Comparison of HY-2B Passive Brightness Temperatures with SSMI/S, GMI, AMSR2 and MWRI in Land Surface

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Abstract. China launched a new marine satellite HaiYang (HY) -2B satellite on October 24, 2018 at 22:57 (UTC time), which provides full-time and all-weather observations with a design life of five years. It can cover 90% of the world's oceans and obtain marine dynamic environment data. The Scanning Microwave Radiometer (SMR) is the main payload onboard the HY-2B, which can provide near-real-time observations. The instrument is a 5-frequency 9-channel microwave observing instrument with the central frequencies set to 6.925, 10.7, 18.7, 23.8, and 37 GHz. Except for 23.8 GHz, which is vertical polarization only, other four frequencies have both vertical and horizontal polarization detection channels. For the past forty years, passive microwave brightness temperature data from the Scanning Multichannel Microwave Radiometer (SMMR), Special Sensor Microwave/Imager (SSM/I), Special Sensor Microwave Imager/Sounder (SSMI/S), Advanced Microwave Scanning Radiometer for Earth Observing System (AMSR-E) and the Microwave Scanning Radiometer 2 (AMSR2), Microwave Radiation Imager (MWRI) and the microwave imager of Global Precipitation Measurement mission (GMI) have provided considerable information on geophysical and climatic research. In order to expand the use of SMR observations on the earth's land surface, in this study, SMR is compared with other on-orbit radiometers (SSMI/S, AMSR2, MWRI and GMI), and is conducted the cross-sensor calibration in land surface, which is critical foundation for the inversion of Earth surface geophysical parameters and climate researches in the near future.

1. Introduction
Recent years, with the development of remote sensing technology, more and more satellites for the earth exploration have been launched into space. Earth observation satellites data hold a lot of information about the earth's climate process [1]. In fact, several types of on-board data have become broad enough in both space and time to provide an important indicator of global change [2].

The outstanding advantage of passive microwave remote sensing data, is its ability to work all day and all weather in comparison with visual and infrared remote sensing. The medium and low frequencies are not affected by clouds, rain and fog. They can work at night and can pass through vegetation, ice and snow and dry sand to obtain near information below the ground, which are widely used in marine research, terrestrial resource surveys and map mapping [1]. Spaceborne passive
microwave sensors play an important role in Earth observation, providing valuable data for inverting various key land surface parameters, such as soil moisture [3], snow depth/snow water equivalent [4-6], sea ice concentration, and precipitable water vapor [7], and studying changes in the Earth's environment in time series [8-10]. Since spaceborne passive microwave sensors have different instrument design characteristics, calibration systems, observation times, and non-overlapping operational records, there is always a slight difference between the luminance temperature data obtained from different radiometers [11]. Therefore, careful cross-comparison and cross-calibration of different radiometer data records is required to ensure reliable, accurate, and consistent observations for consistent geoscience parameter retrieval when long baseline data is required.

Calibration accuracy and consistency over time for instruments are critical performance parameters that directly affect the quality of data products derived from these observations, especially for understanding compulsive factors and predicting climate change consequences [12]. The inter-sensor calibration technique not only provides a practical means of identifying and correcting the relative deviations in the radiation calibration between instruments, but it also bridges the potential data gap between measurement records in critical time series. Cross-platform calibration and validation have been performed for a long time. The Canadian Meteorological Administration's (MSC) assessment of SWE showed that the estimated values obtained from the Scanning Multichannel Microwave Radiometer (SMMR) carried on the Nimbus-7 were systematically and significantly lower than the Special Sensor Microwave/Imager (SSM/I) carried on the Defense Meteorological Satellite Program (DMSP) estimates when the cross-platform brightness temperature adjustment method was not used [13]. Dai et al. developed inter-sensor calibration between SSMI and SSMI/S and found that cross-calibration improved the consistency of China's snow depth and estimated snow area [14]. Jezek et al. compared the SMMR and SSMI passive microwave data and the results indicated that a general anomaly shift between sensors was apparent [15].

