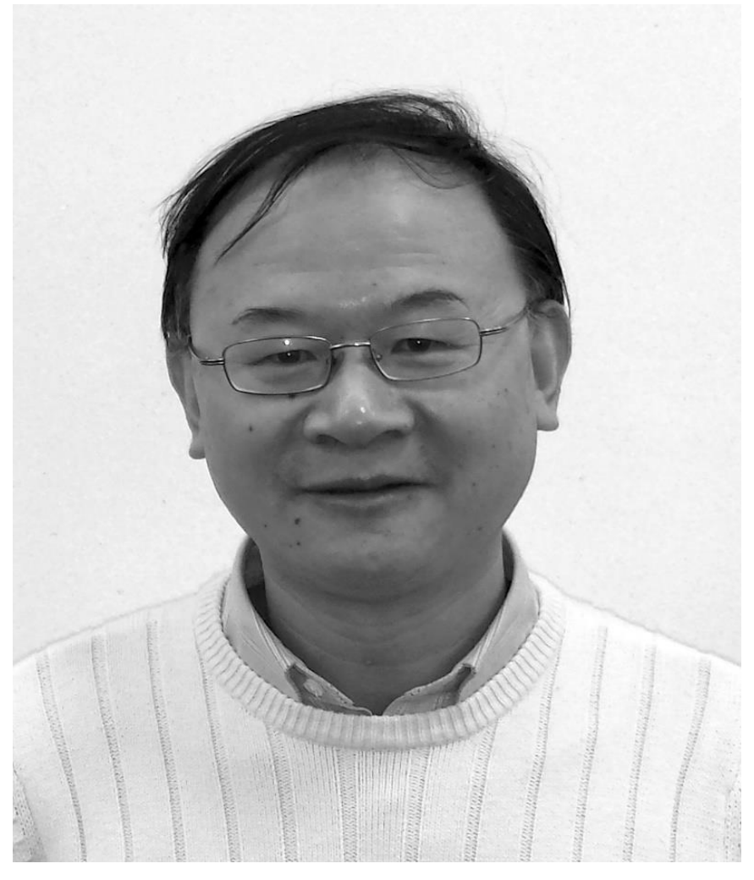

Recent Advances in Global Radiosonde Observations in Support of Satellite Sounding Data Validation

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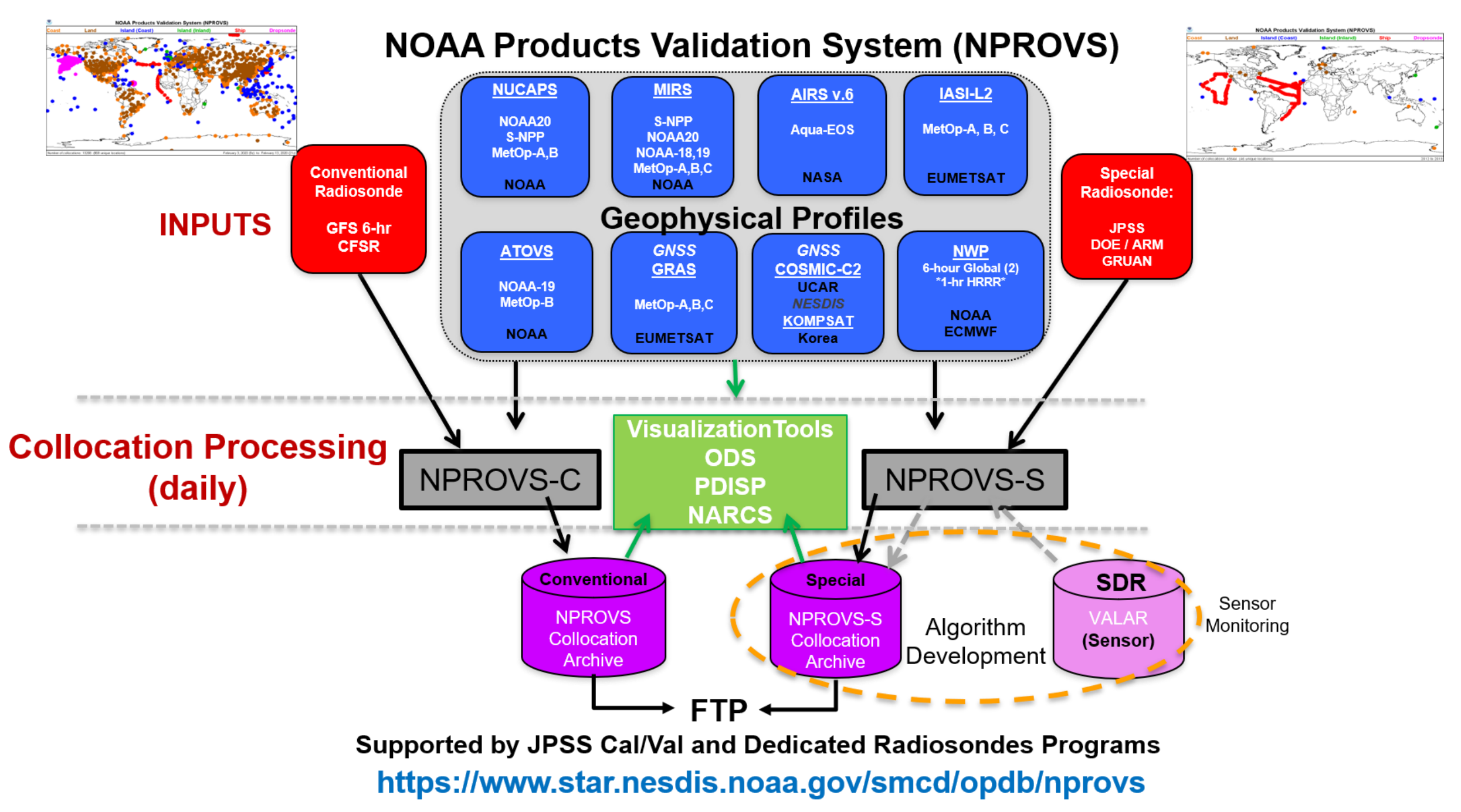
Abstract

This work presents recent advances in global radiosonde observations with respect to their applications in satellite data calibration/validation (cal/val). Improved accuracy of radiosonde temperature and humidity measurements has been achieved through advances in radiosonde sensor technology (*e.g.*, from Vaisala RS92 to RS41) and through advanced radiosonde data processing provided by the GCOS Global Reference Upper Air Network (GRUAN) program. Radiosonde launches supported by the NOAA Joint Polar Satellite System (JPSS) which target polar-orbiting (SNPP and NOAA20) overpasses is another advance which aims to minimize the radiosonde-satellite spatial and temporal mismatch. These "dedicated" radiosondes include those from the Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) sites and research campaigns including trans-Atlantic AERerosols and Ocean Science Expeditions (AEROSE) campaigns.

