Satellite-derived Sea Ice Products Community Workshop Report

Sponsored by WCRP Climate and Cryosphere (CliC) Project Office

NASA Goddard Space Flight Center, Greenbelt, MD

15-16 March, 2011

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II. Workshop Summary

On 15-16 March 2011, twenty-six people attended the WCRP CliC "Satellite-derived Sea Ice Products Community Workshop" at NASA Goddard Space Flight Center, in Greenbelt, Maryland, USA. The focus of the meeting was to bring together people who produce various passive microwave sea ice concentration products as well as users to compare approaches and discuss ways to better collaborate, improve products, and address user needs. Before the meeting, all parties were requested to fill in a template for their products. These were distributed to all attendees and were used as the basis for discussions. These are provided in Appendix III. Detailed minutes were taken during the meeting and are available on request. A list of acronyms used in this report is provided in Appendix I.

The first part of the meeting involved a review and discussion of the various products. Then users discussed related products and needs regarding PM sea ice concentration data sets. The second half of the meeting was a general discussion that ranged across several topics including: creating common, updated land masks and regional masks, developing useful grid-cell level quantitative uncertainty estimates, discussing standards for minimum concentration thresholds and climatology periods, potential integration with other products, encouraging thorough data versioning and appropriate data set citation, and planning for future collaborations.

Outcomes from the meeting include plans to share common products (e.g., land masks), make a request for the U.S. National Ice Center to produce an updated Antarctic land mask, collaborate on a peer-reviewed journal article, follow-up with a session at AGU, and continue collaboration in the future. Key recommendations and future actions are listed in Section III, followed by details on presentations and discussions at the workshop.

Attendees included algorithm/product developers from NASA, NSIDC, NOAA, the University of Illinois, the University of Nebraska, JAXA, Environment Canada, and EUMETSAT as well as user groups from the NOAA SST group, Canadian and U.S. operational ice centers, and Canadian sea ice model development. Comments from invitees who were unable to attend were collected before the meeting and included in the discussions. These are included in Section VII.

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III. Key Recommendations and Future Actions

1. Attendees should continue to work together on an ad hoc basis and collaborate where possible. A follow-on meeting should be held in 2-3 years. Informal meetings could be held in the meantime (e.g., CliC Sea Ice Working Group workshops, EGU/AGU town halls, etc.)

2. Participants will contribute to a CliC Report/White Paper on the meeting. Planned submission by end of summer 2011. The report will provide the basis for an AGU Eos news report on the meeting.

3. A proposal for a special session at the Fall 2011 AGU was submitted, focusing on sea ice and other cryospheric climate records.

4. The idea of an 'ensemble' sea ice product, combining multiple products is a good idea, but difficult to do and there is currently no support. It could perhaps be done occasionally on an ad hoc basis.

5. A peer-reviewed journal review article on the passive microwave sea ice products will be submitted. A primary purpose will be to serve as a reference for the IPCC 5th Assessment Report. The paper will discuss each of the products, intercomparisons of the products, assessment of uncertainties, and ensemble estimates of sea ice area and extent. The target date for submission is by spring 2012, with publication by mid-2012.

6. A common region mask should be created and shared for studies where possible.

   (a) The region mask for the MASIE product will be used as the basis, after adding regional divisions for: the Sea of Japan, Baffin Bay, Labrador Sea, and Davis Strait. Current MASIE regions are here: http://nsidc.org/data/masie/browse_regions.html

   (b) The northern boundaries of the coastal seas of the Arctic Ocean (Beaufort, Chukchi, etc.) should be researched – is there a common definition (e.g., Int'l Hydrographic Office)?

   (c) Antarctic regions will be based off the Parkinson et al. (1999) regions, distributed by NSIDC (http://nsidc.org/data/polar_stereo/tools_masks.html#region_masks)

   (d) Regional maps should be provided as shapefiles and in EASE and polar stereographic grids. CliC should consider a small amount of support from remaining workshop funds to produce these.

7. New land masks are needed, especially in the Antarctic. NIC should be supported to create a new mask.

   (a) Participants will sign joint letter in support of the U.S. National Ice Center to create new masks using SAR imagery (100 m resolution). Initially, this will be for a new Antarctic mask, though a mask for the Arctic will also be useful.

   (b) Mask will be created as a shapefile, which can then be converted into EASE or polar stereographic.

(c) Particularly in Antarctica, there should be up-to-date masks, annually updated. This will better enable near-coastal process studies (e.g., polynyas) as ice shelf boundaries change.

(d) There should be a common land mask for hemispheric climate studies to provide a consistent record for long-term trends.

8. Data citation and data versioning are essential, particularly with so many different sea ice products. Journal articles often only ambiguously cite the data source. Metadata to document processing methods area crucial as well.

9. A common climatology reference period should be used. Currently, 1979-2000 is common, but this is shorter than the frequently used 30-year standard. However, years after 2000 show prominent changes. The "Cryosphere Today" (W. Chapman) has switched to a 1979-2008 climatology, largely in response to public outcry. A key is for the period to be justifiable – are there statistical methods to determine an optimal baseline period for a given data set?

10. A 15% concentration threshold for the sea ice edge is most appropriate for intercomparisons because of its common legacy. However, it does not necessarily represent the true accuracy of the products. Other thresholds may be appropriate for specific studies.

11. HDF5/NetCDF4 is the recommended data format. Most climate models prefer NetCDF4 and it is a standard for Climate Data Record products (e.g., NOAA).

12. Barring sensor/satellite/launch failures, passive microwave sensors are currently planned through at least 2020. The passive microwave sensor record is essential for a long-term record of sea ice concentration and extent and needs to be extended into the foreseeable future. Transitions between missions should include substantial overlap periods (1+ year) for sensor/algorithm intercalibration.

IV. Summary of Presentations

The focus of the workshop was primarily to elicit discussion between the various producers and users of passive microwave sea ice concentration data. However, attendees were encouraged to submit product slides, containing a table of key characteristics of each product, which they would briefly present. Those product slides are included in the appendix at the end of this report. In addition, some attendees were requested to give more in depth talks. Notes on all talks are provided in the Minutes, but here selected talks or groups are talks are more formally summarized. References are not provided in this summary, but a bibliography and list of websites are provided in Sections VIII and IX.

