PRE-LAUNCH PERFORMANCE OF THE ADVANCED TECHNOLOGY MICROWAVE SOUNDER (ATMS) ON THE JOINT POLAR SATELLITE SYSTEM-2 SATELLITE (JPSS-2)

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ABSTRACT

The Advanced Technology Microwave Sounder (ATMS) is a satellite-based microwave radiometer that provides temperature and humidity sounding observations from low Earth orbit. The instrument utilizes 22 channels that cover a frequency range of 23 to 183 GHz. The first ATMS instrument was launched in 2011 on the Suomi National Polar-orbiting Partnership (S-NPP) satellite and the second ATMS was launched in 2017 on the Joint Polar Satellite System-1 (JPSS-1) satellite (now NOAA-20); both on-orbit ATMS instruments are currently operational. This paper will describe the pre-launch performance of the third ATMS instrument, designated for the JPSS-2 satellite, during ground testing and calibration.

Index Terms— calibration, microwave radiometer, Advanced Technology Microwave Sounder (ATMS), Joint Polar Satellite System (JPSS)

1. INTRODUCTION

The Advanced Technology Microwave Sounder (ATMS) is built by Northrop Grumman for NASA. Microwave sounders provide the highest-impact observations ingested by major numerical weather prediction (NWP) forecast models. ATMS combines and improves upon the capabilities of the previous-generation sounders: the Advanced Microwave Sound Units (AMSU-A and AMSU-B) and Microwave Humidity Sounder (MHS).

The JPSS-2 ATMS is the third iteration of the ATMS instrument. The first ATMS instrument was launched in 2011 on the Suomi National Polar-orbiting Partnership (S-NPP) satellite and the second ATMS was launched in 2017 on the Joint Polar Satellite System-1 (JPSS-1) satellite (now known as NOAA-20); both on-orbit ATMS instruments are currently operational. S-NPP ATMS pre-launch performance and calibration are documented in [1] and [2]. Pre-launch performance of the JPSS-1 ATMS is detailed in [3]. An image of the JPSS-2 ATMS instrument is shown in Figure 1.

Figure 1: JPSS-2 ATMS Instrument (Photo courtesy of Northrop Grumman in Azusa, CA)

The 22 channels of the ATMS instrument enable data collection in the K, Ka, V, W, and G bands. The instrument contains two antenna apertures: one for the K, Ka, and V bands and the other for the W and G bands.

The pre-launch performance described in this paper is characterized from thermal vacuum (TVAC) and antenna testing performed by the instrument vendor Northrop Grumman. Parameters characterized include Noise Equivalent Delta Temperature (NEDT), striping index, noise power spectral density, gain stability (ΔG/G), inter-channel noise correlation, nonlinearity, residual nonlinearity, accuracy, dynamic range, and hysteresis. Antenna pattern characteristics such as beam pointing error, beam width and beam efficiency are also evaluated. This paper will cover a subset of the above listed parameters.

2. DATA COLLECTION METHODOLOGY

This section provides a high-level overview of the TVAC calibration and antenna testing activities performed to generate data for instrument characterization. Note that TVAC calibration is one phase of the overall TVAC testing campaign for the instrument.

2.1. Thermal Vacuum (TVAC) Testing

The TVAC setup, procedure, and analytical processes are similar to those described in [1][3], summarized below. The ATMS instrument and associated ground support equipment (GSE) are placed inside the TVAC chamber with electrical pass-throughs for instrument and GSE power and data. The test setup positions two high-emissivity ($\varepsilon > 0.9999$) targets, a cold calibration target (simulating cold space), and a scene target (simulating an Earth-viewing scene), at each of the two ATMS apertures. A target internal to the instrument is used for hot calibration.

The instrument is cycled through three different instrument baseplate temperatures to envelope the expected on-orbit thermal environment of ATMS. At each baseplate temperature the scene target is stepped from the cold target temperature to 330K to characterize the nonlinearity of the instrument. Platinum resistance thermometers (PRTs) are used to monitor the temperature of the instrument and targets.

