Beta/Provisional Maturity Science Review For NOAA-21 VIIRS Polar Winds (VPW)

STAR Winds Science Team:

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1/25/2024

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

1. Beta

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

2. Provisional

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

3. Validated

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

BETA/PROVISIONAL MATURITY REVIEW MATERIAL

Outline

- Algorithm Cal/Val Team Members
- Product Overview/Requirements
- Evaluation of algorithm performance to specification requirements
  - Algorithm version, processing environment
  - Evaluation of the effect of required algorithm inputs
  - Quality flag analysis/validation
  - Error Budget
- User Feedback
- Downstream Product Feedback
- Risks, Actions, and Mitigations
- Documentation (Science Maturity Check List)
- Conclusion
- Path Forward

NOAA-21 Winds Cal/Val Team

Algorithm Cal/Val Team Members

Name	Organization	Major Task
Jaime Daniels	NOAA-NESDIS-STAR-SMCD	Winds Science Team Lead
Jeff Key	NOAA-NESDIS-STAR-SMCD @ U/W-CIMSS	Winds Science Team Advisor
Dave Santek	UW-Madison/CIMSS	Winds Algorithm Development/Validation
Rich Dworak	UW-Madison/CIMSS	Winds Algorithm Development/Validation
Steve Wanzong	UW-Madison/CIMSS	Cloud Algorithm Development/Maintenance; Cloud/Winds Science Team Liaison
Wayne Bresky	IMSG	Winds Algorithm Development/Validation/Maintenance
Andy Bailey	IMSG	Winds Algorithm Development/Validation/Maintenance
Hongming Qi	NOAA-NESDIS-OSPO	Winds Product Area Lead

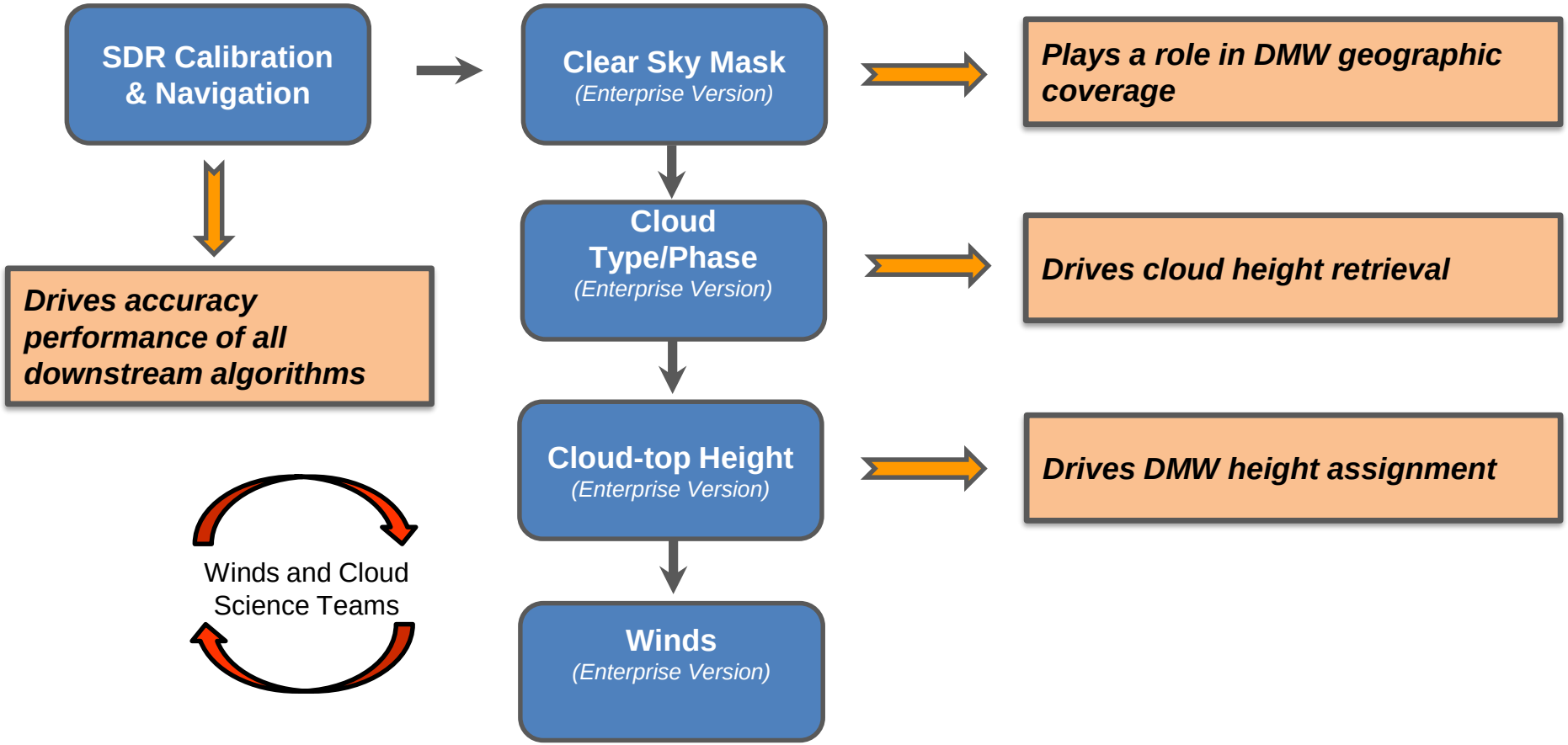
VPW Product Overview

- The Enterprise Winds Algorithm uses the following VIIRS channel
  - M15
- The winds team assumes that all sensor input is valid given the full maturity status of the VIIRS SDRs
- Note - The SRF for NPP/N20 and N21 for the 11µm (M15) and 12µm (M16) channels are noticeably different. This can lead to some differences when comparing the same algorithm among the three satellites.

		Band No.	Driving EDR(s)	Spectral Range (um)	Horiz Sample Interval (km) (track x Scan)	
					Nadir	End of Scan
Reflective Bands	VisNIR	M1	Ocean Color Aerosol	0.402 - 0.422	0.742 x 0.259	1.60 x 1.58
		M2	Ocean Color Aerosol	0.436 - 0.454	0.742 x 0.259	1.60 x 1.58
		M3	Ocean Color Aerosol	0.478 - 0.498	0.742 x 0.259	1.60 x 1.58
		M4	Ocean Color Aerosol	0.545 - 0.565	0.742 x 0.259	1.60 x 1.58
		I1	Imagery EDR	0.600 - 0.680	0.371 x 0.387	0.80 x 0.789
		M5	Ocean Color Aerosol	0.662 - 0.682	0.742 x 0.259	1.60 x 1.58
		M6	Atmosph. Correct.	0.739 - 0.754	0.742 x 0.776	1.60 x 1.58
		I2	NDVI	0.846 - 0.885	0.371 x 0.387	0.80 x 0.789
		M7	Ocean Color Aerosol	0.846 - 0.885	0.742 x 0.259	1.60 x 1.58
	SWMIR	M8	Cloud Particle Size	1.230 - 1.250	0.742 x 0.776	1.60 x 1.58
		M9	Cirrius/Cloud Cover	1.371 - 1.386	0.742 x 0.776	1.60 x 1.58
		I3	Binary Snow Map	1.580 - 1.640	0.371 x 0.387	0.80 x 0.789
		M10	Snow Fraction	1.580 - 1.640	0.742 x 0.776	1.60 x 1.58
		M11	Clouds	2.225 - 2.275	0.742 x 0.776	1.60 x 1.58
		I4	Imagery Clouds	3.550 - 3.930	0.371 x 0.387	0.80 x 0.789
		M12	SST	3.660 - 3.840	0.742 x 0.776	1.60 x 1.58
		M13	SST Fires	3.973 - 4.128	0.742 x 0.259	1.60 x 1.58
Emissive Bands	LWIR	M14	Cloud Top Properties	8.400 - 8.700	0.742 x 0.776	1.60 x 1.58
		M15	Winds	10.263 - 11.263	0.742 x 0.776	1.60 x 1.58
		I5	Cloud Imagery	10.500 - 12.400	0.371 x 0.387	0.80 x 0.789
		M16	SST	11.538 - 12.488	0.742 x 0.776	1.60 x 1.58

VPW Product Overview

Polar (tropospheric) winds are derived by tracking cloud features in infrared channel imagery. Wind speed, direction, and height are measured throughout the troposphere, poleward of approximately 70 degrees latitude, in cloudy areas only. Vertical and horizontal coverage is not uniform. For quality control, winds are derived using three consecutive orbits. Wind vectors are assigned the time of the middle image of the orbit triplet.



VPW Product Overview/Requirements

- JPSS Ground Segment Data Product Specification (Rev H); February 22, 2023

Attribute	DPS	Requirement/Threshold	Performance
Coverage	DPS-104	The Polar Winds product shall provide polar wind vectors, at cloud tops, globally day and night, in cloudy areas, between the surface and the tropopause	
Precision	DPS-107	The Polar Winds product shall provide polar wind vectors with a measurement precision of 3.8 meters/sec, expressed as *the standard deviation about the* mean vector difference. *(should be 4.2 meters/sec!)*	
Accuracy	DPS-108	The Polar Winds product shall provide polar wind vectors with a measurement accuracy of 7.5 meters/sec, expressed as a mean vector difference.	

Note: *Cloud Mask, Cloud-top Phase, Cloud-top Pressure are used as input for the VPW product. VPW product performance is impacted by the quality of these upstream cloud products.*

Algorithm Version and Processing Environment *(1/2)*

- Description of processing environment and algorithms used to achieve the maturity stage:
  - Algorithm version: V3R2
    - This version of the enterprise winds software is now consistent with the enterprise winds software implemented in the GOES-R ground system. Planned operational implementation date in the GOES-R ground system is January 30, 2024

    - Algorithm updates *(applicable to VIIRS*)*
      - Check on the satellite zenith angle (70 deg threshold) associated with the target scene
      - Fail retrieved winds from target scenes dominated by:
        - Ice clouds where wind height assignments are at/below 500mb
        - Liquid clouds where wind height assignments are above 500mb
        - Mixed phase clouds
      - *Threshold changes to DMW and GFS wind quality control check
        - Band 8 DMW (CTWV) – From 10 m/s to 8.5 m/s
        - Band 14 DMW – From 10 m/s to 8 m/s
      - *Replaced a test that checks cloud height retrieval quality flag with a check to ensure a valid cloud top pressure exist
        - Meant as a *temporary fix* to a late discovered bug in the framework software that incorrectly points a variable used in the winds code to the incorrect cloud height retrieval quality flag.
        - Required to recover a large number of good quality low level winds that were being tossed out
        - *The winds team will deliver an updated version of the winds algorithm software to ASSISTT for implementation into operations at a TBD date.*

Algorithm Version and Processing Environment *(2/2)*

- Algorithm Theoretical Basis Documents

  https://www.star.nesdis.noaa.gov/goesr/documentation_ATBDs.php

- Processing Environment

  Production site: NCCF (as provided in the product file attributes)

  Production environment: UAT (as provided in the product file attributes)

- Effective date: November 16, 2023.

  VPW data from November 16 – December 31, 2023 used in the analyses

Quality Flag Analysis/Validation

Data Quality Flag (DQF)	Definition
-3	Good wind, but an alternative channel (band 13) used for feature tracking and an alternative set of channels used for the determination of cloud-top height/AMV height
-2	Good wind, but an alternative set of channels used for the determination of cloud-top height/AMV height assignment
-1	Good wind, but an alternative channel used for feature tracking
0	Good wind
Internal Quality Flag Failure Codes	**Definition**
1	Maximum gradient below acceptable threshold
2	Target located on earth edge or Satellite Zenith Angle greater than 62°
3	Cloud amount failure (less than 10% cloud cover for cloud track winds or greater than 0% cloud cover for water vapor clear-sky winds)
4	Median pressure failure
5	Bad or missing brightness temperature in target scene
6	Multiple cloud layers present
7	Target scene too coherent (not enough structure for reliable tracking)
8	Tracking correlation below 0.6 (not used for nested tracking)
9	u-component acceleration greater than 10 m/s (5 m/s for visible)
10	v-component acceleration greater than 10 m/s (5 m/s for visible)
11	u- and v- component accelerations greater than 10 m/s (5 m/s for visible)
12	Derived wind slower than 3 m/s
13	Target scene too close to day/night terminator (visible and SWIR only)
14	Median pressure used for height assignment outside acceptable pressure range (channel dependent)
15	Match found on boundary of search region
16	Gross difference from forecast wind (channel dependent)
17	Median pressure (used for height assignment) of largest cluster for first image pair is too different from median pressure of largest cluster for second image pair – only valid for nested tracking
18	Search region extends beyond domain of data buffer
19	Expected Error (EE) too high
20	Missing data in search region
21	No winds are available for the clustering algorithm
22	No clusters were found
Catastrophic Failures	
Invalid time interval	
Temporal data not available	
Line segment swath too small (must contain at least the same number of lines as target box size specified in the Winds Configuration File.	
Search region size is less than the target scene size	

Quality checks are done on the:

- Pixel level channel data in the target scene to be tracked *(Target scene suitablilty)*
- Derived wind *(Validity)*
- Assigned pressure height *(Validity)*
- Missing data

No issues with the quality flags

Evaluation of algorithm performance to specification requirements

Validation Strategies

Visual Inspection of Derived Winds

Comparisons to Reference Wind Data

- Radiosonde wind observations
  - 00 UTC and 12 UTC, predominantly
  - Primarily land based
  - Used by all operational satellite processing centers that generate satellite winds

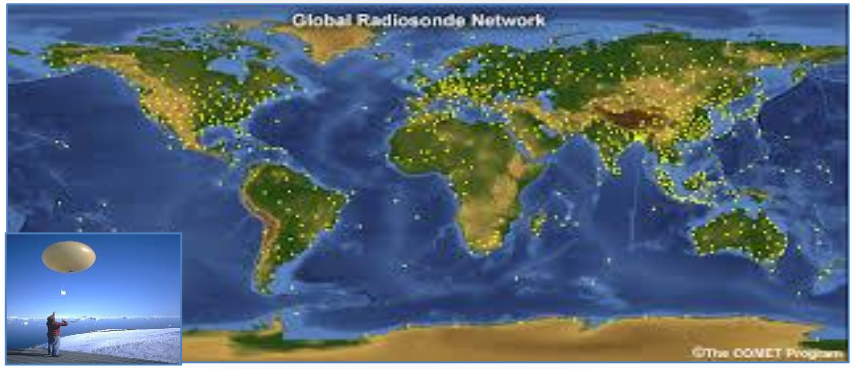
- Commercial Aircraft Wind Observations
  - Continuous temporal observations
  - Land and ocean based
  - Ascent/descent, flight level (predominantly)

- NCEP GFS Analysis Winds
  - 00, 06, 12, and 18 UTC
  - Land and ocean based
  - Get a comparison for every satellite wind