Product Summaries

EUMETSAT Ocean and Sea Ice Satellite Application Facility (OSI SAF) – Lavergne

EUMETSAT is the operational European satellite community, akin to NOAA in the United States, and is a consortium among several countries. A sea ice product was developed to support OSI SAF. The product was developed via an assessment of several algorithms. Two versions exist, a climate record and an operational product. The climate record includes substantial quality control and, rare among sea ice products, quantitative error estimates for each grid cell. The error estimates are based on variation in tie points (algorithm coefficients based on "pure" ice or open water), which are calculated dynamically each day based on the input passive microwave brightness temperatures. A radiative transfer model is used to apply an atmospheric correction (i.e., remove weather effects) based on ECMWF atmospheric reanalysis data and provide input to the error estimate. The error estimate also considers the effect of different footprint sizes of the different channels used in the algorithm. Unlike other products, the algorithm is run on swath data, with concentrations later gridded. The operational near-real-time product does not include dynamic tie points.

ESA Climate Change Initiative (CCI) – Wadhams

The CCI is an initiative to develop and improve Essential Climate Variables (ECVs). Ten ECVs have been initially selected, including sea ice. The sea ice proposal was not funded in the initial round of selections however. The proposal will be re-submitted, with an increased focus on multiyear sea ice and scatterometer data.

NASA/NSIDC sea ice products – Meier, Cavalieri, Comiso, Fetterer

NSIDC distributes two SMMR-SSM/I sea ice algorithm products, from the NASA Team and Bootstrap algorithms, both developed at NASA Goddard. NSIDC also distributes NASA Team 2 (also developed at NASA Goddard) and Bootstrap algorithm products from AMSR-E. The NASA Team and Bootstrap are among the earliest developed algorithms. The Bootstrap product was recently revised so that estimates from AMSR-E and SMMR-SSM/I are as consistent as possible. The final products are provided by NASA Goddard, but NSIDC distributes a near-real-time version of the NASA Team algorithm. This provides a continuous and up-to-date time series for the NSIDC Sea Ice Index, a NOAA-funded site for distributing images and summary time series data. The primary difference between the NRT version and the

Goddard-produced version is that Goddard includes a post-processing manual QC step to remove erroneous data. These data are also the source for NSIDC's Arctic Sea Ice News and Analysis. NSIDC uses a 1979-2000, 22-year baseline for its climatology, but is considering changing to a 30-year period.

The NASA Team 2 product uses an approach similar to the NASA Team, but uses the high frequency channels (85 GHz or 89 GHz) available on the SSM/I and AMSR-E sensors to remove surface ambiguities, along with a radiative transfer model to correct for atmospheric effects on the retrieved sea ice concentrations. It provides much more accurate concentrations compared to the NASA Team retrievals , particularly in the Antarctic, but the NASA Team 2 algorithm is limited to use with the later SSM/I sensors (post-1991) and AMSR-E.

NOAA/NSIDC Sea Ice Climate Data Record – Meier

This is a NOAA-funded project to create a PM sea ice concentration dataset that meets CDR requirements for transparency, reproducibility, and documentation (metadata and provenance information). The product will be delivered by October 2011. The product uses a combination of the NASA Team and Bootstrap algorithm, but unlike the other NSIDC products, the CDR will be processed only at NSIDC using only traceable, automated methods. Software and full documentation will be provided and the data will be distributed in NetCDR format with Climate and Forecasting metadata. Each grid cell will include data quality information.

University of Illinois Cryosphere Today – Chapman

This is a summary product that provides images and time series of sea ice data. Unlike other sites, the focus here is on sea ice area, not extent. The input data for the time series is NSIDC NASA Team data, but AMSR-E data from the University of Bremen are used for the browse images.

ARTIST Sea Ice (ASI) algorithm products – Kern, Heygster

This algorithm uses the high frequency passive microwave channels (85 GHz on SSM/I, 91 GHz on SSMIS, and 89 GHz on AMSR-E) to derive concentration/extent. This provides higher spatial resolution, up to 6.25 x 6.25 km gridded resolution for AMSR-E. The University of Bremen uses the ASI algorithm to create its time series and browse products. These are provided daily in near-real-time.

ArcticROOS – Heygster

ArcticROOS is an unfunded parallel effort to DAMOCLES. Participants volunteer effort and data. Data includes PM sea ice, as well as scatterometer, MODIS, and SAR. Data are publically available except for SAR, which requires a password. MODIS is used to estimate snow grain size and soot (based on albedo).

JAXA sea ice products – Cho, Nihashi

AMSR2 on GCOM-W1 will be launched in early 2012. AMSR2 is a JAXA follow-on to AMSR2, with some improvements. The standard algorithm will be Bootstrap, but NASA Team 2, ASI, and a thin ice product (for Sea of Okhotsk). Value-added products are also being investigated, including a thin ice thickness algorithm, heat flux, salt flux, and ice production.

User input

Sea surface temperature – Brandon

Sea ice retrieval is necessary as a mask for SSTs. As ice concentration increases, SST biases will increase, so with accurate concentration values, a threshold or interpolation scheme can be devised. Because of low resolution of PM sea ice data, it is known that SSTs near the ice edge are not as accurate. NOAA and several other groups produce SST fields, from PM and/or IR data. These groups have collaborated to form the GHRSST. They have an ensemble SST estimated combined from all sources, and an intecomparison site with each individual product (website links in Section VII). This type of approach could be used for sea ice.

Melt onset – Anderson

A NASA project to create a snow ESDR, including snow melt onset over sea ice, is being led by Dave Robinson at the University of Rutgers, with Mark Anderson contributing the melt onset field. The plan is to use the NOAA/NSIDC sea ice CDR as an ice mask for the melt onset algorithm (and then the melt onset field could be used as a quality flag in the sea ice CDR). A significant issue is how to merge the land and sea ice product. Neither the snow nor the sea ice algorithms work well near the coast. Also, there are several snow products at different resolutions, so integrating these into a unified product will be difficult.

