CREATION AND PRESERVATION OF A SEA ICE CLIMATE DATA RECORD

YEAR 3 PROGRESS REPORT

1 MAY 2009 – 30 APRIL 2010

NOAA OAR-CPO-2007-2000636
SCIENTIFIC DATA STEWARDSHIP PROGRAM

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PRINCIPAL INVESTIGATOR:
Walter N. Meier
walt@nsidc.org
303-492-6508

CO-INVESTIGATORS:
Florence Fetterer
fetterer@nsidc.org
303-492-4421

Julienne Stroeve
stroeve@kryos.colorado.edu
303-492-3584

Ruth Duerr
rduerr@nsidc.org
303-735-0136

National Snow and Ice Data Center
Cooperative Institute for Research in the Environmental Sciences
University of Colorado
UCB 449
Boulder, CO 80309
Fax: 303-492-2468

SUMMARY OF OVERALL PROJECT OBJECTIVES

The primary objective of this project is to lay the groundwork for the creation of a sea ice extent/area/concentration climate data record. The current standard sea ice fields are produced from passive microwave satellite brightness temperature fields. These provide complete daily coverage of the polar regions since late 1978. This nearly 30-year record is one of the longer satellite climate records and is a key indicator of climate change. The Arctic has experienced a precipitous decline in sea ice extent, particularly during summer, over the three decade record (e.g., Meier et al., 2007; Comiso and Nishio, 2008). Recent years have been particularly low, culminating in an extreme record minimum in September 2007, with extents 40% below normal and over 20% below the previous record low (Stroeve et al., 2008; Comiso et al., 2008).

However, for several reasons, the sea ice record is not yet at a sufficient level to be considered a true Climate Data Record (CDR). There is not a single authoritative and accepted sea ice product. The products lack grid cell-level or even granule-level error estimates or quality assessments (a granule refers to a coherent set of data, e.g., a daily field of a parameter). Intersensor calibration, while carefully conducted, could be improved. Finally, the metadata for the products is not comprehensive and does not meet the modern standards.

This project aims to address these deficiencies to allow the eventual production of a sea ice CDR. Specifically, the project objectives, as outlined in the original proposal are:

1. Intercalibrate the SMMR-SSM/I with the AMSR-E record to use the most recent, highest technology sensor as a basis for the record. This will also include implementing the NASA Team 2 algorithm over the SSM/I record, where the required high frequency channels (85.5 GHz) exist.
2. Develop data quality fields to accompany the data fields. This will be done through a variety of methods including temporal history and spatial correlation of the concentration fields, ancillary data (e.g., melt onset fields), and further comparisons with other basin-scale sea ice fields (such as AMSR-E concentrations from NSIDC processing).
3. Implement improved metadata and preservation standards. These standards will be FGDC/ISO 19115 compliant at both the file and data set level. The ability to distribute these products in data formats popular with specific user communities will be provided (e.g., NetCDF, GRIB2).

The end result will be higher quality sea ice concentration fields with associated data quality estimates and quality metadata information that will provide long-term preservation and reduce long-term maintenance costs. The production of these fields will provide a stable authoritative climate record into the NPOESS era and beyond.

BACKGROUND

Sea ice estimates are produced from two widely used algorithms, the NASA Team (Cavalieri and Gloersen, 1984) and the Bootstrap (Comiso et al., 1997), both developed at the NASA Goddard Space Flight Center. There are also several other, less widespread, algorithms in use. For the newer NASA Advanced Microwave Scanning Radiometer for EOS (AMSR-E), an enhanced NASA Team algorithm (Markus and Cavalieri, 2000), commonly referred to as NASA Team 2, is employed. Each sea ice algorithm uses combinations of passive microwave frequencies and polarizations to estimate sea ice concentration (percent ice cover within a grid cell), but the algorithms are formulated in different ways and use different combinations of channels. Evaluations of the algorithms have found that some algorithms perform better in some locations and some parts of the year, but that no single algorithm is optimal for all conditions (Comiso et al., 1997; Meier, 2005).

Another deficiency of the sea ice products in relation to CDR standards is that error estimates or quality assessments are lacking. There are only general error estimates based on a few local validation campaigns. Studies have shown that the quality of individual concentration estimates can vary dramatically, even over short distances and timescales (e.g., Meier, 2005).

Table 1. Characteristics of multichannel passive microwave sensors used in production of sea ice products and potential future sources. F8, F11, F13 denote DMSP satellites on which SSM/I was included. All frequencies include channels for both horizontal and vertical polarization, except 21.0/22.2, which has only a vertically polarized channel. MIS is currently planned for NPOESS. †Much of F8 85.5 GHz data missing or of low quality. ‡F15 was used operationally until an issue with the 22.2 GHz frequency corrupted the sea ice algorithm. F17 will begin operational use for sea ice in June 2009..

Sensor	Years of Operation	T_b Frequencies (GHz)	Min. Gridded Conc. Cell Size (km)
SMMR	10/25/78-8/20/87	6.6, 10.7, 18.0, 21.0, 37.0	25
SSM/I F8	7/9/87-12/31/91	19.3, 22.2, 37.0, 85.5†	25
SSM/I F11	12/3/91-9/30/95	19.3, 22.2, 37.0, 85.5	25
SSM/I F13	5/3/95-present	19.3, 22.2, 37.0, 85.5	25
SSM/I F15‡	12/18/99-present	19.3, 22.2, 37.0, 85.5	25
SSMIS F17	1/1/2007-present	19.3, 22.2, 37.0, 89.0	25
AMSR-E	6/18/02-present	6.9, 10.7, 18.7, 23.5, 36.5, 89.0	12.5
MIS	Planned ~2015	6.0-183.0	12.5 or less

The current widely-used sea ice timeseries employ the Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR) from 1978 to 1987 and a series of Special Sensor Microwave/Imagers (SSM/I) on the Defense Meteorological Satellite Program (DMSP) F- series satellites beginning with F8 in 1987 (Table 1). Thus, creation of the long-term sea ice timeseries has required intersensor calibration across numerous sensors. This has been carefully done to assure good consistency over the records (Cavalieri et al., 1999). However, there are some limitations in the intercalibrations. First, some overlap periods were extremely short, as little as three weeks (F8 to F11). Most of the overlap periods (all except F8 to F11) have been in the boreal summer (austral winter). Thus any seasonality effects on the intercalibration could not be accounted for. Ideally, a one-year overlap period should be used to cover the full range of annual variability. The sea ice products were not intercalibrated at the level of the sensor measurements (i.e., brightness temperature). Such an approach was unable to yield consistent results, so the intercalibration was done at the final product level to produce consistent sea ice extents. However, though extents were matched, inconsistency has been found in ice area fields.

Finally, the sea ice products lack comprehensive metadata, particularly at the grid cell or granule level. Current metadata includes basic product-level documentation and, for only some products, rudimentary granule-level information consisting of basic parameter information (date, parameter name, units, scaling, flag values).

YEAR THREE ACCOMPLISHMENTS

The Year Three accomplishments encompassed three major issues: (1) Development of data quality fields, (2) Continued intersensor calibration development, and (3) Metadata development.

Task 1 – Development of data quality fields

1. Obtained updated melt onset field from principal investigators. This will provide better quality fields than the near-real-time fields previously used.
2. Continued evaluation of other parameters such as: proximity to ice edge, proximity to coast, temporal latency (new ice or sporadic ice are indications of lower confidence levels).