The above research results show that the cross calibration has obvious regional characteristics. This paper considers the general applicability of cross-calibration to inversion of terrestrial parameters (such as, soil moisture, snow depth, and snow water equivalent). In order to expand the capabilities of SMR sensors for terrestrial applications, we selected a larger land research area in Eurasia (where the longitude coverage is from 57E to 115E and latitude coverage is from 30N to 65N) to increase the generality of land parameter inversion. We make a land calibration between brightness temperature observations for SMR and the other contemporary sensors (SSMI/S, GMI, AMSR2 and MWRI).

2. Data and Methods

2.1. Datasets
The SMR swath data records are obtained from the National Satellite Ocean Applications Service (NSOAS). Researchers have completed internal calibration and ocean calibration of the SMR radiometer, on the basis of which we conducted land calibration, in order to expand the research and application of Earth's land surface data. The Scanning Microwave Radiometer (SMR) is the main payload onboard the HY-2B, which can provide near-real-time observation records. The instrument is a 5-frequency 9-channel microwave imaging instrument with the central observation frequencies set to 6.925, 10.7, 18.7, 23.8, and 37 GHz. Except 23.8 GHz, which is vertical only, the other frequencies have both vertical and horizontal polarization channels.

The SSMI/S combines the SSMI conically scanning function with the high frequency detection channel. It was first launched on the DMSP F16 satellite in 2003 and the second SSMI/S was launched on the DMSP F17 in 2006. The SSMI/S brightness temperature data are gridded in a common projection- the equal-area scalable earth grid (EASE-Grid) and distributed by NSIDC (https://nsidc.org/).

The GPM core observatory was launched on February 27, 2014 at 18:37 UT in a 65° inclination nonsun-synchronous orbit. GPM focuses on precipitation which is regarded as a critical part of the Earth’s water and energy cycle. The GMI microwave radiometer on the core observatory is a key
component to achieve the scientific goals of GPM with the frequency from 10.65 to 183.31 GHz [16]. The GMI data can be obtained from the Japan Aerospace and Exploration Agency (JAXA).

The AMSR2, as the follow-on instrument, was launched by JAXA on May 18, 2012 to continue the AMSR-E observations [17]. The sensor provides near real-time passive microwave observations for monitoring land, ocean and atmosphere processes and interactions on a global scale with the central frequencies set to 6.925, 7.3, 10.65, 18.7, 23.8, 36.5 and 89.0 GHz. The AMSR2 data can be obtained from the JAXA’s official website http://suzaku.eorc.jaxa.jp/.

The MWRI onboard FY-3C has been in operation since 30 July 2015 in a 98.75° inclination sun-synchronous orbit from the height of 836 km. The instrument is a 5-frequency 10-channel microwave imaging instrument. The MWRI brightness temperature observations can be applied from the official website of the National Satellite Meteorological Center (NSMC) (http://satellite.nsmc.org.cn/).

However, the spatial, temporal and radiation characteristics of different sensors are slightly different. The specific instrument design parameters are shown in Table 1.