All of the radiosondes mentioned have been collected and stored (since 2013) in the NOAA Sounding Products Validation System (NRPOVS, operated at STAR/NESDIS) and subsequently collocated with multiple satellite product systems for use in product assessment and retrieval algorithm development.

NOAA Sounding Products Validation System (NPROVS)



NOAA Products Validation System (NPROVS)

INPUTS

Conventional Radiosonde
GFS 6-hr
CFSR

Geophysical Profiles

NUCAPS: NOAA20, S-NPP, MetOp-A,B; NOAA
MIRS: S-NPP, NOAA20, NOAA-18,19, MetOp-A,B,C; NOAA
AIRS v.6: Aqua-EOS; NASA
IASI-L2: MetOp-A, B, C; EUMETSAT
ATOVS: NOAA-19, MetOp-B; NOAA
GNSS GRAS: MetOp-A,B,C; EUMETSAT
GNSS COSMIC-C2: UCAR, NESDIS, KOMPSAT, Korea
NWP: 6-hour Global (2), "1-hr HRRR"; NOAA, ECMWF

Special Radiosonde: JPSS, DOE / ARM, GRUAN

Collocation Processing (daily)

NPROVS-C
Visualization Tools: ODS, PDISP, NARCS
NPROVS-S

Conventional: NPROVS Collocation Archive
Special: NPROVS-S Collocation Archive
Algorithm Development
SDR: VALAR (Sensor)
Sensor Monitoring
FTP

Supported by JPSS Cal/Val and Dedicated Radiosondes Programs
https://www.star.nesdis.noaa.gov/smcd/opdb/nprovs

Figure 1. NPROVS provides a centralized "Enterprise (*same baseline to assess different systems*) " strategy for compiling collocations of radiosondes including dropsondes, numerical weather prediction model (NWP) outputs and satellite atmospheric temperature and water vapor sounding profiles and providing assessment. The satellite profiles are derived from different satellite platforms (*i.e.*, NOAA, NASA, EUMETSAT, and GPSRO; Infrared, Microwave and Radio Occultation) and associated retrieval algorithms. A single "closest" sounding from each platform (and NWP) is collocated to a given radiosonde that is within 6 hr and 150 km; this preserves respective product yield tracking.

Radiosonde profiles used as the collocation baseline include those from global "Conventional" network (including dropsondes) and "Special" Global Climate Observing System (GCOS) Reference Upper Air Network (GRUAN) and satellite synchronized "dedicated" sondes (JPSS/ARM). This enables "Enterprise Assessment", providing a common baseline for assessing satellite derived profiles from different platforms and retrieval algorithms.

Advance in Sonde Sensor Technology

Figure 2. Vaisala RS41 radiosonde has been replacing the Vaisala RS92, becoming the major sonde type across the GRUAN and Conventional radiosonde networks. (courtesy of https://www.vaisala.com).

Vaisala RS41 includes new sensor technologies aimed at improving measurement accuracy for temperature, humidity and other variables throughout the atmosphere. These include a heated humidity sensor to prevent dew or frost formation in clouds and a separate temperature sensor attached to the humidity sensor. When the humidity sensor temperature differs from the free-air temperature sensor it is simple to express the relative humidity (RH) reading as RH at the free-air temperature.

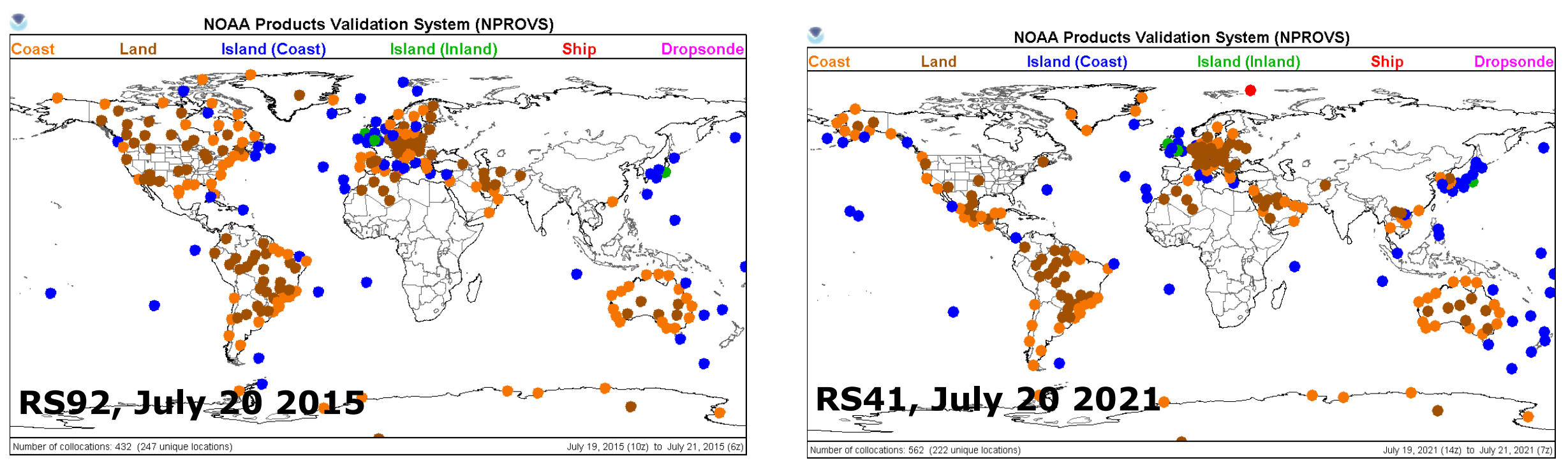


Figure 3. Spatial distribution of RS92 (left) and RS41 (Right).

Vaisala RS92 was a major sonde type in the global operational upper air network and a reference sonde in the Global Climate Observing System (GCOS) Reference Upper Air Network (GRUAN) [1]. However, RS92 has gradually been replaced by Vaisala RS41 starting in late 2013. RS92 production ended in 2017.