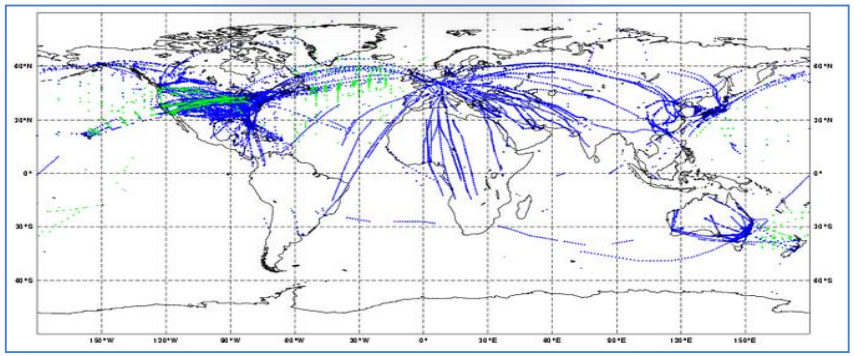
Inter-sensor Comparisons

- Comparisons of NOAA-21, S-NPP, and NOAA-20 winds

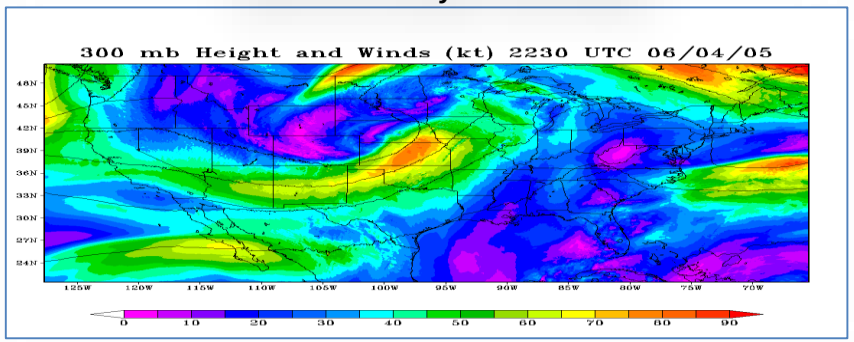
Global Radiosonde Network



Commercial Aircraft Winds

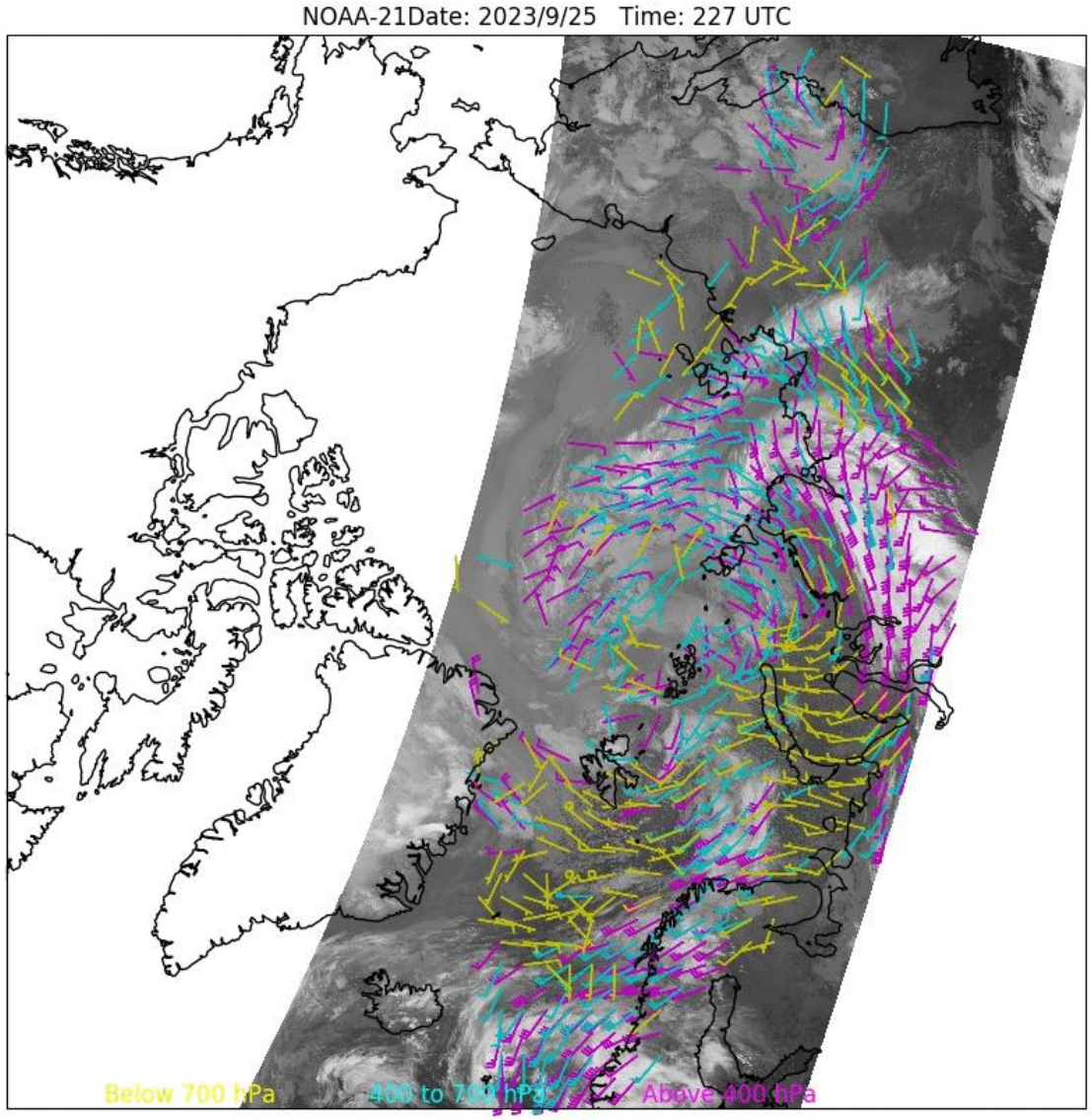


NCEP GFS Analysis Wind Fields

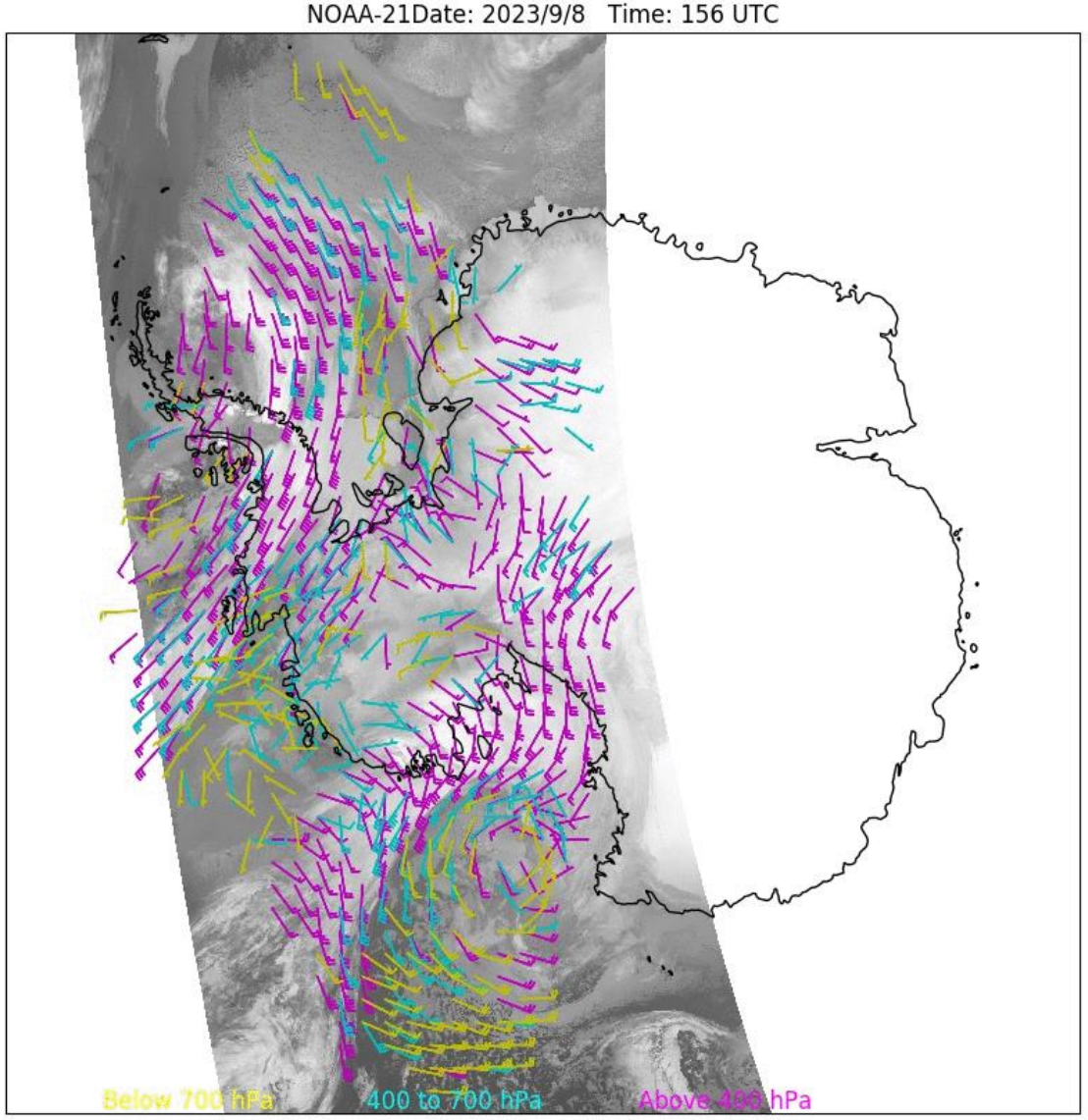


NOAA-21 VPW Product

Arctic



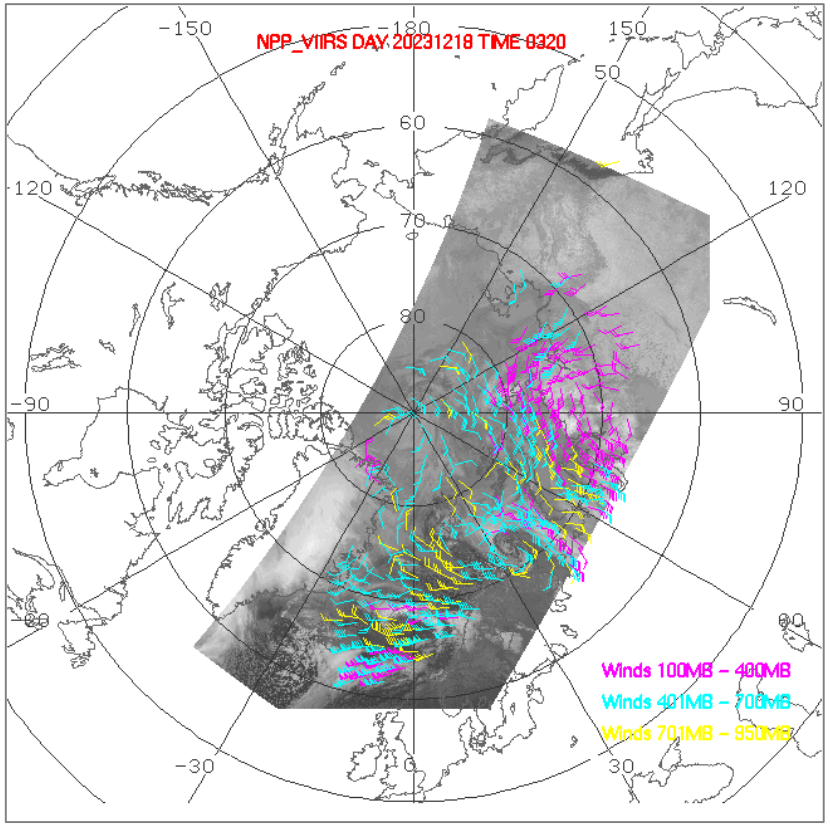
Antarctic



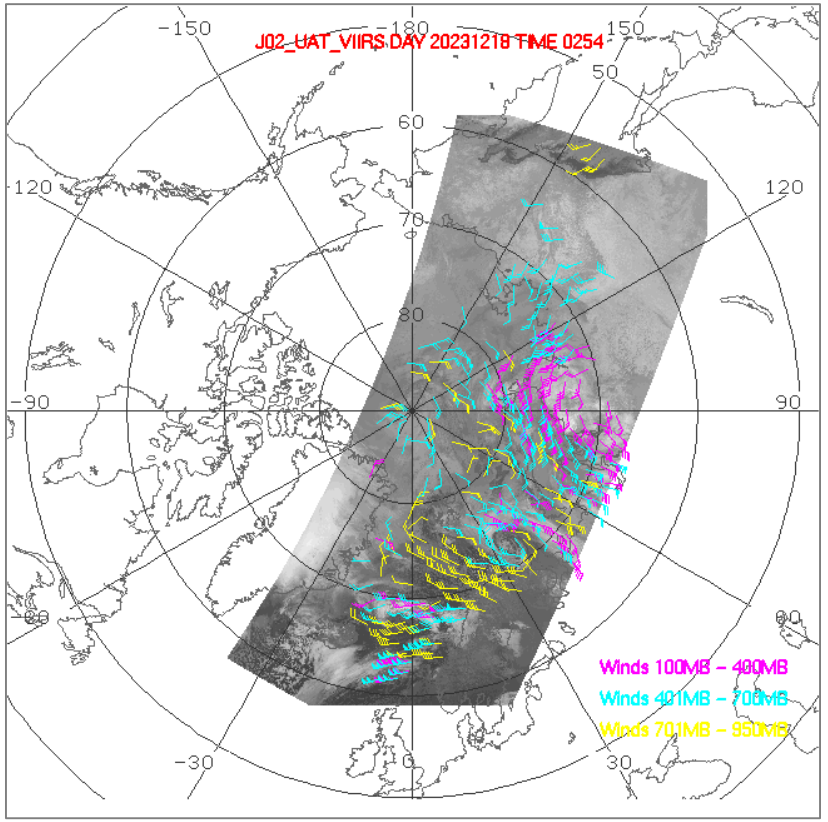
S-NPP, NOAA-21, NOAA-20 VPW Winds (Arctic)