### Table 1. Instrument specifications of SMR, SSMI/S, GMI, AMSR2 and MWRI.

| Sensor | Platform | Time series | Orbit inclination (degrees) | Incidence angle (degrees) | Data acquisition | Swath width (km) | Ascending equator crossing local time (hh:mm) |
|--------|----------|-------------|------------------------------|---------------------------|-----------------|------------------|-----------------------------------------------|
| SMR    | HY-2B    | 2018.10.30-99.34 | 53                           | Daily                      | 1600            | 18:00            |
| Channels (GHz): | footprint (length(km)x width(km)) | 6.925: 150 × 90(V&H) | 10.65: 110 × 70(V&H) | 18.7: 60 × 36(V&H) | 23.8: 52 × 30(V) |
|        | (Polarization) | 37: 35 × 20(V&H) | | | |
| SSMI/S | DMSP-F17  | 2008.01.01-98.6 | 53.1                         | Daily                     | 1700            | 17:31            |
| Channels (GHz): | footprint (length(km)x width(km)) | 19.35: 69 × 43(V&H) | 22: 60 × 40(V) | 37:37 × 28(V&H) | 91: 37 × 28(V&H) |
|        | (Polarization) | | | | |
| GMI    | GPM      | 2014.03.01-65 | 52.8                         | Daily                     | 931             | vary             |
| Channels (GHz): | footprint (length(km)x width(km)) | 10.65: 32 × 19(V&H) | 18.7: 18 × 11(V&H) | 23.8: 16 × 10(V) | 36.5: 15 × 9(V&H) |
|        | (Polarization) | 89: 7 × 4(V&H) | 165.5: 6 × 4(V&H) | 183.31 +/-3: 6 × 4(V) | 183.31 +/-7: 6 × 4(V) |
| AMSR2  | GCOM-W1  | 2012.07.02-98.186 | 55                           | Daily                     | 1450            | 13:30            |
| Channels (GHz): | footprint (length(km)x width(km)) | 6.925: 62 × 35(V&H) | 7:3: 62 × 35(V&H) | 10.65: 42 × 24(V&H) | 18.7: 22 × 14(V&H) |
|        | (Polarization) | 23.8: 19 × 11(V&H) | 36.5: 12 × 7(V&H) | 89: 5 × 3(V&H) | |
| MWRI   | FY-3C    | 2015.07.30-98.75 | 45                           | Daily                     | 1400            | 22:10            |
| Channels (GHz): | footprint (length(km)x width(km)) | 10.65: 85 × 51(V&H) | 18.7: 50 × 30(V&H) | 23.8: 45 × 27(V&H) | 36.5: 30 × 18(V&H) |
|        | (Polarization) | 89: 15 × 9(V&H) | | | |

2.2. Methods

The SMR flies at a nominal altitude of 971 km in a sun-synchronous near polar orbit and the orbital period is 104.5 minutes. In this paper, the time series is from October 30, 2018 through December 31, 2018 for the research data available in which period there were no erroneous scans.

The method of standardizing cross-platform data is linear regression to identify the gap of the brightness temperature from different sensors [18]. First, we need to mosaic the SMR swath data to generate two types of gridded data with geographic information. One of the daily averaged data are binned and gridded into 25 km by 25 km pixels for the EASE grid projection format. Another type is
0.25° by 0.25° pixels. Screen out the ascending and descending orbit data in the common research area for data fitting. AS for the GMI data, the data was not divided into ascending and descending orbit, thus we merged the ascending and descending data. The end product is a series of daily maps of global brightness temperatures.

3. Results

3.1. Pairwise comparison
After data pre-processing, we first compare the average deviation of the SMR channels and the corresponding from the other sensors. The specific results are shown in Figure 1 to Figure 4.

![Figure 1](image1.jpg)  
**Figure 1.** Pairwise comparison results for SMR and SSMI/S: (a) the results at the horizontal polarization, (b) the results at the vertical polarization.

![Figure 2](image2.jpg)  
**Figure 2.** Pairwise comparison results for SMR and GMI: (a) the results at the horizontal polarization, (b) the results at the vertical polarization.
**Figure 3.** Pairwise comparison results for SMR and AMSR2: (a) the results at the horizontal polarization, (b) the results at the vertical polarization.

![Pairwise comparison results for SMR and AMSR2](image1)

**Figure 4.** Pairwise comparison results for SMR and MWRI: (a) the results at the horizontal polarization, (b) the results at the vertical polarization.

Scatterplots of the daily brightness temperatures at corresponding channels for SMR and SSMI/S data were plotted respectively (Figure 5). Due to manuscript length limitation, the scatter plot results of SMR compared with the other three sensors are not shown. From the distribution of scatter plots, there is high correlation between corresponding data channels.

