Journal of Geomatics

Vol 9 No. 2 October 2015

Sea ice occurrence probability data and its applications over the Antarctic

D. Ram Rajak, R.K. Kamaljit Singh, P. Jayaprasad, Sandip R. Oza, Rashmi Sharma and Raj Kumar
Atmospheric and Oceanic Sciences Group, EPSA
Space Applications Centre (ISRO), Ahmedabad, India
Email: rajakdr@sac.isro.gov.in

(Received on: Jul 15, 2015; in final form: Oct 15, 2015)

Abstract: A climatic dataset of Sea Ice Occurrence Probability (SIOP) generated for the Antarctic region has been presented. This dataset was used to compare climatic sea ice growth and melt patterns in the eastern and the western Antarctic regions. This sea ice product over the Antarctic region was developed from a long-term (1978-2012) passive microwave daily-averaged Sea Ice Concentration (SIC) dataset at 25 km grid cell. The SIOP product gives the probability of sea ice occurrence for each date from January 1 to December 31 determined from 34-year SIC dataset. The use of this SIOP dataset for two of the potential applications was demonstrated: (i) to generate sea ice majority mask, and (ii) to assess climatic intra-seasonal SIOP growth and decay gradients over eastern and western sides of the Antarctica. Analysis of temporal gradients of SIOP growth (indicative of sea ice refreezing rate) and decay (indicative of sea ice melting rate) indicated different rates of sea ice growth and refreezing over the eastern and western sides of the Antarctica. It is expected that the global scientific community will find this dataset useful for sea ice research in the Antarctic region.

Keywords: Sea ice occurrence probability, Antarctic, Sea ice concentration, Sea ice melting, Sea ice refreezing

1. Introduction

Sea ice is one of the most important parameters related to the global climate system. Its long term variation can be considered as one of the primary indicators of climate change. Researchers have developed a number of data products pertaining to the study of sea ice e.g., sea ice concentration, extent, freeboard, thickness, drift field etc. (Cavalieri et al., 1996; Maslanik and Stroeve, 1999; Comiso, 2000; Kurtz et al., 2013; Lavergne et al., 2010). However, a limited number of such products give the Sea Ice Occurrence Probability (SIOP). One such product is the Northern Hemisphere EASE-Grid 2.0 (Equal-Area Scalable Earth Grid 2.0) Weekly Snow Cover and Sea Ice Extent Version 4 (Brodzik and Armstrong, 2013). In this data product, the SIOP in Northern Hemisphere (SIOPNH) is available at monthly scale. Monthly probability of occurrence is the percentage of time in a given month that a pixel is either snow or sea ice. However, this product, as the name suggests, is only for the Arctic region and the temporal span is limited till 2011. There is another SIOP product with ocean wind field data from scatterometer (High resolution: ERS.ASPS20.H and Nominal Resolution: ERS.ASPS20.N) over Arctic (ASPS, 2009). This product too has a limited temporal coverage from 1997 to 2010.

Passive microwave Sea Ice Concentration (SIC) data can be used to define the extent of sea ice by giving a threshold value of 15% (Fetterer et al., 2002; Walter et al., 2015). Thus, an image pixel or a grid cell, in such concentration products, can be classified either as an open ocean or a sea ice according to either the concentration is less than or above this cut-off value, respectively.

In this paper, a technique employed in generating new product of probabilistic sea ice occurrence over the Antarctic region is presented. This is derived using a long-term passive microwave SIC dataset. This SIOP dataset will be useful for a number of sea ice studies in the Antarctic. One such application i.e. generation of sea ice majority mask has been demonstrated. Another application of this dataset, to assess climatic intra-seasonal sea ice growth and decay pattern over the Eastern and the Western Antarctic has also been presented in this paper.

2. Dataset and methodology

The primary data used in this study i.e. satellite based daily SIC data products are briefly discussed and then the method for deriving the required products is described.