RS92-minus-RS41, T

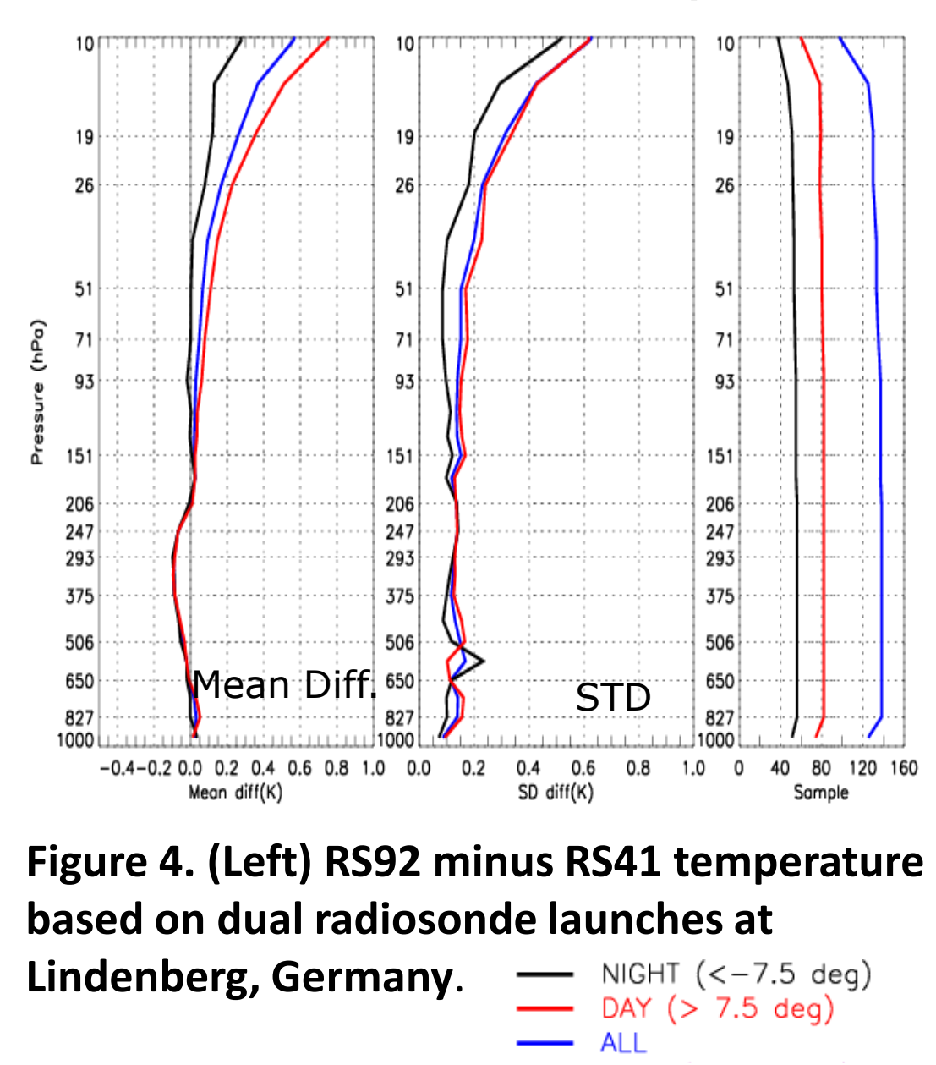


Figure 4. (Left) RS92 minus RS41 temperature based on dual radiosonde launches at Lindenberg, Germany.

EUMETSAT IASI-minus-RAOB, T

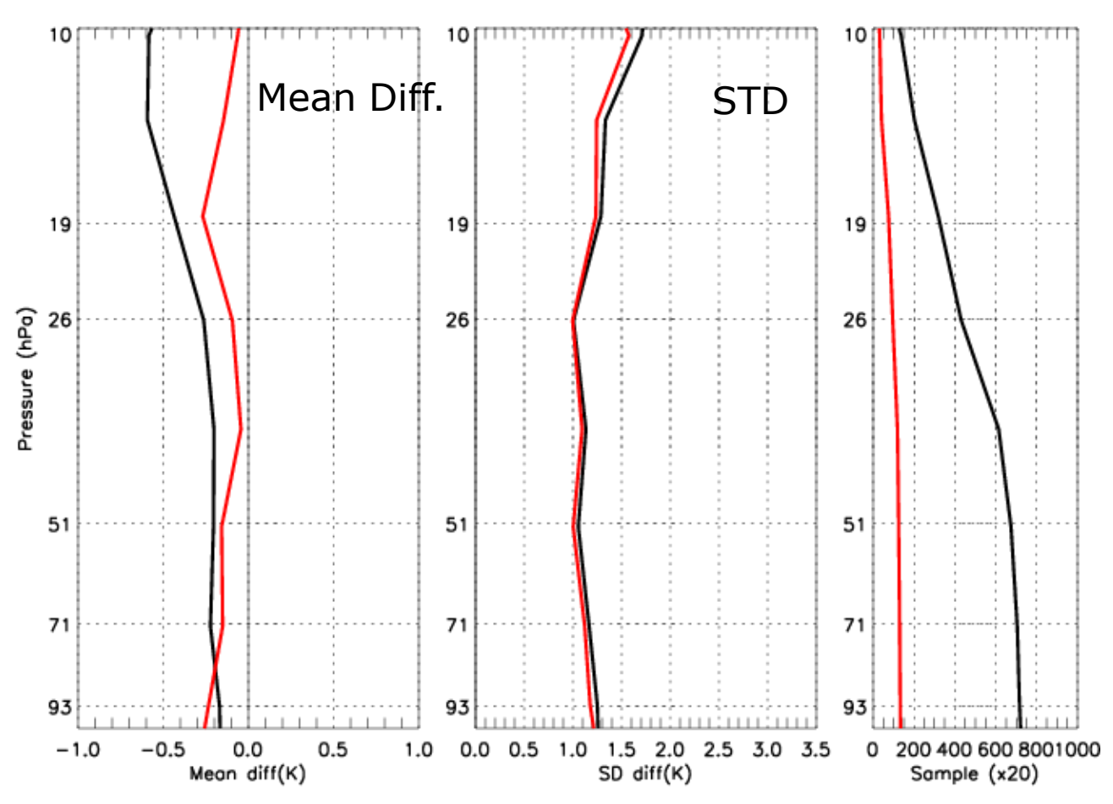


Figure 4. (Right) EUMETSAT IASI minus RS92(black) /RS41(red) based on conventional RAOBs data for Jan 2015 to Jun 2017; collocations (1hr/50km) RS41 shows improvement over RS92 in the assessment.

