Assessment of NUCAPS S-NPP CrIS/ATMS Sounding Products Using Reference and Conventional Radiosonde Observations

Bomin Sun, Anthony Reale, Franklin H. Tilley, Michael E. Pettey, Nicholas R. Nalli, and Christopher D. Barnet

***Abstract*—The NOAA unique combined atmospheric processing system (NUCAPS) sounding products derived from Suomi national polar-orbiting partnership (S-NPP) cross track infrared sounder/advanced technology microwave sounder (CrIS/ATMS) are assessed. This is done using collocated radiosondes from reference sites (i.e., global reference upper air network and satellite synchronized launch sites) and conventional upper air observing sites as the target data. Analysis of satellite retrieval bias and root-mean-square (rms) error, conducted on a global scale and at individual sites with representative climate regimes, indicates the NUCAPS temperature and water vapor retrieval performance meets the operational uncertainty requirements. Caution, however, is needed in this type of approach. In our empirical analyses, we find that the satellite retrieval rms error is sensitive to 1) the time mismatch in radiosonde launch and satellite overpass, particularly near the surface and tropopause for temperature and around the midtroposphere for water vapor, 2) vertical resolution differences between the satellite retrieval and radiosonde that become manifested as a larger rms error in the vicinity of the planetary boundary layer and tropopause, and 3) the accuracy of radiosonde water vapor measurements particularly in the upper troposphere and lower stratosphere where dry bias are prevalent. Examples highlighting these issues in the context of satellite data calibration and validation are provided.**

***Index Terms*—Assessment, NOAA unique combined atmospheric processing system (NUCAPS) Suomi national polar-orbiting partnership (S-NPP) cross track infrared sounder/advanced technology microwave sounder (CrIS/ATMS) sounding products, reference and conventional radiosondes.**

I. Introduction

THE Suomi national polar-orbiting partnership (S-NPP), launched in October 2011, features the hyperspectral cross-track infrared sounder (CrIS) and advanced technology microwave sounder (ATMS), together comprising an advanced sounding system to retrieve environmental data records (EDRs), including atmospheric vertical temperature and moisture profiles. The operational algorithm for retrieving sounding and other EDR products is the NOAA unique combined atmospheric processing system (NUCAPS) algorithm [1], [2].

Its retrieval approach includes procedures of radiance calibration, microwave retrieval, cloud clearing, initial infrared (IR) retrieval, and a final iterative IR physical retrieval. A fast eigenvector regression retrieval is used to obtain initial estimates of temperature and water vapor profiles for computing cloud-cleared radiances. This is followed by a second fast eigenvector regression using the cloud-cleared radiance product to compute the first-guess profile used to initialize the final IR retrieval module. The physical retrieval methodology uses an iterative algorithm to produce the final retrievals. Details of the NUCAPS retrieval algorithm are described by [1], [2], and [8].

Note, that different approaches have been available to conduct satellite IR sounding retrievals (examples see [3]–[5]). NUCAPS is a legacy algorithm adopted from the atmospheric IR sounder (AIRS)/advanced microwave sounding unit (AMSU) retrieval algorithm [6]–[8]. The same NUCAPS algorithm is used with the IR atmospheric sounding interferometer (IASI) to produce the NOAA IASI sounding products.

In this work, the operational NUCAPS S-NPP CrIS/ATMS sounding products are assessed using collocated radiosondes of both reference and conventional observations. Reference radiosondes used in the analysis include those from the global climate observing system reference upper air network (GRUAN) [9], [10], and S-NPP dedicated radiosonde data. Unless otherwise specified, the results reported are for the S-NPP CrIS/ATMS IR and microwave (IR+MW) retrievals. Ambiguities that arise from the temporal and spatial mismatch in radiosonde and satellite data, radiosonde measurement accuracy, and the radiosonde and satellite data vertical resolution differences are discussed. The overall aim is to better understand the NUCAPS performance characteristics. The performance assessment is conducted globally, regionally, and at individual sites covering the various climate regimes across the globe. The baseline datasets used are collocated radiosonde and satellite observations covering 3 years for those containing GRUAN and dedicated radiosondes and 6 months for those containing conventional radiosondes.

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II. Data and Methods

The NUCAPS collocations with conventional and reference radiosondes to be analyzed in this work are collected via the NOAA products validation system (NPROVS) [11] and its expansion NPROVS+. These systems were developed at NOAA NESDIS Center for Satellite Applications and Research and provide a centralized capability for compiling collocations of radiosonde, numerical weather prediction model output, and atmospheric temperature and water vapor sounding profiles. These profiles are derived from different satellites (i.e., NOAA, NASA, EUMETSAT, and global navigation satellite system), sensors (i.e., IR, microwave, and GPS radio occultation), and product suites. NPROVS provides a large number of global conventional radiosondes. NPROVS+ collects a relatively small sample of high-quality reference radiosondes. These two systems are complementary in support of NOAA joint polar satellite system (JPSS) calibration/validation (cal/val) programs for atmospheric soundings from the S-NPP for which they were developed. The collocation approach considers the spatial and temporal aspects of each satellite platform to ensure consistent and robust selection of a single "closest" sounding from each satellite product that lies within 6 h and 150 km of a given radiosonde. This is done to essentially ensure at least one collocated observation for a given satellite and radiosonde.

Reference radiosondes from NPROVS+ used in this report include GRUAN data [9], [10] from over ten current sites across the globe, with plans for future expansion. The JPSS-funded dedicated radiosondes are mainly from the Department of Energy Atmospheric Radiation Measurement (ARM) sites of Northern Slope of Alaska (NSA), Southern Great Plains, OK (SGP), and East North Atlantic in the Azores (ENA) [13]. Special radiosondes taken during ship campaigns including

1) three trans-Atlantic aerosols and ocean science expeditions (AEROSE) campaigns (January–February 2013, November–December 2013, and November–December 2015), conducted within dust-contaminated regimes downwind of the Saharan desert [14], [15],

2) the CalWater/ARM cloud aerosol precipitation experiment over the eastern North Pacific from January to February 2015 [15], and

3) the El Nino rapid response experiment spanning the central and eastern tropical Pacific during February–March 2016 [15] are also included.