National Ice Center – Helfrich, Fetterer

The National Ice Center produces bi-weekly operational ice charts, created by manual data fusion of several data sources, primarily for navigational support. They also produce a daily ice edge, also for navigational support. Finally, they produce the NOAA IMS snow and ice extent product. This is primarily for input into weather models and is created independently of the ice charts and daily ice edge (though much source data is used). The IMS was originally at 24 km resolution, is now at 4 km resolution, and it is planned to go to 1 km resolution in the future. The IMS uses primarily MODIS visible/IR, SAR, and scatterometer data, as well as the high-frequency (89 GHz) AMSR-E brightness temperatures, but uses other PM data if necessary. However, it provides a largely-independent NRT source with which to compare PM sea ice fields. The IMS is only extent (ice or no-ice), but comparison with PM concentration fields can be done by using the 4 km ice or no-ice grid cells to calculate a concentration at 25 km resolution. The IMS fields are distributed directly to users and, in collaboration with NSIDC, through the Multisensor Analyzed Sea Ice Extent website (see Section VII) in multiple formats: GeoTIFF, KMZ, Shapefile, and PNG. Text data fields and browse time series images of total extent are also provided.

Canadian Ice Service – Howell, Carrieres

The Canadian Ice Service produces weekly operational charts for Canadian waters. The charts were created manually using a variety of input satellite, airborne, and surface data. PM data is used in the charts, but since Radarsat's launch in 1996, PM has been used very little. Recently a complete reanalysis of the chart archive has been completed, with QC to remove errors and provide a consistent long-term record, dating back to 1968 for some regions. This product provides a potentially useful comparison product for PM data, especially after Radarsat became the primary source for the charts.

The Canadian Ice Service is also developing data assimilation methods to combine sea ice data and with models to improve analysis and forecasts. PM concentrations are assimilated into the model, but a lot of quality control on the PM data is necessary to remove biases.

Ship observations – Ozsoy-Cicek

Antarctic sea ice observations were collected on a 2006 cruise by the *Oden* with one focus being on AMSR-E validation and comparison with NIC charts. Ship observations were collected every 30 minutes. The AMSR-E data did not detect ice until the ship was in ~20% ice cover. This makes sense because the AMSR-E product uses a 15% threshold. NIC charts did a good job a detecting the ice edge, but that the goal for NIC, so it is not unexpected. At high concentrations (>80%), AMSR-E performed well, but less so at lower concentrations.

V. Summary of Discussion

After presentations were completed, the rest of the meeting focused on discussion of various issues relating to the different products and how they could be made more consistent. A recap of all the issues discussed can be found in the minutes (Section VI). Here a summary is provided of the major themes that surface during the meeting, including: potential ensemble sea ice products, land masks, regional masks, uncertainty estimates, concentration thresholds, climatology period, use of swath vs. gridded input fields, data versioning and citation, and grid/projection.

Ensemble Sea Ice Product

A major issue and one of the drivers of the workshop was the confusion caused by the plethora of sea ice products available. While some users would prefer to have one single sea ice concentration estimate, there is value in have several groups independently producing estimates. Like the myriad global surface temperature products, having several independent estimates provides insight into uncertainties and also provides a cross-validation between products. For example, when one channel of the SSM/I sensor became corrupted in early 2008, the AMSR-E products were useful for finding and diagnosing the issue.

However, there are difficulties in having multiple products. Different products get quoted in different places, both in scientific circles and in the public. For example, the IPCC 4th Assessment used the Bootstrap product, primarily because J. Comiso was a lead author for the sea ice section. Likewise, the NSIDC NASA Team product is being used for the Arctic Council “Snow, Water, Ice, Permafrost in the Arctic” (SWIPA) assessment report, primarily because W. Meier is a lead author for the sea ice section. For the SEARCH Sea Ice Outlook, the NSIDC NASA Team product is the baseline dataset, due to the involvement of NSIDC in the Outlook. Science investigators use whichever product they are familiar with (e.g., NSIDC has significant users for both NASA Team and Bootstrap products).

One approach is to try to follow the GHRSST lead and create an ensemble sea ice product. This was felt to be unwieldy because of the different grids, land masks, etc., employed by the products – it would take significant effort to homogenize the products enough to be combined. A simple approach would be to create an ensemble total extent estimate, or to provide all estimates in one place (e.g., a common website), but this would also take coordination and resources.

Thus, continually updated ensemble estimates are not seen as being feasible at this time. However, there was broad agreement to collaborate on common issues. Collaborating on a joint review paper is planned. This review paper could be a reference for the next IPCC assessment. Below are summaries of some of the primary potential issues for future collaboration.

Land masks

Each group uses potentially different land masks, and even at NSIDC there are different Antarctic land masks for the NASA Team and Bootstrap products. Both use standard land masks developed several years ago for the Arctic, but in the Antarctic, an updated land mask was developed for the Bootstrap product that addressed changes in the ice shelves (e.g., the break-up of the Larsen-B ice shelf) since the original land mask was created. To be clear, "land mask" here refers to a mask that flags all non-ocean grid cells (including ice shelves). These land masks are imbedded within the sea ice concentration fields.

The issue with land masks is one of consistency over the long-term vs. the most accurate at a given time. For process studies – e.g., coastal polynyas – it is important to have the most up-to-date land mask. For example, using the long-term NSIDC Antarctic land mask does not allow users to investigate sea ice in the Larsen-B region. However, using changing land masks introduces inconsistency into the long-term timeseries. For example, removing the ice shelf after Larsen-B broke up allows sea ice to be detected there. This results in an artificial increase in sea ice extent because sea ice occurs where it didn't before, but only because the ice shelf had been present.

There is also a practical matter of creating new land masks. A new land mask might be created every year or at least after any significant change in the coastline. However, who would create these masks and how would resources be found to do this are open questions. NIC stated that they are hoping to update their Antarctic land mask and are trying to find support to do so. It was suggested that a group letter could be provided to NIC would help find support. It was agreed to draft and send such a letter.