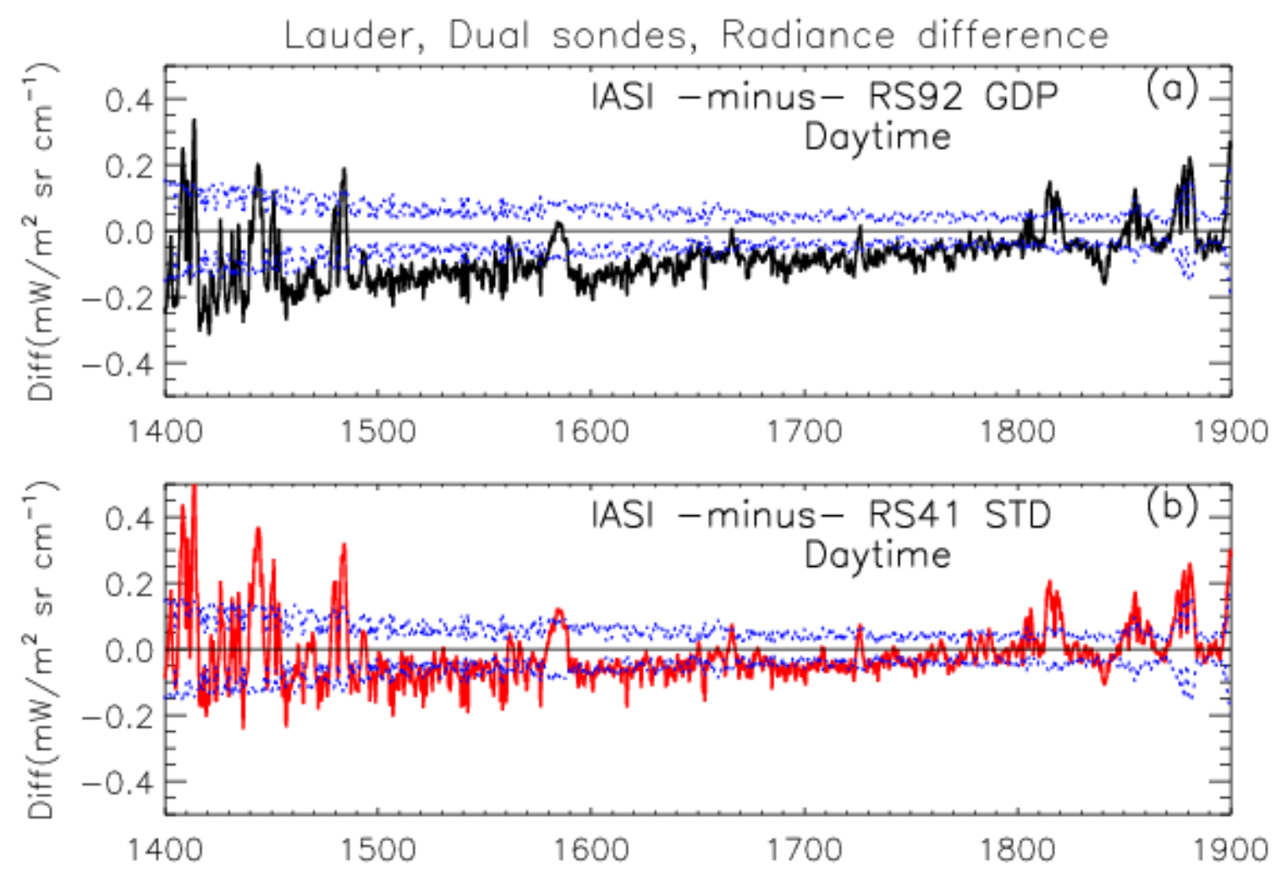


Figure 5. Mean difference (solid) curve between IASI observed and calculated (radiosonde) radiances (OBS-CAL) averaged from 14 daytime dual launch cases at Lauder, New Zealand for Vaisala RS92 (a) and for Vaisala RS41 (b). RAOB launches are within 1 hr of satellite overpasses. Dotted curves show two standard errors of the combined uncertainties.

Daytime upper tropospheric RS41 humidity observations (without GRUAN processing, not yet available) show an improvement over RS92 data (with GRUAN corrections) on the order of 1-2 % RH. The reported RS41 data is found to be consistent with IASI measurements (Sun et al. 2019).

JPSS Dedicated Radiosonde Launches

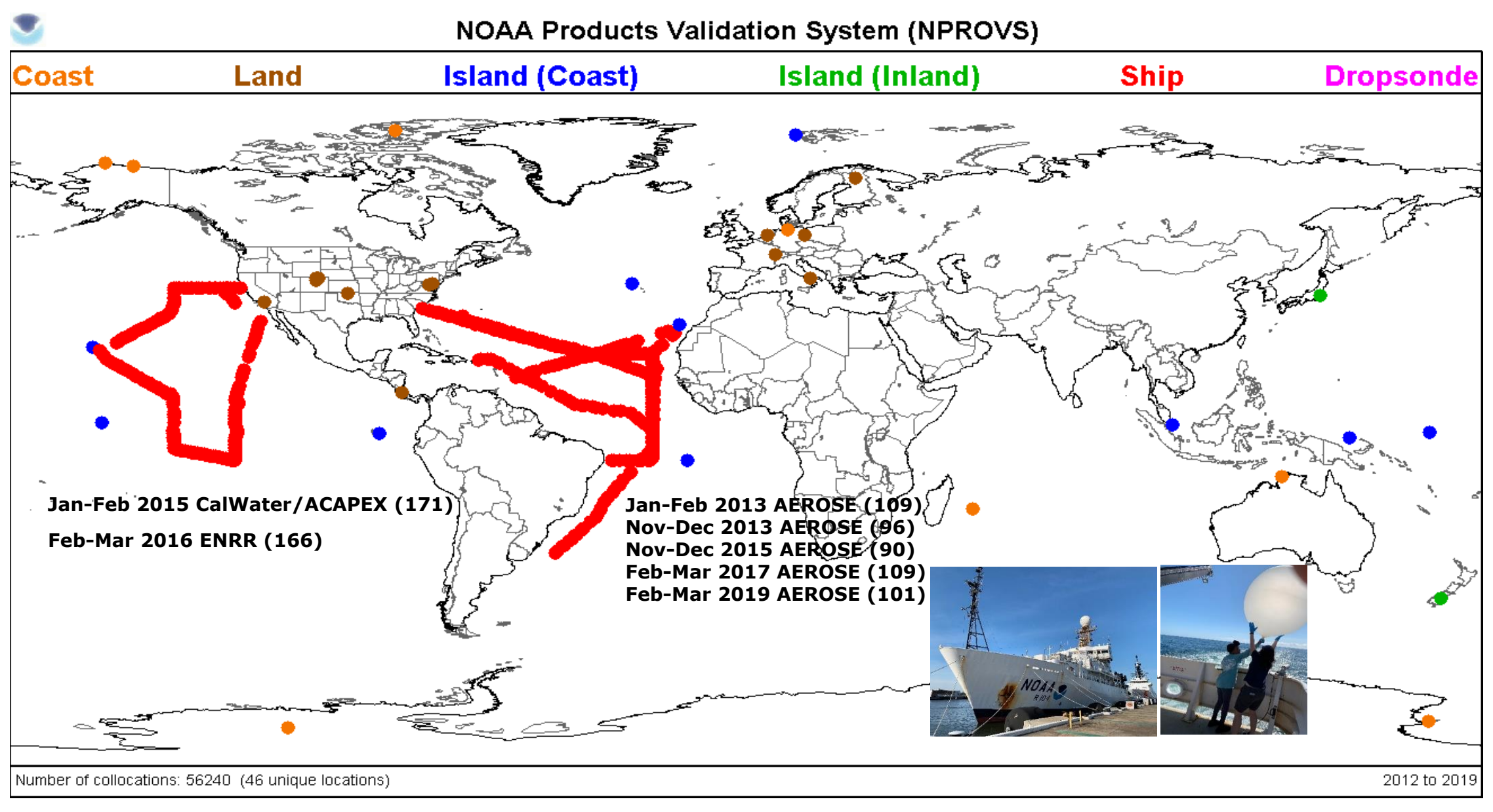


Figure 6. Spatial distribution of JPSS satellite synchronized dedicated radiosonde sites including ship campaigns and GRUAN. There are ~ 74,000 radiosondes (January 2013 through July 2022), of which, 26,500 are synchronized (7700 via JPSS/ARM) with satellite overpasses. Half of the radiosondes from oceanic campaigns are synchronized with MetOp overpasses. Many of these are processed into "reference" radiosonde (STAR/GRUAN coordination).