Nondedicated radiosondes from other field campaigns that were able to be synchronized with S-NPP overpass, including the US National Weather Service (NWS) Sterling test-bed facility and from ARM mobile sites including the two sites located in Antarctica are also collected in the reference dataset.

Vaisala RS92 radiosondes have been primary radiosonde type launched at the sites and campaigns mentioned above. Radiosondes from GRUAN stations are processed using the GRUAN reference processing software [10], which includes traceable uncertainty estimates for each of the profiles and levels. The majority of the data from NSA and SGP and data from the two 2013 AEROSE campaigns have also been GRUAN processed. Collocations of the reference radiosonde observation (RAOB) with NUCAPS for January 2013 through May 2016 accumulated by NPROVS+ are used in the study.

Conventional RAOBs from NPROVS used in this report are the same set assimilated operationally by NOAA National Center for Environmental Prediction (NCEP). Observations rejected by the NCEP assimilation system or having temperature difference 15 K from the NCEP background, as well as those with a vertical extent <5 km or a vertical gap >4 km, are not used. There have been dozens of radiosonde types launched in the conventional network, and the Vaisala RS92 has become the most widely used sonde type (accounting for ~30% of global launches) with the Vaisala RS41 gradually replacing the Vaisala RS92 starting in 2014. Measurements from the RS41 are reported to have improvements over the RS92, particularly for water vapor [17]. Collocations of conventional Vaisala RS92 and RS41 radiosonde data with NUCAPS for the period September 2015 to April 2016 are used in this study.

Consistent with the AIRS validation and statistical computation approach [8], [12], the NUCAPS-minus-RAOB vertical statistics [i.e., bias, root-mean-square error (rms)] computed in this paper are at ~1-km coarse layer for temperature and ~2-km coarse layer for water vapor. Note, the statistics for water vapor are in mixing ratio (MR, g/kg) percent differences (i.e., 100 NUCAPS-minus-RAOB divided by RAOB) weighted by RAOB MR layer amount.

III. Analysis of Uncertainties Involved in Using Satellite-RAOB Collocations for Assessment

A. *Temporal and Spatial Mismatch*

Global collocations of conventional radiosonde and NUCAPS IASI soundings which passed QC for the period 2010–2013 were used to estimate the mismatch impact. During this 3-y period, the retrieval algorithm remained unchanged resulting in large samples and high statistical confidence.

As shown in Fig. 1, the temperature rms differences increase with time mismatch and the largest differences are near the surface [in the planetary boundary layer (PBL)], where the rms increases by 0.12 K/ h. Similar is true for the water vapor mixing ratio (WVMR) rms difference changes with time mismatch but the rms differences peak at the midtropopshere (400 hPa), where the rms difference increases by 2.5%/h. This analysis justifies the importance of radiosonde launch being synchronized with satellite overpass, as have been conducted in the JPSS-funded ARM sites and special field campaigns (i.e., dedicated radiosondes).

Similar analysis was also done for distance mismatch impact, which indicates the change of rms difference with every 25 km increment in mismatch (figures not shown). Temperature rms error does not seem to change much with the mismatch throughout most of the profile, but the WVMR rms error shows a slight increase over 50 km particularly around the midtroposphere. Note that 51% (92%) of IASI-RAOB collocations are within 25 (50) km, limiting the range of the distance mismatch sampling dataset. Also, NUCAPS IASI retrievals are generated at 2 × 2 field-of-regard (FOR) with NUCAPS S-NPP

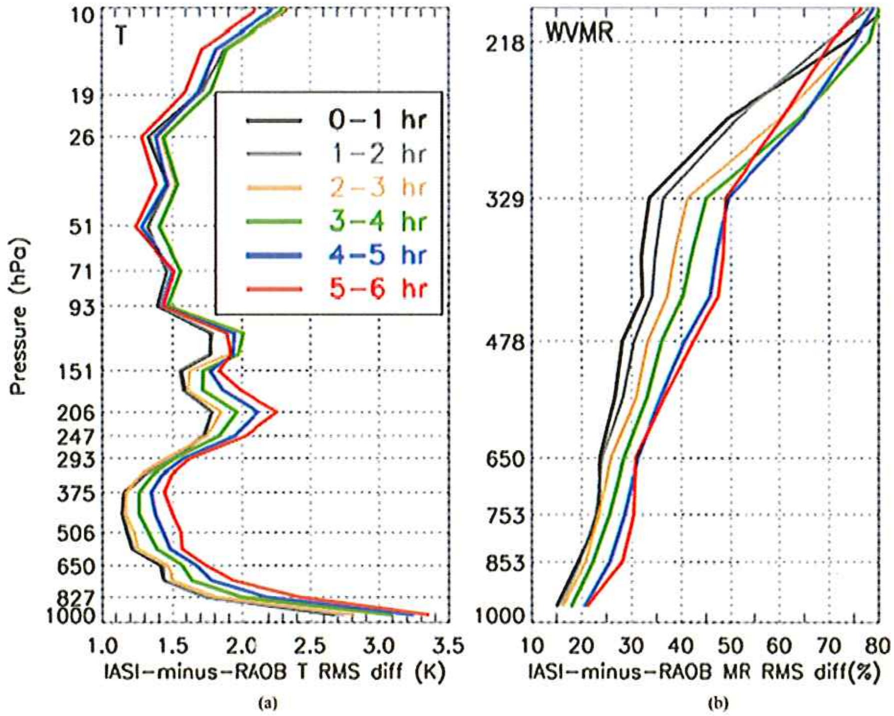


Fig. 1. Changes of satellite-minus-radiosonde profile root-mean-square (rms) difference with 1 h increment in time mismatch between radiosonde launch and satellite overpass. (a) Temperature (T) rms and (b) water vapor mixing ratio (WVMR) percent rms. Three years (2010–2012) of global collocations (506, 354) of NOAA IASI IR+MW retrivals with conventional radiosonde observations (RAOBs) are used to compute the statistics.

at 3 × 3 FOR, both at approximately 50 km horizontal resolution in nadir, making the spatial variability analysis particularly within 50 km challenging.

