STUDY ON THE RETRIEVAL OF SEA ICE CONCENTRATION FROM FY3B/MWRI IN THE ARCTIC

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ABSTRACT

Sea ice is a sensitive indicator of climate change. This study focuses on retrieving sea ice concentrations from the brightness temperatures recorded by the Microwave Radiation Imager (MWRI) on board the FengYun (FY)-3B satellite. After cross calibration with the Advanced Microwave Scanning Radiometer–EOS (AMSR-E) data from July to September 2011, MWRI brightness temperatures are used to calculate the sea ice concentrations based on the Arctic Radiation and Turbulence Interaction Study Sea Ice (ASI) algorithm with different tie points' combinations. The combination corresponding to the most similar results to AMSR-E sea ice products is selected as the new tie points to retrieve the sea ice concentrations in the Arctic. After comparing with the products of AMWR-E and MWRI, the sea ice concentrations from this work are validated by Aqua/Moderate Resolution Imaging Spectroradiometer (MODIS) calibrated radiances data.

Index Terms— sea ice concentration, FY3B/MWRI, MODIS, inter-sensor calibration, brightness temperature

1. INTRODUCTION

Sea ice is an important part of the global ocean. Due to the high reflectivity, sea ice greatly limits the exchange of energy and momentum between the atmosphere and the surface. The long-term trend of sea ice is also one of the important indicators of the global climate change. Therefore, the accurate information of sea ice distribution is an important factor to determine the water heat exchange between the polar ocean and the atmosphere.

Since 1972 when the Electrically Scanning Microwave Radiometer (ESMR) was used to measure the global ice distribution [1], more and more radiometers were applied to monitor the polar sea ice, such as the Scanning Multichannel Microwave Radiometer (SMMR) [2], Special Sensor Microwave/Imager (SSMI) [3, 4], the Advanced Microwave Scanning Radiometer for Earth Observation System (AMSR-E) [5, 6] and the Advanced Microwave Scanning Radiometer 2 (AMSR2).

Currently, the sea ice concentration Algorithms based on microwave radiometer mainly include NT algorithm (NASA Team Algorithm), NT2 algorithm (Enhanced NASA Team Algorithm) [5], BBA algorithm (Bootstrap Basic Algorithm) [7], ABA algorithm (AMSR Bootstrap Algorithm) [8], ASI algorithm (ARTIST(Arctic Radiation and Turbulence Interaction STudy) Sea Ice) [6] and so on.

The Microwave Radiation Imager (MWRI) on board the FengYun(FY)-3B satellite was launched in November 2010 by China Meteorological Administration/National Satellite Meteorological Center (CMA/NSMC). Except for the calibration system, the channel setting and view geometry of MWRI are almost identical to that of AMSR-E [9]. MWRI began to provide Level 2 sea ice concentration products based on the NT2 algorithm on June 27, 2011. Wang Xiaoyu et al. [10] compared the products of MWRI with the AMSR-E level-3 products, and the results showed that the sea ice concentrations from MWRI were generally higher compared to AMSR-E.

In this study, in order to obtain more accurate sea ice concentrations based on FY3B/MWRI brightness temperatures, the ASI algorithm is selected as the basic algorithm for the sea ice concentration regression. As the values of the tie points in the algorithm has seasonal variation characteristics, they will affect the retrieval accuracy of the algorithm. Hao et al. [11] improved the ASI algorithm by using dynamic tie points. And Spreen et al. [6] indicated that the selection of automatic adaptation of the tie points would probably affect the consistency of data products in long time series, and the difference in the regression accuracy between using the proper fixed tie points and the dynamic tie points are small. Therefore, this study is proposed to improve the ASI algorithm to make it applicable for FY3B/MWRI brightness temperatures in the Arctic by changing the fixed tie points to suitable values.

