Response to the reviews of TC-2019-208 "Investigation of spatiotemporal variability of melt pond fraction and its relationship with sea ice extent during 2000–2017 using a new data" by Yifan Ding, Xiao Cheng, Jiping Liu, Fengming Hui, and Zhenzhan Wang

We greatly appreciate the thoughtful comments from the reviewer. According to the reviewer's comments, we revised the original manuscript. All issues raised have been considered thoroughly.

Round 1: General comment by reviewer #1

"*The authors train a neural network with MODIS data and in-situ melt pond observations to retrieve the melt pond fraction (MPF). This is similar to the approach of Rösel et al. (2012) but with a major difference. Rösel et al. (2012) use the mixing equation to solve for three unknown surface types: open water, melt ponds, and snow and ice. This means Rösel et al. estimate the melt pond fraction with respect to the ice surface. The sea ice concentration results as an independent quantity from the MODIS retrieval. In my understanding, the authors of the present manuscript do not retrieve the ice concentration as an independent parameter which means that the coverage of melt ponds is not correctly estimated in areas with ice concentration below 100%. This is obvious in gradients of the MPF in the marginal ice zone where a coverage of >50% is estimated (e.g. Fig. 11 and 12). This is a clear artefact and does not resemble the real melt pond coverage. The new MPF seems to be highly influenced by the ice concentration and is not an independent measure, see Kern et al. (2016) for further details.*

Kern, S., Rösel, A., Pedersen, L. T., Ivanova, N., Saldo, R., and Tonboe, R. T.: The impact of melt ponds on summertime microwave brightness temperatures and sea-ice concentrations, The Cryosphere, 10, 2217–2239, https://doi.org/10.5194/tc-10-2217-2016, 2016."

Response:

First, we would like to provide a description of the deep neural network training in the manuscript. For the training, the input data is the spectral reflectance from four bands of MODIS (Moderate Resolution Imaging Spectroradiometer Terra MOD09A1 Version 6, https://lpdaac.usgs.gov/products/mod09a1v006/) on the 500 m polar stereographic grid. The training (target) data is the field observed melt pond fraction (MPF) relative to grid from six different sources (HOTRAX, DLUT, TransArc, PRIC-Lei, NSIDC, NPI). In the present network, the training (target) data does not include sea ice concentration (SIC) which has been pointed out as a possible issue in the reviewer's comment. However, the field observed SIC from the six sources has been used to transform the MPF relative to sea ice to the MPF relative to grid in the network training.

Second, the reviewer mentioned that "the authors of the present manuscript do not retrieve the ice concentration as an independent parameter which means that the coverage of melt ponds is not correctly estimated in areas with ice concentration below

100%" and "This is obvious in gradients of the MPF in the marginal ice zone where a coverage of >50% is estimated (e.g. Fig. 11 and 12)". In our results (from Fig. 5 to Fig. 15 as well as Table 2 in the TCD manuscript), we have transformed the output of MPF relative to gird to the MPF relative to sea ice (see our figure captions). It should be noted that Fig.1 to Fig.4 and Table 1 in the TCD manuscript are based on the MPF relative to grid. For the transformation, we used the SIC from Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data developed by a revised NASA Team algorithm (NASA Team SIC, https://nsidc.org/data/nsidc-0051). The NASA Team SIC data is independent from the MPF retrieved by our network. Therefore, all our analyses (from Fig. 5 to Fig. 15 as well as Table 2 in the TCD manuscript) are based on the MPF relative to sea ice, which means the MPF is estimated in areas with ice concentration below 100% (Note: we only consider the grid cell with NASA Team SIC greater than 15%, as mentioned in line 201 in the manuscript.). The grid cell with MPF greater than NASA Team SIC have been removed in our analysis. Table 1 (below) shows the percentage of grid cell with MPF greater than NASA Team SIC (Note: these grid cells are considered as bad retrieval). The results show that only less than 2% and less than 0.1% of the grid cells have bad MPF retrieval when considering grid cell with SIC>15% and SIC>30%, respectively. This means that the bad MPF retrievals are primarily located in the sea ice edge area (with small concentration).

