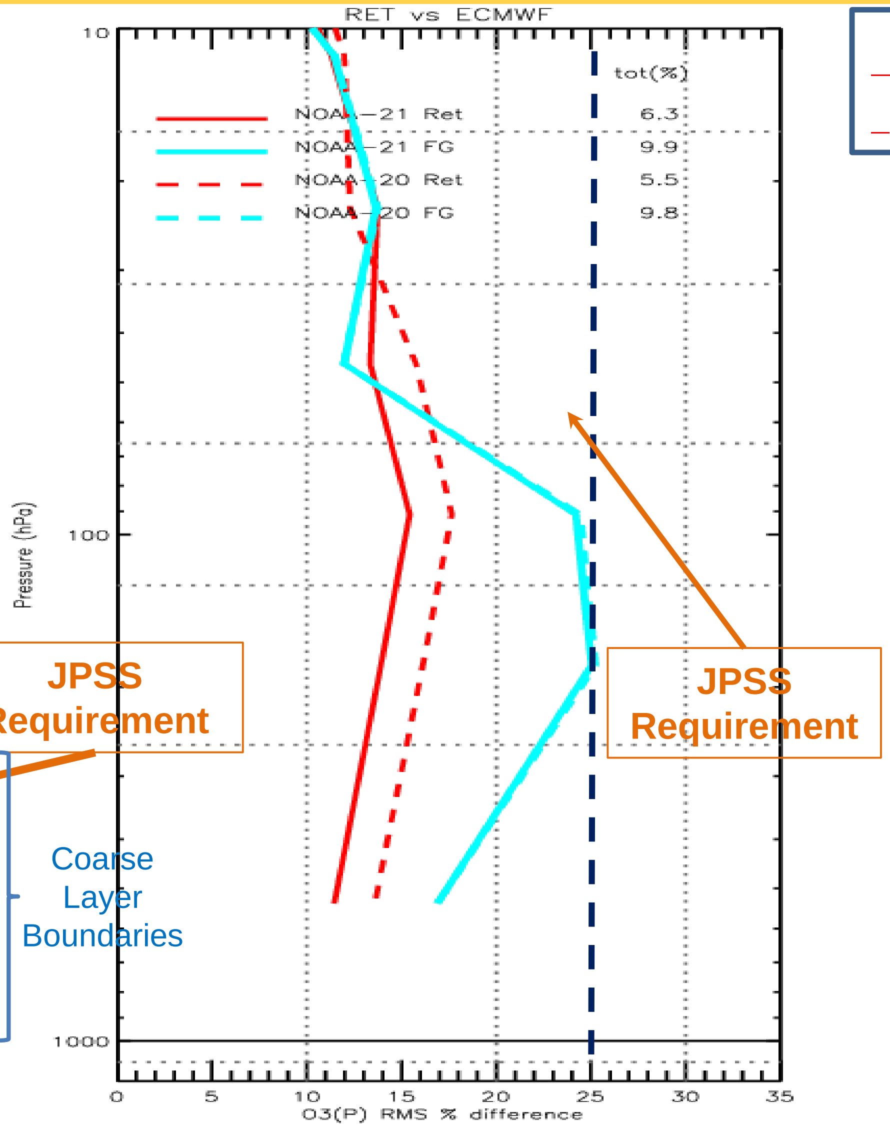




Mean Diff (W/m²)	2.4
STDev (W/m²)	9.0

JPSS NOAA NASA

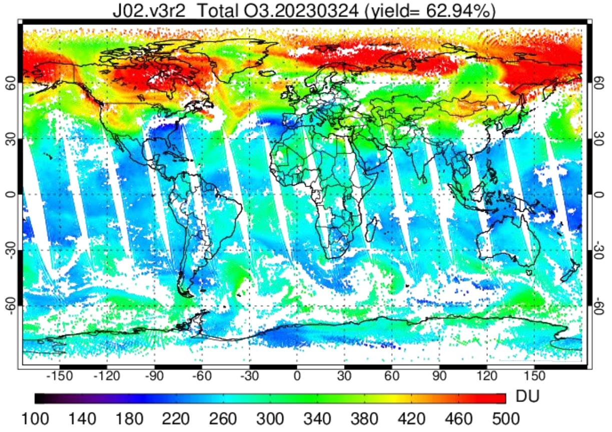




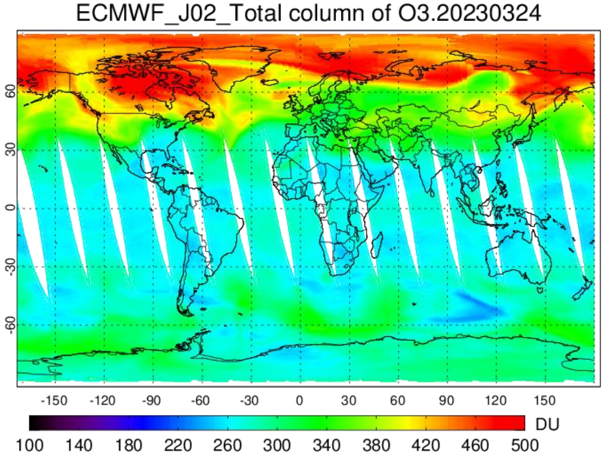
NOAA-21 Global — NOAA-21 Sea-only

NOAA-20 Global — NOAA-20 Sea-only

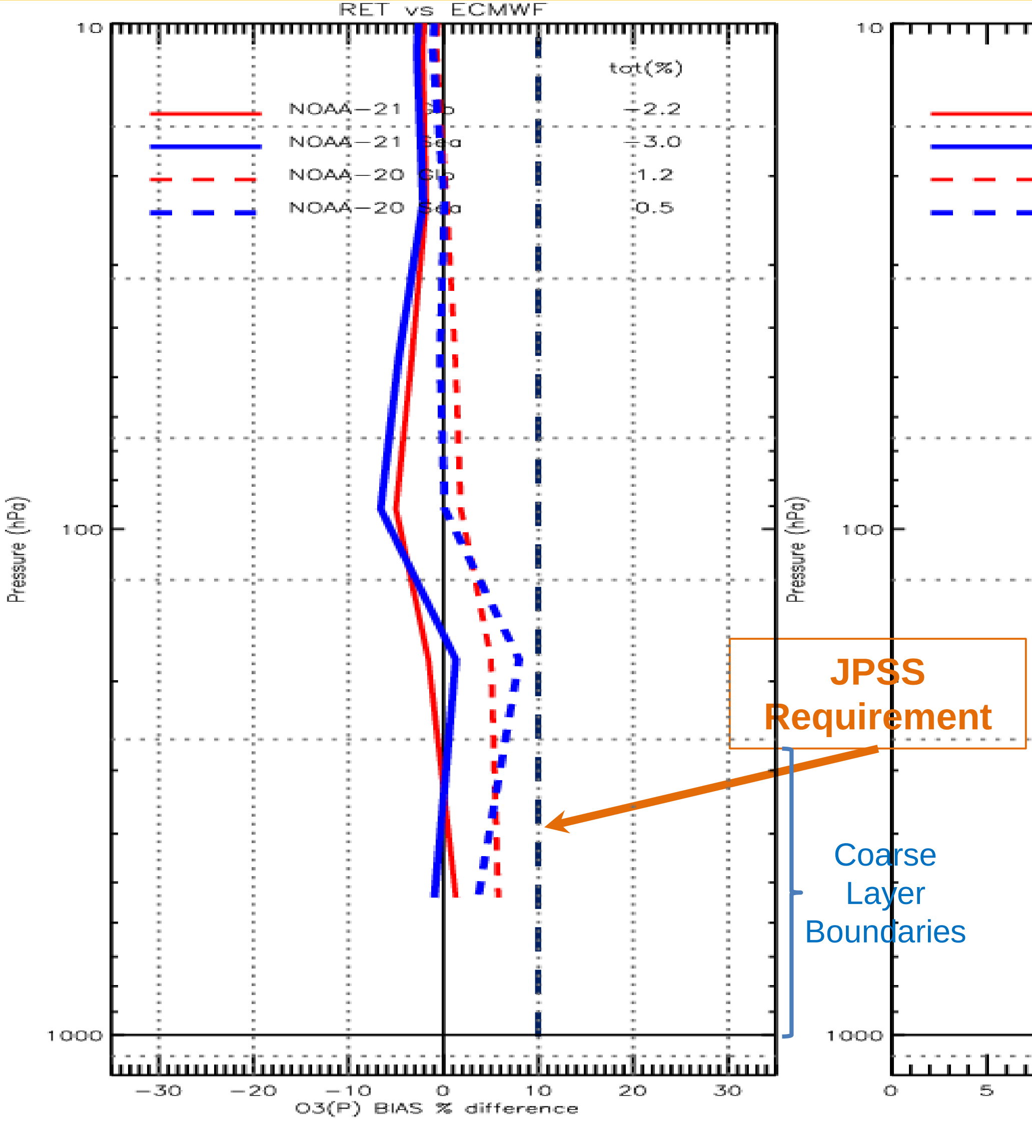
NUCAPS Total Ozone (DU)

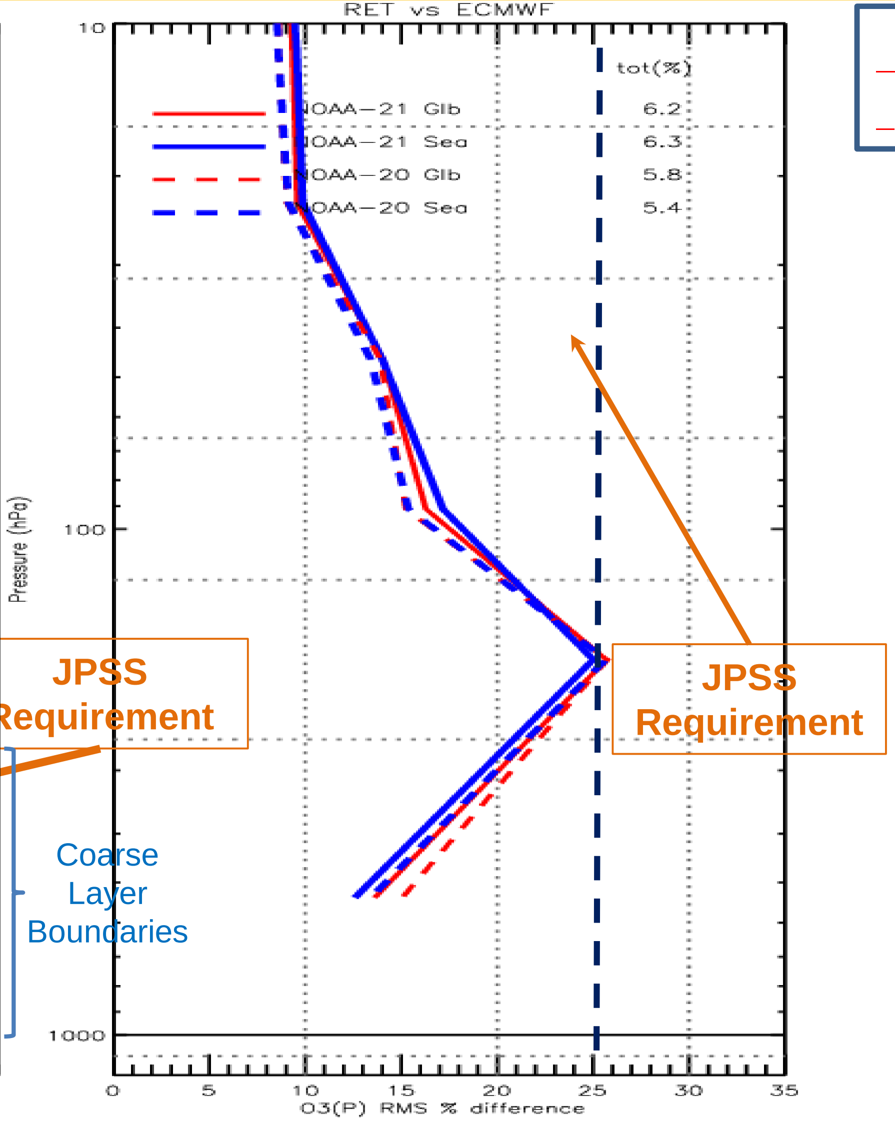


ECMWF Total Ozone (DU)



NOAA-21 Ozone shows good agreement with NOAA-20 and reveals a marginal improvement in Bias & RMS difference with ECMWF