December 18, 2023

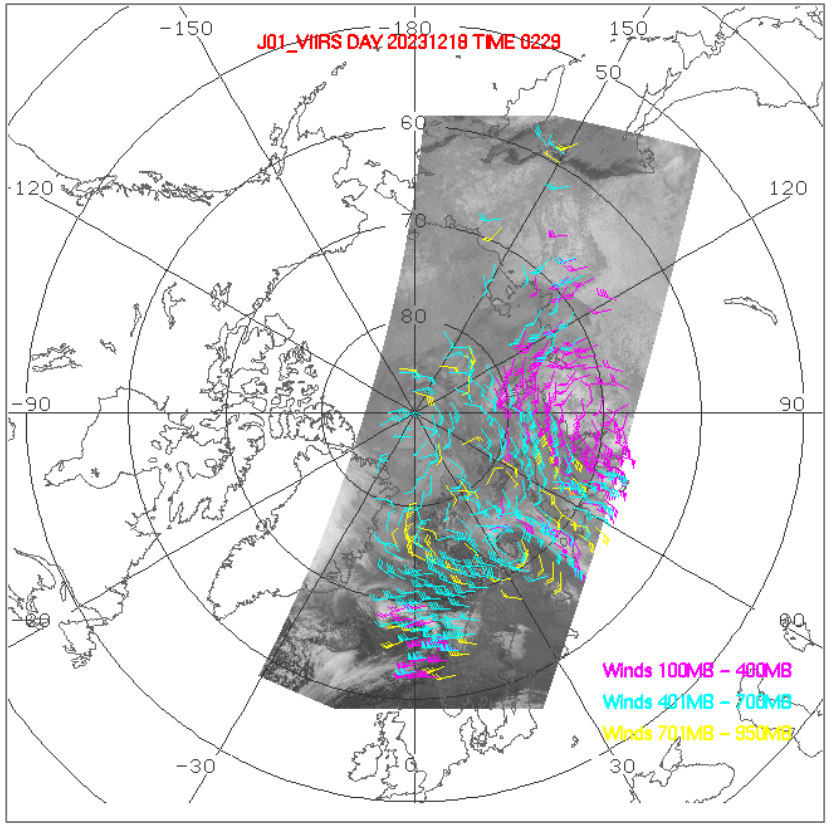
S-NPP



NOAA-21



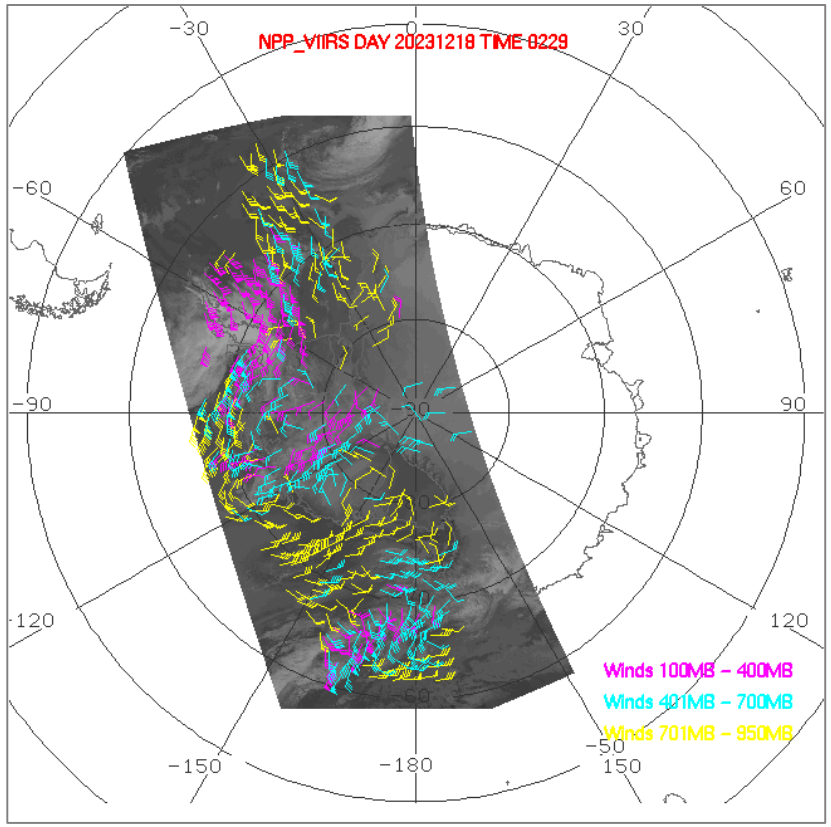
NOAA-20



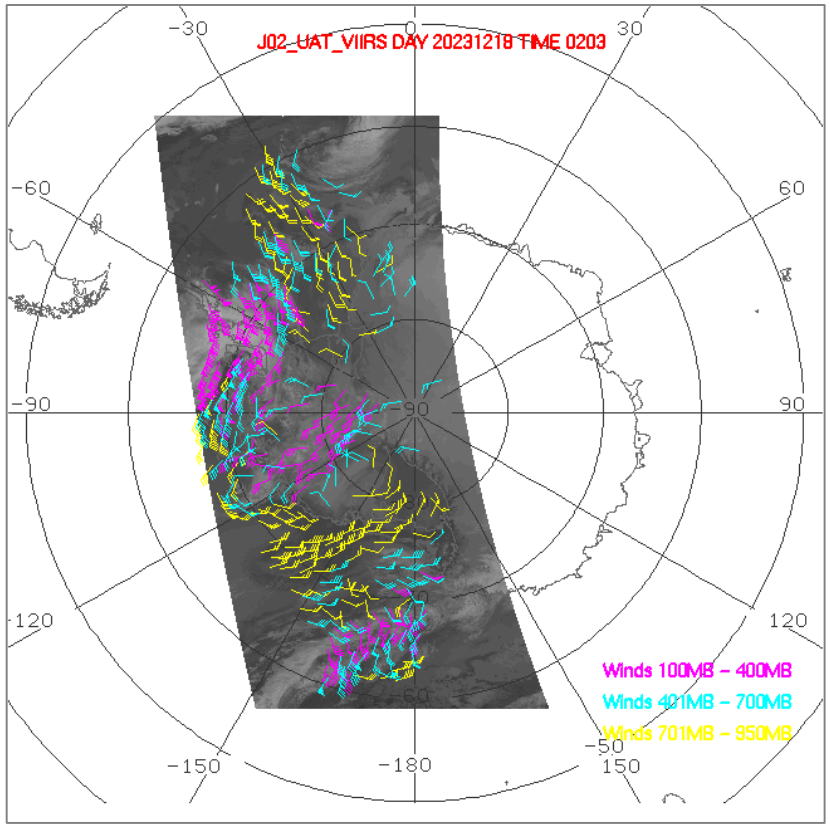
S-NPP, NOAA-21, NOAA-20 VPW Winds (Antarctic)

December 18, 2023

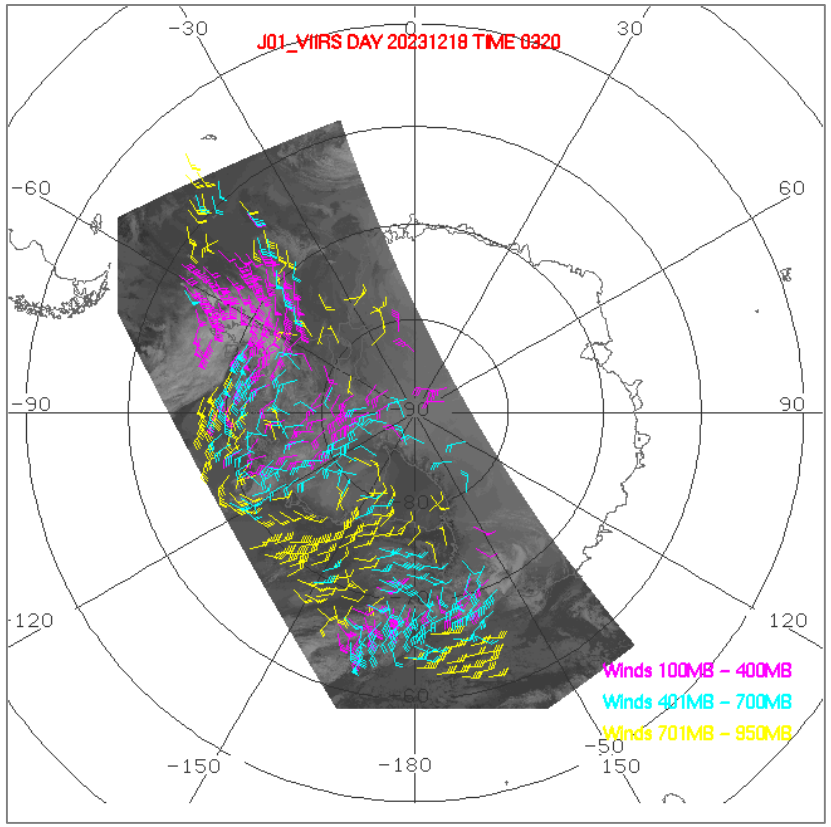
S-NPP



NOAA-21



NOAA-20



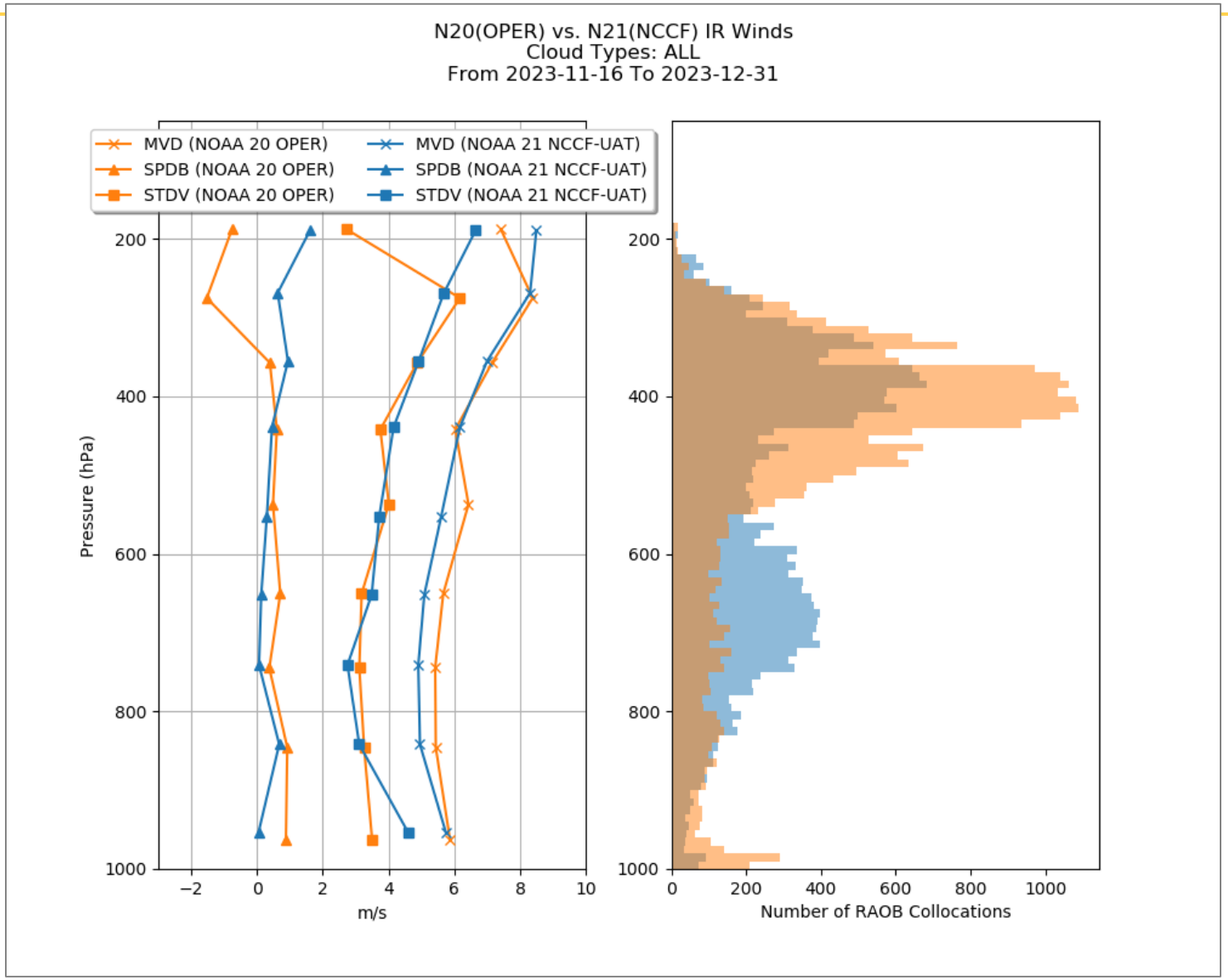
Comparisons to Radiosonde Winds

VPW Comparisons to Radiosonde Winds

NOAA-21 VPW (NCCF-UAT)

vs

NOAA-20 VPW (OPS)



Requirements:
Accuracy: 7.5 m/s
Precision: 4.2 m/s

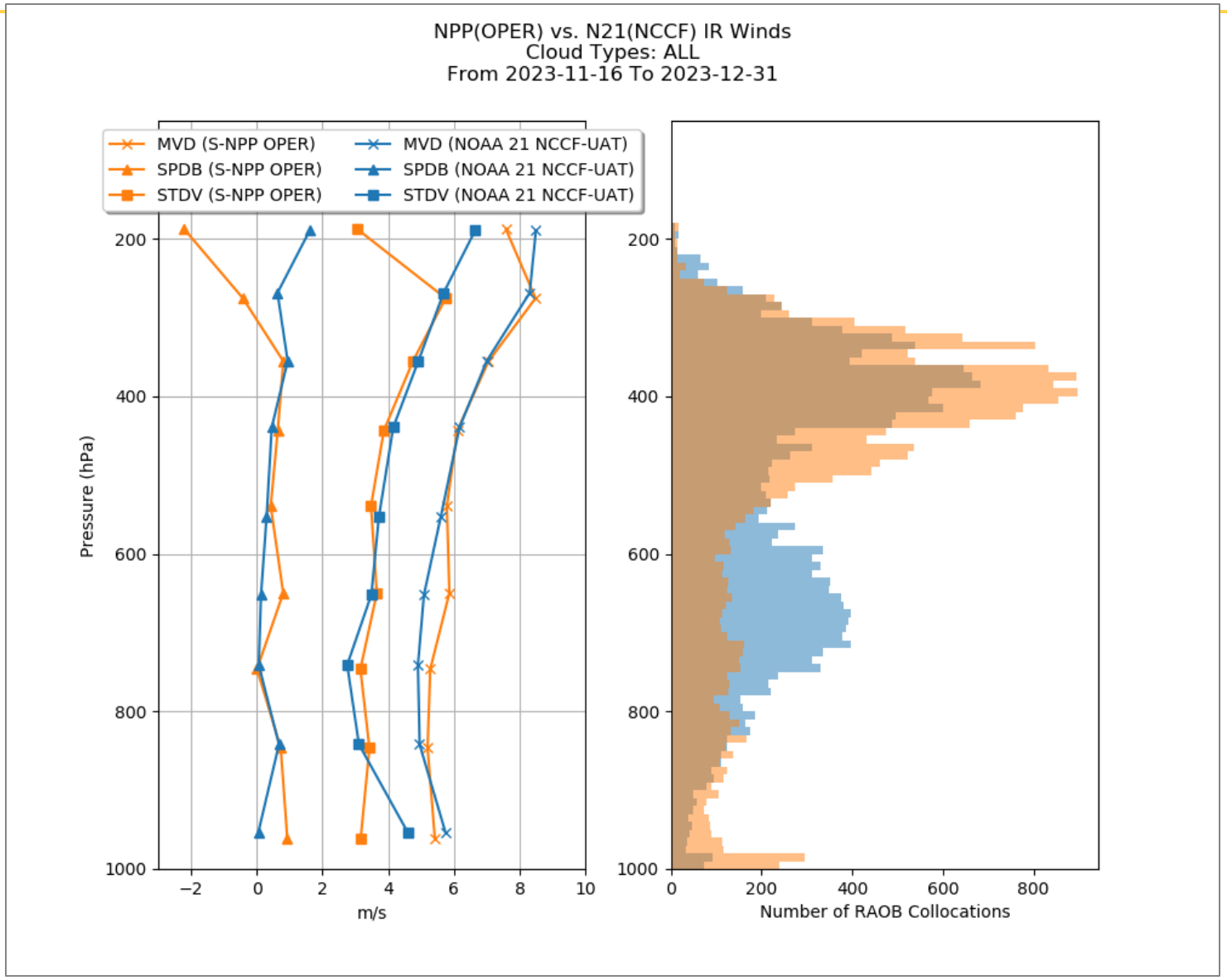
Vertical Profiles *(from left to right):* **Speed Bias (Sat-Raob); Standard Deviation (STDV) = Precision , Mean Vector Difference (MVD) = Accuracy**

VPW Comparisons to Radiosonde Winds

NOAA-21 VPW (NCCF-UAT)

vs

S-NPP VPW (OPS)



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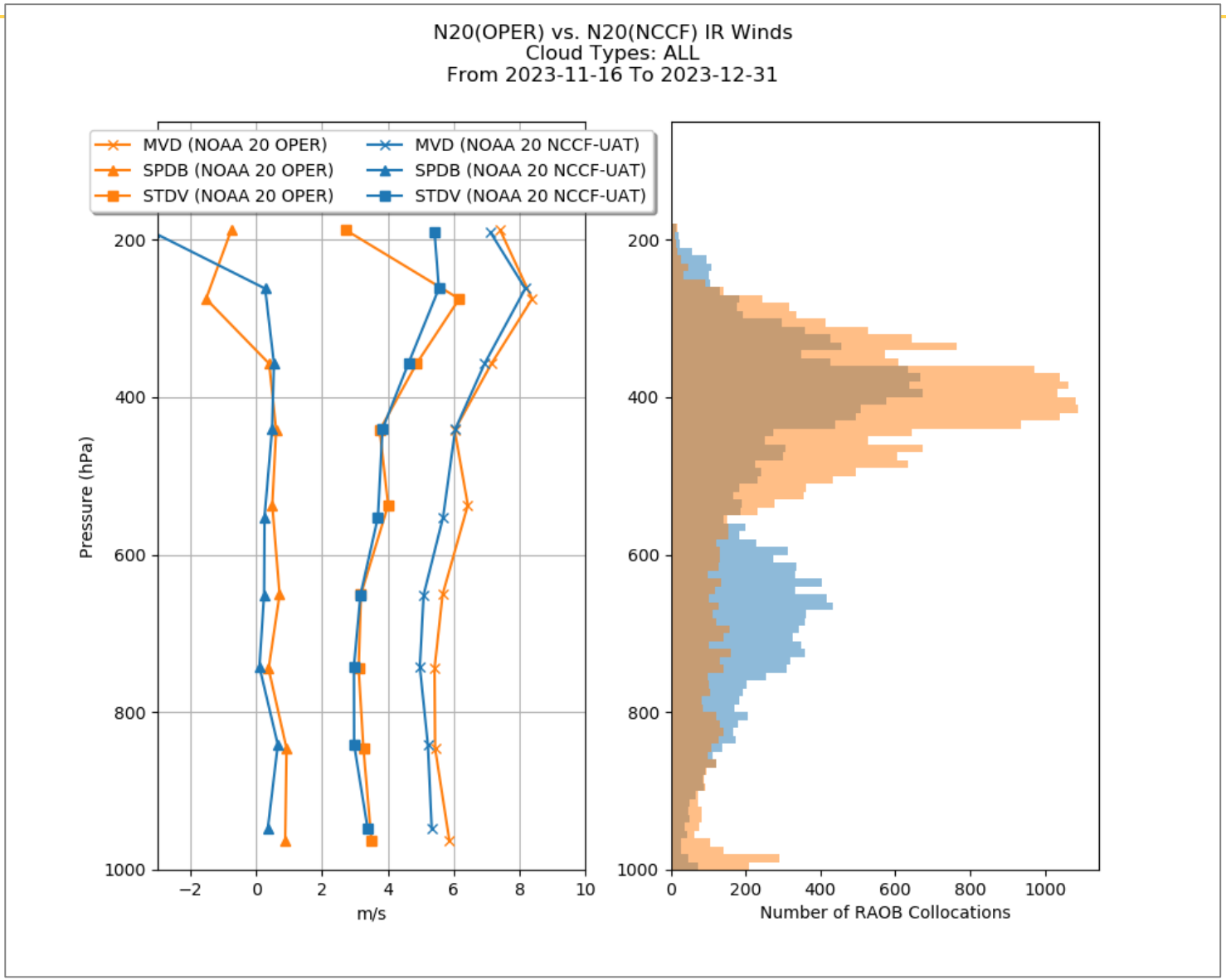
VPW Comparisons to Radiosonde Winds