B. Radiosonde Measurement Accuracy

Radiosonde measurements are generally capable of delineating both small- and large-scale atmospheric structures, which along with their routine availability make them a desirable correlative datasets for satellite data cal/val. However, systematic errors of various proportions are present in the various radiosonde instrument types, including Vaisala RS92, which typically show a radiation-induced warm bias in the upper troposphere and lower stratosphere (UTLS) [18] and dry bias in relatively dry (and cold) environment [19], [20]. Such systematic errors, when present in the validation datasets, could skew the perceived satellite product performance, making the satellite products look artificially worse (or better).

For example, Fig. 2 shows the NUCAPS-minus-RAOB bias differences for daytime versus nighttime collocations of conventional radiosonde. The daytime results show a systematic "cooling" of ~0.3 K in the UTLS compared to the nighttime for NUCAPS, however, this likely reflects the warm bias in daytime radiosondes [18]. Similarly, the perceived "wet" bias shown in Fig. 3 (left) comparing global collocations of Vaisala RS92 radiosonde and NUCAPS water vapor profiles could reflect the dry bias problem in the Vaisala RS92 observations.

Note, however, that the accuracy issue we discuss here is primarily for conventional radiosondes. The GRUAN-processed radiosondes are expected to be more accurate [22], [23], but an

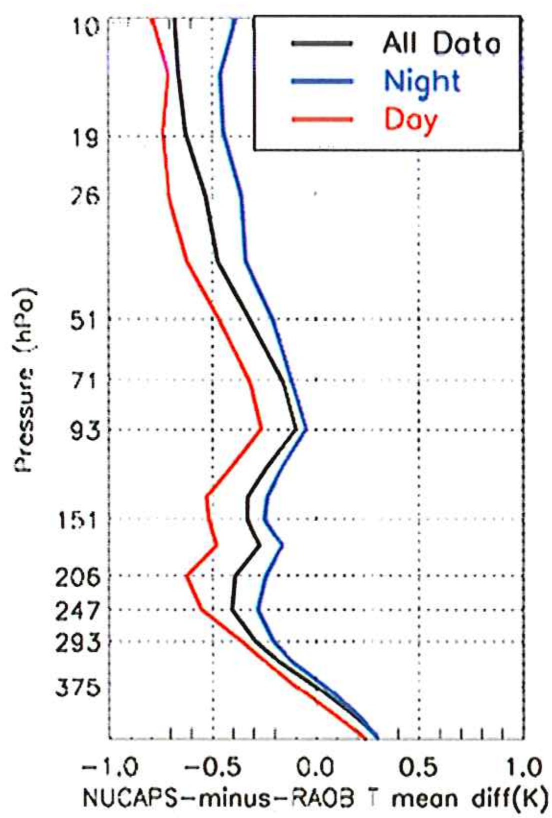


Fig. 2. NUCAPS-minus-RAOB temperature difference for all data, night and day. Collocations within 1 h and 50 km of global conventional RAOBs with NUCAPS (S-NPP) are used. Collocation sample is ~10 100 for night, ~6200 for day, and 20 200 for all. Day and night are defined by the radiosonde launch time.

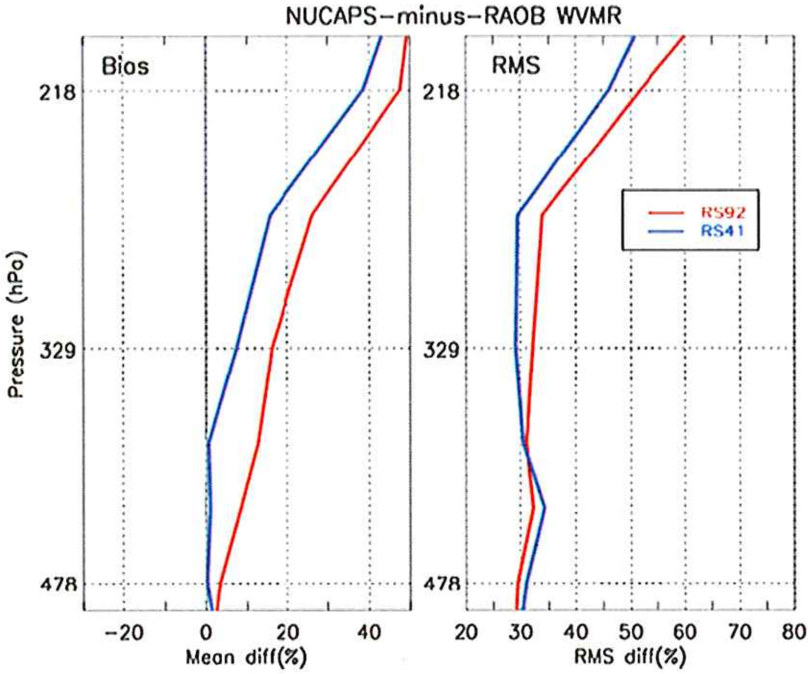


Fig. 3. NUCAPS-minus-RAOB WVMR percent difference computed using global collocations of NUCAPS with conventional Vaisala RS92 and RS41. (Left) bias and (right) rms. The collocations are within 1 h and 50 km. The collocation sample is 6641 for Vaisala RS92 and 1810 for Vaisala RS41.

assessment quantifying the impact of this improvement within satellite product cal/val is a challenge when considering the relative sparseness of GRUAN-processed data at different regions or climate regimes. Meanwhile, Fig. 3 (right) indicates that for Vaisala RS41, due to its improvement in water vapor measurement over Vaisala RS92 [17], the perceived NUCAPS WVMR bias and rms error are reduced 10% and 5%, respectively, in the upper troposphere compared to Vaisala RS92. However, a large difference between NUCAPS and the Vaisala RS41 is still present in the upper troposphere (see Fig. 3). It is not clear whether this is due to NUCAPS being too wet? Further understanding of these issues in order to qualify radiosonde and satellite performance is needed to better serve the satellite data cal/val and climate research community.

C. *Vertical Resolution Inconsistency*

Satellite sounders tend to have limited vertical (2.5 km or more) resolutions which further degrade over altitude layers where thermal lapse rates are small, nonmonotonic and for which the horizontal variations can be highly variable. This includes the PBL and tropopause [21]. Temperature inversion in the PBL, often occurring as surface-based inversion or capping inversion associated with air subsidence at the top of the PBL, is used as an example to illustrate the impact of NUCAPS versus radiosonde vertical resolution differences on the NUCAPS rms error and overall perceived performance.