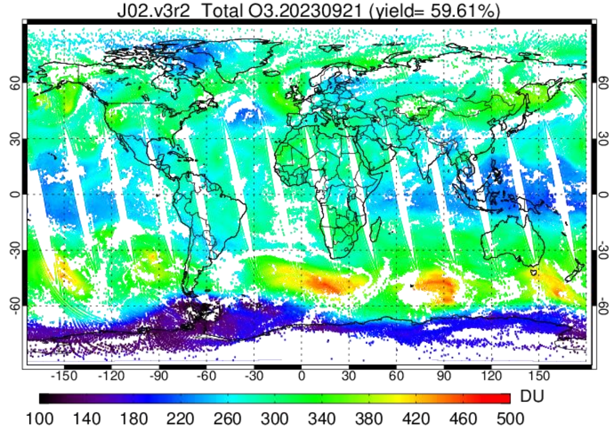




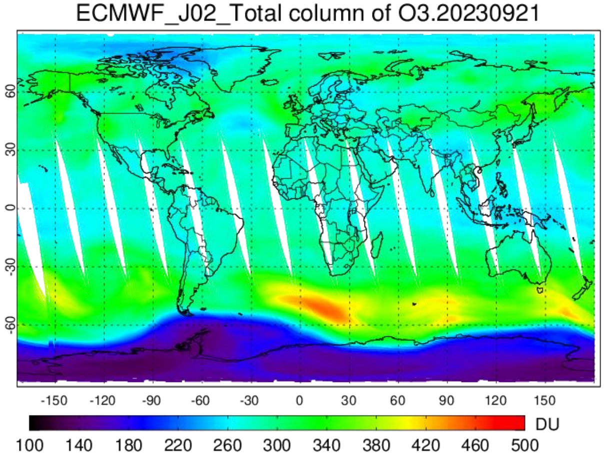
NOAA-21 Global — NOAA-21 Sea-only

NOAA-20 Global — NOAA-20 Sea-only

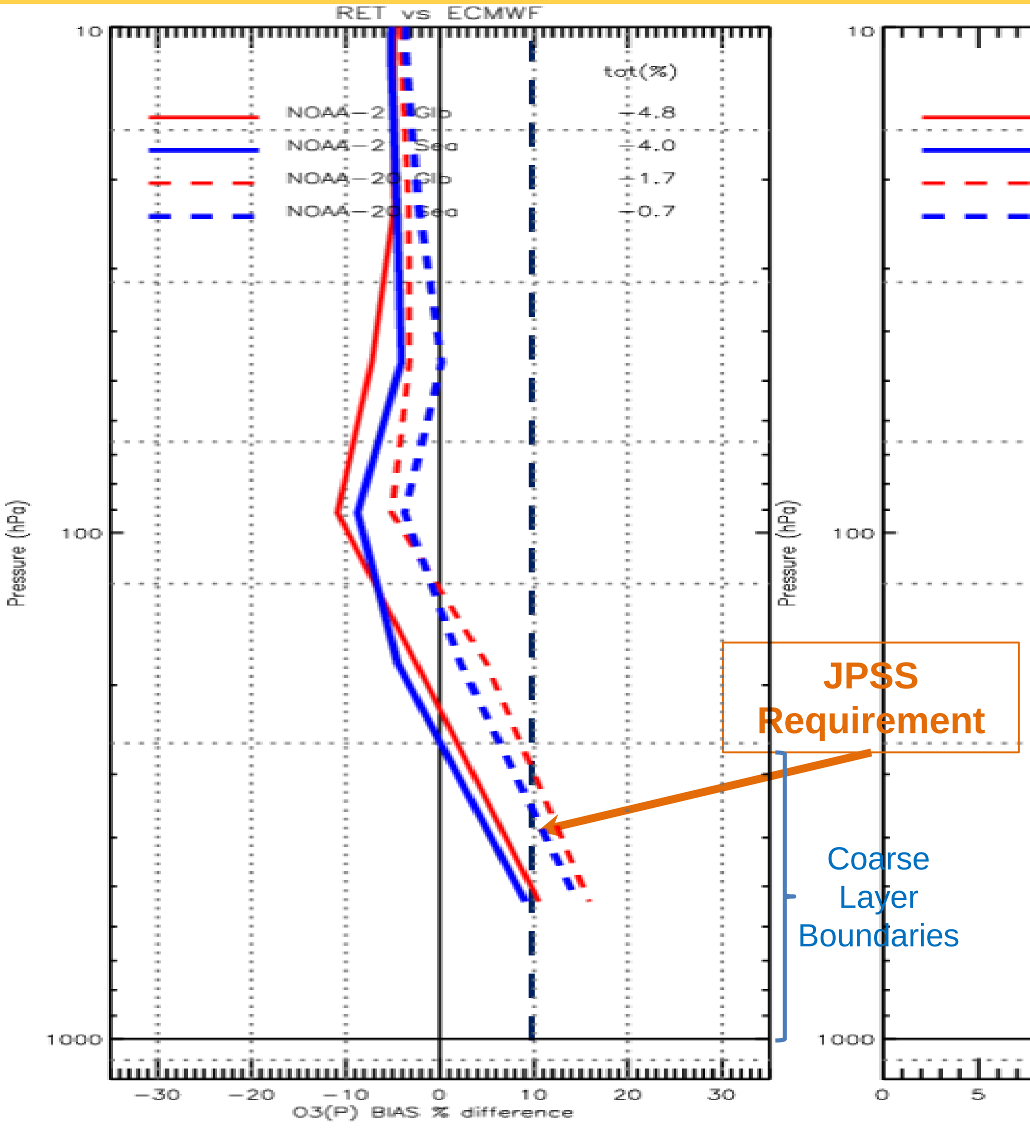
NUCAPS Total Ozone (DU)

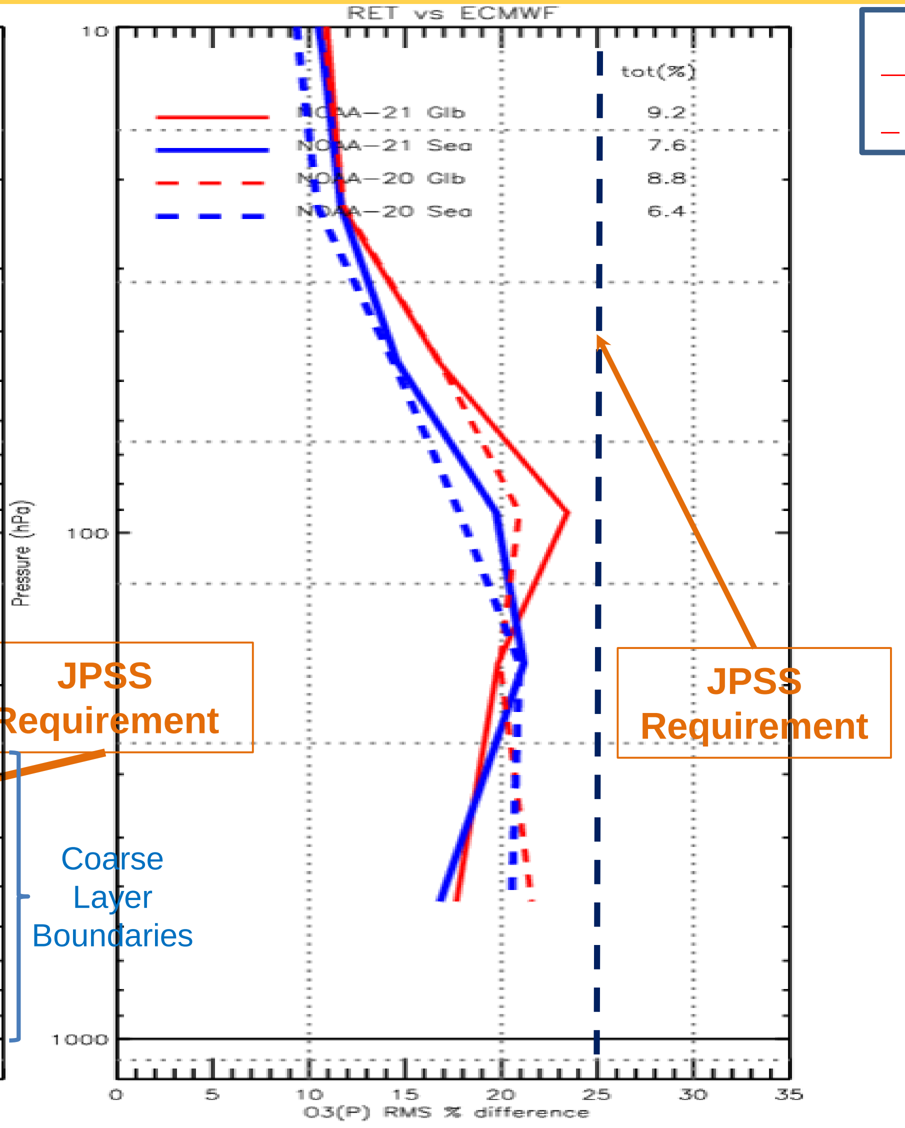


ECMWF Total Ozone (DU)



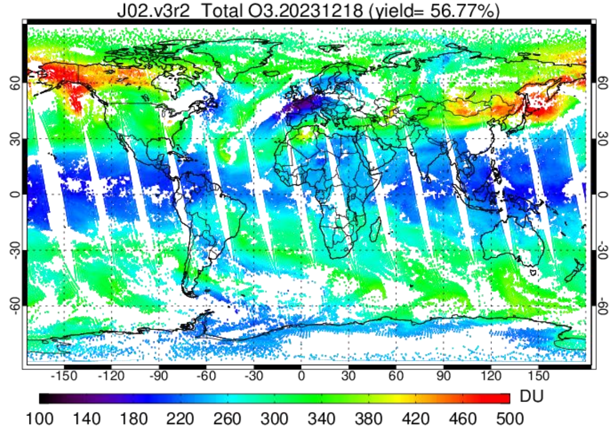
NOAA-21 Ozone shows good agreement with NOAA-20 and reveals a marginal improvement in Bias & RMS difference with ECMWF



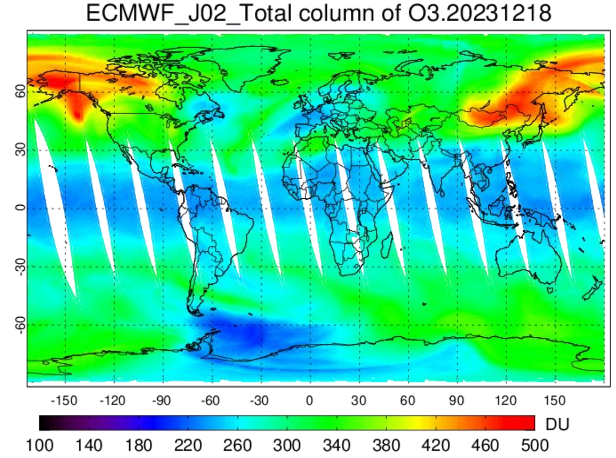


NOAA-21 Global NOAA-21 Sea-only
NOAA-20 Global NOAA-20 Sea-only

NUCAPS Total Ozone (DU)

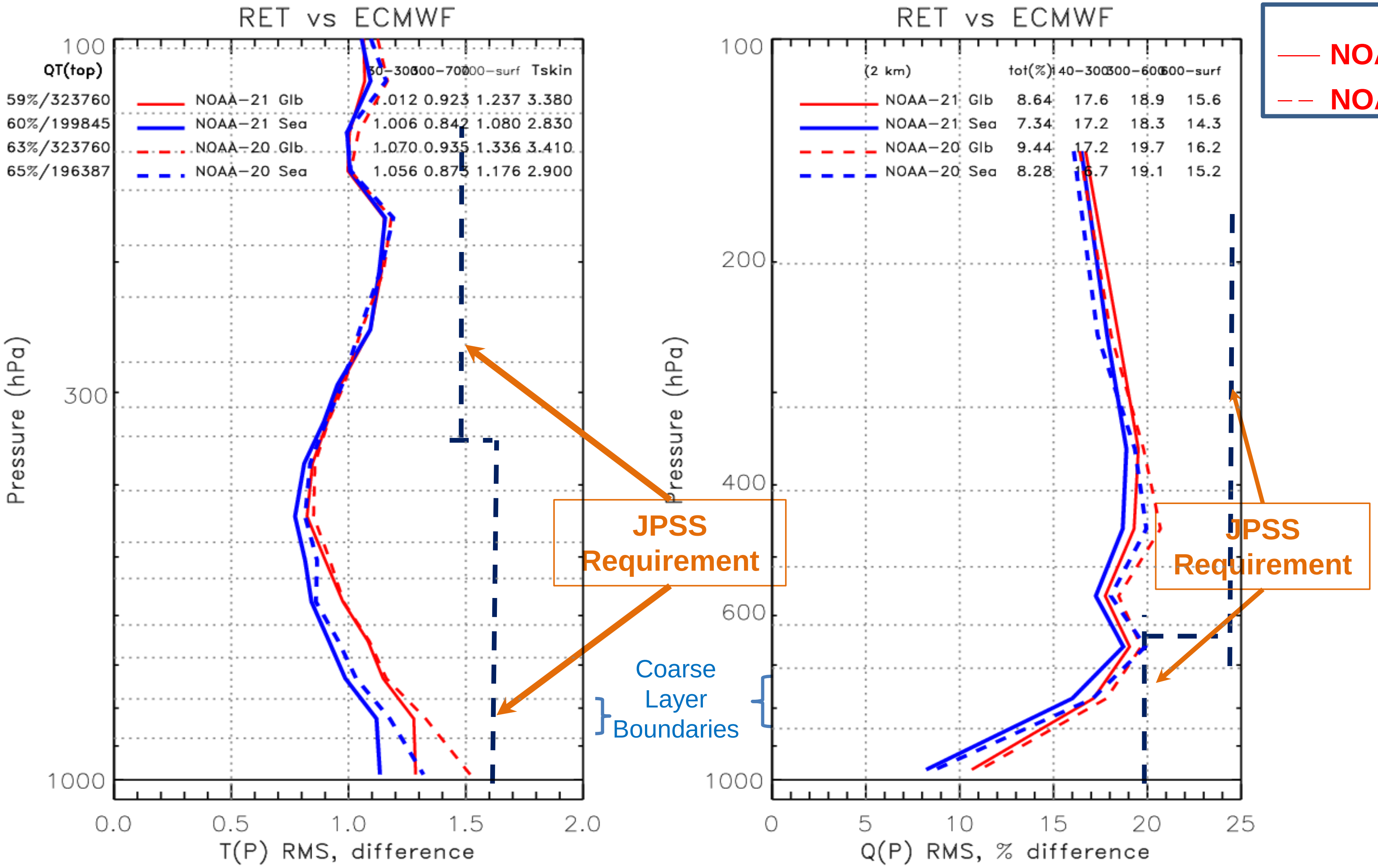


ECMWF Total Ozone (DU)

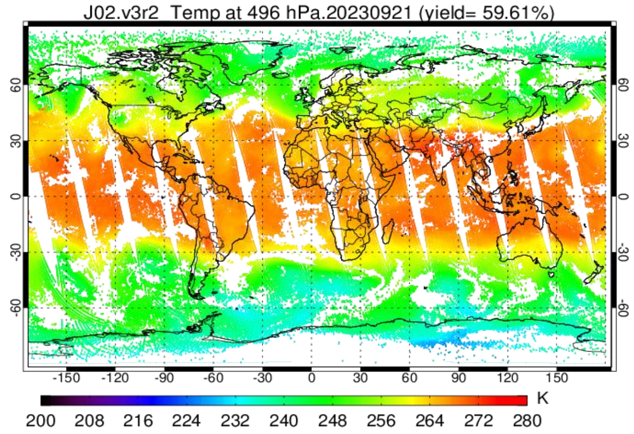


Text

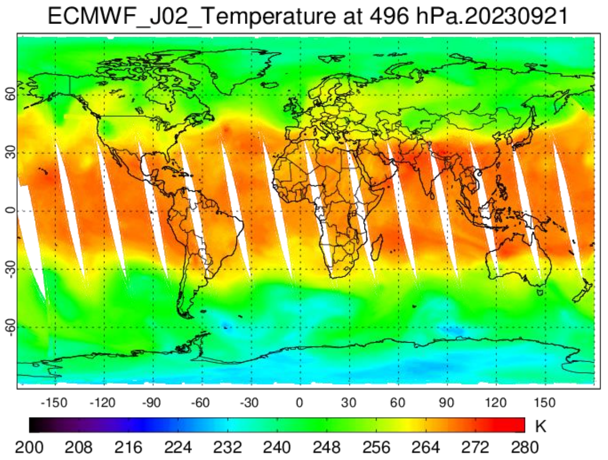
NOAA-21 Global — NOAA-21 Sea-only
NOAA-20 Global — NOAA-20 Sea-only