Table 1. The percentage (%) of the grid cell with MPF relative to grid greater than NASA Team SIC

Year	MPF> NASA Team SIC (SIC>15%)	MPF> NASA Team SIC (SIC>30%)	Total girds (average per day)
2000	1.92	0.09	49127
2001	1.77	0.12	45253
2002	2.13	0.13	47358
2003	2.37	0.12	48097
2004	1.93	0.10	47545
2005	2.24	0.14	45805
2006	1.99	0.14	45281
2007	2.53	0.08	42082
2008	2.09	0.09	43445
2009	1.92	0.08	44937
2010	2.07	0.09	42775
2011	2.31	0.07	41503
2012	2.22	0.09	39476
2013	1.28	0.06	43269
2014	1.76	0.07	43127
2015	1.54	0.03	41843
2016	2.04	0.09	40403
2017	1.38	0.04	41081
Average	1.97	0.09	44023

Third, the reviewer mentioned that the network should also include the SIC as an independent quantity (Note: the current manuscript used the NASA Team SIC as an independent quantity to restrain the grid cell with retrieved MPF over sea ice cover area and make sure the MPF is smaller than the ice concentration.). **In order to further address the reviewer's concern, we have re-trained the networks by adding the sea ice concentration (SIC) as the training (target) data. The results are shown below.**

Round 2: Additional comment by reviewer#1

"*I am still concerned about the correlation of ice concentration and your MPF retrieval. You mention that the bad MPF retrievals are primarily located in the sea ice edge area (with small concentration). For me this sounds like a clear argument that the MODIS MPF retrievals are not independent of the ice concentration. The problem is that the NASA TEAM SIC which you use for correction is estimated on a much coarser resolution. Moreover, the NASA TEAM SIC is strongly influenced by the occurrence of melt ponds. I cannot see how you solved this problem of different spatial scales and correlated measurements*"

Response:

To address the reviewer's concern, here we added observed SIC as the target data in the network training, and also retrieved SIC as the second output. We used the observed SIC from three independent sources as the target and trained the network separately. (note: the first output is MPF, the same as described in section 2 of TCD manuscript). Table 2 provides the detailed information.

Table 2. Details of the target and output for the network

Network	Training Input	Training	Output (target)
DNN_MPF (no SIC)	MOD09A1 bands (Band 1, 2, 3, 5)	Observed MPF	MPF (no SIC)
DNN_MPF+NASASIC		Observed MPF & NASA Team SIC	MPF + SIC
DNN_MPF+FieldSIC		Observed MPF & Observed SIC	
DNN_MPF+AMSRSIC		Observed MPF & AMSR-SIC	

- DNN_MPF (no SIC) is the network trained in the TCD manuscript. The training input is the four MOD09A1 bands (Band 1, 2, 3, 5) on the 500 m polar stereographic grid. The training output is the observed MPF from six sources (HOTRAX, DLUT, TransArc, PRIC-Lei, NSIDC, NPI). The DNN_MPF (no SIC) does not include SIC as the target in the network training.

- DNN_MPF+NASASIC is the network trained by adding the NASA Team SIC (Cavalieri et al., 1996) as the second target. The NASA Team SIC is derived from

Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data using a revised NASA Team algorithm (https://nsidc.org/data/nsidc-0051). In the network training, the NASA Team SIC was resampled from 25 km to the 500 m polar stereographic grid to match the resolution of the MODIS surface reflectance.

- DNN_MPF+FieldSIC is the network trained by adding the observed SIC from multi-sources (HOTRAX, DLUT, TransArc, PRIC-Lei, NSIDC and NPI) as the second target. The observed SIC is obtained from the same sources as the observed MPF. In the network training, the observed SIC was resampled from its original resolution (coverage) to the 500 m polar stereographic grid to match the resolution of MODIS surface reflectance (note: we use the average of the observed SIC from each source located in the same grid as the resampled SIC).