NOAA-20 VPW (NCCF-UAT)

vs

NOAA-20 VPW (OPS)



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S-NPP VPW (NCCF-UAT)

vs

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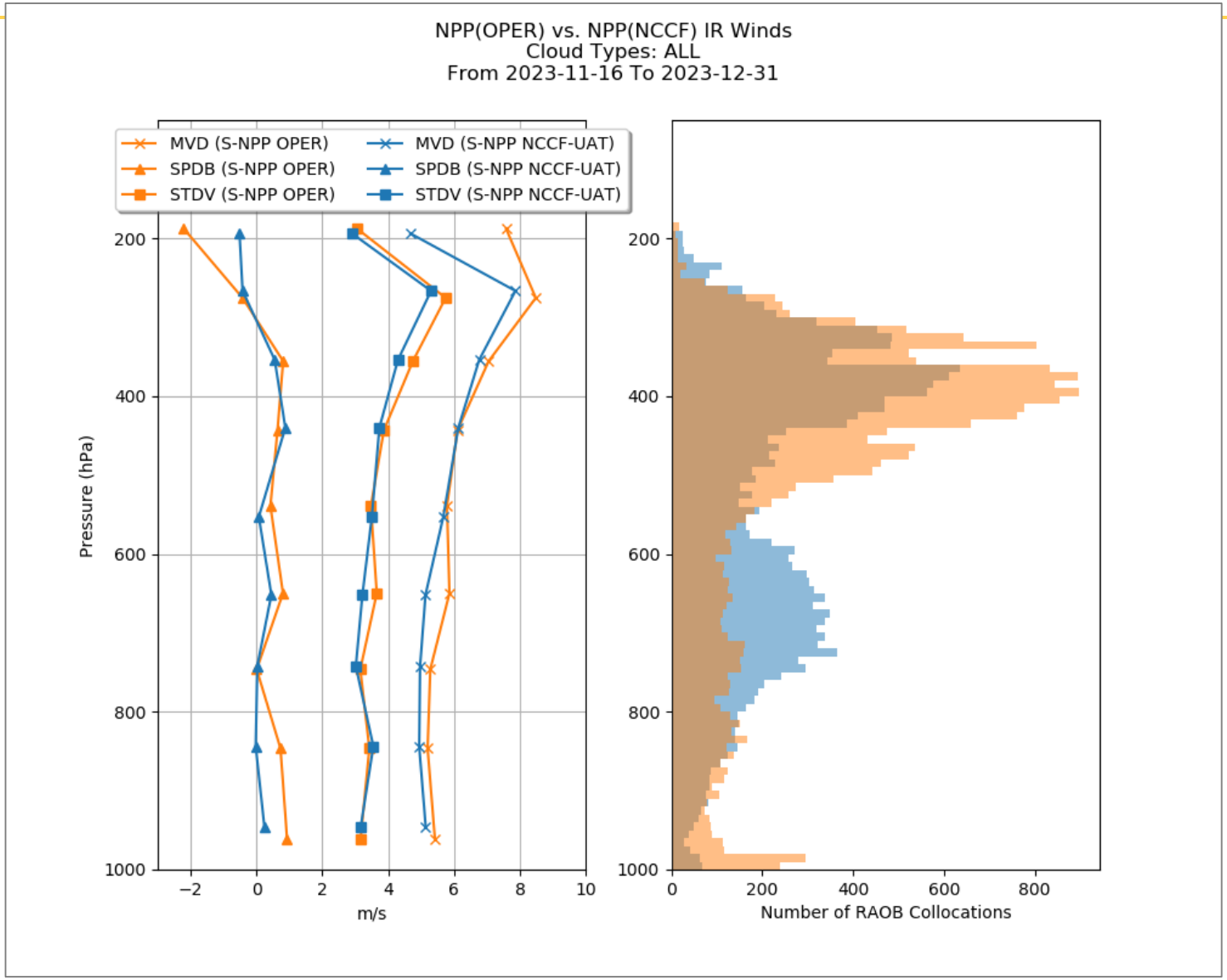

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vs

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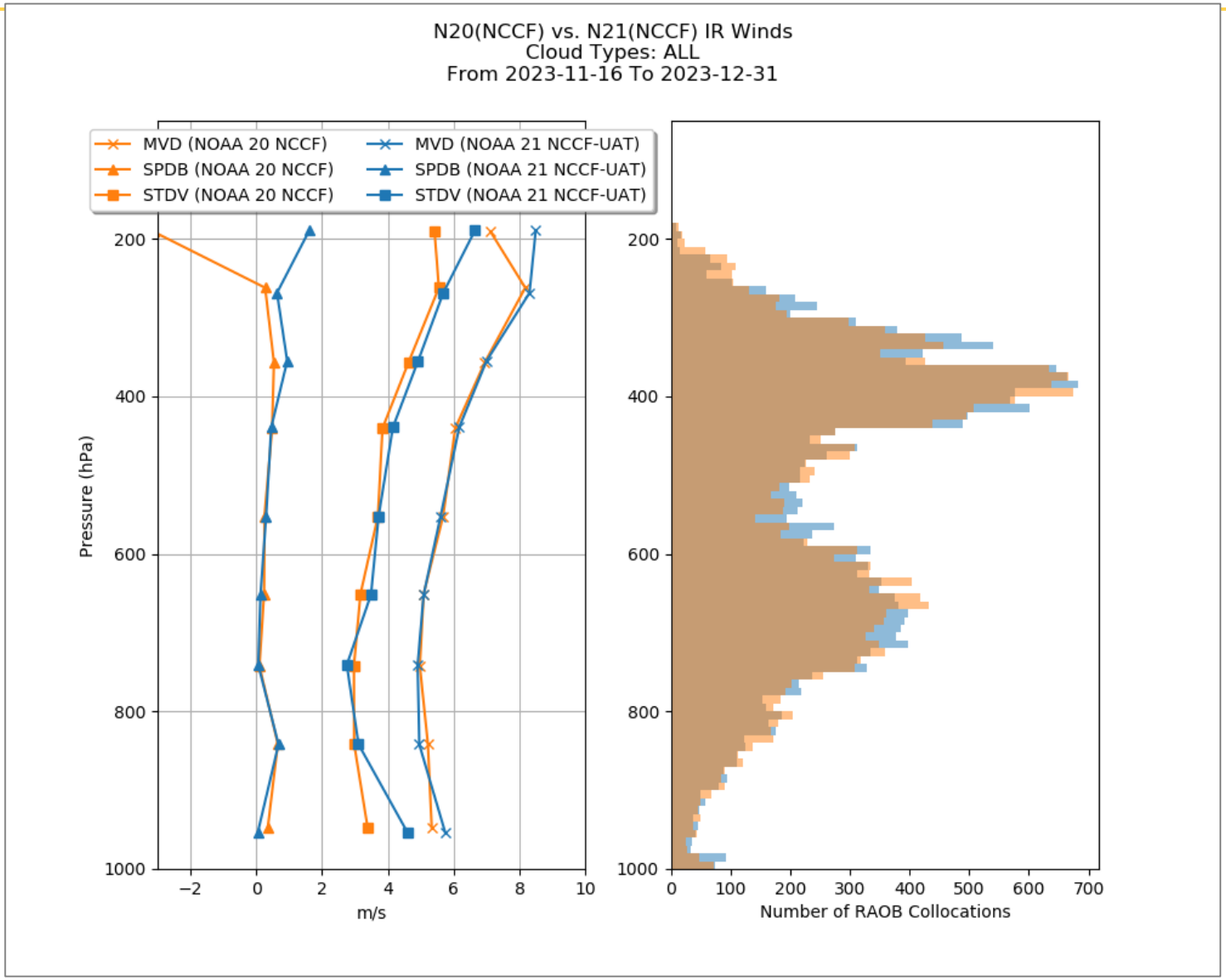

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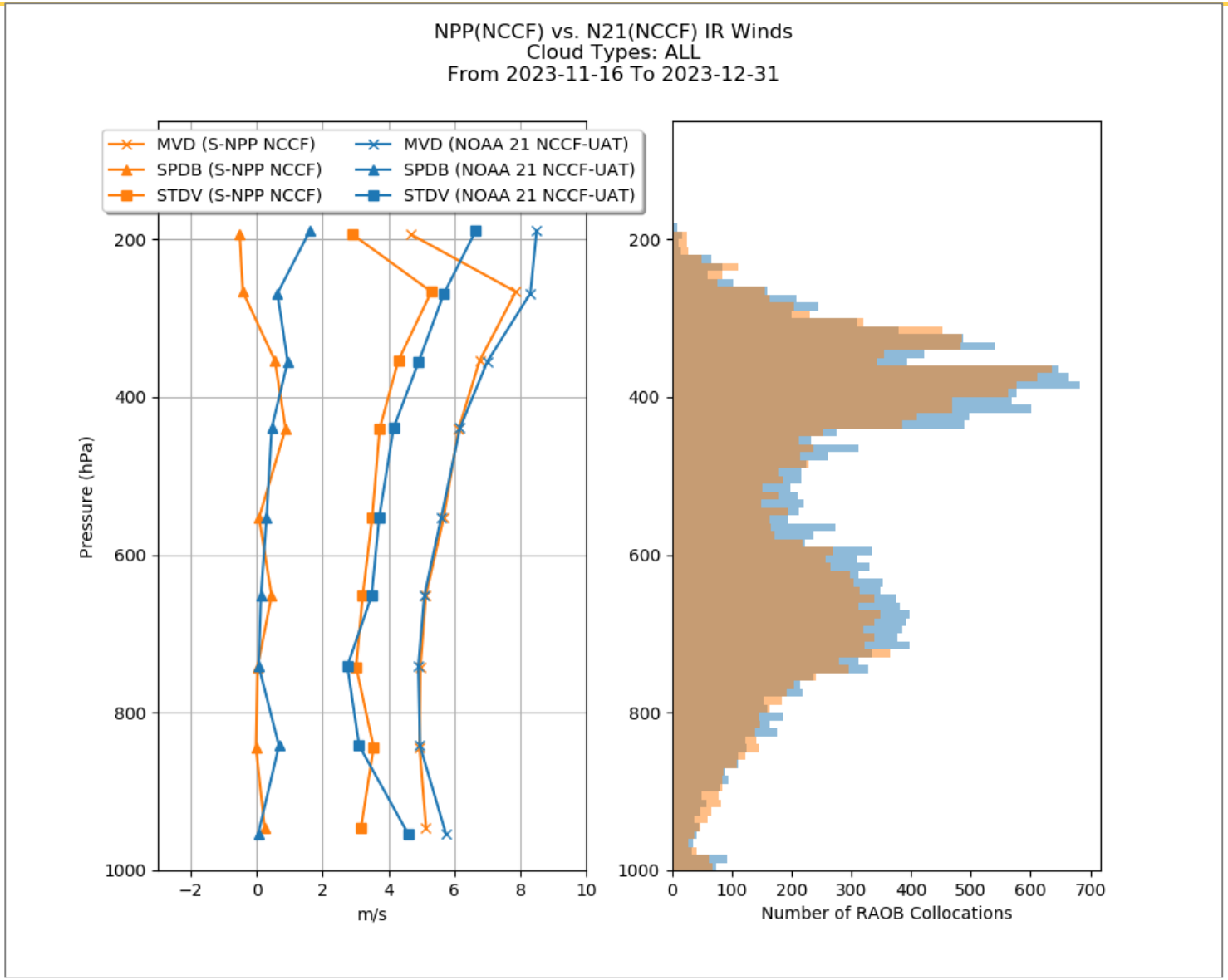
VPW Comparisons to Radiosonde Winds

NOAA-21 VPW (NCCF-UAT)
vs
S-NPP VPW (NCCF-UAT)



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Comparisons to Commercial Aircraft Winds

VPW Comparisons to Commercial Aircraft Winds

November 16 – December 31, 2023

All Levels, All Latitudes	Operational and Test (NCCF-UAT) VPW Winds				
	NOAA-21 (NCCF-UAT)	**S-NPP (OPS)**	**NOAA-20 (OPS)**	**NOAA-20 (NCCF-UAT)**	**S-NPP (NCCF-UAT)**
Accuracy *(m/s)*	**5.44**	**5.90**	**5.71**	**5.57**	**5.65**
Precision *(m/s)*	**3.48**	**3.40**	**3.61**	**3.83**	**3.28**
Speed Bias *(m/s)* *(Sat-Aircraft)*	0.48	0.86	0.71	0.45	0.82
Speed *(m/s)*	18.52	18.83	18.18	18.61	19.45
Sample Size	2854	3357	3033	3288	3321

Mean Vector Difference (MVD) = Accuracy; Standard Deviation (STDV) = Precision

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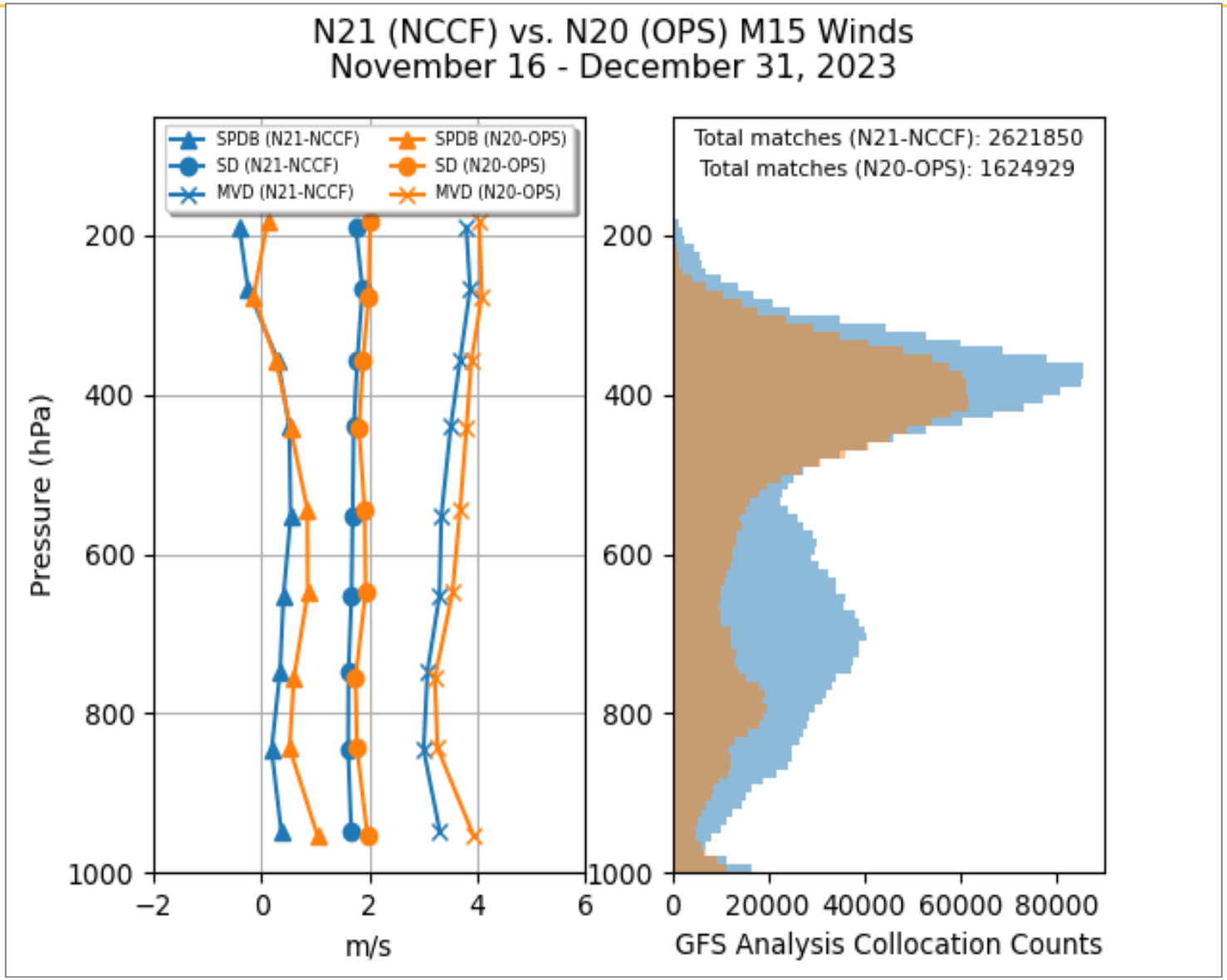
Comparisons to GFS Analysis Winds

VPW Comparisons to GFS Analysis Winds

NOAA-21 VPW (NCCF-UAT)
vs
NOAA-20 VPW (OPS)