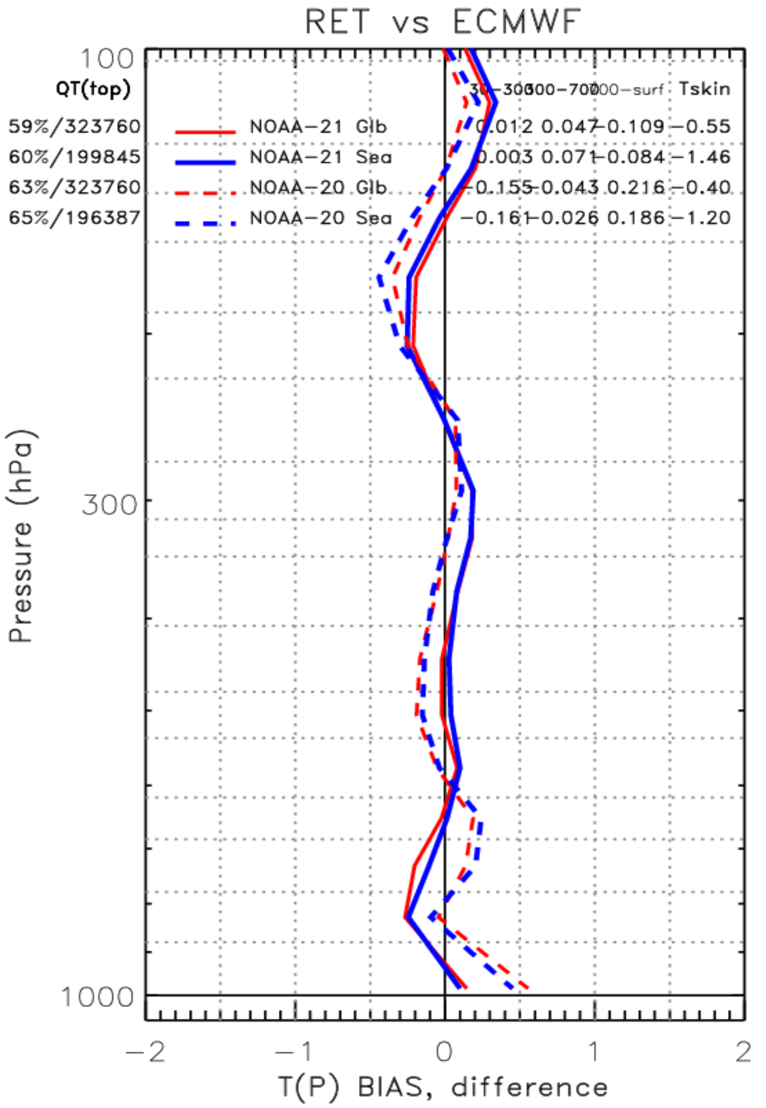
NOAA-21 Ret Temp at 500 hPa

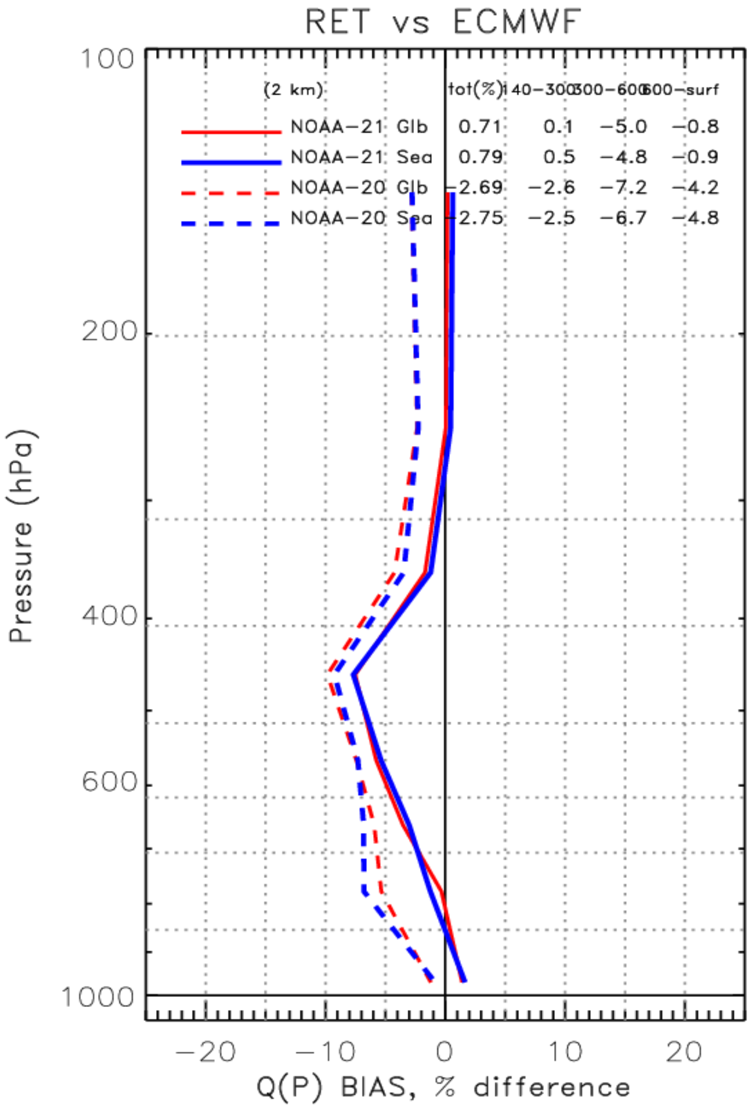


ECMWF Temp at 500 hPa



NOAA-21 AVTP & AVMP show good agreement with NOAA-20 and reveals a marginal improvement in RMS difference with ECMWF

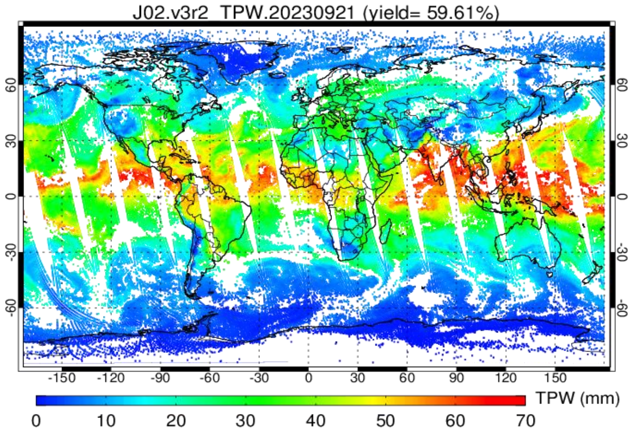




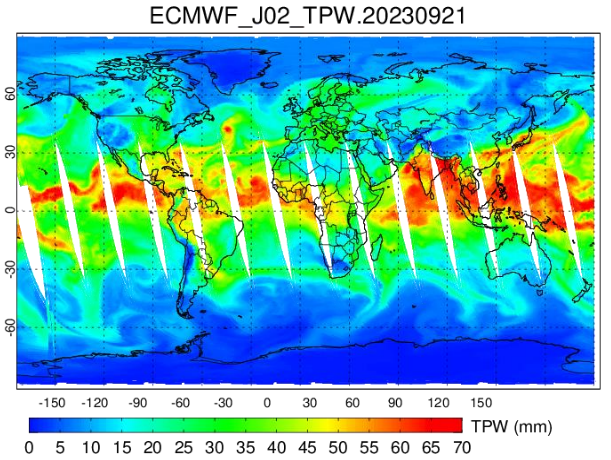
NOAA-21 Global — NOAA-21 Sea-only

NOAA-20 Global — NOAA-20 Sea-only

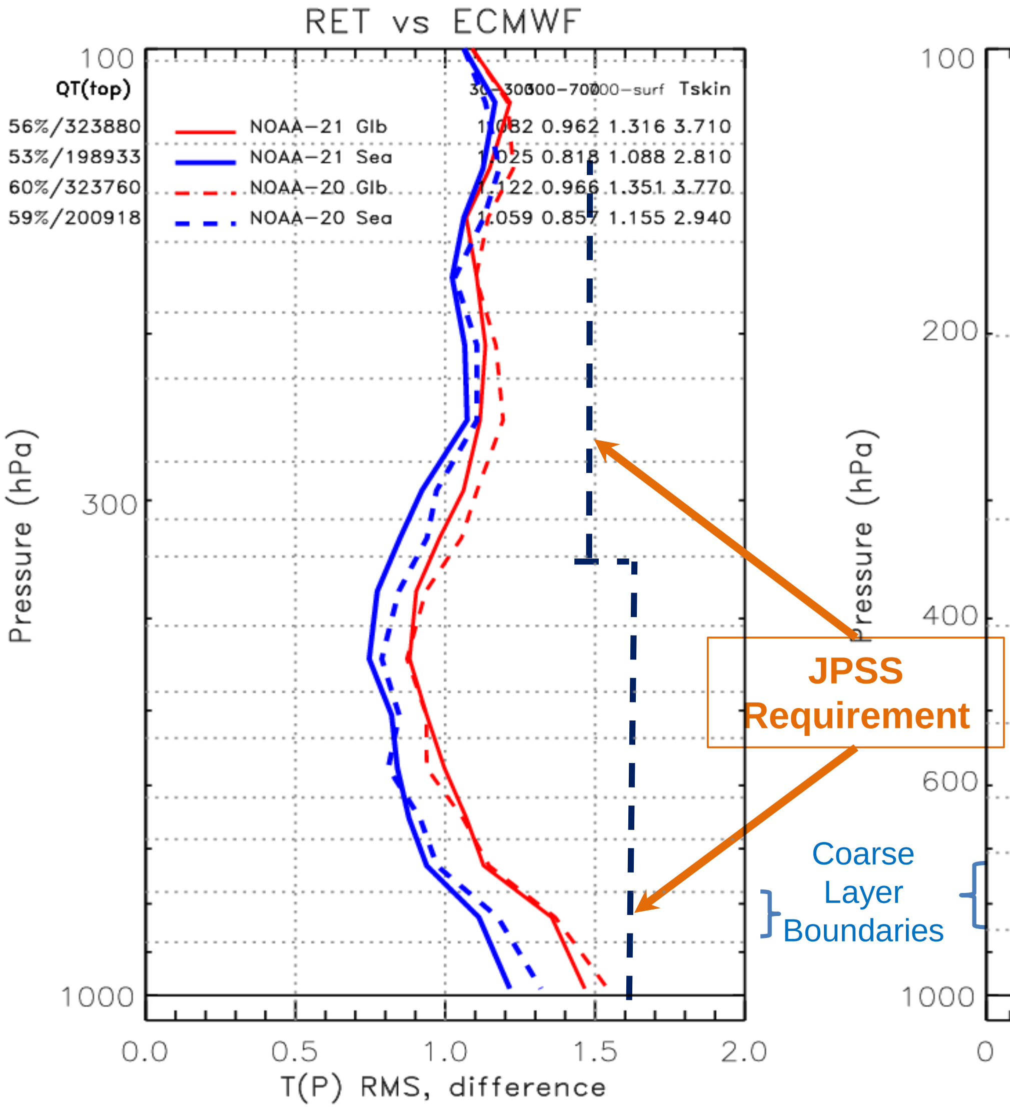
NOAA-21 Computed TPCW (mm)

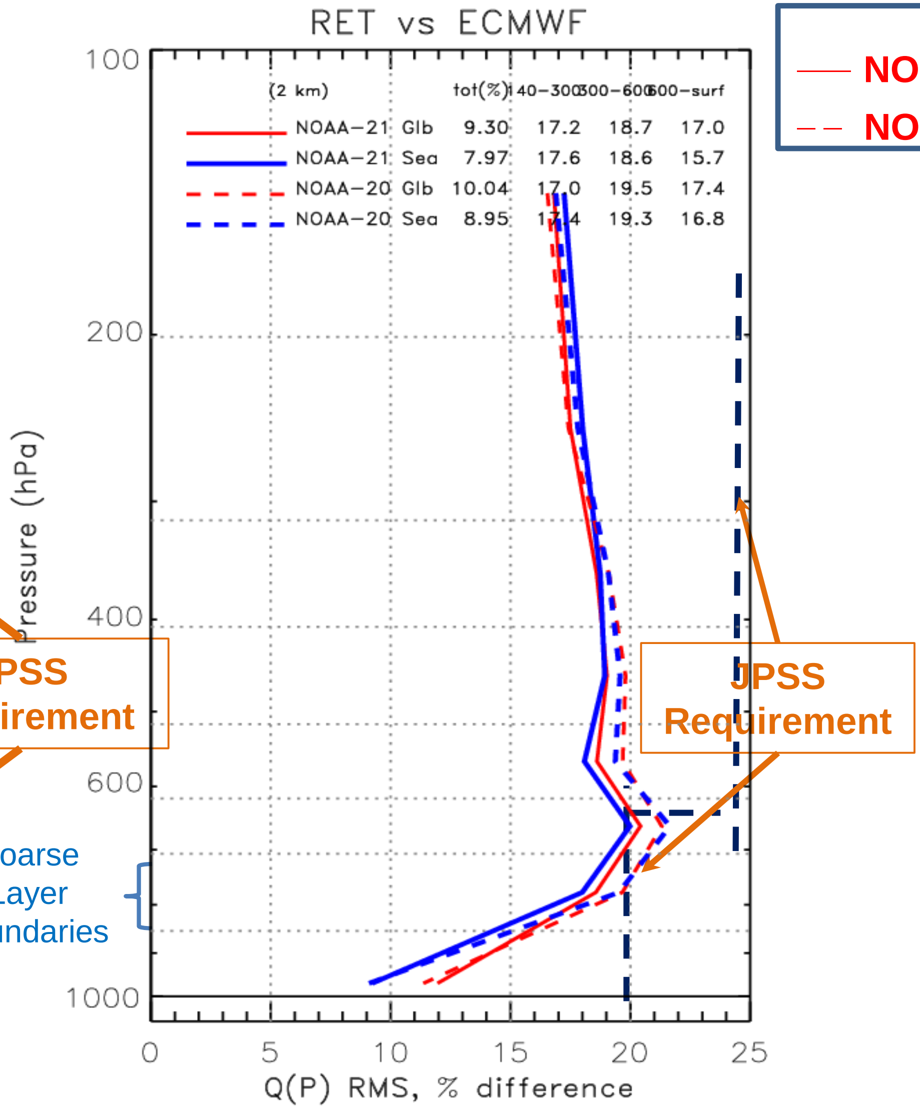


ECMWF TPCW (mm)



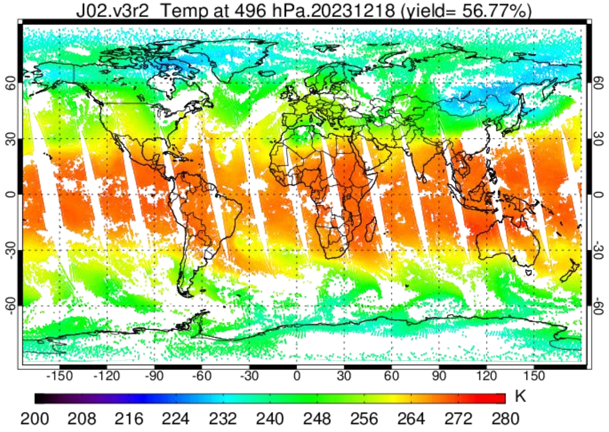
NOAA-21 AVTP & AVMP show good agreement with NOAA-20 and reveals a marginal improvement in Bias with ECMWF