2. DATA

Five data sets are used in this study: (1) the FY3B/MWRI Level 1 swath brightness temperatures record; (2) FY3B/MWRI L2 sea ice concentration product [12]; (3) the AMSR-E L2A Version 3 (V003) Global Swath Spatially-Resampled Brightness Temperatures [13]; (4) AMSR-E Level 3 sea ice product [14]; (5) Aqua/MODIS Level 1B Calibrated Radiances data [15].

The spatial coverage of these data is north of 60°N and the temporal coverage is from July 1 to September 30, 2011, providing overlapping sea ice data between MWRI and AMSR-E.

3. METHODS

The methods used in this work include three steps: (1) Inter-sensor calibration. As the sea ice concentrations product of AMSR-E are selected for comparison with MWRI, the differences between the two sensors, such as the altitude, antenna size and the angle of incidence, will introduce the differences between the two brightness temperatures records. Therefore, the MWRI Level 1 brightness temperatures are inter calibrated to the AMSR-E Level 2A data set firstly. Due to the similar configuration and nearly simultaneous satellite overpass times of the two radiometers, a linear equation is used as the calibration formula. The matching time window was set to 30 minutes. (2) Tie points selection. In this step, based on the ASI algorithm with 121 different combinations of the tie points, the sea ice concentrations are calculated and compared with the AMSR-E Level 3 sea ice products. Based on the mean deviation, standard deviation and root-mean-square error between the two data sets of sea ice concentrations, the combination that lead to the minimum differences are selected as the new tie points. In this study, the tie point for open water is 52K while for sea ice is 13.7K. (3) Sea ice concentrations calculation in the Arctic. Using the calibrated brightness temperatures of MWRI from step 1 and the ASI algorithm with new tie points from step 2, the sea ice concentrations from July 1 to September 30, 2011 are derived. (4) Weather filter. In this step, two different weather filters are applied to eliminate spurious weather effects over the open ocean [16, 17].

4. RESULTS AND DISCUSSIONS

The daily sea ice concentrations in the Arctic from July 1 to September 30, 2011 are obtained. In order to evaluate the results of this study, the retrieved sea ice concentrations are firstly compared with the AMSR-E and MWRI products, and then validated by the Aqua/MODIS Level 1B calibrated radiances data.

4.1 Comparison with products

In this work, the sea ice concentration products of AMSR-E and MWRI are selected to compare with the sea ice concentrations from this study. These three data sets are shown in figure 1, taking July 1(a1, b1, c1), August 1 (a2, b2, c2) and September 1 (a3, b3, c3) as examples. Pictures labeled with “a” is the sea ice concentrations from this work (represented by RSIC), while “b” and “c” represent sea ice concentrations from AMSR-E and MWRI, respectively.

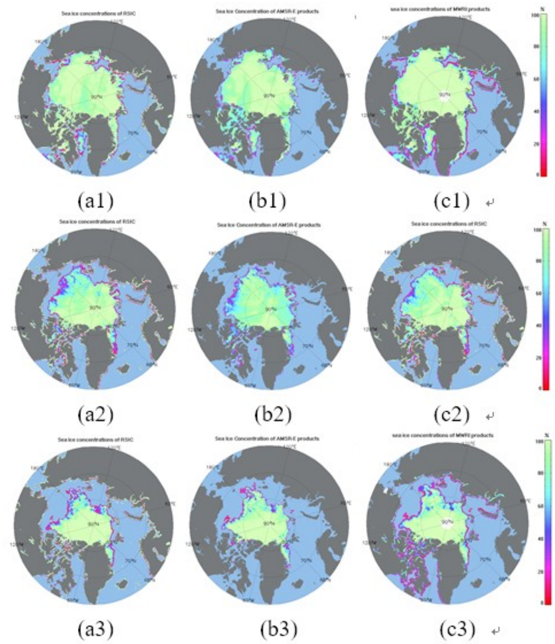

Figure 1. The sea ice concentrations from this work (RSIC) (a1-a3), AMSR-E (b1-b3) and MWRI products (c1-c3), On July 1, August 1 and September 1, 2011, respectively.