Task 2 – Intersensor calibration

1. Worked with NOAA CLASS and the DMSP System Program Office to obtain pre-operational F17 data. Originally, F17 SSMIS data was not released until March 2008 even though launch was in November 2006. However, F13 and F15 SSM/I started having bad or missing data by January 2008. So, without additional F17 data, there would not be overlap of complete, accurate data between sensors. Such an overlap is essential for proper intercalibration of the sea ice concentration products. After much lobbying about the importance of such an overlap, the earlier data is now being processed. When delivered to NSIDC, there will be at least one full year of overlap of brightness temperatures. Having a full year will provide an optimal intercalibration for the sea ice products. We plan to use the calendar year 2007 for the intercalibration.
2. Published extended abstract on F13-F17 near-real-time intersensor calibration and tiepoint adjustment to the MicroRad 2010 Proceedings in Washington, DC. The abstract is attached in Appendix A.
3. Presented paper on F13-F17 near-real-time intersensor calibration at the MicroRad 2010 meeting in Washington, DC, 1-4 March 2010

4. Started preparing manuscript on intersensor calibration for IEEE Transactions on Geoscience and Remote Sensing special issue. The manuscript will be submitted by 1 July 2010, with planned publication in 2011.
5. Began investigating potential full reprocessing of current sea ice products. This would include:
    a. recalibrated input brightness temperatures, possibly from Kummerow/Berg NOAA SDS grant (we've contacted them about timetables and access for their reprocessed product)
    b. calibration of algorithm tiepoints using the newest sensor as the baseline instead of the earliest sensor
    c. correction of minor dataset errors

Task 3 – Metadata development

1. Design for metadata has been completed, which meets ISO 19115-2 standards. A sample table showing the required metadata elements and associated formats and values is included in Appendix B.
2. Design is planned to be coded and tested during summer 2010 and can then be implemented.
3. Implementation will be via an add-on script to the routine processing and will be run for each file.
4. Code will be run on historical data, creating a metadata file for each file.
5. Code will be implemented within operational product stream as part of overall processing architecture redesign (using resources outside of this grant).

Other Year 3 Accomplishments

1. Presented talk on intersensor calibration at American Geophysical Union Fall 2009 meeting, 14-18 December 2009.
2. Presented invited talk to National Academies Polar Research Board on importance of sea ice CDRs and issues being addressed, Washington, DC, 14-15 November 2009.
3. Attended NOAA PI meeting in Ashville, NC, 30 Sep – 1 Oct 2009.
4. Presented poster on sea ice products at ARCUS State of the Arctic meeting, Miami, FL, 15-19 March 2010.
5. Co-chaired advisory panel meeting on cryospheric CDRs with Jeff Key (NOAA/Univ. Wisconsin) at the State of the Arctic meeting. Jeff Key is PI on a NOAA SDS grant for a Cryospheric CDR Product Development Team on which the PI for this grant (Meier) is a

member. The meeting was attending by ~15 scientists who provided valuable input on the

6. Invited presenter/panel member at WCRP Climate and Cryosphere (CliC) Science Steering Group meeting, Valdivia, Chile, 5-8 February 2010. Presented status of sea ice climate data record progress and discussed outstanding issues, including algorithm selection. A summary of the presented material is included in Appendix C.

7. Submitted proposal to CliC to host an advisory panel meeting to make final recommendations on algorithm (or algorithm suite) for sea ice concentration products, and data quality information for a CDR. The panel will include several invited international expert researchers and sea ice product users. They will be asked to provide input on the best algorithm or suite of algorithms to form the basis of a sea ice CDR, necessary data quality information, as well as recommendations on data format, etc. This meeting will, hopefully, develop a consensus on on final sea ice CDR product and provide international legitimacy for the product. The proposal is currently under review. If approved, the meeting will likely be held in fall 2010, either in Boulder, CO or Washington, DC. A summary of the background and goals of the meeting are presented in Appendix D and the proposal to CliC is included in Appendix E.

8. The PI (Meier) accepted invited membership to CliC Sea Ice Working Group. My role will be to provide guidance on recommendations for remote sensing sea ice data products, including algorithms, data quality, and data formats. As with the proposed advisory panel meeting, serving on this working group will allow this CDR project to have wider impact and greater acceptance within the international community. The PI (Meier) will attend the working group meeting in Tromso, Norway, 4-5 June 2010 and discuss sea ice CDRs.

Other Ongoing Tasks

1. Became a member of advisory panel for CDR development with Sheldon Drobot, University of Colorado, and David Robinson, Rutgers University. Attended panel meeting at the 2010 American Geophysical Union

2. Continued discussion with ESA EUMETSAT Satellite Application Facility for possible collaboration when their reanalysis is complete (delayed from 2009). They have completed their processing and we are working with them to check the consistency of their results with our products

3. Investigation of metadata standards.

PLANS FOR REMAINDER OF THE PROJECT

There are several planned accomplishments for remainder of grant, including:

1. Continue intersensor calibration studies, particularly looking at possible improvements to previous intercalibrations during the SMMR-SSM/I era.
2. Implement intercalibration using final calibrated F17 SSMIS brightness temperature data from NSIDC's source at Remote Sensing Systems, Incorporated. These are expected to be delivered by the end of summer.
3. Implement NASA Team 2 algorithm and compare extents between F13, F17, and AMSR-E. Also, compare NASA Team 2 fields with NASA Team fields.
4. Continue developing grid cells- and granule-level error estimates and quality assessments. Instead of simply combining the eight algorithm outputs, more optimal schemes will be investigated.
5. Implement metadata standards and process for the archived datasets. Coordinate with NSIDC operations and management group to integrate the metadata code into the processing stream.
6. Submit peer-reviewed journal article to IEEE Transactions on Geoscience and Remote Sensing describing the intersensor calibration and a second manuscript on other aspects of the CDR project.
7. Continue participation in WCRP CliC activities, serving on the Sea Ice Working group, including attending the working group meeting in Tromso, Norway, 4-5 June 2010.
8. Continue collaborations with S. Drobot and D. Robinson on their CDR project. Also continue collaborations with the EUMETSAT sea ice reanalysis project; their reanalysis is expected to be complete later this year and we will coordinate with them on possible mutually-beneficial collaborations.

To complete these tasks, we plan to request a no-cost extension. There are several reasons for this request. First, the funding for the project was delayed, which delayed start of the work. Second, there have been delays in various elements of the project. For example, considerable time was spend obtaining, processing, and deriving preliminary intercalibration on F17 SSMIS data to continue the current sea ice timeseries. We are still waiting for final calibrated F17 SSMIS brightness temperatures from our source at Remote Sensing Systems, Inc. There also have been delays due to resource limitations at NSIDC, particularly for programming support, due to other projects and changes in personnel. We also have been waiting for input from European colleagues at EUMETSAT for input from their CDR efforts. Finally, with our new connections to WCRP CliC, we feel it is prudent to use this resource to develop support from the international community and to include their input in our final decisions for algorithm selection, etc.

Thus we plan to request a one-year no-cost extension, through 31 July 2011.

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APPENDIX A:

Extended Abstract on Intersensor Calibration,
Published in MicroRad 2010 Proceedings

INTERCALIBRATION OF NEAR-REAL-TIME SNOW AND SEA ICE PRODUCTS FROM PASSIVE MICROWAVE DATA

Walter Meier, Mary J. Brodzik, Siri Jodha Singh Khalsa

National Snow and Ice Data Center

ABSTRACT

Global estimates of snow and sea ice from passive microwave imagery are among the longest satellite-derived climate records in existence. The speed of observed changes in the cryosphere is pushing demand for near-real-time information that can provide at least preliminary estimates of evolving conditions. Such data are also valuable in the production of other geophysical products and as input to climate and weather models. Issues may arise in dealing with near-real-time satellite data that necessitate adaptive and quick intercalibration, and adjustments to production algorithms. Here we discuss issues that have affected production at the National Snow and Ice Data Center (NSIDC) of near-real time snow and sea ice products derived from DMSP passive microwave sensors. These issues include: sudden loss of data due to malfunctioning satellite data recorders, corruption of the signal on some channels, calibration errors in the source data, transitioning to a new sensor (from SSM/I to SSMIS), and dealing with changes in data providers and data format. The lessons learned from our experiences should prove beneficial as more real-time and near-real-time data streams become available and the demand for these products, and rapid response science, increases.

***Index Terms*—** Passive microwave, calibration, sea ice, snow cover

1. INTRODUCTION

Since 1987 the Special Sensor Microwave/Imager (SSM/I) on the Defense Meteorological Satellite Platform (DMSP) has been a stalwart for tracking sea ice extent and area. Combined with the earlier Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR) record (1978-1987), satellite passive microwave has yielded an ongoing 30+ year time series of sea ice conditions. This is one of the longest satellite climate records available and has been a key indicator of climate change.

The time series is not created from a single sensor but rather is stitched together from SMMR and a series of SSM/I sensors on the DMSP F-series satellites. To provide a consistent, high-quality time series through the period of record, it is essential to perform an intercalibration between the snow and sea ice products. This is accomplished by adjustments to the input data and algorithm coefficients. Historically, the period of overlap for the sensors has been short, limiting the intercalibration to a period of at most a few weeks. Thus, potential effects from seasonal variability could not be accounted for. Ideally, at least an entire year of overlap should be used to fully account for intra-annual variations in sensor characteristics.