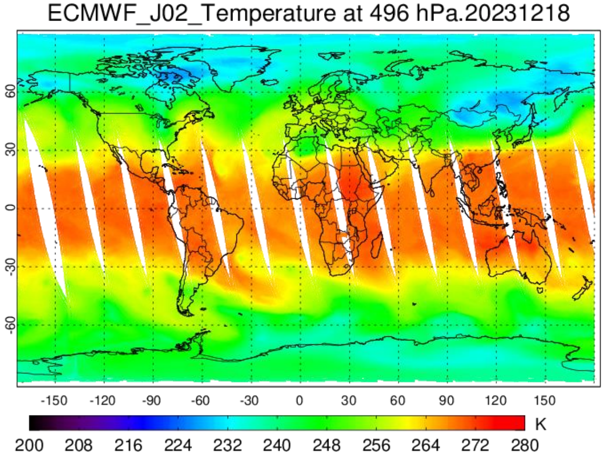


— NOAA-21 Global —— NOAA-21 Sea-only
– – NOAA-20 Global – – – NOAA-20 Sea-only

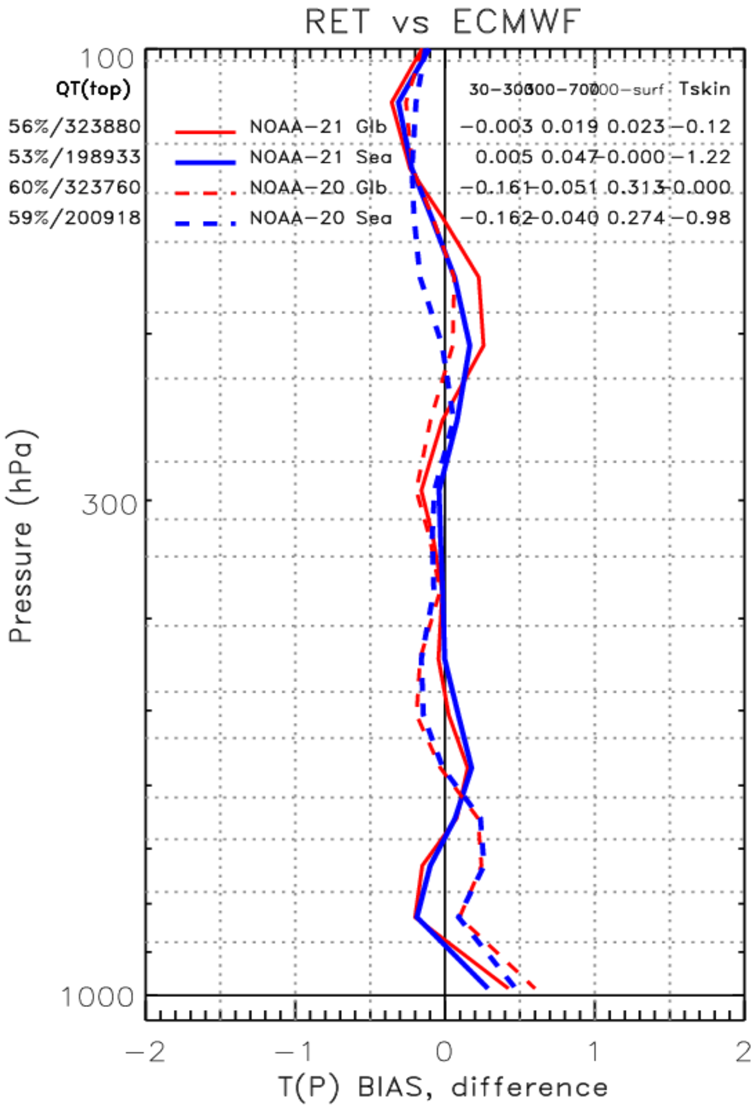
NOAA-21 Ret Temp at 500 hPa

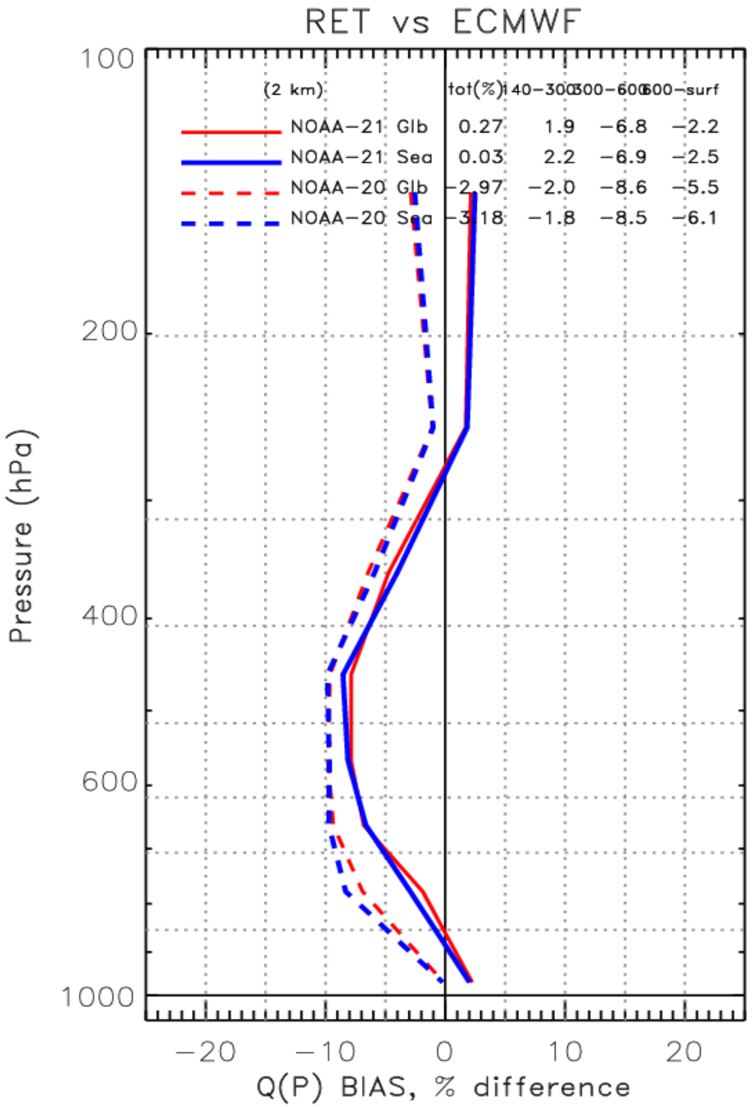


ECMWF Temp at 500 hPa



NOAA-21 AVTP & AVMP show good agreement with NOAA-20 and reveals a marginal improvement in RMS difference with ECMWF

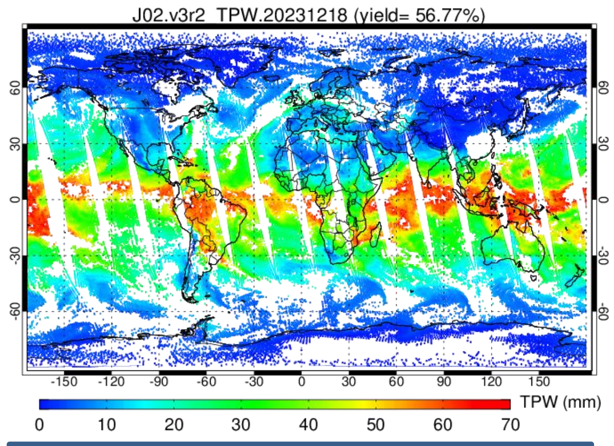




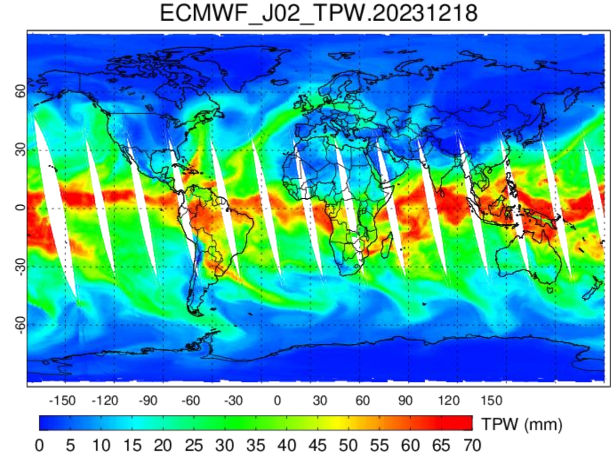
NOAA-21 Global — NOAA-21 Sea-only

NOAA-20 Global — NOAA-20 Sea-only

NOAA-21 Computed TPCW (mm)

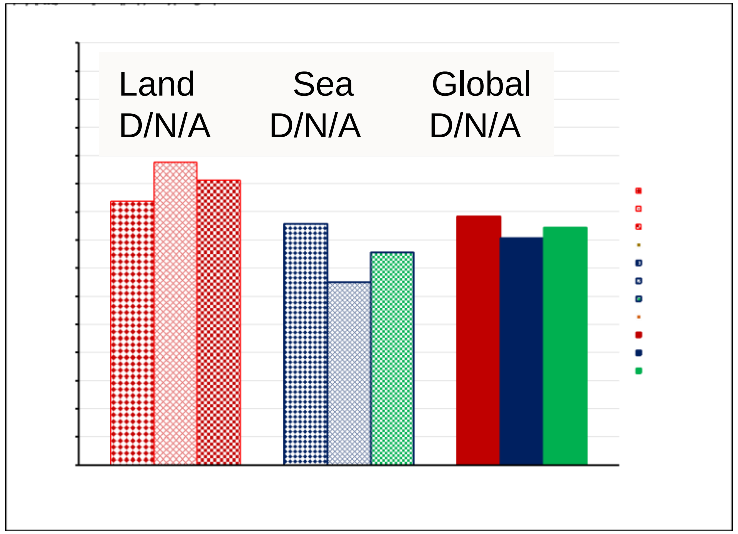


ECMWF TPCW (mm)

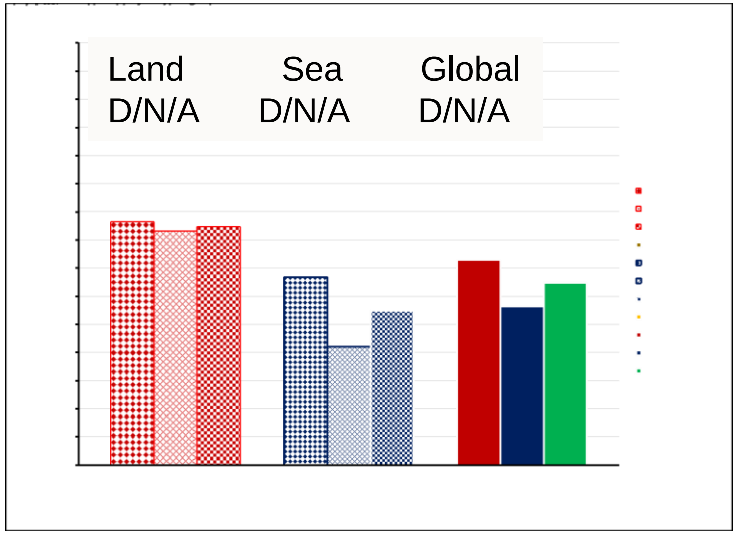


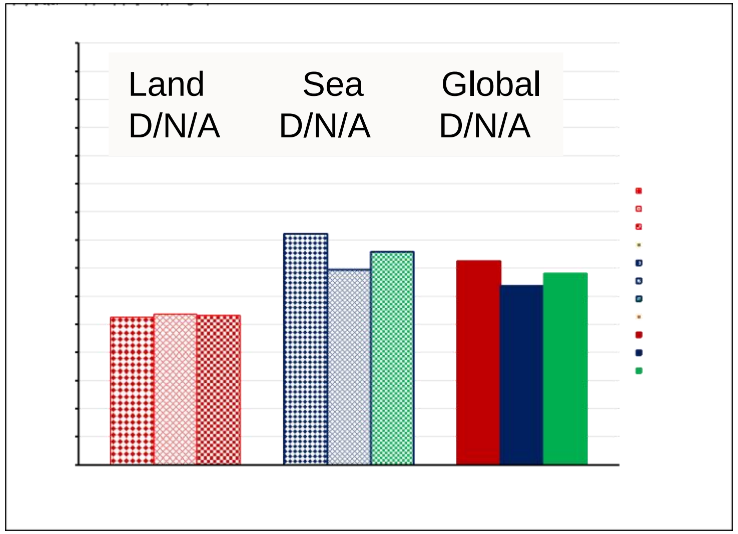
NOAA-21 AVTP & AVMP show good agreement with NOAA-20 and reveals a marginal improvement in Bias with ECMWF

Focus Days: 24 Mar 2023 || 21 Sep 2023 || 18 Dec 2023
NOAA-20 vs NOAA-21 Accepted Samples (%) New

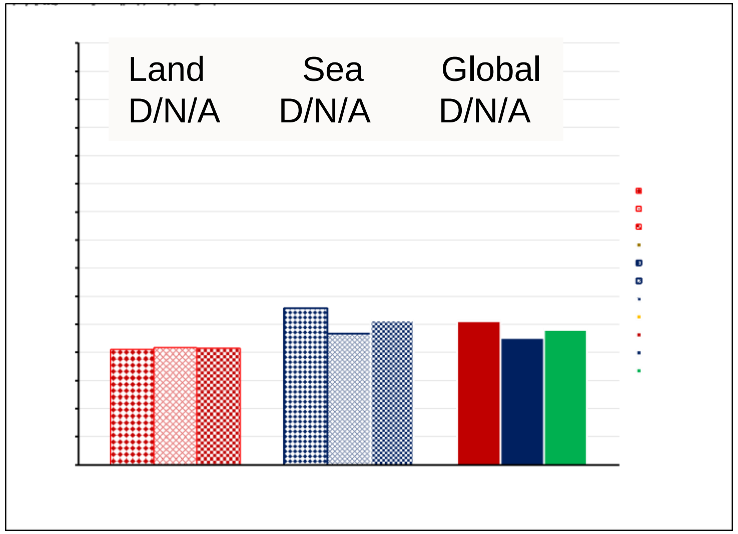


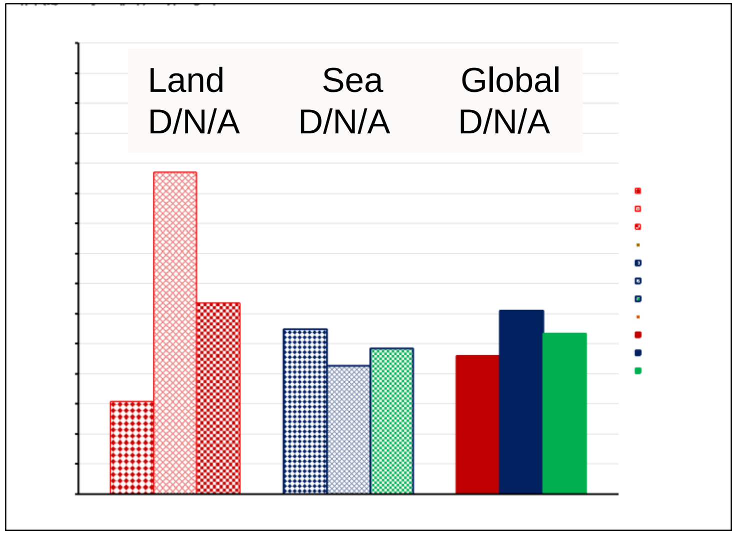
24 Mar 2023
NOAA-20 (66.9%) || NOAA-21 (62.9%)