As seen from figure 1, the trends of the three data sets are similar on September 1, while different on July 1 and August 1. The sea ice concentrations of this study are closer to AMSR-E products, and both are significantly lower than MWRI products in some sea areas, especially the edge areas.

In order to further compare the three data sets, the time series of averaged sea ice concentrations from three data sets are shown in figure 2 from July 1 to September 30, 2011 in the Arctic.

It can be seen that the variation trends of the three sea ice concentration data sets are almost the same. The sea ice concentrations from RSIC have similar overall trends to MWRI, but similar values to the AMSR-E product. The lowest values of sea ice concentration from the three products appear in mid-August, and then show increasing trend in September. The products of MWRI have higher values every day than the other two data sets. The sea ice concentrations from RSIC are lower than that of MWRI products, higher than AMSR-E in July and mid-August, and lower than AMSR-E in September.

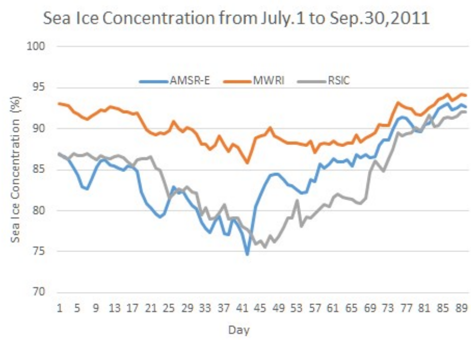

Figure 2. Time series of averaged sea ice concentrations from three data sets from July 1 to September 30, 2011.

Table 1. The quantitative assessment of differences

Data set	Bias (%)	STD (%)	RMSE (%)
MWRI - AMSRE	6.27	11.56	13.38
RSIC- AMSRE	4.89	13.56	14.24

The sea ice concentrations from RSIC and MWRI products are compared to the AMSR-E sea ice concentration products respectively. Table 1 shows the difference. The first column means the two data sets minus AMSR-E products, separately.

The differences between RSIC and AMSR-E products are smaller than that between MWRI and AMSR-E. The bias decreases by 1.38%, while the STD and RMSE increase. This may be the results of that the products of MWRI and AMSR-E are both calculated by NT2 algorithm, while the algorithm used in this study is ASI algorithm which may have different trend comparing to NT2 algorithm, although the mean value of RSIC are closer to AMSR-E products.

4.2 Validation

In this work, the Aqua/MODIS Level 1B calibrated radiances data with a resolution of 250m are selected as the verification data to further evaluate the performance of the algorithm used in this work. Firstly, the data are preprocessed, including correction of solar zenith angle, radiation calibration, bow-tie removal and polar stereoscopic projection. Then in order to match the resolution of RSIC dataset (12.5km), the sub regions in the MODIS scene are extracted to sub-regions with the size of 500*500 pixels to calculate the sea ice concentrations. Firstly, each pixel is determined whether water or ice. According the gray scale statistical histogram of each sub-region, the dynamic reflectance thresholds of ice are set. By calculating the number of ice points and the percentage to total points of one sub region, 32 scenes of the 12.5km sea ice concentrations are obtained based on the MODIS data in clear conditions. In order to further evaluate the algorithm, based on the overall comparison, the sea ice concentrations of MODIS are divided into two cases: less than 95% and more than 95%, and the RSIC and the MWRI products are evaluated separately. The quantitative assessment is shown in table 2.