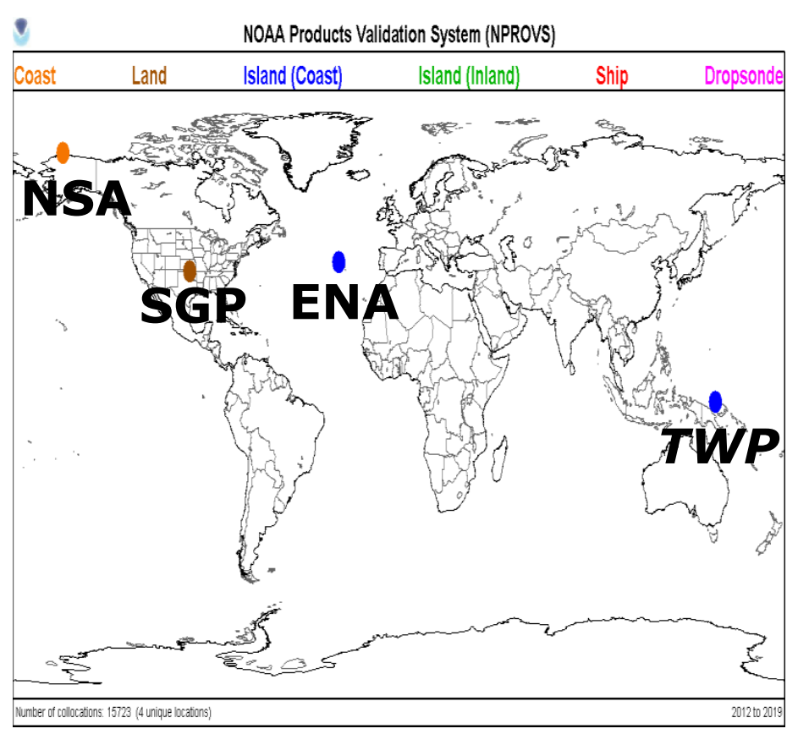


Figure 7. Dedicated radiosonde launches, funded by NOAA JPSS, at three DOE Atmospheric Radiation Measurement (ARM) sites: Southern Great Plains at Oklahoma (SGP), Northern Slope of Alaska (NSA), and East North Atlanta (ENA). The Tropical Western Pacific (TWP) site was decommissioned in October 2014. Two launch configurations are utilized: single launch (20 min prior to the overpass), and sequential launch (5 min for the first launch and followed by the second launch 40 min later).
Beginning February 2018, the Radiosonde Intercomparison and Validation (RIVAL) at ARM sites made unique sets of dual radiosonde launches comprised of Vaisala RS41 and RS92 instrument types concurrent with satellite overpasses.

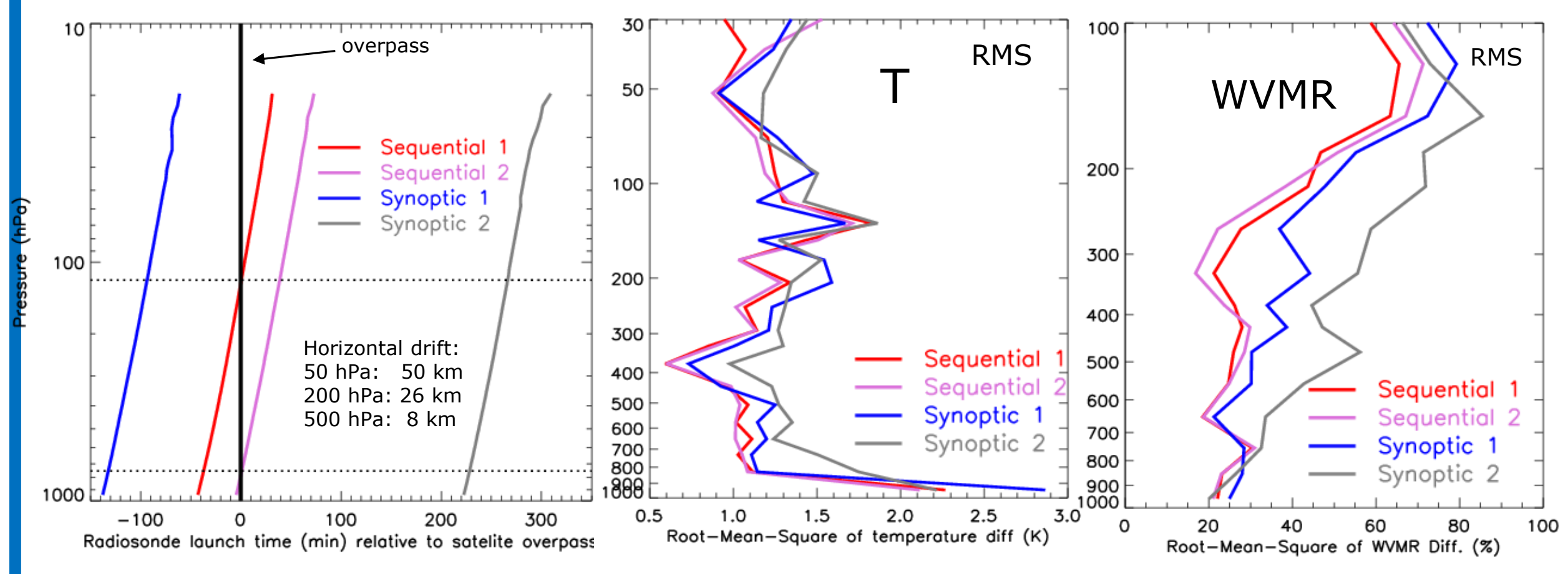


Figure 8. (Left) Time trajectories of sequential radiosonde launches at SGP targeting for NOAA20. Vertical black line indicates the NOAA20 overpass time. Time trajectories of synoptic sondes are also included. Composite of 30 pairs of sequential sondes. (Middle) Room-mean-square (RMS) difference of NUCAPS minus radiosonde for atmospheric temperature. (Right) for water vapor mixing ratio (MR) RMS.