- DNN_MPF+AMSRSIC is the network trained by adding the SIC derived from Advanced Microwave Scanning Radiometer-Earth Observing System and Advanced Microwave Scanning Radiometer 2 (hereafter referred to as AMSR SIC, Spreen et al., 2008) as the second target. The AMSR SIC is developed by the University of Bremen using the ARTIST Sea Ice (ASI) algorithm (https://seaice.uni-bremen.de/sea-ice-concentration). In the network training, the AMSR SIC was resampled from 6.25 km to the 500 m polar stereographic grid to match the resolution of MODIS surface reflectance.

For the final MPF and SIC data retrieval, the data on the 12.5 km polar stereographic grid were used in the ensemble-based network (note: MOD09A1 on the 12.5 km polar stereographic grid was used as the input). The only difference between DNN_MPF (no SIC) and the other three networks (DNN_MPF+NASASIC, DNN_MPF+FieldSIC and DNN_MPF+AMSRSIC) is that the three networks contain SIC as the second target in network training. Therefore, the final dataset from DNN_MPF (no SIC) only contains MPF on the 12.5 km polar stereographic grid and the final dataset from the other three networks contains MPF and SIC on the 12.5 km polar stereographic grid.

Figure 1 shows the correlation coefficients and the RMSE of MPF from the above four network training. It appears that the correlation coefficients of the four networks with independent SIC are comparable. This is also true for the RMSE. This suggests that the influence of the ice concentration on the retrieved MPF is minor. This further increases the reliability of our MPF retrieval. We check the spatial correlation coefficients and RMSE of the MPF from three re-trained networks with the MPF from DNN_MPF (no SIC) in each year during 2000-2017. The results show that the average spatial correlation coefficient is ~0.99 and the RMSE is ~0.012. This suggests that the MPF from the re-trained networks are generally consistent with that from DNN_MPF (no SIC).