The ATMS parameters for NEDT, accuracy, nonlinearity, noise power stability, $\Delta G/G$, repeatability, and inter-channel noise correlation are evaluated and compared with the values for ATMSs on S-NPP [1] and NOAA-20 [3].

2.2. Compact Antenna Test Range (CATR)

J2 ATMS antenna pattern tests were conducted in the Compact Antenna Test Range (CATR) at Northrop Grumman's Azusa, CA facility. The main purpose of the tests was to evaluate the antenna performance. For beam pointing testing, the antenna pattern test results were derived at five scan positions of 1, 24, 48, 72, and 96. For beam width and beam efficiency tests, the antenna pattern was measured at scan positions 1, 48, and 96. At each scan position, four antenna pattern cuts were measured at azimuth angles of 0°, 45°, 90°, and 135°, with elevation angle spanning from -180° to +180° for each cut. Using the measured antenna patterns, antenna parameters such as the beam pointing error, beam width, and beam efficiency, are computed. Additionally, other antenna pattern correction parameters are computed such as Earth-view scan bias correction, Earth limb sidelobe, and satellite blockage.

3. RESULTS

This section describes the results of the pre-launch JPSS-2 ATMS characterization efforts. Pre-launch measurements provide the majority of the calibration characterization for ATMS since the conditions are tightly controlled. Results fall into two categories: a) evaluation of JPSS-2 ATMS performance by itself, and b) comparison of important performance parameters across all three builds (S-NPP, JPSS-1, and now JPSS-2). Discussion on the parameters listed in section 2, along with accompanying charts and figures will be provided as part of a). With respect to b), trending across the three builds will be presented.

3.1. Noise Equivalent Delta Temperature (NEDT)

NEDT is a key radiometer sensitivity and noise performance metric. The NEDT of ATMS is characterized during TVAC testing via time domain measurements and the noise power spectrum. Figure 2 shows the time-domain NEDT for all 22 channels, showing consistency among all three ATMS builds to date along with general improvement from S-NPP to JPSS-2. The time-domain NEDT was determined from observations of known calibration targets and interpolating as needed to a common 300K reference temperature for trending purposes. The NEDT determined from noise power spectral density measurements considers both white and 1/f noise contributions.

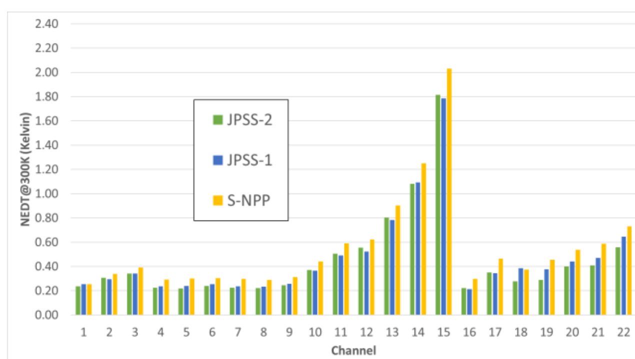

Figure 2: NEDT for all 22 channels for all three ATMS builds to date showing consistency and general improvement.

3.1.1. Striping Index

A calibration artifact was found during early evaluation of the S-NPP ATMS, which was named striping due to its scan-by-scan variation [4][5]. The root cause was identified as increased flicker noise [1]. The Sensor Data Record (SDR) science team chose a new metric to quantify the striping noise called the Striping Index (SI) [6]. SI is defined as the ratio of the along-track variance (sampling period of 8/3 seconds) to cross-track variance (sampling period of the integration period, i.e., 18.18 microseconds) of the observed brightness temperature. Flicker noise causes the scan-to-scan variation (i.e., along-track) to be greater than the intra-scan variation (i.e., cross-track), so a SI greater than one indicates high flicker noise and therefore higher SI. If the channel is dominated by thermal noise (i.e., white), then the ratio should be equal to one. Figure 3 shows the trend of the SI across the three ATMS builds using pre-launch calibration data while viewing a constant-temperature precision calibration target. Typically the decreasing trend in SI is supported by the decreasing flicker noise found in the next section describing the power spectral densities.