RMS computed using sequential sondes are much smaller than the ones using synoptic sondes, indicating we need dedicated sondes to accurately characterize satellite products. Profiles time-interpolated from sequential sondes further improve the validation accuracy in the troposphere (figures not shown). More studies are need to examine the value of dedicated sondes in validating satellite radiance measurements.

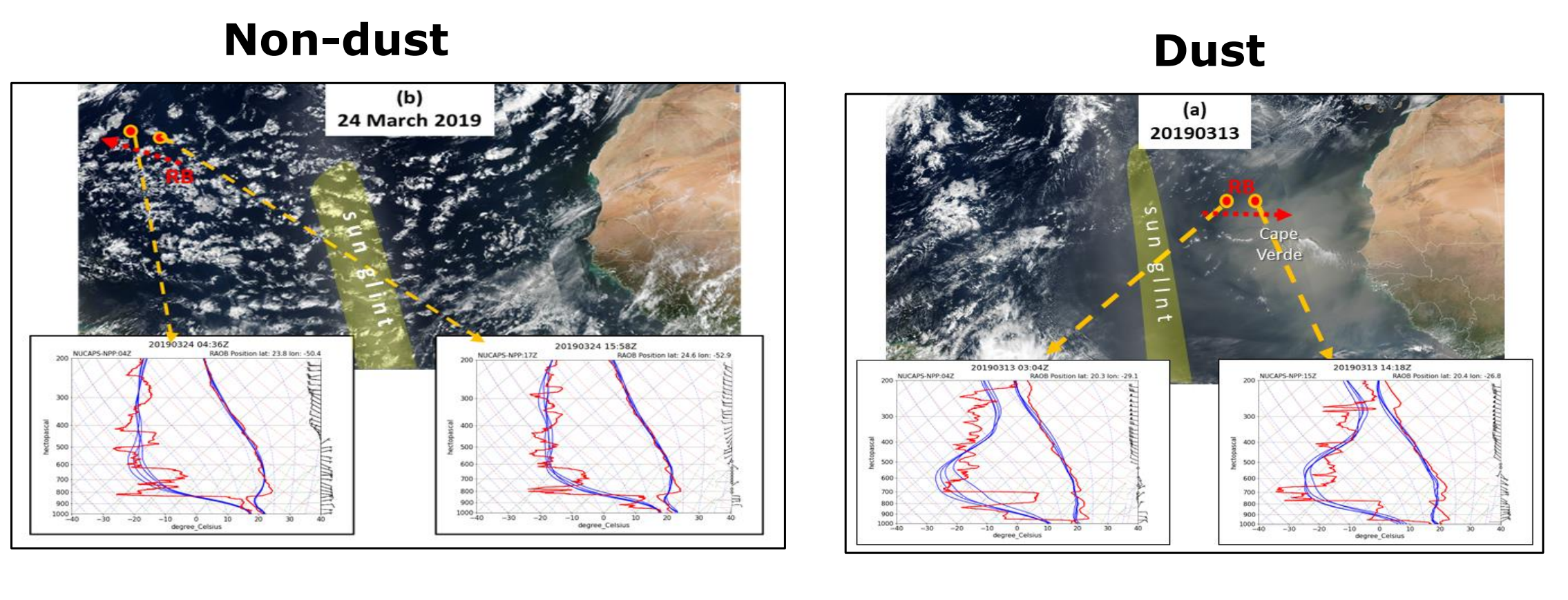


Figure 9. AEROSE campaign (March 2019) radiosonde data are used to examine the NUCAPS SNPP and NOAA20 skills in profiling Saharan dust. SNPP true color plots of Non-dust (Left) and Dust (Right) conditions during the *Ron Brown* cruise paths. Skew-T plots: solid red and blue curves are temperature and dew point temperatures from radiosondes and NUCAPS, respectively.

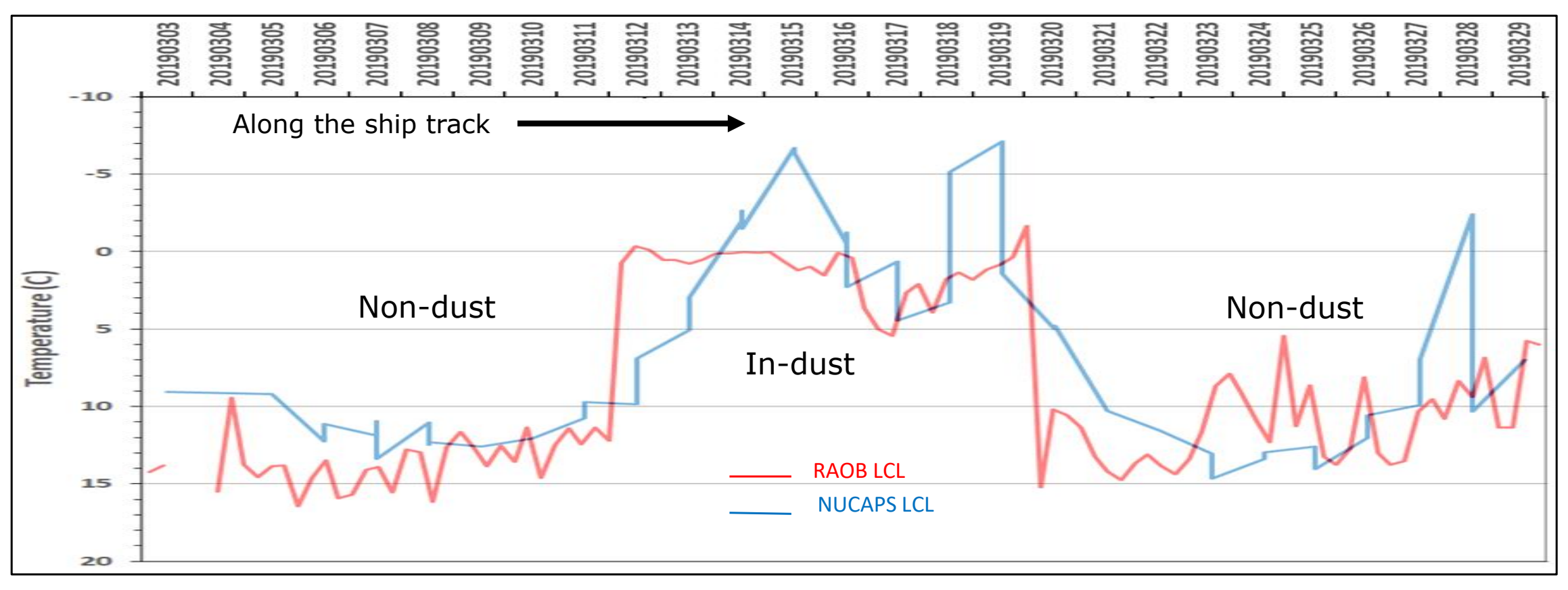


Figure 10. Near-surface-based lifting condensation (LCL) throughout the AEROSE 2019 campaign (3-29 March 2019) between radiosondes in red and NUCAPS (SNPP and NOAA20) in blue.
Combined Figures 9 and 10, AEROSE radiosonde profiles verifies that NUCAPS shows skill in distinguishing dust rom non-dust atmospheric conditions over the tropical and subtropical Atlantic.