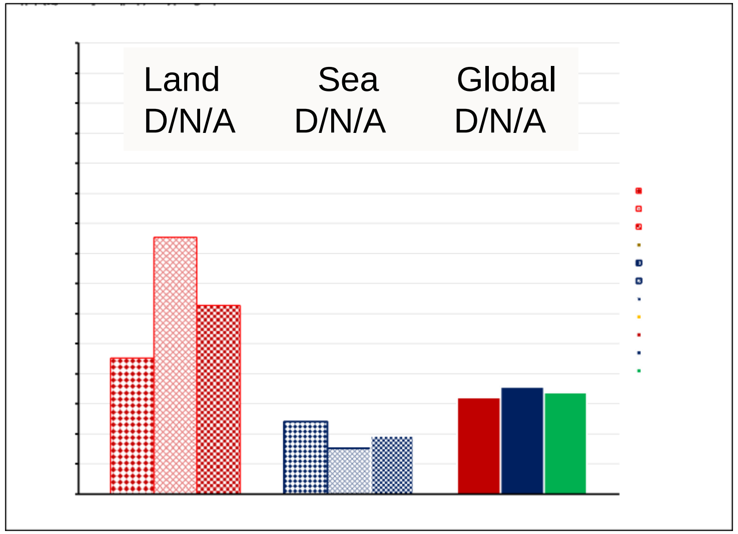


21 Sep 2023
NOAA-20 (63.6%) || NOAA-21 (59.6%)



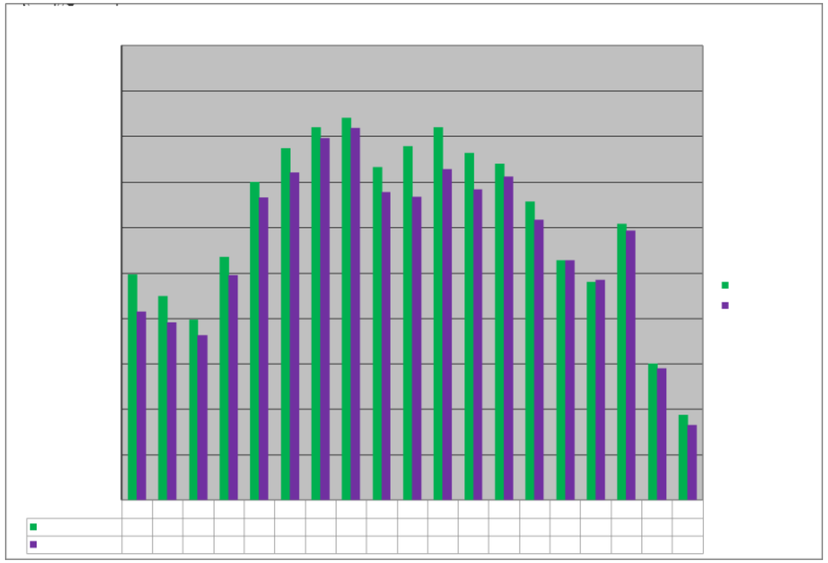


18 Dec 2023:
NOAA-20 (60.7%) || NOAA-21 (56.8%)



NOAA-20 vs NOAA-21 Latitudinal Distribution of Accepted Samples
Focus Days: 24 Mar 2023 || 21 Sep 2023 || 18 Dec 2023

24 Mar 2023
NOAA-20 (66.9%) || NOAA-21 (62.9%)

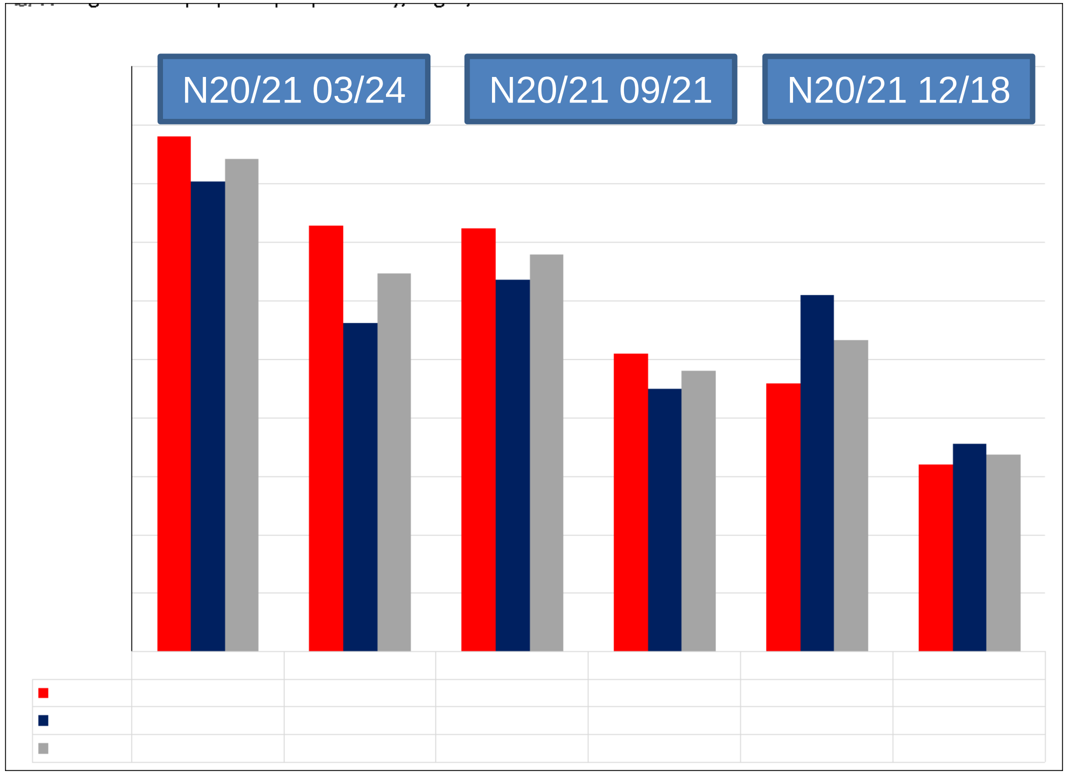


21 Sep 2023
NOAA-20 (63.6%) || NOAA-21 (59.6%)

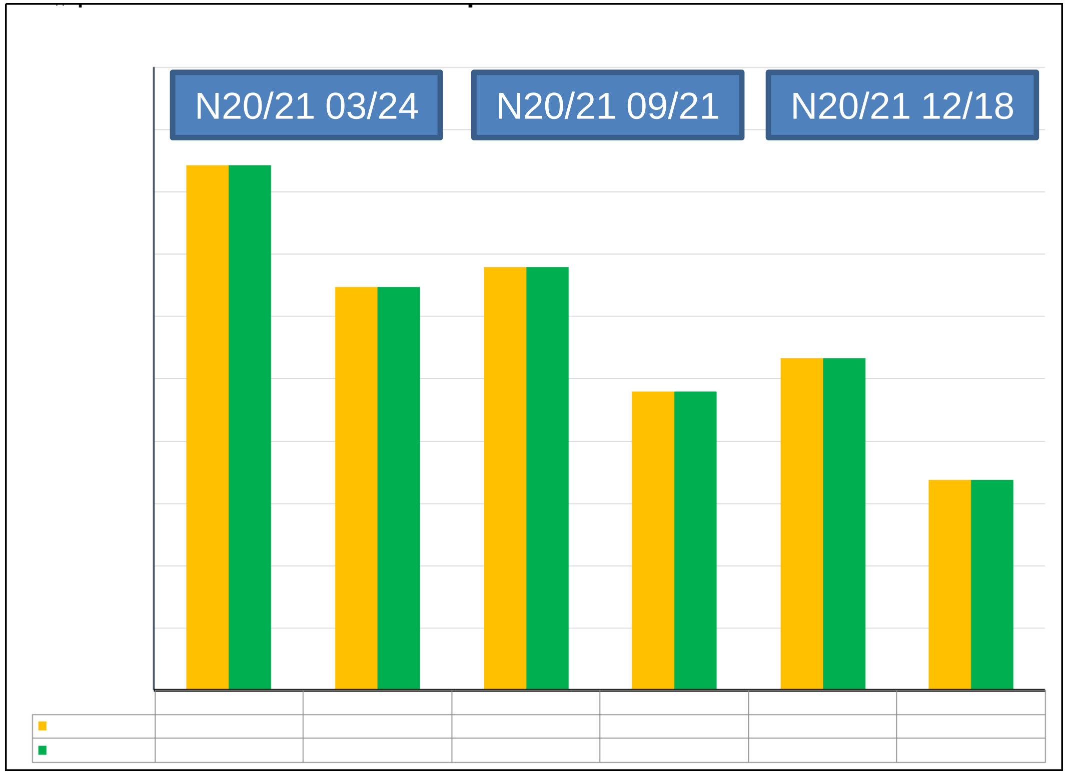
18 Dec 2023:
NOAA-20 (60.7%) || NOAA-21 (56.8%)

NOAA-20 vs NOAA-21 Accepted Samples

Accepted Samples Day/Night/All



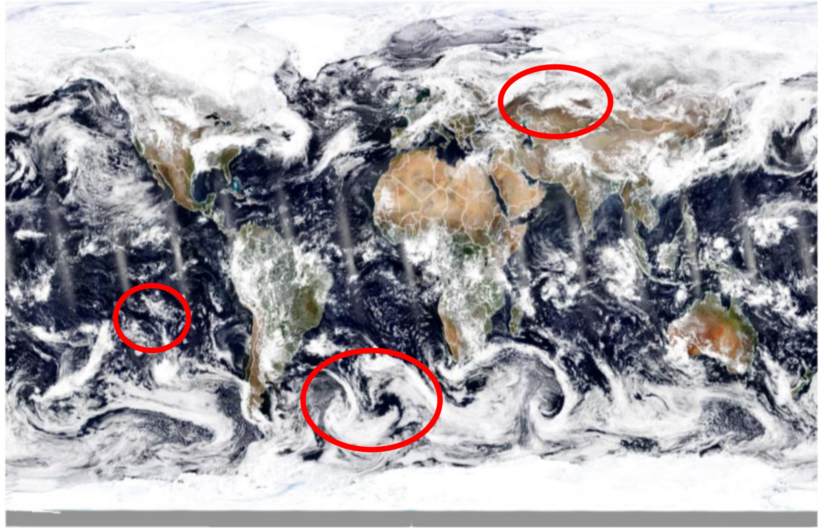
Accepted Samples FG vs RET

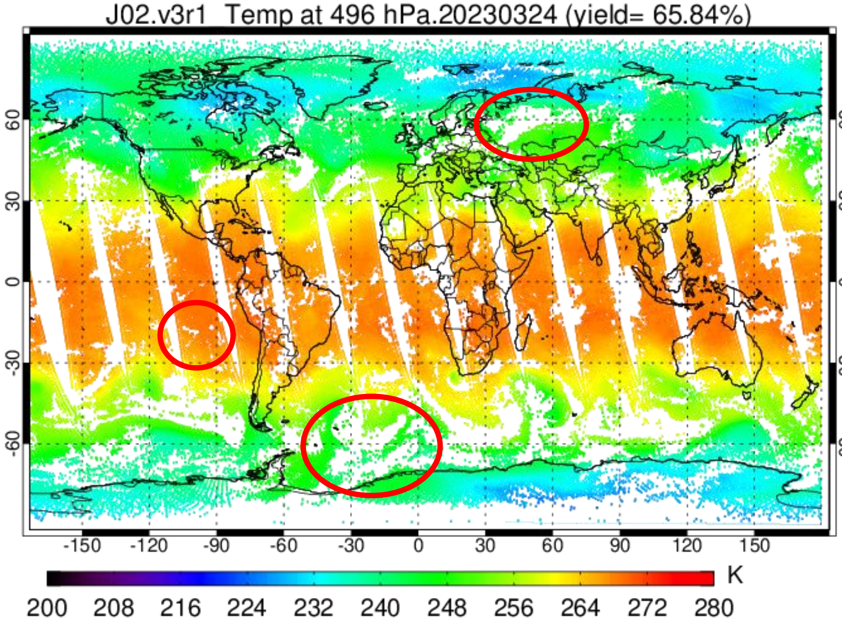


24 Mar 2023	21 Sep 2023	18 Dec 2023:
NOAA-20 (66.9%) || NOAA-21 (62.9%)	NOAA-20 (63.6%) || NOAA-21 (59.6%)	NOAA-20 (60.7%) || NOAA-21 (56.8%)

NOAA-20 V3.1, NOAA-21 V3.1 NOAA-21 V3.2 (20230324)