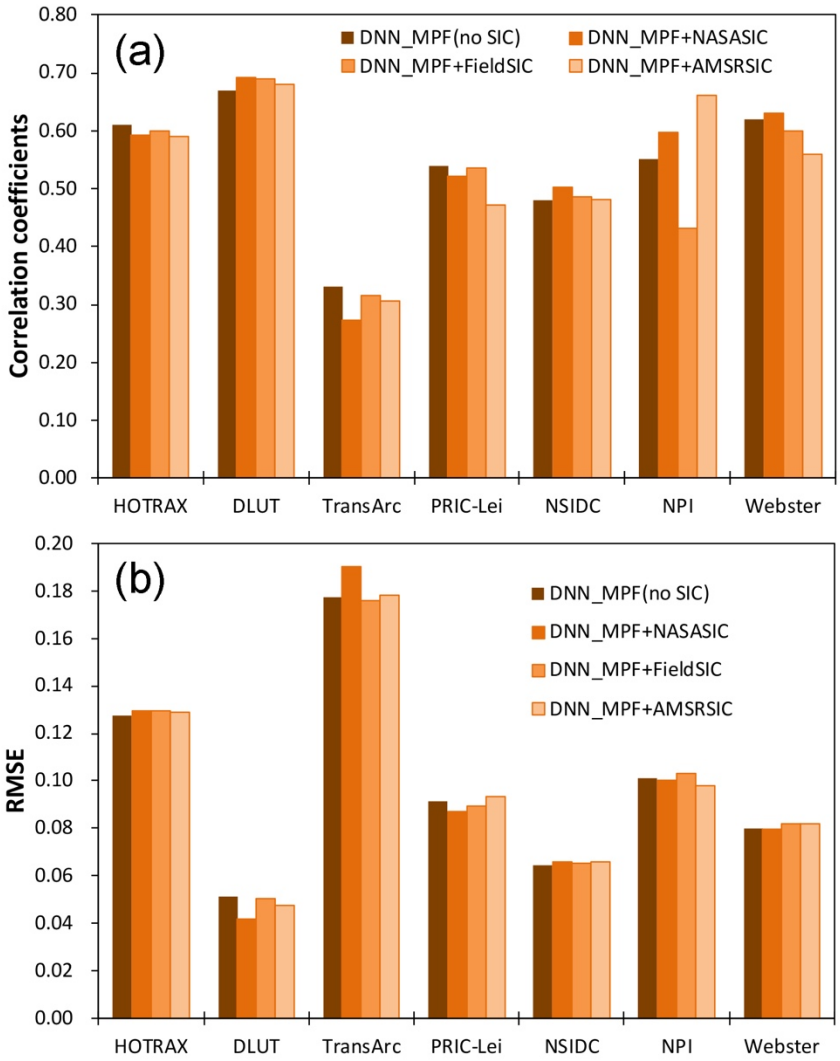

Figure 1. Validation of the MPF from four networks against the observed MPF: (a) correlation coefficients and (b) RMSE. (repetition of Fig.4 in the TCD manuscript).

For further comparison, we show the MPF (relative to grid) in 2017 from DNN_MPF (no SIC) and the three re-trained networks (DNN_MPF+NASASIC, DNN_MPF+FieldSIC and DNN_MPF+AMSRSIC). The results show that the spatial MPF during May to September in 2017 from DNN_MPF (no SIC) (Fig.2) are almost the same with that from the three networks added SIC (Fig.3 to 5). This further suggests that the SIC only has very limited effect on the MPF retrieval in our method.

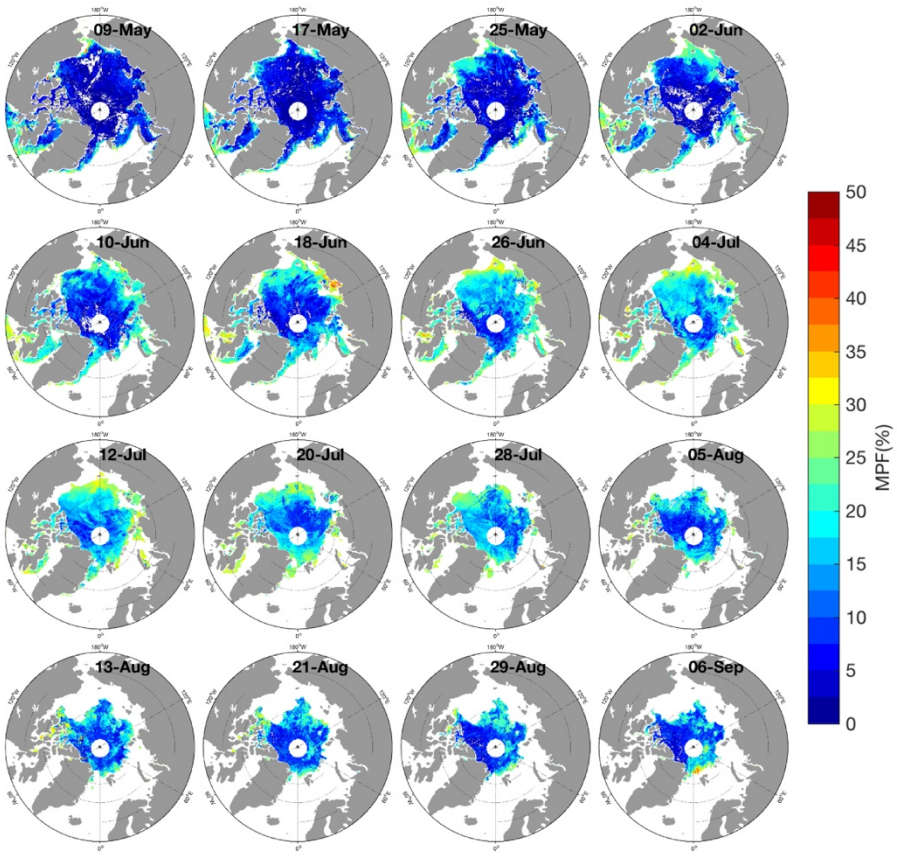

Figure 2. The evolution of the MPF from DNN_MPF (no SIC) relative to grid from early May to early September in 2017.