Table 2. The quantitative assessment of sea ice concentrations of RSIC and MWRI products

Data set minus MODIS	Bias (%)	STD (%)	RMSE (%)
MWRI (<95%)	11.01	15.51	19.02
RSIC (<95%)	-1.81	12.20	12.33
MWRI (≥95%)	-4.00	6.06	7.26
RSIC (≥95%)	-4.64	5.29	7.04
MWRI (total)	2.17	13.23	13.41
RSIC (total)	-2.05	9.31	9.53

Compared with MWRI products, the Bias, STD and RMS error of RSIC are significantly reduced comparing to MWRI when the sea ice concentration is less than 95%, while when it is more than 95%, the difference between RSIC and MODIS data is larger than that of MWRI products. For all data, the bias of RSIC is similar to MWRI products, but the standard deviation and root mean square error are greatly reduced than MWRI products. Therefore, it can be concluded that the retrieved sea ice concentrations in this study are better than MWRI products.

4.3 Discussion

From the results described in sections 4.1 and 4.2, the sea ice concentrations retrieved in this study are reasonable and the method is viable. The differences between the results and AMSR-E products are mainly due to the followings: (1) The differences in brightness temperatures between the two sensors. (2) The difference of spatial resolution. (3) Using different retrieval algorithms with the different coefficiences that may result in differences on sea ice concentrations.

The main reasons for the differences between the RSIC and MODIS data set are as follows: (1) the difference of spatial resolution. The spatial resolution of MODIS is 250 m, which is much smaller than MWRI's 12.5 km resolution, and this may lead to errors in results. (2) The difference of temporal resolution. MODIS sea ice concentration product is calculated based on radiances data at a certain time, while the RSIC is the result of daily average, which may lead to differences in sea ice concentrations between them. (3) Error of MODIS sea ice concentrations. Since the data are calculated from radiances data, there may be some errors due to the changes of surface radiances. Meanwhile, without considering the impact of different sea ice types, it may also introduce errors. (4) MODIS data selected in this work are mainly distributed in the sea ice margin area, less high concentration area may result errors.

5. CONCLUSION

Using the FY-3B/MWRI brightness temperature, the retrieval of sea ice concentrations is studied based on ASI algorithm in the Arctic. Firstly, MWRI brightness temperatures are cross calibrated with AMSR-E. Then, by changing the value of tie points in ASI algorithm, the results corresponding to 121 sets of tie points' combinations are compared with AMSR-E sea ice concentration products, and the combination lead to the smallest difference is selected as the new tie points to retrieve the sea ice concentrations in the Arctic. Finally, in order to verify the feasibility of the algorithm, the results are compared with the AMSR-E and MWRI sea ice concentration products in the same period, and then they are preliminarily verified by 32 sets of MODIS sea ice concentrations obtained from the radiances data. The main conclusions are as follows: (1) From July to September 2011, the retrieved sea ice concentrations in this study are consistent with AMSR-E and MWRI products as to the basic trend. The results in this work are closer to AMSR-E products than MWRI products. (2) Validation by MODIS data shows that the bias of the results is similar to MWRI products, and the standard deviation and root mean square error are significantly lower than MWRI. Therefore, the retrieved sea ice concentrations of this study are better than the MWRI products.

6. ACKNOWLEDGEMENTS

The NSMC FengYun Satellite Data Center provides the FY-3B/MWRI data. NSIDC provides the AMSR-E Level 2A and Level 3 data. The Level 1 and Atmosphere Archive & Distribution System (LAADS) Distributed Active Archive Center (DAAC) provides the MODIS Level 1B calibrated radiances data. The National Key Research and Development Program of China (2016YFC1402704) and Global Change Research Program of China (2015CB953901) provide funding for this work.

7. REFERENCES

[1] P. Gloersen, T.T. Willicit, T.C. Chang, W. Nordberg, and W.J. Campbell, "Microwave maps of the polar ice of the Earth,"*Bulletin of the American Meteorological Society*, vol. 55, pp.1442–1448, 1974.

[2] P. Gloersen, and F.T. Barath, "A scanning multichannel microwave radiometer for Nimbus-G and SeaSat-A," *IEEE Journal of Oceanic Engineering*, vol. 2, no. 2, pp. 172–178, 1977.

