Lessons Learned from SMAP Radiometer Pre-/Post-launch Calibration

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I. INTRODUCTION

The Soil Moisture Active Passive (SMAP) mission was launched on 31st January 2015 in a 6 AM/ 6 PM sun-synchronous orbit at 685 km altitude to measure soil moisture and free/thaw globally [1]. The passive instrument of SMAP is a fully polarimetric L-band radiometer (1.4GHz) operating with a bandwidth of 24MHz. The radiometer uses a combination of noise-diodes and Dicke-loads for internal calibration with a design similar to that used by the Aquarius or Jason series radiometers [2,3]. Pre-launch calibration activities had been performed since 2012 on the engineering model of the radiometer. Post-launch calibration activities have been performed to fine-tune and validate the results from the pre-launch calibration. The major calibration activities and lessons learned in the past 8 years will be described in the following sections.

II. PRE-LAUNCH CALIBRATION ACTIVITIES AND LESSONS LEARNED

The pre-launch calibration activities include the characterizations of 1) the radiometer's calibration sources (the internal/external noise sources and the reference loads); 2) RF front-end losses; 3) the losses of the antenna assembly (feedhorn, radome and mesh reflector); 4) receiver linearity; 5) Phase imbalance between the V- and H-pol receiving channels. Because the radiometer is also sensitive to its own ambient temperature, the temperature sensitivities of Items 1~3 were also characterized as much as possible.

The block diagram of the radiometer is described in [3]. The external noise source is connected to the coupler right behind the OMT (orthomode transducer), and there are several lossy RF components (OMT, coupler, diplexer, and the cables connecting them) between the Feedhorn and the RFE (radiometer front end). The calibration approach for TOPEX radiometer [4] was used for characterizing the SMAP radiometer calibration sources. Two thermal vacuum (TVAC) tests were performed. The first one was performed with well-known coaxial/external calibration sources to obtain the linear function of the equivalent brightness temperatures (TB) of the radiometer calibration sources to the ambient temperatures of the coupler, diplexer and RFE. The second TVAC test was performed with the OMT and feedhorn installed observing a flat ferrite tile absorber plate to obtain the sensitivity of the TBs of the calibration sources to the physical temperature of OMT and the loss factor of the feedhorn. In this way, the TBs of the calibration sources can be modeled as a linear function of the ambient temperatures of the RF front-end components.

The emissivity of the mesh-reflector was measured by the individual pole. The whole reflector was divided into 96 section and the physical temperature of each section is modeled based on the Sun incidence beta angle. The emissivity of the radome was tested several times using different approaches, but the results didn't match within reasonable range due to the thickness control of the paint on the radome surface. Same as the reflector, there is no temperature sensor for the radome and the physical temperature of the radome is modeled.

The SMAP radiometer directly samples the IF signal instead of using envelop detector. This method significantly increases the linearity of SMAP radiometer receiver. Nonlinearity is less than 0.3 K when the input signal strength is less than 800 K.

The SMAP radiometer is a polarimetric microwave radiometer. Besides the measured antenna temperatures (TAs) of the vertical and horizontal polarizations, their correlation magnitude and phase (represented by using the 3^{rd} and 4^{th} Stokes parameters) are also measured to correct for the impact of the ionosphere, so accurate measurement of the 3^{rd} and 4^{th} Stokes is important for obtaining TBs over the Earth's surface from the measured TAs which are derived from the radiometer output counts by removing the impacts (gain fluctuation, phase imbalance between polarization channels, etc) from the radiometer itself. Besides using the conventional calibration approach to characterize the radiometer's receiver gain and offsets (or the receiving noise temperature), various approaches have been used to characterize the phase imbalance between the V- and H-pol receiving channels. The phase imbalance characterization is very successful during pre-launch and it's validated during post-launch by comparing the derived Faraday rotation angle and modeled Faraday rotation angle over ocean. After this validation, post-launch has only focused on the calibration of V- and H-polarization channels.

III. Post-Launch Calibration Activities and Lesson Learned

The post-launch calibration includes but is not limited to fine-tuning of the calibration parameters starting with initial values obtained from the pre-launch calibration activities. In addition, the characterization of the reflector and radome was limited before launch. Uncertainties existed and they were expected to be characterized or reduced by post-launch calibration after the mesh reflector had been fully deployed and data were available over a long period. Various calibration activities have been performed, and three versions (Versions 3-5) of the radiometer L1B_TB data have been released to the public since 2015. All versions of the L1B_TB data satisfy the requirements on the radiometer even though different calibration approaches are used.

For Version 3, which was released in 2016 [5,6], the temperature sensitivity coefficient of the internal noise source has been fine-tuned to compensate the change of the radiometer ambient temperatures during bake-out period (Apr 6~9, 2015). The radiometer's antenna gain was then calibrated by using a special Cold Sky maneuver at a 180 ° pitch angle with the backlobe observing a transition from ocean to the Amazon rainforest, followed by adjusting the equivalent noise temperature of the internal noise source using the global ocean as the external calibration target. The reflector's loss factor (or emissivity) was untouched.

For Version 4, which was released in 2018 [7,8], L1B data calibration was in 2 steps. First, the reflector loss factor was calibrated by using three independent approaches and different dataset. All three approaches agree within 0.5% for the reflector loss. Approximately additional 1.3% needs to be added to reflector loss factor characterized before launch. The 2^{nd} step is to concurrently retrieve all other three calibration parameters (the corrections to T_{nd}, Tref and the antenna gain) with observations over various calibration targets. In general, the global ocean and the CS are used as the external hot and cold calibration target, respectively. Besides the calibration, ocean wind speed dependent reflected galactic correction is also applied to the correction algorithms to get the Earth's surface TB from the calibrated TA.