2. NSIDC PASSIVE MICROWAVE PRODUCTS

The National Snow and Ice Data Center currently archives a complete time series of SMMR and SSM/I brightness temperatures. NSIDC produces daily gridded brightness temperature fields on a 25-kilometer polar stereographic projection (with true latitude at 70°) by pixel-wise averaging of input swath data. NSIDC also produces brightness temperatures fields on EASE-Grid (separated into ascending and descending passes).

The archive consists primarily of data from a single satellite except for periods of overlap (Table 1). Early overlap periods were often very short. In more recent years, data from multiple SSM/I sensors are available, but have not been archived at NSIDC.

Satellite	Sensor	Dates of Data at NSIDC	Overlap Previous Sensor (Days)
Nimbus-7	SMMR	1978-10-25 – 1987-08-20	
DMSP F-8	SSM/I	1987-07-09 – 1991-12-18	22
DMSP F-11	SSM/I	1991-12-03 – 1995-09-30	16
DMSP F-13	SSM/I	1995-05-30 – 2008-12-31	123
DMSP F-17	SSMIS	2008-03-28 – present	365+

Table 1. NSIDC passive microwave brightness temperature archive. Note that SMMR provided data only every other day.

2.1. POLAR STEREOGRAPHIC SEA ICE PRODUCTS

NSIDC produces a standard near-real-team polar stereographic sea ice concentration product based on daily composite brightness temperatures [5]. The product uses the NASA Team Algorithm [2][3]. The algorithm uses ratios of channels to estimate the concentration of sea ice within a grid cell. It relies on empirically-derived coefficients, or 'tiepoints', for three pure surface types – an open water type and two sea ice types. In the Northern Hemisphere, the two sea ice types correspond to first-year ice (FYI) and multiyear ice (MYI). Due to little MYI coverage and differing ice conditions, in the Southern Hemisphere the sea ice types are simply denoted “Type A” and “Type B”. NSIDC also archives sea ice products using the Bootstrap Algorithm [4].

2.2. NISE

In 1998 NSIDC began producing a daily Near-real-time Ice and Snow Extent (NISE) product, containing estimates of both sea ice concentration and snow-covered area based on F-13 brightness temperatures [6]. The data are distributed in 25 km Southern Hemisphere and Northern Hemisphere EASE-Grids. Sea ice is computed using the same algorithm described in 2.1 and snow cover is computed using the spectral difference algorithm developed by Armstrong and Brodzik [1].

3. PASSIVE MICROWAVE SENSOR TRANSITIONS

No single satellite sensor can provide a long-term climate record because sensor design lifetimes are limited to a few years. Though some sensors may last well beyond their planned missions, it will always be necessary to stitch together data from several sensors when compiling a long-term satellite climate record.

Due to differences in sensor design and satellite orbits, it is necessary to adjust sensor outputs to intercalibrate sensors and create a consistent record. For example, sensors on satellites in sun-synchronous orbits (including the Nimbus-7 and the DMSP F-series) with different ascending node crossing times will yield different results due to diurnal effects. Even if crossing times were the same and the sensors were the same there would still be differences simply due to uncontrollable variations during sensor construction.

Intersensor calibrations have been done on SSM/I brightness temperatures, generally focused on ocean products (e.g., [7]). It has been found that these intercalibrations do not produce a sufficiently consistent sea ice product. A regression between brightness temperatures from the overlapping sensors is a necessary first step to adjust the tiepoints for the new sensor [3]. However, because grid cells are rarely a single surface type and because there can be substantial variation of the surface emissive properties (and hence the brightness temperature signal) even within a certain surface type, Cavalieri et al. found than an additional adjustment to some tiepoints was also required [3].

3.1. NSIDC F-13 SSM/I to F-17 SSMIS Transition

Starting in January 2008, the brightness temperature record from F-13 was degraded by data gaps resulting from failing data recorders on the satellite. These data gaps appeared most frequently in more equatorward data where there are only one or two passes per day over the region. Thus, the effects were most pronounced near the winter maxima when the sea ice extends far toward the equator (especially in the Arctic). The resulting gaps in the sea ice fields can be filled in via a temporal interpolation from surrounding days.

Because of these data gaps and the fact that F-13 was well beyond its planned mission lifetime, NSIDC switched to the F-17 Special Sensor Microwave Imager/Sounder (SSMIS) as its near-real-time source for passive microwave sea ice products. The SSMIS is a new instrument replacing SSM/I on DMSP satellites. The lower frequency channels used in the sea ice products are the same as SSM/I, but there are additional higher frequency atmospheric sounding channels. The most substantial differences between the two sensors relevant for sea ice and snow cover products are the swath width and the ascending node crossing time (Table 2).

	F-13 SSM/I	**F-17 SSMIS**
Channels for Sea Ice (GHz)	19.3, 22.0, 37.0	19.3, 22.0, 37.0
Altitude (km)	850	850
Asc. Node Local Crossing Time (as of 2009-03-01)	18:25	17:28
Swath Width (km)	1400	1700

Table 2. Relevant satellite and sensor characteristics for F-13 and F-17.

3.2. F-13 SSM/I and F-17 SSMIS Intercalibration

Since beginning distribution of near-real-time snow and sea ice products, NSIDC had used F-13 SSM/I as the source data. Switching to F-17 SSMIS required a near-real-time intersensor calibration for F-17. This is the first time such a near-real-time calibration has been done for sea ice products.

The procedure NSIDC implemented essentially follows the method outlined by Cavalieri [3]. A notable difference with the previous efforts however is that NSIDC conducted the intercalibration with a full year of overlap data (1 April 2008 – 31 March 2009). Thus, the intercalibration fully accounts for seasonal effects in the brightness temperature differences between the sensors.

The first step in the intercalibration is a regression between the brightness temperatures. This was done independently for all points in the Northern Hemisphere and Southern Hemisphere for each day on each channel used in the NASA Team algorithm (19V, 19H, 37V). The regression is a simply a linear best-fit to the data resulting in slope and intercept coefficients, e.g.,

$$Y = a + b*X \quad (1)$$

where Y is the new sensor (F-17 SSMIS) and X is the old sensor (F-13 SSM/I). Regressions were done for each day. While there was some day-to-day variation in the regression coefficients, the daily values were averaged to produce average coefficient values (Table 3).

Channel	Slope (*b*)	Intercept (*a*)	Std. Error
	Northern Hemisphere		
19V	0.982	5.098	1.80
19H	0.990	2.494	2.95
37V	0.980	5.655	3.50
	Southern Hemisphere		
19V	0.985	4.118	2.02
19H	0.992	1.686	3.38
37V	0.980	5.739	4.23

Table 3. Mean regression coefficients for brightness temperatures comparison between F-13 SSM/I and F-17 SSMIS. Std. Error = RMS($Y-Y_{est}$).

The regression coefficients were then used to adjust the F-13 tiepoints for the F-17 brightness temperatures. Cavalieri found that this procedure did not yield sufficiently consistent sea ice fields, so they did a subjective manual adjustment of some of the tiepoints, particularly the open water (OW) tiepoints [3]. This 'tuning' was done subjectively. There is inherent subjectivity in the procedure because (1) there is not necessarily a unique combination of adjustments that minimize the differences, and (2) it is not possible to simultaneously minimize errors in both the total extent (the total of all cells having sea ice concentrations greater than 15%) and total area (cells weighted by their concentrations).

Here we used a more methodical procedure to reduce the subjectivity in the adjustment process. A cost function was defined (Equation 2), which was then minimized via a bracketed iterative approach.

$$\text{Cost} = A*f(\text{Extent}_{summer}) + B*f(\text{Extent}_{winter}) + C*f(\text{Area}_{summer}) + D*f(\text{Area}_{winter}) \quad (2)$$

where f(X) is a function evaluating the difference in the given parameter. Here RMS and Mean Difference functions were used. For each iteration, a full year of daily total sea ice extent and area were calculated for F-17 and compared to the original F-13 values varying four of the tiepoints: the three open water tiepoints and the 37V FYI/A tiepoint. The initial iteration was centered on zero (no change between F-17 and F-13). For each subsequent iteration, the new interval was centered on the coefficient values that minimized the cost function from the previous iteration. At each iteration the interval was halved, so that eventually we arrived at an optimal set of coefficients. The iterations continued until the interval reached 0.1 K, which is the radiometric resolution of the sensors.