Fig. 4 shows the NUCAPS-minus-RAOB rms difference for cases in which the radiosonde showed a surface inversion or not. Cases exhibiting inversions show an increased rms error of about 1K highly restricted to the surface. Temperature inversions are defined as increasing temperature with height in the surface layer with the inversion depth at least 300 m. As pointed out

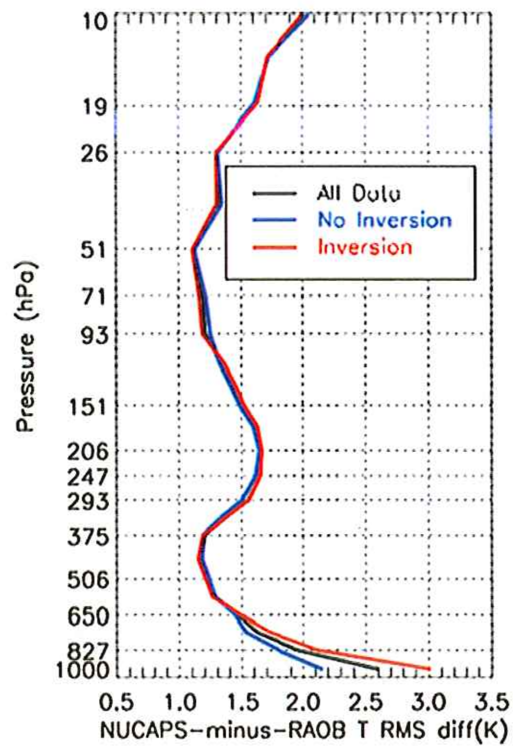


Fig. 4. NUCAPS-minus-RAOB temperature rms difference for all data, RAOBs with "no inversion" and "inversion." See text for the definition of inversion. NUCAPS (S-NPP) collocations within 1 h and 50 km with global conventional RAOBs are used. The collocation sample is ~10 500 for "no inversion," ~13 500 for "inversion," and ~24 000 for all data.

in Section II, the vertical statistics in Fig. 4 are computed over 1 km coarse layer. Although the layer averaging reduces the magnitude of rms difference (see also [12]), it is not enough

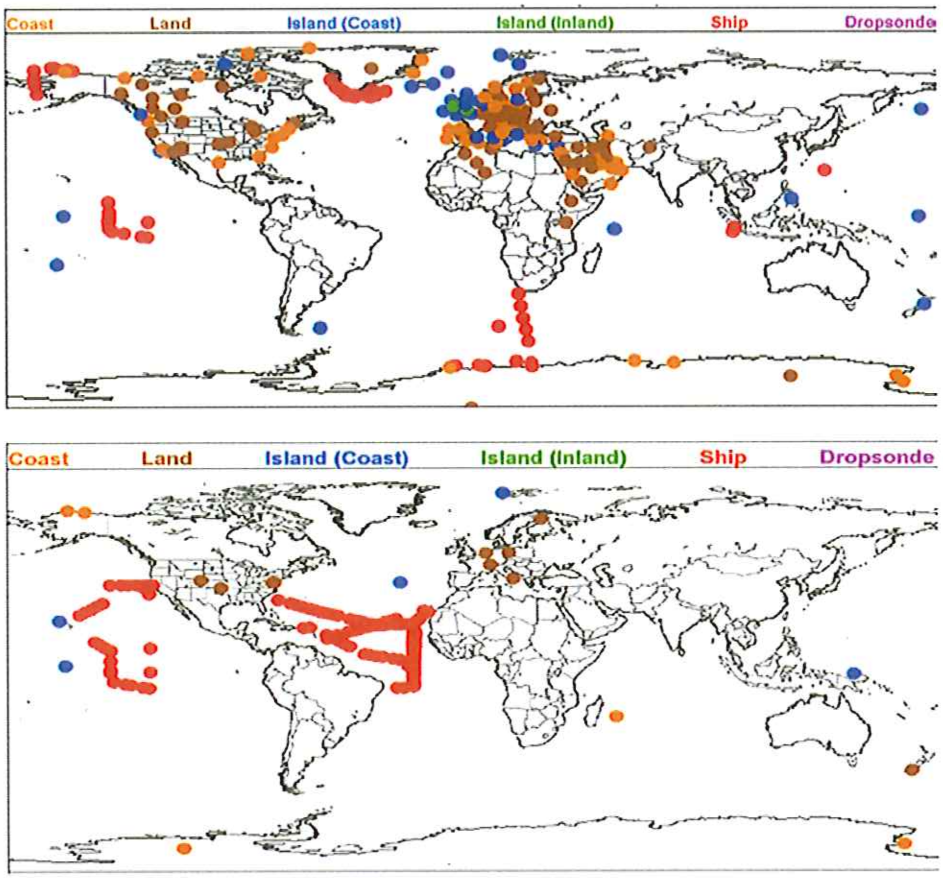


Fig. 5. Spatial distribution of NUCAPS and RAOB collocations (within 1 h and 50 km) denoted by circles. Different colors for different terrain types as indicated on the map legend. (a) Collocations with conventional RAOBs and (b) collocations with reference (GRUAN and dedicated) RAOBs.

to average out the intrinsic radiosonde versus satellite vertical resolution difference.

IV. NUCAPS Retrieval Assessment Results

This section provides an assessment of the NUCAPS soundings for S-NPP in the context of issues discussed in the previous section. Temporal and spatial mismatch impacts on the assessments are mitigated by restricting collocations of NUCAPS retrieval with radiosondes to within 1 h and 50 km. Only Vaisala RS92 and Vaisala RS41 instrument types from the conventional observing network and Vaisala RS92 from the reference data are used.