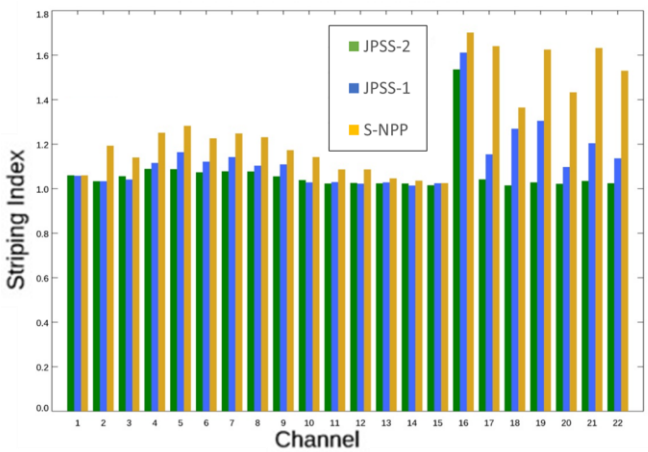

Figure 3: Pre-launch Striping Index of brightness temperature for S-NPP, JPSS-1/NOAA-20, and JPSS-2. Unity indicates noise is primarily thermal/white.

3.1.2. Noise Power Spectral Density

For every instrument built, S-NPP, JPSS-1, & JPSS-2 ATMS, we performed short term gain fluctuation or stability study to compare their on-orbit sensor performance. It is typically in terms of noise power spectral density versus frequency analysis. The noise power consists of two important features: thermal (white) noise and flicker or *1/f* noise, see Fig. 4 below. The 1/f noise is generally used to identify the striping noise in the instrument collected data. Typically the lower flicker noise in Figure 4 is supported by the lower NOAA-20 (JPSS-1) ATMS SI in Figure 3. Similarly, as shown in Figure 4, JPSS-2 has much smaller flicker noise than JPSS-1 and S-NPP. Thus, we expect that JPSS-2 has much less striping noise in the ATMS collected data. Most JPSS-2 channels show improvement over flicker and white noise from JPSS-1 and S-NPP except channels 15 and 16, which show comparable performance. This implies that JPSS-2 will have better on-orbit performance than JPSS-1 and S-NPP.

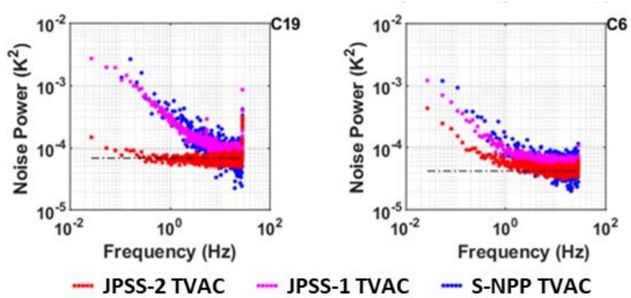

Figure 4: Noise Power Spectral Density for Channels 19 (left) and 6 (right)

3.1.3. Inter-channel Noise Correlation

Previous analyses identified that ATMS noise, i.e., NEDT, had increased inter-channel correlation when compared to heritage sensors like AMSU-A [4][1]. The data assimilation community initially assumed uncorrelated inter-channel error matrices [4], but have since started to account for inter-channel correlation in the data assimilation process [7]. Figure 5 shows the ATMS trend of the brightness temperature inter-channel correlation using pre-launch calibration data. There is a clear decrease in the inter-channel correlation (i.e, off diagonal values) from S-NPP to JPSS 2. This is assumed to be due to the decrease in flicker noise in active components that are shared across channel groupings.