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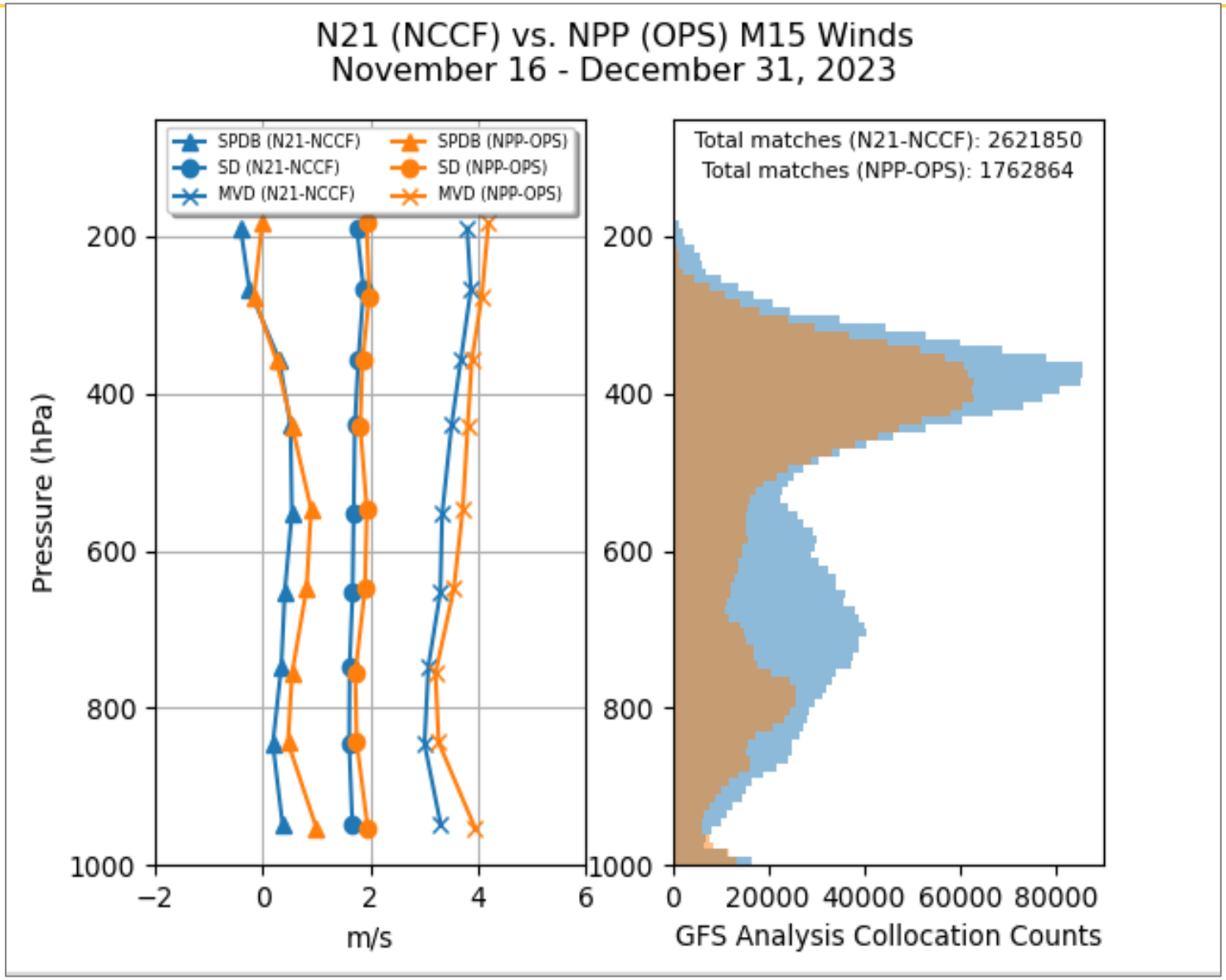

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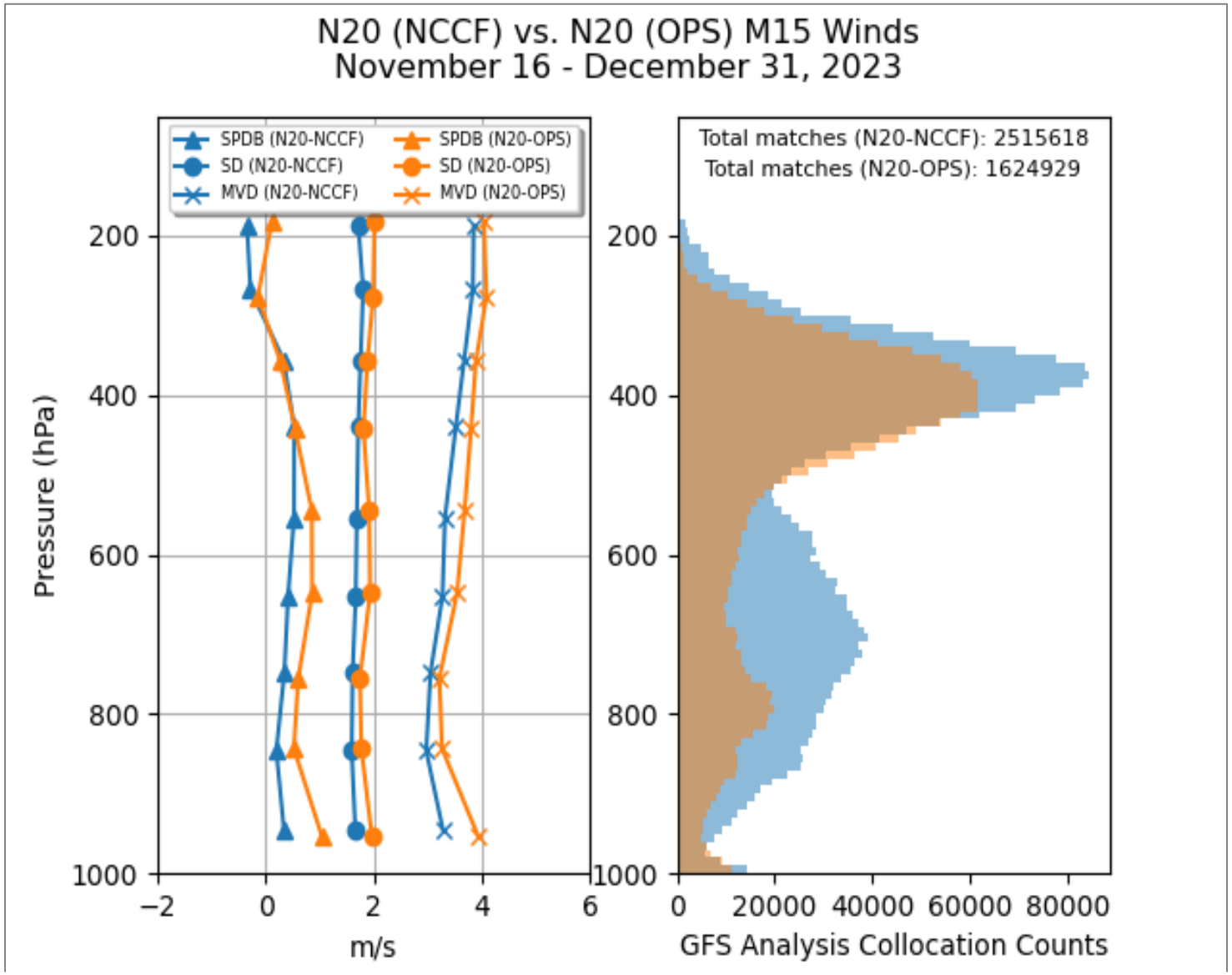

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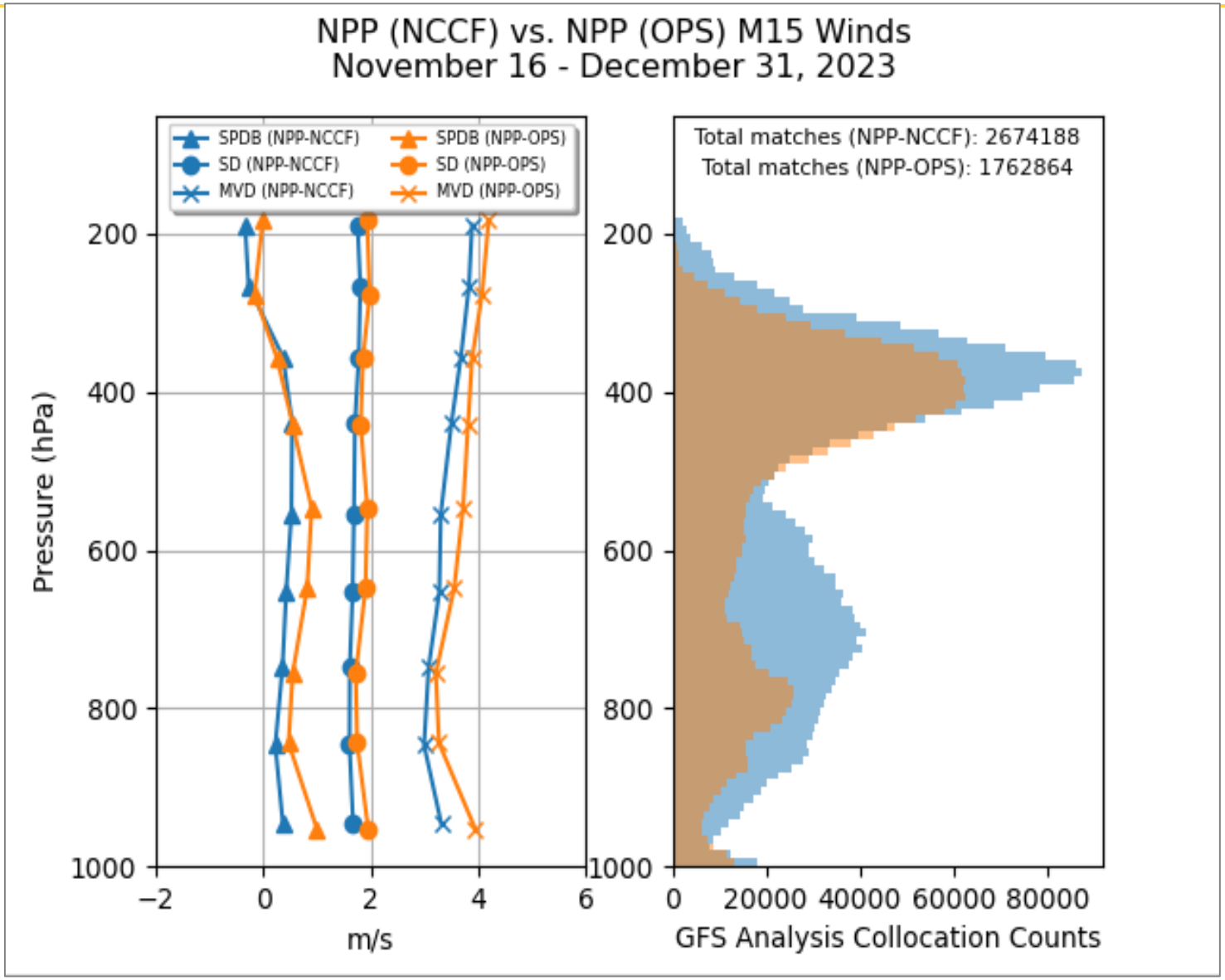

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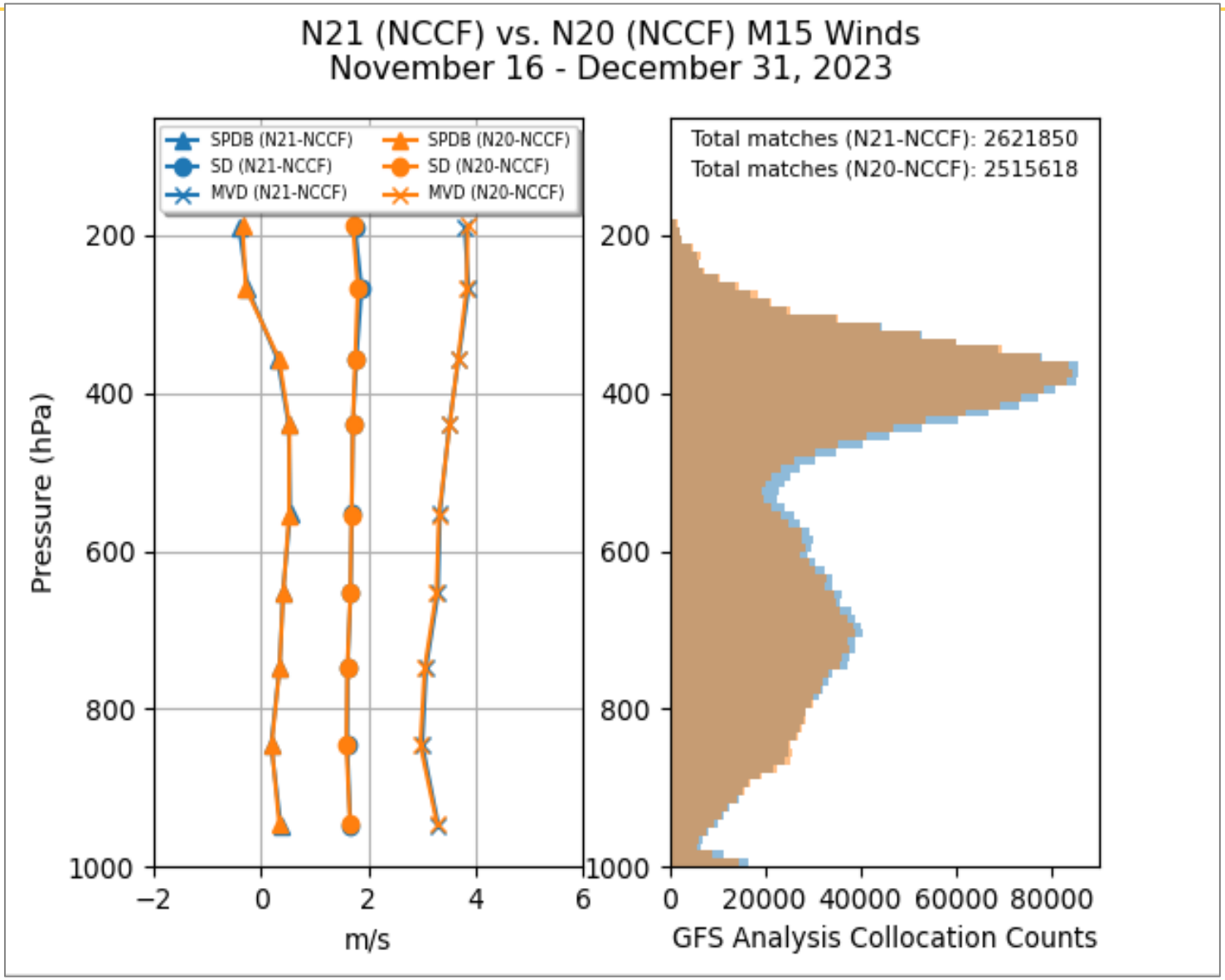

