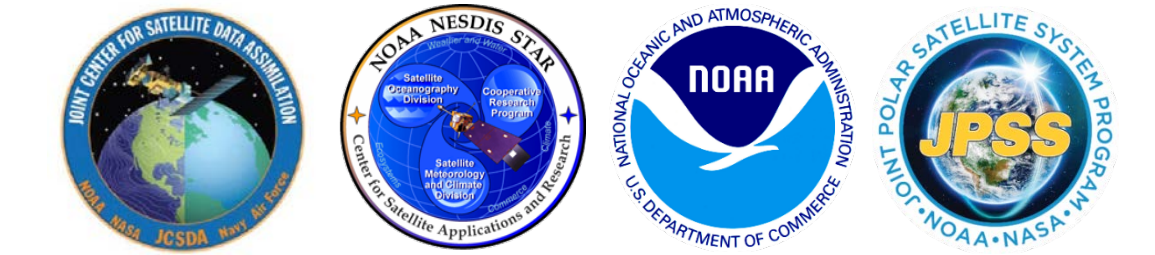


Validation of the Environmental Data Record (EDR) product suite from the SNPP/NOAA-20 NOAA Unique Combined Atmospheric Sounding System (NUCAPS)



Nicholas R. Nalli^{1,2}, C. Tan^{1,2}, M. Divakarla^{1,2}, A. Gambacorta¹, M. Wilson^{1,2}, J. Warner³, T. Zhu^{1,2}, T. Reale², B. Sun^{1,2}, T. Wang^{1,2}, L. Borg⁵, C. D. Barnett⁴, K. Pryor², L. Zhou⁶, et al.

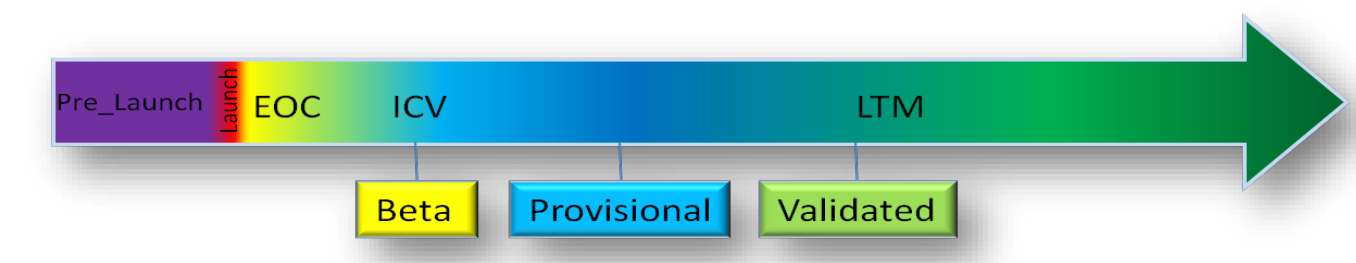
¹NOAA/NESDIS/STAR ²MSG, Inc. ³UMD ⁴STC, Inc. ⁵UW/CIMSS ⁶NOAA JPSS Program Office ⁷Formerly IMSSG, Inc.



JSTAR Cal/Val Program

JSTAR Cal/Val Phases (Zhou, Divakarla, and Liu 2016)

- Pre-Launch
- Early Orbit Checkout (EOC)
- Intensive Cal/Val (ICV)
 - Validation of EDRs against multiple correlative datasets
- Long-Term Monitoring (LTM)
 - Routine characterization of all EDR products and long-term demonstration of performance



• Sounder EDR validation methodology is based upon AIRS and IASI (Nalli et al., 2013, JGR Special Section on SNPP Cal/Val)

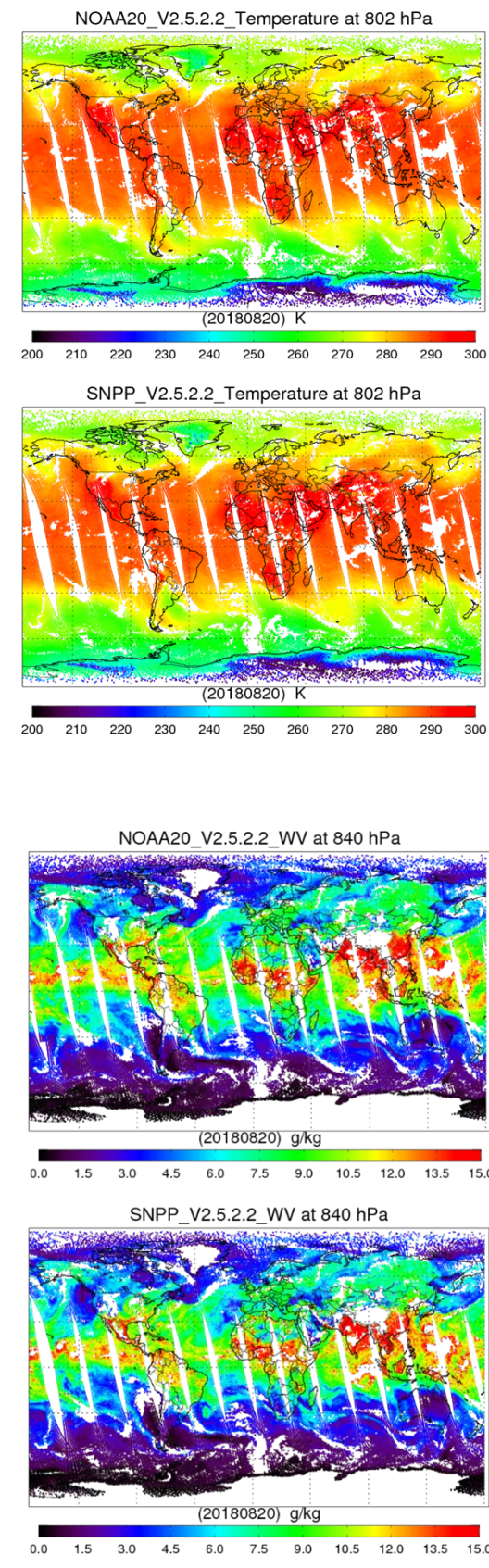
• J-1 (NOAA-20) sounder EDR Cal/Val Plan (Dec 2015)

- The Cal/Val Plan included for the first time the validation of carbon trace gas EDRs (CO, CH₄, and CO₂), but the details had not been completely ironed out at that time.

NUCAPS Algorithm

Operational algorithm

- NOAA Enterprise Algorithm for CrIS/IAS/AIRS (AST v5.9; after Susskind, Barnett and Blaisdell, 2003)
- Global non-precipitating conditions
- Atmospheric Vertical Temperature and Moisture Profiles (AVTP, AVMP)
- Trace gases: O₃, CO, CO₂, CH₄
- V2.5.2.2 (offline OPS version)
 - Full spectral tunings for SNPP and N-20
 - Regression update for N-20
 - MW tuning updates for SNPP and N-20
- Candidate for October 2019 DAP



Users

- Weather Forecast Offices (AWIPS)
 - Nowcasting / severe weather
 - Alaska (cold core)
- NOAA/CPC (OLR)
- NOAA/ARL, NOAA/ESRL (IR ozone, trace gases)
- NOAA TOAST product (IR ozone EDR)
 - Basic and applied science research (e.g., Pagano et al., 2014)
 - Stability Indices (e.g., Bloch et al., 2019; Iturbide-Sanchez et al., 2018)