2.1 Passive microwave Sea Ice Concentration (SIC) data

The primary dataset (Figure 1) used in this study is the Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR) and SSM/I-SSMIS Sea Ice Concentration product (henceforth, SSMISIC) archived at the U.S. National Snow and Ice Data Centre (NSIDC), University of Colorado, Boulder (Cavalieri et al., 1996). The data were generated using the NASA team algorithm developed by the Oceans and Ice Branch, Laboratory for Hydrospheric Processes at NASA Goddard Space Flight Centre (GSFC). The data were downloaded from ftp site: ftp://sidads.colorado.edu/pub/DATASETS/nsidc0051_gsfc_nasateam_seaice/final-gsfc/south/daily/. The time-period of the SIC dataset used in this study ranges from 1978 to 2012. SSMI SIC is a daily gridded dataset derived from brightness temperatures from Nimbus-7 SMMR, Defence Meteorological Satellite Program (DMSP) series of Special Sensor Microwave Imager (SSM/I) radiometers on-board F-8, F-11 and F-13 platforms and the Special Sensor Microwave Imager/Sounder (SSMIS) on-board F-17. This dataset is in polar stereographic projection at a grid cell of 25×25 km^2. This dataset provides a consistent SIC time series derived using satellite based data from several passive microwave instruments. It is useful in monitoring sea ice extent, in validation of various numerical climate models and analysis of air-ice-ocean interactions (Cavalieri et al., 1996). Further details may be obtained from http://nsidc.org/data/docs/daac/nsidc0051_gsfc_seaice.gd.html.

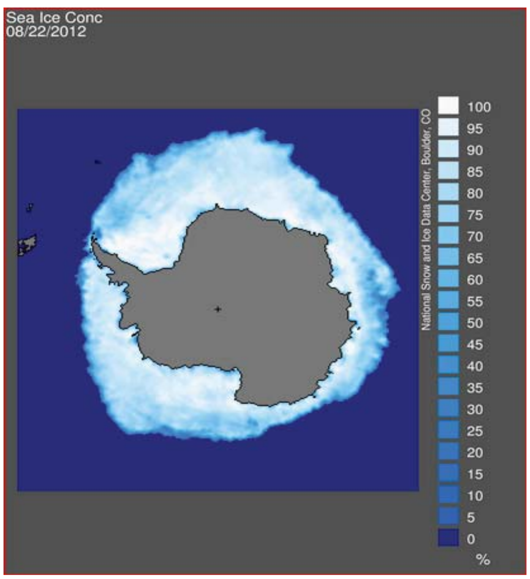

Figure 1: A sample of Antarctic sea ice concentration from Nimbus-7 SMMR and SSM/I, SSMIS. (Source: US National Snow and Ice Data Centre, University of Colorado, Boulder).

2.2 Determining probability of sea ice occurrence

The probability of sea ice occurrence for a particular date was calculated as the number of times a pixel has been classified as sea ice during the 34-yr period of study on that date, expressed in percentage (Figure 2). This was done over the Antarctic region. The general rule of classifying a pixel as sea ice was followed: a pixel is classified as sea ice if the ice concentration in that pixel is equal or greater than the cut-off value of 15%, but less than or equal to 100% (Fetterer et al., 2002; Walter et al., 2015). In this calculation, the missing values contained in the ice concentration product were taken into consideration. For a particular pixel, the probability of occurrence of sea ice Pr(i) on a particular date i –

$$Pr(i) = 100 \times N(i) / [\ Y(i) - n(i)\ ] \quad (1)$$

where, N(i) is the number of times the pixel has been classified as sea ice on date i; Y(i), is the total possible observations (maximum 34 in this case), and n(i) is the number of times the data is not available on date (i). This SIOP data product prepared using 34 years SIC input data is named as SIOP34.

It is worth noting here that the temporal availability of SIC data is every alternate day until June 1987 because till 1987 SMMR was operating on every alternate days due to its power limitation (Cavalieri et al., 1996). However, since July 1987, when SMMR was replaced by SSM/I (DMSP F-8), the data availability is on daily basis. Thus, the value of Y(i) in Eq. 1 will depend on the particular day of interest, e.g., day 1 of January appears 28 times during the whole study period of 34 years.

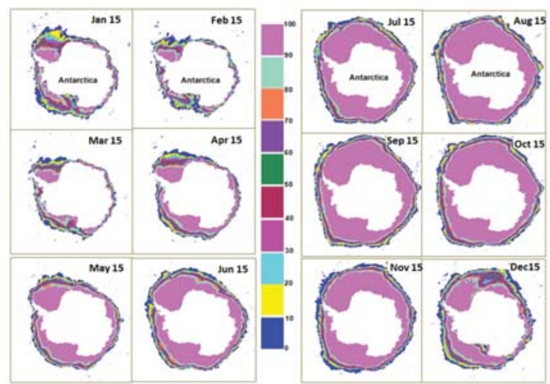

Figure 2: Mid-month SIOP images generated from the (1978-2012) SMMR-SSM/I sea ice concentration data. The colour-bar represents the SIOP value in percentage.