The mean and RMS difference using several combinations of coefficients (A-D) were tested. It was found that using the RMS difference with equal weighting between coefficients (i.e., A = B = C = D = 0.25) provided the best overall results. Using an RMS difference accounts for the spread of the difference instead of simply the overall bias and RMS gives more weight to larger differences. There was little difference in the results using different weighting coefficients.

The daily differences in total extent and area, computed after applying the final F-17 tiepoints, are shown in Figures 1 and 2. The regression and adjustment has a small, but non-negligible effect on the total extent estimates, but the largest effects are on the total area estimates, which are substantially improved by the regression and adjustments.

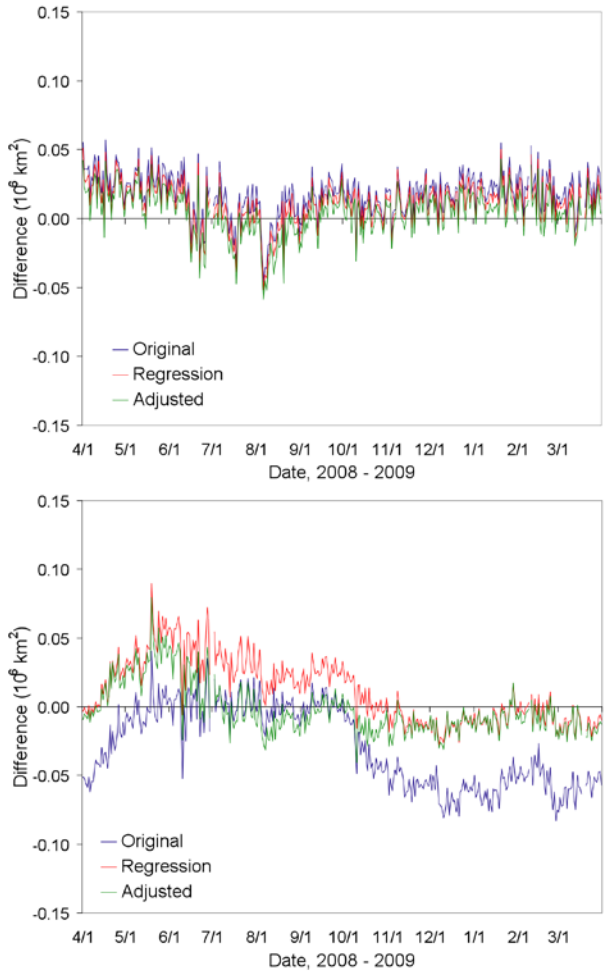

Figure 1. Northern Hemisphere daily total sea ice extent (top) and sea ice area (bottom) difference between F-17 SSMIS and F-13 SSM/I using: (blue) original F-13 tiepoints, (red) tiepoints from regression, and (green) adjusted tiepoints.

With the adjusted tiepoints, the extent and area differences between F-13 SSM/I and F-17 SSMIS are small (Tables 4 and 5). The mean differences are on the order of 10,000 km^2 and RMS differences are on the order of 40,000 km^2. This puts the differences with the range the sensitivity of the brightness temperature measurements and the NASA Team algorithm. Thus the consistency between the F-13 and F-17 time series is within limits of the sensor and algorithm capabilities.

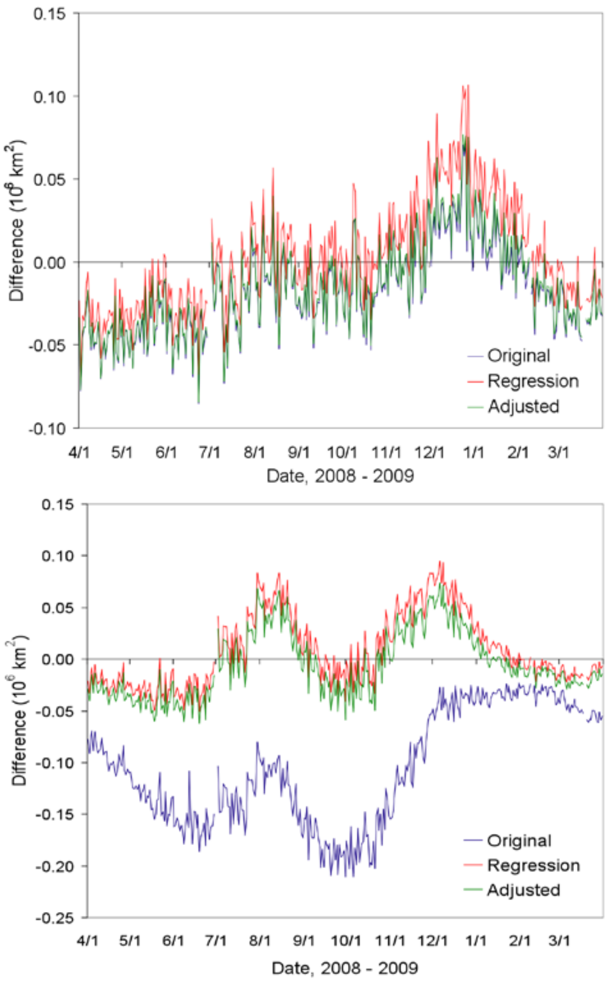

Figure 2. Southern Hemisphere daily total sea ice extent (top) and sea ice area (bottom) difference between F-17 SSMIS and F-13 SSM/I using: (blue) original F-13 tiepoints, (red) tiepoints from regression, and (green) adjusted tiepoints.

Northern Hemisphere	**Total**		**Summer (6/1-8/31)**		**Non-Summer**	
	10^6 km^2	*%*	*10^6 km^2*	*%*	*10^6 km^2*	*%*
Extent						
Mean	0.0044	0.052	0.0090	0.100	-0.0094	-0.136
RMS	0.0172	0.195	0.0155	0.167	0.0214	0.301
Max. Abs.	0.0588	1.053				
Area						
Mean	-0.0020	-0.029	-0.0033	-0.043	0.0020	0.041
RMS	0.0190	0.256	0.0187	0.232	0.0201	0.399
Max. Abs.	0.0796	1.054				

Table 4. Northern Hemisphere F17-F13 total sea ice extent and area difference.

Southern Hemisphere	**Total**		**Summer (12/1-3/31)**		**Non-Summer**	
	10^6 km^2	*%*	*10^6 km^2*	*%*	*10^6 km^2*	*%*
Extent						
Mean	-0.0150	-0.131	-0.0236	-0.166	0.0025	0.043
RMS	0.0316	0.252	0.0329	0.225	0.0290	0.430
Max. Abs.	0.0844	1.639				
Area						
Mean	-0.0054	-0.063	-0.0091	-0.082	0.0020	0.055
RMS	0.0322	0.333	0.0347	0.304	0.0264	0.617
Max. Abs.	0.0736	1.605				

Table 5. Southern Hemisphere F17-F13 total sea ice extent and area difference.

The maximum absolute differences are all under 100,000 km^2, which is reasonable. Concentration difference fields for the dates of maximum absolute differences (largest overestimation and underestimation by F-17 relative to F-13) shows that differences were generally small except near the ice edge (Figure 3). The larger differences appear in the Northern Hemisphere near spring and fall, where diurnal effects are largest. There also appear to be possible effects in regions toward the south where the limited number of

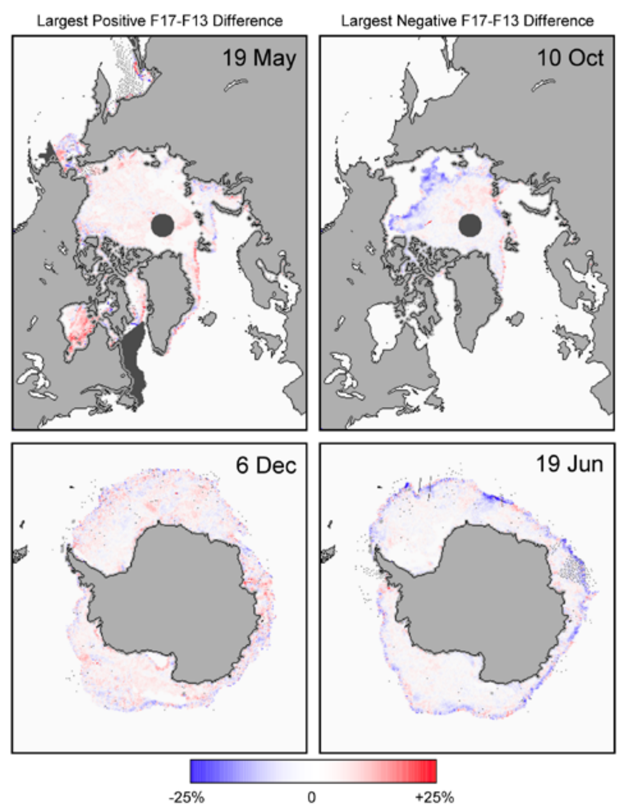

Figure 3. Sea ice concentration difference, F17-F13 dates of (left) largest positive difference (i.e., F17 > F13) and (right) largest negative difference (i.e., F13 > F17). All dates are in 2008.

overpasses per day can lead to greater diurnal effects (e.g., in Hudson Bay on 19 May). In the Southern Hemisphere, the differences are largest near the solstices, where fastchanging ice conditions in the Antarctic may have a larger influence than diurnal effects.