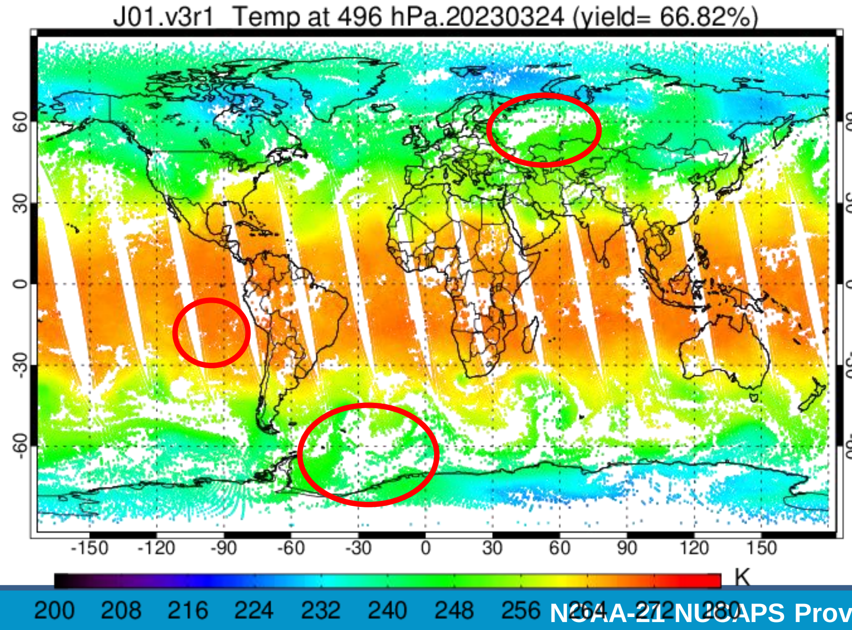
VIIRS J02
Cloud Mask

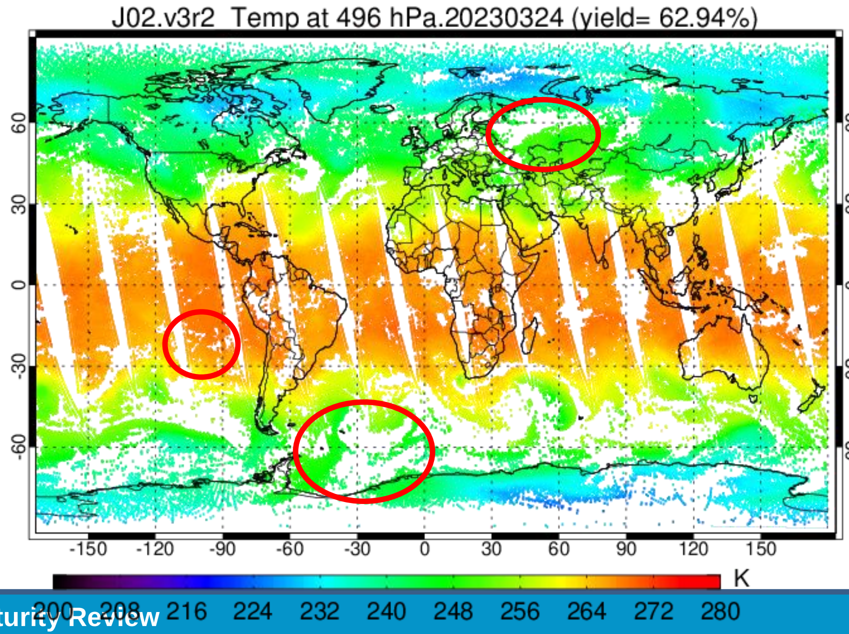




NOAA-21
V3.1

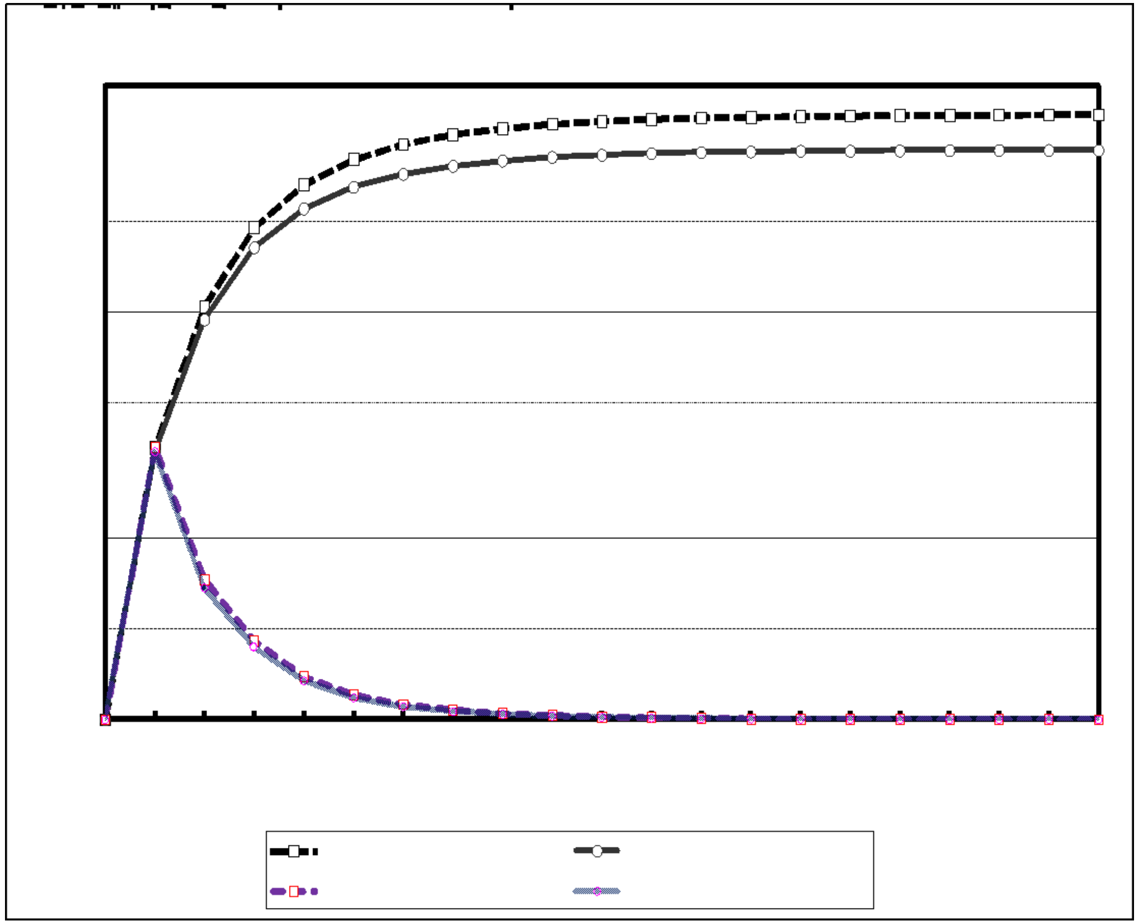
NOAA-20
V3.1



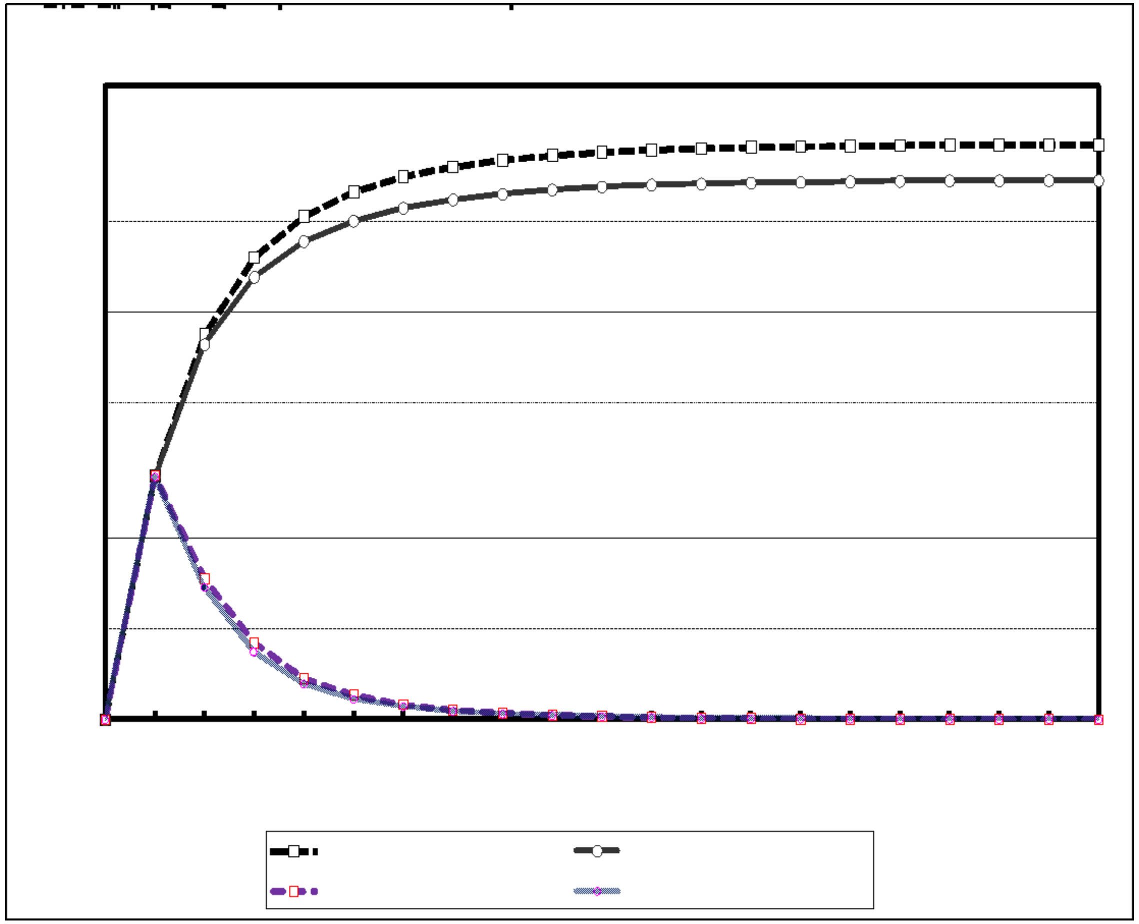


NOAA-21
V3.2

NOAA-20 vs NOAA-21 Cloud-Clearing & Noise Amplification



24 Mar 2023
NOAA-20 (66.9%) || NOAA-21 (62.9%)



21 Sep 2023
NOAA-20 (63.6%) || NOAA-21 (59.6%)

Supplemental Slides

(S.2) NPROVS Evaluations with RAOBs

Supplemental Slides

(S.4) NUCAPS v3.1 Improvements
V3.2 Updates

v3.1 (going into OPS in Jan 2024) Improvements/Validation

- **NUCAPS v3.1** CCAP delivery to NCCF is expected in June 2023
  - ✔ OSPO successfully completed Software Code Review (Feb 2023) and the ASSISTT Team plans to submit the CCAP in May/June 2023
  - ✔ Provides compressed Averaging Kernels at the trapezoid layers for all the NUCAPS products - T(p), q(p), O3(p), CO (p), CH_4(p), and CO2 (p) as part of the NUCAPS netCDF product file.
  - ✔ Ozone a-priori improvements improve ozone retrievals globally and, especially over the Antarctica spring to summer transition
  - ✔ Surface correction improvements alleviate NUCAPS product use by user groups without misinterpretations
- V3.1 NOAA-20 NUCAPS products have been validated using a hierarchy of validation data sets and show no detrimental impact to the operational NOAA-20 NUCAPS products (v3.0)
- AVTP and AVMP products have been validated using matched ECMWF, and global RAOB collocations (NPROVS)
  - ✔ Ozone product has been validated with ECMWF and historic WOUDC data sets
  - ✔ Trace gas products have been evaluated with TROPOMI (CO, CH_4) and OCO-2 v11 (CO_2)
  - ✔ Validation with historic Validation Archive (VALAR) data sets is nearing completion

NUCAPS System Upgrades (in Operations May 2023)

Update	Need	Mitigation/Fix
1. Averaging Kernels for JPSS and MetOp-B/C	• Users require AKs (PGRR initiatives, NOAA-GML)	• Implemented into the NUCAPS Post Processor AMS-2023, Murty et al.,
2. Temperature Damping Factor	• Improve temperature bias at the surface (0.5 ^{O}K improvement over land)	• Namelist changes AMS-2022, Changyi et al.,
3. Ozone Climatology a-priori change	• Improve O3 retrievals during Antarctic spring to summer transition	• Namelist changes AMS-2023, Tong et al.,
4. CO2 First Guess Update (JPSS and MetOp-B/C)	• The original CO2 coefficients for NUCAPS S-NPP and NOAA-20 were developed using in situ and model data prior to 2016. Due to global CO2 values rising rapidly in the last two years, we updated NUCAPS CO2 coefficients recently.	• The new CO2 first guess was created with updated ESRL CO2 monthly mean (for trend), and Carbon Tracker 2019B (monthly mean profiles up to 201903) + NRT v2022-1 (up to 202102). We used 2-degree polynomial to fit trends AMS-2023, Juying, et al.,
5. Surface Correction: NUCAPS reports temperatures, mixing ratios, and column densities at all levels up to 1100 hPa, even those underground.	• This was done by design (as an extrapolation) but tends to confuse users • Caveat: Users must apply surface correction to the profile and calculate LBOT and BLMULT themselves.	• Worked with Rebekah Esmaili (STC) to develop a solution for operational implementation. • Implemented into the NUCAPS Post Processor AMS-2023, Murty et al.,

AMS-2023 NUCAPS Presentations Highlighting v3.1 Improvements

Lead Author	Abstract Title
Changyi Tan	The Improvement of NUCPAS PBL Temperature Retrieval using Dynamic Weighting, Poster, AMS-2022, R236, Monday, January 24, 6:00 – 7:30 PM (EST) https://ams.confex.com/ams/102ANNUAL/meetingapp.cgi/Paper/391038
Tong Zhu et al.	“NUCAPS Ozone A-Priori Improvements and Validation with Averaging Kernel Analysis.” Tuesday, January 10, 5:00 PM to 6:30 PM https://ams.confex.com/ams/103ANNUAL/meetingapp.cgi/Paper/419637
Nick Nalli et al.	“Validation of Carbon Gas Retrievals from the Metop-B,-C NOAA-Unique Combined Atmospheric Processing System.” Thursday, January 12, 2:00 PM – 2:15 PM https://ams.confex.com/ams/103ANNUAL/meetingapp.cgi/Paper/415732
Murty Divakarla et al.	NUCAPS Abstract: “NUCAPS Products from JPSS-CrIS and MetOp-IASI: Advances, Optimization, and Augmentation for JPSS-2 and IASI-NG Hyperspectral Sounders.” Thursday, January 12, 1:30 PM – 1:45 PM https://ams.confex.com/ams/103ANNUAL/meetingapp.cgi/Paper/412347
Juying Warner et al.	“Recent Updates to the NUCAPS Trace Gas Product Algorithms and Intercomparisons with Other Satellite Products.” Tuesday, January 10, 5:00 PM to 6:30 PM https://ams.confex.com/ams/103ANNUAL/meetingapp.cgi/Paper/421295

The Improvement of NUCAPS PBL Temperature Retrieval using Dynamic Weighting

Changyi Tan[1], Murty Divakarla[1], Chris Barnet[2], Ken Pryor[3], Shu-peng Ho[3], Mike Wilson[1], Nick Nalli[1], Tong Zhu[1], Juying Warner[4], and Tianyuan Wang[1]

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Introduction :

The NOAA Unique Combined Atmospheric Processing System (NUCAPS) retrieves temperature, moisture, and trace gas profiles using the synergy of hyperspectral infrared (IR) sounding instruments and accompanied microwave sounders aboard the Joint Polar Satellite System (JPSS) and Meteorological Operational Satellite Program (MetOp) series of polar-orbiting satellites. NUCAPS products are disseminated through NOAA Comprehensive Large Array-data Stewardship System (CLASS) for worldwide users and Direct Broadcast (DB) services with improved latency for regional applications. In addition, temperature and water vapor retrievals are ingested into the Advanced Weather Interactive Processing System (AWIPS-2) for their utility in analyzing atmospheric instabilities and now-casting applications. All of the NUCAPS products have reached the validated maturity. However, there is scope for further improvements to these products.

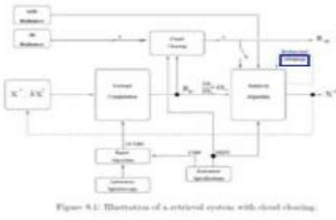
The NUCAPS algorithm uses an eigenvector regression first guess for temperature and water and climatology for ozone, CO, CH4, and CO2 as the background state. It perturbs the background state to minimize the difference between the calculated radiances from the retrieved atmospheric state and cloud-cleared radiances using an iterative solution to produce the final retrieval. There is always a dynamic equilibrium if one believes more in the background states (a priori) or the last retrieval based on observed radiances. Sometimes, the background states are far apart from the truth. Other times the observed radiances are noisier (low signal-noise ratio) to provide a realistic retrieval. Therefore, a dynamic weighting to background a priori and radiance noise is necessary to obtain the optimal retrieval results under various atmospheric conditions.

One of the concerns with the NUCAPS temperature retrieval is the seasonal summertime warm bias observed over daytime land cases concerning global radiosonde measurements in the Planetary Boundary Layer. The PBL plays a vital role in driving the atmospheric instabilities, and biases observed in the temperature retrieval could lead to erroneous calculations of stability parameters and errors in analyzing potential outbreaks of severe weather. This paper presents an attempt to alleviate the PBL biases by optimizing the dynamic weighting in the retrieval algorithm for optimal retrieval.

A set of focus day sets spanning various seasons is used to generate NUCAPS retrievals and study the impact of damping factors on the PBL boundary temperature retrievals. NUCAPS global temperature retrieval bias and RMS differences with collocated ECMWF analysis fields are used to study the effects of varying the damping factor and define an optimized damping factor.

