INTER-COMPARISONS AMONG PASSIVE MICROWAVE SEA ICE CONCENTRATION PRODUCTS FROM FY-3D MWRI AND AMSR2

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ABSTRACT:

Passive microwave (PM) sensors on satellite can monitor sea ice distribution with their strengths of daylight- and weather-independent observations. Microwave Radiation Imager (MWRI) sensor aboard on the Chinese FengYun-3D (FY-3D) satellites was launched in 2017 and provides continuous observation for Arctic sea ice since then. In this study, sea ice concentration (SIC) product is derived from brightness temperature (TB) data of MWRI, based on an Arctic Radiation and Turbulence Interaction Study Sea Ice (ASI) dynamic tie points algorithm. Our product is inter-compared with a published MWRI SIC product by the Enhanced NASA Team (NT2) algorithm, and three Advanced Microwave Scanning Radiometer 2 (AMSR2) SIC products by the ASI, Bootstrap (BST) and NT2 algorithm. Results show that MWRI SIC are generally higher than AMSR2 SIC and the median of monthly SIC differences are larger in summer. Regional analysis indicates that the smaller differences between AMSR2 SIC and MWRI-ASI SIC occur in the higher SIC areas, and the biases are within ±5% in the Beaufort Sea, Chukchi Sea, East Siberian Sea, Canadian Archipelago Sea and Central Arctic in summer. Regional analysis indicates that the smaller differences between AMSR2 SIC and MWRI-ASI SIC occur in the higher SIC areas, and the biases are within ±5% in the Beaufort Sea, Chukchi Sea, East Siberian Sea, Canadian Archipelago Sea and Central Arctic in summer. Regional analysis indicates that the smaller differences between AMSR2 SIC and MWRI-ASI SIC occur in the higher SIC areas, and the biases are within ±5% in the Beaufort Sea, Chukchi Sea, East Siberian Sea, Canadian Archipelago Sea and Central Arctic in summer. 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The ASI algorithm, based on the rationale that the polarization difference defined as the difference V-polarization minus H-polarization near 90 GHz is similar for all ice types and much larger than open water, was applied to AMSR-E and AMSR2 data (Spreen et al., 2008; Melsheimer, 2019). The SIC outside the area of maximum ice extent to 0%. The SIC based on the ASI, BST and NT2 algorithms were also used to correct bias between MWRI and AMSR2 TB data in 2018 (Table 1).

| Channel | Slope | Intercept |
|---------|-------|-----------|
| 18.7 V  | 0.900 | 28.014    |
| 23.8 V  | 0.956 | 15.642    |
| 36.5 V  | 0.973 | 11.178    |
| 36.5 V  | 0.970 | 12.454    |
| 89 H    | 0.972 | 8.625     |
| 89 V    | 0.979 | 8.237     |

Table 1. The regression coefficients of yearly models for bias correction at six channels.

3.2 ASI Dynamic Tie Points Algorithm

The ASI algorithm, based on the rationale that the polarization difference defined as the difference V-polarization minus H-polarization near 90 GHz is similar for all ice types and much smaller than open water, has been applied to AMSR-E and AMSR2 data (Spreen et al., 2008; Melsheimer, 2019). The SIC is a third-order polynomial of polarization difference, written as:

\[
C = d_3 P^3 + d_2 P^2 + d_1 P + d_0
\]

where

- **C** = SIC
- **P** = polarization difference
- \(d_3, d_2, d_1, d_0\) = coefficients