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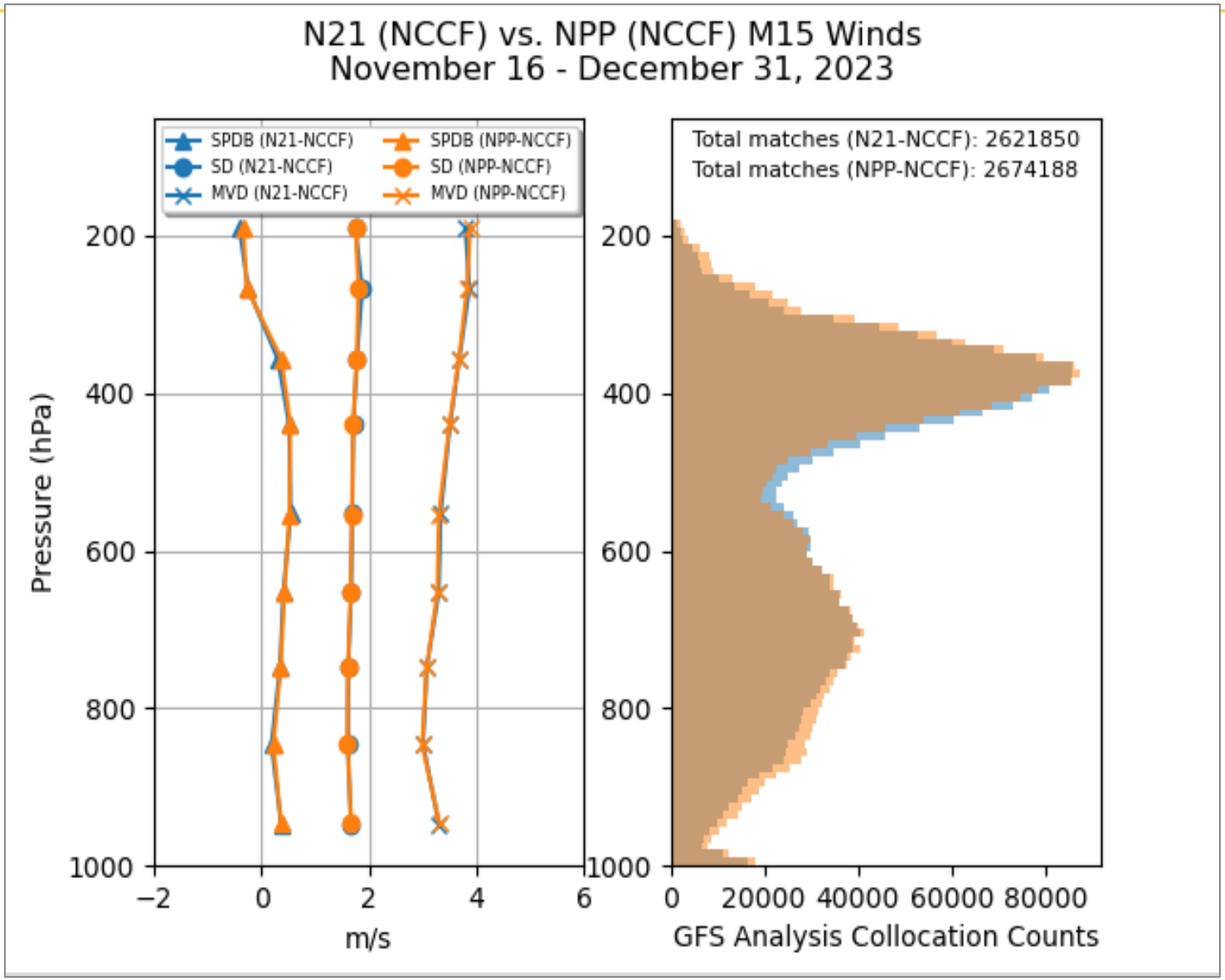
vs
S-NPP VPW (NCCF-UAT)



Requirements:
Accuracy: 7.5 m/s
Precision: 4.2 m/s

Vertical Profiles *(from left to right):* **Speed Bias (Sat-Raob); Standard Deviation (STDV) = Precision , Mean Vector Difference (MVD) = Accuracy**

Error Budget

Attribute Analyzed	DPS	Requirement/ Threshold	Pre-Launch Performance	On-orbit Performance			Meet Requirement?	Additional Comments
				NOAA-21	NOAA-20	S-NPP		
Accuracy	108	7.5 m/s		~6 m/s	~6 m/s	~6 m/s	yes	Comparison to radiosonde winds
Precision	107	4.2 m/s		~4 m/s	~4 m/s	~4 m/s	yes	

Attribute Analyzed	DPS	Requirement/ Threshold	Pre-Launch Performance	On-orbit Performance			Meet Requirement?	Additional Comments
				NOAA-21	NOAA-20	S-NPP		
Accuracy	108	7.5 m/s		5.44	5.57	5.65	yes	Comparison to aircraft winds
Precision	107	4.2 m/s		3.48	3.83	3.28	yes	

- On-orbit performance metrics are for VPWs generated with the enterprise winds algorithm
- The “Meet Requirement” response applies to all VPW data (e.g., all levels, Arctic, Antarctica)
- Accuracy and precision metrics are based on comparisons to Radiosonde and Aircraft winds since these are independent reference wind observations

User Feedback – NCEP/EMC

Brett Hoover @ NCEP/EMC is performing the testing with NCEP's Global Forecast System (GFS). Results reported here are from him.

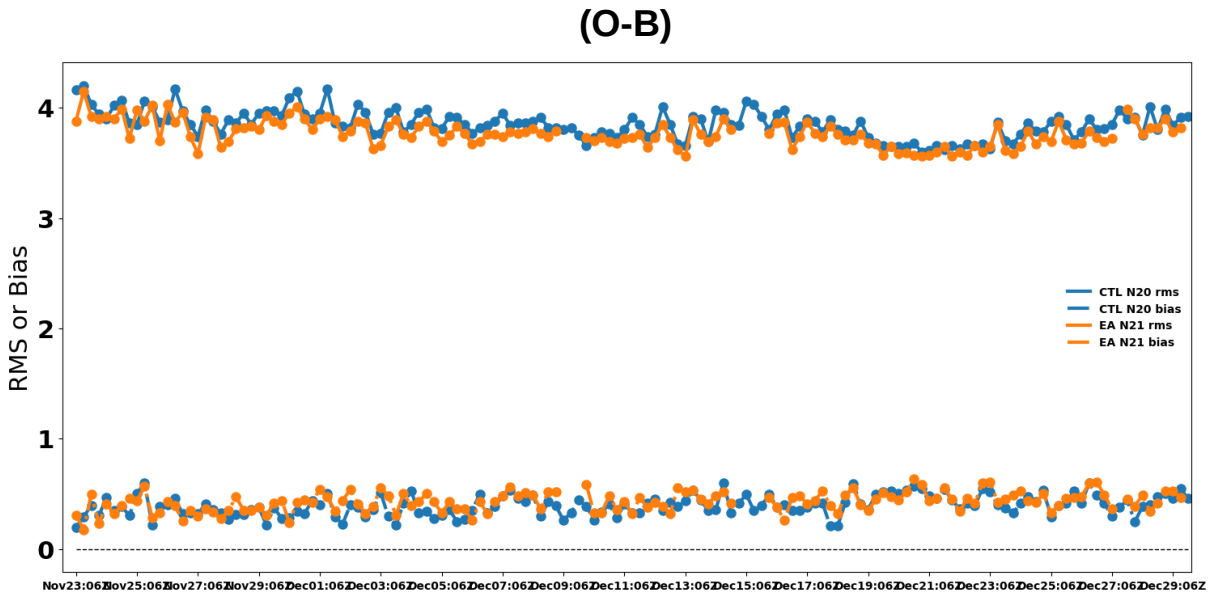
- NOAA-21, NOAA-20, and S-NPP Enterprise VPW data pulled from the NESDIS PDA (UAT)

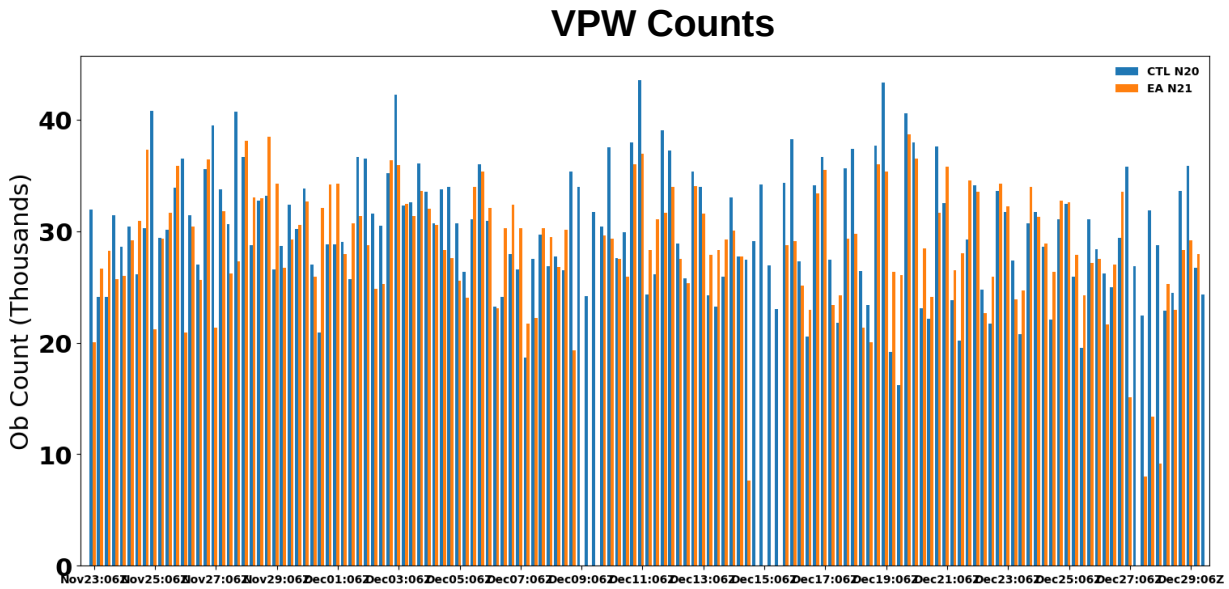
- **Experiment 1** (Completed)
  - November 23 – December 29, 2023
  - Testing the difference between the Operational S-NPP and NOAA-20 VPW data ***(control)*** and the S-NPP and NOAA-20 Enterprise (v3r2) VPW data ***(Test)*** with no changes to the operational configuration
  - NOAA-21 VPW data are only monitored in this experiment
  - Impacts can be viewed here: https://www.emc.ncep.noaa.gov/users/Brett.Hoover/v16.3.10_VIIRSEA/
  - **"Overall, test results are good"**

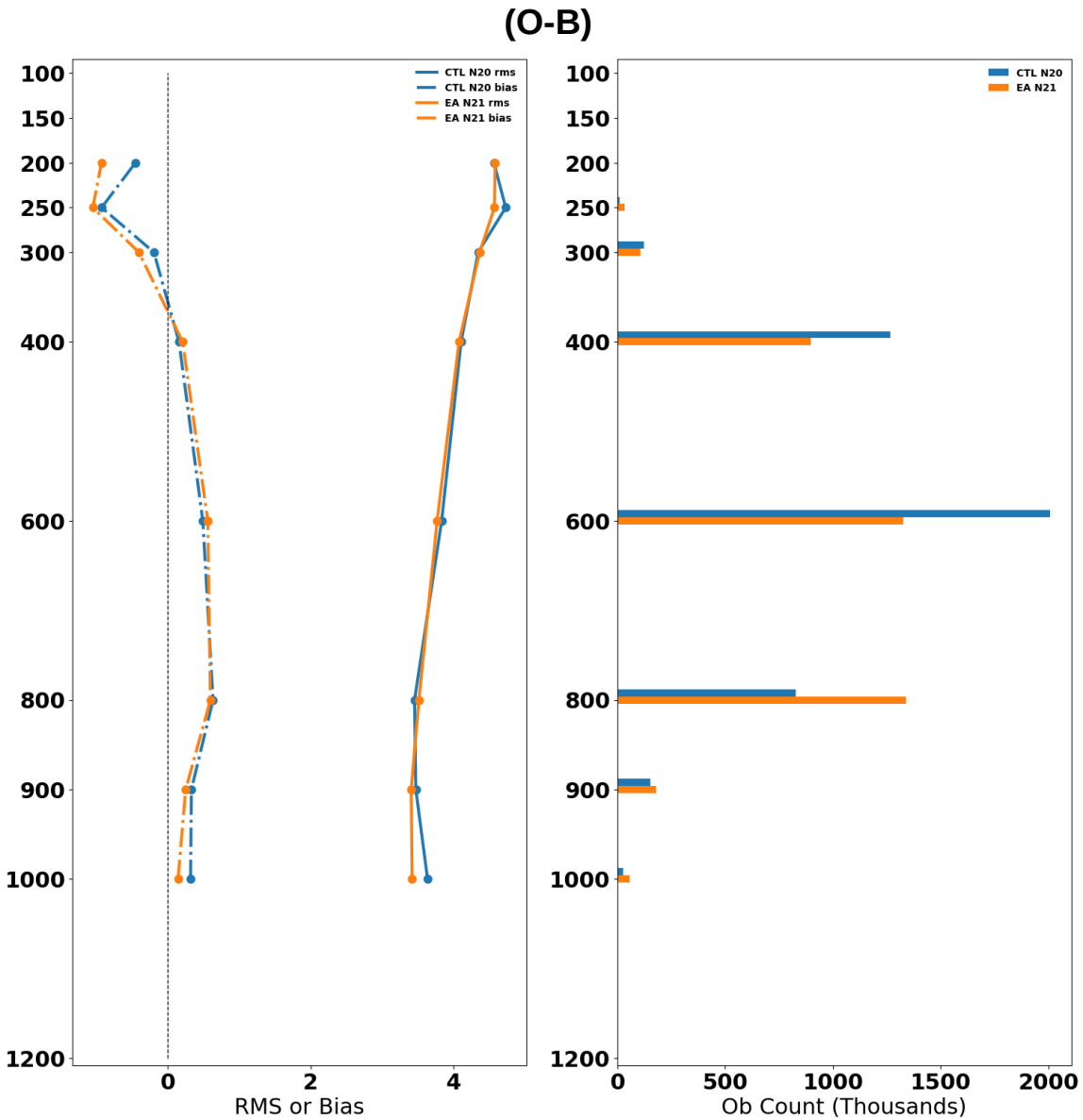
- **Experiment 2** (In progress; 18 days in)
  - November 23 – December 29, 2023
  - Testing the impact of assimilating NOAA-21 Enterprise (v3r2) VPW data on top of the Experiment 1 Test

Experiment 1

Control (Opr NOAA-20 VPW) vs Test (v3r2 NOAA-21 VPW)