The optimal plan would be to create land masks for each year, or an update after each significant change in the coastlines. This "basic" land mask could be imbedded in each daily or monthly ice concentration field. Then a "climate land mask" would also be available that would overlay the fields and provide a consistent mask over the entire timeseries for tracking trends and variability. The "climate land mask" would mark any location as land that had been land at any point during the timeseries. The NOAA/NSIDC CDR product plans to take this approach, where the input NASA Team and Bootstrap retain their individual land masks, but the sea ice CDR parameter uses a combined land mask that flags land in either NASA Team or Bootstrap as land.

Regional masks

In addition to total extent over the entire Arctic and Antarctic, examination of sea ice in specific regions is also of interest as the ice trends and variability differs depending on location, as well as for regional process studies. Parkinson et al., (JGR, 1999) developed a regional mask for the Arctic and Antarctic to track these trends. The Antarctic mask consists of longitudinally-bounded sectors that encompassed the major coastal seas. The Arctic is delineated by the Arctic Ocean, seas surrounding the Arctic Ocean proper (e.g., Sea of Okhost, Bering Sea), and other distinct bodies of water (e.g., Hudson Bay, Canadian Archipelago waters). Meier et al., (Ann. Glaciol., 2007) adapted the Parkinson regional divisions, splitting the single Arctic Ocean region into separate components of its coastal seas (e.g., Beaufort, Chukchi) and a central Arctic region around the pole. The MASIE product used those regions as a general guide for its Arctic regions (though the MASIE regions were drawn independently).

One point of discussion was of the northern boundary of the Arctic Ocean coastal seas. There is not clear geographic boundary for some of the seas, though the northern points of Russian islands provide some rationale for seas on the Siberian coast. Is there an agreed upon maritime definition? A web search was conducted, but nothing definitive was found.

Other groups have used other regional divisions, but it was agreed that the Cavalieri/MASIE divisions were generally reasonable, though the operational ice centers suggested breaking up some regions (e.g., the Sea of Japan from the Sea of Okhotsk). The MASIE regions will be formalized by NSIDC and produced in different formats (GIS, gridded) and made available to all. For the Antarctic, the original Parkinson regions were deemed acceptable and NSIDC will produce the mask in the same formats as for the Arctic.

Uncertainty estimates

A key deficiency of most sea ice concentration products is a lack of grid cell uncertainty estimates. Several validation case studies have been conducted and general error characteristics are well-known within the sea ice community. For example, algorithms tend to underestimate concentration under melt conditions; thin ice also tends to be underestimated. Uncertainties are high near the ice edge due spatial resolution, temporal averaging, atmospheric and ocean emission. False ice can occur along the coast due to the effect of mixed land-open water grid cells and in the open ocean due to wind roughening and/or liquid water in the atmosphere.

Many users desire a quantitative uncertainty estimate, or at least some indicator of data quality at each grid cell. This is extremely useful when combining with other data or within models (assimilation). The OSI-SAF product is the only current product that supplies quantitative grid-cell error estimates. The NOAA/NSIDC CDR will provide a data quality flag and a quantitative indicator of uncertainty, though not a specific error estimate. The NASA Team 2 product (in AMSR-E) could produce an uncertainty estimate based on the radiative transfer model used for the algorithm, but it is not currently doing so.

Uncertainty estimates can be based empirically, based only on PM data – e.g., scatter of brightness temperatures around the designated tie points, or they may be derived in conjunction with ancillary data from other sources of sea ice data (e.g., visible/IR, SAR) and/or atmospheric fields.

Concentration thresholds

Because of the low spatial resolution of PM sensors, the precision of the ice edge location is limited and it is inevitable that some ice will be missed in some conditions and will be overestimated in other conditions. A concentration threshold is generally set to provide a consistent cut-off and to eliminate spurious ice due to weather effects. The most common threshold is 15%, though the ArcticROOS uses a 30% threshold. A 15% threshold is useful because it is fairly low, but still cuts off most spurious ice. In some past validation studies, the 15% threshold appeared to match reasonably well with the true ice edge determined from comparison data. However, the amount of agreement depends considerably on the character of the ice edge and errors of 10s of kilometers may occur, regardless which threshold is used.

Climatology period

The typical climate “normal” period is 30 years. This was chosen to be long enough to remove most large scale interannual climate variability (e.g., effects of ENSO, the Arctic Oscillation, etc.) yet short enough to likely be relatively stable (i.e., small trends). NSIDC originally chose a 22-year climatology period (1979-2000). Originally, this was solely based on how much data was available at the time. Since then, it has been preserved for two reasons. First, it provides a consistent baseline, year after year. Second, since 2000, the sea ice has experienced a significant downward trend, which introduces a strong trend over part of the "normal" period. However, using only part of the time series as the basis for the climatology gives the appearance of cherry-picking and NSIDC and other groups have had several critiques because of its short climatology period. In response to criticism, the University of Illinois Cryosphere Today recently switched to a 30-year 1979-2008 period. A simple approach, used by NASA Goddard, is to simply use all the data and continually update the climatology as new comes in. This avoids any charge of cherry-picking and avoids the need to develop a justification for the specific period. However, it results in constantly changing reference period and as the timeseries extends into the future, a baseline that could incorporate two (or more) very different sea ice regimes.

While the choice of climatology is minor from a scientific standpoint (it doesn't change the raw numbers or scientific conclusion), the user base has changed substantially in the past decade. Users of sea ice data has gone from only Arctic or Antarctic scientists to scientists in other fields, educators, the press, and the general public. User perception is becoming more important in climate science. The appearance of cherry-picking hurts the public's view of the data.

There was overall agreement that going to a 30-year climatology is probably best and NSIDC agreed to do that in the coming months, when resources allow. There was also some discussion of whether there were any statistical criteria or other rationale for a 30-year period (or any other length) that may be used as a justification for a decision. This will be looked into further.