JPSS Level 1 Requirements

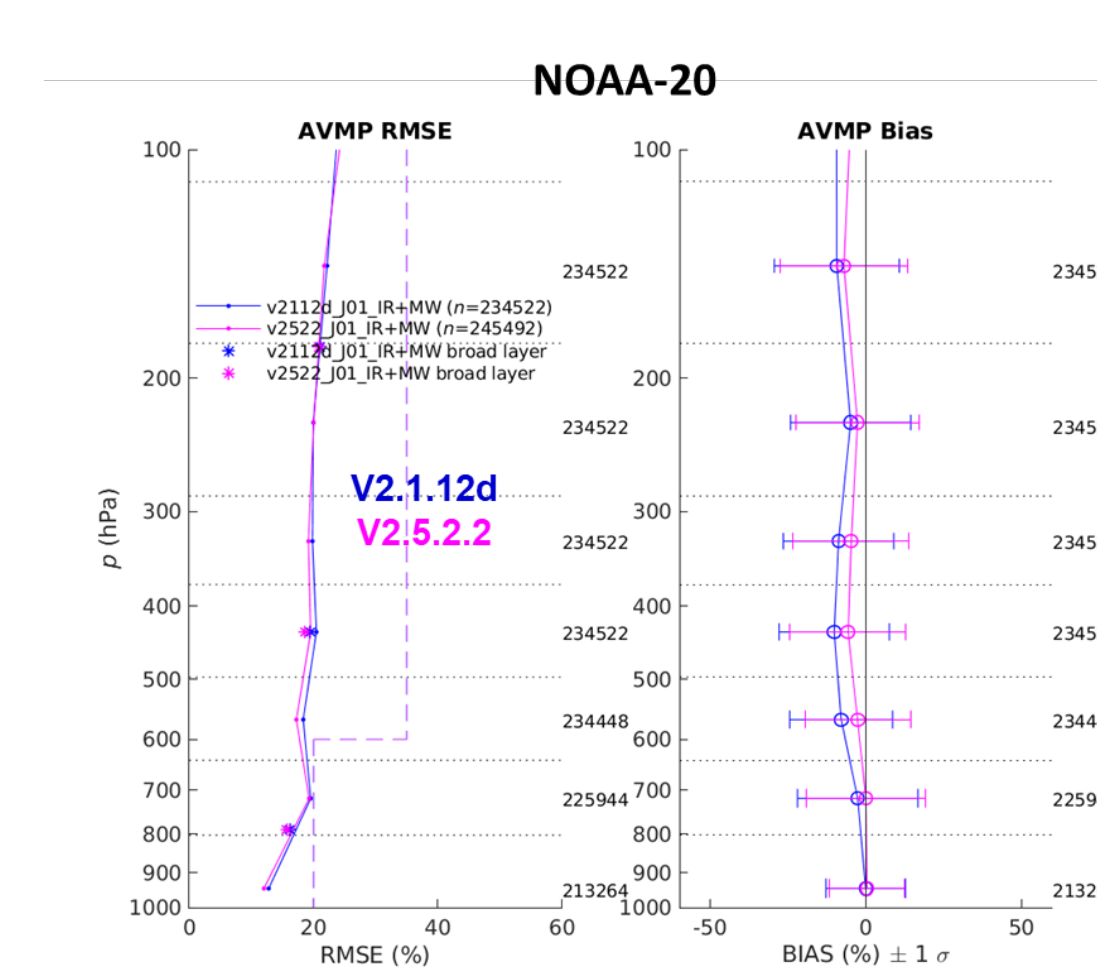
PARAMETER	THRESHOLD	OBJECTIVE
AVTP: Cloud fraction < 50%, surface to 300 hPa	1.6 K / 3-km layer	0.5 K / 3-km layer
AVTP: Cloud fraction < 50%, 300-300 hPa	1.5 K / 3-km layer	0.5 K / 3-km layer
AVTP: Cloud fraction < 50%, 300-1 hPa	1.5 K / 5-km layer	0.5 K / 5-km layer
AVTP: Cloud fraction < 50%, 1-0.5 hPa	3.5 K / 5-km layer	0.5 K / 5-km layer
AVTP: Cloud fraction < 50%, surface to 200 hPa	2.5 K / 3-km layer	0.5 K / 3-km layer
AVTP: Cloud fraction < 50%, 200-300 hPa	1.5 K / 3-km layer	0.5 K / 3-km layer
AVTP: Cloud fraction < 50%, 300-1 hPa	1.5 K / 5-km layer	0.5 K / 3-km layer
AVTP: Cloud fraction < 50%, 1-0.5 hPa	3.5 K / 5-km layer	0.5 K / 5-km layer

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% or 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%, 400-300 hPa	Greater of 40% or 0.1 g kg ⁻¹ / 2-km layer	NS

PARAMETER	THRESHOLD	OBJECTIVE
O ₃ (Ozone) Profile Precision, 4-260 hPa (6 statistic layers)	20%	10%
O ₃ (Ozone) Profile Precision, 260 hPa to sf (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 sf (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 sf (1 statistic layer)	25%	15%
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% (4 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 ppbv)	NS

AVTP, AVMP and IR Ozone Profile Highlights

NUCAPS IR+MW AVMP vs ECMWF Global Clear-to-Partly Cloudy Focus Day 20-Aug-2018

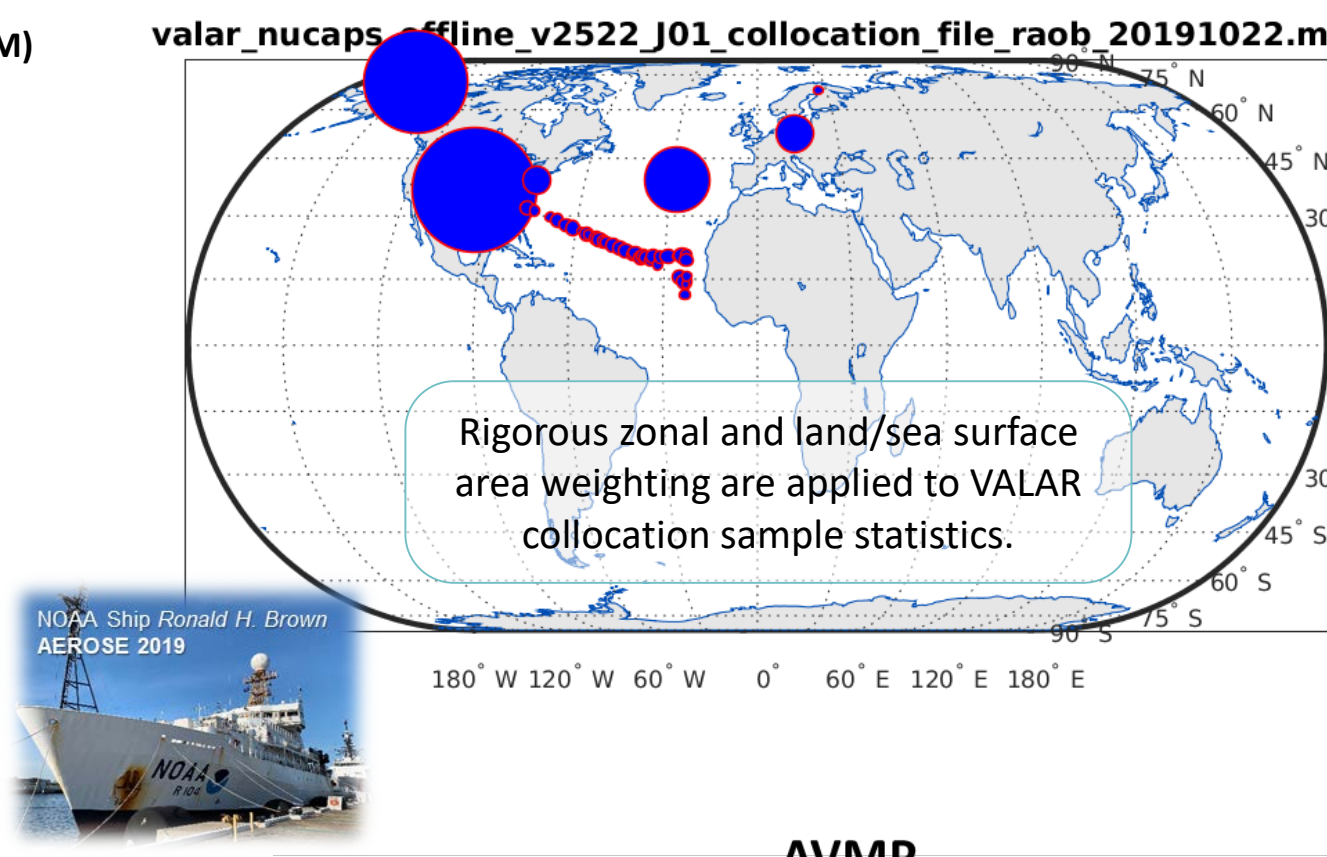


NUCAPS NOAA-20 AVTP/AVMP vs Dedicated RAOB

Validation Archive (VALAR)