3. The SIOP34 product description and analysis

A long-term sea ice occurrence probability product (SIOP34) for each date from January 1 to December 31 over the Antarctic region is generated. Probability values are calculated from 34-yr SSMISIC product. The product is given in Polar Stereographic projection with a grid size of 25 km × 25 km in latitude and longitude respectively. The grid coordinates of the upper left pixel are 39.2º S, 42.2º W. There are 316 columns and 332 rows. Data are stored as IEEE floats representing probabilities in the range 0-100% (valid range is 0.0294% to 100%). Pixels with zero values can be either on the land or in the open ocean. The product is available in three formats: Binary, GeoTIFF and PNG (Portable Network Graphics).

The SIOP34 data consist of 366 data files corresponding to 366 days with the first file representing 1st January and the last, 31st December (February 29 included). The file naming nomenclature follows SIOP34_MMDD_S.bin[.tif /.png] format; where MM refers to month number (01 to 12, 01 being January), DD refers to date of the month, and the character S refers to the Southern Hemisphere. Data formats are indicated by .bin (Binary), .tif (GeoTIFF) and .png.

Mid-month SIOP34 images over the Antarctic are given in Figure 2. Regions with the lowest probability values (blue shades) appear in the Marginal Ice Zone (MIZ), which is expected and well known distribution pattern of sea ice. Higher probability values are confined to the regions well within this MIZ. During the summer months of January-March, on the eastern part of the Antarctic Peninsula in the Weddell Sea, parts of Bellingshausen-Amundsen Seas and parts of Western Pacific Ocean, distributed pixels having probability values of 90-100% are visible. In the Antarctic, because of the Antarctic Circumpolar Current (ACC), most of the sea ice is drifted away toward the north and not much of the ice is left to form multi-year ice. Majority of the multi-year ice that forms is confined to the regions such as the eastern Antarctic Peninsula region of the Weddell Sea (NSIDC, 2013). The consistent formation of polynya near Ross Ice Shelf is indicated by lower (less than 10%) SIOP34 values during December-January months.

Validation of the generated SIOP34 dataset was carried out with respect to AMSR2 ASI 3.125km SIC data (Beitsch et al., 2013) for 2014. The success of SIOP34 value equal to 100% in predicting the sea ice occurrence during 15th of each month in the Antarctic region was assessed. The pixels with SIC values greater than 15% were taken as sea ice from AMSR2 ASI 3.125km SIC data and they were compared with the pixels having probability equal to 100% in SIOP34 dataset. On average SIOP34 gave success rate of 99.2% for mid-month dates of 2014. Success rates during different mid-month dates (January 15 to December 15, 2014) are shown in Figure 3.

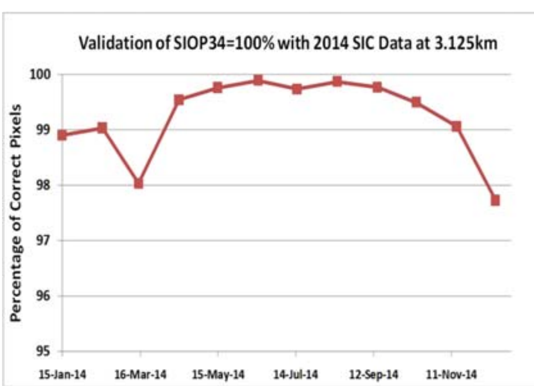

Figure 3: Success rate of SIOP34 equal to 100% pixels in predicting sea ice occurrence during 2013 as assessed with 3.125km SIC data for mid-month dates.

4. Product dissemination

The sea ice product, SIOP34, at 25 km x 25 km pixel size in Polar Stereographic Projection (datum: WGS 84) is freely made available to global science community. It is hosted at a 24x7 Meteorological and Oceanographic Satellite Data Archival Centre (MOSDAC) site, located at Space Applications Centre (SAC), Indian Space Research Organisation (ISRO), Ahmedabad, India. It is an open access dataset downloadable in three formats, as stated earlier.