![Scatterplots of daily brightness temperatures](image2)
Figure 5. Pairwise comparison results for SMR and SSMI/S, left figures are for ascending data and the right results are for the descending data: (a) (b) 19.35H/18.7H, (c)(d) 19.35V/18.7V, (e)(f) 22V/23.8V, (g)(h) 37H/37H, (i)(k) 37V/37V.

3.2. inter-sensor calibration models in land surface

The SMR radiometer can provide near-real-time brightness temperature to serve the scientific researches and applications. By comparing the results, we found that the SMR data was stable and the data quality was high. The SMR swath data was internal calibrated and ocean calibrated, we provide the cross coefficients in land surface to serve retrievals of the land surface parameters. The results are listed in Table 2.

Table 2. Regression coefficients between two sensors: (a) coefficients between SMR and SSMI/S (X=SMR), (b) coefficients between SMR and GMI (X=SMR and X=GMI), (c) coefficients between SMR and AMSR2 (X=SMR), (d) coefficients between SMR and MWRI (X=SMR)
| (a) | Slope (Ascending) | Intercept(K) (Ascending) | R | Slope (Descending) | Intercept(K) (Descending) | R |
|-----|------------------|--------------------------|---|--------------------|----------------------------|---|
| 19.35/18.7H | 0.9198 | 24.4600 | 0.9609 | 0.9014 | 28.7300 | 0.9227 |
| 19.35/18.7V | 0.9349 | 22.2100 | 0.9640 | 0.9407 | 20.8500 | 0.9399 |
| 22/23.8V | 0.8784 | 34.9100 | 0.9765 | 0.8955 | 30.5100 | 0.9536 |
| 37/37H | 0.9828 | 5.1310 | 0.9829 | 0.9999 | 0.7566 | 0.9678 |
| 37/37V | 0.9765 | 7.8850 | 0.9885 | 1.0020 | 1.5610 | 0.9783 |

| (b) | Slope (X=SMR) | Intercept(K) (X=SMR) | R | Slope (X=GMI) | Intercept(K) (X=GMI) | R |
|-----|---------------|-----------------------|---|---------------|-----------------------|---|
| 10.65/10.7H | 0.9993 | 0.9491 | 0.9688 | 0.8814 | 27.9600 | 0.9688 |
| 10.65/10.7V | 0.9802 | 5.8480 | 0.9742 | 0.9190 | 19.9100 | 0.9742 |
| 18.7/18.7H | 1.0120 | 1.7210 | 0.9728 | 0.8885 | 22.2300 | 0.9728 |
| 18.7/18.7V | 1.0090 | 2.7160 | 0.9824 | 0.9023 | 19.7800 | 0.9824 |
| 23.8/23.8V | 1.0060 | 1.3660 | 0.9849 | 0.9353 | 13.4900 | 0.9849 |
| 36.5/37H | 1.0220 | -6.8000 | 0.9789 | 0.8981 | 25.6600 | 0.9789 |
| 36.5/37V | 1.0050 | -1.7240 | 0.9883 | 0.9490 | 13.1500 | 0.9883 |

| (c) | Slope (Ascending) | Intercept(K) (Ascending) | R | Slope (Descending) | Intercept(K) (Descending) | R |
|-----|------------------|--------------------------|---|--------------------|----------------------------|---|
| 6.925/6.925H | 1.0450 | 6.5230 | 0.9531 | 1.0740 | -1.5080 | 0.9493 |
| 6.925/6.925V | 1.0790 | -0.7665 | 0.9477 | 1.0290 | 10.4900 | 0.9694 |
| 10.7/10.65H | 0.9829 | 11.1600 | 0.9502 | 0.9981 | 5.4940 | 0.9589 |
| 10.7/10.65V | 1.1140 | -21.1300 | 0.9618 | 0.9608 | 16.1400 | 0.9629 |
| 18.7/18.7H | 0.8343 | 50.9100 | 0.8749 | 1.0158 | 5.2620 | 0.9140 |
| 18.7/18.7V | 0.9713 | 20.6600 | 0.9174 | 1.0330 | 1.6420 | 0.9329 |
| 23.8/23.8V | 0.9745 | 18.5100 | 0.9265 | 1.0575 | -4.9500 | 0.9416 |
| 36.5/37H | 0.8972 | 31.9200 | 0.9317 | 0.9817 | 7.2800 | 0.9588 |
| 36.5/37V | 0.9646 | 17.0400 | 0.9332 | 0.9803 | 9.2210 | 0.9612 |