Fig. 5 shows the global distributions of conventional (top) and reference (bottom) radiosondes, used for the NUCAPS global assessment. For conventional RAOBs, NPROVS, we obtain ~14 000 collocations globally, of which 255 are over sea covering a 6-month period; for reference radiosondes, NPROVS+, we obtain ~4200 collocations of which 167 are at sea during a 3-year period (see Section II). As can be seen, the global distribution of the collocations from the conventional network (NPROVS) appears more robust than for the reference observations (NPROVS+). However, as shown later, despite these differences, the respective statistical analysis shows a fairly consistent NUCAPS performance. This suggests that each network constitutes a fairly consistent global representation in the context of the NUCAPS product performance in a global context.

Next, statistical analyses of the NUCAPS retrievals are conducted using global (sea + land) data and sea-only data, to evaluate their contrast. This is followed by using data at individual sites within different climate regimes across the globe to assess regional differences. The JPSS level 1 specified requirements for temperature and water vapor retrievals [Source: JPSS program level 1 requirements supplement – Final, Version 2.10, 25 June 2014, NOAA/NESDIS], specifically defined as a global target parameter, are indicated on each of the plots in Figs. 6–10. Technically, global performance assessment is required to meet these specifications for a given product to be unconditionally approved for operational implementation and distribution.

A. Global Versus Sea

Fig. 6(a) and (b) shows NUCAPS-minus-RAOB bias and rms error for conventional versus reference networks. As can be seen, the patterns of bias and rms error of global versus sea shown in using conventional [see Fig. 6(a)] versus reference [see Fig. 6(b)] are overall similar despite the spatial representation differences of each network. The temperature bias is generally within 0.5 K of RAOB throughout most of the atmosphere. Daytime warm bias in RAOB discussed in Section III-A could be

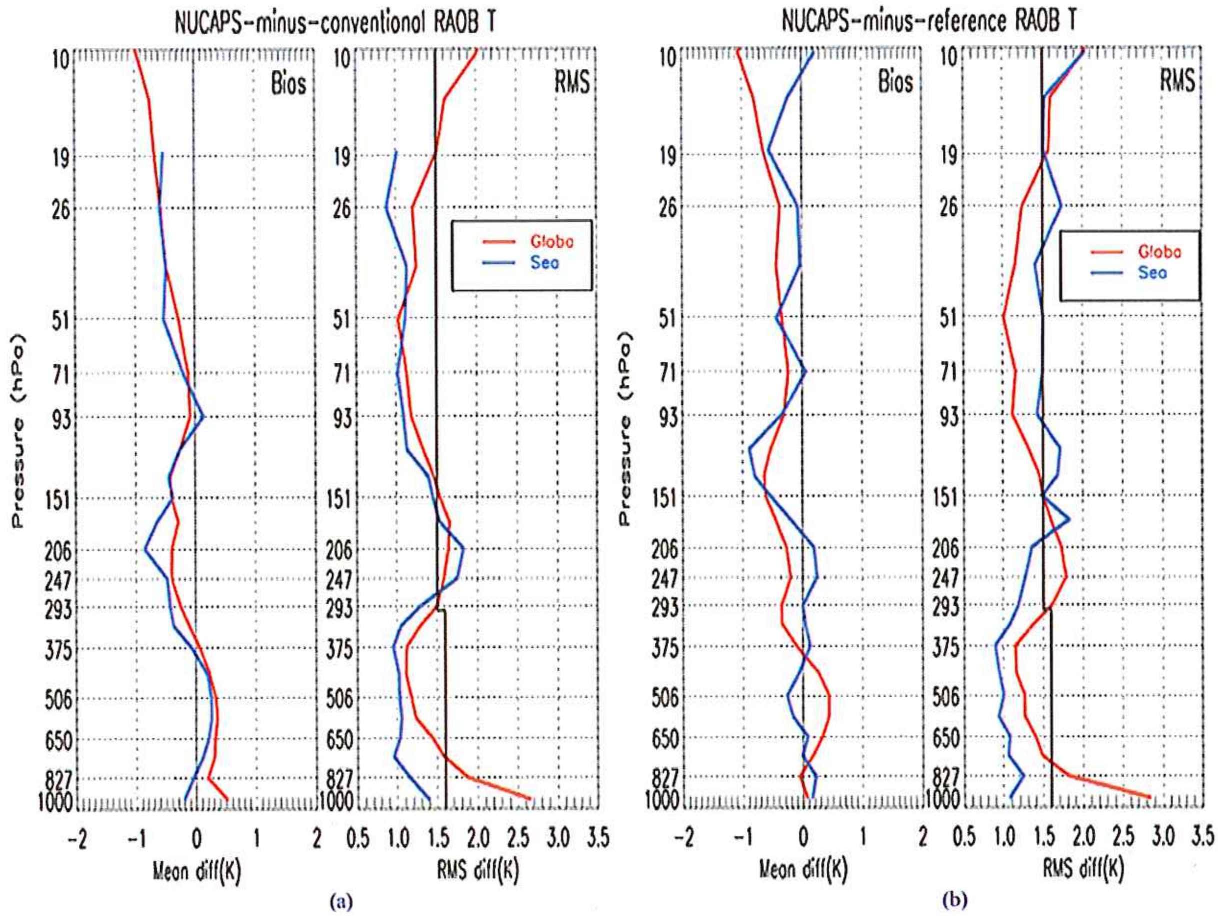


Fig. 6. Bias and rms difference of NUCAPS temperature retrieval versus conventional (a) and reference (b) RAOBs collocations within 1 h and 50 km from global and sea only used. The sample of collocations with conventional RAOB is 8881 for global, and 101 for sea, and the sample of collocations with reference RAOB is 3074 for global and 167 for sea. Vertical lines on the rms plots denote the JPSS level 1 specification requirements.