4. SEASONALITY OF INTERSENSOR CALIBRATION AND IMPLICATIONS FOR PREVIOUS SENSOR OVERLAPS

It is quite clear in Figures 1 and 2 that there is a seasonal signal in the intercalibration due to diurnal variations in what the two sensors observe. This is likely due to differences in overpass times between the satellites and the effect of melt and other surface effects. In the Arctic the largest differences are generally found in the summer melt period. In the Antarctic, there is a bimodal pattern, with the largest differences in the late-winter/early-spring and the late-fall/early-winter.

By having the full year for intercomparison, it is apparent that improvements could be made by using seasonal tiepoints and conducting intercalibration by season. This was not done here to be consistent with the previous SMMR-SSM/I approach.

However, the seasonal effect has likely impacted previous intercalibrations because the overlap periods were very short and thus only encompassed part of the full seasonal cycle. Having the full year affords us the opportunity to investigate these effects. We did this by using only a subset of the full year F17-F13 overlap, corresponding to the previous sensor overlap periods, and recalculating the F17-F13 intercalibration, using our iterative method. Then the new "short-interval" tiepoints were used to produce the full year of sea ice extent and areas. The differences were then compared with results using the full year overlap interval.

This comparison does not necessarily provide a direct error estimate of the previous sensor intercalibration because the sensor characteristics are different as are the physical environmental conditions (e.g., concentration, onset of melt, other surface emissive properties). However, it suggests that the intercalibration is sensitive to the time interval of the overlap and points to the potential limitations of having only a short overlap period.

	Northern Hemisphere		**Southern Hemisphere**	
	Mean	*RMS*	*Mean*	*RMS*
Full Year (4/1 – 3/31)	-0.0020	0.0190	-0.0054	0.0322
F13-F11 Overlap (5/30 – 9/30)	-0.0185	0.0307	-0.0043	0.0347
F11-F8 Overlap (12/3 – 12/18)	0.0223	0.0309	-0.0604	0.0711
F8-SMMR Overlap (7/9 – 8/20)†	-0.0120	0.0295	-0.0204	0.0384

Table 6. Mean and RMS average total sea ice area difference in km^2 using different overlap periods to derive new F-17 tiepoints. †SMMR collected data every other day.

Total area was most affected by the change in time periods, with the shorter overlap periods yielding larger differences (less consistency) compared to using the full year overlap period (Table 6). Extent showed similar behavior, but with smaller magnitude differences (not shown). This is not unexpected and others (e.g., [3]) have commented on the need for at least a full year of overlap for an optimal intersensor calibration.

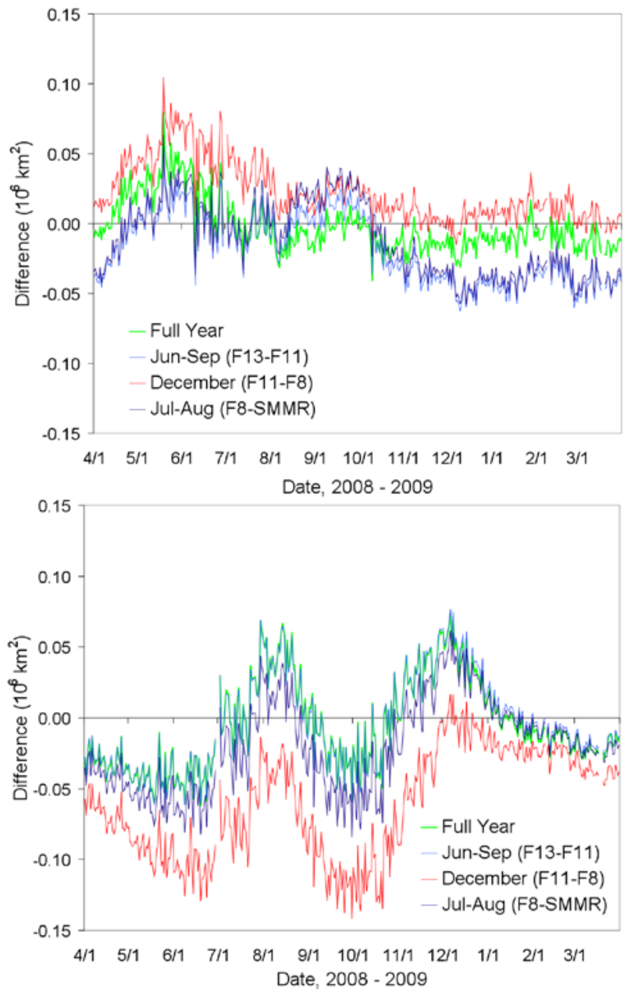

Figure 4. Northern hemisphere (top) and Southern Hemisphere (bottom) daily total sea ice area difference between F-17 SSMIS with adjusted tiepoints and F-13 SSM/I using an overlap period of: (green) full year, (light blue) Jun-Sep F-13-F11, (red) December F11-F8, and (dark blue) July-August F8-SMMR.

Using shorter overlap periods did not necessarily result in larger magnitude differences. It appears the season of the overlap period plays a role. In the Antarctic, the overlap periods during the austral winter (F13-F11 and F8-SMMR) yielded better results than the summer. In the Arctic, this difference is not apparent in the summary statistics (Table 6), possibly because there is not a true boreal winter period. However, the closest period, during December for F11-F8, does show lower magnitude differences through much of the year, except during the peak summer melt season (Figure 4) where, as expected, the summer overlap is much more successful at reducing the differences.

It is hoped that future intercalibrations can be conducted for a full year as this clearly provides superior results. However, the results here show that if a full year is not available, the timing of the overlap can be important in the overall quality of the intercalibration.

5. CONCLUSION

An intersensor calibration of sea ice fields from F-17 SSMIS with F-13 SSM/I has been completed for NSIDC near-real-time sea ice products. The calibration yields good consistency between the two products, providing confidence in a consistent long-term data record.

Sensitivity tests were done to determine the potential effects from using shorter intervals for intersensor calibration as were employed for previous SSM/I and SMMR transitions. The shorter intervals resulted in less consistency, confirming previous speculation that using a full year of overlap is essential for optimal consistency. There is also a clear seasonal signal in the intersenor differences seen during the full year overlap, suggesting that using seasonal tiepoints and conducting intercalibration for each individual season could result in a more consistent time series.

NSIDC also performed intercalibration on the NISE snow cover product, using somewhat different procedures. The details of those results will be published in a separate manuscript. However, we note here that in addition to the standard intercalibration issues discussed above, we identified errors in the F17 37H channel data that occurred during spring and summer 2009. These affected the snow products but not the sea ice products. This problem complicated the snow product intercalibration and raised some concerns about the reliability of the near-real-time source data. Fortunately, these problems were resolved by a change in the ground data processing system in August 2009; since then, we have noticed no further problems. With the high visibility of sea ice products, it is important to have consistent and reliable input data sources.

6. REFERENCES

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[7] Wentz, F., "A well-calibrated ocean algorithm for special sensor microwave/imager," *J. Geophys. Res.*, 102(C4), 8703-8718, 1997.