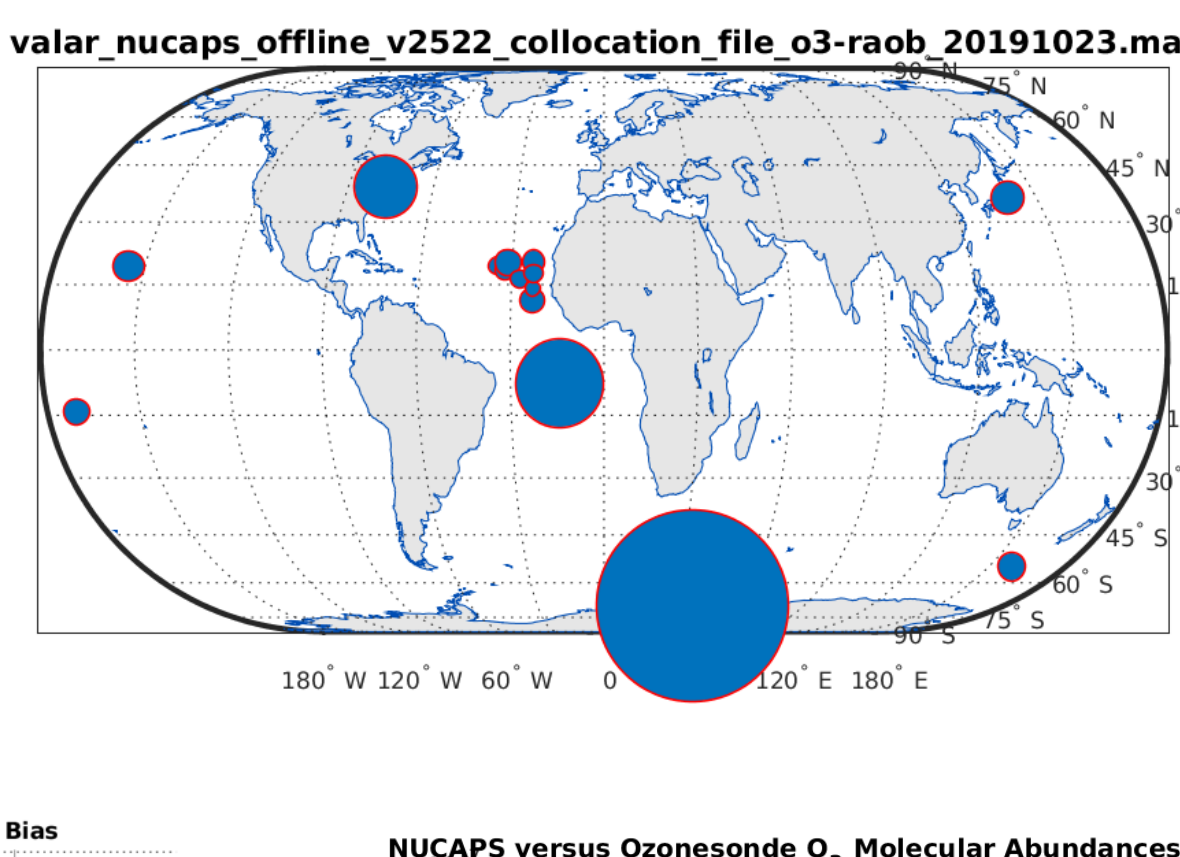
- CrIS/ATMS granules SDR/TDR matched with truth data using NPROVS collocation files
- Atmospheric Radiation Measurement (ARM) Sites (Tobin et al. 2006)
 - Eastern North Atlantic (ENA)
 - Southern Great Plains (SGP)
 - North Slope of Alaska (NSA)
 - Radioisotope Intercomparison and Validation (RIVAL) campaign
- GRUAN Sites (Bodeker et al. 2016)
 - Lindenberg, Germany (LIN)
 - Sodankyla, Finland (SOD)
 - Beltville, Maryland (BEL/HUBC)
- 2019 NOAA AEROSSE campaign (Nalli et al. 2011; Morris et al. 2006)
 - Mar 2019, tropical Atlantic Ocean

Geographic Histogram of Dedicated RAOB NOAA-20 Collocations (Equal Area) (δx ≤ 100 km, -100 < δt < +5 min)

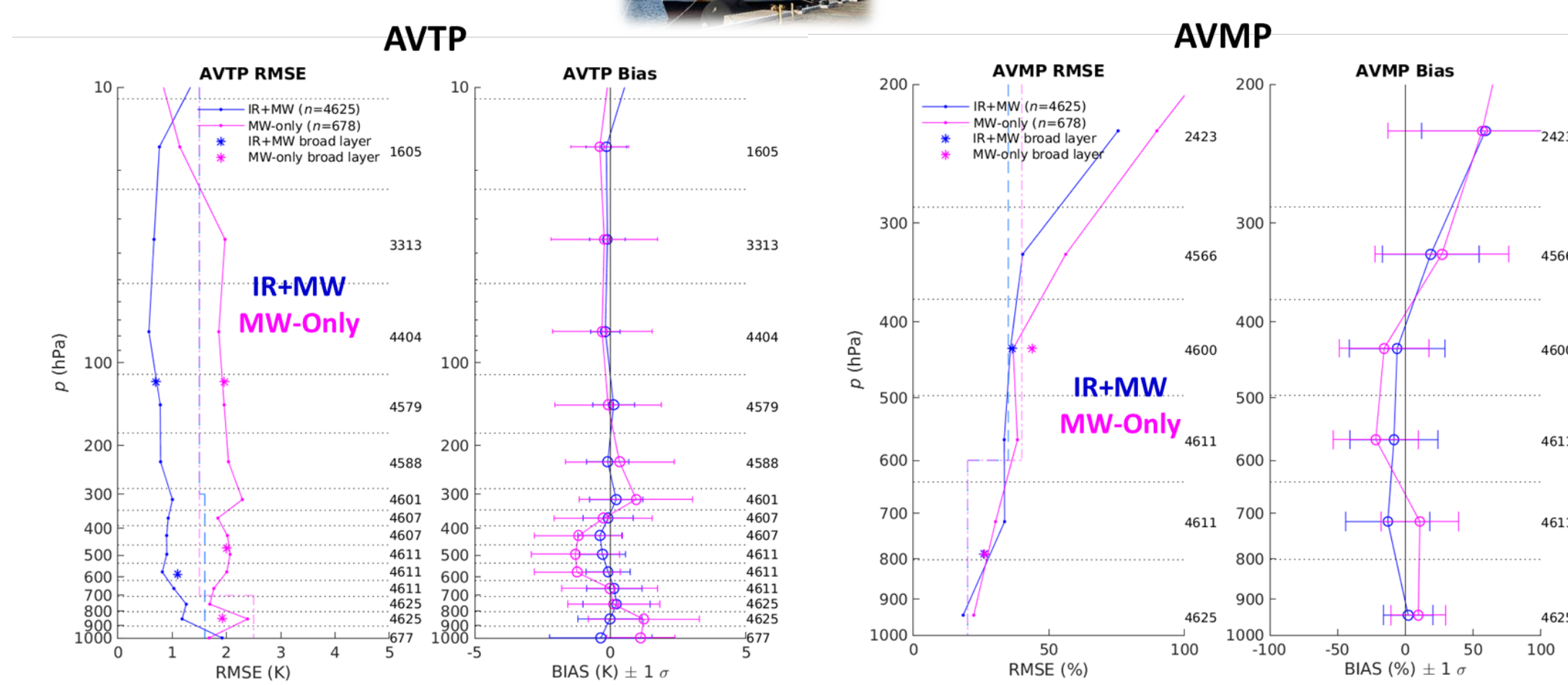
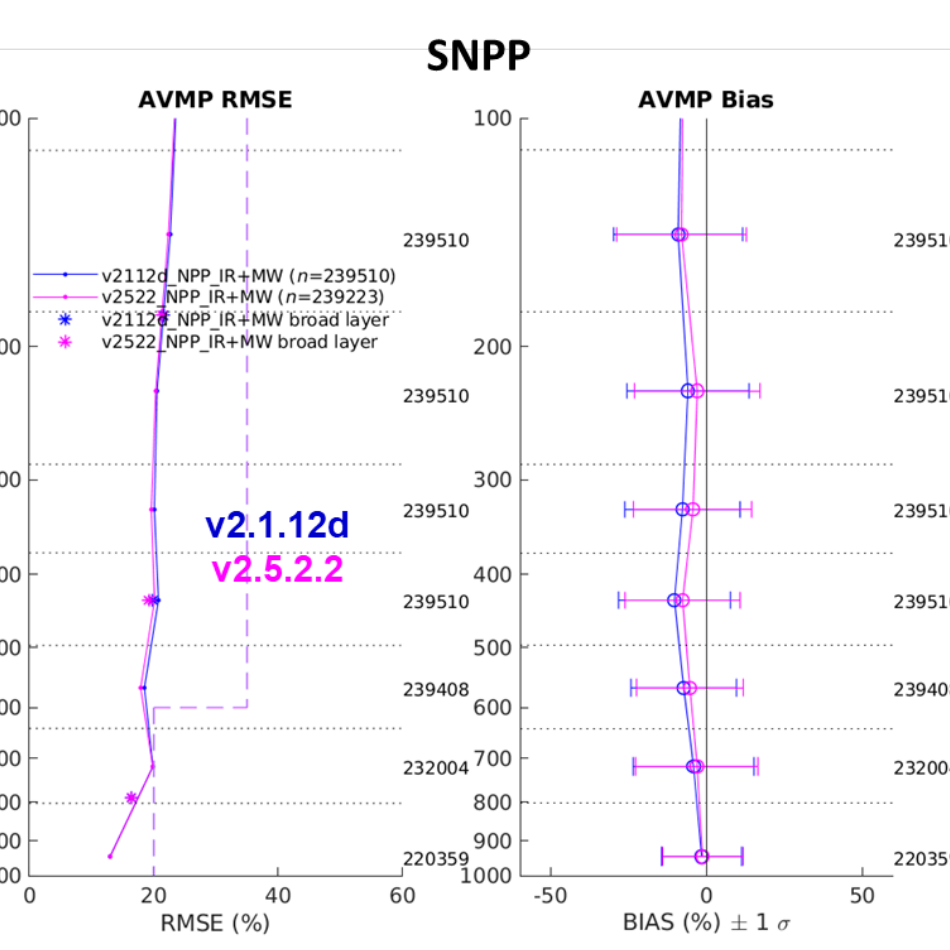
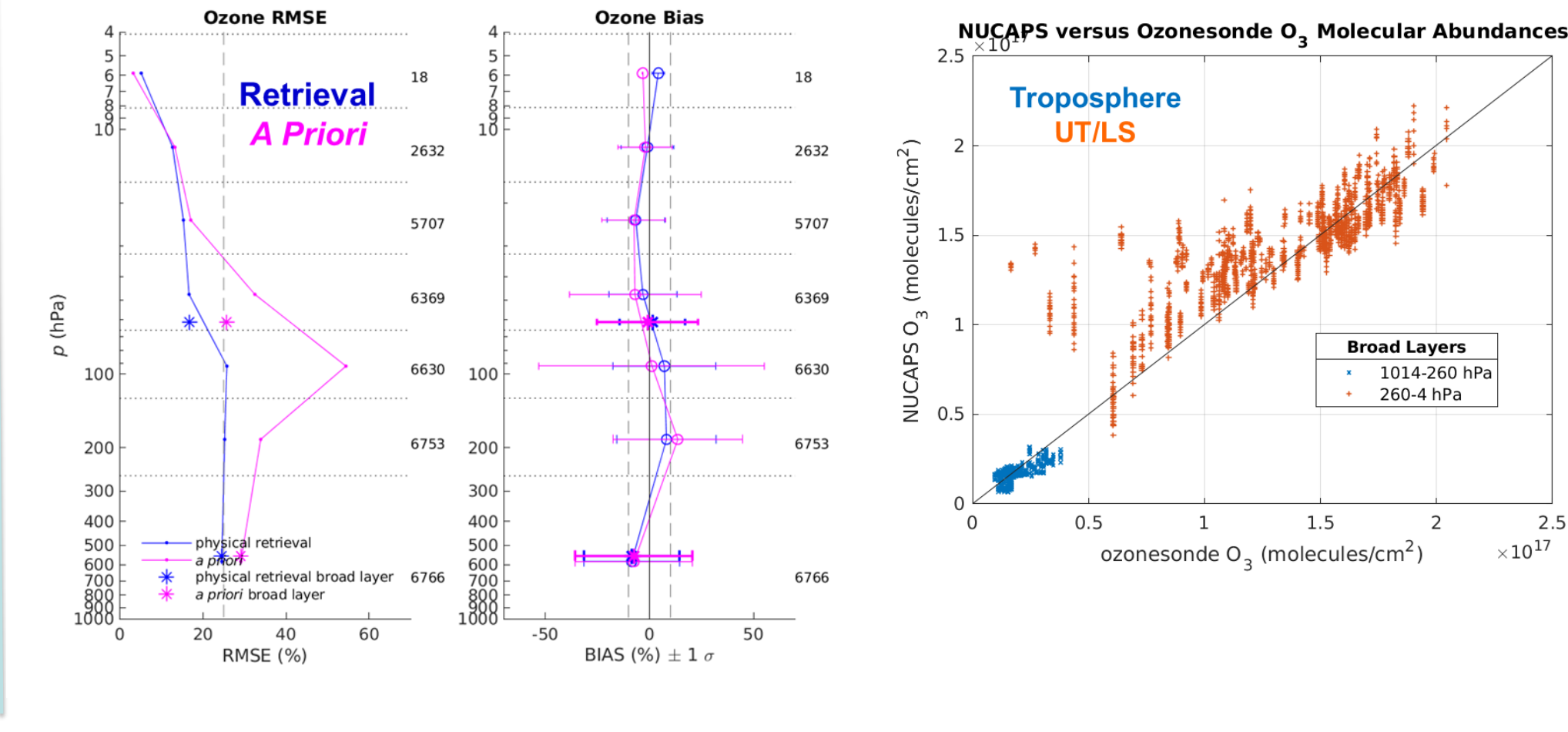