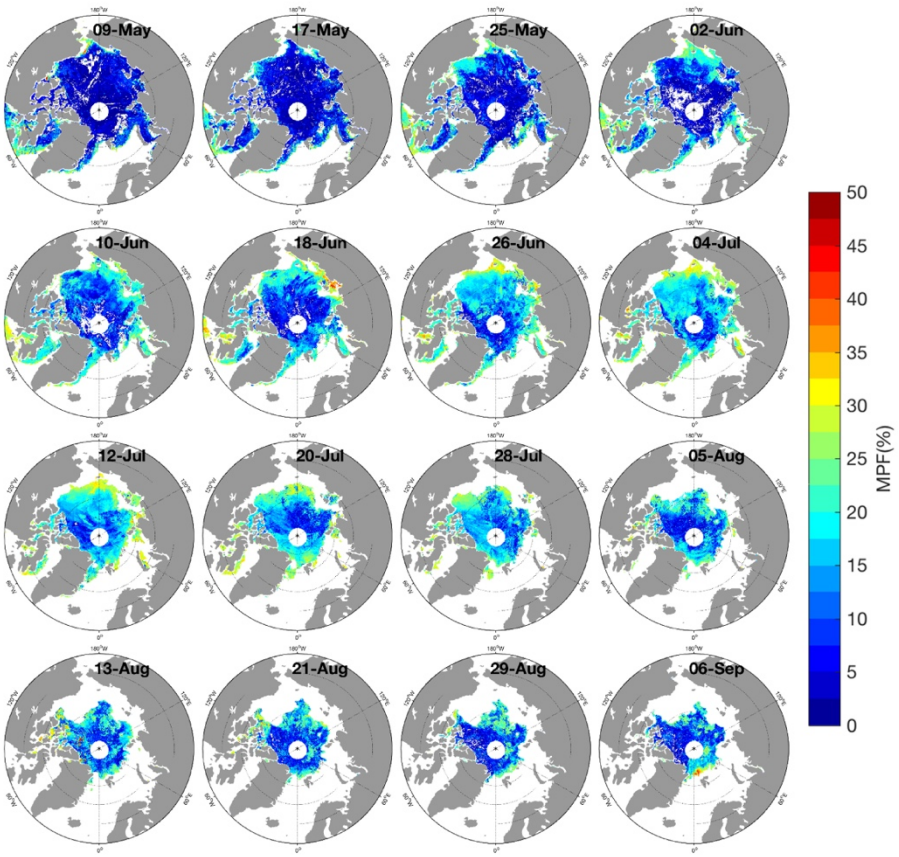

Figure 3. Same as Fig.2, except for the MPF from DNN_MPF+NASASIC.