APPENDIX B:

Metadata Table Example

Metadata Element	**Format**	**Value**
fileIdentifier	CharacterString	File name - .bin + .xml
language	CharacterString	eng
characterSet	MD_CharacterSetCode	utf8
parentIdentifier	CharacterString	file name of the metadata file for the dataset
hierarchyLevel	MD_ScopeCode	dataset scope code
hierarchyLevelName	CharacterString	dataset
contact	CI_ResponsibleParty	same as in dataset metadata
dateStamp	Date	Date metadata was generated
metadataStandardName	CharacterString	ISO 19115 Geographic Information - Metadata First Edition
metadataStandardVersion	CharacterString	ISO 19115:200(E)
dataSetURI	CharacterString	ftp://sidads.colorado.edu/pub/DATASETS/seaice/polar-stereo/bootstrap/final-gsfc/....
identificationInfo*	MD_Identification	see relevant table
metadataMaintenance*	MD_MaintenanceInformation	" "
metadataExtensionInfo*	MD_MetadataExtensionInformation	" "
referenceSystemInfo*	MD_ReferenceSystem	" "
spatialRepresentationInfo*	MD_SpatialRepresentation	" "
dataQualityInfo*	DQ_DataQuality	" "
contentInfo*	MD_ContentInformation	" "
metadataConstraints*	MD_Constraints	" "
distributionInfo[0..1]	MD_Distribution	Same as in dataset metadata
acquisitionInformation	MI_AcquisitionInformation	Same as in dataset metadata

* objects are defined in a separate table

As an example the identificationInfo table is included below:

Metadata Element	**Format**	**Value**
__citation[1]__		
title		Bootstrap Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I [list dates you used]
alternateTitle	CharacterString	NSIDC-0079
__date__		
date	Date	date of the data collection

dateType	CI_DateTypeCode	creation
edition		2
editionDate		2/1/00
identifier		NSIDC-0079
__citedResponsibleParty__		Same as dataset level
__resourceConstraints__	MD_Constraints	
useLimitation[0..*]	CharacterString	Documentation->Limitations of the data;Documentation->summary->Important Note
__MD_LegalConstraints__		
useConstraints	MD_RestrictionCode	from data set level
otherConstraints	CharacterString	Documentation->Citation (To broaden awareness of our services, NSIDC requests that you acknowledge the use of data sets distributed by NSIDC. Please refer to the citation below for the suggested form, or contact NSIDC User Services for further information. We also request that you send us one reprint of any publication that cites the use of data received from our Center. This helps us to determine the level of use of the data we distribute. Thank you.)
__MD_SecurityConstraints__		
classification	MD_ClassificationCode	unclassified
__resourceFormat__	__MD_Format__	
name	CharacterString	original Goddard Space Flight Center (GSFC) flat binary two-byte integer format
version	CharacterString	same as data set version
specification	CharacterString	Documentation->Detailed Data Description->Format
__aggregationInfo__	__MD_AggregateInformation__	Citation information for the dataset

aggregateDataSetNam	Bootstrap Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I	
associationType	DS_AssociationTypeCode	largerWorkCitation
Spatial Resolution	See spatial coverage section in section 2 of documentation	

APPENDIX C:

Summary of Presentation to WCRP CliC Science Steering Group Meeting, Valdivia, Chile, 5-8 February 2010

Calibrating sea ice climate products

Walt Meier
National Snow and Ice Data Center

Sea ice data from space-borne passive microwave sensors provide one of the longest satellite climate records. The 30+ record shows significant declining trends in Arctic sea ice extent, particularly during the summer, and a small increasing trend with strong regional and interannual variability in the Antarctic.

However, there are several issues with the passive microwave data that could be improved to make the derived estimates a true climate data record. In addition, there have been several satellite/sensor issues in recent years, as well as potential future issues, that threaten to degrade the quality of the record.

Sea ice concentration products summary

Sea ice concentrations are derived from the measured brightness temperature – a function of the physical temperature and the microwave emissivity of the surface – using empirically derived algorithms. Over the years, several algorithms have been developed. Each algorithm is able to reasonably track the season and interannual variability, but each has limitations and significant uncertainties, most notably during summer melt conditions, over thin new ice, and near the ice edge. No single algorithm has been found to be clearly superior. Thus, several different products have been developed (see below for list of sources). The most commonly-used algorithms in the scientific community are the NASA Team and Bootstrap algorithm, both developed at NASA Goddard. An enhanced NASA Team algorithm (often called NASA Team 2) has been developed for use with AMSR-E (see below for acronyms). Other algorithm products include the Norsex (Nansen Environmental and Remote Sensing Center Arctic ROOS) and ARTIST (University of Bremen) algorithms.

Sea ice concentration intersensor calibration

Another issue with passive microwave sea ice products is that unlike many other satellite-derived geophysical quantities, calibration at the sensor product level (i.e., brightness temperatures) is not sufficient to assure consistency between sensor transitions. Instead, it is necessary to intercalibrate at the product level by adjusting algorithm coefficients. This adds another level of complexity and uncertainty. This product-level adjustment is necessary because of the heterogeneity of the sea ice surface and the effect of the strong seasonality in the sea ice cover. The seasonality is of particular concern because the emissive properties of the surface depend significantly on whether water is in the liquid or solid phase – i.e., the emissive character varies substantially between summer and winter). Thus, ideally a full-year of overlap is desired to encompass all seasonal variability of sea ice in both the Arctic and Antarctic. However, sensor overlaps have generally been much shorter, with as little as two weeks of overlap.

Developing climate products from operational sensors

Even though sea ice concentration/extent is a key climate variable, the satellite sources for such data are largely operational satellites (a series of SSM/I and SSMIS sensors on U.S. Department of Defense DMSP satellites, denoted by an "F-series" number). Because of the operational nature, there are not resources for long overlaps and attention to climate applications.

Of late, this issue has become a particular concern. The SSM/I sensor on F-13 had been the primary source of passive microwave sea ice records since 1995 through early 2008. In January 2008, one of F-13's onboard data recorders failed. This resulted in significant data gaps over large areas. The operational back-up at the time was F-15. However, in August 2006, a "radcal" beacon on F-15, needed for operational support, had been turned on. This corrupted an important channel for the sea ice algorithms. A correction was applied allowing F-15 to be usable for near-real-time sea ice data, but the correction was not suitable for a consistent climate data record.

The operational successor for F-13 was F-17. F-17 was launched in November 2006. However, data was not released until the end of March 2008. Thus between January and March 2008 there are degraded products. Adjustments were made to the F-13 data recording to reduce the data gaps and F-13 was able to provide usable data until another data recorder failure in May 2009. Nonetheless, there is no overlap of complete (without gaps) F-13 data and F-17 with which to do an optimal intersensor calibration of the sea ice products. F-16 is a possible gap-filler, but this is not optimal because F-16 is in a different sun-synchronous orbit and passes over locations at a different local time of day. Because of diurnal effects on sea ice (particularly near the equinoxes), different overpass times result in inconsistencies in the sea ice products.

Another issue is that up through F-15, a series of SSM/I sensors, with consistent manufacturing and instrumentation, was employed. However, with F-16, a new sensor, SSMIS, was used. SSMIS includes the same basic channels as SSM/I, but also includes additional atmospheric sounding channels and is new manufacturer. Though intersensor calibration is needed regardless, the transition from SSM/I to SSMIS is more complicated. Near-real-time sea ice products are currently being produced, but more quality-controlled brightness temperature sources are delayed.

There have been issues using near-real-time SSM/I and SSMIS data. After the data recorder issue of F-13 described above, F-15 was used for near-real-time sea ice products. In February 2009, the "radcal" beacon effect on the channel relevant for sea ice changed dramatically, resulting in significant errors in sea ice fields distributed by the National Snow and Ice Data Center (NSIDC). (As a result, the near-real-time sea ice production at NSIDC temporarily switched back to F-13 until F-17 processing was implemented).

Another error occurred with F-17 SSMIS data. For several months during summer 2009, there was a calibration error in the source data for one of the channels. Fortunately this was not a channel used in at least some distributed sea ice algorithm products (e.g., NASA Team concentrations distributed by the NSIDC), but it was a channel potentially used by other algorithms and was also used in NSIDC snow products. This error went undetected by the operational center until NSIDC notified them and a correction was made.

Such errors can be later corrected for in final quality-controlled climate products. However, there is more and more demand for near-real-time products, by scientists, policymakers, and the public. Errors that are not immediately caught can effect science and policymaker decision and erode public confidence in the data.

Creating Climate Data Records

A climate data record is a long-term, consistent, authoritative climate record, including thorough documentation and metadata, as well as detailed uncertainty estimates. Passive microwave sea ice records are long-term and reasonably consistent because of the intersensor calibration. However, metadata at the file level is minimal and uncertainty estimates are general averages based on case-study validations. There needs to be data quality information at the grid cell level to more fully detail the uncertainties in the retrieved parameters.