Swath vs. Gridded input brightness temperature fields

The sea ice algorithms have typically been run on daily-average brightness fields. So the input data is a composite of the passive microwave signature over a day. It would be better to run the algorithms on swath data and then create a daily average concentration field if desired. This is the approach now used by the OSI-SAF product and the NASA Team 2 product. W. Meier and T. Markus independently conducted comparisons between the two approaches, though neither has been published. Overall, the differences were fairly small, but there could be some significant difference near the ice edge, particularly in spring and fall when diurnal effects are largest. Doing a further study and publishing the results was discussed.

Data versioning and citation

The sea ice products were originally developed as research products and used by a small community familiar with the products. For many of the products, this continues to be the case. However, the user community has expanded considerably. At the same time, the issue of transparency in data processing and reproducibility of climate data have become more of a focus. Thus, data versioning is becoming more important. This includes versioning of the input data sets. For example, NSIDC and NASA use brightness temperatures from Remote Sensing Systems, Inc. for their sea ice concentration products. The version of these TBs has changed over the years, but NSIDC and NASA have not explicitly noted changes in versions and reprocessing has not been done when a new input data set version has been released. It was agreed that all parties should be more careful with data versioning.

Data citation is also becoming an important issue. Many users simply cite the organization as the source of the data. However, for example, NSIDC distributes several sea ice data set, so it is important to cite the specific data set, including the version number. There are international strategies being developed to make data set citation more formal, e.g., through the use of DOI numbers for data sets as well as journal articles. NSIDC is participating in these discussions and plans to participate as new guidelines are introduced.

Grid and projection

The passive microwave sea ice products are generally produced in one of two polar grids: polar stereographic or EASE (Equal-Area Scalable Earth) Grid. The polar stereographic grid has the longest heritage and is used for NSIDC and NASA standard products. It has the advantage of using the smallest grid that encompasses all sea ice areas, so file size is smaller. Also, it was designed to have minimal distortion near the ice edge. However, the polar stereographic grid is not equal-area complicating area calculations. EASE-Grid is equal area and provides hemispheric coverage, but for sea ice products, a significant part of the grid is not used. Smaller subsets of EASE-Grid have been developed, one of which is used for the OSI-SAF gridded product. A new EASE2 Grid is being developed by NSIDC. This will essentially be the original EASE, but will use an elliptical instead of a spherical ellipsoid that will make products more easily ingested into modern geographical information systems. More information can be found in the web sites in Section IX.

Different grids and projections make direct intercomparison or integration with different data sets or models difficult. However, both EASE and polar stereographic now have long legacies and there are tools to re-project data, so this issue can be dealt with and developing a one-for-all sea ice grid is not necessary.

VII. Comments/Input from Non-Attendees

Several people were invited, but were unable to attend. Input was requested from those people and provided to attendees before the meeting. The input is provided below. Many of the issues raised were discussed at the meeting.

Dirk Notz, Max Planck Institute (in situ obs., modeling)

Your email is actually particularly timely since we've just installed a new little working group at Max Planck Institute that is primarily supposed to improve the way in which data are used in our model-development efforts. The idea for that group was born out of the observation that model developers often only use the most simple data sets available, rather than any more state-of-the-art products that are being made available by the remote-sensing community. For example, for sea ice, it usually comes down to compare visually model results with NSIDC sea-ice maps and to decide according to such comparison if the albedo needs tuning, for example. A somewhat more advanced, and more automated way, for handling model deficiencies clearly would be desirable and that's what we are supposed to be working on during the coming months.

The main issue, to me, still seems to be a lack of communication between the two communities, at least back here in Europe. Not sure if things are better in the US? Hence, it might be a good idea to invite a few sea-ice modelers to the workshop and to see how/if their requirements can be made to work.

I personally can just now think of the following issues, in particular after some work on nudging sea ice to observations in our model:

1 Error estimates
It would be very helpful for any attempt to get a better agreement between models and observations to have an easy-to-use reliability parameter or even error range available for any remote sensing data that would allow one to judge how much weight one can give to the observed concentration relative to the modeled one. The possibly easiest approach would be a multi-algorithm composite with standard deviation estimates

2 Coarser resolution
Given that most models currently work on resolution that are often somewhat coarser than the satellite record, I was just wondering if any error estimate, or maybe a more precise concentration, could result from algorithm that would work on a somewhat coarser resolution. In principle, I would hope that such coarser resolution could provide for a more reliable estimate than any interpolation/averaging of the final concentration product

3 Data formats
It would be very helpful if satellite data would be provided in the same data format that is usually used by modeling centers, i.e. in particular NetCDF or GRIB.

Ron Lindsay, Univ. Washington (modeling)

1. Jinlun assimilates the NCEP ice concentration in the PIOMAS model (right Jinlun?) which uses the SSMI ice concentration, but I don't know which algorithm. I also regularly use the Sea Ice Index ice extent for the seasonal forecasting exercise and check the monthly ice index values.

2. I used to have difficulty getting real time AMSR ice concentration data from NSIDC and had to go to the Germans for it. I think you have it now, although I tried to find it just now and was stymied. (the ftp_pool link takes you to another web page, not the data).

3. Error bars for the daily and monthly total ice area and ice extent time series in the Ice Index would be very useful. The errors may be highly correlated so that assuming independent errors may not work. This could be a tough question to solve. The error in concentration is dependent on the ice coverage...it is small for a concentrations of 0 or 1 and large for the MIZ and in the summer. The errors in the MIZ will directly impact the ice extent estimates. So figuring out how to evaluate the errors and how well the errors are correlated in space and time is the biggest issue in my mind.

Lars Kaleschke, Univ. Hamburg (remote sensing)

> Error estimates and/or data quality information:
* Surface melting and melt ponds

* Sensitivity for true ice variability near 100% concentration

* ice type, new/lead ice concentration

References:

Rösel, A., Kaleschke L., Comparison of different retrieval techniques for melt ponds on Arctic sea ice from Landsat and MODIS satellite data, Ann. Glac., accepted

Röhrs, J. and Kaleschke, L.: An algorithm to detect sea ice leads using AMSR-E passive microwave imagery, The Cryosphere Discuss., 4, 183-206, 2010

Maaß, N., L. Kaleschke, Improving passive microwave sea ice concentration algorithms for coastal areas - Applications to the Baltic Sea, Tellus A, Volume 62, Issue 4, Pages: 393–410, 2010

Sean Helfrich, U.S. Nat'l Ice Center (operational)

I believe one topic for discussion is 'what are product requirements for the Sea Ice products from satellites". It seems that user requirements are not understood, so the products from satellites are not truly meeting customer needs. Customers are often settling for "what is best and simplest sea ice products we can find already" rather than having a nationally or internationally defined set of requirements that researchers can aim for.