The dynamic tie points are introduced to modify the algorithm in this study. The polarization difference of pure pixels with the SIC equal 0% is open water tie points \(p0\), while those with the SIC equal 100% is sea ice tie points \(p1\). The initial SIC using AMSR-E fixed tie points \(p0=47\) K and \(p1=11.7\) K was calculated to collect tie points samples, and the weather filters and maximum ice extent mask were not applied to the initial SIC. For open water tie points, the pixels with initial SIC between -10% and 10% were picked out as samples, which were restricted northern than 50° N, between 200 km and 350 km further away from the monthly NSIDC maximum ice extent climatology (Stroeve, Meier, 2018) and 100 km off the coastal lines. For sea ice tie points, the pixels with initial SIC larger than 95% were selected as samples, which were constrained to geographically southern than 87° N, inside the monthly NSIDC maximum ice extent climatology and 100 km off the coastal lines. The daily \(p0\) and \(p1\) were generated by averaging polarization difference of all selected samples in a central temporal sliding window (±7 days). The dynamic tie points of MWRI for the full year 2018 are shown in Figure 1. The annual mean of open water tie points \(p0\) is 50.4 K, and that of sea ice tie points \(p1\) is 10.0 K.

To remove spurious ice over open water due to weather influence, two weather filters were used, one using the gradient ratio of the 36.5 and 18.7 GHz channels, i.e. GR(36.5/18.7) (Gloersen, Cavaliere, 1986) and the other using the gradient ratio of the 23.8 and 18.7 GHz channels, i.e. GR(23.8/18.7) (Cavaliere et al., 1995). The threshold values are 0.045 and 0.04 for GR(36.5/18.7) and the GR(23.8/18.7), respectively. The SIC are set to 0% where the coincident GR values exceed these thresholds. Since there may be still spurious ice over open water after the weather filters were employed, a maximum ice extent mask during that month in the past 40 years (Stroeve, Meier, 2018) was applied to set the SIC outside the area of maximum ice extent to 0%. The SIC based on an ASI dynamic tie points algorithm was derived from MWRI TB (MWRI-ASI) during the whole year of 2018. The four example days in different seasons are displayed in Figure 2.

For inter-comparisons among these five SIC products temporally and spatially, the AMSR2-ASI SIC was resampled to 12.5 km spatial resolution, and the same land mask, maximum ice extent mask and pole hole (greater than 87° N) were applied to all the SIC products. All the differences were computed by AMSR2 SIC products minus MWRI SIC products. Sea ice extent and sea ice area as two basic parameters of sea ice distribution were derived.
from these SIC products. Sea ice extent is defined as the sum of the areas of pixels with SIC exceeding 15%. Sea ice area is defined as the integrated sum of each pixel area times the corresponding SIC within the sea ice extent.

Figure 2. The SIC product derived from FY-3D MWRI TB data by an ASI dynamic tie points algorithm on 15th March, 08th June, 21th September, and 28th December 2018.

4. RESULT

The median of monthly differences between AMSR2-ASI, AMSR2-BST, AMSR2-NT2 and MWRI-ASI, MWRI-NT2 SIC were reported in Table 2. Because the released MWRI-NT2 SIC product started only from July 2018, the median of monthly differences between AMSR2 SIC products and MWRI-NT2 were computed from July. In general, the SIC differences show seasonal pattern, and the median of monthly differences are larger in summer. The median of monthly differences between AMSR2-ASI and MWRI-ASI SIC are 0.00% except July and August with the values of −0.82% and −0.64%, indicating that MWRI-ASI shows higher SIC in July and August compared to AMSR2-ASI. Comparison between two SIC products based on the NT2 algorithm, the median of monthly differences are 0.00% in November to December, while MWRI-NT2 SIC is 1.00% higher than AMSR2-NT2 SIC from July to October. Besides, compared with MWRI-NT2 SIC, the MWRI-ASI SIC has smaller median of monthly differences with AMSR2 SIC products.
| Month | AMSR2-ASI / % | AMSR2-BST / % | AMSR2-NT2 / % |
|-------|---------------|---------------|---------------|
|       | MWR1-ASI | MWR1-NT2 | MWR1-ASI | MWR1-NT2 | MWR1-ASI | MWR1-NT2 |
| Jan.  | 0.00     | -         | 0.00     | -         | 0.00     | -         |
| Feb.  | 0.00     | -         | 0.00     | -         | 0.00     | -         |
| Mar.  | 0.00     | -         | 0.00     | -         | 0.00     | -         |
| Apr.  | 0.00     | -         | 0.00     | -         | 0.00     | -         |
| May   | 0.00     | -         | 0.00     | -         | 0.00     | -         |
| Jun.  | 0.00     | -         | 0.00     | -         | 0.00     | -         |
| Jul.  | −0.82    | −3.52     | −1.61    | −5.00     | 0.00     | −1.00     |
| Aug.  | −0.64    | −3.00     | −1.00    | −3.00     | −0.33    | −1.00     |
| Sep.  | 0.00     | −0.47     | −1.00    | −1.00     | 0.00     | −1.00     |
| Oct.  | 0.00     | −0.11     | −0.13    | −1.00     | 0.00     | −1.00     |
| Nov.  | 0.00     | −0.29     | 0.00     | −1.00     | 0.00     | 0.00      |
| Dec.  | 0.00     | −0.33     | 0.00     | −1.00     | 0.00     | 0.00      |