NUCAPS NOAA-20 IR Ozone Profile vs Ozonesondes

Geographic Histogram of NOAA-20 Ozonesonde Collocations (Equal Area) (δx ≤ 125 km, -240 < δt < +120 min)

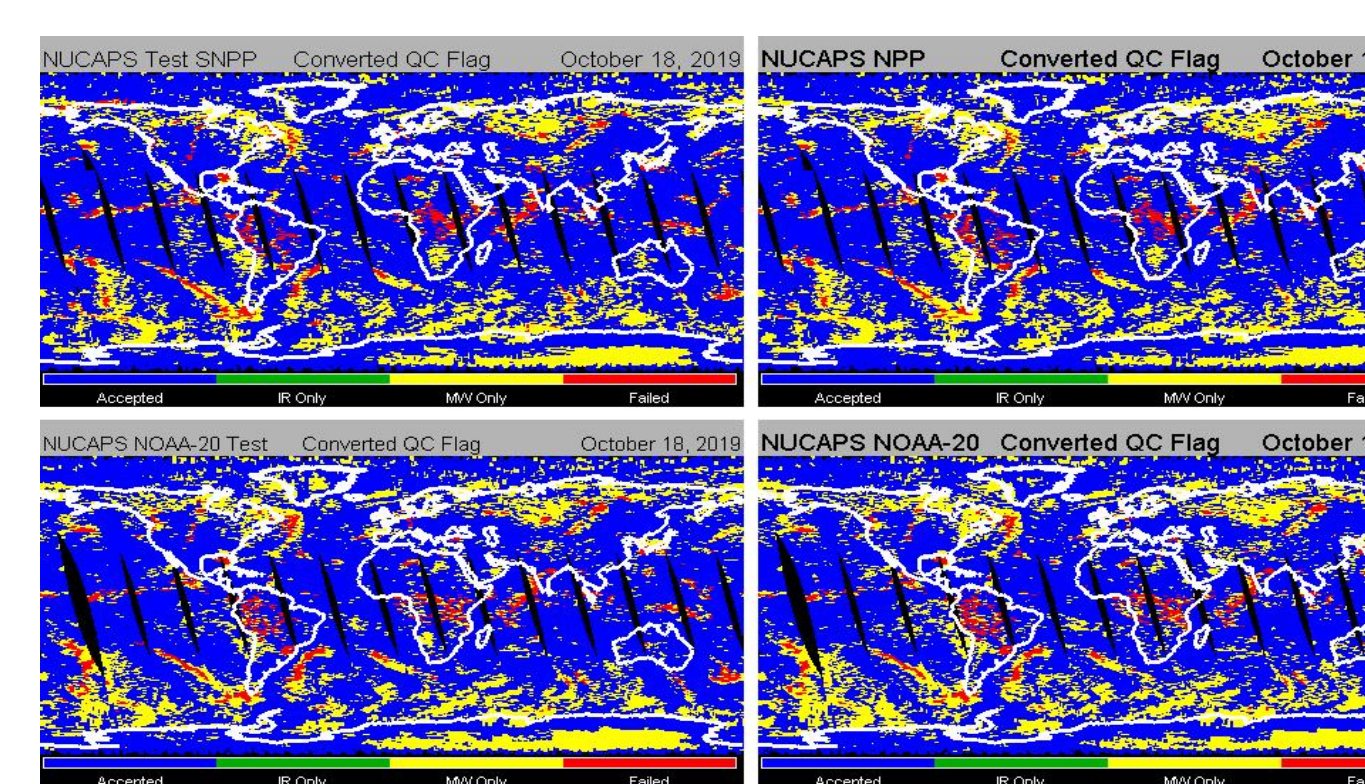


- Dedicated Ozonesondes
 - 2019 AEROSSE campaign (Nalli et al. 2011; Morris et al. 2006)
 - Howard University Beltsville (HUBC) site
- Land-Based Sites
 - World Ozone and Ultraviolet Radiation Data Centre (SHADOZ) (Thompson et al. 2004, 2007)
 - Ascension
 - Hilo
 - American Samoa
 - WMO World Ozone and Ultraviolet Radiation Data Centre (WUOUC)
 - STN034
 - STN029
 - STN101