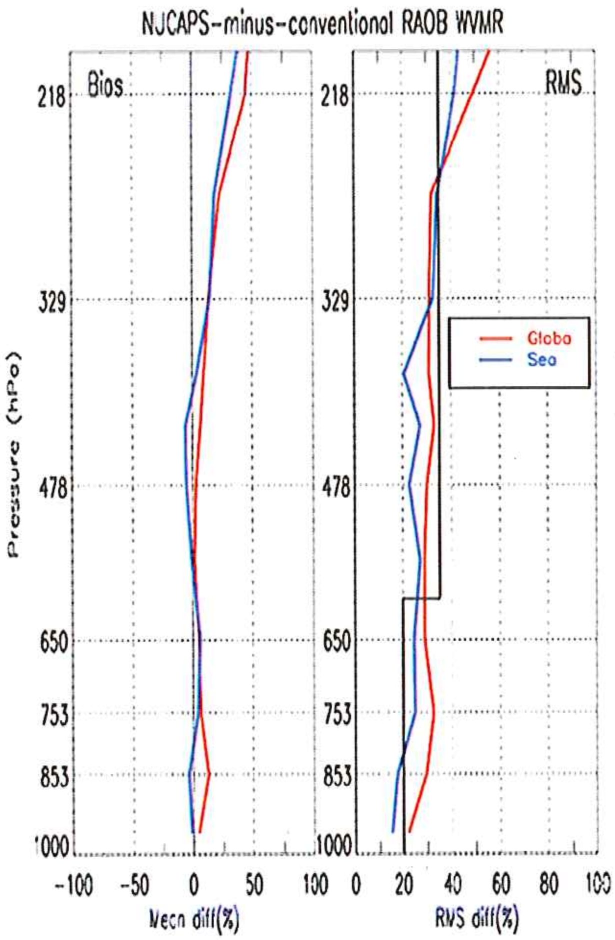
contributing to the UTLS cooling bias in the NUCAPS data seen for both networks. For conventional data, the sea rms error is smaller than the global rms error particularly over the troposphere and stratosphere. For reference data, the rms error for sea is smaller than for the global data below the troposphere, but the sea rms error appears to be greater than the global data by 0.5 K at the altitudes above 200 hPa. Except at the PBL and around the tropopause, overall, temperature rms errors are within or close to the JPSS requirements for both conventional and reference data, in general agreement with the reported JPSS validation results for the S-NPP NUCAPS temperature profiles [16].

The corresponding NUCAPS WVMR statistics shown in Fig. 7 indicate good consistency to the radiosonde data in the low-mid troposphere for global and particularly for sea, and for both conventional and reference data. The "wet" bias in the upper troposphere, smaller in sea than in global data, could partly reflect the radiosonde dry bias issue as discussed in Section III-B. The NUCAPS WVMR rms differences for sea evaluated using both conventional and reference data are close to or within the JPSS requirements for the low-mid troposphere. The rms errors for global are within the JPSS requirements at the altitudes of around 500–300 hPa (in agreement with the reported JPSS validation results for the S-NPP NUCAPS moisture profile EDR [16]), but appear to fall outside of JPSS requirements between 850 and 500 hPa. The reason for this remains unclear but could be related to increased water vapor variability, both spatially and temporally, in the low-mid troposphere regions. Another factor stems from disproportionate Earth surface area weighting arising from the use of RAOB collocation samples, whereas the JPSS requirements were derived based upon global model simulations [16].

Note, the reference RAOB sea data consist of data from five ship campaigns described in Section II. It was found that (not shown) the NUCAPS temperature and water vapor retrievals perform overall better over the Atlantic campaigns than over the Pacific, most probably due to more dynamic meteorological environments (e.g., moister atmosphere and stronger convection) and stronger spatial variability over the latter regions.

B. Individual Sites

We now examine NUCAPS temperature retrieval performance at individual sites. We forgo water vapor as greater understanding of the accuracy of radiosonde water vapor is still needed, particularly in the UTLS and/or cold environment, as discussed earlier in the paper.



(a) (b)

Fig. 7. Sample as Fig. 6 but for WVMR percent difference.

1) Beltsville and Sterling Sites: Fig. 8 shows NUCAPS-minus-RAOB bias and rms differences from the Beltsville, Maryland GRUAN station, and US NWS operational and test site facility at Sterling, Virginia. These two sites, 83-km apart, provide subsets of coordinated S-NPP synchronized launches of Vaisala RS92 radiosondes on an approximate weekly basis. Despite the sample difference (Sterling did not begin synchronized launches until early in 2016), the rms errors for these two sites are similar and both well within the JPSS global requirements throughout the atmosphere except in vicinity of the tropopause and PBL for reasons as discussed in Section III-C.

2) Three ARM Sites: Fig. 9 shows NUCAPS-minus-RAOB bias and rms differences from the three ARM sites, SGP, NSA, and ENA. Each represents significantly different climate regimes, as demonstrated in the relatively high differences among the curves. Strong and frequent near-surface temperature inversion occurrence at NSA contributes to the positive bias of over 1K and the rms error of over 2 K in the lower troposphere. The tropopause at ENA is found to be higher in altitude and sharper than those at the other two sites, making the bias and rms error around the tropopause at ENA greater than at the other two sites. Overall, NUCAPS retrievals have the best agreement with RAOBs at the ENA site given the more uniform marine subtropical environment. Correspondingly, the retrievals have increasingly more difficulty at the SGP and NSA sites as we move to more variability midlatitude and polar land-based sites.

3) Three Polar Sites: Fig. 10 shows NUCAPS-minus-RAOB bias and rms differences from the polar GRUAN site Ny-Alesund, Norway along with WAIS and McMurdo which are two ARM mobile sites deployed under the ARM West Antarctic radiation experiment (AWARE) [24]. The AWARE sites are approximately 1600 km apart with the experiment mission to seek a better understanding of the cloud and aerosol effects on radiation budget and climate change over Antarctica. Radiosondes are being launched at the two ARM sites during southern hemisphere summer beginning in 2015 and continuing to 2016. Although the rms differences are fairly similar for these three polar sites, sharp difference in bias is noted related to the fact that the AWARE data were restricted to the Antarctic summer period. The systematic cold bias, ∼1.0 K in the upper troposphere shown in the NUCAPS temperature at WAIS and McMurdo, which appears greater than at other two polar sites, Ny-Alesund and NSA (see Fig. 8), is also likely related to the seasonal difference in observations. Nevertheless, the temperature rms errors from these three polar sites are on a par with the JPSS global