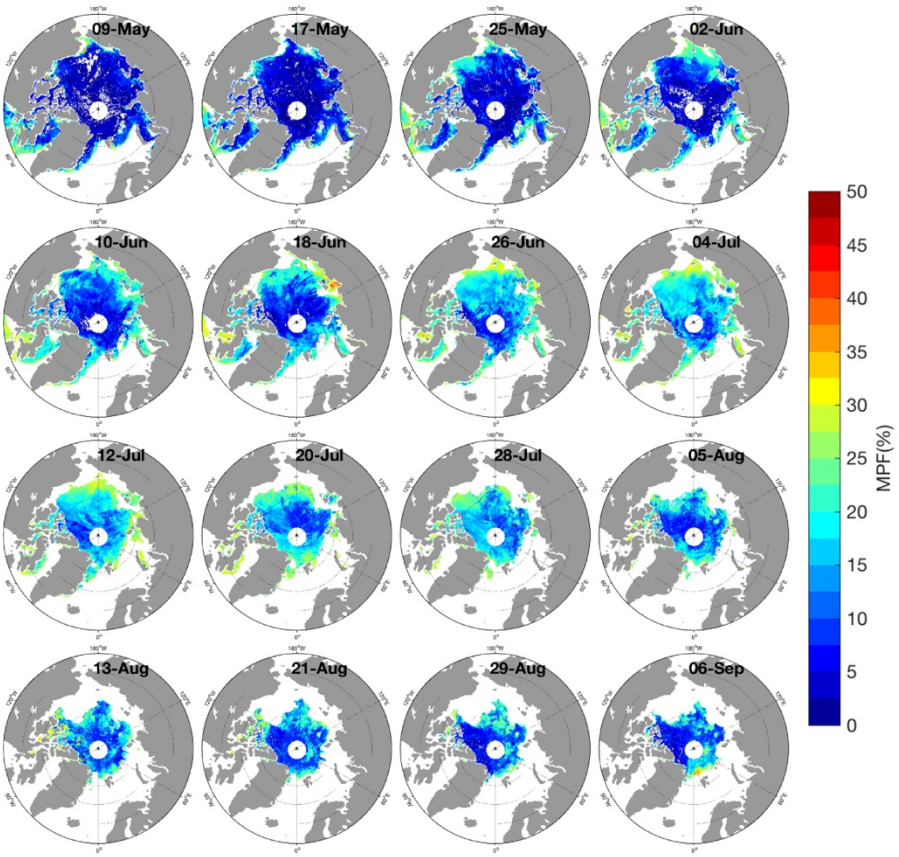

Figure 4. Same as Fig.2, except for the MPF from DNN_MPF+FieldSIC.

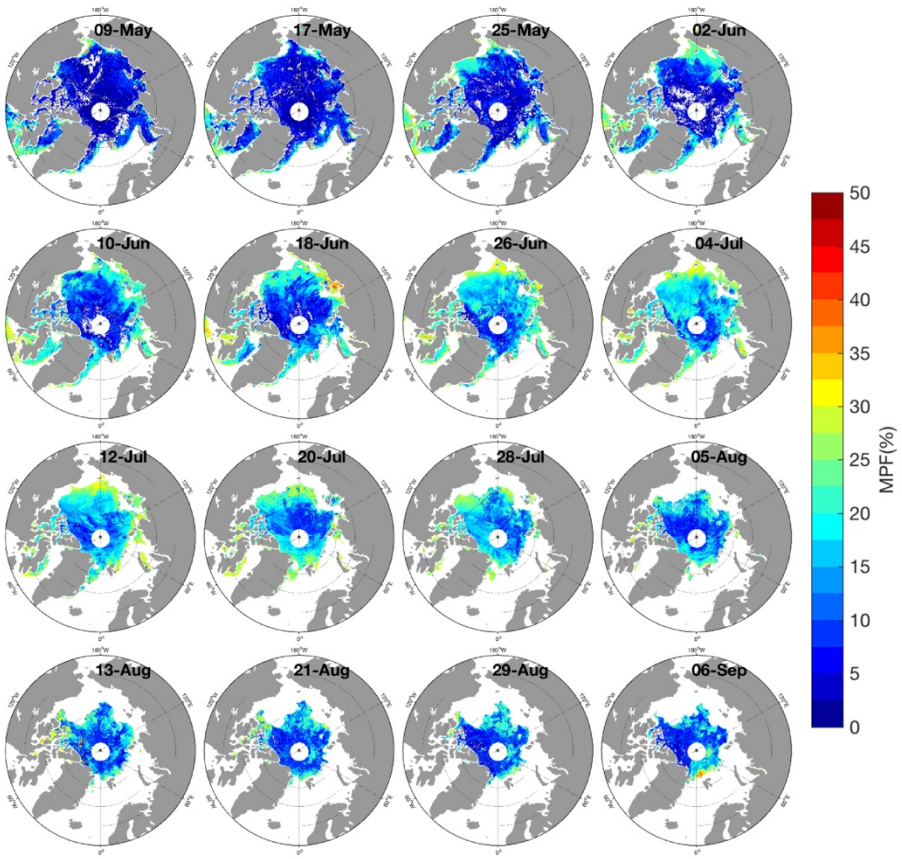

Figure 5. Same as Fig.2, except for the MPF from DNN_MPF+AMSRSIC.