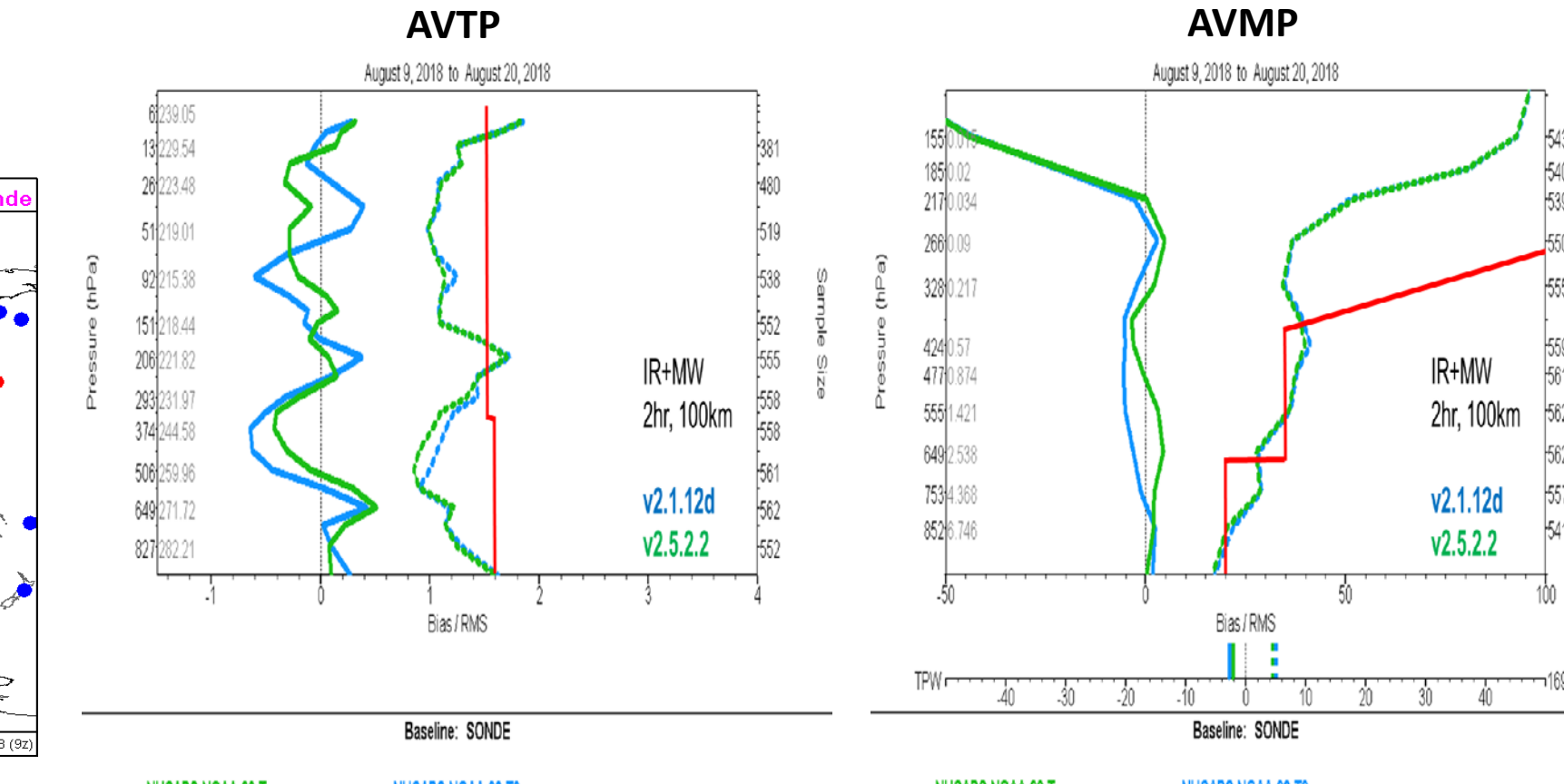
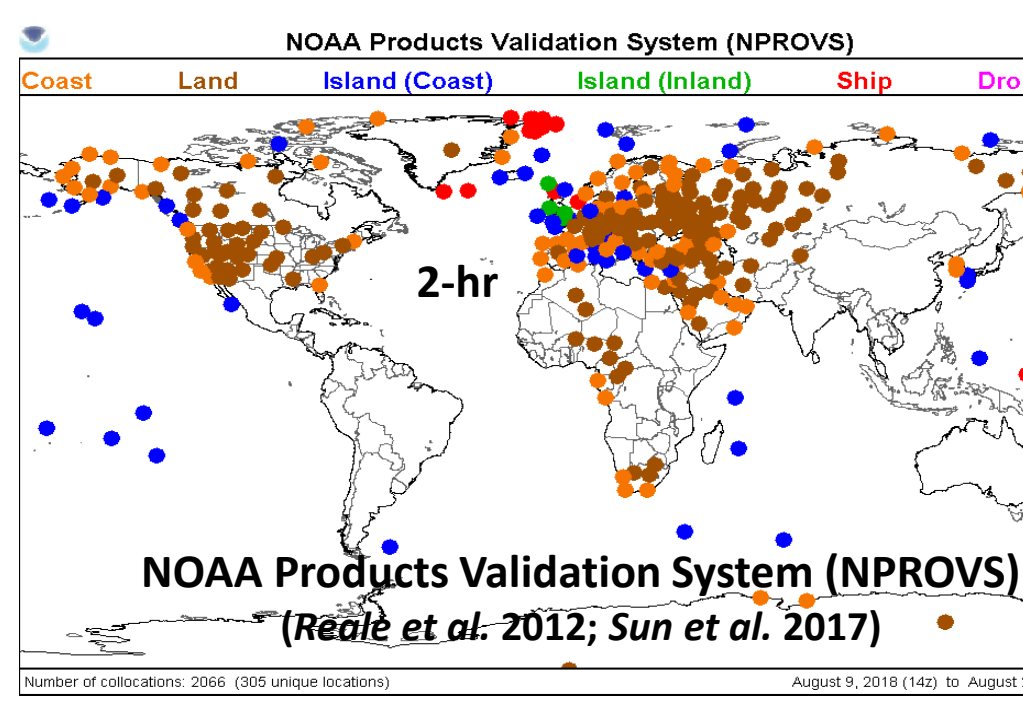


NUCAPS NOAA-20 AVTP/AVMP vs NPROVS Conventional RAOB

NUCAPS QA Acceptance Flags, Ascending (NPROVS ODS)

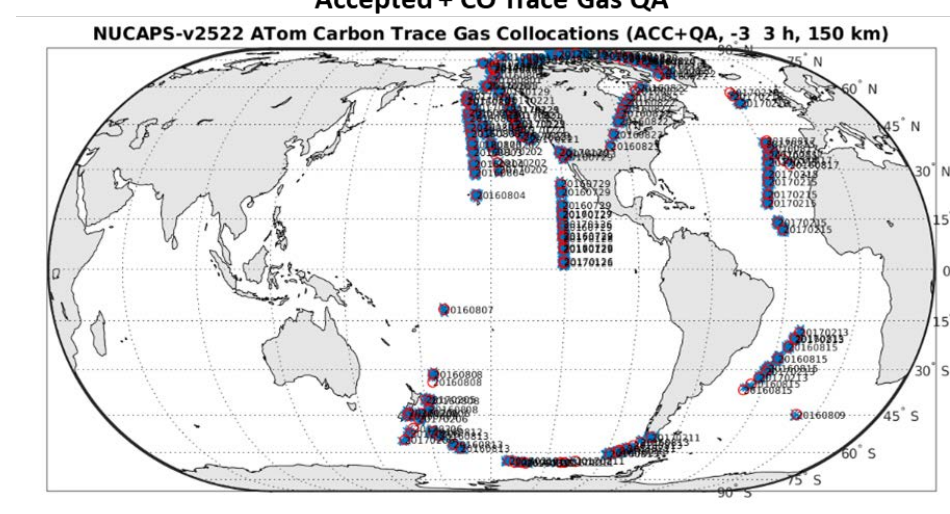
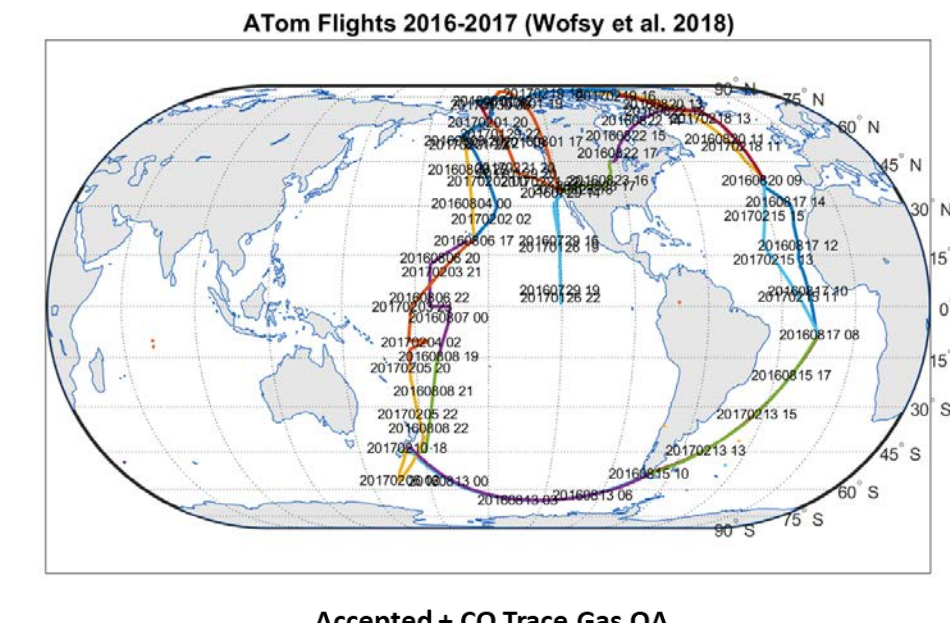