Also, the NIC is considering moving away from global chart production. I'm proposing internally a semi-automated global daily gridded product line that would have 1 km (or better) resolution, with key variables (total concentration, MY concentration, ice thickness, etc) both updated by satellite sources and by NIC analysts. I want to know if there are other agencies that would look to partner with NIC in the development, production, and dissemination of this product. We have no current funds other than man power towards its development, but it could vastly improve the current monitoring of sea ice operationally. It would be useful for both navigation and numerical modeling.

Todd Arbetter, U.S. Nat'l Ice Center (operational)

The obvious topic that NIC would be interested in is improving new/existing products; providing them for evaluation at NIC as candidates for the operational production of its charts, as well as proposed/existing entities like the National Ice Service/National Climate Service. NIC Science & Applied Tech exists to identify, acquire, and evaluate such products for inclusion in the operational data stream. Products which improve either spatial resolution (eg AMSR-E over SSM/I), accuracy in lower ice concentrations (summer ponding and/or concentrations ~40% confound the sensors in passive microwave sensors), or replace/improve upon instruments lost due to platform failure or lack of funding (eg RADARSAT to RADARSAT2 represented a sharp increase in cost per image with no corresponding increase in funding) are sought out. NIC has a limited team of scientists who can internally evaluate the products but external interactions with data providers could help identify and tailor product formats. Accurate products that improve the quality of NIC's operational suite of products and/or speed the production of them would be of great value.

Cecilia Bitz, Univ. of Washington (modeling)

As far as my own thoughts, we would love to have more confidence in the sea ice area. The extent is not easy to compare across resolutions and differing periods of time-averaging. The area is better because it can be described by physics. I would be very pleased to see more validation of the area from PM. In particular what is the uncertainty in grid point area and basin-scale averages? Is it systematic or only random? Is anyone planning to validate PM with the high-resolution products from the spy satellites?

Jinlun Zhang, Univ. of Washington (modeling)

(1) As Ron said, I used to assimilate NCEP ice concentration (polar.ncep.noaa.gov) in the PIOMAS model. I also assimilated NCEP data in the GIOMAS (Global Ice/Ocean Modeling and Assimilation System) model and the BESTMAS (Bering Ecosystem STudy Ice/Ocean Modeling and Assimilation System) model. But later, I found that there are a lot of missing points in the NCEP ice concentration for 2009. So I started to assimilate NSIDC (or NASA) near real time ice concentration data (n4ftl01u.ecs.nasa.gov). Because we often do ensemble seasonal ice prediction, we need near real time products for assimilation. Both NCEP and NSIDC data are near real time and therefore fit our needs. But both data sets only cover 1996-present, we are now trying to use the NSIDC NASA team data set to extend coverage to 1978.

(2) I also do model only simulations without assimilating ice concentration data. In these cases, ice concentration is used for model validation.

(3) I agree with Ron that getting a good handle on the uncertainty of the data (particularly the SSM/I data that I use) would be very useful. My model only simulations generally show bigger ice extent than the SSMI derived. So knowing the data errors would help to estimate the model errors.

(4) The bad thing about the NCEP data is missing points, but the good thing is that it is on a global grid, which is easier to use for GIOMAS. I would love to see NSIDC near real time data on a global grid.

Adrian Tivy, UAF

My suggestion is to generate regional numbers as well as the overall extent for the Outlook. Maybe area as well as extent for the regions. The regional boundaries for the outlook are a bit arbitrary now.

Meier comment: Another issue for consistency/collaboration – what regions should be defined and what should be the areal boundaries?

Nick Rayner, Hadley Centre

Although inter-comparisons have been made, I have never seen anything comprehensive either in terms of algorithms, regions or seasons. Users need these to understand how the different products relate. Having said that, unless a serious attempt is made to estimate uncertainties in the products, i.e. on a pixel-by-pixel basis by understanding the limitations of the algorithms, the significance of differences found during inter-comparisons is hard to understand.

François Massonnet (model validation) and Pierre Mathiot (assimilation), Université Catholique de Louvain, Belgium

* File format: the data should be provided in at least the two most widespread formats, namely Netcdf and Grib. I (FM) have spent hours finding how to convert Grib to Netcdf, so another option would be that a grib-to-netcdf routine would be provided.

* Gaps in the data (in space and time): they are undesirable when we want to compare integrated quantities (extent, area), especially for model validation because they induce severe bias in the mean cycle as well as in the anomalies.

* The frequency of data should be daily, which is perfect for data assimilation.

* Errors should be provided for each data point. Flags are more than welcome (e.g. "in this area the data have been interpolated due to the absence of satellite trace")

* Gridded files are much more comfortable and easy-to-use, especially for later interpolation onto model grid (for data assimilation and model validation)

* Operational products are very useful, for online sea ice assimilation. But how much confidence can we place into them?

* Products of ice thickness/freeboard, ice concentration and ice drift should be consistent: if concentration is 0 somewhere, then thickness should be 0 as well, and so for drift. Cross-validation should be operated.

VII. Bibliography

This section contains selection journal articles and other resources on passive microwave sea ice concentration products. This is list is not meant to be comprehensive, but provide major references for the various algorithm products and other background information.

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Andersen, S., R. Tonboe, L. Kaleschke, G. Heygster, and L.T. Pedersen (2007). Intercomparison of passive microwave sea ice concentration retrievals over the high-concentration Arctic sea ice. *J. Geophys. Res.*, 112, C08004, doi:10.1029/2006JC003543.

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Meier, W.N., J. Stroeve, and F. Fetterer (2007). Whither Arctic sea ice? A clear signal of decline regionally, seasonally and extending beyond the satellite record, *Ann. Glaciol.*, 46, 428-434.