Table 2. The median of monthly differences between AMSR2-ASI, AMSR2-BST, AMSR2-NT2 and MWR1-ASI, MWR1-NT2 SIC.

Differences of the four SIC products, i.e. AMSR2-ASI, AMSR2-BST, AMSR2-NT2 and MWR1-ASI, show spatial variability in each Arctic sea area (Figure 3). Due to the time coverage gap of MWR1-NT2, it was not included in this comparison. It is obvious that regions with higher annually averaged SIC entail smaller SIC differences, such as in the Beaufort Sea, Chukchi Sea, East Siberian Sea, Canadian Archipelago Sea and Central Arctic Sea, with the biases within ±5% for each AMSR2 SIC products. The Central Arctic Sea has highest averaged annual SIC and smallest differences in SIC (Bias = −0.77%, −0.60%, and 0.19% for AMSR2-ASI, AMSR2-BST and AMSR2-NT2, respectively). In Kara Sea, Bering Sea, Sea of Okhotsk and Barents Sea, where the annual mean SIC are low, the biases are larger, with the largest value of −22.13% in Bering Sea for AMSR2-ASI SIC. In the majority of Arctic sea areas, we can see bars representing SIC differences located on the left side which indicates MWR1-ASI SIC are generally larger than AMSR2 SIC products. However, there are five bars of AMSR2-NT2 on the right side, demonstrating that the MWR1-ASI SIC are lower than AMSR2-NT2 in the Beaufort Sea, Chukchi Sea, East Siberian Sea, Canadian Archipelago Sea and Central Arctic Sea. The spatial distributions of the SIC differences on four example days in 2018 for AMSR2-ASI, AMSR2-BST, AMSR2-NT2 minus MWR1-ASI are represented in Figure 4. The differences at ice edge are larger than in inner ice generally. In comparison to AMSR2-ASI SIC, the underestimations of MWR1-ASI occur in pack ice, while the SIC at the ice edge are overestimated by MWR1-ASI.