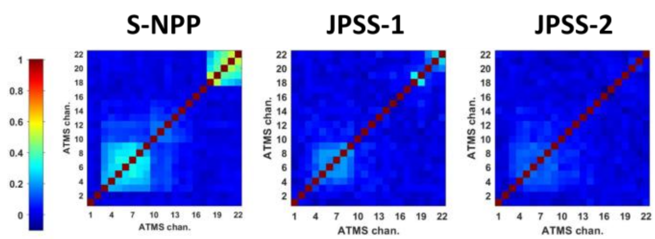

Figure 5: Pre-launch inter-channel correlation coefficients of ATMS noise (i.e., NEDT) across the three builds with same color scale. Ideally, there will be no off-diagonal (i.e., inter-channel) correlation.

3.2. Accuracy

On-orbit radiometric accuracy prediction is obtained through a combination of measured test data, analysis of the test results, and allocations for on-orbit error sources and aging. The radiometric accuracy considers long-term effects and therefore applies over a time scale greater than 24 hours. Nonlinearity uncertainty due to quadratic correction is factored into the radiometric accuracy prediction. The other primary contributors to radiometric accuracy error are hot calibration and cold space observation errors. Hot calibration error sources are due to target emissivity uncertainty, physical temperature measurement uncertainties, thermal gradients within the target, and radiometric leakage when viewing the target. Cold calibration errors are due to the Rayleigh-Jeans approximation for cold space radiation and the antenna sidelobe intercepts with the Earth and the spacecraft. A comparison of the S-NPP, JPSS-1, and JPSS-2 ATMS pre-launch prediction for on-orbit radiometric accuracy is provided in Figure 6. The data for all three instruments have been processed with the latest model for this comparison and are representative of performance at the end of the mission life. The predicted radiometric accuracy is consistent across all ATMS builds and is compliant with the required performance for the design.

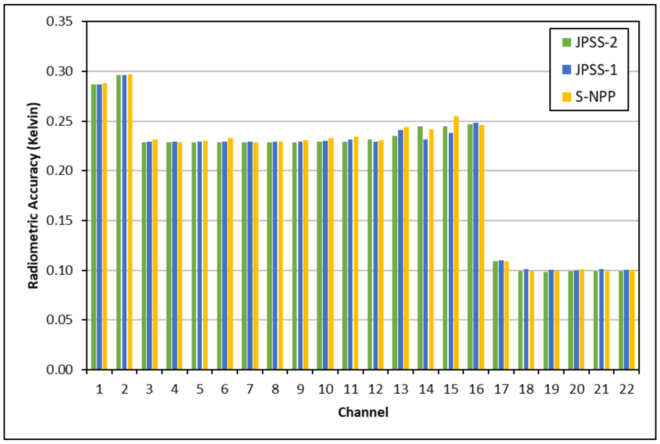

Figure 6: Radiometric Accuracy predicted on orbit performance trended across the JPSS-2, JPSS-1, and S-NPP ATMS shows consistent performance across the various builds.

3.3. Antenna Pattern

The calculated 3dB beam width for JPSS-2 ATMS antenna is 5.4° for K band, 5.5° for Ka band, 2.2° for V band, 2.1° for W band, and 1.2° for G band. The main beam efficiency are above 95% for all channels. For beam pointing accuracy, the instrument-level cross-track/down-track errors are less than 0.1°/0.03° for all bands. Final numbers will be determined after the instrument is mounted on the spacecraft. Analysis results show that for JPSS-2 ATMS, antenna performance meets the requirements. General improvements in the measurement results were observed, especially in G band.

4. CONCLUSION

This paper describes the pre-launch performance evaluation of the JPSS-2 ATMS instrument. Comparisons are also made to the performance of the previous two ATMSs currently in orbit.

The receiver and antenna performance measurements are consistent with those from the S-NPP and NOAA-20 units, with definite improvements to NEDT for channels 18-22, and inter-channel noise correlation. The pre-launch test results also predict lower striping noise. Additional performance tests will be performed once the JPSS-2 ATMS is on-orbit.

5. REFERENCES

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