The results of this study indicate that believing observed radiances more with an optimized damping factor improves PBL temperature retrievals without detrimentally impacting other downstream retrieval products. In addition, preliminary evaluation results revealed an improvement in reducing bias by about 25% in the PBL. Results from these investigations and the impact of improving the PBL bias characteristics on computing stability, evaluation with truth data sets, and associated improvements in the downstream trace gas products will be presented at the conference.

Definition of the Dynamic Weighting (or Damping Factor) in NUCAPS



Courtesy of Chris Barnet's note

The damping factor describes a dynamic equilibrium of the magnitude of retrieved profiles that deviate from the background states (or a priori) according to the observed radiances. For this particular variable λ_k^s, the smaller values, the retrievals rely more on the background states; the larger values, the retrievals have more degrees of freedom.

$$\text{d.o.f.} = \sum_{k=1}^{K} \phi_k^{s,\ell} = \sum_{k=1}^{K} \frac{\lambda_k^{s,\ell}}{\lambda_k^{s,\ell} + \Delta\lambda_k^{s,\ell}}$$

$$\phi_k^{s,\ell} = \frac{\lambda_k^{s,\ell}}{\lambda_k^{s,\ell} + \Delta\lambda_k^{s,\ell}} \quad \begin{cases} 0 & \text{completely damped} \\ 1 & \text{completely no damped} \end{cases}$$

$$\Delta A_j^{s,\ell+1}(\theta) = U_{jk}^{s,\ell} \cdot \Delta B_k^{s,\ell+1}(\theta) = U_{jk}^{s,\ell} \cdot \frac{1}{\lambda_k^{s,\ell}} \cdot \left(U_{k,j}^T\right)^{s,\ell} \cdot \left(S_{j,n}^T\right)^{s,\ell} \cdot \left(N_{n,n}^s\right)^{-1} \cdot \Delta\Theta_n^{s,\ell}$$

$$\delta B_{max}^s = \frac{1}{\sqrt{\lambda_k^s}} \quad \text{or}$$

$$\boxed{\lambda_k^s} = \left(\frac{1}{\delta B_{max}^s}\right)^2$$

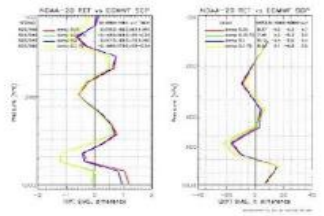
The CrIS instruments onboard the JPSS series satellites measure more precise infrared radiances with less instrument noises (see https://www.star.nesdis.noaa.gov/jpss/CrIS.php). It is a right time to do the experiments of adjusting the NUCAPS algorithm to deviate more from the background states by adjust the damping factor. In this study, we only focus on the temperature retrieval damping factor and examine the impacts on the final physical retrieval.

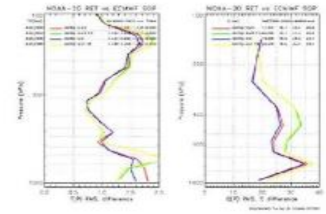
Data Sets and Experiments

In this study, we select NOAA-20 NUCAPS (CrIS/ATMS) data to analyze. The focus day is April 30, 2020. We select the Southern Great Plains (SGP) sub-dataset to study the impacts on the NUCAPS land retrieval and global dataset to study the overall impacts. The SGP sub-dataset is within 200 km around the center coordinates (36.4363983528783, -96.1198975377271, see below image). The day time and night time retrievals are both included. We modify the temperature damping factors as 0.25, 0.3, 0.5, 0.6, 0.8, 1.0, 1.2. We benchmark the NUCAPS retrievals with the collocated ECMWF profiles.

Courtesy of Google Map

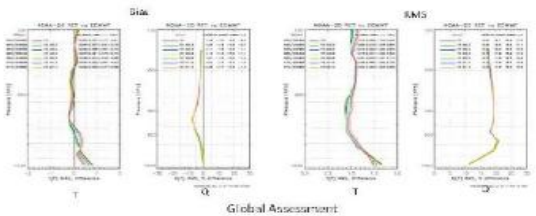
SGP Experiments cont'd



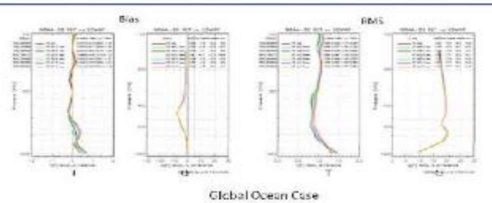


Compare the background states and retrieval

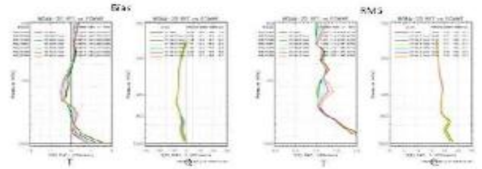
The Global Experiments



Global Assessment



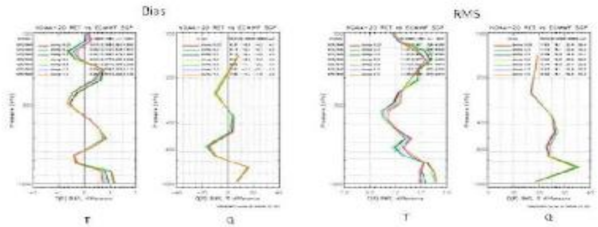
Global Ocean Case



Global Land Case

Note that the truth is the ECMWF data.

SGP Experiments



Note that the truth is the ECMWF data.

Summary and Discussion

- ❑ The temperature damping factor adjustments impact the temperature profiles of the physical retrievals, vertically from the PBL all the way to the upper stratosphere.
- ❑ The temperature damping factors should be relaxed and optimized to allow the retrievals reflect more the atmospheric state truths. Probably, 0.5~0.6 is an optimized value. But more validations with averaging kernels are needed to be done to confirm it.
- ❑ This is the first step to revisit the damping factors. The moisture and other trace gas (O3, CO, CH4, CO2) damping factors will be adjusted, tested and assessed in next steps.

Poster ID# 391038, 18th Annual Symposium on Operational Environmental Satellite Systems, 102nd AMS Annual Meeting, 24 January 2022, HOUSTON, TX.

Corresponding Author: Changyi.Tan@noaa.gov

NUCAPS Ozone A-Priori Improvement and Validation with Averaging Kernel Analysis

Tong Zhu1, Murty Divakarla1, Irina Petropavlovskikh2, Ken Pryor3, Nicholas R. Nalli1,
Changyi Tan4, Mike Wilson5, Juying Warner6, Lihang Zhou7, Zaizhong Ma1

Objective:

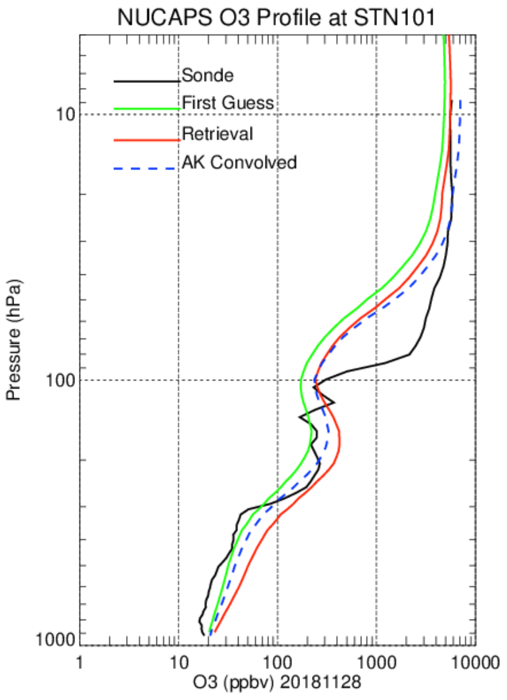
- Update NUCAPS V3.1 with a new ozone climatology, and evaluate the ozone retrievals with WOUDC ozonesonde measurements by applying Averaging Kernel (AK) analysis

Results:

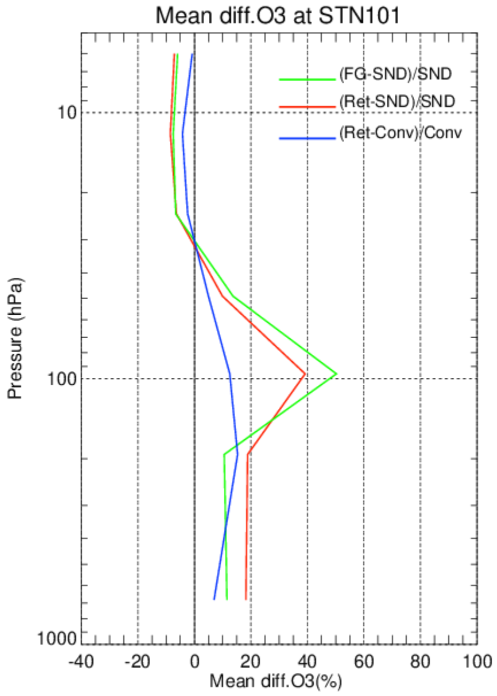
- The ozone profile and near surface temperature retrievals are improved based on the statistics of 12 focus days evaluation over the globe in 4 seasons.
- The validation with WOUDC ozonesonde measurements in 77 days shows that NUCAPS O3 retrieval is better than first guess in high latitudes around Antarctic region,
- The comparison between O3 retrieval and AK convolved ozonesonde shows better agreement, and indicates a small bias in the retrieval comes from the a-priori.

Comparison of O3 profiles at
WOUDC Station101: Lat/Lon: -69.01, 39.58
03/13/2018 - 06/26/2019 (55 days)

1-day

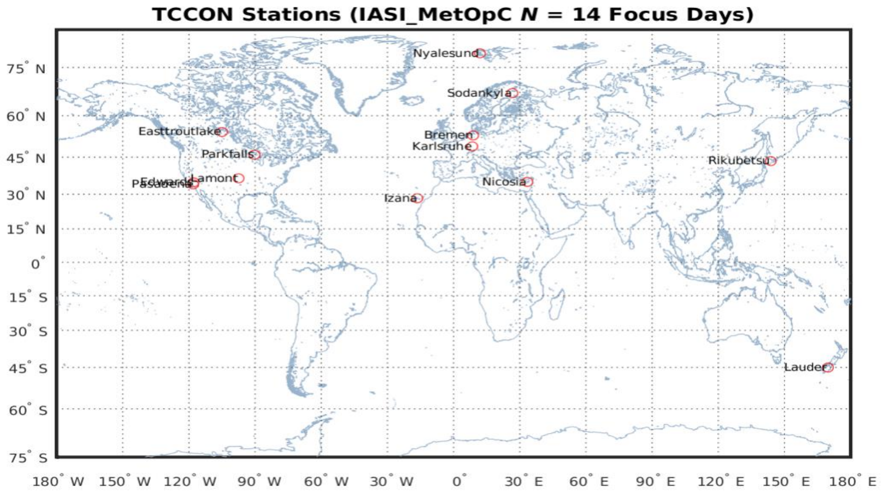


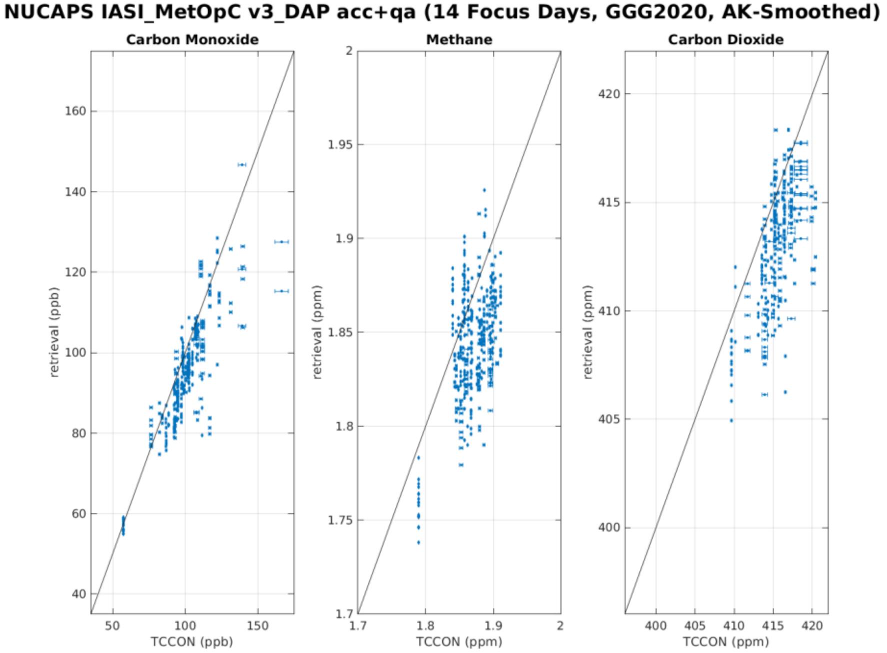
Mean differences



Validation of Carbon Gas Retrievals from the Metop-B,-C NUCAPS (Nalli et al.)