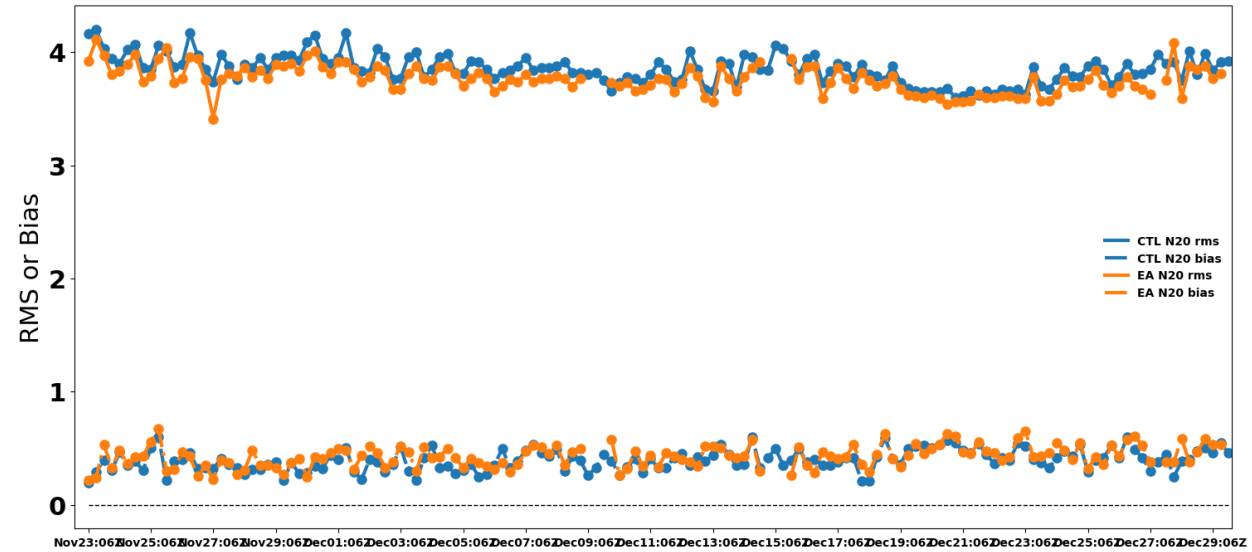


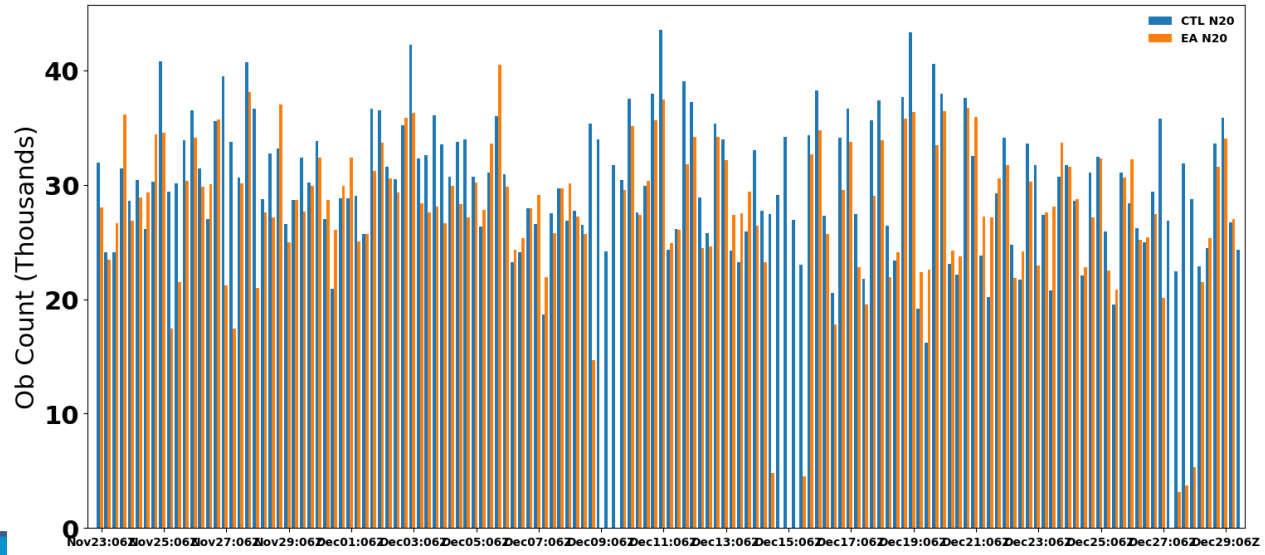


Experiment 1

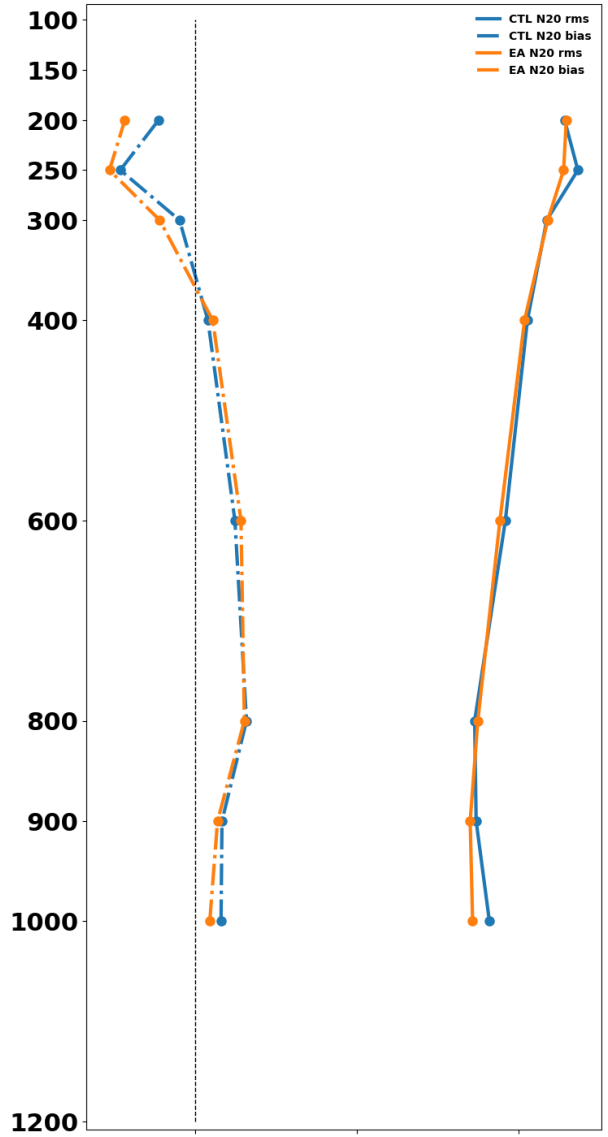
Control (Opr NOAA-20 VPW) vs Test (v3r2 NOAA-20 VPW)

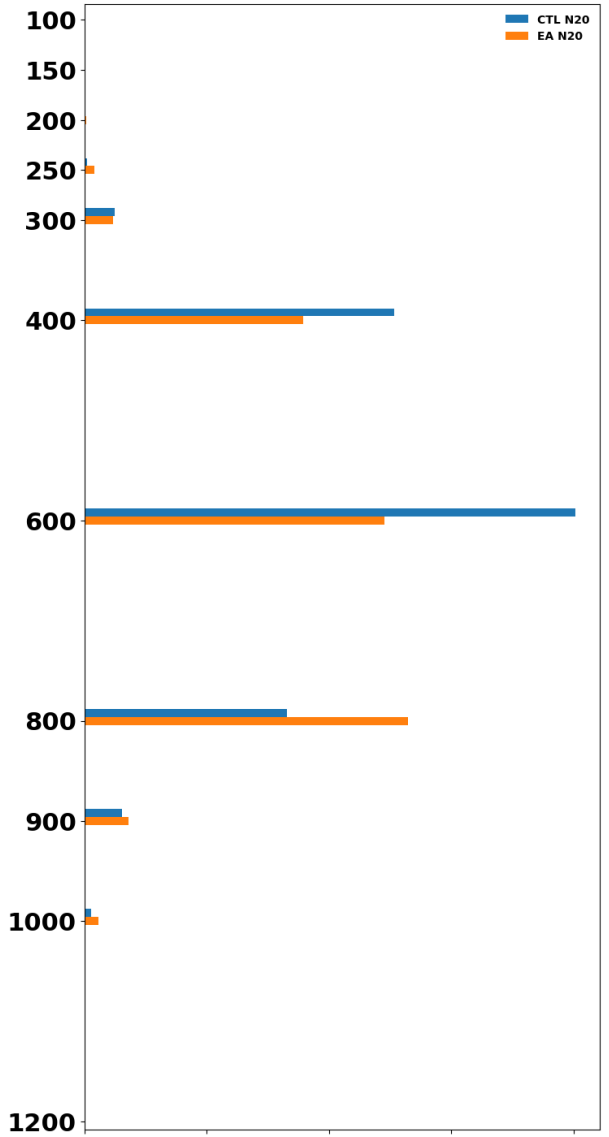
(O-B)





(O-B)

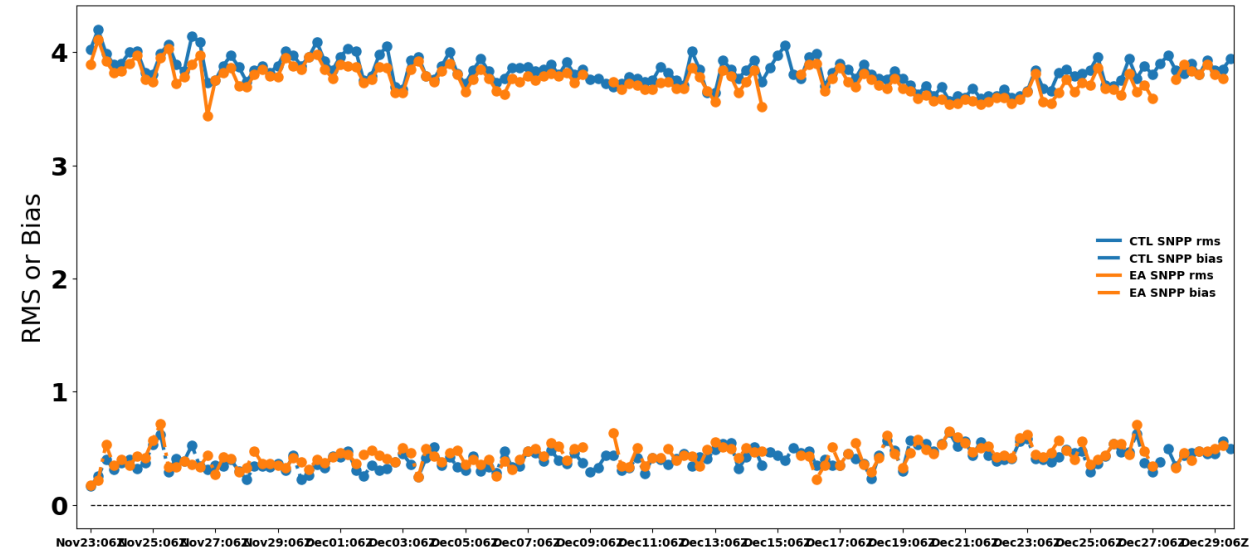


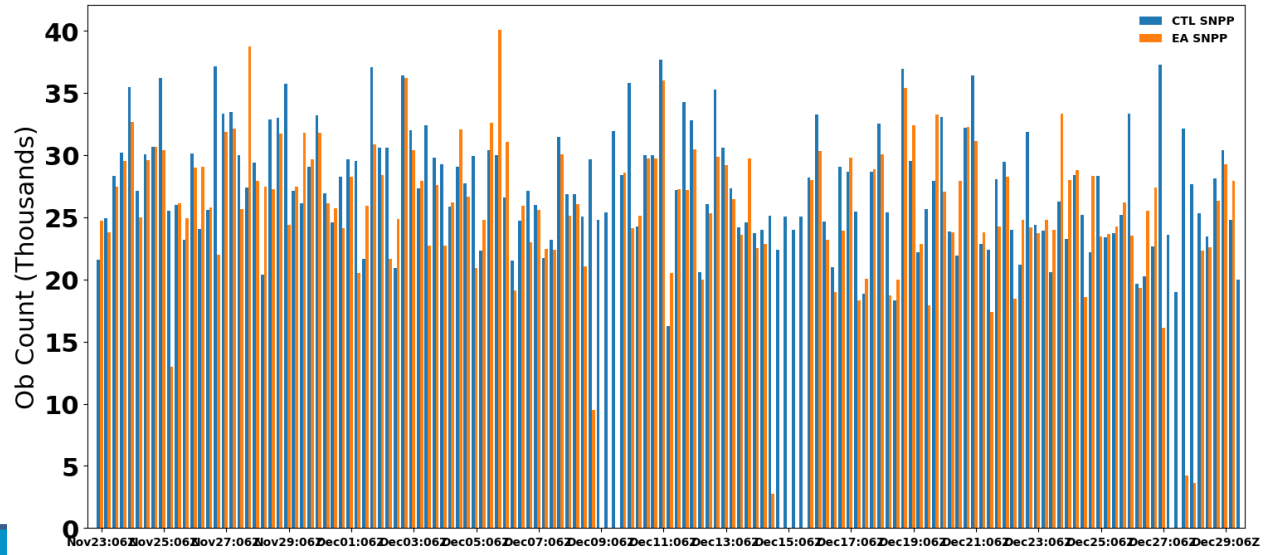


Experiment 1

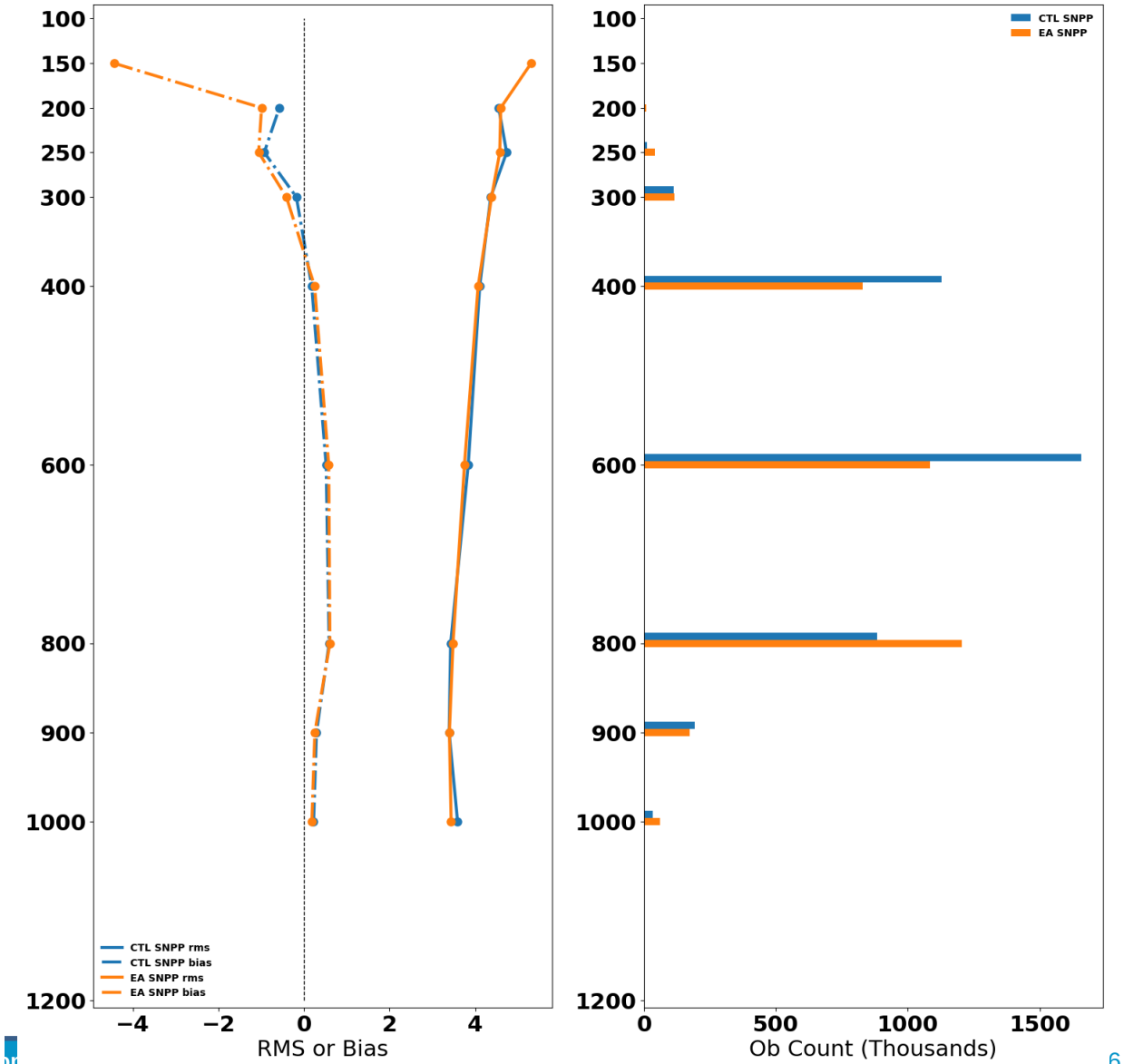
Control (Opr S-NPP VPW) vs Test (v3r2 S-NPP VPW)

(O-B)





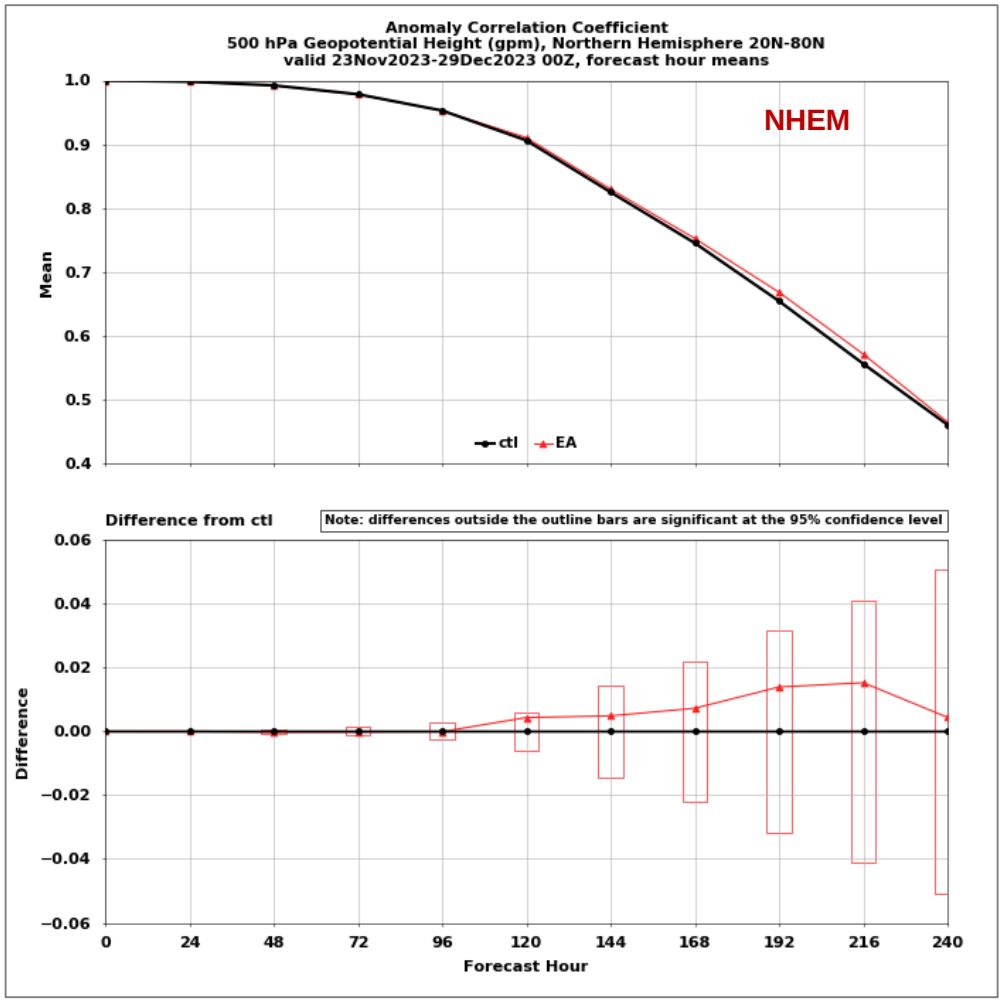
(O-B)