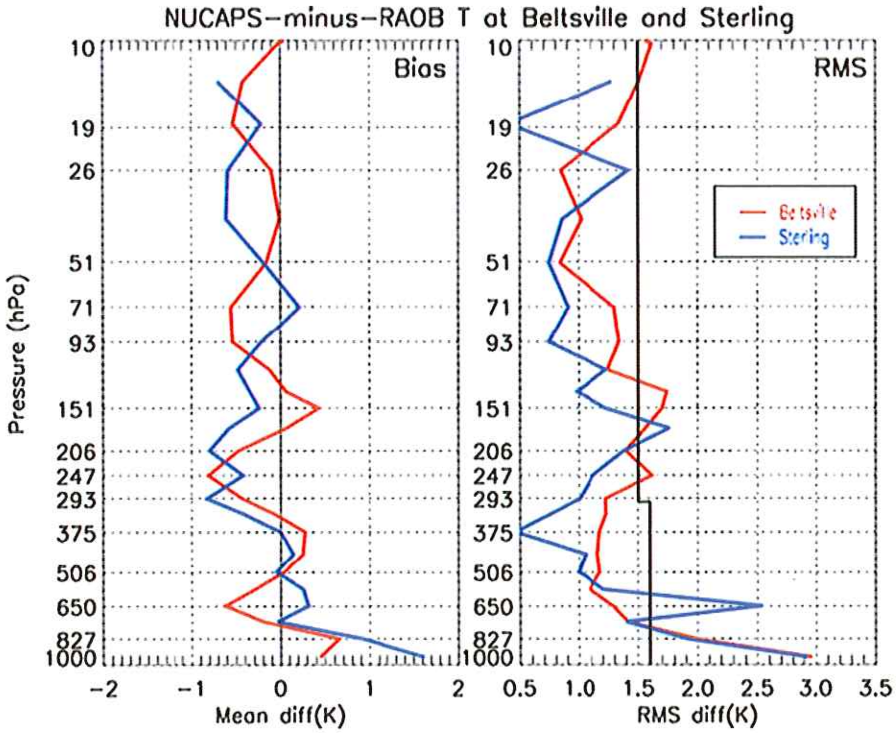


Fig. 8. Bias and rms difference of NUCAPS temperature retrievals at Beltsville, Maryland (39.0 °N, 76.9 °W), and Sterling, Virgina (39.0 °N, 77.5 °W). Collocations with 90 dedicated radiosondes at Beltsville and 8 dedicated radiosondes at Sterling are used to compute the statistics. Vertical lines on the rms plot denote the JPSS level specification requirements.

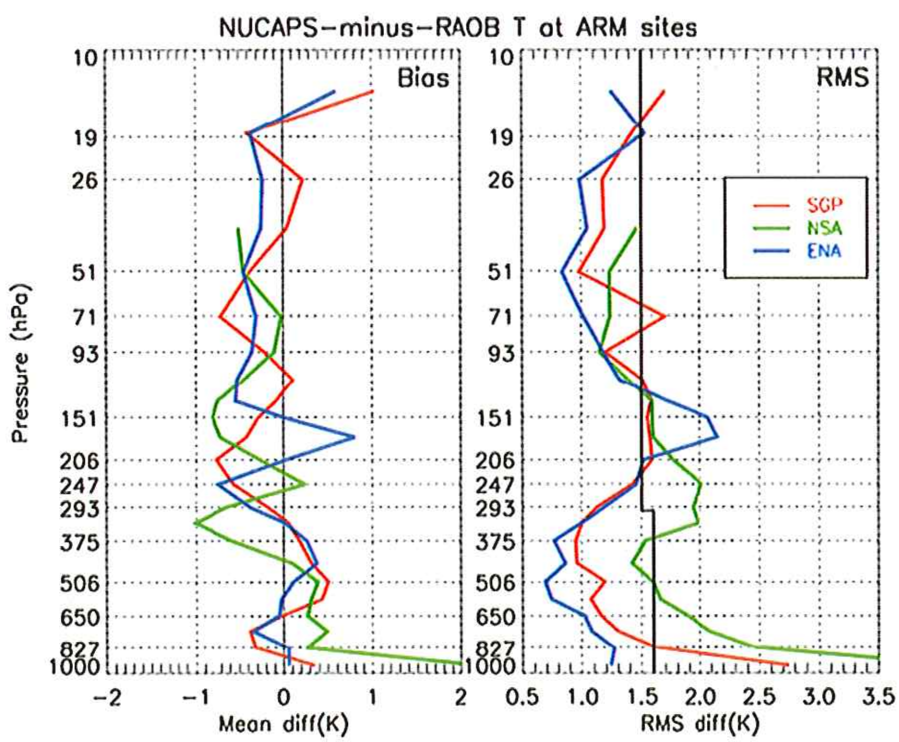


Fig. 9. Same as Fig. 8 but for three ARM sites: SGP (36.6 °N, 97.5 °W), NSA (71.3 °N, 156.6 °W), and ENA (39.1 °N, 28.0 °W). Collocations with 367 dedicated radiosondes at SGP, 341 at NSA, and 73 at ENA are used to compute the statistics.