Collocated Radiosonde and N20/SNPP NUCAPS (IR+MW pass QC, 10-20 Aug 2018)

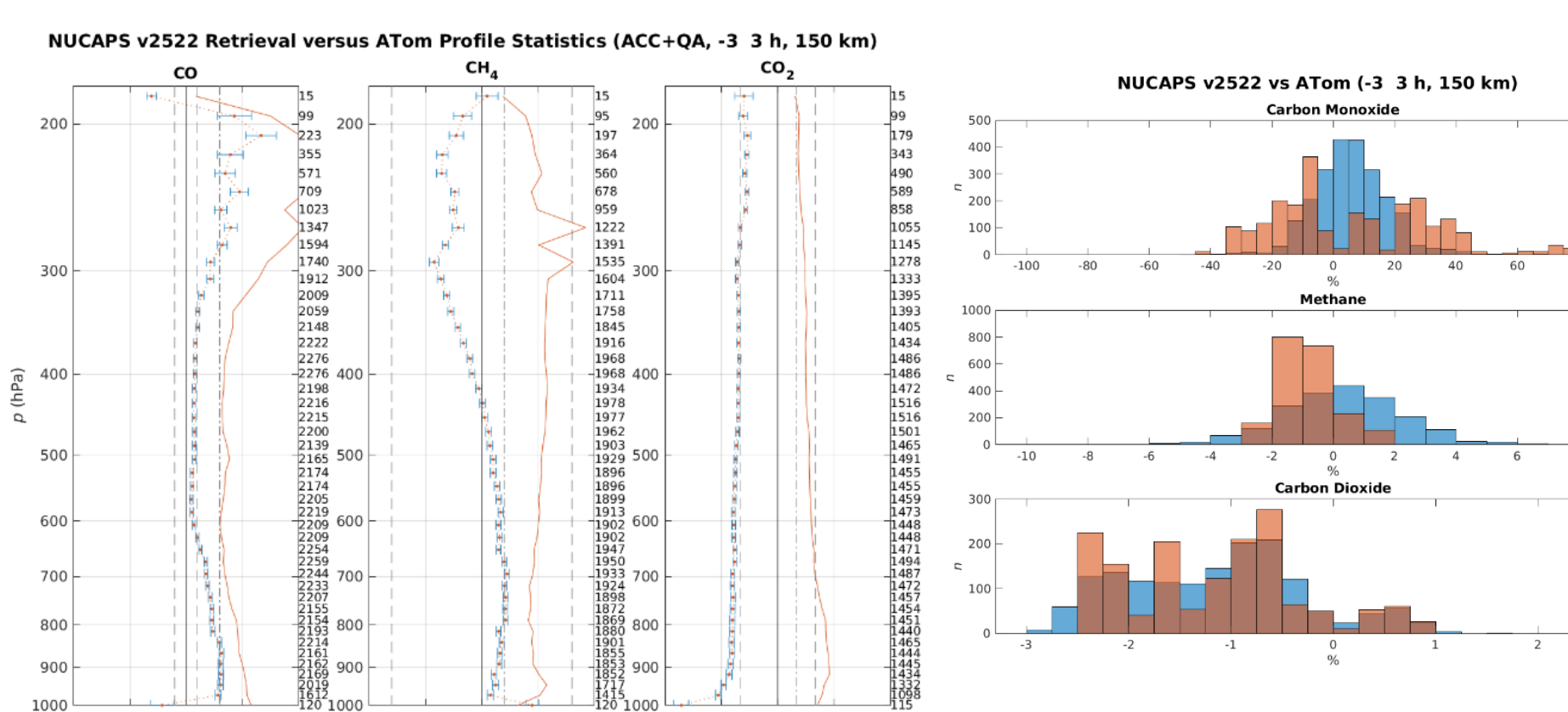


Atmospheric Tomography (ATom) Mission (Wofsy et al. 2018)

- ATom deployed extensive gas and aerosol payloads on the NASA DC-8 aircraft for global-scale sampling of the atmosphere, profiling continuously from 0.2-12 km altitude
- Flights occurred spanning 4 seasons originating from the Armstrong Flight Research Center, Palmdale, California
- In this work we use the NOAA Picarro ATom-1 and -2 datasets
 - Pls: Kathryn McKain and Colm Sweeney (CIRES, U. of Colorado, NOAA/ESRL)
- Source: <https://espo.nasa.gov/atom/>



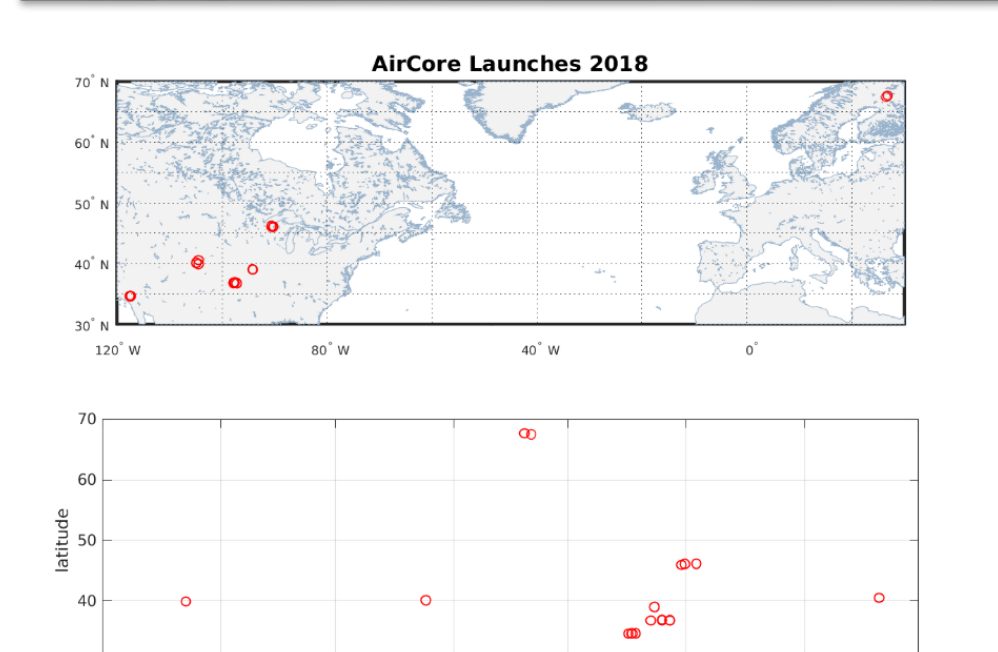
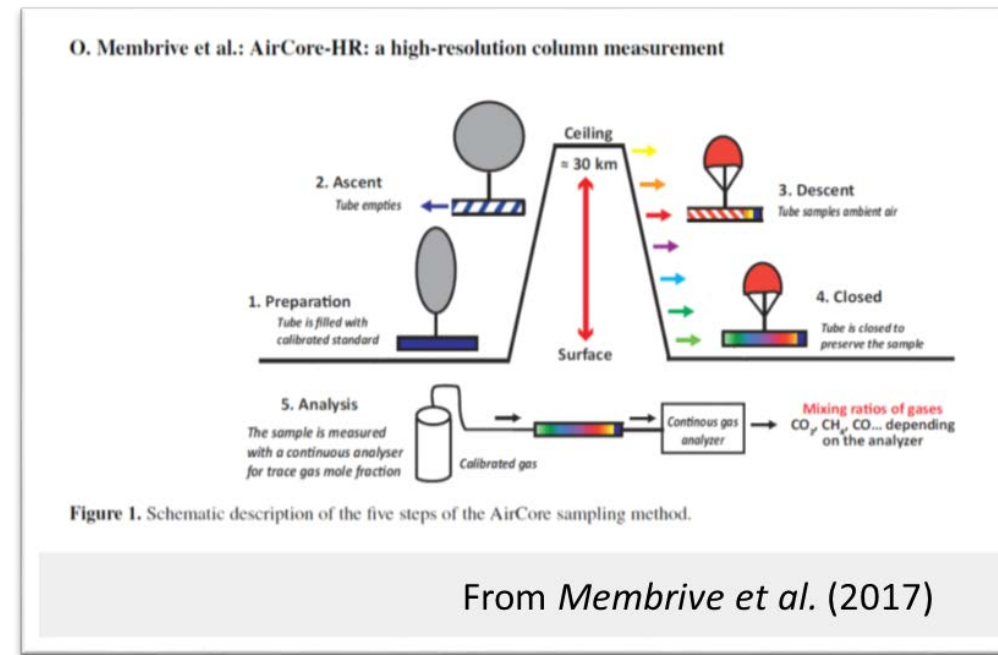
NUCAPS SNPP (V2.5.2.2) versus ATom Accepted+QA, ±3 hr, 150 km