Global Reference Upper Air Network (GRUAN)

GCOS Reference Upper-Air Network

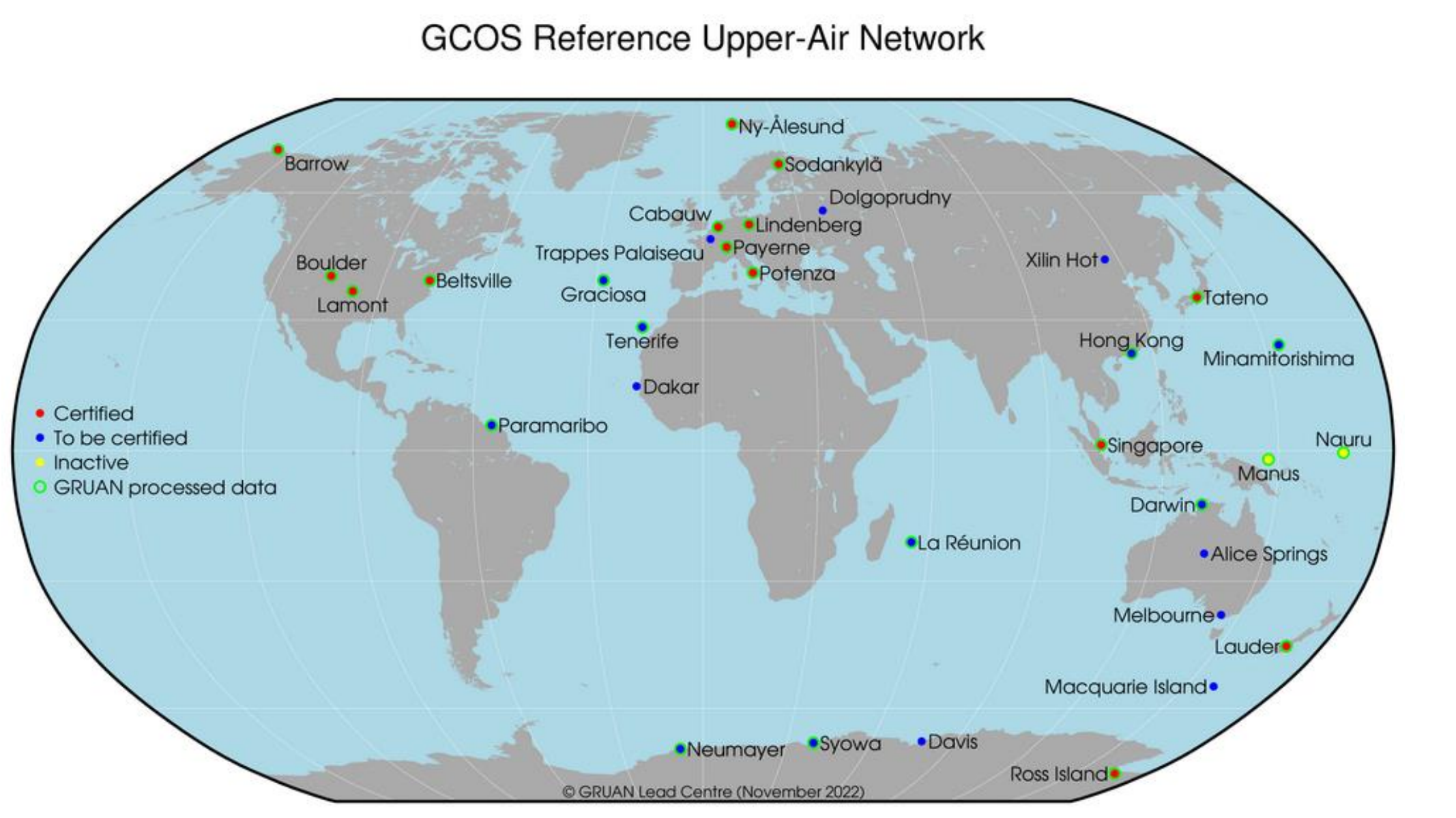


Figure 11. The Global Climate Observing System (GCOS) Reference Upper Air Network (GRUAN) is envisaged as a network of 30-40 sites leveraging existing observational networks and capabilities. As at November 2022, GRUAN comprises of 31 sites, 14 of which have been GRUAN certified.

GRUAN is an international observing network for monitoring climate. GRUAN strives to fill major gaps in the current global observing system by providing fully characterized "reference" observations. The GRUAN radiosondes provide with uncertainty estimates for each individual observation. GRUAN products have the quality thus being suited to provide reference standard for satellite data calibration/validation. Many of the JPSS dedicated radiosonde are GRUAN processed, effectively expanding GRUAN.

$$|m_1 - m_2| < k\sqrt{\sigma^2 + u_1^2 + u_2^2}$$

Where sigma is the uncertainty related to time and space mismatch, and u_1 and u_2 are of variable m_1 and m_2, respectively.
$k \le 1$ indicates m_1 and m_2 consistency, and $1<k<2$ indicates agreement.

The above formula allows to estimate satellite retrieval uncertainties traceable to GRUAN radiosondes. "k" measures the comparability of satellite and GURAN profiles. We can estimate "k" value by assuming collocation error and satellite uncertainty being zeros, which is the "worst" case for "k".