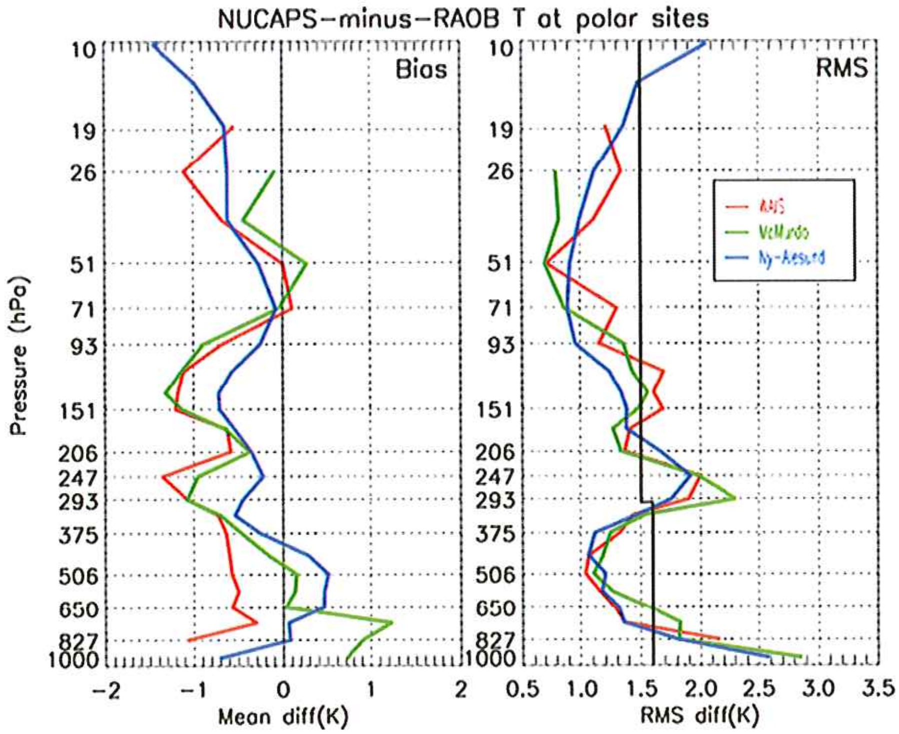


Fig. 10. Same as Fig. 8 but for Ny-Alesund, Norway (78.9 °N , 11.9 °E), WAIS (79.5 °S, 112.1 °W), and McMurdo (77.9 °S, 166.7 °E). Collocations with 398 radiosondes at Ny-Alesund, 30 at WAIS, and 28 at McMurdo are used to compute the statistics.

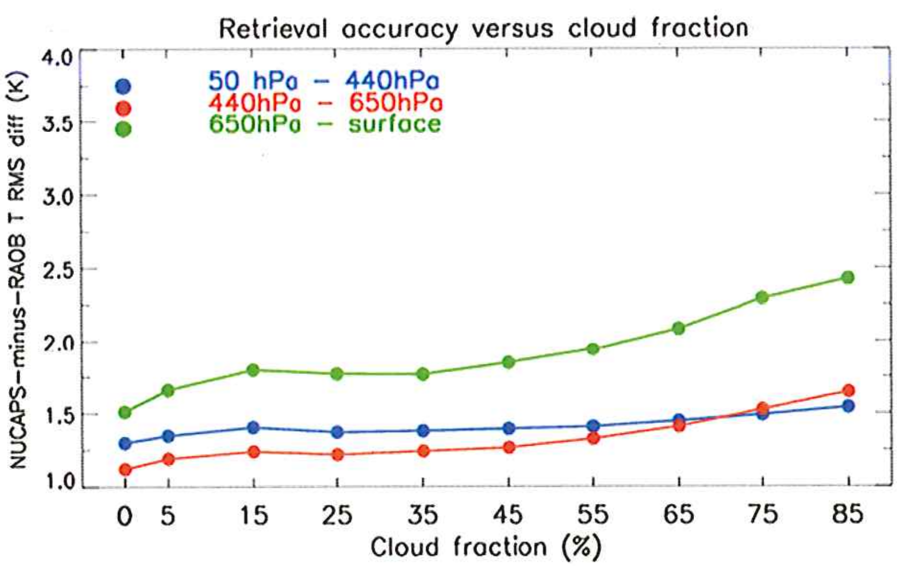


Fig. 11. Variations of NUCAPS-minus-RAOB T rms difference with NUCAPS effective cloud fraction for the lower, middle, and upper tropospheric layers as designated in the figure legend. Six months of global collocations of NUCAPS with RAOB within 3 h and 50 km (67 150 collocations as the total) are used to compute the statistics. The rms values are divided into bins of 10% cloud fraction intervals centered from 5% to 85%. The 0% cloud fraction bin is separate from the 5% bin, which covers cloud fraction from >0% to 10%.

requirements except the lower troposphere and the tropopause as expected and observed from other sites in this study.

V. Discussion and Summary

The NUCAPS IR+MW profiles evaluated in the work were produced with effective cloud fraction up to 80% at the 3 × 3 FOR via cloud clearing process, one of the critical steps in the sounding retrieval algorithms. Different approaches are available to conduct cloud clearing [8], [24], and their ultimate effect is to estimate the radiance for cloudy condition as if no clouds were in the scene, with the resulting cloud-cleared radianes being used to retrieve the atmospheric profiles.

The cloud clearing process and its accompanied noise amplification (the ratio of cloud-cleared random error to the error in a single CrIS FOV) play a major role in determining the accuracy of retrieval [8]. We thus expect the uncertainty in the retrievals to have sensitivity to clouds [8], [25].

Fig. 11 shows the NUCAPS IR+MW temperature rms difference between retrieved 1 km tropospheric layer mean temperatures and the collocated radiosonde data for all accepted cases as a function of retrieved effective cloud fraction. Satellite-RAOB collocations for all radiosonde types are used for the analysis in order to gain enough samples. Agreement degrades with increasing cloud cover, but only slowly. This basically indicates that NUCAPS cloud-clearing methodology is effective. The largest errors are in the two lowest layers in the atmosphere, at moderate to high cloud faction, where the percentage acceptance rate is low (e.g., 4.7% for cloud fraction of 80%).

To summarize, the NUCAPS S-NPP CrIS/ATMS sounding products were assessed using NPROVS-collocated (within 1 h and 50 km) reference (i.e., GRUAN and satellite synchronized dedicated, ~4200) and conventional (~14 000) radiosonde observations. Bias and rms errors of the retrievals on a global average and at individual sites with representative climate regimes indicate that the NUCAPS temperature and water vapor retrievals are performing within the JPSS specification except in cases where the sensor cannot resolve the smaller scale vertical structures. Globally, relative to radiosonde data, the temperature retrieval biases are within about 0.5 K from surface up to the lower stratosphere and the water vapor retrieval biases are within 20% up to 400 hPa.

Caution is needed using radiosonde data as the truth for satellite sounding products assessment. The satellite retrieval rms error is sensitive to the time mismatch in radiosonde launch and satellite overpass, particularly over the lower troposphere for temperature and around midtroposphere for water vapor. The vertical resolution differences between the satellite retrieval (sensor) and radiosonde data are also evident (i.e., reflected as large rms errors) in ~1-km coarse averaging statistics in the vicinity of PBL and tropopause. Further understanding of the accuracy of radiosonde water vapor measurements (dry bias) in the UTLS, evidenced by a consistent moist bias in NUCAPS water vapor profiles aloft, is clearly needed.

Acknowledgment

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