For Version 5 which was released in September 2020 [9], all of the calibration parameters for the L1B data were retrieved concurrently. After comparing the performances of using the global ocean or the radiometer's internal reference load as the hot calibration target, the latter is selected. The final decision is mostly due to that 1) the bias in the GMF emissivity model [10] is unknown; and 2) the SMAP SM community prefer smaller TB over land.

The correction to the reflector loss factor for Version 5 data is 1.004 so that the total reflector loss factor is about 1.007. This value should include the loss factor of the radome.

The gain of the SMAP antenna assembly is also calibrated during the post-launch calibration for all of the three released versions. Although the corrections to the gain in all of the 3 released versions are within the expectation (<1%, absolute value), their signs are different. For Version 3, the sign of the correction to the gain is positive which means that the antenna gain should be higher, while for Versions 4 & 5, the sign of the correction is negative which means that the antenna gain should be lower. The positive sign in Version 3 is due to the fact that the calibration of the antenna gain was performed individually and in the first step, so there must be a calibration error in the measured TAs which used the pre-launch calibration results for the internal calibration.

It was found that the SMAP SAR transmitter on/off changes not only the radiometer ambient temperatures but also the measured TA. Evidence shows that the SMAP pre-launch calibration approach works well and the measured TA rise (>1 K) when the SAR transmitter is powered on is due to the SMAP SAR transmitter output noise in the radiometer's working frequency band.

IV. CONCLUSIONS AND DISCUSSIONS

The SMAP radiometer has had 3 released versions of L1B_TB data. The prelaunch calibration has successfully characterized 1) linearity of the receivers; 2) the sensitivity of the equivalent noise temperatures of the internal noise sources to the ambient temperatures of the RF front-end and 3) the phase imbalances between the V- and H-pol receiving channels. The post-launch calibration has successfully decreased the uncertainty from the pre-launch calibration. Among all of the calibration approaches/options tried in the past years, concurrent calibration to retrieve all of the calibration parameters leads to the best performance so far. Further calibration activities are being explored to improve the calibration performance and data quality to benefit science application (e.g. SSS) besides soil moisture.

In addition, wind speed dependent reflected galaxy correction applied to the calibrated TA can result in consistent result of the TB over the Earth's surface and it has been verified over ocean.

REFERENCES

[1] D. Entekhabi et al., "The Soil Moisture Active Passive (SMAP) Mission," *Proc. IEEE*, v98, no. 5, pp. 704-716, May 2010.

[2] J.R. Piepmeier et al., "SMAP Algorithm Theoretical Basis Document: L1B Radiometer Product," SMAP Project, NASA GSFC SMAP-006, NASA Goddard Space Flight Center, Greenbelt, MD. [online]. Available: http://smap.jpl.nasa.gov/files/smap2/L1B_TB_RevA.pdf

[3] J.R. Piepmeier et al., "SMAP L-Band Microwave Radiometer: Instrument Design and First Year on Orbit," *IEEE Trans. Geosci. Remote Sens.,* vol. 55, no. 4, pp. 1954-1966, April 2017. doi: 10.1109/TGRS.2016.2631978

[4] C.S. Ruf et al., "TOPEX/POSEIDON Microwave Radiometer (TMR): I. Instrument description and antenna temperature calibration," *IEEE Trans. Geosci. Remote Sens*., **33**(1), 125-137, 1995.

[5] J. Peng et al., "Soil Moisture Active/Passive (SMAP) L-Band Microwave Radiometer Pre-Launch Calibration", *IEEE Trans. Geosci. Remote Sens.,* vol. 55, no. 9, pp. 5339-5354, Sept. 2017. doi: 10.1109/TGRS.2017.2705342

[6] J.R. Piepmeier et al., "SMAP Project Radiometer Brightness Temperature Calibration for the L1B_TB and L1C_TB Validated Version 3 Data Products".

SMAP Project, Jet Propulsion Laboratory, Pasadena, CA. November 29, 2016. [Online] https://nsidc.org/data/smap/data_versions.

[7] J. Peng et al., "Soil Moisture Active/Passive (SMAP) L-Band Microwave Radiometer Post-Launch Calibration Upgrade," *IEEE J. Sel. Topics Appl. Earth Obs. Remote Sens.,* vol. 12, no. 6, pp. 1647-1657, 2019.

[8] J. Peng et al., "SMAP Radiometer Brightness Temperature Calibration for the L1B_TB, L1C_TB (Version 4), and L1C_TB_E (Version 2) Data Products", SMAP Project, Jet Propulsion Laboratory, Pasadena, CA. June 6, 2018. [Online] https://nsidc.org/data/smap/data_versions.

[9] J. Peng et al., "SMAP Radiometer Brightness Temperature Calibration for the L1B_TB, L1C_TB (Version 5), and L1C_TB_E (Version 3)", Data Products, SMAP Project, Jet Propulsion Laboratory, Pasadena, CA. August 8, 2020 [Online] https://nsidc.org/data/smap/data_versions.

[10] S.H. Yueh et al., "L-Band Passive and Active Microwave Geophysical Model Functions of Ocean Surface Winds and Applications to Aquarius Retrieval," *IEEE Trans. Geosci. Remote Sens.*, v. 51, no. 9, pp.4619–4632, Sept. 2013. doi: 10.1109/TGRS.2013.2266915