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VIII. Sea Ice Products and Other Reference Web Sites

Climate record projects:

ESA Climate Change Initiative: http://earth.eo.esa.int/workshops/esa_cci/

ESA CCI Sea Ice Document: http://earth.eo.esa.int/workshops/esa_cci/Annex_E_Sea_Ice_CCI.pdf

OSI SAF: http://saf.met.no/

NOAA CDR: http://www.ncdc.noaa.gov/cdr/

Sea ice timeseries/imagery products:

University of Bremen: http://www.iup.uni-bremen.de/seaice/amsr/

JAXA: http://www.ijis.iarc.uaf.edu/cgi-bin/seaice-monitor.cgi?lang=e

NSIDC Sea Ice Index: http://nsidc.org/data/seaice_index/

NASA Goddard: http://neptune.gsfc.nasa.gov/csb/index.php?section=234

Cryosphere Today: http://arctic.atmos.uiuc.edu/cryosphere/

ArcticROOS: http://arctic-roos.org/observations

DMI Centre for Ocean and Ice: http://ocean.dmi.dk/arctic/icecover.uk.php

Other Operational Products (incl. non-passive microwave):

U.S. National Ice Center: http://www.natice.noaa.gov/

Canadian Ice Service: http://ice-glaces.ec.gc.ca/

NOAA Microwave Integrated Retrieval System (MIRS): http://mirs.nesdis.noaa.gov/

NOAA/NCEP: http://polar.ncep.noaa.gov/seaice/support/ssmi.about.shtml

NSIDC/NIC MASIE: http://nsidc.org/data/masie/

NOAA and GHRSST Sea Surface Temperature Site

GHRSST Ensemble:
http://ghrsst-pp.metoffice.com/pages/latest_analysis/sst_monitor/daily/ens/index.html

NOAA NODC: http://www.nodc.noaa.gov/SatelliteData/ghrsst/intercomp.html

Grid and projection information:

Polar stereographic grid: http://nsidc.org/data/polar_stereo/ps_grids.html

EASE-Grid: http://nsidc.org/data/ease/ease_grid.html

Other links:

SEARCH Sea Ice Outlook: http://www.arcus.org/search/seaiceoutlook/

CliC Sea Ice Working Group Note on the Accuracy and Reliability of Satellite-derived Passive Microwave Estimates of Sea Ice Extent:
http://www.climate-cryosphere.org/export/sites/clic/documents/CliC_seaice_reliability_oct28.pdf

German Sea Ice Links: http://www.seaice.de/

Univ. Hamburg KlimaCampus: http://icdc.zmaw.de/icdc.html?&L=1

Hokkaido University: http://wwwod.lowtem.hokudai.ac.jp/polar-seaflux/

Appendix I. Acronyms

ALOS – JAXA Advanced Land Observing Satellite

AMSR-E – Advanced Microwave Scanning Radiometer for EOS

AMSU – Advanced Microwave Sounding Unit

ArcticROOS – Arctic Regional Ocean Observing System

ASAR – ESA Advanced Synthetic Aperture Radar sensor

ASI – ARTIST Sea Ice algorithm

ASINA – NSIDC Arctic Sea Ice News and Analysis website

AVHRR – Advanced Very High Resolution Radiometer

BT – Bootstrap algorithm

CCI – ESA Climate Change Initiative

CDR – Climate Data Record

CIS – Canadian Ice Service

CliC – WCRP Climate and Cryosphere project

CliC SSG –CliC Science Steering Group

DAMOCLES – Developing Arctic Modeling and Observing Capabilities for Long-term Environmental Studies

DMPS – U.S. Department of Defense Meteorological Satellite Program

DOI – Digital Object Identifier

EASE Grid – Equal-Area Scalable Earth Grid

ECV – Essential Climate Variable

EOS – NASA Earth Observing System satellite program

EPS – EUMETSAT Polar System

ESA – European Space Agency

ESDR – Earth Science Data Record

ESMR – Electrically Scanning Microwave Radiometer

EUMETSAT – European Organisation for the Exploitation of Meteorological Satellites

GCOM-W – Global Change Observation Mission – Water

GHRSST – Group for High Resolution Sea Surface Temperatures

GSFC – NASA Goddard Space Flight Center

HDF – Hierarchal Data Format

ICESat – NASA EOS Ice, Cloud, and land Elevation Satellite

IHO – International Hydrological Organization

IMS – NOAA Interactive multisensor snow and ice Mapping System

IPY – International Polar Year

JAXA – Japan Aerospace Exploration Agency

JPSS – U.S. Joint Polar Satellite System (replaced NPOESS)

MASIE – NSIDC Multi-sensor Analyzed Sea Ice Extent

MODIS – NASA EOS Moderate Resolution Imaging Spectroradiometer

MYR/MYI – multiyear/multiyear ice

NCDC – NOAA National Climate Data Center

NCEP – U.S. National Center for Environmental Prediction

NetCDF – Network Common Data Format

NIC – U.S. National Ice Center

NPOESS – U.S. National Polar-Orbiting Satellite System (now JPSS)

NRT – Near-real-time

NSCAT – NASA Scatterometer

NSIDC – National Snow and Ice Data Center

NT – NASA Team algorithm

NT2 – NASA Team 2 (Enhanced NASA Team) algorithm

OSI SAF – EUMETSAT Ocean and Sea Ice Satellite Application Facility

PALSAR – JAXA Phased Array type L-band Synthetic Aperture Radar

PIOMAS – Pan-Arctic Ice-Ocean Modeling and Assimilation System (University of Washington Polar Science Center)

PM – passive microwave (sensor, remote sensing)

PoDAG – NASA Polar DAAC (Distributed Active Archive Center) Advisory Group (NSIDC advisory group)

RSS – Remote Sensing System, Inc.