5. Applications of SIOP data

SIOP data may be used as climatological dataset for the Antarctic environmental studies and sea ice modelling. The data may be used for deriving maximum probable sea ice latitudinal extent at any longitude. It will be useful for the decision makers during sea ice advisory dissemination for safer ship routing through the Antarctic sea ice regions. In absence of real time sea ice extent, a threshold based most probable sea ice extent may be prepared from SIOP34 data. The SIOP values may be used as a-priori information for sea ice classification using satellite remote sensing data. It can be used to prepare sea ice majority mask generation. These are some of the potential applications where global scientific community may find this data to be useful. One of such applications is the assessment of intra-seasonal SIOP growth and decay temporal gradients, which are indicators of sea ice growth and decay rates respectively. Two of the above mentioned applications of this dataset are demonstrated and described below.

5.1 Sea ice majority mask generation

The SIOP34 data product was used to prepare a daily binary mask of pixels whose sea ice occurrence probability values are greater than 50%. A pixel value of one was assigned to such pixels in the mask; other pixels are assigned zero. This product was called the daily majority of sea ice occurrence (MSIO). Dimensions, projection and other properties are the same as SIOP product. Mid-month images of such masks are shown in Figure 4. Such data product may be found useful by sea ice researchers for identifying sea ice dominant regions.

5.2 Climatic intra-seasonal sea ice growth and decay gradient

Another application of the SIOP34 in relation to the long-term intra-seasonal growth and decay of SIOP over parts of the Antarctic was demonstrated. For this, fourteen sites on a linear transect along 90^{o} E and 90^{o} W longitudes extending northward 7^{o} latitude from eastern and western coasts of Antarctica were taken. SIOP values (average of 3x3 windows) over each site were extracted for all the 366 dates (January 1 to December 31, including February 29). Hence, seven of the sites (AE01 to AE07) were on eastern part and the other seven (AW01 to AW07) were on the western part of the Antarctica (see Table 1). These sites were selected in such a way that they represented the intra-seasonal variability of the Antarctic sea ice cover right from the coast to the outermost peripheral regions of marginal sea ice zones. In the eastern Antarctic the Mean Annual Sea Ice Probability (MASIP) varies from

93.4% near coast to 14.1% at marginal zone. In the Western Antarctic the MASIP varies from 90.6% near coast to 6.2% at marginal zone. The rightmost column of Table 1 represents the MASIP values for all the study sites. It is evident from these differences, especially in the marginal zones that the occurrence of sea ice in the Eastern Antarctic is more stable than in the Western Antarctic.

Table 1: Details of the fourteen study sites

Antarctic region	Site name	Central latitude	Central longitude	Probability (%)
The east Antarctic	AE01	66°S	90°E	90.6
	AE02	65°S	90°E	76.9
	AE03	64°S	90°E	62.1
	AE04	63°S	90°E	53.7
	AE05	62°S	90°E	42.7
	AE06	61°S	90°E	30.7
	AE07	60°S	90°E	14.1
The west Antarctic	AW01	71°S	90°W	93.4
	AW02	70°S	90°W	88.3
	AW03	69°S	90°W	71.6
	AW04	68°S	90°W	55.2
	AW05	67°S	90°W	33.7
	AW06	66°S	90°W	17.1
	AW07	65°S	90°W	6.2

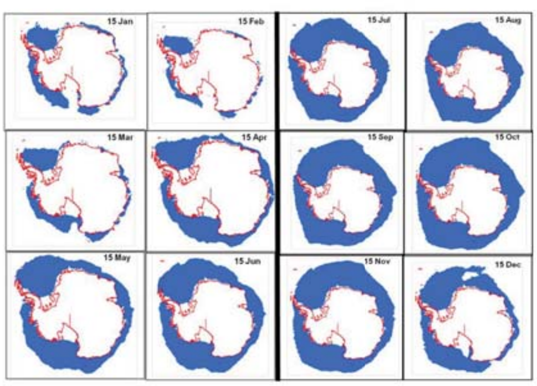

Figure 4: Mid-month sea ice majority of occurrence generated from the (1978-2012) SMMR-SSM/I sea ice concentration data. Blue shade represents the region with SIOP value greater than 50%.