Figure 3. Annual mean MWR1-ASI SIC (The color code gives the SIC between 50 and 100%). Biases (The left is negative, and the right is positive) between AMSR2-ASI (orange), AMSR2-BST (purple), AMSR2-NT2 (green) and MWR1-ASI SIC in Arctic sea area in 2018. The dash line indicates the Arctic Circle.
Daily sea ice extent and daily sea ice area for the four SIC products: AMSR2-ASI, AMSR2-BST, AMSR2-NT2 and MWRI-ASI, were inter-compared in the full year of 2018 (Figure 5). Quantitative inter-comparisons of sea ice extent and sea ice area calculated from AMSR2-ASI, AMSR2-BST, AMSR2-NT2 and MWRI-ASI, MWRI-NT2 were made during the overlapped period (Table 3). The patterns observed in Figure 5a and 5c are almost same. The trends of sea ice extent and sea ice area derived from the three AMSR2 SIC products are very consistent with those from the two MWRI SIC products, with correlation coefficients all greater than 0.997. Differences of sea ice extent and sea ice area in Figure 5b and 5d demonstrate a similar pattern for three AMSR2 SIC products respectively. The curves almost locate below the reference line of MWRI-ASI except the AMSR2-NT2 curves for sea ice area during winter period (see Figure 5d). For both sea ice extent and sea ice area, the biases are negative between AMSR2-ASI and MWRI-ASI, indicating that MWRI-ASI gives larger sea ice extent and sea ice area than AMSR2-ASI. For sea ice extent, AMSR2-BST shows the lowest absolute biases with MWRI-ASI and MWRI-NT2 with the values of $-0.29 \times 10^6$ km$^2$ and $-0.39 \times 10^6$ km$^2$, respectively. There are the lowest absolute biases between AMSR2-NT2 and two MWRI sea ice area, with the values of $-0.13 \times 10^6$ km$^2$ and $-0.44 \times 10^6$ km$^2$ for MWRI-ASI and MWRI-NT2, respectively. Compared to sea ice extent and sea ice area derived from three AMSR2 SIC products, the biases of MWRI-ASI are around $0.10 \times 10^6$ km$^2$ and $0.30 \times 10^6$ km$^2$ lower for sea ice extent and sea ice area than MWRI-NT2, respectively.

Figure 4. Differences maps of SIC on 15th March, 08th June, 21st September, and 28th December 2018 of AMSR2-ASI minus MWRI-ASI (top), AMSR2-BST minus MWRI-ASI (middle) and AMSR2-NT2 minus MWRI-ASI (bottom).
Table 3. Biases and correlations between AMSR2-ASI, AMSR2-BST, AMSR2-NT2 and MWRI-ASI, MWRI-NT2 sea ice extent, sea ice area during 12th July to 31th December in 2018.

| SIC Products | Bias          | Correlation   |
|--------------|---------------|---------------|
|              | Sea Ice Extent / 10⁶ km² |     |     |
|              | MWRI-ASI     | MWRI-NT2     | MWRI-ASI | MWRI-NT2 |
| AMSR2-ASI    | -0.83        | -0.93        | 0.9988   | 0.9986   |
| AMSR2-BST    | -0.29        | -0.39        | 0.9986   | 0.9991   |
| AMSR2-NT2    | -0.61        | -0.70        | 0.9987   | 0.9990   |
|              | Sea Ice Area / 10⁶ km² |     |     |
|              | MWRI-ASI     | MWRI-NT2     | MWRI-ASI | MWRI-NT2 |
| AMSR2-ASI    | -0.45        | -0.77        | 0.9987   | 0.9988   |
| AMSR2-BST    | -0.23        | -0.55        | 0.9977   | 0.9987   |
| AMSR2-NT2    | -0.13        | -0.44        | 0.9989   | 0.9997   |

5. CONCLUSION

This study generated SIC by an ASI dynamic tie-point algorithm from newly released FY-3D MWRI TB data. Inter-comparisons were made among two FY-3D MWRI and three AMSR2 SIC products. The negative median of monthly differences show that AMSR2 SIC are lower than MWRI SIC. The SIC differences are seasonal, with the median of monthly differences larger in summer and 0.00% in winter. Regional analysis indicates that SIC differences between AMSR2-ASI, AMSR2-BST, AMSR2-NT2 and MWRI-ASI are small in high SIC regions, with the biases within ±5% in the Beaufort Sea, Chukchi Sea, East Siberian Sea, Canadian Archipelago Sea and Central Arctic Sea. The Central Arctic Sea has the smallest SIC differences with the biases of −0.77%, −0.60%, and 0.19% for AMSR2-ASI, AMSR2-BST and AMSR2-NT2, respectively. The trends of sea ice extent and sea ice area are very similar for MWRI and AMSR2, with correlation coefficients all greater than 0.997. Mean SIC, sea ice extent and sea ice area of MWRI-ASI are more consistent with those of AMSR2 than MWRI-NT2. The above results suggest that our MWRI-ASI SIC product may outperform published MWRI-NT2, and more detailed validation should be done to confirm these primary results.
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