| (d) | Slope (Ascending) | Intercept(K) (Ascending) | R | Slope (Descending) | Intercept(K) (Descending) | R |
|-----|------------------|--------------------------|---|--------------------|----------------------------|---|
| 10.65/10.7H | 1.0170 | -8.6370 | 0.9644 | 0.9543 | 11.4800 | 0.9364 |
| 10.65/10.7V | 1.0230 | -3.3960 | 0.9807 | 1.0380 | -9.1750 | 0.9598 |
| 18.7/18.7H | 1.0000 | 3.5740 | 0.9735 | 0.9443 | 19.6300 | 0.9530 |
| 18.7/18.7V | 1.0680 | -13.7000 | 0.9844 | 1.0440 | -3.6840 | 0.9615 |
| 23.8/23.8V | 1.0550 | -13.6400 | 0.9857 | 1.0150 | 0.3262 | 0.9645 |
| 36.5/37H | 1.0310 | 13.9000 | 0.9828 | 0.9277 | 15.7800 | 0.9701 |
| 36.5/37V | 1.0520 | -18.9000 | 0.9851 | 1.0390 | -10.9000 | 0.9664 |
4. Conclusion
On October 24, 2018 (UTC time), the Chinese marine satellite family added a new member, the HY-2B satellite. At present, China Ocean Satellite has realized the transition from a single model to multiple spectrums, from experimental applications to business services, and has rapidly moved toward serialization and business.

While the SMR radiometer achieves the scientific goals centered on marine environmental detection, it is vigorously developing its application capability to the land surface. The long-time multi-constellation passive microwave brightness temperature data is of great significance for studying the temporal and spatial changes of geophysical parameters and climatic research on the earth's environment. The purpose of this paper is to determine the systematic bias in land surface between SMR and other on-orbit radiometers and to unify them by establishing correction equations. Through detailed comparative analysis, SMR brightness temperature data are highly consistent with SSMI/S, GMI, AMSR2 and MWRI data from the correction coefficients and statistical results.

When conducting scientific research and social applications, a variety of onboard data can be uniformly utilized across constellations. The combined observations from different sensors can establish long-term consistent successive monitoring data records in order to better monitor changes in the global environment. Further research is needed to perform retrievals of Earth surface parameters such as snow water equivalents and soil moisture to investigate the practical application potential of the data.