Figure 5 shows the intra-seasonal variations of SIOP for the east and the west Antarctic sites, respectively. The plotted SIOP values were calculated using a 3×3 average window centred at each of these fourteen sites. A visual inspection of these SIOP growth/decay graphs clearly brings out that, in general, downward gradients (sea ice melting phase) are steeper than upward gradients (sea ice refreezing phase) for the east Antarctic sites. The steepness for the west Antarctic sites is just reversed i.e. upward gradients are steeper than downward gradients. These upward and downward gradients represent Temporal Gradients of Sea Ice Occurrence Probability (TGSIOP) during sea ice growth/refreezing and decay/melting cycles, respectively. Hence, these gradients characterize the rate of growth and decay of sea ice during winter and summer, respectively. The median TGSIOP values for sea ice growth and decay over both the regions are shown in Figure 6.

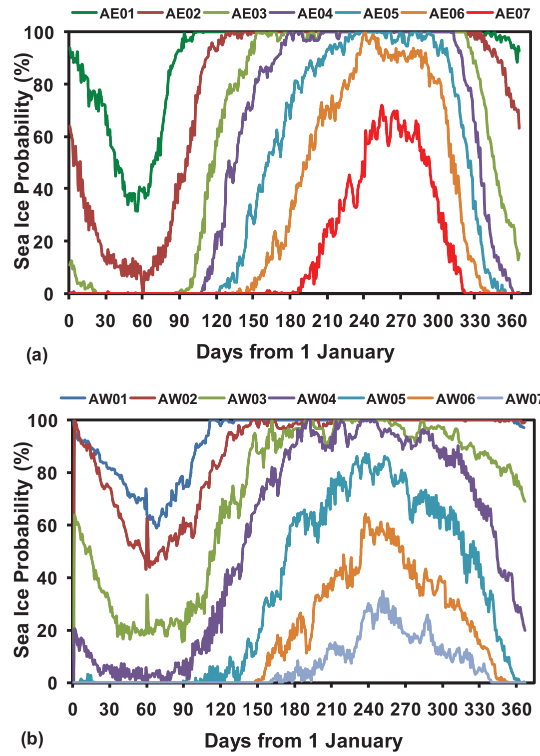

Figure 5: Variations of SIOP values during the sea ice growth (upward) and decay (downward) cycles in (a) the east Antarctic, and (b) the west Antarctic for the fourteen study sites.

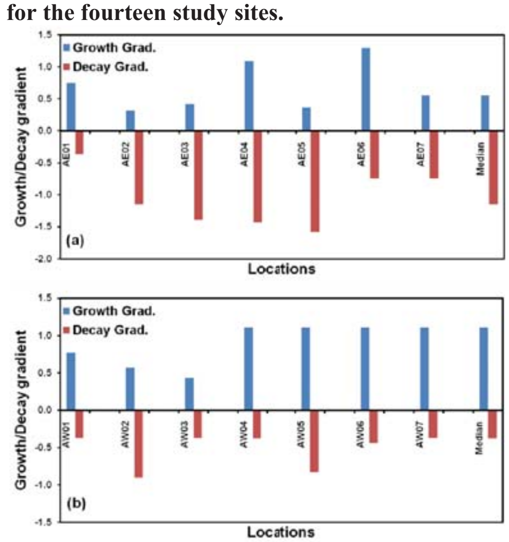

Figure 6: Temporal Gradients of Sea Ice Occurrence Probability (TGSIOP) values of sea ice growth/decay cycles over the fourteen study sites in (a) the east Antarctic (AE01 to AE07) and (b) the west Antarctic (AW01 to AW07) along with median TGSIOP values of the two regions.

It may be concluded from these observations that the rate of sea ice decay/melting is higher than the rate of sea ice growth/refreezing in the east Antarctic region with corresponding median TGSIOP being -1.145 and 0.555, respectively. Similarly, it may also be concluded that the rate of sea ice growth/refreezing is higher than the rate of sea ice decay/melting in the west Antarctic region with corresponding median TGSIOP being 1.11 and -0.375, respectively.