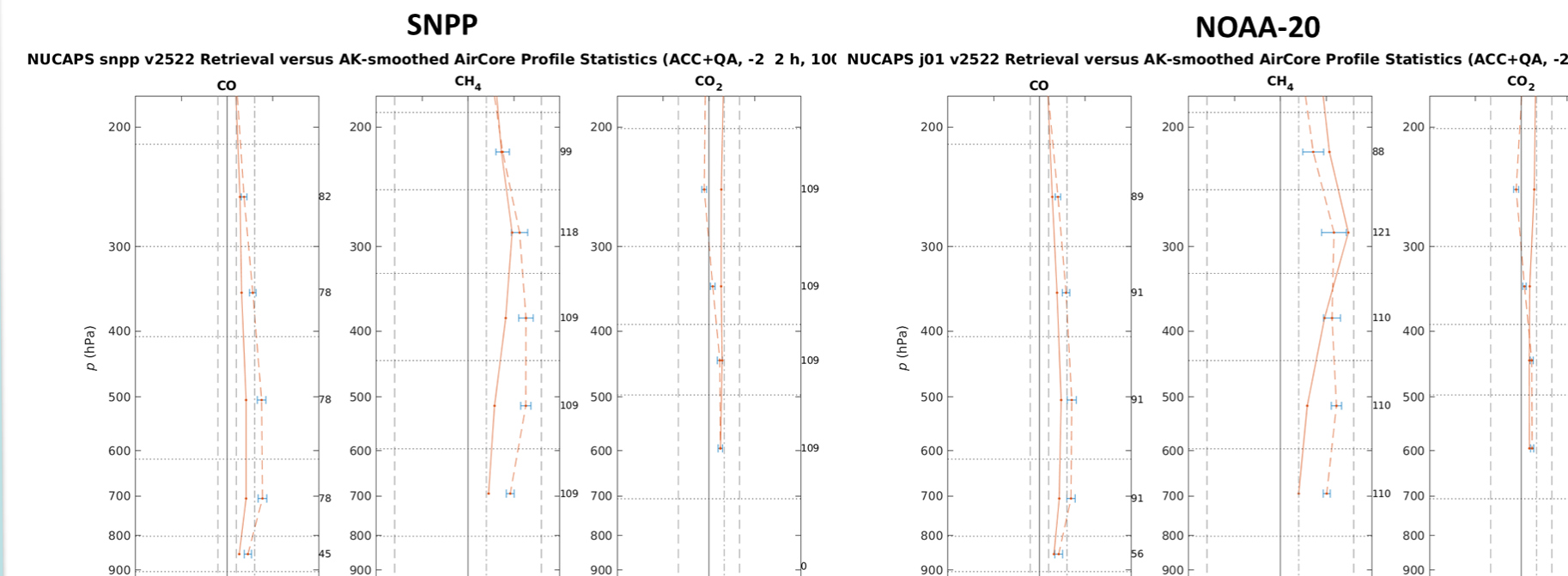
Carbon Trace Gas Highlights

NOAA/ESRL AirCore (Membrive et al. 2017; Karion et al. 2010)

- Innovative, balloon-borne *in situ* sampling system
- Uses long stainless steel tube, open at one end and closed at the other
- Collects a sample (or "core") of the ambient atmospheric air column during its descent.
- The "core" is recovered, sealed, then brought back to the lab for analysis using a Picarro trace gas analyzer.
- Advantages
 - Geographic coverage over land
 - Relatively high vertical resolution profiles over full tropospheric column
 - We obtained ~27 soundings since for the NOAA-20 validation effort (courtesy of Colm Sweeney and Monika Kopacz)
 - Balloon launches were timed for satellite overpasses
 - Original soundings rigorously reduced to 100 layer RTA
 - Serves as SNPP ↔ NOAA-20 transfer standard

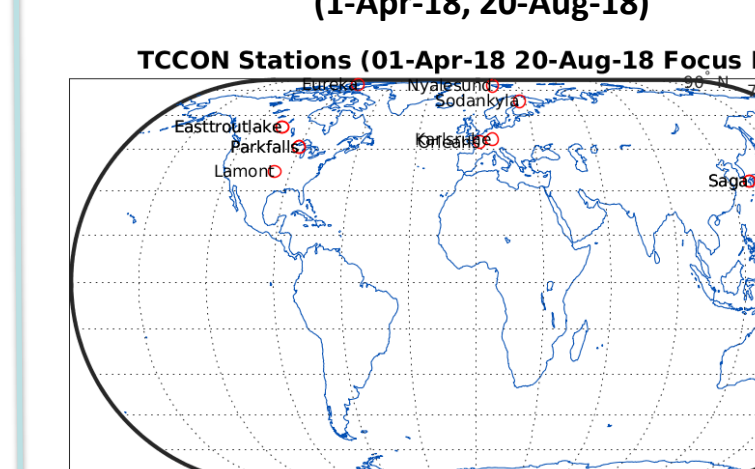


NUCAPS (V2.5.2.2) versus AirCore AK-Smoothed, Accepted Cases + QA, ±2 hr, 100 km

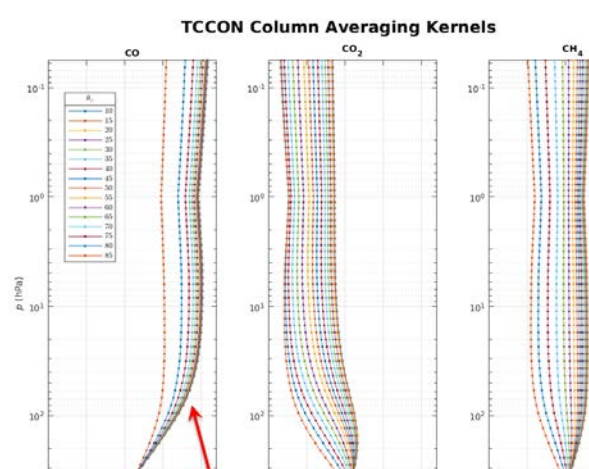


Total Carbon Column Observing Network (TCCON) (Wunch et al. 2011)

Focus Day Station Collocations (1-Apr-18, 20-Aug-18)

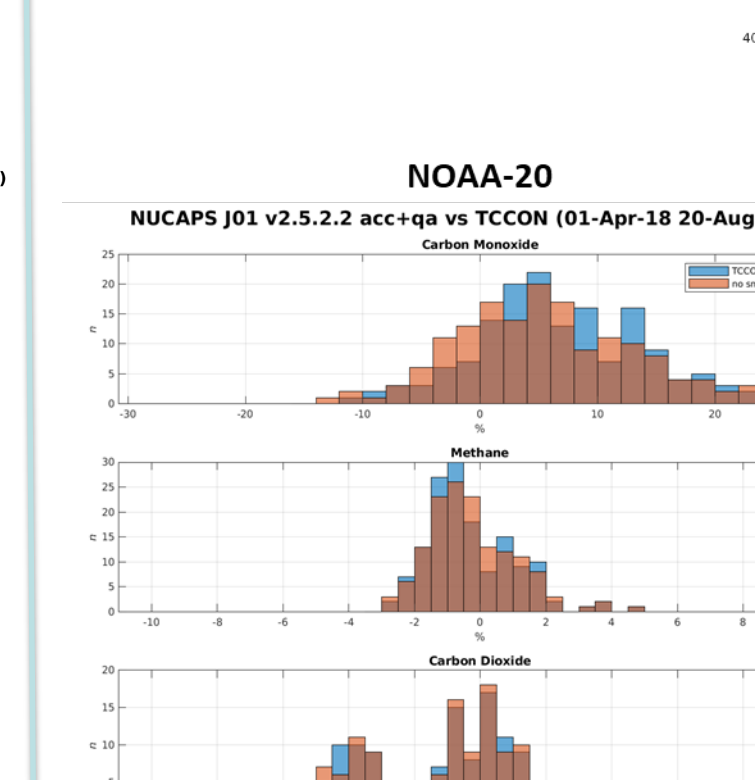


TCCON Column Averages



TCCON (Wunch et al. 2011)