Table 3 shows the percentage of grid cell with MPF greater than SIC (regarded as bad retrieval). The MPF (relative to grid) and SIC used here are both from the three re-trained networks (DNN_MPF+NASASIC, DNN_MPF+FieldSIC and DNN_MPF+AMSRSIC). The results show that 0.84-1.31% of the grid cells have bad MPF retrieval when considering grid cell with SIC>15%. It can be reduced to 0.05-0.19% of the grid cells when considering SIC>30%. The bad retrieval (MPF larger than SIC) has been removed in the analyses. Compared to Table 1 in the preliminary response to the review#1, the percentage of the grid with MPF larger than SIC does not change much whether the MPF is from DNN_MPF (no SIC) or the three re-trained networks (note: 1.97% and 0.09% of the grid cells have bad MPF retrieval when considering grid cell with SIC>15% and SIC>30% in DNN_MPF (no SIC)). This suggests that the SIC has very limited effect on the MPF retrieval in our method, which further increases the reliability of our method.

In order to minimize the bad MPF retrievals that are primarily located in the sea ice edge area with small concentration. In this revision, we only consider the grid cell with sea ice concentration greater than 30%, instead of 15%. The original MPF from DNN_MPF (no SIC) has been replaced by the retrieval from DNN_MPF+NASASIC.

Table 3. The percentage of the grid cell with MPF relative to grid greater than SIC

Year	MPF > Retrieved SIC						Total grids
	DNN_MPF+NASASIC		DNN_MPF+FieldSIC		DNN_MPF+AMSRSIC		
	SIC>15%	SIC>30%	SIC>15%	SIC>30%	SIC>15%	SIC>30%	
2000	1.85	0.17	1.29	0.08	1.14	0.27	49127
2001	1.45	0.13	0.92	0.03	0.77	0.22	45253
2002	1.30	0.10	1.02	0.04	0.84	0.21	47358
2003	1.50	0.13	1.19	0.07	1.01	0.18	48097
2004	1.29	0.12	0.96	0.04	0.96	0.20	47545
2005	1.46	0.12	1.18	0.06	1.00	0.22	45805
2006	1.60	0.12	1.21	0.06	1.05	0.25	45281
2007	1.49	0.11	1.21	0.05	1.04	0.20	42082
2008	1.52	0.11	1.41	0.09	1.18	0.16	43445
2009	1.71	0.13	1.44	0.09	1.24	0.22	44937
2010	1.50	0.12	1.17	0.04	0.86	0.22	42775
2011	1.42	0.10	1.21	0.05	0.86	0.19	41503
2012	0.93	0.09	0.91	0.03	0.57	0.11	39476
2013	1.05	0.08	0.85	0.02	0.44	0.13	43269
2014	1.23	0.09	1.05	0.05	0.99	0.17	43127
2015	0.66	0.07	0.57	0.01	0.33	0.11	41843
2016	0.87	0.08	0.62	0.02	0.42	0.16	40403
2017	0.82	0.08	0.78	0.05	0.49	0.11	41081
Average	1.31	0.11	1.06	0.05	0.84	0.19	44023

Reference:

Cavalieri, D. J., Parkinson, C. L., Gloersen, P., and Zwally, H. J.: Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data, Version 1 (updated yearly), NASA National Snow and Ice Data Center Distributed Active Archive Center, https://doi.org/10.5067/8GQ8LZQVL0VL, 1996.

Spreen, G., Kaleschke, L., and Heygster, G.: Sea ice remote sensing using AMSR-E 89 GHz channels, J. Geophys. Res., 113, C02S03, https://doi.org/10.1029/2005JC003384, 2008.