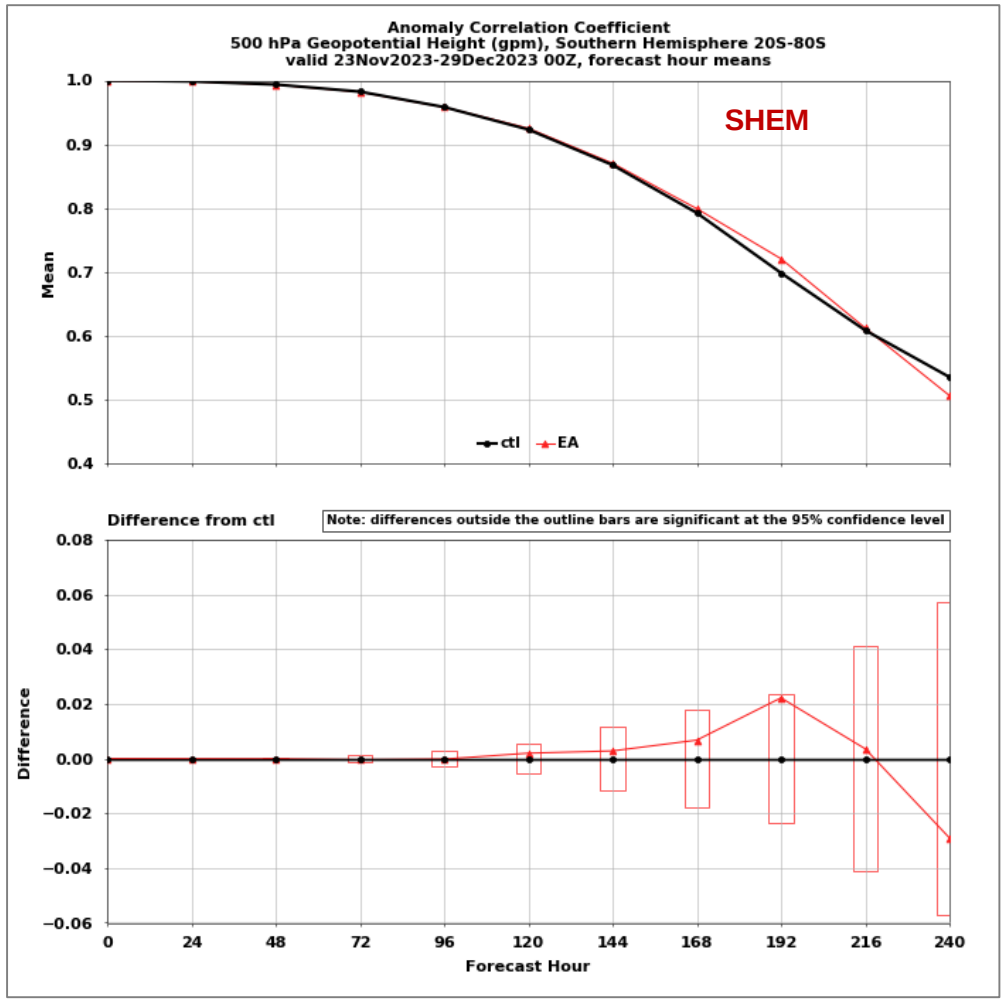


Experiment 1

Anomaly Correlation (ACC) Scores – 500 hPa Geopotential Heights

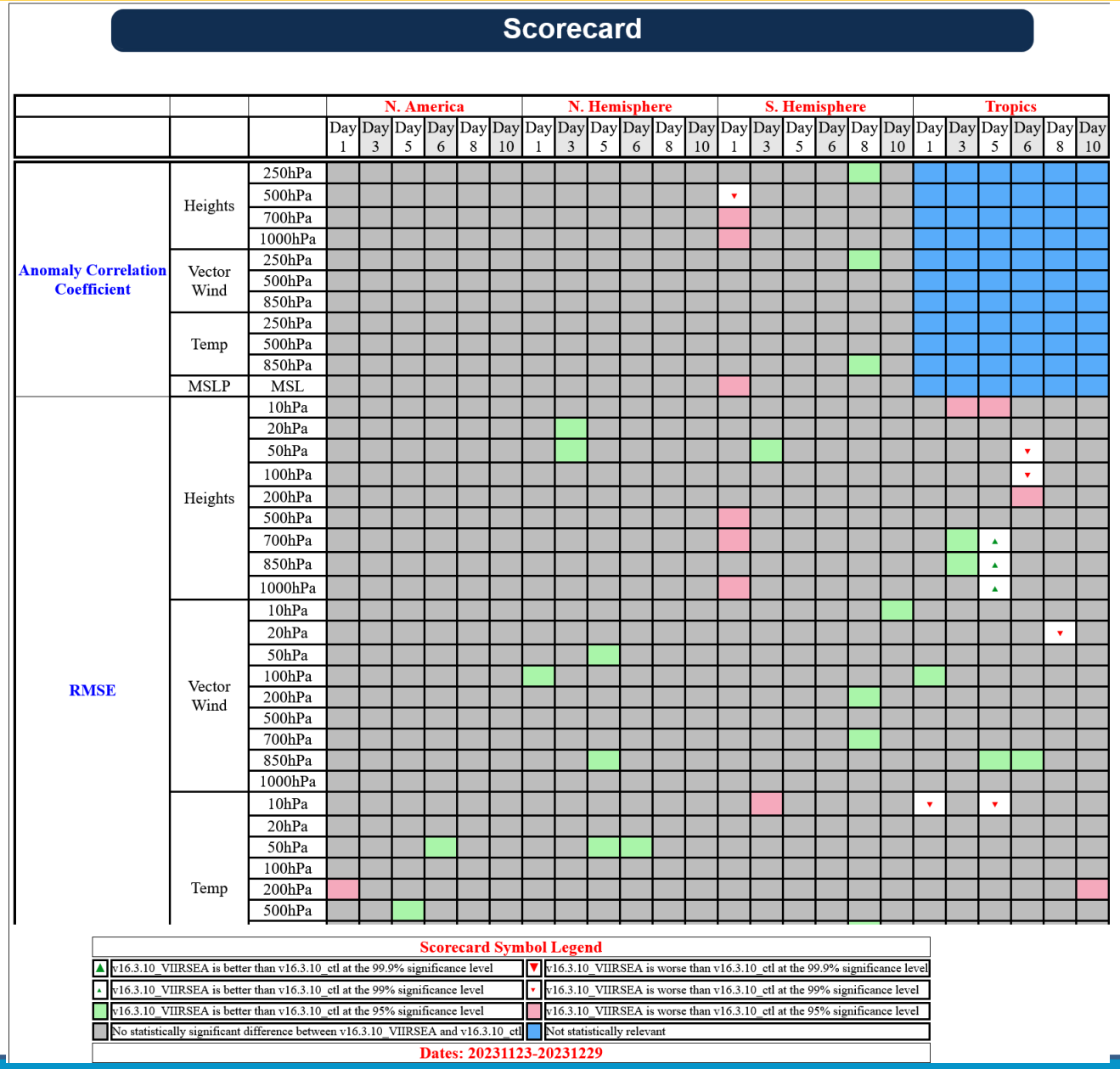
Control vs Test (v3r2 Enterprise winds – NOAA-20, S-NPP)





Forecast Impact: Neutral

Overall Impact Scorecard - Assimilation of v3r2 NOAA-20 & S-NPP VPWs



Overall neutral impact

User Feedback – NRL

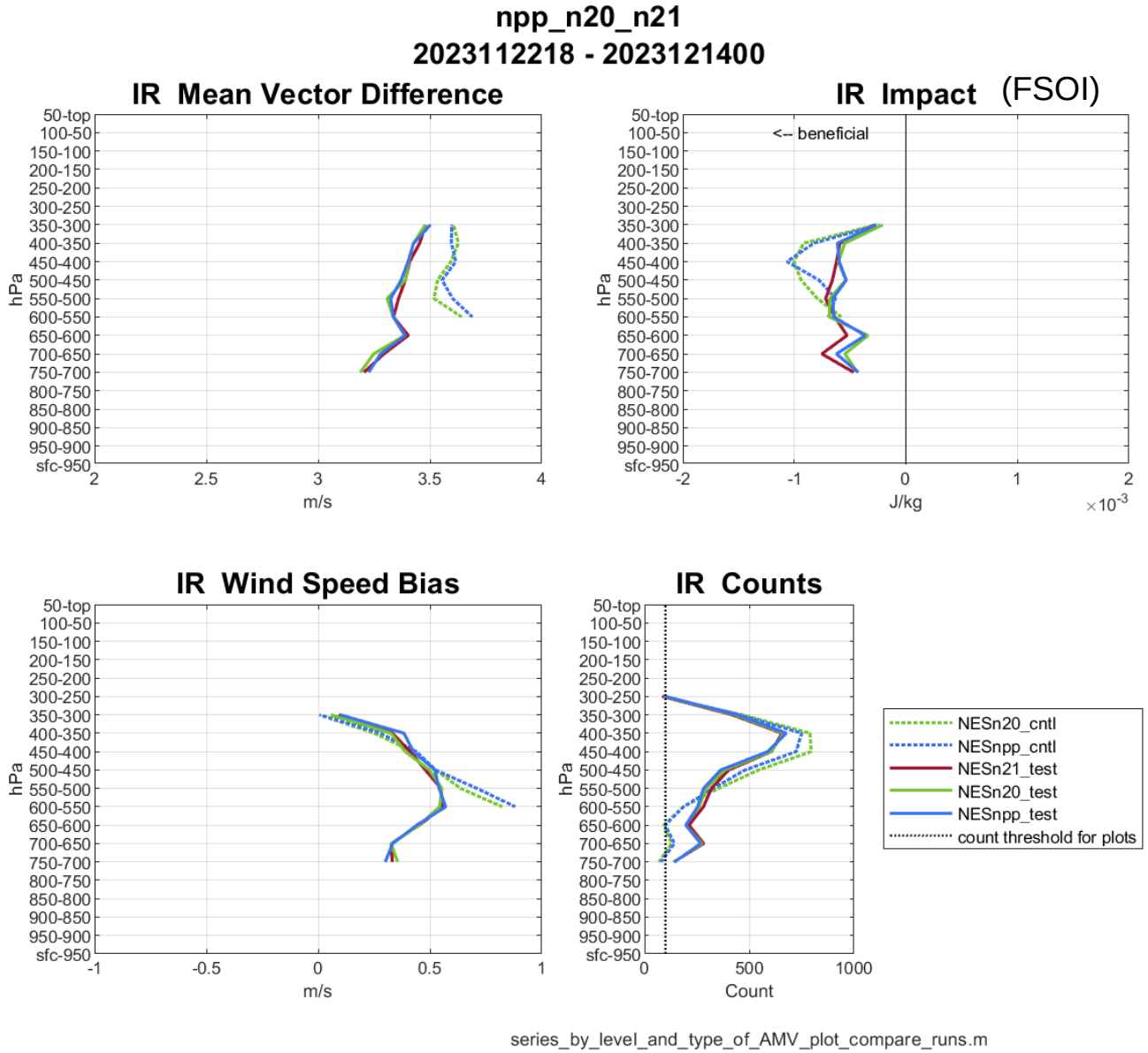
Rebecca Stone @ NRL is performing the testing with the Navy's Global NAVGEM Forecast System. Results reported here are from her.

Experimental Setup

- Model: NAVGEM T681
- Statistics period
  - 2023112218 – 2023121400 (a few small gaps, 72 DTGs)
- Quality Control (QC)
  - As in OPS, 175 hPa top limit, 975 hPa bottom limit
- Results
  - NESn21 compared with NESnpp and NESn20 in test run
  - NESn21 comparable to NESnpp and NESn20
  - NESnpp, NESn20, NESmetop compared in control and test
  - MVD, OmB speed bias improved, counts comparable
  - FSOI beneficial and in proportion
  - NESmetop fit to background improved in test

Caution:
These results have not been approved yet by NRL for public release, so they cannot be posted online yet. Results can be shared among NRL and NOAA.

User Feedback – Naval Research Laboratory (NRL)



- **Wind Counts**
  - Slight reduction in wind counts between 400-500 hPa for the N21, N20, S-NPP VIIRS test (v3r2 enterprise) winds relative to the N20, SNPP control winds
  - Slight increase in wind counts below 500 hPa for the N21, N20, S-NPP VIIRS test (v3r2 enterprise) winds relative to the N20, SNPP control winds
- **OmB Statistics**
  - Mean vector difference and speed bias stats are consistent between the N21, N20, S-NPP VIIRS test (v3r2 enterprise) winds
  - Reduction in mean vector difference (all levels) for the N21, N20, S-NPP VIIRS test (v3r2 enterprise) winds relative to the N20, SNPP control winds
  - Wind speed bias above 500 mb about the same for the N21, N20, S-NPP VIIRS test (v3r2 enterprise) winds and the N20, SNPP control winds
  - Wind speed bias below 500 hPa looks good for the N21, N20, S-NPP VIIRS test (v3r2 enterprise) winds
- **FSOI Statistics**
  - N21, N20, S-NPP VIIRS test (v3r2 enterprise) winds (all levels) show beneficial impact, with slight reduction in FSOI scores between 400-500 hPa and now reportable beneficial impact 500-700 hPa relative to N20, S-NPP control winds

Downstream Product Feedback

- No issues with reformatting of netCDF4 VPW product datasets to BUFR.

Risks, Actions, and Mitigations

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

Identified Risk	Description	Impact	Action/Mitigation and Schedule
Enterprise Winds Algorithm	Latest enterprise winds algorithm (v3r2) replaces check that uses cloud height retrieval quality flag with a temporary check to ensure a valid cloud top pressure exist	Low	• Correction to framework software is necessary to allow the enterprise winds software access to the cloud height retrieval flag • Reinstate check that uses cloud height retrieval quality flag • Schedule: Next algorithm update cycle
Enterprise Cloud Height Algorithm	The latest enterprise cloud algorithm has a tendency to generate a lot of cloud-top pressures at 986 mb.	Low	• Investigate reasons for and resolve • Schedule: Next algorithm update cycle

Documentation (Science Maturity Check List)

Science Maturity Check List	Yes ?
ReadMe for Data Product Users	Will be provided after review.
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
Regular Validation Reports (at least annually) (Demonstrates long-term performance of the algorithm)	Long term monitoring available on STAR web site, on demand.

Check List - Provisional Maturity

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

Conclusion

- Visual and quantitative assessments of the NOAA-21 VPW product was conducted and shown to meet product requirements
- NCEP/EMC and NRL assessments show that the quality of the NOAA-21, and S-NPP VPW products are of good quality with slight reductions in OmB statistics and overall neutral impact (relative to control) on forecast skill.
- The Winds and Cloud Science Teams will continue to closely interact on future updates (addressed earlier) to the cloud height and winds algorithms
- The Winds Science Team and the OSPO PAL will continue their close collaborations with the NWP user community
- **The Winds Science Team recommends that the NOAA-21 VIIRS polar wind products have reached Beta and Provisional maturity status.**

Path Forward

- Further improvements
  - Additional tuning of the cloud height algorithm aimed at further improving the height assignments of the VIIRS polar winds
  - Addition of the VIIRS SWIR 2.25um band to the enterprise winds algorithm enabling generation of VIIRS SWIR winds leading to additional high quality winds in the polar regions *(Plan: FY24 algorithm update)*
  - Tandem (doublet and triplet) VIIRS wind products generated in the overlap region of two different JPPS satellites *(Plan: FY25 algorithm update)*

- For “Full Maturity”: continue to collect and perform longer-period product assessment, including regional/seasonal variations

Backup Slides

AMV Performance Metrics

AMVs (QI>60) are matched and compared against RAOBS or GFS model analysis winds. Accuracy is the mean vector difference (mean VD or MVD). Precision is standard deviation around the MVD.

$$Accuracy = \frac{1}{N}\sum_{i=1}^{N}(VD_i)$$

$$\Pr ecision = \sqrt{\frac{1}{N}\sum_{i=1}^{N}((VD_i)-(MVD))^2}$$

where:

$$(VD)_i = \sqrt{(U_i - U_r)^2 + (V_i - V_r)^2}$$

U_i and V_i ---> AMV
U_r and V_r ---> “Truth”