- NUCAPS JPSS (SNPP & NOAA-20) carbon trace gas EDRs have previously achieved validated maturity based on comprehensive reference datasets serve as a baseline
- In this work we validated the **NUCAPS v3 Metop-B,-C** carbon trace gas EDRs using collocated **Total Carbon Column Observing Network (TCCON)** data
  - TCCON are a global network of ground-based FTS that accurately measure total column abundances of CO_2, CO, CH_4, N_2O trace gases
  - Allow for convenient collocations with the Metop orbits, which are different from JPSS
  - Serve as **transfer standard** with validated JPSS versions
  - We adopted the **new TCCON version GGG2020** which has several significant improvements over GGG2014; the new data format required quite a bit of code updates on our end
- The statistical results show **comparable performance with the JPSS series versions**





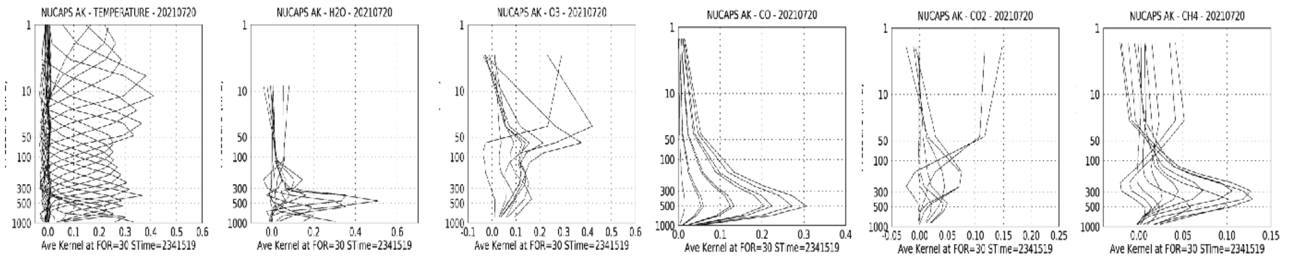
NUCAPS Products from JPSS-CrIS and MetOp-IASI: Advances, Optimization, and Augmentation for JPSS-2 and EPS-SG IASI-NG Hyperspectral Sounders

Murty Divakarla[1], Ken Pryor[2], Tong Zhu[1], Juying Warner[2], Nick Nalli[1],Changyi Tan[2], Mike Wilson[1], Letitia Soulliard[3], and Zaizhong Ma[1]

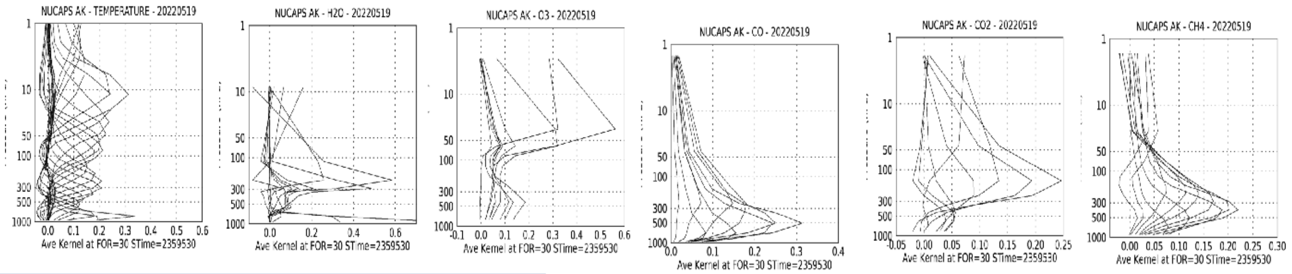
SUMMARY

- Operational Products from JPSS NOAA-20 (CrIS), MetOp-B/C (IASI)
  - AVTP, AVMP, O3, CO, CH_4, and CO_2
- NUCAPS System Upgrades
  - Averaging Kernels as part of the NUCAPS product file for JPSS (NOAA-20), MetOp-C
  - O3 product improvement during Antarctic spring to summer transition
  - Surface Corrections to facilitate user request and easy use of NUCAPS products
  - CO_2 first guess updates using extended ESRL CO_2 measurements and Carbon Tracker model
- On-going Activities/Plans
  - Addition of Ammonia product to the NUCAPS Operations
  - Mission-long reprocessing for S-NPP/NOAA-20 Products

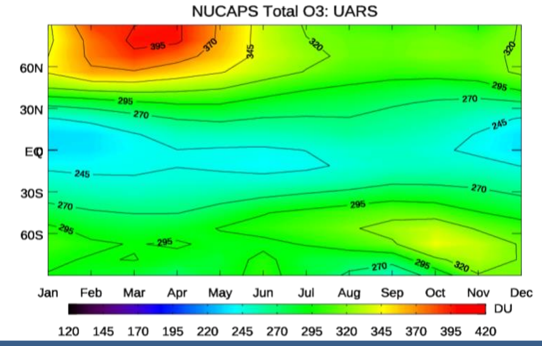
NOAA-20 Averaging Kernels: V3.1 run 20210720, scan_time:2341519, FOR:30



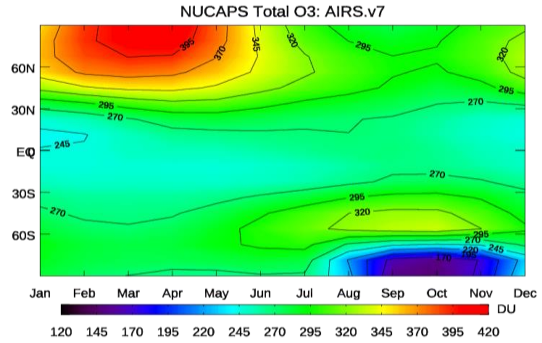
MetOp-C Averaging Kernels: V3.1 run 20220519, scan_time:235930, FOR:30



NUCAPS OPS: Ozone a-priori
Ozone Validated Maturity version



NUCAPS v3.1: Ozone new a-priori



NUCAPS Output Products (NOAA-20 and NOAA-21)

	Product	NUCAPS JPSS Products		NUCAPS JPSS Products with Averaging Kernels		Users
		Number of Files/Day	Size/Day	Number of Files/Day	Size/Day	
1	NUCAPS ALL FOVs	2700*	25 G	2700	25 G	BUFR toolkit and OSPO
2	NUCAPS 431 (CrIS), 616 (IASI) ALL FOVs Thinned Radiances	2700	5.4 G	2700	5.4 G	BUFR toolkit
3	NUCAPS PCS Monitoring	2700	11 M	2700	11 M	OSPO
4	NUCAPS Retrieval Monitoring	2700	11 M	2700	11 M	OSPO
5	L1C Metadata.xml (for IASI only)	N/A	N/A	N/A	N/A	CLASS
6	EDR NetCDF	2700	7.8 G	2700	9.4 G	CLASS and OSPO
7	CCR Archive NetCDF	2700	2.9 G	2700	2.9 G	CLASS
8	OLR NetCDF	2700	170 M	2700	170 M	CPC
9	0.5 × 2 NUCAPS EDR global grids	2	1.4 G	2	1.4 G	OSPO
10	0.5 × 2 OLR global grids	2	6.1 M	2	6.1 M	OSPO
	Total	**16204**	**38.7 G**	**16204**	**40 G**	

NUCAPS Enterprise System has been implemented on both JPSS NOAA-20 and NOAA-21.The NUCAPS daily product output file sizes are approximately of the same order for both NOAA-20 and NOAA-21.

Surface Corrections

Temperature (100x120)

FOR = 1	FOR = 2	FOR = 3
206.3	206.5	206.1
210.9	211.1	210.7
219.9	220.1	219.7
230.1	230.3	230.0
239.2	239.5	239.1
…	…	…
296.3	294.5	294.5
298.0	296.4	296.1
300.7	299.6	298.9
302.3	299.6	300.5
302.3	299.6	300.5
302.3	299.6	301.5
302.3	299.6	301.5

**Currently repeating *below surface*

$$[P_{surf} - P_{lev}(P_{bot})] \geq 5\ hPa$$

$$BL_{mult} = \frac{P_{surf} - P_{lev}(P_{bot}-1)}{P_{lev}(P_{bot}) - P_{lev}(P_{bot}-1)}$$

BLMULT(120) must be calculated

FOR = 1	FOR = 2	FOR = 3
1.0	1.2	0.8

Lbot(120) must be calculated

FOR = 1	FOR = 2	FOR = 3
97	96	99

$$T_{surf} = T(P_{bot} - 1) + BL_{mult} \times [\,T(P_{bot}) - T(P_{bot} - 1)]$$

Sample Tsurf calcs for each FOR…

1) 300.7-1.0*(302.3-300.7) = 299.4
2) 296.4-1.2*(299.6-296.4) = 292.6
3) 300.5-0.8*(301.5-300.5) = 299.7

Temperature (100x120) for NUCAPSv3

FOR = 1	FOR = 2	FOR = 3
206.3	206.5	206.1
210.9	211.1	210.7
219.9	220.1	219.7
230.1	230.3	230.0
239.2	239.5	239.1
…	…	…
296.3	294.5	294.5
298.0	296.4	296.1
300.7	292.6	298.9
299.4	nan	300.5
nan	nan	300.7
nan	nan	299.7
nan	nan	nan

Replace with corrected value, fill with missing values (e.g., -999.9, -9999.9, etc.) (Slide from Rebekah)

Supplemental Slides

(S.4) NUCAPS Products Requirements

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

Temperature Profile

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

"Clear to Partly-Cloudy"
(Cloud Fraction < 50%)
↕
IR+MW retrieval

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

Moisture Profile

CrIS/ATMS Atmospheric Vertical Moisture Profile (AVMP) Measurement Uncertainty – 2-km Layer Average Mixing Ratio % Error		
PARAMETER	**THRESHOLD**	**OBJECTIVE**
AVMP, Cloud fraction < 50%, surface to 600 hPa	Greater of 20% or 0.2 $g \cdot kg^{-1}$ / 2-km layer	10%
AVMP, Cloud fraction < 50%, 600–300 hPa	Greater of 35% or 0.1 $g \cdot kg^{-1}$ / 2-km layer	10%
AVMP, Cloud fraction < 50%, 300–100 hPa	Greater of 35% or 0.1 $g \cdot kg^{-1}$ / 2-km layer	10%
AVMP, Cloud fraction ≥ 50%, surface to 600 hPa	Greater of 20% of 0.2 $g \cdot kg^{-1}$ / 2-km layer	10%
AVMP, Cloud fraction ≥ 50%, 600–400 hPa	Greater of 40% or 0.1 $g \cdot kg^{-1}$ / 2-km layer	10%
AVMP, Cloud fraction ≥ 50%, 400–100 hPa	Greater of 40% or 0.1 $g \cdot kg^{-1}$ / 2-km layer	NS

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

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

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)

DPS	Requirement	Performance
DPS-160	The Atmospheric Vertical Temperature Profile product shall provide atmospheric vertical temperature profiles, globally day and night, for all scenes, for each field of regard (FOR) comprised by multiple fields of view (FOVs), at the refresh rates of the instrument.	✔ Yes
DPS-161	The Atmospheric Vertical Temperature Profile product shall provide atmospheric vertical temperature profiles with a horizontal cell size of 50 kilometers at nadir.	✔ Yes
DPS-162	The Atmospheric Vertical Temperature Profile product shall provide atmospheric vertical temperature profiles with vertical reporting intervals of 20 millibar (mb) from the surface to 850 mb; 50 mb from 850 to 300 mb; 25 mb from 300 to 100 mb; 20 mb from 100 mb to 10 mb; 2 mb from 10 mb to 1.0 mb; 0.2 mb from 1.0 mb to 0.5 mb.	✔ Yes
DPS-163	The Atmospheric Vertical Temperature Profile product shall provide atmospheric vertical temperature profiles with a cloud-free or partly cloudy measurement uncertainty of 1.6 kelvin (K) per layer from the surface to 300 mb; 1.5 K per layer from 300 mb to 1 mb; 3.5 K per layer from 1 mb to 0.5 mb.	✔ Yes
DPS-164	The Atmospheric Vertical Temperature Profile product shall provide atmospheric vertical temperature profiles with a cloudy-condition measurement uncertainty of 2.5 kelvin (K) per layer from the surface to 700 mb; 1.5 K per layer from 700 mb to 1 mb; 3.5 K per layer from 1 mb to 0.5 mb.	✔ Yes

DPS	Requirement	Performance
DPS-166	The Atmospheric Vertical Moisture Profile product shall provide atmospheric vertical moisture profiles, globally day and night, for all scenes, for each field of regard (FOR) comprised by multiple fields of view (FOVs), at the refresh rates of the instrument.	✔ Yes
DPS-167	The Atmospheric Vertical Moisture Profile product shall provide atmospheric vertical moisture profiles with a horizontal cell size of 50 kilometers at nadir.	✔ Yes
DPS-168	The Atmospheric Vertical Moisture Profile product shall provide atmospheric vertical moisture profiles with vertical reporting intervals of 20 millibar (mb) from the surface to 850 mb; 50 mb from 850 to 100 mb.	✔ Yes
DPS-169	The Atmospheric Vertical Moisture Profile product shall provide atmospheric vertical moisture profiles with a cloud-free and partly-cloudy measurement uncertainty of the greater of 20% or 0.2 gram per kilogram (g/kg) from the surface to 600 mb; greater of 35% or 0.1 g/kg from 600 mb to 100 mb.	✔ Yes
DPS-170	The Atmospheric Vertical Moisture Profile product shall provide atmospheric vertical moisture profiles with a cloudy-condition measurement uncertainty of the greater of 20% or 0.2 g/kg from the surface to 600 mb; greater of 40% or 0.1 g/kg from 600 mb to 100 mb.	✔ Yes

Requirement Check List – CrIS Infrared Ozone Profile

DPS	Requirement	Performance
DPS-189	The Infrared Ozone Profile product shall provide infrared ozone profiles, globally day and night, at the refresh rates of the instrument.	✔ Yes
DPS-190	The Infrared Ozone Profile product shall provide infrared ozone profiles from the top of atmosphere to the surface, on the native vertical reporting interval of the radiative transfer model grid used in the retrieval.	✔ Yes
DPS-192	The Infrared Ozone Profile product shall provide infrared ozone profiles with a measurement precision of 20% from the surface to 260 millibars (mb) in one statistic layer, and from 260 mb to 4 mb in 6 statistic layers.	✔ Yes
DPS-193	The Infrared Ozone Profile product shall provide infrared ozone profiles with a measurement accuracy of 10% from the surface to 260 millibars (mb) in one statistic layer, and from 260 mb to 4 mb in 6 statistic layers.	✔ Yes

Requirement Check List – Outgoing Longwave Radiation

DPS	Requirement	Performance
DPS-205	The Outgoing Longwave Radiation product shall provide outgoing longwave radiation, globally day and night, for all scene conditions, over the measurement range of the instrument, at the refresh rates of the instrument.	✔ Yes
DPS-208	The Outgoing Longwave Radiation product shall provide outgoing longwave radiation with a measurement precision of 12 watts per square meter (W/m^2).	✔ Yes
DPS-209	The Outgoing Longwave Radiation product shall provide outgoing longwave radiation with a measurement accuracy of 5 W/m^2.	✔ Yes

Requirement Check List – Carbon Monoxide (CO)

DPS	Requirement	Performance
DPS-398	The Carbon Monoxide product shall provide carbon Monoxide volume density, geolocated, globally, for the total vertical column, in all weather conditions, day and night, at the refresh rates of the instrument.	✔ Yes
DPS-399	The Carbon Monoxide product shall provide carbon Monoxide volume density with a measurement range of 0 to 200 parts per billion by volume (ppbv).	✔ Yes
DPS-400	The Carbon Monoxide product shall provide carbon Monoxide volume density with a horizontal resolution of 100 km.	✔ Yes
DPS-402	The Carbon Monoxide product shall provide carbon monoxide column value with a measurement precision of 15%.	✔ Yes
DPS-403	The Carbon Monoxide product shall provide carbon Monoxide column value with a measurement accuracy of 5%.	✔ Yes

Requirement Check List – Methane (CH_4)

DPS	Requirement	Performance
DPS-382	The Methane product shall provide methane volume density, geolocated, globally, for the total vertical column, in all weather conditions, day and night, at the refresh rates of the instrument	✔ Yes, see slide 51.
DPS-381	The Methane product shall provide methane volume density with a measurement range of 1100 to 2250 parts per billion by volume (ppbv)	✔ Yes, see slide 125.
DPS-383	The Methane product shall provide methane volume density with a horizontal resolution of 100 km	Yes. The NUCAPS algorithm produces a CO_2 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-385	The Methane product shall provide methane volume density with a measurement precision of 1% or 20 ppbv	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. Recent field measurements (conducted since the time when the requirements were devised) suggest that the CH_4 precision threshold is too stringent. The team recommends a waver for a relaxed total/partial column CH_4 precision requirement (TBD), along with the proper use of averaging kernels (AKs).
DPS-386	The Methane product shall provide methane volume density with a measurement accuracy of 4% or 80 ppbv	As above regarding *in situ* data collection.

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 CO_2 product geolocated, globally, for the total vertical column, in all weather conditions, day and night, at the refresh rates of the instrument. See slide 55.
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. See slide 125.
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 CO_2 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	✔ 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.