Conclusion

This paper discusses a technique of developing long-term sea ice occurrence probability (SIOP) product over the Antarctic region. The product at 25 km grid cell is prepared from 34-years sea ice concentration dataset over the Antarctic region. The sea ice product can be used to provide climatological masks in generation of sea ice extent and other climatological studies over polar region. SIOP can also be used as a-priory value during classification of remotely sensed data for water and sea ice discrimination. The product can serve as an initial input for safer ship routing through sea ice regions, in absence of near-real time information. The data has been used to assess the temporal gradient of SIOP growth (indicative of sea ice refreezing rate) and decay (indicative of sea ice melting rate) in eastern and western sides of the Antarctica. It is found that while sea ice decay gradient is higher compared to growth gradient in the east Antarctic region; growth gradient is higher than decay gradient in the west Antarctic region. It indicates faster melting than refreezing in the east Antarctic while faster refreezing than melting in the west Antarctic.

Acknowledgements

We profoundly acknowledge the various datasets used in this study which are freely available from the scientific community (The NASA Team-derived SMMR-SSM/I sea ice concentration data from the U.S. National Snow and Ice Data Centre, University of Colorado, Boulder). The authors would like to thank Chairman – ISRO for his continuous encouragement for polar ice studies. The constant guidance provided by Director – SAC and Deputy Director – EPSA, and continuous support provided by Group Director – AOSG are highly acknowledged. We extend our sincere thanks to the entire MOSDAC team for facilitating data hosting at data server site.

References

ASPS (2009). ASPS Product Format. European Space Agency. ERSE-GSEV-EOPG-RS-06-0002, 2 (4). (https://eopi.asi.it/documents/10174/13019/WS_ASPS_Product_ Format.pdf).

Beitsch, A., L. Kaleschke and S. Kern (2013). AMSR2 ASI 3.125 km sea ice concentration data, V0.1. Institute of Oceanography, University of Hamburg, Germany, digital media (ftp-projects.zmaw.de/seaice/), [Jan 2014 – Dec 2014].

Brodzik, M. and R. Armstrong (2013). Northern Hemisphere EASE-Grid 2.0 Weekly snow cover and sea ice extent, Version 4. Boulder, Colorado USA: NASA DAAC at the National Snow and Ice Data Centre. (http://nsidc.org/data/docs/daac/nsidc0046_nh_ease_snow_seaice.gd.html#doc_info).

Cavalieri, D.J., C.L. Parkinson, P. Gloersen and H. Zwally (1996). Sea ice concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS passive microwave data. [October 1978 to December 2012]. Boulder, Colorado USA: NASA National Snow and Ice Data Centre Distributed Active Archive Centre. (http://nsidc.org/data/docs/daac/nsidc0051_gsfc_seaice.gd.html#data_description).

Comiso, J.C. (2000). Bootstrap sea ice concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS, Version 2. [1978-2012]. Boulder, Colorado USA: NASA National Snow and Ice Data Centre Distributed Active Archive Centre.

Fetterer, F., K. Knowles, W. Meier and M. Savoie (2002). Sea Ice Index. [October 1978 to December 2012]. Boulder, Colorado USA: National Snow and Ice Data Centre. http://dx.doi.org/10.7265/N5QJ7F7W.

Kurtz, N.T., S.L. Farrell, M. Studinger, N. Galin, J.P. Harbeck, R. Lindsay, V.D. Onana, B. Panzer and J.G. Sonntag (2013). Sea ice thickness, freeboard and snow depth products from operation IceBridge airborne data. The Cryosphere, 7:1035-1056, doi:10.5194/tc-7-1035-2013.

Lavergne, T., S. Eastwood, Z. Teffah, H. Schyberg and L.-A. Breivik (2010). Sea ice motion from low resolution satellite sensors: An alternative method and its validation in the Arctic. J. Geophys. Res., 115, C10032, doi:10.1029/2009JC005958.

Maslanik, J. and J. Stroeve (1999). Near-Real-Time DMSP SSM/I-SSMIS Daily Polar Gridded Sea Ice Concentrations. Boulder, Colorado USA: NASA DAAC at the National Snow and Ice Data Centre. (http://nsidc.org/data/docs/daac/nsidc0081_ssmi_nrt_seaice.gd.html).

MOSDAC : www.mosdac.gov.in

NSIDC (2013). All about sea ice: Multiyear ice. (http://nsidc.org/cryosphere/seaice/characteristics/multiyear.html). Accessed 25 November 2013.

Walter, N.M., F. Florence, S.J. Scott and S. Sean (2015). How do sea-ice concentrations from operational data compare with passive microwave estimates? Implications for improved model evaluations and forecasting. Annals of Glaciology 56(69) 2015, doi: 10.3189/2015AoG69A694.