- Global network of ground-based FTs that accurately measure total column abundances of CO₂, CO, CH₄, N₂O trace gases
- Serves as SNPP ↔ NOAA-20 transfer standard, complementing the SNPP ATom analysis



Summary and Future Work

- Validated Maturity Review successfully completed 28 Oct 2019
 - NOAA-20 T/H₂O/O₃ Validated Maturity (pending)
 - SNPP/NOAA-20 Carbon Trace Gases
 - CO Validated Maturity (pending)
 - CH₄ Beta-Provisional Maturity (pending)
 - CO₂ Beta Maturity
 - Recent NUCAPS upgrades have focused on upgrades/optimizations for the CO and CH₄ trace gas EDRs
 - Validation of SNPP NUCAPS CO/CH₄/CO₂ versus ATom-1, -2 truth datasets show
 - CO currently meets JPSS Requirements
 - CH₄ and CO₂ are close to meeting requirements
 - TCCON and AirCore are used as "transfer standards" between SNPP and NOAA-20
- Future Work
 - Ongoing NUCAPS development, Cal/Val and Long-Term Monitoring
 - Continue v2.x algorithm optimizations, including MW-only retrieval
 - Further upgrades/optimizations for CH₄ and CO₂ products
 - Continue support of dedicated RAOBs (ARM, RIVAL, AEROSSE, HUBC)
 - Other Related Work
 - Surface emissivity upgrades/updates
 - IR sea surface emissivity (RSSE) model upgrades (cf. Nalli et al. poster)
 - Implement CAMEL land surface emissivity as a priori
 - Continued support EDR user applications (AWIPS, AR/SAL, atmospheric chemistry users)

Acknowledgements

- Sounder EDR Validation Dataset collection
 - U.S. DOE Atmospheric Radiation Measurement (ARM) program dedicated RAOBs
 - D. Holdridge and J. Mather (ARM Climate Research Facility)
 - NOAA AEROSSE: V. M. Morris, M. Oyola, E. Roper (HU/NCAS-M); P. J. Minnett (UM/RSMAS); D. Wolfe, Ludovic (NOAA/ESRL)
 - Beltville Site: R. Sakai, A. Flores, Siwei Li (HU/JNCAS)
 - GRUAN Lead Center: Rued Dirksen
 - World Ozone and Ultraviolet Radiation Data Centre (WUOUC) data contributors (DWD-GRUAN, & INPE, & KNMI, & NASA-WFF, & SMNA. <http://www.wuo.ucr.edu>)
 - SHADOZ: Southern Hemisphere Additional Ozonesondes (A. Thompson et al.)
 - Carbon Trace Gases: Monika Kopacz (NOAA/UCAR), Greg Frost (NOAA/ESRL)
 - NASA Sounder Science Team: E. Olsen, T. Pagano, E. Fetzer (NASA/JPL)
 - Total Carbon Column Observing Network (TCCON) (D. Wunch et al.), TCCON Data Archive, hosted by the Carbon Dioxide Information Analysis Center (CDIAC), tcon.onr.gov
 - Atmospheric Tomography (ATom) Mission: Kathryn McKain, Colm Sweeney (NOAA/ESRL), <https://doi.org/10.3334/ORNLDAAC/1581>
 - AirCore: Colm Sweeney, Bianca Baier (NOAA/ESRL)
- The NOAA Joint Polar Satellite System (JPSS-STAR) Office (M. D. Goldberg, L. Zhou, et al.) and the NOAA/STAR Satellite Meteorology and Climatology Division.
- Sounder validation effort (past and present): A.K. Sharma, F. Iturbide-Sanchez, M. Pettey, C. Brown, E. Maddy, W. Wolf (STAR); L. Borg, R. O. Knuteson, D. Tobin (UW/CIMSS)

The views, opinions and findings contained in this report are those of the authors and should not be construed as an official NOAA or U.S. Government position, policy or decision.

Selected References

- Divakarla, M. G., C. D. Barnett, M. D. Goldberg, L. M. McMillin, E. Maddy, W. Wolf, L. Zhou, and X. Liu (2006). Validation of atmospheric infrared sounder temperature and water vapor retrievals with matched radiosonde measurements and forecasts. *J. Geophys. Res.*, **111**, D09S15, doi:10.1029/2005JD006116.
- Maddy, E. S. and C. D. Barnett. Vertical resolution estimates in Version 5 of AIRS operational retrievals. *IEEE Trans. Geosci. Remote Sensing*, **46**(8), 2375-2384, 2008.
- Membrive, O., C. Crovisier, C. Sweeney, F. Danabas, A. Hertzog, A. Engel, H. Bonisch, and L. Picou. AirCore-HR: a high-resolution column sampling to enhance the vertical description of CH₄ and CO₂. *Atmos. Meas. Tech.*, **10**, 2163-2181, doi.org/10.5194/amt-10-2163-2017, 2017.
- Nalli, N. R., et al. (2006). Ship-based measurements for infrared sensor validation during Aerosol and Ocean Science Expedition 2004. *J. Geophys. Res.*, **111**, D09S04, doi:10.1029/2005JD006385.
- Nalli, N. R., A. Gambacorta, Q. Liu, C. D. Barnett, C. Tan, F. Iturbide-Sanchez, T. Reale, B. Sun, M. Wilson, L. Borg, and V. R. Morris. Validation of atmospheric profile retrievals from the SNPP NOAA Unique Combined Atmospheric Processing System. Part 1: Temperature and moisture. *IEEE Trans. Geosci. Remote Sensing*, **56**(1), 180-190, 2018.
- Nalli, N. R., A. Gambacorta, Q. Liu, C. Tan, F. Iturbide-Sanchez, C. D. Barnett, E. Joseph, V. R. Morris, M. Oyola, and J. W. Smith (2018). 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.
- Nalli, N. R., C. D. Barnett, A. Reale, D. Tobin, A. Gambacorta, E. S. Maddy, E. Joseph, B. Sun, L. Borg, A. Moliner, V. R. Morris, M. Divakarla, X. Liu, P. J. Minnett, R. O. Knuteson, T. S. King, and W. W. Wolf. Validation of satellite sounder environmental data records: Application to the Cross-track Infrared Microwave Sounder Suite. *J. Geophys. Res. Atmos.*, **118**, 13,628-13,643, 2013.
- Reale, T., B. Sun, F. H. Tilley, and M. Pettey. The NOAA Products Validation System (NPROVS). *J. Atmos. Ocean. Technol.*, **29**(5), 629-645, 2012.
- Rodgers, C. D. and B. J. Connor. Intercomparison of remote sounding instruments. *J. Geophys. Res.*, **108**(D3), 4116, 2003.
- Sun, B., A. Reale, F. H. Tilley, M. E. Pettey, N. R. Nalli, and C. D. Barnett. "Assessment of NUCAPS-NPP CrIS/ATMS sounding products using reference and conventional radiance observations." *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, **10**(6), 2499-2509, 2017.
- Susskind, J., C. D. Barnett, and J. M. Blaisdell. Retrieval of atmospheric and surface parameters from AIRS/ATMS/HSB data in the presence of clouds. *IEEE Trans. Geosci. Remote Sensing*, **41**(2), 390-409, 2003.
- Thompson, A. M., J. C. Witte, S. J. Oltmans, and F. J. Schmidlin. SHADOZ—A tropical ozonesonde-radiosonde network for the atmospheric community. *Bull. Amer. Meteorol. Soc.*, **85**(10), 1549-1564, 2004.
- Wofsy, S., et al. ATom: Merged atmospheric chemistry, trace gases, and aerosols, 2018. [Online]. Available: https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1581
- Wunch, D., G. C. Toon, J.-F. Blavier, R. A. Washenfelder, N. Notholt, B. J. Connor, D. W. T. Griffith, V. Sherlock, and P. O. Wennberg. The total carbon column observing network. *Phil. Trans. R. Soc. A*, **369**, 2087-2112, 2011.
- Zhou, L., M. Divakarla, and X. Liu. An overview of the Joint Polar Satellite System (JPSS) science data product calibration and validation. *Remote Sens.*, **8**(2), 139, 2016.

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