[3] D.J. Cavalieri, J. Crawford, M. Drinkwater, W.J. Emery, D.T. Eppler, L.D. Farmer, M. Goodberlet, R. Jentz, A. Milman, C. Morris, R. Onstott, A. Schweiger, R. Shuchman, K. Steffen, C.T. Swift, C. Wackerman, and R.L. Weaver, "NASA sea ice validation program for the DMSP SSMI: Final report," *NASA Technical Memorandum 104559. National Aeronautics and Space Administration*, Washington, D.C., USA, 1992.

[4] T. Markus, and D.J. Cavalieri, "An enhancement of the NASA team sea ice algorithm," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 38, no. 3, pp. 1387– 1398, 2000.

[5] J.C. Comiso, D.J. Cavalieri, and T. Markus, "Sea ice concentration, ice temperature, and snow depth using AMSR-E data," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 41, no. 2, pp. 243-252, Feb. 2003.

[6] G. Spreen, L. Kaleschke, and G. Heygster, "Sea ice remote sensing using AMSR-E 89-GHz channels," *Journal of Geophysical Research,* vol.113, pp. 447-453, 2008.

[7] J.C. Comiso, "SSM/I Sea Ice Concentrations Using the Bootstrap Algorithm," *NASA Report*, vol.1380, 1995.

[8] J.C. Comiso, and H.J. Zwally, "Temperature Corrected Bootstrap Algorithm," *IEEE International Geoscience and Remote Sensing, 1997. IGARSS 97. Remote Sensing—A Scientific Vision for Sustainable Development.* IEEE, Singapore, pp. 857-861, 1997.

[9] H. Yang, F. Z. Weng, L. Q.Lv, et al., "The fengyun-3 microwave radiation imager on-orbit verification," *IEEE Transactions on Geoscience and Remote Sensing,* vol. 39, no. 11, pp. 4552-4560, Nov. 2011.

[10] X.Y. WANG, L. GUAN, and L.L. LI, "Comparison and Validation of Sea Ice Concentration from FY-3B/MWRI and Aqua/AMSR-E Observations," *Journal of Remote Sensing*, 2018, Vol. 22, no. 5, pp. 723-736, 2018. In Chinese.

[11] G.H. Hao, and J. Su, "A study on the dynamic tie points ASI algorithm in the Arctic Ocean," *Acta Oceanologica Sinica*, vol. 34, no.11, pp.126-135, 2015.

[12] H. Yang, X.L. Zou, X.Q. Li, et al., "Environmental data records from FengYun-3B microwave radiation imager," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 50, no. 12, pp. 4986–4993, 2012.

[13] P. Ashcroft, and F.J. Wentz, "AMSR-E/Aqua L2A Global Swath Spatially-Resampled Brightness Temperatures, Version 3," *NASA National Snow and Ice Data Center Distributed Active Archive Center*. Boulder, Colorado USA.

[14] D.J. Cavalieri, T. Markus, and J.C. Comiso, "AMSR-E/Aqua Daily L3 12.5 km Brightness Temperature, Sea Ice Concentration, & Snow Depth Polar Grids, Version 3," *NASA National Snow and Ice Data Center Distributed Active Archive Center*, Boulder, Colorado, USA. doi: http://dx.doi.org/10.5067/AMSR-E/AE_SI12.003, 2014.

[15] MODIS Characterization Support Team (MCST), "MODIS 500m Calibrated Radiance Product," *NASA MODIS Adaptive Processing System, Goddard Space Flight Center, USA*, 2015.

[16] P. Gloersen, and D.J. Cavalieri, "Reduction of weather effects in the calculation of sea ice concentration from microwave radiances," *Journal of Geophysical Research Oceans,* vol. 91, no. C3, pp. 3913-3919, 1977.

[17] D.J. Cavalieri, K.M.S. Germain, and C.T. Swift, "Reduction of weather effects in the calculation of sea-ice concentration with the DMSP SSM/I[J]," *Journal of Glaciology*, vol. 41, no. 139, pp. 455-464, 1995.