The NOAA Scientific Data Stewardship program is funding several projects to create climate data records, including from passive microwave sea ice fields. These projects are ongoing and feedback from the science community is encouraged.

Other passive microwave sea ice climate products

The focus above has been on sea ice concentration and extent records, because it is for these products that there is the greatest concern over intersensor calibration. However, there are other products of note that will contribute to sea ice climate records. These include: melt onset and freeze-up (and hence length of melt season), ice motion, multiyear ice fraction, and Lagrangian-tracked ice age.

And there are other relevant sea ice parameters from other space-borne sensors such as: albedo/temperature from visible/infrared, thickness from laser and radar altimeters, multiyear fraction from scatterometers, leads/ridges/deformation from synthetic aperture radars. Airborne and in situ measurements are also crucial, both as climate records in their own right, but also as sources for calibration/validation of the satellite products.

List of sea ice concentration products:

National Snow and Ice Data Center: http://nsidc.org/data/seaice/
University of Illinois, Cryosphere Today: http://arctic.atmos.uiuc.edu/cryosphere/
Nansen Environmental and Remote Sensing Center Arctic ROOS: http://www.arctic-roos.org/
University of Bremen: http://www.iup.uni-bremen.de:8084/amsr/amsre.html
NASA Goddard: http://polynya.gsfc.nasa.gov/seaice_datasets.html
JAXA: http://www.ijis.iarc.uaf.edu/cgi-bin/seaice-monitor.cgi?lang=e
PolarView: http://www.seaice.dk/

Passive microwave sensor summary

Nimbus-5 Electonically Scanning Microwave Radiometer (ESMR), 1972-1977
Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR), 1978-1987
Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave/Imager (SSM/I), 1987-2009
DMSP Special Sensor Microwave Imager & Sounder (SSMIS), 2002-present
NASA Earth Observing Satellite Program Advanced Microwave Scanning Radiometer (AMSR-E), 2002-present

See next page for more detailed information on passive microwave sensors.

PASSIVE MICROWAVE SNOW AND ICE SOURCES – PAST, PRESENT, AND FUTURE						
Satellite	**Sensor**	**Frequencies (GHz)**	**Launch Date (Data Available) [Data at NSIDC]**	**Ascending Equatorial Crossing Time At Launch (Most Recent, Date)**	**Swath Width (km)**	**Mean Altitude (km)**
Sensors Archived at NSIDC, not used for Snow/Ice Climate Record						
NIMBUS N5	ESMR	19	12/11/72 (12/12/72-5/16/77) [12/12/72-12/31/76]		3000	1095
Sensors used for NSIDC Snow/Ice Climate Record						
NIMBUS N7	SMMR	6,10,18, 37	10/24/78 [10/25/78-8/20/87]	12:00	783	955
DMSP F8	SSM/I	19,22,37,85	6/18/87 [7/9/87-12/30/91]	06:15 (06:17, 9/2/95)	1400	840
DMSP F11	SSM/I	19,22,37,85	11/28/91 (12/6/91-5/16/00) [12/3/91-9/30/95]	18:11 (18:25, 9/2/95)	1400	859
DMSP F13	SSM/I	19,22,37,85	3/24/95 (3/25/95-11/19/09) [5/3/95-12/31/08]	17:42 (18:33, 11/28/07)	1400	850
EOS Aqua	AMSR	7,10,19,23,37,89	5/4/02 [6/18/02-present]	13:30	1445	705
Sensors not yet used by NSIDC for quality-controlled final products						
DMSP F15	SSM/I	19,22,37,85	12/12/99 (1/24/00-present)	(20:41, 11/28/07)	1400	850
DMSP F16	SSMIS	19,22,37,85,+	10/18/03 (11/4/05-present)	(20:13, 11/28/07)	1700	850
DMSP F17	SSMIS	19,22,37,85,+	11/4/06 (3/26/08-present)	(17:31, 11/28/07)	1700	850
Future Sensors						
DMSP F18	SSMIS	19,22,37,85,+	10/18/09 (1/29/10-present)	20:00	1700	833
DMSP F19	SSMIS	19,22,37,85,+	10/2010	17:30	1700	833
GCOM W1	AMSR	7,10,19,37,89	1/2012	13:30	1445	700
DMSP F20	SSMIS	19,22,37,85,+	10/2012	17:30	1700	833
GCOM W2	AMSR	7,10,19,37,89	2015			
NPOESS C2	MIS	19,22,37,85,+	2016	17:30		833
GCOM W3	AMSR	7,10,19,37,89	2018			
NPOESS C4	MIS	19,22,37,85,+	2022	17:30		833
Previous sensors not used by NSIDC for sea ice climate records						
NIMBUS N6	ESMR	37	6/12/75 (6/17/75-8/10/77		3000	1097
NASA Seasat	SMMR	6,10,18,37	6/28/78 (7/7/78-10/10/78)		600	800
DMSP F10	SSM/I	19,22,37,85	12/1/90 (3/9/92-11/4/97)	19:42 (22:08, 9/2/95)	1400	785
DMSP F12	SSM/I	19,22,37,85	8/28/94 (9/8/94-present)		1400	
DMSP F14	SSM/I	19,22,37,85	4/10/97 (4/14/97-present)	18:36	1400	852
JAXA ADEOS-2	AMSR	6,10,19,37,89	12/14/02 [1/27/03-10/24/03]	10:30	1600	803

Updated as of 1 February 2010

ADEOS = Advance Earth Observing Satellite (JAXA)
AMSR = Advanced Microwave Scanning Radiometer
DMSP = Defense Meteorological Satellite Program
EOS = Earth Observing System (NASA)
ESMR = Electronically Scanning Microwave Radiometer
GCOM-W = Global Change Observing Mission for Water (JAXA)
JAXA = Japanese Aerospace Exploration Agency
MIS = Microwave Imager/Sounder (NOAA/DMSP/NASA)
NPOESS = National Polar-orbiting Operational Environmental Satellite System (NOAA/DMSP/NASA)
SMMR= Scanning Multichannel Microwave Radiometer
SSM/I = Special Sensor Microwave/Imager
SSMIS = Special Sensor Microwave Imager and Sounder

APPENDIX D:

The Way Forward

Summary of needed steps for an internationally accepted sea ice CDR

Proposed to WCRP CliC SSG

The Way Forward for Calibrating Sea Ice Products

Walt Meier
National Snow and Ice Data Center

Background

Sea ice data from space-borne passive microwave sensors provide one of the longest satellite climate records. The 30+ record shows significant declining trends in Arctic sea ice extent, particularly during the summer, and a small increasing trend with strong regional and interannual variability in the Antarctic.

Sea ice concentrations are derived from the measured brightness temperature – a function of the physical temperature and the microwave emissivity of the surface – using empirically derived algorithms. Over the years, several algorithms have been developed. Each algorithm is able to reasonably track the season and interannual variability, but each has limitations and significant uncertainties, most notably during summer melt conditions, over thin new ice, and near the ice edge. No single algorithm has been found to be clearly superior. Thus, several different products have been developed. The most commonly-used algorithms in the scientific community are the NASA Team and Bootstrap algorithm (e.g., Comiso et al., 1997), both developed at NASA Goddard. Other algorithm products include the Norsex (Nansen Environmental and Remote Sensing Center Arctic ROOS) and ARTIST (University of Bremen) algorithms. Other algorithms that are not (to my knowledge) used for publically distributed products include the Cal/Val or AES York (Hollinger et al., 1991; Ramseier et al, 1988), the Bristol (Smith, 1996).

Other algorithms, including an enhanced NASA Team algorithm (Markus and Cavalieri, 2000; often called NASA Team 2) and the ARTIST algorithm (Spreen et al., 2007) have been developed to take advantage of high frequency channels (85.5 GHz or 89 GHz) on SSM/I and AMSR-E (see below for acronyms) sensors. The algorithms provide improved spatial resolution and improved discernment of surface properties. However, they are not consistent with other algorithms and they are not applicable to the earlier period (1978-1987) of the SMMR period, as well as some parts of the SSM/I record. Thus, they are not able to provide the longest consistent time series.

The problem with comparing algorithms is that it is not possible to do basin-scale validation – there simply isn't available "truth" data. Validation has been done primarily through case study evaluations using SAR, visible/infrared, and/or in situ data in limited regions over limited time periods (e.g., Kwok, 2002; Emery et al., 1994; Steffen, K., 1991; Cavalieri et al., 1991). Two of the more comprehensive evaluations compared the passive microwave concentrations over a variety of conditions and times of year (Andersen et al., 2007; Meier, 2005) found that the performance of the algorithms varied depending on atmospheric and surface conditions. It was not possible to determine a clearly superior algorithm.