References
[1] Shi, J.C., Y. Du, J.Y. Du, L.M. Jiang, L.N. Chai, K.B. Mao, P. Xu, W.J. Ni, C. Xiong, Q. Liu, C.Z. Liu, P. Guo, Q. Cui, Y.Q. Li, J. Chen, A.Q. Wang, H.J. Luo, and Y.H. Wang 2012 Sci. China, Ser. D Earth Sci. Progresses on microwave remote sensing of land surface parameters pp 1052-78
[2] Barnett, T.P., J.C. Adam, and D.P. Lettenmaier 2005 Nature Potential impacts of a warming climate on water availability in snow-dominated regions pp 303-9
[3] Chen, Q., J.Y. Zeng, C.Y. Cui, Z. Li, K.S. Chen, X.J. Bai, and J. Xu 2018 IEEE Trans. Geosci. Remote Sens. Soil moisture retrieval from SMAP: A validation and error analysis study using ground-based observations over the Little Washita Watershed pp 1394-408
[4] Kelly, R.E., A.T. Chang, L. Tsang, and J.L. Foster 2003 IEEE Trans. Geosci. Remote Sens. A prototype AMSR-E global snow area and snow depth algorithm pp 230-42
[5] Pulliainen, J. and M. Hallikainen 2001 Remote Sens. Environ. Retrieval of regional snow water equivalent from space-borne passive microwave observations pp 76-85
[6] Takala, M., K. Luojus, J. Pulliainen, C. Derksen, J. Lemmetyinen, J.P. Karna, J. Koskinen, and B. Bojkov 2011 Remote Sens. Environ. Estimating northern hemisphere snow water equivalent for climate research through assimilation of space-borne radiometer data and ground-based measurements pp 3517-29
[7] Du, J.Y., J.S. Kimball, R.H. Reichle, L.A. Jones, J.D. Watts, and Y. Kim 2018 Remote Sensing Global satellite retrievals of the near-surface atmospheric vapor pressure deficit from AMSR-E and AMSR2
[8] Kilic, L., R.T. Tonboe, C. Prigent, and G. Heygster 2019 Cryosphere Estimating the snow depth, the snow-ice interface temperature, and the effective temperature of Arctic sea ice using Advanced Microwave Scanning Radiometer 2 and ice mass balance buoy data pp 1283-96
[9] Zabolotskikh, E. and B. Chapron 2015 Adv. Meteorol. Validation of the New Algorithm for Rain Rate Retrieval from AMSR2 Data Using TMI Rain Rate Product
[10] Zeng, J.Y., Z. Li, Q. Chen, H.Y. Bi, J.X. Qiu, and P.F. Zou 2015 Remote Sens. Environ. Evaluation of remotely sensed and reanalysis soil moisture products over the Tibetan Plateau using in-situ observations pp 91-110
[11] Du, J.Y., J.S. Kimball, J.C. Shi, L.A. Jones, S.L. Wu, R.J. Sun, and H. Yang 2014 Remote Sens. Inter-calibration of satellite passive microwave land observations from AMSR-E and AMSR2 using overlapping FY3B-MWRI sensor measurements 6 pp 8594-616

[12] Chander, G., T.J. Hewison, N. Fox, X.Q. Wu, X.X. Xiong, and W.J. Blackwell 2013 IEEE Trans. Geosci. Remote Sens. Overview of intercalibration of satellite instruments 51 pp 1056-80

[13] Derksen, C., A. Walker, E. LeDrew, and B. Goodison 2003 J. Hydrometeorol. Combining SMMR and SSM/I data for time series analysis of Central North American snow water equivalent 4 pp 304-16

[14] Dai, L.Y., T. Che, and Y.J. Ding 2015 Remote Sensing Inter-calibrating SMMR, SSM/I and SSMI/S data to improve the consistency of snow-depth products in China 7 pp 7212-30

[15] Jezek, K.C., C.J. Merry, and D.J. Cavalieri 2017 Ann. Glaciol. Comparison of SMMR and SSM/I passive microwave data collected over Antarctica 17 pp 131-6

[16] Hou, A.Y., R.K. Kakar, S. Neeck, A.A. Azarbarzin, C.D. Kummerow, M. Kojima, R. Oki, K. Nakamura, and T. Iguchi 2013 Bull. Amer. Meteorol. Soc. The global precipitation measurement mission 95 pp 701-22

[17] Imaoka, K., T. Maeda, M. Kachi, M. Kasahara, N. Ito, and K. Nakagawa 2012 In Proceedings of the International Society for Optical Engineering (Kyoto: in Earth Observing Missions and Sensors-Development, Implementation, and Characterization Ii)

[18] Derksen, C. and A.E. Walker 2003 IEEE Trans. Geosci. Remote Sens. Identification of systematic bias in the cross-platform (SMMR and SSM/I) EASE-grid brightness temperature time series 41 pp 910-5

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