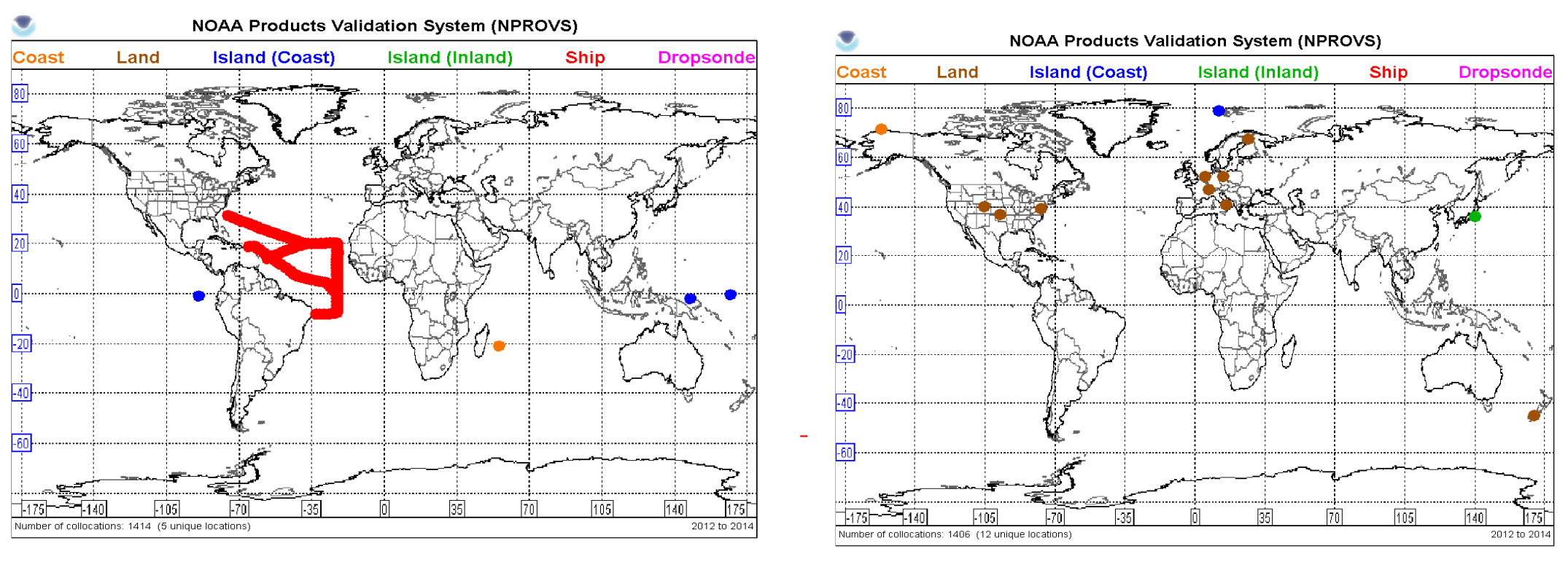


Figure 12. Collocations of GRUAN radiosondes with satellite products (within 3 hr) for 2013 to 2014 used for the satellite retrieval products assessment. Tropical sea (left), and non-tropical land (right).

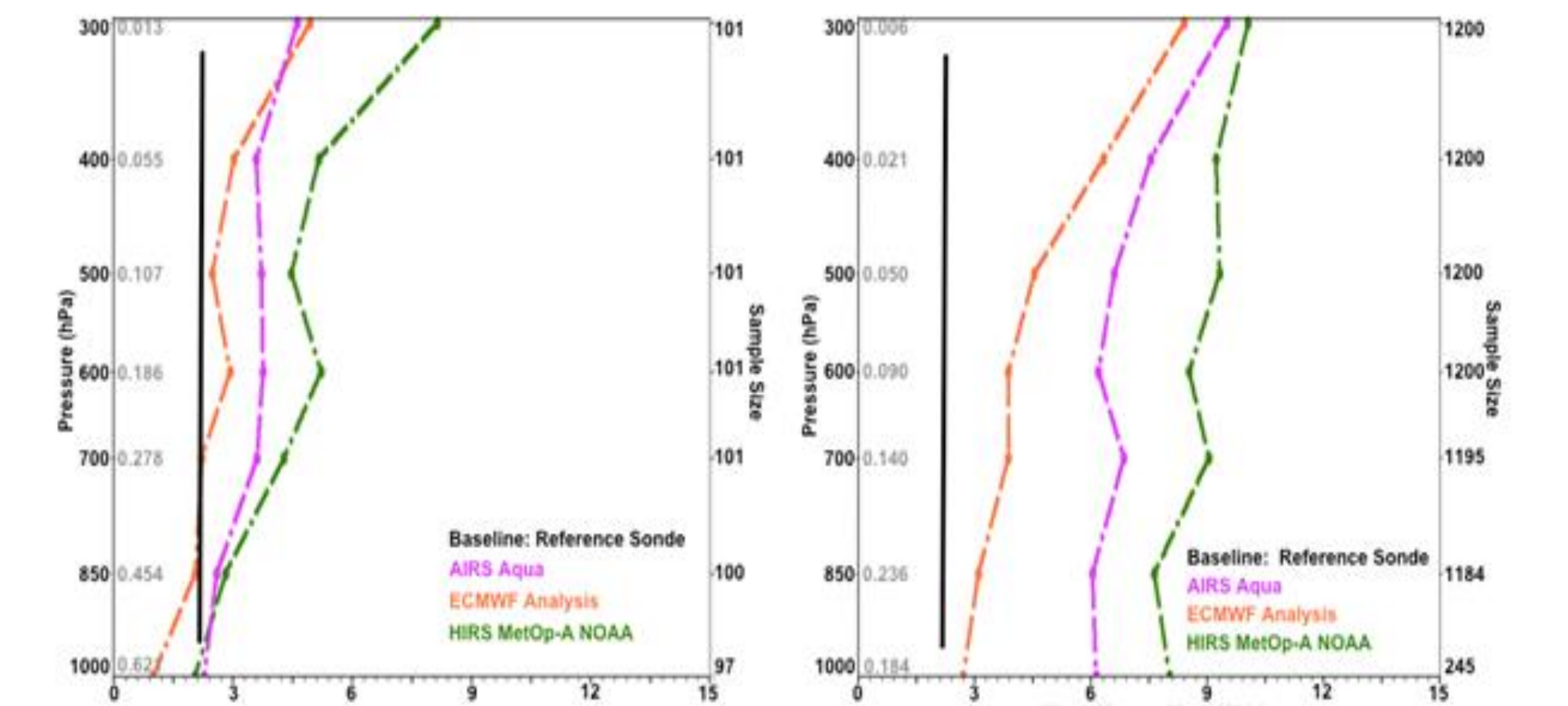


Figure 13. Mean "K" vertical profile for collocated GRUAN radiosondes, HIRS from MetOp-A (green), Aqua AIRS (purple), and the ECMWF analysis (orange) over tropical sea (left) and non-tropical land (right) with GRUAN Mean water vapor mixing ratio (MR) uncertainty along inside left and sample along right axes; black Line denotes k=2. The k profiles are estimated using the above formula by assuming the radiosonde-satellite collocation error is zero and satellite product uncertainties zero.

Figure 13 indicates that all three satellite and NWP retrievals are more comparable to GRUAN for tropical sea than for non-tropical land.

Summary

Recent advances in global radiosonde observations are summarized as beow:

1. **Advance in sonde sensor technology for making more accurate measurements, *e.g.*, from Vaisala RS92 to RS41.**
2. **NOAA JPSS supporting dedicated radiosonde launches covering both land (*i.*e., ARM sites) and ocean (*e.g.*, AEROSE) campaigns.**
3. **GRUAN radiosondes and particularly GRUAN processed dedicated radiosondes providing the quality being suited for reference for satellite data calibration and validation.**

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