Impacts of Multiple Sea Ice Products

For each of the algorithm products, there are dedicated user communities, particularly for the NASA Team and Bootstrap algorithm, both of which are distributed by NSIDC. (There are roughly three times as many NASA Team users [737 users according to latest user statistics] as Bootstrap [286 users]). There are also a number of users of the AMSR-E sea ice products, which in addition to the NASA Team 2 concentration also makes available a Bootstrap product. It should be noted here that the follow-on to AMSR-E, AMSR2, to be launched in late 2011, on the JAXA GCOM-W satellite, has selected the Bootstrap to be the primary algorithm, although the NASA Team 2 and ARTIST products will be available as "research products". A different standard algorithm product is possible for the NPOESS MIS sensor if and when it is launched.

So, if anything, the family of sea ice products is growing and diversifying. Within each dedicated knowledgeable user community, the issues may not be relevant. As long as they understand the algorithms and their limitations and use them properly, any algorithm is potentially suitable. However, sea ice has been found to be an important component of the global climate system with impacts across a broad spectrum of activities – e.g., climate modeling, biological monitoring, native populations, resource access, national sovereignty, national defense, tourism. These varied communities do not have the detailed experience with the vagaries of passive microwave remote sensing. They need one sea ice product, with clear associated uncertainty estimates and metadata. In addition, sea ice has become an icon of climate change in the non-science community of politicians, educators, students, media, and the general public. They also do not understand the details of the different products and varied estimates from the products sows confusion within the public discourse.

The Way Forward

While individual products will likely continue into the future due to dedicated user bases who want continuity in their research, the way forward is to come to a consensus on a general "authoritative" reference product that can be referenced by the wider (i.e., non sea ice scientist) community. Essentially, the need is for a climate data record that includes a standard sea ice concentration field, a data quality field, and associated metadata and documentation to allow for proper use.

There are several NOAA Climate Data Record (CDR) projects being funded, including at least two directly relating to sea ice products (W. Meier is PI on one and co-PI on the other) through the NOAA Scientific Data Stewardship program. There are also NASA Earth Science Data Record (the equivalent of CDRs) projects, though none (to my knowledge) specifically focused on passive microwave sea ice products. Finally, the European Space Agency is also developing a CDR to use as a basis for their operational sea ice products (and potentially other users).

The NOAA projects are developing metadata standards and parameters for data quality information as well determining a single standard product to be archived as a CDR. However, selection of a standard product should be a community decision. Thus, input from the scientific community is needed to develop a consensus view. It may be that a combined algorithm will prove to be the best decision or it may be one of the current products that have already been developed. A dedicated workshop with a representative group of invited users to review the current products and recommend future directions would be most useful, though town hall meetings at a scientific conference (e.g., AGU) where interested parties are likely to attend and/or some sort of online survey may be sufficient. CliC's support of such an activity would be beneficial because CliC can act an impartial arbiter and has the reputation within the polar science community to build a consensus. (NSIDC, as distributor of products, is not able to officially endorse either NASA Team or Bootstrap [or other algorithm] products.)

Because there is already a dedicated user community for several products, it is not likely that current products will be discontinued. However, they could be kept as secondary products at a lower level of support and little future development, while the official CDR would be the primary and most visible resource. In addition, because sensor systems have improved over time and algorithms to exploit those improvements (e.g., NASA Team 2 and ARTIST for AMSR-E), it likely makes sense to provide parallel CDRs: (1) a climate CDR that uses a consistent algorithm and methods from the beginning of the passive microwave record in 1978, and (2) an operational CDR that uses the best available sensor, algorithm, spatial resolution, etc. for any given time period to provide the most accurate estimates at that time (but will not be consistent over time, so not suitable for tracking long-term trends and variability over the full passive microwave record).

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List of sea ice concentration products:

National Snow and Ice Data Center: http://nsidc.org/data/seaice/
University of Illinois, Cryosphere Today: http://arctic.atmos.uiuc.edu/cryosphere/
Nansen Environmental and Remote Sensing Center Arctic ROOS: http://www.arctic-roos.org/
University of Bremen: http://www.iup.uni-bremen.de:8084/amsr/amsre.html
NASA Goddard: http://polynya.gsfc.nasa.gov/seaice_datasets.html
JAXA: http://www.ijis.iarc.uaf.edu/cgi-bin/seaice-monitor.cgi?lang=e
PolarView: http://www.seaice.dk/

Passive microwave sensor summary

Nimbus-5 Electonically Scanning Microwave Radiometer (ESMR), 1972-1977
Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR), 1978-1987
Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave/Imager (SSM/I), 1987-2009
DMSP Special Sensor Microwave Imager & Sounder (SSMIS), 2002-present
NASA Earth Observing Satellite Program Advanced Microwave Scanning Radiometer (AMSR-E), 2002-present
JAXA Global Change Observation Mission for Water (GCOM-W) AMSR2, planned launch Nov. 2011

APPENDIX E:

Proposal to CliC for a workshop on sea ice climate data records

CliC and CliC-related meeting proposal/plan for 2010

1. Who proposes the meeting and in which capacity (e.g. CliC Theme and WG leader, etc.)

Walt Meier, member of Sea Ice Working Group and Observation Products Panel

2. Title of meeting or workshop

Toward a passive microwave climate data record

3. Proposed venue

Boulder, CO or Washington, DC

4. Proposed dates

October-November 2010 (Possibly before/after NSIDC User Working Group Meeting in DC during that timeframe (specific dates TBD)

5. Proposed attendees, including likely number

~15-20; selected NSIDC User Working Group members (3-4), NASA Goddard sea ice persons (2-3), CDR project personnel (J. Key, NOAA; D. Robinson, Rutgers Univ.; J. Maslanik, Univ. Colorado), European algorithm developers (G. Heygster, Univ. Bremen; L.T. Pedersen, DMI; L.A. Breivik, met.no; S. Eastwood, met.no), data users (modelers – e.g., M. Holland, NCAR; R. Lindsay, Univ. Washington; F. Kauker, AWI; - other users, e.g., C. Geiger (CRREL), D. Perovich (CRREL), W. Abdalati, Univ. Colorado, Antarctic users (e.g., T. Worby, S. Ackley); CliC personnel (D. Yang, or K. Steffen)

6. Rationale and relevance to CliC themes and future activities

Sea ice is a primary component of the climate system and in the Arctic is one of the most dramatic indicators of climate change. However, there have been several algorithms developed, none of which is clearly superior. In addition, the algorithms have little data quality information and/or metadata information. An authoritative, consistent sea ice concentration product – a single algorithm, a combined algorithm, or a small suite of algorithms – would provide a community-wide accepted baseline for model validation/input, process studies, and use by non-sea ice remote sensing experts (e.g., biologists, oceanographers, modelers, etc.).

7. Specific objectives and key agenda items

Discuss various algorithms, their strengths and weaknesses, uncertainties (in specific terms), select algorithms, error/uncertainty information that should be included, data format (e.g., projection, file format, etc.).

8. Anticipated outcomes (deliverables)

A clear decision and way forward on at least an approach to determine an optimal algorithm or suite of algorithms for use by a broad community, selection of necessary parameters to assess data quality and/or confidence levels and the process to derive these parameters, and finally input into data format (projection, file types, etc.). The work in implementing these decisions would be done through currently-funded NOAA Scientific Data Stewardship grants, and possibly other support (e.g., EUMETSAT).

9. Science Organising Committee (if any or relevant)

Walt Meier and Waleed Abdalati

10. Local Organising Committee (if any or relevant)

NSIDC (W. Meier) if in Boulder, NASA Goddard if in DC

11. Proposed funding sources and anticipated funding request from WCRP

Funding is requested to support travel for key personnel. Boulder or DC locations would allow several parties to be on-site. A target of 15-20 persons attending, with a few local and hopefully some that may have their own funding would result in travel support for ~10-15 persons. Having the meeting in coordination with the NSIDC User Working Group meeting could also limit travel costs for the UWG participants. Travel costs are estimated to be $10,000 for 10 US attendees ($1000 each), and $5000 for 2 European attendees ($2500 each). Refreshment cost is about $1000. The total request is $16,000.

12. Additional comment and information, web link etc. (if any)