SAR – Synthetic Aperture Radar

SIGRID –Sea Ice Gridded data format

SIMBA – Sea Ice Mass Balance in the Antarctic experiment

SIPEX – Sea Ice Physics and Ecosystems Experiment

SLAR – Side-Looking Active Radar

SMMR – Scanning Multichannel Microwave Radiometer

SSM/I – Special Sensor Microwave/Imager

SSMIS – Special Sensor Microwave Imager and Sounder

SST – Sea Surface Temperature

TB – brightness temperature

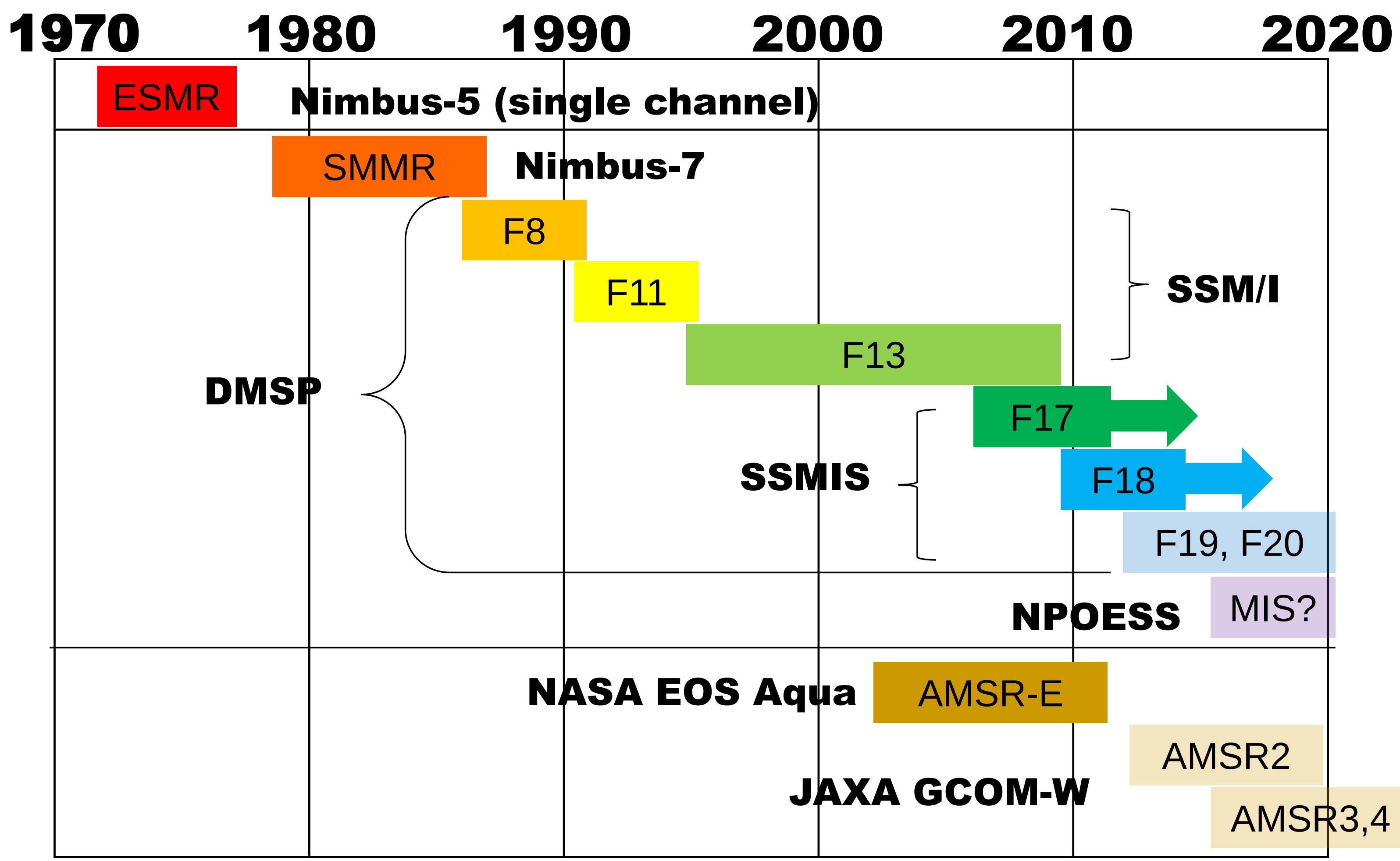
WCRP – World Climate Research Programme

Appendix II. Passive Microwave Sensor Information

Passive Microwave Sea Ice Sources – Past, Present, and Future						
Satellite	**Sensor**	**Frequencies (GHz)**	**Launch Date (Data Available)**	**Ascending Equatorial Crossing Time At Launch (Most Recent, Date)**	**Swath Width (km)**	**Mean Altitude (km)**
Single channel sensors with sea ice products, but not commonly used in sea ice climate records						
NIMBUS N5	ESMR	19	12/11/72 (12/12/72-5/16/77)		3000	1095
Sensors commonly used for sea ice climate records						
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)	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)	17:42 (18:33, 11/28/07)	1400	850
EOS Aqua	AMSR	7,10,19,23,37,89	5/4/02 (6/18/02-10/4/11)	13:30 (122:35, 07/01/11	1445	705
DMSP F15	SSM/I	19,22,37,85	12/12/99 (1/24/00-present)	(16:26, 07/01/11)	1400	850
DMSP F16	SSMIS	19,22,37,85,+	10/18/03 (11/4/05-present)	(18:30, 07/01/11)	1700	850
DMSP F17	SSMIS	19,22,37,85,+	11/4/06 (3/26/08-present)	(17:32, 07/01/11)	1700	850
DMSP F18	SSMIS	19,22,37,85,+	10/18/09 (1/29/10-present)	20:00	1700	833
Future Sensors						
DMSP F19	SSMIS	19,22,37,85,+	2012	17:30	1700	833
GCOM W1	AMSR	7,10,19,37,89	3/2012	13:30	1445	700
DMSP F20	SSMIS	19,22,37,85,+	2013-2015	17:30	1700	833
GCOM W2	AMSR	7,10,19,37,89	2015			
NPOESS C2	MIS?	19,22,37,85,+	2017?	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 commonly used 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 15 October 2011

Timeline of selected passive microwave sensors for sea ice



Appendix III. Sea Ice Product Slides